

CENTER FOR REMOTE SENSING, INC.

## Digital Sounder: HF Diagnostics Module: Ionosonde

Dual Channel (001-2000)  
Eight Channel (004-2006)

HF diagnostic system 00X-200Y is a family of (X indicating configurations) flexible, modular and versatile HF Radar that allows advanced digital ionosonde operation as well as various HF diagnostics. It is developed to allow sophisticated HF diagnosis of the ionosphere, which was not possible using earlier generation technologies. It utilizes a streamlined architecture consisting of a flexible waveform generator, high performance HF transmitter, sophisticated digital receiver with extremely large dynamic range, and an advanced radar controller with unprecedented flexibility and usability. All the user interaction, control, monitoring, real time processing, analysis, and visualization are performed through a Windows® based GUI allowing user control over complex operations (if needed). It also provides straightforward menu based operations over more standard and monitoring functions such as ionograms and time histories.

The flexibility of the HF Diagnostic system allows it to be used for numerous ionospheric experiments, channel monitoring, and channel characterization.

The model 001-2000 in the basic ionosonde mode will sound the ionosphere at regular intervals programmed by the user using menu-driven interfaces. Various waveforms can be transmitted, and a friendly scheduler allows sequencing of different events. Echoes are received and selected using sophisticated signal processing techniques. All the relevant parameters of the echoes can be displayed in real-time and stored for further analysis. Along with conventional ionograms, amplitude plots, phase plots, Doppler, angle of arrival (requires multiple receiving antenna), polarization etc. are derived. Various plot functions allow visualization of real-time analysis and processing of various kinds. All intermediate data products are available, making HF diagnosis transparent to the user.



Scaling of the ionograms and other parameters are performed using automated expert systems. The scaled parameters are both displayed and stored. The scaled ionogram can be used for real-time inversion using both conventional ionogram inversion routines (provided) as well as interactive processing techniques. The data and the results can be visualized, stored and sent through the Internet.

Model 00X-200Y is highly modular and provides various upgrades over the basic unit. Multiple receiving antennas can be used with optional antenna sequencer or with multiple receiving modules. Multiple data outputs from different antennas are used to derive angle of arrivals and “sky-map.” Digital beam forming can be used to provide echoes from different scattering centers. For such echoes, equivalent horizontal component of Doppler (drift) may be inferred.

Correlation analysis between spaced antennas may also provide horizontal drift of the diffraction pattern on the ground (spaced receiver techniques). Since the nature of the ionosphere reflection process and the nature of the echoes vary with geographic location, time, and geophysical conditions, flexibility is needed to infer the data products. The HF 00X-

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200Y provides these capabilities to the user.

The basic unit can be upgraded with GPS based timing allowing independent Rx and Tx operation and bistatic operation. It can thus be operated as oblique sounder, chirp sounder, channel sounder, and forward scatterer.

With upgraded power amplifiers and optional software, the unit can be used for partial reflection, wave interaction, Interferometry, and Radar Holography. In short, the system opens up new possibilities that remain unrealized in the very ionospheric diagnosis.

The complete core system (001) is modular and consists of:

- 1) Radar Controller unit with receiver and associated peripherals. Radar controller accepts commands from a Windows® GUI and provides appropriate controls to receiver and waveform generator including P.A. driver.
- 2) Power amplifier unit generates the desired RF power to the antennas. It has built in power supply and control system to ensure safe operation.
- 3) GUI computer and software
- 4) Antenna for Tx and Rx portions

Various other add-ons include:

- GPS timing for synchronization of bistatic system
- Additional modules for receivers
- Add-on P.A.

00X-200Y incorporates all solid-state electronics and utilizes most contemporary DSPs and FPGAs for advanced processing and flexible software implementation. Special care is taken to provide improved instantaneous and effective dynamic ranges, spurious response, and linearity in the receiver ensuring clean traces even in the presence of strong interferers. Transmit power, receiver attenuation, and filters are automatically controlled to dynamically adjust to obtain good SNR throughout the entire range. The receiver can be configured for different effective bandwidths and with pre-amplifier depending on the user requirements and environments.

The transmitter unit provides the output through a 50  $\Omega$  coaxial line and both the forward and reflected powers are monitored. Automatic tripping of the Tx unit occurs when the VSWR exceeds the set point. The P.A. unit can be used to drive additional units, if very high powers (greater than KW) is needed for partial reflection and wave interaction. Flexible waveform shaping allows minimization of interferences.

