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CRRES Plasma Wave Experiment

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The CRRES plasma wave experiment is designed to provide information on the plasma wave environment and the total plasma density in the Earth's radiation belts and throughout the CRRES orbit. This information is valuable both for studying the naturally occurring wave-particle interactions affecting the plasma and particle environment in the plasmasphere and magnetosphere as well as for studying the chemical releases. The electric field sensors for this instrument consist of two long electric dipole antennas (~100 m tip-to-tip), and the magnetic field sensor is a search coil magnetometer mounted at the end of a 6-m boom. The instrument has two receivers: a 14-channel spectrum analyzer covering the frequency range from 5.6 Hz to 10 kHz and a 128-step sweep frequency receiver covering the frequency range from 100 Hz to 400 kHz. Measurements from these receivers provide the intensity of the electromagnetic and electrostatic fields as functions of frequency and time from which the emissions and wave modes can be identified and analyzed and from which the total plasma number density can be determined.

Introduction

THE major objectives of the CRRES mission include studies of the natural radiation belt environment and studies of the effects of the radiation environment on microelectronic components, performance of active chemical release experiments in the ionosphere and magnetosphere, and low-altitude studies of ionospheric irregularities. In-situ measurements of the fields and waves in the vicinity of the CRRES spacecraft are essential to meet these objectives. Plasma waves can play a major role in changing the thermal plasma and the energetic particle populations through pitch-angle scattering, particle heating, and other wave-particle interaction processes which exchange energy and/or momentum between the waves and the particles.[1] Direct measurements of the plasma wave modes and intensities are essential for calculating pitch-angle diffusion coefficients and for assessing the effects of the plasma waves on the energetic particles and the background thermal plasma.[2] The plasma wave measurements along with the field, plasma, and particle measurements from the other CRRES experiments will provide valuable data for long-term studies of the radiation belt environment as well as for event studies such as those associated with geomagnetic storms and substorms and with the chemical releases.

An important output from the plasma wave measurements will be the electron number density derived from observed upper hybrid resonance frequency (F_{UHR}) emissions and cutoffs at the electron plasma frequency.[3,4] These measurements are obtained independent of spacecraft charging and without perturbing the plasma.

Instrumentation

The CRRES plasma wave experiment instrumentation has been designed to measure the plasma wave environment in the Earth's radiation belts with emphasis on high-frequency and time resolution, a large dynamic range, and sufficient frequency response to cover all of the characteristic frequencies of the plasma that are of interest. The CRRES plasma wave experiment provides measurements of electric fields from 5.6 Hz to 400 kHz and magnetic fields from 5.6 Hz to 10 kHz with a dynamic range of at least 100 dB (a factor of 10^5 in amplitude). Magnetic field measurements from 10–400 kHz are also possible but the dynamic range will be reduced due to the roll-off of the search coil magnetometer above 10 kHz. Electrostatic dN/N measurements from 5.6 Hz up to 400 kHz are also possible via signals from the electric field/Langmuir probe (EF/LP) experiment.[5]

The plasma wave experiment measures the electromagnetic and/or electrostatic fields detected by three sensors: 1) a 100-m tip-to-tip extendable fine wire long electric dipole antenna (designated WADA for wire antenna deployment assembly), 2) a search coil magnetometer mounted at the end of a 6-m boom, and 3) a 94-m sphere-to-sphere double probe electric antenna (designated SWDA for spherical-double-probe wire deployment assembly) which is part of the EF/LP experiment. The first two sensors are the primary sensors for the plasma wave experiment whereas the third sensor is the primary sensor for the EF/LP experiment. A drawing of the CRRES spacecraft showing the locations of the sensors is shown in Fig. 1. The diameter of the spacecraft is approximately 3 m.

