An HF Radar System for Ionospheric Research and Monitoring

TECHNICAL MANUAL
Operation and Maintenance

Document Version 1.2.11

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REVISION LOG

This log identifies those portions of this document which have been revised since the original issue released on January 28, 2009.

Rev.	Date	Description	Initiator
IR	01-28-09	Initial release	
1.0.1	01-05-10	Small changes like capitalization, keep with text, etc.	
1.2.0	03-30-10	1. Modify header to include document version information 2. Add information regarding receive antenna proximity to metal fencing on page 2-5 3. Add addendum regarding remote ON / OFF Modification to Section 6 (Annex B)	RH
1.2.1	6-01-10	1. Accepted changes from 1.2.0, and update text to include LDI. 2. Updated text on section 1 paragraph 102 3. Updated figure 6-12 4. Added TOC to front of document 5. Updated: Digisonde 4D Specifications Table 6. Updated: Figure 2-1, Figure 2-2, Figure 3-46	SM
1.2.2	9-14-10	Applied ARINC "redline" suggested edits 1. Added Digisonde 4D to Figure 1-2 2. Numbered paragraphs are consistent throughout sections and Footers in Annex sections updated. 3. Updated Antenna array in Table 1-1 4. Para 1:26 changed "seven dimensional" to "six dimensional 5. Figure 1-17 removed "VI" from caption 6. Para 2:7 changed "consists of one or two" to "usually consists of two" 7. Para 2:17a reworded & Para 2:21 reworded 8. Para 2:28 removed "or magnetic compass north" 9. Para 2:30 – 2:33 added "Surge protectors" 10. Para 2:56 replaced ImposedRestriction.UDD" with "StationSpecific.UDD" 11. Fig 4-4, Fig 4-23 & Fig 4-24 added "Block Diagram" to caption 12. Para 4:11, Para 4:40 – 4:42 reworded 13. Removed "continue" from Figure 4-21 caption 14. Figure 4:16 & Figure 4:18 updated	SM

		15. Table 5:4 Replaced <60 with ≤60 16. Para 6:16 – Para 6:19 added figure reference 17. Table 6A:1 Updated	
1.2.3	2-11-11	1. Updated Para 6:34 & 6:35 2. Repagination	SM
1.2.4	12-2-11	1. Updated code in Para 1:33 (changed 0 to -1) 2. Updated Para 1:34, 1:40, 1:42, 1:48, 1:50, 1:57 3. Updated figure 2-2 4. Updated Para 2:30 & 2:31 5. Removed Para 2:67 – 2:72 (Verification of RX Combined Phase Response) 6. Removed Figure 2-1: Calibration of Combined Phase Response of Cables, Preamplifiers and Antenna Switch 7. Removed Figure 2-9: Program for External Loopback Validation of Digisonde 4D Receiver Setup 8. Figure 2-10: Data from External Loopback Validation of Digisonde 4D Receiver Setup 9. Updated Para 3:45 (added UMS) 10. Added new Para 3:46 – 3:49 “Programming HF Surveillance Measurements” 11. Updated figure 3-19, 12. Added new figures 3-20, 3-21, 3-22, 3-23 13. Updated para 3:147, 3:148, Note, 3:152, 3:153 14. Added new para 3:149, 3:150	SM
1.2.5	1-18-13	1. Updated Figure1.2 2. Replaced VN with $\sqrt{N}$ in 1:41 & 1:51 3. Renumbered Equations in Section1 4. Updated text 2:8, 2:10 5. Removed figure 2-10(Mirror Antenna Layout) 6. Table 5A-6. updates a. added version3 to title b. Antenna option and range c. Polarizations d. Number of Integrated Repeats (range) e. Automatic gain control (range) f. Save Data Flags (and range) g. Number of Ranges to Output (range) h. DIG_MODEL change to TX_ST_MODEL i. Blue highlights and yellow highlights updated 7. Added paragraph numbering to Section5 – Annex A,B,C 8. Updated Section 5 – ANNEX C(added UMS, Tables 5C-27, 5C-28, 5C-29)	SM

		9. Updated note 5.92 10. Added "®" to all instances of Digisonde in the manual 11. Updated figure6-5 12. Updated section 6 numbering 13. Updated 6-4	
1.2.6	9/17/13 3/27/14	1. In Table 5C-37 updated #46, #47-48 2. Changed reference to Table 6-3 in Table 5C-38 & Table 5C-43 to 5C-37 3. Globally changed DPS-1 to DPS1, DPS-4 to DPS4, DPS-4D to DPS4D, Digisonde® 4D to Digisonde-4D, Digisonde® 128 to Digisonde-128, Digisonde® 256 to Digisonde-256 4. Updated caution statement after 2:16 5. Added a new Figure 2-1 6. Updated 2:19 text.	SM
1.2.7	10/8/15	1. Global update of text and figures	SM
1.2.8	06/08/18	1. Made changes to all sections to include changes due to new data computer hardware and migration to Linux operating system.	RH, DK, SM
1.2.9	4/16/19	1. Section 1 replaced "Windows XP" with "Linux" 2. Removed all references c:\ or d:\ and placed linux paths. 3. Section 4, added a missing paragraph number 4:28 for the Preprocessor Card section. 4. Updated Configuring GPS text (4:56)	SM, RH
1.2.10	4/23/20	1. Updated Section 2:8-2:18 in regards to Vegetation/Conductive Obstructions	DK, RH, SM
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Version format is X.Y.Z.

X denotes major release.

Y denotes addition to a section or significant modification to one or more sections.

Z denotes small grammatical corrections and modifications.

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SECTION 1

GENERAL SYSTEM DESCRIPTION

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CHAPTER 1

THE DIGITAL PORTABLE SOUNDER DPS4D

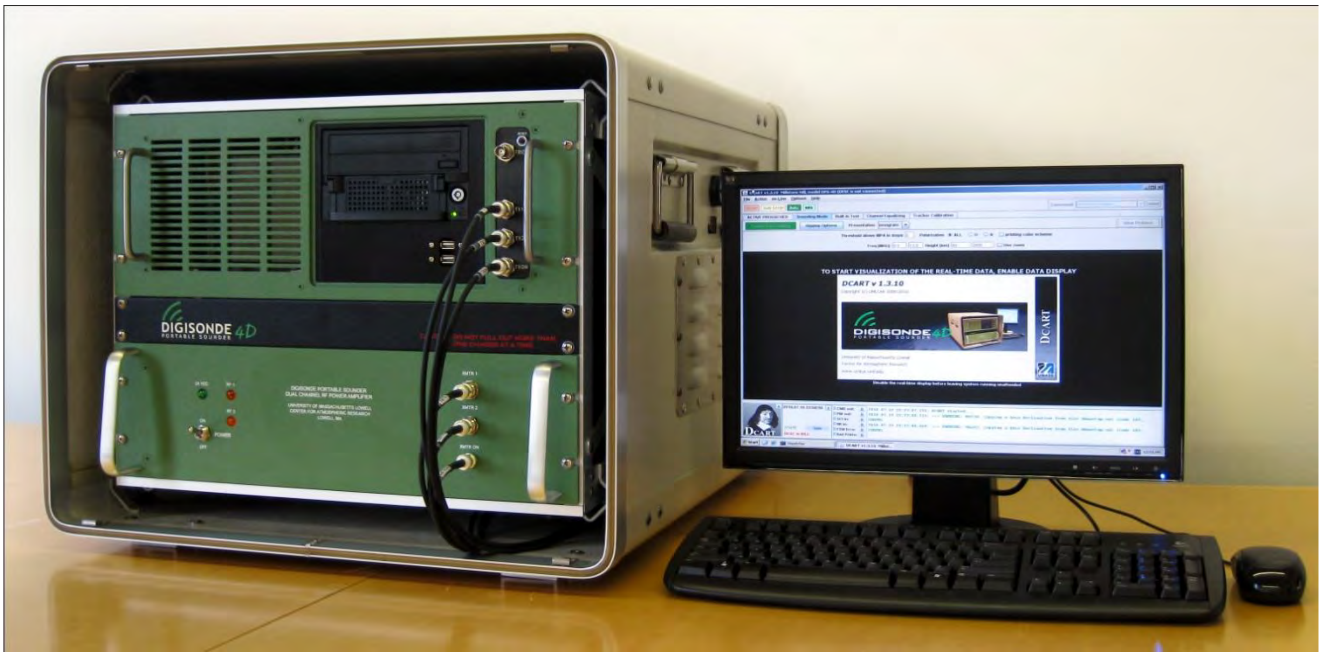

Figure 1-1: DPS4D

ORGANIZATION OF THE MANUAL

1:1. The DPS4D manual has 6 sections:

a. Section 1 provides a general description of the DPS4D sounder and background information on ionospheric sounding and relevant signal processing techniques.

b. Site preparation and installation instructions are provided in Section 2 of this manual.

c. Operating instructions are given in Section 3.

d. A full technical description of the sounder is provided in Section 4 (hardware) and Section 5 (software).

e. Instructions for organisational and depot level maintenance plus reference to technical data required to support depot level fault finding and repair of sub-assemblies are contained in Section 6.

DIGISONDE® FAMILY OF IONOSPHERIC SOUNDERS

1:2. The Digisonde® Portable Sounder 4D, sometimes referred to as DPS4D or simply Digisonde-4D is the latest digital ionosonde that was developed during 2004-2008 (**Figure 1-1**). While preserving the basic principles of the Digisonde® family – the Digisonde-128, the Digisonde-256, the Digisonde® Portable Sounder DPS1, and the DPS4 – the Digisonde- 4D model introduces a number of important hardware and software changes that implement the latest capabilities of new digital radio frequency (RF) circuitry and embedded computers. The “D” in the new model refers to the digital transmitters and receivers in the Digisonde-4D, which uses digital up- and down-converter IC chips that implement the classic functions of radio transmitters and receivers by numeric techniques. It also uses new software solutions for data acquisition, hardware control, user commanding, and data processing.

Figure 1-2: Evolution of the Digisonde®

GENERAL DESCRIPTION

1:3. Vertical radio sounding makes use of the fact that radio waves are reflected in the ionosphere at the height where the local cutoff frequency equals the frequency of the radio wave. The original analog ionosondes used for ionospheric sounding since Breit and Tuve described the concept in 1926 started to be replaced by digital instruments in the 1970s. Modern digital ionosondes are highly flexible high frequency (HF) radar systems tasked to reliably describe the status of the ionospheric density distribution on a continuous basis. Robust automated operation is a *sine qua non* for the monitoring function of the ionosonde, and measuring flexibility and precision are required for research applications.

1:4. Unlike incoherent scatter radar systems, ionosondes must be built at low cost and easy to install to make operations at many sites around the world feasible. As for the previous DPS models, the Digisonde-4D uses one simple crossed delta antenna for transmission, and an array of four small crossed loops for reception. The integrated transceiver package of Digisonde-4D is shown in **Figure 1-1**, and one of the four crossed magnetic loop receive antennas in **Figure 1-3**.

Figure 1-3: Turnstile Receive Antenna with Attached Preamp Module

1:5. Noteworthy technology involved in Digisonde-4D system includes:

- Fast 16-bit analog to digital (A/D) converters for the digital receivers
- Electronically switched active crossed loop receiving antennas
- 15 decibel (dB) signal processing gain from phase coded pulse compression
- 21 dB additional signal processing gain from coherent Doppler integration
- Up to 35 dB signal gain via RF Interference Mitigation algorithm
- Two embedded computing platforms for hardware control, data acquisition user commanding, data processing, storage, publishing, and dissemination
- Software implementation of the signal processing functions applied to the time domain data
- Automatic ionospheric layer identification and parameter scaling by an embedded expert system ARTIST 5
- World-wide web access to real-time measurement data

Digisonde-4D Block Diagram

1:6. **Figure 1-4** shows the Digisonde-4D block diagram identifying the Digital Transmitter card, the Digital Receiver card, the Preprocessor card, four tracking filters, two 150 W Power Amplifiers with half-octave filters, and two embedded computers responsible for hardware control and data acquisition (Control Platform) and data processing and remote access (Data Platform).

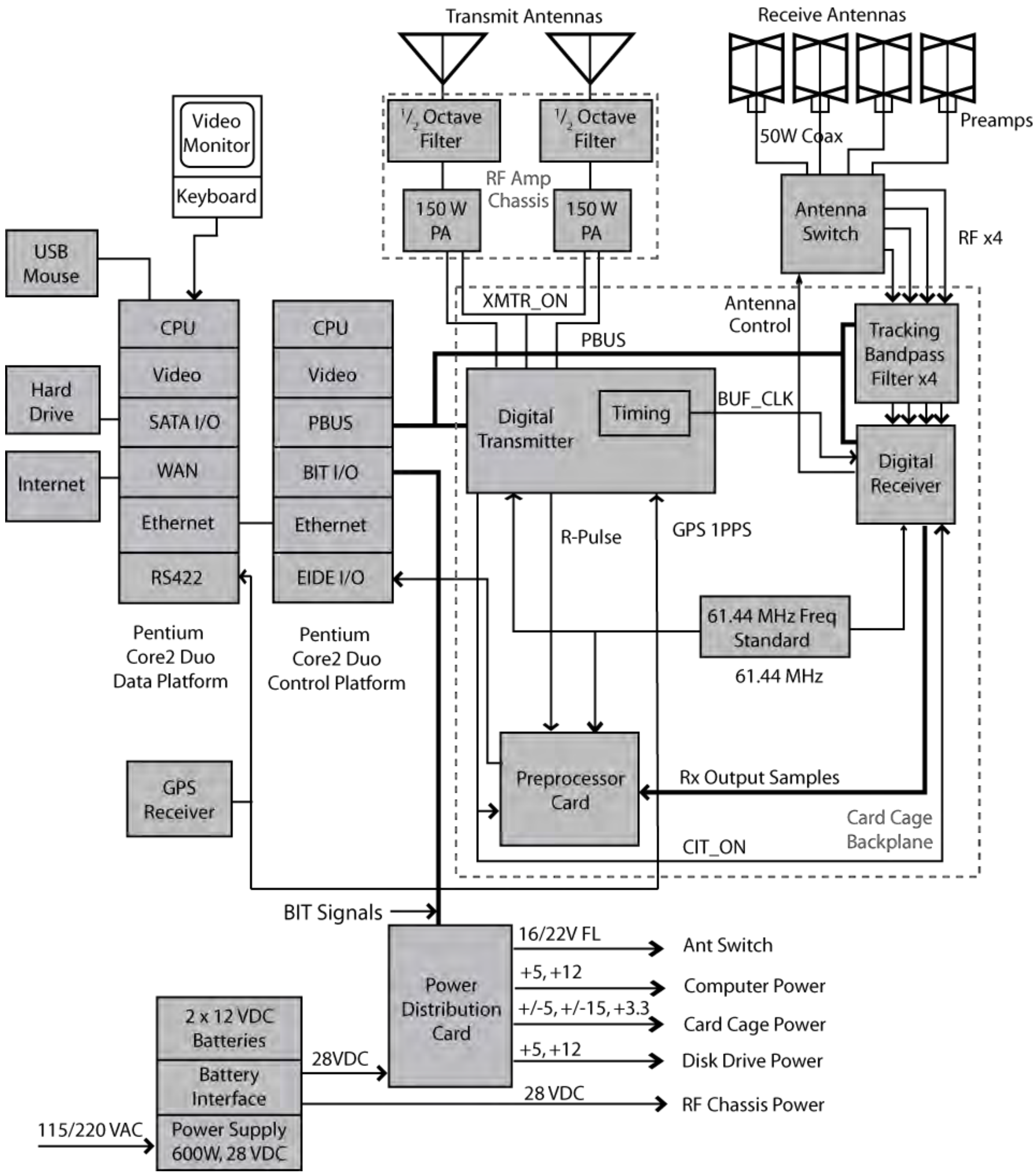

Figure 1-4: Block Diagram of Digisonde-4D

1:7. The new 16-bit analog-to-digital converters (ADCs) and the digital receivers provide increased precision for amplitude and phase measurements and reduced temperature sensitivity. Since the Digisonde-4D must operate over a large frequency band of more than eight octaves (from 0.1 MHz to 30 MHz), it is important to protect the ADCs from saturation by strong interferers operating in this large band. Saturation of the ADC would destroy the narrowband filtering of the digital receiver. An analog tracking filter in combination with automatic digitally controlled amplifier gain at the receiver input limit the ADC input voltages to specified value.

1:8. The physical dimensions of the Digisonde-4D remain unchanged since the Digisonde® Portable Sounder was introduced in 1990, consisting of two 19" chassis, one housing the two-channel transmitter power amplifiers and half-octave filters, the other the signal synthesizers, receivers, and digital signal processors. The system compensates for a low power transmitter (300 W vs. 10 kW for original Digisonde-128 and 256 models) by employing intrapulse complementary phase coding with digital pulse compression, Doppler integration, and the patented Radio Frequency Interference Mitigation algorithm RFIM which enhances the processing gain by 35 dB.

1:9. The Main (upper) Chassis (see **Figure 1-5**) contains the following functional assemblies:

a. Cardcage with Digisonde-4D electronics

b. Digital transmitter / timing card

c. Digital receiver card

d. Four analog tracking filter cards ("tuners")

e. Pre-processor card

f. Built-in test (BIT) card

g. Backplane with 61.44 MHz Master Frequency Standard

h. Two embedded computer platforms (Control Platform and Data Platform)

i. DVD R/W mass storage drive

j. Removable Hard Disk tray

k. Power distribution board with DC/DC converters

l. Antenna switch

m. Three axial fans

1:10. The Power Amplifier Chassis (lower) **Figure 1-6** contains the following assemblies:

a. Two 150 W peak power solid state amplifiers

b. Two half-octave filter boards for harmonic suppression

c. Input power relay

d. Two axial fans

1:11. The outer moulded case, and its removable front and rear covers, protect the main and power chassis during operation, transit and storage. As well as containing chassis mounting hardware and miscellaneous fittings, the case houses a 28 VDC power supply unit, two high volume axial fans, a power and signal distribution panel and main on/off switch, power interface box (formerly the battery interface), and a Radio Frequency Interference (RFI) filter for the AC mains input power (**Figure 1-7**).

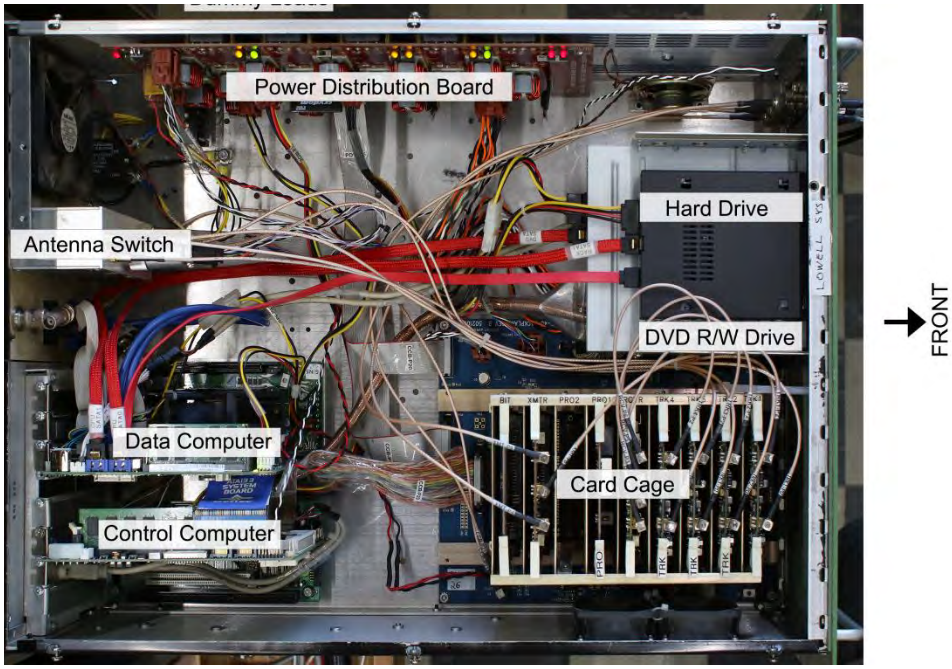

Figure 1-5: Main Chassis of the Digisonde-4D

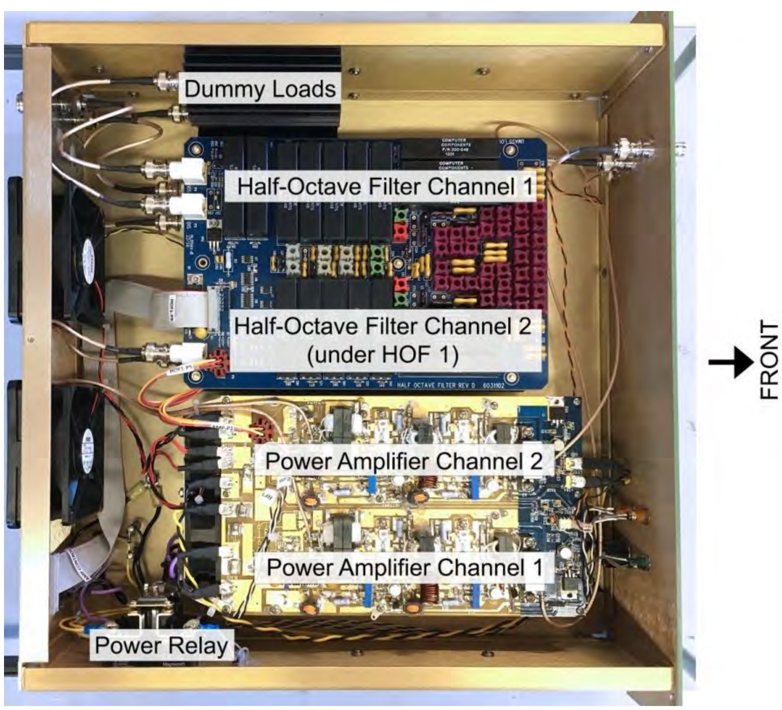

Figure 1-6: Power Amplifier Chassis of the Digisonde-4D

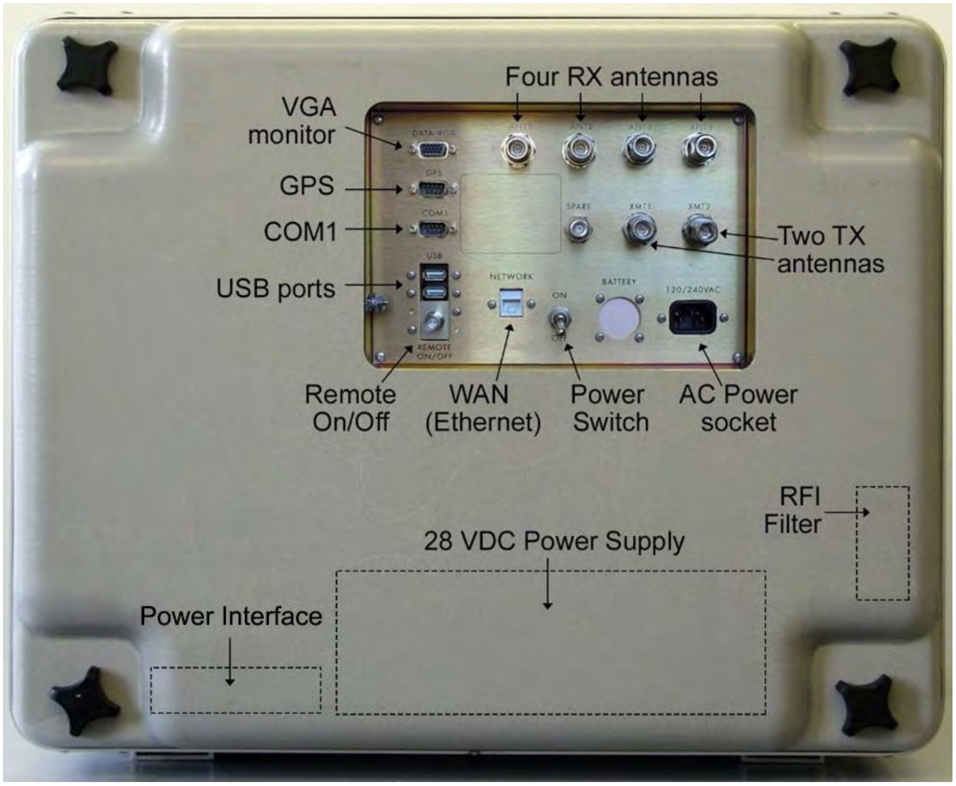

Figure 1-7: Sounder Transceiver Sub-System (Rear View)

1:12. A color monitor and keyboard are provided for installation, maintenance, and testing purposes, but are not required for remote operation. The GPS receiver is mounted externally to the sounder site building.

SPECIFICATIONS

1:13. **Table 1-1** provides Digisonde-4D specifications.

Table 1-1: Digisonde-4D Specifications

Quad Receiver	
Frequency Range	0.5 – 30 MHz (all modes of operation)
Bandwidth	34 kHz @ 3 dB
Input Impedance	50 Ω
Noise Figure	11 dB (at receiver antenna preamplifier)
Receiver Sensitivity	-130 dBm (+/-6 dB) into main chassis; better at preamplifier (amount depending on preamp gain setting)
Dynamic Range	>90 dB instantaneous >140 dB total operating range including gain control
Recovery Time	40 µs
Output	16-bit quadrature samples

RF Output	
Frequency Scan	0.5 - 30 MHz, start, stop, and step size selectable to 1 kHz
Restriction of Transmission	Programmable list of frequencies without RF transmission
Ionogram Scan Time	Standard VIS ionogram 2 - 200 sec (varies with programmable settings)
Frequency Synthesis	Fully digital (frequency switching time < 1µs)
Pulse Repetition Rate	100 and 200 pps
Pulse Width	533µs (16 chips of 33 µs) waveform with 30 kHz signal bandwidth
Peak Pulse Power	2 channels @ 150 W each
Output Impedance	50 Ω
Transmitter Type	Dual RF MOSFET Amplifiers for polarized transmission using turnstile transmit antenna
Lightning Protection	In-line spark gap discharge devices
User Interface	
Unattended Operation	Controlled by 128 measurement programs, 128 schedules, automatic schedule switch rules, and preprogrammed campaign events
Remote Access & Control	Network TCP/IP) interface for Input/Output access to schedules, measurement data, diagnostic data, and operating software. Standard Remote Control Interface uses Microsoft Remote Desktop over Internet or LAN.
Time Setting	Integrated GPS receiver keeps time to +/-25µs
Built-in-Test (BIT)	Full diagnostics to isolate failures to line replaceable units runs automatically, remotely accessible
Self Calibration	Built-in internal cal automatically updates phase/ amplitude adjustment tables. Remotely accessible results.
Signal Processing	
Processors	Two Embedded Intel Core 2 Duo Dual Core processor SBCs (Control and Data Platforms)
Number of Range Bins	Selectable: 256 or 512
Height Range	0-1200 km (0 km used for self-calibration)
Height Resolution	2.5 km sample spacing. 500 m using differential phase technique
RF Interference Mitigation	RFIM reduces coherent interference up to 35 dB
Waveform Processing	Pulse compression of 16-chip phase code provides 15 dB signal processing gain
Doppler Processing	4 to 128 integrations can provide up to 21 dB signal processing gain
Doppler Range	+/-3 Hz to +/-50 Hz
Doppler Resolution	.0125 to 12.5 Hz
Amplitude Resolution	< 0.01 dB
Wave Polarization	Alternating transmission with O and X, synchronized receive antenna polarizations (doubles reliability of O/X identification by ARTIST). Linear polarization on request.

Standard Operating Modes	Linear Frequency Scan for Ionogram Multiplexed Frequency Scan (finer Doppler resolution) Multi Fixed-Frequency (for TID and absorption studies) Plasma Drift & Ionospheric Tilt (direction and velocities) Synthesized Multi-beam Reception (detects off-vertical echoes) Precision Group Height (0.5 km h' accuracy) HF Surveillance Mode
Software (included with system)	
System Software	Linux and Real-Time Executive for Multiprocessor Systems (RTEMS)
WEB Server for Real-Time Data Monitoring	Apache, with access to real-time displays of ionogram, directogram, skymap, drift velocity data and BIT
Operating Software	DESC (Control platform). DCART, Dispatcher, ARTIST with NHPC, DDA (Data platform).
Online Ionogram Scaling	Automatic Real-Time Ionogram Scaling with True Height Analysis (ARTIST)
Online Drift Data Processing	DDA (Drift Data Analysis) software, skymap generation, drift velocity analysis, and calculation of ionospheric tilt
Online Data Delivery	FTP to multiple destinations
4 Receiver Antennas	
Antenna Type	Active Crossed loops – Turnstile antennas (1.5m diameter)
Antenna Array	4 antennas in equilateral triangle 45-60 meters with the fourth antenna located at the center of the three.
Construction	Schedule 80 PVC, with wire braid loop elements
Electronics	Preamplifier (powered via RF cable) with electronically switched polarization.
Preamplifier Sensitivity	-123 dBm (in 34kHz bandwidth, not including signal processing)
Specifications for Transmitter Antenna	
Antenna Type	Turnstile Delta or Rhombic (2 orthogonal radiating elements)
Tower	30 m or larger recommended
Data Post-Analysis Workstation	
Computer Hardware	Intel Dual Core processor, 19" LCD monitor, DVD R/W, Color Printer
Computer Software	Linux
Ionogram Editing and Profile Inversion	SAO Explorer with NHPC electron density profile inversion tool, International Reference Ionosphere model, and access to the UML DIDBase data repository
Drift Data Analysis	Drift Explorer with access to UML Drift-DB data repository

CHAPTER 2

METHODOLOGY, THEORETICAL BASIS, AND IMPLEMENTATION

BACKGROUND: IONOSPHERIC PROPAGATION OF RADIO WAVES

1:14. An ionospheric sounder uses basic radar techniques to detect the electron density (equal to the ion density since the bulk plasma is neutral) of ionospheric plasma as a function of height. The ionospheric plasma is created by energy from the sun transferred by particles in the solar wind as well as direct radiation (especially ultra-violet and x-rays). Each component of the solar emissions tends to be deposited at a particular altitude or range of altitudes and therefore creates a horizontally stratified medium where each layer has a peak density and to some degree, a definable width, or profile. The shape of the ionized layer is often referred to as a Chapman Function [Davies, 1989] which is a roughly parabolic shape somewhat elongated on the top side. The peaks of these layers usually form between 70 and 300 km altitude and are identified by the letters D, E, F1 and F2, in order of their altitude.

1:15. By scanning the transmitted frequency from 1 MHz to as high as 40 MHz and measuring the time delay of any echoes (i.e., apparent or virtual height of the reflecting medium) a vertically transmitting sounder can provide a profile of electron density vs. height. This is possible because the relative refractive index of the ionospheric plasma is dependent on the density of the free electrons (N_e), as shown in **Equation 1-1** (neglecting the geomagnetic field):

$$\mu^2(h) = 1 - k\,(N_e/f^2) \qquad \textbf{1-1}$$

where k = 80.5, N_e is electrons/m^3, and f is in Hz [Davies, 1989; Chen, 1987].

1:16. The behavior of the plasma changes significantly in the presence of the Earth's magnetic field. An exhaustive derivation of m [Davies, 1989] results in the Appleton Equation for the refractive index, which is one of the fundamental equations used in the field of ionospheric propagation. This equation clearly shows that there are two values for refractive index, resulting in the splitting of a linearly polarized wave incident upon the ionosphere, into two components, known as the ordinary and extraordinary waves. These propagate with a different wave velocity and therefore appear as two distinct echoes. They also exhibit two distinct polarizations, approximately right hand circular and left hand circular, which aid in distinguishing the two waves.

1:17. When the transmitted frequency is sufficient to drive the plasma at its resonant frequency there is a total internal reflection. The plasma resonance frequency (f_p) is defined by several constants, e – the charge of an electron, m – the mass of an electron, ε_o – the permittivity of free space, but only one variable, N_e – electron density in electrons/m^3 [Chen, 1987]:

$$f_p^2 = (N_e\, e^2/4\pi\varepsilon_o m) = kN_e \qquad \textbf{1-2}$$

A typical number for the F-region (200 to 400 km altitude) is 10^{12} electrons/m^3, so the plasma resonance frequency would be 9 MHz. The value of μ in **Equation 1-2** approaches 0 as the operating frequency, f, approaches the plasma frequency. The group velocity of a propagating wave is proportional to μ, so μ = 0 implies that the wave slows down to zero which is obviously required at some point in the process of reflection since the propagation velocity reverses.

1:18. The total internal reflection from the ionosphere is similar to reflection of RF energy from a metal surface in that the re-radiation of the incident energy is caused by the free electrons in the medium. In both cases the wave penetrates to some depth. In a plasma the skin depth (the depth into the medium at which the electric field is 36.8% of its incident amplitude) is defined by:

$$\delta = \frac{\lambda_0 / 2\pi}{\sqrt{\left(fp/f \right)^2 - 1}} \qquad \textbf{1-3}$$

where λ_0 is the free space wavelength.

1:19. The major difference between ionospheric reflection and reflection from a metallic surface is that the latter has a uniform electron density while the ionospheric density increases roughly parabolic ally with altitude, with densities starting at essentially zero at stratospheric altitudes and rising to a peak at about 200 to 400 km. In the case of a metal there is no region where the wave propagates below the resonance frequency, while in the ionosphere the refractive index and therefore the wave velocity change with altitude until the plasma resonance frequency is reached. Of course if the RF frequency is above the maximum plasma resonance frequency the wave is never reflected and can penetrate the ionosphere and propagate into outer space. Otherwise what happens on a microscopic scale at the surface of a metal and on a macroscopic scale at the plasma resonance in the ionosphere is very similar in that energy is re-radiated by electrons which are responding to the incident electric field.

MOTIVATION FOR A SMALL FLEXIBLE IONOSPHERIC SOUNDER

1:20. Current applications of ionospheric sounders fall into two categories:

a. Support of operational systems, including shortwave radio communications and Over-The-Horizon (OTH) radar systems. This support can be in the form of predictions of propagating frequencies at given times and locations in the future (e.g., over the ensuing month) or the provision of real-time updates (updated as frequently as every 15 minutes) to detect current conditions such that system operating parameters can be optimized.

b. Scientific research to enable better prediction of ionospheric conditions and to understand the plasma physics of the solar-terrestrial interaction of the Earth's atmosphere and magnetic field with the solar wind.

1:21. There has been considerable effort in producing global models of ionospheric densities, temperature, chemical constitution, etc, such that a few sounder measurements could calibrate the models and improve the reliability of global predictions. It has been shown that if measurements are made within a few hundred kilometers of each other, the correlation of the measured parameters is very high [Rush, 1978]. Therefore a network of sounders spaced by less than 500 km can provide reliable estimates of the ionosphere over a 250 km radius around them.

1:22. The areas of research pursued by users of the more sophisticated features of the Digisonde® sounders include polar cap plasma drift, auroral phenomena, equatorial spread-F and plasma irregularity phenomena, and sporadic E-layer composition [Buchau et al., 1985; Reinisch 1987; and Buchau and Reinisch 1991]. There may be some driving technological needs (e.g., commercial or military uses) in some of these efforts, but many are simply basic research efforts aimed at better understanding the manifestations of plasma physics provided by nature.

1:23. The accurate measurement of all of the parameters, except frequency (it being precisely set by the system and need not be measured) depends heavily on the signal to noise ratio of the received signal. Therefore vertical incidence ionospheric sounders capable of acquiring high quality scientific data have historically utilized powerful pulse transmitters in the 2 to 30 kW range. The necessity for an extremely good signal to noise ratio is demanded by the sensitivity of the phase measurements to the random noise component added to the signal level. For instance, to measure phase to 1 degree accuracy requires a signal to noise ratio better than 40 dB (assuming a Gaussian noise distribution which is actually a best case), and measurement of amplitude to 10% accuracy requires over 20 dB signal to noise ratio. Of course, is it desirable that these measurements be immune to degradation from noise and interference and maintain their high quality over a large frequency band. This requires that at the lower end of the HF band the system's design has to overcome absorption, noise and interference, and poor antenna performance and still provide at least a 20 to 40 dB signal to noise ratio.

SIGNAL PROCESSING IN DIGISONDE-4D

General Considerations

1:24. Several advances in ionospheric sounding were made over the past four decades to move significantly beyond the basic pulse techniques developed in the 1930's. Introduced techniques include:

- Coherent integration of several pulses transmitted at the same frequency
- Spectral pulse integration applicable to moving reflectors
- Pulse compression for improved signal-to-noise ratio
- Multiple receiver arrays
- Transmission and reception of circularly polarized signals
- Frequency multiplexing for improved Doppler resolution
- Precision ranging on two closely separated frequencies
- Mitigation of RF Interference (RFI)
- Pulse modulation for twin frequency sounding

1:25. Like its Digisonde® predecessors, the Digisonde-4D simultaneously measures seven observable parameters of reflected (or in oblique incidence, refracted) signals received from the ionosphere:

1) Frequency
2) Range (or height for vertical incidence measurements)
3) Amplitude
4) Phase
5) Doppler Shift and Spread
6) Angle of Arrival
7) Wave Polarization

1:26. Because the physical parameters of the ionospheric plasma affect the way radio waves reflect from or pass through the ionosphere, it is possible by measuring all of these observable parameters at a number of discrete heights and discrete frequencies to map out and characterize the structure of the plasma in the ionosphere. Both the height and frequency dimensions of this measurement require hundreds of individual measurements to approximate the underlying continuous functions. The resulting measurement is called an ionogram and comprises a six dimensional measurement of signal amplitude vs. frequency and vs. height as shown in **Figure 1-8**.

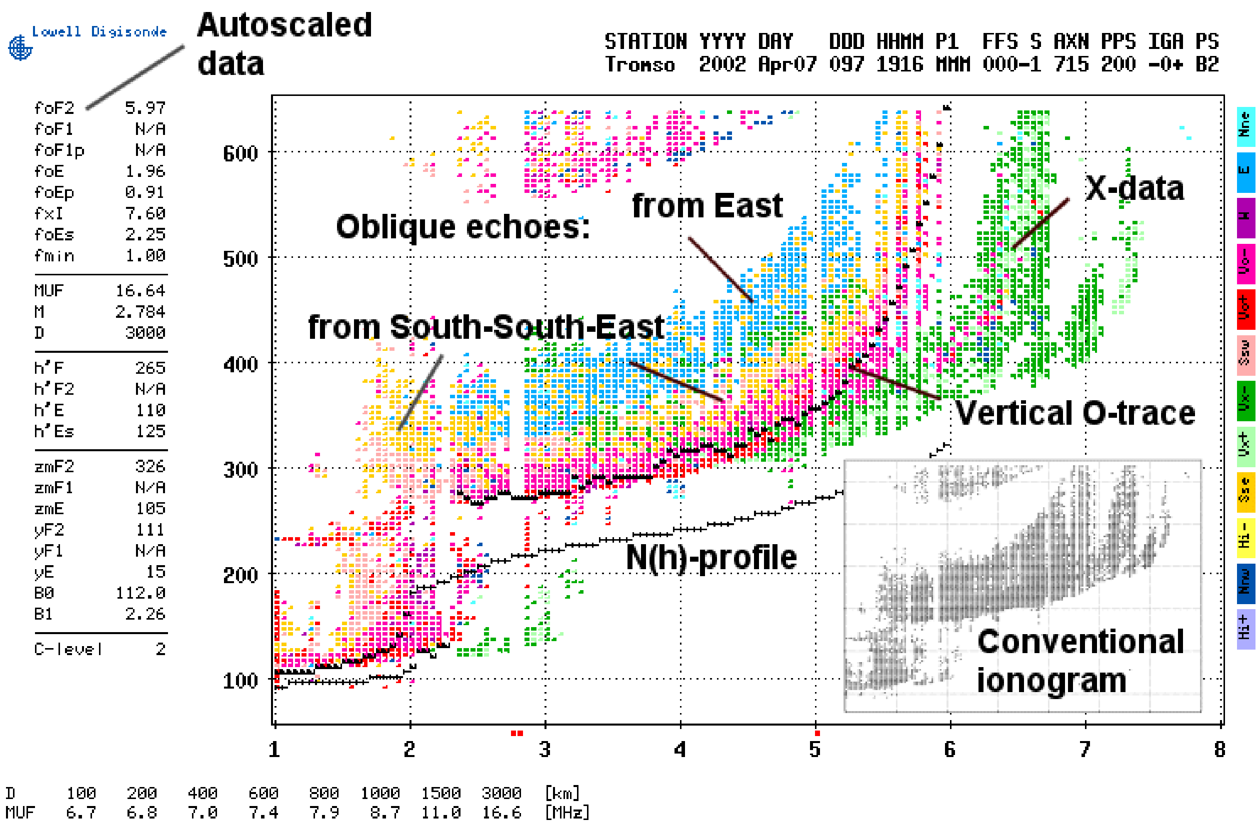

Figure 1-8: Six-Dimensional Ionogram

1:27. **Figure 1-8** is a six-dimensional display, with sounding frequency as the abscissa, virtual reflection height (simple conversion of time delay to range assuming propagation at 3×10^8 m/sec) as the ordinate, signal amplitude as the dot size, and echo status (polarization, Doppler shift, and angle of arrival) mapped into 12 available distinct colors. The wave polarizations are shown as two different color groups (the green scale, "neutral" colors showing extraordinary polarization, the red scale, "demanding attention" colors showing ordinary polarization. The angle of arrival is shown by different colors (using the "warm" scale for South and the "cold" scale for North), and the Doppler shift is indicated by the color shades. For comparison, the insert in **Figure 1-8** shows a conventional, three-dimensional ionogram with the signal amplitude shown as intensity. The left side of **Figure 1-8** shows a table of ionospheric characteristics scaled automatically by the ARTIST software.

Coherent Pulse Integration in Time Domain

1:28. Historically, first improvement in sounding technique was the coherent integration of several pulses transmitted at the same frequency. Two signals are coherent if, having a phase and amplitude, they are able to be added together (e.g., one radar pulse echo received from a target added to the next pulse echo received from the same target, thousandths of a second later). Two extreme cases of coherent summation may result a sum of zero (if the two signals are exactly out of phase with each other) or double the amplitude (if they are exactly in phase). Coherent integration of N signals can provide a factor of N improvement in power. This technique was first used in the Digisonde-128 [Bibl and Reinisch, 1975] and further expanded to the case of moving reflectors by employing Doppler integration as further discussed below in Paragraph 1:49 *et seq*.

Coded Pulses to Facilitate Pulse Compression Radar Techniques

1:29. Another general technique to improve on the simple pulse sounder is to stretch out the pulse by a factor of N, thus increasing the duty cycle so the pulse contains more energy without requiring a higher power transmitter (power x time = energy). However, lengthening the pulse deteriorates its range resolution properties. To maintain the higher range resolution of the simple short pulse, the long pulse can be phase modulated with a code to enable the receiver to create a synthetic pulse with the original (i.e., that of the short pulse) range resolution. Bi-phase, or phase reversal modulation was implemented in a network of sounders operated by the U.S. Navy in the 1960's using a 13-bit Barker Code.

1:30. The critical factor in the use of pulse compression waveforms for any radar type measurement is the correlation properties of the internal phase code. Phase codes proposed and experimented with included the Barker Code [Barker, 1953], Huffman Sequences [Huffman 1962], Convoluted Codes [Coll, 1961], Maximal Length Sequence Shift Register Codes (M-codes) [Sarwate and Pursley, 1980], or Golay's Complementary Sequences [Golay, 1961], which have been implemented in the VHF mesospheric sounding radar at Ohio State University [Schmidt et al., 1979] and in the DPS.

1:31. The Digisonde-4D is able to be miniaturized by lengthening the transmitted pulse beyond the pulse width required to achieve the desired range resolution where the radar range resolution is defined as,

$\Delta R = c / 2\beta$, where β is the system bandwidth of 30 kHz, or

$= cT / 2$ for a simple rectangular pulse waveform, with T being the width of a rectangular pulse of 33.333 μs **1-4**

The longer pulse allows a low voltage solid state amplifier to transmit an amount of energy equal to that transmitted by a high power pulse transmitter (energy = power x time, and power = V^2/R) without having to provide components to handle the high voltages required for tens of kilowatt power levels. The time resolution of the short pulse is provided by intrapulse phase modulation using programmable phase codes (user selectable and firmware expandable), the Complementary Codes, and M-codes are standard. The use of a Complementary Code pulse compression technique is described in this chapter, which shows that at 300 W of transmitter power the expected measurement quality is the same as that of a conventional sounder of about 500 kW peak pulse power.

1:32. The transmitted spread spectrum signal $s(t)$ is a biphase (180° phase reversal) modulated pulse. As illustrated in **Figure 1-9**, bi-phase modulation is a linear multiplication of the binary spreading code $p(t)$ (a.k.a. a chipping sequence, where each code bit is a "chip") with a carrier signal $\sin(2\pi f_0 t)$ or in complex form, $\exp[j2\pi f_0 t]$, to create a transmitted signal,

$$s(t) = p(t)\exp[j2\pi f_0 t] \quad \textbf{1-5}$$

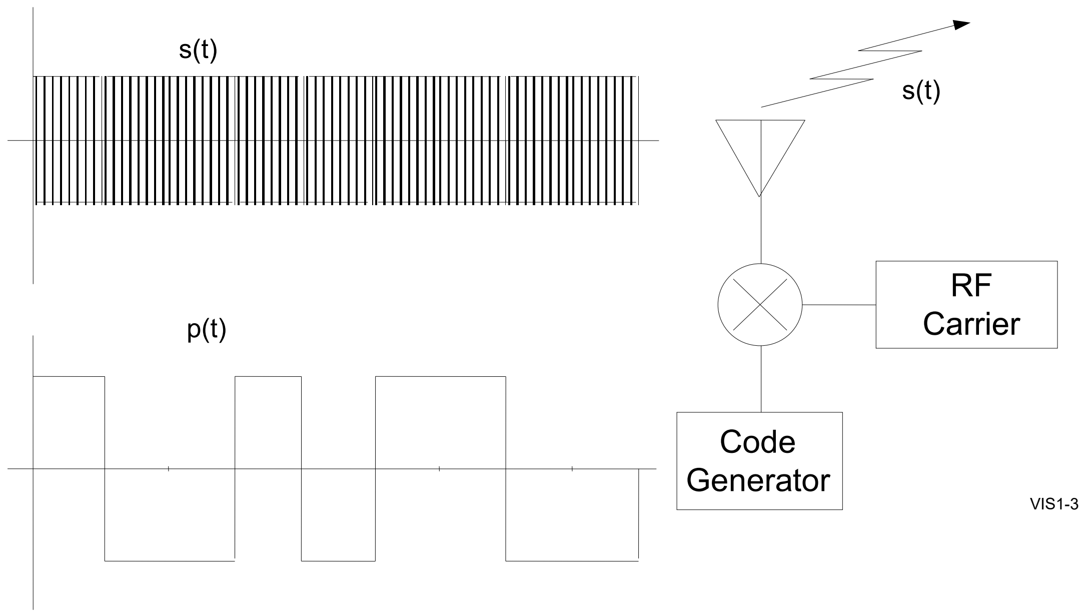

Figure 1-9: Generation of a Bi-phase Modulated Spread Spectrum Waveform

NOTE

Notation throughout this chapter will use *s*(*t*) as the transmitted signal, *r*(*t*) the received signal and *p*(*t*) as the chip sequence. Functions $r_1(t)$ and $r_2(t)$ will be developed to describe the signal after various stages of processing in the receiver.

The term *chip* is used rather than *bit* because for spread spectrum communications many chips are required to transmit one bit of message information, so a distinct term had to be developed. **Figure 1-10** on the following page depicts the modulation of a sinusoidal RF carrier signal by a binary code (notice that the code is a zero mean signal, i.e., centered around 0 volts amplitude). Since the mixer in **Figure 1-9** can be thought of as a mathematical multiplier, the code creates a 180° (π radians) phase shift in the sinusoidal carrier whenever p(t) is negative, since $-\sin(\omega t) = \sin(\omega t+\pi)$.

1:33. The binary spreading code is identical to a stream of data bits except that it is designed such that it forms a pattern with uniquely desirable autocorrelation function characteristics as described later in this chapter. The 16-bit Complementary Code pair used in the Digisonde-4D is 1,1,-1,1,1,1,1,-1,-1,1,1,1,-1,1,-1,-1 modulated onto the odd-numbered pulses and -1,-1,1,-1,-1,-1,-1,1,-1,1,1,1,-1,1,-1,-1 modulated onto the even-numbered pulses. This pattern of phase modulation chips is such that the frequency spectrum of such a signal (as shown in **Figure 1-10**) is uniformly spread over the signal bandwidth, thus the term “spread spectrum”. In fact, it is interesting to note that the frequency spectrum content of the spread spectrum signal used by the DPS and Digisonde-4D is identical to that of the higher peak power, simple short pulse used by the Digisonde-256, even though the physical pulse is 8 times longer. Since they have the same bandwidth, **Equation 1-4** would suggest that they have the same range resolution. It will be shown later in this chapter, that the ability of the Digisonde- 256 and the DPS to determine range (i.e., time delay), phase, Doppler shift and angle of arrival is also identical between the two systems, even though the transmitted waveforms appear to be vastly different.

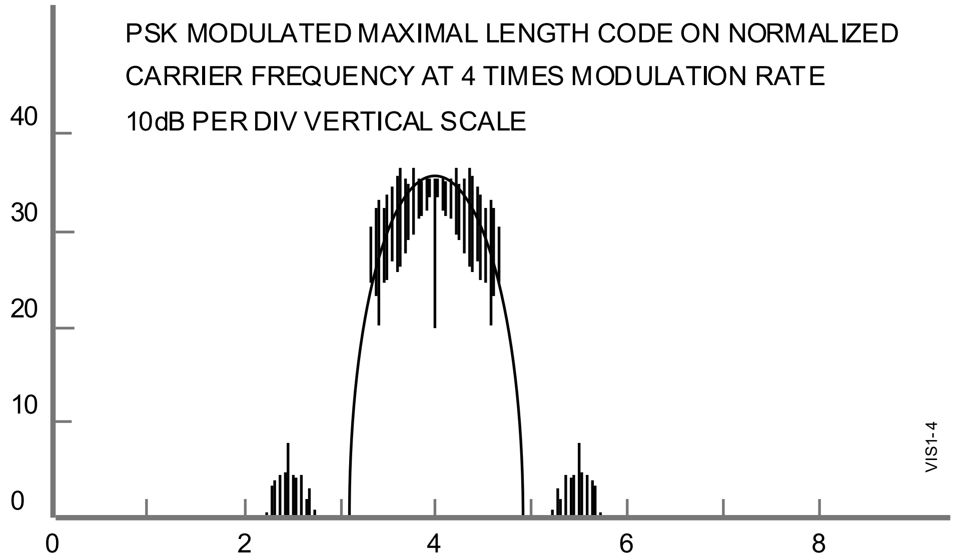

Figure 1-10: Spectral Content of a Spread-Spectrum Waveform

1:34. Since the transmitted signal would obscure the detection of the much weaker echo in a monostatic system the transmitted pulse must be turned off before the first E-region echoes arrive at the receiver which, as shown in **Figure 1-11**, is about T_E = 600 µsec after the beginning of the pulse. Also, since the receiver is saturated when the transmitter pulse comes on again, the pulse repetition frequency is limited by the longest time delay (listening interval) of interest, which is at least 5 msec, corresponding to reflections from 750 km altitude. To meet these constraints, a 533 µsec pulse made up of sixteen 33.33 µsec phase code chips (15 000 chips/sec) is selected which allows detection of ionospheric echoes starting at 80 km altitude. To avoid excessive range ambiguity, a highest pulse repetition frequency of 200 pps is chosen, which allows reception of the entire pulse from a virtual height of 670 km (the pulse itself is 80 km long) altitude before the next pulse is transmitted. This timing captures all but the highest multihop F-region echoes which are of little interest. Under conditions where higher unambiguous ranges, and therefore longer receiver listening intervals, are desired 100 pps can be selected under software control.

1:35. The key to the pulse compression technique lies in the selection of a spreading function, p(t), which possesses an autocorrelation function appropriate for the application. The ideal autocorrelation function for any remote sensing application is a Dirac delta function (or instantaneous impulse, δ(t) since this would provide perfect range accuracy and infinite resolution. However, since the Dirac delta function has infinite instantaneous power and infinite bandwidth, the engineering tradeoffs in the design of any remote sensing system mainly involve how far one can afford to deviate from this ideal (or how much one can afford to spend in more closely approximating this ideal) and still achieve the accuracy and resolution required. More to the point, for a discussion of a discrete time digital system such as the DPS, the ideal signal is a complex unit impulse function, with the phase of the impulse conveying the RF phase of the received signal. The many different pulse compression codes all represent some compromise in achieving this ideal, although each code has its own advantages, limitations, and trade-offs.

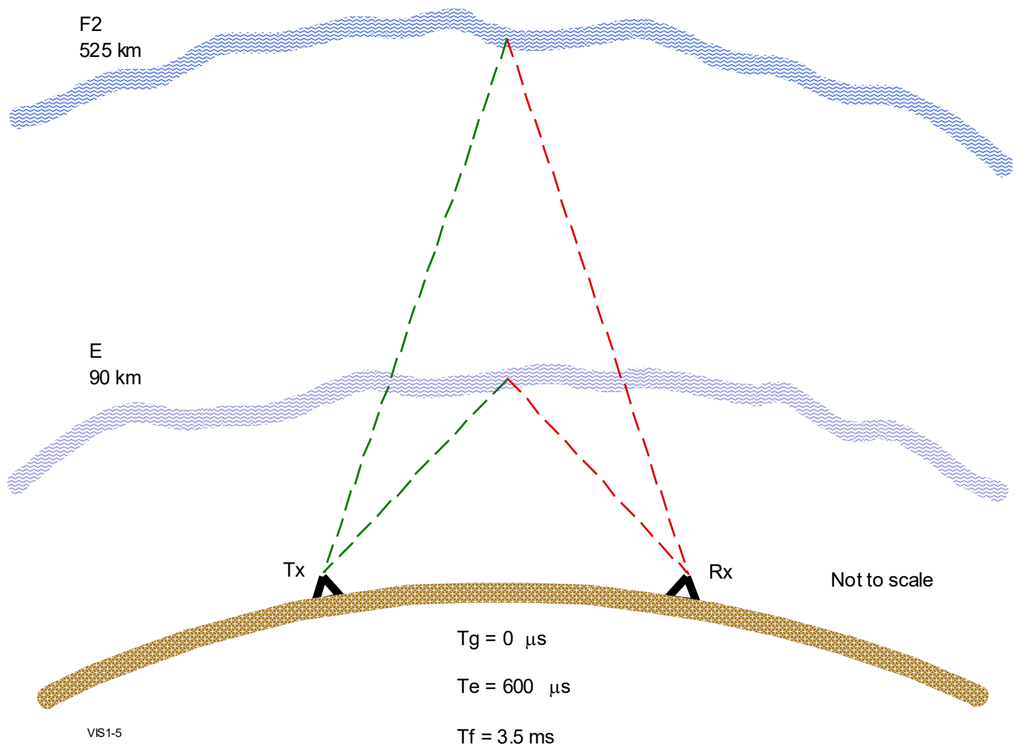

Figure 1-11: Natural Timing Limitations for Monostatic Vertical Incidence Sounding

1:36. The autocorrelation function as applied to code compression in the DPS is defined as:

$$R(k) = \sum_{n} p(n)p(n+k) \qquad \textbf{1-6}$$

Therefore the ideal as described above is $R(k) = \delta(k)$.

1:37. For ionospheric applications, the received spread-spectrum coded signal, $r(t)$, may be a superposition of several multipath echoes (i.e., echoes which have traveled over various propagation paths between the transmitter and receiver) reflected at various ranges from various irregular features in the ionosphere. The algorithm used to perform the code compression operates on this received multipath signal, $r(t)$, which is an attenuated and time delayed (possibly multiple time delays) replica of the transmitted signal $s(t)$ (from **Equation 1-5**), which can be represented as:

$$r(t) = \sum_{i=1}^{P} a_i s(t-\tau_i) \qquad \text{or}$$

$$r(t) = \sum_{i=1}^{P} a_i p(t-\tau_i)\exp[j2\pi f_0 t - \phi_i] \qquad \textbf{1-7}$$

where Σ shows that the P multipath signals sum linearly at the receive antenna, a_i is the amplitude of the ith multipath component of the signal, and τ_i is the propagation delay associated with multipath i. The carrier phase ϕ_i of each multipath could be expressed in terms of the carrier frequency and the time delay τ_i ; however, since the multiple carriers (from the various multipath components) cannot be resolved, while the delays in the complex code modulation envelope can be, a separate term, ϕ_i, is used. Next, when the carrier is stripped off of the signal, this RF phase term will be represented by a complex amplitude coefficient α_i rather than a_i.

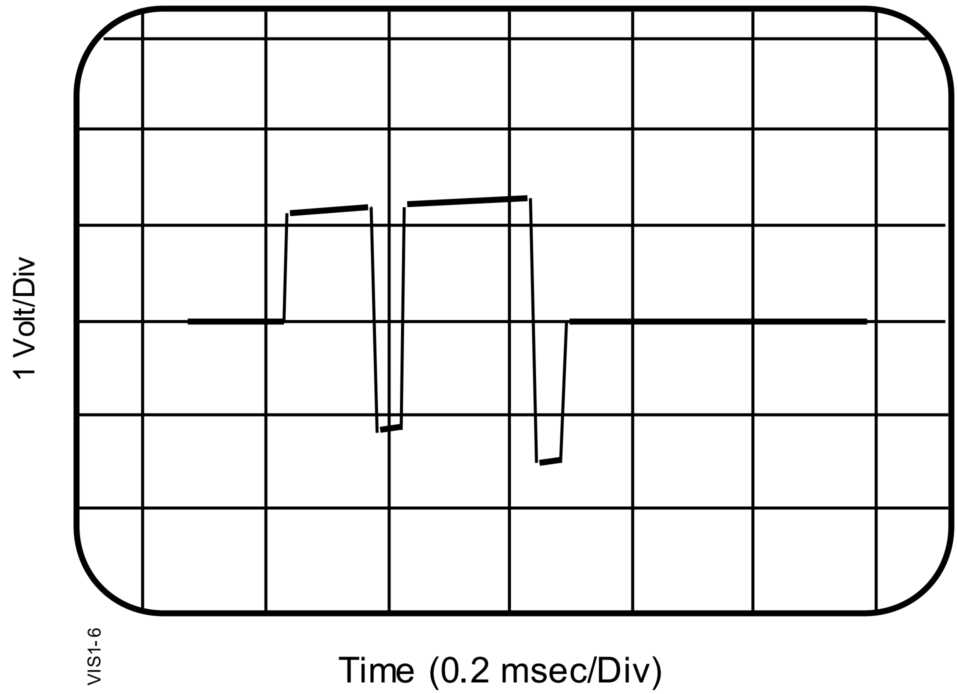

Figure 1-12: Conversion to Baseband by Undersampling

1:38. By down-converting to a baseband signal (a digital technique is shown in **Figure 1-12**), the carrier signal can be stripped away, leaving only the superposed code envelopes delayed by P multiple propagation paths. **Figure 1-12** presents one way to strip the carrier off a phase modulated signal. This is the screen display on a digital storage oscilloscope looking at the RF output from the DPS system operating at 3.5 MHz. Notice that the horizontal scan spans 2 msec, which if the oscilloscope was capable of presenting more than 14,000 resolvable points, would display 7,000 cycles of RF. The sample clock in the digital storage scope is not synchronized to the DPS, however, the digital sampling remains coherent with the RF for periods of several milliseconds. The analog signal is digitized at a rate such that each sample is made an integer number of cycles apart (i.e., at the same phase point) and therefore looks like a DC level until the phase modulation creates a sudden shift in the sampled phase point. Therefore the 180º phase reversals made on the RF carrier show up as DC level shifts, replicating the original modulating code exactly. The more hardware intensive method of quadrature demodulation with hardware components (mixers, power splitters and phase shifters) can be found in any communications systems textbook, such as [Peebles, 1979]. After removing the carrier, the modified r(t), now represented by $r_1(t)$ becomes:

$$r(t) = \sum_{i=1}^{P} \alpha_i p(t - \tau_i) \qquad \textbf{1-8}$$

where the carrier phase of each of the multipath components is now represented by a complex amplitude α_i which carries along the RF phase term, originally defined by ϕ_i in **Equation 1-7**, for each multipath. Since the pulse compression is a linear process and contributes no phase shift, the real and imaginary (i.e., in-phase and quadrature) components of this signal can be pulse compressed independently by cross-correlating them with the known spreading code $p(t)$. The complex components can be processed separately because the pulse compression (Equation 1–10) is linear and the code function, $p(n)$, is all real. Therefore the phase of the cross-correlation function will be the same as the phase of $r_1(t)$.

1:39. The classical derivation of matched filter theory [e.g., Thomas, 1964] creates a matched filter by first reversing the time axis of the function $p(t)$ to create a matched filter impulse response $h(t) = p(-t)$. Implementing the pulse compression as a linear system block (i.e., a "black box" with impulse response $h(t)$) will again reverse the time axis of the impulse response function by convolving $h(t)$ with the input signal. If neither reversal is performed (they effectively cancel each other) the process may be considered to be a cross-correlation of the received signal, $r(t)$ with the known code function, $p(t)$. Either way, the received signal, $r_2(n)$ after matched filter processing becomes:

$$r_2(n) = r_1(n) * h(n) = r_1(n) * p(-n) \qquad \textbf{1-9}$$

or by substituting **Equation 1-8** and writing out the discrete convolution, we obtain the cross-correlation approach,

$$r_2(n) = \sum_{i=1}^{P} \alpha_i \sum_{k=1}^{M} p(k-\tau_i)p(k-n) = \sum_{i=1}^{P} M\alpha_i \delta(n-\tau_i) \qquad \textbf{1-10}$$

where n is the time domain index (as in the sample number, n, which occurs at time $t = nT$ where T is the sampling interval), P is the number of multipaths, k is the auxiliary index used to perform the convolution, and M is the number of phase code chips. The last expression in **Equation 1-10**, the δ(n), is only true if the autocorrelation function of the selected code, $p(t)$, is an ideal unit impulse or "thumbtack" function (i.e., it has a value of M at correlation lag zero, while it has a value of zero for all other correlation lags). So, if the selected code has this property, then the function $r_2(n)$, in **Equation 1-9** is the impulse response of the propagation path, which has a value α_i, (the complex amplitude of multipath signal i) at each time $n = \tau_i$ (the propagation delay attributable to multipath i).

1:40. **Figure 1-13** illustrates the unique implementation of **Equation 1-10** employed for compression of Complementary Sequence waveforms. A 4-bit code is used in this figure for ease of illustration but arbitrarily long sequences can be synthesized (the DPS4D uses a Complementary Code 16-chips long). It is necessary to transmit two encoded pulses sequentially, since the Complementary Codes exist in pairs, and only the pairs together have the desired autocorrelation properties. **Equation 1-8** (the received signal without its sinusoidal carrier) is represented by the input signal shown in the upper left of **Figure 1-13**. The time delay shifts (indexed by n in **Equation 1-10** are illustrated by shifting the input signal by one sample period at a time into the matched filter. The convolution shifts (indexed by k in **Equation 1-10** sequence through a multiply-and-accumulate operation with the four ± 1 tap coefficients. The accumulated value becomes the output function $r_2(n)$ for the current value of n. The two resulting expressions for **Equation 1-10** (an $r_2(n)$ expression for each of the two Complementary Codes) are shown on the right with the amplitude M=4 clearly expressed. The non-ideal approximation of a delta function, $\delta(n-\tau_i)$, is apparent from the spurious a and –a amplitudes. However, by summing the two $r_2(n)$ expressions resulting from the two Complementary Codes, the spurious terms are cancelled, leaving a perfect delta function of amplitude $2M$.

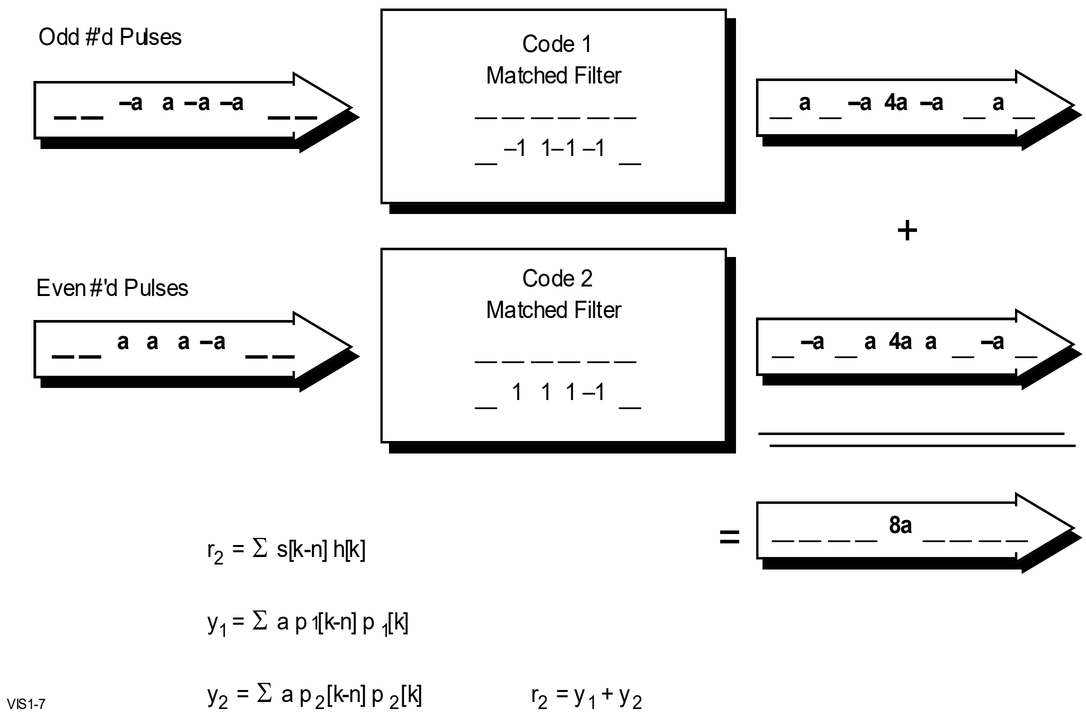

Figure 1-13: Illustration of Complementary Code Pulse Compression

1:41. The amplitude coefficient M in **Equation 1-10** is tremendously significant! It is what makes spread-spectrum techniques practical and useful. The M means that a signal received at a level of 1 µV would result in a compressed pulse of amplitude M µV, a gain of $20 \cdot \log_{10}(M)$ dB. Unfortunately, the benefits of all of that gain are not actually realized because the RMS amplitude of the random noise (which is incoherently summed by **Equation 1-10**) which is received with the signal goes up by a factor of $\sqrt{M}$. However, this still represents a power gain (since power = amplitude^2) equal to M, or $10 \cdot \log_{10}(M)$ dB. The $\sqrt{M}$ coefficient for the incoherent summation of multiple independent noise samples is developed more thoroughly in the following section on Coherent Spectral Integration, but the factor of M-increase for the coherent summation of the signal is clearly illustrated in **Figure 1-13**.

1:42. The next concern is that the pulse compression process is still valid when multiple signals are superimposed on each other as occurs when multipath echoes are received. It seems likely that multiple overlapping signals would be resolved since **Equation 1-9** and the free space propagation phenomenon are linear processes, so the output of the process for multiple inputs should be the same as the sum of the outputs for each input signal treated independently. This linearity property is illustrated in **Figure 1-14**. Two 4-chip input signals (a 4-bit code is used in this figure for ease of illustration), one three times the amplitude of the other, are overlapped by two chips at the upper left of the illustration. After pulse compression, as seen in the lower right, the two resolved components, still display a 3:1 amplitude ratio and are separated by two chip periods.

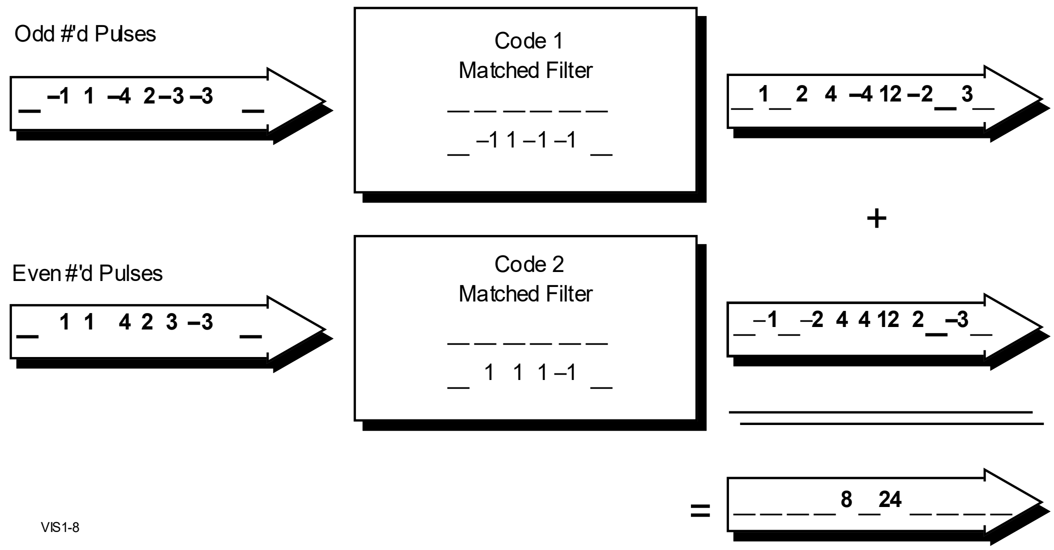

Figure 1-14: Resolution of Overlapping Complementary Coded Pulses

1:43. The phase of the received signal is detected by quadrature sampling; but, how is the complex quantity, α_i, or $a_i \cdot \exp[\phi_i]$, related to the RF phase (ϕ_i) of each individual multipath component? It can be shown that this phase represents the phase of the original RF signal components exactly. As shown in **Equations 1-11 and 1-12**, the down-converting (frequency translation) of $r(t)$ by an oscillator, $\exp[j2\pi f_0 t]$ results in:

$$r_1(t) = \sum_{i=0}^{P} a_i p(t-\tau_i) \exp\left[j2\pi f_0 t - j\phi_i\right] \exp\left[j2\pi f_0 t\right] = \sum_{i=0}^{P} a_i p(t-\tau_i) \exp\left[j\phi_i\right] \qquad \textbf{1-11}$$

or

$$r_1(t) = \sum_{i=0}^{P} \alpha_i p(t-\tau_i), \qquad \text{where } \alpha_i = a_i \exp\left[j\phi_i\right] \text{ is a complex amplitude} \qquad \textbf{1-12}$$

This signal maintains the parameter ϕ_i which is the original phase of each RF multipath component. Note that the oscillator is defined as having zero phase ($\exp[j2\pi f_0 t]$).

1:44. Due to many possible mechanisms the pulse compression process will have imperfections, which may cause energy reflected from any given height to leak or spill into other heights to some degree. This leakage is the result of channel induced Doppler, mathematical imperfection of the phase code (except in the Complementary Codes which are mathematically perfect) and/or imperfection in the phase and amplitude response of the transmitter or receiver. Several codes were simulated and analyzed for leakage from one height to another and for tolerance to signal distortion caused by band-limiting filters. All of the pulse compression algorithms used are cross-correlations of the received signal with a replica of the unit amplitude code known to have been sent. Therefore, since **Equation 1-10** represents a "cross-correlation" (the unit amplitude function $p(t)$ is cross-correlated with the complex amplitude weighted version) of $p(k)$ with itself, it is the leakage properties of the autocorrelation functions which are of interest.

1:45. The autocorrelation function of the Complementary phase code is shown in **Figure 1-15**.

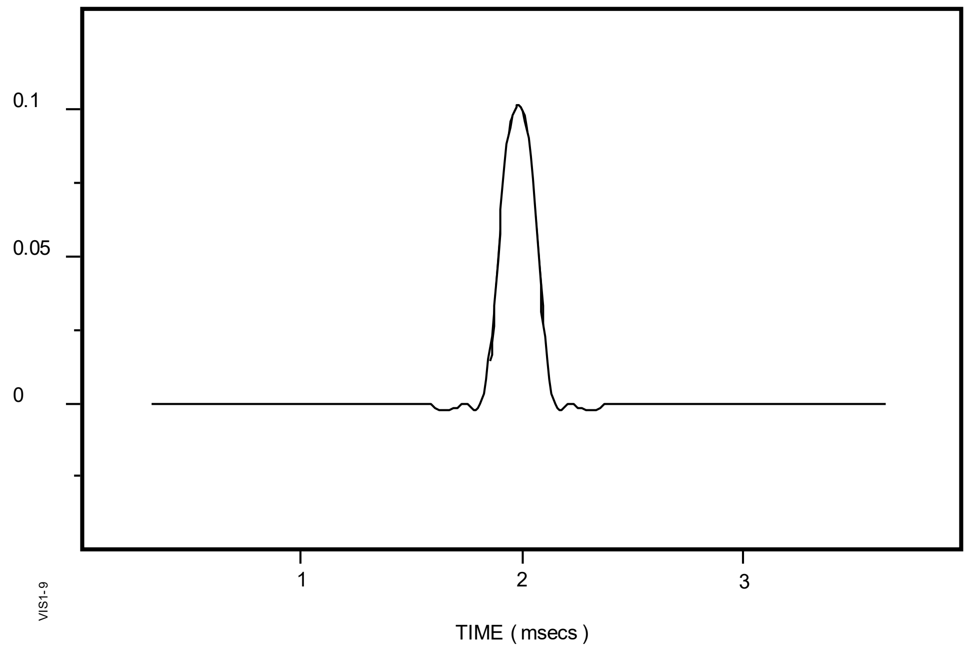

Figure 1-15: Autocorrelation Function of the Complementary Series

1:46. Since the Complementary Series pairs do not leak energy into any other height bin this phase code scheme seemed optimum and was chosen for the Digisonde-4D vertical incidence measurement mode in order to provide the maximum possible dynamic range in the measurement. If there is too much leakage (for instance at a –20 dB level) then stronger echoes would create a “leakage noise floor” in which weaker echoes could not be detectable.

1:47. Even though the Complementary Code pairs are theoretically perfect, the physical realization of this signal may not be perfect. The Complementary Code pairs achieve zero leakage by producing two compressed pulses (one from each of the two codes) which have the same absolute amplitude spurious correlation peaks (or leakage) at each height, but all except the main correlation peak are inverted in phase between the two codes. Therefore, simply by adding the two pulse compression outputs, the leakage components disappear. Since the technique relies on the phase distance of the propagation path remaining constant between the sequential transmission of the two coded pulses, the phase change vs. time caused by any movement in the channel geometry (i.e., Doppler shift imposed on the signal) can cause imperfect cancellation of the two complex amplitude height profile records. Therefore, the Complementary Code is particularly sensitive to Doppler shifts since channel induced phase changes which occur between pulses will cause the two pulse compressions to cancel imperfectly, while with most other codes we are only concerned with channel induced phase changes within the duration of one pulse. However, if given the parameters of the propagation environment, we can calculate the maximum probable Doppler shift, and determine if this yields acceptable results for vertical incidence sounding.

1:48. With 200 pps, the time interval between one pulse and the next is 5 msec. If one pulse is phase modulated with the first of the Complementary Codes, while the next pulse has the second phase code, the interval over which motions on the channel can cause phase changes is only 5 msec. The degradation in leakage cancellation is not significant (i.e., less than –15 dB) until the phase has changed by about 10 degrees between the two pulses. The Doppler induced phase shift is:

$$\Delta f = 2\pi T f_D \text{ radians} \qquad \textbf{1-13}$$

where f_D is the Doppler shift in Hz and T is the time between pulses.

The Doppler shift can be calculated as:

$$f_D = (f_0 v_r)/c \qquad \text{(or for a 2-way radar propagation path)} \qquad \textbf{1-14}$$

$$f_D = (2 f_0 v_r)/c$$

where f_0 is the operating frequency and v_r is the radial velocity of the reflecting surface toward or away from the sounder transceiver. The radial velocity is defined as the projection of the velocity of motion (**v**) on the unit amplitude radial vector (**r**) between the radar location and the moving object or surface, which in the ionosphere is an isodensity surface. This is the scalar product of the two vectors:

$$v_r = \mathbf{v} \cdot \mathbf{r} = |\mathbf{v}| \cos(\theta) \qquad \textbf{1-15}$$

A phase change of 10° in 5 msec would require a Doppler shift of about 5.5 Hz, or 160 m/sec radial velocity (roughly half the speed of sound), which seldom occurs in the ionospheric except in the polar cap region. The 16-chip complementary phase code pulse compression and coherent summation of the two echo profiles provides a 32-fold increase in signal amplitude, and a 8-fold increase in noise amplitude for a net signal processing gain of 15 dB. The Doppler integration, as described later can provide another 21 dB of SNR (signal to noise ratio) enhancement, for a total signal processing gain of 36 dB, as shown by the following discussion.

Coherent Spectral Integration

1:49. In ionospheric sounding, the motion of the ionosphere often makes it impossible to integrate by simple coherent summation for longer that a fraction of a second, although it is not rare to receive coherent echoes for tens of seconds. However, with the application of spectral integration (which is a byproduct of the Fourier transform used to create a Doppler spectrum) it is possible to coherently integrate pulse echoes for tens of seconds under nearly all ionospheric conditions [Bibl and Reinisch, 1978]. The integration may progress for as long a time as the rate of change of phase remains constant (i.e., there is a constant Doppler shift, Δf). The Digisonde-128PS, and all subsequent versions perform this spectral integration.

1:50. The pulse compression described above occurs with each pulse transmitted, so the SNR improvement for 16-bit complementary phase codes is achieved without even sending another pulse. However, if the measurement can be repeated phase coherently, the multiple returns can be coherently integrated to achieve an even more detectable or "cleaner" signal. This process is essentially the same as averaging, but since complex signals are used, signals of the same phase are required if the summation is going to increase the signal amplitude. If the phase changes by more than 90° during the coherent integration then continued summation will start to decrease the integrated amplitude rather than increase it. However, if transmitted pulses are being reflected from a stationary object at a fixed distance, and the frequency and phase of the transmitted pulses remain the same, then the phase and amplitude of the received echoes will stay the same indefinitely.

1:51. The coherent summation of N echo signals causes the signal amplitude, to increase by N, while the incoherent summation of the noise amplitude in the signal results in an increase in the noise amplitude of only $\sqrt{N}$. Therefore with each N pulses integrated, the SNR increases by a factor of $\sqrt{N}$ in amplitude which is a factor of N in power. This improvement is called signal processing gain and can be defined best in decibels (to avoid the confusion of whether it is an amplitude ratio or a power ratio) as:

$$\text{Processing Gain} = 20\frac{S_p/Q_p}{S_i/Q_i} \quad \textbf{1-16}$$

where S_i is the input signal amplitude, Q_i the input noise amplitude, S_p the processed signal amplitude, and Q_p the processed noise amplitude. Q is chosen for the random variable to represent the noise amplitude, since N would be confusing in this discussion. This coherent summation is similar to the pulse compression processing described in the preceding section, where N, the number of pulses integrated is replaced by M, the number of code chips integrated.

1:52. Another perspective on this process is achieved if the signal is normalized during integration, as is often done in an FFT algorithm to avoid numeric overflow. In this case S_p is nearly equal to S_i, but the noise amplitude has been averaged. Thus by invoking the central limit theorem [Freund, 1967 or any basic text on probability], we would expect that as long as the input noise is a zero mean (i.e., no DC offset) Gaussian process, the averaged RMS noise amplitude, σ_{np} (p for processed) will approach zero as the integration progresses, such that after N repetitions:

$$\sigma_{np}^2 = \sigma_{ni}^2 / N \quad \text{(the variance represents power)} \quad \textbf{1-17}$$

1:53. Since the SNR can be improved by a variable factor of N, one would think, we could use arbitrarily weak transmitters for almost any remote sensing task and just continue integrating until the desired signal to noise ratio (SNR) is achieved. In practical applications the integration time limit occurs when the signal undergoes (or may undergo, in a statistical sense) a phase change of 90°. However, if the signal is changing phase linearly with time (i.e., has a frequency shift, $\Delta\omega$), the integration time may be extended by Doppler integration (also known as, spectral integration, Fourier integration, or frequency domain integration). Since the Fourier transform applies the whole range of possible phase shifts needed to keep the phase of a frequency shifted signal constant, a coherent summation of successive samples is achieved even though the phase of the signal is changing. The unity amplitude phase shift factor, $e^{-j\omega t}$, in the Fourier Integral (shown as **Equation 1–18**) varies the phase of the signal $r(t)$ as a function of time during integration. At the frequency (ω) which stabilizes the phase of the component of $r(t)$ with frequency ω over the interval of integration (i.e., makes $r(t)\, e^{-j\omega t}$ coherent) the value of the integral increases with time rather than averaging to zero, thus creating an amplitude peak in the Doppler spectrum at the Doppler line which corresponds to ω:

$$\mathbf{F}[r(t)] = R(\omega) = \int r(t) e^{-j\omega t} dt \quad \textbf{1-18}$$

1:54. Does this imply that an arbitrarily small transmitter can be used for any remote sensing application, since we can just integrate long enough to clearly see the echo signal? To some extent this is true. There is no violation of conservation of energy in this concept since the measurement simply takes longer at a lower power; however, in most real world applications, the medium or environment will change or the reflecting surface will move such that a discontinuous phase change will occur. Therefore a system must be able to detect the received signal before a significant movement (e.g., a quarter to a half of a wavelength) has taken place. This limits the practical length of integration that will be effective.

1:55. The discrete time (sampled data) processing looks very similar (as shown in **Equation 1-19**). For a signal with a constant frequency offset (i.e., phase is changing linearly with time) the integration time can be extended very significantly, by applying unity amplitude complex coefficients before the coherent summation is performed. This stabilizes the phase of a signal which would otherwise drift constantly in phase in one direction or the other (a positive or negative frequency shift), by adding or subtracting increasingly larger phase angles from the signal as time progresses. Then when the phase shifted complex signal vectors are added, they will be in phase as long as that set of "stabilizing" coefficients progress negatively in phase at the same rate as the signal vector is progressing positively. The Fourier transform coefficients serve this purpose since they are unity amplitude complex exponentials (or phasors), whose only function is to shift the phase of the signal, $r(n)$, being analyzed.

1:56. Since the Digisonde® sounders have always done this spectral integration digitally, the following presentation will cover only discrete time (sampled data rather than continuous signal notation) Fourier analysis.

$$\mathbf{F}\left[r(t)\right] = R(k) = \sum_{n=0}^{N} r[n] e^{-jnk2\pi / NT} \qquad \textbf{1-19}$$

where $r[n]$ is the sampled data record of the received signal at one certain range bin, n is the pulse number upon which the sample $r[n]$ was taken, T is the time period between pulses, N is the number of pulses integrated (number of samples $r[n]$ taken), and k is the Doppler bin number or frequency index. Since a Doppler spectrum is computed for each range sampled, we can think of the Fourier transforms as $\mathbf{F}_{56}[\omega]$ or $\mathbf{F}_{192}[\omega]$ where the subscripts signify with which range bin the resulting Doppler spectra are associated.

1:57. By processing every range bin first by pulse compression then by coherent integration, all echoes from each range have gained at least 21 dB of processing gain (depending on the length of integration) before any attempt is made to detect them.

NOTE

Further explanation of Equation 1–19 which can be gathered from any good reference on the Discrete Fourier Transformation, such as [Openheim & Schaefer, Prentice Hall, 1975], follows. The total integration time is NT, where T is the sampling period (in the Digisonde-4D, the time period between transmitted pulses). The frequency spacing between Doppler lines, i.e., the Doppler resolution, is 2π/NT rads/sec (or 1/NT Hz) and the entire Doppler spectrum covers 2π/T rad/sec (with complex input samples this is ± π/T, but with real input samples the positive and negative halves of the spectra are mirror image replicas of each other, so only π/T rad/sec are represented).

1:58. What is coherently integrated by the Fourier transformation in the Digisonde-4D (as in any pulse-Doppler radar) is the time sequence of complex echo amplitudes received at the same range (or height) that is, at the same time delay after each pulse is transmitted. **Figure 1-16** shows data layout with range or time delay vertically and pulse number (typically 32 to 128 pulses are transmitted) horizontally which hold the received samples as they are acquired. After each pulse is transmitted, one column is filled from the bottom up at regular sampling intervals, as the echoes from progressively higher heights are received (33.3 msec/5 km). These columns of samples are referred to as height profiles, which are not to be confused with electron density profiles, but rather mirror the radar terminology of a "slant range profile" (range becomes height for vertical incidence sounding) which is simply the time record of echoes resulting from a transmitted pulse. A height profile is simply a column of numeric samples which may or may not represent any reflected energy (i.e., they may contain only noise).

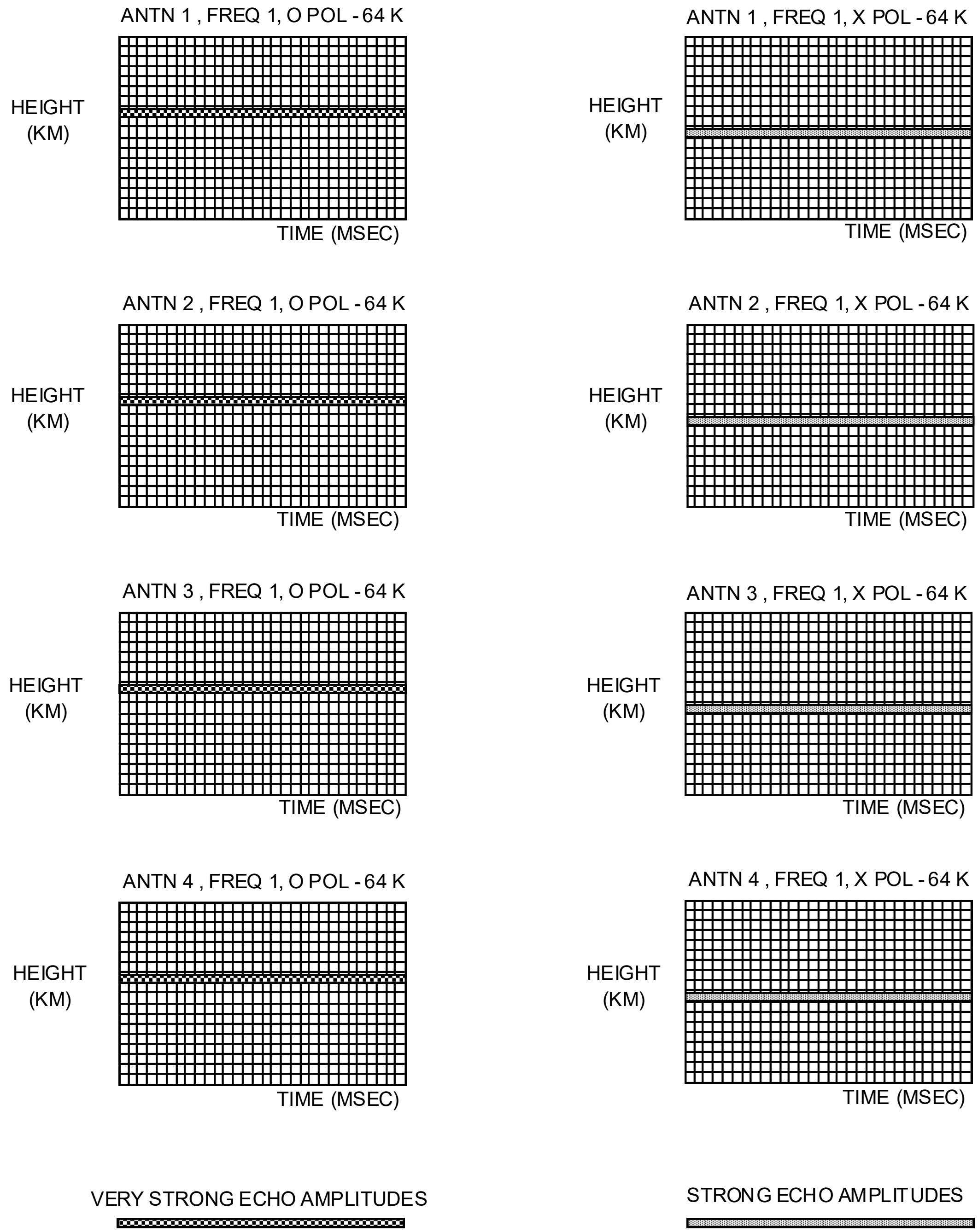

Figure 1-16: Eight Coherent Parallel Buffers for Simultaneous Integration of Spectra

Complex Windowing Function

1:59. With T, the sampling period between subsequent samples of the same coherent process, i.e., the same hardware parameters) defined by the measurement program, the first element of the Discrete Fourier Transform (i.e., the amplitude of the DC component) will have a spectral width of $1/NT$. This spectral resolution may be so wide that all Doppler shifts received from the ionosphere fall into this one line. For instance, in the mid-latitudes it is very rare to see Doppler shifts of more that 3 Hz, yet with a ±50 Hz spectrum of 16 lines, the Doppler resolution is 6.25 Hz, so a 3 Hz Doppler shift would still appear to show "no movement". For sounding, it would be much more interesting if instead of a DC Doppler line, a +3.25 Hz and a –3.25 Hz line were produced, such that even very fine Doppler shifts would indicate whether the motion was up or down. The DC line is a seemingly unalterable characteristic of the FFT method of computing the Discrete Fourier Transform, yet with a true DFT algorithm the Fourier transform coefficients can be chosen such that, the centre of the Doppler lines analyzed can be placed wherever the designer desires them to be. What was needed was a –½ Doppler line shift which would be correct for any value of N or T.

1:60. Because the end samples in the sampled time domain function are random, a tapering window had to be used to control the spurious response of the Doppler spectrum to below –40 dB (to keep the SNR high enough to not degrade the phase measurement beyond 1°). Therefore a Hanning function, H(n), which is a real function, was chosen and implemented early in the DPS development. The reader is referred to [Oppenheim and Schafer, 1975] for the definition and applications of the Hanning function. The solution to achieving the ½ Doppler line shift was to make the Hanning function amplitudes complex with a phase rotation of 180° during the entire time domain sampling period NT. The new complex Hanning weighting function is applied simply by performing complex rather than real multiplications. This implements a single-sideband frequency conversion of ½ Doppler line before the FFT is performed. In the following equation, each received multipath signal has only one spectral component ($k = D_i$) such that it can be represented as, $\alpha_i \exp[j2\pi nD_i]$:

$$r(n) = \{\sum_{i=1}^{P} \alpha_i \exp[-j2\pi(nD_i)\} \, |H(n)| \exp[-j2\pi(n/2NT)]$$

$$= |H(n)| \sum_{i=1}^{P} \alpha_i \exp[-j2\pi(nD_i + n/2NT)) \qquad \textbf{1-20}$$

Multiplexing

1:61. When sending the next pulse, it need not be transmitted at the same frequency, or received on the same antenna with the same polarization. With the Digisonde-4D it is possible to "go off" and measure something else, then come back later and transmit the same frequency, antenna and polarization combination and fill the second column of the coherent integration buffer, as long as the data from each coherent measurement is not intermingled (all samples integrated together must be from the same coherent statistical process). In this way, several coherent processes can be integrated at the same time. **Figure 1-16** shows eight coherent buffers, independently collecting the samples for two different polarizations and four antennas. This can be accomplished by transmitting one pulse for each combination of antenna and polarization while maintaining the same frequency setting (to also integrate a second frequency would require eight more buffers), in which case, each subsequent column in each array will be filled after each eight pulses are transmitted and received. This multiplexing continues until all of the buffers are filled with the desired number of pulse echo records. The DPS can keep track of 64 separate buffers, and each buffer may contain up to 32 768 complex samples. The term "pulse" is used generically here. For Complementary Coded waveforms a pulse actually requires two pulses to be sent. However, in both cases, after each pulse compression, one complex amplitude synthesized pulse, $r_2(n)$ in **Equation 1-10** which is equivalent to a 67 μsec rectangular pulse exists which can be placed into the coherent buffer.

1:62. The full buffers now contain a record of the complex amplitude received from each range sampled. Most of these ranges have no echo energy; only externally generated manmade and natural noise or interference from radio transmitters. If a particular ionospheric layer is providing an echo, each height profile will have significant amplitude at the height corresponding to that layer. By Fourier transforming each <u>row</u> of the coherent buffer a Doppler spectrum describing the radial velocity of that layer will be produced. Notice that the sampling frequency <u>at that layer</u> is less than or equal to the pulse repetition frequency (on the order of 100 Hz).

1:63. After the sequence of N pulses is processed, the pulse compression and Doppler integration have resulted in a Doppler spectrum stored in memory for each range bin, each antenna, each polarization, and each frequency measured. The program now scans through each spectrum and selects the largest one amplitude per height. This amplitude is converted to a logarithmic magnitude (dB units) and placed into a new one-dimensional array representing a height profile containing only the maximum amplitude echoes. This technique of selecting the maximum Doppler amplitude at each height is called the modified maximum method, or MMM. If the MMM height profile array is plotted for each frequency step made, this results in an ionogram display, such as the one shown in **Figure 1-17**.

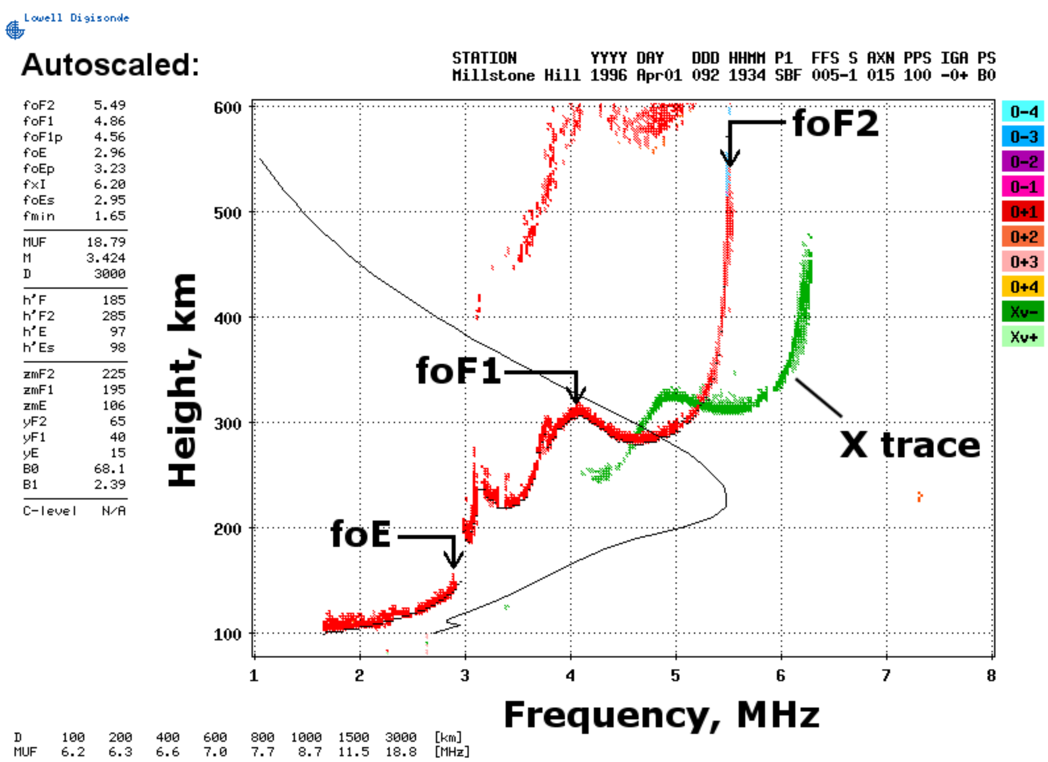

Figure 1-17: Ionogram Consisting of Amplitudes of Maximum Doppler Lines

Radio Frequency Interference Mitigation (RFIM)

1:64. Except for the FM/CW chirp sounder which operates well on transmitter power levels of 10 to 100 W (peak power) the above techniques and cited references typically employ a 2 to 30 kW peak power pulse transmitter. This power is needed to get sufficient signal strength to overcome an atmospheric noise environment which is typically 20 to 50 dB (CCIR Noise Tables) above thermal noise (defined as kTB, the theoretical minimum noise due to thermal motion, where k = Boltzman's constant, T = temperature in °K, and B = system bandwidth in Hz). More importantly, however, since ionogram measurements require scanning of the entire propagating band of frequencies in the 0.5 to 20 MHz RF band (up to 45 MHz for oblique measurements), the sounder receiver will encounter broadcast stations, ground-to-air communications channels, HF radars, ship-to-shore radio channels and several very active radio amateur bands which can add as much as 60 dB more background interference. Therefore, the sounder signal must be strong enough to be detectable in the presence of these large interfering signals.

1:65. To make matters worse, a pulse sounder signal must have a broad bandwidth to provide the capability to accurately measure the reflection height, therefore the receiver must have a wide bandwidth, which means more unwanted noise is received along with the signal. The noise is distributed quite evenly over bandwidth (i.e., white), while interfering signals occur almost randomly (except for predictably larger probabilities in the broadcast bands and amateur radio bands) over the bandwidth. Thus a wider-bandwidth receiver receives proportionally more uniformly distributed noise and the probability of receiving a strong interfering signal also goes up proportionally with increased bandwidth.

1:66. The 33 μs wide chips of the DPS transmitter pulses imply a transmission bandwidth of 30 kHz requiring a receiver bandwidth of at least 30 kHz. This large bandwidth makes the receiver susceptible to a variety of "contaminating" radio emissions that are received together with the signal. **Figure 1-18** illustrates the typical situation when a wideband signal is mixed with two types of radio contamination, wideband background noise and narrow-band interferers.

