DESCRIPTION OF THE WIDEBAND PLASMA WAVE INVESTIGATION FOR CLUSTER

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ABSTRACT

The Wideband Plasma Wave investigation for CLUSTER is designed to provide the high resolution spectral analysis required to clearly identify many types of plasma waves detected in the Earth's magnetosphere. The wideband measurements are of particular importance for the identification and study of plasma emissions which have very complex frequency-time characteristics. The CLUSTER wideband receiver system provides wideband waveform measurements of both electric and magnetic fields in selected frequency ranges from 10 Hz to 600 kHz. Continuous waveforms are digitized, formatted, and transferred to the spacecraft telemetry system using either a 250 kbits/sec real-time mode or a 100 kbits/sec burst-data mode. The real-time data requires direct acquisition by a NASA DSN ground receiving station while the burst mode data is stored on the spacecraft tape recorder for subsequent playback.

Keywords: Wideband Receiver, Plasma Waves, Magnetosphere, Waveform

1. INTRODUCTION

The Wideband Plasma Wave (WBD) investigation for CLUSTER provides wideband waveform measurements of plasma waves in the Earth's magnetosphere. A wideband receiver system which measures electric and magnetic fields over the frequency range 10 Hz to 600 kHz is provided by the WBD investigation as part of the Wave Experiment Consortium instrumentation. The wideband receiver system provides unique measurement capabilities required for the detailed study of terrestrial plasma waves and radio emissions. A list of investigators participating in the WBD investigation is provided in Table 1.

The importance of wideband measurements in the study of VLF radio emissions was recognized over two decades ago, when the technique was first introduced on the Alouette 1 (Ref. 1) and Injun 3 (Ref. 2) satellites. Since that time, wideband measurements have become a standard technique for the study of space plasma waves, and wideband instrumentation has been carried by many spacecraft, including OGO 1 through 6, IMP 6 and 8, S(3), GEOS 1 and 2, S3-3, ISEE 1 and 2, Prognoz 8, Voyager 1 and 2, and DE 1. The CLUSTER wideband receiver is similar to instruments flown on ISEE 1 and DE 1.

The wideband technique involves transmitting band-limited waveform data to a ground station using a high-rate data link. The primary advantage of this approach is that complete, continuous waveforms are available for detailed high resolution frequency-time analysis, which may be performed to a level limited only by the uncertainty principle, $\Delta\omega\Delta t \sim 1$. Since the frequency resolution ($\Delta\omega$) and time resolution (Δt) may be selected and modified during data processing on the ground, the wideband technique is an extremely effective and flexible method for resolving features of interest in the plasma wave data.

The high resolution nature of the wideband technique is of particular importance for the proper identification and

Table 1. Investigators

Principal Investigator	Affiliation
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Co-Investigators	
Jean-Louis H. Bougeret	Observatoire de Meudon
Patrick Canu	CRPE/Centre Nat'l d'Etudes Telecommunications
Gerard Daigne	Observatoire de Bordeaux
George Gustafsson	Swedish Inst. of Space Physics
Gerhard Haerendel	Max-Planck-Institut
Robert A. Helliwell	Stanford University
Umran S. Inan	Stanford University
Dyfrig Jones	British Antarctic Survey
Gerald S. Levy	Jet Propulsion Laboratory
Warren L. Martin	Jet Propulsion Laboratory
Robert L. Mutel	University of Iowa
Bent Pedersen	Observatoire de Meudon
Alain Roux	CRPE/Centre Nat'l d'Etudes Telecommunications
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study of plasma emissions which have very complex frequency-time characteristics. The distinctive fine structures of chorus and auroral kilometric radiation, for example, were first identified using wideband measurements. To illustrate the flexibility and extremely high resolution available from wideband data, Figure 1 provides representative spectrograms of several types of plasma emissions observed in the Earth's magnetosphere. The spectrogram in panel (a), for example, has been processed using a very expanded time scale to resolve the fine structure in whistler-mode chorus emissions. The spectrogram in panel (b) has been processed with a greatly expanded frequency resolution at low frequencies to resolve the narrow band structure of electrostatic ion cyclotron waves. The spectrums in panels (c) and (d) were obtained in a frequency conversion mode of operation and show the extremely complicated fine structure of $(n + 1/2)f_{ce}$ electron cyclotron waves near the upper hybrid resonance (UHR) and the complex narrowband structure of auroral kilometric radiation. Finally, to illustrate the use of wideband data as a means for obtaining very high resolution measurements of basic plasma parameters, panel (e) shows a spectrum of auroral hiss which has a sharp upper frequency cutoff at the electron plasma frequency, f_{pe}. This cutoff provides very accurate (few percent), high time resolution (0.1 sec) measurements of the electron density in the auroral zone and over the polar cap.

