THE PLASMA WAVE AND QUASI-STATIC ELECTRIC FIELD INSTRUMENT (PWI) FOR DYNAMICS EXPLORER-A

STANLEY D. SHAWHAN, DONALD A. GURNETT and DANIEL L. ODEM
Department of Physics and Astronomy, The University of Iowa, Iowa City, IA 52242, U.S.A.

and

ROBERT A. HELLIWELL and CHUNG G. PARK
Radio Science Laboratory, Stanford University, Stanford, CA 94305, U.S.A.

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Abstract. The Plasma Wave Instrument (PWI) on Dynamics Explorer-A measures both plasma wave phenomena and quasi-static electric fields. The quasi-static electric fields are measured parallel to the spacecraft spin axis in a range of 2 mV m^{-1} to 2 V m^{-1} and perpendicular to the spin axis 0.5 mV m^{-1} to 2 V m^{-1} at 16 samples/s. The ac electric field sensors include a 200 m tip-to-tip long wire antenna and a 0.6 m short electric antenna both perpendicular to the spin axis and a 9 m tip-to-tip tubular antenna parallel to the spin axis. AC electric wave fields are measured over a frequency range of 1 Hz to 2 MHz and an amplitude range of 0.03 μV m^{-1} to 100 mV m^{-1}. Magnetic wave fields are sensed with a search coil from 1 Hz to 1 kHz and a loop antenna 100 Hz to 400 kHz with a noise level of 0.1 γ-Hz and $\approx$ 100 dB dynamic range. The Step Frequency Correlator provides an 128-point spectrum (100 Hz to 400 kHz) every 32 s for two sensors plus an in-phase and quadrature-phase correlation between the two signals. The Low Frequency Correlator provides 8-point spectra (1 Hz to 100 Hz) and in-phase and quadrature phase correlation for two sensors in 32 s. Wideband analog data directly modulate the transmitter with a logarithmic-amplitude response for 0–1 and 0–10 or 0–40 kHz basebands or for 10 or 40 kHz bandwidths mixed down from selected frequencies to 2 MHz. Alternatively, a linear-amplitude response receiver can be selected for bands of 1.5–3 kHz, 3.11 $\pm$ 7 1/2%, 3–6 or 10–16 kHz. Unique capabilities of the PWI include distinction between electromagnetic and electrostatic wave phenomena, determination of wave polarization and wave propagation direction (up or down the magnetic field line), and measurement of growth rates for naturally occurring or man-made emissions along the DE-A orbit.

1. Introduction

A large variety of electric field and plasma wave phenomena have been discovered in the terrestrial magnetosphere [1, 2]. A number of these phenomena are intimately associated with the regions to be covered by the Dynamics Explorer (DE) satellite pair and with the related plasma phenomena being measured by the other DE instruments. The objectives of the Plasma Wave Instrument (PWI) are as follows:

(1) Measure the intensity and spectrum of electromagnetic and electrostatic waves associated with auroral, plasmaspheric, polar cusp, and other magnetospheric plasma processes in the frequency range of 1 Hz to 2 MHz;

(2) Identify regions of large quasi-static electric fields, especially those associated with auroral electron acceleration;

(3) Determine growth rates and spectral characteristics of waves stimulated by VLF transmitters and naturally occurring VLF waves in the plasmapause region;

(4) Measure wave propagation direction (Poynting vector), wave normal angle and

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wave polarization components to identify the source regions and source characteristics of kilometric radiation and other plasma waves;

(5) Assess the characteristics and the importance of electrostatic waves in plasma processes such as particle acceleration and particle diffusion, especially in the auroral and plasmapause regions; and

(6) Associate the measured plasma wave characteristics with plasma distribution functions, current systems, plasma flow parameters, auroral images, electric field regions and characteristics of the ionosphere and upper atmosphere measured by the other DE instruments to discern the plasma processes coupling the magnetosphere and atmosphere.

A 9 m tip-to-tip tubular electric antenna along the spin axis and a 200 m tip-to-tip long wire electric antenna perpendicular to the spin axis are the sensors for detecting regions of nearly static electric fields. These sensors along with a 0.6 m short electric antenna, a search coil magnetometer and a magnetic loop antenna, which are mounted on a 6 m boom to reduce the spacecraft interference levels, detect the AC plasma wave fields (see [4]).

The pair of Step Frequency Receivers that make up the Step Frequency Correlator and the Wideband Analog Receiver are derived from the plasma wave instruments flown on ISEE-1 and 2 [3]. With the Step Frequency Correlator operating from 100 Hz to 400 kHz and with the pair of 8 Fixed-Filter Receivers which comprise the Low Frequency Correlator operating from 1 to 100 Hz, the correlation of signals from selected pairs of sensors is determined onboard.

By correlating magnetic and electric sensors it is possible to discriminate between electrostatic and electromagnetic emissions. This measurement is particularly important for determining the source mechanisms and propagation characteristics of phenomena such as electrostatic ion cyclotron waves, hiss and auroral kilometric radiation in the auroral zones, UHR emission bands, continuum radiation, electron gyroharmonic emissions and Siple-stimulated emissions in the equatorial regions. Also, the measurement of correlation change with spacecraft spin for electromagnetic emissions can provide an estimate of the wave normal vector direction and of the wave propagation direction – up or down the magnetic field line (Poynting vector). Correlation of crossed electric antennas allows a determination of wave polarization for all electric wave emissions. For electrostatic waves the comparison of amplitudes between the three electric antennas of 200, 9, and 0.6 m length along with the phase measurement between the long wire and short electric antennas will provide an estimate of wavelength and phase velocity since these waves have wavelengths comparable to the antenna lengths.