The basic CRRES plasma wave experiment instrumentation includes two receivers: 1) a multichannel spectrum analyzer to provide high-time-resolution spectra from 5.6 Hz to 10 kHz, and 2) a sweep frequency receiver for high-frequency-resolution spectrum measurements from 100 Hz to 400 kHz. The dynamic range for each of the receivers is about 100 dB beginning at the respective receiver's noise level. Signals from the plasma wave experiment sensors and the EF/LP experi-

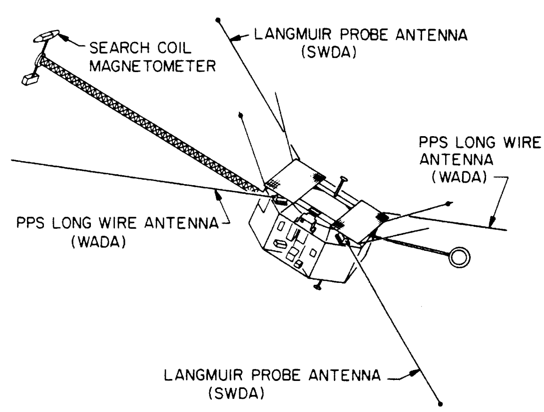

Fig. 1 Drawing of the CRRES spacecraft showing the locations of the sensors for the plasma wave experiment.

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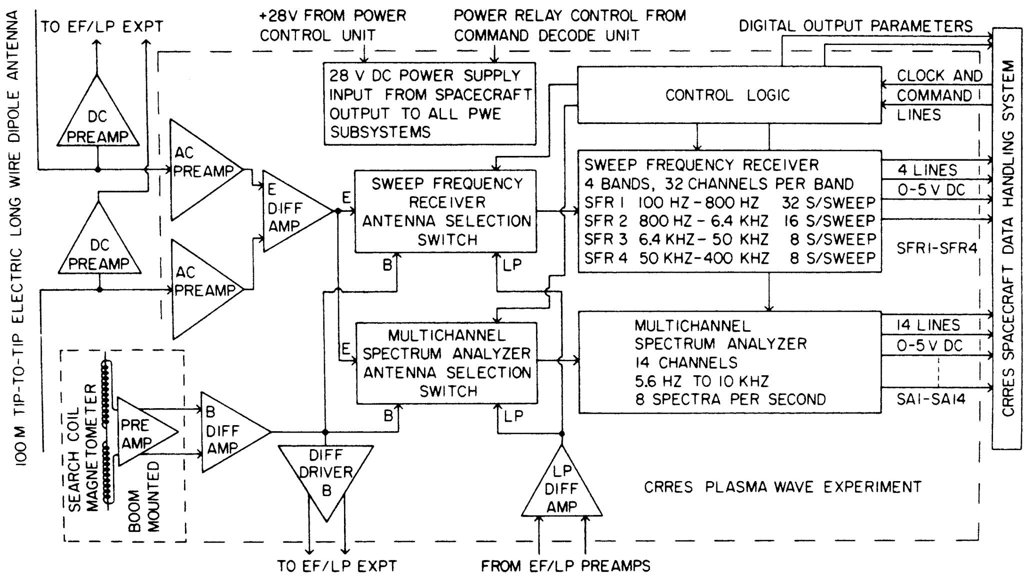


Fig. 2 Block diagram of the CRRES plasma wave experiment.

ment sensors, after buffering by appropriate preamplifiers and differential amplifiers, are routed via two sets of antenna selection switches to the sweep frequency receiver and the multichannel spectrum analyzer in the plasma wave experiment. Signals from the plasma wave experiment sensors are also provided to the EF/LP experiment where they can be used for measuring the dc and low-frequency electric fields and for waveform measurements using the burst memory. Signals from the CRRES plasma wave experiment sensors routed to the EF/LP experiment can subsequently be routed to the wave-particle correlator in the low-energy plasma analyzer experiment. A block diagram of the CRRES plasma wave experiment is shown in Fig. 2.