2. SCIENTIFIC OBJECTIVES

The eccentric polar orbit selected for the CLUSTER mission carries the spacecraft through most of the important regions of the magnetosphere, including the polar cusp, the plasma mantel, the magnetopause boundary layer, the polar cap, the auroral zones, the plasma sheet, the plasma sheet boundary layer, and the plasmapause. Many diverse types of plasma waves are identified with these regions. Some of the more

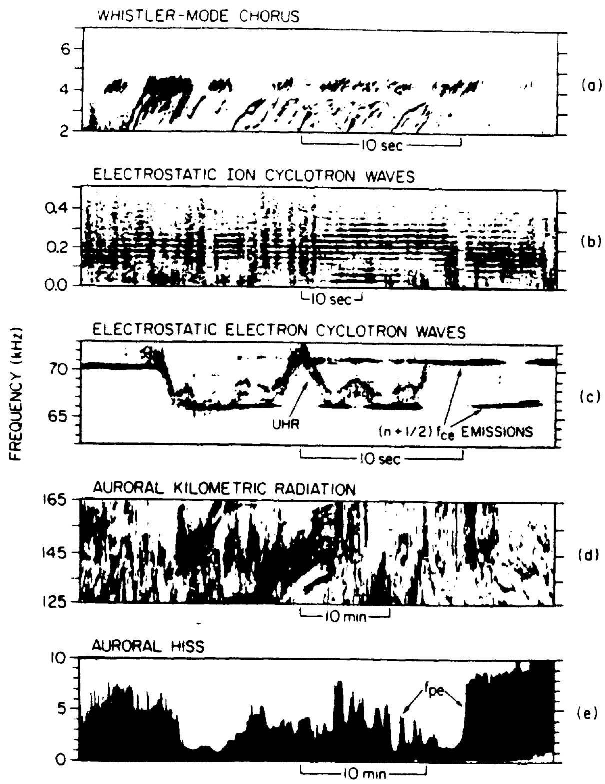

Fig. 1. Frequency-time spectrograms of plasma emissions observed in the Earth's magnetosphere using wideband instrumentation.

important of these include electrostatic ion cyclotron waves, broadband electrostatic noise, whistler-mode chorus, auroral hiss, auroral kilometric radiation, continuum radiation, electrostatic electron cyclotron waves, upper hybrid emissions, and lower hybrid waves. The primary purpose of the Wideband Plasma Wave investigation is to provide the high resolution spectral analysis required to clearly identify the types of plasma waves detected in various regions of the magnetosphere. At boundaries and other regions with steep spatial gradients, the wideband data will also provide high time resolution measurements for comparison with data from other instruments with good temporal resolution, such as the magnetometer and plasma instruments. In this way, waves produced by current-driven instabilities and other mechanisms involving spatial inhomogeneities can be clearly identified. In cases where the upper hybrid or electron plasma frequency can be identified, the wideband data also provides very high resolution passive measurements of the electron density.

As often as is feasible, two-point measurements of magnetospheric plasma emissions are to be obtained with the CLUSTER wideband system. Two-point comparisons of electron densities from the upper cutoff of auroral hiss, for example, can be used to analyze the motion and evolution of plasma structures in the auroral zone and polar cap. Also, timing measurements performed when two spacecraft are located along the same magnetic field line can provide propagation speeds, which are important for identifying the wave propagation mode.

Some specific scientific objectives of the WBD investigation are summarized below.