To acquire high time and frequency resolution for the identification and analysis of specific types of plasma wave phenomena, the spacecraft transmitter is directly modulated with the output of analog waveform receivers. The automatic-gain-controlled Wideband Analog Receiver provides a 0–1 kHz baseband channel and a 10 or 40 kHz band at baseband or mixed down from selected frequencies to 2 MHz (see Table III) from any sensor. These data are processed on the ground through a spectrum analyzer with 512 frequency channels and 40 ms time resolution. The results are displayed on film.

The Linear Wave Receiver provides a waveform output with a 30 dB linear amplitude response for bands of 1.5–3.0, 3.11 ± 7 1/2%, 3–6 or 10–16 kHz for a selected magnetic or electric sensor. This receiver is utilized to measure growth rates for waves stimulated by the Siple VLF transmitter or by natural wave phenomena. In processing, a 100 Hz filter tracks the stimulated wave and the amplitude vs time characteristic is determined.

A summary of the measured PWI geophysical parameters is given in Table I.

TABLE I

DC Electric fields	(16 samples/s both gains)
Along spin axis (E_z)	LO-Gain 20 mV m^{-1} to 2 V m^{-1}
	HI-Gain 2 mV m^{-1} to 200 mV m^{-1}
Perpendicular to spin (E_x)	LO-Gain 20 mV m^{-1} to 2 V m^{-1}
	HI-Gain 0.5 mV m^{-1} to 50 mV m^{-1}
Electromagnetic waves	
AC electric field	0.03 μV m^{-1} to 100 mV m^{-1}
	1 Hz to 2 MHz
AC magnetic field	<35 kHz: 0.1 γ-Hz to 3 × 10^4 γ-Hz (dB/dt)
	>35 kHz: ≈2 × 10^{-5} γ (B)
Narrowband spectrum (SFC)	100 Hz to 400 kHz in 32 s
	1% resolution at 128 frequencies
(LFC)	1 to 100 Hz in 32 s
	30% resolution at 8 frequencies
Wideband analog spectrum (WBR)	10 or (40 kHz BW) at 0, 31, 62, 125, 250, 500, 1000, and 2000 kHz
(LWR)	1.5–3 kHz, 3–6 kHz, 10–16 kHz and 3.11 kHz ±7 1/2%
Wave vector components: Poynting, polarization and wave normal	1 Hz to 400 kHz in spin period
Electrostatic waves	
Frequency range	1 Hz to 2 MHz
Wavelength samples	0.6, 9, and 200 m
Correlation baseline	6 meters E (short) vs E (wire)

2. PWI Electric and Magnetic Wave Sensors

Detailed characteristics of the five PWI electric and magnetic sensors are listed in Table II. The locations of these sensors on the DE-A spacecraft are pointed out in the article describing the spacecraft [4].

Since there is only one electric antenna perpendicular to the spin axis for the measurement of the quasistatic field, it is not possible to obtain an instantaneous vector electric field measurement. However, the orthogonal component is obtained as the antenna rotates in a quarter spin period (≈1.5 s). Both the search coil magnetometer and magnetic loop are located on a boom at a distance of 6 m from the spacecraft to attenuate radiated magnetic interference [4]. The short electric antenna is also located on the boom

TABLE II

PWI Sensor characteristics

Long wire antenna (E_x)	
Frequency range	DC to 2 MHz
Elements	Two 100 m wires deployed in spin plane with 5 g tip mass.
Insulation	Inboard 71.1 m insulated with Styland.
Wire	BeCu with 7 strands of 5-mil diam each.
Effective electrical length	173.1 m DC and 101.4 m AC
Manufacturer	Fairchild Space and Electronics Co.
Heritage	Same as Heppner antenna on ISEE-1 [5]
Tubular electric (E_z)	
Frequency range	DC to 2 MHz
Elements	Two 4 m tubes deployed along spin axis.
Construction	Silver-plated BeCu 2.8 cm diam elements.
Insulation	Inboard 3 m teflon-insulated.
Effective electrical length	8.0 m DC and 5.0 m AC
Manufacturer	Fairchild Space and Electronics Co.
Heritage	Similar to San Marco and DE-B VEFI elements [6]
Short electric (E_s)	
Frequency range	20 Hz to 100 kHz
Construction	Two 10 cm diam wire spheres separated by 0.6 m with fiberglass booms.
Location	Mounted on PWI 6 m Astromast boom, oriented to measure electric field parallel to the long wire antenna E_x.
Effective electrical length	0.6 m AC
Manufacturer	TRW Defense and Space Systems Group
Heritage	Flight spare unit from ISEE [3].
Magnetic loop (B)	
Frequency range	100 Hz to 35 kHz responds to dB/dt; 35 kHz to 400 kHz responds to B.
Construction	Single loop of aluminum tubing of 0.8 by 1.25 m size and 1.0 m^2 area.
Coupling	Integral secondary transformer and preamplification giving 370 $\mu V/\gamma$-Hz.
Location	Mounted on PWI 6 m Astromast, oriented to measure spin-modulated component of B parallel to the long wire antenna E_x.
Manufacturer	University of Iowa
Heritage	Similar to IMP-8 unit
Magnetic search coil (H)	
Frequency range	1 Hz to 1 kHz responds to dB/dt
Construction	Two coils of 5000 turns of #40 copper wire on a 40 cm laminated high-permeability core enclosed in fiberglass housing coated with silver conducting paint, lacquer and vacuum-deposited aluminum.