The CRRES plasma wave experiment main electronics package includes the multichannel spectrum analyzer, the sweep frequency receiver, a power supply, and antenna selection switches. Two electric field preamps and the search coil magnetometer are also a part of the CRRES plasma wave experiment. The mass of the main electronics package is 5.06 kg. The entire plasma wave experiment complement draws 0.175 A at 28 V at room temperature for a total power consumption of 4.9 W. This includes slightly less than 50 mW each (3 × 50 mW = 150 mW total) for the two electric field preamplifiers and the search coil magnetometer.

Sensors

Two diametrically mounted WADA units simultaneously deployed a dipole wire antenna with a tip-to-tip length of 100 m in the spin plane of the satellite. Each WADA unit contains approximately 50 m of a 0.813 mm (0.032 in.) diam Teflon-coated 7-strand beryllium-copper wire and a 33 g (0.073 lb) insulated stainless-steel tip mass. The insulation is stripped from the outer 10 m of the wire. The weight of the coated wire is 1.98 g/m and the weight of the uncoated wire is 1.16 g/m. The mass of each WADA unit including wire and tip mass is 2.68 kg. Two high-input-impedance electric field preamplifiers are located on the spacecraft near the base of each half of the extendable fine wire long electric dipole. The mass of each of the two electric field preamplifiers is 0.303 kg.

The search coil magnetometer contains a high permeability μ-metal core 0.41 m long, wound with 10,000 turns of #42 wire, and a preamplifier. The mass of the search coil magnetometer is 0.290 kg and it consumes approximately 50 mW of power. The sensitivity of the search coil magnetometer is 35 μV/nT-Hz up to 10 kHz and then falls off at a 12 dB per octave rate thereafter.

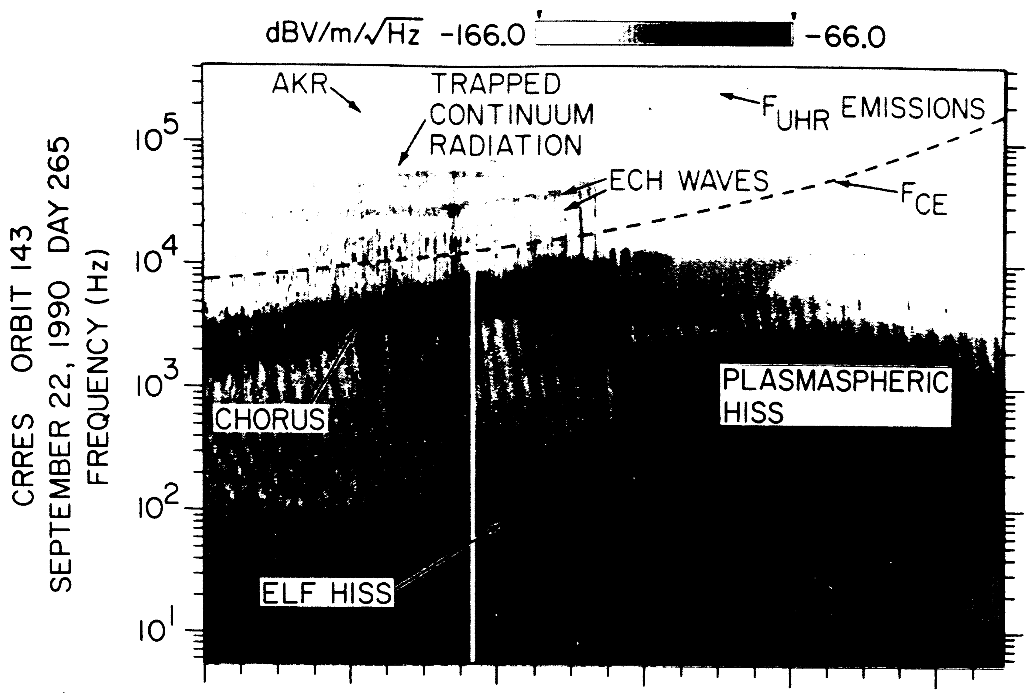
The SWDA spherical-double-probe sensors are described in detail in the EF/LP experiment article in this journal (Ref. 5). Signals from these sensors can be used by the plasma wave experiment for electric field measurements when they are in the potential mode and for electrostatic dN/N measurements when they are in the current mode.