(1) Obtain wideband measurements of plasma turbulence in the polar cusp and use this data in conjunction with low-rate wave measurements to investigate the origin of this turbulence.

(2) Compare high time resolution wideband measurements with four-point magnetic field measurements to identify current-driven instabilities.

(3) Compare high time resolution wideband spectrums with plasma density and temperature gradients at boundary crossings to identify density- and temperature-gradient instabilities.

(4) Use wideband data to investigate the origin of the intense narrowband structure which characterizes the auroral kilometric radiation. Also, search for a non-structured background component in the AKR.

(5) Use wideband spectrums to study the fine structure and origin of the whistler-mode auroral hiss and Z-mode radiation in the auroral zone and polar magnetosphere.

(6) Study the scattering of whistler-mode waves into short wavelength electrostatic waves by interactions with small-scale density irregularities.

(7) Use wideband high resolution data to study the spin modulation patterns of whistler-mode waves so as to infer the wave propagation directions and coherence properties.

(8) Use wideband electric field waveform measurements to identify and study double layers, electrostatic ion cyclotron waves, lower hybrid emissions, and other narrowband or impulsive electrostatic phenomena in the auroral acceleration region.

(9) Use wideband electric field waveform measurements to search for and study Langmuir wave solitons in the region upstream of the bow shock and in the auroral acceleration region.

(10) Use measurements of the upper cutoff of whistler-mode auroral hiss at the electron plasma frequency

to study the highly structured electron density variations in the auroral plasma cavity and over the polar cap.

3. DESCRIPTION OF THE WIDEBAND RECEIVER SYSTEM

A simplified block diagram of the wideband receiver is provided in Figure 2. The wideband receiver processes signals from one of four sensors which can be chosen via an antenna selection switch located at the receiver input. The four selectable inputs consist of two electric field signals, and two magnetic field signals. These inputs are provided by the electric and magnetic field experiments.

Input bandpass filters limit the incoming signal to one of four possible frequency bands ranging from baseband to 500 kHz. The band-limited signal then goes to a single-sideband frequency conversion stage which determines the range of frequencies to be received. Under this scheme, the filtered input signal is mixed with conversion frequencies f and $f\angle 90^\circ$. The input signals are thereby converted to baseband with upper and lower sidebands superposed and with a phase difference of 180 degrees. A quadrature phase shift network shifts one converted signal by an additional 90 degrees so that when the converted signals are summed, the upper sideband components add and lower sideband components cancel. The output of the conversion stage then goes to one of a set of three bandpass filters which determines the bandwidth of the output waveform.

Because of the large dynamic range of the input signal, and in order to maintain a high signal-to-noise ratio for the processed signal, an incremental automatic gain control amplifies the signal to the proper level in steps of 10 dB over a range of 0 dB to 80 dB. The output from the gain select then goes to an analog-to-digital converter which provides 1-bit, 4-bit, or 8-bit resolution for a selection of sample rates.

Finally, a format generator organizes the digitized waveform data into a data frame suitable for the spacecraft telemetry system. The digitized wideband data is then transferred to the spacecraft data system in either a 250 kbits/sec real-time data mode, which requires direct acquisition by a NASA DSN ground station, or a 100 kbits/sec burst-data mode, which provides data to the spacecraft tape recorder via the Wave Experiment Consortium data processing unit (DWP). This latter mode provides the capability for acquiring data when the spacecraft cannot be tracked by a DSN station, and also provides the means for collecting data from more than one spacecraft at a time. Commanding of the wideband receiver is managed by the DWP.

A summary of wideband instrument parameters is given in Table 2. Individual aspects of the wideband receiver system are discussed in detail in the following sections.