Table II *(continued)*

Coupling	Integral secondary winding and preamplifier giving 360 μV/γ-Hz.
Location	Mounted on PWI 6 m Astromast, oriented to measure non-spin modulated *B* component parallel to spin axis.
Manufacturer	University of Iowa
Heritage	Flight spare unit from ISEE [3]

to provide a spatial separation from the long wire for measurement of electrostatic wave length through correlation of the two signals. The particular orientations of the sensors were chosen to provide the most significant components of the wave vectors – polarization, propagation direction and wave normal. The search coil responds to the component of B parallel to the spin axis and therefore spin modulation is minimized. The loop responds to the B component parallel to the E_x direction which yields two wave vector components due to the spin modulation. The short electric field antenna E_s responds to the same electric field component as E_x for electrostatic wave measurements.

3. PWI Receiver Systems

The overall PWI sensor-receiver scheme is depicted in the block diagram of Figure 1. Detailed characteristics for the basic receiver systems are listed in Table III. In this section additional features of the preamplifiers, quasi-static electric field measurement system, AC wave receivers, analog data modes, commands, calibration scheme and data display technique are discussed.

3.1. DC and AC Preamplifiers

A DC and AC preamplifier module is contained in a gold plated magnesium housing located close to each electric antenna element dispenser. The dc amplifier is an inverting operational amplifier with a gain of 0.04 to allow for dc potentials up to 400 V. A 10^{10} Ω resistor (Victoreen Mox 1100) is in series with the input to minimize the current drawn from the plasma. The AC amplifier is a bootstrap unity gain design which provides an impedance of $> 1 \times 10^9$ Ω from 5 Hz to 2 MHz to voltage match the preamplifier to the antenna. The FET input is coupled with a 91 pF capacitor. At 10 kHz, the preamplifiers have a spot noise of ≈ 50 nV/Hz$^{1/2}$. A preamplifier is utilized for each element of E_x and E_z. For each antenna the pair of preamplifier outputs is converted into a differential measurement by a differential amplifier in the main electronics box to reject common mode noise generated in the spacecraft itself.

3.2. Quasi-static Electric Field Measurement System

Quasi-static field measurements are made on both the E_x electric long wire and the E_z tubular electric antennas through the DC preamplifiers for each element and a differential amplifier. Each system has two simultaneous outputs – Hi-gain and Lo-gain as given

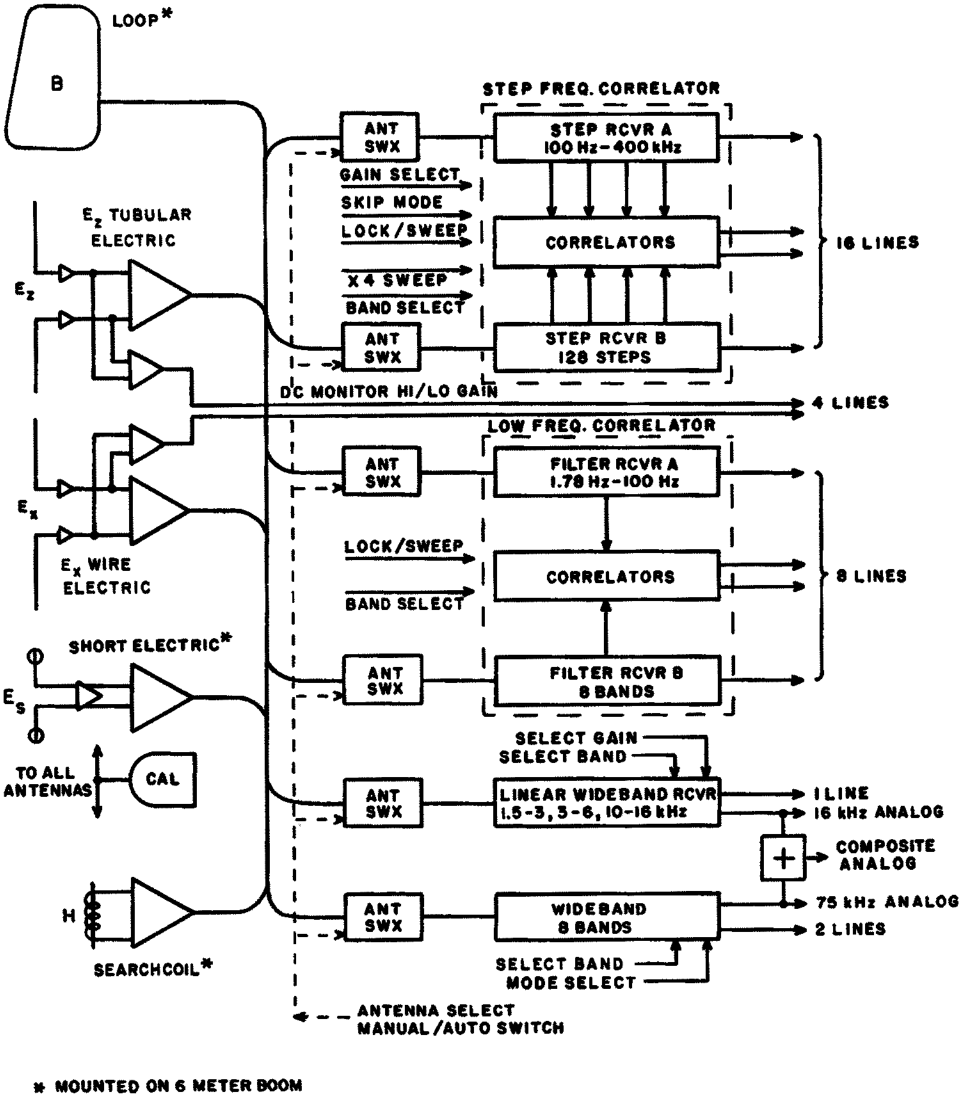

Fig. 1. Block diagram of DE-A plasma Wave Instrument (PWI).

in Table I – so that range switching is not required. Each output is sampled at 16 samples/s. The E_x system is ac coupled to respond from 0.03 to 5 Hz since the antenna rotates in the dc field at the 10 RPM (0.17 Hz) spin rate.