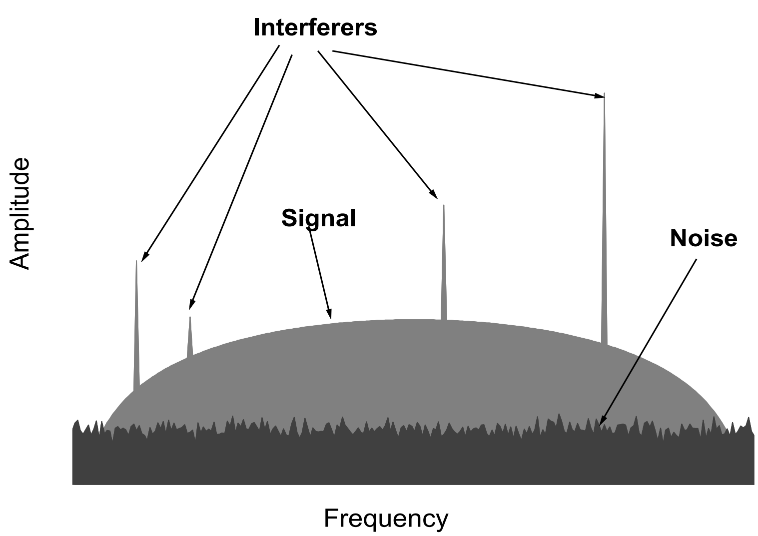

Figure 1-18: Wideband Received Signal Spectrum Contaminated by Interferences and Background Noise.

1:67. Effective methods for mitigating the background noise exist such as signal integration/accumulation, inter-pulse phase switching, pulse modulation, or increased transmission power, but removing narrow-band interferers poses a significant challenge. Such interferers are typically signals from other transmitters, in many cases broadcasting stations, with unpredictable occurrences at a priori unknown frequencies.

1:68. To largely suppress these narrow-band interferers we implemented the digital RFIM technique, which is based on a patented technique developed by Bibl [2005]. This technique determines (a) the exact frequency with sub-frequency spectral resolution of the largest contributor to the spectrum of the input signal, (b) amplitude and phase of the found contributor by using a single-line spectral analysis of the input signal at the determined frequency, and then (c) subtracts the interferer signal from the input signal in the time domain, and (d) repeats the algorithm for the next biggest interferer, etc.

1:69. **Figure 1-19** illustrates the RFIM performance in a lab test configuration with a coherent interference signal infused at 20 dB above the loopback test signal. The upper panel in **Figure 1-19** displays the Fourier spectrum of the Digisonde® signal (16-chip phase-coded pulse). The lower panel shows the spectrum of the same signal with the added interferer appearing as a spike near 16 kHz.

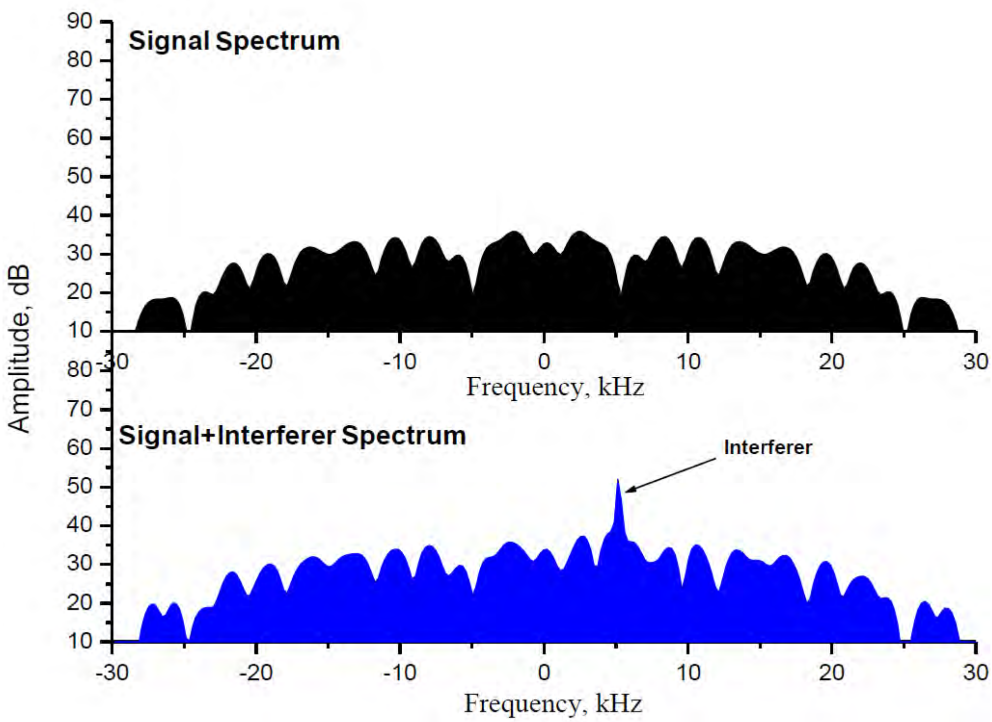

Figure 1-19: Spectrum of the Received Signal Without Interferer (Top) and With Interferer (Bottom).

1:70. The objective of the RFI mitigation algorithm is to remove the interferer signal before any further signal processing is done. To subtract this interference signal from the input signal requires knowledge of its exact frequency, phase, and amplitude. **Figure 1-20** shows the spectrum of a truncated monochromatic wave. The width of the main spectral peak is inversely proportional to the length of the time period over which the spectrum is calculated.

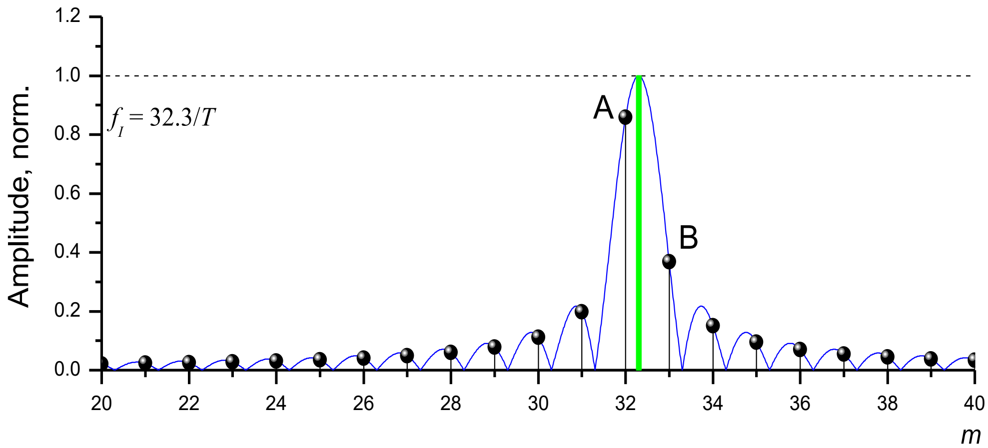

Figure 1-20: Spectrum of a Truncated CW Signal.

1:71. Conventional DFT algorithms calculate the spectral amplitudes of the integer-indexed frequencies that are multiples of $1/T$ where T is the coherent integration time. In general, the interferer frequency f_I will not be a harmonic of $1/T$, i.e., $f_I \neq m/T$ (**Figure 1-20**). The frequency f_I is given by:

$$f_I = f_A + \frac{1}{T} \cdot \frac{B}{A+B}, \qquad \textbf{1-21}$$

where f_A is the frequency of the stronger of the two strongest spectral components, and A and B are their amplitudes. We have experimentally verified that this algorithm works reliably. Once the precise frequency is known, a single-line discrete Fourier transformation determines the amplitude and phase of the interferer:

$$\tilde{C}_I = \frac{1}{N+1} \sum_{n=0}^{N} \tilde{S}_n \exp(i\, 2\pi\, f_I\ n) \qquad \textbf{1-22}$$

where $\tilde{C}_I$ is the complex spectral amplitude, $\tilde{S}_n$ are the complex signal time samples, and N is the total number of samples. The inverse transform of (2) gives the precise time domain presentation of the interferer

$$\tilde{I}_n = \tilde{C}_I \exp(-i\, 2\pi\, f_I\, n), \qquad \textbf{1-23}$$

This function can now simply be subtracted from the input data. The RFIM procedure steps are summarized in **Table 1-2**.

Table 1-2: RFIM Procedure Steps

Step #	Step description
1	Calculate the DFT of the received signal. Find the strongest amplitude A in the spectrum.
2	If the strongest spike does not qualify as a narrow-band interferer, stop.
3	Determine the exact frequency of the interferer via Eq. (1).
4	Do “single line spectral analysis” to determine the exact interferer amplitude and phase and perform the inverse Fourier transformation.
5	Subtract the interferer signal from the received signal.
6	If the specified number of iterations is reached, stop. Otherwise, go to Step 1 to determine next strongest interferer

Angle of Arrival Measurement Techniques

1:72. Another new development in the 1970's was the coherent multiple receiver array [Bibl and Reinisch, 1978] which allows angle of arrival (incidence angle) to be deduced from phase differences between antennas by standard interferometer techniques. Given a known operating frequency, and known antenna spacing, by measuring the phase or phase difference on a number of antennas, the angle of arrival of a plane wave can be deduced. This interferometry solution is invalid, however, if there are multiple sources contributing to the received signal (i.e., the received wave therefore does not have a planar phase front). This problem can be overcome in over 90% of the cases as was first shown with the Digisonde-256 [Reinisch et al., 1987] by first isolating or discriminating the multiple sources in range, then in the Doppler domain (i.e., isolating a plane wavefront) before applying the interferometry relationships.

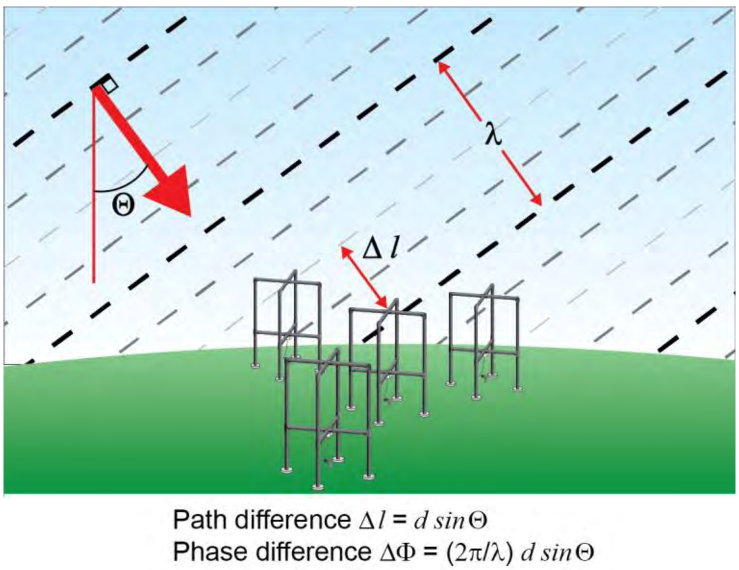

Figure 1-21: Angle of Arrival Interferometry

1:73. The Digisonde-4D system uses two distinct techniques for determining the angle of arrival of signals received on the four antenna receiver array,

a. An *aperture resolution technique* using digital beamforming, in which four antennas are used to form seven beams and then select the beam with the largest amplitude as the best representation of the echo arrival angle; and

b. A *super-resolution technique,* in which signal phases in antenna triplet combinations are used to restore the angle direction to the reflecting source in the ionosphere.

1:74. Both techniques utilize the basic principle of interferometry, which is illustrated in **Figure 1-21**. This phenomenon is based on the free space path length difference between a distant source and each of some number of receiving antennas. The phase difference (Δϕ) between antennas is proportional to this free space path difference (Δl) based on the fraction of a wavelength represented by Δl.

$$\Delta l = d \sin\theta \quad \text{and}$$
$$\Delta\phi = (2p\Delta l)/\lambda = (2\pi\, d \sin\theta)/\lambda \qquad \textbf{1-24}$$

where θ is the zenith angle, d is the separation between antennas in the direction of the incident signal (i.e., in the same plane as θ is measured), and λ is the free space wavelength of the RF signal. This relationship is used to compute the phase shifts required to coherently combine the four antennas for signals arriving in a given beam direction, and this relationship (solved for θ) is also the basis of determining angle of arrival directly from the independent phase measurements made on each antenna.

1:75. **Figure 1-22** shows the physical layout of the four receiving antennas. The various separation distances of 17.3, 34.6, 30 and 60 m are repeated in six different azimuthal planes (i.e., there is six way symmetry in this array) and therefore, the Δϕ's computed for one direction also apply to five other directions. This six-way symmetry is exploited by defining the six azimuthal beam directions along the six axes of symmetry of the array, making the beamforming computations very efficient. Section 2 of this manual contains detailed information for the installation of receive antenna arrays.

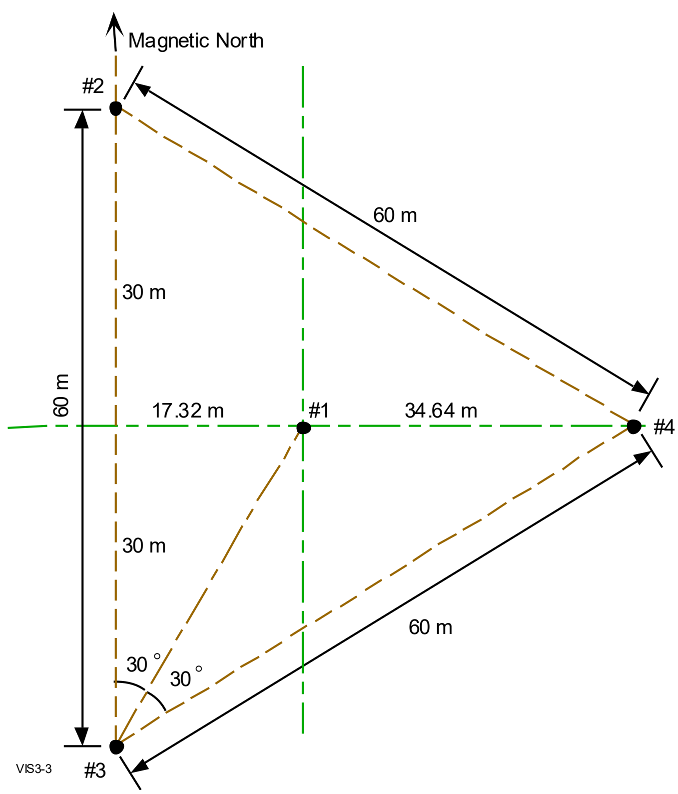

Figure 1-22: Antenna Layout for 4-Element Receiver Antenna Array

Digital Beamforming (Aperture Resolution Technique)

1:76. Digital beamforming is done by taking four complex amplitudes observed in a particular Doppler line of the spectrum on four antennas and forming seven beams shown in **Figure 1-23**, one overhead (0° zenith angle) and six oblique beams (the nominal 30° zenith angle can be changed by the operator) centered at North and South directions and each 60° in between. All seven beams are formed using the same four complex samples, at one reflection height at a time.

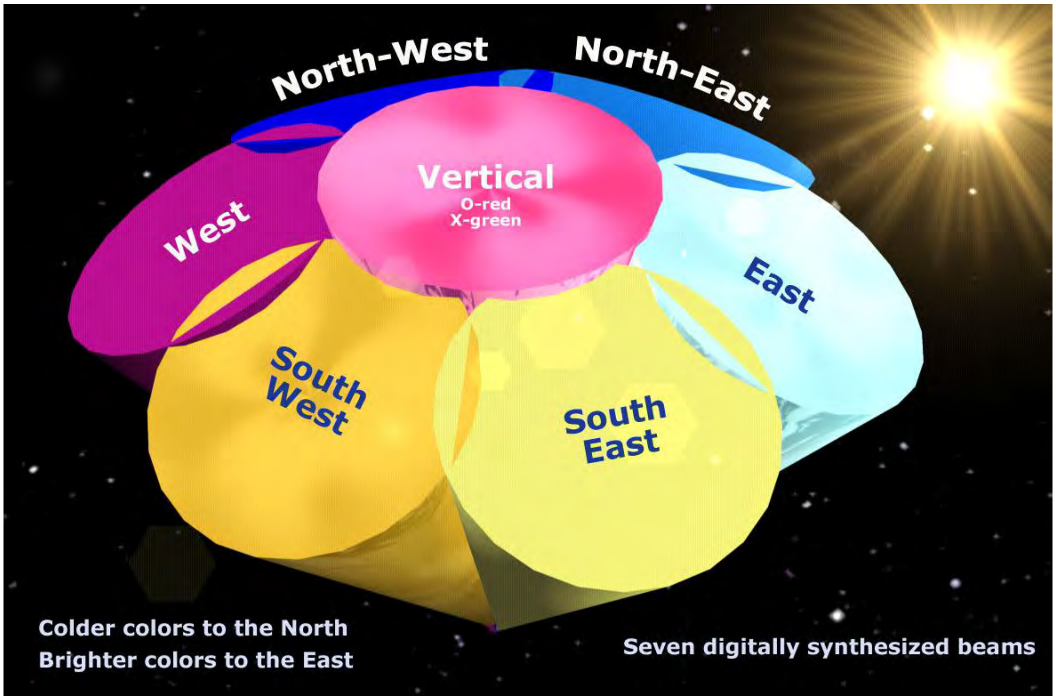

Figure 1-23: Seven Digitally Synthesized Beams for the Angle of Arrival Measurement in Ionogram Mode

1:77. Oblique beams are formed by phase shifting the four complex amplitudes to compensate for the additional path length in the direction of each selected beam. If a signal has actually arrived from near the centre of one of the beams formed, then after the phase shifting, all four signals can be summed coherently, since they now have nearly the same phase, so that the beam amplitude of the sum is roughly four times each individual amplitude. The farther the true beam direction is away from a given beam centre the farther the phase of the four signals drift apart and the smaller the summed amplitude. However, in the DPS system the beams are so wide that even at the higher frequencies the signal azimuth may deviate more than 30° from the beam centers and the four amplitudes will still sum constructively [Murali, 1993].

1:78. The technique for finding the angle of arrival is then simply to compare the amplitude of the signal on each beam and declare the direction as the beam centre of the strongest beam. The accuracy of this technique is limited to 30° in azimuth and 15° in elevation angle (the six azimuth beams are separated by 60° and the oblique beams are normally set 30° away from the vertical beam); as opposed to the Drift angle of arrival technique described in the next section which obtains accuracies approaching 1°. The fundamental principle of this technique is that there is no direction which can create a larger amplitude in a given beam than the direction of the centre of that beam. Therefore, detecting the direction by selecting the beam with the largest amplitude can never be an incorrect thing to do. One has to avoid thinking of the beam as excluding echoes from other directions and realize that all that is needed is that a beam favours echoes more as their angle of arrival becomes closer to the centre of that beam. In fact with a four element array the summed amplitude in a wrong direction may be nearly as strong as it is in the correct beam, however, given that the same four complex amplitudes are used as input it cannot be stronger.

1:79. The phase shifts required to sum echoes into each of the seven beams depend on four variables:

a. the signal wavelength,

b. the antenna geometry (separation distance and orientation),

c. the azimuth angle of arrival, and

d. the zenith angle of arrival.

The antenna weighting coefficients are unity amplitude with a phase which is the negative of the extra phase delay caused by the propagation delay, thereby removing the extra phase delay. The phase delays for antenna is resulting from arrival angle spherical coordinates (θ_j, ϕ_j) which corresponds to the direction of beam j, are described (using **Equation 1-24** by the following:

$$\Delta\Phi_{ij} = (2\pi \sin\theta_j / \lambda)\, d_{ij}' \qquad \textbf{1-25}$$

where $\Delta\Phi_{ij}$ is the phase difference between antenna *i*'s signal and antenna 1's signal, θ_j is the zenith angle (0 for overhead), and d_{ij}' is the projection of the antenna separation distance (from antenna i to antenna 1) upon the wave propagation direction. The parameter d' is dependent on the antenna positions which can be placed on a Cartesian coordinate system with the central antenna, antenna 1, at the origin and the X axis toward the North and the Y axis toward the West. With this definition the azimuth angle ϕ is 0° for signals arriving from the North and:

$$d_{ij}' = (x_i \cos \phi_j + y_i \sin \phi_j) \qquad \textbf{1-26}$$

Since antenna 1 is defined as the origin, x1 and y1 are always zero, so $\Delta\phi_i$ has to be zero. This makes antenna 1 the phase reference point which defines the phase of signals on the other antennas. The correction coefficients β_i are unit amplitude phase conjugates of the propagation induced phase delays:

$$\beta_{ij} = 1.0 \angle \Delta\Phi i(f,x_i,y_i,\theta_j,\phi_j) = 1\angle{-\Delta\Phi_{ij}} \qquad \textbf{1-27}$$

Because they are frequency dependent, these correction factors must be computed at the beginning of each CIT when the beamforming mode of operation has been selected. A full description as well as some modeling and testing results were reported by [Murali, 1993].

1:80. Although the received signal is resolved in range/height before beamforming, the beamforming technique is not dependent on isolating a signal source before performing the angle of arrival calculations. If two sources exist in a single Doppler line then these components (the amplitude of the Doppler line can be thought of as a linear superposition of the two signal components) then some of each of them will contribute to an enhanced amplitude in their corresponding beam direction. Conversely, the Drift technique assumes that the incident radio wave is a plane wave (thus requiring isolation of any multiple sources).

Example A.:

Given the antenna geometry shown in ***Figure 1-22****, at an operating frequency of 4.33 MHz (l = 69.28 m), a beam in the eastward direction and 30° off vertical would, according to* **Equation 1-24***, require a phase shift of 90° on antenna 4, –45° on antennas 2 and 3, and 0° on antenna 1. If an echo is received from that direction it would be received on the four antennas as four complex amplitudes at the height corresponding to the height (or more precisely, the range, since there may be a horizontal component to this distance) of the reflecting source feature. Therefore, a single number per antenna can be analyzed by treating one echo height at a time, and by selecting only one (the maximum) complex Doppler line at that height and that antenna. Assume that the following four complex amplitudes have been receive on a DPS system at, for instance, a height of 250 km. This is represented (in polar notation) as:*

Antenna 1: $830 \angle 135^{\circ}$

Antenna 2: $838 \angle 42^{\circ}$

Antenna 3: $832 \angle 182^{\circ}$

Antenna 4: $827 \angle 179^{\circ}$

To these sampled values add the +90° and –45° phase corrections mentioned above producing:

Antenna 1: $830 \angle 135^{\circ}$ *or* $-586 + j586$

Antenna 2: $838 \angle 132^{\circ}$ *or* $-561 + j623$

Antenna 3: $832 \angle 137^{\circ}$ *or* $-608 + j567$

Antenna 4: $827 \angle 134^{\circ}$ *or* $-574 + j594$

East Beam (sum of above) = $-2329+j2370$ *(*$3329\angle 134.5^{\circ}$ *in polar form)*

Since the sum is roughly four times the signal amplitude on each antenna there has been a coherent signal enhancement for this received echo because it arrived from the direction of the beam. It is interesting to note here, that these same four amplitudes could have been phase shifted corresponding to another beam direction in which case they would not add up in-phase. The DPS does this seven times at each height, using the same four samples, then detects which beam results in the greatest amplitude at that height. Of course at a different height another source may appear in a different beam, so the beamforming must be computed independently at each height.

Drift Mode – Super-Resolution Direction Finding

1:81. By analyzing the spatial variation of phase across the receiver aperture, using **Equation 1-24**, the two-dimensional angle of arrival (zenith angle and azimuth angle) of a plane wave can be determined precisely using only three antennas. The term super-resolution applies to the ability to resolve distinct closely spaced points when the physical dimensions (in this case, the 60 m length of one side of the triangular array) of the aperture used is insufficient to resolve them (from a geometric optics standpoint). Therefore, the use of interferometry provides super resolution. This is required for the Drift measurements because the beam resolution achievable with a 60 m aperture at 5 MHz is about 60°, while 5° or better is required to measure plasma velocities accurately. Using beamforming to achieve a 5° angular resolution at 5 MHz would require an aperture dimension of 600 m, which would have to be filled with on the order of 100 receiving antenna elements. Therefore the Drift technique described here is a tremendous savings in system complexity. The Drift mode concept appears at first glance to be similar to the beamforming technique, but it is a fundamentally different process.

The Drift mode depends on a single echo source being isolated such that its phase is not contaminated by another echo (from a different direction but possibly arriving with the same time delay). This technique works amazingly well because at a given time, the overhead ionosphere tends to drift uniformly in the same direction with the same velocity. This means that each off-vertical echo will have a Doppler shift proportional to the radial velocity of the reflecting plasma and to cos a where a is the angle between the position vector (radial vector from the observation site to the plasma structure) and velocity vector of the plasma structure, as presented in **Equation 1-14**.

1:82. Both isolating the sources of different radial velocities and resolving echoes having different ranges (into 10 km height bins), results in very effective isolation of multiple sources into separate range/Doppler bins. If multiple sources exist at the same height they are usually resolved in the Doppler spectrum computed for that height, because of the sorting effect which the uniform motion has on the radial velocities. If the resolution is sufficient that a range/Doppler bin holds signal energy from only one source, the phase information in this Doppler line can be treated as a sample of the phase front of a plane wave. Even though many coherent echoes have been received from different points in the sky, the energy from these other points is not represented in the complex amplitude of the Doppler line being processed. This is important because the angle of arrival calculation is accomplished with standard interferometry (i.e., solving **Equation 1-24** for θ), which assumes no multiple wave interference (i.e., a perfect plane wave).

1:83. A fundamental distinction between the Drift mode and beamforming mode is that in the Drift mode the angle of arrival calculation is applied for each Doppler line in each spectrum at each height sampled, not just at the maximum amplitude Doppler line. A data dependent threshold is applied to try to avoid solving for locations represented by Doppler lines that contain only noise, but even with the threshold applied the resulting angle of arrival map may be filled with echo locations which result from echoes much weaker than the peak Doppler line amplitudes. In beamforming, only the echoes representing the dominant source at each height are stored, therefore no other source echoes are recoverable from the recorded data.

1:84. It has been found that vertical velocities are roughly 1/10th the magnitude of horizontal velocities [Reinisch et al, 1991]. Since the horizontal velocities from echoes directly overhead result in zero radial velocity to the station, the Drift technique works best in a very rough, or non-uniform ionosphere, such as that found in the polar cap regions or the equatorial regions, because they provide many off-vertical echoes.

1:85. For a smooth spherically concentric (with the surface of the earth) ionosphere all the echoes will arrive from directly overhead and the resulting Drift skymaps will show a single source location at zenith angle = 0°. For horizontal gradients or tilts within that spherically concentric uniform ionosphere however, the single source point would move in the direction of the ΔN/N (N as in **Equation 1-1**) gradient (the local electron density gradient), one degree per degree of tilt, so the Drift measurement can provide a straightforward measurement of ionospheric tilt.

1:86. Resolution of source components by first isolating multiple echoes in range then in Doppler spread (velocity distribution) combined with interferometer principles is a powerful technique in determining the angle of arrival of superimposed multipath signals.

Two Frequency Precision Ranging Mode

1:87. The phase of an echo from a target, or the phase of a signal after passing through a propagation medium is dependent on three things:

1. the absolute phase of the transmitted signal;
2. the transmitted frequency (or free space wavelength); and
3. the phase distance, d, where:

$$d = \int_0^D \mu(f,x,y,z)\, dl \qquad \textbf{1-28}$$

is the line integral over the propagation path, scaled by the refractive index if the medium is not free space. If the first two factors, the transmitted phase and frequency, can be controlled very precisely, then measuring the received phase at two different frequencies makes it possible to solve for the propagation distance with an accuracy proportional to the accuracy of the phase measurement, which in turn is proportional to the received SNR. This is often referred to as the dϕ/df technique. The two measurements form a set of linear equations with two equations and two unknowns, the absolute transmitted phase and the phase distance. If there are several "propagation path distances" as is the case in a multipath environment, then measurement at several wavelengths can provide a measure of each separate distance. However, instead of using a large set of linear equations, the phase of the echoes have chosen to be analyzed as a function of frequency, which can be done very efficiently with a Fast Fourier Transform. The basic relations describing the phase of an echo signal are:

$$\phi(f) = -2\pi f\tau_p = -2\pi d/\lambda = -2\pi(f/c)d \qquad \textbf{1-29}$$

where d is the propagation path length in meters (the phase path described in **Equation 1-28**, f in Hz, ϕ in radians, λ in meters and τ_p is the propagation delay in seconds. Note that the first expression casts the propagation delay in terms of time delay (# of cycles of RF), the second in terms of distance (# of wavelengths of RF), and the third relates frequency and distance using c.

1:88. For monostatic radar measurements the distance, d is twice the range, R, so **Equation 1-29** becomes:

$$\phi(f) = -4\pi R/\lambda = -4\pi(f/c)R \qquad \textbf{1-30}$$

If a series of N RF pulses is transmitted, each changed in frequency by Δf, one can measure the phases of the echoes received from a reflecting surface at range R. It is clear from **Equation 1-30** that the received phase will change linearly with frequency at a rate directly determined by the magnitude of R. Using **Equation 1-30** one can express the received phase from each pulse (indexed by i) in this stepped frequency pulse train:

$$\phi_i\,(f_i) = -4\pi f_i\tau_p = -4\pi f_i(R/c) \qquad \textbf{1-31}$$

where the transmitted frequency f_i can be represented as:

$$f_i = f_0 + i\Delta f \qquad \textbf{1-32}$$

a start frequency plus some number of incremental steps.

1:89. This measurement forms the basis of the DPS's Precision Group Height mode. By making use of the simultaneous (multiplexed) operation at multiple frequencies (i.e., multiplexing or interlacing the frequency of operation during a coherent integration time (CIT) it is possible to measure the phases of echoes from a particular height at two different frequencies. If these frequencies are close enough that they are reflected at the same height then the phase difference between the two frequencies determines the height of the echo.

1:90. The following development of the two frequency ranging approach leads to a general theory (but not expoused here) covering FM/CW ranging and stepped frequency radar ranging. Using **Equation 1-30** a two frequency measurement of ϕ allows the direct computation of R, by:

$$\phi_2 - \phi_1 = 4\pi R(f_1 - f_2)/c = 4\pi R\Delta f/c \qquad \textbf{1-33}$$

$$R = c(\phi_2 - \phi_1)/4\pi\Delta f \qquad \textbf{1-34}$$

1:91. It is easy to see from **Equation 1–29** that if the range is such that $R\Delta f/c$ is greater than 1/2 then the magnitude of ϕ_2-ϕ_1 will exceed 2π which is usually not discernible in a phase measurement, and therefore causes an ambiguity. This ambiguity interval (D for distance) is

$$R = D_A = (1/2)c/\Delta f = c/2\Delta f \qquad \textbf{1-35}$$

> ***Example B.**:*
>
> *The measured phase is (ϕ_2 - ϕ_1) = π/8 while Δf = 1 kHz, then R = 9.375 km.*
>
> *In the example above with Δf = 1 kHz, the ambiguous range D_A is 150 km. Since a 0 km reflection height must certainly give the same phase for any two frequencies (i.e., 0°), then given that the ambiguity interval is 150 km, then for this value of Δf, the phase difference must again be zero at 150, 300, 450 km etc, since 0 km is one of the equal phase points, and all other ranges giving a phase difference of 0° are spaced from it by 150 km. If the phase measurements ϕ_2 and ϕ_1 were taken after successive pulses at a time delay corresponding to a range of 160 km (at least one sample of the received echo must be made during each pulse width, i.e., at a rate equal to or greater than the system bandwidth, see **Equation 1-4**), one would conclude that there is an extra 2π in the phase difference and that the true range is 159.375 km, not 9.375 km. Therefore, the measurement must be designed such that the raw range resolution of the transmitted pulse is sufficient to resolve the ambiguity in the $d\phi/df$ measurement.*

1:92. The validity of the two-frequency precision ranging technique is lost if there is more than one source of reflection within the resolution of the radar pulse. The phase of the received pulse will be the complex vector sum of the multiple overlapping echoes, and therefore any phase changes (ϕ_i) will be partially influenced by each of the multiple sources and will not correctly represent the range to any of them. Therefore, in the general propagation environment where there may be multiple echo sources (objects producing a reflection of RF energy back to the transmitter), or for multipath propagation to and from one or more sources, many frequency steps are needed to resolve the different components influencing f_i. This “many step” approach can be performed in discrete frequency steps as in the DPS’s HRR mode, or by a continuous linear sweep, as done in a chirpsounder described in [Haines, 1994].

Passive RF Sensing Measurements

1:93. The concept of passive ionospheric RF sensing is to receive signals from remote transmitters of opportunity in order to infer characteristics of the ionospheric channel that received signals have traveled. Typical area of interest to passive RF measurements is imaging of small-scale ionospheric irregularities, especially if such observations can be made multi-static. Use of the Digisonde® in passive RF sensing has been constrained by the need to capture highly voluminous time-domain data for processing, until release of the Digisonde-4D model in 2007-2008 whose high bandwidth interfaces and modern embedded computers were adequate for the task.

1:94. In order to use the DPS system for the oblique sounding with signals from external transmitters of opportunity, there is an important problem to be solved. It concerns the inconsistency between the DPS effective sampling rate and the frequency bandwidth of the receive signals. To generate a valid digital presentation of the received broadcasting signal, the sampling rate must be at least twice the signal bandwidth. The maximum number of samples in the DPS spectrum is 128. With an integration time of 40 sec this results in a sampling rate of 3.2 Hz and an unambiguous spectral range of ±1.6 Hz (considering the quadrature sampling). The signals of most broadcasting stations have a bandwidth of the order of 5 kHz [*FCC Regulations*, 1998] as shown in **Figure 1-24**. Because of the low effective sampling rate and large receive bandwidth, the side modulation frequency (sideband) components would be "aliased", or "folded" into the frequency band of the analysis and distort the measurements. If one were only to measure the Doppler frequency shift of the signal, this effect would not present a significant problem as long as the carrier frequency spectral line has an amplitude significantly larger than that of the sideband, which is usually the case (carrier frequency is at least 20 dB stronger than the sidebands). But signal angles of arrival are calculated from the phase measurements, and for these parameters the aliasing effect is a problem. This is because the phases of the sideband spectral components are random-like and fluctuate significantly during the coherent integration time.

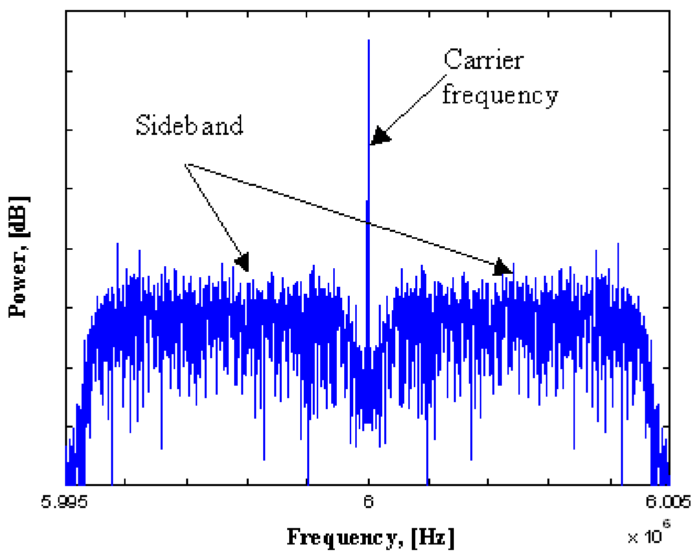

Figure 1-24: Spectrum of the Signal of Broadcasting Stations with 6 MHz Carrier Frequency.

1:95. To remove the aliasing effect, it is necessary to either increase the sampling rate, or decrease the receiver bandwidth by using a narrow-band filter, either analog or digital. Implementing a digital filter provides certain advantages, mainly the flexibility of the system, and requires no additional hardware parts. Such a filter was designed and implemented as a part of this work.

1:96. **Figure 1-25** helps understanding the digital filtering algorithm. To simplify the picture only real samples of the digitized signal are drawn, and a single operating frequency is assumed. The top panel shows the digitizer samples for the 10 km height resolution. As shown, for each sounding pulse 512 samples are averaged and the resulting value is stored in the DSP memory as the first height sample (bottom panel). After this, the spectrum is calculated for the first height range only, just as in the regular DPS signal processing for the drift mode of operation.

1:97. The design of this narrow-band filter is just the realization of a finite impulse response (FIR) filter with decimation. The theory of such filters is documented in literature and can be found, for example in *Oppenheim and Schafer* [1975]. The principal scheme of a FIR filter is shown in **Figure 1-26**, with all α_k coefficients set equal to 1. The amplitude frequency response of the filter can be calculated using the theory of *z*-transform [*Oppenheim and Schafer*, 1975]. If the number of taps (heights over which the averaging is performed) is 512 then the filter bandwidth is around 60 Hz (±29 Hz) at zero amplitude level, as shown in **Figure 1-27**. Both analog and digital filters were designed, tested, and built into the DPS system proved to be working stable, providing good system performance. For some of the DPS systems that were temporarily used at the Millstone Hill Observation site, it was possible to implement a 256-tap filter. This resulted into a twice wider filter bandwidth, approximately corresponding to that of the designed analog filter.

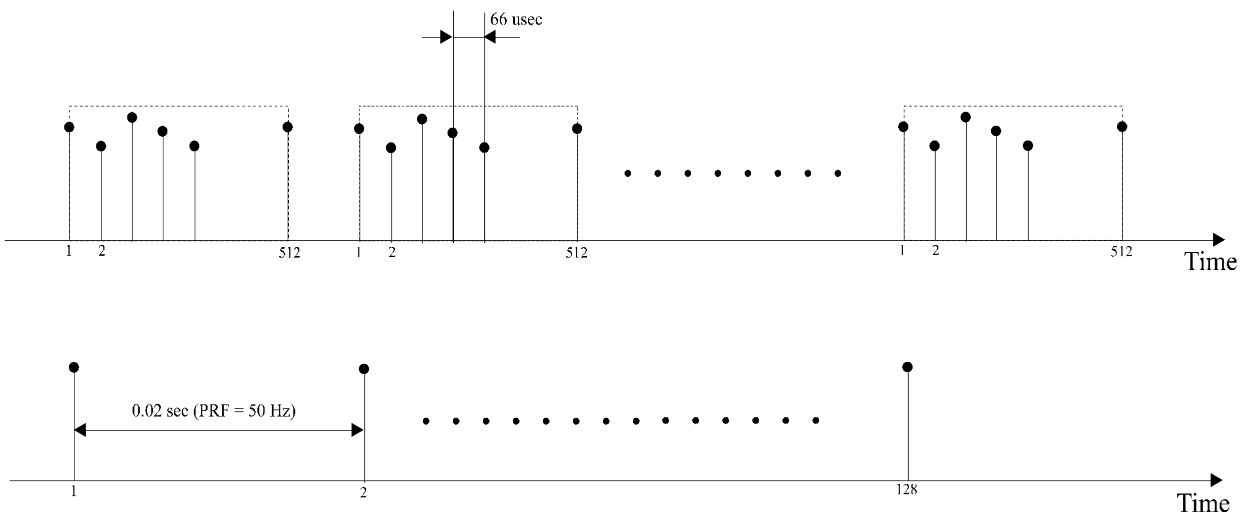

Figure 1-25: Digital Filtering Algorithm.
(Sampled Signal is Averaged Before The Spectrum Is Calculated.)

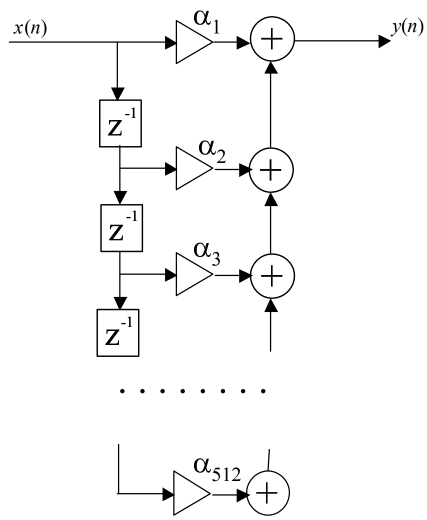

Figure 1-26: System Diagram of a FIR Filter (Samples Delayed by a Number of Unit Delays (Denoted by z^{-1}) are Summed with Corresponding Tap Coefficients α_k.)

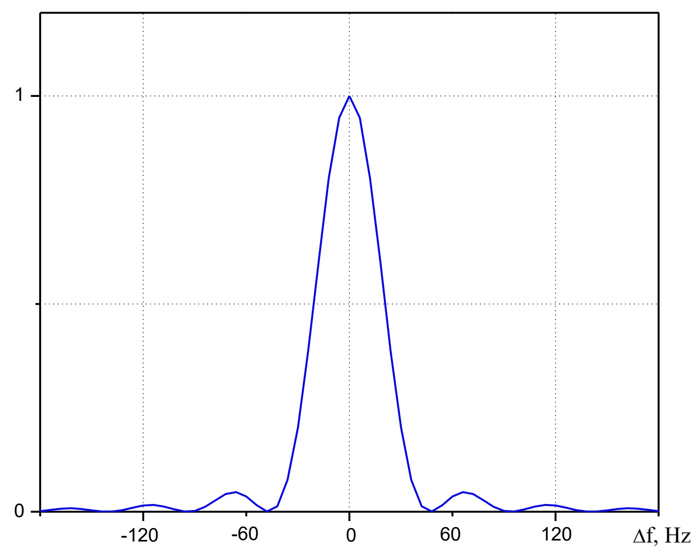

Figure 1-27: Calculated Amplitude Frequency Characteristic of the Digital Filter

RF SYSTEM DESIGN CONSIDERATIONS

1:98. The detailed design and synthesis of a RF measurement system (or any electronic system) must be based on several criteria:

a. The performance requirements necessary to provide the needed functions, in this case scientific measurements of electron densities and motions in the ionosphere.

b. The availability of technology to implement such a capability.

c. The cost of purchasing or developing such technology.

d. The risk involved in depending on certain technologies, especially if some of the technology needs to be developed.

e. The capabilities of the intended user of the system, and its expected willingness to learn to use and maintain it; i.e., how complicated can the operation be before the user will give up and not try to learn it.

1:99. The question of what technology can be brought to bear on the realization of a new ionospheric sounder was answered in a survey of existing technology in 1989, when the DPS portable sounder development started in earnest. This survey showed the following available components, which showed promise in creating a smaller, less costly, more powerful instrument. Many of these components were not available when the previous generation of Digisonde® (circa 1980) was being developed:

- Solid-state 300 W MOSFET RF power transistors
- High-speed high precision (12, 14 and 16 bit) analog to digital (A–D) converters
- High-speed high precision (12, 14 and 16 bit) digital to analog (D–A) converters
- Single chip Direct Digital Synthesizers (DDS)
- Wideband (up to 200 MHz) solid state op amps for linear feedback amplifiers
- Wideband (4 octaves, 2–32 MHz) 90^{o} phase shifters
- Proven Digisonde-256 measurement techniques
- Fast, single board, microcomputer systems and supporting programming languages

1:100. Many of these components are inexpensive and well developed because they feed a mass market industry. The MOSFET transistors are used in Nuclear Magnetic Resonance medical imaging systems to provide the RF power to excite the resonances. The high speed D–A converters are used in high resolution graphic video display systems such as those used for high performance workstations. The DDS chips are used in cellular telephone technology, in which the chip manufacturer, Qualcomm, is an industry leader. The DSP chips are widely used in speech processing, voice recognition, image processing (including medical instrumentation). And of course, fast microcomputer boards are used by many small systems integrators which end up in a huge array of end user applications ranging from cash registers to scientific computing to industrial process controllers.

1:101. The performance parameters were well known at the beginning of the DPS development, since several models of ionospheric pulse sounders had preceded it. The frequency range of 1 to 20 MHz for vertical sounding was an accepted standard, and 2 to 30 MHz was accepted as a reasonable range for oblique incidence measurements. It was well known that radio waves of greater than 30 MHz often do propagate via skywave paths; however, most systems relying on skywave propagation don’t support these frequencies, so interest in this frequency band would only be limited to scientific investigations. A required power level in the 5 to 10 kW range for pulse transmitters had provided good results in the past. The measurement objectives were to simultaneously measure all seven observable parameters outlined at Paragraph 1:26 above in order to characterize the following physical features:

- The height profile of electron density vs. altitude
- Position and spatial extent of irregularity structures, gradients and waves
- Motion vectors of structures and waves

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SECTION 2

INSTALLATION, SETTING UP AND FIELD VALIDATION

SECTION CONTENTS

List of Figures

List of Tables

GENERAL WARNINGS

1. ALTHOUGH THE SOUNDER HAS BEEN DESIGNED FOR RELATIVELY SIMPLE INSTALLATION, THE COMPLETE PROCESS, INCLUDING FIELD CALIBRATION AND GAINING ACCESS TO THE INSIDE OF THE SOUNDER, REQUIRES SPECIAL KNOWLEDGE GAINED BY ATTENDING A TRAINING COURSE AND DEVELOPMENT OF THE REQUIRED PRACTICAL SKILLS. THEREFORE NO ATTEMPT SHOULD BE MADE TO INSTALL, CONNECT POWER TO, OR CALIBRATE THE SOUNDER AND ITS ANCILLARY DEVICES BY UNQUALIFIED PERSONS.

2. WHEN PACKED FOR SHIPMENT THE SOUNDER WEIGHS APPROXIMATELY 60 KGS. THEREFORE AT ALL TIMES AT LEAST TWO PERSONS MUST LIFT AND CARRY THE EQUIPMENT SAFELY BY THE CASE CARRYING HANDLES.

3. NO AUTHORIZED INSTALLATION, OPERATION OR MAINTENANCE TASK REQUIRES THE MAIN AND POWER AMPLIFIER CHASSIS TO BE EXTENDED OUT OF THE CASE AT THE SAME TIME. IF BOTH ARE EXTENDED, THE COMBINED MASS OF THE TWO CHASSIS, WILL ALTER THE SOUNDER'S CENTER OF GRAVITY AND WILL CAUSE THE EQUIPMENT TO TOPPLE FORWARD POTENTIALLY CAUSING INJURY TO PEOPLE AND/OR DAMAGE TO CABLES AND OTHER EQUIPMENT.

CHAPTER 1

GENERAL SOUNDER CONFIGURATION

2:1. The sounder is provided with a fiberglass field transit case (see Figure 1-1) which is also used to protect the internal components during normal use. During installation, all external connections to the sounder are made with both chassis secured in their normal operating position (i.e., closed) and the rear shipping cover in place. The front cover should normally be left in place during normal operation.

2:2. Under normal operating conditions, the sounder and most of its ancillary equipment, including a monitor and keyboard, shall be installed in a clean, air-conditioned environment. It will normally be placed on a level table, with no special or fixed mounting requirements being necessary. Desirably, the table shall also serve as an operator's and maintainer's work bench. Its exact position shall be dictated by the proximity to any antenna through-wall feeders specified by the facility design.

2:3. A single phase double power outlet will be required within approximately 2 m of the table. Where back-up power is required, an appropriate UPS shall be installed.

2:4. Specifications on the sounder hardware are provided in Section 6 and Annex A of the manual.

PRE-INSTALLATION CHECK

2:5. Prior to installation, place the sounder on a desk or table preferably in the position where it will be permanently operated. Allow at least 40 cm clearance between the rear of the case and any vertical surface to provide access to the rear I/O panel.

2:6. Remove the front and rear covers and inspect all external fittings for damage. Replace the rear cover before making any cable connections. In turn, release each chassis from the case, remove the chassis cover and inspect for shipping damage. Check for and make good any loose connectors and unseated cards.

EXTERNAL CONNECTIONS

ANTENNA INSTALLATION

General Requirements

Vegetation/Conductive Obstructions

2:7. The antenna field usually consists of two transmit antennas crossed on a single mast (TCI 656 designed by LDI), and four receive antenna stations. The installation site requires to be cleared and kept cleared of all vegetation within a 0.5 m radius from the antenna and isolated from conductive obstructions by at least a ratio of 10:1 (separation distance : longest dimensions of the obstruction).

2:8. The transmit antenna mast must not be closer than 30 m to the closest receive antenna station, and when using RG-213 cable, desirably it should not be more than 120 m from the sounder. If the transmit antenna is to be installed at a distance greater than 300 m from the sounder use of a Heliax type cable is suggested. If one is considering locating the transmit antenna at a distance greater than 500 m from the sounder, it is suggested to consult with LDI.

2:9. Any of the receive antennas should be at least 16 meters, preferably a little more, from any part of the transmit antenna.

2:10. Placement of receive antennas near fencing, walls, buildings, or other structures which contain horizontal conductors are of special concern. Horizontal conductors located near receive antenna could short out the electric field component of signals received by the receive loops parallel to those conductors. Buildings and other structures which contain horizontal conductors that are 15 m or less from the center of a receive antenna should be evaluated on a case by case basis. If a receive antenna is to be placed near metallic fencing or walls containing horizontal conductors (such as rebar) please use the following general recommendations:

2:11. The center of the receive antenna should be no less than 7 m minimum distance from a metallic fence or wall 1 m in height.

2:12. The center of the receive antenna should be no less than 10 m minimum distance from a metallic fence or wall 1.5 m in height.

2:13. The center of the receive antenna should be no less than 15 m minimum distance from a metallic fence or wall 2.5 m in height or greater.

2:14. Trees are probably not a serious issue, but they certainly should not overhang the antennas. Ideally, looking upward from any antenna there should be a 45 degree (measured from zenith) cone clear of any obstruction. Other antennas or masts, such as GPS antennas, which do not have significant horizontal extent, are probably not an issue as long as they are not inside the above described cone.

2:15. The receive antennas must be as far as possible from high voltage power transmission lines. It is difficult to be specific since the noise radiated from such lines varies tremendously. Certainly an antenna should be at least 10 meters away from even the lowest voltage overhead power lines.

2:16.

It is likely that Arc Discharge lights, particularly those used for street lights, will generate considerable electrical noise picked up by the Digisonde receive antennas. Arc discharge lights include sodium vapor, high pressure sodium vapor, mercury vapor, metal halide, high intensity discharge technologies. It is difficult to be definitive, but arc discharge lights beyond 150 meters will probably be ok. If there is significant interference, LDI recommends removing such lighting. There is a trend among utilities to replace arc discharge lights with more efficient , longer life, LED lights. According to the FCC all US manufacturers of such lighting are supposed to meet FCC 15.107 and 15.109 standards, but such standards do not apply worldwide. It is also possible that lights generating the electrical noise picked up by the Digisonde may be malfunctioning, and so may be operating outside of typical behavior. In any case, without acquiring further data LDI can only recommend that any lights within 50 meters of the receive antenna field be incandescent or quartz halogen. Further away LED lights may be reasonable. The best way to evaluate noise present at any potential installation site is to temporarily field the Digisonde without transmit antenna and observe the noise in the data collected.

Antennas not on level terrain

2:17. Ideally, the area where the transmit and receive antennas will be installed should be flat and level. This is more critical for the transmit antenna where one will encounter physical or mechanical problems if the center of the antenna and the four corners differ more than a meter or so in height. The transmit antennas' concrete foundation must be laid on level ground.

2:18. However the receiving antenna field may have a uniform gradient of up to 10°. If the site is not level, do not attempt to "flatten" the array by raising individual antennas (i.e., by extending the legs.) The receive loop antennas should be installed at roughly (within 1/2 meter) the same height above the ground since the performance of the antennas is somewhat dependent on the antennas height above the ground. After installation LDI will add "correction cables" to the higher antennas to electrically put the antennas in a horizontal plane. To do this the measured relative heights of the antennas to 0.2 meters or so must be known. Then cables can be fabricated to be added the higher antennas of length 2/3 (assuming a cable velocity factor or 0.66 for RG213) the height difference between the higher antenna and the lowest antenna. Alternatively, the short RG-58 cables between the lightening suppressors and the back of the DPS4D box can be shortened by 2/3 the height difference between the highest antenna and the lower antennas.

Lightning Protection

2:19. Surge protectors are fitted on all external cables (two Tx antennas, four Rx antennas, and GPS receiver) in order to reduce the effects of lightning surge upon the sounder and ancillary items.

2:20. It is recommended the customer provide surge protection for all external connections, including power and network interfaces.

Distance Constraints

2:21. The following spatial distance constraints in the system layout must be adhered to in order to ensure optimum operation:

a. Standard RG-213 cable length from any receive antenna to the sounder is 150 m. Depending on the local RF environment up to 300 m lengths of RG-213 can be used. If the distance to the sounder from any receive antenna is to be greater than 300 m then consult with LDI.

b. The distances between the three antennas at the corners of the equilateral triangle should be the same to within 1 meter. Similarly, the distances from the center antenna to the three corners of the triangle should be the same within 1 meter.

c. If there are difficulties with the receive antenna layout, it is allowable to reduce the size of the triangle from 60 meters to 45 meters. If space permits, the default receive antenna array orientation is to have one leg of the triangle running North - South Geographically, but this is not critical and secondary to some other considerations. In any case, it will be necessary to know the relative positions of the four receive antennas with 1/2 meter accuracy for the DPS4D configuration files.

d. If there is any question about the proper positioning of the Receive Loop antennas, particularly in regard to proximity to obstructions and the transmit antenna, it might be best to install them temporarily, just sitting on top of the ground, and pour concrete only after LDI has evaluated the performance of the antennas.

Transmit Antenna

2:22. The crossed delta transmit antenna has been designed using the NEC modeling program. The design objectives were for a simple antenna that optimally transmits circularly polarized waves vertically upward for frequencies between 2 and 16 MHz. LDI usually has this transmit antenna built by a major antenna manufacturer. The Digisonde® user may build his own transmit antenna in consultation with LDI. The tower is 30.5 meters (100 ft.) high. It will require a square ground area 44 meters x 44 meters (144 ft. x 144 ft.) for installation. In addition there are recommendations for spacing from the receive antennas.

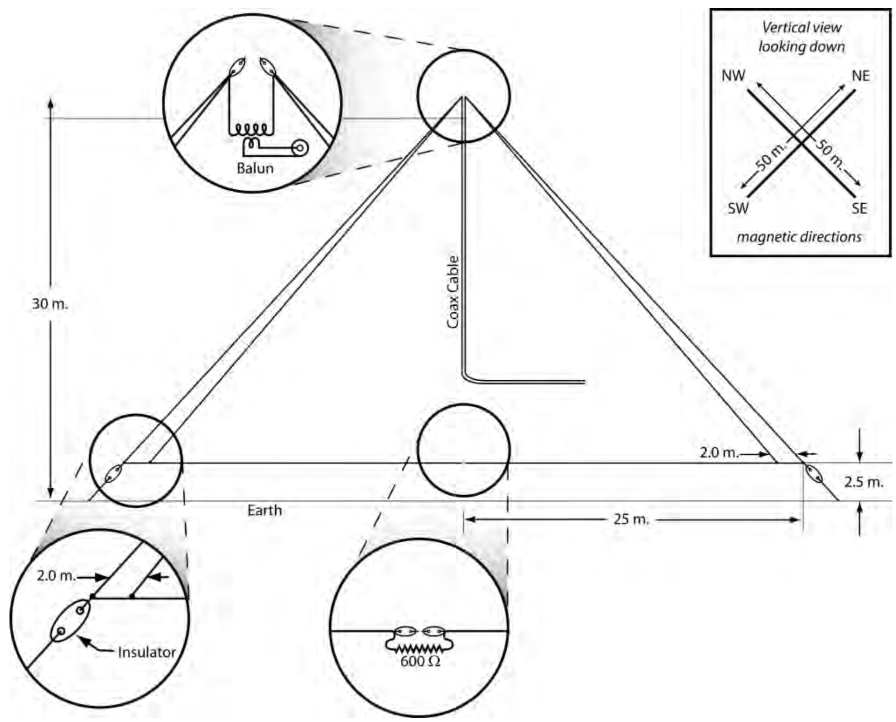


Figure 2-1: Schematic Representation of one Delta of the Cross Delta Transmit Antenna.

2:23. TCI (a division of SPX) has made available an antenna according to the LDI design. With the TCI model 656 implementation of the design, the four elements attached to the top of the tower are also used as guy wires. The four elements / guy wires must be attached to ground anchors embedded in concrete according to the TCI instructions. The TCI Installation Manual has specifications for the concrete base for the tower itself, for concrete ground anchors for the four top elements / guy wires, and for the three concrete ground anchors for the lower sets of guy wires. If a smaller antenna is absolutely necessary, such as for a temporary installation, consult LDI regarding alternative antenna solutions.

2:24. The Baluns are attached to the tower at the top. The Termination Resistors are attached at the bottom. The two coaxial cables which feed the baluns at the top of the tower are attached to the tower every meter or two. These baluns and termination resistors are supplied with the TCI model 656. In addition, LDI can supply these components if the Digisonde® user constructs their own transmit antenna.

Transmit Antenna Interface Requirements

Mechanical

2:25. The two transmit antenna feeder cables of equal length are connected to the Surge Protector then to the back of the sounder rear I/O panel by N-to-N connectors.

Electrical

2:26. The sounder supplies RF energy to the transmit antenna. No high voltage electrical power is required nor supplied by the system.

Receive Antenna

Receive Antenna General Description

2:27. The receive antenna is an array of four crossed loop antennas. Each of the antennas is comprised of two loop antennas at right angles to each other. The Pre-amp / Polarization Switch mounted under the crossed loop antenna then combines the signals from each of the two loops to receive lefthand or righthand circularly polarized waves from overhead. Each crossed loop antenna occupies a square 1.2 meters x 1.2 meters (4 ft. x 4 ft.) and stands about 1.5 meters (6 ft.) high (see **Figure 2-2**).

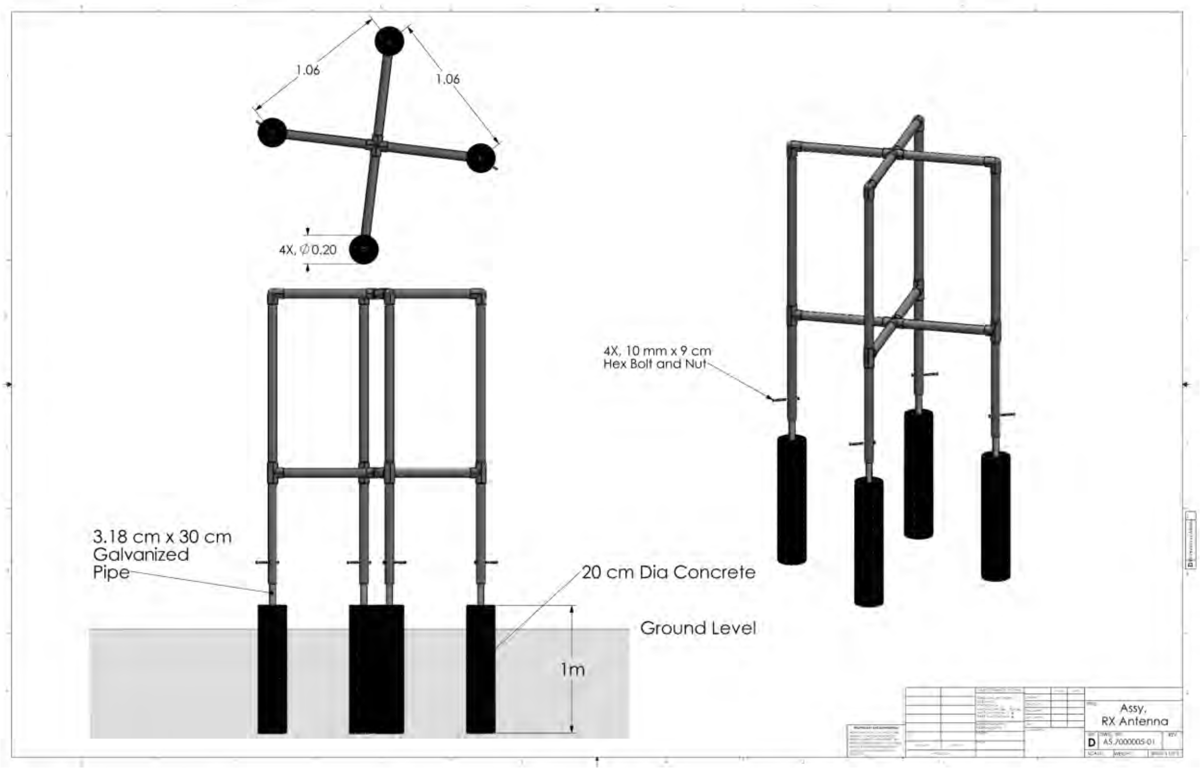


Figure 2-2: Receive Antenna Typical Dimensions

Receive Antenna Array Layout

2:28. The sounder installation uses a receive antenna array consisting of four antenna stations, three of which form an equilateral triangle, the fourth station is located at its center. **Figure 2-3** details array layout measurements and antenna orientation. The location of each crossed-loop antenna station in each antenna field shall be in accordance with the installation drawings.

2:29. Deviations from the standard antenna array configuration shown in **Figure 2-3** are acceptable if the available space for the antenna field does not accommodate the standard configuration. Deviations shall be properly reflected in the station personalization files (see Paragraph 2:52, *et seq*.).

2:30. The orientation of the individual antennas is not critical as long as all four receive antennas are parallel to each other within 1 degree. i.e., if one antenna has its legs NW, NE, SE, and SW, then the other antennas must have their legs positioned exactly the same. Most commonly one loop is positioned magnetic North - South, and the other loop is positioned magnetic East - West.

2:31. Orienting the antenna array with respect to the Geographic North simplifies configuration of the analysis software. If orientation is done with respect to the ground level compass North, the configuration files need to store deviation of the antenna array axis from the Geographic North at the time of installation to account for movement of the magnetic North Pole with time.

2:32. The vertical plane polarization and East-West (i.e., orientation of North-south loop planes) of all four turnstile antennas must be within ±1° of the datum line. All antenna preamplifier boxes must be oriented identically on each receive antenna station. Orientation of the Antenna #3 / Antenna #2 side of the triangle should be preferably Geographic North (see **Figure 2-3**).

2:33. Each receive antenna station comprises four crossed-loop active elements. Physical details of the antenna station including its concrete footing are provided in **Figure 2-2** showing a small concrete pad for each antenna leg. There certainly are alternative ways of installing the antennas depending on local weather and soil conditions. However the antenna legs are installed, the antennas should be restrained from being blown around by wind or being inadvertently moved from position. The Polarization Switch (pre-amp) mounted under the lower cross of the loops should be high enough to be out of any vegetation.

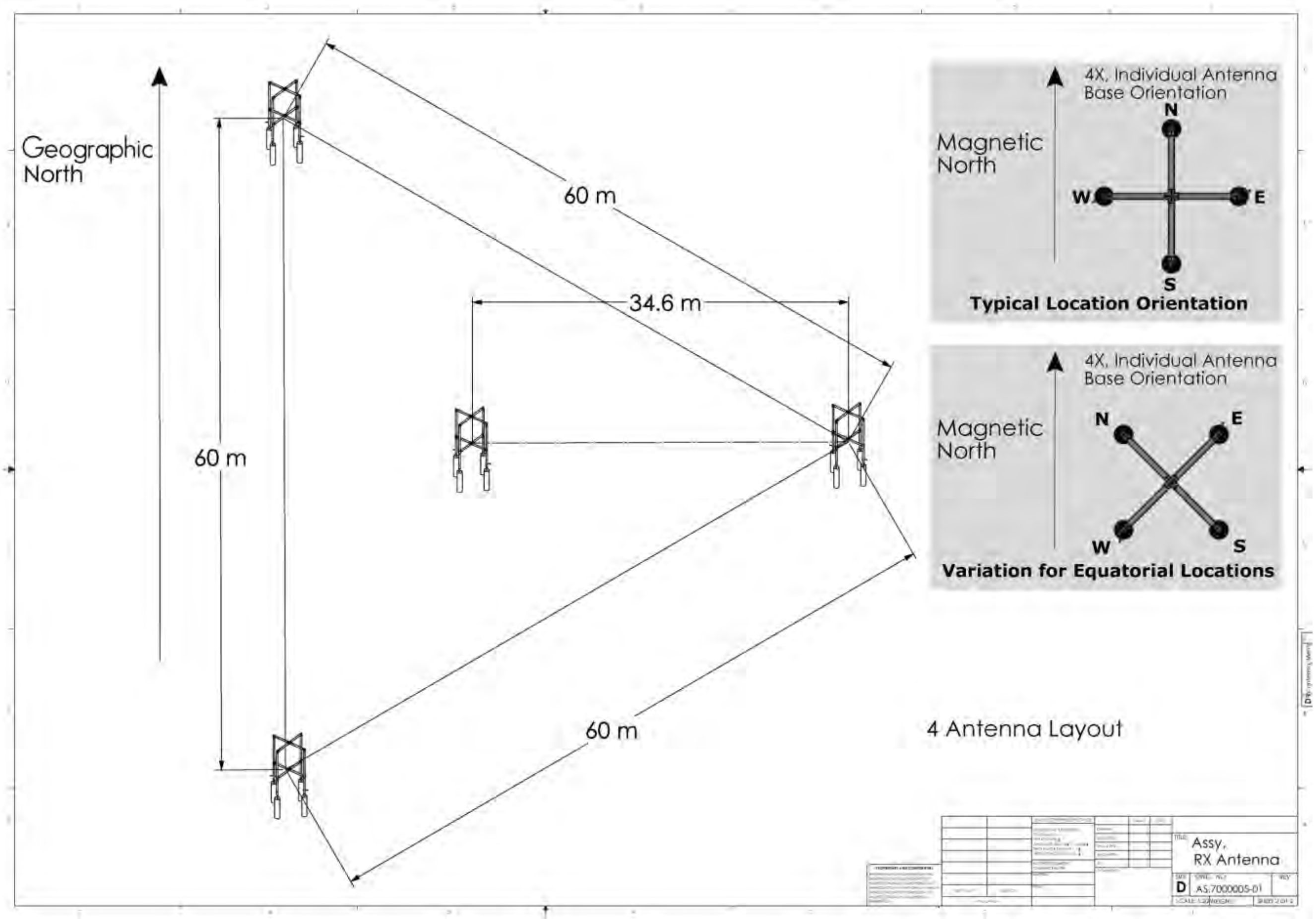


Figure 2-3: Standard Receive Antenna Array

Antenna Cable Connections

2:34. Connect each transmit, receive, and GPS antenna directly to the Surge Protectors then to the back of the Sounder using the supplied 7.6 m RG-58 cable, with a MALE "N" type connectors. The four receive antennas cable lengths must be matched to within 6 inches or 20 cm of each other. The maximum receive antenna cable length for RG-213 is 300 m, and depending on the local RF noise environment, shorter lengths many be suggested. For distances greater than 300 m use of a Heliax type cable is suggested.

2:35. Connect the two transmit antenna cables to the Surge Protectors then to the XMT1 and XMT2 outputs on the sounder's rear I/O panel using the supplied 7.6 m RG-58 cable.

CAUTION

EACH ANTENNA MUST ONLY BE CONNECTED TO ITS RESPECTIVE REAR I/O PANEL CONNECTOR (E.G., ANTENNA #1 TO CONNECTOR #1)

2:36. Connect the four receive antenna cables to the Surge Protector then to the respective ANT1, ANT2, ANT3 and ANT4 connectors on the rear I/O panel. When installing the receive antenna array and running the cables, verification must be made to confirm that the markings at the sounder end of the cable corresponds to the respective receive antenna location as shown in **Figure 2-3**.

INSTALLING THE GLOBAL POSITIONING SYSTEM (GPS) RECEIVER

2:37. The sounder derives absolute time from the external GPS receiver that is part of the sounder subsystem. The GPS receiver is connected through the Surge Protector then over the serial port to the Data Platform, where it is used by the operating system to maintain synchronism of the Data Platform clock to UT. The GPS also provides 1 PPS "heartbeat" signal to accurately synchronize Digisonde-4D hardware timing to the GPS. The Control Platform clock is synchronized with UT by periodic messages from the Data Platform carrying UT stamp that will be effective at the next 1 PPS event.

2:38. The current model of GPS receiver is a Trimble Navigation receiver which is a single self-contained unit, weighing less then 500 g. A 30 m interface cable fitted with a lightning surge suppresser is supplied with the receiver. The receiver is also shipped with a threaded section of pipe and mounting flange.

2:39. Mount the receiver in an area open to the sky, typically on top of the shelter or building, making sure that it is fixed in a vertical position, and with a relatively unobstructed line of sight to the horizon. Connect the receiver to the sounder using the interface cable, with the 12-pin Conxall connector connected to the receiver and the 9-pin sub-D connector connected to the GPS port on the back of the rear I/O panel (see **Figure 1-7**).

CONNECTING COMPUTER PERIPHERALS

2:40. The Data computer monitor is connected independently to the electrical power supplied to the site. Refer to the equipment manufacturer's instructions to ensure that proper safety procedures are carried out.

2:41. The user should connect the monitor to a video output connector (VGA) and a keyboard and mouse to the available USB ports as shown in the diagram.

CONNECTING TO THE WIDE AREA NETWORK (WAN)

2:42. The sounder uses standard Ethernet RJ45 cable for connections to the WAN.

ELECTRICAL POWER CONNECTION

2:43. A standard 3-pin EIA connector is fitted on the rear panel for connection of the sounder to the AC mains power source. An appropriate EIA power cable is needed for connection to the AC mains power outlet. Input power in the range of voltages 110-240 VAC and 50/60 Hz is supported.

Backup power source

2:44. Generally most DPS4D installations make use of commercially available UPS (Uninterruptable Power Supply) backup power sources. Lowell Digisonde International (LDI) can supply assistance selecting an appropriate UPS if necessary. Earlier models of the DPS4D had provisions for connecting two external 12 volt automobile storage batteries as an alternative to a UPS. LDI can provide assistance to users who have this feature and wish to make use of it. Realistically, considering the availability of commercial UPSes, such UPSes should be the preferred approach and commercial UPSes have software which can be installed in the Data computer to effect an orderly shutdown when the UPS shuts off the power.

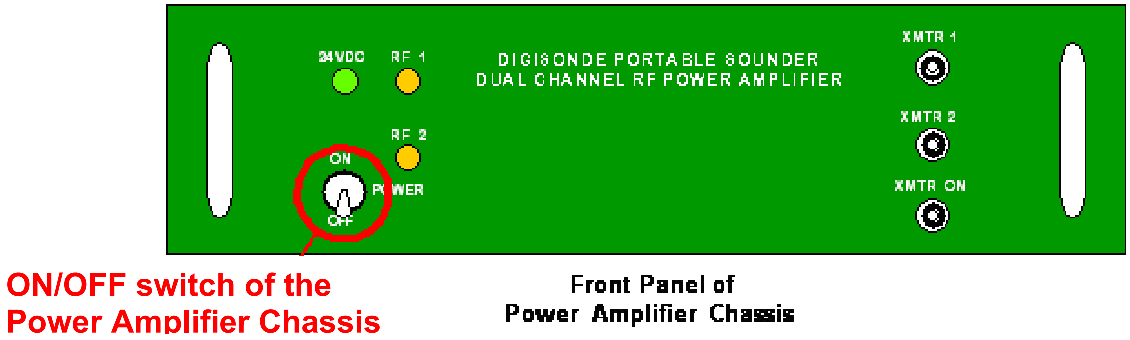


Figure 2-4: Location of the Front Panel ON/OFF Switch for the Power Amplifier

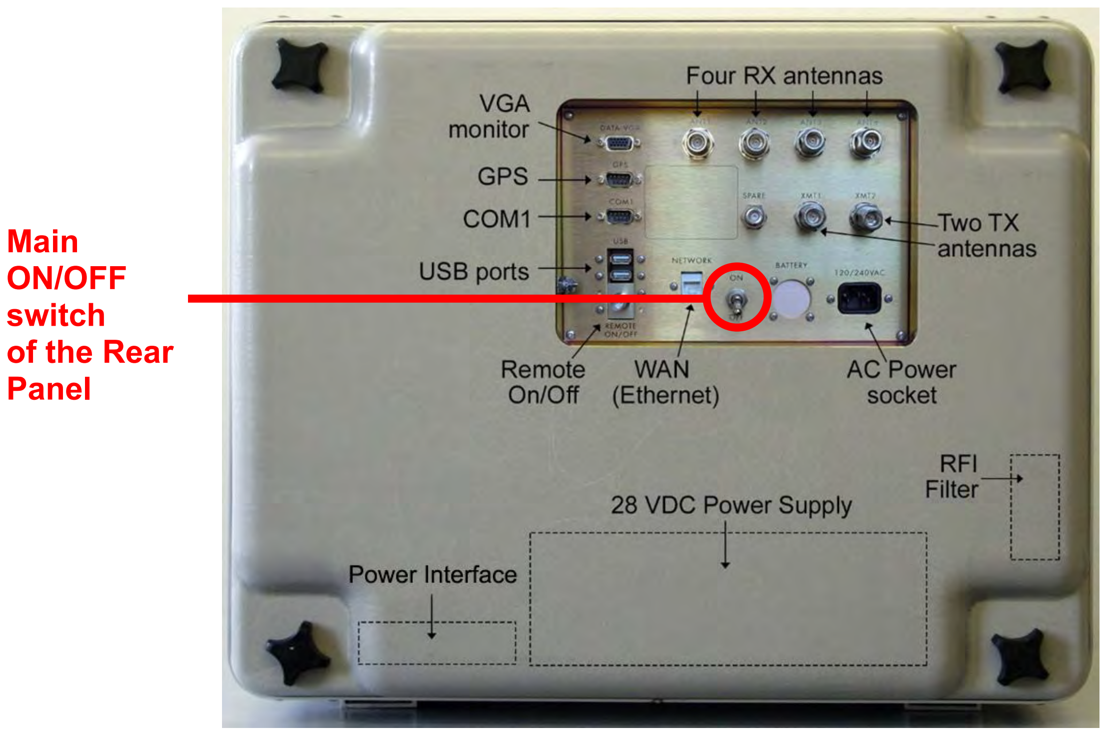


Figure 2-5: Location of the Rear Panel ON/OFF Switch and Connectors

POWERING UP PROCEDURE

POWERING ON THE MAIN SYSTEM

2:45. At this stage the sounder should be correctly connected to the:

a. correct power source, and all power switches in the OFF (down) position,

b. transmit and receive antennas,

c. GPS receiver, and

d. external computer monitor and keyboard.

2:46. Switch the ON/OFF switch on the rear I/O panel to ON. This will activate the cooling fans, switch the power relay in the lower chassis, and boot the Control and Data computers.

2:47. At the completion of the boot-up sequence, which will take over one minute, the DCART control software will display the welcome screen (**Figure 2-6**).

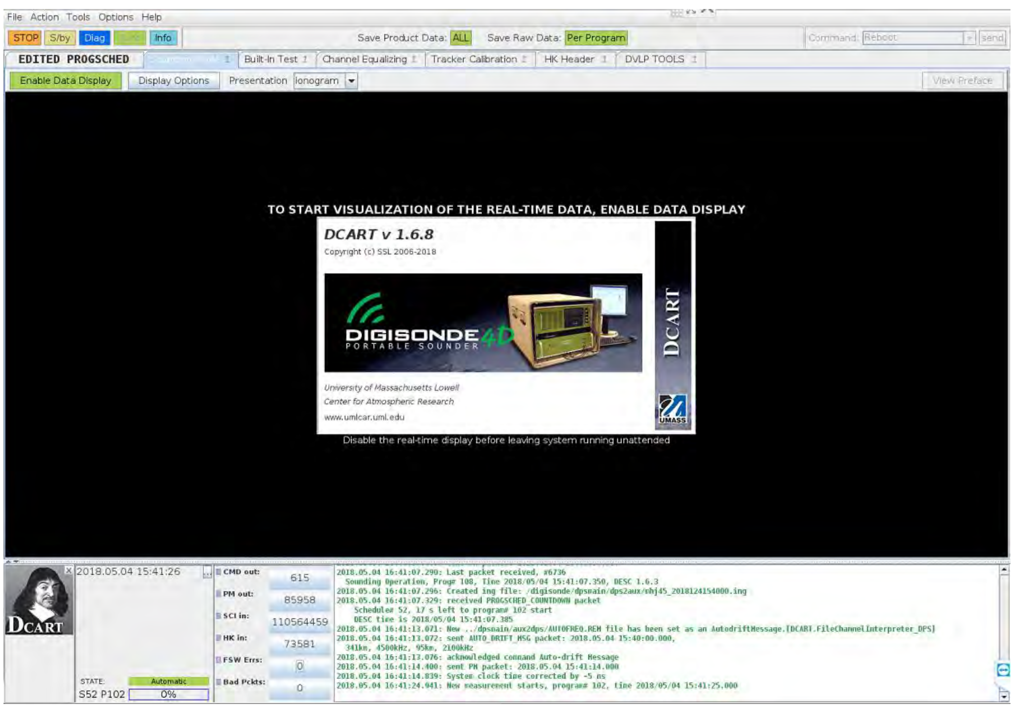


Figure 2-6: DCART Welcome Screen

POWERING ON THE RF AMPLIFIER AND ANTENNA SUB-SYSTEM

CAUTION

THE TRANSMIT ANTENNAS MUST BE CONNECTED TO THE SOUNDER PRIOR TO APPLYING POWER

2:48. To power on the RF amplifier, simply turn the power switch on the front panel of the Power Amplifier Switch to ON.

NOTE

The power switch on the Power Amplifier Chassis front panel energizes the power amplifier ONLY, not the entire system.

CONFIGURATION MANAGEMENT OF SITE-SPECIFIC DATA

2:49. Each sounder is pre-configured for its destination site prior to shipment. However, site-specific data may need to be adjusted in case of relocation, changes to instrument configuration, or availability of more precise site-specific data.

2:50. The following ID tags are assigned to each sounder:

STATION ID. A unique 3-digit number that is used to label all data products. REQUIRED. Post-analysis software reads the Station ID from the data records to locate Station UDD file with station constants, including location at which they were acquired and the sounder configuration. The Station ID shall be changed if the sounder is relocated, unless its operations imply constant relocation. Changes to Station ID shall be coordinated with LDI where a repository of Station IDs is maintained to avoid conflicts with existing IDs. It is possible to keep history of minor configuration changes in Station UDD file without changing the Station ID. For example, it is possible to reflect upgrades to the sounder's hardware and antenna array pattern and retain the same Station ID.

URSI CODE. A unique 5-character code given by the URSI to observatories. REQUIRED. The URSI code is associated with the location of the sounder, not its model or hardware configuration. The URSI Code is written in the SAO records holding ionogram-derived data to be reported to the WDC and other users.

SERIAL NUMBER. A unique number given to each DPS sounder made by LDI, in the sequence of their production. PROVIDED BY LDI. Serial number is not stored with the data.

2:51. Site-specific information can be found in the text files holding software configuration data. **Table 2-1** enlists the configuration files.

Table 2-1: Software Configuration Files Holding Site-Specific Data

FILENAME	LOCATION	GENERAL DESCRIPTION
DCART.ini	/digisonde/dispatch/	Defines the Station ID for the sounder, stores configuration data for DCART processing
xxx.UDD (xxx = Station ID)	/digisonde/dispatch/resources/UDD	Station UDD file. Provides station constants for post-processing and visualization software. Stores records of changes to ensure that retrospective data are processed correctly. Station ID files are kept at LDI under version control management and distributed together with the analysis software to other users of Digisonde® data
ddasetup.onl	/digisonde/dispatch	Provides station constants for the DDAV software
Dispatcher.ini	/digisonde/dispatch	Stores time zone specifics and text of labels for the web scripts supporting homepage operations of the sounder

RECEIVER ANTENNA ARRAY CONFIGURATION

2:52. Knowledge of antenna array configuration is required for interpretation of oblique beam codes stored in directional ionograms and for all software that processes four-channel data.

2:53. Four-channel data are processed using full specification of the antenna array given in the Station UDD file. Full specification of any antenna array (standard or non-standard) includes:

ANTENNA POSITIONS (X,Y,Z) specified in the right-hand system of coordinates with the central antenna #1 placed at the origin (0,0,0) and Z axis pointing up.

DECLINATION ANGLE of the X axis of the coordinate system from Geographic North Pole, using positive angles for clockwise direction from X axis towards the North Pole.

NOTE

It is customary to select X axis parallel to a side of antenna array and pointing towards North (see Figure 2-3, where X axis is line connecting antenna #2 and #3). In this case Y Axis of the coordinate system points due West.

2:54. Aligning antenna pattern with respect to the Geographic North as in the **Figure 2-3** is preferable, in which case the X-axis Declination Angle is zero. Use of the ground level compass North to orient the antenna array is often more convenient. Such orientation is acceptable, as long as the X-axis Declination Angle at the time of installation (equal to the Declination angle of the magnetic field) is recorded in the Station UDD file.

2:55. When antenna field allows placement of antennas in one of the standard configurations, the following parameters are specified for the software that processes four-channel data:

ANTENNA LAYOUT, which can be standard or mirror (**Figure 2-7**). In the standard Antenna Layout, enumeration of antennas 2-3-4 goes counter-clockwise. In the mirror Antenna Layout, antennas 2-3-4 are enumerated clockwise. In either cases, the antenna triangle is equilateral with the length of the side specified as ANTENNA MAXDIST. **Table 2-2** specifies Antenna Positions for standard and mirror configurations in the assumption of the X axis going from antenna 3 to antenna 2.

ANTENNA MAXDIST is the maximum distance between any two antennas in the configuration.

ANTENNA DEVN is the deviation angle of the line connecting antenna 3 and 1 from the X axis of the antenna coordinate system, positive for counter-clockwise deviation.

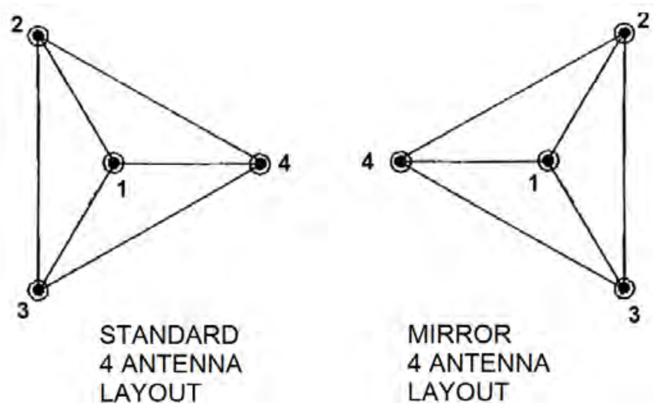


Figure 2-7: Two Common Digisonde-4D Antenna Layouts

Table 2-2: Antenna Positions for Standard and Mirror Antenna Layouts (Assuming MAXDIST of 60 m)

LAYOUT	Coord	Ant 1	Ant 2	Ant 3	Ant 4
STANDARD	X	0	30 m	-30 m	0
	Y	0	17.32 m	17.32 m	-34.64 m
	Z	0	0	0	0
MIRROR	X	0	30 m	-30 m	0
	Y	0	-17.32 m	-17.32 m	34.64 m
	Z	0	0	0	0

2:56. For the standard Digisonde-4D antenna configuration depicted in **Figure 2-3**:

e. ANTENNA LAYOUT is STANDARD,

f. ANTENNA MAXDIST is 60 m,

g. ANTENNA DEVN is -30 degrees, and

h. DECLINATION ANGLE is 0 degrees.

2:57. For antenna configurations that deviate from the equilateral triangle as in the **Figure 2-7**, ANTENNA LAYOUT is NON_STANDARD and only ANTENNA POSITIONS and DECLINATION ANGLE are applicable.

2:58. Directional ionogram data are processed using reduced specification of the antenna array given in the Station UDD file. Ionogram visualization software uses reduced specification to interpret beam codes stored in the ionogram file. Reduced specification of any antenna array is:

ANTENNA PATTERN, which can be one of the following four options:

0 = Standard per manual

1 = Rotated 180 degrees

2 = Mirror

3 = None of the above

RESTRICTED FREQUENCIES

2:59. Refer to the frequency authorization operating license obtained for the sounder at the installation site and note any frequencies to be protected. The restricted frequency intervals are stored in stationSpecific.udd file in the /digisonde/dispatch folder of the Data Platform. Restrictions for both ionogram and drift measurements can be specified by use of the parameter numbers *946 and *961 respectively. Separate lists of restrictions for ionogram vs drift measurements were implemented due to the difference between the two measurements' dwell time. Typical ionogram measurements remain sounding on any one frequency for less than one second, while typical drift measurements may remain on any one frequency for tens of seconds. This separation of restrictions allows the user to specify additional restrictions for the drift mode, if necessary, since the likelihood is somewhat greater that it would be detected by another HF user. Restrictions are specified as the lower end and upper end of each frequency band to be avoided during transmission. When specifying restricted frequency bands the system theoretical bandwidth of 30 kHz should be taken into account; increasing the band size by 15 kHz on both the lower and upper bounds. Further increasing the band size pushes the closet sounding frequency further away from the band restriction, which further decreases the amount of energy put into the restricted band. The bands are comma-separated; multiple *946 lines can be provided in one file, e.g.:

```
*946 < 40000-45000, 70000-75000 >
*946 < 81500-82150 >
```

SUMMARY OF STATION PERSONALIZATION SETTINGS

2:60. **Table 3-2** summarizes all station-specific configuration items that need to be personalized for the sounder.

Table 3-2: Site-specific configuration items to personalize for DPS4D

FILENAME	ITEM #	CONTENTS	SOFTWARE COMPONENT
DCART.ini[1]	SID	Station ID	DCART: tagging of data files See Section 5 for description of other DCART options
stationSpecific.UDD	946	Ionogram restricted frequencies	DCART
	961	Drift restricted frequencies	DCART
Station UDD file (xxx.UDD)	304	Station name	DCART, ARTIST 5, DFT2SKY, TILT, DRGMaker, online image tools, SAO Explorer
	101	Geographic latitude	
	102	Geographic longitude	
	104	Gyrofrequency	
	105	Dip angle	
	106	Magnetic declination	
	307	URSI Code	
	032	Digisonde® model	
	079	X AXIS DECLINATION ANGLE	
	080-082	ANTENNA POSITIONS	
	086	ANTENNA PATTERN	

FILENAME	ITEM #	CONTENTS	SOFTWARE COMPONENT
	090	ANTENNA LAYOUT	
	091	ANTENNA DEVN	
	092	ANTENNA MAXDIST	
Dispatcher.ini	StationId	URSI Code	Dispatcher: filename generation
ddasetup.onl	185	Station constants	DDAV : drift velocity calculations
	184, 170, 177	Antenna coordinates	

[1] DCART.ini file need not be edited directly, but rather via the DCART Options menu selections.

FIELD VALIDATION

CAUTION

AT ANY TIME DO NOT PATCH TX1 OR TX2 DIRECTLY INTO ANY OF THE ANT CONNECTORS ON THE REAR I/O PANEL TO SET UP A LOOPBACK. THE ANT CONNECTORS HAVE 24 VDC ON THEM TO POWER THE RECEIVE ANTENNAS.

TO CONNECT AN EXTERNAL LOOPBACK, BLOCKING CAPACITORS MUST BE CONNECTED IN SERIES WITH THE ANTENNA SWITCH INPUTS AT THE REAR OF THE MAIN CHASSIS.

2:61. Although the sounder is subjected to detailed testing during manufacture and prior to shipping, final system validation must be completed in the sounder's ultimate operating environment to ensure that the sounder and antenna sub-systems are correctly matched and deliver optimum performance. Field validation process involves:

a. Matching the antenna cable lengths,
b. Adjustments to the cable lengths for varying antenna heights,
c. Detecting defective cables and Antenna Pre-amps,
d. Verifying the correct directions in both Ionogram and Drift modes of operation.

PRELIMINARY REQUIREMENTS

2:62. Field calibration shall only be performed by personal who have qualified on an authorized Digisonde® Sounder training course, and who have access to the relevant calibration equipment specified in this section. Proficiency in sounder operations as described in Section 3 of this manual is mandatory.

2:63. Before any field calibration is performed the sounder and antenna sub-systems must be installed as per the preceding instructions.

CROSS-CHANNEL EQUALIZING VIA INTERNAL LOOPBACK (EXCLUDING ANTENNAS AND CABLES)

2:64. Identical response of all receive channels of the Digisonde-4D to the input signal is required to ensure correct directional analysis of four-channel data. Frequency-dependent mismatches in phase and amplitude response characteristics are introduced primarily by the narrowband analog circuitry that is used in the Tracking Filter cards and analog amplifiers of the Receiver card.

2:65. Periodically running a Cross-Channel Equalizing program removes the cross-channel, frequency-dependent phase and amplitude variation in the Digisonde-4D sounder. The results of the cross-channel equalization are saved in the latest.ceq file in /digisonde/dispatch folder. This file automatically corrects phase and amplitude differences in the four receiver channels for all subsequent Ionogram and Drift measurements.

2:66. A Cross-Channel Equalizing program is configured by setting Operation mode to “Channel Equalizing” and Operation Option to “Internal Loopback” (see **Figure 2-8** and **Section 3**). An appropriate Cross-Channel Equalizing program is pre-configured prior to the sounder shipment, but it is important that its frequency coverage is appropriately adjusted with time to match the range of operating frequencies. In the Cross-channel equalizing mode with internal loopback, the sounder:

i. a. Switches the XMT card output through an attenuator (on the XMT card) and injects it directly into the antenna switch assembly (via the coaxial cable labeled “Cal In”).

j. b. Disables the RF power amplifier by gating off the XMTR pulse signal (accessible on the front panel) which normally activates the bias voltage of the RF power FET.

k. c. Switches the antenna switch inputs from the four external antennas to the directly injected transmitter signal.

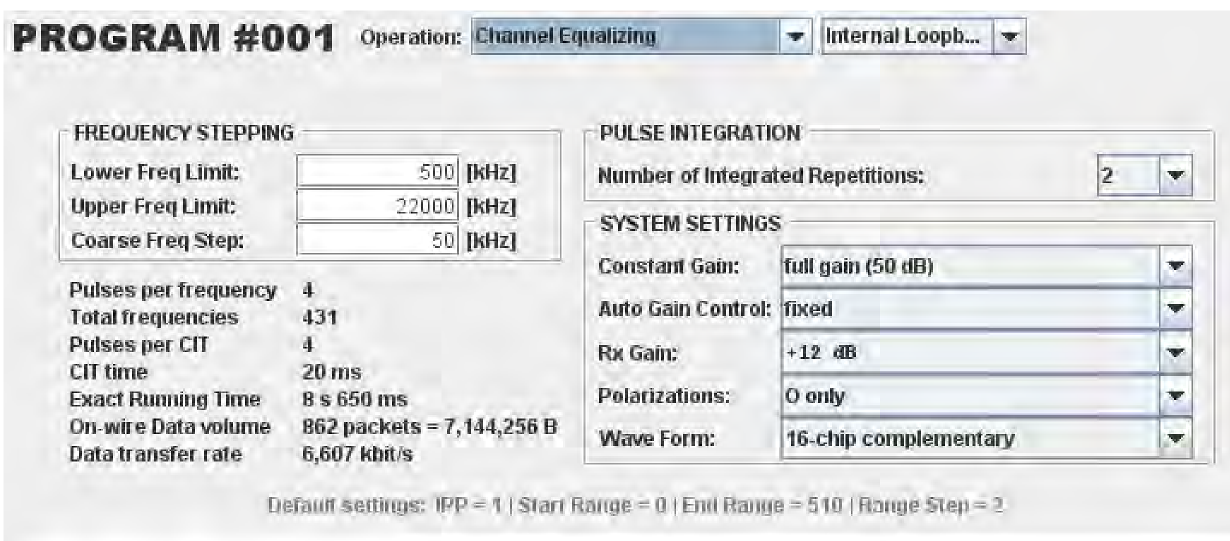


Figure 2-8: Program for Cross-Channel Equalization

2:67. Cross-Channel Equalization program shall be run prior to checking cable lengths and the phase response of the loop antenna pre-amplifiers.

VERIFICATION OF CABLES AND ANTENNA PRE-AMPLIFIERS VIA EXTERNAL LOOPBACK

2:68. Cable and antenna pre-amplifier verification must be performed at system installation to identify and correct phase errors, and may be repeated periodically to see if corrections are necessary.

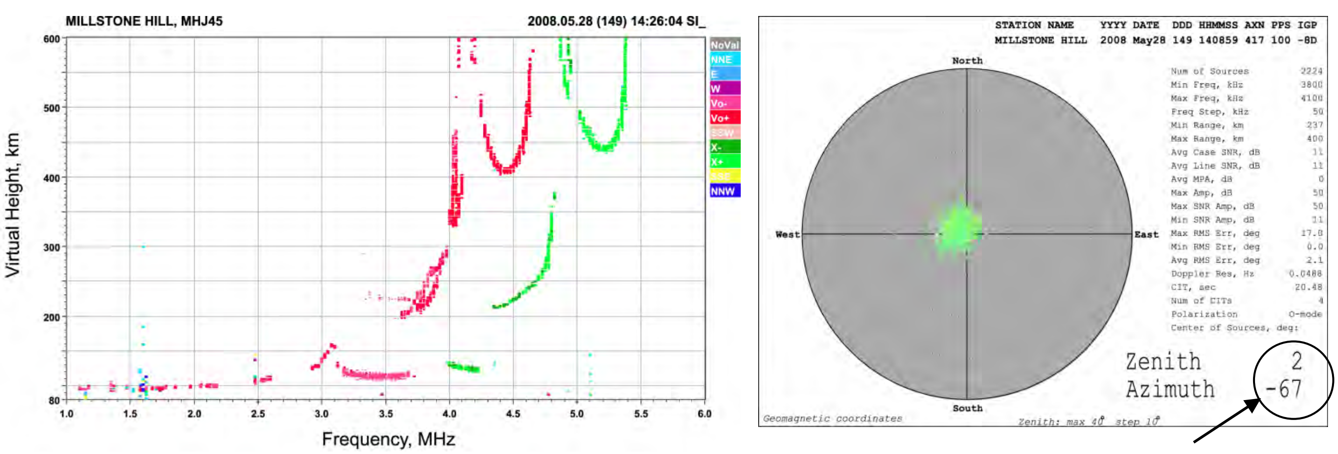
Matching Antenna Cable Lengths

2:69. Ideally all the antenna cables should be matched to 6 inches or 20 cm. They can be matched using either physical or electrical techniques. . To match cable lengths electrically, use a Time Domain Reflectometer (TDR). The far ends of the cables should either all be either open or shorted. Be aware if the acquired cables are from different manufacturers or lot numbers cables may have significantly different physical length when matched electrically (most likely due to differences in dielectric when manufactured).

FIELD VALIDATION OF INSTALLED ANTENNAS AND CABLES

2:70. With a quiet ionosphere, skymaps and RSF ionograms should generally appear to be overhead. **Figure 2-9** is a sample of the skymap showing ionospheric tilt close to 0 (zenith angle of 2°, azimuth angle is irrelevant).

2:71. After verifying that the ionograms and skymaps generally appear to be overhead, add two test cables to artificially tilt antenna array as follows. For a four antenna array, 60 meters on a side, temporarily add a 18 meter extension to an outer antenna cable and temporarily add a 6 meter extension to the center antenna cable. This will tilt the antenna beam approximately 20 degrees in the direction away from outer antenna which has the extra cable length. **Figure 2-12** and show extension cable connections and expected tilt of the antenna beam for standard and mirror antenna layouts. Such a large artificial tilt should be clearly evident on both the skymap and ionogram data.



(a) (b)

Figure 2-9: Ionogram (a) and Skymap (b) for Almost Overhead Ionosphere (No Test Cables Inserted)

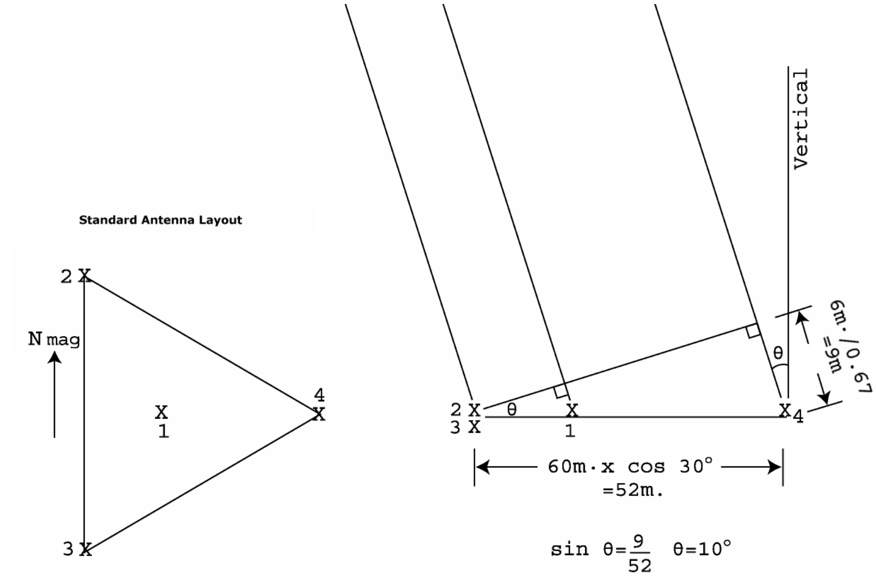


Figure 2-10: Rx Antenna Calibration Setup with Added Test Cable Segments (Standard Antenna Layout)

2:72. Example ionogram and skymap obtained in the tilted antenna array configuration are shown in **Figure 2-11**, where tilt is accomplished in the mirror antenna configuration, thus corresponding to the apparent eastward direction of the echoes.