It can be used to drive various types of antennas with suitable balun and impedance transformers. The range includes detla, rhombic, yagi, and flat dipoles.

The receiving antenna can be small dipole or loop antennas. Multiple antennas can be configured to operate either sequentially or in parallel (with add-on receiver modules).

Direction of arrival information can be obtained and visualized in 2-D and 3-D against time sounding, frequency or height of scattering centers. Velocity vectors can be derived using Dopplers from the echoes. High frequency resolution is achieved (without sacrificing observational time) by using scrambling frequency sounding mode, where the coherent transmissions are repeated at longer intervals. These high resolution Doppler observations are delineated as velocity vectors and can be displayed against time, frequency or equivalent heights.

Alternative drift measurements using three or more spaced antennas can also be performed where the complex echo patterns from different antennas are correlated and the drift of scattering centers inferred therefrom.

The equipment can be upgraded with multiple receiving antennas to provide imaging interferometry or holography.

With multiple antennas, the system can be used for experimentation as MIMO radar, time reversal and other sophisticated techniques.

The software is structured to operate on various levels of data. The raw samples (level 0) are processed through high performance FPGAs and provide matched filtered I and Q components (level 1). Further processing is performed to provide level 2 data (filtered power, phase, complex FFTs) and the processed data are presented as ionogram plots, time series plots, Doppler plots, sky-maps, etc. in level 3. Echo selection is performed if desired and the real-time analysis such as ionogram inversion and interpretation is performed in level 4.

Drift and other experiments are implemented using level 3 data and are add-on at level 4.

The flexibility of the software allows the user to interact, log, and visualize any or all intermediate products from level 1 to level 4. This allows extreme confidence and transparency to the HF diagnostics.

All the frequency sources and timing information in the 00X-200Y units are derived from a single source-ensuring coherency. They provide a built-in test, monitoring and diagnosis unit. Front panel (LCD) display the status of the system and the operating parameters during various stages of operation. Status information is also available through the central control and can be available through the Internet.

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## SIGNAL PROCESSING

The model 00X-200Y receiving system provides several advanced signal processing modules including: echo selection using matched filtering and correlation. Various waveforms such as pulse modulation, FM CHIRP and various phase modulation schemes are built in. Users can provide their own waveforms. The standard Phase modulations included in the system are:

- 1) Barker Codes (several lengths)
- 2) Complimentary Codes (several lengths)
- 3) Both the amplitude and phase information are processed in conventional mode and the outputs are made available.
- 4) Doppler processing is provided with Doppler bins. Besides obtaining the Doppler information, this type of processing decreases the noise in each Doppler bin. This technique can be used for detecting weak signals by suitable weighted averaging of multiple Doppler bins.

Scrambling of different probing frequencies can be used to obtain finer Doppler resolution without increasing the overall scan duration.

## DATA PROCESSING AND VISUALIZATION

Various levels of data are available for storage and visualization. The basic raw (level 0) I&Q samples, the power and the phase samples, can be visualized in the oscilloscope type real time trace. This is conventional A-scan type display. The magnitudes can also be color-coded. Matched filtered outputs can also be displayed in real-time. The echo-selection can be automatic or the user can select threshold. The selected echoes can be highlighted in the displays.

Parameters for the selected echoes (level 1) (Power, Phase, DOA\* (requires multiple receiving antennas), polarization, Doppler) are stored and also available for visualization in real-time. In this mode the parameters are presented either as 2-D traces (with magnitude vs. time) as intensity plots with magnitude as intensity or color vs. time, or as a combination of both of the above. Multiple echoes can be displayed in the plots and the familiar Windows® environment allows displaying various windows (from past data, from different frequencies, etc.) to be compared. The plots are useful for obtaining:

- Amplitude vs. Time
- Phase vs. Time
- Doppler vs. Time
- Height vs. Time
- DoA vs. Time, Velocity Vectors vs. Time

All of these plots can be used for single frequency and stepped frequency type sounding. These can be used for

following isoionic contours or for following the selected echoes. These features make the model 001-2000 a versatile HF diagnostics with capabilities that have never been available. The instrument in these modes can be used for partial reflection, phase sounding, Doppler sounding, wave interaction, IDI radar, etc.

Visualization is also provided for Doppler spectra of each individual height as well as for selected echoes.