The electric field value is determined by the measurement of the potential difference between the two antenna elements divided by the effective electrical length given in Table II. This double probe technique and its associated uncertainties are described for the ISEE long wire system [5] and for the DE-B VEFI system [6]. In processing the data, the component due to the motion of the spacecraft across the earth's magnetic field is

TABLE III

PWI Receiver characteristics

Step Frequency Correlator (SFC)	
Frequency range	4 channels: 100–800 Hz, 0.8–6.4 kHz, 6.4–50 kHz, 50–400 kHz simultaneously for two receivers
Frequency resolution	128 frequency steps log-spaced 100 Hz–400 kHz with 1% bandwidth
Time resolution	Normal mode: 32 s/spectra, with option for 8 s/spectra
Amplitude resolution	Normal mode: 100 dB with option for 30 dB attenuator
Sensors	Any pairs from E_x, E_z, E_s, and B
Correlator resolution	±5% normalized correlation and ±5° phase
Optional modes	Lock frequency; skip every 8 steps with 8 s dwell/step; auto switch pairs of antennas
Technique	Two double-conversion, single-sideband, synchronous step frequency receivers (SFR's) driven by common frequency synthesizer. Amplitude derived from 100 dB logarithmic compressor amplifiers. Waveforms are correlated in EXOR circuits (one-bit) to give in-phase and quadrature phase correlation products
Heritage	Similar to ISEE-1 SFR receiver [3]
Low Frequency Correlator (LFC)	
Frequency range	2 receivers with filters at 1.8, 3.1, 5.6, 10, 18, 31, 56, and 100 Hz
Frequency resolution	8 filters 1.8–100 Hz with ±15% bandwidth
Time resolution	32 s/spectra at 1.8–10 Hz and 8 s/spectra 18–100 Hz
Amplitude resolution	100 dB
Sensors	Any pair from E_x, E_z, E_s, and H
Correlator resolution	±5% normalized correlation and ±5° phase
Optional modes	Lock frequency; auto switch pairs of antennas
Technique	Corresponding sets of four filters are switched to a logarithmic compressor amplifier for a 100 dB amplitude range. Waveforms are correlated in EXOR circuits (one-bit) to give in-phase and quadrature phase correlation products
Heritage	Similar to ISEE spectrum analyzer [3]
Wideband Analog Receiver (WBR)	
Frequency range	0–1 and 0.65–10 or 0.65–40 kHz or selection of 10 or 40 kHz bandwidth with lower band edge at 31.25, 62.5, 125, 250, 500, 1000, or 2000 kHz
Amplitude range	100 dB
Sensors	Any one of E_x, E_z, E_s, B or H

Table III *(continued)*

Optional modes	62.5 kHz reference tone, 0–1 kHz on 13.5 kHz FM subcarrier and 0.65–10 kHz or 0.65–40 kHz in 4 combinations; auto switch between sensors
Technique	Bandpass filter at 0–1 kHz into a logarithmic compressor amplifier; bandpass filters at 0.65–10 kHz and 0.65–40 kHz for baseband or for single-sideband down-conversion into an AGC amplifier
Heritage	Identical to ISEE wideband receiver [3]
Linear Wave Receiver (LWR)	
Frequency range	4 channels: 1.5–3.0, 3.0–6.0, 10–16 kHz, and 3.11 kHz ±7 1/2%
Amplitude range	70 dB in 10 dB steps with 30 dB linear detector range in each step
Sensors	Any one of E_x, E_z, B, or H
Optional modes	Set amplitude range by command; auto switch between sensors
Technique	Bandpass filters into receiver with 10, 20, and 40 dB amplifiers; gain state selected to set noise level 30 dB below maximum input signal to transmitter; tone frequency indicates gain state
Heritage	New design by University of Iowa

subtracted and the remaining vector components are resolved along geographic directions for display.

3.3. Sweep Frequency Correlator (SFC)

The Sweep Frequency Correlator consists of two identical high resolution narrow band Sweep Frequency Receivers (SFR's). Each SFR has 4 bands of 32 steps each for a total of 128 narrow band ($\approx 1\%$) amplitude measurements between 100 Hz and 400 kHz (see Table III). The frequency steps are logarithmically spaced over the frequency range. A crystal controlled frequency synthesizer provides a variable conversion frequency to obtain the step frequency function and a fixed intermediate frequency to a mixer/filter circuit. The variable conversion frequency is selected by using a ROM to generate the appropriate frequency codes to the synthesizer. The selected bands are single-sideband converted to near baseband by the IF frequency in each channel, band pass filtered and presented at the input to the respective logarithmic-amplitude compressor. Each compressor has two outputs: a DC output which is a 0–5 V analog voltage proportional to the logarithm of its input signal over a dynamic range of ≈ 100 dB and an ac output which is an amplified, but clipped, version of the input signal from the selected sensor used for correlation between respective channels. The AC outputs of the corresponding compressors for each of the four bands are compared in the correlation detectors.