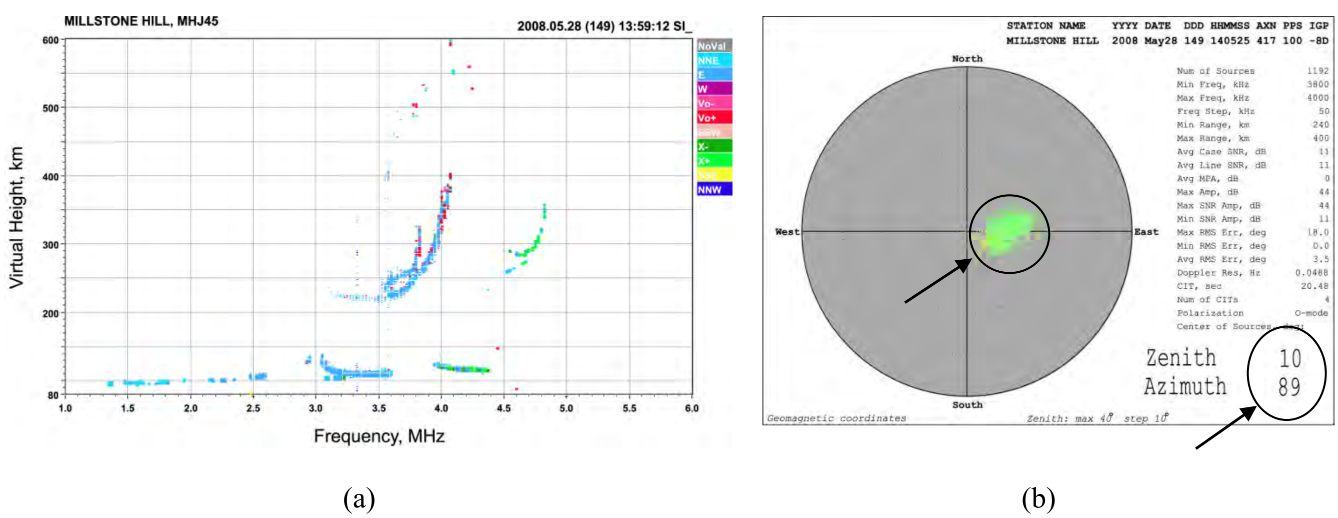


Figure 2-11: Example Ionogram (a) and Skymap (b) Obtained with Extension Cables Inserted (Skymap shows apparent shift of 10° zenith to East (azimuth 89°), and ionogram echoes are tagged as oblique East)

POST INSTALLATION CHECKS

2:73. At this stage it is recommended that the operator tests the system by modifying and running measurement programs as outlined in Section 3 (Operating Modes and Instructions) of this manual.

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SECTION 3

OPERATING INSTRUCTIONS

SECTION CONTENTS

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CHAPTER 1

PROGRAMMING DIGISONDE® MEASUREMENTS

PROGRAMS, SCHEDULES, AND SCHEDULE START TIMES

3:1. The Digisonde® is a configurable scientific instrument that offers a variety of measurement modes and corresponding data products. The basis of all its operations is a *measurement program*, or simply *program*, a set of operational parameters that define one logically complete set of measurements performed by the Digisonde®. For example, a Digisonde® program can define an ionogram measurement. Digisonde-4D keeps up to 128 active program definitions in its memory.

3:2. A measurement program can be started manually by a keyboard/mouse command or, during autonomous operations, triggered by the system software in accordance with the current *schedule*, a repetitive sequence of measurement programs (**Figure 3-1**). For example, a Digisonde® schedule can instruct Digisonde® to make ionogram measurements every 10 minutes. When a schedule is running, its measurement programs are started automatically in an endless loop. Digisonde-4D stores up to 128 active schedule definitions in its memory.

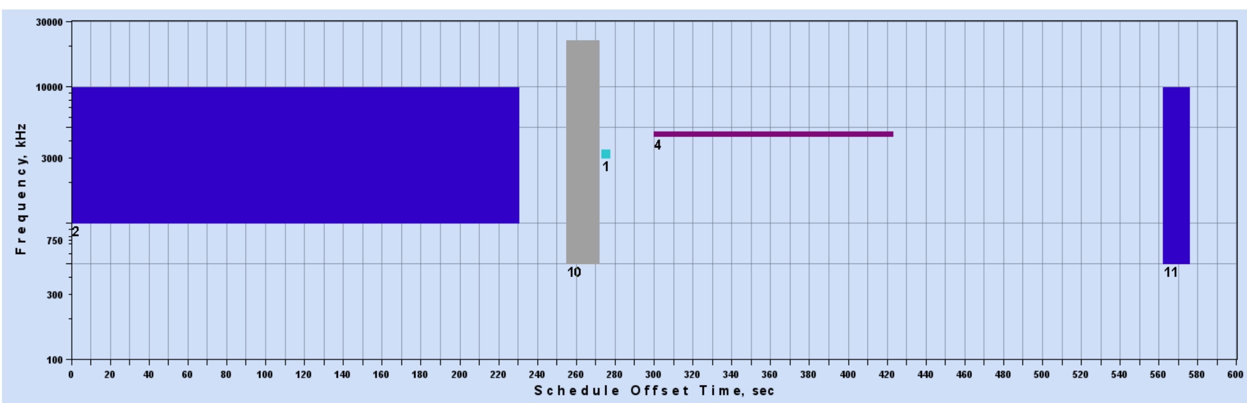


Figure 3-1: Digisonde® Example of a 10 minute schedule

3:3. A measurement schedule can be started manually by a keyboard/mouse command or, during autonomous operations, triggered by the system software using the concept of *Schedule Start Time (SST)*. One SST consists of (1) schedule number and (2) UT timestamp when the schedule shall be started. A SST Task is responsible for starting the Schedule Task at requested times. The SST Task periodically checks an *SST Queue* holding individual SSTs. When the system clock matches the earliest SST in the queue, The SST Task invokes the Schedule Task and removes expired SST from the queue. As an example, Schedule Start Time rules can be used to determine when the day and night schedules start.

3:4. The SST Queue has to be replenished with new SSTs that are usually calculated automatically in accordance with the top-level definition of the measurement planning. For example, such planning can have two different schedules for daytime and nighttime. Programming the Digisonde® to switch schedules automatically is further discussed in Chapter 2.

SCIENCE MODES AND DATA PRODUCTS

3:5. The following types of scientific measurements are available for the Digisonde® operations:

1) Ionogram

(a) Vertical Incidence (VI) ionogram:

- VI ionogram with Doppler analysis of echoes
- VI Doppler ionogram with evaluation of the echo's angle of arrival

  Multi-beam processing

  Source interferometry processing
- VI Doppler ionogram with multi-beam processing and two frequency precision ranging

(b) Oblique Incidence (bi-static) ionogram between two Digisonde®

2) Drift measurement (detection of multiple echoes and evaluation of their source velocities).

3) Passive RF Sensing mode for monitoring transmitters of opportunity.

3:6. Digisonde® employs data processing software to obtain *derived data products* from acquired ionogram and drift measurement data:

1) Ionogram-derived data

(a) Automatically scaled ionospheric characteristics, ionogram traces, and electron density profile

(b) Maximum Usable Frequency (MUF) report

(c) Directogram showing a daily plot of oblique echoes

2) Drift-derived data

(a) Skymap showing location of reflection sources

(b) Drift velocity derived in the assumption of a bulk motion of plasma across the station

(c) Zenith and azimuth of the ionospheric tilt

3:7. **Figure 3-2** presents an overview of the Digisonde® data products in terms of their origin, data storage and display options. The upper panel enlists science data types that are acquired in the process of Digisonde® measurements. Yellow circles are used to denote created data file types. In addition to the three major science data modes, ionogram (RSF+SBF), drift (DFT), and Passive RF Sensing (TAV), it is possible to store raw sample data (RAW). The rest of data products are derived using data post-analysis software that runs autonomously (the lower panel). Arrows in the **Figure 3-2** indicate data flow for derivation and display of the products. Two types of display are distinguished, real-time monitoring of the measurement process, and images available for viewing over the Internet (Web displays).

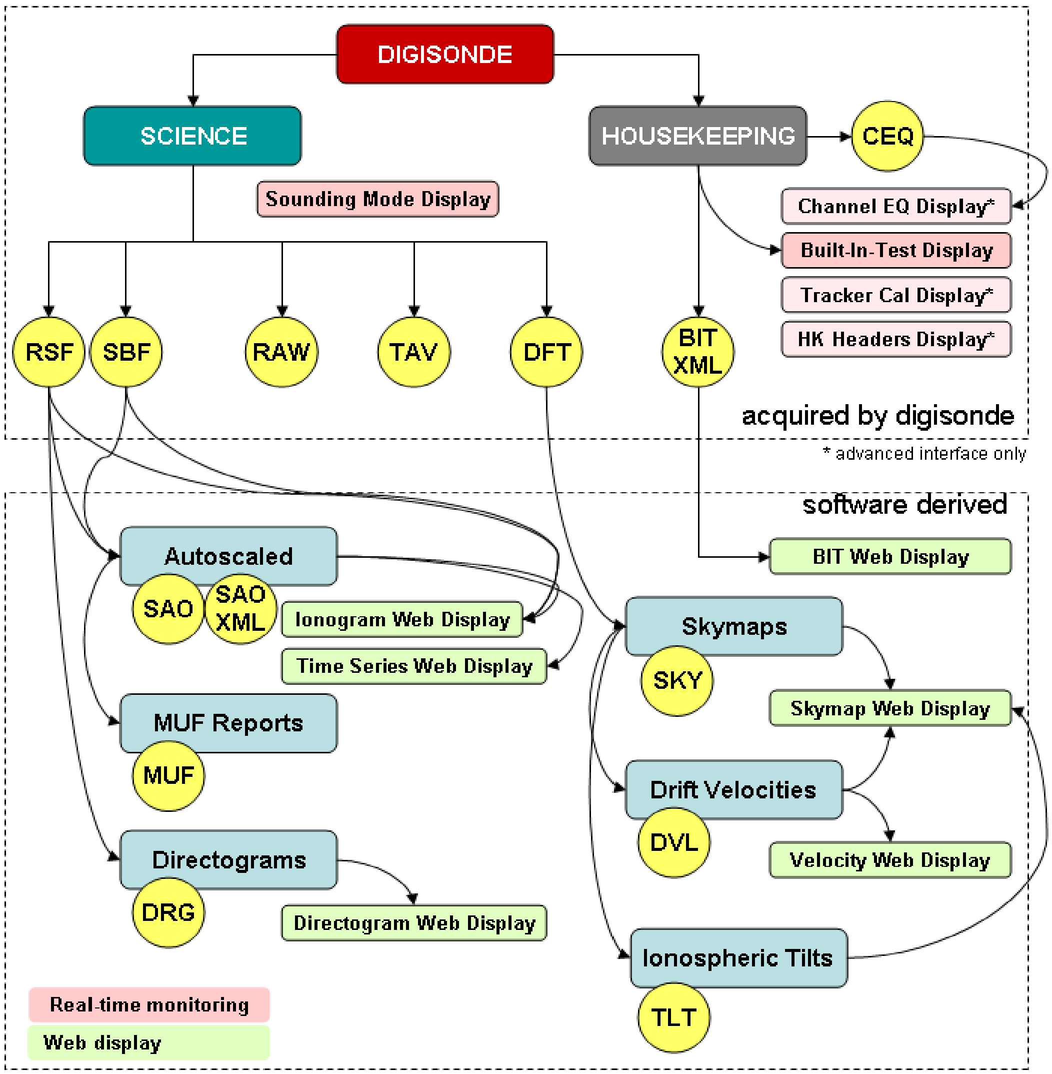


Figure 3-2: Overview of the Digisonde® Data Products and Displays

PROGRAMMING SCIENCE MEASUREMENTS

General Considerations

3:8. Fundamentally, ionogram and drift measurements use the same remote sensing approach described in Section 1, in which Digisonde® transmits a sequence of pulses on an operating frequency, listens for the echoes on its four antennas, performs signal processing (RFIM, cross-channel equalizing, pulse compression), and obtains set of four Doppler spectra for each sampled range bin (one spectrum per receiver channel). Then, in the drift measurement mode, all Doppler spectra are stored in the output product file for subsequent derivation of the skymap and bulk drift velocity, whereas in the ionogram mode, only one echo is recorded per range bin by reducing four Doppler spectra to one echo status (amplitude, Doppler shift, angle of arrival, etc.).

3:9. Practically, programming ionogram and drift measurements has several subtle differences.

a. Separation of the overlapping echoes by their Doppler frequency is instrumental to efficient skymap construction. In order to accomplish high Doppler frequency resolution necessary for the drift/skymap measurement, the coherent integration time (CIT) has to be selected as high as 20 or 40 sec, so that corresponding Doppler resolution is 0.05 or 0.025 Hz. Ionogram measurement at such high integration times per frequency would take too much time to complete, and thus integration times in the ionogram mode have to be selected much lower, generally in the order of 1 sec or less.

b. For ionogram measurements, number of pulses per frequency, *N*, is kept sufficiently small to reduce the ionogram running time. Because smaller *N* means lower signal-to-noise ratio, such selection has to consider implications of reducing the overall ionogram quality. While such selection is station-dependent, it is generally recommended to have 16 pulses per frequency. Smaller *N* values are possible for campaign periods requiring fast ionograms (below 30 sec). In the drift mode where Doppler frequency resolution is high, number of pulses per frequency *N* (i.e., number of spectral lines in the Doppler spectrum) has to be as high as possible to cover sufficient range of Doppler frequencies.

c. Drift measurements produce relatively large volumes of data for storage. A number of data reduction measures are taken to keep drift file sizes reasonably small. In particular, it is customary to run drift measurement on a small subset of fixed frequencies rather than sweep the whole frequency range as in the ionogram mode. Digisonde-4D offers an automated *frequency override* mode, in which selected set of fixed frequencies for drift measurement is shifted up and down in frequency using data from recent autoscaled ionogram, so that these frequencies are optimally positioned to target the F region of ionosphere.

Frequency Multiplexing

3:10. Frequency multiplexing is commonly used in the drift mode to effectively increase the integration time without increasing overall measurement time. To illustrate the principle of frequency multiplexing, let's consider example where 8 pulses per frequency are transmitted, and the measurement includes 4 frequencies. **Figure 3-3** shows progression of the non-multiplexed case in time. First, Digisonde® sends and processes 8 pulses on frequency f1, then another 8 for frequency f2, then frequency f3, and finally the last 8 pulses for frequency f4. **Figure 3-3** shows frequency multiplexing when frequency sequence f1-f2-f3-f4 is repeated 8 times. Both cases involve transmission of 8x4 = 32 pulses using the same amount of time. However, coherent integration time for each frequency in the multiplexed case is 4 times larger, resulting in 4 times better Doppler resolution of the measurement. Further details on frequency multiplexing can be found in Section 1.

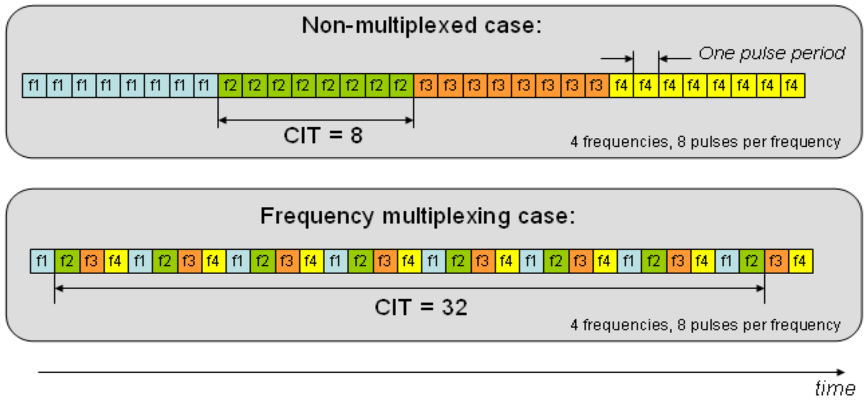


Figure 3-3: Frequency Multiplexing as a Means to Increase Doppler Frequency Resolution.

3:11. In order to accommodate specification of the frequency multiplexing in Digisonde® programs, three program parameters are used (see **Figure 3-4**):

a. Fine frequency step (FFS) = frequency step inside a block of multiplexed frequencies

b. Number of fine frequency steps (NFS) in the block

c. Coarse frequency step (CFS) = frequency step between blocks of multiplexed frequencies

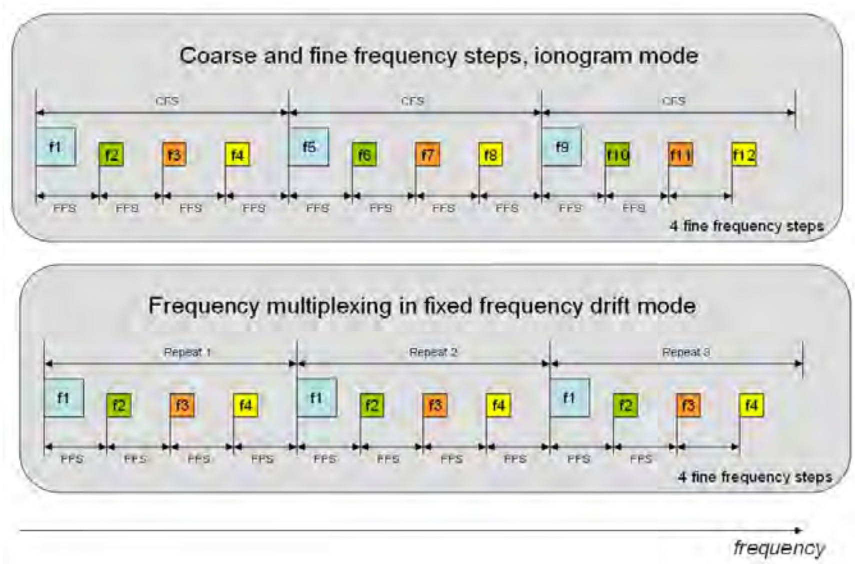


Figure 3-4: Frequency Multiplexing in Ionogram and Drift Measurements.

3:12. For example, suppose 50 kHz linear frequency stepping and x4 advantage in Doppler resolution is required for an ionogram. Then fine frequency step (FFS) is 50 kHz, number of fine steps (NFS) is 4, and coarse frequency step is CFS = NFS * FFS = 200 kHz. The same ionogram measurement but without x4 Doppler resolution improvement would be made by setting CFS to 50 kHz and NFS to "none" (thus disabling multiplexing).

3:13. Frequency Stepping, Range Sampling, and Pulse IntegrationFigure 3-5 compares two typical examples of programming frequency/range stepping & pulse integration for ionogram & drift modes.

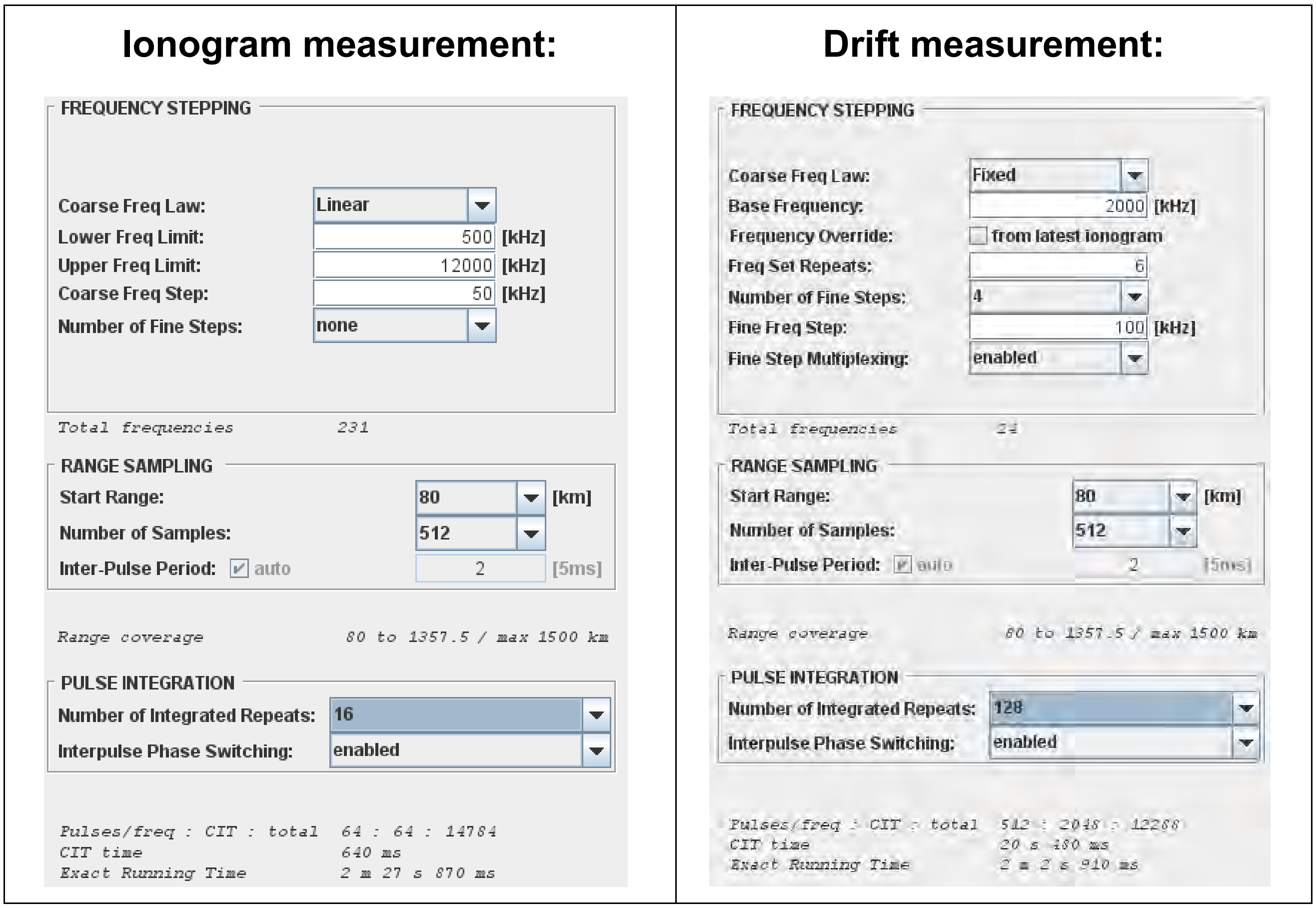


Figure 3-5: Programming Frequency Stepping and Range Sampling for Ionogram and Drift Measurements

3:14. The left panel of Figure 3-5 specifies a frequency sweep from 0.5 to 12 MHz, typical for the ionogram mode. Frequency multiplexing is disabled, and linear frequency stepping with 50 kHz is set, resulting in 231 frequency steps in the ionogram. Interpulse period of 2 x 5 ms = 10 ms (1500 km radar range) is selected to accommodate 512 range steps of 2.5 km each (from 80 to 1357.5 km). Number of integrated repeats per frequency is set to 16, resulting in the Doppler spectra with 16 lines. Each integrated repeat involves 2 pulses with complementary codes of phase modulation, and two separate transmissions for O and X polarizations. Thus 64 pulses are transmitted on each frequency, totaling 64 x 231 = 14784 pulses needed to complete the ionogram measurement. At 10 ms interpulse period, pulse transmission during this ionogram requires 14784 x 10 ms = 147.84 sec = 2m 27s 840ms. Additional 30 ms of time overhead are required to manage FIFO buffers and time synchronization, resulting in the exact ionogram running time of 2m 27s 870ms. Without multiplexing, CIT time is 64 x 10 ms = 640 ms, so that Doppler resolution is 1/0.64s = 1.5625 Hz.

3:15. Choice of the upper frequency for the ionogram sweep is determined by the maximum expected frequency at which echoes can still be observed. The upper frequency shall be high enough to accommodate unusual increases in the ionospheric plasma density. It is recommended to program daytime and nighttime ionograms separately and setup nighttime ionograms with a lower upper frequency but finer frequency steps to improve quality of the ARTIST ionogram autoscaling.

3:16. Choice of the lower frequency for the ionogram sweep is influenced by new capability of the Digisonde-4D to mitigate powerful RF interference from broadcasting stations that operate below 1.5 MHz. Depending on Digisonde® location and RFI environment, it may be possible to observe echoes at frequencies as low as 0.5 MHz.

3:17. Interpulse phase switching is another RFI mitigation technique in which phase of odd pulses is flipped by 180º on both transmission and reception, so that when integration of multiple pulses is performed, coherent interferers are suppressed while signals are still enhanced.

3:18. specifies a fixed-frequency drift measurement with 4 multiplexed frequencies separated by 100 kHz. The set of 4 frequencies 100 kHz apart is positioned at 2 MHz, unless the latest data from the ionogram autoscaling is available to move the set to a more appropriate anchor frequency. With 6 repeats of 4 frequency sets, total number of frequency [operations] is 24. On each of these 24 frequencies, N = 128 integrated repetitions are made, each repetition consisting of 2 complementary codes (and only one polarization is recorded to reduce data volume). This, total number of pulses needed to complete this measurement is 24 x 256 = 6144. Although 256 pulses are sent on each frequency, frequency multiplexing provides 4x improvement in Doppler resolution, raising CIT from 256 x 10 ms = 2.56 sec (non-multiplexed) to 256 x 4 x 10 ms = 10 sec 240 ms. With this CIT duration, Doppler resolution is 0.098 Hz, and Doppler spectra cover 128 x 0.098 = +/- 6.3 Hz.

3:19. While range sampling is configured identically in both ionogram and drift mode, motivation for these choices is different. The ionogram measurement sets upper range to 1357.5 km to make sure that echoes from the raised F2 layer, whose virtual ranges can go well above 800 km during storm conditions, are still observed. Setting the interpulse period to 5 ms (thus cutting ionogram running time in half) and recording virtual ranges from 80 to 717.5 km might suffice in majority of the geophysical conditions, except perhaps the most interesting cases of the storm activity. It is therefore recommended to always use 2.5 x 512 range sampling mode during ionogram measurements. For the drift mode, choice of 10 ms for the interpulse period is driven primarily by the need to increase CIT time.

Autogain Evaluation and Control

3:20. The Digisonde-4D design takes into account operation in noisy RF environments where strong interferers could saturate the receiver inputs rendering the receivers insensitive to smaller message signals. For ionospheric sounding, AM radio stations in the 0.55-1.65 MHz band and the 6-24 MHz HF communications bands can pose serious problems for ground-based receivers. At some locations we have measured interference levels of >1 V at the receive antennas compared to <1 µV message signals. Digital receivers that directly digitize RF signals are especially prone to this problem since ADCs have a limited dynamic range. The ADCs need to be protected from powerful out-of-band interference as well as from saturating in-band signals. In the Digisonde-4D, a combination of gain controls in the wideband input amplifiers and the analog tracking bandpass filters limit the input voltages at the ADCs to the maximum allowed values.

3:21. **Figure 3-6** shows a diagram of the Receiver path in the Digisonde-4D indicating gain stages. Wide band circuitry is exposed to the cumulative environment where dynamics of the individual sources of interference is smeared out. The Digisonde-4D implements three kinds of gain control,

a. Fixed Gain in antenna preamplifiers (site-specific, adjusted manually in response to RF noise environment at installation time)

b. Constant Gain in antenna switch and tracking filters (does not change during the measurement, but can be programmed to adapt to the larger time scale changes such as day/night)

c. Auto Gain which adjusts the gain of the receiver's variable gain amplifier (VGA) that changes from frequency to frequency

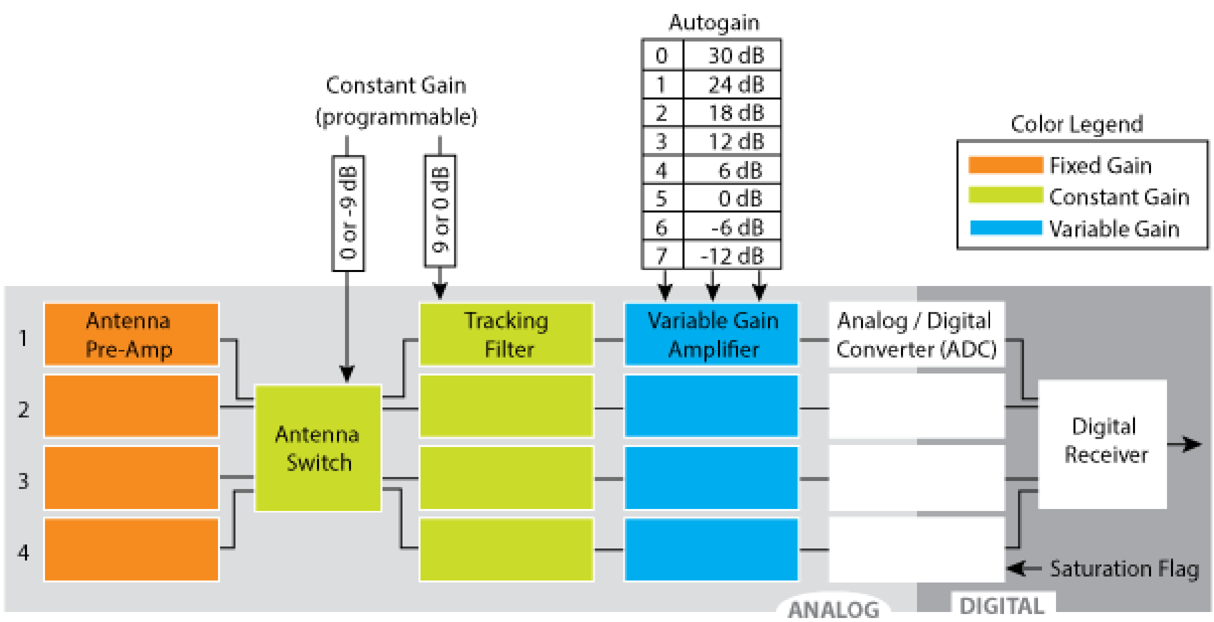


Figure 3-6: Gain Control Steps in Digisonde-4D

3:22. Automatic gain control in the Digisonde-4D is arranged prior to digitization to prevent A/D converters from under/over voltage conditions. At this stage of the receiver, the signal bandwidth continues to be large (varying for different operating bands of the tracking filters, but in the order of ~1 MHz) and therefore less sensitive to fast changes in characteristics of the individual interferers. To keep measurement run time predictable, all Digisonde measurements are performed with a pre-determined table of the automatic gain settings, gain evaluation is not made prior to each frequency transmission.

3:23. The autogain table shall be periodically refreshed, typically once per schedule, which is accomplished by running an ionogram measurement with "create gain table" option. Such ionogram starts with the process of table creation that takes varying time, depending on the number of optimization steps needed on each frequency, usually in the order of 10-20 sec. If precise time synchronization of measurements is not important for the Digisonde® observations, then every ionogram can be configured to start with the gain table creation. However, it is quite acceptable to schedule gain creation to run only periodically, e.g., once a schedule. Such "gain table creation" ionogram can be configured to suppress output ionogram file (see **Figure 3-7**), so that the only outcome of its operation is to refresh the gain table.

NOTE

If DCART scheduler does not detect "create gain table" programs in a schedule, it issues a warning to the operator. Such schedule is likely to run with non-optimal automatic gain settings.

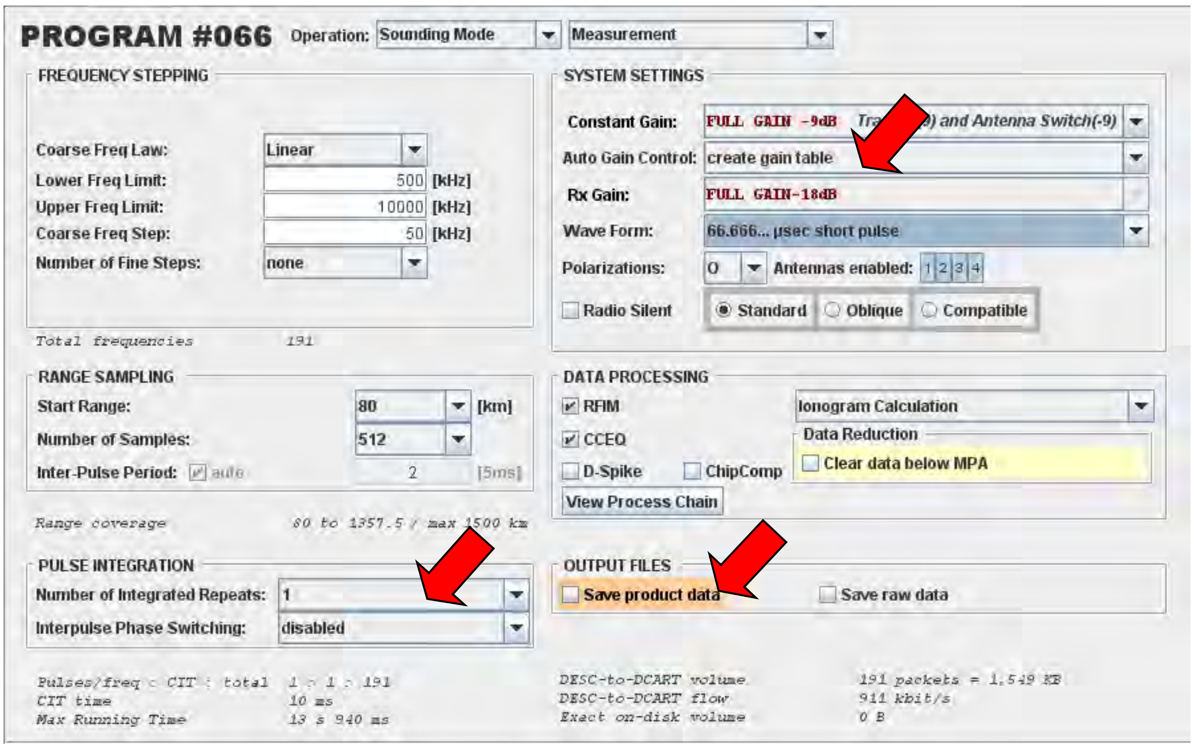


Figure 3-7: "Create Gain Table" Program that Refreshes the Autogain Table (Ionogram File is not Made)

3:24. It is recommended to switch Digisonde® to a lower constant gain setting during the night, when smaller absorption in the ionosphere results in stronger signals.

NOTE

It is important that "create gain table" measurement is configured to the same constant gain settings as the rest of measurement programs in the schedule.

Programming Vertical Incidence Ionogram Measurement

3:25. The following data processing options shall be considered when programming the ionogram measurement:

a. OUTPUT FILES: RSF versus SBF output format.

- Default setting is RSF (Routine Scientific Format), ionogram with echo directions
- SBF (Single Byte Format), for ionograms without echo directions, used for sustaining operations during periods of hardware faults in one or more receiver channels

b. TWO-FREQUENCY PRECISION RANGING / PRECISION GROUP HEIGHT (PGH)

- Precision ranging is disabled by default.
- Precision ranging is enabled by (a) setting number of fine steps to 2 and (b) selecting fine frequency step of 5 kHz. Then data from the second frequency are used to calculated precise range of echoes with 1 km resolution and then discarded.

NOTE

Ionograms with enabled two-frequency precision ranging take double time to complete.

- Precision ranging mode requires RSF format for the output ionograms

c. DATA REDUCTION: enabled/disabled

- Data reduction is disabled by default.
- For locations with a limited Internet bandwidth available for data delivery to the external data repositories, it may help to threshold data below the noise level (as determined by most probable amplitude, MPA) for a better file compression.

d. RFIM:

- RF Interference Mitigation removes powerful narrowband interferers in the receiver bandwidth

RSF Ionogram with Echo Directions

3:26. Typical example of the RSF ionogram measurement program and corresponding ionogram display is shown in **Figure 3-8**. The concept for assigning colors to echo directions is explained in Section 1, Chapter 1. The insert in **Figure 3-8** summarizes the mapping and provides direction codes used in the color legend. “No Value” color is used for signals whose direction of arrival could not be determined reliably.

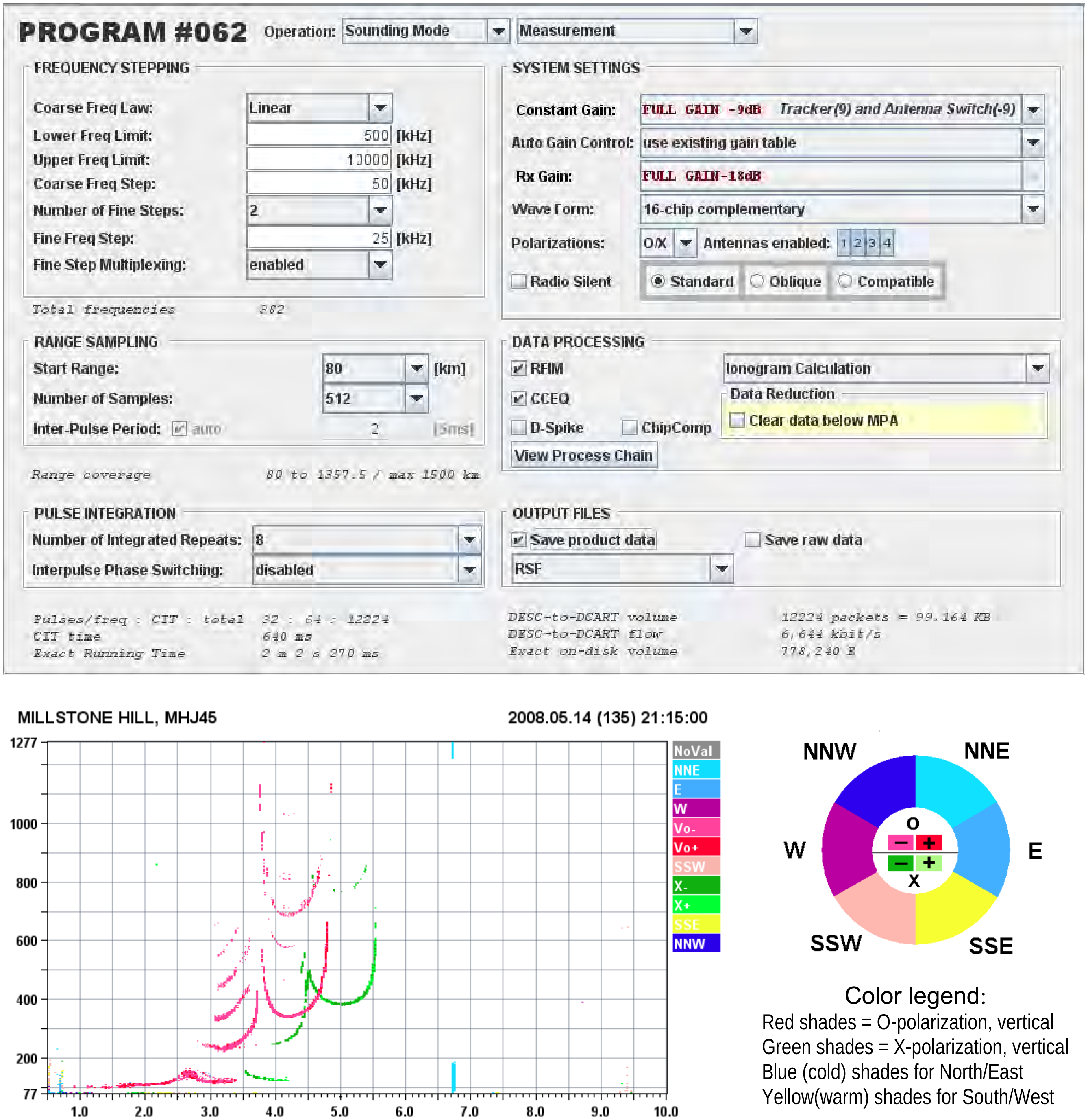


Figure 3-8: RSF Ionogram with Echo Directions, Running Time ~2 minutes

RSF Ionogram with Echo Directions and Precision Ranging

3:27. Precision ranging is enabled by (a) setting number of fine steps to 2 and (b) selecting fine frequency step of 5 kHz (**Figure 3-9**).

Figure 3-9: RSF Ionogram with Echo Directions and Precision Ranging (Running Time ~4 minutes)

SBF Ionogram without Echo Directions

3:28. Single Byte Format (SBF) is selected to make ionograms without echo directional analysis, which can be considered as a temporary operating mode for periods of hardware faults in one or more receiver channels.

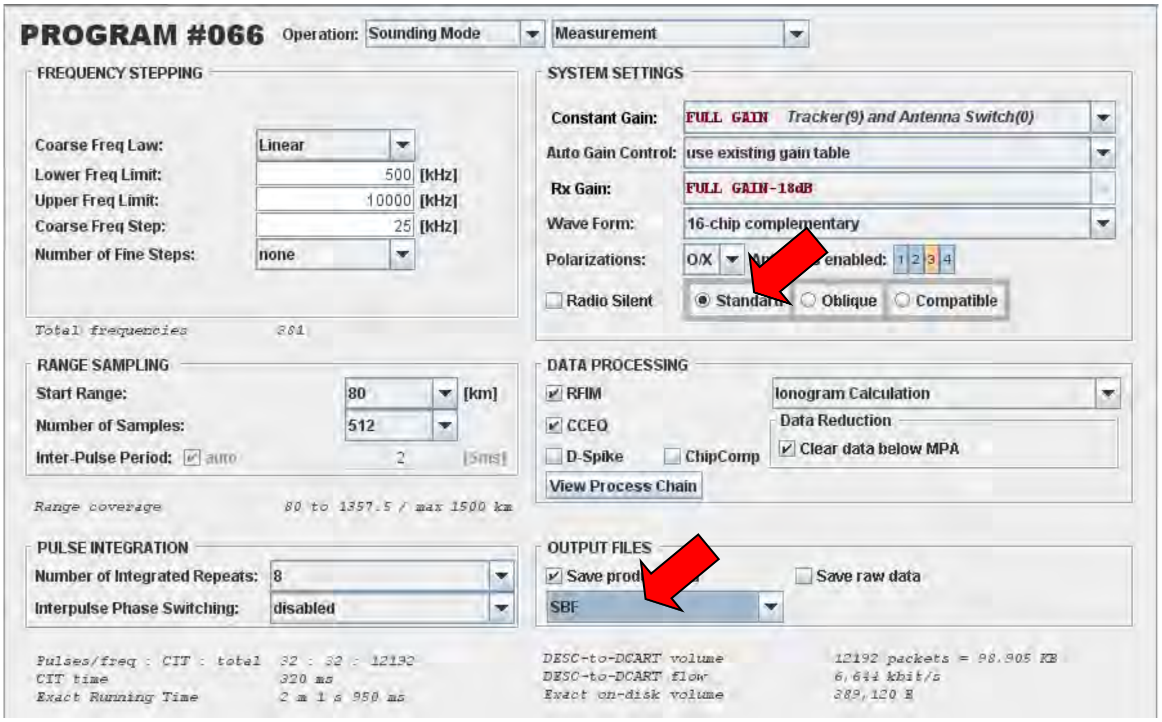


Figure 3-10: SBF Ionogram Without Echo Directions, Antenna 3 Disabled

3:29. SBF ionogram mode can be also used as a reduced data volume solution for locations with a limited Internet bandwidth for data delivery. It is however recommended that the data reduction option is exercised first before resorting to the SBF ionogram mode, as the scientific value of SBF ionograms is inferior to the RSF ionogram mode with echo directions.

Data Products Derived from Vertical Incidence Ionogram Measurement

Automatic Ionogram Scaling with ARTIST

3:30. The Automatic Real-Time Ionogram Scaler with True height (ARTIST) is an intelligent system developed for extraction of ionospheric specification data from Digisonde® ionograms. The automatic ionogram interpretation ("scaling") is a computer-hard problem that requires a model of human visual perception to extract useful ionogram image signatures and a syntactic analyzer to identify and characterize them. A common approach to the ionogram autoscaling in ARTIST is to (1) adaptively threshold the ionogram image to remove background noise, (2) reduce echoes to edgels (edge elements) corresponding to the leading edge of the echo, (3) string echoes into traces, and (4) identify traces and determine their characteristics.

3:31. The ARTIST software reads ionogram files in RSF or SBF format and produces three types of output files for subsequent storage and dissemination: (1) complete set of scaled data in SAO 4.2 format, legacy standard, (2) complete set of scaled data in SAOXML 5.0 format, current Digisonde® network standard, and (3) set of MUF frequencies calculated for pre-configured path distances. All three types of the output files can be selected for local storage on the Digisonde®'s hard disk, archival on removable media (CD, DVD), as well as scheduled for delivery to remote servers via FTP or SFTP protocols, as further explained below in Chapter 4.

3:32. **Figure 3-11** shows an example of ionogram picture prepared by Ion2PNG utility for the Digisonde® webpage, in which the raw ionogram data are combined with the ARTIST-derived ionospheric characteristics, NHPC-calculated profile of the electron density plasma, and table of the maximum usable frequencies (MUF) obtained for a pre-specified list of distances. The table of autoscaled characteristics include confidence level of the autoscaling ranging from 55 (low confidence) to 11 (high confidence), as well as the version of the ARTIST software used to obtain the scaled data.

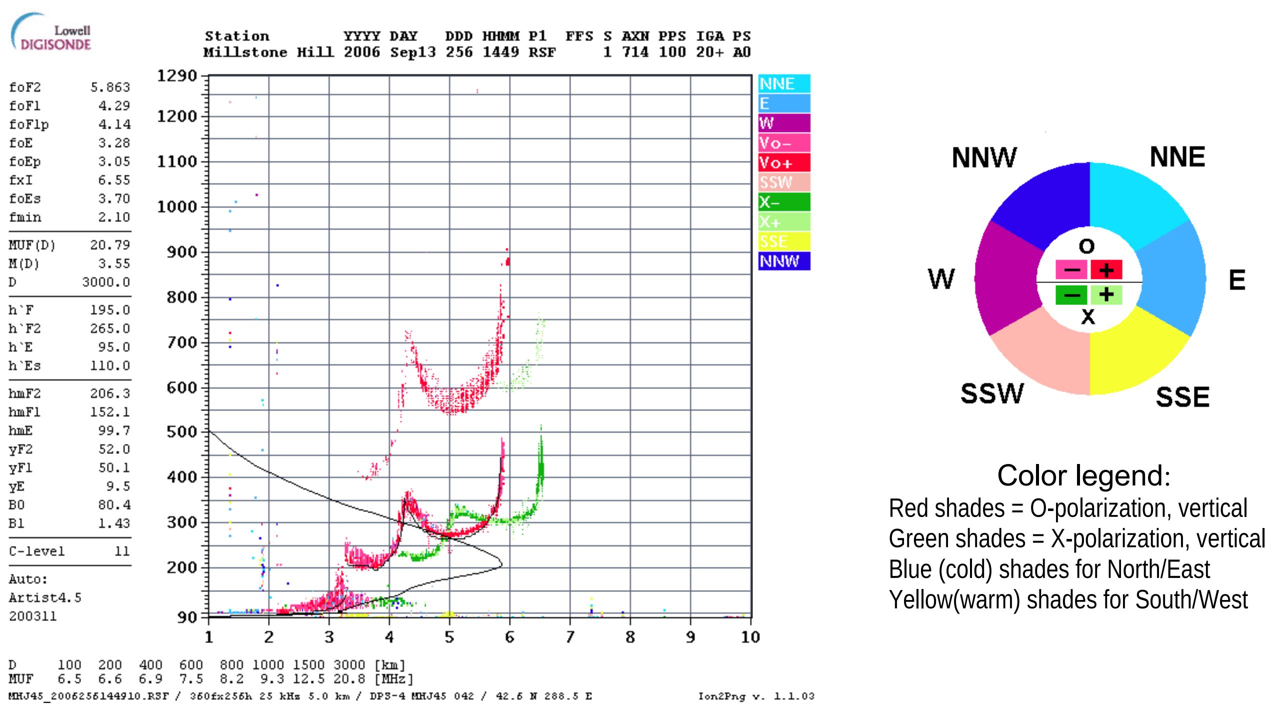


Figure 3-11: Ionogram Display Produced by Ion2PNG Software for Digisonde® WWW Homepage

Presentation of Directional Ionogram Data as Daily Directogram

3:33. The directogram display is useful to view large-scale plasma irregularities as they drift across the Digisonde® location. It uses RSF ionogram data to derive ground distances to the plasma structures responsible for the oblique echoes in the ionograms and then to plot them using direction, Doppler, and amplitude information of the echoes. The left panel of **Figure 3-12** presents an example of the directogram plotted by Drg2PNG software using one day of RSF ionograms collected at Jicamarca, Peru. Each horizontal line of the directogram represents one ionogram measurement, with time going downwards. There are two vertical panels, with the left panel corresponding to echoes arriving from west, northwest and southwest, and right panel for echoes from east, northeast and southeast. The central line between the panels corresponds to the vertical reflection at zero zenith angle. The directogram on **Figure 3-12** does not show much activity between 10:00 and

24:00 UT, at which time passing day-night terminator causes generation of several ionospheric disturbances traveling east. Shades of blue in the directogram correspond to general direction of plasma drift from west to east, and shades of red are used to represent drift in the opposite direction from east to west.

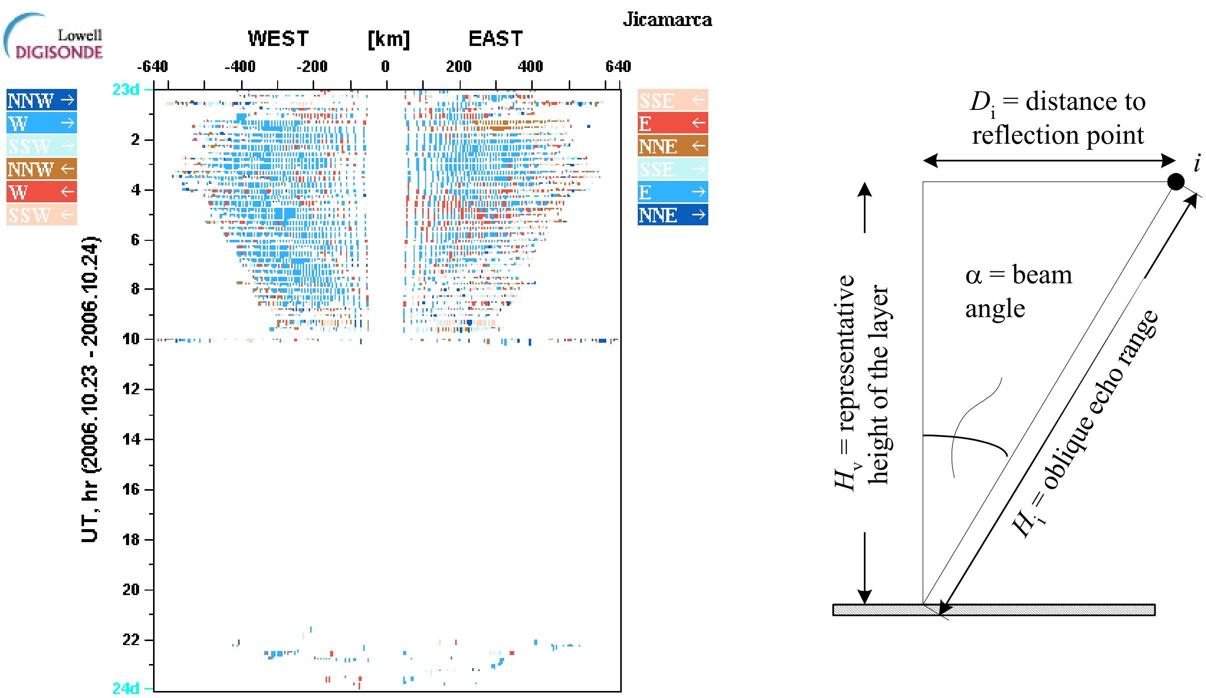


Figure 3-12: Daily Directogram. (Left panel) Sample Directogram made by Drg2PNG Software, (Right Panel) Calculation of Distance to the Reflection Point, D_i

3:34. The right panel of **Figure 3-12** illustrates calculation of the ground distance to the reflection point that is plotted along the x axis on directograms. Ground distance to the reflection point, D_i, is calculated individually for each oblique echo range H_i corresponding to a plasma structure:

$$D_i = \sqrt{H_i^2 - H_V^2}$$

where H_v is a representative vertical height of the F layer that is estimated from the ionogram by locating the section of the vertical incidence F trace where amplitudes are high and height gradient is low. When manually scaled trace is available, hminF can be used reliably as H_v. For the autoscaled data, more consistent results are obtained by calculating summary amplitudes for each ionogram height and selecting H_v as the height of the highest summary amplitude.

Programming Oblique Incidence Ionogram Measurement

3:35. Digisonde-4D can be configured to receive signals from other Digisonde® systems in the area, in which case transmitted signals arrive via oblique propagation mode (**Figure 3-13**). Both the transmitting and the receiving Digisonde® must be synchronized to UT time using their GPS receivers so as to start and progress the oblique incidence (OI) measurement in precise synchronization. In order for the Digisonde-4D to transmit or receive signals in synch with the older DPS4 model, it inserts additional pauses between individual CITs to replicate delays that DPS4 requires to complete internal processing and data transfer. Such timing mode for oblique sounding is called "Oblique" (for reception from DPS4) and "Compatible" (for transmission to DPS4).

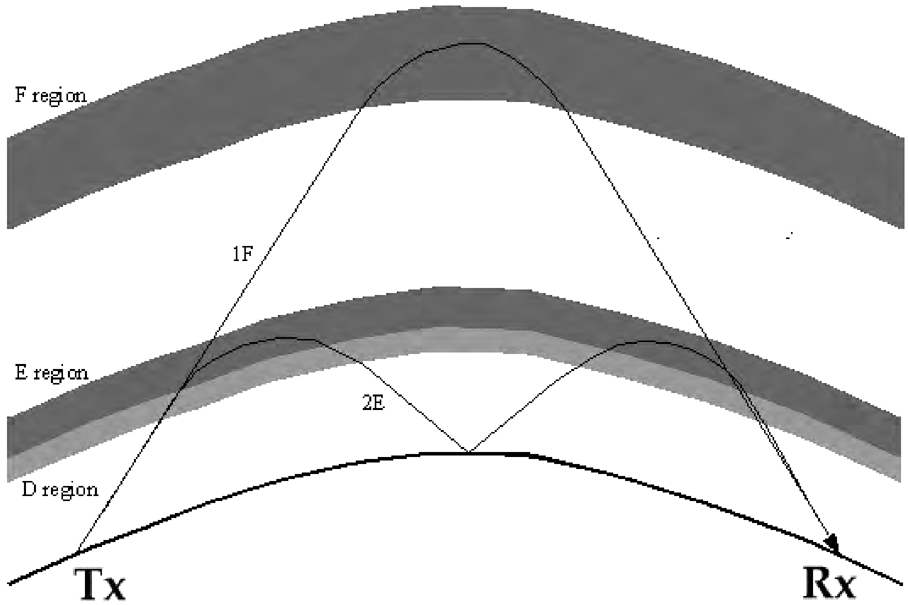


Figure 3-13: Signal Propagation During Oblique Incidence Ionogram Measurement Between Two Digisonde® Systems.

3:36. For a Digisonde-4D to *receive only* oblique incidence signals, it is necessary to:

- Disable transmission of its own pulse (by selecting Radio Silent option),
- Select appropriate interpulse period to match transmitter mode, and
- Select transmitting Digisonde-4D or DPS4 station from the list of stations[1].
  - When a particular Digisonde® station is selected as transmitter, DCART automatically
    - calculates delay start of receiver sampling (start range) to skip the bottom ranges at which no signal can be observed, and
    - selects appropriate timing synchronization mode (Digisonde-4D or DPS4).
  - It is possible to select UNKNOWN transmitter from the list to allow manual specification of the delay and synchronization mode.
  - It is possible to manually specify the reception delay via modifying either the path or delay parameters if the propagation time between the stations is longer than one listening period.

3:37. Sample oblique incidence program specification is shown in **Figure 3-14**. There are two options for the interpulse period; 5 ms (256 samples resulting in 1500 km range coverage) and 10 ms (512 sampels resulting in 3000 km). The sampling start delay is determined by two controls, (1) integer number of 5 ms periods (1500 km delay) to skip prior to starting sampling, (2) choice of the leading edge (0 km delay) or trailing edge (160 km delay) of the R pulse to trigger sampling.

[1] When DCART starts up, it reads available station UDD files in its /UDD folder to discover all Digisonde-4D and DPS-4 station. The URSI codes of qualifying digisondes are then added to the drop-down menu of transmitters.

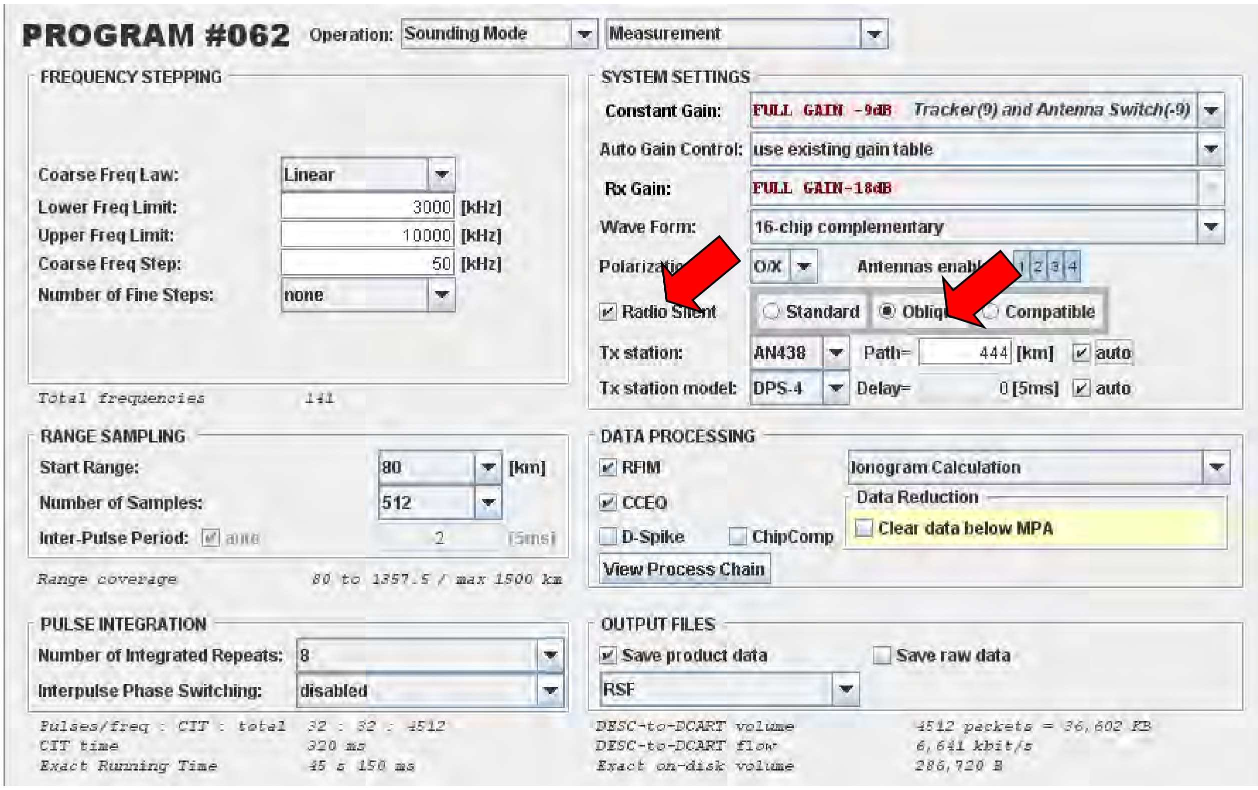


Figure 3-14: Digisonde-4D at Jeju Island, Korea, Configured to Receive Signal from Anyang DPS4 (444 km Ground Distance) Via Oblique Propagation.

3:38. For a Digisonde-4D to receive oblique incidence signals in addition to receiving its own vertical transmission it is only necessary that the two stations be operating using exactly the same program and schedule definitions, and be physically close enough for oblique reception to occur.

Programming Drift Measurement

3:39. Sample drift measurement and real-time screen display of raw drift data are shown in **Figure 3-15**. As explained previously in Paragraph 3:9, 3:18 and 3:19, the drift measurement is programmed to ensure high coherent integration time (CIT) and to reduce data volume by running a small number of fixed frequencies and output ranges. For the example shown in **Figure 3-15**,

A. the CIT is set at 20.48 seconds by using N of 128 (maximum supported by the DFT file format), 10 ms inter-pulse period, and 8x CIT increase by frequency multiplexing,

B. 8 frequencies spaced by 50 kHz are used with the lower frequency limit set at the ARTIST-recommended value, and

C. 8 best ranges are picked for file storage by looking for the strongest echo in the interval of ranges between 140 and 500 km, which ensures that Digisonde® observes plasma drift in the F region.

The real-time display shows data from 4 receiver channels (spectral amplitudes in the left panel, and phases in the right panel), selected at the best height out of 8 available as determined by the maximum signal strength.

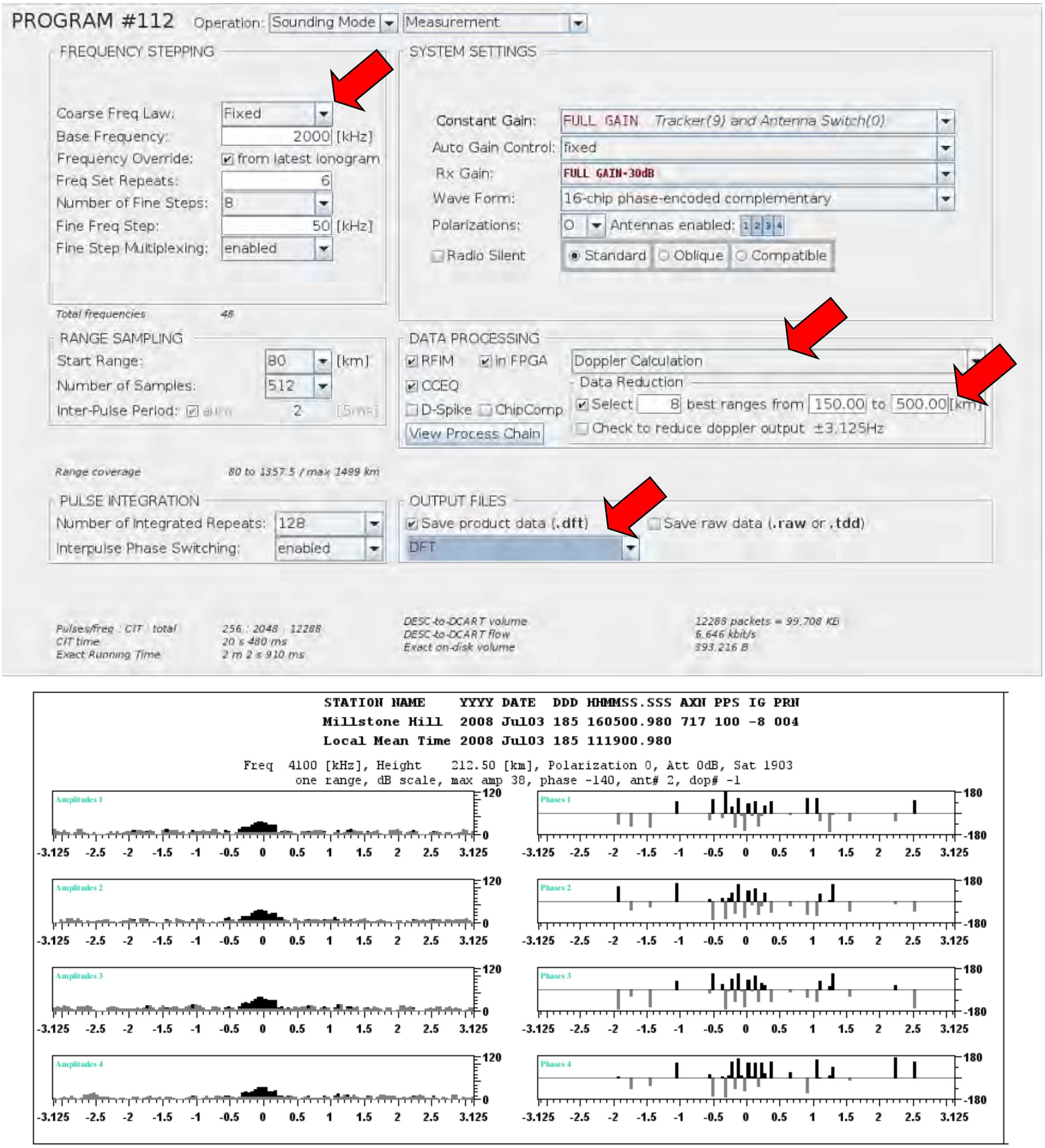


Figure 3-15: Drift Measurement Program and Real-Time Display.

Data Products Derived from Drift Measurement

Doppler Skymap

3:40. The *Doppler skymap* is a presentation technique for the drift measurement data in which a large number of individual echoes from the ionosphere ("sources") are resolved by their time of arrival and further by their Doppler shift that corresponds to the line-of-sight velocity of the reflecting area of plasma. Then, for each range/Doppler bin that is now assumed to contain a single ionospheric echo, four channel phases are used for the interferometry calculation of the azimuth and zenith angles of the source. DFT2Sky software is used to extract sources from the drift data for multiple frequencies and ranges and then save them in the SKY output file. SKY2PNG software is then used to plot sources as a skymap (**Figure 3-16**) where the azimuth and zenith angles of each source are used to place it on the skymap plane using a symbol whose shape and color indicate the Doppler velocity (positive Doppler uses + symbol and blue shades of color, negative Doppler uses o symbol and red shades of color). Further description of the skymap technique can be found in Section 1 of the manual, chapter "Drift Mode – Super-Resolution Direction Finding".

Bulk Plasma Drift Velocity

3:41. The first order approach of describing plasma movement in the ionosphere is to assume its uniform drift over the station as a fixed 3D bulk pattern moving in the same direction with one velocity. In this case the off-vertical sources show the appropriate Doppler velocities (positive for the sources corresponding to the plasma drifting towards the station and negative for sources drifting away from the station). It turns out that such approximation works well in many situations, reflecting the large scale dynamics of the ionosphere at the sounder location. The bulk drift velocity is calculated using a least-squared fit to the skymap sources data in SKY files and output in DVL files. Daily plots of bulk drift velocities are produced for the Digisonde® webpage (see paragraph 3:44 below).

Ionospheric Tilt

3:42. Skymap sources can also be used to estimate local tilt of the ionosphere by calculating offset of the "gravity center" of skymap sources from the nadir. Zenith and azimuth angles of the local tilt are used to appropriately morph the 3D plasma distribution in the area surrounding the station, thus improving the accuracy of raytracing applications. TILT software is used to calculate zenith and azimuth angles and store them in .TLT file.

Skymap Display for WWW Homepage

3:43. The skymap display (**Figure 3-16**) combines the skymap of ionospheric echoes calculated by the DFT2Sky software with bulk drift velocity obtained by DDAV software and ionospheric tilt parameters derived by the TILT software. The bulk Doppler velocity is shown in **Figure 3-16** as the triple tick marks indicating the drift azimuth and horizontal velocity magnitude, as well as two labels that show the horizontal and vertical velocity components in m/s. The ionospheric tilt is described on the skymap display in terms of the zenith and azimuth angles of the source center.

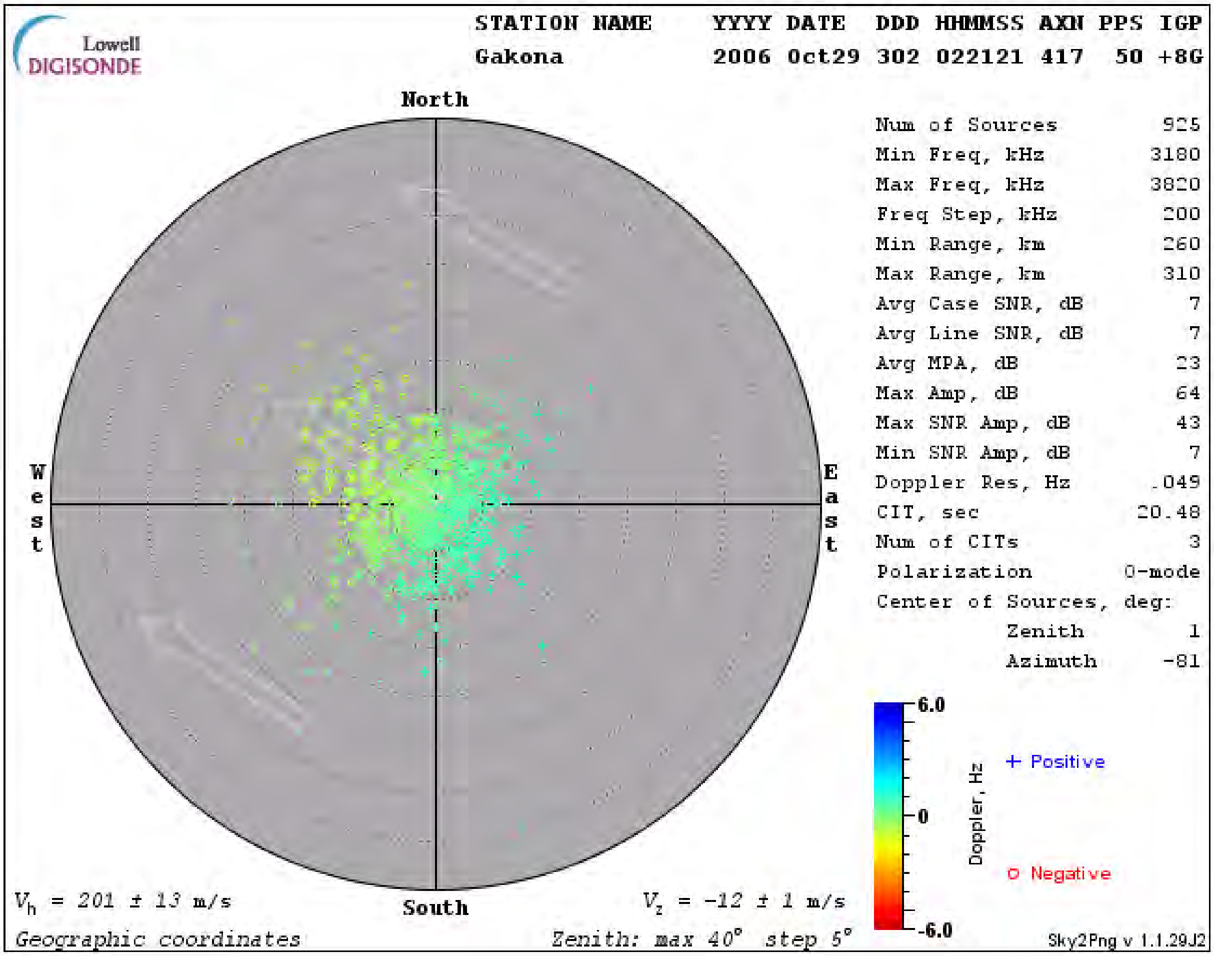


Figure 3-16: Skymap Display for WWW Homepage

Daily Velocity Plot for WWW Homepage

3:44. Daily plots of the ionospheric drift velocity are produced by DVL2PNG software for webpage publishing (see **Figure 3-17**). The plot shows 5 panels, with the top three panel showing three components of the velocity and bottom two panels showing ranges as frequencies of the skymap sources contributed to the calculation of the velocity.

Programming Passive RF Sensing Measurements

3:45. In the passive ionospheric RF sensing mode, Digisonde-4D receives signals from remote transmitters of opportunity in order to infer characteristics of the ionospheric channel that received signals have traveled. Refer to Section 1 for further details on additional signal processing in the passive RF sensing mode. **Figure 3-18** presents an example of Millstone Hill Digisonde-4D measurement of the EISCAT signal at 4040 kHz.

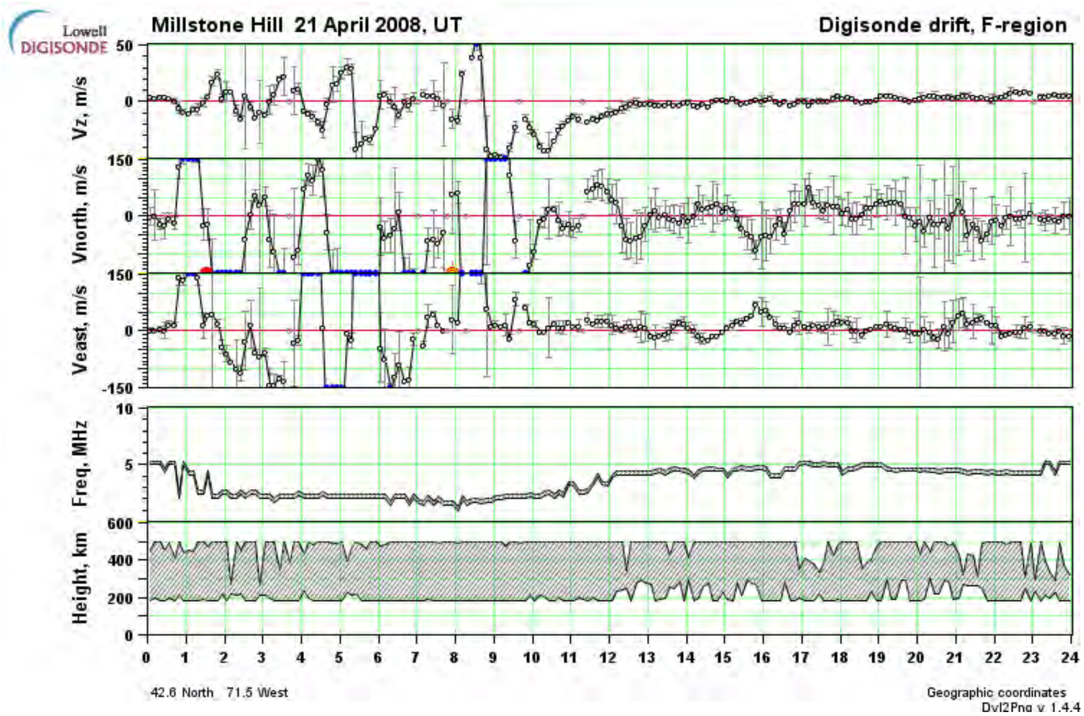


Figure 3-17: Daily Drift Velocity Plot for WWW Homepage

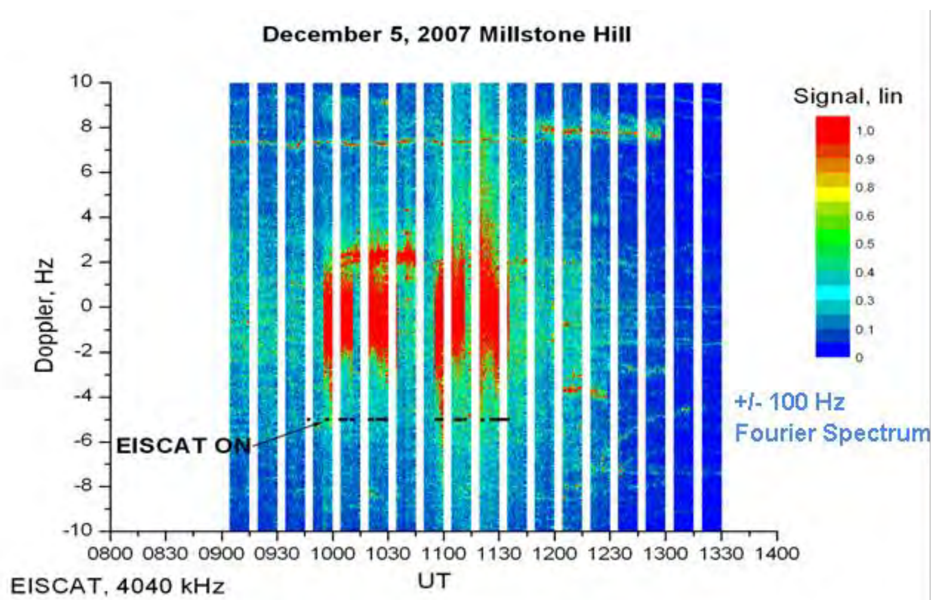


Figure 3-18: Sample Passive RF Sensing Measurement of EISCAT Signal at 4040 kHz

3:46. **Figure 3-19** presents the measurement program specification for the EISCAT signal reception data shown in **Figure 3-18** to serve as an example of a program that listens to a transmitter of opportunity. The raw data is processed by an averaging filter and saved in the Uniform Measurement Storage (UMS) format with full 4 antenna data storage option (.TAV files) for offline analysis in DCART.

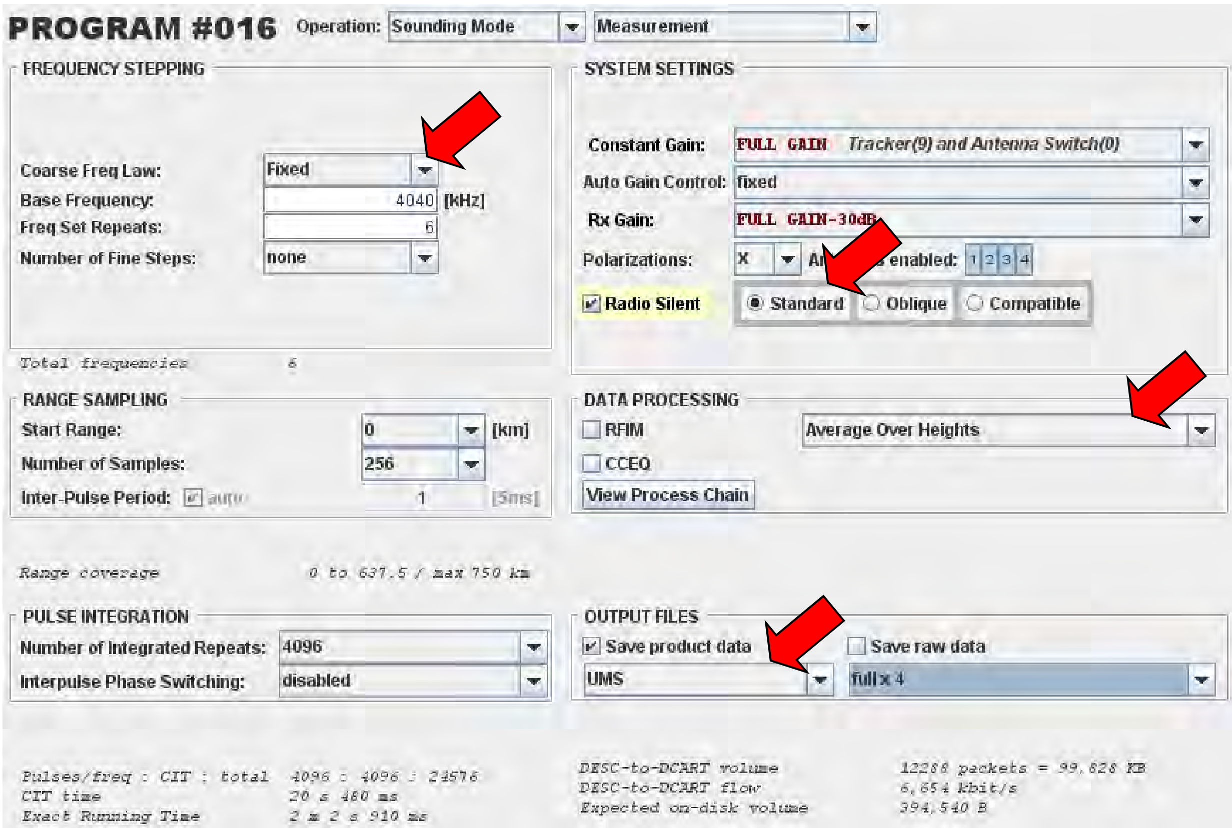


Figure 3-19: Fixed-frequency Passive Measurement of the EISCAT Signal

Programming HF Surveillance Measurements

3:47. The Digisonde-4D can be used as a passive HF Surveillance Monitor to record levels of background radio emissions within its nominal range of operating frequencies from 100 kHz to 30 MHz. The following options are available for the HF Surveillance:

A. **Best: Use a dedicated radio-silent time-averaging mode measurement.** In Option A, receiver bandwidth is 120 Hz (5 ms time per frequency) or 60 Hz (10 ms time per frequency). Frequency stepping between individual measurements can be selected as high as 1 kHz for an accurate identification of the narrowband emissions (see discussion of TAV measurements in Section 1). The data format is UMS, and the file extension is TAV.

B. **Good: Use a dedicated radio-silent ionogram mode measurement.** In Option B, data is collected with a receiver bandwidth of 43 kHz, the time per frequency is 5 ms, and the frequency resolution can be selected at 3 or 5 kHz. To reduce the receiver bandwidth at each frequency step, individual samples can be additionally filtered in post-analysis using custom software. The data format is UMS and the, file extension is ION.

3:48. Example of Option A Surveillance program is given in **Figure 3-20**. It covers the operating frequency band from 0.3 to 15 MHz in 14703 linear steps of 1 kHz, taking 1 min 13 sec to complete the measurement. One 5 ms period of data sampling is used per frequency; all pre-processing is disabled. This program collects about 680 kB of data for storage.

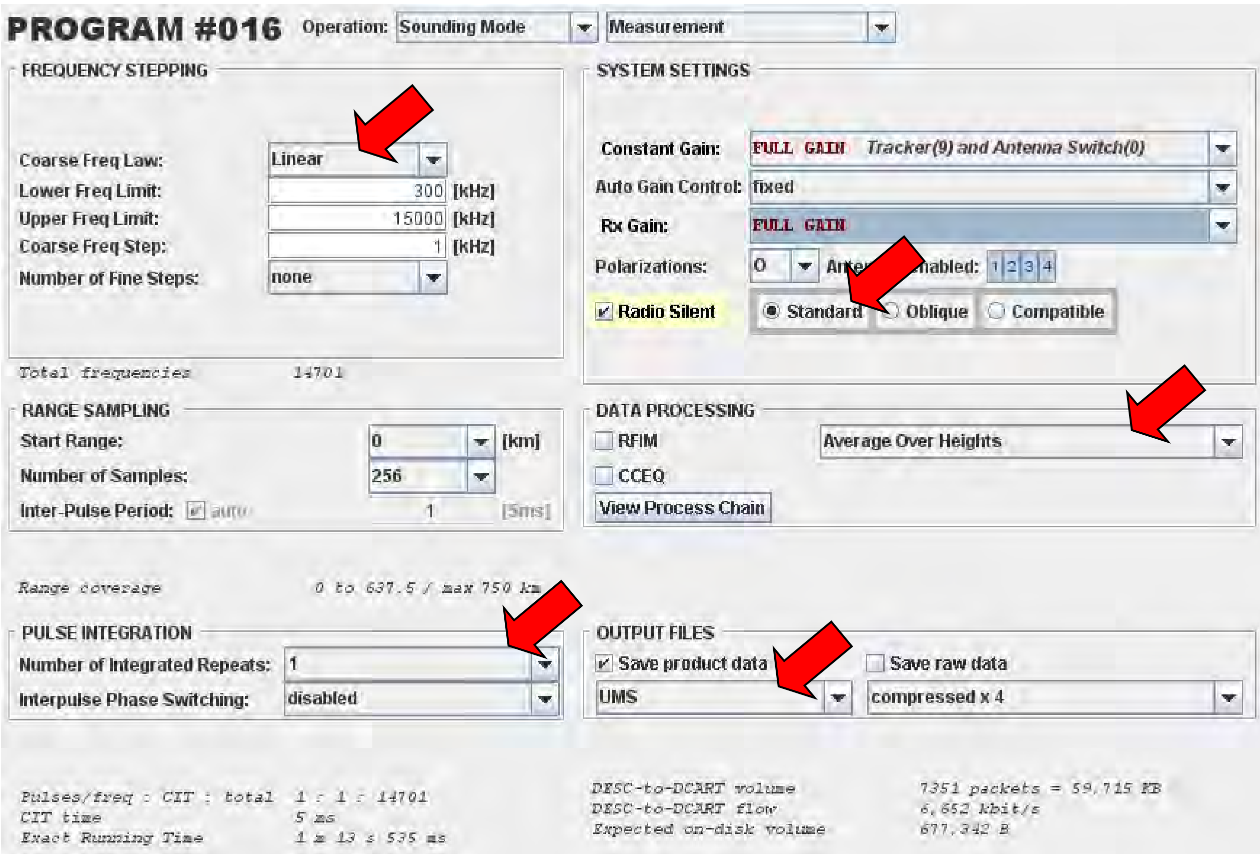
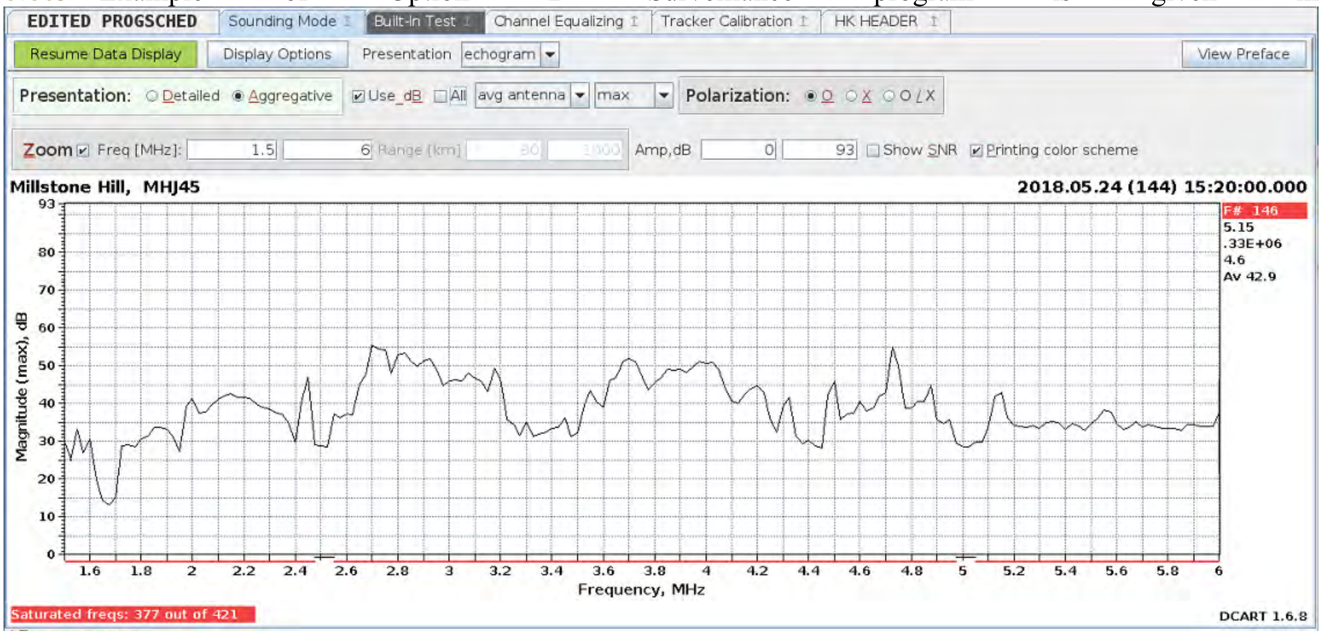


Figure 3-20: Time-averaging measurement for HF Surveillance

3:49. DCART can open a TAV file produced in this mode for export to an ASCII file for visualization using a suitable 3rd party software. **Figure 3-21** presents a frequency spectrum occupancy chart that was produced using a Digisonde® data interval between 500 and 1200 kHz using Option A (**Figure 3-20**). The chart was plotted by MS Excel software. The frequency stepping is 1 kHz, and the receiver bandwidth is 120 Hz.

3:50. Example of Option B Surveillance program is given in



3:51. **Figure** 3-23. It covers the operating frequency band from 0.5 to 15 MHz in 2901 linear step of 5 kHz, taking 14.5 sec to complete the measurement. One 5 ms period of data sampling is used per frequency; all pre-processing and thresholding is disabled. This program collects about 6 MB of data for storage. DCART can open an UMS file produced in this mode for visualization as a spectrogram.

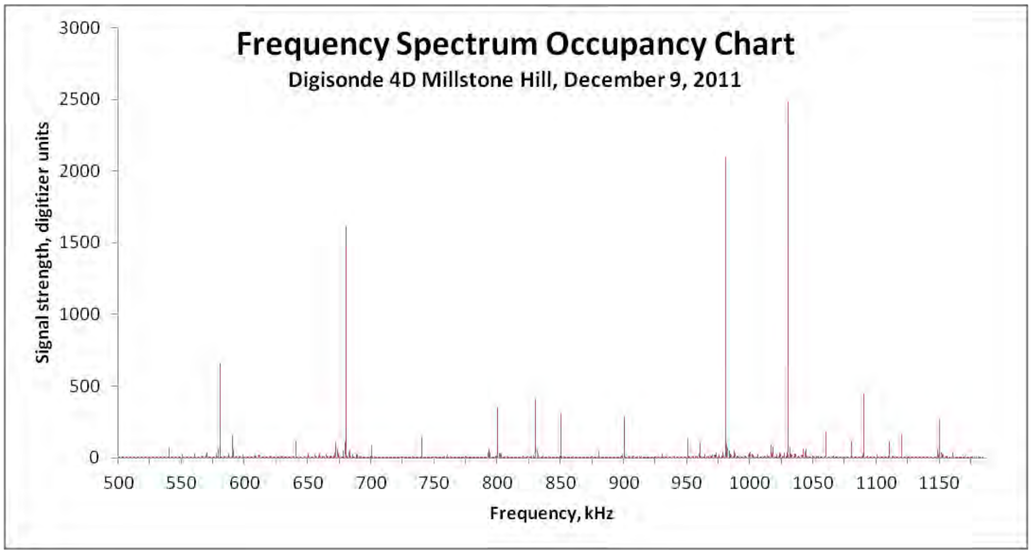


Figure 3-21: Frequency spectrum occupancy chart, 0.5 to 1.2 MHz, produced from TAV file (Option A)

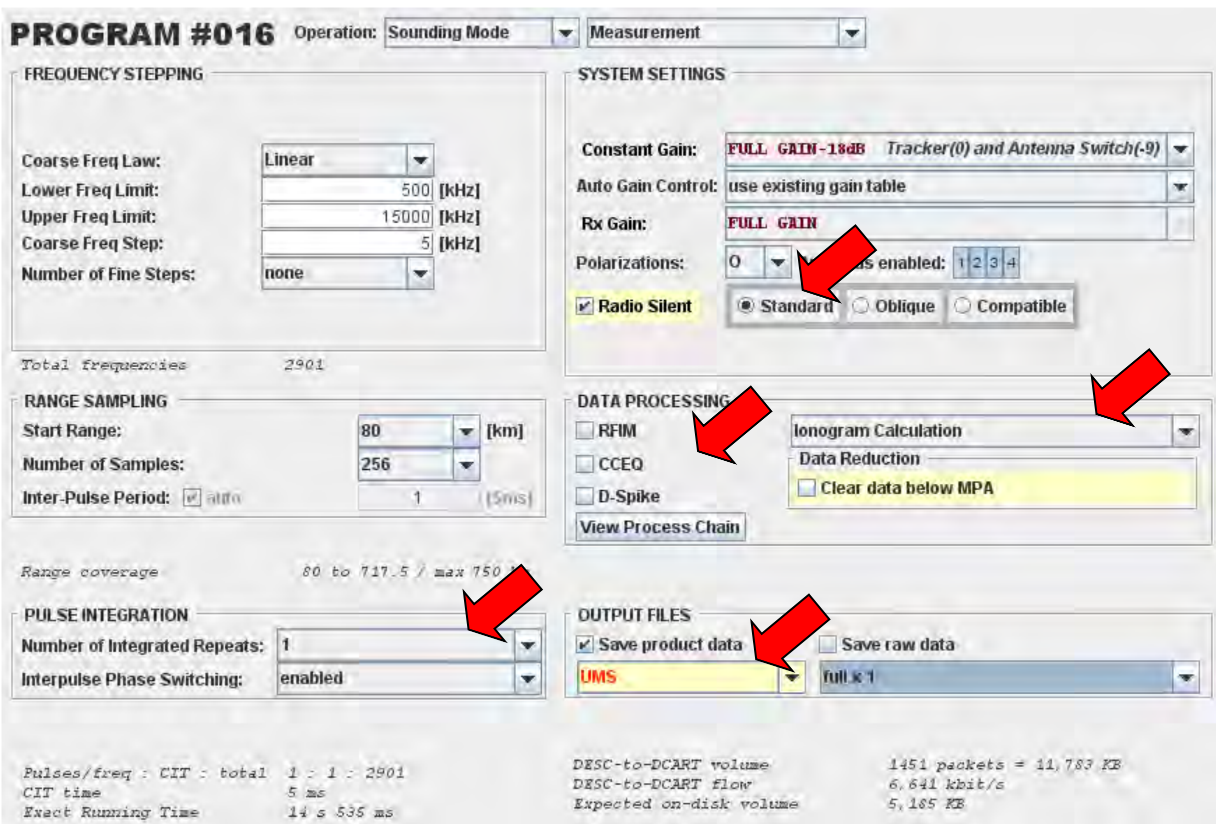


Figure 3-22: Radio silent measurement for HF Surveillance.

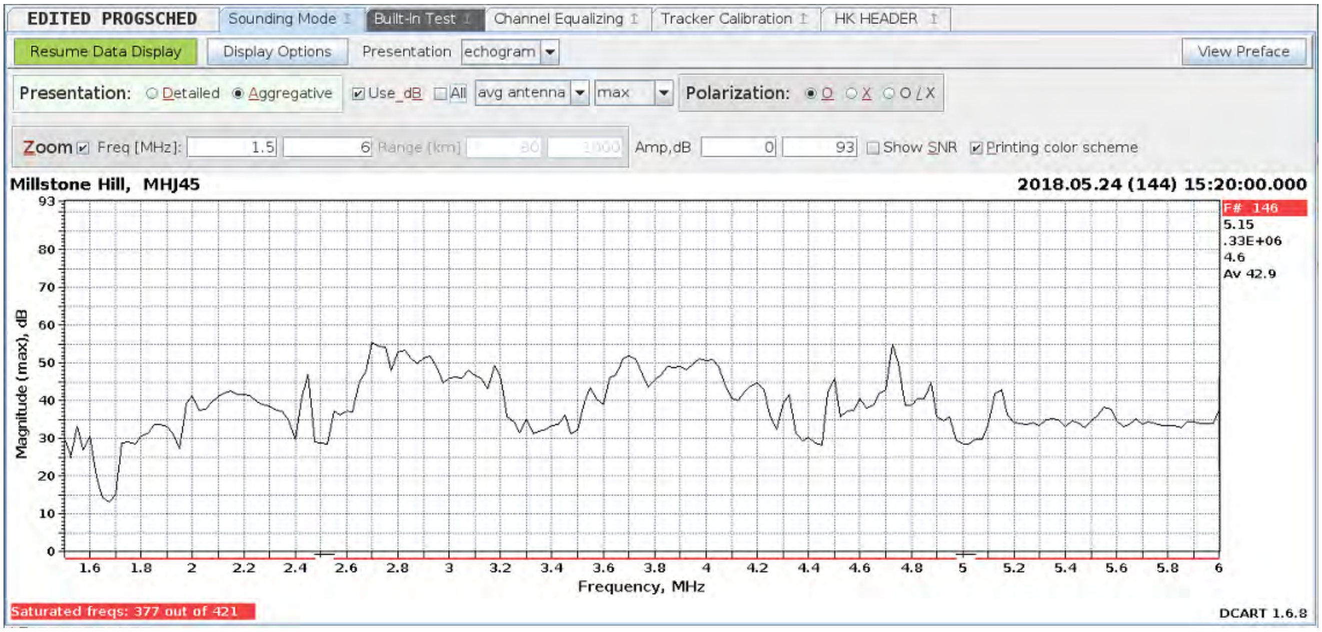


Figure 3-23: Spectrogram display of HF Surveillance measurement (Option B).

SPECIFICATION OF RESTRICTED FREQUENCIES

3:52. DCART offers two separate lists of restricted frequency intervals (RFIL) where transmission shall be prohibited per site operating license, (1) for measurements with CIT ≤ 2 sec, (2) for measurements with CIT > 2 sec. Generally, this rule means that ionogram and drift measurements will be made with two different lists of restricted frequencies, so that swept-frequency ionogram measurement that stays on a particular frequency only for a short time and thus does not create much interference can have a less restrictive list. Drift measurements with CIT of 20 to 40 sec and multiple repetitions within several minutes of drift observations produce substantially greater EMI impact on radio systems, and their RFIL is expected to be more restrictive.

3:53. Both RFILs for low and high EMI impact are stored in StationSpecific.UDD file located in /digisonde/dispatch folder on DATA computer.

3:54. **Table 3-1** provides an example of RFIL specification for Millstone Hill observatory.

Table 3-1. Specification of Restricted Frequency Interval List (RFIL) in StationSpecific.UDD Configuration File

```
%5 RESTRICTED FREQUENCY

Restricted Frequency Table.
Use format:  Beginning-End Freq, (pairs define restricted bands)
Restricted Frequency Table.
Use format:  Beginning-End Freq, (pairs define restricted bands)
Remove asterisks to ignore restrictions

Restricted frequency list for ionograms (code 946):
---------------------------------------------------
*946 < 2175-2195, 2850-3155 >
*946 < 3400-3500 >
*946 < 4000-4150, 4650-4750, 4985-5015 >
*946 < 5450-5730 >
*946 < 6200-6765 >
*946 < 8355-8370, 8815-9040 >
*946 < 9985-10015 >
*946 < 11175-11400 >
*946 < 13200-13410 >
*946 < 14990-15100 >
*946 < 17900-18030 >
*946 < 19990-20010 >
*946 < 21850-21870, 21924-22000 >
*946 < 23200-23350 >
*946 < 24990-25010  >
*946 < 25550-25670  >

Restricted frequency list for drifts (code 961):
------------------------------------------------

*961 < 1800-2000 > Amateur Radio Band
*961 < 2175-2195, 2850-3155 >
*961 < 3400-3500 >
*961 < 3501-4000 > Amateur Radio Band
*961 < 4001-4150, 4650-4750, 4985-5015 >
*961 < 5450-5730 >
*961 < 6200-6765 >
*961 < 7000-7300 > Amateur Radio Band
*961 < 8355-8370, 8815-9040 >
*961 < 9985-10015 >
*961 < 11175-13199 > frequency pairs cannot overlap each other
*961 < 13200-13410 >
*961 < 14000-14350 > Amateur Radio Band
*961 < 14990-15100 >
*961 < 17900-18030 >
*961 < 18068-18168 > Amateur Radio Band
*961 < 19990-20010 >
*961 < 21000-21450 > Amateur Radio Band
*961 < 21850-21870, 21924-22000 >
*961 < 23200-23350 >
*961 < 24890-24990 > Amateur Radio Band
*961 < 24991-25010  >
*961 < 25550-25670  >
```

HOUSEKEEPING MEASUREMENTS AND DATA PRODUCTS

3:55. In addition to the scientific measurements, Digisonde® conducts the following housekeeping activities:

1) Built-In Test (BIT) that determines state of the Digisonde® hardware health, including

(a) Generation of data containing software test pattern, and

(b) Generation of data containing hardware test pattern

2) Transmitter-receiver loopback measurements, including

(a) Cross-channel equalizing (CCEQ) of receiver channels via internal loopback

3) Tracking filter calibration

3:56. BIT operation and data analysis is described in Section 6. Loopback and tracker calibration operations are described below in Chapter 4. Note that all housekeeping measurements produce data products:

- BIT operation produces .BIT.XML files containing system health status reports,
- CCEQ loopback operation generates .CEQ files and keeps the latest results in latest.ceq file
- Tracking calibration produces trackers.dat file for subsequent use in tracker configuration.