The conventional ionogram scan can be visualized using either raw data (level 2) or using selected echoes (level 3). All visualization modules operate in a familiar Windows® 98 environment. They are user friendly and intuitive. A schematics based GUI allows easy and intuitive configuration of the experimental system and processing hierarchy. Various experimental configurations can be sequenced. These features make the model 00X-200Y to be a truly versatile diagnostic and test instrument.

The ionogram data are further processed for deriving the conventional critical parameters (level 4) (such as critical frequencies and heights). Up to 10 such parameters are generally extracted. These extracted values are displayed along with the ionogram. Post processing modules, such as ionogram inversion is integrated and can be used for real-time inversion (level 4). Interactive ionogram inversion techniques can be used to avoid the pitfalls of conventional inversion (valley, lower ionization).

All of the data - level 1 to level 4 are stored in hard-disk and are available for post processing as well as for delivery through the Internet. Replay feature allows visualization of all the levels of data for post processing.

## OPERATING MODES

Flexibility of the HF 001-2000 is manifested not only in enabling various levels of data products to be easily accessed and visualized but also in enabling various modes of operation to be selected for adaptive control over the ionospheric diagnostics (see Table 1).

## FEATURES

- Software based control, processing and display
- Allows access to all intermediate and final data products. Transparency of all analysis techniques.
- Flexibility, versatility, reconfigurability
- High performance receiver, controller, and transmitter. High interference immunity.
- Run time and off-line data visualization
- Various operating modes
- Modular structure allows optimized system for individual users

# Digital Sounder

## CONFIGURATIONS

- Conventional and advanced digital ionosonde mode (one button operation)
- HF diagnostic system configured by the user
- Versatile radar controller:
  - ⊕ Extension to VHF, UHF bands
  - ⊕ Extension to partial reflection, wave interaction
  - ⊕ Extension to MIMO system
- Monostatic or Bistatic operation (using GPS based time synchronization)
  - ⊕ Channel monitoring
  - ⊕ Chirp sounding

## CONTROLS

- User configuration of receiver bandwidth, LNA, antennas, and their sequencing
- Complete frequency and waveform control on pulse to pulse basis
- Instantaneous user control over (on pulse to pulse basis)
  - ⊕ Receiver gain
  - ⊕ Transmit power
  - ⊕ Waveform and frequencies
- Remote operation for all control, operation, and visualization
- Automatic scheduler
- Replay feature for post processing

## DATA AND VISUALIZATION

Numerous data products structured from level 0 to level 4:

- Virtual height, absorption, Doppler, phase
- Ionograms—scaled and unscaled (user interaction)
- True height profiles—automatic or user interaction
- Time histories
- DOA (sky-map), digital beamforming
- Doppler interferometry
- Doppler based drift (based on scattering from different oblique angles)
- Spaced receiver drift (based on autocorrection between spaced antenna)

All data can be visualized in real time in various modes. Typically, they are presented as time histories in 2-D and 3-D displays or as ionograms with various parameters (Doppler, DOA, absorption) superimposed on the conventional ionogram traces. Replay feature allows the data sequence to be replayed using the stored data.

## SPECIFICATIONS

- Waveforms:
  - ⊕ BPSK:
    - ↵ Barker Codes (13 bit up to 40 bits standard), unlimited length optional
    - ↵ Complimentary codes
    - ↵ User defined codes
  - ⊕ Chirp:
    - ↵ Start frequency
    - ↵ Stop frequency
    - ↵ Chirp rate commensurate with bandwidth
  - ⊕ CW:
    - ↵ 100 KHz to 1 MHz
  - ⊕ Pulse Duration: 4 µsecs to 520 µsecs
  - ⊕ Pulse Repetition: 100 Hz (typical), variable 1 KHz to 10 Hz
  - ⊕ Pulse Sequencing: arbitrary. Scrambled frequency mode allow coherent revisit.
  - ⊕ Carrier RF:
    - ↵ 1 to 30 MHz – resolution to 1 Hz
    - ↵ Unlimited number of selected frequencies
    - ↵ Frequency values may be pre-stored or altered on the fly
- Receiver:
  - ⊕ Frequency Range: 1.0 to 30.0 MHz
  - ⊕ Dynamic Range: 110 dB
  - ⊕ RF Bandwidth: selectable 100 KHz, 200 KHz, 1 MHz (25 KHz optional)
  - ⊕ Matched Filter Bandwidth: 25 KHz to 1 MHz
  - ⊕ Coherent Filter Bandwidth: 0 to 1 KHz
  - ⊕ Instantaneous Linear Dynamic Range: 70 dB, 110 dB (optional)
  - ⊕ Programmed attenuation: up to 40 dB in 1 dB steps in addition to 30 dB (LNA)
  - ⊕ Image Rejection: 110 dB (minimum)
- Transmitter:
  - ⊕ Frequency Range: 1 – 30 MHz (50 MHz option)
  - ⊕ Output Power: 600 Watts (2 KW, 4 KW optional)
  - ⊕ Duty Cycle: 25%, maximum, @ 600 Watts output
- General:
  - ⊕ Main Power: 120/230 VAC, 50-60 Hz
  - ⊕ Power Consumption: < 500 W
  - ⊕ Temperature Range: 0-50° C
  - ⊕ 95% non-condensing, maximum
  - ⊕ Altitude: 0-10000 feet
  - ⊕ Size: 19 inch rack mountable or table top enclosures
    - ↵ Controller Unit: 19x17x17"
    - ↵ P.A.: 19x17x7"
  - ⊕ Weight:

\* *Waveform shaping to minimize interference.*

**TABLE 1: SUMMARY OF SOUNDER OPERATING MODES**

## 1. IONOGRAM MODE

Conventional ionograms\*

Frequency span	1-30 MHz
Interpulse period	8-10 ms (typical); variable 1-100 ms
Pulse width	4-250 $\mu$ s; variable to CW
Waveform	BPSK—(min) 2-20 $\mu$ sec chip, variable bits Chirp—commensurate with bandwidth
RF Bandwidth	100 KHz to 1 MHz
Dynamic Range	95 dB/115 dB
Frequency resolution*	10-30 kHz (typical); variable to 1 Hz
Frame duration*	10-30 s (typical); variable for 1 sec to hrs

## 2. CRITICAL FREQUENCY

High-resolution foF2 and hmax

Frequency span	$\approx$ 1 MHz (typical); variable
Frequency resolution	$\approx$ 10 kHz (typical); variable
Frame duration	$\approx$ 1 s (typical); variable to < 0.1 sec

## 3. STEPPED FREQUENCY AND FIXED FREQUENCY

High-resolution ionization contours

Discrete frequency steps

Radio absorption, phase path, Doppler, Polarization, DOA, Drift

Irregularity structure, Ionospheric Modification, ST Radar, Backscatter Radar, Drivers for Partial Reflection, Wave Interaction

## 4. DOPPLER DRIFT MODE

High resolution Doppler using scrambled frequency steps and multiple (4) receiver antennas provides DOA and Doppler from different directions (depending on scattering centers). Velocity components are derived from these scattered echoes.

## 5. SPACE RECEIVER DRIFT MODE

Multiple spaced receiver echoes (3 minimum) are used to determine drift vectors using correlation between the echoes.

## 6. HOLOGRAPHY OR IMAGING INTERFEROMETRY MODE

Multiple spaced receiver (>4) are used for imaging or holographic reconstruction of irregularities.

\* Using scrambled frequency steps, the frame duration can be reduced and Doppler resolution improved.

**TABLE 1: SUMMARY OF SOUNDER OPERATING MODES CONT.**

**7. RECEIVE ONLY\***

Calibration, HF noise reception, HF surveillance, Radio function, spectral analysis

Ducting, anomalous propagation, long-delay echoes, bi-static operation, beacon receiver, ionospheric modification

**8. TRANSMIT ONLY\***

Channel Probe and Channel monitoring, chirp sounder, Ducting, anomalous propagation, long-delay echoes

Irregularities, sporadic E, Ionospheric Modification, Bi-Static Mode

*\* Synchronization is achieved using built in GPS receiver (optional)*

**DUAL CHANNEL DIGITAL SOUNDER (001-2000)**

- Basic Digital Sounder with two receiving channels
- Provides all HF-Diagnosis capabilities except DOA and “horizontal drift components.”

**EIGHT CHANNEL DIGITAL SOUNDER (004-2006)**

- Eight independent receivers with 4 sets of crossed antennas
- Provides all HF diagnosis capabilities including DOA, digital beam-forming and inferring “horizontal drift components” for scattered signals.
- Receiving antennas can be spaced to provide “space receiver drift.”
- Dynamic range of 110 dB

**OPTIONS**

- Output Power Level:
- Number of Power Amplifiers: 1 or 2
- Number of Receiver Channels
- GPS Receiver based timing
- Software for interactive ionogram analysis
- Frequency span—1 to 50 MHz
- Fixed Frequency at VHF