In-phase and quadrature-phase correlation is obtained via Exclusive OR circuits. The quadrature phase correlations provide a measurement of the phase to $\pm 5°$ and of the normalized correlation coefficient to 5% between signals from the two selected input sensors which is used to discriminate electrostatic from electromagnetic phenomena and to discern wave polarization and wave propagation direction. (These results can be displayed in a spectrogram form similar to Figure 4.)

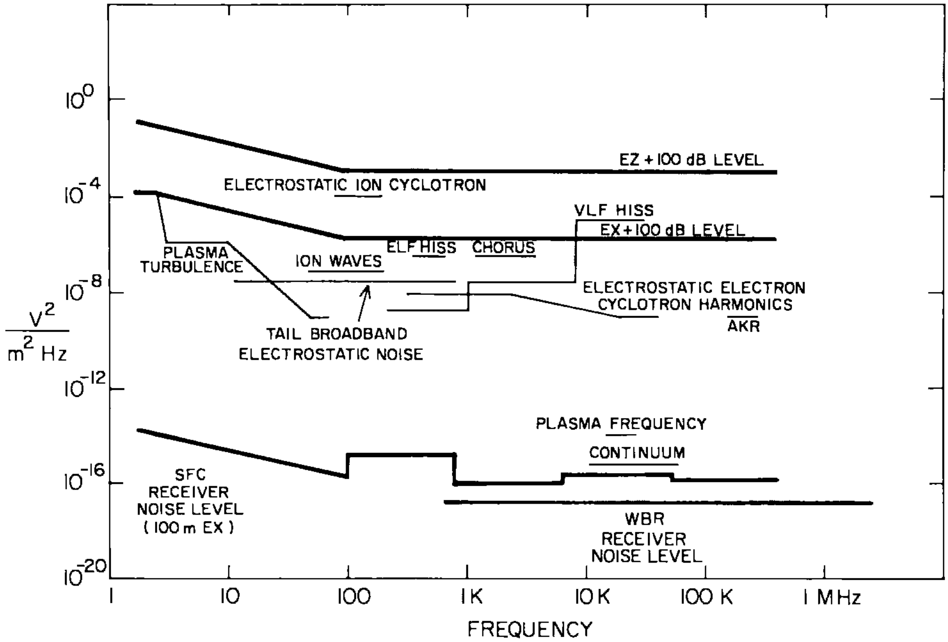

Fig. 2. Electric field spectral density response of the PWI electric field sensors and receivers. Also indicated are the maximum spectral densities of a variety of plasma wave phenomena.

The SFR will sequentially advance through its 32 steps at one second intervals in the sweep mode or any one of the 32 steps can be selected in the lock mode. In addition, a third mode (skip mode) sequentially selects only every eighth step but remains in this step for 8 s. In both sweep modes a times 4 sweep rate is available so an entire spectrum is available in 8 s. However, in the sweep mode at the times 4 rate the low frequency band (100–800 Hz) does not have enough settling time to give a reliable amplitude value. Amplitude and phase information from each of the four bands is sampled at 4 times/s. To improve the dynamic range, a 30 dB attenuator can be inserted or can automatically toggle in/out every 2 samples. The overall dynamic range with frequency for the sensor-receiver systems is indicated in Figures 2 and 3 and the maximum spectral densities for a variety of observed plasma wave phenomena are also indicated. An example of an ISEE SFR amplitude spectrogram similar to one expected for DE is shown in Figure 4.

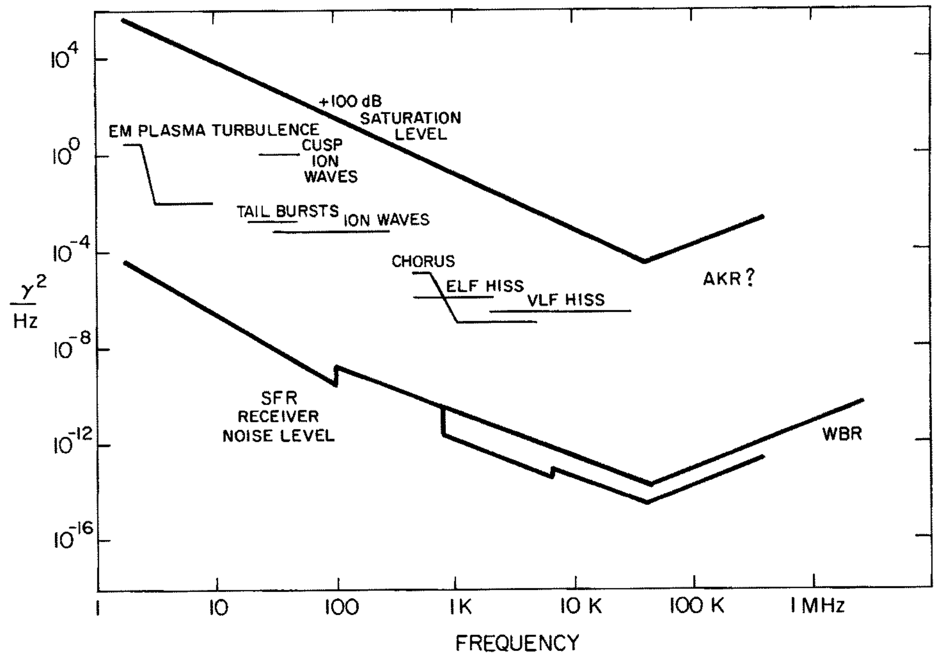

Fig. 3. Magnetic field spectral density response of the PWI magnetic field sensors and receivers. Also indicated are the maximum spectral densities of a variety of plasma wave phenomena.