COMMAND AND TELEMETRY TRAFFIC

3:57. The Digisonde-4D has two embedded computer platforms that exchange command and telemetry data over the Ethernet connection between them **(Figure 3-24)**.

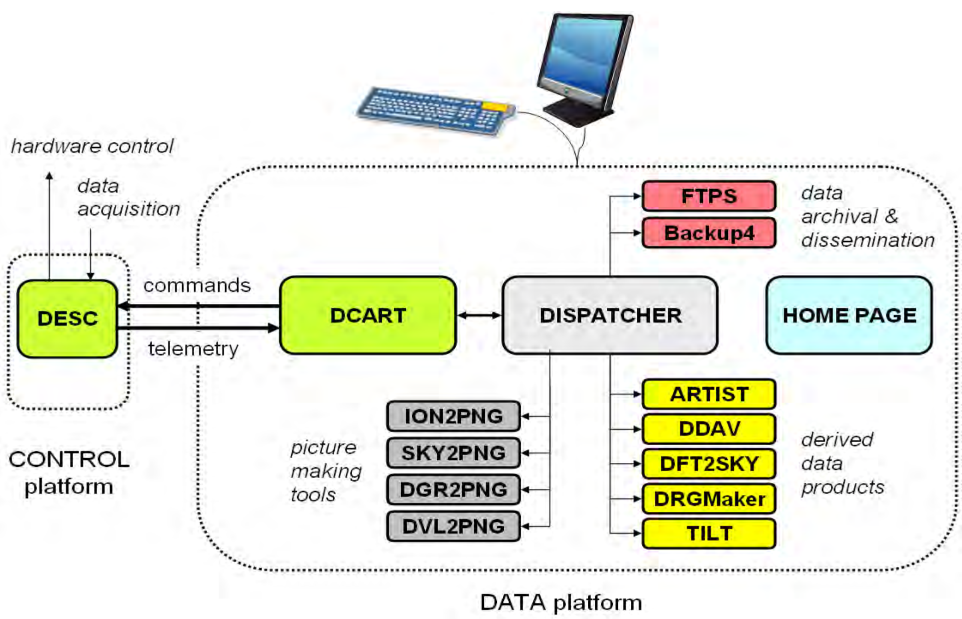


Figure 3-24: Digisonde-4D Computer Configuration with CONTROL and DATA Platforms

3:58. The CONTROL platform is responsible for:

(1) measurement progression control in accordance with the program specification,

(2) data acquisition,

(3) packaging and delivery of the sample data to the DATA platform,

(4) scheduling DPS4D measurements,

(5) synchronization to the GPS time reference,

(6) responding to user commands.

The Control Platform operating software, Digisonde® Embedded System Control (DESC), runs under the management of the real-time operating system Reat Time Executive for Multiprocessor Systems (RTEMS) that ensures time-deterministic execution of the software tasks.

3:59. The Data Platform is responsible for:

(1) accepting raw data samples collected by the CONTROL Platform for processing, visualization, packaging in standard files, local backup to mass storage media, and delivery to external data recipients;

(2) provision of the user interface for manual and unattended operations of the Digisonde-4D;

(3) design of measurement programs, schedules, schedule switch planning rules, campaign requests;

(4) commanding Digisonde-4D operations; and

(5) publishing of the acquired science and housekeeping data to the Digisonde® homepage.

3:60. The dual platform configuration of the Digisonde-4D has a counterpart in space engineering applications where the CONTROL platform is a payload instrument onboard a satellite (without monitor and keyboard), and DATA platform is a ground systems console. With this analogy in mind, the traffic between CONTROL and DATA platforms is categorized as *commands* (from DATA to CONTROL) and *telemetry* (from CONTROL to DATA). The analogy with the space engineering applications is helpful in understanding that interactive editing of the Digisonde® configuration using at the DATA platform does not affect ongoing Digisonde® operations until new configuration is actually commanded (uploaded) to the CONTROL platform.

3:61. The Digisonde® Commanding and Acquisition Remote Terminal (DCART) sends commands and collect telemetry data, processes raw sample data to create data products (ionograms, drift, and passive RF sensing records), and provides the user interface for manual and unattended operations of the Digisonde-4D. Chapter 2 and 3 of this Section describe DCART user interface in a greater detail.

CHAPTER 2

BASIC OPERATION OF DCART

BASIC PRINCIPLES

3:62. Digisonde® Commanding and Acquisition Remote Terminal (DCART) is the software component of the Digisonde-4D sounder that is responsible for

- interfacing the Control Platform to send commands and acquire telemetry data,
- reducing collected raw data to data products (ionograms, drift and TAV records, etc.), and
- providing the user interface for manual and autonomous operations of the Digisonde-4D, including:
    - design of measurement programs and schedules,
    - design of autonomous measurement plan, including routine and campaign periods,
    - manual operation of the instrument for science, engineering, and housekeeping tasks, and
    - real-time data visualization.

3:63. This Chapter describes user interface of the DCART software intended for basic operation of the Digisonde-4D in its manual and autonomous regimes. Advanced features of DCART interface are discussed in Chapter 3 of this Section. Design concepts and data interface of DCART software are described in Section 5.

Normal and Advanced Modes of DCART Interface

3:64. Many of DCART functions are applicable to system development and troubleshooting tasks that are not needed during normal sounder operations. In order to reduce complexity of the user controls and associated screen clutter, DCART can be configured into the normal simplified interface mode, in which screen controls and data visualization panels are reduced to a minimum required for the basic sounder operations. Advanced interface mode and functions are described below in Chapter 3 of this Section. **Figure 3-25** shows General Options panel where selection between Normal and Advanced interface modes is done.

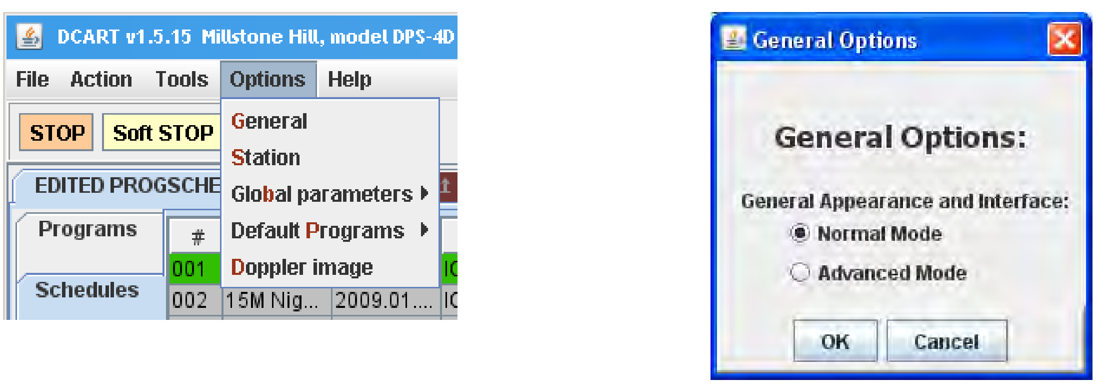


Figure 3-25: Configuring DCART in Normal Interface Mode (General Options)

DCART Screen Layout

3:65. **Figure 3-26** describes general contents of the DCART screen. The bottom section contains DCART logo, real-time system clock (corresponding to both DATA and CONTROL computer clocks), DESC status window, and DCART log with software messages. The top section of the DCART screen has three operational state controls, Info button, and a drop-down menu with manual commands to CONTROL platform. The central section of the DCART window is taken by the *tabbed panel* whose contents depend on the selected content tab of the three available selections:

- "PROGSCHED" with specification of programs, schedules, and SST planning rules,
- "Sounding Mode" with visualization panel for sounding data, and
- "Built-In Test" with visualization panel for BIT data.

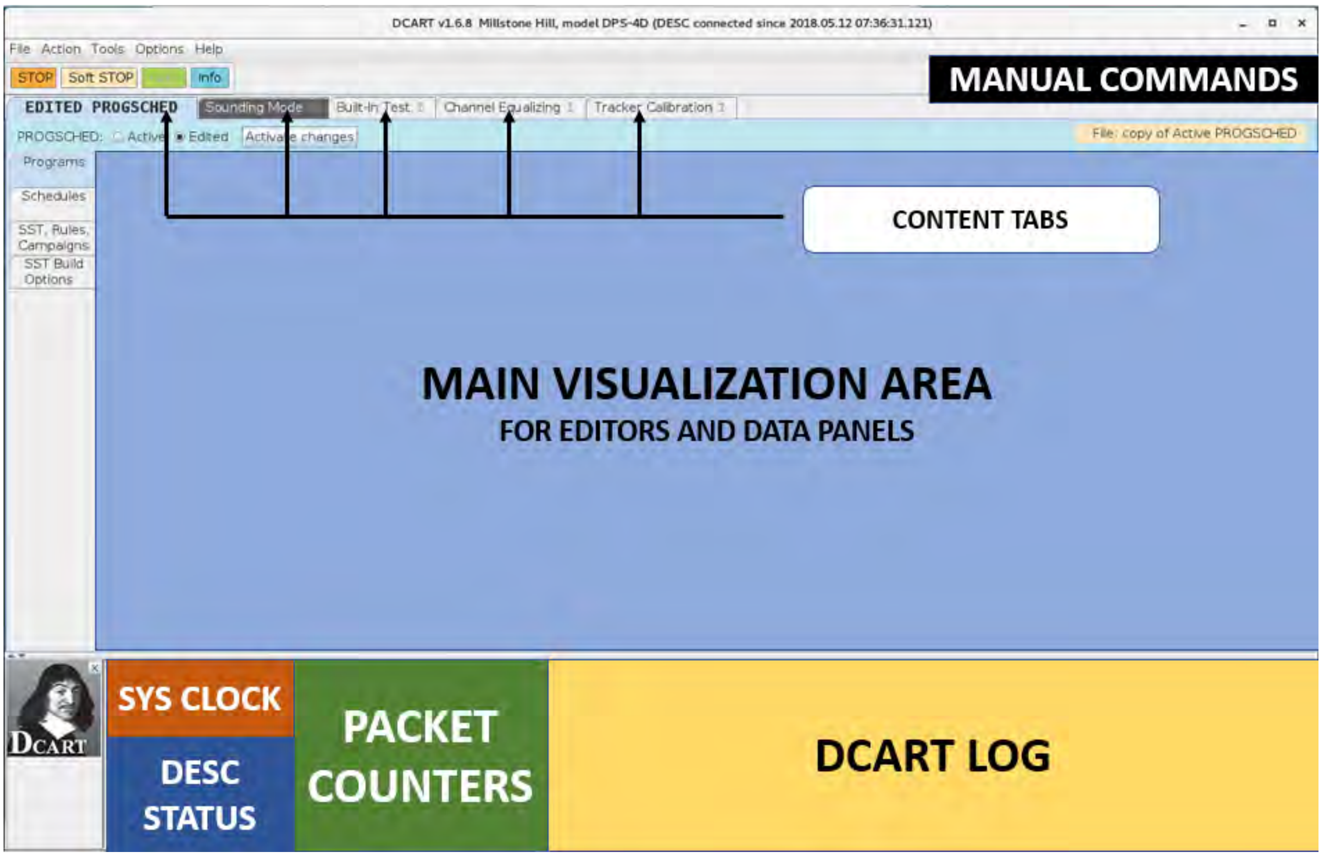


Figure 3-26: DCART Screen Layout (Normal Interface)

DCART Color Concept

3:66. Screen elements and controls of DCART software are color-coded to draw the operator's attention to particular conditions and selections:

- **RED** Error that requires operator's action to resolve
- **YELLOW** Notable/unusual item
- **ORANGE** Important item affecting quality/amount of science data
- **GREEN** Recommended option for normal sounder operations

Autonomous and Manual Digisonde® Operations

3:67. The *autonomy* of sounder operations implies existence of *planning rules* that the instrument uses to execute particular measurements automatically. Complexity of the planning rules varies from simple specification of exact UT times for the planned measurements to intelligent algorithms that analyze external information to devise the measurement plan correspondingly. Once the planning rules are defined for the instrument, its continuing operation does not require further manual intervention.

3:68. The Digisonde-4D implements its autonomous operation mode by triggering start of *measurement schedules* at particular UT times called Schedule Start Time (SST). In the autonomous mode, the CONTROL platform of Digisonde-4D repeatedly checks contents of its *SST Queue* to start the earliest schedule in the queue when its SST matches system clock time. It is the responsibility of the DCART software to replenish SST Queue with new items as SSTs expire. See Paragraphs 3:3 and 3:4 in this Section for a more detailed description of the schedule, SST, and SST Queue.

3:69. Manual Digisonde-4D operation means that a particular measurement program or schedule is triggered by manually sending the Start command to the CONTROL platform. In the manual operation mode, the SST Queue content is ignored.

CAUTION

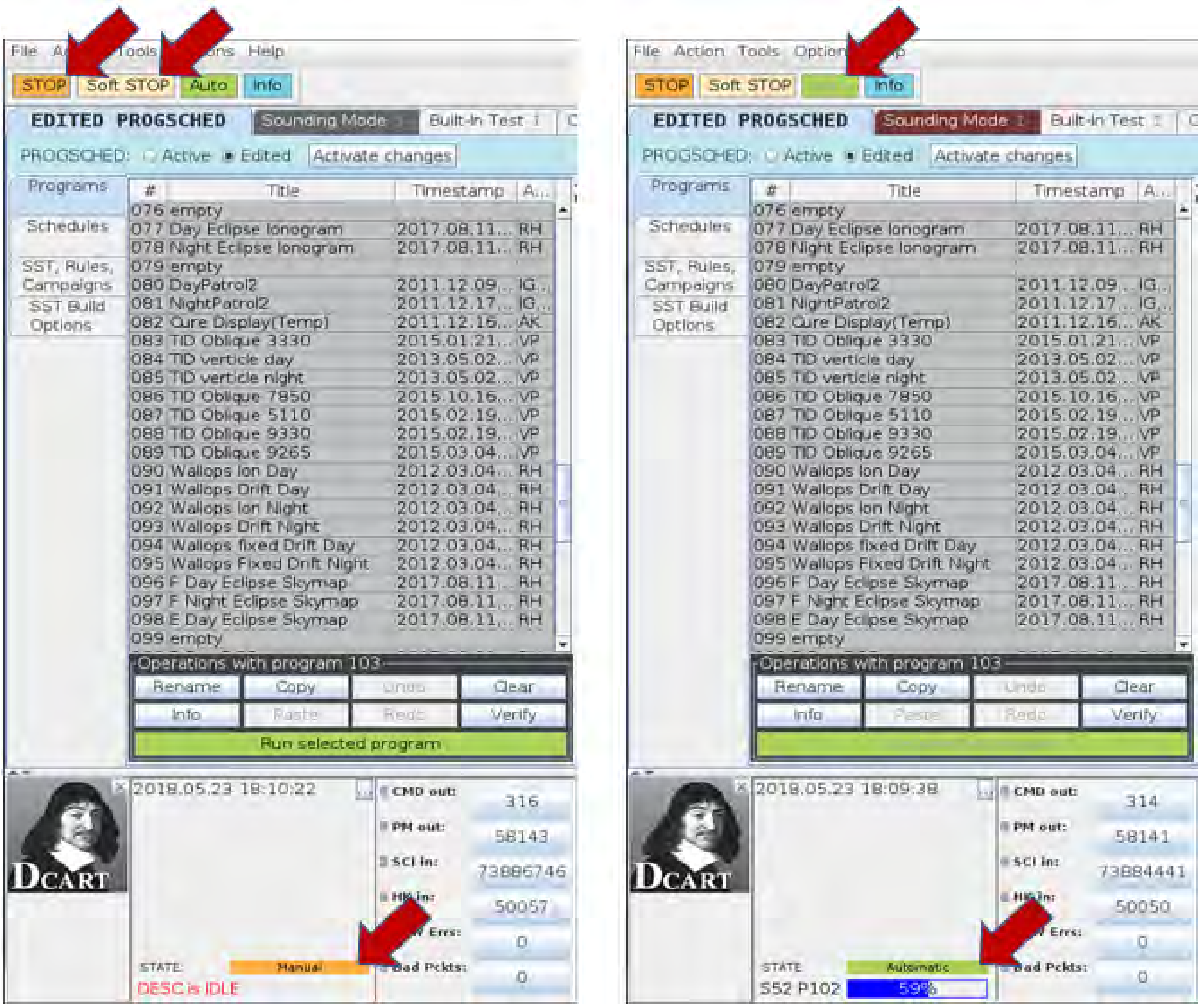
THE OPERATOR SHALL NOT LEAVE THE SOUNDER OBSERVATORY WITH DIGISONDE® ACCIDENTALLY IDLING OR RUNNING IN THE MANUAL MODE.

IT IS IMPORTANT TO LEARN HOW TO DISTINGUISH WHETHER THE DIGISONDE® IS IN ITS AUTOMATIC OR MANUAL MODE.

3:70. **Figure 3-27** shows section of DCART main window with the DESC state (bottom part of the Figure) indicated as (a) Manual and (b) Automatic. In both modes shown in **Figure 3-27**, Digisonde® is running Program #1 of Schedule #2. However, in the manual mode of operations (the left panel of **Figure 3-27**), DESC will continue running schedule #2 indefinitely (or until the system is manually commanded into different schedule or state). In the Autonomous mode (the right panel of **Figure 3-27**), sounder will be switching measurement schedules automatically per SST planning rules.

3:71. In order to switch Digisonde-4D into its Autonomous mode, push **Auto** button (see **Figure 3-27**). There are two ways to stop autonomous operations and switch the sounder to its manual mode:

- **STOP** – stop current measurement immediately (data product file will be truncated), and
- **Soft STOP** – let currently running program to complete before switching into manual mode



(a) Digisonde® in the Manual Mode (b) Digisonde® in the Autonomous Mode

Figure 3-27: Digisonde® in its (a) Manual and (b) Autonomous Modes of Operation (Push "Auto" Button to Switch to the Autonomous Mode. Push STOP or Soft STOP to Switch to the Manual Mode.)

3:72. When Digisonde-4D is commanded into Autonomous Operations mode,

- DESC is switched into its automatic state (i.e., it triggers schedules in its SST Queue),

3:73. When DCART is in the Automatic mode of operations, several screen controls and menu options are disabled until DCART returns to the manual mode:

- DCART window cannot be closed,
- Manual start of schedules and programs is disabled,

PROGSCHED Management

3:74. "PROGSCHED" \prōg-skĕd'\ is a nickname for the data structure that holds all measurement configuration data pertaining to Digisonde-4D programs, schedules, schedule start times (SSTs), and SST planning rules and campaign requests.

Active and Edited PROGSCHED

3:75. **Figure 3-28** illustrates management of PROGSCHED by DESC and DCART components of the operating software. It is important to understand that, at all times, it is the CONTROL platform that conducts Digisonde® measurements using the *active* PROGSCHED specification that resides in its operating memory. Digisonde® operator has access only to the *edited* PROGSCHED that is stored in DATA platform.

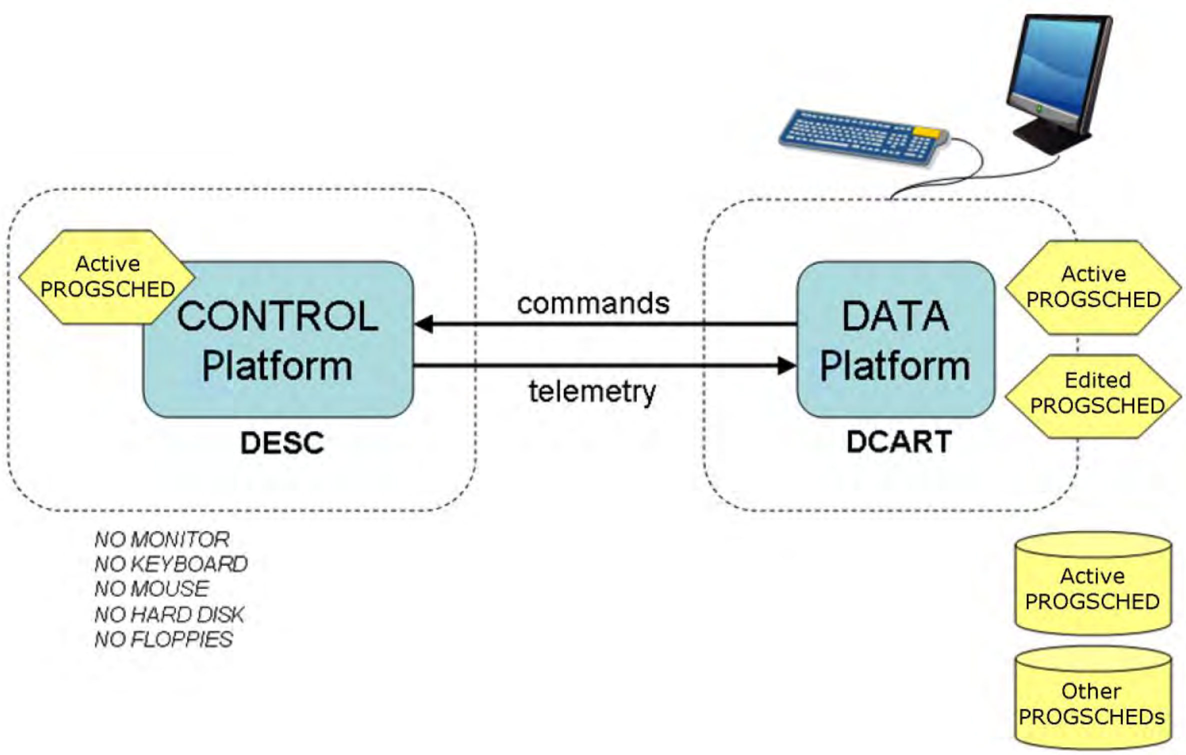
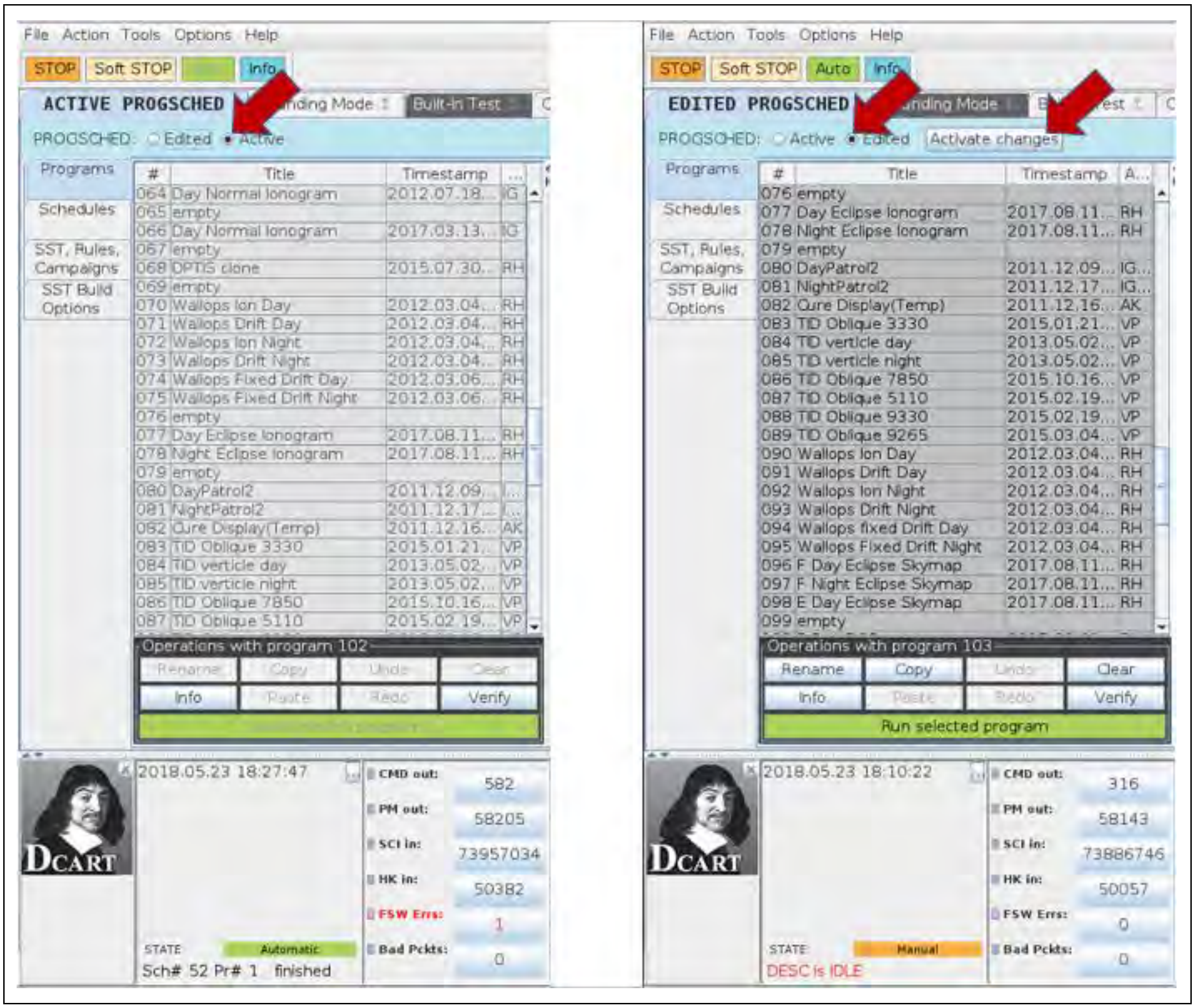


Figure 3-28: Management of PROGSCHED by DESC and DCART Software

3:76. DCART software has screen editors for all components of PROGSCHED; programs, schedules, and start schedule times. DCART has two copies of PROGSCHED available for display in the editors, (1) active PROGSCHED is a copy of the PROGSCHED on the Control computer. The active PROGSCHED can be only viewed but not modified. (2) edited PROGSCHED can be modified using editor controls. DCART allows single-click switch between active and edited copies of PROGSCHED (see **Figure 3-29**). The active copy of PROGSCHED is displayed grayed-out to indicate that it is impossible to edit it.



(a) Active PROGSCHED shown in the editor (b) Edited PROGSCHED shown in the editor

Figure 3-29: Display of the (a) Active and (b) Edited PROGSCHED in DCART

NOTE

Program and schedule definitions displayed on the Digisonde-4D screen may not correspond to the measurements that CONTROL platform of the sounder is actually running -- if DCART shows the edited PROGSCHED with changes that have not been activated.

PROGSCHED Activation

3:77. Operator-introduced changes to the edited PROGSCHED that is currently visible in DCART has to be *activated* in order for the sounder to starting using it in new measurements. "Activate changes" button above the system clock display in **Figure 3-29** is used for PROGSCHED activation. As illustrated in **Figure 3-30**, when "Activate changes" button is pressed, the following actions are taken:

- Edited PROGSCHED is validated (tested for possible programming errors),
- Program definitions, Schedule definitions, and current SST Queue from the Edited PROGSCHED are copied to CONTROL platform using DCART-DESC commanding protocol,
- Full specifications of the Edited PROGSCHED are saved in the PROGSCHED file in the /digisonde/Control progsched file (for resuming operations in case of a system reset).

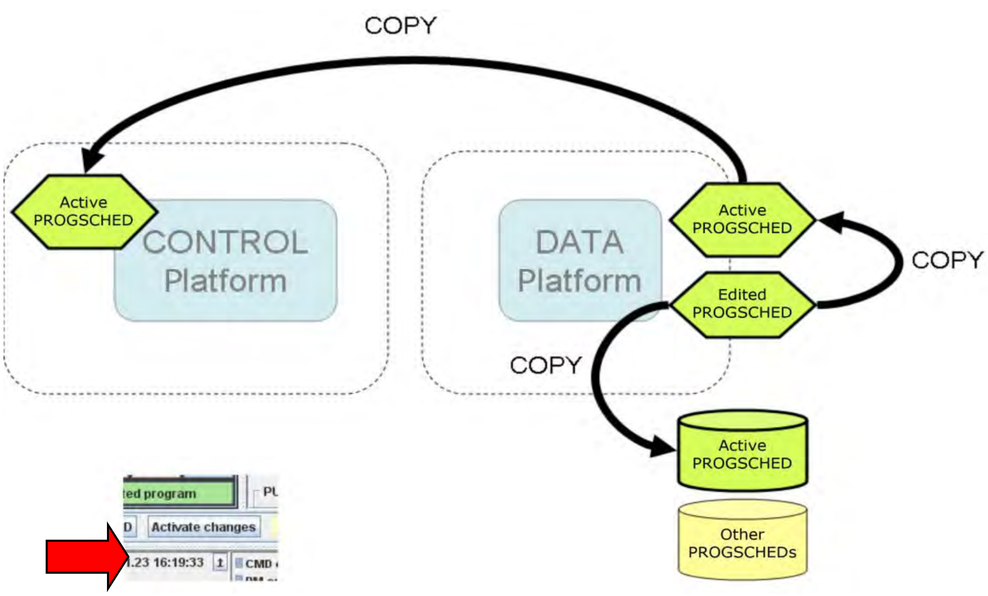


Figure 3-30: Activation of the Edited PROGSCHED

3:78. Activation of the Edited PROGSCHED can be done while the sounder is in the Autonomous mode of operations and currently runs a measurement. When "Activate changes" button is pressed and sounder is running, DCART:

- commands DESC into manual state using "Soft STOP" command (display of the DESC state changes on the screen accordingly),
- waits until DESC completes currently running measurement, if any,
- commands CONTROL platform in "Standby" state for configuration updates,
- uploads new PROGSCHED definitions, and
- returns CONTROL platform into automatic state to resume scheduled operations.

Offline PROGSCHED editing

3:79. DCART can be used for offline editing of PROGSCHED definitions stored as files on DATA computer. Such files can be opened for reading, editing in DCART, and writing back to the hard disk. **Figure 3-31** illustrates the process of offline PROGSCHED editing using File menu of DCART.

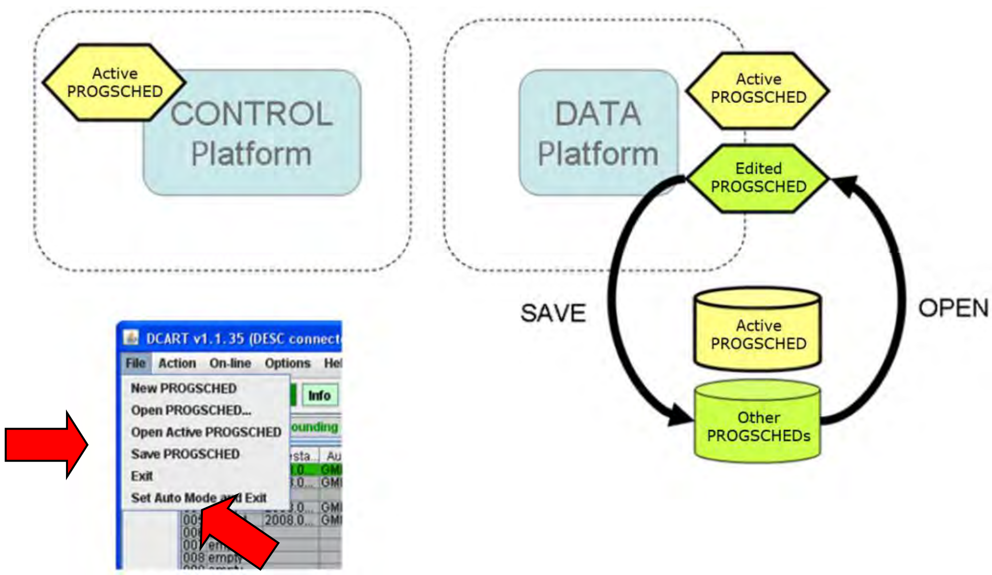


Figure 3-31: Offline Editing of External PROGSCHED Files on DATA Platform

3:80. The File menu contains:

- "New PROGSCHED" item that will initialize an empty Edited PROGSCHED.
- Open PROGSCHED item that will read PROGSCHED definitions from a file specified by the user.
- "Open Active PROGSCHED" item that will re-read Active PROGSCHED definitions from the external storage to make sure that Edited PROGSCHED displays the Active PROGSCHED and not some other PROGSCHED file.
- Save PROGSCHED which allows the user to save a copy of the current Edited PROGSCHED to another file.

REAL-TIME DATA VISUALIZATION

3:81. Two of the content tabs in **Figure 3-26** are used for real-time visualization of science ("Sounding Mode") and housekeeping ("Built-In Test") data.

NOTE

Real-time data visualization is a task that requires substantial resources of the DATA platform. The real-time displays have to be disabled before leaving the sounder working in the autonomous mode.

3:82. **Figure** 3-32 shows the "Sounding Mode" real-time display of DCART in its disabled state. Push button "Enable Data Display" to start visualization. When the sounding mode display is no longer needed (when leaving the station, for example), disable it by pushing "Suspend Data Display" to lower processing load on the computer. In the Suspended state, the latest sounding mode data will be preserved on the screen and will not be updated when a new measurement starts.

3:83. The real-time data display of DCART has the capability of showing intermediate steps of data processing. **Figure 3-33** shows the "Sounding Mode" real-time display showing ionogram measurement in progress, with Display Option window invoked by pushing "Display Options" button. The Display Option window shows *Processing Chain,* a list of processing steps that DCART applies to the source data (in this case raw time domain data stream from DESC). Radio buttons are available to select final or intermediate steps of the processing chain.

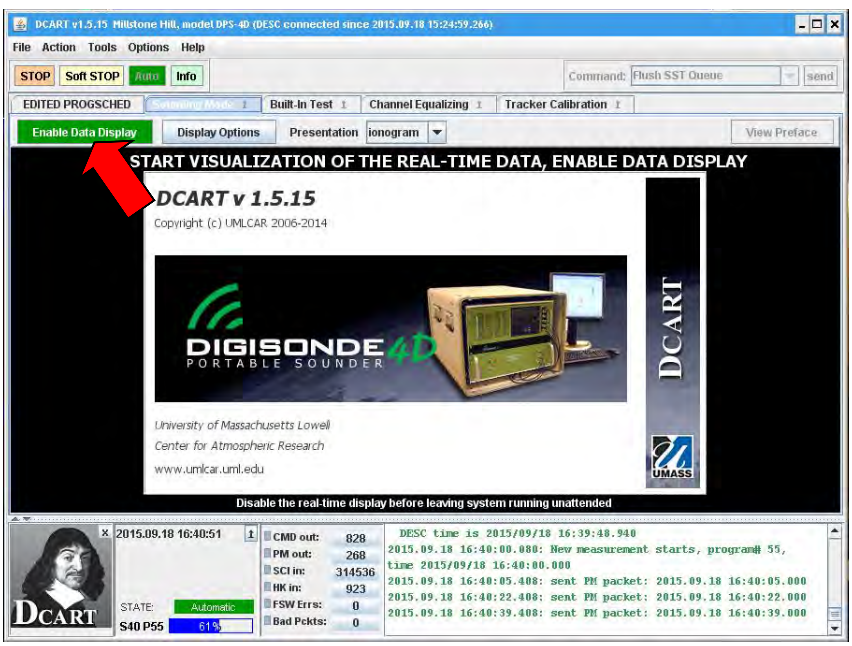


Figure 3-32: Real-time "Sounding Mode" Display of DCART (Disabled, click to Enable)

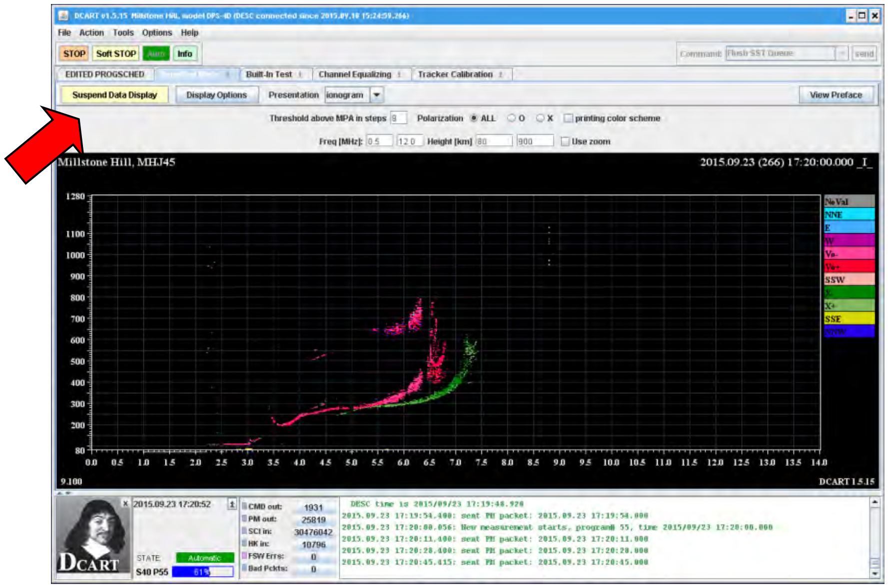


Figure 3-33: Real-time "Sounding Mode" Display of DCART (Enabled, click to Disable)

DCART Processing Chain

3:84. Detailed description of the processing steps that are applied to Digisonde-4D time domain samples can be found in Section 1. **Table 3-2** summarizes contents of the full Processing Chain in DCART. Steps 1-4 are performed in the time domain for 4 antenna channels individually. Doppler analysis (step 5) is applied to sample sets collected across multiple repetitions of pulses at the same frequency for the same range bin. Reduction to ionogram (step 6) is done for ionogram mode only by selecting only one Doppler line from the 4 channels of spectra for each range bin, and calculating direction of echo arrival for selected Doppler line only. Different types of real-time display are provided in DCART for steps 1-4, 5, and 6.

Table 3-2. DCART Processing Chain

#	Step Contents	Comments
1	RFI Mitigation	optional
2	Cross-channel Equalizing (CCEQ)	optional
3	Pulse Compression	
4	Sum of complementary codes	
5	Dopper calculation	
6	Ionogram calculation	max Doppler/beam, for ionogram mode only

Real-time Display of Time-Domain Data (Steps 1-4 of Processing Chain)

3:85. **Figure 3-34** shows real-time Time Domain display (labeled TIME DOMAIN in the background) showing four channels of data with magnitude of signal in the left column and phase in the right column. The plot shows measurement of the internal loopback signal from the transmitter card to the antenna switch; phase plots clearly display the 16-chip phase code of the signal modulation. Available screen controls for data visualization are shown in **Table 3-5**

Table 3-3. Display Options for Time-Domain Real-Time Window

Location	Control	Function
Top Bar	"dB scale" checkbox	represent amplitudes in dB scale or 16-bit linear scale.
	"Re/Im", "Mag/Phase" radio buttons	Cartesian (Real and Imaginary) versus Polar (Magnitude and Phase) representation of the sample data.
	"Time domain", "Freq domain" radio buttons	Time domain data are raw samples, frequency domain data are produced by applying DFT to [unsorted] time domain samples.
	"Phase difference" checkbox	Option to subtract phase of channel 1 from all channels.
	"Min amplitude to show phase" text field	Threshold value of magnitude below which phase val-ues are not plotted (to reduce clutter)
	"Export" button	Produce text file with sample data for one coherent integration period
Left zoom panel	"Use Zoom" checkbox	Enable / disable zooming
	"Min hgt km" and "Max hgt km"	Min/max height values for zoomed displays
	"Alt colors" checkbox	Option to use alternative colors for neighboring values to facilitate counting of values

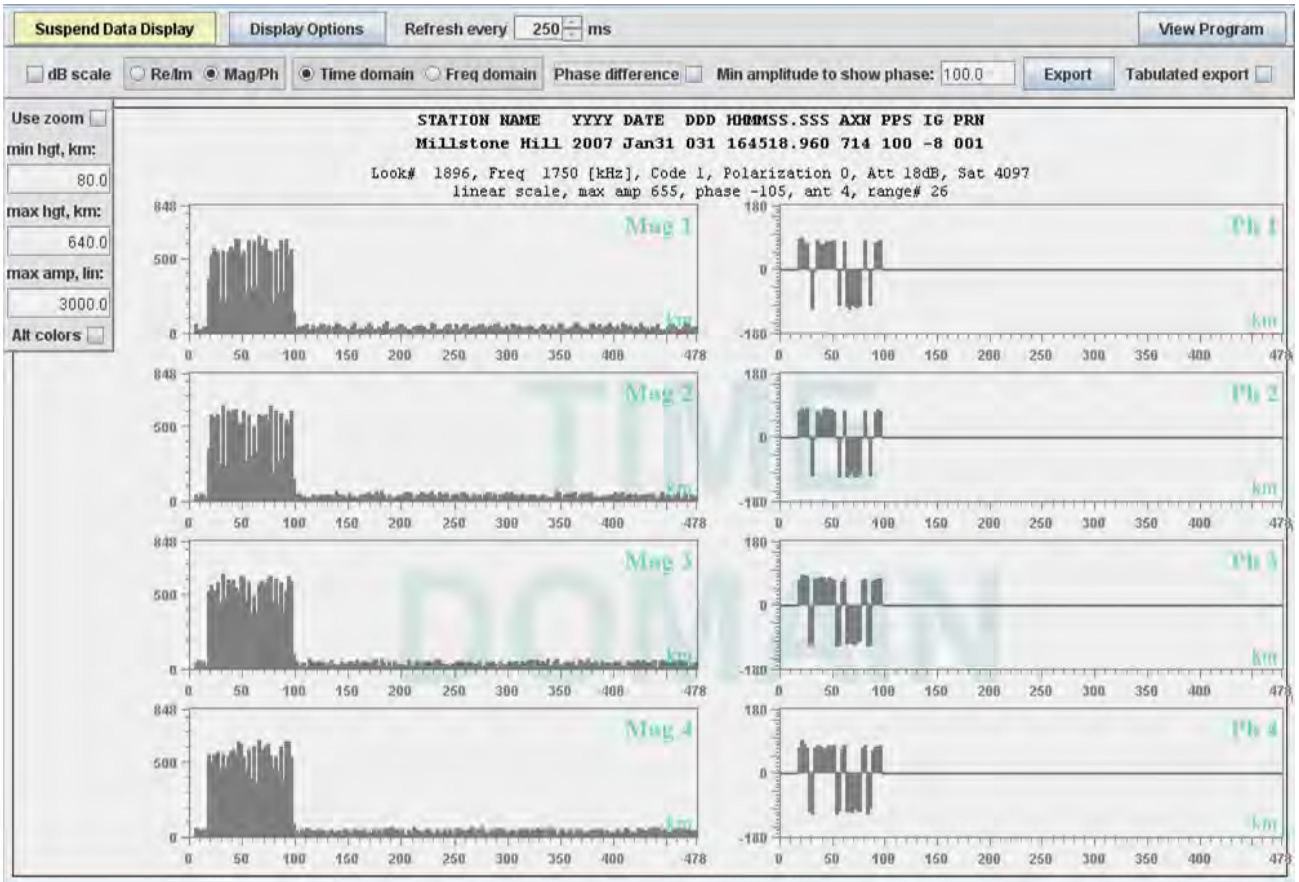


Figure 3-34: Real-time "Sounding Mode" Display, Time Domain Plot (Steps 1-4 of the Processing Chain)

Real-time Display of Doppler Spectra (Step 5 of Processing Chain)

3:86. **Figure 3-35** shows real-time "single range" Doppler Spectra display, in which FFT is taken over sorted samples belonging to the same range bin across pulse repetitions. The plot shows four channels of data with the magnitude of signal in the left column and phase in the right column. Note that abscissa of the plots uses Doppler Frequency in Hz. Available screen controls for data visualization are shown in **Table 3-4**.

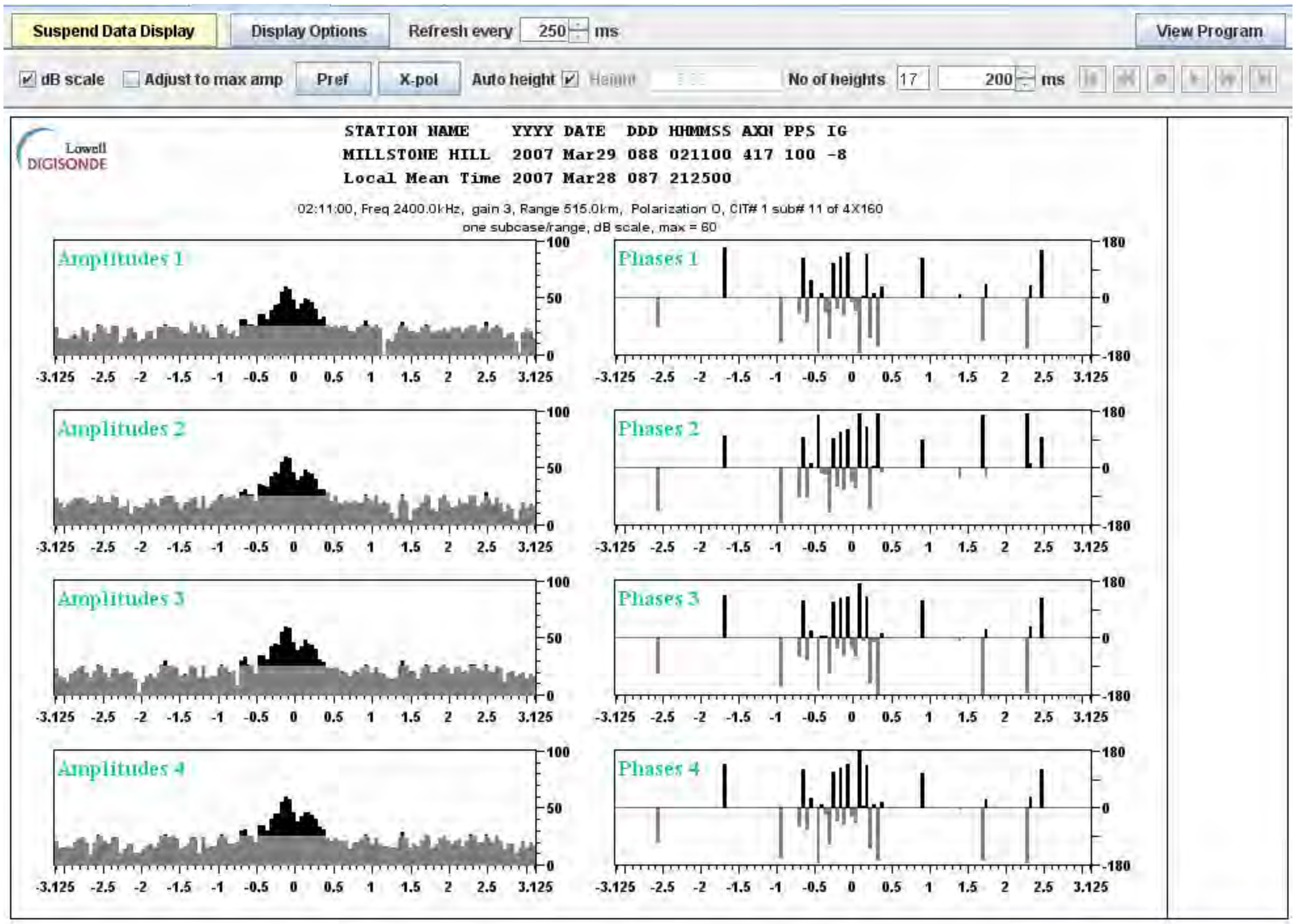


**Figure 3-35: Real-time "Sounding Mode" Display, Doppler Spectra Plot
(Step 5 of the Processing Chain)**

Table 3-4. Display Options for Doppler Spectra Real-Time Window

Location	Control	Function
Top Bar	"dB scale" checkbox	Represent amplitudes in dB scale or linear scale
	"Adjust to max amp" checkbox	Adjust the Y axis to fit maximum amplitude across 4 channels
	"Pref" button	Open options window to select Doppler image preferences, see Figure 3-36 and explanations below
	"O/X Pol" toggle button	Select O or X polarization for display
	"Auto Height" checkbox	Option to pick height for display at which signal is the strongest, or specific "Height" index for display
	"Height" text field	Height index for display if not in AutoHeight mode
	"No of heights" text field	Number of height in the waterfall representation (see Figure 3-36 for selection of the waterfall representation)
	Refresh rate spinner field	Refresh rate of the screen in ms

3:87. Doppler Image Options which can be found within the main Options button (**Figure 3-36**) has a number of options for display of the Doppler spectra in the sounding mode display window of DCART. The window layout and contents is re-used from the LDI Drift Explorer project libraries. Certain options are not applicable for real-time visualization.

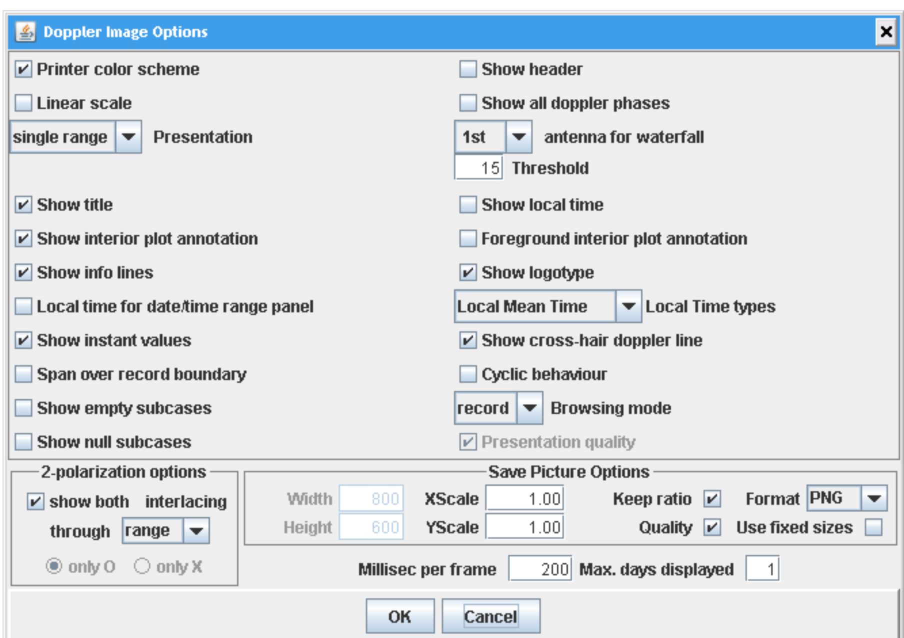


Figure 3-36: Doppler Image Options for the Real-Time Doppler Spectra Plot

Table 3-5. Display Options for Doppler Image

Category	Control	Function
Data Presentation	"Linear scale" checkbox	Represent amplitudes in dB scale or linear scale
	"Single range" or "Waterfall" presentation	Presentation as single range (**Figure 3-35**) or waterfall (**Figure 3-37**)
Processing	"Global MPA" checkbox	Use amplitude thresholding, display amplitudes above threshold in black
	"Threshold" text field	Threshold value above MPA
Visual Attributes	"Printer color scheme" checkbox	Use black on white background (printer) versus white on black background (screen) display
	"Show title" checkbox	Show standard preface information as title
	"Show local time" checkbox	Show additional line in the title with local time
	"Local Time types" combobox	Type of LT for displays of local time
	"Show interior plot annotation" checkbox	Add Amplitude/Phase labels to the plot background
	"Foreground interior plot annotation" checkbox	Bring plot annotations to the foreground
	"Show infoline" checkbox	N/A
	"Show logotype" checkbox	Show Digisonde® logo in the upper left corner
Crosshair Line	"Show instant values" checkbox	Add a side window to display values at the crosshair position
	"Show cross-hair Doppler line" checkbox	Add cross-hair line to spectra plots
Browsing Controls	Browsing and spanning modes	N/A to real-time display
Picture options	Picture format options	N/A to real-time display

Waterfall Presentation of the Drift Data

3:88. In Doppler Image Options window, set "Presentation" drop-down menu to "Waterfall" to obtain waterfall display (see **Figure 3-37**).

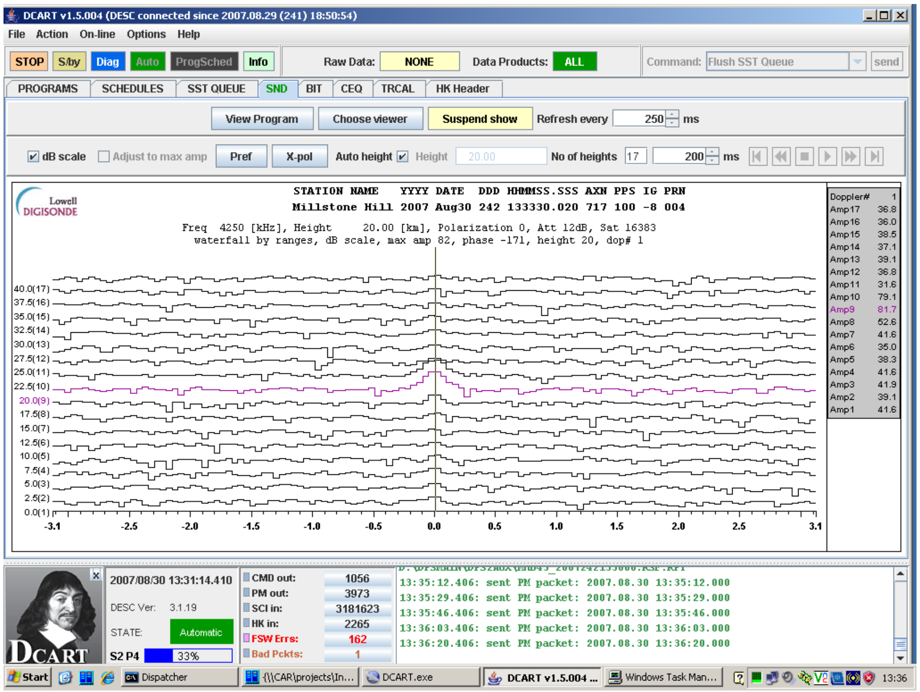


Figure 3-37: Waterfall Display of Drift Data in Real-Time

Real-Time Display of Ionograms (Step 6 of Processing Chain)

3:89. **Figure 3-38** shows a typical display of ionogram measurement in progress using the ionogram presentation, in which colors are used to represent echo status (polarization, Doppler shift, and angle of arrival). Available options allow one to change the thresholding parameter, select polarization channel for display, zoom the image to particular ionogram section, and use printer or screen color scheme.

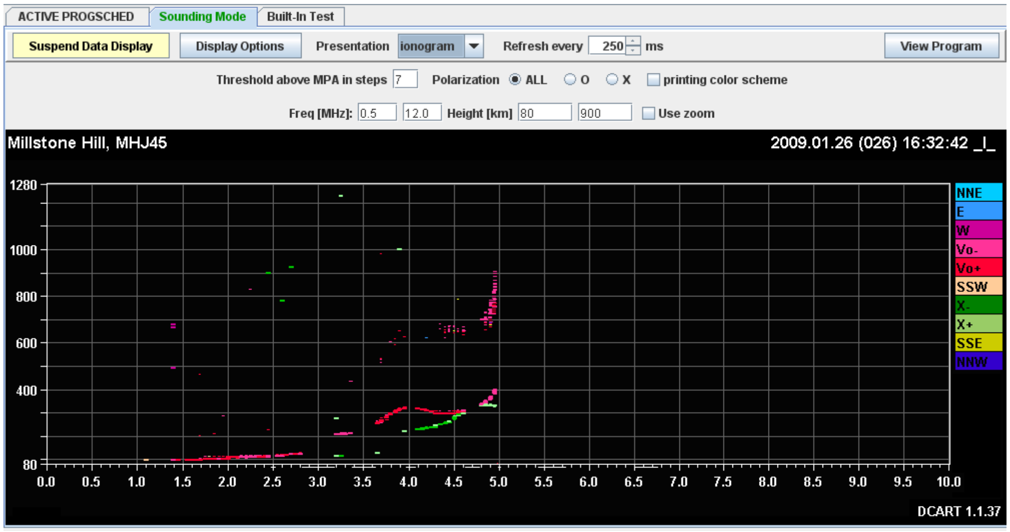


Figure 3-38: Real-Time Display of Ionogram Measurement in Progress (Ionogram Presentation)

Ionogram measurement can be additionally presented as an *echogram*, which when selected makes available several additional display types. Once the echogram has been selected, two additional presentation modes are made available "Detailed", and "Aggregative." The echogram display controls are shown in Figure 39

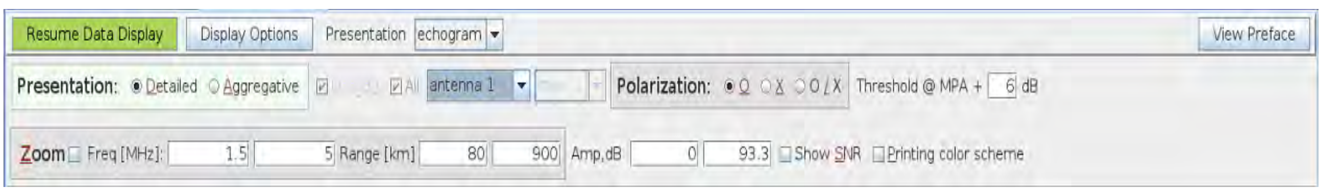


Figure 39: Echogram presentation display controls

Detailed echogram presentation display

3:90. When "Detailed" presentation is selected from within the echogram display window data is displayed as frequency and height, andcolor is used to represent signal amplitude (see **Figure 3-40**) instead of polarization and direction as in the traditional ionogram. In addition to the common options for the ionogram visualization, the echogram display allows selecting individual antennas, and assigning different maximum amplitude value to the color legend. When selecting "O/X" within the Polarization block the display switches back to a simplified version of the standard ionogram display where color represents polarization.

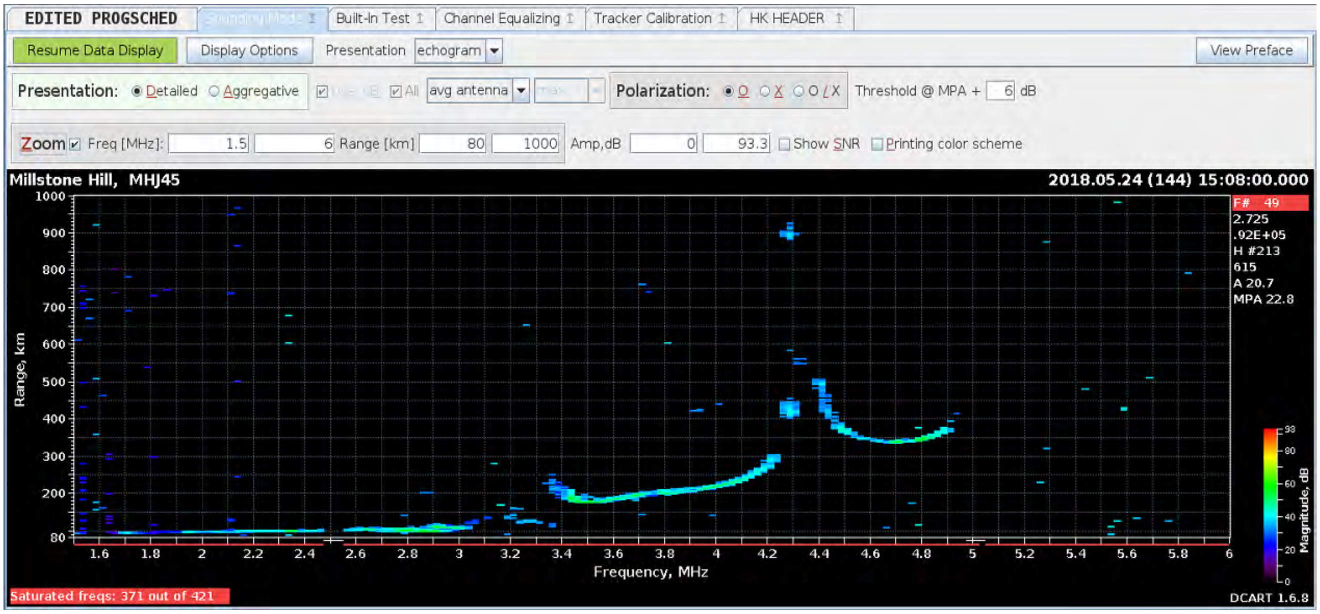


Figure 3-40: Real-Time Display of Ionogram Measurement in Progress (Echogram Presentation)

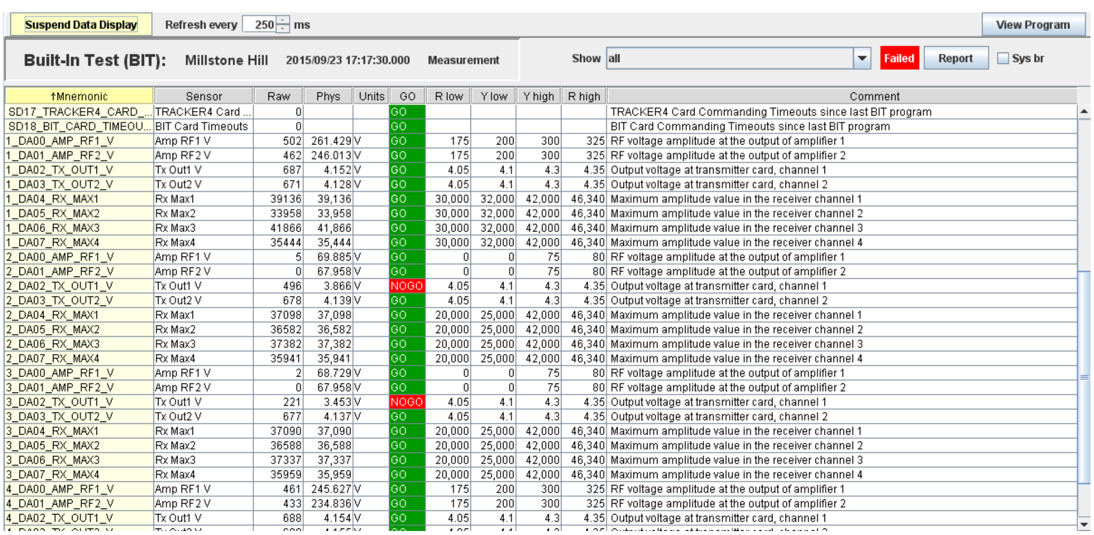
Aggregative echogram presentation display

3:91. When “Aggregative” presentation is selected from within the echogram display controls the display presents the ionogram data in the frequency surveillance style as shown in **Figure 3-41**. It is possible to select maximum, minimum, median, or spectral maximum amplitude out of all available data per frequency for plotting on the spectrogram. In addition to the frequency surveillance at the sounder location, spectrogram presentation can be useful for tracker calibration, evaluation of the receiver transfer function, and monitoring of the system noise floor.

Figure 3-41: Echogram Presentation of the Same Ionogram as in Figure 3-40, Shown as Spectrogram

Real-Time Display of BIT Results

3:92. **Figure 3-42** shows example of a failed Built-In Test display. Further recommendations for using BIT in system troubleshooting, with relevant displays and in-depth analysis, can be found in Section 6 of this Manual.



Suspend Data Display | Refresh every 250 ms | View Program

Built-In Test (BIT): Millstone Hill 2015/09/23 17:17:30.000 Measurement | Show all | Failed | Report | Sys br

↑Mnemonic	Sensor	Raw	Phys	Units	GO	R low	Y low	Y high	R high	Comment
SD17_TRACKER4_CARD_...	TRACKER4 Card ...	0			GO					TRACKER4 Card Commanding Timeouts since last BIT program
SD18_BIT_CARD_TIMEOU...	BIT Card Timeouts	0			GO					BIT Card Commanding Timeouts since last BIT program
1_DA00_AMP_RF1_V	Amp RF1 V	502	261.429	V	GO	175	200	300	325	RF voltage amplitude at the output of amplifier 1
1_DA01_AMP_RF2_V	Amp RF2 V	462	246.013	V	GO	175	200	300	325	RF voltage amplitude at the output of amplifier 2
1_DA02_TX_OUT1_V	Tx Out1 V	687	4.152	V	GO	4.05	4.1	4.3	4.35	Output voltage at transmitter card, channel 1
1_DA03_TX_OUT2_V	Tx Out2 V	671	4.128	V	GO	4.05	4.1	4.3	4.35	Output voltage at transmitter card, channel 2
1_DA04_RX_MAX1	Rx Max1	39136	39,136		GO	30,000	32,000	42,000	46,340	Maximum amplitude value in the receiver channel 1
1_DA05_RX_MAX2	Rx Max2	33958	33,958		GO	30,000	32,000	42,000	46,340	Maximum amplitude value in the receiver channel 2
1_DA06_RX_MAX3	Rx Max3	41866	41,866		GO	30,000	32,000	42,000	46,340	Maximum amplitude value in the receiver channel 3
1_DA07_RX_MAX4	Rx Max4	35444	35,444		GO	30,000	32,000	42,000	46,340	Maximum amplitude value in the receiver channel 4
2_DA00_AMP_RF1_V	Amp RF1 V	5	69.885	V	GO	0	0	75	80	RF voltage amplitude at the output of amplifier 1
2_DA01_AMP_RF2_V	Amp RF2 V	0	67.958	V	GO	0	0	75	80	RF voltage amplitude at the output of amplifier 2
2_DA02_TX_OUT1_V	Tx Out1 V	496	3.866	V	NOGO	4.05	4.1	4.3	4.35	Output voltage at transmitter card, channel 1
2_DA03_TX_OUT2_V	Tx Out2 V	678	4.139	V	GO	4.05	4.1	4.3	4.35	Output voltage at transmitter card, channel 2
2_DA04_RX_MAX1	Rx Max1	37098	37,098		GO	20,000	25,000	42,000	46,340	Maximum amplitude value in the receiver channel 1
2_DA05_RX_MAX2	Rx Max2	36582	36,582		GO	20,000	25,000	42,000	46,340	Maximum amplitude value in the receiver channel 2
2_DA06_RX_MAX3	Rx Max3	37382	37,382		GO	20,000	25,000	42,000	46,340	Maximum amplitude value in the receiver channel 3
2_DA07_RX_MAX4	Rx Max4	35941	35,941		GO	20,000	25,000	42,000	46,340	Maximum amplitude value in the receiver channel 4
3_DA00_AMP_RF1_V	Amp RF1 V	2	68.729	V	GO	0	0	75	80	RF voltage amplitude at the output of amplifier 1
3_DA01_AMP_RF2_V	Amp RF2 V	0	67.958	V	GO	0	0	75	80	RF voltage amplitude at the output of amplifier 2
3_DA02_TX_OUT1_V	Tx Out1 V	221	3.453	V	NOGO	4.05	4.1	4.3	4.35	Output voltage at transmitter card, channel 1
3_DA03_TX_OUT2_V	Tx Out2 V	677	4.137	V	GO	4.05	4.1	4.3	4.35	Output voltage at transmitter card, channel 2
3_DA04_RX_MAX1	Rx Max1	37090	37,090		GO	20,000	25,000	42,000	46,340	Maximum amplitude value in the receiver channel 1
3_DA05_RX_MAX2	Rx Max2	36588	36,588		GO	20,000	25,000	42,000	46,340	Maximum amplitude value in the receiver channel 2
3_DA06_RX_MAX3	Rx Max3	37337	37,337		GO	20,000	25,000	42,000	46,340	Maximum amplitude value in the receiver channel 3
3_DA07_RX_MAX4	Rx Max4	35959	35,959		GO	20,000	25,000	42,000	46,340	Maximum amplitude value in the receiver channel 4
4_DA00_AMP_RF1_V	Amp RF1 V	461	245.627	V	GO	175	200	300	325	RF voltage amplitude at the output of amplifier 1
4_DA01_AMP_RF2_V	Amp RF2 V	433	234.836	V	GO	175	200	300	325	RF voltage amplitude at the output of amplifier 2
4_DA02_TX_OUT1_V	Tx Out1 V	688	4.154	V	GO	4.05	4.1	4.3	4.35	Output voltage at transmitter card, channel 1

Figure 3-42: Real-Time BIT Display

OFFLINE DATA VISUALIZATION

3:93. DCART provides additional display capabilities for offline visualization of data previously saved. The offline display selections can be found in Action menu of DCART. All viewing actions of DCART open a separate window with similar displays as in the real-time sounding mode visualization of data, with additional controls for opening files and browsing its contents.

AUTONOMOUS OPERATIONS OF DIGISONDE-4D

3:94. In order to configure Digisonde 4D for autonomous operations, it is necessary to complete the following tasks:

1) Prepare measurement program specifications

2) Assemble programs in schedules

3) Design planning rules for schedule switching within one day

4) Add campaign requests if needed

5) Switch the sounder into autonomous mode

3:95. It is recommended to have different schedules for routine daytime and nighttime operations, and for campaign periods:

- DAYTIME ionogram measurements typically have wider frequency coverage, coarser frequency resolution, and higher receiver gain.
- NIGHTTIME ionogram measurements typically have smaller frequency coverage, finer frequency resolution, and lower receiver gain to accommodate stronger returns from ionosphere when no D region absorption occurs.
- CAMPAIGN periods usually require higher cadence of measurements.

Basic Schedule Editing with DCART

3:96. Once a schedule is started, it repeats the measurement programs defined within it in an unending loop until the schedule is stopped. In order to arrange 15 minute cadence of Digisonde-4D measurements (4 times an hour), it is sufficient to define a 15 minute schedule. If a schedule has to combine operations of different cadences, its duration shall match the least frequent cadence. For example, if 15 minute ionogram measurements have to be combined with an hourly passive sensing observation, the usual solution is to create a 1 hour schedule with 4 copies of ionogram measurement and one passive operation. Refer to Chapter 1 of this Section, Para 3:2 and onward, for review of programs and schedules.

3:97. The DCART Schedule Editor panel is used to assemble programs in schedules**. Figure 3-43** shows a sample schedule #17 that makes ionograms every 15 minutes. The left column of the DCART screen displays the list of available schedules. The central panel made up by two Schedule editor components, the Program List (upper section), and Schedule Image (lower section). Schedule #17 has fixed length of 15 minutes and, in addition to the daytime ionogram measurement program #8 at the schedule start, it also contains three additional support programs: Built-In Test program #11 to evaluate system health status, Cross-Channel Equalizing program #25 to calculate compensations for inequalities in 4 receiver channels, and CreateGainTable program #27 to refresh the autogain table (see discussion in Para 3:23 and **Figure 3-7**). The ionogram measurement is placed at the schedule start so that ionograms are made at minutes 0, 15, 30, and 45 of each hour; historically a common Ionosonde cadence. The autogain program is placed at the end of the schedule to evaluate current noise environment as close to the ionogram start as possible. Placement of the BIT and CCEQ programs within the available idle time of this schedule is arbitrary.

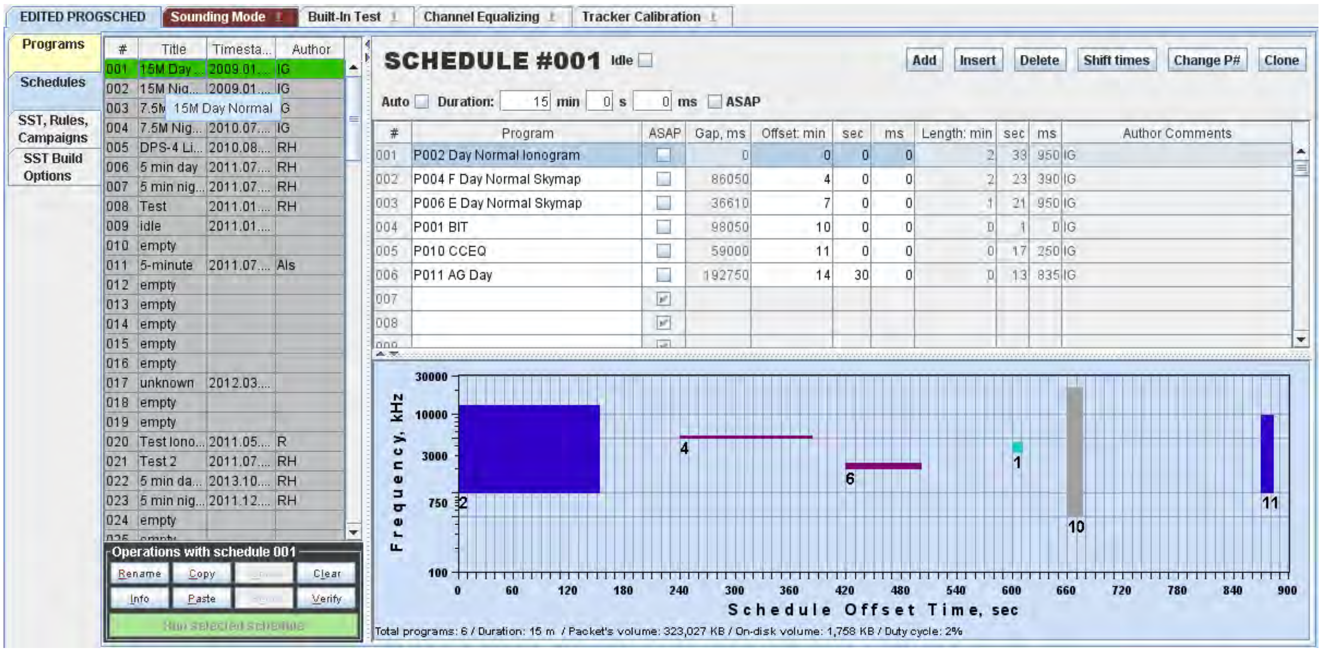


Figure 3-43: Example of 15 Minute Ionogram Schedule

NOTE

It is recommended to include in each schedule one BIT program, one CCEQ program covering appropriate frequency range, and one 'Create Gain Table' program with appropriate constant gain.

3:98. Upper controls of the Program List panel, "Add", "Insert", "Delete", "Shift times", "Change P#" and "Clone", are used to modify schedule contents.

- The Add button will add a new program entry *beneath* the currently select schedule entry.
- The Insert button will add a new program entry *above* the currently selected schedule entry.
- The Delete button deletes the currently selected entry.
- Shift Times will move the time of the currently selected entry and all subsequent entries by the specified amount (even negative amounts). For example, this feature can be used to move all programs after a certain point to make room for an additional program.
- Change P# button will search the schedule from the selected entry onward, replacing a program specified "N" with one "M". For example, if you wanted to search and replace all instances of program number 5 with program 10, then one would select the very first entry in the schedule (thereby selecting

the entire schedule), click “Change P#” and enter “ 5,10 “. This would replace every instance of program 5 with program 10.

- The Clone button allows you to duplicate the current schedule some number of times to create longer schedules. For example, if you were editing a 15 minute schedule, and desired to maintain the current program cadence but increase the schedule duration to 60 one would click Clone and then enter “3”. In this example 3 is the number of times you wish to clone the existing schedule which results in a new schedule 60 minutes in duration.

3:99. **Figure 3-44** shows a commonly used daytime Digisonde® schedule that includes two skymap measurements for E and F region and increases cadence of 8 measurements per hour.

3:100. “Idle” checkbox is used to create an empty schedule. The empty schedule can be useful for adding periods of radio silence to the measurement plan (often they have a place in campaigns). If an unplanned radio silence of the Digisonde® is needed, it is best accomplished by switched it into Manual Operations state.

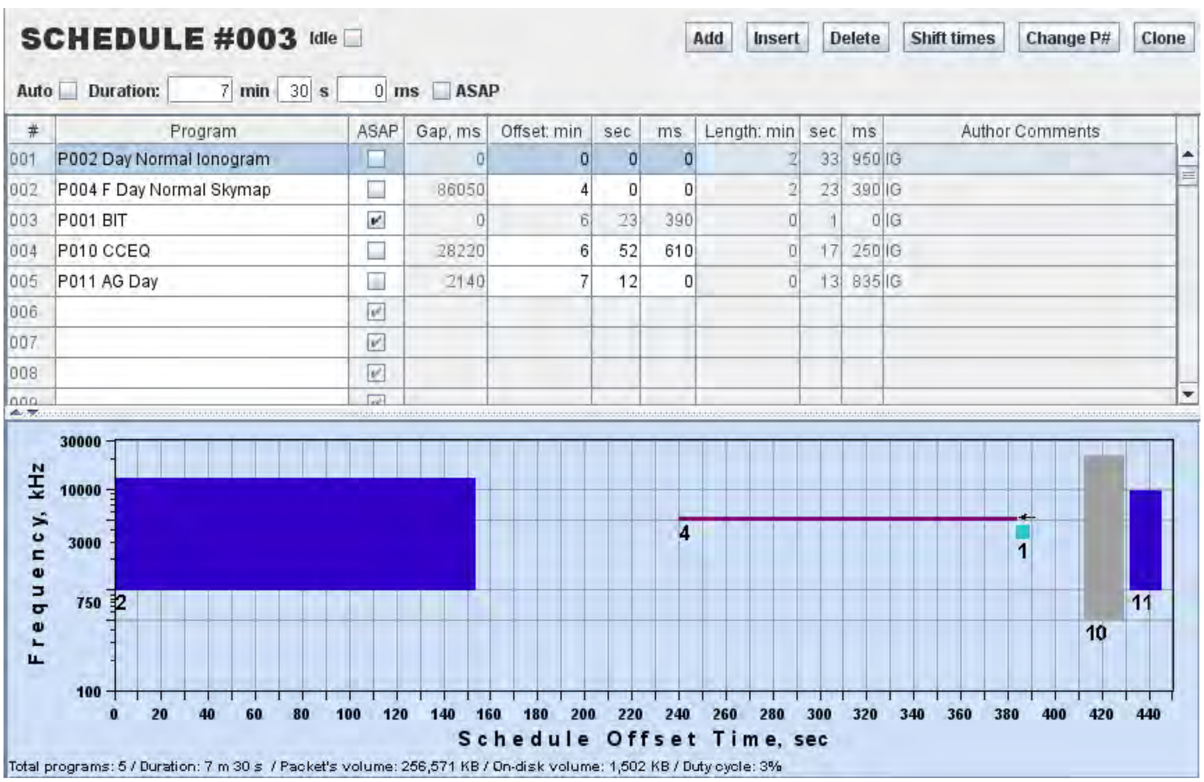


Figure 3-44: Typical Example of 7.5 Minute Ionogram Schedule

NOTE

For routine scientific observations of the ionosphere it is recommended to keep Digisonde® at 5 or 7.5 min cadence to ensure sufficient coverage of occasional periods of elevated ionospheric activities such as geomagnetic storms. It is also important to have the radar range set at 1500 km (10 ms inter-pulse period) for ionogram and drift programs to capture dynamics of ascending ionosphere during the storm activities.

Advanced Schedule Editing with DCART

3:101. The "Auto" checkbox of the Schedule Editor switches the editor into the automatic placement mode (**Figure 3-45**) in which gaps between scheduled programs are forced to a fixed value (1000 ms for the example shown in **Figure 3-45**), and schedule duration can be padded to a needed value by entering appropriate "last" gap value (2000 ms for the example shown in **Figure 3-45**). "Adjust" button is used to enforce automatic placement rules on all programs in the schedule. "Between" and "last" buttons are used to make adjustments to individual parts of the schedule.

Manual Placement mode:

Automatic Placement mode:

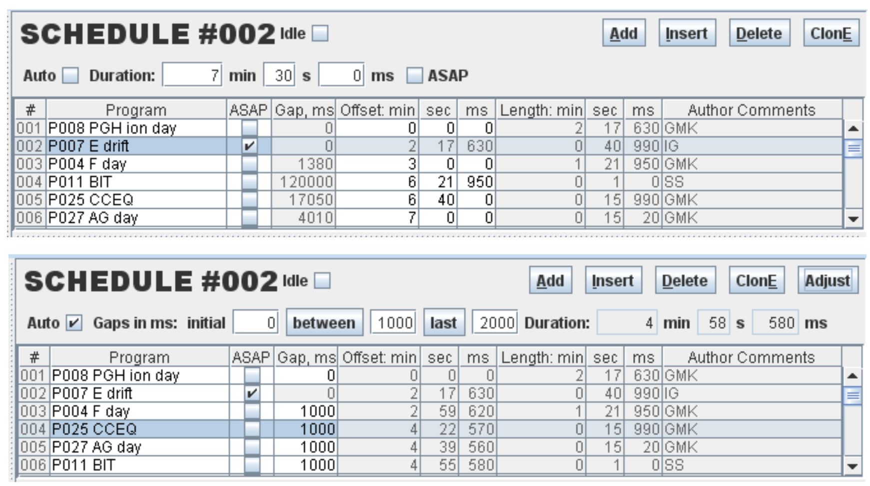


Figure 3-45: Manual and Automatic Placement Modes of the Schedule Editor

3:102. ASAP (As Soon As Possible) modifier replaces fixed offset and duration times of the schedule with instruction to the DESC software to start next program as soon as current program completes. The ASAP modifier brings uncertainty of the actual program start time because the time is not synchronized to the computer clock anymore. Although CONTROL platform warrants deterministic execution of the programs, their actual duration can still be affected by unaccounted events in the system. The ASAP modifier is used to start programs whose absolute timing is not required within the schedule duration period (e.g., skymaps, CCEQ, autogain programs). The ASAP modifier can also be placed on the schedule duration itself, which may be useful for continuous observations without absolute timing of their start (as in space applications, for example).

Programming SSTs with Planning Rules and Campaign Requests

3:103. Calculation of new Schedule Start Times (SST) is needed for appropriate switching of Digisonde® schedules within a day (e.g., daytime and nighttime) or in support of joint observational campaigns with other instruments. There are two distinct mechanisms for calculation of SSTs working in conjunction:

- RULES: algorithms to appropriately start schedules within one day
- CAMPAIGNS: specification of UT periods (start and stop times) to override the rule-calculated SSTs

3:104. **Figure 3-46** shows SST Editor panel of DCART. The upper section of SST Editor has Status bar and two tables with rules and campaigns, and the lower section displays Timeline window with optional SST Table. The Timeline window has Timeline Image with zoom-in controls and option selectors. Timeline example in

Figure 3-46 shows 1 hour of Digisonde® operations from 2018.05.24 02:00UT to 2018.05.24 03:00UT, during which daytime schedule #52 is switched to nighttime schedule #53, at 2:32 UT.

NOTE

Timeline image may not show individual programs if selected timeline interval produces programs that are so close as to be too dense to see. Use Programs and Schedules text fields in the Timeline panel to specify the threshold at which detailed view is no longer provided because of screen clutter.

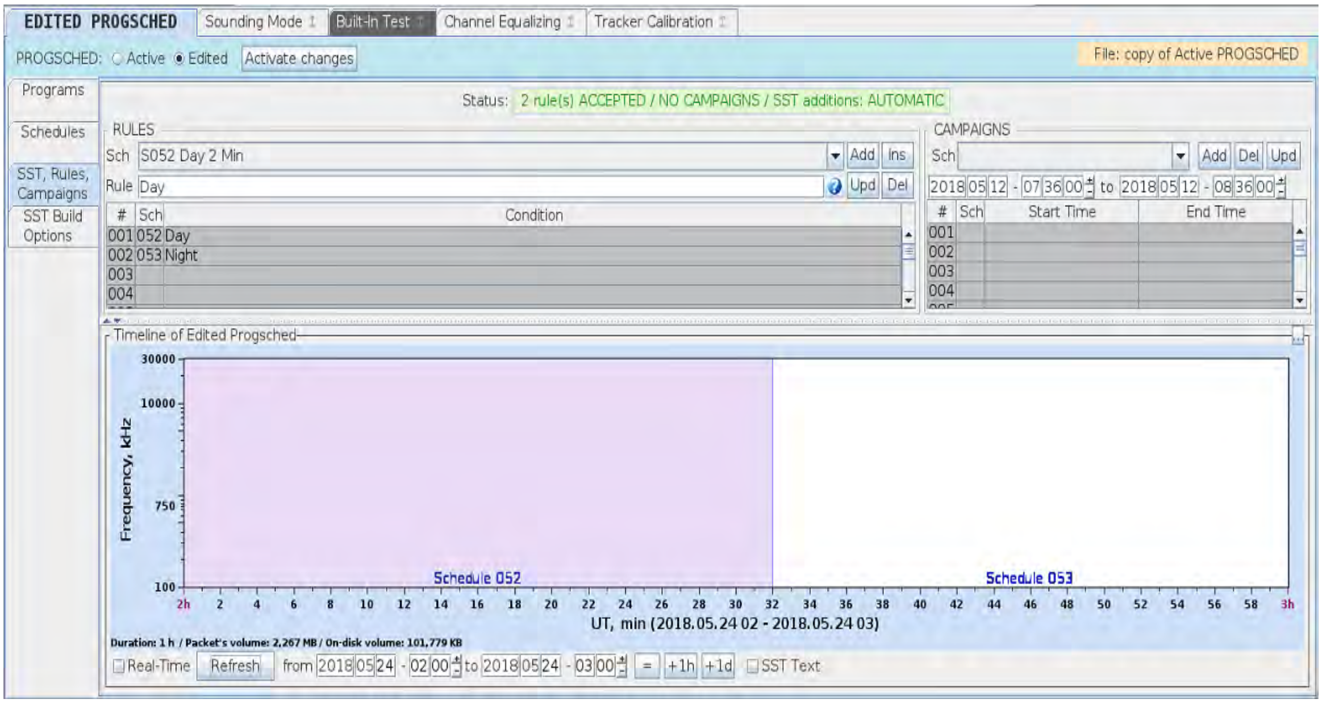


Figure 3-46: SST Editor

Planning Rules

3:105. One Planning Rule contains (a) *Schedule Number* and (b) *Condition* that can be one of three kinds:

- START CONDITION for the schedule to start,
- INTERVAL CONDITION for the schedule to start and finish, or
- DEFAULT CONDITION for the schedule to run when no other conditions apply.

3:106. Rule conditions can be written as simple formulas that use

- UT time of the day (keywords *StartUT* and *RangeUT*) specified in **hh:mm:ss.sss** format
- Daylight time in the F region (keyword *Day* and its boundaries *Day.Start* and *Day.End*)
- Nighttime in the F region (keyword *Night* and its boundaries *Night.Start* and *Night.End*)
- Offset from condition one row higher in the table (keyword *Offset*)

3:107. Condition formulas can modify the keyword or its boundaries by adding or subtracting *time deltas*. For example, to start a schedule 30 minutes before daylight time in the F region, condition *Day.Start-30m* is used in the rule. Time deltas can be specified as negative or positive times in hours, minutes, seconds, milliseconds, or in schedule iterations (units of schedule duration):

- Time Delta Format 1 (time): [-,+] [*N***h**] [*K***m**] [*L***s**] [*M***ms**]
- Time Delta Format 2 (time): [-,+] *L.M***s**
- Time Delta Format 3 (schedule iterations): ***I*i**

START CONDITIONS

3:108. **Table 3-6** lists types of start conditions, in which the schedule starts at the specified time and runs until another rule condition becomes effective.

Table 3-6. Start Conditions

Keyword	Example		Usage Notes
StartUT	StartUT 10	Start schedule at 10:00UT	Analogous to DPS4 stock scheduler
	StartUT 10:20	Start schedule at 10:20UT	
	StartUT 10:20:00.250	Start schedule at 10:20:00.250UT	10 ms resolution
Day.Start	Day.Start	Start schedule at day start	Calculated individually for all locations and days of year
	Day.Start-30m	Start schedule 30 minutes prior to day start	Refer to foF2 daily plot to select optimal day/night switch
Day.End			Night.Start is preferred for clarity
Night.Start	Night.Start	Start schedule at night start	Calculated individually for all locations and days of year
	Night.Start+1h	Start schedule 1 hour after night start	Refer to foF2 daily plot to select optimal day/night switch
Night.End			Day.Start is preferred for clarity
Offset	Offset 1h	Start this schedule after 1 hour of previous schedule operations	
	Offset 10i	Start this schedule after 10 iterations of previous schedule	Useful for testing

INTERVAL CONDITIONS

3:109. **Table 3-7** lists types of interval conditions, in which the schedule starts and finishes at the specified times. When the schedule finishes, SST planning algorithm reviews other rules to decide which schedule to run next.

Table 3-7. Interval Conditions

Keyword	Example		Usage Notes
RangeUT	RangeUT(10,20)	Run schedule from 10:00 to 20:00UT	
	RangeUT(10,10:30)	Run schedule from 10:00 to 10:30UT	10 ms resolution
Day	Day	Run schedule during daytime	Calculated individually for all locations and days of year
	Day(-30m, +1h)	Start schedule 30 minutes prior to day start, finish schedule 1 hour past day end	Refer to foF2 daily plot to select optimal day/night switch
Night	Night	Run schedule during nighttime	Calculated individually for all locations and days of year
	Night(+1h, -30m)	Same as Day(-30m, +1h)	Refer to foF2 daily plot to select optimal day/night switch
Offset	Offset(10m, 30m)	Start schedule 10 min after previous condition in the list, stop after 30 min of operation	
	Offset(10i, 20i)	Start schedule after 10 iterations of previous schedule and run 20 iterations of current schedule	

NOTE

Start times suggested by planning rules that use Day and Night conditions, as well as their boundaries Start and End, are subject to "Snap to UT grid" analysis that shifts the start time to the nearest end of previous schedule iteration, so that the SST planner does not interrupt schedules in the middle.

COMBINING PLANNING RULES IN THE RULES TABLE

3:110. The Rule Table can have multiple rules with start and interval conditions, and one default rule. As a minimum, the Rule Table has to have one rule which is not the default rule, in which case no schedule switching is occurring, and the sounder remains in the schedule specified in the rule indefinitely. There is no start or end time associated with the default rule; it is a fallback rule that will define operation if there is an absence in the schedule not described by other rules. It is for this reason that if there is only a single rule in the Rule Table, it cannot be the default rule.

3:111. When more than one planning rule is specified in the Rule Table, DCART planning algorithm parses the rules to calculate SSTs within the day period. It is possible that more than one condition applies to the same period of time of day, in which case planning algorithm considers rule priority (rules placed higher in the Rule Table have higher priority). The planning algorithm concepts can be summarized as follows:

- Schedule with a start condition finishes as soon as another condition starts.
- Schedule does not start if another schedule is running with a higher priority interval condition.
- When schedule with interval condition finishes, new running schedule is selected as the highest priority schedule applicable.
- Default schedule has lowest priority.

3:112. Table provides two examples of priority analysis.

Table 3-8. Examples of Priority Analysis

#	Rule Table Example	Action
1	RangeUT(10,20) for Schedule #1	Run #1 from 10 to 20 UT, run #2 from 20 to 22UT, run #3 from 22 to 10 UT
	RangeUT(14,22) for Schedule #2	
	Default Schedule #3	
2	RangeUT(14,22) for Schedule #2	Run #1 from 10 to 14 UT, run #2 from 14 to 22UT, run #3 from 22 to 10 UT
	RangeUT(10,20) for Schedule #1	
	Default Schedule #3	

Campaign Requests

3:113. One Campaign Request contains (a) *Schedule Number*, (b) *Start UT*, and (c) *End UT* for the schedule to run. The campaign request overrides the existing SST planning rules. In addition to the campaign requests typed into Campaign Table manually, DCART can accept external .RCR files (Remote Campaign Request) to handle copious schedule switches that may be needed, for example, to support daily spacecraft overpasses. The RCR files can be generated automatically by ADRES subsystem of the DIDBase repository using data from orbit propagators.

Real-Time Display of Schedule Progression in SST Editor

3:114. Enabling “Real-Time” checkbox in DCART Timeline window switches it to display of schedule progression using current system clock time as the Timeline start and setting the Timeline end to a window of configurable length (see **Figure 3-47**).

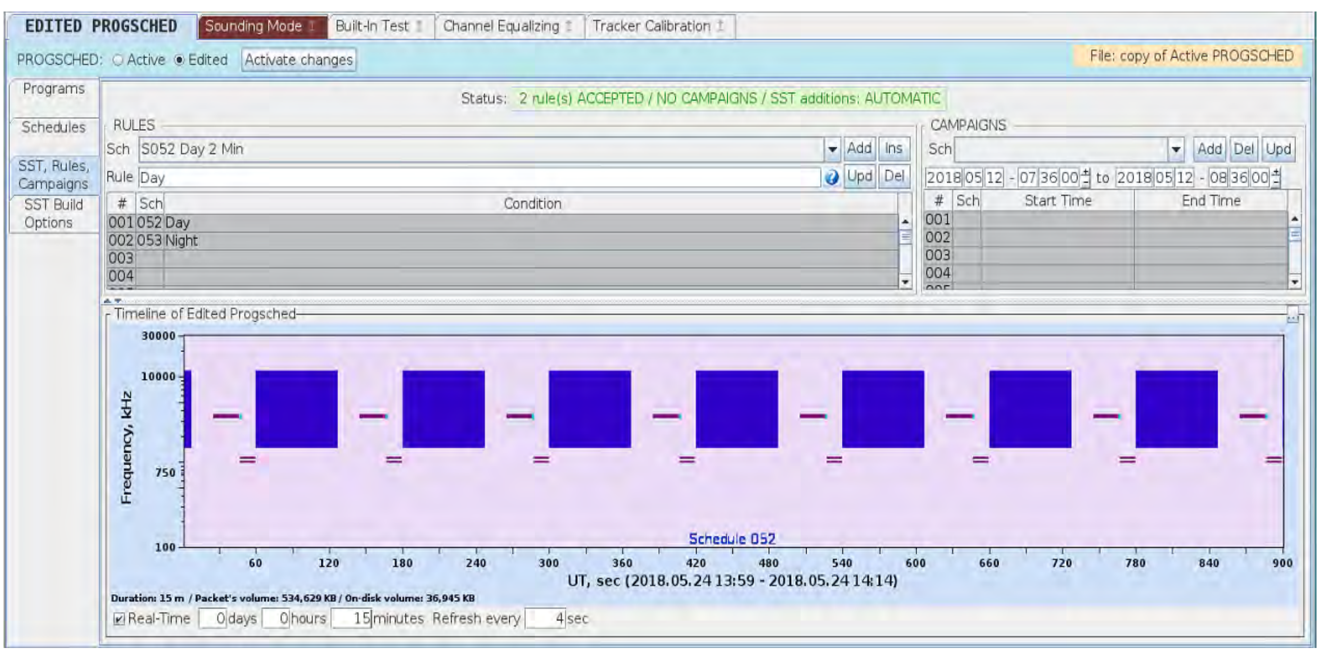


Figure 3-47: Real-Time Timeline Display of Schedule Progression

MANUAL OPERATIONS OF DIGISONDE-4D

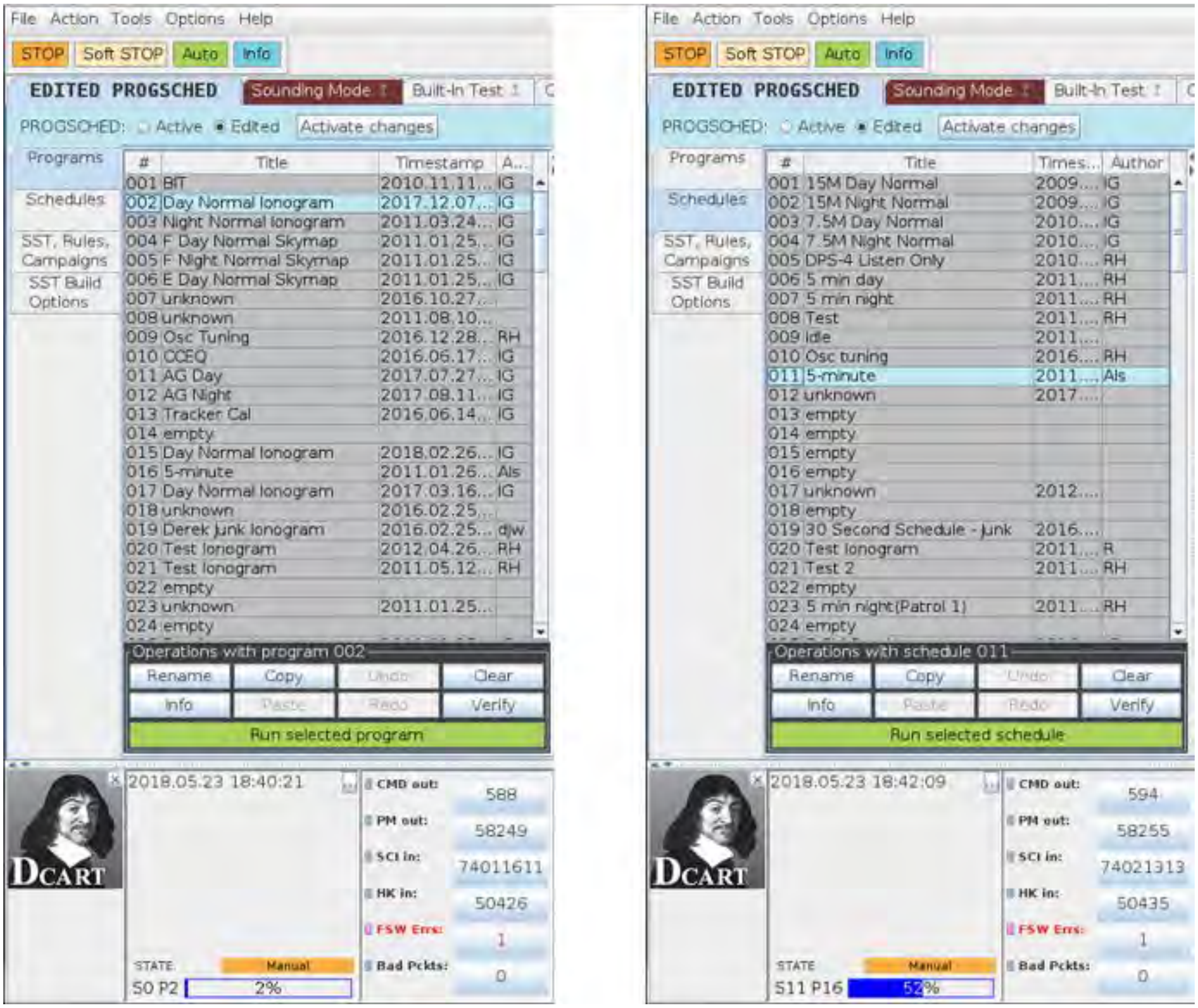
3:115. Manual operation of the sounder may be needed as a part of its testing, troubleshooting, or during development of new science programs and schedules.