Multichannel Spectrum Analyzer

The CRRES multichannel spectrum analyzer consists of 14 narrowband filters logarithmically spaced in frequency (4 filters per decade in frequency) from 5.6 Hz to 10 kHz followed by 14 logarithmic compressors. The design for the multichannel spectrum analyzer is identical to the magnetic spectrum analyzer flown on ISEE 1.[6] The nominal 3 dB sine-wave bandwidth points of each narrowband filter are at ±15% of the center frequency except for the two highest frequency channels (5.62 and 10.0 kHz) whose bandwidths are ±7.5% of the center frequency. The multichannel spectrum analyzer characteristics are listed in Table 1. The logarithmic compres-

Table 1 Multichannel spectrum analyzer characteristics

Channel number	Center frequency	Effective noise bandwidth	Noise level, V^2/Hz	Minimum detectable sine-wave amplitude, V
01	5.6 Hz	1.12 Hz	1.5×10^{-10}	$1.3 \pm 0.1 \times 10^{-5}$
02	10.0 Hz	2.00 Hz	2.4×10^{-11}	$7.0 \pm 0.3 \times 10^{-6}$
03	17.8 Hz	3.56 Hz	9.8×10^{-12}	$5.9 \pm 0.3 \times 10^{-6}$
04	31.1 Hz	6.22 Hz	4.0×10^{-12}	$5.0 \pm 0.3 \times 10^{-6}$
05	56.2 Hz	11.2 Hz	2.5×10^{-12}	$5.3 \pm 0.5 \times 10^{-6}$
06	100. Hz	20.0 Hz	2.0×10^{-12}	$6.4 \pm 0.4 \times 10^{-6}$
07	178. Hz	35.6 Hz	6.2×10^{-13}	$4.7 \pm 0.4 \times 10^{-6}$
08	311. Hz	62.2 Hz	3.0×10^{-13}	$4.3 \pm 0.3 \times 10^{-6}$
09	562. Hz	112. Hz	2.5×10^{-13}	$5.3 \pm 0.4 \times 10^{-6}$
10	1.00 kHz	200. Hz	1.1×10^{-13}	$4.6 \pm 0.3 \times 10^{-6}$
11	1.78 kHz	356. Hz	7.3×10^{-14}	$5.1 \pm 0.3 \times 10^{-6}$
12	3.11 kHz	622. Hz	3.3×10^{-14}	$4.5 \pm 0.3 \times 10^{-6}$
13	5.62 kHz	560. Hz	2.3×10^{-14}	$3.6 \pm 0.4 \times 10^{-6}$
14	10.0 kHz	1.00 kHz	7.8×10^{-15}	$2.8 \pm 0.3 \times 10^{-6}$



UT (HRMN)	2130	2150	2210	2230	2250	2310
R (R_E)	4.89	4.50	4.04	3.50	2.88	2.16
MLT (HRS)	7.61	7.97	8.41	8.96	9.73	10.97
MAG LAT	10.14°	10.06°	9.94°	9.54°	8.81°	7.06°
L	5.06	4.64	4.14	3.56	2.89	2.13
F_{CE} (kHz)	7.13	9.76	13.62	21.15	38.39	92.05

Fig. 3 CRRES plasma wave experiment data obtained near the inbound plasmapause crossing on orbit 143.

sors produce an analog output voltage approximately proportional to the logarithm of the input signal. The 14 0.0-5.10 V dc analog outputs are sampled simultaneously 8 times/s by the spacecraft data handling system.