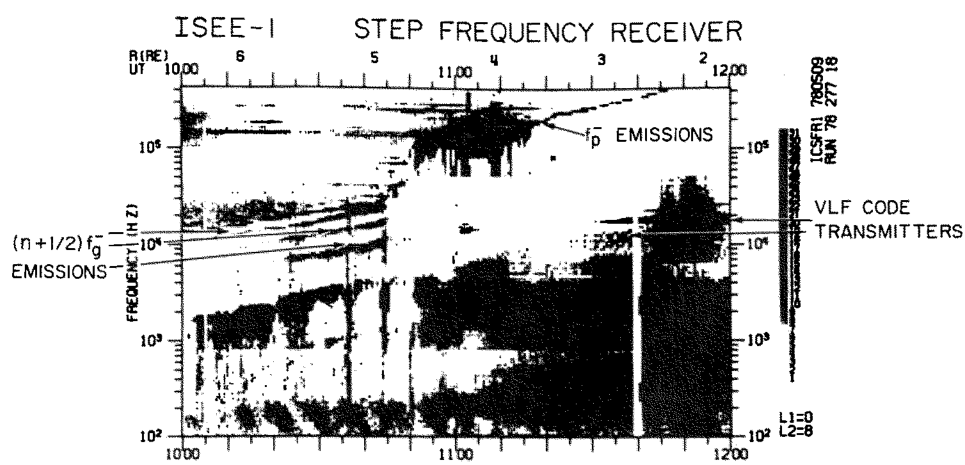

Fig. 4. Step Frequency Receiver electric field spectrogram from ISEE-1. Note that VLF code transmissions, noise near the plasma frequency (*fp*) and $(n + 1/2)$ *fg* electron gyroharmonics are clearly visible. At frequencies below 10 kHz there is a mixture of hiss and chorus. This spectrogram covers approximately the same altitude range as will DE-A.

3.4. Low frequency correlator (LFC)

The Low Frequency Correlator consists of two identical 8 channel spectrum analyzers of ±15% bandwidth active filters covering 1.78 Hz to 100 Hz, plus associated correlation circuitry (see Table III). The filter outputs for the Lo-band and the Hi-band group of four are sequentially connected to logarithmic-amplitude compressors at intervals of 8 s for the Lo-band and 1 s for the Hi-band in the sweep mode or a single filter of the group can be selected by minor mode command. The ac outputs of each pair of compressors are correlated in Exclusive OR circuits to provide information on the phase and correlation coefficient similar to that for the SFC.

3.5. Wideband receiver (WBR)

The purpose of the wideband receiver is to transmit wideband waveform signals to the ground via an analog transmitter so that detailed high resolution frequency-time analysis can be performed. The signals will be transmitted in one of 4 configurations selected via minor mode command. The components of the 75 kHz wide spectrum include a 0.65 to 10 kHz or 0.65 to 40 kHz band, a 1 Hz to 1 kHz band modulating a 13.5 kHz FM subcarrier and a 62.5 kHz reference signal derived from the local mixing oscillator. These components are selected to make up four combinations under Mode A indicated in Figure 5.

Selected 10 or 40 kHz bandwidths are single-sideband mixed down from seven higher frequencies up to 2 MHz as listed in Table III. Reception of this signal along with the

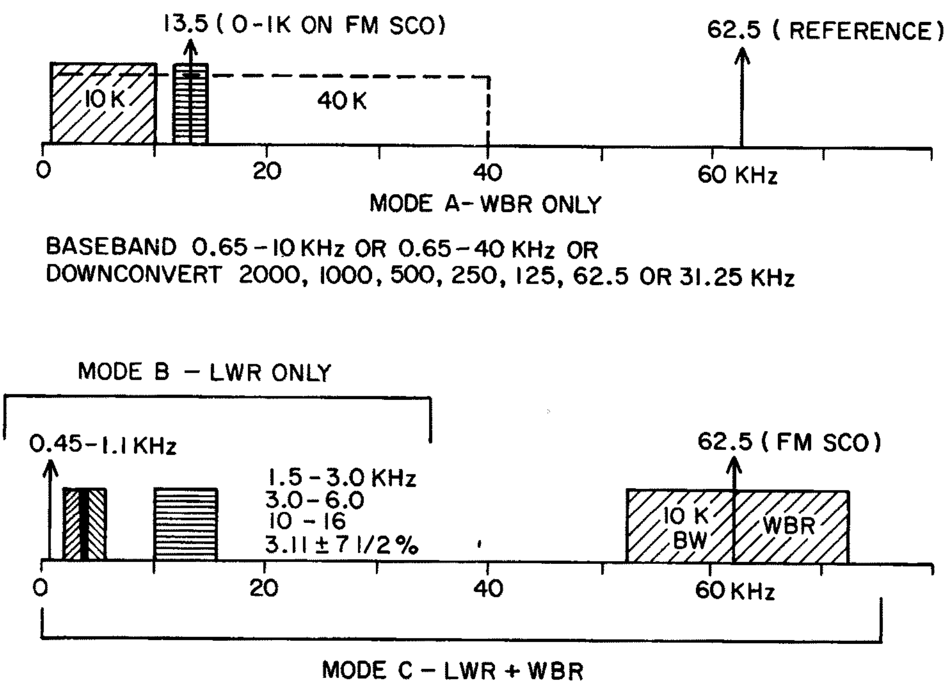

Fig. 5. Spectra of the three analog data modes which directly modulate the downlink transponder.

reference tone and that of a similar ISEE signal can be utilized to perform long baseline interferometry [7]. An automatic gain control maintains a nearly constant signal level output to the wideband transmission link to maximize the modulation index and hence signal-to-noise ratio for the 650 Hz-10 kHz or 40 kHz band. A log compressor performs a similar function for the 1 kHz information. Since this AGC action removes amplitude information, the AGC Gain and Compressor DC voltages are included as part of the science data. The wideband receiver has a nominal 110 dB dynamic range which is reduced somewhat by the spacecraft interference levels. The wideband receiver can be connected to any of the sensors in an automatic 8 s sequential step mode or any one of the sensors can be selected by command. The ground-processed frequency-time spectrogram is recorded on film.