NOTE

Development of new programs, schedules, and SST planning rules can be done without interrupting ongoing sounder operations using DCART console of the sounder. Note that physical presence at the sounder site is not required for PROGSCHED editing. Refer to "Remote operations" Chapter of this Section for further information, including use of a stand-alone version of DCART installed on another (remote) computer for offline editing.

3:116. Use the "Soft STOP" command to switch the sounder into its Manual Operations mode. Once in the manual mode, use Programs and Schdedules tabs for manual start of programs and schedules.

3:117. When developing new programs or schedules, it is not necessary to always activate changes (using Activate changes" button of the PROGSCHED tab). In manual operating mode it is sufficient to run a new program or schedule by using "Run Selected Program" in the Program List or "Run Selected Schedule" in the Schedule List (see **Figure 3-48**). Manual runs of a program or a schedule includes upload of its new definition to CONTROL platform, but does not overwrite local copies of active PROGSCHED in DCART memory and on the hard disk. Once development is completed, the changes may be activated or discarded. To discard introduced changes, load the active PROGSCHED the disk using File – Open Active PROGSCHED and then activate it so that it completely refreshes DESC and DCART definitions.



(a) Manual Mode, running program #2 (b) Manual Mode, running schedule #11

Figure 3-48: Digisonde® in its Manual Operations Mode, Running (a) Program #1 and (b) Schedule #11

3:118. Commonly used keyboard shortcuts for the manual program runs:

F9	Run selected program
F10	Stop

CHAPTER 3

DIGISONDE-4D PROGRAMMING RECOMMENDATIONS

QUALITY CONTROL OF PROGSCHED DEFINITIONS

3:119. DCART editors have a comprehensive built-in system of quality control that makes it difficult to program Digisonde-4D measurements erroneously. If a program or schedule design violates any of the included quality checks, the editor places a red-colored "Show Design Error" button on the top panel of the editor and generates a warning window if the operator navigates away from the definition that raised the error flag. Pressing the "Show Design Error" button opens a report window with explanation of the error condition.

3:120. Typical classes of errors that DCART editors identify automatically to raise the error flag are:

- PROGRAM SETTINGS INCOMPATIBLE WITH OUTPUT DATA FORMAT
    - use of RSF/SBF ionogram format with frequency stepping other than linear,
    - use of DFT drift format with N above 128.
- INCOMPATIBLE SETTINGS WITHIN ONE PROGRAM
    - sampling beyond the boundary of next repetition period,
    - incorrect placement of fine steps within the coarse step,
    - use of directional analysis when antenna array is incomplete.
- SCHEDULES WITH OVERLAPPING PROGRAMS
- MISSING GAIN EVALUATION
    - all programs in the schedule use autogain table, but no program evaluates it

VALID PROGRAMS UNSUITABLE FOR SCIENCE OBSERVATIONS

3:121. There are several kinds of valid measurement programs that do not result in valid science data:

- Programs with 0 km start range
- Programs with "loopback" option instead of "measurement"
- Programs with "HW pattern" or "SW pattern" option instead of "measurement"
- Programs with "Save Product File" option disabled

VALID PROGRAMS WITH POTENTIAL PROBLEMS

3:122. Measurement programs that capture raw data stream in output files (program option "Save raw file" or top level option "Save all raw data") have potential implication of overfilling the hard disk of DATA platform.

3:123. "Radio Silent" option may not be intended for ionogram measurement, unless it is oblique sounding experiment.

VALID PROGRAMS SUBOPTIMAL FOR SCIENCE OBSERVATIONS

Ionogram measurement

3:124. Program design recommendations for the ionogram measurements are summarized in **Table 3-9**.

Table 3-9. Program Design Recommendations for Ionogram Measurements

#	Recommendation	Motivation	Usage Implications
1	Use beam-forming analysis to calculate echo directions unless malfunction of the receiver channel(s) is suspected	Echo directions help interpretation of ionograms, both manual and automatic by ARTIST	State of hardware health, channel equalization, and antenna array placement shall be adequate to use phase-aware techniques to calculate directions
2	Use precision ranging option	Precision ranging removes range bias, improves resolution, and ultimately helps automatic interpretation by ARTIST	Dual-frequency analysis for precision ranging doubles the ionogram running time and may require coarser frequencies stepping, lowering on the N (number of integrate pulses) or the upper frequency limit.
3	Use 10 ms inter-pulse period for 1500 km radar range	Provides capability of recording ionospheric uplift during periods of storm activity. Ionograms with 750 km radar range miss important ionospheric information.	Setting 10 instead of 5 ms IPP doubles the ionogram running time and may require time reduction measures (see usage implications for recommendation 2).
4	Use appropriate frequency resolution of 50 or 25 kHz	ARTIST performance improves with better frequency resolution.	Smaller frequency step means longer running time, which may require time reduction measures (see usage implications for recommendation 2).
5	Watch for fxF2 exceeding the upper limit of ionogram	Avoid truncated ionograms	Ionograms with higher upper limit run longer and may require adjustments to the schedules that use them.

Drift measurement

3:125. Program design recommendations for the drift (Doppler skymap) measurements are summarized in **Table 3-10**

Table 3-10. Program Design Recommendations for Drift Measurements

#	Recommendation	Motivation	Usage Implications
1	Set CIT time to 20 (day) or 40 seconds (night) by using appropriate inter-pulse period, number of pulses per frequency, and frequency multiplexing.	Improved Doppler resolution for a better signal analysis and echo resolution in skymaps	Higher EMI on radio systems, longer minimum running time. Doppler frequency bandwidth at 40 sec CIT may not be sufficient for polar locations.

VALID SCHEDULES SUBOPTIMAL FOR SCIENCE OBSERVATIONS

3:126. The following deficiencies of schedule designs are not reported automatically:

- No loopback CCEQ program is included,
- No BIT program is included,
- Gain evaluation program uses constant gain setting different from subsequent science programs, and
- CCEQ or Gain evaluation program use incompatible frequency range and step with subsequent science programs.

GENERAL RECOMMENDATIONS FOR DIGISONDE® OPERATIONS

3:127. General recommendations for Digisonde-4D operations are summarized in **Table 3-11**.

Table 3-11. General Recommendations for Digisonde-4D Operations

#	Recommendation	Motivation	Usage Implications
1	Use 7.5 or 5 minute measurement cadences for better coverage of storm time developments in ionosphere	15 minute cadence is not sufficient to capture storm timeline	Increased data volume
2	Use appropriate list of restricted frequencies	Frequency allocation authority fines	Decreased quality of data
3	Run tracker calibration schedule every 3 months	Reflect long-term changes in the analog electronics	None
4	Do not leave Digisonde® observatory with DCART showing real-time data on screen	Data visualization uses computer resources	None
5	Do not leave Digisonde® observatory with the sounder idling or running in the Manual/Diagnostic state.	Data loss	None

CHAPTER 4

ADVANCED INTERFACE OF DCART

SUMMARY OF ADVANCED FEATURES IN DCART

3:128. The following categories of DCART operations are considered to be available to advanced users:

- Programming and analysis of Cross-Channel Equalizing (CCEQ) data,
- Programming and analysis of Tracking Filter Calibration data,
- Direct hardware commanding,
- Global redefinition of data production options,
- Commanding of DESC into Diagnostic and Standby state for manual uploads, and
- Manual production of SSTs.

3:129. Use Options – General menu of DCART to switch it into Advanced interface mode, in which DCART windows shows additional controls and content tabs (see **Figure 3-49**).

Cross-Channel Equalizing of the Receiver Channels

3:130. The CCEQ operation switches Digisonde-4D into internal loopback configuration, in which antenna switch is commanded to use loopback signal from Transmitter Card instead of receiving antennas (**Figure 3-49**).

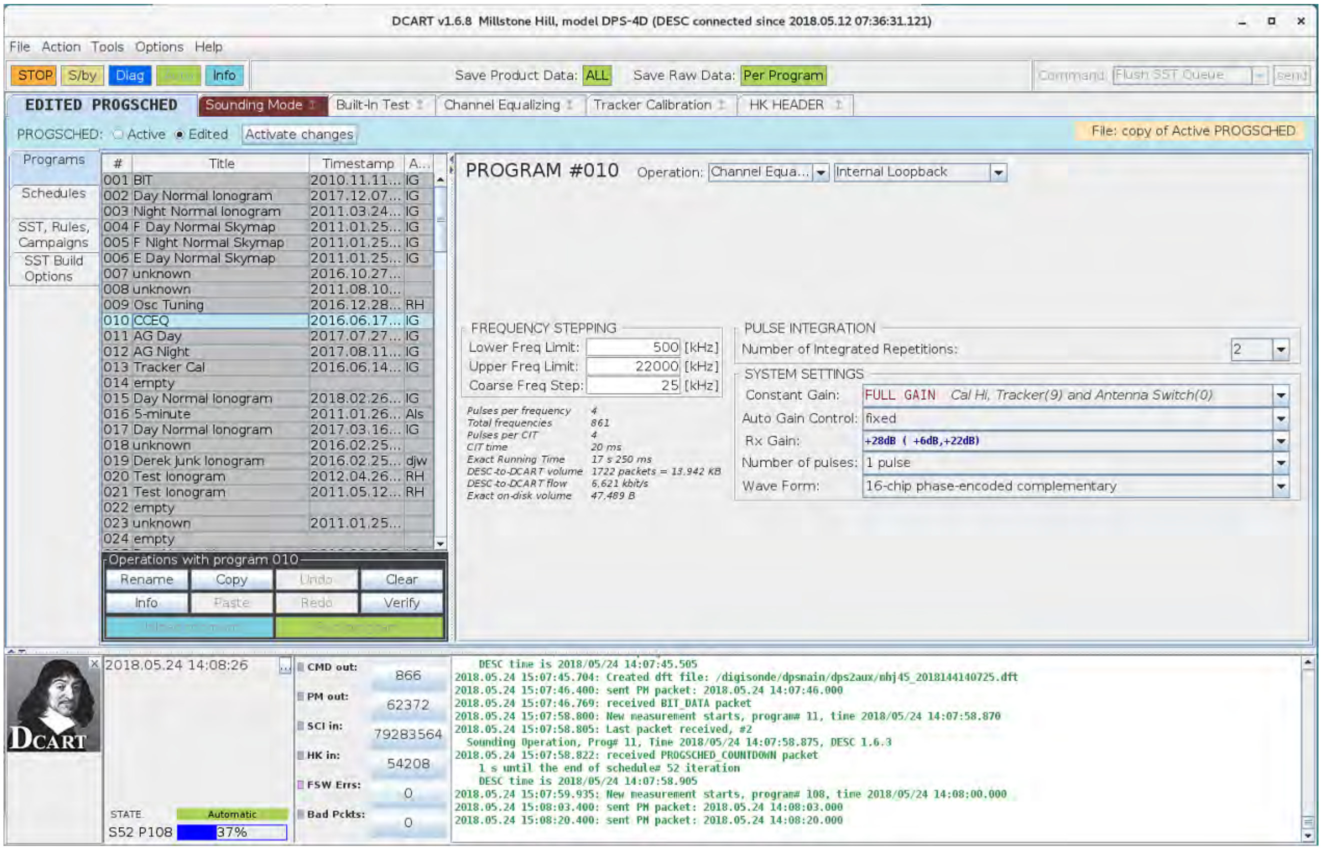


Figure 3-49: Advanced Mode of DCART Interface (Showing CCEQ Program Definition)

3:131. CCEQ data are acquired to derive complex correction coefficients to channels 2, 3, and 4 that would equalize their transfer function to match channel 1. The CCEQ data are stored in text form in .CEQ files and sent to Dispatcher for their post-management (assembly in daily files, delivery to remote destinations, etc.). A copy of the latest CEQ operation is stored in /digisonde/dispatch folder as LATEST.CEQ to use it for equalization step of the Processing Chain (see Chapter 1 for further details of signal processing in Digisonde-4D). Sample content of the .CEQ files is given in **Table 3-12**.

Table 3-12: Sample CCEQ Data File

```
DIGISONDE CHANNEL EQUALIZING DATA
Version: 0
Time of measurement: 2006.08.15 (227) 20:53:59
 FREQ   A1/A2 Ph1-Ph2   A1/A3 Ph1-Ph3   A1/A4 Ph1-Ph4
  500   .9886    -.31   .9664   -1.27   .9248    1.45
  550   .9673    1.17   .9351     .08   .9043    2.82
  600   .9706    1.48   .9378     .47   .8974    3.31
  650   .9556    1.28   .9357    -.77   .8995    1.70
  700   .9612     .38   .9520   -1.23   .9107     .80
  750   .9494     .09   .9315    -.58   .8959    1.13
  800   .9724    -.75   .9628   -1.57   .9336    -.95
  850   .9599    -.68   .9427    -.42   .9199    -.70
  900   .9506   -2.03   .9252   -1.66   .9026   -2.09
  950   .9522   -2.54   .9283   -2.33   .9071   -3.18
 1000   .9761   -2.81   .9542   -2.80   .9332   -3.91
 1050   .9803   -1.28   .9612    -.78   .9360   -2.05
```

3:132. CCEQ data are shown in the “Channel Equalizing” tab of DCART main display area using the standard 4-channel panel display shown in **Figure 3-34** and **Figure 3-35**.

Calibration of Tracking Filters

3:133. Tuning of the voltage-sensitive varicaps in the tracking filters of Digisonde-4D requires a calibration algorithm that finds the optimal control voltages for a predefine set of operating frequencies (see **Figure 3-50** and **Table 3-13**).

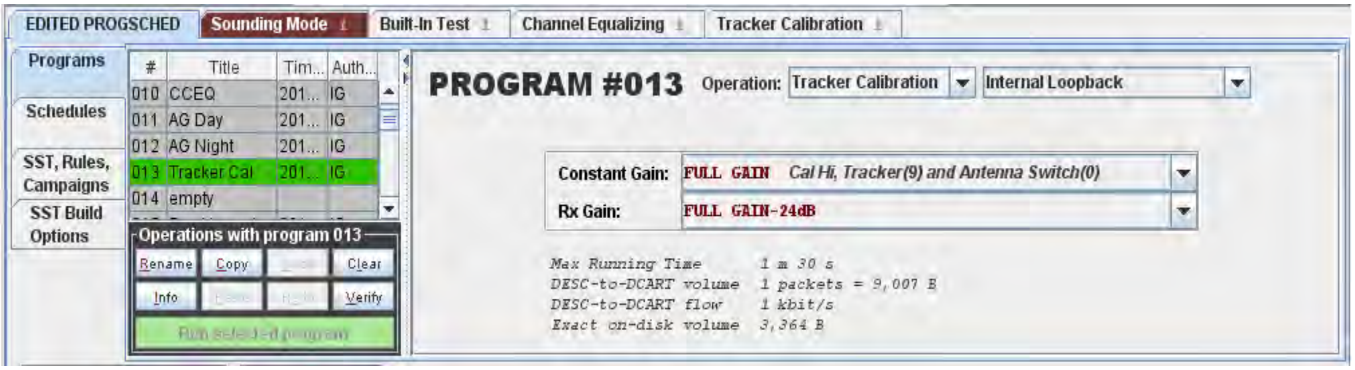


Figure 3-50: Tracker Calibration Program

Table 3-13. Tracker Calibration Frequencies

#	Filter Band	Frequency range, MHz	Frequency Stepping
0	Low-Pass	Below 0.5	none
1	Band 1	0.5 – 1.2	5 kHz
2	Band 2	1.2 – 2.92	10 kHz
3	Band 3	2.92 – 7.02	25 kHz
4	Band 4	7.02 – 15.67	50 kHz
5	Band 5	15.67 – 32 MHz	100 kHz
6	High-Pass	Above 32 MHz	none

3:134. Tracking filter calibration results are stored in TRACKER.DAT file in binary format, and can be exported from the Tracker Calibration visualization tab into a plane text file.

DATA PRODUCTION MODES

3:135. It is possible to instruct Digisonde-4D to temporarily disable production of outgoing data files while design of the optimal measurement programs and schedules is underway. Click “Save Product Files” toggle button to NONE to disable file generation (see **Figure 3-49**).

3:136. It is also possible to alter the way DCART saves raw data in local files for every measurement made by sounder. Click “Save Raw Files” toggle button (see **Figure 3-49**) to modify raw file generation:

- Raw Data = NONE (no raw data are saved),
- Raw Data = PER PROGRAM (raw data are saved for those programs that have the option enabled),
- Raw Data = ALL (raw data are saved for every measurement made).

CHAPTER 5

HOMEPAGE AND DATA DISSEMINATION

INTRODUCTION

3:137. The sounder operates a WWW server that allow remote computer platforms to connect for data visualization and monitoring of the system health status. **Figure 4-17** shows the sounder's web homepage with access to the available visualization features.

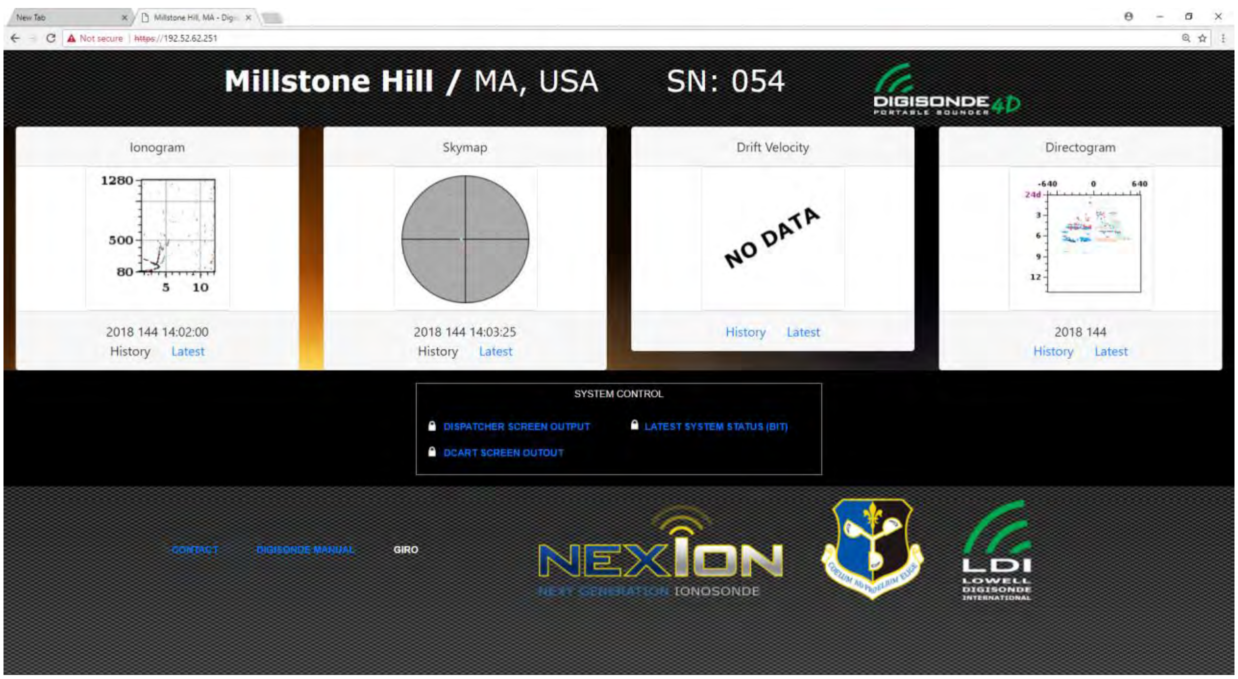


Figure 3-51: Digisonde® Homepage

3:138. The sounder homepage provides several publicly accessible "latest data" displays that automatically refresh remote screens with new data. There are also several interactive browsing pages that allow access to the images in the short-term archive at the sounder that holds recently made data (up to one month or more). Standard reports of the system health status, as well as screen capture from the DCART and Dispatcher programs are available on the sounder homepage, but access requires authentication with username and password.

3:139. The Dispatcher utility of the Digisonde-4D is responsible for all post-analysis of data product files generated by DCART, and delivery of the source and derived products over the Internet to remote servers using

FTP or SFTP. None of Dispatcher operations involve user interaction, and data delivery options are changed by editing of the configuration files on DATA platform.

3:140. FTP or SFTP deliveries of data files to multiple destination servers are organized by buffering of the file copies that need to be delivered in the outgoing folders /digisonde/buffers/*folderName* , where *folderName* is a descriptor for the server(for example: “FTP1” or “Lowell”). When delivery of a file to the destination server is successful, the file is deleted from the buffer folder.

3:141. FTP/SFTP deliveries are initiated (a) as soon as current measurement is completed and data products are available, and (b) periodically in between measurements to attempt resending the files that previously could not be delivered.

3:142. **Table 3-14** lists the configuration files and their relevant sections that are involved in FTP/SFTP deliveries.

Table 3-14. Configuration files Involved in FTP/SFTP Data Deliveries

#	File	Configuration item	Comments
1	Dispatcher.ini	Data Delivery Destination	Each destination configured for delivery should start with a [Data Delivery Destination] block
		DataDeliveryDestinationDir	Folder name within /digisonde/buffers where outgoing files and login credentials for that delivery are stored
		DeliverAsis	List of standard file extensions for delivery without compression
		DeliverCompressed	List of standard file extensions for delivery of compressed files
		CompressedFilename	File naming convention of the compressed file
		SaoxmlFileSuffix	Selection of either _SAO.XML or .SAO.XML file name for SAO files
		RemoteDir	Folder at the destination server to change to
		MinuteSelection	Deliver files made on the given minutes of the hour
		FTProtocol	Selects either FTP or SFTP
		FTPImplementation	Either Built in or External
		ExtCallLineTemplate	Specified command line for external utility if “External” is selected in FTPImplementation
		FileTransferExtention	Specifies temporary extension to be used during file transfer
		AcceptHost	Will accept host public key automatically if set to true
		DelayDeliverySecureFiles	1 – delay delivery of data until they are released into public domain
2	connect.ini	Host	IP or domain name of the destination server
		Port	Connection port
		User	Username to use for this connection
		Password	Password to use for this connection

CHAPTER 6

REMOTE ACCESS

INTRODUCTION

3:143. Accessing the Digisonde-4D sounder from remote locations is certainly convenient to avoid physical presence at the Digisonde® observatory to perform commanding, configuration, software updating, and certain system diagnostic and troubleshooting tasks. Use of the commercial remote access tools is one possibility whose degree of success depends on the bandwidth and reliability of the communications line to the sounder, as well as computer security considerations. Use of the low-level file transfer mechanisms for remote access is certainly less convenient but still a powerful way to control the sounder from afar.

REMOTE ACCESS USING REMOTE DESKTOP SOFTWARE

3:144. There are many remote desktop solutions available on the current market and selection of an appropriate solution may vary on circumstance and network requirements. It is important to select a remote desktop solution that makes use of the current user session instead of creating a new session for a different user as that could cause termination of LDI's digisonde software or create an addition instance of that software. A remote desktop solution will be provided by LDI for the equipment which can be replaced by the customer if desired.

REMOTE ACCESS USING FTP/SFTP CONNECTION TO DIGISONDE®

3:145. In order for the DATA platform to accept message files from remote commanding consoles over the Internet, there are two common software solutions:

- A standard secure shell server that includes SFTP server is commonly provided and does not require a high speed connection to operate.

NOTE

It is important to upload message files with added .TMP extension and rename them to the intended filename when the upload is completed, so that DCART or Dispatcher do not operate on the file while it's transfer is still in progress.

Commanding DESC Operations

3:146. Limited commanding of the CONTROL platform is available via uploading COMMAND.REM file containing one line of text with the following possible contents:

- REBOOT DESC -- reboot CONTROL platform
- STOP DESC -- send STOP command to DESC
- GO TO DIAG -- send Switch to Diagnostic mode command
- SOFT STOP -- equivalent to GO TO DIAG
- GO TO AUTO -- send "Switch to Automatic mode" command

You can enclose commands in angle brackets, so any text outside the angle brackets will be ignored.

Updates to PROGSCHED

3:147. Contents of the active PROGSCHED at the sounder can be updated by uploading the [edited] PROGSCHED file to the DCART incoming folder /digisonde/dpsmain/aux2dps as DCD.REM or PROGSCHD.REM.

3:148. DCART first checks your PROGSCHED file for correctness, and does not update the active PROGSCHED if it finds any error. When updating the active PROGSCHED, DCART will not interrupt the currently running program. Instead, DCART waits until the running program completes then replaces the active PROGSCHED with your PROGSCHED, and switches back to Automatic mode.

3:149. The message "System Progsched has been changed through file channel interface" is written into the logfile, if the operation finishes successfully. Otherwise the appropriate error message is written into the logfile, which shows the PROGSCHED error in details.

NOTE

Development of new programs, schedules, and SST planning rules shall always start with downloading currently active PROGSCHED from the sounder site. Active PROGSCHED file resides in /digisonde/dispatch/Control folder as file progsched.

Uploads of the edited PROGSCHED files shall not be done by overwriting the active PROGSCHED file in /digisonde/dispatch/Control folder. Instead, upload PROGSCHED to /digisonde/dpsmain/aux2dps and rename it to DCD.REM.

Control of Dispatcher

3:150. Simple remote control of Dispatcher operations is provided by uploading remote request files (.REQ) to incoming folder /digisonde/secure/incoming. It is possible to:

- Restart DATA platform by placing RESET.REQ file with single line containing digit 2,
- Re-read Dispatcher configuration file DISPATCH.UDD by placing an empty NEW_SETTINGS.REQ file.

Upload of Campaign Requests

3:151. DCART supports standard remote campaign requests (RCR) files generated by the ADRES request subsystem of the DIDBase. RCR files have two or more lines of plain text as described in **Table 3-16**.

Table 3-15 Contents of Remote Campaign Request File

Line #	Contents	Format	Comments
1	Version descriptor	VNN, where NN is version number	Folder for buffering outgoing files
2	Campaign Start timestamp	yyyy.mm.dd hh:mm:ss,	Three items, comma separated
	Campaign Stop timestamp	yyyy.mm.dd hh:mm:ss,	
	Schedule Number	I3	
3	Same contents and format as Line #2		Additional lines may be used to specify more than one campaign request

3:152. Remote campaign request (RCR) files must use the following naming convention:

UUUUU_YYYYDDDHHMMSS.RCR

where UUUUU is URSI code of the Digisonde® station and YYYYDDDHHMMSS is campaign start date and time. RCR files are placed in the remote-command-incoming folder of DCART, usually configured to be /digisonde/dpsmain/aux2dps.

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SECTION 4
HARDWARE DESCRIPTION

SECTION CONTENTS

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CHAPTER 1

HARDWARE OVERVIEW

SYSTEM DESCRIPTION

4:1. The system configuration is shown in Figure 4-1, with the layout of the Main and Power Chassis major components shown in Figure 4-2 and Figure 4-3. Figure 4-4 and Figure 4-5 show the front and the rear views of the sounder.

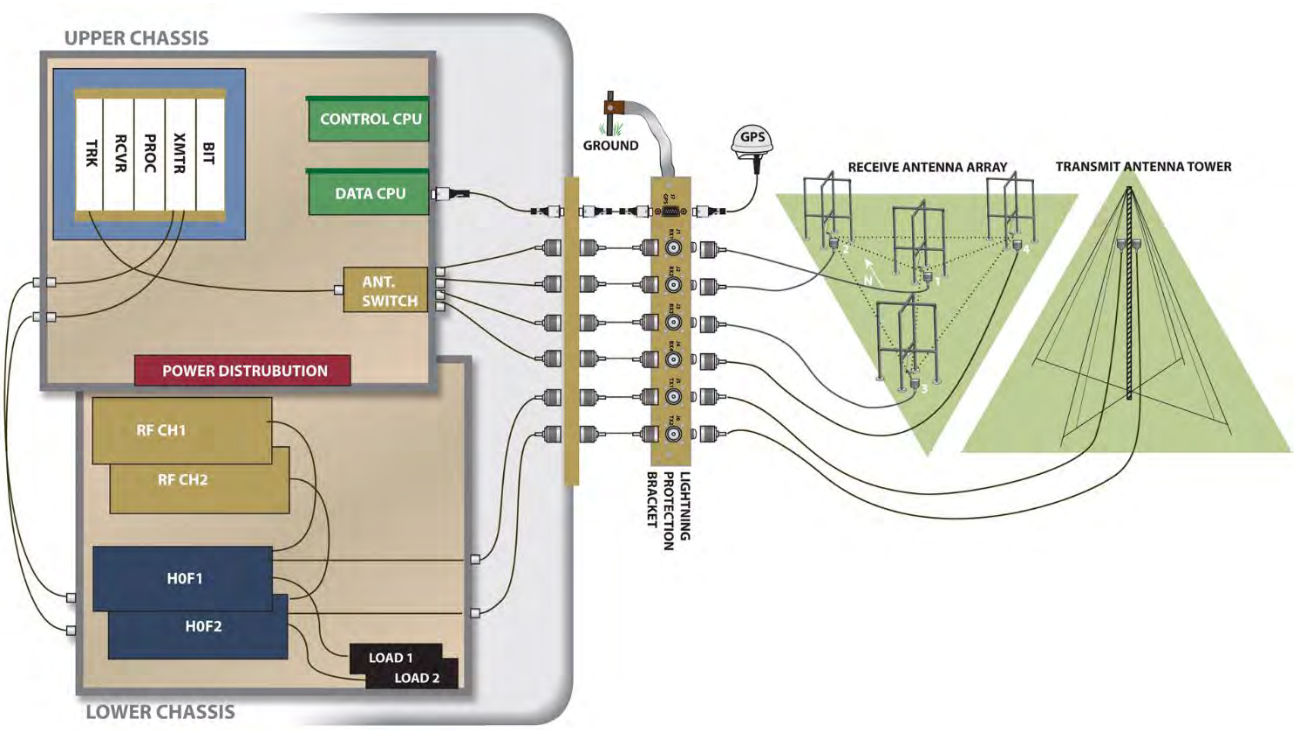


Figure 4-1: Block Diagram of Digisonde-4D

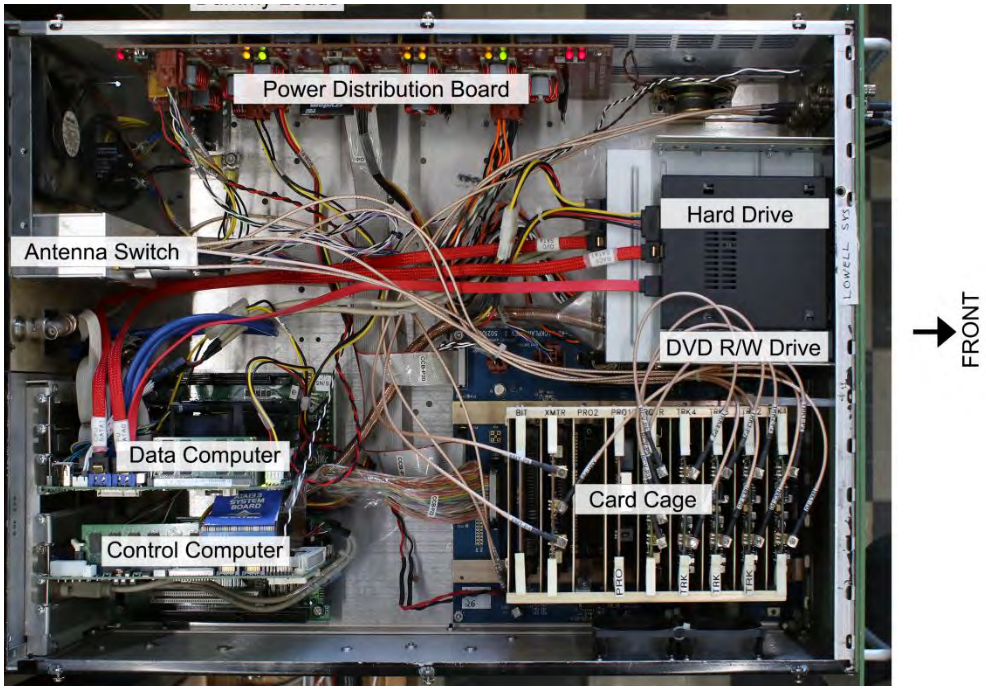


Figure 4-2: Main Chassis of the Digisonde-4D

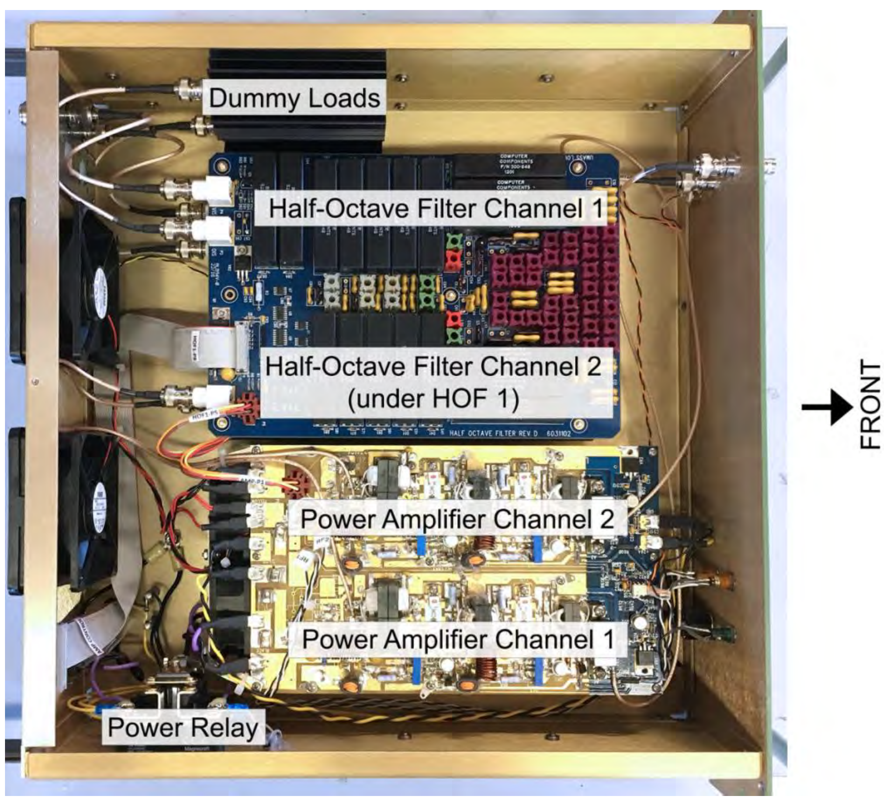


Figure 4-3: Power Amplifier Chassis of the Digisonde-4D

Figure 4-4: Digisonde-4D Front View

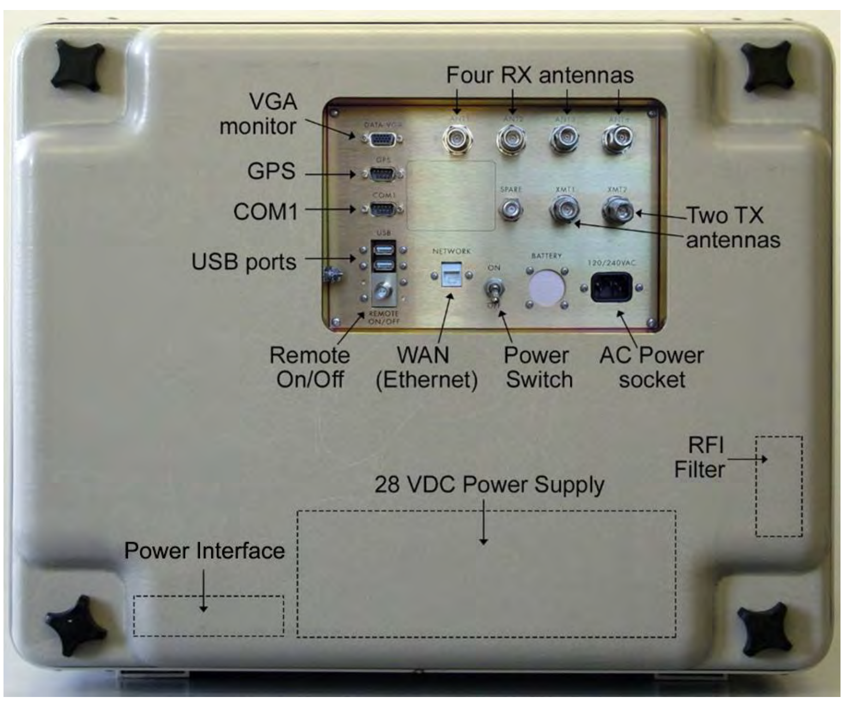


Figure 4-5: Digisonde-4D Rear View

4:2. The major sub-assemblies of Digisonde-4D include:

a. Oven controlled 61.44 MHz frequency source (the Master Oscillator).

b. Card cage with analog and digital cards for signal generation and reception.

   i. Digital Transmitter/Timing card

   ii. Four Tracking Bandpass Filter cards (trackers)

   iii. Digital Receiver card

   iv. Pre-Processor card

   v. Built In Test (BIT) card

   vi. Backplane

c. Data Platform Computer embedded PCE-4129 single board computer with passive backplane. Computer sub-system components are:

   a. Intel Xeon E3

   b. 32 DB DDR4 RAM

   c. Intel C236 Chipset

   d. 4 x SATA 3.0 ports

   e. 7 x USB 2.0 and 3x USB 3.0 ports

   f. LAN 1: Intel I219LM

   g. LAN 2: Intel 1210AT

   h. 2 x RS-232 ports

   i. 4 x RS-422/485 via LPC connector and daughter card

d. Control Platform Computer- embedded HS- single board computers with passive PISA back-planes. Computer sub-system components are:

   i. Intel Pentium Core2 Duo processor

   ii. (Up to) 2 GB DDR2 667 MHz RAM

   iii. Intel 945GM Graphic Controller

   iv. 2 x Intel 82573L Gigabit Ethernet Controllers

   v. 2 x Serial ATA Interfaces

   vi. 1 x ATA Controller

   vii. 1 RS232 port

   viii. 1 RS232/RS422 port

   ix. 4 USB 2.0 ports

   x. 1 Mini PCI Socket

   xi. Compact Flash Type II Socket

xii. ISA and PCI Interface via backplane

e. The Power Distribution board converts the 24 to 28 V DC primary power to the +15, –15, +12, +5, +3.3, and –5 volts needed by various components in the system. The RF power amplifier circuitry can utilize the 24 to 28 V DC directly.

f. Two x 150 W solid state RF power amplifiers operating over a range of 1 MHz to 30 MHz.

g. Electronically switchable right or left hand circularly polarized active receiving antennas, powered and controlled by the Antenna Switch.

4:3. The Digisonde-4D hardware has been designed not only to replace the analog RF circuitry with their digital counterparts, but also to rework configuration of the embedded computers and corresponding data interfaces. As new powerful embedded computers and fast interface solutions have become available, it is now feasible to capture the complete set of raw data for processing in the computer by implementing data processing functions in software.

4:4. All relevant computations in the Digisonde-4D are managed by two embedded computer platforms. The Control Platform provides low-level hardware control and data acquisition functions and the Data Platform processes the raw sample data. Processing in the Data Platform is done independently of the time-deterministic processes involved in controlling the measurements, thus permitting cleaner structuring of the real-time operations and their implementation as separate, well defined tasks under management of the RTOS.

CHAPTER 2

PROPRIETARY CIRCUIT BOARDS

DIGITAL TRANSMITTER CARD

4:5. The transmitter specifications are given in Table 4-1.

Table 4-1: Transmitter Specifications

Function	Value	Note
Output frequency	0.1 MHz to 30 MHz	Programmable, 32-bit precision
Output voltage in transmission mode	0.5 V_{p-p} to 1.5 V_{p-p}	
Output voltage in inter-channel calibration	45 mV_{p-p} or 1 V_{p-p}	
Size	4" ½ X 5"	
Control interface	Parallel Port	EPP mode, 3.3 V
Supply voltages	+/- 5, +/- 15, +3.3 V	

Functional Description

4:6. **Figure 4-5** shows the functional block diagram of the Digital Transmitter. Like its predecessor the DPS4, the DPS4D uses two transmitter channels to form left or right-hand polarized signals by driving two orthogonal antennas. The transmitter design features two digital up-converters AD9857 by Analog Devices that can be independently programmed to have + or -90° of inter-channel phase difference (or 0º if linear polarization is required).

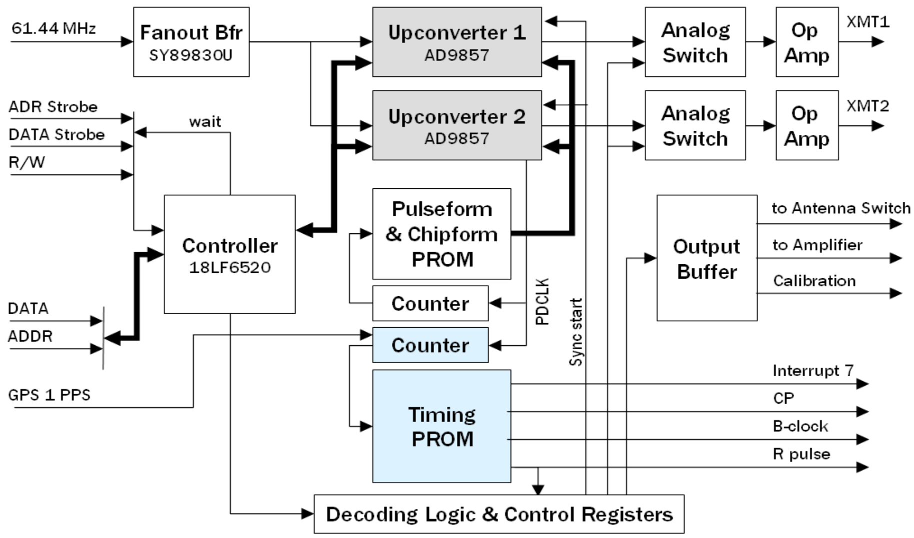


Figure 4-5: Digital Transmitter Block Diagram

4:7. Both upconverters produce RF phase-coded pulses at the selected operating frequency using 16-chip Golay complementary codes. Onboard flash memory stores 16-chip code 1 and 2 sequences, as well as a 66 µs uncoded waveform, 64-chip, and 128-chip complimentary codes. The 64-chip and 128-chip complimentary coded waveforms are designed for oblique operation only. A sinusoidal chip shape is provided for DPS4D transmission (see **Figure 4-6**). Changing the chip waveform shape from square-wave to sinusoidal results in a narrower transmission bandwidth. Initial measurements show that at 40dB below the main signal the sinusoidal waveform chip is 4 times narrower than its square-wave equivalent. Cleaner transmission comes at the expense of reduced transmitter power associated with the sinusoidal chip form, which was compensated by additional processing of the received signal.

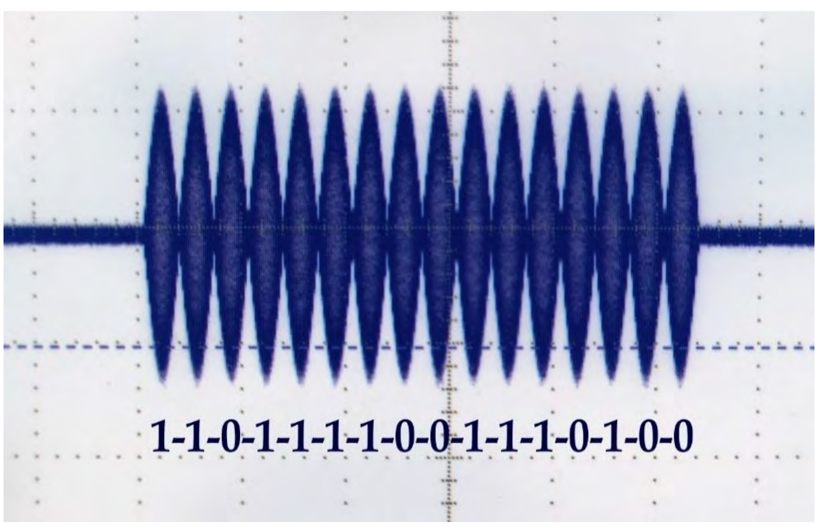


Figure 4-6: Phase-Modulated 16-Chip Code Sequence with the Sinusoidal Shape of the Chips Achieves Narrower Transmission Bandwidth

4:8. The phase modulation data are stored as *I* (real) and *Q* (imaginary) samples that determine the amplitude and phase of the up-converter output. *I* and *Q* data are read from the flash memory using a 1920 KHz PDCLK strobe produced by one of the up-converters to transfer 60 kHz digital receiver data to the Pre-Processor in nibbles. The PDCLK strobe clocks a counter that consecutively pre-fetches the modulation data from the memory, so that they become available to the transmitter by the next PDCLK.

Transmitter and Receiver Synchronization

4:9. In order to sustain phase coherence of the digital up-converters and down-converters whose built-in frequency synthesizers are independent of each other, we synchronize them by the same 61.44 MHz clock provided as the LVDS (Low Voltage Differential Signal) from the master oscillator located on the card cage backplane. We also provide a synchronous start signal, called the reference or R-pulse and make sure that all up- and down-converters lock their phases to the R-pulse with high precision and minimum latency.

4:10. The transmitter board hosts a Timing memory that provides R-pulses, together with other synchronization signals, including the hardware interrupt to the Control Platform. The Timing memory holds 1 sec of DPS4D life time, synchronized to the external GPS 1-sec pulse. Both memories of the transmitter board are controlled by the same PDCLK. When the up-converters detect the R-pulse, they immediately clear the phase to zero. Resetting of the phase in AD9857 requires temporary setting of the operating frequency to zero, which is accomplished by momentarily switching the internal on-chip profile to a special profile with zero frequency.

4:11. To get the correct system time the sounder uses an external GPS receiver usually mounted on the roof of the building the DPS is installed in. The DPS4D communicates with GPS through RS-422 port on the data computer board. The GPS is powered using +12V constant voltage from the data computer. There is a surge protector device between the GPS and the DPS4D mounted on the lightning suppression bracket.

4:12. Exact synchronization occurs at the front pulse edge of the one pulse per second signal from GPS. The GPS generates one pulse per second to synchronize all internal time-critical circuits. It is connected to transmitter card timing logic through the inverting buffer on the card. There is a pull-up resistor on the transmitter card making positive idle voltage if GPS is disconnected from the system. That allows the system run without the GPS.

Transmitter Control

4:13. The DPS4D implements a new approach to the task of embedding control functions in hardware by using a combination of microcontrollers and programmable logic devices (PLDs). Though reliable microcontroller-based systems require a substantial initial investment in time and effort to put together, they accept future modifications at a low overhead, which comes as a benefit to evolving projects. We are particularly interested in engineering of the multiple-channel transceiver systems where sequential commanding of each channel in the transmitter and receiver appears inefficient. Microcontrollers relieve the Control Platform from repetitive transfers of the frequency commands over the control bus.

4:14. Our choice of the “P-Bus” for the system control bus still stands after three decades of Digisonde® development. The parallel port protocol remains a simple, commonly available solution in computers that, in its enhanced EPP mode, admits bi-directional operation and reaches adequate transfer speeds of 2 Mbit/s. For the transmitter board, we use the PIC18LF6520 microcontroller by MicroChip with two PLDs ATF1504ASV by Atmel. It takes about 2 µs for the PIC18LF6520 to accept one byte over the P-Bus, well below the P-bus timeout of 10 µs. To ensure deterministic synchronism of bus operations, the microcontroller is clocked with a 15.36 MHz signal derived from the master 61.44 MHz clock.

The AD9857 up-converters use the serial command interface, thus assigning the first task to the micro-controller to translate the parallel bytes from the system control bus to a serial 8-bit sequence. Direct routing of the incoming control bytes to the transmitter is done in so-called “pass-through” mode of micro-controller operations.

Transmitter Output Modes

4:15. Phase-aware multiple-channel RF instrumentation requires an additional design effort to have cross-channel differences in transfer functions calibrated out. In addition to the standard mode of transmitter operation when the output from the up-converters is routed to the RF power amplifiers, an internal loopback mode is available to support cross-channel equalizing (CEQ) operations. In the internal loopback mode, a small calibration signal is routed to the antenna switch, instead of the RF power amplifiers, for direct input to the receiver channels. Transmission modes are realized by using switches within the antenna switch that ensure signals are present on either two main outputs or CEQ output.

Transmitter Card

4:16. **Figure 4-7** shows the transmitter card in its four-channel version (presently only two channels are used in the DPS4D with the currently available software).

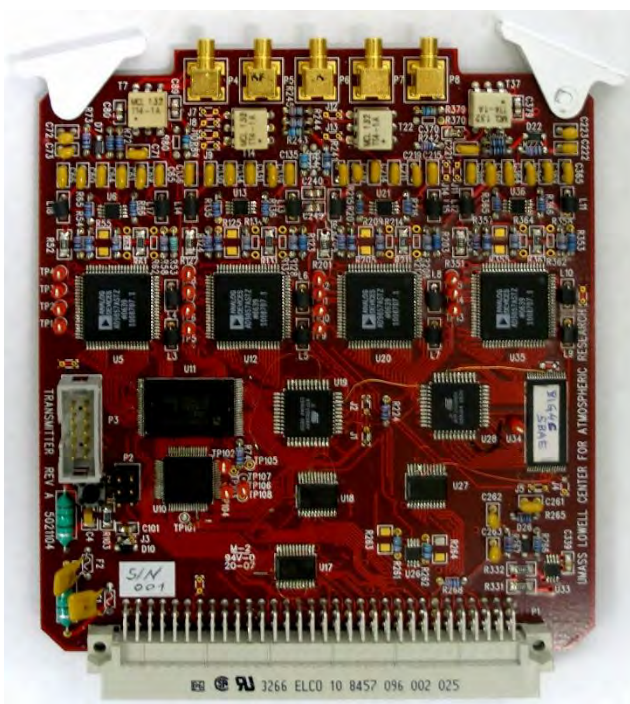


Figure 4-7: Transmitter PCB

DIGITAL RECEIVER

4:17. The receiver design considers operation in noisy RF environments where strong interferers could saturate the receiver inputs rendering the receivers insensitive to smaller message signals. For ionospheric sounding, AM radio stations in the 0.55-1.65 MHz band and the 6-24 MHz HF communications bands can pose serious problems for ground-based receivers. At some locations we have measured interference levels of >1 V signals at the receive antennas compared to <1 μV message signals. Digital receivers that directly digitize RF signals are especially prone to this problem since ADCs have a limited dynamic range.

4:18. The ADCs need to be protected from powerful out-of-band interference as well as from saturating in-band signals. In the DPS4D, a combination of gain controls in the wideband input amplifiers and the analog tracking bandpass filters limit the input voltages at the ADCs to the maximum allowed values.

Gain Control Prior to Digitization

4:19. The tracking bandpass filters feed the RF signals to the ADCs via variable-gain amplifiers (**Figure 4-8**) that are digitally controlled in eight steps of 6 dB from -12 to +30 dB. Additional gain adjustments of 9 dB in the antenna switch and 9 dB in the Tracking Bandpass Filter are available. Total dynamic range of the gain adjustments prior to digitization then reaches 42+18 = 60 dB. Including the 96 dB dynamic range of the 16-bit ADC, the receivers can accommodate input signals varying over a range of 156 dB.

4:20. Amplifications in the Antenna Switch and the Tracking Filters (**Figure 4-1**) are time-controlled to accommodate diurnal changes in HF spectrum occupancy and ionospheric absorption. The variable-gain amplifiers (**Figure 4-8**) are controlled on a per-frequency basis using a combination of the local under/over voltage (UOV) sensor and external commanding from the Control Platform. The UOV sensor monitors the three most significant bits at the 60-Msps ADC output and determines one of the three possible states, *S* = saturation, *L* = under-voltage, or *N* = no change needed. The UOV state is cleared immediately after the trailing edge of transmitter pulse and reported to the Control Platform prior to the next pulse. The Control Platform software makes appropriate 6 dB gain corrections if the S or L state is observed. Effectively, the automatic gain control ensures that the ADC input peak voltage remains below 1 V, that is, 6 dB below its saturation level of 2 V.

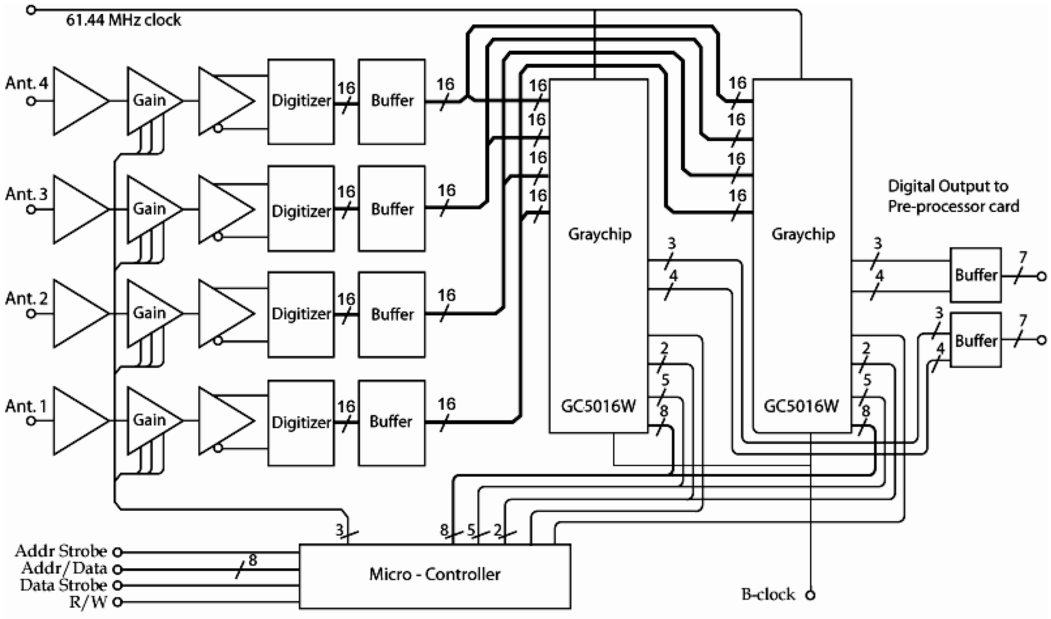


Figure 4-8: Digital Receiver Block Diagram
(Only One of the Graychips is Used for Current Operation)

4:21. A table of automatic gain selections for each of the operating frequencies is stored at the Control Platform and continuously updated with each run of the gain evaluation programs that cover frequencies from 0.1 to 30 MHz with 600 50 kHz steps. This table holds the gain settings for each frequency that will be used in the next ionogram sounding.

Digital Receivers with TI Graychip

4:22. The Digital Receiver is designed around the Texas Instrument Graychip GC5016 (**Figure 4-8**) which has four independent digital synthesizers and four 16-bit digital inputs. **Figure 4-9** shows the functional block diagram for one channel of the GC5016 chip configured as a digital down-converter.

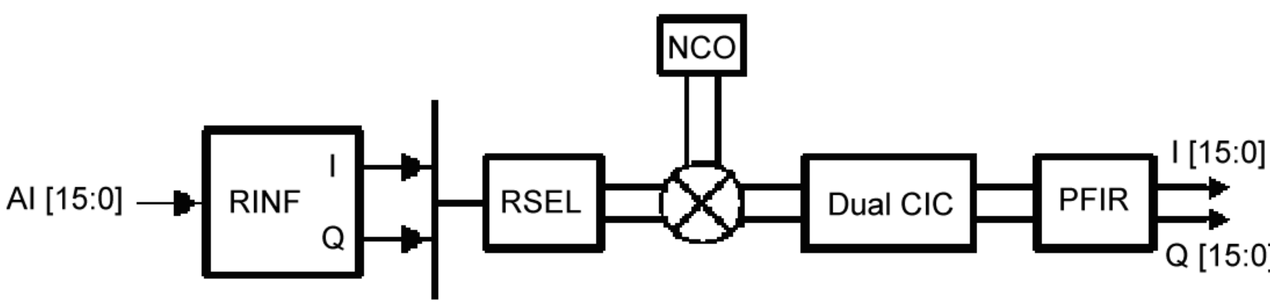


Figure 4-9: Block Diagram of a Single Channel of the GC5016 Chip
(RINF is receive input formatter, RSEL is receive input channel selector, NCO denotes digital oscillator, CIC is cascade integrator comb filter, and PFIR is programmable finite impulse response filter.)

4:23. The input data on port A[15..0] are converted to a complex input format (I and Q samples) in the receive input formatter (RINF). In this common configuration, each down-conversion channel demodulates the sampled data down to the baseband, then performs a low-pass filter operation, reduces the signal rate (decimation), and outputs I and Q baseband data. The mixer stage provides the receive input channel selector (RSEL), digital oscillator (NCO), and complex mixing logic (mixer) to translate the input data down to the baseband. After the mixer, the 5-stage cascade integrator comb (CIC) is used for filtering and decimation. After the CIC complex filter, the programmable finite impulse response (PFIR) filter provides CIC correction, spectral shaping, and further decimation.

4:24. A microcontroller (**Figure 4-8**) provides the bi-directional interface between the Control Platform and the receiver to arrange automatic gain control and appropriate frequency selection. The transmitter-generated B-Clock clears the receiver phases to zero in order to synchronize its operation with the transmitter.

Digital Receiver Board

4:25. **Figure 4-10** shows the front side of the Digital Receiver card. The four coaxial connectors on top of the card feed four input signals to the receiver circuits. The digital output signals are fed through the 96-pin DIN connector to the Preprocessor card. Each of the four inputs to the receiver card is transformer coupled to a low-noise push-pull amplifier AD8008. The amplifier outputs are transformer coupled to the digitally controlled variable gain amplifier (CLC5526), followed by a symmetric driver (THS4503) of the 16-bit ADC (LTC2205) (**Figure 4-8**). The ADCs feed two GC 5016 Graychips (total of 8 receiving channels). Eight receiving channels are provided in this design for possible future expansion to twin frequency transmission.

Figure 4-10: Digital receiver PCB

TRACKING BANDPASS FILTERS

4:26. Analog bandpass filters at the receiver front end efficiently suppress the out-of-band interference since the filters are synchronously tracking the transmitter frequency. **Figure 4-11** shows the block diagram of the Tracking Bandpass Filter. The input transformer splits the entire frequency range into five bands with switch points at 1.2, 2.9, 6.5, and 15.9 MHz, plus one low-pass filter for $f < 0.5$ MHz and one high-pass filter for $f > 32$ MHz (for future applications). The main filtering in each band is achieved with serial circuits in the input that are tuned with voltage-sensitive varicaps. For the high frequency band ($f \geq 16$ MHz), an additional tuned parallel circuit at the output (top of **Figure 4-11**) further attenuates all signals with frequencies different from the tuning frequency.

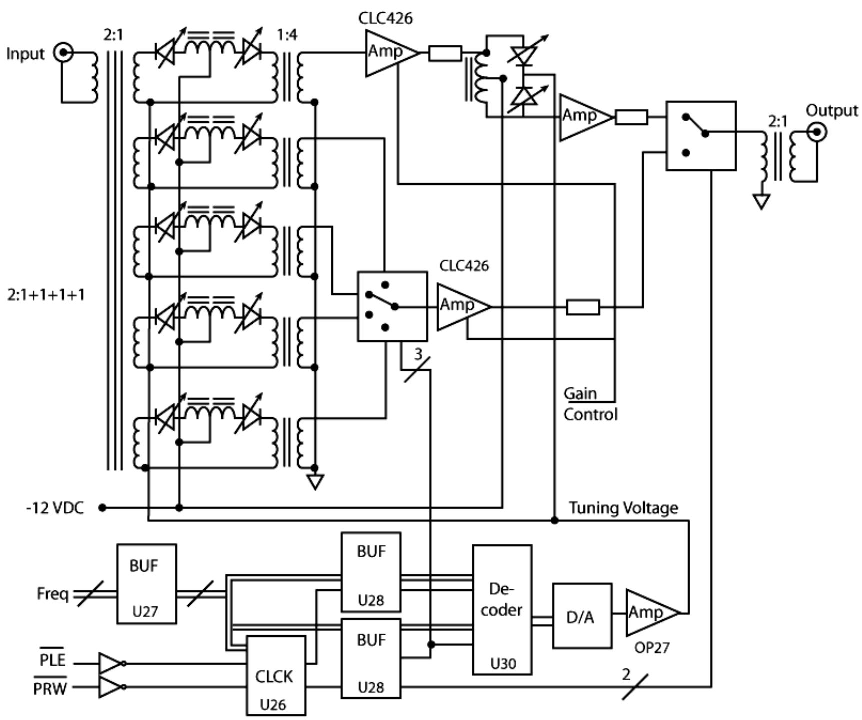


Figure 4-11: Tracking Bandpass Filters Suppress Out-of-Band Interferers

4:27. The bandwidth of a serial filter is $\Delta f_s = R_s / 2\pi L_s$, where R_s and L_s are the serial resistance and inductance of the tuned circuit, respectively. Using varicaps for the tuning keeps L_s constant, i.e., Δf_s is constant in each band. The L_s values for each band were selected so as to make the relative bandwidth for each band ~10%. To make Δf_s sufficiently small requires R_s to be small, which is accomplished by a step-down at the input and a step-up at the output of the serial filters. The bandwidth of a parallel resonance circuit, Δf_p, is proportional to $1/C_p$, and therefore increases with f^2 since $1/C_p = L_p (2\pi f)^2$. **Figure 4-12** shows one of the four Tracking Bandpass Filter PCBs.

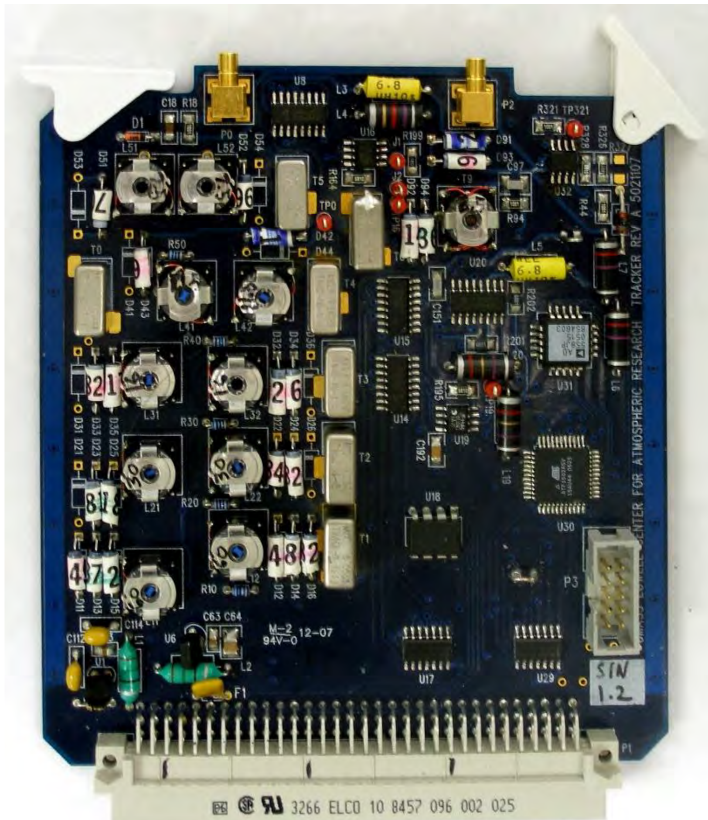


Figure 4-12: Tracking Bandpass Filter PCB

PREPROCESSOR CARD

4:28. The Preprocessor card has been developed for the DPS4D as a part of our strategic use of dedicated digital signal processing (DSP) hardware to build low-power, light-weight instrumentation. The pre-processor performs all data formatting, routing, buffering, and output function selections, along with Radio Frequency Interference Mitigation (RFIM) processing.

Functional Description

4:29. **Figure 4-13** shows the block diagram of the Preprocessor card assuming twin frequency operation. The gray blocks represent functions that are implemented inside FPGA. Since the Graychips each output 16-bit samples as a sequence of four 4-bit nibbles, the first Preprocessor operation assembles the nibbles into 16-bit words. Next, the two simultaneous receiver sample streams are interleaved with receiver 1 samples followed by receiver 2 samples. Then the interleaved samples are written to memory 1 sorted by receiver/antenna. At the end of the first sample record, the Preprocessor switches to copying mode and simply copies memory 1 into memory 2. After the copy, the Preprocessor switches back to sampling mode. During the next sampling interval, the second sample record is stored in memory 1 while the previous sample record is read from memory 2 to the control computer

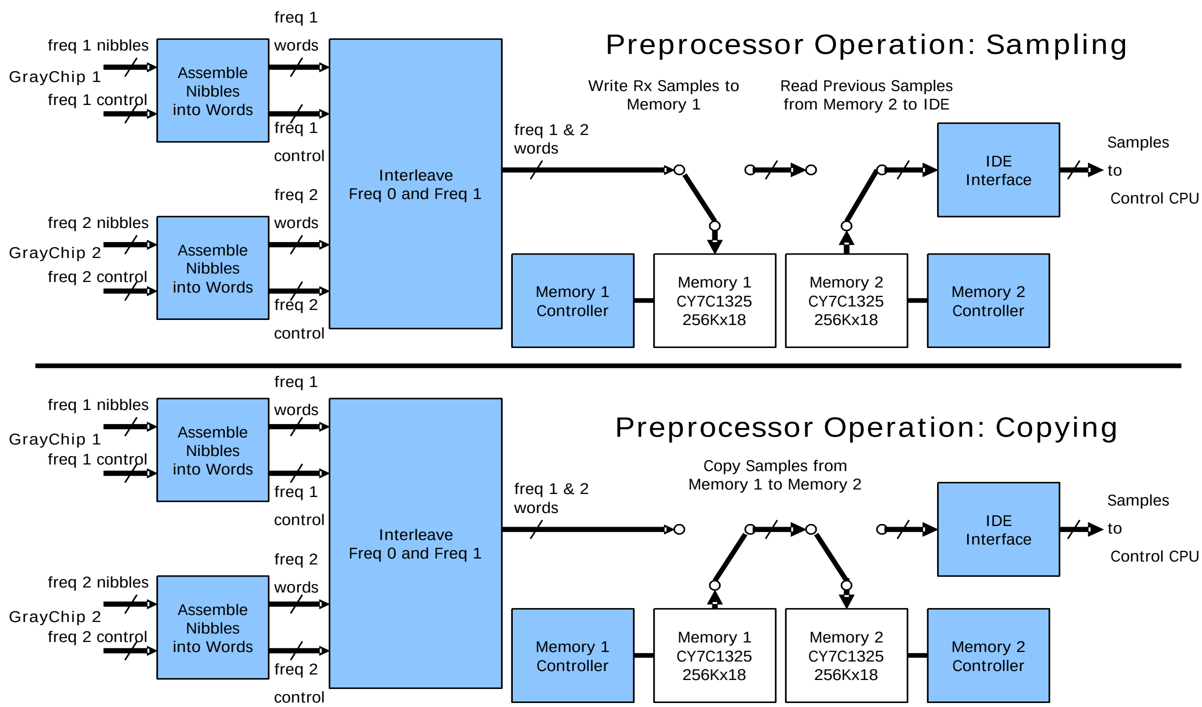


Figure 4-13: Preprocessor Card Block Diagram and Operations

4:30. The purpose of the two memory chips is to provide double-buffering of the samples obtained from the Graychips. As the samples are stored in memory 1, they are sorted by antenna.

Data Interface to Control Platform

4:31. A suitable PCI data acquisition board could be added to the Control Platform to arrange data delivery from the Preprocessor card. However, we found the ATA standard, i.e., the IDE interface for hard disk drives and CD-ROMs, to be adequate for the task of interfacing the Preprocessor to the Control Platform. The IDE controller in the Control Platform recognizes the Preprocessor card as a hard disk. Read operations are done by addressing an appropriate head (antenna) and sector (block of 128 ranges).

4:32. All necessary protocol support for direct memory access (DMA) to Control Platform memory has been provided in the Preprocessor's FPGA. In this way, the load of the Control Platform is reduced and the data transfer speed significantly increased. In fact, preprocessor transfers are much faster in comparison with the several milliseconds typical for an actual hard disk drive. The DMA protocol is arranged appropriately, with the interrupts raised by the DMA controller of the preprocessor card once the DMA transfer is done.

Preprocessor Board

4:33. **Figure 4-14** shows the Preprocessor PCB. Most of the logic on the Preprocessor card is implement-ed in the Altera Stratix EP1S25F780 FPGA. The EP1S25F780 FPGA has 500,000 equivalent gates, 2 M-bits of on-chip RAM, and 597 I/O pins. In addition to the FPGA, the card has two Cypress Semiconductor CY7C1325 256K x 18 synchronous SRAM memories. Data nibbles from the Graychips arrive via the 96-pin DIN connector. Properly formatted output samples are sent to the same connector that supports all signals of the standard IDE interface in DMA mode.

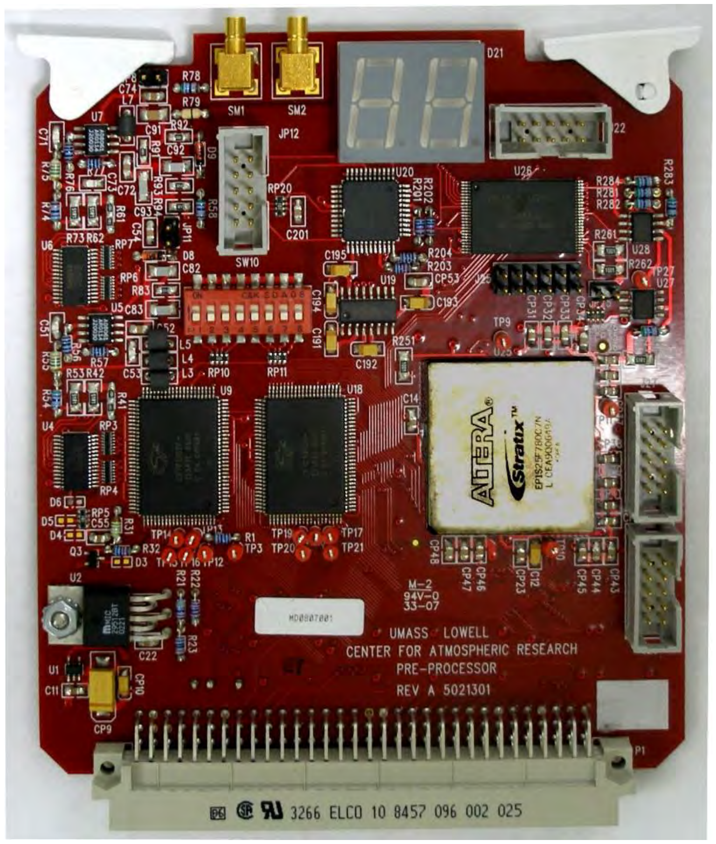


Figure 4-14: Preprocessor PCB

BUILT-IN TEST CARD

4:34. The Built-in Test (BIT) operation is a diagnostic mode of the DPS4D used to determine the system state of health. The BIT operation reads data from sensors incorporated in the hardware as shown in **Figure 4-15**. The Control Platform commands the BIT card to collect sensor signals in the multiple operating configurations of the DPS4D so as to evaluate collected information for determination regarding the status of both directly and indirectly sensed Digisonde® components. Further description of BIT function is provided in Section 6.

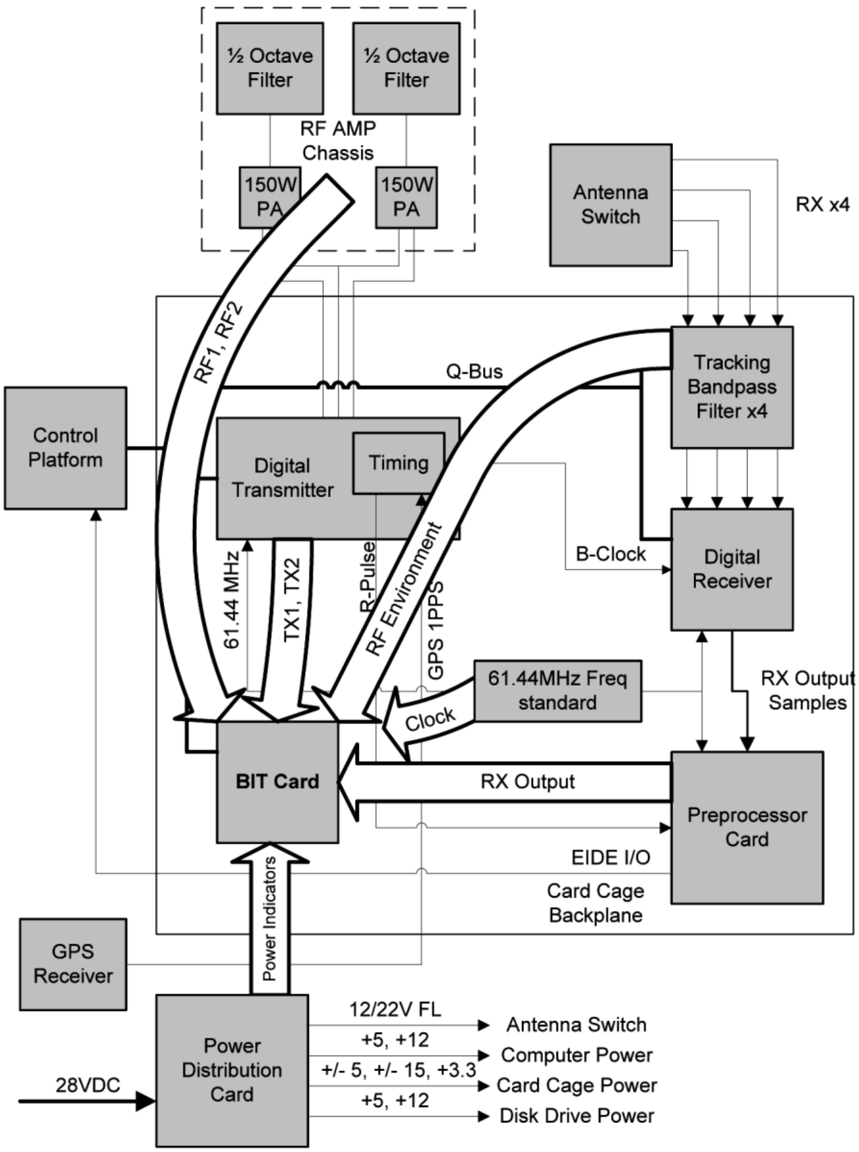


Figure 4-15: General Diagram of BIT Signal Sampling

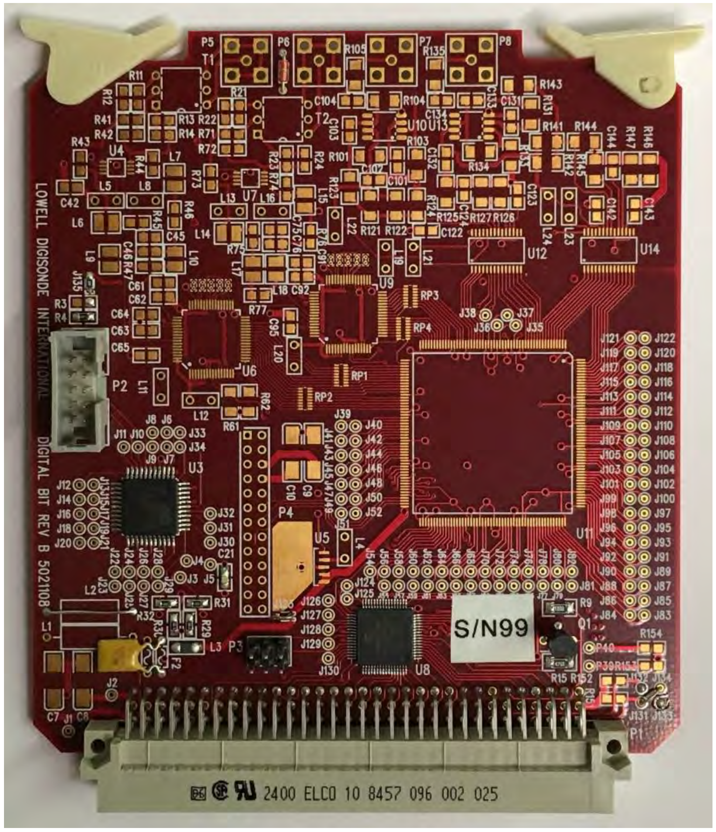


Figure 4-16: BIT Card

ANTENNA SWITCH

4:35. Four identical input stages (Inputs #1 through #4) receive signals from each of four receive antennas. The block diagram is shown in **Figure 4-17**. The RF coaxial cables coming in from the antenna field are routed through lightning suppressers to isolate the chassis from current surges (induced by lightning or power faults). Also, the DC voltage to power the receive antenna pre-amplifiers is applied to these cables: +16.5 V or +22.5 V switched voltage (O/X) is applied to the center conductor (+16.5 V signals the pre-amplifier to use left-hand circular polarization while the 22.5 V indicates right-hand polarization). O/X voltage enters from the Power Distribution Card through J1.5. T1, T2, T3 and T4 match the 50 Ω signal from the coaxial cables to input impedances of U1, U2, U3, and U4. Protection diodes (not shown) limit saturation from the transmitter pulse. A_0, A_1, A_2, HIGH, LOW, and G5 control the antenna switch gain and channel enabling / disabling.

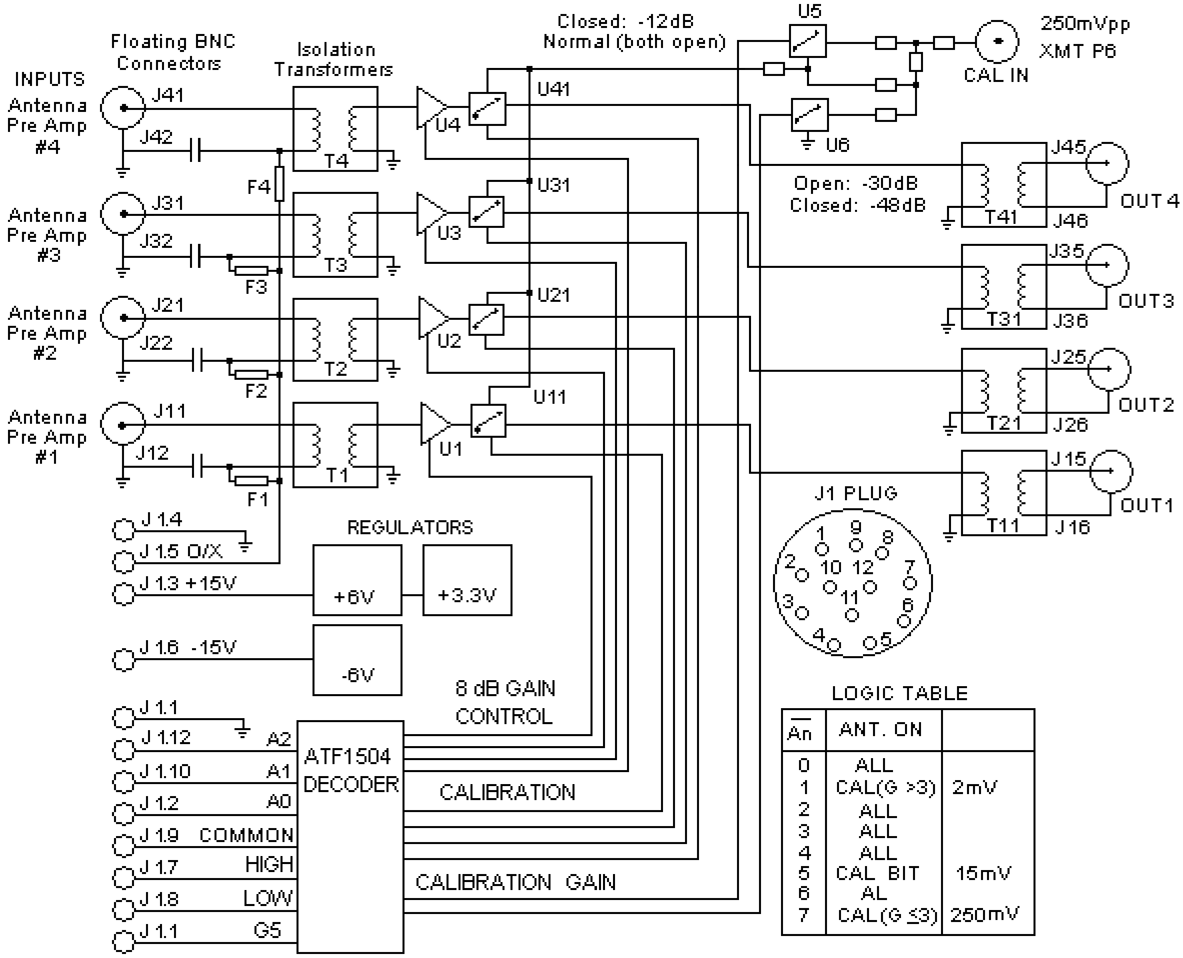


Figure 4-17: Antenna Switch Block Diagram

4:36. The input comes via short wires from BNC connectors mounted on the rear of the Antenna Switch's RF shielded enclosure. The four inputs are fed through transformers T1-T4, then through op amps U1-U4 into analog switches U11, U21, U31, and U41. The second input to the switches is a calibration signal generated on the Transmitter Card. The choice of switching between the antenna inputs and calibration signal is software controlled by the CAL command on the J1 plug to the switchbox. The calibration signal level is dependent on the gain setting selected by the user in the DCART menu. The software configures switches U5 and U6 to attenuate the level. The four outputs of the antenna switch, either antenna signals or calibration signals, are fed out of the switchbox on SMB connectors, into the top of the (four) Tracker Card(s).

4:37. Every amplifier U1, U2, U3, U4 has a programmable gain control for signals from antennas using switches U11, U21, U31, U41 accordingly. The decoder can set two gains with 9 dB difference.

4:38. The decoder is based on flash memory and can be reprogrammed on-board using the 10-pin JTAG connector J3.

POLARIZATION SWITCH

4:39. With two channels, one for the North (N) – South (S) loop and another for the West (W) – East (E) loop, the Polarization Switch (**Figure 4-18**) allows the receiver to receive circularly polarized signals arriving from overhead (i.e., small zenith angles) and to change the desired sense of rotation of the polarization vector.

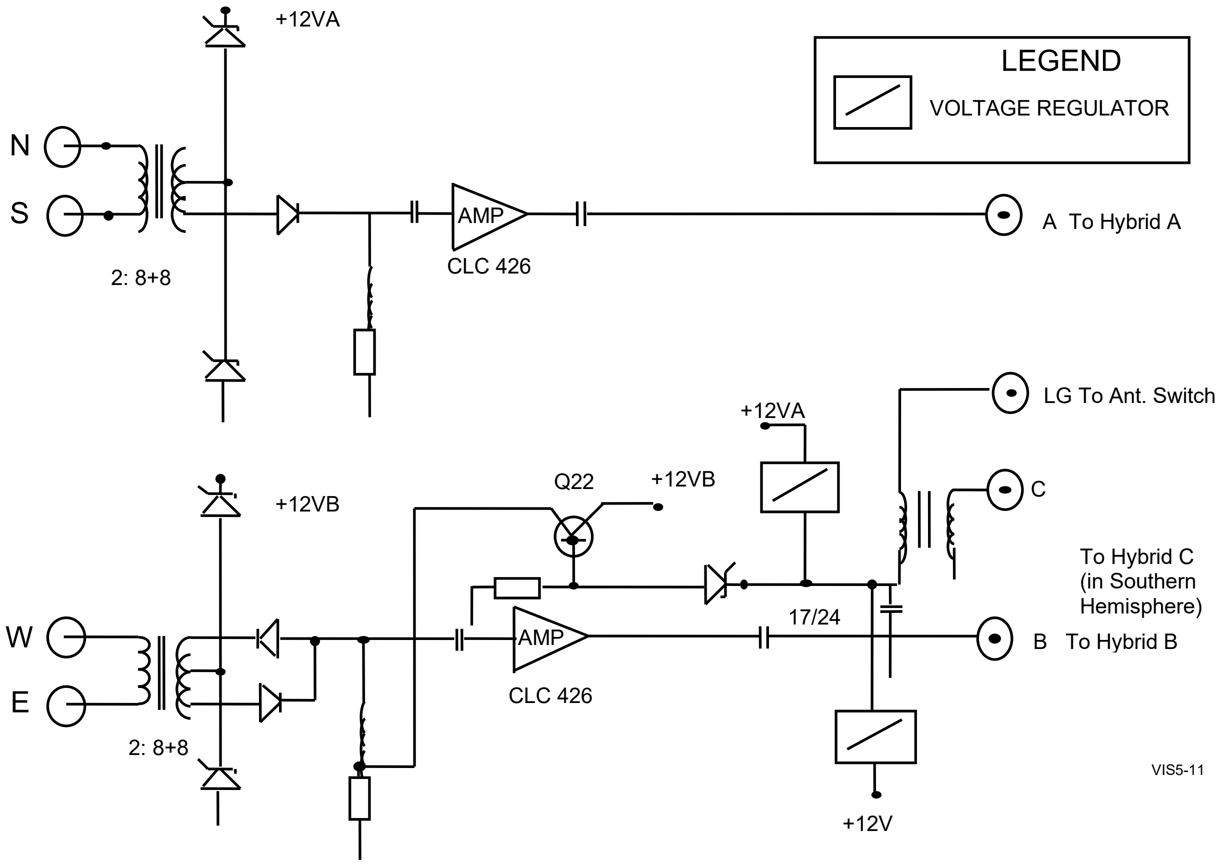


Figure 4-18: Polarization Switch Block Diagram

4:40. For that purpose a 90° phase shifter is attached to the two outputs of the low-noise amplifiers which are equal to within 1 dB in amplification for the whole frequency band used. Thus the two channels are almost equal in design although only the W–E channel is switched.

4:41. Polarization switching is accomplished by switching the DC power fed through the same cable that brings the RF signal to the Antenna Switch. Two voltage regulators make the voltage (12 VDC) applied to the amplifier independent of the supply power, which changes between 17 and 24 VDC. This change is sensed by a transistor, the base of which feeds this voltage to a Zener diode.

4:42. The transistor current or the current to ground make one of the two diodes conduct which connects one or the opposite output of the input transformer to the W–E amplifier. This 180° change in one of the two channels provides the polarization change of the turnstile loop antenna with the help of a 90° wideband hybrid adder.

4:43. For signals arriving from remote stations with larger than 45° zenith angles the suppression of unwanted polarization depends strongly on the orientation of the turnstile antennas. An optimum configuration would be for the loop planes to be ±45° off the direction toward the remote sounder.

POWER DISTRIBUTION CARD

4:44. Power distribution within the sounder chassis is centralized in the Power Distribution (PWR) Card (shown in **Figures 4-20** and **4-21**). Fusing (with self-resetting overload devices), voltage regulation and current limiting are applied as necessary. Along the top of the card are LED's to indicate the presence of various voltages. Red LED's indicate a positive voltage, green indicate negative voltages and amber indicate the 24 V – 28 V input power for all DC/DC converters. An auxiliary function of this card is to switch the voltage level of the power sent to the magnetic loop preamplifiers to switch received polarization sensitivity (left-hand and right-hand circular). The card also provides a mounting for the DC/DC converters and collects several BIT signals into connector P5 to output them to the BIT Card. **Figure 4-22** shows the overall power distribution within the sounder system.

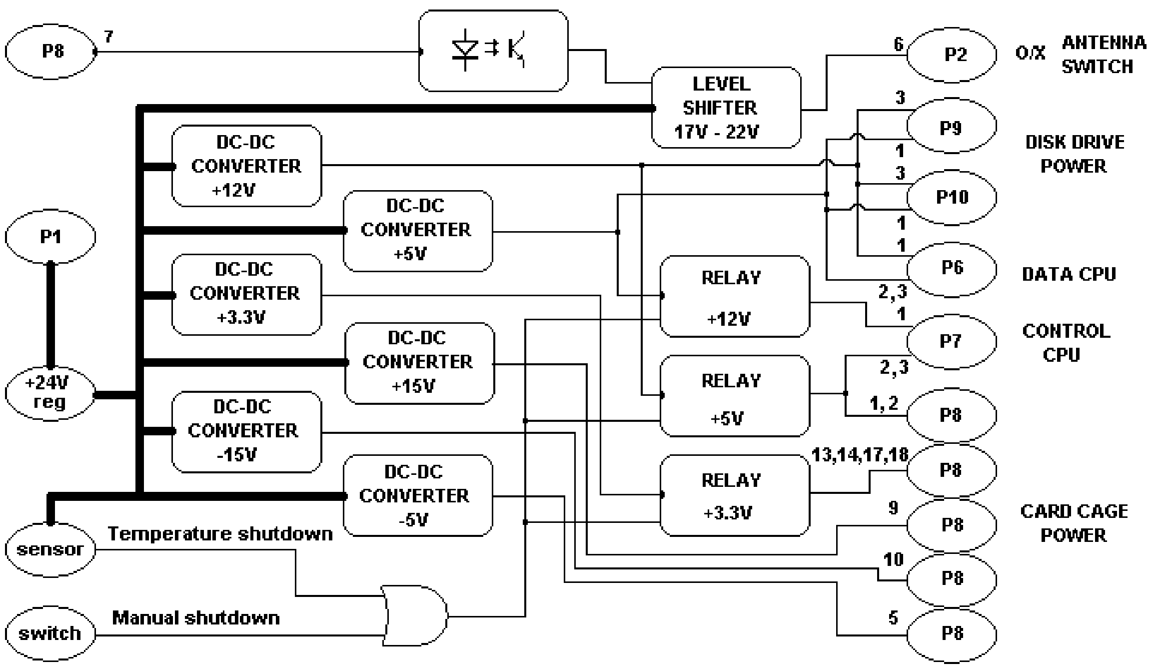


Figure 4-19: Power Distribution Card Block Diagram (System Power)

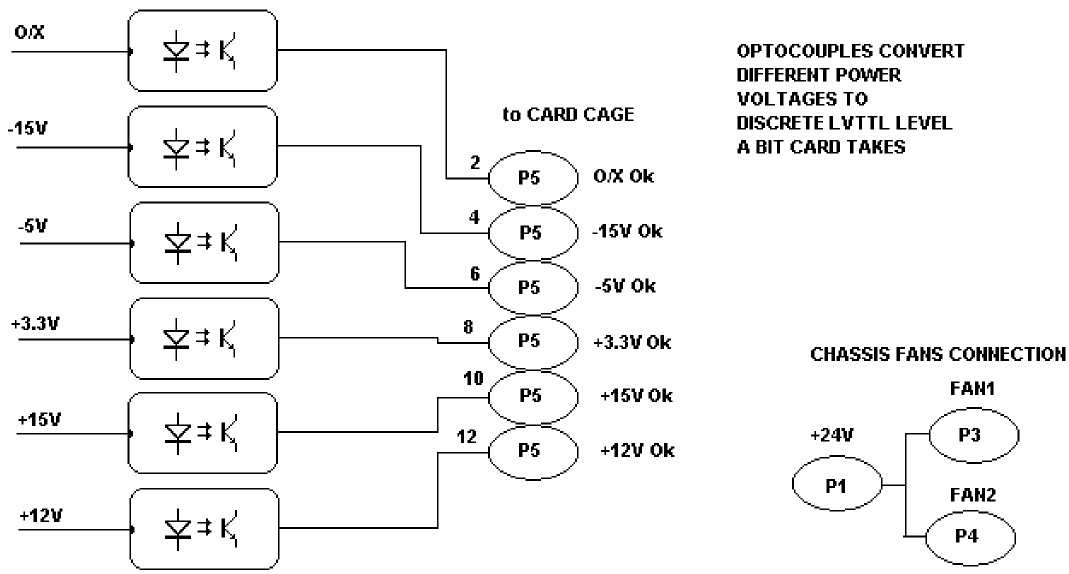


Figure 4-20: Power Distribution Card Block Diagram (BIT Card Interface)

POWER INTERFACE BOX

4:45. The functions of the power interface are to provide:

a) power connections to the VIS chassis, the RF Amp, and the cooling fans

b) remote switching on/off of all power via connection to J8/J9

c) a digital voltmeter to monitor the +28V power supply output.

d) In previous versions of the DPS4D the power interface served also as a battery interface and provided over voltage, under voltage, and over current protection. LDI can supply information about the older versions upon request.

4:46. Upon power up or opening the external connection between J8 and J9, the two parallel P-channel power MOSFETS (Q4 and Q5) are turned on, and current is provided to the RF Amp, VIS chassis, and cooling fans through the terminal strip connections on top of the Power Interface Box housing.

RF POWER AMPLIFIER CHASSIS

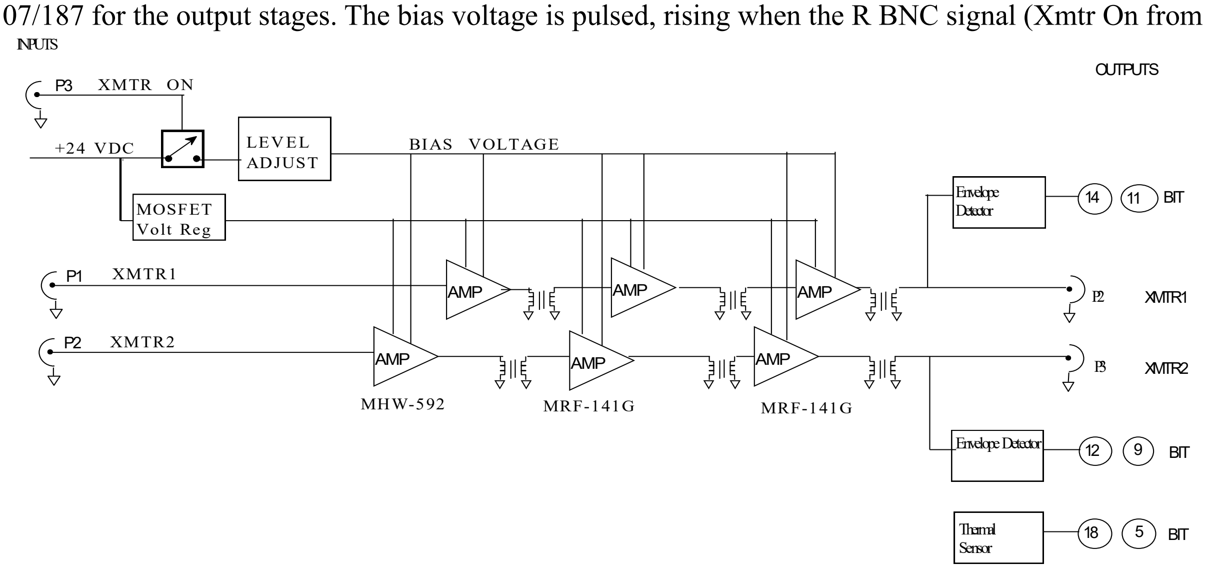
4:47. The RF Amplifier consists of the aluminum chassis drawer, a power relay (24V solenoid) for switching the (approx) +27.5V input from the power supply. The power relay is controlled by the front panel switch and by an FET on the RF Amp card which is commanded by input from the upper chassis via the RF Amp IO connector. The chassis also houses the dual channel RF Power Amplifier card, with two independent amplifiers both capable of 150W output, and the two Half-Octave Filter (HOF) cards. The chassis front panel green LED displays the presence of primary power to the cards, and the two amber LED's indicate the presence of transmitted power being output to the antennas from each of the two independent amplifiers located on the RF Amplifier card.

RF Amplifier Card

4:48. The RF Amplifier is comprised of two independent wideband amplifiers (referred to below as the two channels) consisting of three stages, two drivers and a final (see **Figure 4-23**). The input signal to each amplifier channel is 1.4Vp-p, falling off slightly at the higher frequencies. Each input stage (comprised of a Motorola hybrid module) amplifies 10mW up to 0.5W. The output of the second stage is 20W (40Vp-p across 22 ohms at the input to the final) and the output of the final stage is 150W. The entire 10 inch x 6 inch board is mounted to a 10 inch by 6 inch heat sink. The input voltage is the system's primary power of 25 to 28VDC. This input voltage is protected through a 8A fuse (not shown on the block diagram) at the input of the 25 to 28V DC to the board. The primary power is applied at the output end of the amp board where it feeds power, via the center tap on the primary of the 1:6 wideband transformers, to the 250Vpp output stages. It is also routed back off the board to a twisted pair which runs down the underside (the fin side) of the heatsink to feed power to the small signal end of the board. Keeping this twisted pair on the back side of the AMP heat sink reduces coupling between output RF and input power, thus reducing the danger of a positive feedback situation (i.e. oscillation).

Figure 4-21: RF AMP Block Diagram

4:49. The critical setting in the RF AMP is the bias voltage set by R67/147 for the input stages and R107/187 for the output stages. The bias voltage is pulsed, rising when the R BNC signal (Xmtr On from the



regulated front panel input from the upper chassis) rises. The R BNC, via U41 and Q52/53 also applies the regulated +18V to amplifiers A1 and A2. The turn-on voltage for various batches of MRF-141G MOSFET transistors varies widely, but the bias voltage needed to set an idle current of about 2A is usually in the range of 3-4V. When the negative swing of an input sine wave exceeds 1V below the bias level, the FET is in its non-linear cutoff range, thus causing harmonic distortion in the output signal. The input and feedback resistors linearize these amplifiers greatly since the gate voltage becomes a virtual ground (i.e. the signal should theoretically approach zero since the output is inverted compared to the input and is larger by the same ratio as the feedback resistance–to-input resistance).

4:50. The design of the wideband transformers is crucial. A transmission line transformer needs to be constructed with a transmission line which has an impedance which is the geometric mean of the input and output impedances. For instance, matching a MOSFET output impedance of 2 ohms (1.5 ohms augmented with the 0.5 ohm resistors) to a 50 ohm output impedance requires a 10 ohm transmission line.