Table 2. Wideband Instrument Parameters

Sensors	Two electric dipole antennas; two search coil magnetometers
Conversion Frequencies	0, 125 kHz, 250 kHz, 500 kHz
Bandpass Filter Ranges	1 kHz to 100 kHz 50 Hz to 25 kHz 10 Hz to 10 kHz
Frequency Resolution	Limited by FFT (75 Hz, typical)
Time Resolution	10-20 msec (per FFT spectrum)
Gain Select	10 dB steps, 8 levels, dynamic range 80 dB, automatic ranging or set by command
A/D Converter	1-, 4-, or 8-bit resolution for a selection of sample rates

3.1 Antennas

On CLUSTER, the plasma wave sensors consist of two orthogonal spherical electric antennas located in the spin plane of the spacecraft, and a triaxial search coil magnetometer oriented with two measurement axes in the spin plane and the third measurement axis oriented parallel to the spacecraft spin axis. The electric antennas, which are provided by the Electric Fields (EFW) investigation, have sphere-to-sphere separations of about 100 m. The spheres each contain a high-impedance preamplifier which provides signals to the EFW main electronics, and to the wideband receiver and other wave instruments. The three orthogonal search coils are part of the STAFF instrumentation, and provide magnetic field signals up to 4 kHz.

The wideband receiver has the capability of processing signals from one of four sensors which may be selected by spacecraft command. Under the control of the DWP, the wideband receiver may be switched to either of the electric sensors, to a spin-plane search coil, or to the spin-axis search coil.

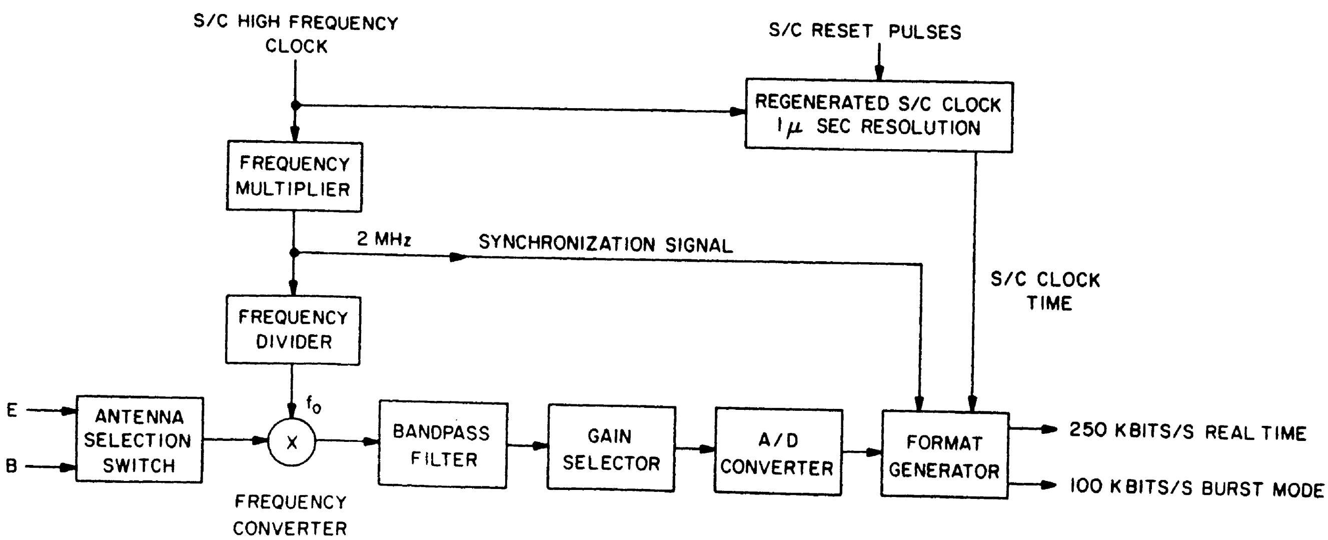

Fig. 2. Block diagram of the CLUSTER wideband receiver.

3.2 Frequency Bands

The input frequency range of the wideband receiver can be shifted by the frequency converter to any one of four frequency ranges, where the conversion frequency f determines the lower edge of the frequency range to be received. The conversion frequency is obtained by dividing down a 2 MHz reference oscillator. To maintain phase stability in the entire system, the 2 MHz oscillator is synchronized to a spacecraft high frequency clock signal.

A spacecraft command to select a particular frequency band causes the DWP to switch the wideband receiver to the appropriate input bandpass filter and to select the appropriate conversion frequency. If baseband (f = 0) is selected, the mixing stage is bypassed so that the signal is routed directly to the output bandpass stage with no frequency conversion.