3.6. Linear wave receiver (LWR)

The Linear Wave Receiver (LWR) measures wave amplitude in the frequency range of 1.5–16 kHz. The LWR can be connected to one of four sensors (E_x, E_z, B, or H) via major mode command or it can be commanded to cycle between B and E_x. The primary antenna is the magnetic loop (B) with a threshold sensitivity of $6 \times 10^{-7}\ \gamma/\mathrm{Hz}^{1/2}$ at 6 kHz. One of four passbands can be selected via minor mode command (see Table III).

The selected passband is coupled to a programmable amplifier. The gain of this amplifier can be set in 10 dB steps over a 70 dB range either manually (via minor mode command) or automatically by an autoranging circuit. The gain is updated every 8 s in the autoranging mode with a time constant of 2 s. The system has linear response over a 10–30 db range in any gain position.

The gain state of the programmable amplifier is encoded so that a tone between 450 and 1100 Hz representing the gain status appears on the wideband spectrograms recorded on film. Antenna selection information is also encoded by the following scheme: the gain state VCO output will be continuous when the Loop Antenna is selected. The gate timing is 4 s on/4 s off for other antennas. The selected band plus the VCO tone directly modulate the transmitter as shown in Figure 5, 'Mode B-LWR Only'.

The PWI electronics box, the four electric field preamps, the search coil magnetometer and the short electric field antenna are pictured in Figure 6.

3.7. Analog data downlink operations

Transmission of analog data from DE-A requires realtime use of the transponder and an appropriate ground station to receive and record the data for 2 to 3 h/d. During these transmissions 16 kbps science data are tape recorded for later playback, as usual. As indicated in Figure 5, three downlink combinations of WBR and LWR are possible: Mode A-WBR Only, Mode B-LWR Only and Mode C-WBR + LWR. In the case of Mode C the LWR is transmitted on baseband and the 10 kHz WBR data are transmitted via a 62.5 kHz FM subcarrier.

Use of the WBR is intended primarily for survey work since it responds over a very wide dynamic range and can capture several phenomena in the passband at the same time. The LWR is utilized primarily for wave-stimulation experiments with VLF trans-