Half-Octave Filter (HOF) Cards (2 per system):

4:51. In an effort to reduce transmission harmonics, the final output is passed through one of eight low-pass filters, depending on output frequency. The switch points are controlled by software in the /digisonde/dispatcher/stationspecific.udd file. The upper cutoff frequency in MHz for each band is given as:

1. 1.69
2. 2.45
3. 4.10
4. 5.55
5. 10.95
6. 16.15
7. 22.1
8. 42.0

4:52. The filter channel is selected by 3 digital bits F0-F2 from the upper chassis (originating in the XMT card, and fed through the 25-pin AMP IO connector) which activate reed relay switches which conduct the RF signal to the selected filter. Two more bits F3 & F4 command the two output switches (also RF reed relays), directing the power to one of two antennas. Nominally one antenna is oriented for vertical incidence (thus VIS) and the other is oriented for oblique incidence (thus OIS). In case of vertical only configuration, OIS output is connected to dummy load. Dummy load is a 50 Ohm resistor is used for built-in-test purposes. The LS138 logic ICs decode the F0-F2 bits and the high voltage (+18V is connected through the solenoid winding to the IC's output pin) open-collector non-inverting buffer (7407) provides the drive to pull down the relays of the appropriate filter channel (see **Figure 4-24**).

4:53. The power off command comes from BIT card and controls a large relay to connect power amplifier to lower chassis main power. If there is no BIT card at appropriate spot in upper chassis this relay is ON by default as lower chassis is powered.

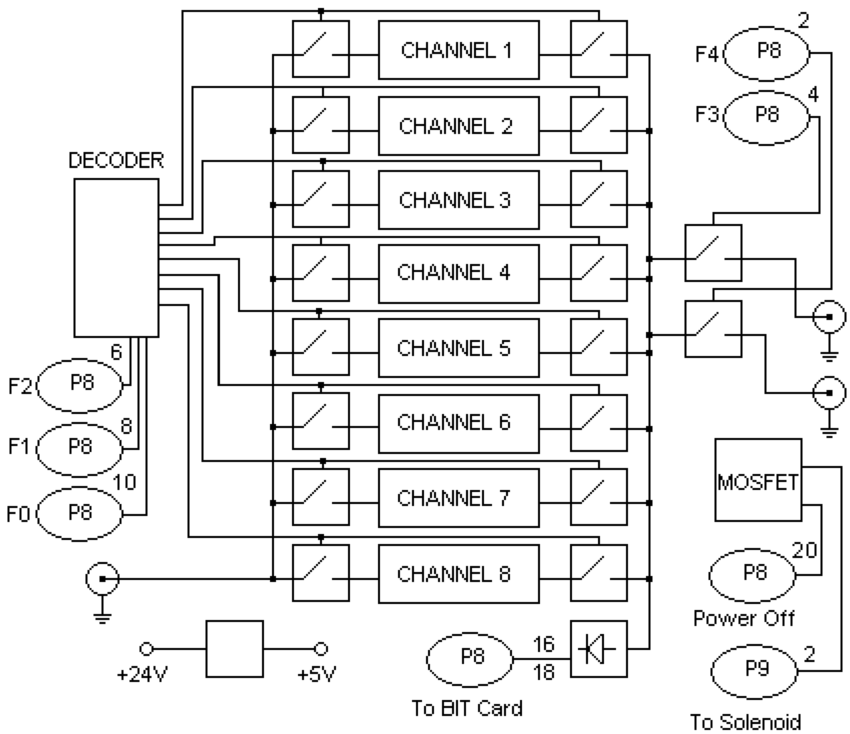


Figure 4-22: HALF OCTAVE FILTER (HOF) Block Diagram

CHAPTER 3

COMMERCIAL HARDWARE

CARDS AND ASSEMBLIES SUPPLIED FROM OTHER MANUFACTURERS

4:54. There are cards and assemblies provided by external manufacturers that are integrated into the Digisonde®. For simplicity, reference is directed to the applicable literature provided with each of these cards and assemblies. Copies of these documents are shipped with unit. For additional copies please contact:

Lowell Digisonde International, LLC
175 Cabot Street, Suite 200
Lowell, MA 01854, USA
Bodo.Reinisch@Digisonde.com or www.Digisonde.com

4:55. A listing of card assemblies and applicable commercial documentation is provided in **Table 4-2**.

Table 4-2: Listing of Commercial Peripheral Literature (TBR)

Board/Assembly Description	Manufacturer	Document Title
GPS Receiver	Trimble Navigation	Smart Antenna Developer's Guide, Acutis, Acutime, Acutime II, Acutime GG
Single Board Computer	Commell HS-872P	User Guide
DVD Drive	Industrial Computer Source	
Hard Disk	Industrial Computer Source	

CONFIGURING GPS FOR OPERATIONS WITH DIGISONDE-4D

4:56. There is a special utility loaded on the data computer to configure and control the GPS receiver. Before running the utility, one must stop the NTP time service. To stop the NTP time service run the following command "systemctl stop ntpd". Once the NTP service has been stopped the GPS receiver can be configured for use in a Digisonde-4D by running the following command
"/digisonde/miscellaneous/trimble/trimble_gps_query –dps4d"

Once the receiver has been configured restart the NTP service via "systemctl start ntpd".
The NTP service communicates with the GPS receiver to correct the system time on the data computer.

4:57. GPS is pre-configured to work with DPS4D. In case of troubleshooting or replacing of the receiver see GPS configuration instructions in **Table 4-3**.

Table 4-3: Configuring GPS Receiver

Configure GPS Settings

- Desktop / Utilities / NTP Time Server Monitor
  - Click "Stop NTP Service"
  - Minimize NTP Time Server Monitor Utility
- Desktop / Utilities / AcuGold_Mon

  Serial Port Selection: COM 2

  Are you using Acutime Gold with NTP monitoring? Yes
  - ☐ Setup / Packet Masks and Options…
    - Synchronous 8F-0B on Port A: Unchecked
    - Event 8F-0B on Port A: Checked
    - Synchronous 8F-0B on Port B: Unchecked
    - Event 8F-0B on Port B: Checked
    - Synchronous 8F-AD on Port A: Checked
    - Event 8F-AD on Port A: Checked
    - Synchronous 8F-AD on Port B: Checked
    - Event 8F-AD on Port B: Checked
    - Auto TSIP Outputs: Checked
    - 8F-20 on Port B: Checked
    - 8F-AB on Port A, Port B: Unchecked
    - 8F-AC on Port A, Port B: Unchecked
    - Output XYZ ECEF (Packet 83): Unchecked
    - Output LLA (Packet 84): Checked
    - LLA Output MSL geoid: Unchecked
    - LLA Input MSL geoid: Unchecked
    - Double-Precision: Checked
    - Output 8F-20: Unchecked
    - Output XYZ ECEF (Packet 43): Unchecked
    - Output ENU (Packet 56): Checked
    - Position fix time tags in UTC: Checked
    - Compute fix on integer second: Unchecked
    - Output fix on request only: Unchecked
    - Synchronize measurement: Unchecked
    - Minimize projections: Unchecked
    - Raw measurements (Packet 5A): Unchecked
    - Doppler smoothed codephase: Checked
    - Output signal level in dBc/Hz: Unchecked
    - (Click the appropriate "Set"s)
  - ☐ Setup / Timing Outputs…
    - Driver Switch: Enabled
    - Time Base: UTC
    - Polarity: Positive (but the 1PPS is negative going, because we are taking off the 1PPS minus [there are 2 1PPS out-

puts provided for in the GPS])

- PPS Offset: 0e+00
- Bias Uncertainty Threshold: 300.00
- Output Options: Always
- PPS Width: 1.000e-05
- (Click the appropriate "Set"s)

- Setup / Save Configuration Segments — OK and Exit
- NTP Time Server Monitor / Start NTP Service

Verify GPS and Cable

- ☐ **GPS can communicate with NTP service and set the computer time.**
  - Instructions: Go to NTP Time Server Monitor / NTP Status and ensure the "Reach" parameter is not zero and the line is not grey. If it is then attempt to set the computer time using the GPS manually through the AcuGold utility (File).
  - **Notes:**
- ☐ **GPS 1PPS is present and negative going, 10us.**
  - Notes:

SECTION 5
SYSTEM SOFTWARE

SECTION CONTENTS

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CHAPTER 1

SYSTEM SOFTWARE OVERVIEW

GENERAL DESCRIPTION

5:1. The purpose of the system software is to automatically operate the ionospheric sounder transceiver system to produce displays and product data files of real-time measurements, to report acquired data to remote data subscribers, provide public access to the local repositories of data, and to allow remote commanding and maintenance of the sounder.

5:2. The sounder contains two embedded computing platforms, CONTROL and DATA, running in parallel. Both computers load the software automatically on power-up and operate in the multitasking environment executing tasks of different priorities simultaneously. CONTROL platform operations are described in Chapter 2 of this Section. Chapter 3 details system software of the DATA platform.

CHOICE OF SOFTWARE VERSUS HARDWARE IMPLEMENTATIONS

5:3. Current choice of the Digisonde-4D digital signal processing (DSP) architecture balances both specialized and generic computing platforms. Development of specialized DSP hardware continues to be part of LDI's strategy to build low-power, light-weight, space-qualified radio sounding instrumentation. At the same time, for the ground-based applications that do not require radiation hardening, inexpensive small-format embedded computers present a feasible alternative to custom DSP hardware. Digisonde-4D system software reflects the existing balance between software and hardware DSP solutions. .

5:4. The Control Platform is an embedded computer that manages hard real-time tasks under control of the RTEMS operating system. The digital receivers are designed to appear to the Control Platform as an IDE hard disk drive whose contents can be read using a standard HDD driver. The Data Platform is another embedded PC that performs processing of the acquired sample data to create data products. The Data Platform runs a suite of processing algorithms ranging from pulse compression to ARTIST ionogram autoscaling and EDP calculation, and the derivation of ionospheric tilt angles from Doppler skymaps.

5:5. Software components in the signal processing pipeline are designed to accommodate real-time data stream of varying bandwidth, depending on the selection of measurement program parameters. All internal communications are protected with the packet queues that dynamically buffer data to wait for the destination component to become available. Online data visualization engine in DCART uses the mailbox mechanism to adaptively decimate data that are displayed in real-time.

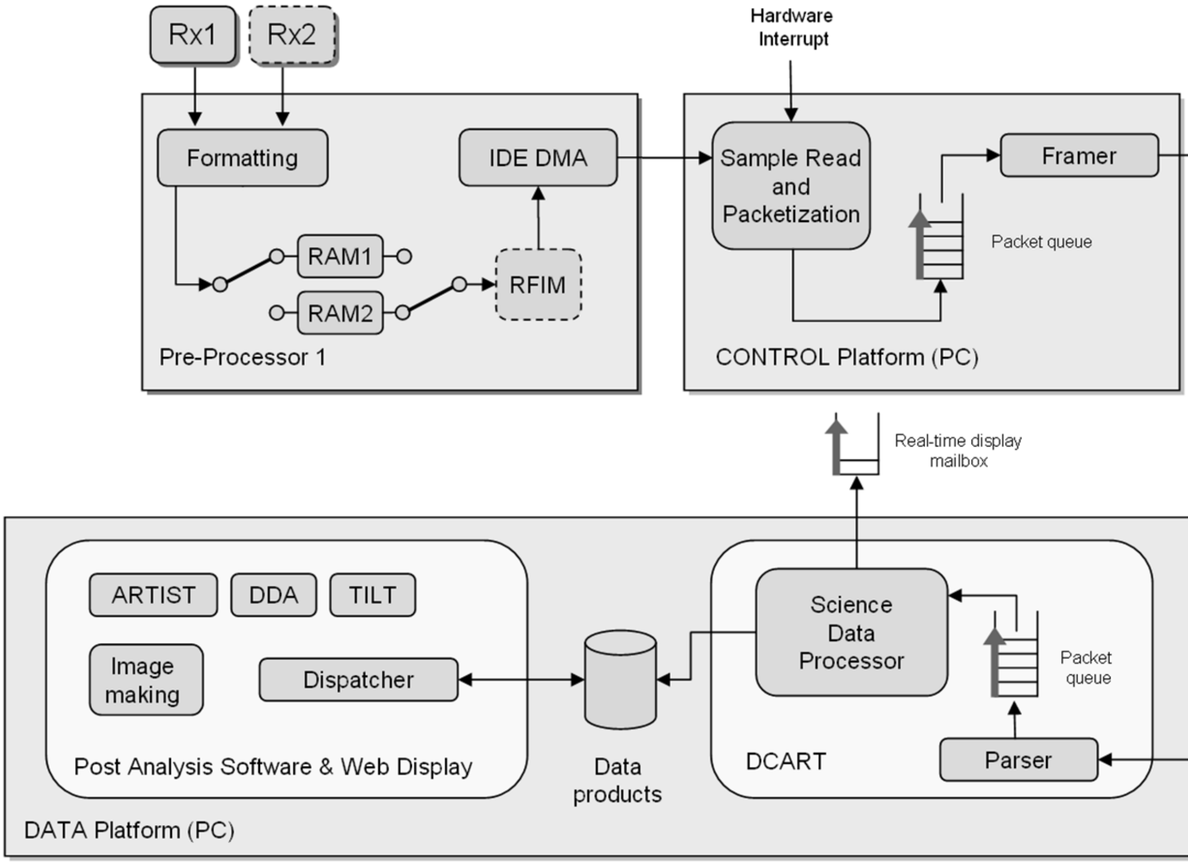

Figure 5-1: Digital Data Processing Architecture of the Digisonde-4D

CHAPTER 2

SYSTEM SOFTWARE OF CONTROL COMPUTER

INTRODUCTION

5:6. The Control Platform of Digisonde-4D sounder is responsible for:

- Measurement progression control in accordance with the program specification
- Hardware control
- Setting up transmission and reception in all measurement modes
- Initiation of hardware tasks
- Data Acquisition
- Collection of raw data during the measurements
- Collection of housekeeping data during BIT
- Packaging and delivery of the sample data to the Data Platform,
- Scheduling Digisonde® measurements
- Schedule progression control in accordance with the schedule specification
- Switching schedules at given times
- Synchronization to the GPS time reference
- Accepting configuration changes:
- Program and schedule definitions,
- Schedule start times,
- Restricted Frequency Interval Lists (RFIL),
- Digital receiver configuration,
- Tracking filter configurations.
- Switching operational states in response to commands

5:7. The Control Platform operating software, *Digisonde® Embedded System Control* (DESC), runs under the management of a Real-Time Operating System (RTOS) "RTEMS" that ensures time-deterministic execution of the software tasks.

DESC BLOCK DIAGRAM

5:8. Block diagram of DESC is shown in **Figure 5-2**. Red lines in the DESC diagram denote "hard" real-time events driven by the 1 PPS heartbeat signal from the GPS receiver, 5 ms interrupts produced by the Timing memory, and Data interrupt from Preprocessor card. These events are related to hardware control and acquisition operations that are precisely timed in the hardware by the Reference pulse (R pulse). The 5 ms interrupt occurs prior to the R pulse for software to setup hardware registers and arrange for transfer of available data from Preprocessor card.

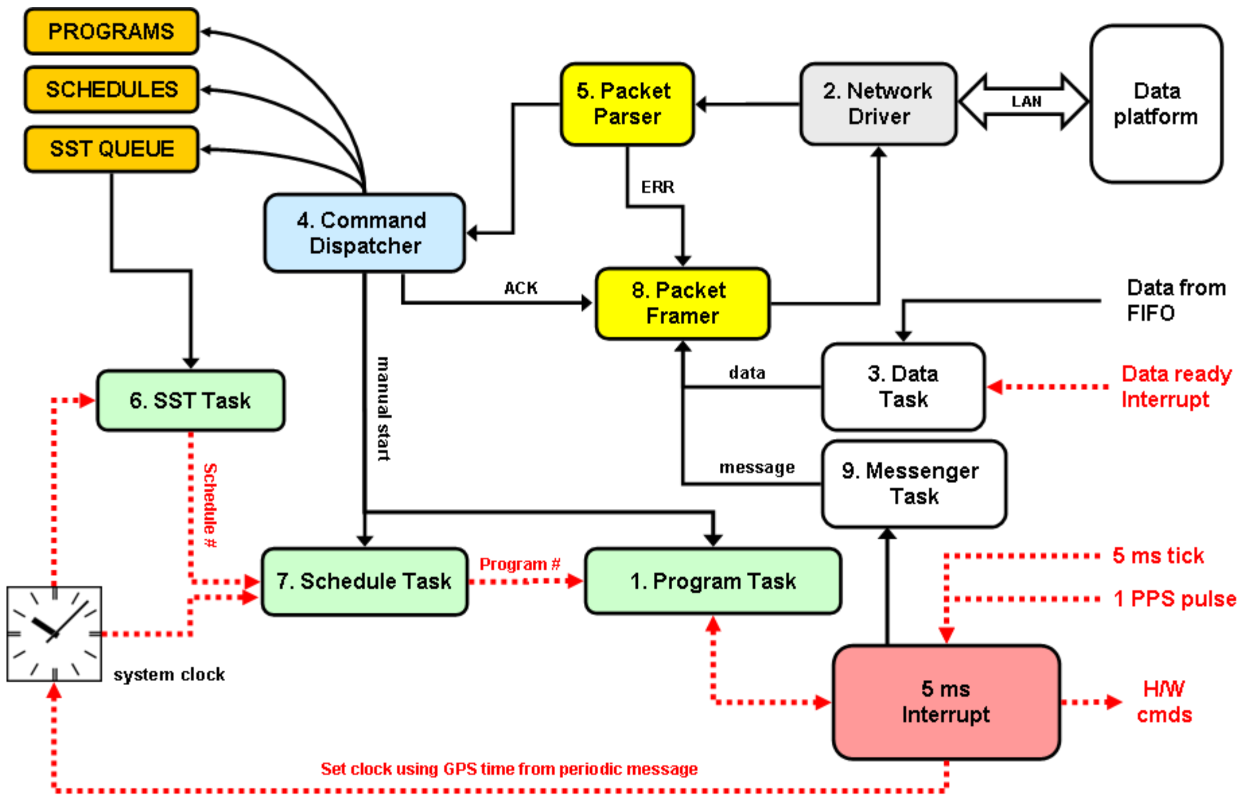

Figure 5-2: Block-Diagram of DESC Software

5:9. Individual tasks managed by the RTOS are enumerated in **Figure 5-2** to indicate their priority levels used by the RTOS scheduler to allocate computer resources to the tasks that are ready to run.

5:10. Green boxes in **Figure 5-2** correspond to the software tasks that are responsible for progression of the measurements in accordance with the PROGSCHD specifications of programs and schedules, and schedule start time (SST) queue. In order to start specified measurement schedules at specified start times, SST Task monitors the clock time to detect approaching match of the system clock time with the top SST in the queue. When the match is imminent, SST Task forwards the required schedule number to the Schedule Task for initiation. The Schedule Task follows the schedule specifications to start Program Task at appropriate times relative to the actual start time of the schedule. The Program Task is responsible for conducting measurement programs from the start to finish. It no longer uses the system clock for timing of events; instead, it counts 5 ms interrupts to progress the measurement (setup transmitter and receiver for each measurement look, enable transmission and reception). The Data task is responsible for acquiring 256 range samples that become available in the FIFO buffer of the Pre-processor card and forming data packets for delivery to DATA platform. The Data task is invoked by the interrupt handler that in turn is triggered by the Data interrupt from the IDE controller on preprocessor card.

5:11. Parser and Framer tasks (shown as yellow boxes in **Figure 5-2**) are responsible for communications with the DATA Platform. The Parser Task accepts incoming command packets to assure their proper format and forwards them for execution to the Command Dispatcher. The Framer Task accepts outgoing telemetry data to format them appropriately for delivery to the DATA Platform.

GPS SYNCHRONIZATION

5:12. All Digisonde-4D operations are kept synchronous with the GPS Universal Time (UT). The DATA platform runs standard Network Time Protocol (NTP) that accepts NTP messages from the GPS receiver over the RS-422 port to keep the operating system clock matched to UT. Synchronization of the Digisonde® circuitry is done in hardware: each Second-In-The-life (SITL) written in the Timing memory is triggered by the heartbeat 1 PPS signal from the GPS receiver. As for the CONTROL platform, its synchronization involves combination of both software and hardware solutions. The same Timing memory that is triggered to produce timing signals for one SITL of the sounder also generates 5 ms external tick interrupt that drives the computer clock of CONTROL platform. Thus, no drift of the CONTROL platform clock shall be expected unless 5 ms interrupt becomes unstable. To verify healthy synchronization of the CONTROL platform, and also to initialize its system clock after powering up, DESC software periodically analyzes UT stamp[1] from the Periodic Messages generated by DCART. When the 5 ms interrupt handler of DESC identifies the "golden" interrupt (out of 200 per second) that coincides with the external 1 PPS heartbeat signal from GPS, DESC:

- Checks if no measurement is ongoing and verifies that the latest periodic message from DCART is less than 1 sec old, in which case:
- Compares its system clock with the (UT stamp from DCART periodic message + 1 sec), and if a mismatch is observed:
    - o Ignores 3 cases of the time difference exactly ±1 sec, in which case accidental latency problem in the handling of the periodic messages is suspected.
    - o Otherwise, changes the CONTROL platform clock time and generates software event message TYPE=0x02 with EventID=0009h (System clock changed) into outgoing telemetry stream.

NOTE

During normal operations of the sounder, no software messages "System clock changed" have to be observed in DCART log window, except for the first message when CONTROL platform clock is initialized.

5:13. Additional testing of CONTROL platform synchronization is done by DESC packet parser that monitors latency of DCART periodic messages and reports continuous resets of the CONTROL platform system clock, or mismatches greater than 1 sec, as software error message TYPE=0x03 with ErrorID=0011h (Unstable clock, cannot set time).

[1] DCART Periodic Messages are generated on the round second, typically once a minute, with UT stamp given at 1 sec resolution.

CHAPTER 3

SYSTEM SOFTWARE OF DATA COMPUTER

INTRODUCTION

5:14. The Data Platform is responsible for:

- Accepting raw sample data collected by the Control Platform for
  - processing,
  - visualization,
  - packaging in standard files,
  - local backup to mass storage media, and
  - delivery to external data recipients.
- Provision of the user interface for manual and unattended operations of the DPS4D
  - Design of measurement programs, schedules, schedule switch rules, campaign requests
  - Commanding DPS4D operations
- Publishing of the acquired science and housekeeping data to the WWW

Block Diagram of Data Platform Software

5:15. Block diagram of Data Platform operating software is shown in **Figure 5-3**. Digisonde® Commanding and Acquisition Remote Terminal (DCART) is responsible for interfacing DESC operating software on the Control Platform to send commands and collect telemetry data, as well as reduction of the acquired raw data to ionograms and drift records and provision of user interface for manual and unattended operations of the DPS4D. Dispatcher arranges processing of the ionogram and drift records to obtain derived data products, manages storage and dissemination of all recorded information, and produces graphic representation of acquired data for publishing to the WWW. There is a collection of WWW support tools that service remote user requests for data displays and files.

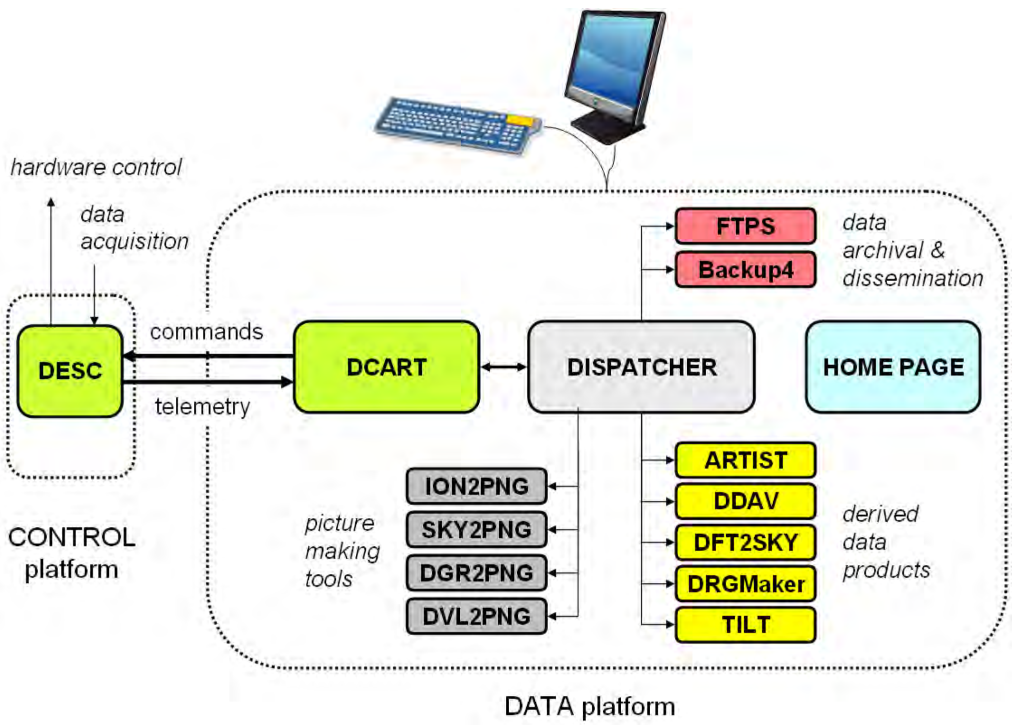

Figure 5-3: Digisonde-4D Computer Configuration with CONTROL and DATA Platforms

5:16.

DCART

5:17. Main functions of DCART software are:

- Support of Science Operations
  - Program design
  - Schedule design
  - Daily operations design (scheduling rules)
  - Campaign events design
- Real-time Data Processing and Visualization
  - Science data
  - Housekeeping data
- Manual Commanding
  - Start and stop
  - Switching operating states

5:18. **Figure 5-4** shows the block diagram of DCART software. DCART handles two distinct data streams, *telemetry* (incoming data from CONTROL Platform) and *commanding* (outgoing data to Control Platform). Correspondingly, the telemetry part of interface has the Parser thread responsible for syntactic analysis of in-coming packets from the Network Driver, extracting their payload section, and referring it to the queue of the Payload Dispatcher. The commanding part of interface has the Framer thread responsible for proper packaging of the command payloads from its queue and delivering them to Control Platform via the Network Driver.

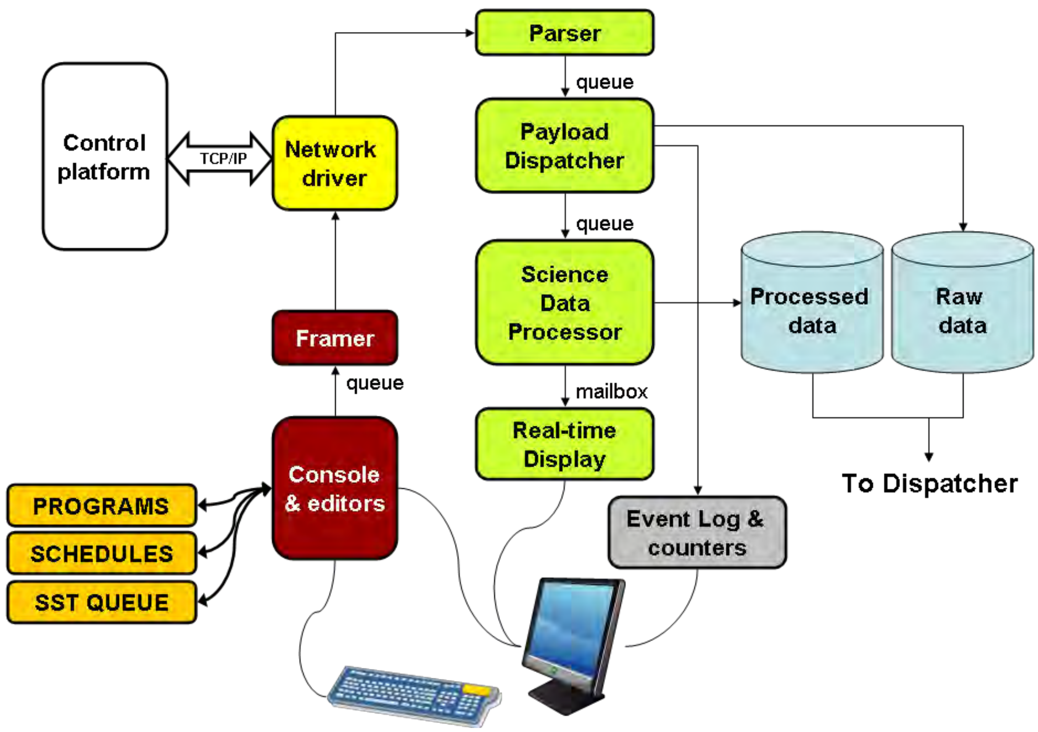

Figure 5-4: Block Diagram of DCART Software

5:19. The Interface Control Document (ICD) for Command and Telemetry (C&T) traffic between DCART and DESC software components of Digisonde-4D is detailed in Annex A. Further details on the DCART science data processing and examples of the real-time displays can be found in the Section 3, Chapter 2 of the Manual.

DISPATCHER

5:20. Dispatcher component of the DATA Platform is responsible for arranging generation of derived data products (scaled characteristics, directograms, skymaps, drift velocities, ionospheric tilts, MUF tables), WWW publishing and data dissemination to remote servers, and all associated file management. Dispatcher routes incoming files from DCART to appropriate post-processing software components, collects their data products, spawns picture-making tools for the WWW pages, prepares daily data files, manages secure and public sectors of local storage, arranges data delivery over the Internet by calling FTP and SFTP clients, and sends appropriate control data to DCART. Figure 5-4 shows a block diagram of data routes within the DATA Platform.

5:21. The DATA Platform maintains two types of local data archives, (1) short-term archive holding selected raw and derived data for 7-10 days (or more); and (2) long-term archive storing daily files for a prolonged period of time (years).

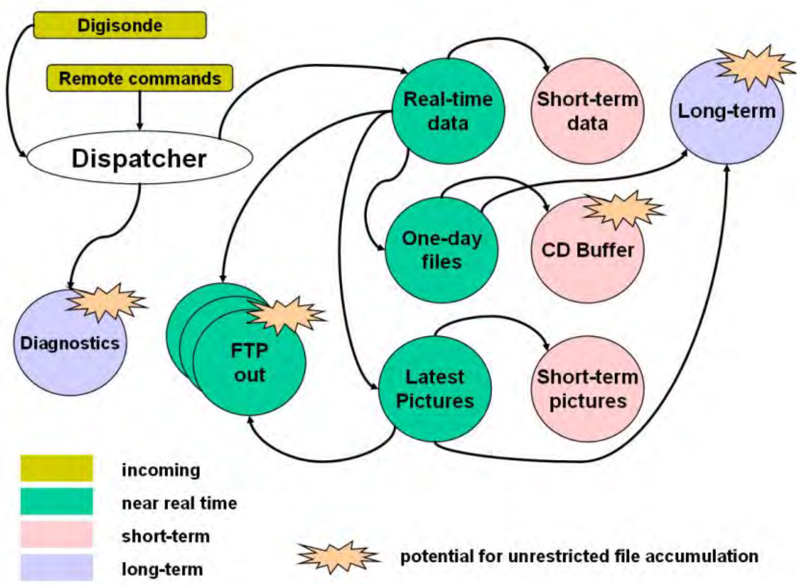

Figure 5-5: Data Routing Within AUX Computer

5:22. Newly made sounder data files appear in the Digisonde® incoming folder from DCART. Dispatcher initiates processing of each new file and collects all associated source and derived data products in the Real-time data folder. As soon as processing is complete, new data records are appended to corresponding one-day files in One-day files folder, outgoing files for remote servers are placed in the appropriate FTP out folders, and image making programs are called to produce pictures for WWW publishing and place resulting image files in Latest pictures folder.

5:23. As soon as the hold-off time for restricted access to the latest data expires, individual files in Real-time data and Latest pictures folders are moved for public access to the Short-term data and Short-term pictures folders. The default behavior configures expiration time to be 0, so that data are released to public folders immediately.

5:24. At the end of the day, Dispatcher finalizes one-day files residing in One-day files folder. It is possible to archive selected one-day files on removable media (CDs or DVDs) and keep them on the hard disk in the public long-term archive. Depending on configuration of Dispatcher, one-day files are copied to CD Buffer folder for archiving to removable media, or to Long-term folder for storage on the hard disk. Considering limited local hard disk space at the DATA Platform computer, it is recommended to store only one-day SAO files with ionogram-derived data in the long-term archive.

5:25. Dispatcher is configured to keep system log files and copies of ionograms that caused ARTIST software problems in Diagnostics folder.

5:26. Dispatcher keeps files in FTP-out folders if the recipient is not ready to accept the data. This creates potential for unlimited accumulation of the files in these folders if the recipient does not come online for a long time (e.g., remote data server is inaccessible over the network). Together with the Diagnostics folder that holds ionograms causing ARTIST problems, and Long-term folder holding one-day files indefinitely, these folders may cause disk overfill condition on the DATA computer.

5:27. Table 5-1 lists physical locations of the appropriate directories on the hard disk.

Table 5-1: Physical Locations of Data Archival and Incoming Folders on AUX Computer

NAME	LOCATION	FUNCTION
Digisonde®	/digisonde/dpsmain/dps2aux	Incoming files from Digisonde®
Remote commands	/digisonde/secure/incoming	Incoming commands from remote platforms
Real-time data	/digisonde/secure/individualfiles	All real-time individual files produced by the sounder
One-day files	/digisonde/secure/onedayfiles	One-day files in progress (for the current day)
Pictures	/digisonde/www/ionogif /digisonde/www/drggif /digisonde/www/skygif /digisonde/www/velgif	Image for public access
FTP out	/digisonde/buffers/ftp1 /digisonde/buffers/ftp2, etc.	Outgoing buffers for FTP-delivered data
Short-term data	/digisonde/secure/public/shortterm	Short-term archive of data files
Long-term	/digisonde/secure/public/longterm	Long-term archive of one-day files
Diagnostics	/digisonde/secure/diagnostics	Diagnostic data

5:28. The preferred mode of sounder operations is "online delivery", with newly acquired data immediately delivered to a remote central data repository over the FTP or SFTP connection. In this mode, no data management expertise is required locally at the sounder observatory, and all data operations are conducted at the central site where efficient management of multiple Digisonde® locations is possible.

5:29. Continuous FTP deliveries shall minimize irrecoverable data loss in case of a complete loss of hard disk contents. Table 5-2 lists the locations of long-term and buffered data files that may be lost in the unlikely event of such permanent hard disk failure.

Table 5-2: Digisonde® Data That Can be Lost in Case of Irrecoverable DATA Computer Hard Disk Failure

LOCATION	CONTENTS	STORAGE PERIOD	RECOVERY
/digisonde/buffers/ftpx	Outgoing files for delivery to remote data servers	Nominally not more than a few minutes, unless remote server is inaccessible and data are buffered until server comes back online.	Latest data are impossible to recover. Buffered data for inaccessible servers may be found on other online servers
/digisonde/secure/public/longterm	Long-term archive of one-day SAO files	many years	Recoverable from offsite locations or backup media

NOTE

DATA Platform stores no irreplaceable software, and data loss in case of the hard disk failure are minimal (see Table 5-2). it is recommended that a copy of the hard disk contents is kept available at the sounder site to restore the disk in case of hardware failure or Internet security breach.

5:30. All file copy operations within DATA Platfrom, including data deliveries, are made by first copying the file under a different file extension (TMP) and then renaming it to the original file extension. In this way, other software components do not attempt operations on files whose transfer is still ongoing.

DISPATCHER DIRECTLY CONTROLS DATA DELIVERY TO ALLOW CLOSER MONITORING OF THE DATA DELIVERY PROCESS. ALL SERVER REPLIES ARE CAPTURED IN ORDER TO IDENTIFY NETWORK DELAYS AND ERROR CONDITIONS. THE FILE IS DECLARED SUCCESSFULLY DELIVERED ONLY AFTER RECEIVING ACKNOWLEDGEMENT OF THE RENAME OPERATION FOR THE DESTINATION FILE AND CONFIRMATION THAT ITS SIZE ON THE REMOTE PLATFORM IS NOT ZERO. THREE TIMEOUTS ARE ENFORCED ON ANY PARTICULAR FTP TRANSFER, (1) MAXIMUM DELAY OF ANY SINGLE PACKET TRANSFER, (2) AVERAGE PACKET DELAY OF THE SEQUENTIAL TRANSFERS, AND (3) MASTER TIMEOUT OF THE FTP DELIVERY SESSION. THE FTP DATA DELIVERIES TO MULTIPLE DESTINATIONS ARE SERVICED IN THE PRIORITY ORDER SPECIFIED IN THE DISPATCHER.INI SETTINGS FILE.

CHAPTER 4

POST-PROCESSING SOFTWARE

POST-PROCESSING AT DATA PLATFORM

5:31. The Digisonde-4D sounder comes with pre-installed suite of software responsible for generation of derived data products. The list of installed post-processing software applications is given in **Table 5-3**. Annex B details data format for all source and derived data products of Digisonde-4D.

Table 5-3: Post-Processing Software Applications Running on DATA Platform

NAME	LOCATION	CONFIGURATION FILE	FUNCTION
ARTIST	/digisonde/dispatch	Artist.ini, xxx.UDD, xxx.RSL	Ionogram Autoscaling
DFT2SKY	/digisonde/dispatch	DFT2Sky.ini, xxx.UDD	Skymap calculation
DDAV	/digisonde/dispatch	DDASETUP.ONL	Calculation of drift velocity
DRGMaker	/digisonde/dispatch	DRGMaker.ini, xxx.UDD	Calculation of directogram
TILT	/digisonde/dispatch	Tilt.ini, xxx.UDD	Calculation of ionospheric tilt
Ion2PNG	/digisonde/dispatch	Ion2Png.ini, xxx.UDD	Ionogram image production
Sky2PNG	/digisonde/dispatch	Sky2Png.ini, xxx.UDD	Skymap image production
Drg2PNG	/digisonde/dispatch	Drg2Png.ini, xxx.UDD	Daily Directogram image production
Dvl2PNG	/digisonde/dispatch	Dvl2Png.ini, xxx.UDD	Daily drift plot production

5:32. Most of the post-processing components read Station ID number from the input file to acquire station constants from the appropriate Station UDD file located in /digisonde/dispatch/UDD. The Station UDD file is an ASCII text file containing setup parameters which select optional features of the sounder software. Each line in the file may be one of the following entries:

PARAMETER LINE (preceded with an asterisk * in column 1)
The asterisk is immediately followed by a 3-digit parameter number and its body enclosed within < >).

EXTERNAL COMMENT LINE (no special character in column 1)
Contains instructions regarding the following parameter line.

INTERNAL COMMENT LINE (preceded with a percent sign % in column 1)
A comment line invisible to software that reads the file.

5:33. Details of the file format, including the site specific and system specific setup variables, are provided in **Table 5-4**. For additional information on the antenna array definitions please refer to Section 2.

Table 5-4: Station UDD File

PARAMETER NAME	PARAMETER NO.	UNITS	RANGE	ACCURACY	PRECISION	DATA TYPE	FORMAT
Section 1 - GEOPHYSICAL PARAMETERS AND SITE INFORMATION							
Station Name	*304	Descriptive Text				String	<60 chars
URSI Code	*307	5 symbols				String	<60 chars
Site Latitude	*101	Deg	–90 to 90	0.1°	0.1°	Real	Free [2]
Site Longitude	*102	Deg East	0 - 359.9	0.1°	0.1°	Real	Free
Site Gyrofrequency	*104	MHz	0.5 - 2.0	0.1MHz	0.1 MHz	Real	Free
Site Dip Angle	*105	Deg	–90 to 90	1°	1°	Integer	Free
Site Declination	*106	Deg	–90 to 90	1°	1°	Integer	Free
Section 2 – DIGISONDE® MODEL AND ANTENNA CONFIGURATION (refer to Section 2 for details)							
Digisonde® Model	*032	Units	5 for Digisonde-4D	1 unit	Integer	Integer	Free
Declination of Antenna X axis from Geographic North Pole	*079	Deg	–90 to 90	0.1°	0.1°	Real	Free
Antenna Positions X coordinates	*080	m	-34.64 to +34.64	0.01 m	0.01 m	Real	Free
Antenna Positions Y coordinates	*081	m	-34.64 to +34.64	0.01 m	0.01 m	Real	Free
Antenna Positions Z coordinates	*082	m	-34.64 to +34.64	0.01 m	0.01 m	Real	Free
Antenna Pattern for Ionogram Displays	*086	Units	0,1,2,3	1 unit	Integer	Integer	Integer
Antenna Layout	*090	Units	0,1,2,3,4	1 unit	Integer	Integer	Integer
Antenna DEVN	*091	Deg	-180 ..+180	0.1°	0.1°	Real	Free
Antenna MAXDIST	*092	m	≤60	0.01 m	0.01 m	Real	Free
Section 3 – CONTACT INFORMATION							
Person Name	*410	Text				String	<60 chars
Organization	*411	Text				String	<60 chars
Address	*412	Text				String	<60 chars
Email	*413	Text				String	<60 chars

5:34. Refer to Section 3 for description and examples of derived data products produced by Digisonde-4D.

2 Format specification "Free" allows the numeric value of the ASCII digits to be converted to the appropriate numeric value

ARTIST

5:35. The Automatic Real-Time Ionogram Scaler with True height (ARTIST) is an intelligent system developed for the extraction of ionospheric specification data from ionograms. The automatic ionogram interpretation ("scaling") is a computer-hard problem that requires a model of human visual perception to extract useful ionogram image signatures and a syntactic analyzer to identify and characterize them. Introduction of the ARTIST in the early 1980s was the single most influential advance in the ionospheric sounding technology that had brought the Digisonde® data outside of a narrow circle of experts into realm of the operational 24/7 space weather systems.

5:36. INPUT FILES: RSF, SBF. OUTPUT FILES: SAO, SAOXML, MUF.

5:37. A common approach to the ionogram autoscaling in all ARTIST versions is to (1) adaptively threshold the ionogram image to remove background noise, (2) reduce echoes to edgels (edge elements) corresponding to the leading edge of the echo, (3) string echoes into traces, and (4) identify traces and determine their characteristics.

5:38. Digisonde-4D are supplied with the version 5 of ARTIST software. Further details on ARTIST-5 algorithms can be found in [Galkin *et al*., 2007].

Autoscaling Confidence Level (ACL) of ARTIST-5

5:39. The Autoscaling Confidence Level (ACL) is determined indirectly and automatically by examining the ionogram features and the autoscaling outcome for various anomalies. Such examination of the ARTIST results resembles other software solutions that use multiple criteria to spot commonly observed autoscaling problems, including

- high mismatch of the extracted trace with the trace restored from the calculated electron density profile,
- unreasonable separation of O- and X-cusps in the F2 echo traces,
- excessive frequency gap between E and F layer traces,
- unreasonably high variability of the scaled values from ionogram to ionogram.

5:40. Since the mid-1990s, a two-digit ARTIST "confidence level" value is routinely provided with each autoscaled ARTIST record to help end user applications with automatic accept/reject decisions. Still, independently of the ARTIST development, other post-evaluation algorithms have been developed to characterize and mitigate autoscaling errors. In particular, the USAF QUALSCAN system is used at the Mirrion server in Boulder, CO to tag out those autoscaled records that did not pass QUALSCAN quality criteria.

5:41. ARTIST-5 software is not only able to check its result using common "sanity checks", but also to detect anomalies in the ionogram interpretation process itself. For example, if the F2 trace cusp extraction algorithm detects the presence of multiple trace segments that are representing the assumed foF2 cusp, confidence in the correctness of such ionogram evaluation is decreased. Post-evaluation algorithms like QUALSCAN are not able to sense such complications of the interpretation process.

ARTIST-5 Ionogram Qualifiers

5:42. In addition to the ACL value determined by ARTIST-5 by inspecting autoscaling process and its outcome for anomalies, another level of ionogram qualification is provided by automatic classification of each ionogram in terms of the level of the ionosphere/ionogram disturbance. A total of six ionogram categories is defined for the error analysis by assigning the following ionogram qualifiers:

QC	= Quiet ionospheric conditions, Confident ARTIST scaling	ACL = 1
MC	= Moderate Spread F conditions, Confident ARTIST scaling	ACL = 1
HC	= Heavy Spread F conditions, Confident ARTIST scaling	ACL = 1
QL	= Quiet ionospheric conditions, Low confidence of ARTIST scaling	ACL = 0
ML	= Moderate Spread F conditions, Low confidence of ARTIST scaling	ACL = 0
HL	= Heavy Spread F conditions, Low confidence of ARTIST scaling	ACL = 0

5:43. For certain locations such as Jicamarca (Peru), Gakona (Alaska), or Campo Grande (Brazil), we observed another class of ionograms for which it is impossible to derive any meaningful vertical electron density profile from the ionogram because of extremely heavy spread F conditions. Such class received a separate qualifier EH:

EH = Excessively Heavy Spread F conditions, no autoscaling results attempted

5:44. Using this system of ionogram qualifiers, it is possible to better reflect long-term statistical differences in the ARTIST accuracy by isolating anomalous records that tend to distort the Gaussian error distribution into separate categories for which the long-term accuracy is expected to be worse and likely non-Gaussian. By excluding the outliers from the main categories of the confidently scaled data, their distributions get closer to the Gaussian.

Long-term Statistical Evaluation of Digisonde-4D Accuracy

5:45. The DPS error analysis focuses on the errors introduced by the automatic scaling and assumes correct manual scaling. Clearly the instrumental errors in measuring the virtual heights h’ and the plasma density are small (see below) compared to the errors introduced by the autoscaling. The long-term statistical accuracy of DPS4D ionogram-derived data is evaluated by calculating error bars for the scaled characteristics and the resulting error boundaries for the EDP. The error bars and boundaries describe the probability that the true value lies within specified bounds placed around the reported automatically derived values. In this approach, the probability is fixed at a particular level acceptable to the user application (e.g., 95%, 1σ, etc.), and the bounds are then determined from statistical comparison of reported (autoscaled) values to the true (manually scaled) values. Once the bounds are determined from the comparison set of ionograms, they are applied to the rest of the data. Such method benefits from ionogram classification into subcategories in which data possess statistically different accuracy. In this case, ARTIST-5 software determines the ionogram subcategory (using the system of ionogram qualifiers) and then applies the appropriate set of error measures to describe its accuracy.

Sensitivity Study of Ionogram-Derived Data Accuracy

5:46. A full scale study of the ARTIST data was conducted to determine ionogram subcategories that would reveal different levels of accuracy. Close to 250,000 manually scaled Digisonde® ionograms were involved in the study that tested dependence of the autoscaled errors on location, season, time of day, level of ionospheric disturbance, and autoscaling confidence level. The study results demonstrated clear dependence of the accuracy on the location of the sounder, level of ionospheric disturbance, and ACL. For the purpose of this study, the accuracy was still evaluated for ACL=0 data, and because it indeed appears to be considerably worse, rejecting ACL=0 data from assimilation makes sense. Alternatively, they still could be assimilated, but with large error bars. No visible difference was found in the accuracies calculated for different time periods of the day and seasons.

Error Bars for Autoscaled Critical Frequencies

5:47. **Figure 5-6** illustrates the approach taken for evaluation of the error bars for the critical frequencies. It shows an example error histogram for the critical frequency of the F2 layer, foF2, obtained for 20,675 manually scaled Průhonice DPS4 ionograms. The error histogram plots the percent of records as a function of observed error, i.e. the difference between manual and ARTIST values. A negative error means that the autoscaled value is underestimated, and a positive error corresponds to ARTIST overshooting the true foF2.

5:48. Using the histogram data, we select the percent level (horizontal line in **Figure 5-6**) so that 95% of all ionograms are contained above it. Corresponding intersections of the 95% percent line with the histogram curve then serve as the lower and upper uncertainty bounds that secure 95% probability for the true value to fall within provided bounds. For the Průhonice DPS4, such intersection points are -0.45 and +0.15 MHz, so that future autoscaled foF2 values can then be reported with uncertainty bounds of -0.15 to +0.45 MHz.

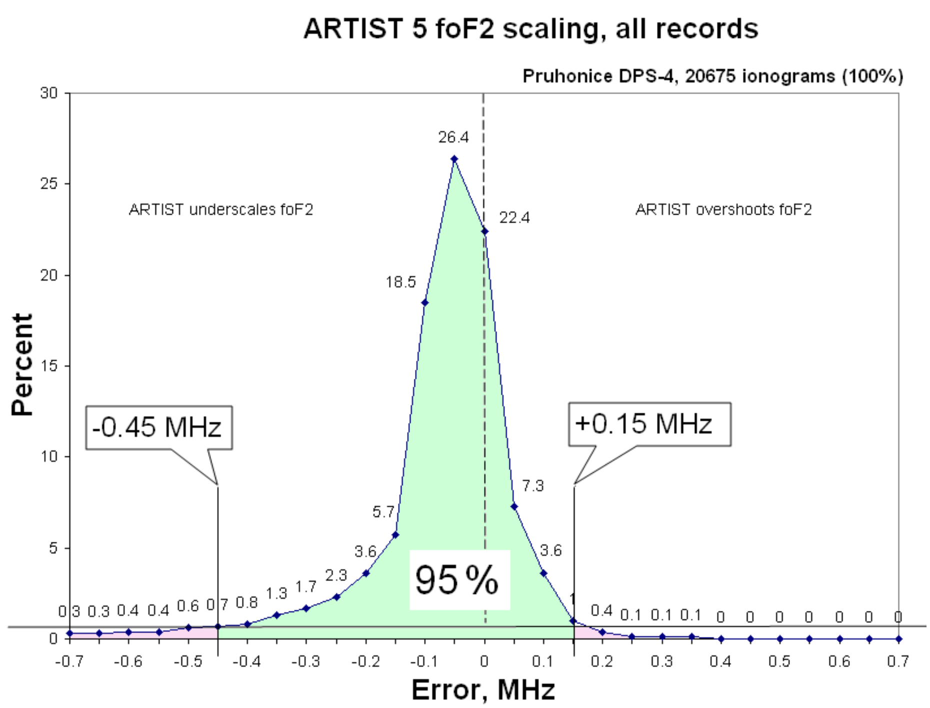

Figure 5-6: Error Histogram of Autoscaled Critical Frequencies of F2 Layer Obtained for 20675 Ionograms from DPS4 Ionosonde at Průhonice, Czech Republic

(95% of all autoscaled values lie within the -0.45 to +0.15 MHz interval from the true values provided by manual scalers.)

5:49. **Figure 5-7** illustrates the benefits of sorting ionograms in subcategories to statistically capture differences of autoscaling performance for different classes of ionograms. It shows the error histogram built using only ionograms taken during quiet ionospheric conditions and autoscaled with at a high confidence level (ionogram qualifier QC). Comparison of **Figure 5-6** and **Figure 5-7** shows improvement of the lower error bound enclosing 95% of all data from 0.45 to 0.3 MHz.

Remarkably, 81% of all ionograms taken at Průhonice, a typical mid-latitude location, fall in the QC category (quiet ionosphere, confidence scaling). Similar ratio has been observed at other mid-latitude locations.

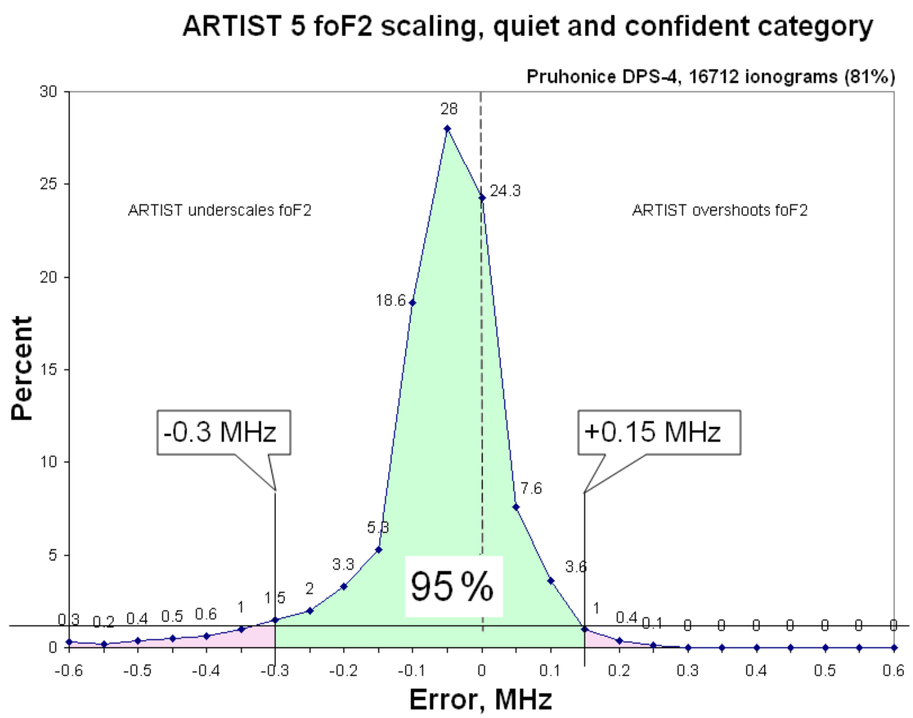

Figure 5-7: Error histogram of autoscaled critical frequencies of F2 layer obtained for 16,712 ionograms from DPS4 ionosonde at Průhonice taken during quiet ionospheric conditions and auto-qualified as high confidence.

Lower bound for foF2 error bar specification has improved from -0.45 to -0.3 MHz in comparison to the all ionogram case shown in Figure 5-6.

Error Boundaries for EDP

5:50. **Figure 5-8** illustrates the placement of the error boundaries on EDPs derived from the ionograms. Inner and outer boundaries are calculated using two Chebyshev polynomials representing the profile shape that are derived from the original profile coefficients to fit anchor points that are placed at the error bars for the critical frequencies, the valley between E and F regions, and the unknown starting height of the ionosphere. To avoid crossing of the boundaries in the valley region between E and F layers, the inner boundary gets a wider valley width W_{in} and a deeper valley depth D_{in}, and the outer boundary has a narrower valley W_{out} and shallower depth D_{out} (see insert in **Figure 5-8**).

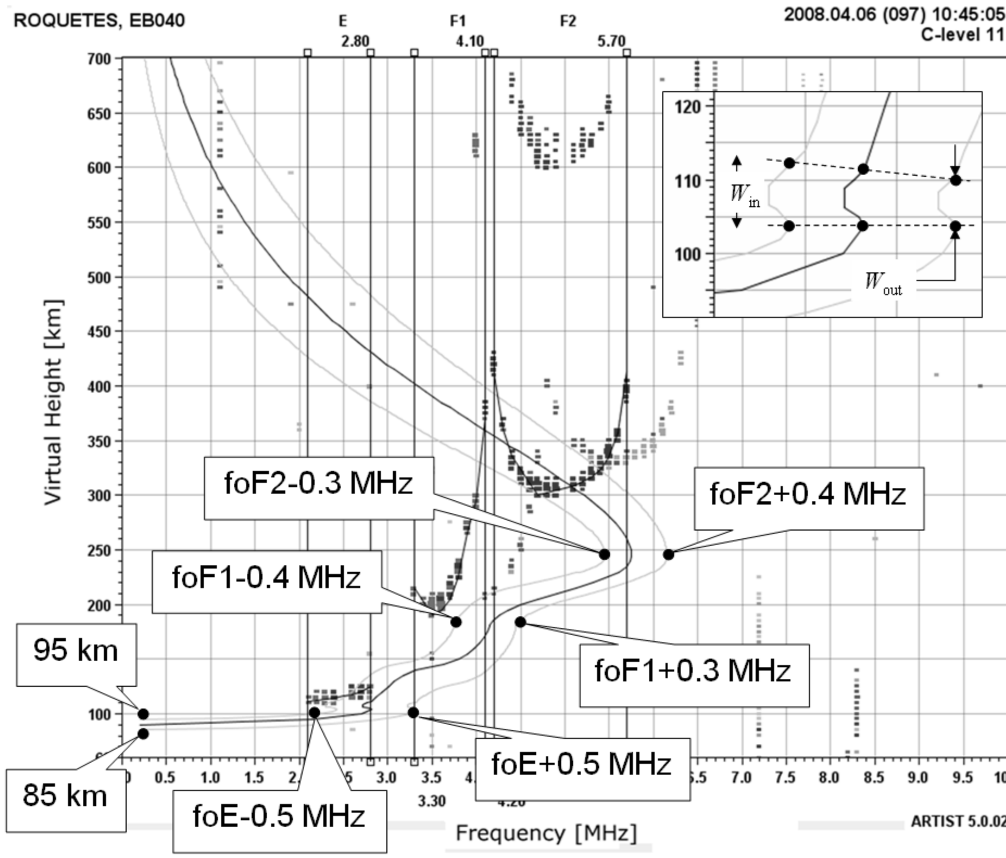

Figure 5-8: Autoscaled Ionogram from Roquetes, Spain, with Inner and Outer Error Boundaries for Calculated EDP.

The Error Boundaries are Obtained by Modifying the Original Profile Coefficients so that the Boundary Fits the Anchor Points as Indicated. Error Bars for foE, foF1. and foF2 Critical Frequencies are Specific to the Quiet Confident Ionograms at Roquetes (95% Probability Level).

Processing Precise Ranging Data in ARTIST

5:51. The ARTIST-5 software takes advantage of the PR processing in the ionograms that were taken in the PR mode by a technique that verifies consistency of the precise range measurements and interpolates missing values. The technique is illustrated in **Figure 5-9** where the ARTIST trace extracted without PR information is shown as the yellow line along the leading edge of the echo trace, and the white line corresponds to the updated h'-trace in which all range values are corrected using available PR data. The PR value calculated for each echo bin is shown as a white number within the bin giving the accurate h' for this echo. The star symbols indicate PR values that passed consistency criterion and were directly used to update the initial trace derived exclusively from the amplitude information. Diamond shapes show PR values that are inconsistent over the pulse width interval, for which the trace point is adjusted using an average bias of the range evaluated from all consistent PR values. Finally, circle shapes are used to show interpolated trace gaps that are re-interpolated using new trace values.

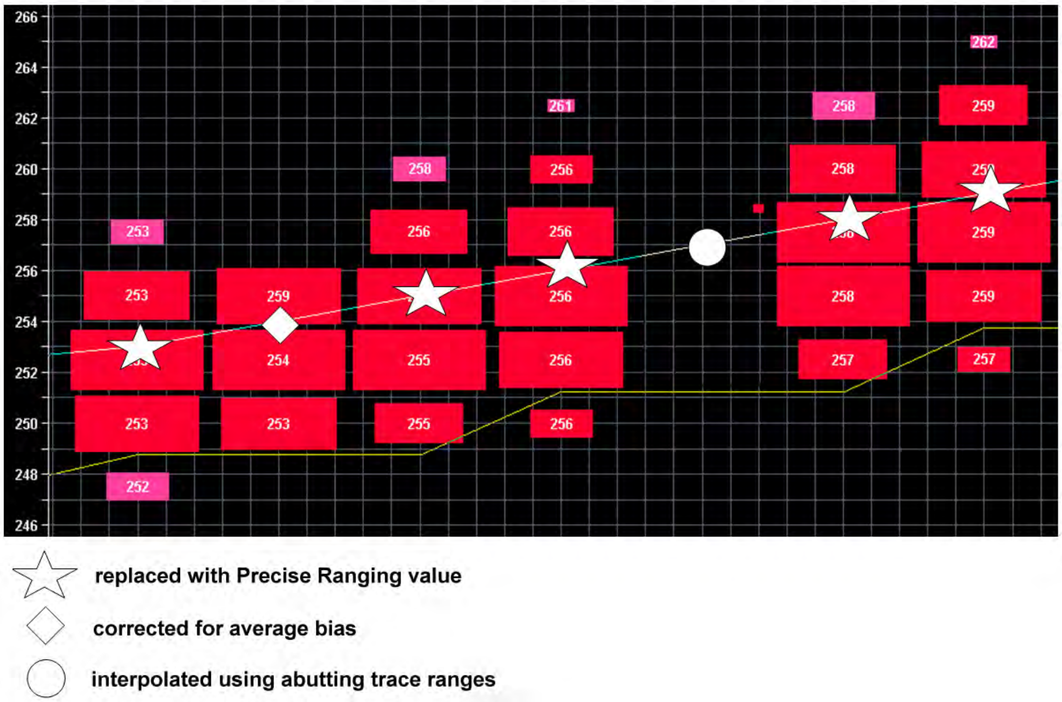

Figure 5-9: Precision Ranging (PR) Processing in ARTIST-5.
(The Original ARTIST Trace is Shown as the Yellow Line, and the Trace Updated with (PR) Data is Shown as the White Line.
Calculated PR Values for Each Echo Bin are Shown as White Numbers Within the Bin. When PR Values are Consistent Over Abutting Range Bins for the Same Frequency, their Value (Shown as White Stars) is Used to Replace the Conventional Range Directly.)

DFT2SKY

5:52. DFT2SKY uses drift measurements to identify angle of arrival for all reflected signals ("sources") observed in the data. The angles are then plotted as dots on a 'Doppler skymap' in which center of the plot corresponds to the vertical direction, the radial distance from the plot center represents the zenith angle, and the azimuthal angle is counted clockwise with the top of the plot corresponding to the North direction.

5:53. INPUT FILE: DFT. OUTPUT FILE: SKY

DDAV

5:54. DDAV uses skymaps to calculate the full three-dimensional plasma drift vector in the assumption that the plasma moves uniformly within the field of view of the Digisonde®.

5:55. INPUT FILE: SKY. OUTPUT FILE: DVL

TILT

5:56. TILT uses skymaps to calculate the offset of the center of skymap sources from the zenith, i.e., the overall tilt of ionospheric isodensity contours at the sounder location.

5:57. INPUT FILE: SKY. OUTPUT FILE: TLT

DRGMAKER

5:58. DRGMAKER uses ionograms with directional information to calculate directograms as described in Section 3.

5:59. INPUT FILE: RSF. OUTPUT FILE: DRG

ION2PNG

5:60. ION2PNG produces image of ionograms with superimposed scaled ionospheric characteristics, electron density profile (EDP), error boundaries for the EDP, and MUF table.

5:61. INPUT FILE: RSF, SAOXML. OUTPUT FILE: PNG

SKY2PNG

5:62. SKY2PNG produces image of the Doppler skymap with superimposed calculated drift velocity and included zenith and azimuth angles of ionospheric tilt.

5:63. INPUT FILE: SKY, DVL, TLT. OUTPUT FILE: PNG

DRG2PNG

5:64. DRG2PNG produces image of the daily directogram.

5:65. INPUT FILE: DRG (daily file). OUTPUT FILE: PNG

DVL2PNG

5:66. DVL2PNG produces image of the daily plot of drift velocities in the ionosphere.

5:67. INPUT FILE: DVL (daily file). OUTPUT FILE: PNG

ANNEX A

DESC TO DCART INTEFACE CONTROL DOCUMENT

COMMON DEFINITIONS

Structured data

5:68. Structured Data or, simply, Structure is the ordered collection of fields.

Field

5:69. Field is either

- Primitive Field,
- Structure (a collection of Fields),
- Array of Primitive Fields, or
- Array of Structures.

5:70. No memory gaps are present between the Fields in a Structure, i.e. all Fields start immediately after the end of the previous Field. The first Field of a Structure starts at the memory address of the Structure. Thus, values of Fields in the Structure can be uniquely obtained as soon as its memory address is known.

5:71. Field descriptions are given as a table in which rows are fields of structured data and columns are common characteristics of these fields. Common characteristics of the Field are given in **Table 5A- 1**

Table 5A- 1: Characteristics of Field

Name	Description
BYTE OFFSET	Byte offset from the start of structure
BYTE LEN	Length in bytes
MNEMONIC	Short name. This name must be unique within structure this field belongs to.
DESCRIPTION	Verbal description
UNITS	Physical units
TYPE	For primitive field we use notation shown below in Section 1.3.2. For structured field we can mention its structure name or table number that describes corresponding structure.
RANGE	Legal range of values. Used for primitive fields.

Primitive field types

5:72. Column 'type' in many tables describing fields of various structured data will mean all necessary things you need to extract field value from memory.

5:73. Common primitive data types used in this document are listed in **Table 5A- 2**

Table 5A- 2: Primitive Field Types

Abbreviation	Byte Len	Description
INT8U	1	8 bits unsigned
INT8S	1	8 bits signed
INT16U	2	16 bits unsigned
INT16S	2	16 bits signed
INT32U	4	32 bits unsigned
INT32S	4	32 bits signed
INTU ACD	Variable, 1- 15	**U**nsigned integer represented as **A**SCII **C**oded **D**ecimal Each decimal digit of integer number takes one byte of external memory and its ASCII code will be saved there. If length of the field is larger than length of bytes occupied by integer number then this number has to be shifted to the right edge of the field and has to be padded either by ASCII code of '0' or ASCII code of SPACE.
INTS ACD	Variable, 1- 15	**S**igned integer represented as **A**SCII **C**oded **D**ecimal Each decimal digit of integer number takes one byte of external memory and its ASCII code will be saved there. ASCII code of sign can be saved as first byte. If length of the field is larger than length of bytes occupied by integer number then this number has to be shifted to the right edge of the field and has to be padded either by ASCII code of '0' or ASCII code of SPACE.

5:74. Any of these basic types can be used to construct an array, for example, **INT8U array**.

COMMON PACKET FORMAT

5:75. Generally, all DPS V6 packets consist of the following 5 sections (**Table 5A- 3**):

- **Sync Pattern,** used for frame synchronization in the lossy communication environments. Sync pattern for DPS V6 is 3 byte sequence 0xFEFA31[3].
- **Length** (byte count of the packet contents, including all packet elements from sync pattern to the checksum)
- **Packet Type**, used to distinguish it from other packets requiring different actions
- **Packet Data** (Data Section of Packet)
- **Checksum (XOR of all bytes in the packet)**

5:76. Length, Packet Type and Packet Data constitute the packet Payload.

Table 5A- 3: Common Packet Format

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	3	**SYNC**	**Sync Pattern** **0xFE, 0xFA, 0x31**	-	INT8U	Constant
3	2	**LENGTH**	**Length of packet including SYNC, LENGTH, TYPE, DATA, and CS**	byte	INT16U	0..65535
5	1	**TYPE**	**Type of packet**	-	INT8U	0..255
6	Variable	**DATA**	**Packet Data**	byte	INT8U array	-
Last	1	**CS**	**Checksum**	byte	INT8U	0..255

[3] FEFA30 header is used for RPI, and FEFA32 header is used for TNT.

COMMON DATA ELEMENTS

Measurement Program

5:77. Measurement program, or simply *Program*, is a set of parameters that uniquely specify particular measurement taken by the DPS. All Program types have the same first field, "Operation Code" (OpCode), which is followed by *Operation*, a specific structure of parameters defining the DPS operation. DPS keeps an array of 128 Program specifications in memory. There are four kinds of Programs, each having different Op-Code and Operation structure:

5:78. *1. Empty Operation* (OpCode = 0) is a no-action operation. It is used to label unused entries in the array of Programs. If **DESC** is commanded to run an *Empty Operation,* it generates an error message. The Operation structure of this command is empty.

5:79. *2. Sounding Operation* (OpCode = 1) represents the most commonly used measurement mode of the DPS when **DESC** commands hardware to transmit signals and sample antenna voltages. The Ionogram and Drift measurements both fall into this category.

5:80. *3. Built-in Test Operation* (OpCode = 2) is a housekeeping mode of DPS operations in which **DESC** collects sensor data in various modes to diagnose condition of the Digisonde® hardware. This test returns result data, which is useful for engineers and also can be used by **DCART** for sending alert messages.

5:81. *4. Channel Equalizing operation* (OpCode = 3) represents operational mode in which DPS is configured to send an attenuated transmitter signal to Antenna Switch to determine amplitude and phase differences between four receiver channels.

5:82. When **DESC** or **DCART** software need to interpret one Program object, they read the Operation Code first, and then they have enough information to appropriately unpack the rest of the Operation structure.

Empty Program

Table 5A- 4 contains a description of the *Empty Program*.

Table 5A- 4: Empty Program Specification (Length 1 Byte)

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	1	**OP_CODE**	**Operation code. Contains constant 0.**	-	INT8U	0

Sounding Program

5:83. The *Sounding Program* has the largest number of user-selected parameters in its *Operation* structure. The parameters can be divided in three sections:

- Operation Option
- Common Specification of the sounding measurement
- Data Processing Selection:
  - All processing steps that have to be applied to raw data
  - Processing steps that preferably to be applied by DESC, - these processing steps matched to some starting subsequence of all processing steps

5:84. **Operation Option** is used to describe whether Digisonde® produces actual measurement data or simulates one of available test patterns.

5:85. **Common Specifications** define all parameters that are common to both ionogram and drift mode of Digisonde® operations. This part includes, for example, frequency and range stepping, number of pulses per frequency, signal waveform, etc. Common Specifications determine how the time domain data are collected by the **DESC** and forwarded to **DCART**.

5:86. There is a variety of **Data Processing** that both DESC and DCART can apply to the collected time domain data in order to produce the final data product to be archived (i.e., an ionogram or a drift measurement). Number and sequential order of the processing steps that are required to derive the final DCART data product from the raw time domain data depend on:

- choice of data product (i.e., ionogram, drift record, or intermediate step data),
- choice of DPS signal waveform, and
- optional processing, such as the RF Interference Mitigation (RFIM).

5:87. The variety of processing steps and processors that execute them is described in terms of one linear sequence of *Data Process Steps*, called *Process Chain*. The Process Chain has the following properties:

- Data Process Steps in the chain are applied successively to the raw time domain data
- The complete Process Chain has the following sequence of 5 process steps

  0. Raw data (no processing applied)
  1. Pulse Compression
  2. Sum of complementary code sequences
  3. Doppler Processing
  4. Ionogram Calculation

- Process Chain can be made shorter to produce intermediate step data, but only by removing steps from the end of the chain.
- Each step in the Process Chain can have any number of optional unchained process steps attached to its output.

5:88. The main Process Chain can be described by one byte, the ID of the last data process step (0 to 4). Selection of the unchained steps can be described by one byte, where each bit corresponds to the one of the available unchained steps. Currently two unchained steps are provided,

0x1. Channel Equalizing (CEQ), applied at the output of chained step 0

0x2. RFI Mitigation, applied at the output of chained step 0

5:89. Therefore, the following settings of the unchained step selection are possible:

0 = no unchained steps called,
1 = Channel EQ
2 = RFI Mitigation,
3 = both RFIM and Channel EQ.

Table 5A- 5 shows specification of the Data Processing structure.

Table 5A- 5: Data Processing Structure (Length 2 Bytes)

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	1	**CHAINED_PROC**	**Chained process step to be applied:** 0 = Do not process (raw data) 1 = Pulse compression 2 = Sum complimentary 3 = Doppler calculation 4 = Ionogram calculation **Note**: temporarily constant, set to *Do not process*	-	INT8U	0 … 4
1	1	**UNCHAINED_PROC**	**Bit-mask for unchained process steps to be applied.** 0x1 = Channel EQ 0x2 = RFI mitigation	-	INT8U	0 .. 3

Table 5A- 6 contains description of the *Sounding Program*. The Common Specification section of the sounding program definition is highlighted in blue. Parameters that are ignored by DESC are highlighted in yellow. **Table 5A- 7** describes contents of the Flexible Frequency List ("flex-list"), which is used for specification of varying number of arbitrary operating frequencies for the sounding operation.

Table 5A- 6: Sounding Operation Version 3 (Variable Length)

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	1	**OP_CODE**	**Operation code. Contains constant 1 (Sounding).**		INT8U	1
1	1	**OP_OPTION**	**Operation option:** 0 = Measurement 1 = Internal loopback 2 = HW (digitizer card hardware) test pattern 3 = SW (software) test pattern	-	INT8U	-
2	2	**ALL_PROC**	**All data processing steps desired to be applied to raw data**	-	Data Processing structure	N/A
4	2	**DESC_PROC**	**Processing desired to be done prior to delivery of data to DCART. This Data Processing is equal to some incomplete part of ALL_PROC or to the whole ALL_PROC.** **Notes:** Although DCART can run all processing steps described by **ALL_PROC,** these steps can be delegated, partially or completely, to the Digisonde® hardware and the embedded computer system, thus relieving DCART from some of the work to be done. It is possible to control where particular processing steps occur by specifying **DESC_PROC**. Data Processing that has really been applied by **DESC** is reflected in corresponding field of **Data Preface** structure and it should not exceed Data Processing described by this field.		Data Processing structure	N/A
6	bits: 0-3	**FILE_FORMAT**	**File format** that will be used for final product data file after applying all processing steps defined by ALL_PROC. The following file data format options are available: 0 – **Generic Format**. This format exists for any kind of data as Raw Data, Doppler Data, Ionogram Data 1 – **DFT** format. Only for Doppler Data 2 – **RSF** format. Only for Ionogram Data **Note:** this field is ignored by **DESC**	-	INT4U	0, 1, 2

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
	bits: 4-7	**BIN_FORMAT**	**Databin format.** It is defined only for Generic format, in which case the databin format number is: a). For Raw or Time Domain data type 0 - uncompressed 1 - compressed b). For Doppler data type 0 - uncompressed 1 - compressed c) For Ionogram data type 0 - all-antennas uncompressed 1 - all-antennas compressed 2 - antenna-convolved uncompressed 3 - antenna-convolved compressed 4 - antenna-convolved very compressed	-	INT4U	
7	2	**L**	**Lower Frequency Limit** This field's used when Frequency Stepping Law is Linear or Logarithmic	1 kHz	INT16U	1000 kHz - 30000 kHz
9	2	**U**	**Upper Frequency Limit** This field's used when Frequency Stepping Law is Linear or Logarithmic	1 kHz	INT16U	1000 kHz - 30000 kHz
11	2	**FF**	**Fixed Frequency** This field's used when Frequency Stepping Law is Fixed Frequency	1 kHz	INT16U	1000 kHz - 30000 kHz
13	1	**FFR**	**Fixed Frequency Repeats** This field's used when Frequency Stepping Law is Fixed Frequency	-	INT8U	0...255
14	1	**FST**	**Frequency Stepping Law** 0 = Linear 1 = Logarithmic 2 = Fixed Frequency (Lower Frequency Limit value is used) 3 = Flex List (user-defined list of operating frequencies)	-	INT8U	0,1,2,3
15	1	**FLS**	**Flex List Size** Size of Flex List (number of user-defined frequencies). This field's used when Frequency Stepping Law is Flex List.	-	INT8U	0…255
16	2	**CFS**	**Coarse Frequency Step** This field's used when Frequency Stepping Law is Linear or Logarithmic	1 % (log) 1 kHz (lin)	INT16U	1-100% 1 kHz-1MHz
18	2	**FFS**	**Fine Frequency Step**	1 kHz	INT16U	1 kHz-1MHz
20	1	**NFS**	**Number of fine steps**	-	INT8U	1...8
21	1	**MX**	**Fine step multiplexing** 0 = no multiplexing 1 = multiplexing	-	INT8U	0, 1
22	1	**M**	**Multiple frequency operation** (constant, set to *single frequency mode*) 0 = single frequency mode 1 = dual frequency mode 2 = quadruple frequency mode	-	INT8U	0, 1, 2
23	1	**W**	**Waveform** 1 = 16-chip complimentary code 2 = 67 µs short pulse	-	INT8U	1, 2
24	1	**IPS**	**Interpulse phase switching** (constant, set to *disabled*) 0 = disabled 1 = enabled	-	INT8U	0, 1
25	1	**TM**	**Transmitter mode** 0 = off 1 = on	-	INT8U	0, 1

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
26	1	**A**	**Antenna option** (bit mask of enabled antennas) Bit 0 = antenna 1 Bit 1 = antenna 2 Bit 2 = antenna 3 Bit 3 = antenna 4	-	INT8U	0…15
27	1	**POL**	**Polarizations** 0 = O and X 1 = O only 2 = X only	-	INT8U	0, 1, 2
28	1	**N**	**Number of Integrated Repeats** (excluding code pairs and polarizations)	2^N	INT8U	3...7
29	1	**IPP**	**Inter-Pulse Period**	5ms	INT8U	
30	2	**START_RANGE**	**Start Range**	1.25 km	INT16U	0...1023
32	2	**END_RANGE**	**End Range**	1.25 km	INT16U	0...1023
34	1	**RANGE_STEP**	**Range Step**	1.25 km	INT8U	2
35	1	**CG**	**Constant Gain** **In OP_OPTION = Measurement** 0 = full gain, Tracker (9) and Antenna Switch (0) 1 = -9 dB in Tracker (9) and Antenna Switch (-9) 2 = -9 dB in Tracker (0) and Antenna Switch (0) 3 = -18 dB in Tracker (0) and Antenna Switch (-9) **In OP_OPTION = Internal loopback** 0 = Full gain, Cal Hi, Tracker (9) and Antenna Switch (0) 1 = -9 dB, Cal Hi, Tracker (9) and Antenna Switch (-9) 2 = -18 dB, Cal Hi, Tracker (0) and Antenna Switch (-9) 3 = -35 dB, Cal Hi, Tracker (0) and Antenna Switch (-26) 4 = -9 dB, Cal Hi, Tracker (0) and Antenna Switch (0) 5 = -26 dB, Cal Hi, Tracker (9) and Antenna Switch (-26) 6 = Full gain, Cal Lo, Tracker (9) and Antenna Switch (0) 7 = -9 dB, Cal Lo, Tracker (9) and Antenna Switch (-9) 8 = -18 dB, Cal Lo, Tracker (0) and Antenna Switch (-9) 9 = -35 dB, Cal Lo, Tracker (0) and Antenna Switch (-26) 10 = -9 dB, Cal Lo, Tracker (0) and Antenna Switch (0) 11 = -26 dB, Cal Lo, Tracker (9) and Antenna Switch (-26)	-	INT8U	0..3 for Meas-urement 0..11 for Internal loopback
36	1	**RX_G**	**Rx Gain** 0 = +30 dB 1 = +24 dB 2 = +18 dB 3 = +12 dB 4 = +6 dB 5 = 0 dB 6 = -6 dB 7 = -12 dB	6 dB	INT8U	0..7
37	1	**AGC**	**Automatic gain control** 0 = fixed gain 1 = create gain table before sounding program and use it 2 = use existed gain table 3 = use trial pulses on each frequency	-	INT8U	0, 1,2
38	1	**AUTO_DRIFT**	**Auto-Drift frequency commanding** 0 – disabled 1 – enabled If enabled: Frequency Stepping Law must be – 2 (Fixed Frequency) See also: Auto-drift Message Packet	-	INT8U	0, 1

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
39	1	**SAVE_DATA_F**	**Save Data Flags** **Bit 0 Save Raw Data flag** **Bit 1 Do Not Save Product Data** **Bit 2 Ionogram Data Reduction, when set then databins with amplitudes ≤ MPA will be lost** **Bit 3 Ionogram PGH (Precision Group Height) mode** **Notes:** DCART has a global option that can override Save Raw Data flag selection to produce no raw files or produce raw files for all available programs. Option 'Do not Save Product Data' is used for testing and some cases when you do not need to save produced data	-	INT8U	0,1
40	2	**TOP_RANGE**	**Top Range of the search window for the strongest echo** Search window is used to select a subset of ranges (see NRO) around the strongest echo (199 E-layer, 400 F-layer) Presently this parameter is used only by Doppler processing when creating Doppler/Drift data product. See also: Auto-drift Message Packet	1.25 km	INT16U	0…1023
42	2	**BOT_RANGE**	**Bottom Range of the search window for the strongest echo** Search window is used to select a subset of ranges (see NRO) around the strongest echo (80 E-layer, 200 F-layer) Presently this parameter is used only by Doppler processing when creating Doppler/Drift data product. See also: Auto-drift Message Packet	1.25 km	INT16U	0...1023
44	1	**NRO**	**Number of Ranges to Output** **(reduced number of ranges selected around the strongest echo on each frequency)** Presently this parameter is used only by Doppler processing when creating Doppler/Drift data product. Set this parameter to 0 if you want all ranges to be output	-	INT8U	0…255
45	4	**PULSE_SEQ**	**Order of Pulse Sequencing: list of 4 IDs from the slowest changing to the fastest changing index within one CIT. Available IDs are:** 0 = Fine Frequency 1 = Polarization 2 = Integrated Repetition 3 = Complementary Code	-	INT8U array	
49	1	**DELAY**	**Sampling Start Delay** In support of oblique sounding mode Shall be specified in increments of 5 msec (1500 km)	5 msec	INT8U	0…255
50	1	**DIG_MODEL**	**Digisonde® model from UDD** **2 = DPS1** **3 = DPS4** **5 = DPS4D**	-	INT8U	
51	6	**TX_ID**	**Transmitter ID** In support of oblique sounding and Tx surveillance modes For oblique sounding experiments with other DPS transmitters, TX_ID is 000XXX, where XXX is Station ID. For not oblique sounding this field is equal to ' ' (6 space characters). 000000 means UNKNOWN station	-	INT8U array	Text
57	FLS * 2	**FL**	**Flex List Frequencies (Table of Frequencies,** Table 5A- 7)	kHz	INT16U array	-

Table 5A- 7: Frequency for Flex List (Length 2 Bytes)

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	2	**FR**	**Frequency, element of Flex List Frequencies array**	kHz	INT16U	1000 kHz – 30000 kHz

Built-In Test Operation

Table 5A- 8 contains description of the *Built-in Test Program*.

Table 5A- 8: Built-in Test Operation Version 3 (Length 4 Bytes)

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	1	**OP_CODE**	**Operating code. Contains constant 2.**		INT8U	2
1	1	**OP_OPTION**	**Operation option:** 0 = Measurement 1 = SW (software) test pattern	-	INT8U	0,1
2	2	**FREQ**	**Frequency** **Run BIT on this frequency**	1 kHz	INT16U	1000 kHz - 30000 kHz

Cross-Channel EQ Operation

Table 5A- 9 contains description of the *Channel EQ Program*.

Table 5A- 9: Channel Equalizing Operation Version 3 (29 Bytes)

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	1	**OP_CODE**	**Operating code. Contains constant 3 (Channel EQ).**		INT8U	3
1	1	**OP_OPTION**	**Operation option:** 0 = Measurement 1 = Internal loopback 2 = HW (digitizer card hardware) test pattern 3 = SW (software) test pattern	-	INT8U	0,1,2,3
2	2	**ALL_PROC**	**All data processing steps applied to acquired sample data.**	-	Data Processing structure	N/A
4	2	**DESC_PROC**	**Processing done prior to delivery of data to DCART.** **Notes:** Although DCART can run all processing steps described by **ALL_PROC,** these steps can be delegated, partially or completely, to the Digisonde® hardware and the embedded computer system, thus relieving DCART from some of the work to be done. It is possible to control where particular processing steps occur by specifying **DESC_PROC**. Data Processing that have been applied by **DESC** will be reflected in corresponding field of **Data Preface** structure and it will not exceed Data Processing described by this field.		Data Processing structure	N/A
6	2	**L**	**Lower Frequency Limit** This field's used when Frequency Stepping Law is Linear or Logarithmic	1 kHz	INT16U	1000 kHz - 30000 kHz
8	2	**U**	**Upper Frequency Limit** This field's used when Frequency Stepping Law is Linear or Logarithmic	1 kHz	INT16U	1000 kHz - 30000 kHz
10	2	**CFS**	**Coarse Frequency Step** This field's used when Frequency Stepping Law is Linear or Logarithmic	1 % (log) 1 kHz (lin)	INT16U	1-100% 1 kHz-1MHz
12	1	**W**	**Waveform** 1 = 16-chip complimentary code 2 = 67 µs short pulse	-	INT8U	1, 2
13	1	**IPS**	**Interpulse phase switching** (constant, set to *disabled*) 0 = disabled 1 = enabled	-	INT8U	0, 1

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
14	1	**POL**	**Polarizations** 0 = O only 1 = X only 2 = O and X	-	INT8U	0, 1, 2
15	1	**N**	**Number of Integrated Repeats** (excluding code pairs and polarizations)	2^N	INT8U	3..7
16	1	**IPP**	**Inter-Pulse Period**	5ms	INT8U	
17	2	**START_RANGE**	**Start Range**	1.25 km	INT16U	0..1023
19	2	**END_RANGE**	**End Range**	1.25 km	INT16U	0..1023
21	1	**RANGE_STEP**	**Range Step**	1.25 km	INT8U	2
22	1	**CG**	**Constant Gain** **In OP_OPTION = Measurement** 0 = full gain 1 = -9 dB in Antenna Switch 2 = -9 dB in Tracker 3 = -18 dB in Tracker and Antenna Switch **In OP_OPTION =** Internal loopback 0 = full gain 1 = -9 dB in Antenna Switch 2 = -18 dB in Tracker and Antenna Switch 3 = -35 dB in Tracker and Antenna Switch	-	INT8U	0, 1
23	1	**RX_G**	**Rx Gain** 0 = +30 dB 1 = +24 dB 2 = +18 dB 3 = +12 dB 4 = +6 dB 5 = 0 dB 6 = -6 dB 7 = -12 dB	6 dB	INT8U	0..7
24	1	**AGC**	**Automatic gain control** 0 = fixed gain 1 = create gain table before sounding program and use it 2 = use existed gain table 3 = use trial pulses on each frequency	-	INT8U	0, 1,2
25	4	**PULSE_SEQ**	**Order of Pulse Sequencing: list of 4 IDs from the slowest changing to the fastest changing index within one CIT. Available IDs are:** 0 = Fine Frequency 1 = Polarization 2 = Integrated Repetition 3 = Complementary Code	-	INT8U array	

Tracker Calibration

Table 5A- 10 contains description of the *Trackers Calibration Program*.

Table 5A- 10: Trackers Calibration Operation Version 3 (29 Bytes)

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	1	**OP_CODE**	**Operating code. Contains constant 4.**		INT8U	4
1	1	**OP_OPTION**	0 = Measurement 1 = Internal loopback 2 = SW (software) test pattern	-	INT8U	0,1
2	1	**CG**	**Constant Gain** **In OP_OPTION = Measurement** 0 = full gain 1 = -9 dB in Antenna Switch 2 = -9 dB in Tracker 3 = -18 dB in Tracker and Antenna Switch **In OP_OPTION =** Internal loopback 0 = full gain 1 = -9 dB in Antenna Switch 2 = -18 dB in Tracker and Antenna Switch 3 = -35 dB in Tracker and Antenna Switch	-	INT8U	0, 1
3	1	**RX_G**	**Rx Gain** 0 = +30 dB 1 = +24 dB 2 = +18 dB 3 = +12 dB 4 = +6 dB 5 = 0 dB 6 = -6 dB 7 = -12 dB	6 dB	INT8U	0..7
4	1 + 4 * BND_QTY	**TR_BANDS**	**Trackers Bands structure (see** Table 5A- 11**)**	-	structure	-

Table 5A- 11: Trackers Bands (Variable Length)

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	1	**BND_QTY**	**Number of trackers bands**	-	INT8U	1…255
1	structTrucker-BandLength * BND_QTY	**BANDS**	**Array of Trackers Bands (see** Table 5A- 12**)** Elements should be in increasing order of Start Trackers and without duplicating them.	-	structure	-

Table 5A- 12: Tracker Band (Length 5 Bytes)

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	2	**START_FREQ**	**Start of Tracker Band.** Note: There is no End of Tracker Band in this structure, but having in mind this structure is used only as an element of array, the End of Tracker Band is equaled to the Start Frequency of next element in array.	kHz	INT16U	1…65535
2	2	**STEP_FREQ**	**Step inside band.** All tuning frequencies in the band are given as follows: 1st tuning frequency is equal to START_FREQ, 2nd tuning frequency is equal to 1st + STEP_FREQ, 3rd tuning frequency is equal to 2nd + STEP_FREQ, etc. up to, but not including, the End of Band Note: Value 0 means that START_FREQ is the only tuning frequency in the band	kHz	INT16U	0…65535
4	1	**HW_CMD**	**Commanding byte to select band**	-	INT8U	0..255

Time Stamp

5:90. Time stamps are provided in UT with precision of 1 ms. **Table 5A- 13** describes common presentation of the time in the DPS packets (totaling 17 bytes).

Table 5A- 13: Time Stamp (Length 17 Bytes)

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	4	**YR**	**Year:** **YYYY**	Year	INTU ACD	-
4	2	**MON**	**Month:** **MM**	Month	INTU ACD	-
6	2	**DAY**	**Day of month:** **DD**	Day	INTU ACD	-
8	2	**HR**	**Hour:** **HH**	Hour	INTU ACD	-
10	2	**MIN**	**Minutes:** **MM**	Minute	INTU ACD	-
12	2	**SEC**	**Seconds:** **SS**	Second	INTU ACD	-
14	3	**MS**	**Milliseconds:** **Sss**	Milli-second	INTU ACD	-

Schedule

5:91. Measurement schedule, or simply *schedule*, describes sequence of program, up to 32 entries, running with relative time offset from the schedule start time. Schedule specification is a common part of commanding streams. Schedule contents are described in **Table 5A- 14** and schedule entry structure in **Table 5A- 15**.

NOTE

If the first schedule element Entry Table Size (ETS) is zero, then Duration (DUR) and Entry Table (ET) are omitted from Schedule, so that the empty Schedule occupies just 1 byte

Table 5A- 14: Schedule (Variable Length)

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	1	**ETS**	**Entry Table Size, i.e. number of entries in Entry Table** **If equals to 0 then DUR field is omitted.**	-	INT8U	0-32, 0 means empty schedule if duration is also 0, otherwise it is Idle schedule
1	4	**DUR**	**Schedule duration** 0 = immediate iteration after the last program of the schedule completes >0 = duration	msec	INT32U	0-4G ms, or 0-1192 hours, or 50 days
5	ETS x 5	**ET**	**Entry Table, consists of Schedule Entries (see** Table 5A-15)	-	Array of Schedule Entries	-

Table 5A- 15: Schedule entry (length 5 Bytes)

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	1	**PRN**	**Program Number**	-	INT8U	1 – 255
1	4	**OFF**	**Offset from the schedule beginning** **-1 = run immediately after previous program is done**	msec	INT32S	0-2G ms, or 0-596 hours, or 25 days

Housekeeping Header

5:92. Housekeeping Header structure is included in housekeeping packets, such as "I'm alive", Event Message, Error Message.

Table 5A- 16: Housekeeping Header (Length = 39)

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	3	**DESC_VERSION**	**DESC Release Version**	-		
3	1	**OP_STATE**	**Operation State:** 1 = Standby 2 = Diagnostic 3 = Scheduled Operations	-	INT8U	1, 2, 3
4	17	**TIME_STAMP**	**System clock time**	-	Table 5A- 13	N/A
21	17	**TOP_SST**	**Top SST in the SST queue**	-	Table 5A- 13	N/A
38	1	**TOP_SCHED**	**Top schedule number in the SST queue**	-	INT8U	0 … 64

Restricted Frequency Interval List

5:93. Restricted Frequency Interval List is a set of intervals of frequencies forbidden to transmit. Restricted Frequency Interval List contents are described in **Table 5A- 17** and **18**

Table 5A- 17: Restricted Frequency Interval List (Variable Length)

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	**1**	**RFIL_VER**	**Version of RFIL**	**-**	INT8U	>0
1	1	**N_D**	**Number of Restricted Frequency Intervals for Doppler**	-	INT8U	0 – 255
2..	RFI * N_D	**RFIL**	**Restricted Frequency Interval List (Restricted Frequency Intervals structure, see** Table 5A- 18)	-	RFI array	-
2 + RFI*N_D	1	**N_I**	**Number of Restricted Frequency Intervals for Ionogram**	-	INT8U	0 – 255
2 + RFI*N_D+1	RFI *N_I	**RFIL**	**Restricted Frequency Interval List (Restricted Frequency Intervals structure, see Table 5A- 18** Table 5A- 18: Restricted Frequency Interval (Length 4 Bytes))	-	RFI array	-

Table 5A- 18: Restricted Frequency Interval (Length 4 Bytes)

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	2	**SRFI**	**Start of Restricted Frequency Interval**	kHz	INT16U	1 kHz – 30000 kHz
2	2	**ERFI**	**End of Restricted Frequency Interval**	kHz	INT16U	1 kHz – 30000 kHz

SCIENCE DATA PACKETS

Science Data considerations

5:94. Science Data that produced by running some *Sounding Program* are called *Measurement*.

5:95. From the general point of view, *Measurement* characterized by Location, Time, Program, and Applied Processes List and contains scientific data that was taken at these location and time by implementing this Program and then have been processed further by applying all the processes in the Applied Processes List.

5:96. Each *Measurement* data are produced by running some Program that sends, using transmitter, a series of "Pulses" with specified interval between them. After any Pulse transmitted and before next Pulse, Program samples incoming signal many times producing Raw Science Data. Say, Raw Science Data are Science Data without any process applied to them. So we can see that Raw Science Data grouped by Pulses.

5:97. Further Raw Sciences Data undergo several known processes. Here are most popular of them given in the sequence of applying:

1. Channel Equalizing, mandatory. No data reduction.
2. RFI mitigation, recommended but may be omitted. No data reduction.
3. Pulse compression if applicable. No data reduction.
4. Sum complementary codes if applicable. Data are reduced by two times.
5. Regrouping by frequencies and calculation of Dopplers. No data reduction.
6. Ionogram calculation:
    i. Choosing the strongest (having maximum amplitude over all antennas) Doppler for each height.
    ii. Calculating angle of arrival for strongest Doppler.
    iii. For each height (for both ordinary and extraordinary data), leaving only, Doppler value itself, average amplitude over antennas of strongest Doppler, and angles of arrival.

5:98. We see that Science Data are grouped either by *Look* (*=Pulse*) or by *Frequency* so we can say about *Look* or *Frequency Groups*, or simply *Groups*, where each *Group* has one *Group Header* (containing information unique to this *Group*) and calculated, using Program and Applied Processes List, number of *Databins*.

5:99. Science Data are grouped by Pulse up to step 4 and grouped by Frequency after step 4.

5:100. Measurement size is big enough to fit into one or several packets. Usually hundreds or thousands of packets are needed to transmit data from **DESC** to **DCART**. One measurement may often exceed 100MB. So **DESC**, at the time of producing Measurement data, makes packets of this data and sends them to **DCART**. Having this in mind and the fact that even Frequency Group is big enough to fit into one packet, next section will be clearer for understanding.

Science Data Packet structure, packet type 0x81

5:101. The following is true.

1. Each Science Data packet includes only part of measurement.
2. All packets of the same measurement are enumerated starting from 1 and this number is called *Serial Number* of packet.
3. Packet may contain one or more *Groups*.
4. Packet may contain fractional part of *Group*.
5. Packet may contain not integral number of *Groups*.
6. Group may be split between packets.
7. Every packet duplicates some information (for example, Program), which is necessary to be interpreted even if not all packets of measurement reach **DCART**.

5:102. The data section of the science data packets contains the following parts:

- **DESC Release Version, Table 5A- 19**
- **Science Data Packet General Header**, **Table 5A- 20**, holding information related to the data packaging technique,
- **Preface**, **Table 5A- 21**, containing **Program** structure (which is the ***exact*** copy of Program that has been used by **DESC** for generating this measurement), **Time Stamp of start of measurement, Data Processing applied to the data so far,** and some other information.
- **Group**
  - **Group Header, Table 5A- 22**, repeated for each group
  - **Databins**

Major Release Version

Table 5A- 19: DESC Release Version, Length 3 Byte

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	1	**DESC_MAJ_VER**	**DESC Major Version**	-	INT8U	0 … 255
1	1	**DESC_MIN_VER**	**DESC Minor Version**	-	INT8U	0 … 255
2	1	**DESC_BLD_VER**	**DESC Build Version**	-	INT8U	0 … 255

Science Data Packet General Header

Table 5A- 20: Science Data Packet General Header, Length 15

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	4	**SER_NUM_PACKET**	**Serial Number of Packet within the measurement, counting from 1**	-	INT32U	> 0
4	4	**GROUP_INDEX**	**Group Index of the first Group in packet. All Groups are indexed starting from 0**	-	INT32U	
8	1	**N_GROUPS**	**Number of Groups in packet**	-	INT32U	1 … 255
9	4	**SER_NUM_DATABIN**	**Serial number of the first databin in the first Group, Counting from 1**	-	INT32U	> 0
13	2	**N_DATABINS**	**Number of Databins in the last Group**	-	INT32U	1 … 65535

Packet Preface

Table 5A- 21: Packet Preface Specification, Length Variable

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	17	**TIME_STAMP**	**Time Stamp of start time** (Table 5A- 13)	-	TS	
17	1	**SCH_NUMBER**	**Schedule Number (**0 means manual start of sounding)	-	INT8U	0…255
18	1	**PROG_NUMBER**	**Program Number**	-	INT8U	1…255
19	2	**PROC_APPLIED**	**Data Processing applied to data so far**	-	Data Processing structure	N/A
21	LEN	**PROG**	**Program Specification** (see Table 5A- 6 to Table 5A- 9)	-	-	-

Packet Group Header

Table 5A- 22: Packet Group Header, Length 6 (12 for Debugging)

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	4	**TIME_OFFSET**	**Time Offset of Frequency sounding from measurement start time (ST)**	ms	INT32U	0 to 4,294,967,296 ms or approx. 50 days
4	1	**RESTR_FLAG**	**Restricted Frequency Flag (0 – not restricted, 1 – restricted)**	-	INT8U	0, 1
5	1	**AS**	**Attenuation Selection** **Notes:** **1. It is value commanded to Rx gain control.** **2. Attenuation selection does not include Constant Gain (from Program)**	-	INT8S	0 … 7
6	2	**MAX**	**Absolute maximum value Re or Im data (saturation)** **12 bit – DPS4S** **14 bit – DPS4D**	-	INT16U	12 bit – 0… 2048, saturation 2049 14 bit – 0 … 8196 saturation 8197 16 bit – 0 … 32536 saturation 32537
8	2	**FREQ**	[4]**Frequency**	kHz	INT16U	100 to 30000 kHz
10	1	**POL**	[5]**Polarization (Ordinary – 0, Extraordinary – 1)**	-	INT8U	0, 1
11	1	**CODE**	[6]**Complementary Code Number:** -1 - Code is undefined for this program 1 - Code 1 2 - Code 2	-	INT8S	-1, 1, 2

Databins

5:103. We consider three types of Databins, Raw Databin, Doppler Databin, and Ionogram Databin.