The bandwidth of the wideband receiver output waveform is determined by one of three bandpass filters selected in response to the appropriate spacecraft command. Conversion frequencies and bandpass filter ranges are given in Table 2.

3.3 Gain Control

The gain select stage of the wideband receiver employs three dual-gain amplifiers which may be selected to provide gain control in increments of 10 dB. This programmable amplifier stage consists of amplifiers having gains of 0/10 dB, 0/20 dB, and 0/40 dB gain. The gain combinations used are listed in Table 3.

Table 3. WBD Gain Select

Gain Step	Amplifier Combination	Total Gain (dB)
0	0 + 0 + 0	0
1	10 + 0 + 0	10
2	0 + 20 + 0	20
3	10 + 20 + 0	30
4	0 + 0 + 40	40
5	10 + 0 + 40	50
6	0 + 20 + 40	60
7	10 + 20 + 40	70

In manual gain select mode, the total receiver gain can be set to one of the eight levels by the appropriate spacecraft command.

Additionally, the wideband receiver has the capability of auto-ranging through the gain steps. The auto-ranging mode is enabled by command and allows the wideband receiver to automatically manage large changes in signal intensity. In this operational mode, the output from the programmable amplifier is compared to a pair of reference amplitudes. If the criteria for changing the gain are met, the gain state is either increased by one step (10 dB) or decreased by one step, accordingly. In order to avoid excessive toggling between gain steps, a 3 dB threshold must be exceeded in either direction.

Since CLUSTER is a spinning spacecraft, it is expected that signals measured by the wideband receiver will often show a strong modulation pattern caused by the rotating antenna, with nulls at intervals of one-half the spin period. In order to avoid changes in gain state due to antenna rotation, the gain is to be changed at intervals comparable to one spacecraft spin period.

3.4 A/D Converter and Format Generator

The output analog waveform is sampled by an analog-to-digital converter which provides sampling resolution and data output rates which are listed in Table 4.

Table 4. WBD Data Rates

Resolution (bits)	Data Rate (samples/sec)	Data Rate (bits/sec)	Duty Cycle
1	250k	250k	100%
*4	25k	100k	100%
4	62.5k	250k	100%
4	250k	1000k	25%
8	31.25k	250k	100%
8	250k	2000k	12.5%

*For burst-mode transfer to the spacecraft tape recorder

For sample rates where the bit rate exceeds the spacecraft telemetry data rate (250 kbits/sec), the digitized wideband data is buffered by the format generator and read out at a reduced average bit rate of 250 kbits/sec. The format generator organizes the digitized waveform data into an output frame or packet tagged with a sample of the spacecraft clock time (1 microsecond resolution) and transfers the frame or packet to the spacecraft telemetry system.

3.5 Wideband Receiver Output Modes

The wideband receiver has two different output modes for providing digitized data to the spacecraft telemetry system. These modes consist of a real-time data mode which provides data at about 250 kbits/sec and a burst-data mode which provides data at 100 kbits/sec.

3.5.1 Real-Time Data. In the 250 kbits/sec real-time data mode, wideband data is read out to the spacecraft telemetry system and transmitted via a real-time link to a DSN ground receiving station.

3.5.2 Burst-Mode Data. The 100 kbits/sec burst mode provides high-rate data to the spacecraft tape recorder via the DWP. This data mode uses a high rate serial interface between the wideband receiver and the DWP. Data is transferred to the DWP through this serial interface, and the DWP, in turn, transfers the wideband data to the spacecraft data system for recording and subsequent playback.

3.6 Instrument Status and Housekeeping Data

Since the wideband receiver has the capability of auto-ranging through gain states in response to variations in the input signal level, the gain state must be available so that the actual signal amplitude can be recovered during data analysis. The gain status, along with all other status information (auto/fixed gain, gain select, frequency select, output bandwidth select, A/D mode select, and antenna select) are sampled by the DWP and provided as housekeeping parameters. Also, in order to facilitate processing of the wideband data, the gain status is included in the 250 kbit/sec real-time data stream.

4. REFERENCES

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