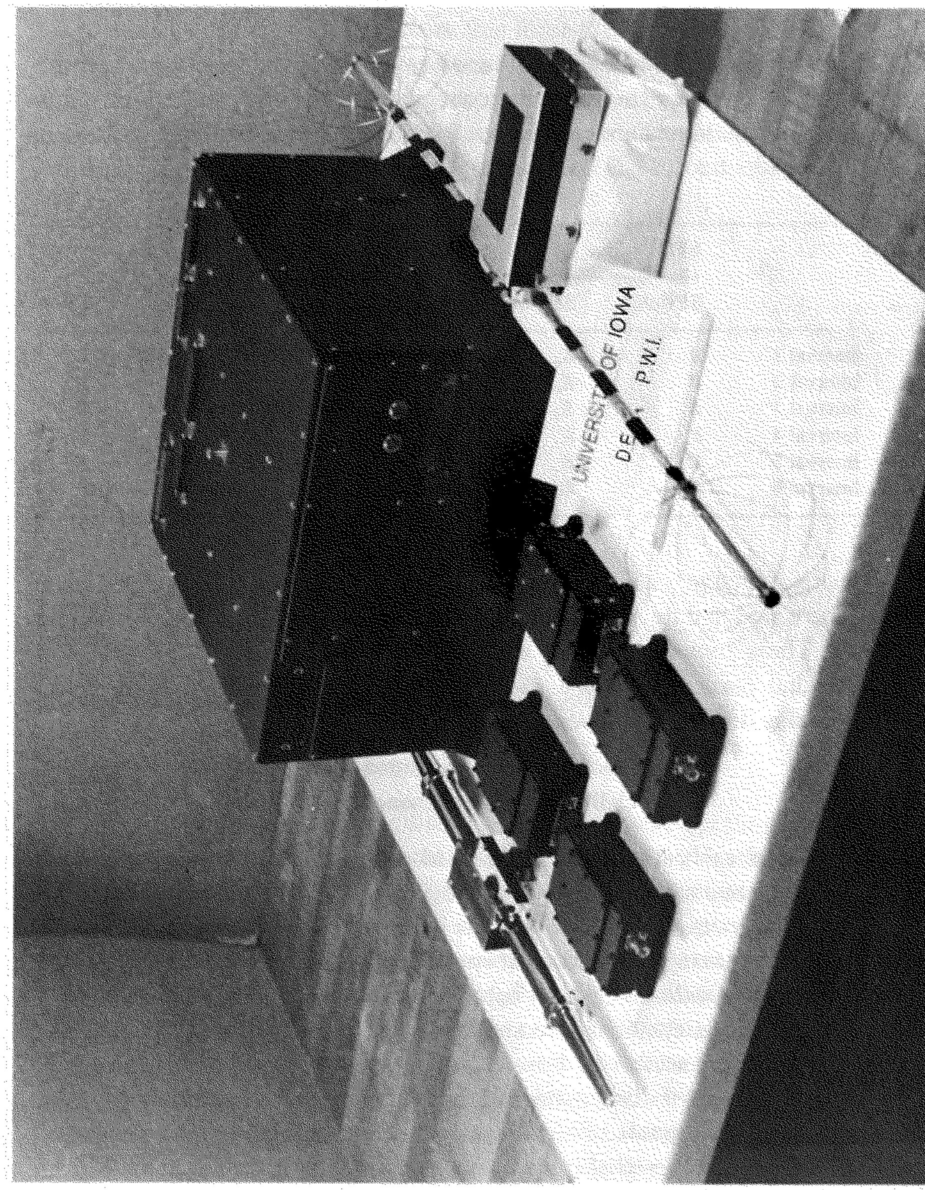

Fig. 6. DE-A PWI Instrument Components. Search Coil Magnetometer – Electric Field Preamps (4) – Main Electronics Unit – Short Electric Antenna. (Magnetic Loop is not shown.)

mitters such as the one at Siple, Antarctica. This receiver can be used to measure rapid growths (≈30 ms) of narrowband (≈100 Hz) features in the passband whether man-made or natural.

3.8. Antenna selection system

Antenna inputs to the various receiver systems can be selected at their respective differential amplifier outputs either via pulse commands or automatically. In the automatic mode the antenna inputs are switched at 8 s intervals according to the following format.

	SFC		LFC			
	SFR-A	SFR-B	SA-A	SA-B	WBR	LWR
Interval 1	B	E_z	H	E_z	H	E_x
Interval 2	B	E_s	H	E_s	E_s	B
Interval 3	B	E_x	H	E_x	B	E_x
Interval 4	E_x	E_s	E_x	E_s	E_x	B
Interval 5	E_x	E_z	E_x	E_z	E_x	E_x
Interval 6	E_z	E_s	E_z	E_s	E_z	B

The automatic function can be overridden at any time via the Auto/Manual commands. There are separate Auto/Manual commands for the LFC, SFC, WBR, and LWR systems. These commands revert antenna selection control to Antenna Select commands for that particular section. Both the Auto/Manual and Antenna Select commands are relay drive major mode commands.

4. Calibration of Instrument

Extensive bench-level calibration has been carried out as a function of temperature, signal level, frequency and relative amplitudes and phase. In addition, these calibrations have been checked at room temperature with the instrument completely installed in the spacecraft. Relative phase measurements between the magnetic and the electric sensors were carried out at the Goddard Space Flight Center Magnetic Test Site.

Results of these calibrations verify the amplitude response in excess of 100 dB and the frequency response and selectivity. Low frequency correlation measurements to $\pm 5°$ and $\pm 5\%$ are valid over a 90 dB dynamic range if the two signals are nearly the same amplitude (± 20 dB). For signals of significantly different amplitudes the phase and correlation values must be corrected through an extensive look-up table. At the highest SFC channel of 50 to 400 kHz there is crosstalk at the -50 dB level so that the correction factors are large but still applicable. Crosstalk is at the -70 dB level or below for the lower channels.

Measurements of the conducted and radiated spacecraft fields have been extensive [4]. These measurements indicated that there is no conducted or radiated electric field interference of significance. However, the radiated magnetic field levels can be 30 dB higher than the instrument noise levels at some discrete frequencies (harmonics of the 21 kHz pulse-width regulator). In the SFC only a few channels are affected. For the WBR, however, these harmonics fall within the wide passbands and affect the dynami range somewhat. Experience indicates that these high frequency levels may not change significantly in orbit. However, it has been found that low frequency noise (< 1 kHz) can increase significantly due to solar array effects (for example, see [3]).

During the in-orbit Antenna Calibration sequence all sensors but the Short Electric Antenna are stimulated at the following frequencies at 4 second intervals. The sequence will repeat itself until commanded to cease.

Interval	Frequency
1	1.81 Hz
2	44.44 kHz
3	5.55 kHz
4	3.175 kHz
5	694 Hz
6	99.21 Hz
7	10.85 Hz
8	1.81 Hz

The calibration signal differentially drives each set of electric field preamps through a low (≈ 1.5 pf) capacitance. The Search Coil Magnetometer and the Magnetic Loop are stimulated via a calibration winding coupling to their sensing coils. The sequence starts with the initiation of the Calibration Enable.

5. Operations and Expected Results

The DE-A spacecraft is power-limited to a 50% duty cycle and the ground-contact time for the realtime analog data is limited to $\approx 10\%$. Therefore, the times of operation and the instrument modes must be chosen to provide the measurements necessary to meet the primary science objectives.

Results expected from the SFR in terms of spectral information are shown in Figure 4 from ISEE. For DE, additional spectral information is available from 1 to 100 Hz to provide a 5 1/2 decade frequency survey with a 100 dB dynamic range. With the cross-correlation capability, cross-spectra which indicate electrostatic vs electromagnetic waves, polarization and propagation direction are possible for association with features in other parameter sets. By locking on a selected frequency, correlation measurements are available at 4 s^{-1} for detailed analysis. Analog data from the WBR or LWR or both are particularly important for identifying the phenomena seen with the SFC and LFC and for analyzing the fine time and frequency structure. Regions of particle acceleration and transverse plasma flows can be identified from the quasi-static electric field measurements. Locations of large electric field regions and the magnitude and direction of these fields are to be compared in detail with the vector electric field measurements on DE-B and with other distinct features such as current sheets, energetic particle precipitation or auroral light emissions.

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