5:104. Raw Databin is one quadrature sample, so it is equivalent to pair of numbers, which constitute one complex number and described in **Table 5A- 23**.

5:105. Doppler Databin is the piece of information that is used in Ionogram Data Structure and pertained to specified frequency, polarization, height, antenna, and Doppler. Doppler Databin described in **Table 5A- 24**.

5:106. Ionogram Databin is the piece of information that is used in Ionogram Data Structure and pertains to specified frequency, polarization and height. Ionogram Databin described in

[4] This is temporary field. It is used only for debugging
[5] See previous note
[6] See previous note

5:107. **Table 5A-** 25, **Table 5A- 26**, and **Table 5A- 27**.

5:108. The program specification and Process Applied determine Databin's layout and total number of data-bins collected in one Group. So, there are several cases.

A. ***Raw Data Structure***

5:109. For Raw data, data after RFI Mitigation or data after Pulse Compression have absolutely the same structure and we call this structure *Raw Data Structure*. The following is true for this structure.

1. *Group* is *Look*
2. Layout inside of *Look*: two dimensional array of *Raw Databins*, where the first dimension is Number of Antennas and the second dimension is Number of Heights to Sample, or shortly

   'Number of Antennas' x 'Number of Heights to Sample'
3. Layout of Data without fine frequencies multiplexing: five dimensional array of Looks, where
   a) 1st dimension is Number of Coarse Frequency Steps
   b) 2nd dimension is Number of Fine Frequency Steps
   c) 3rd dimension is Number of Integrated Repeats
   d) 4th dimension is Number of Polarizations
   e) 5th dimension is Number of Codes
4. Layout of Data with fine frequencies multiplexing: five dimensional array of Looks, where
   a) 1st dimension is Number of Coarse Frequency Steps
   b) 2nd dimension is Number of Integrated Repeats
   c) 3rd dimension is Number of Fine Frequency Steps
   d) 4th dimension is Number Polarizations
   e) 5th dimension is Number of Codes

B. ***Summed Complementary Data Structure***

5:110. We have this Data Structure after *Sum Complementary* process. It is absolutely the same structure as *Raw Data Structure* except just one thing, Layout of Data has only 4 dimensions as Code dimension disappeared.

C. ***Doppler Data Structure***

5:111. We have this Data Structure after *Doppler Calculation* process. The following is true for this structure.

1. *Group* is *Doppler Frequency Group*
2. Layout inside of *Doppler Frequency Group*: four-dimensional array of *Doppler Databins*, where

a) 1st dimension is Number of Polarizations

b) 2nd dimension is Number of Heights to Sample. It is equaled to Number of Ranges if measurement program parameter NRO (**N**umber of **R**anges to **O**utput) is zero, otherwise it is equaled to NRO.

c) 3rd dimension is Number of Antennas

d) 4th dimension is Number of Dopplers (= Number of Integrated Repeats)

3. Layout of Data: two dimensional array of *Doppler Frequency Groups*, where

a) 1st dimension is Number Of Coarse Frequency Steps or Number of Fixed Frequency repeats

b) 2nd dimension is Number Of Fine Frequency Steps

D. *Ionogram Data Structure*

5:112. We have this Data Structure after *Ionogram Calculation* process. The following is true for this structure.

1. *Group* is *Ionogram Frequency Group*

2. Layout inside of *Ionogram Frequency Group*: two-dimensional array of *Ionogram Databins*, where

a) 1st dimension is Number Of Polarizations

b) 2nd dimension is Number of Heights to Sample

3. Layout of Data: two dimensional array of *Ionogram Frequency Groups*, where

c) 1st dimension is Number of Coarse Frequency Steps

d) 2nd dimension is Number of Fine Frequency Steps

Table 5A- 23: Raw Databin, Length 4

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	2	**RE**	**Real part of quadrature, from 0 to 65535**	-	INT16U	0... 65535
2	2	**IM**	**Imaginary part of quadrature, from 0 to 65535**	-	INT16U	0 ...65535

Table 5A- 24: Doppler Databin Format, Length 4

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	2	**AMP**	**Amplitude, in linear scale, from 0 to 65535**	-	INT16U	0... 65535
2	2	**PH**	**Phase, from 0 to 360, but not including 360**	**360/65536 deg**	INT16U	0 ...65535

Table 5A- 25: Ionogram Databin Format 1, without PGH, Length 17

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	1	**DOPPLER**	**Sequential number of Doppler**	-	INT8U	0…255
1	2	**AMP1**	**1st antenna amplitude, linear scale, from 0 to 65535**	-	INT16U	0... 65535
3	2	**PH1**	**1st antenna phase, from 0 to 360, but not including 360**	**360/65536 deg**	INT16U	0 ...65535
5	2	**AMP2**	**2nd antenna amplitude, linear scale, from 0 to 65535**	-	INT16U	0... 65535
7	2	**PH2**	**2nd antenna phase, from 0 to 360, but not including 360**	**360/65536 deg**	INT16U	0 ...65535
9	2	**AMP3**	**3rd antenna amplitude, linear scale, from 0 to 65535**	-	INT16U	0... 65535
11	2	**PH3**	**3rd antenna phase, from 0 to 360, but not including 360**	**360/65536 deg**	INT16U	0 ...65535
13	2	**AMP4**	**4th antenna amplitude, linear scale, from 0 to 65535**	-	INT16U	0... 65535
15	2	**PH4**	**4th antenna phase, from 0 to 360, but not including 360**	**360/65536 deg**	INT16U	0 ...65535

Table 5A- 26: Ionogram Databin Format 2, with PGH, Length 19

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	1	**DOPPLER**	**Sequential number of Doppler**	-	INT8U	0…255
1	2	**AMP1**	**1st antenna amplitude, linear scale, from 0 to 65535**	-	INT16U	0... 65535
3	2	**PH1**	**1st antenna phase, from 0 to 360, but not including 360**	**360/65536 deg**	INT16U	0 ...65535
5	2	**AMP2**	**2nd antenna amplitude, linear scale, from 0 to 65535**	-	INT16U	0... 65535
7	2	**PH2**	**2nd antenna phase, from 0 to 360, but not including 360**	**360/65536 deg**	INT16U	0 ...65535
9	2	**AMP3**	**3rd antenna amplitude, linear scale, from 0 to 65535**	-	INT16U	0... 65535
11	2	**PH3**	**3rd antenna phase, from 0 to 360, but not including 360**	**360/65536 deg**	INT16U	0 ...65535
13	2	**AMP4**	**4th antenna amplitude, linear scale, from 0 to 65535**	-	INT16U	0... 65535
15	2	**PH4**	**4th antenna phase, from 0 to 360, but not including 360**	**360/65536 deg**	INT16U	0 ...65535
17	2	**PH_DIFF**	**Phase difference between this and next close frequency. This difference calculated for PGH mode, from 0 to 360, but not including 360**	360/65536 deg	INT16U	0 …65535

Table 5A- 27: Ionogram Databin Format 3, Length 4

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	1	**SDN**	**Sequential number of [7]Strongest Doppler**	-	INT8U	0 … 255
1	1	**AMP**	**Amplitude of strongest Doppler that averaged over antennas, given in dB scale**	dB	INT8U	0 … 255
2	1	**ZENITH**	**Zenith of source that corresponds to strongest Doppler, 0 to 90 Degrees**	0.35Deg = 90 / 255	INT8U	0 … 255
3	1	**AZIMUTH**	**Azimuth of source that corresponds to strongest Doppler, given as east deviation from geographic north direction, from 0 to 360 Degrees in east/clockwise direction.**	1.412Deg = 360 / 255	INT8S	-128 … 127

[7] Strongest doppler is the doppler that has maximum averaged value over antennas amplitude

HOUSEKEEPING PACKETS

I'm alive packet TYPE=0x01, Length = 38.

5:113. DESC send this packet to DCART every minute if no science data are being produced.

Table 5A- 28: "I'm Alive" Packet Structure

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	39	**HK_HEADER**	**Housekeeping Header**	-	Table 5A- 16	N/A

Event Message packet TYPE=0x02, Length is variable but not less than 41

5:114. DESC sends this packet to report a detected software condition.

Table 5A- 29: Event Message Packet Structure

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	39	**HK_HEADER**	**Housekeeping Header**	-	Table 5A- 16	N/A
39	2	**MESSAGE_ID**	**Message Ident**	-	INT16U	Table A-1
41	1	**ITEM_COUNT**	**Number of auxiliary information items**	-	INT8U	0 … 9
42	2 * ITEM_COUNT	**AUX_INFO**	**Auxiliary information items**	-	INT16U array	

Error message packet TYPE=0x03, Length is variable but not less than 41

5:115. DESC sends this packet to report a detected software error.

Table 5A- 30: Error Message Packet Structure

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	39	**HK_HEADER**	**Housekeeping Header**	-	Table 5A- 16	N/A
39	2	**ERROR_ID**	**Error Ident**	-	INT16U	Table A-2
41	1	**ITEM_COUNT**	**Number of auxiliary information items**	-	INT8U	0 … 9
42	2 * ITEM_COUNT	**ERROR_INFO**	**Auxiliary information items**	-	INT16U array	

PROGSCHED Countdown packet TYPE=0x04, Length = 45 bytes

5:116. DESC sends this packet to report upcoming start of a scheduled program or time left for the current running schedule.

Table 5A- 31: PROGSCHED Countdown Packet Structure

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	39	**HK_HEADER**	**Housekeeping Header**	-	Table 5A- 16	N/A
39	1	**SCHD_NUM**	**Current Schedule Number**	-	INT8U	1-255
40	1	**PROG_NUM**	**Upcoming Program Number** 0 = use to report time till the end of the current schedule	-	INT8U	0, 1-255
41	4	**TIME_LEFT**	**Time left until the event**	sec	INT32U	0..4G

BIT packet TYPE=0x05, Payload length =179 bytes

5:117. DESC sends the BIT housekeeping packets to report hardware sensor readings. The analysis of sensor readings for yellow/red high/low tolerance limits is responsibility of the DCART software.

Table 5A- 32: Hardware Sensors Payload Structure

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	39	**HK_HEADER**	**Housekeeping header**	-	Table 5A- 16	-
39	1	**SCH_NUMBER**	**Schedule Number (**0 means manual start of sounding)	-	INT8U	0…255
40	1	**PROG_NUMBER**	**Program Number**	-	INT8U	1…255
41	LEN	**PROG**	**BIT Program Specification** (see Table 5A- 6)	-	-	-
41+LEN	20	**STATIC SENSORS**	**Static sensor data collected in digital and analog channels**		Table 5A- 33	
61+LEN	16	**CASE0**	**Sensor data collected in Case #0 of BIT**	-	Table 5A- 34	-
77+LEN	16	**CASE1**	**Sensor data collected in Case #1 of BIT**	-	Table 5A- 34	-
93+LEN	16	**CASE2**	**Sensor data collected in Case #2 of BIT**	-	Table 5A- 34	-
109+LEN	16	**CASE3**	**Sensor data collected in Case #3 of BIT**	-	Table 5A- 34	-

Table 5A- 33 Static Sensor Data Collected in BIT

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	4	**DIGITAL**	**Status of 32 digital sensors A, B, C, and D** (Table 5A- 35)	-	4 x INT8U	n/a
4	16	**ANALOG**	**Status of static analog sensors** (Table 5A- 36) For each sensor, the maximum sensor value over a set of collected samples is obtained by DESC to report here	-	8 x INT16U	0..1023 (10 bit ADC)
Test ref			Table 5A- 33			

Table 5A- 34: Dynamic sensor data collected in BIT case 0, 1, 2, and 3

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	16	**ANALOG**	**Status of 8 dynamic analog sensors** (Table 5A- 37) For each sensor, the maximum sensor value over a set of collected samples is obtained by DESC to report here	-	8 x INT16U	-

Table 5A- 35: Digital Sensors

Bit #	Mnemonic on schematics	DCART Mnemonic	Description	Go condition
0	O/X	PWR_PREAMP_V	Preamp power	0
1	-15V	PWR_M15_V	-15 Volt power	0
2	-5V	PWR_M5_V	-5 Volt power	0
3	+3.3V	PWR_P3.3_V	+3.3 Volt power	1
4	+15V	PWR_P15_V	+15 Volt power	1
5	+12V	PWR_P12_V	+12 Volt power	1
6	OverTemp	PWR_OVER_TP	Power card overheating condition	1
7	HW Test Pat	PREP_HW_TESTPAT	Preprocessor HW test pattern	1
8	Tx_Card_Timeouts	TX_CARD_TIMEOUTS	Tx Card Commanding Timeouts since last BIT program	0
9	+18V	PWR_P18_V	+18 Volt power	1
10	Cmd_Timeouts	CMD_TIMEOUTS	Commanding Timeouts since last BIT program	0
11	RF_Noise_Low_V	RF_NOISE_LOW_V	Environment RF noise Voltage in Antenna with 0 dB gain in antenna switch measured at the Tracker #4 input	0
12	RF_Noise_High_V	RF_NOISE _HIGH_V	Environment RF noise Voltage in Antenna with 9 dB gain in antenna switch measured at the Tracker #4 input	0
13	Rx_Card_Timeouts	RX_CARD_TIMEOUTS	Rx Card Commanding Timeouts since last BIT program	0
14	TRACKER1_Card_Timeouts	TRACKER1_CARD_TIMEOUTS	TRACKER1 Card Commanding Timeouts since last BIT program	0
15	TRACKER2_Card_Timeouts	TRACKER2_CARD_TIMEOUTS	TRACKER2 Card Commanding Timeouts since last BIT program	0
16	TRACKER3_Card_Timeouts	TRACKER3_CARD_TIMEOUTS	TRACKER3 Card Commanding Timeouts since last BIT program	0
17	TRACKER4_Card_Timeouts	TRACKER4_CARD_TIMEOUTS	TRACKER4 Card Commanding Timeouts since last BIT program	0
18	BIT_Card_Timeouts	BIT_CARD_TIMEOUTS	BIT Card Commanding Timeouts since last BIT program	0
19				
20				
21				
22				
23				

Table 5A- 36: Analog Static Sensors

Word #	Mnemonic on schematics	DCART Mnemonic	Description	Range
0	TEMP_SENSE	AMP_TP	Temperature sensor in amplifier chassis	0..1023
1	PDT	PWR_TP	Temperature sensor on power card	0..1023
2	-	-	-	-
3	-	-	-	-
4	RPD	TIM_DATACLK_FR	Up converter Data I&Q Clock frequency	0..1023
5	CP/PE	TIM_PARPORT_FR	Parallel port timing clock	0..1023
6	-	-	-	-
7	-	-	-	-

Table 5A- 37: Analog Dynamic Sensors

Word #	Mnemonic on schematics	DCART Mnemonic	Description	Range
0	**RF1**	**AMP_RF1_V**	**RF voltage amplitude at the output of amplifier 1** -1 if R pulse is missing	0..1023
1	**RF2**	**AMP_RF2_V**	**RF voltage amplitude at the output of amplifier 2** -1 if R pulse is missing	0..1023
2	**TX1**	**TX_OUT1_V**	**Output voltage at transmitter card, channel 1** -1 if R pulse is missing	0..1023
3	**TX2**	**TX_OUT2_V**	**Output voltage at transmitter card, channel 2** -1 if R pulse is missing	0..1023
4	-	**RX_MAX1**	**Maximum amplitude value in the receiver channel 1** 65535 if R pulse is missing	0..46340
5	-	**RX_MAX2**	**Maximum amplitude value in the receiver channel 2** 65535 if R pulse is missing	0..46340
6	-	**RX_MAX3**	**Maximum amplitude value in the receiver channel 3** 65535 if R pulse is missing	0..46340
7	-	**RX_MAX4**	**Maximum amplitude value in the receiver channel 4** 65535 if R pulse is missing	0..46340

Trackers Calibration data packet TYPE=0x06, Payload length is variable

5:118. DESC sends the Tracker Calibration packet as a result of running of Trackers Calibration program. This packet, which contains information needed to tune hardware to any particular frequency, will be permanently saved by DCART and will be transferred to DESC each time upon the connection.

Table 5A- 38: Tracker Calibration payload structure

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	39	**HK_HEADER**	**Housekeeping header**	-	Table 5A- 16	-
39	1	**SCH_NUMBER**	**Schedule Number (**0 means manual start of sounding)	-	INT8U	0…255
40	1	**PROG_NUMBER**	**Program Number**	-	INT8U	1…255
41	P_LEN	**PROG**	**Trackers Calibration Program Specification** (see Table 5A- 6)	-	-	-
LEN	V_LEN	**VOLT**	**Voltages.** **Each voltage occupies one byte and corresponds to its tuning frequency in the Trackers Band List described in PROG structure**	-	Array of INT8U	

TELEMETRY PACKET SUMMARY

Table 5A- 39: Telemetry Packet Summary

Packet ID	Packet Mnemonic	Packet Title
0x81	SCI_DATA	Science Data
0x01	HK_ALIVE	I Am Alive
0x02	HK_EVENT	Event Message
0x03	HK_ERROR	Error Message
0x04	HK_CNTDOWN	PROGSCHD Countdown
0x05	HK_BIT	Hardware Sensors Report

ERROR/EVENT ID AND AUXILIARY INFORMATION

Table 5A- 40: Error Message ID and Auxiliary Information

Error ID	Message Text	Item Count	Information
0001h	Command stream out of sync, skipped %d bytes to next sync pattern	1	Number of skipped bytes until next sync pattern
0002h	Bad checksum in packet 0x%02X	1	Command ID
0003h	Command packet is %d byte long, too large for packet pool	1	Byte Count
0004h	Unknown Command 0x%02X	1	Command ID
0005h	Wrong packet length of %d bytes for command 0x%02X	2	Command ID Byte Count
0006h	Not in Standby state for upload command 0x%02X to proceed	1	Command ID
0007h	Upload packet 0x%02X with grouping flag 0x%02X and sequence count %d is out of sequence	3	Command ID Grouping Flag Sequence Count
0008h	Incomplete upload sequence of %d packets is discarded	1	# of accepted packets
0009h	Upload data not available to execute command 0x%02X	1	Command ID
000Ah	System in Standby state, cannot run command 0x%02X	1	Command ID
000Bh	System in Standby state, cannot start schedule %d at SST %4d.%02d.%02d %02d:%02d:%d.03%d	8	Schedule # Year Month Day Hour Minute Second Millisecond
000Ch	Command 0x%02X: bad EEPROM bank number %d	2	CommandID Bank #
000Eh	Cannot execute command 0x%02X, command queue is full	1	CommandID

0011h	Unstable clock, time drift is %d sec or, if information parameter value is 0, Can not set time, check transmitter card	1	Time drift in sec 0 is a special value that means time can not be set due to malfunction of transmitter card
0012h	Bad timing while running program %d, processed %d looks	2	Program # Processed # of looks
2101h	Bad program number %d in PROG_UPLOAD command	1	Program #
2201h	Bad schedule number %d in SCHD_UPLOAD command	1	Schedule #
2202h	Bad program number %d in schedule %d definition	2	Program # Schedule #
3101h	Cannot add schedule %d at %4d.%02d.%02d %02d:%02d:%d.03%d: Bad timestamp in SST	8	Schedule # Year Month Day Hour Minute Second Millisecond
3102h	Cannot add start of schedule %d at %4d.%02d.%02d %02d:%02d:%d.03%d: SST queue is full	8	Schedule # Year Month Day Hour Minute Second Millisecond
3701h	Schedule %d is empty, cannot SCHD_RUN	1	Schedule #
3A01h	Program %d is empty, cannot PROG_RUN	1	Program #
8401h	Nothing to run in Scheduled Operations state: SST Queue is empty	0	-

Table 5A- 41: Event Message ID and Auxiliary Information

Message ID	Message Text	Item Count	Information
0007h	Program %d has been terminated	1	Program #
0008h	Schedule %d has been terminated	1	Schedule #
0009h	System clock time corrected by %d ms	1	Time correction in ms -1 if the value is outside the representation limits
1086h	Command Half-Octave Filter Switch Frequencies Table acknowledged	0	-
1006h	Command Trackers Calibration Data acknowledged	0	-
1030h	Commanding Bus acknowledged	0	-
1032h	Command SST_FLUSH acknowledged	0	-
1033h	Auto-drift message acknowledged	0	-
1071h	Command PROG_UPLOAD acknowledged, new program %d is accepted	1	Program #
1072h	Command PROG_START acknowledged, starting program %d	1	Program #
1073h	Command STOP acknowledged	0	-
1074h	Command SCHD_UPLOAD acknowledged, new schedule %d is accepted	1	Schedule #
1075h	Command SCHD_START acknowledged, starting schedule %d	1	Schedule #
1076h	Command ADD_SST acknowledged, adding schedule %d at %4d.%02d.%02d %02d:%02d:%d.03%d	8	Schedule # Year Month Day Hour Minute Second Millisecond
1077h	Command RFIL_UPLOAD acknowledged, new RFIL version is %d	1	RFIL version
1078h	Command RFIL_FLUSH acknowledged	0	-
1081h	Command STATE_STANDBY acknowledged	0	-
1082h	Command STATE_DIAG acknowledged	0	-
1084h	Command STATE_OPER acknowledged	0	-
1085h	Command Global Parameters acknowledged	0	-

ANNEX B

DCART TO DESC INTEFACE CONTROL DOCUMENT

COMMAND PACKETS

5:119. DCART send these packets to DESC.

Periodic Message packet TYPE=0x70, Length = 17.

5:120. The packet is used to set time on the DESC computer.

Table 5B- 1: Periodic Message packet TYPE=0x70, Length = 17

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	Time LEN	**TS**	**Time Stamp** (see Table 5A- 13)	-		

Switch to Standby state packet TYPE=0x81, Length = 0.

5:121. The packet is used to set DESC in Standby state.

Switch to Diagnostic state packet TYPE=0x82, Length = 0.

5:122. The packet is used to set DESC in Diagnostic state.

Switch to Scheduled Operations state packet TYPE=0x84, Length = 0.

5:123. The packet is used to set DESC in Scheduled Operations state.

Load program packet TYPE=0x71, Length = LEN.

5:124. The packet is used by DCART to upload program to DESC that uses it to fill the appropriate program definition structure (see **Table 5A- 6 to Table 5A- 9**)

Table 5B- 2: Load program packet TYPE=0x71, Length = LEN

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	1	**PRN**	**Program Number**	-	INT8U	1..255
1	LEN	**PR**	**Operation** (Table 5A- 6 **to** Table 5A- 9)		PR struct	

Start program packet TYPE=0x72, Length = 1

5:125. The packet is used to start program. DESC should stop current program and start new program immediately.

Table 5B- 3: Start program packet TYPE=0x72, Length = 1

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	1	PRN	Program Number	-	INT8U	1..255

Stop currently running program packet TYPE=0x73, Length = 0.

5:126. The packet is used to stop any currently running program.

Load schedule packet TYPE=0x74, Length is variable

5:127. The packet is used to load schedule to the schedule structure (**Table 3-3**)

Table 5B- 4: Load schedule packet TYPE=0x74, Length is variable

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	1	SCHN	Schedule Number	-	INT8U	1..255
1	LEN	SCH	Schedule (Table 5A- 14)		SCH struct	

Start schedule packet TYPE=0x75, Length = 1

5:128. The packet is used to start schedule. DESC should stop current schedule and current program and start new schedule immediately.

Table 5B- 5: Start schedule packet TYPE=0x75, Length = 1

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	1	SCH_N	Schedule Number	-	INT8U	1..255

Load Start Schedule Time (SST) packet TYPE=0x76, Length = 18

5:129. The packet is used to start schedule at certain time. At that time DESC should stop current schedule and current program and start new schedule.

Table 5B- 6: Load Start Schedule Time (SST) packet TYPE=0x76, Length = 18

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	1	SCH_N	Schedule Number	-	INT8U	1..255
1	17	TS	Time stamp (Table 5A- 13)	-	TS struct	

Flush Start Schedule Time (SST) Queue packet TYPE=0x32, Length = 0

5:130. The packet is used as a request to flush SST queue in DESC memory.

Load Restricted Frequency Interval List packet TYPE=0x77, Length is variable

5:131. The packet is used to set list of restricted frequencies. DESC should not transmit on these frequencies but still collects and reports data.

Table 5B- 7: Load Restricted Frequency Interval List packet TYPE=0x77, Length is variable

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	RFIL LEN	**RFIL**	**Restricted Frequency Interval List** (Table 5A-17)	-	RFIL struct	

Clean Restricted Frequency Interval List packet TYPE=0x78, Length = 0

5:132. The packet is used to clean list of restricted frequencies.

Reboot TYPE=0x79, Length = 0.

5:133. The packet is used to reboot Control computer.

Auto-drift Message packet TYPE=0x33, Length = 25.

5:134. The packet is used to set new recommended frequency in the auto-drift programs on the DESC computer. Two frequencies are available in the packet, FR1 for F layer, and FR2 for E layer drift. The appropriate frequency is selected by comparing height parameters HR1 and HR2 that accompany frequencies FR1 and FR2 with the bottom-top settings on the auto-drift programs. If the height parameter is within the bottom-top range of the sounding operation and time is not more than 1.5 hour from current time than DESC replaces the nominal fixed frequency value in the program specification with the new recommended value from the packet. DESC attempts to set FR1 using H1 and after that FR2 using H2.

5:135. Heights are given in the units compatible with bottom-top range fields of the sounding operation.

Table 5B- 8: Auto-drift Message packet TYPE=0x33, Length = 25

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	Time LEN	**TS**	**Time Stamp** (see Table 5A- 13)	-		
17	2	**H_F-LAYER**	**Height range one (F layer, range 80 is 100 km)**	1.25 km	INT16U	0 km – 2000 km
19	2	**FR_F-LAYER**	**Recommended frequency for drift measurements at HR1** **0 = no recommendation available**	kHz	INT16U	0, 1 kHz – 30000 kHz
21	2	**H_E-LAYER**	**Height range two (E layer, range 160 is 200 km)**	1.25 km	INT16U	0 km – 2000 km
23	2	**FR_E-LAYER**	**Recommended frequency for drift measurements at HR2** **0 = no recommendation available**	kHz	INT16U	0, 1 kHz – 30000 kHz

Global Parameters packet TYPE=0x85, Length = 3.

5:136. The packet is used to set global parameters on the DESC computer. Packed must be send at DCART-DESC reconnect, and at Global Parameters change.

Table 5B- 9: Global Parameters packet TYPE=0x85, Length = 3

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	1	**DELAY_0_KM**	**Delay for 0 km (from beginning of R-Pulse) depends on receiver script.**	1.25 km	INT8U	0..255
1	1	**DELAY_80_KM**	**Delay for 80 km (from beginning of R-Pulse) depends on receiver script.**	1.25 km	INT8U	0..255

2	1	**ENABLE_TR_BAND**	**Enable tracker band switching** **1 = enable, normal operational mode (always 1 in operational state)** **0 = disable, only for band's width and shape testing**	boolean	INT8U	0, 1
3	4	**CRISTAL_CONTROL**	**2 x (COMMAND BYTE, DATA BYTE)** **This data are sending to DAC to provide correction of voltage to Digisonde® general clock Oven Controlled 61.44 MHz Oscillator. This is DCART Global parameter. It need to be tuned for every particular Digisonde®.** **Controlling address for DESC to command is 0x2C.** **It is two possible ways to command:** **First - command byte 0x01, data XX** **Second - command byte 24, data XX** **or** **First - command byte 0x05, data XX** **Second - command byte 20, data XX**	-	4 x INT8U	-

Trackers Calibration Data packet TYPE=0x06, Payload length is variable

5:137. DCART sends the Load Tracker Calibration Data packet at the time of the connection. This packet contains information needed for tuning hardware to any particular frequency.

Table 5B- 10: Trackers Calibration Data packet TYPE=0x06, Payload length is variable

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	39	**HK_HEADER**	**Housekeeping header**	-	Table 5A- 16	-
39	1	**SCH_NUMBER**	**Schedule Number (**0 means manual start of sounding)	-	INT8U	0…255
40	1	**PROG_NUMBER**	**Program Number**	-	INT8U	1…255
41	P_LEN	**PROG**	**Trackers Calibration Program Specification** (Table 5A-10 - Table 5A- 12)	-	-	-
LEN	V_LEN	**VOLT**	**Voltages.** **Each voltage occupies one byte and corresponds to its tuning frequency in the Trackers Band List described in PROG structure**	-	Array of INT8U	

5:138. This is exactly the same structure as for Payload Trackers Calibration which is created by DESC as the result of running Trackers Calibration program.

Amplifier Half-Octave Filter Switch Frequencies Table TYPE=0x86, Payload length is variable

5:139. DCART sends the Amplifier Half-Octave Filter Switch Frequencies Table at the time of the connection. This packet contains information needed to switch amplifier to the correct filter band for any particular frequency.

Table 5B- 11: Amplifier Half-Octave Filter Switch Frequencies Table TYPE=0x86, Payload length is variable

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	1	**SIZE**	**Size – number of switch Frequencies**	-	INT8U	1…7
1	SIZE * 2	**FREQ**	**List of Switch Frequencies**	kHz	INT16U	0, 1 kHz – 30000 kHz

5:140. Current Amplifier has seven switch frequencies. Typical example from StationSpecific.UDD:

*936 < 1690 2450 4100 5550 10950 16150 22100 >

COMMAND LIST SUMMARY

Table 5B- 12: COMMAND LIST SUMMARY

Command ID	Command Mnemonic	Command Title
0x70	PM	Periodic Message
0x71	PROG_UPLOAD	Upload program definition
0x72	PROG_START	Start program
0x73	STOP	Stop currently running program
0x74	SCHD_UPLOAD	Upload schedule definition
0x75	SCHD_START	Start schedule
0x76	SST_UPLOAD	Upload new SST
0x32	SST_FLUSH	Flush SST table
0x77	RFIL_UPLOAD	Upload new RFIL table
0x78	RFIL_FLUSH	Clear RFIL table
0x79	SYS_REBOOT	Reboot control computer
0x81	STATE_STANDBY	Switch to standby state
0x82	STATE_DIAG	Switch to diagnostics state
0x84	STATE_OPER	Switch to scheduled operations state

ANNEX C

DCART INTEFACE CONTROL DOCUMENT FOR DATA PRODUCTS

UNIFORM MEASUREMENT STORAGE, VERSION 3

General considerations

5:141. **UMS** stands for Uniform Measurement Storage, which is the format for **DPS4D** data. **UMS** comprises many different types of DPS4D science data; ionograms, drift, raw, and others. This format is comprehensive in the sense that it contains not only the data produced by **DPS4D**, but also all supplemental information that is necessary for data understanding and analysis.

5:142. **UMS** format is backward compatible format, it is assumed that not only the latest version of the format will be maintained by up-to-date software (DCART, SAO-X, Drift-X), but all previous **UMS** versions will be also compatible with it. UMS version 3 is the current/latest version. Also be aware, the format includes many different structures, and several of the substructures are also version controlled. The version of the substructure cannot be greater than **UMS** version.

5:143. Science Data are arranged in Measurements. From a general point of view, Measurements are characterized by Location, Time, Program, and Applied Processes List, and contain scientific data that was collected at the Location and Time by implementing aProgram and then processed further by applying the processes in the Applied Processes List.

5:144. Measurement data is produced by collecting a series of samples at a program defined rate of either 100 Hz or 200 Hz. Incoming data samples are collected in chunks called “looks” which can contain either 256 or 512 samples per channel (program depending). The term “look” is in reference to the period of time during which the equipment collects samples while listening (or looking) for some signal of interest. This output without further processing is known as Raw Science Data.

5:145. Further Raw Science Data will undergo several known processing stages. Here they are in the sequence applied:

1. Channel equalizing. Mandatory. No data reduction.
2. Radio Frequency Interference Mitigation. Recommended, but may be omitted. No data reduction.
3. Pulse Compression, if applicable. No data reduction.
4. Sum complementary codes, if applicable. Data are reduced by two times.
5. Regroup by frequencies and calculate Dopplers. No data reduction.

5:146. At this point processing splits into two branches depending on Program purpose to either produce an Ionogram “snapshot” of ionosphere taken over a large number of frequencies with coarse Doppler resolution, or Drift Data, a high resolution Doppler measurement of the ionosphere taken over a small number of selected frequencies.

5:147. There exist two branches of processing after step 5, for Ionogram and for Drift Data.

For Ionogram Data:

A. Choose the strongest (having maximum amplitude over all antennas) Doppler for each height.

B. Calculate the angle of arrival for strongest Doppler.

C. For each height (for both ordinary and extraordinary data) we leave, Doppler value itself, average amplitude over antennas of strongest Doppler, and angles (zenith and azimuth) of arrival.

For Drift Data:

A. Reduce Drift Data by excluding weak Dopplers, i.e. Dopplers that have "average over antennas" amplitude less than most probable amplitude (for Dopplers of the same frequency and height) plus sum threshold. The strong Dopplers, are also called Sources of Reflection (or just "Sources"). DFT2Sky.exe program does this.

B. Calculate angles of arriving for all Sources, reducing data further, approximately 4 times for 4 antennas. Presently it can be done only by DFT2Sky.exe. Produced data is called Skymap Data.

C. Calculate bulk velocity using statistical behavior of Sources. Currently this processing is performed by the utility DDAV.EXE. The data product is called Velocity Data.

5:148. Let's put aside Skymap and Velocity Data as they differ from others. We see that Science Data are grouped either by Look or by Frequency, so we can say about Look or Frequency Groups, where each Look/Frequency Group has one Look/Frequency Header (containing information unique to the look/frequency) and, predicted out of Program and Applied Processes List, constant number of Databins collected on the look or frequency.

5:149. Science Data are grouped by Looks up to step 5 and grouped by Frequency after step 5. We will use the following structures:

Measurement, Measurement Signature, Measurement Header, Measurement General Header, Preface, Look Group, Frequency Group, Look Header, Frequency Header and also auxiliary structures as Antenna Configuration, Antenna Coordinates Array, Coordinates.

5:150. Measurement consists of:

- Measurement Header
- Look or Frequency Groups, repeated as many times as describes in Preface

5:151. Measurement Header consists of:

- Measurement Signature
- Generic Format Measurement Version
- Measurement General Header
- Versioned Preface

Table 5C- 1: Version 3 Measurement Header, length is variable

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	6	**SIGNATURE**	**Measurement Signature contains six bytes fixed data 0xFE, 0xFA, 0x31, 'D', 'P', 'S'** **Each Measurement starts from these bytes.**	N/A	INT8U array	N/A
6	1	**UMS_VER**	**UMS format version.** **Contains 3, as this is description of version 3 Measurement format.**	N/A	INT16U	3-255
7	7	**MGHDR**	**Measurement General Header**	N/A	N/A	N/A
14	P_len	**V_PREF**	**Versioned Preface, see** Table 5C- 3	N/A	N/A	N/A

Table 5C- 2: Measurement General Header, length 7 bytes

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	4	**M_LEN**	**Length of Measurement, in bytes. Signature is included.** **Value 0 means abnormal stop of measurement creating process and so this measurement has to be considered as damaged and not to be underwent further normal consideration.**	N/A	INT16U	0 … 4,294,967,295
4	1	**M_COMPL**	**Completeness.** **It is calculated as ratio of length of measurement taken from field LENGTH to complete length of measurement.** **So the maximum possible value 100 means measurement is completed and any other value means some incompleteness.** **The less value – the more incompleteness.**	%	INT8U	0 … 100
5	1	**M_TRUNC**	**This field can keep only two values:** **0 – measurement is not truncated, means tail of measurement is present.** **1 – measurement is truncated, means tail of measurement is lost.**	N/A	INT8U	0 or 1
6	1	**M_N_GAPS**	**Number of gaps in measurement data.** **For completed measurement this value is always 0.** **Value 255 means 255 or more gaps.**	N/A	INT8U	0 … 255

Table 5C- 3: Versioned Preface Specification, length is variable

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	1	**VER**	**Preface version**	N/A	INT8U	1 …255
1	P_LEN	**PREF**	**Preface of version specified in previous byte.** **See table** Table 5C- 4 **for Preface v. 1**	N/A	INT8U	0 … 100

Table 5C- 4: Preface v.1 specification, length is variable

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	2	**SID**	**Station Identification Number**	N/A	INT16U	0 … 65535
2	17	**TIME_STAMP**	**Time Stamp of start time** **See table** Table 5A- 13	N/A	TS	N/A
19	4	**M_RUNTIME**	**Real length of measurement**	Ms	INT32U	0 …4,294,967,295 Up to 50 days, approx.
23	2	**LAT**	**Latitude, from -90 deg to 90 deg**	Hun-dredth of Degrees	INT16S	-9000 to 9000
25	2	**LON**	**Eastern Longitude, from 0 to 360 deg**	Hun-dredth of Degrees	INT16U	0 to 36000
27	5	**URSI**	**URSI code given in ASCII characters**	N/A	ASCII bytes	N/A
32	20	**STN**	**Station name given in ASCII characters**	N/A	ASCII bytes	N/A
52	58	**ANT_CONF**	**Antennas configuration (table 5C-5)**	N/A	ACONF	N/A
110	8	**EQUIP**	**Equipment, given as ASCII characters**	N/A	ASCII bytes	N/A
118	1	**DESC_MAJ_VER**	**DESC Major Version** **Informative field**	N/A	INT8U	0 … 255
119	1	**DESC_MIN_VER**	**DESC Minor Version** **Informative field**	N/A	INT8U	0 … 255
120	2	**DESC_BLD_NUM**	**DESC Build Number** **Informative field**	N/A	INT8U	0 … 65535
122	1	**DCART_MAJ_VER**	**DCART Major Version** **Informative field**	N/A	INT8U	0 … 255
123	1	**DCART_MIN_VER**	**DCART Minor Version** **Informative field**	N/A	INT8U	0 … 255
124	2	**DCART_BLD_NUM**	**DCART Build Number** **Informative field**	N/A	INT8U	0 … 65535
126	1	**SCH_NUM**	**Schedule Number** **0 means manual start of sounding**	N/A	INT8U	0…255
127	1	**PROG_NUM**	**Program Number**	N/A	INT8U	1…255
128	1	**NAPS**	**Number of Applied Process Steps**	N/A	INT8U	
129	**NAPS**	**APS**	**Applied Process Steps. Each Process Steps occupies one byte and contain Process Step Code as following:** **1 – RFIM** **2 – Pulse Compression** **3 – Sum Complementary Codes** **4 – Doppler Calculation** **5 – Ionogram Producing**	N/A	Array of Process Codes	N/A
129 + NAPS	1	**NP_DESC**	**Number of Processes that have been done by DESC.** **If 0 then all processes have been done by DCART, otherwise it indicates number of first processes in APS that have been done by DESC.**	N/A	INT8U	0 … 255
130 + NAPS	**P_LEN**	**V_PROG**	**Versioned Program Specification** **First byte contains the version of Program structure, which has to be equal to 3, presently. See one of the Tables, depending of the value of the second byte, Operation Code:** **5A-6 for Sounding Operation, Op Code 1** **5A-8 for Built-In Test Operation, Op Code 2** **5A-9 for Channel Equalizing Operation, Op Code 3** **5A-10 for Trackers Calibration Operation, Op Code 4**	N/A	N/A	N/A
130 + NAPS + P_LEN	**GP_LEN**	**GLOB_PAR**	**Global parameters** **See table** Table 5C-30	N/A	N/A	N/A

130 + NAPS + P_LEN + GP_LEN	**SP_LEN**	**PROCS_STEP_PARAMS**	**Applied processing step's parameters** **This structure will not be present if no processing steps were applied, i.e. for raw data.** **On the other hand, if at least one processing step has been applied then "raw data processing step" also will be added at the beginning.** **See table** Table 5C- 32: Processing Steps' parameters, variable lengthTable 5C- 32	N/A	N/A	N/A
130 + NAPS + P_LEN + GP_LEN + SP_LEN	**1**	**CCEQ_FLAG**	**If 0 then no CCEQ correction table will be appended after this byte.** **If 1 then CCEQ correction table will appended after this byte.**	N/A	INT8U	0, 1
131 + NAPS + P_LEN + GP_LEN + SP_LEN	**CT_LEN**	**CCEQ_TBL**	**Correction table for channel equalization.** **Note that correction coefficients will be only for those frequencies that are presented in this measurement according to program definition.** **See table** Table 5C- 34	N/A	N/A	N/A

Table 5C- 5 : Antennas configuration, length is variable, (58 for 4 antennas)

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	1	**ANT_NUM**	**Number of antennas**	N/A	INT8U	4
1	1	**ANT_LOUT**	**Antenna Layout:** **0 - non-standard layout** **3 - four-antenna standard** **4 - four-antenna mirrored**	N/A	INT8U	0, 3, 4
2	2	**ANT_DEVN**	**Antenna Deviation:** **Deviation, in of degrees, of direction 3-1 from compass north. Values are from -180 to 180. Positive means counter-clockwise.** **It is used only for standard layouts**	Hundredth of Degrees	INT16S	-18000 .. 18000 (from -180 deg to 180 deg)
4	4	**ANT_MAXD**	**Antenna Max Distance:** **The max distance between antennas in meters.** **It is used only for standard layouts.** **As all standard layouts assumed equilateral triangles then MAXDIST for 4-antennas standard layout is equal to the length of triangle side.**	Centimeter	INT32U	1 … 4,294,967,295 (from 1 cm to approx. 42K km)
8	2	**X_AXIS_DECL**	**DECLINATION (angle) OF X-AXIS from Geographic Pole. Values from 0 to 180 degrees mean clockwise declination and values from 0 to -180 degrees mean anti-clockwise declination**	Hundredth of Degrees	INT16S	-18000 .. 18000 (from -180 deg to 180 deg)
10	12 x **ANT_NUM**	**ANT_COOR**	**Array of Coordinates structure** (Table 5C- 6)	N/A	COOR array	N/A

5:152. Antennas coordinates array, number of elements = number of antennas

This is an array of Coordinates structures, 1st element is the first antenna coordinates and so on.
The following is true.

A. Antenna 1 at (0, 0, 0)
B. X-axis is on the ground level and declines from geographic pole direction by X_AXIS_DECL degrees
C. Y-axis is on the ground level and points 90 degrees counterclockwise from X-axis

Table 5C- 6: Coordinates configuration, length 12

Byte Offset	Byte Len	Mnemonics	Description	Units	Type	Range
0	4	**X**	**X-coordinate in centimeters**	Centimeter	INT32S	-2,147,483,648 to 2,147,483,647 (from -21K km to 21K km, approx.)
4	4	**Y**	**Y-coordinate in centimeters**	Centimeter	INT32S	-2,147,483,648 to 2,147,483,647 (from -21K km to 21K km, approx.)
8	4	**Z**	**Z-coordinate in centimeters**	Centimeter	INT32S	-2,147,483,648 to 2,147,483,647 (from -21K km to 21K km, approx.)

Table 5C- 7: Look Header, length 22

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	4	**LN**	**Look Number, sequential number starting from 0**	N/A	INT16U	0 …4,294,967,295
4	4	**PSO**	**Time Offset of Look from measurement start time (ST)**	ms	INT32U	0 to 4,294,967,295 ms or approx. 50 days
8	2	**F_OFF**	**Offset of applied frequency from nominal frequency.** **Nominal frequency calculated using Look Number and Frequency Stepping Law (from Program structure)**	kHz	INT16S	-32768 … 32767
10	1	**RFF**	**Restricted Frequency Flag (0 – not restricted, 1 – restricted)**	N/A	INT8U	0, 1
11	8	**S_F**	**Scale Factor. When data are saved into external storage they are checked against overflowing and if it is occurred than all data in this look divide on this calculated Scale Factor. Upon restoring from you need multiply data on Scale Factor.** **Note, that for raw data this coefficient will be equal to 1, 0x3FFF0000 in hexadecimal** **Reference for double number representation format IEEE754:** **http://steve.hollasch.net/cgindex/coding/ieeefloat.html**	N/A	Double that follows specification IEEE754	As any non-negative double value in Java
19	1	**AS**	**Attenuation that has been applied to the data** There are only 8 possible values can be reported presently, -30dB, -24dB, -18dB, -12dB, -6dB, 0dB, 6dB, 12dB Negative values mean gain, for example, -30dB means 30dB gain has been applied Note: Attenuation selection does not include Constant attenuation (from Program)	dB	INT8S	Only the following 8 values are valid: -30, -24, -18, -12, -6, 0, 6, 12
20	2	**SAT**	**Saturation value. The following values are possible:** 8192 – no saturation but need more gain 16384 – no saturation, perfect gain 32768 – might be saturated, need less gain	N/A	N/A	8192, 16384, 32768

Table 5C- 8: Frequency Header, length 22

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	4	**FRN**	**Frequency Number, sequential number starting from 0**	N/A	INT16U	0 …4,294,967,295
4	4	**FSO**	**Time Offset of Frequency sounding from measurement start time (ST)**	ms	INT32U	0 to 4,294,967,296 ms or approx. 50 days
8	2	**F_OFF**	**Offset of applied frequency from nominal frequency.** **Nominal frequency calculated using Look Number and Frequency Stepping Law (from Program structure)**	kHz	INT16S	-32768 … 32767
10	1	**RFF**	**Restricted Frequency Flag (0 – not restricted, 1 – restricted)**	N/A	INT8U	0, 1

11	8	**S_F**	**Scale Factor. When data are saved into external storage they are checked against overflowing and if it is occurred than all data in this look divide on this calculated Scale Factor. Upon restoring from you need multiply data on Scale Factor.** **Note, that for raw data this coefficient will be equal to 1, 0x3FFF0000 in hexadecimal** **Reference for double number representation format IEEE754: http://steve.hollasch.net/cgindex/coding/ieeefloat.html**	N/A	Double that follows specifi-cation IEEE754	As any non-negative double value in Java
19	1	**AS**	**Attenuation Selection** There are only 8 possible values can be reported presently, -30dB, -24dB, -18dB, -12dB, -6dB, 0dB, 6dB, 12dB Negative values mean gain, for example, -30dB means 30dB gain has been applied Note: Attenuation selection does not include Constant attenuation (from Program)	dB	INT8S	Only the following 8 values are valid: -30, -24, -18, -12, -6, 0, 6, 12
20	2	**SAT**	**Saturation value. The following values are possible:** 8192 – no saturation but need more gain 16384 – no saturation, perfect gain 32768 – might be saturated, need less gain	N/A	N/A	8192, 16384, 32768

Table 5C- 9: Height-restricted Frequency Header , length 26

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	22	**F_HEAD**	**Frequency Header structure**	N/A	N/A	N/A
22	4	**S_HGT**	**Start height/range of successively output heights/ranges, total number of ranges for output is equal to NRO parameter of measurement program structure**	meter	INT32U	0 to 4,294,967,295 m or ≈ 675 Re

Table 5C- 10: Look Group, length is variable but the same for all groups within the same measurement

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	20	**PHDR**	**Look Header**	N/A	N/A	N/A
22		**PDATA**	**Look Data, two-dimensional array containing Look Databins (see tables** Table 5C- 13, Table 5C- 14**) with 1st dimension equals to Number of Antennas and second dimension equals to Number of Heights.**	N/A	Two dimensional Array of Look Databins	N/A

Table 5C- 11: Doppler Frequency Group, length is variable but the same for all groups within the same measurement

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	20	**FHDR**	**Frequency Header**	N/A	N/A	N/A
22		**FDATA**	**Doppler Frequency Group Data.** **Four dimensional array of Doppler Databins (see** Table 5C- 15, Table 5C- 16**):** **NumberOfPolarizations x NumberOfRanges x NumberOfAntennas x NumberOfDopplers**	N/A	Four dimensional Array of Doppler Databins	N/A

Table 5C- 12: Ionogram Frequency Group, length is variable but the same for all groups within the same measurement

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	20	**FHDR**	**Frequency Header**	-	N/A	N/A
22		**FDATA**	**Ionogram Frequency Group Data.** **Two dimensional array of Ionogram Databins (see tables** Table 5C- 17 **through** Table 5C- 26**):** **NumberOfPolarizations x NumberOfRanges**	-	Two dimensional Array of Iono-gram Databins	N/A

Table 5C- 13: Raw Databin uncompressed format (format 0), length 4

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	2	**RE**	**Real part of quadrature, from 0 to 65535**	N/A	INT16U	0... 65535
2	2	**IM**	**Imaginary part of quadrature, from 0 to 65535**	**N/A**	INT16U	0 ...65535

Table 5C- 14: Raw Databin compressed format (bin format 1), length 2

Bit Offset	Bits Len	Mnemonic	Description	Units	Type	Range
0	7	**AMP**	**Amplitude, in dB scale, from 0 to 96**	96/127 dB	INT7U	0... 127
7	9	**PH**	**Phase, from 0 to 360, but not including 360**	**360/512 deg**	INT9U	0 ...511

Table 5C- 15: Doppler Databin uncompressed format (bin format 0), length 4

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	2	**AMP**	**Amplitude, in linear scale, from 0 to 65535**	-	INT16U	0... 65535
2	2	**PH**	**Phase, from 0 to 360, but not including 360**	**360/65536 deg**	INT16U	0 ...65535

Table 5C- 16: Doppler Databin compressed format (bin format 1), length 2

Bit Offset	Bits Len	Mnemonic	Description	Units	Type	Range
0	7	**AMP**	**Amplitude, in dB scale, from 0 to 96**	96/127 dB	INT7U	0... 127
7	9	**PH**	**Phase, from 0 to 360, but not including 360**	**360/512 deg**	INT9U	0 ...511

Table 5C- 17: Ionogram Databin uncompressed format (bin format 0), without PGH, length 17

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	1	**DOPPLER**		-	INT8U	0…255
1	2	**AMP1**	**1st antenna amplitude, linear scale, from 0 to 65535**	-	INT16U	0... 65535
3	2	**PH1**	**1st antenna phase, from 0 to 360, but not including 360**	**360/65536 deg**	INT16U	0 ...65535
5	2	**AMP2**	**2nd antenna amplitude, linear scale, from 0 to 65535**	-	INT16U	0... 65535
7	2	**PH2**	**2nd antenna phase, from 0 to 360, but not including 360**	**360/65536 deg**	INT16U	0 ...65535
9	2	**AMP3**	**3rd antenna amplitude, linear scale, from 0 to 65535**	-	INT16U	0... 65535
11	2	**PH3**	**3rd antenna phase, from 0 to 360, but not including 360**	**360/65536 deg**	INT16U	0 ...65535
13	2	**AMP4**	**4th antenna amplitude, linear scale, from 0 to 65535**	-	INT16U	0... 65535
15	2	**PH4**	**4th antenna phase, from 0 to 360, but not including 360**	**360/65536 deg**	INT16U	0 ...65535

Table 5C- 18: Ionogram Databin uncompressed format (bin format 0), with PGH, length 19

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	1	**DOPPLER**		-	INT8U	0…255
1	2	**AMP1**	**1st antenna amplitude, linear scale, from 0 to 65535**	-	INT16U	0... 65535
3	2	**PH1**	**1st antenna phase, from 0 to 360, but not including 360**	**360/65536 deg**	INT16U	0 ...65535
5	2	**AMP2**	**2nd antenna amplitude, linear scale, from 0 to 65535**	-	INT16U	0... 65535
7	2	**PH2**	**2nd antenna phase, from 0 to 360, but not including 360**	**360/65536 deg**	INT16U	0 ...65535
9	2	**AMP3**	**3rd antenna amplitude, linear scale, from 0 to 65535**	-	INT16U	0... 65535
11	2	**PH3**	**3rd antenna phase, from 0 to 360, but not including 360**	**360/65536 deg**	INT16U	0 ...65535
13	2	**AMP4**	**4th antenna amplitude, linear scale, from 0 to 65535**	-	INT16U	0... 65535
15	2	**PH4**	**4th antenna phase, from 0 to 360, but not including 360**	**360/65536 deg**	INT16U	0 ...65535
17	2	**PH_DIFF**	**Phase difference between this and next close frequency. This difference calculated for PGH mode, from 0 to 360, but not including 360**	360/65536 deg	INT16U	0 …65535

Table 5C- 19: Ionogram Databin compressed format (bin format 1), without PGH, length 9

Bit Offset	Bit Len	Mnemonic	Description	Units	Type	Range
0	8	**DOPPLER**		-	INT8U	0…255
8	7	**AMP1**	**1st antenna amplitude, dB scale, from 0 to 96**	96/127 dB	INT7U	0... 127
15	9	**PH1**	**1st antenna phase, from 0 to 360, but not including 360**	**360/512 deg**	INT9U	0 ...511
24	7	**AMP2**	**2nd antenna amplitude, dB scale, from 0 to 96**	96/127 dB	INT7U	0... 127
31	9	**PH2**	**2nd antenna phase, from 0 to 360, but not including 360**	**360/512 deg**	INT9U	0 ...511
40	7	**AMP3**	**3rd antenna amplitude, dB scale, from 0 to 96**	96/127 dB	INT7U	0... 127
47	9	**PH3**	**3rd antenna phase, from 0 to 360, but not including 360**	**360/512 deg**	INT9U	0 ...511
56	7	**AMP4**	**4th antenna amplitude, dB scale, from 0 to 96**	96/127 dB	INT7U	0... 127
63	9	**PH4**	**4th antenna phase, from 0 to 360, but not including 360**	**360/512 deg**	INT9U	0 ...511

Table 5C- 20: Ionogram Databin compressed format (bin format 1), with PGH, length 10

Bit Offset	Bit Len	Mnemonic	Description	Units	Type	Range
0	8	**DOPPLER**		-	INT8U	0…255
8	7	**AMP1**	**1st antenna amplitude, dB scale, from 0 to 96**	96/127 dB	INT7U	0... 127
15	9	**PH1**	**1st antenna phase, from 0 to 360, but not including 360**	**360/512 deg**	INT9U	0 ...511
24	7	**AMP2**	**2nd antenna amplitude, dB scale, from 0 to 96**	96/127 dB	INT7U	0... 127
31	9	**PH2**	**2nd antenna phase, from 0 to 360, but not including 360**	**360/512 deg**	INT9U	0 ...511
40	7	**AMP3**	**3rd antenna amplitude, dB scale, from 0 to 96**	96/127 dB	INT7U	0... 127
47	9	**PH3**	**3rd antenna phase, from 0 to 360, but not including 360**	**360/512 deg**	INT9U	0 ...511
56	7	**AMP4**	**4th antenna amplitude, dB scale, from 0 to 96**	96/127 dB	INT7U	0... 127
63	9	**PH4**	**4th antenna phase, from 0 to 360, but not including 360**	**360/512 deg**	INT9U	0 ...511
72	8	**PH_DIFF**	**Phase difference between this and next close frequency. This difference calculated for PGH mode, from 0 to 360, but not including 360**	360/256 deg	INT8U	0 …255

Table 5C- 21: Ionogram Databin, antennas-convolved uncompressed format (bin format 2) without PGH, length 7

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	1	**DOPPLER**	**Sequential number of strongest Doppler**	-	INT8U	0 … 255
1	2	**AMPL**	**Amplitude, in linear scale**	-	INT16U	0 ... 65535
3	2	**ZENITH**	**Zenith of arrival, from 0 to 90**	90/65536 deg	INT16U	0 …65535
5	2	**AZIMUTH**	**Azimuth of arrival, from 0 to 360, but not including 360**	360/65536 deg	INT16U	0 …65535

Table 5C- 22: Ionogram Databin, antennas-convolved uncompressed format (bin format 2) with PGH, length 9

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	1	**DOPPLER**	**Sequential number of strongest Doppler**	-	INT8U	0 … 255
1	2	**AMPL**	**Amplitude, in linear scale**	-	INT16U	0 ... 65535
3	2	**ZENITH**	**Zenith of arrival, from 0 to 90**	90/65536 deg	INT16U	0 …65535
5	2	**AZIMUTH**	**Azimuth of arrival, from 0 to 360, but not including 360**	360/65536 deg	INT16U	0 …65535
7	2	**PH_DIFF**	**Phase difference between this and next close frequency. This difference calculated for PGH mode, from 0 to 360, but not including 360**	360/65536 deg	INT16U	0 …65535

Table 5C- 23: Ionogram Databin, antennas-convolved compressed format (bin format 3) without PGH, length 4

Bit Offset	Bit Len	Mnemonic	Description	Units	Type	Range
0	8	**DOPPLER**	**Sequential number of strongest Doppler**	-	INT8U	0 … 255
8	7	**AMPL**	**Amplitude, in dB scale**	96/127 dB	INT7U	0 ... 127
15	7	**ZENITH**	**Zenith of arrival, from 0 to 90**	90/127 deg	INT7U	0 …127
22	10	**AZIMUTH**	**Azimuth of arrival from 0 to 360, but not including 360**	360/1024 deg	INT10U	0 …1023

Table 5C- 24: Ionogram Databin, antennas-convolved compressed format (bin format 3) with PGH, length 5

Bit Offset	Bit Len	Mnemonic	Description	Units	Type	Range
0	8	**DOPPLER**	**Sequential number of strongest Doppler**	-	INT8U	0 … 255
8	7	**AMPL**	**Amplitude, in dB scale**	96/127 dB	INT7U	0 ... 127
15	7	**ZENITH**	**Zenith of arrival, from 0 to 90**	90/127 deg	INT7U	0 …127
22	9	**AZIMUTH**	**Azimuth of arrival, from 0 to 360, but not including 360**	360/512 deg	INT9U	0 …511
31	9	**PH_DIFF**	**Phase difference between this and next close frequency. This difference calculated for PGH mode, from 0 to 360, but not including 360**	360/512 deg	INT9U	0 …511

Table 5C- 25: Ionogram Databin, very compressed format (bin format 4) without PGH, length 2

Bit Offset	Bit Len	Mnemonic	Description	Units	Type	Range
0	3	**DOPPLER**	**Sequential number of strongest Doppler**	-	INT3U	0 …7
3	5	**AMPL**	**Amplitude, in dB, from 0 to 93**	3 dB	INT5U	0 ... 31
8	3	**ZENITH**	**Zenith of arrival, from 0 to 48**	8 deg	INT3U	0 …7 Note: value 7 signals ‘zen-ith/azimuth values are not calculable’
11	5	**AZIMUTH**	**Azimuth of arrival, from 0 to 360, but not including 360**	360/32 = 11.25 deg	INT5U	0 …31 Note: For supposedly better compression, all 1’s will be put in azimuth field when zenith/azimuth values are not calculable

Table 5C- 26: Ionogram Databin, very compressed format (bin format 4) with PGH, length 2

Bit Offset	Bit Len	Mnemonic	Description	Units	Type	Range
0	3	**DOPPLER**	**Sequential number of strongest Doppler**	-	INT3U	0 …7
3	5	**AMPL**	**Amplitude, in dB, from 0 to 93**	3 dB	INT5U	0 ... 31
8	3	**ZEN_AZ**	**Zenith + Azimuth are coded as follows:** **0 - vertical** **1 - oblique, azimuth is 0 degrees** **2 - oblique, azimuth is 60 degrees** **3 - oblique, azimuth is 120 degrees** **4 - oblique, azimuth is 180 degrees** **5 - oblique, azimuth is 240 degrees** **6 - oblique, azimuth is 300 degrees** **7 - zenith/azimuth are not calculable**	-	INT3U	0 …7
11	5	**PH_DIFF**	**Phase difference between this and next close frequency. This difference calculated for PGH mode, from 0 to 360, but not including 360**	360/32 = 11.25 deg	INT5U	0 …31

Table 5C-27: Ionogram Databin, nondirectional uncompressed format 5, length 3

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	1	**DOPPLER**	**Sequential number of strongest Doppler**	-	INT8U	0 … 255
1	2	**AMPL**	**Amplitude, in linear scale**	-	INT16U	0 ... 65535

Table 5C- 28: Ionogram Databin, non-directional compressed format 6, length 2

Byte Offset	Byt e Len	Mnemonic	Description	Units	Type	Range
0	1	**DOPPLER**	**Sequential number of strongest Doppler**	-	INT8U	0 … 255
1	1	**AMPL**	**Amplitude, in dB scale**	127/255 dB	INT8U	0 ... 255

Table 5C- 29: Ionogram Databin, non-directional very compressed format 7, length 1

Bit Offset	Bit Len	Mnemonic	Description	Units	Type	Range
0	3	**DOPPLER**	**Sequential number of strongest Doppler**	-	INT3U	0 …7
3	5	**AMPL**	**Amplitude, in dB, from 0 to 93**	3 dB	INT5U	0 ... 31

Table 5C-30: Global parameters, variable length

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	1	**NUM_PAR**	**Number of global parameters**	N/A	INT8U	0 …255
1	vari-able	**GPARS**	**NUM_PAR Global parameters given as pairs (name,value).** **See table** Table 5C-30 **for one Global Parameter encoding**	N/A	INT5U	N/A

Table 5C- 31: Parameter, variable length

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	1	**NAM_LEN**	**Number of bytes in parameter name**	N/A	INT8U	0 …255
1	N_LEN	**NAME**	**Name of parameter, given as ASCII character string**	N/A	ASCII string	N/A
1 + N_LEN	1	**VAL_LEN**	**Number of bytes in parameter value**	N/A	INT8U	0 …255
2 + N_LEN	V_LEN	**VALUE**	**Value of parameter, given as ASCII character string**	N/A	ASCII string	N/A

Table 5C- 32: Processing Steps' parameters, variable length

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	vari-able	PROCS_STEP_PARAMS	**Array of parameters for all applied processing steps** **Each element of array corresponds to one applied processing step.** **Note that if no processing steps were applied then this array will be empty.** **From other hand, if at least one processing step has been applied then "raw data processing step" also will be added at the beginning.** **See table** Table 5C- 34 **for description of One Processing Step Parameters structure**	N/A	Array of PROC_STEP_PARAM structures	N/A

Table 5C- 33: One Processing Step parameters, variable length

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	1	PS_ID	**Processing Step ID**	N/A	INT8U	0…255
1	1	NUM_PAR	**Number of parameters for this step**	N/A	INT8U	0 …255
2	vari-able		**NUM_PAR parameters given as pairs (name,value).** **See table** Table 5C- 31 **for one Parameter encoding**	N/A	N/A	N/A

Table 5C- 34: Channel Equalizing correction table structure, variable length

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	17	TIME_STAMP	**Time Stamp when Channel Equalizing coefficients were calculated** **See table** Table 5A- 13	N/A	TS	N/A
17	1	CH_QTY	**Number of channels** **Equals to number of antennas for present version of DSP4-D**	N/A	INT8U	4 …255
18	1	REF_CH_IND	**Referenced channel's index** **0 for channel 1, 1 for channel 2, and so on** **Referenced channel is the channel other channels are comparing to.**	N/A	INT8U	0 …255
19	2	ENT_QTY	**Number of correction's entries**	N/A	N/A	N/A
21	vari-able	ARR_ENT	**Correction entries' array** **Length of this array equals to the numbers of different possible frequencies in this measurement, so each entry contains frequency and corrections for all channels except referenced channel** **Note, entries are in increase order by frequency** **See table** Table 5C- 35 **for one entry correction structure**	N/A	N/A	N/A

Table 5C- 35: Channel Equalizing: One Frequency Correction entry, variable length

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	4	**FREQ**	**Frequency in Hz**	Hz	INT8U	0…30,000,000
1	4 * length of array	**ARR_CH_CORR**	**Array of channel's correction for this frequency** **The length of this array is one less than the number of channels, as this array does not include referenced channel** **See table** Table 5C- 36 **for one channel correction structure**	N/A	N/A	N/A

Table 5C- 36: Channel Equalizing: One Channel Correction entry, 4 bytes

Byte Offset	Byte Len	Mnemonic	Description	Units	Type	Range
0	2	**AMP_CORR**	**Multiplicative correction for amplitude** **To equalize amplitude of this channel/antenna with referenced channel, you have to multiply it by this correction (divided by 1000, of course)**	1/1000	INT16U	0…65,535
2	2	**CH_CORR**	**Additive correction for phase** **To "equalize" phase of this channel/antenna with referenced channel, you have to add this correction (divided by 100, of course) to it**	1/100 deg	INT16S	-18000…18000

LEGACY SCIENCE DATA FORMATS: RSF AND SBF IONOGRAMS

5:153. The header of raw data files contains General Purpose PREFACE. The format of PREFACE is outlined in **Table 5C- 37**. Refer to Section 4 (Operating Instructions) for the explanation of options and default values of operator-selectable PREFACE parameters.

Table 5C- 37: General Purpose PREFACE Specification

Byte #	Description	Units	Range	Type	Format
1	Year	years	0-99	packed BCD	2 digits
2,3	Day of Year	days	1-366	packed BCD	4 digits
4	Month	months	1-12	packed BCD	2 digits
5	Day of Month	days	1-31	packed BCD	2 digits
6	Hour	hours	0-23	packed BCD	2 digits
7	Minute	minutes	0-59	packed BCD	2 digits
8	Second	seconds	0-59	packed BCD	2 digits
9, 10,11	Station ID: Receiver	-	000-999	char	3 chars
12, 13,14	Station ID: Transmitter	-	000-999	char	3 chars
15	Schedule	-	1-6	packed BCD	2 digits
16	Program	-	1-7 (A-G)	packed BCD	2 digits
17, 18,19	Start Frequency, *LL*	100 Hz	010000 - 450000	packed BCD	6 digits
20, 21	Coarse Frequency Step, *C*	1 kHz	1-2000	packed BCD	4 digits

Byte #	Description	Units	Range	Type	Format
22, 23, 24	Stop Frequency, *UU*	100 Hz	010000 - 450000	packed BCD	6 digits
25, 26	Fine Frequency Step, *F*	1 kHz	0 - 9999	packed BCD	4 digits
27	Number of small steps in a scan, *S*	-	-15 to +15 negative value means no multiplexing	signed char	I3
28	Phase Code, *X*	-	1 (complim.) 2 (short) 3 (75% duty) 4 (100% duty) +8 (no phase switch)	packed BCD	2 digits
29	Multi-antenna sequencing and O/X polarization options, *A*	-	0 (sum), 1-4 (individual antennas), 7 (antenna scan), +8 (only O polarization), *negative* for alternative antennas	signed char	I3
30	Number of samples for FFT, *N*	encoded, actual # is power of 2	3-7 (power of 2)	packed BCD	2 digits
31, 32	Pulse Repetition Rate, *R*	pps	50, 100, 200. nibble 4: 0 - Active Mode 1 - Radio Silent Mode	packed BCD	1 + 3 digits
33,34	Range Start, *E*	1 km	0 - 9999	packed BCD	4 digits
35	Range Increment, *H*	encoded	2 (2.5 km) 5 (5 km) 10 (10 km)	packed BCD	2 digits
36.37	Number of heights, *M*	units	128, 256, 512	packed BCD	4 digits
38,39	Delay, *K*	15 km	0 - 1500	packed BCD	4 digits
40	Base Gain, *G*	dB	0-7 (0-42 dB) +8 (+auto gain)	packed BCD	2 digits
41	Frequency Search Enabled, *I*	-	0 (no) 1 (yes)	packed BCD	2 digits
42	Operating Mode, *Y*	-	0 (VI) 1 (Drift Std) 2 (Drift Auto) 3 (Calibration) 4 (HRR) 5 (Beam) 6 (PGH) 7 (Test)	packed BCD	2 digits
43	Data Format, *D*	-	0 (no data) 1 (MMM) 2 (Drift) 3 (PGH) 4 (RSF) 5 (SBF) 6 (BIT) high nibble: 0 (no Artist)	packed BCD	2 digits

Byte #	Description	Units	Range	Type	Format
			1 (with Artist)		
44	Printer Output, *P2*	-	0 (none) 1 (b/w) 2 (color)	packed BCD	2 digits
45	Threshold	3 dB over the MPA	0 - no threshold 1 - MPA - 27 dB ... 9 - MPA - 3 dB 10 - MPA 11 - MPA + 3 dB 12 - MPA + 6 dB ...	packed BCD	2 digits
46	Constant Gain Code		0 (full gain: tracker high, switch high), 1 (-9 dB: tracker high, switch low), 2 (-9 dB: tracker low, switch high), 3 (-18 dB: tracker low, switch low)	packed BCD	2 digits
47-48	Spare				
49, 50	CIT Length	msec	0-40000	unsigned int	I5
51	Journal	-	bit0: new gain bit1: new height bit2: new freq. bit3: new case	char	Z4
52, 53	Bottom of the height window, *B*	1 km	0-9999	packed BCD	4 digits
54, 55	Top of the height window, *T*	1 km	0-9999	packed BCD	4 digits
56, 57	Number of heights to store, *O*	units	1-512	packed BCD	4 digits

RSF Format: File Specification

5:154. An RSF ionogram file consists of a variable number of 4 096 byte blocks. Each block contains a Header and a variable number of Frequency Groups. The RSF Header structure is described in the **Table 5C-38**.

Table 5C- 38: The RSF Header

Item	Description	Units	Range	Accuracy	Precision	Type	Format
Record Type	Block identification	-	7 (first block) 6 (all other blocks)	exact	exact	char (1 byte)	Z2
Header Length	Total number of bytes taken by Header	-	60, fixed	exact	exact	char (1 byte)	I2
Version Marker	Version control char	-	FF (hex), fixed	-	-	char (1 byte)	Z2
General Purpose PREFACE	See **Table 5C- 37**						

5:155. Each Frequency Group contains a 6-byte PRELUDE and a single height profile of a variable length. **Table 5C-39** summarizes the possible settings of Frequency Group lengths depending on the number of heights selected by the operator.

Table 5C-39: Length of the RSF Frequency Groups Depending on Ionogram Settings

NUMBER OF HEIGHTS PREFACE Char #36-37)	NUMBER OF FREQUENCY GROUPS IN A BLOCK	NUMBER OF RANGE BINS STORED IN A GROUP	LENGTH OF A FREQUENCY GROUP (BYTES)
128	15	128	262
256	8	249	504
512	4	501	1008

5:156. For each sounding frequency, one or two Frequency Groups are stored depending on a setting of O/X polarization option, *A*, PREFACE Char #29. If *A* is less than 8, both polarizations are stored each taking an individual Frequency Group, otherwise only O polarization height profile is stored for each frequency.

Each range bin takes 2 bytes in an RSF Frequency Group (see **Table 5C-40** and **Table 5C-41**)

Table 5C-40: Content of an Individual Range Bin in RSF File Format

MSB	LSB	
5-bit Amplitude	3-bit Doppler Number	Byte 1
5-bit Phase	3-bit Azimuth	Byte 2

Table 5C-41: Individual Bit Sections of the Range Bin

Item	Units	Range	Accuracy	Precision	Type	Format
Amplitude	3 dB	0-31	1	1	5 bit unsigned integer	-
Doppler Number	See text	0-7	1	1	3 bit unsigned integer	-
Phase or PGH	11.25° or 1 km	0-31	1	1	5 bit unsigned integer	-
Azimuth	60°	0-7 (0-359°)	1	1	3 bit unsigned integer	-

5:157. The 6-byte PRELUDE precedes each set of range bins in a Frequency Group (see **Table 5C- 42**). The PRELUDE uses a *packed-BCD* encoding scheme where each byte contains two 4-bit digits (0-9) each taking a nibble. The frequency reading stored in PRELUDE is the actual sounding frequency. The offset from the nominal frequency is stored in byte #4. If offset was caused by forcing of sounding out of restricted frequency range, the actual frequency reading is given and the offset is set to E (hex) to indicate the case.

5:158.

Table 5C- 42: RSF PRELUDE Byte Organization

Byte #		Description	Units	Range	Accuracy	Precision	Type	Format
1	high nibble	Polarization	-	3 (O) 2 (X)	-	-	BCD nibble	1 digit
	low nibble	Group size	encod-ed	2 (262), 3 (504), 4 (1004)	-	-	BCD nibble	1 digit
2, 3		Frequency Reading	10 kHz	within the ionogram frequency range	10 kHz	10 kHz	packed BCD	4 digits
4	high nibble	Offset	encod-ed	0 (-20 kHz) 1 (-10 kHz) 2 (no offset) 3 (+10 kHz) 4 (+20 kHz) 5 (search failure) E (forced) F (no transmission)	-	-	nibble	Z1
	low nibble	Additional Gain	3 dB	0-15	3 dB	3 dB	nibble	Z1
5		Seconds	sec	00-59	1	1	packed BCD	2 digits
6		Most Probable Amplitude	3 dB	0-31	3 dB	3 dB	packed BCD	2 digits

5:159. The last block of an RSF ionogram may be incomplete. To indicate END-OF-IONOGRAM (EOI), a 6-byte EOI marker consisting of EE(hex) is put on place of the PRELUDE.

SBF Format: File Specification

5:160. The SBF ionogram file consists of a variable number of 4096 byte blocks. Each block contains a Header and a variable number of Frequency Groups. The SBF Header structure is described in **Table 5C- 43**.

Table 5C- 43: The SBF Header

Item	Description	Units	Range	Accuracy	Precision	Type	Format
Record Type	block identification	-	3 (first block) 2 (all other blocks)	exact	exact	char (1 byte)	Z2
Header Length	total number of bytes taken by Header	-	60, fixed	exact	exact	char (1 byte)	I2
Version Marker	Version control char	-	FF (hex), fixed	-	-	char (1 byte)	Z2
General Purpose PREFACE	See **Table 5C- 37**						

5:161. Each Frequency group contains a 6-byte PRELUDE and a single height profile of a variable length. **Table 5C- 44** summarizes the possible settings of Frequency Group lengths.

Table 5C- 44: Length of the SBF Frequency Groups Depending on Ionogram Settings

NUMBER OF HEIGHTS (PREFACE Char #36-37)	NUMBER OF FREQUENCY GROUPS IN A BLOCK	NUMBER OF RANGE BINS STORED IN A GROUP	LENGTH OF A FREQUENCY GROUP (BYTES)
128	30	128	134
256	15	256	262
512	8	498	504

5:162. For each sounding frequency, one or two Frequency Groups are stored depending on a setting of O/X polarization option, *A*, PREFACE Char #29. If *A* is less than 8, both polarizations are stored each taking an individual Frequency Group, otherwise only an O polarization height profile is stored for each frequency. Each range bin takes 1 byte in a SBF Frequency Group (see **Table 5C- 45** and **Table 5C- 46**).

Table 5C- 45: Content of an Individual Range Bin in SBF File Format

MSB	LSB	
5-bit Amplitude	3-bit Doppler Number	Byte 1

Table 5C- 46: Individual Bit Sections of the Range Bin

Item	Units	Range	Accuracy	Precision	Type	Format
Amplitude	3 dB	0-31	1	1	5 bit unsigned integer	-
Doppler Number	See text	0-7	1	1	3 bit unsigned integer	-

5:163. The 6-byte PRELUDE precedes each set of range bins in a Frequency Group (see **Table 5C- 47**). The PRELUDE uses a *packed-BCD* encoding scheme, and the stored frequency reading is the actual sounding frequency. The offset from the nominal frequency is stored in byte #4. If the offset was caused by forcing of sounding out of restricted frequency range, the actual frequency reading is given and the offset is set to E (hex) to indicate the case.

5:164.

Table 5C- 47: SBF PRELUDE Organization

Byte #		Description	Units	Range	Accuracy	Precision	Type	Format
1	high nibble	Polarization	-	3 (O) 2 (X)	-	-	BCD nibble	1 digit
	low nibble	Group size	encod-ed	1 (134), 2 (262), 3 (504)	-	-	BCD nibble	1 digit
2, 3		Frequency Reading	10 kHz	within the ionogram frequency range	10 kHz	10 kHz	packed BCD	4 digits
4	high nibble	Offset	encod-ed	0 (-20 kHz) 1 (-10 kHz) 2 (no offset) 3 (+10 kHz) 4 (+20 kHz) E (forced) F (no transmission)	-	-	nibble	Z1
	low nibble	Additional Gain	3 dB	0-15	3 dB	3 dB	nibble	Z1
5		Seconds	sec	00-59	1	1	packed BCD	2 digits
6		Most Probable Amplitude	3 dB	0-31	3 dB	3 dB	packed BCD	2 digits

5:165. The last block of an SBF ionogram may be incomplete. To indicate END-OF-IONOGRAM (EOI), a 6-byte EOI marker consisting of EE(hex) is put on place of the PRELUDE.

LEGACY SCIENCE DATA FORMATS: DFT

5:166. The DFT drift data file consists of a variable number of 4 096 byte blocks, each block containing 8-bit amplitudes and phases of the Doppler spectra. The smallest data entity is a *sub-case* which contains a four Doppler spectrum for each antenna obtained at one frequency, one height gate, and one polarization setting. Each Doppler spectrum in a sub-case is 2^N elements long, where N is selected by the operator. The amplitudes of individual Doppler spectra are grouped in sets of 128 elements for storage in the DFT file, each set of 128 amplitudes may contain data from one to four antennas depending on the setting of N. 128 amplitudes are followed by 128 phase values of the same Doppler spectrum or spectra.

5:167. The first byte of the first block in the DFT file is always forced to be a Record Type 10 (Hex). The structure shown by **Table 5C- 48** on the next page illustrates the arrangement.

Table 5C- 48: DFT File Structure

Block Count	Byte Count	Data Description
1	1	Record Type 10 (hex) fixed
	2-128	1st 128/2^N * 8-bit amplitude spectra (as log-amplitudes in 3/8 dB units) with least significant bit replaced by serially written header data
	129-256	128 8-bit Phase values of Doppler lines stored in previous 128 bytes
	257-4096	Repeat previous 256 bytes 15 more times. Order of spectra is antenna 1-4, heights, frequencies, polarization
2	4096-...	Repeat 4 096 byte blocks until end of data, placing 256 bytes of EE (hex) at end of data. If not end of a 4 096 byte block, then zero fill

5:168. For one frequency a variable number of height gates may be selected. All sub-cases recorded for a single frequency comprise a *Height Set* and all those recorded simultaneously during one CIT are called a *CIT Set*. All sub-cases contained within one 4 096 block of drift data comprise a *Case*.

5:169. The drift HEADER information is stored serially in the LSB of spectra amplitude bytes, LSB of the values first. The HEADER consists of Record Type (8 bits), Header Length (16 bits), Version Indicator (8 bits), Drift PREFACE (228 bits), and a variable number of sub-case headers (52 bits each). This arrangement is illustrated in **Table 5C- 49**.

Table 5C- 49: Drift Header Information Stored Serially in LSB of Amplitudes

Bits Required	Description
8	Record type (10 in hexadecimal form, 0x0a for Drift) -1 byte
16	# of bytes in header
8	PREFACE Version Indicator FF (hex) fixed
228	Drift Data PREFACE (57 items)
52	Subcase Header (Next 5 items): Actual Frequency in kHz (5 nibbles) Height in km of Maximum Amplitude Signal for first Subcase (4 nibbles) Height Bin Number (2 nibbles) Automatic Gain Offset 6 dB units of attenuation (in addition to base gain) Polarization (X=0, O=1)
52	Repeat Subcase Headers for all heights (1st freq and polarization) , then store another group of heights for all frequencies, then store another height/freq group for X polarization (if selected)

5:170. The Drift Data PREFACE structure is shown in **Table 5C-50**. Each PREFACE value is a 4-bit nibble and thus takes four bytes of the spectra amplitudes to be stored.

* Where 2^N is # of Doppler lines in the stored spectra

Table 5C-50: Drift Data Specification

Item #	Description	Units	Range	Accuracy	Precision	Type	Format
1, 2	Year	years	0-99	-	-	4-bit BCD	2 digits
3, 4, 5	Day of Year	days	1-366	-	-	4-bit BCD	4 digits
6, 7	Hour	hours	0-23	-	-	4-bit BCD	2 digits
8, 9	Minute	minutes	0-59	-	-	4-bit BCD	2 digits
10, 11	Second	seconds	0-59	-	-	4-bit BCD	2 digits
12	Schedule #	-	1-6	-	-	4-bit BCD	1 digit
13	Program	-	1-7 (A-G)	-	-	4-bit BCD	1 digit
14, 15	Drift Data Flag	-	FF (plain) FE (1/2 width Doppler shift)	-	-	4-bit hex	-
16	Journal, *J*	bit-encoded	bit 0: new gain bit 1: new height bit 2: new freq bit 3: new case	-	-	4-bit hex	binary
17	First height of sam-pling window	10 km	00-99	10 km	10 km	4-bit BCD	2 digits
18	Height resolution	encoded	2 - 2.5 km 5 - 5 km 10 - 10 km	2.5 km	2.5 km	4-bit hex	binary
19	Number of Heights	encoded	8 - 128 0 - 256	-	-	4-bit BCD	1 digit
20 - 25	Start Frequency	100 Hz	010000 - 450000	1 kHz	100 Hz	4-bit BCD	6 digits
26	Disk IO	-	Ah	-	-	4-bit hex	binary
27	Frequency Search Enabled	-	0 (no) 1 (yes)	-	-	4-bit BCD	1 digit
28. 29	Fine Frequency Step	10 kHz	0-255	10 kHz	10 kHz	nibbles of the 1 byte binary	unsigned char
30	Number of small steps in a scan, *S*, absolute value	-	0 to 15	-	-	4-bit hex	binary
31, 32	Number of small steps in a scan, *S*	-	-15 to +15 negative value means no multi-plexing	-	-	nibbles of the 1 byte binary	signed char
33, 34	Start Frequency, *LL*	1 Mhz	01 to 45	1 MHz	1 MHz	4-bit BCD	2 digits
35	Coarse Frequency Step, or number of repetitions	encoded	0 (200 kHz) 1 (100 kHz) 2 (50 kHz) 3 (25 kHz) 4 (10 kHz) 5 (5 kHz)	-	-	4-bit BCD	1 digit
36, 37	Start Frequency, *LL*	1 Mhz	1 to 45	1 MHz	1 MHz	4-bit BCD	2 digits

Item #	Description	Units	Range	Accuracy	Precision	Type	Format
38	Bottom Height, *B*	100 km	0 to 15	100 km	100 km	4-bit hex	binary
39	Top Height, *T*	100 km	0 to 15	100 km	100 km	4-bit hex	binary
40	Unused	-	-	-	-	-	-
41 - 43	Station ID	-	000 to 999	-	-	4-bit BCD	3 digits
44	Phase Code, *X*	-	1 (complim.) 2 (short) 3 (75% duty) 4(100% duty) +8 (no phase switch)	-	-	4-bit hex	binary
45	Multi-antenna sequencing and O/X polarization options, *A*	-	0 (sum), 1-4 (individual antennas), 7 (antenna scan), +8 (only O polarization)	-	-	4-bit hex	binary
46, 47	CIT length	sec	0 - 255	1 sec	1 sec	nibbles of the 1 byte binary	unsigned char
48	Number of Doppler lines, *N*	encoded, actual value is power of 2	3 - 7 (power of 2)	-	-	4-bit BCD	1 digit
49	Pulse Repetition Rate, *R*	encoded	0 (50 pps) 2 (100 pps) 3 (200 pps)	-	-	4-bit BCD	1 digit
50	Waveform, *X*	-	1 (complim.) 2 (short) 3 (75% duty) 4 (100% duty) +8 (no phase switch)	-	-	4-bit hex	binary
51	Delay, *D*	50 msec	0 - 15	50 msec	50 msec	4-bit hex	binary
52	Frequency Search Enabled, *I*	-	0 (no) 1 (yes)	-	-	4-bit BCD	1 digit
53	Base Gain, *G*	6 dB	0 - 7 (0 - 42 dB) +8 (+auto gain)	6 dB	6 dB	4-bit hex	binary
54, 55	Heights to Output, *O*	-	0 - 255	-	-	nibbles of the 1 byte binary	unsigned char
56	Number of polarizations	-	1 or 2	-	-	4-bit BCD	1 digit
57	Start Gain	6 dB	0 - 15	-	-	4-bit hex	binary

LEGACY SCIENCE DATA FORMATS: SAO

5:171. The SAO v 4.3 format description can be found publicly at http://ulcar.uml.edu/~iag/SAO-4.3.htm

SCIENCE DATA FORMATS: SAO.XML 5.0

5:172. The SAO.XML v 5.0 format description can be found publicly at http://ulcar.uml.edu/SAOXML/

SECTION 6
MAINTENANCE

SECTION CONTENTS

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CHAPTER 1

SYSTEM MAINTENANCE FEATURES

MAINTENANCE CHARACTERISTICS

6:1. The Digisonde® Portable Sounder and associated sub-systems have been designed to provide high reliability with the least possible demand on human intervention to attend to maintenance tasks. Preventative maintenance tasks are restricted to replacement of air-filters and ensuring that cable terminations and exposed hardware are kept clean. Corrective maintenance tasks initiated by BIT detection of a fault are also described.

PHYSICAL AND ELECTRICAL SPECIFICATIONS

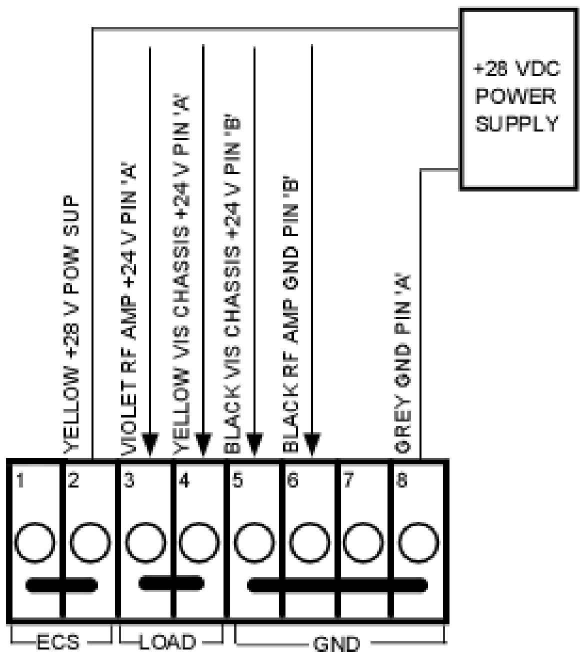
6:2. The physical and electrical specifications of the sounder and line replaceable units (LRU) and modules (LRM) are listed in **Table 6A- 1** .

SYSTEM POWER

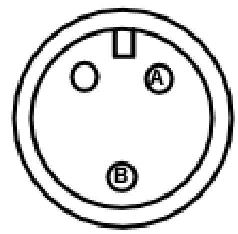
6:3. Input power specifications for the sounder are:

- Power Supply Input: Nominal 120/240; Range 85-265 VAC, 50/60Hz
- Power Supply Output: Nominal 28 VDC @ 23.0 Amp at Temperature -10 to 50 C; AC input line filter (Corcom 10VN1)

POWER MANAGEMENT

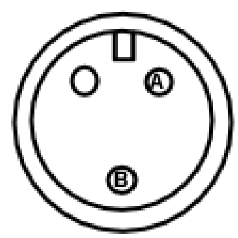


DC TERMINAL STRIP WIRING



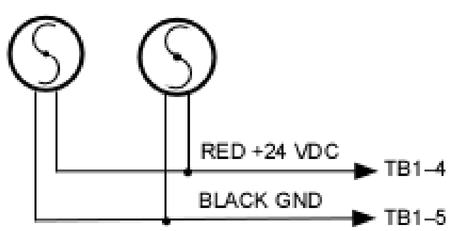
AMPLIFIER DC POWER SOCKET

SOCKET LETTER	VOLTAGE	WIRE COLOUR
A	+24 V	VIOLET
B	GND	BLACK



MAINS CHASSIS DC POWER SOCKET

SOCKET LETTER	VOLTAGE	WIRE COLOUR
A	+24 V	YELLOW
B	GND	BLACK



COOLING FANS (2) 24 V 100 CFM

Figure 6-1: Power Management (Connections)

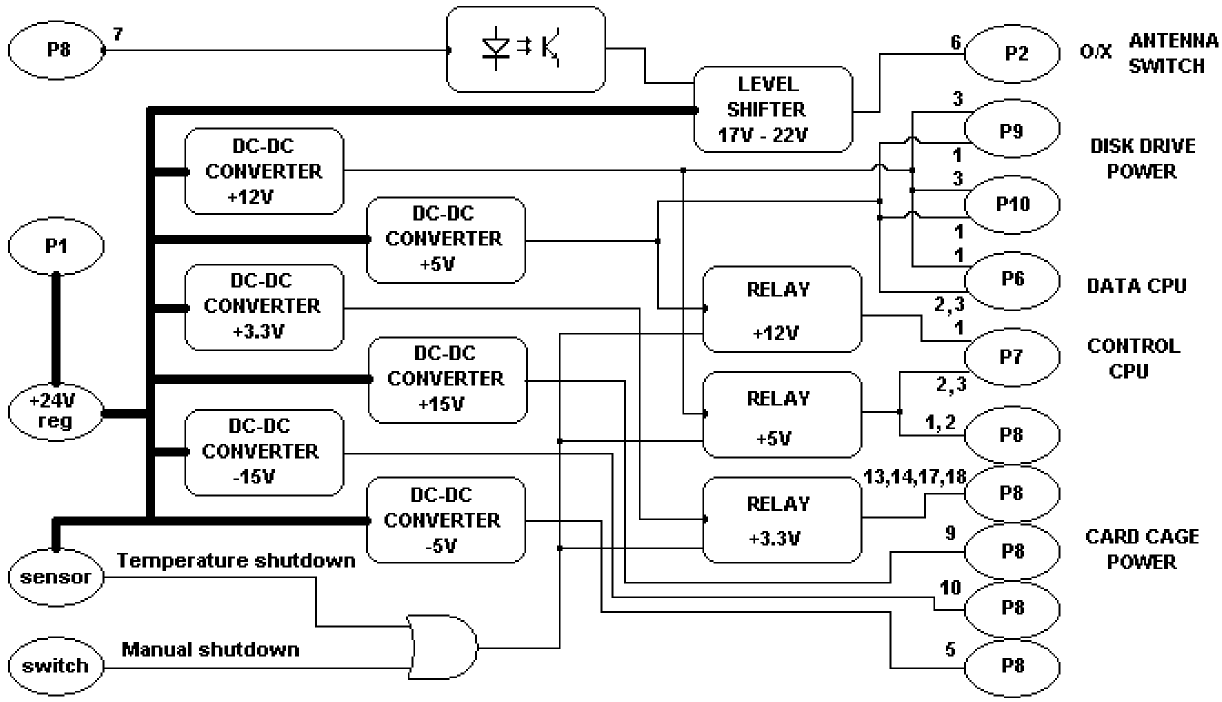


Figure 6-2: Power Management (System Power)

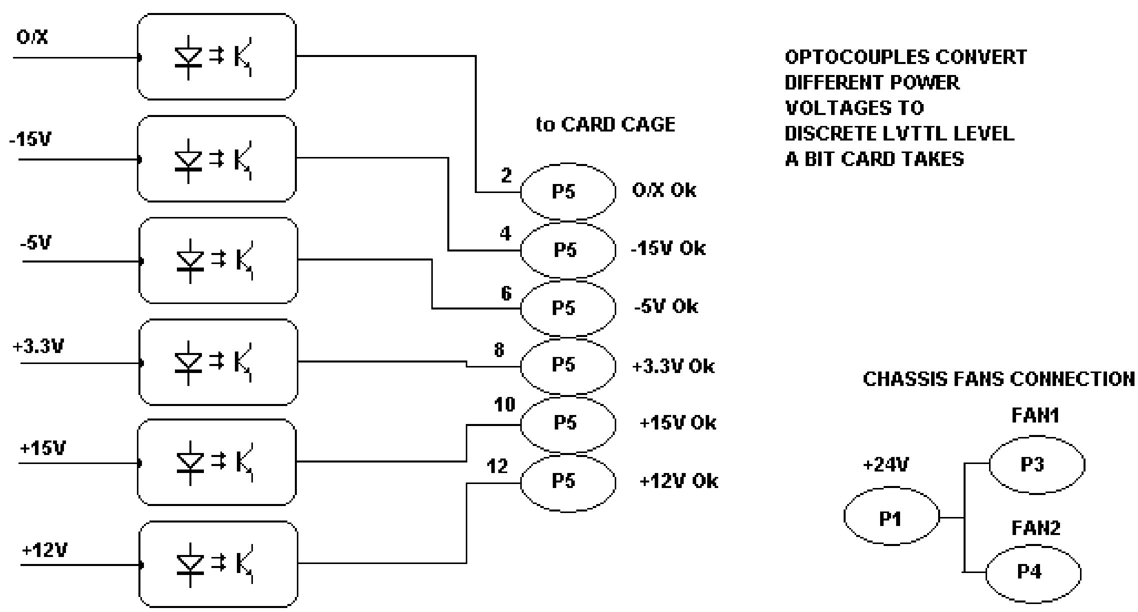


Figure 6-3: Power Management (BIT Card Interface)

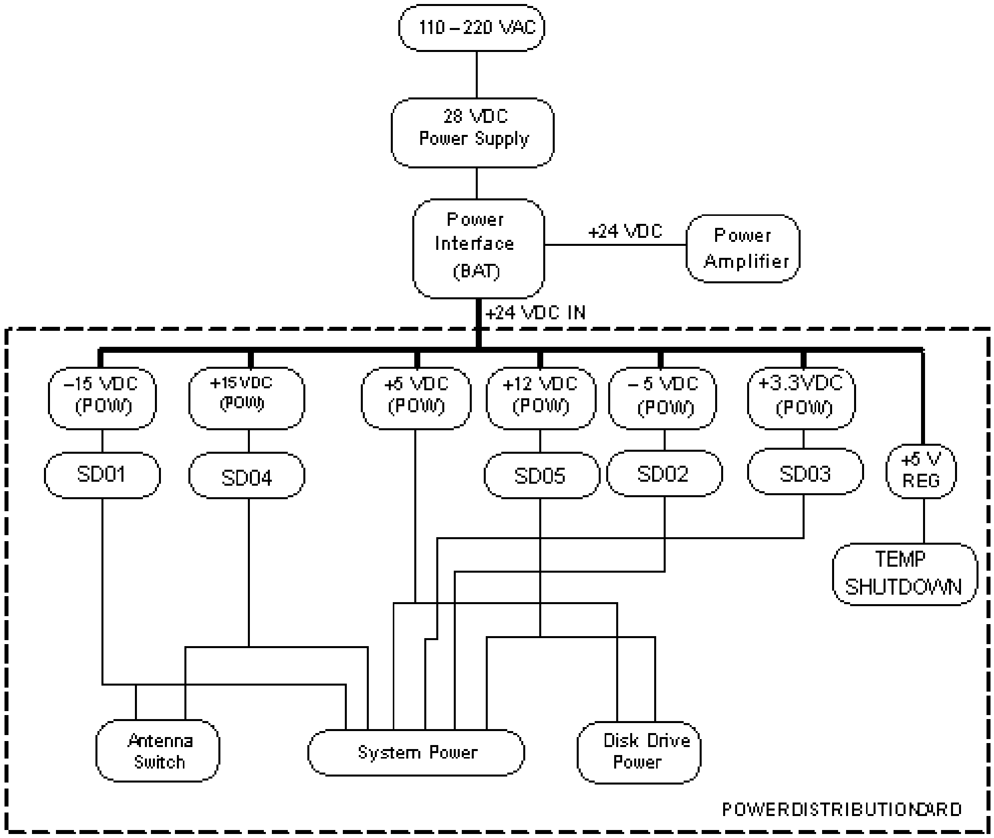


Figure 6-4: Internal Power Dependency

6:4. The sounder is protected by a 7.5 A circuit breaker in the main chassis, and a 30 A fuse in the power amplifier chassis.

INTERNAL CABLING

6:5. Internal signal and power distribution has been logically divided into functional buses as shown in **Table 6-1**.

Table 6-1: Signal and Power Buses

BUS	FUNCTION	BACKPLANE REFERENCE
A-Bus	control bus for the receive antennas switches	P17
P-Bus	connection between the control computer parallel port and the sounder custom hardware mounted in the card cage via the Digital Transmitter/Timing card	P13
IDE-Bus (DMA)	connects the system's pre-processor card to the control computer	P19
F-Bus	control bus for the power amplifier	P14
Power Bus	supplies power to the card cage and antennas switches	P16
BIT I/O Bus	conducts BIT sensor information	P20

FRONT PANEL CONNECTORS AND CONTROLS

6:6. The functions of and circuit references for the front panel coaxial connectors and controls are listed in **Table 6-2**.

Table 6-2: Front Panel Connectors And Controls

ITEM	FUNCTION	CONNECTOR REFERENCE
TRIG	Scope Trigger Signal for RF transmissions	BCK-P15
TX1	Digital Transmitter Channel 1 to RF Amp	XMT-P4
TX2	Digital Transmitter Channel 2 to RF Amp	XMT-P8
TX ON	Output transmitter ON pulse	BCK-P21
CONTROL COMPUTER RESET	Momentary push button. Triggers Control computer reset pulse	BCK-P15

ROUTINE MAINTENANCE TASKS SUGGESTED AT YEARLY INTERVALS

6:7. Except for routine attention to cleanliness of the air intake system, adjustment of the reference clock, and tracker calibration no periodic maintenance tasks are required. The six air filters should be maintained as shown in **Table 6-3**.

Table 6-3: Air Filter Maintenance

LOCATION	NO.	PERIODICITY	MAINTENANCE TASKS
Sounder enclosure Expanded metal type.	2	Inspect twice a year if possible and during every site visit.	Examine for build-up of dust. If present, wash the filters with mild detergent solution, and dry and refit.
Rear of main chassis. Synthetic foam type.	1	Inspect twice a year if possible and during every site visit.	Wash in mild detergent solution or discard and replace if damaged.
Rear of PA chassis. Synthetic foam type.	2	Inspect twice a year if possible and during every site visit..	Wash in mild detergent solution or discard and replace if damaged.

6:8. To remove the expanded metal air filters:

Pull the RF Amp chassis forward or remove it entirely (**see section 6:75**). Remove the three nuts on the front side of the filter carrier and slide the filter out. The filters fit in the carrier somewhat tightly and a screwdriver may be necessary to assist in the filter removal.

6:9. To remove the main chassis foam filter:

Remove the rear cover of the DPS chassis by turning the four fastener knobs counter-clockwise. Locate the fan filter on the rear panel. Unclip the plastic filter holder that clips over the edges of the fan. Remove the holder and take the filter out.

6:10. To remove the RF chassis foam filters:

Pull the RF Amp chassis fully forward or remove it entirely (**see section 6:75**). Locate the fan filter on the rear panel. Unclip the plastic filter holder that clips over the edges of the fan. Remove the holder and take the filter out.

6:11. Fans - At least once a year all the fans in the system should be checked for normal quiet operation.

- Case – 2 fans
- Upper chassis – 3 fans
- Data Computer – 1 CPU fan
- Control computer – 1 CPU fan
- Lower chassis – 2 fans
- Transmitter heat sink (2018 and later) – 2 fans
- 28 volt power supply – 1 fan

TRACKER CARD CALIBRATION

6:12. The following procedure describes the process of running and evaluating a tracker calibration. Tracker cards mostly consist of several analog filters whose components are subject changes in performance due to aging. Performing a tracker calibration corrects for these changes.

6:13. Run Tracker Calibration and Cross Channel Equalization (CCEQ) programs.

6:14. Make sure DCART is not operating automatically by clicking the STOP button in the upper left corner of the DCART screen.

6:15. Navigate to DCART / PROGSCHED tab (either EDITED or ACTIVE).

6:16. Select "**Prog**" on from the list of tabs on the left, under the PROGSCHED tab.

6:17. Locate and select a program labeled "**Tracker Cal**", and click the "**Run selected program**"

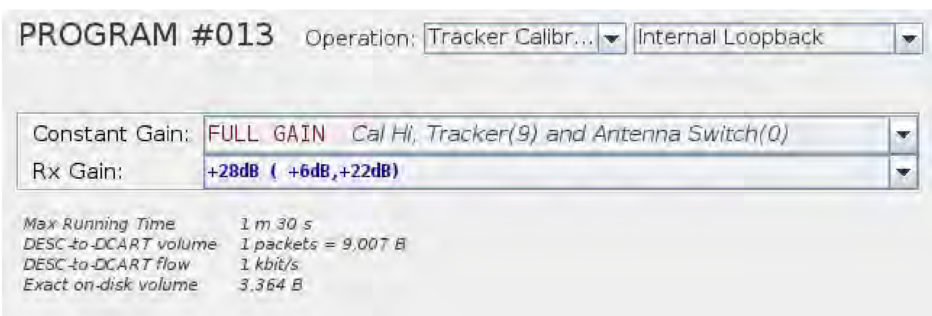


Figure 6-5: Tracker Cal Program

6:18. Locate and select a program labeled "**CCEQ**" and click the "**Run selected program**"

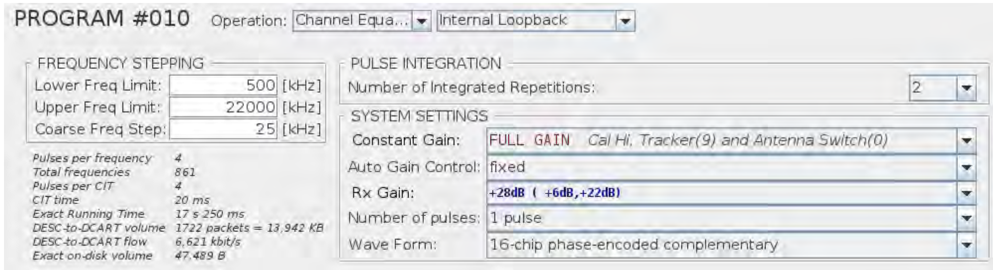


Figure 6-6: CCEQ Program

6:19. Verify All 4 channels work in "**internal loopback**".

6:20. Create/find the following "**Sounding Mode**" "**Internal Loopback**" program: (name it **TRKR Test**)

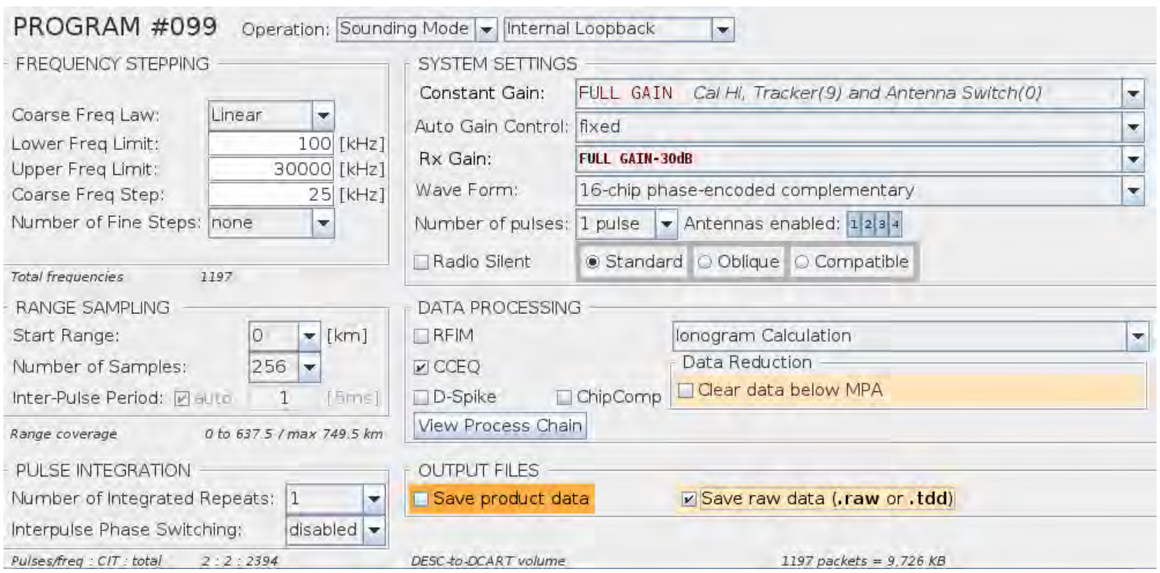


Figure 6-7: TRKR Test Program

6:21. Run the program.

6:22. Navigate to the "**Sounding Mode**" tab.

6:23. If the data display is not enabled, then enable it by clicking "**Enable Data Display**" in the upper left hand corner of the screen.

6:24. Ensure the following display settings are set:

6:25. "**Presentation**" is set to "**echogram**", "**Use dB**" is checked, "**All**" is checked, and dropdown menu is set to "**max**"

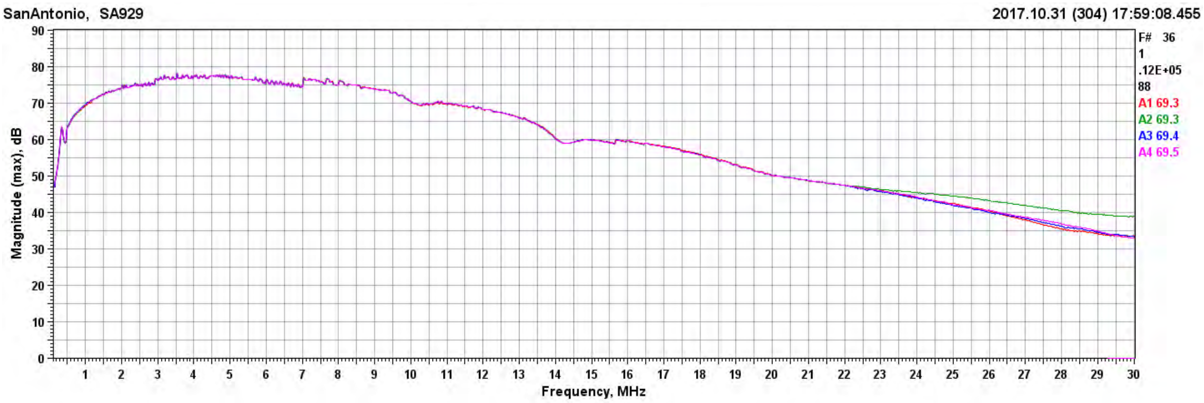


Figure 6-8: Ensure all 4 channels behave similarly as shown

OOSCILLATOR ADJUSTMENT OR TUNING

The following is an excerpt from the document “DPS-4D Transmitter Oscillator Testing and Tuning Procedure”

6:26. Introduction: All the timing and frequency generation in the DPS-4D is derived from a 61.44 MHz oven controlled voltage-controlled crystal oscillator or OCVCXO on the backplane near the front left corner of the chassis. The stability and resolution to which this crystal oscillator can be set is generally better than 1 part in 10^7 and possibly on the order of 1 part in 10^8. However, like all quartz crystal oscillators, the frequency drifts due to aging something on the order of 4 parts / 10^8 / year and should be re-adjusted yearly. The following procedure details adjusting or tuning the OCVCXO . The reference for adjusting the OCVCXO frequency is the GPS receiver component of the DPS-4D. The GPS receiver has a 1 pps (pulse per second) output which the DPS-4D uses for time synchronization. This GPS 1 pps is essentially an absolute reference derived from the U. S. Naval Observatory Master Clock. However, there is 50 to 100 nanosecond jitter on the 1 pps signal so the operator performing the following testing and tuning generally has to watch and compare the GPS 1 pps to the 1 pps generated by the DPS-4D and study the average drift between the two signals on an oscilloscope. It should be possible to adjust the Digisonde's crystal oscillator so that the drift between the two signals is less than 10 ns per second (1 part in 10^8)

6:27. Prepare programs and schedules for tuning the 61.44 MHz master oscillator

6:28. Tuning the 61.44 Mhz master oscillator of the DPS-4D system involves using an oscilloscope, observing two signals: the GPS 1pps and the R-Pulse trigger, and changing values of DCART ***Oven Control Oscillator DAC*** values from within ***On-line Global Parameters*** in an effort to minimize the observed drift between those two signals.

6:29. The GPS 1 pps is used as a reference signal against which the R-Pulse trigger output is to be compared. This R-Pulse trigger signal (the BNC connector labeled TRIG on the front upper right of the transceiver chassis) is only present when the system is transmitting. By creating an appropriate program and schedule the DPS-4D system can be used to produce its own 1 pps signal (or actually one pulse every 2 seconds, 1/2 pps). That signal will be compared with the GPS 1 pps during this procedure.

6:30. To tune the oscillator, first it is required to build the proper program and schedule to allow the DPS-4D to produce a 1/2 pps signal. This program may already exist from previous oscillator adjustment in which case check the parameters to ensure they agree with this document. Some parameters may have changed in order to be compatible with the latest version of DCART. The name of the program may not be exactly ***Osc Tuning*** as suggested below.

6:31. Click ***STOP*** in the upper left to put the system in Manual / Diagnostic mode.

6:32. Within the DCART ***EDITED PROGSCHED / Programs*** tab create the following ***Sounding Mode,*** program shown in **Figure 6-9**, and name it ***Osc Tuning***.

6:33. It is important to remember that the goal of this program is to simply produce a single pulse. It is possible to create many different program definitions all which produce a single pulse. To this end, many settings of this program do not matter; Fixed frequency, start range, number of samples, Rx Gain, etc all do not affect the program length and so can be set arbitrarily. It is useful to keep that fact in mind when creating such a program.

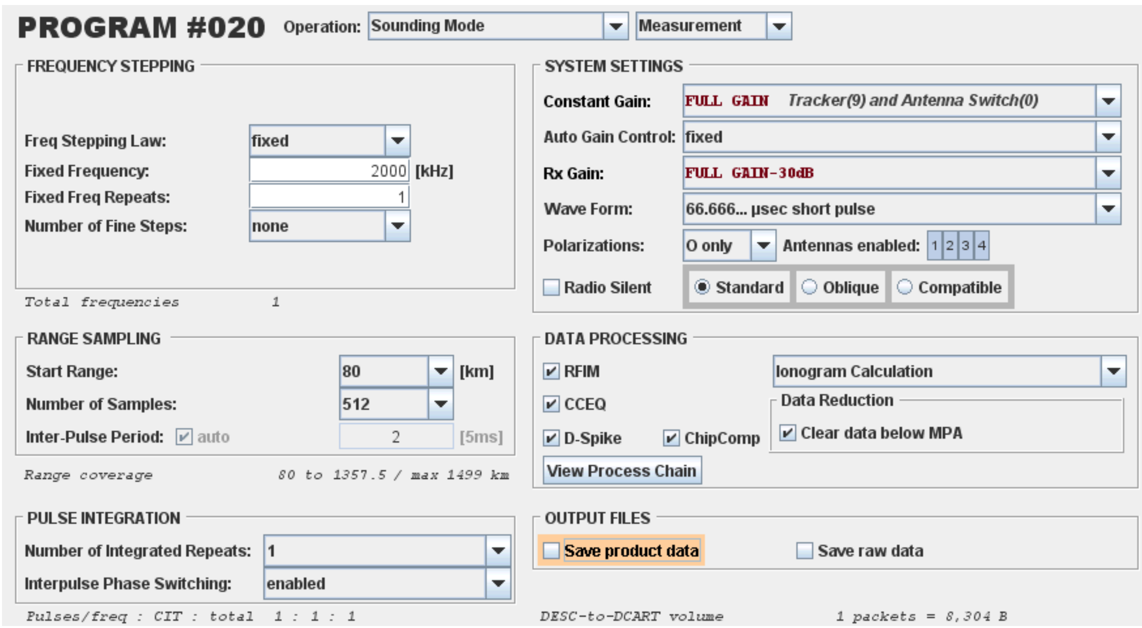


Figure 6-9: Single pulse program

6:34. Next, a two second schedule should be created that contains the ***Osc Tuning*** program. Within the DCART ***EDITED PROGSCHED / Schedules*** tab create the following two second duration schedule shown in Figure 6-10, and name this schedule ***Osc Tuning***. This schedule may already exist from previous oscillator adjustment in which case check that the duration is set to 2 seconds, not 1 second. The name of the program may not be exactly ***Osc Tuning***.

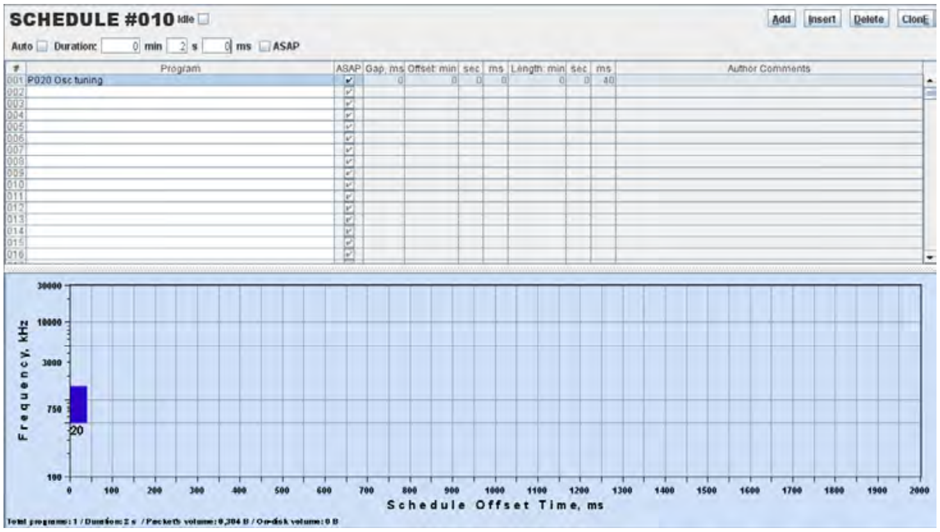


Figure 6-10: 2 second duration schedule

6:35. Navigate to DCART ***EDITED PROGSCHED / SST, Rules, Campaigns*** tab and make a record of the currently running schedules and their rules. Next, within the ***CAMPAIGNS*** section of the page configure the ***Osc Tuning*** schedule such that it will run as a campaign similar to how it's shown in **Figure 6-11**.

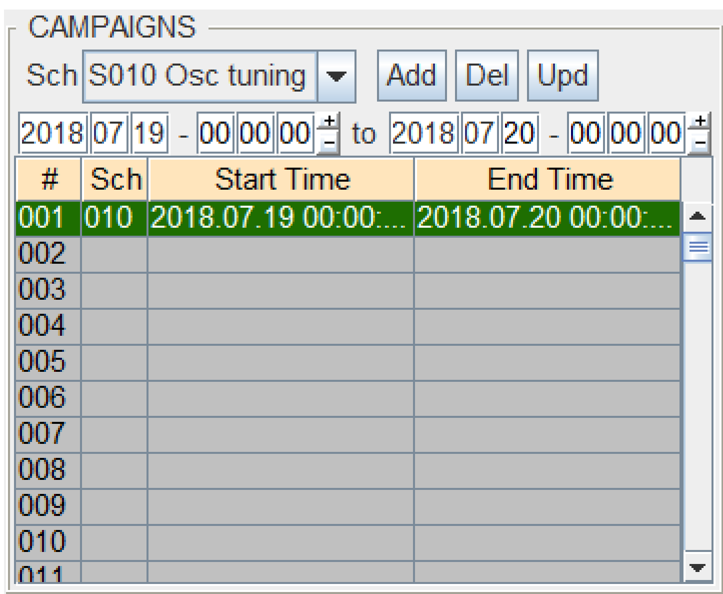


Figure 6-11: Osc tuning schedule entered as a campaign

6:36. Using the ***Sch*** dropdown menu select the ***Osc Tuning*** schedule and specify start and end times for the campaign such that it will provide sufficient time for you to conduct the tuning procedure. Once the campaign has been configured press ***Add*** to add it to the campaign list. Ensure you click on ***Activate changes*** to transfer the new program, schedule, and campaign information to DESC. Click the ***Auto*** button in upper left of DCART to initiate automatic operations. With the system in ***Auto*** mode you should be able to hear an audible click, once every two seconds, emanating from the speaker in the transceiver chassis. Normally, when running a measurement the system will emit a tone as the system is transmitting continuously. Since the system is transmitting only once every two seconds you will only hear noise (a click) once every two seconds.

6:37. Connect the oscilloscope and prepare for tuning

6:38. Extend the transceiver chassis to its stops and remove its cover. Ensure you take proper ESD (Electrostatic Discharge) precautions when working with an open chassis. It is suggested that a grounding ESD wrist strap be used. There is aging of the quartz crystal oscillator, perhaps both long term and short term. We recommend having the oscillator running under power for a day before making final adjustments. If it is a new backplane (oscillator), letting it run under power for a few days is probably in order.

6:39. Ensure your oscilloscope is configured so all channels are set to 1 MΩ impedance.

6:40. Locate where the GPS 1pps signal enters the transceiver chassis in the center rear next to the antenna switch via a BNC bulkhead connector. On the inside of the chassis disconnect the 1pps BNC cable, connect a BNC T connector to the 1pps BNC bulkhead, and reconnect the 1pps cable to the BNC T. Be careful not to drop a cable so that the BNC connector short circuits anything in the chassis. Note: If the GPS Receiver is the Trimble 360 model (mfg 2017 or later) and the transmitter card is rev. C3 or earlier, there will be a small capacitor (4.7 nf) box in series with the BNC connector on one side or the other of the rear panel. It does not matter which side of this capacitor box you put the T for the oscilloscope.

6:41. Connect a BNC cable from the BNC T to the oscilloscope channel 1 input.

6:42. Connect a BNC cable from the TRIG output on the front of the transceiver chassis to the oscilloscope channel 2 input.

6:43. Set the oscilloscope trigger source to channel 2 and trigger on the leading edge of the negative going, 2 volt TRIG 1/2 pps signal on channel 2 by adjusting the vertical and horizontal position knobs, and the horizontal scale as necessary. Put the GPS 1pps signal in the center of the oscilloscope display. The leading edge of the negative going 1 pps from the GPS should show up about 7 µsecs after the leading edge of the negative going 1/2 pps from the TRIG connector on the front panel when synchronization occurs every 17 seconds or sometimes a multiple of 17 seconds, 34, 51 seconds.

6:44. It is recommended to start with a horizontal scale of approximately 4 µsecs per division, and decrease the scale from there as you minimize oscillator drift. With a typical digital oscilloscope it will be possible to "move" the triggering point of the TRIG signal well off to the left of the display and have a horizontal scale of 1 µsec per division, then 400 ns per division.

6:45. Making changes to the DAC output values requires that DCART be in the advanced mode user interface. To change DCART to advanced mode navigate to the DCART ***Options*** menu and select ***General***. Under ***General Appearance and Interface***: click ***Advanced Mode***.

6:46. (Please remember to change back to ***Normal Mode*** after completing this procedure.)

6:47. Navigate to DCART ***Options / Global Parameters / On-line***. Leave data1 set to wherever it is, probably 0x7F (7F). Make changes to the data2 values in ***Oven Control Oscillator DAC*** to minimize the observed GPS 1 pps drift on the oscilloscope. If in the following procedure data 2 gets close to its limits (0x00 or 0xFF) feel free to make a change to data1. Data1 and data2 are summed and have equal weights.

6:48. The negative going leading edge of the GPS 1 pps should resynchronize to the TRIG 1/2 pps every 17 seconds so every 17 seconds the leading edge of the GPS signal should jump back to the point about 7 µsecs after the TRIG 1/2 pps negative going leading regardless of where it drifted to during the 17 seconds.

6:49. Once you have entered a new value in the data2 field, press Enter to make "***Apply***" active at the bottom of the window. Then click "Apply" to accept the new Data2 value.

6:50. Note that increasing data2 (or data1) will make the GPS 1 pps drift to the right on the screen if you are triggering the oscilloscope with the TRIG 1/2 pps. Decreasing data2 will make the GPS 1 pps drift to the left on the screen. A change to data2 (or data1) of one unit (one bit, or LSB and do remember that these are hexadecimal values, 0 1 2 3 4 5 6 7 8 9 A B C D E F) is equivalent to approximately a change in the drift between the GPS and R pulses of 7 ns (nanoseconds) /second or 0.1 µs per 17 seconds.

6:51. The following steps are generally not necessary but once you have the drift down to less than 200 ns / 17 seconds, it might be helpful to watch the drift for a longer period of time, perhaps as long as 4 or 5 minutes in order to get down to the least significant bit of data2. To stop the automatic resynchronizing every 17 seconds, disconnect the 1 pps BNC cable from the BNC Tee which you have temporarily installed in the chassis.

6:52. Be careful not to drop the cable so that the BNC connector short circuits anything in the chassis.

6:53. After making a change to data2 the GPS pulse will jump well off the screen of the oscilloscope. It will be necessary to reconnect the 1 pps GPS cable back to the BNC Tee for as long as 17 seconds or until resynchronization occurs and the GPS 1 pps signal is back to 7 µs after the TRIG 1/2 pps. Then disconnect the cable again and watch the drift for 4 or 5 minutes.

6:54. Adjust data2 to achieve minimum drift in either direction. You should be able to get down to the LSB of data2 so that the drift of the GPS 1 pps is very slow in one direction and a change in data 2 of one unit makes the drift very slow in the other direction. This minimum drift should be on the order of 3 or 4 ns (nanoseconds) / second or 1 µs in 4 minutes (240 seconds).

6:55. It is possible, but unlikely that to achieve the minimum drift data2 would exceed the maximum possible limits for its adjustment, i.e., 00 (0x00) or FF (0xFF). If that is the case it will be necessary to adjust data1 in the same direction you are trying to go with data2. Data1 and data2 have equal weights. A change of one LSB in data1 will have the same effect as a change of one LSB in data2.

6:56. When done with this tuning procedure return to the normal operational schedule and change back to "normal" operation. To change DCART back to normal mode, navigate to the DCART ***Options*** menu and select ***General***. Under ***General Appearance and Interface:*** click ***Normal Mode***. Please remember to change back to ***Normal Mode*** after completing this procedure. To return to the standard operational schedule first navigate to ***PROGSCHED / SST, Rules, Campaigns*** tab. Within the ***CAMPAIGNS*** section of the page select the campaign entered earlier in this procedure and click ***Del*** to delete the entry from the list of currently applied campaigns. Click on ***Activate Changes*** to apply the new campaign settings, and click ***Auto*** to resume the normal rule based scheduling.

MAINTENANCE SPARES RECOMMENDATION

6:57. A listing of recommended maintenance spares showing manufacturer's part number, quantity fitted in the system, recommended support sparing level, and recommended maintenance policy is provided in **Table 6-4**. It is recommended that spares be held in appropriate locations to support fielded systems in accordance with the overall system maintenance support plan.

Table 6-4: Maintenance Spares Recommendation

#	Item	Part	Placement	QTY
1	AS-5021107 Rev D	DPS4D Tracker Card	Card File slots 1,2,3,4	1
2	AS-5021105 Rev B	DPS4D Receiver Card	Card File slot 5	1
3	AS-5021104 Rev C	DPS4D Transmitter Card	Card File slot 6	1
4	AS-5021301 Rev B	DPS4D Pre-Processor Card	Card File slots 7,8	1
5	AS-5021108 Rev B	DPS4D BIT Card	Card File slot 9	1
6	AS-5021202 Rev H	DPS4D Power Dist Card	Processor Chassis	1
7	AS-7020103 Rev C	DPS4D Ant. Switch Assbly	Processor Chassis	1
8	HS-872PEDG2	DPS4D Control Computer	Processor Chassis	1
8a	PCE-4129G2-00A1E	DPS4D Data Computer	Processor Chassis	1
8b	1960053207N001	DPS4D Data Computer CPU Fan	Processor Chassis	1
8c	PCE-3B03A-00A1E-LDI	DPS4D Data Computer Backplane modified by LDI w/ volt. regulators	Processor Chassis	
8d	PCE-1G-01	DPS4D Data Computer Network Card	Processor Chassis	
9	MZ-75E500B/AM	DPS4D SSD for Data Platform	Processor Chassis	1
10	Gain Resistor Set	Resistor Set	Receive antenna boxes	1
11	AS-7040010 Rev J	DPS4D Preamp/Polariz. Box	Receive antenna	1
12	3610KL-05W-B50	Fan Axial, 92 mm	DPS4D Enclosure	1
13	AFB0624HH	Fan Axial, 60 mm	DPS4D Enclosure	2
14	09362-F/45	Filter, Air, 92 mm	DPS4D Enclosure	3
15	8 Amp Fuse	8 Amp Fuse	RF Amplifier Chassis	2

BUILT-IN TEST: PERIODIC SELF-DIAGNOSTICS

6:58. The Built-In Test diagnostic system is comprised of a set of hardware sensors, a BIT card with a micro-controller that digitizes the sensor data, and the BIT program software. The BIT program uses measurement data in addition to the data collected by the BIT card to determine the health of the system. There are three types of BIT sensors. *Digital* (Go/No Go) sensors are used to monitor power supplies and over-temperature conditions. *Static Analog* sensors are analog signals that are always present such as temperature signals. *Dynamic Analog* sensors are signals that are present only during sounding.

Sensors collected by the BIT Card:

- Power Distribution card power for Preamplifier/Polarization Box (digital)
- Power Distribution card –15V, -5V, +3.3V, +15V, +12V(digital)
- Power Distribution card over-temperature condition (digital)
- Power Amplifier power for first stage amplifier +18V (digital)
- Transceiver Chassis Temperature (static analog)
- Power Amplifier Chassis Temperature (static analog)
- Transmitter card channel 1 & 2 output (dynamic analog)
- RF Power Amplifier channel 1 & 2 output (dynamic analog)
- Saturation sensor from Tracker #4 (digital)

Other measurement data collected and used by the BIT program:

- Receiver card channel 1, 2, 3, 4 output (dynamic analog, “routine data”)
- Hardware Test Pattern from Pre-Processor (digital, gathered by DESC)
- Parallel Bus Data Timeouts (digital, determined by DESC)

6:59. **Figure 6-12** shows the location of the sensors and data collection points.

6:60. The BIT program puts the system in four different configurations (cases) using switches in the antenna switch, tracker cards, and RF amplifier output switching to make a determination about system health.

6:61. Case 1 is external loopback (**Figure 6-13**). The system transmits normally as though making a measurement. The signal enters the receivers through the antennas. The program listens at 0 km height for the transmit pulse.

6:62. Case 2 is internal loopback (**Figure 6-14)**. A low level calibration signal from the digital transmitter is routed through the antenna switch to the inputs of the tracker cards.

6:63. Case 3 is internal loopback with tracker cards bypassed (**Figure 6-15**). A low level calibration signal from the digital transmitter is routed through the antenna switch to the inputs of the tracker cards. Switches on the tracker cards connect the inputs to the outputs, effectively bypassing the bandpass filters.

6:64. Case 4 is transmission into dummy loads (**Figure 6-16**). The system transmits normally but the RF output from the half octave filters in the power amplifier are routed to dummy loads rather than the transmit antenna. The health of the transmit antenna can be determined by comparing the levels of the RF 1 & 2 sensors with the results from Case 1.

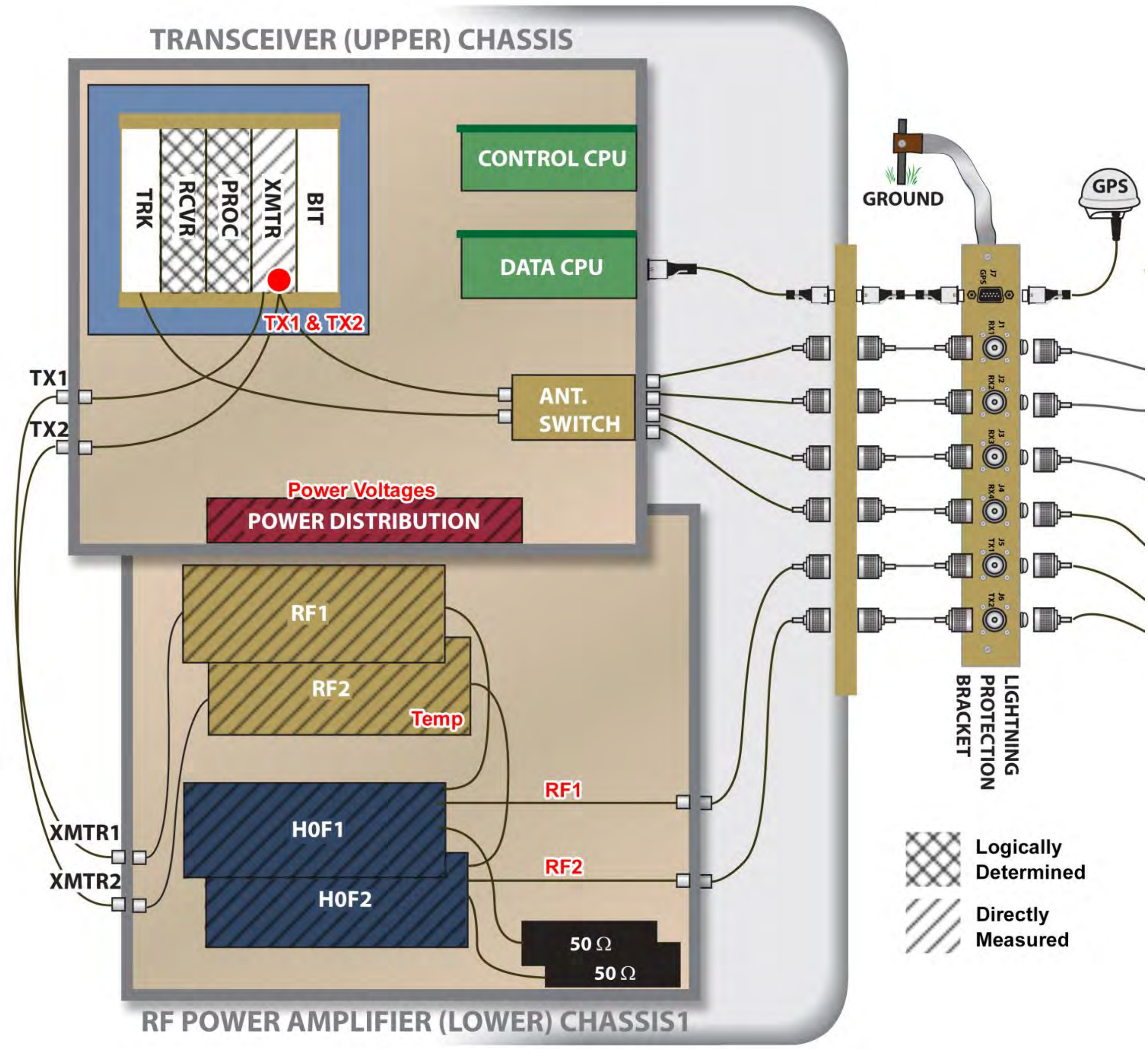


Figure 6-12: BIT Sensor Locations

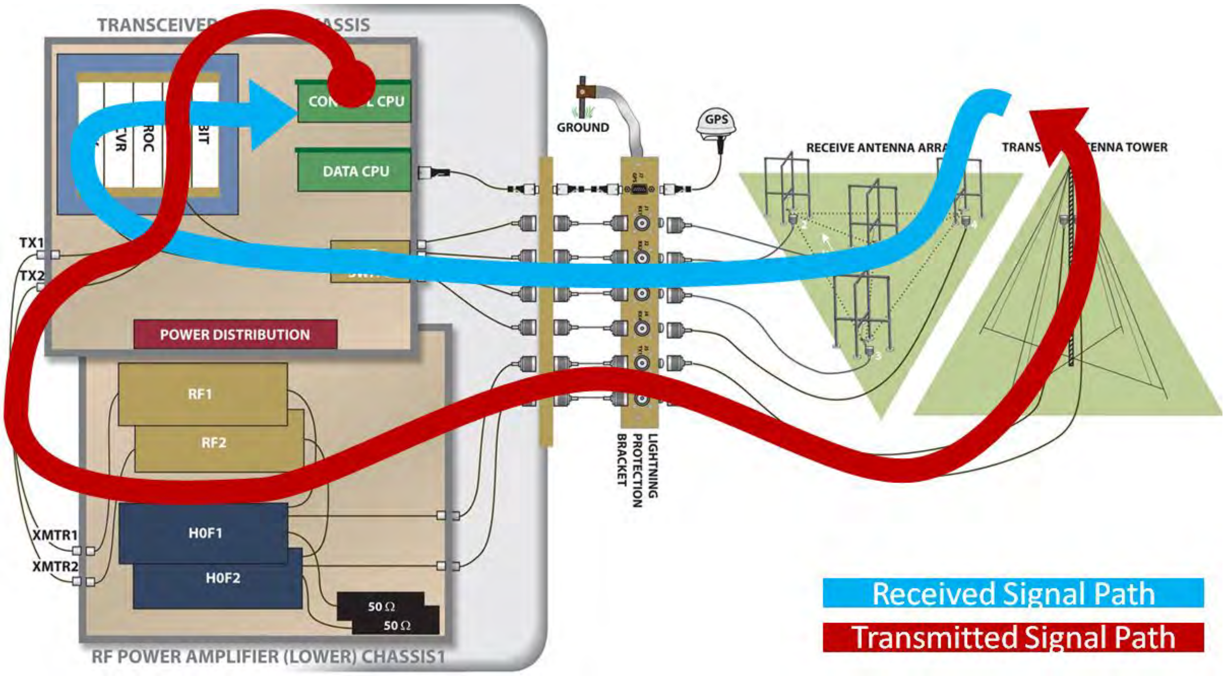


Figure 6-13: BIT Case 1 – External Loopback resulting signal path is shown

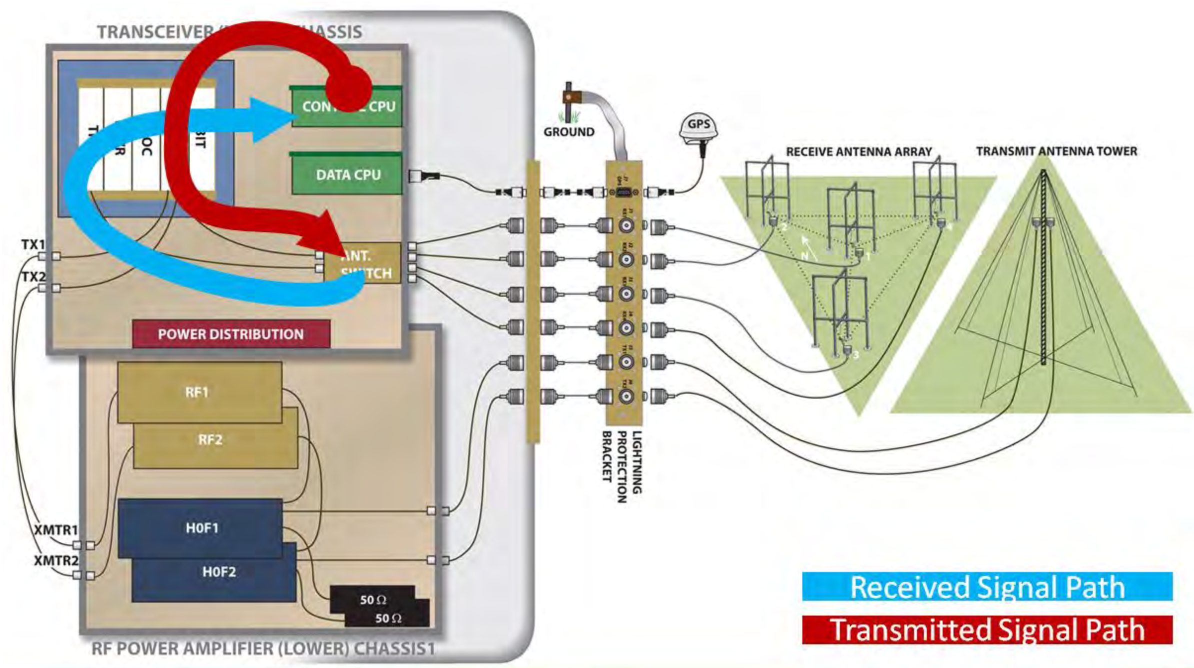


Figure 6-14: BIT Case 2 – Internal Loopback resulting signal path is shown

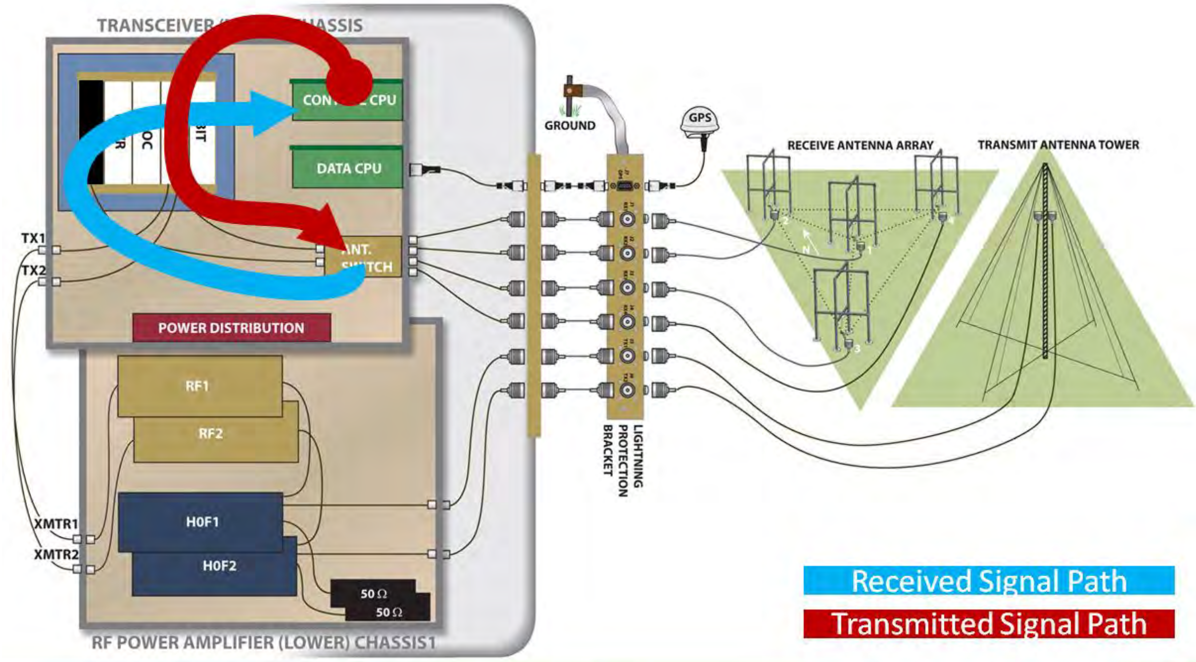


Figure 6-15: BIT Case 3 – Internal Loopback (Without Trackers) resulting signal path is shown

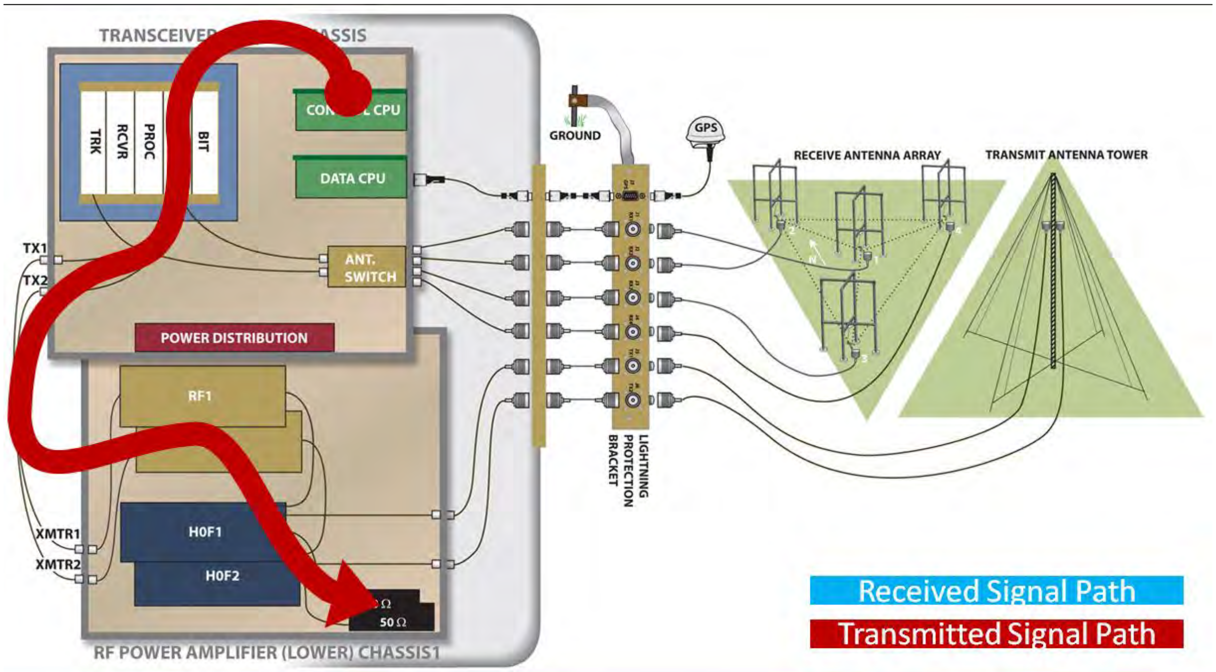


Figure 6-16: BIT Case 4 – Transmission into Dummy Loads resulting signal path is shown

6:65. BIT is a program that has to be scheduled (see **Figure 6-17**). It should be included in the routine sounding schedule. It can also be manually run in "Diagnostic" mode from the DCART's Program screen. BIT data can be viewed in two forms: a Built-In Test display and a BIT Report. The Built-In test display is accessed from a tab in the DCART menus. It displays the sensor's mnemonic, name, measurement data, go/no go status, and the limits used for the go/no go decision (see **Figure 6-18**).

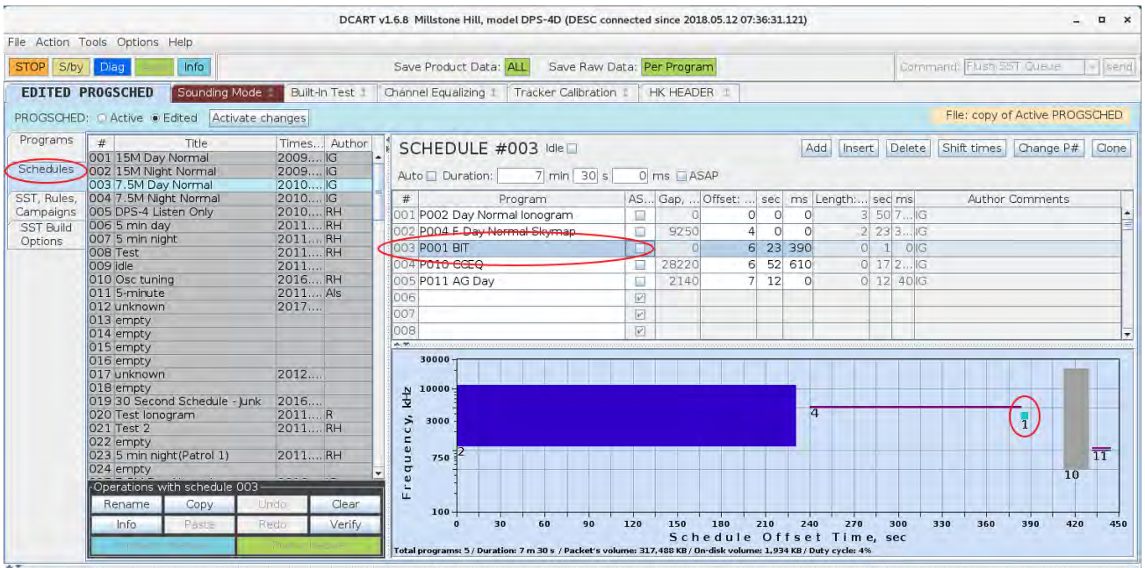


Figure 6-17: BIT program has to be scheduled

6:66. At the upper right of the Built-in Test display is a "Report" button. If the button is pressed a BIT report is displayed (see **Figure 6-19**). The BIT report is designed to help isolate the Line Replaceable Module (LRM) in the case of a failure. The BIT report provides the following information:

- Shows a system failure if one occurs
- Lists suspected components
- Provides troubleshooting recommendations
- Lists failed sensors, including "case" where failure occurred
- Lists hardware by state; GO, NOGO, UNKNOWN
- Lists sensor definitions

6:67. The BIT report can also be accessed remotely from the system's web page through the main menu.

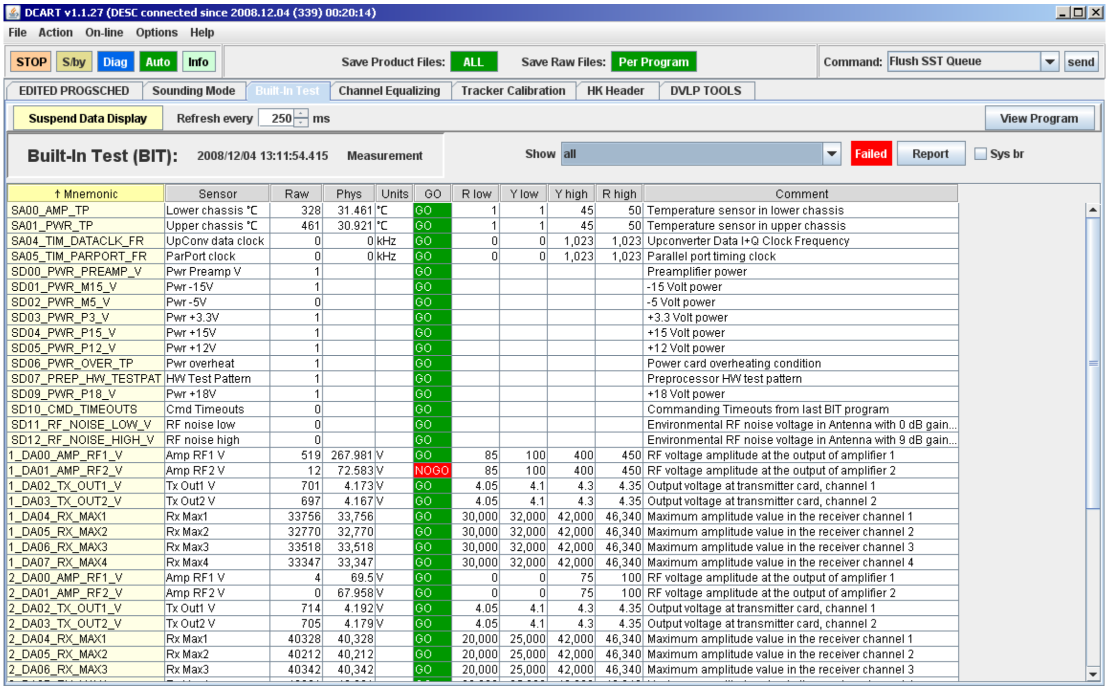


Figure 6-18: Built-In Test Display

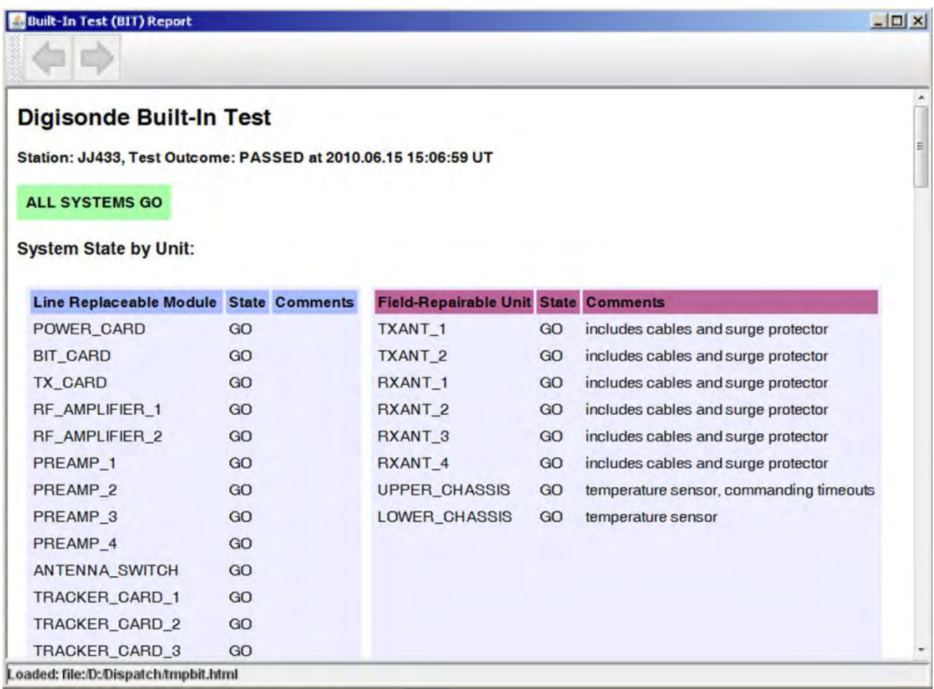


Figure 6-19: Built-In Test Report

CHAPTER 2

REPLACEMENT OF MODULES

ACCESSING OR REPLACING LRM'S IN THE DPS MAIN CHASSIS.

NOTE:

A ground strap should be worn when handling LRM's to avoid damaging them by electrostatic discharge (ESD)

6:68. Access to Main Chassis

1. Shut off power.
2. Remove DPS enclosure front cover by turning the four fastener knobs counter-clockwise.
3. Remove the four panel mount screws at left and right sides of DPS main chassis front panel.
4. Slide the main chassis forward (toward you) until slides lock.
5. Remove the top cover by loosening six #6-32 screws at the top left and right sides of the main chassis.
6. Locate the LRM to be replaced (see **Figure 6-20**). The Tracker, Digital Receiver, Pre-processor, Digital Transmitter, and BIT cards are located in the card cage. The card cage is silk screened to show the locations of the individual cards.

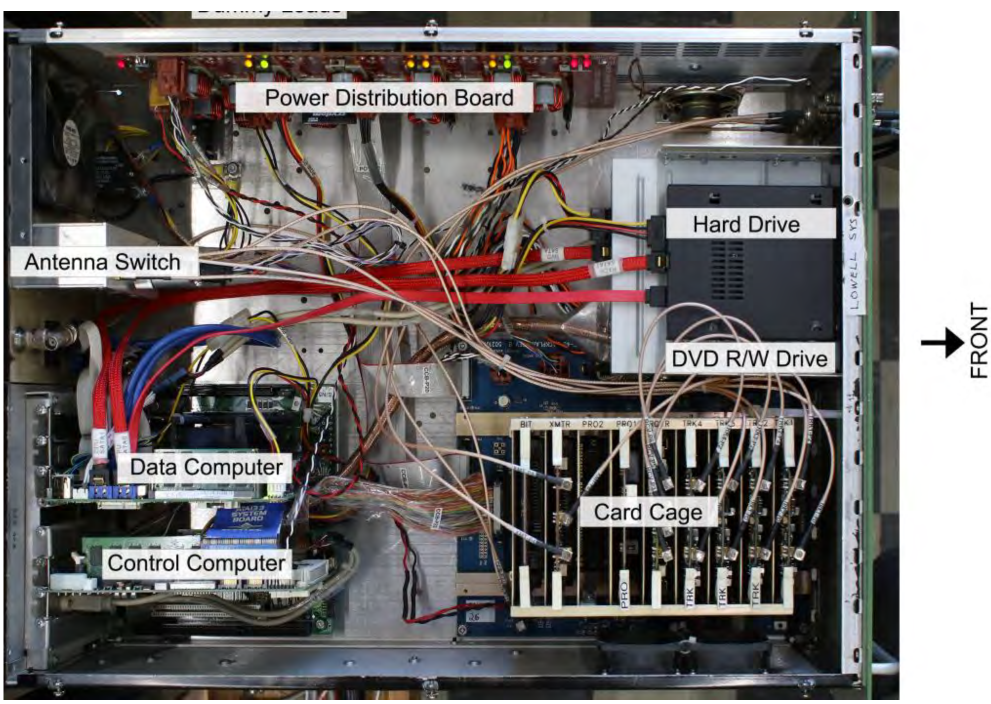


Figure 6-20: Digisonde® Upper Chassis

6:69. Power Distribution card.

1. Press slide lock button on right hand side of chassis and push the slide toward the rear of the chassis until the inner part of the slide is disengaged.
2. Locate Power Distribution card. (see **Figure 6-20**).
3. Disconnect all cable connections.
4. Remove 15 #4-40 mounting screws from side panel of Main Chassis.
5. Remove suspect Power Distribution card.
6. Remove and replace preformed thermal gasket between heat sink surfaces of replacement card and right side panel..
7. Repeat steps (1 - 5) in reverse order to replace Power Distribution card.

6:70. Tracker, Digital Receiver, Pre-processor, Digital Transmitter, and BIT cards.

1. Locate the card cage in the DPS Main Chassis (see **Figure 6-20**).
2. Locate the LRM to be replaced (see silkscreen on edge of card cage).
3. Remove any interconnect cables at top edge of board assembly to be replaced.
4. Remove suspect LRM.
5. Replace LRM and re-attach cables.

6:71. Antenna Switch.

1. Release chassis slide locks and slide Main Chassis out far enough to gain access to the rear of the Main Chassis.
2. Locate Antenna Switch LRM.
3. Remove 4 cables at rear of chassis marked ANT1- ANT4.
4. Remove J1, CAL IN and RF OUT connections from Antenna Switch.
5. Remove 4 #6-32 screws at rear of chassis.
6. Repeat steps 6.4.1 - 6.4.5 in reverse order to replace Antenna Switch assembly.

6:72. Data Computer PCE-4129

1. Locate the Data Computer is the DPS Chassis (see **Figure 6-20**)
2. Release chassis slide locks and slide Main Chassis out far enough to gain access to the rear of the Main Chassis.
3. Refer to **Figure 6-21**, **Figure 6-22,** and **Figure 6-23** making a note of all connections.
4. Unscrew the Data Computer's VGA connector from the rear of the computer and disconnect it from the computer.
5. Disconnect the RJ-45 connector from the LAN 1 connector.
6. Remove cables connected to SATA0, SATA1, Front Panel USB45, and the GPS ribbon cable connected to the RS485 daughter board.
7. Remove the #6-32 screw holding the Data Computer in place via its mounting bracket.
8. Remove the computer from its backplane.
9. Repeat steps above in reverse order to replace the Data Computer.

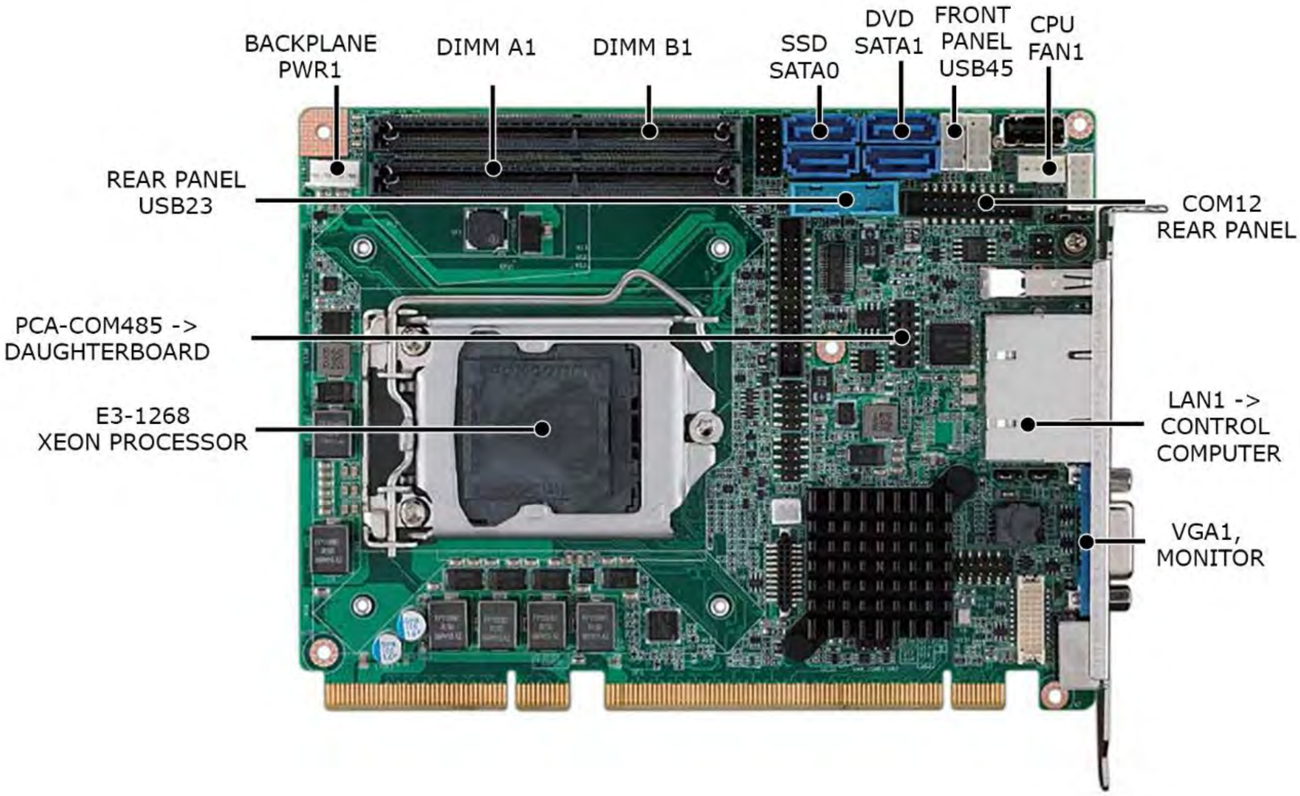


Figure 6-21: Data Computer PCE-4129

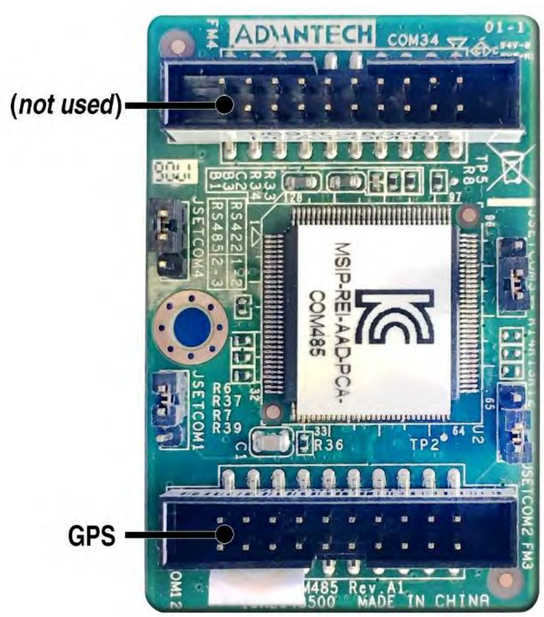


Figure 6-22: Data Computer RS485 Daughter Board PCA-COM485-00A1E

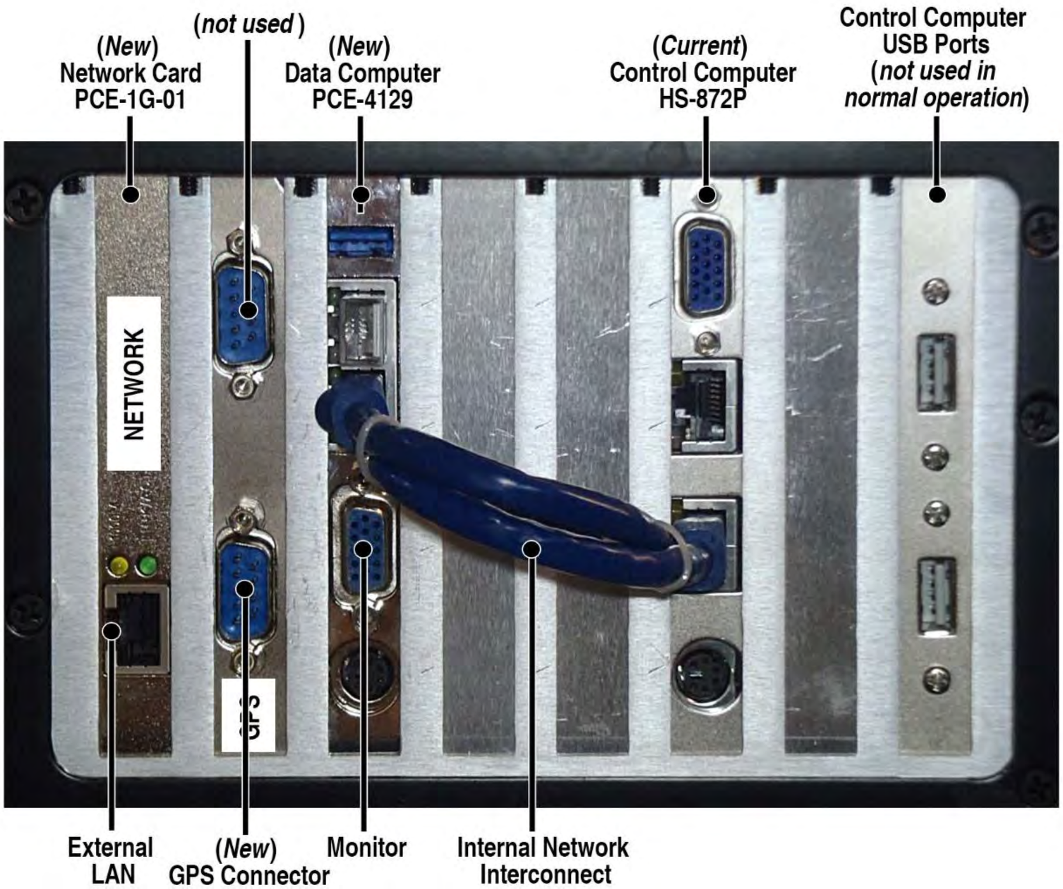


Figure 6-23: Computer Connections to Processor Chassis Rear Panel

6:73. PCE-1G-01 Network Card

1. Locate the network card in the DPS Chassis (see **Figure 6-20**).
2. Release chassis slide locks and slide Main Chassis out far enough to gain access to the rear of the Main Chassis.
3. Remove the network cable from the rear of the network card.
4. Remove the #6-32 screw securing the network card's bracket in the chassis.
5. Installation is reverse of removal.
6. Note: The backplane which the network card is installed in has PCIe slots that are a non-standard distance from each other. For this reason, when installed properly, one can observe that the network card circuit board is slightly flexed. This is expected and will not damage the network card in any way.

DUAL POWER AMPLIFIER CHASSIS

6:74. **Table 6-5** lists BIT faults pertaining to the Dual Power Amplifier Chassis. Upon detection the PA chassis should be replaced and repair concluded at depot level.

Equipment needed: #1 Philips and flat head screwdriver

Table 6-5: BIT Faults of the Dual Power Amplifier Chassis

BIT Sensor Fault	Condition	Remarks
RF1	NO-GO	---
RF2	NO-GO	---
+18V	NO-GO	---
Amp Temp	NO-G0	Thermal protection shutoff, threshold adjustable in StationSpecific.udd

6:75. Removal procedure for Dual RF Power Amplifier (PA) Chassis

1. Remove DPS enclosure front cover by turning the 4 fastener knobs counter-clockwise.
2. Remove four panel mount screws at left and right sides of PA chassis front panel.
3. Slide PA chassis out of enclosure until slides lock.
4. Disconnect all cables from rear of PA chassis.
5. Press in slide lock buttons and remove PA chassis from enclosure.
6. To replace PA chassis repeat steps 1 - 5 in reverse order.

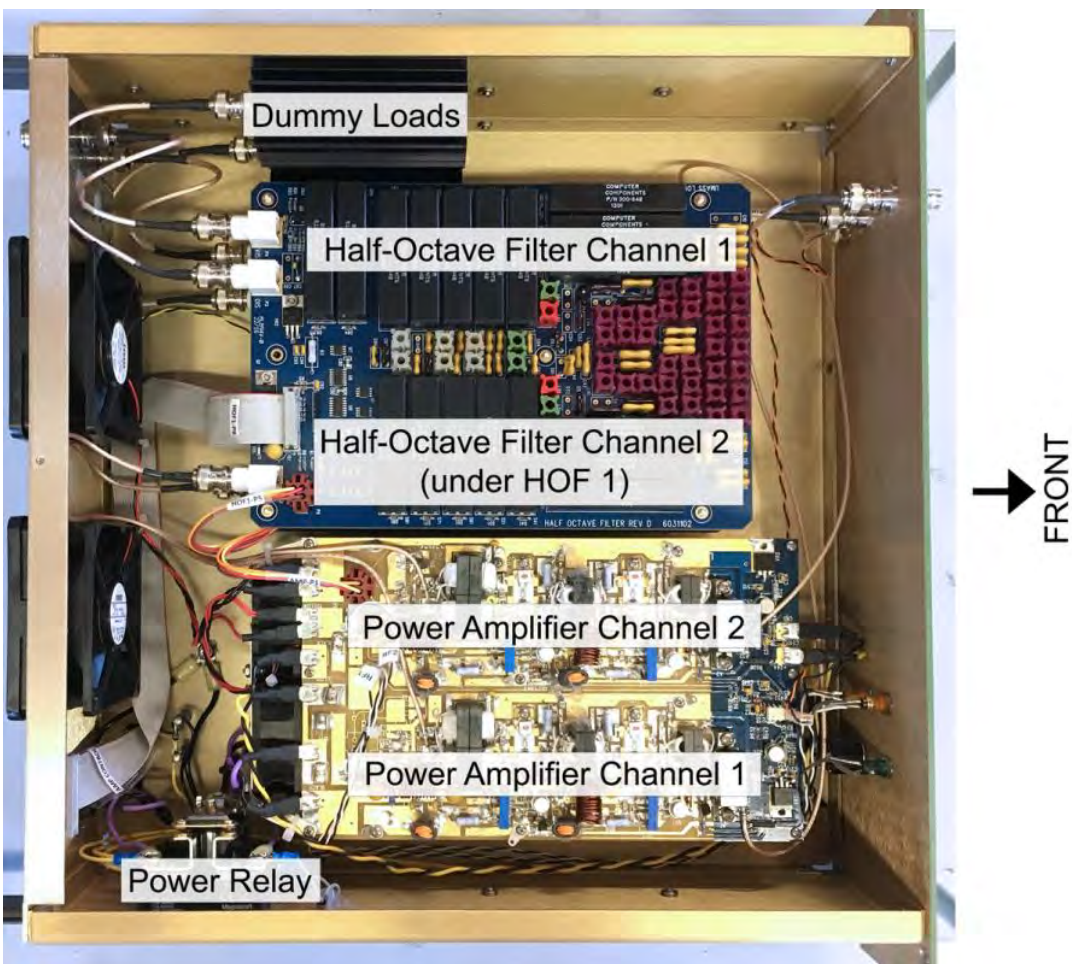


Figure 6-24: PA Chassis

ANTENNA SUB-SYSTEMS

6:76. **Table 6-6** lists BIT faults (refer to Built-In Test Display Figure, **Figure 6-18**) pertaining to the Receive and Transmit Antenna sub-systems.

Equipment needed: None

Table 6-6: BIT Faults of the Receive and Transmit Antenna Sub-system

BIT Sensor Fault	Condition	Remarks
RxAnt	NO-GO	Fault occurs when an RX antenna is faulty.
TxAnt	NO-GO	Fault occurs when VSWR mismatch is detected on either TX antenna

6:77. Periodic evaluation of RX Antenna sub-systems is performed by the BIT program. If a bad channel is indicated, cables from the receive antennas can be swapped on the rear panel of the DPS or at the Lightning Protection Bracket to check for a bad cable or antenna preamp; however, they must be returned to their original positions once the antenna has been repaired to ensure the Drift (.dft) data displays correct directional information. O/X switching voltage (17-22 VDC) can be measured at the antenna preamp on the N-type connector. No voltage can indicate a break in the receive cable. If a TDR (Time Domain Reflectometer) is available it may be used to locate the cable break.

CHAPTER 3

TROUBLESHOOTING

REPAIR OF FAILED MODULES

6:78. LRM troubleshooting will normally be performed under special arrangements with the manufacturer. The LRM to be diagnosed may have been found faulty by the Built-In Test at the operating site, or by finding that replacement of the LRM returned the system to normal operating status. To assist with the identification of discrete components and non-specialized fault finding on proprietary circuit boards, a technical data package comprised of circuit board layouts, parts lists, and schematics is provided separately to the customer.

6:79. Due to the small size and density of the integrated circuits on the LRM's in the main chassis, it is recommended that the boards be diagnosed and repaired by the manufacturer. Without proper tools and experience it is easy to damage these boards.

6:80. It is possible for a customer to test and repair some of the modules outside the main chassis. Diagnostic procedures are included in the following paragraphs.

6:81.

TROUBLESHOOTING DATA COMPUTER

6:82. Digisonde operations require a fully functional Data platform. It is unusual that the Data Computer boots successfully but is then unable to start necessary LDI software DCART and Dispatcher. For that reason, it is overwhelmingly the case if DCART and Dispatcher software programs run that the Data Computer is functioning normally.

6:83. Most commonly when the Data Computer fails to work properly it fails to boot. This could be caused by a failed hard drive, memory, or CPU failure due to a fan failure. Should these failures occur, the Data Computer should be replaced with its spare.

6:84. One should first ensure that the Data Computer itself is functional. If it is, it should emit a beep or series of beeps indicating that its Power On Self Test (POST) has completed successfully. If this audio event does not occur and no video output can be observed on the connected monitor, then one must suspect a computer hardware failure.

6:85. In the event the Data Computer does not POST one can attempt to replace the PCE-4129 Data Computer Board.

6:86. If the Data Computer does POST and it appears the single board computer hardware is functioning properly, the next step is to ensure the boot device is working properly. It is recommended to replace the Solid State Disk (SSD) drive with a spare or attempt to connect the SSD directly to the Data Computer instead of having the SSD connected through its caddy and tray. Should you not spare SSDs at the site, ensure you bring a fully configured drive with you if hard drive failure is suspected.

TROUBLESHOOTING CONTROL COMPUTER

6:87. The message "DESC connected since ……." at the top of DCART window confirms the Control computer is operating and is connecting by the internal LAN connection. Additionally, current DESC status displayed in the lower left hand corner of the DCART window is an indication of Control computer connectivity as without a network connection DCART will report a DESC status of "connecting".

6:88. A monitor can be connected to the VGA connector of the Control computer on the rear of the computer card. Messages seen on the screen during boot up may clarify where the system is hanging on an unsuccessful boot-up. The Control computer makes no use of a mouse or keyboard after POST. It may be necessary to Restart the Control Computer after connecting a monitor. This may be accomplished by moving the slide switch at the top of the Power Distribution card forward briefly and then back to cycle the power or by pressing the red reset button on the front of the chassis.

6:89. Common difficulties with the Control computer are related to a failure of communication between Data and Control computers. One should monitor the boot progress of the Control computer after connecting a monitor as described above ensuring the DHCP and TFTP processes running on the Data computer are working as expected. Also ensure the network cable is physically connected to the correct network port on the rear of the computer. The dedicated network lane for communication between the Data and Control computers should be connected to the lower of the two network ports on the HS-872P Control computer.

6:90. Power for Control Computer as well as the Card Cage with LDI manufactured cards is controlled with a slide switch (SW12) at top of Power Distribution card. This switch, SW12, should be used to remove power from the Card Cage while removing and reinstalling cards in the Card Cage. Toggling the switch can also be used to Restart the Control Computer.

6:91. Pressing reset button on the front of the Main Chassis should result in a Control Computer POST beep if the computer is functioning.

6:92. If the Control Computer does not beep (signifying successful Power On Self Test or POST) and there is no video output once a monitor is connected (It may be necessary to Restart the Control Computer as described in 6:85.) then it is suggested to replace the Control Computer with a spare.

6:93. Assuming the Data Computer is operating, the information displayed on the BIT page accessible from the BIT tab in the DCART window may provide some assistance in locating a fault.

TROUBLESHOOTING THE POWER INTERFACE BOX

Special Test Equipment: Digital Multimeter
Reference Documents: Power Interface Schematic
Test Components: N/A

6:94. Under normal operating conditions, if a voltage at terminals BT1 & BT2 (nominally 27 – 27.5 volts but certainly between 22 and 30 volts) is present, this voltage should be conducted by the power MOSFETs in the box to the output at BT3 & BT4. If not, confirm that the toggle switch on the rear panel of the case is UP and disconnect the remote switch connector. If still no power shows up on BT3 and BT4 one can further test for failure of the power interface by bypassing it. Power down the system and connect the outputs on terminals BT3 & BT4 to the inputs BT1 and BT2. If the system powers on normally when power is restored the Power Interface is faulty and should be replaced.

TROUBLESHOOTING THE POWER DISTRIBUTION CARD

Special Test Equipment: Digital Multimeter
Reference Documents: Power Interface Schematic

6:95. There are 6 DC/DC converters present on the power distribution card and 7 different voltages produced. If all voltage indicator LEDs are lit most likely all output voltages are healthy. However, if there is any question concerning output voltages they can be measured with a digital multimeter. Figure 6-25 shows the power distribution card, identifying locations to measure its DC/DC converter outputs. With the digital multimeter set to measure DC voltages, place the positive probe in the location indicated with a red circle or arrow, and the negative probe in the location indicated with a black circle or arrow to measure each labeled voltage output. The DC voltages measured should be as labeled in Figure 6-25 ± 10%. The O/X switching output should be 22.7V ± 10% when in O mode and 16.7V ± 10% when in X mode. The following is a description of those measurement points.

1. +15V output is measured on DC/DC converter DC5 between pins 7 and 5.
2. -15V output is measured on DC/DC converter DC4 between pins 7 and 5.
3. +5V output is measured on DC/DC converter DC3 between pins 7 and 5.
4. +3.3V output is measured on DC/DC converter DC2 between pins 7 and 5.
5. +12V output is measured on DC/DC converter DC1 between pins 7 and 5.
6. -5V output is measured on DC/DC converter DC6 between pins 7 and 5.
7. O/X switching voltage output is measured between regulator VR12 pin 2, and DC/DC converter DC5 pin 4.

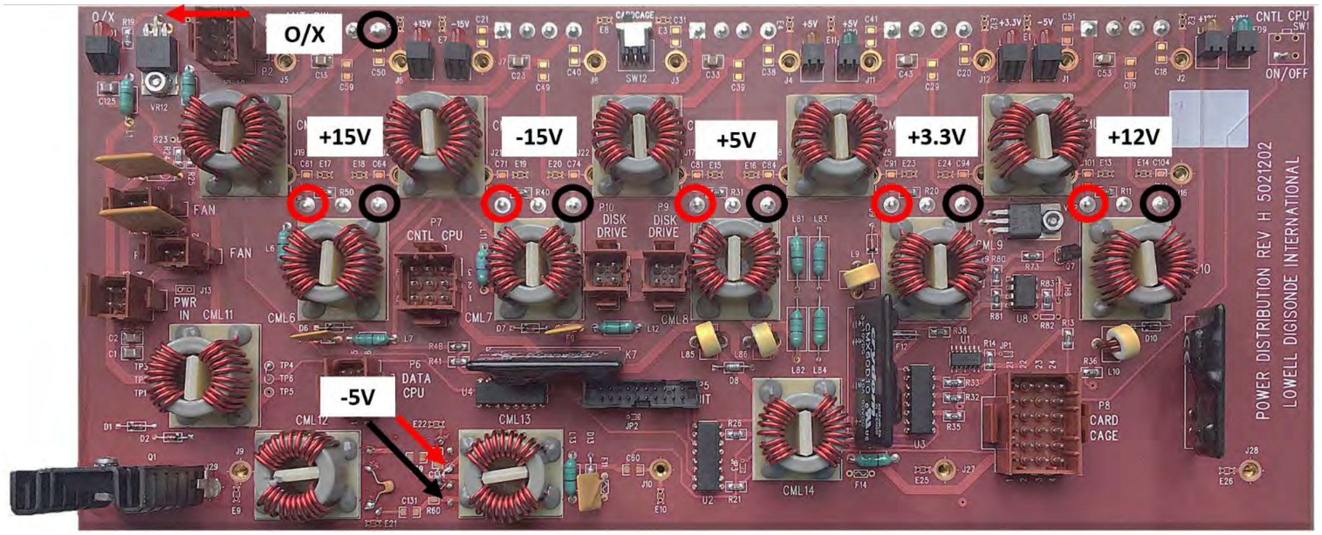


Figure 6-25: Power Distribution Card Showing Locations to Measure Output Voltages

TROUBLESHOOTING THE RF POWER AMPLIFIER MODULE

Special Test Equipment: 100MHz Oscilloscope
Reference Documents: RF Power Amplifier Schematics

6:96. The RF Amplifier card comprises two independent (referred to below as the two channels), three stage wideband amplifiers. The entire 10 inch x 6 inch board is mounted to a 10 inch by 6 inch heat sink. The input voltage is the system's primary power of 25 to 28VDC, from the power supply via the power interface box which contains FET switches.. The primary power is applied at the output end of the AMP board where it feeds power to the 250V output stages. It is also routed back off the board to a twisted pair which runs down the underside (the fin side) of the heat sink to feed power to the small signal end of the board. Keeping this twisted pair on the back side of the AMP heat sink reduces coupling between output and input, thus reducing the danger of a positive feedback situation.

6:97. The input signal to each amplifier channel is 1.7Vp-p, falling off slightly at the higher frequencies. The input cable is terminated in a PI attenuator made up of a 68, 330 (or 220 in later production), and 68 ohm resistors where the 330 (or 220) ohm resistor is bypassed by a 47pF (or 68 pf) capacitor to boost up the high frequency output. The input signal is amplified to 12-14V by A1/A2 (36dB gain 500kHz to 500MHz amplifier modules), which can be probed at the input of T7/T15. As a quick check, the output of T9/17 can be probed at the input of the series resistors R124/126 or R204/206. There should be 20-25Vp-p at this point. Then the output voltage 240-300Vp-p can be probed at the vertical wire connection (from T13/T21 to the PC board trace) at the output of T13/T21.

6:98. The critical setting in the RF AMP is the bias voltage set by R67/147 for the input stages and R107/187 for the output stages. This bias voltage is pulsed, rising when the R BNC signal (Xmtr On from the front panel input from the upper chassis) rises. The R BNC, via U41 and Q52/53 also applies the regulated +18V to amplifiers A1 and A2. For waveform 1 this is 750usec every 5, or 10msec, so the bias voltage level can only be measured by probing it with an oscilloscope. The bias voltage should be set to draw 2 to 4A idle current for the input stages U8 and U16, and 0.75 to 1.5A for the output stage, U12 and U20, when no input signal is applied (see procedure below). Since much larger signals are fed to the output stage it is somewhat self-biasing and does not need a high bias level. The bias level is given in amps of idle current rather than a voltage since the turn-on voltage for various batches of MRF-141G MOSFET transistors varies widely. An initial setting of 2.4V should be a safe starting point for all production lots of these devices. The bias level can be probed by measuring voltage on the gate of the MRF-141G MOSFET.

6:99. Once an initial bias voltage level has been set, or if checking an operating AMP, the system should be operated with 50 ohm terminators connected to the rear case RF1 and RF2 outputs. Attaching two probes, one on each side of the surge limiting resistors R60/600, and setting the oscilloscope to an A-B display, multiply the voltage drop observed by 10 (R60/600 is 0.1ohm) to get the idle current. Similarly, checking across R131/219 and multiplying by 20 gives the idle current in the output stage. If no A-B setting is available, the voltage referenced to ground can be probed on each side of the resistors and the subtraction performed on paper. If adjustment is necessary, turning the 15-turn potentiometers (R67/147/107 and 187) CCW increases the voltage and CW decreases the voltage, at about 0.3V/turn.

6:100. Since the MRF-141G device is a matched pair of FETs it is possible that only one has failed. If a stage is biased properly but does not make the gain it should, then check that a very similar signal can be detected at each drain (output) tab on the suspected MRF-141. If the entire device has shorted, the 27V from the drain often feeds through to the gate (the input tab) which should normally have the 2.4V bias pulse on it. If this is the case replace the FET.

ANNEX A

PHYSICAL AND ELECTRICAL SPECIFICATIONS

Table 6A- 1: Physical and Electrical Attributtes

SYSTEM ASSEMBLY	VOLTS (V)	CURRENT (A)	POWER (W)	WEIGHT (KG)
Digital Transmitter Card	±5 +15	0.3 0.02	1.5 0.3	0.11
Digital Receiver Card	±5 +3.3	0.1 1.5	0.5 5	0.11
Pre-Processor Card	+5 +3.3	0.2 0.16	1.0 2.5	0.11
BIT Card	±5 +3.3	0.01 0.1	0.05 1.5	0.09
Tracker Card	±15 ±5 +3.3	0.2 0.1 0.3	1.5 0.5 1	0.11
Backplane	+15 +5 +3.3	0.2 0.1 0.1	3 0.5 0.33	0.68
Power Distribution Card	+24-27	3.6	7.5	1.12
Antenna Switch	±15	0.2	3	0.3
Polarization Switches (x4)	+17-22	0.06	1.5	3
Cables				0.5
Control Computer (HS-872P)	+5 +12	3 0.4-0.8	15 4.8-9.6	0.9
Data Computer (PCE-4129) Including Backplane, Network card, GPS	+12	2-3	24-36	1.5
Solid State Drive (SSD)	+5	0.07-0.3	0.35-1.5	0.2
Optical Drive (DVD)	+5 +12	0.5 1-2	2.5 12-24	1.3
GPS	+12	0.04	0.5	0.4
RF Amp (heat sink PCB)	+27	3.75 (Avg) 0.2 (Standby)	90 5	2.34
Half Octave Filters (x2)	+27	0.1	2.4	1.1
Power Interface Box	+27	0.1	2.4	0.3
Power Supply	110-230 VAC	2.25/1.13	600	5.5
Power Amp Chassis (fans)	+27	0.4	4.8	4.5
Main Chassis (total)	+27	4	108	
Main Chassis (fans only)	+27	0.5	13.5	6.0
ECS Enclosure (fans)	+27	0.3	7	23.6
Rear I/O Panel & Connectors	-	-	-	1.8
TOTAL			**215.5**	**54.15**

.

Table 6A-2 Critical Dimensions

	HEIGHT (MM)	WIDTH (MM)	DEPTH (MM)	WEIGHT(KG)
Enclosure Assembly	464	586	846	30.65
Chassis Assembly	178	482.5	584	13.56
RF Amp Chassis Assembly	133.5	482.5	406.5	8.29

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SECTION 7

Computer Upgrade
Hardware Refresh Installation Instructions

SECTION CONTENTS

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HARDWARE REFRESH INSTALL INSTRUCTIONS

7:1. These instructions have been validated with a current production DPS4D. There may be some minor variations pertaining to older DPS4Ds which will require small changes. These instructions do not go into exhaustive detail as it is assumed that the personnel performing these upgrades will have some familiarity with the DPS4D hardware as well as some basic hands on electrical/computer engineering experience. We will welcome any improvements others can suggest to these instructions.

1. **See appendix at end of this document for packing list of hardware upgrade kit.**
2. **Tools required – basic electronic hand tools including:**
    a. #1 Philips screwdriver
    b. #2 Philips screwdriver
    c. Small flat blade screwdriver
    d. 3/16" nut driver
    e. Small diagonal cutters
    f. Small long nose pliers
    g. Flashlight
    h. Small 3/32 rat tail file (possibly required for "moving" screw holes)
    i. Soldering iron, etc. (just in case)

3. **Prepare DPS4D for upgrade:**
    a. Remove front and rear covers from case.
    b. Connect Mouse and Keyboard and Log into Windows.
        i. Copy configuration files as required unless a preconfigured hard drive running Linux has been provided.
        ii. Shut Windows down.
    c. Turn off power with toggle switch at back of case. Unplug power cord.
    d. Remove front panel screws and slide Upper chassis out so rear panel of chassis is approximately 4 inches from rack in order to allow getting one's hand on the rear panel connectors.
    e. Remove top cover of chassis.

4. **Disconnect following cables from chassis rear panel connectors:**
    a. Disconnect GPS DB9 cable at metal strip connector bracket.
    b. Disconnect from the metal strip connector bracket at rear of old HS-872 Data computer
        i. Monitor VGA DB15(HD) cable
        ii. Two RJ45 network cables
    c. Disconnect COM1 DB9 cable from COM1 DB9 connector on rear panel of chassis.

   d. Disconnect two USB cables from USB ports on rear panel of chassis.

5. **Move the metal connector strip bracket with two Control computer USB ports at the rear of the chassis from in between the Data computer and the Control computer to a position on the other side of the Control computer at the far left of the chassis.**

6. **Remove old Data computer hardware:**
   a. Remove metal connector strip bracket with GPS RS422 DB9 connector and short flat cable from rear of chassis.
   b. Remove Data computer from its backplane after disconnecting and cutting wire ties as required:
      i. Remove two SATA cables
      ii. Two USB header (9 pin) connectors
      iii. COM1 header connector
   c. Remove POW-P6 cable from Power distribution board cutting wire ties where necessary.
   d. Remove Data computer backplane by undoing 4 screws (6-32) under the chassis.
   e. Remove two Data computer USB ports on rear of chassis.
   f. Install two new USB ports (short blue cable) on rear panel where USB ports were removed in above step using screws previously removed. Note: Standard convention is for the “tongue” inside the USB port to be on the top of the connector.
   g. Remove COM1 DB9 connector and short flat cable from rear panel of chassis.
   h. Attach new COM1 connector to rear panel of chassis. Make sure the unused COM2 connector is secured out of the way so it doesn’t short anything.

7. **Drive stack rework:**
   a. Remove power and data cables from rear of DVD and HDD rack.
   b. Remove two screws under chassis securing disk drive stack.
   c. Lift disk drive stack out of chassis carefully guiding front panel USB cables through bottom of drive stack. Cut wire ties where necessary.
   d. Remove 8 screws securing DVD and HDD rack in stack.
   e. Reinstall DVD in the lower position. Leave screws loose as most likely the screws for the new SSD drive rack above will be a tight fit.
   f. Install new SSD drive rack (which is pre-installed in a 3.5 in. to 5.25 in. drive adapter) in the upper position using screws just removed or new screws provided with drive adapter. If difficulty is encountered lining up the screw holes,

press the 3.5 in. to 5.25 in. drive adapter down firmly. It may be necessary to elongate the 4 screw holes in the drive stack with a small rat tail file. Tighten all 8 screws. New key for the drive rack should be secured.

g. Lower drive stack into chassis feeding front panel USB cables through the opening in the bottom of the stack. Attach drive stack to the chassis with the two 6-32 screws previously removed.

8. Installation of new computer hardware:

a. Attach new Data computer backplane (pre-assembled on an adapter plate) to floor of chassis using screws from underneath which were previously removed or the new screws provided with the adapter plate.

b. Some rearrangement of the metal connector (or blank) strip brackets at the rear of the chassis will be necessary. See attached rear panel photo.

c. Plug new PCE-4129 Data computer into new backplane and secure with screw at top.

d. Install new PCE-1G-01 network card in backplane. Secure with screw at top. It is expected that the network card will have to be "flexed" slightly.

e. Install new metal strip connector bracket with GPS RS422 DB9 connector on rear panel of chassis in between PCE-1G-01 network card and PCE-4129 computer board. Secure with screw at top.

9. Connections to new Data computer inside chassis:

a. Connect the SATA power cable adapter in the kit to the 4 pin Molex connector going to P9 or P10 on the Power distribution board and to the SATA power connector at the rear of the SSD drive rack. Reconnect the origin al SATA power connector to the rear of the DVD drive.

b. Connect POW-P6 cable from backplane to P6 on Power distribution board.

c. Connect 20 pin header socket on short flat cable from GPS DB9 connector on metal strip bracket to the <u>lower</u> 20 pin header on the PCE-COM485 RS422 daughter board which is installed on the PCE-4129 computer board.

d. Connect 20 pin header socket on short flat cable from the COM1 DB9 connector on rear panel of chassis to 20 pin COM12 header near top rear of PCE-4129 computer board next to the processor cooler fan power connector.

e. Connect blue 20 pin header socket on short blue cable from USB ports on rear panel of chassis to blue USB23 header near top rear of PCE-4129 computer board.

f. Using the supplied short 2 mm to 0.100 inch pitch USB header adapter cable, connect the 9 pin header socket on the black or grey twin cable from the front panel USB ports to the USB45 header near top rear of PCE-4129 board. This will be the 9 pin header adjacent to the SATA connectors. Note: these header sockets are keyed to ensure correct placement of the connectors.

g. Connect PWR1 cable from backplane to 4 pin PWR1 connector at top front of PCE-4129 board (upper left looking at PCE-4129 card).
h. Connect 4 pin molex connector (yellow and black wires) from GPS DB9 connector on metal strip connector bracket on rear of chassis) to 4 pin molex connector (yellow and black wires) coming from front of the backplane.
i. Connect the new latching type SATA data cables from the drive stack to the cluster of SATA connectors at the top of the PCE-4129 computer card as follows:
    i. SATA1 data from SSD rack to SATA0 (upper left in cluster looking at PCE-4129 card)
    ii. SATA data from DVD to SATA1 (upper right in cluster looking at PCE-4129 card)
    iii. Not really necessary since LDI doesn't envision its use but one of the original SATA data cables could be used to connect SATA2 on the SSD rack to SATA2 (lower right in cluster looking at PCE-4129 card)
j. Tie wrap cables as required in chassis. Pay particular attention to making sure no wires can interfere with the cooling fan on the processor heat sink of the new PCE-4129 computer board.

10. Connections at rear panel of chassis:

a. Connect two USB cables from rear panel of case to new USB ports just installed on rear of chassis.
b. Connect COM1 cable from rear panel of case to new COM1 connector just installed on rear of chassis.
c. Connect network cable from rear panel of case to RJ45 connector on metal strip bracket of the new PCE-1G-01 network card just installed.
d. Connect GPS cable from rear panel of case to <u>lower</u> DB9 connector (GPS) on new metal strip connector bracket on rear of chassis.
e. Connect Monitor VGA cable from rear panel of case to VGA connector on the metal strip bracket of the PCE-4129 at the rear of the chassis.
f. Connect network cable from the Control computer to the <u>lower</u> RJ45 connector on the metal strip of the PCE-4129 at the rear of the chassis. If the plug at either end of this network cable does not snap firmly into the socket on the respective computer, loosen the screw at the top of the computer board and move the computer slightly to the left (looking from the front of the chassis). Note that the upper RJ45 connector on the PCE-4129 has a blank plug in it to discourage its use.

11. If it isn't already installed, install configured SSD running Linux on small caddy into the lower (SATA1) bay of the new SSD rack. Follow appropriate NG protocols for use of the keylock. Note the Windows hard drive cannot be used with the new computer.

12. Turn power on.

13. Check CMOS setup. Hold Delete key down as instructed on screen.

a. Main, Date and Time. (very important: time is UT, not local time) Should be within a few seconds.
b. Advanced, CSM Configuration
    i. "Boot option filter" should be "UEFI only".
c. Chipset, PCH-IO
    i. SATA Configuration, "SATA 0" should be Samsung 500GB and "SSD", not "HDD".
    ii. "Restore AC Power Loss" should be "S0" (means ON).
d. Save & exit.
    i. Save changes.
    ii. Save as "User Defaults". Not sure what the benefit of this might be.
    iii. Exit

14. Reboot and Logon as DPS4D-operator. Password "operator" as provided by LDI. This password should be changed to something more secure as soon as possible.

15. Check External Network access. Use Firefox browser for web page such as http://www.digisonde.com. (May not be appropriate for NIPRNet.)

16. Check GPS function. Click on Desktop icon, NTPQ. Reach should be > 0

17. Make sure Control computer. DESC, is connecting to DCART. See top of DCART window for connection status.

18. **Shut down Linux, click upper right of Desktop, Power off and Power on. Repeat steps 14., 15., 16., and 17.** (Make the numbering of these steps linked to the actual steps.)

19. **Replace covers, etc.**

APPENDIX 1. HARDWARE REFRESH KIT PACKING LIST

A. Assembled PCE-4129 Computer board, Advantech Start up Instruction Sheet, in black anti-static bag.

B. Assembled PCE-3B03A Backplane, extra 6-32 screws in nuts on adapter plate, in pink anti-static bag

C. 3.5 – 5.25 drive adapter with mounted SSD rack containing 2 SSD Caddies. #1 (lower) will have a blank SSD in it. #2 (upper) Caddy will have the OEM plastic filler piece. Rebox in Adapter box with Key and two flat head 4 mm long 3 mm screws.

D. PCE-1G-01 Network Card (labeled "External Network") in original clear plastic bag / box

E. Bag containing:
   1. SATA Power cable adapter in a clear plastic bag
   2. Rear panel blue USB cable w/screws
   3. Front panel USB header adapter
   4. COM1 Cable w/mounting posts (screws)
   5. GPS Connector Bracket
   6. Two labeled SATA Data cables
   7. A few small tie-wraps.

F. DPS4D Computer Upgrade Hardware Refresh Installation Instructions

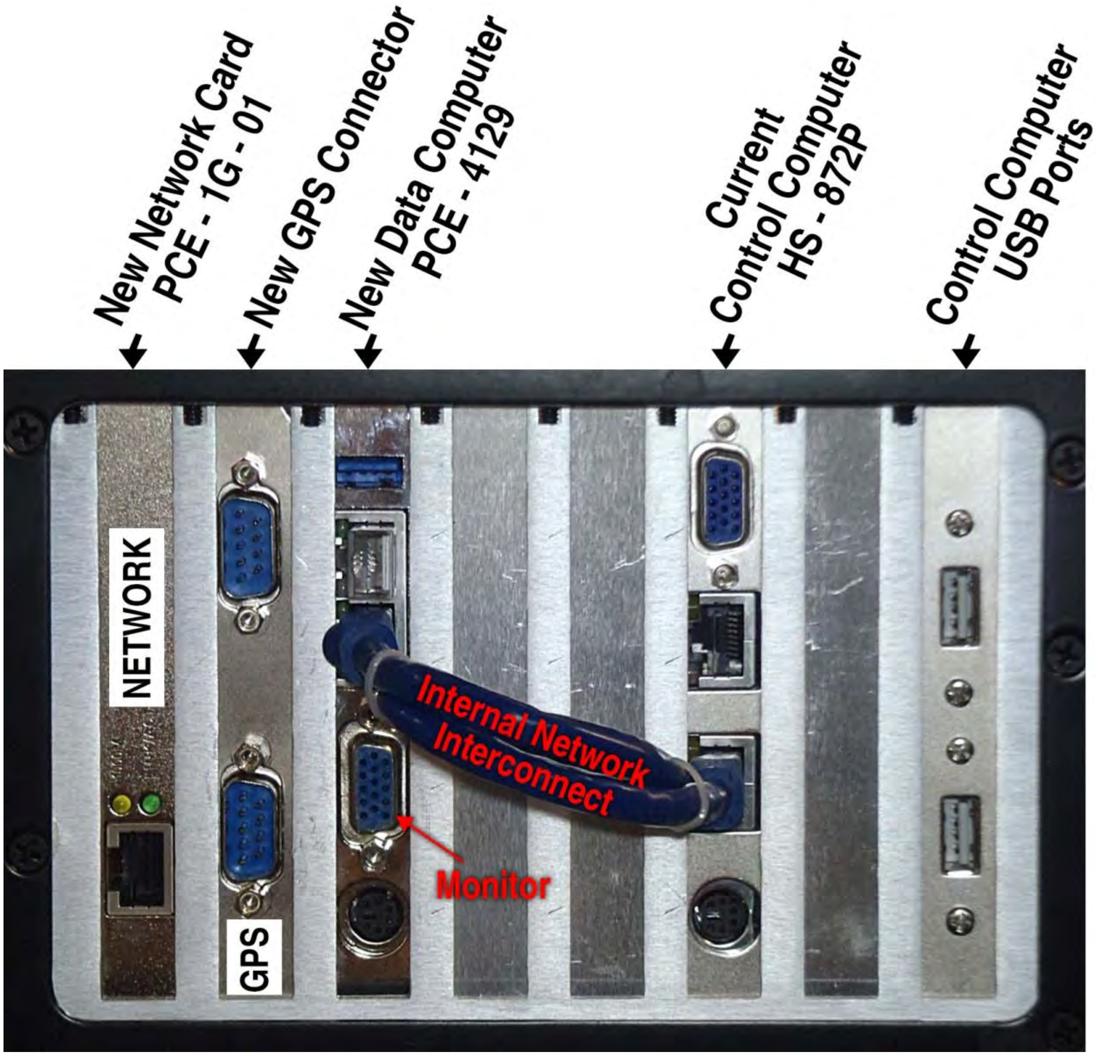

Figure 7:1: Rear Panel Photo