Sweep Frequency Receiver

The sweep frequency receiver covers the frequency range from 100 Hz to 400 kHz in four bands with 32 steps per band. The fractional step separation of the sweep frequency receiver, df/f, is about 6.7% across the entire frequency range. Band 1 (100-800 Hz) is sampled 1 step/s or 32 s/sweep. Band 2 (800 Hz-6.4 kHz) is sampled 2 steps/s or 16 s/sweep. Band 3 (6.4-50 kHz) and band 4 (50-400 kHz) are each sampled 4 steps/s or 8 s/sweep. The sweep frequency receiver on ISEE 1, after which the CRRES receiver has been patterned, had each of the four bands sampled 1 step/s or 32 s/sweep.[6] To accomplish the faster sampling rates on the three upper bands on CRRES, two additional frequency synthesizer circuits were added. The nominal bandwidths of the four bands are 7 Hz, 56 kHz, 448 Hz, and 3.6 kHz, respectively. The four bands each have a logarithmic compressor which measures the signal amplitude over about a 100 dB dynamic range beginning at the noise level of the receiver and produces a 0.0-5.10 V dc analog output approximately proportional to the logarithm of the input amplitude. The sampling of the four sweep frequency receiver analog outputs (one for each band) are done by the spacecraft data handling system. Table 2 lists the noise levels and the minimum detectable sine-wave amplitudes for the four CRRES sweep frequency receiver bands.

Commands and Data Handling

The spacecraft data handling system provides the clock and command lines for controlling the receivers and the sampling and the analog-to-digital conversions of the receivers' 0.0-5.10 V dc analog outputs. The CRRES plasma wave experiment has two high-level relay commands and one 16-bit serial-digital command. The high-level relay commands turn the experiment power on and off. The serial-digital command determines which sensor is connected to which receiver and whether or not the receivers are locked onto a single sensor or cycle through all of the sensors. The sweep frequency receiver and the multichannel spectrum analyzer can each be independently commanded to either have their inputs locked to a single sensor or to cycle through all three sensors. The sweep

Table 2 Sweep frequency receiver noise levels and minimum detectable sine wave-amplitude

	Noise level, V^2/Hz	Minimum detectable sine-wave amplitude, V
Band 1 (100-800 Hz)		
(Bandwidth = 7 Hz)	1.6×10^{-12}	$3.4 \pm 1.1 \times 10^{-6}$
Band 2 (800 Hz to 6.4 kHz)		
(Bandwidth = 56 Hz)	1.4×10^{-14}	$0.9 \pm 0.3 \times 10^{-6}$
Band 3 (6.4-50 Hz)		
(Bandwidth = 448 Hz)	7.2×10^{-15}	$1.8 \pm 0.1 \times 10^{-6}$
Band 4 (50-400 kHz)		
(Bandwidth = 3.6 kHz)	1.2×10^{-15}	$2.1 \pm 0.1 \times 10^{-6}$

frequency receiver when commanded to the cycle mode cycles E-B-E-LANG at a 32 s/sensor rate (E is the WADA long wire antenna, B is the search coil magnetometer, and LANG is the input from the EF/LP experiment SWDA sensor). When commanded to the cycle mode, the multichannel spectrum analyzer cycles B-E-B-LANG at a 4 s/sensor rate.

The CRRES plasma wave experiment has three status words: two analog words, the low-voltage power supply monitor, and the search coil magnetometer temperature, and the serial-digital status word which identifies the antenna selection status for each receiver and the frequency step for the Sweep Frequency Receiver (SFR). The total bit rate for the plasma wave experiment is 970 bits per/s.

Initial Results

CRRES was launched on July 25, 1990, into a geosynchronous transfer orbit with a perigee altitude of 350 km and an apogee 6.3*Re* (Earth radii) geocentric. The inclination was 18.2 deg, the orbital period was 9 h and 52 min, and the initial magnetic local time at apogee was 0800 MLT. The CRRES plasma wave experiment has performed perfectly ever since it was turned on three days after launch. The electric antennas were fully extended in the few weeks after launch. The WADA has a tip-to-tip length of 100 m (for an effective antenna length of 50 m) and the SWDA has a sphere-to-sphere length of 94 m. Following the antenna extensions, the spacecraft was spun down to approximately 2 rpm. The normal mode of operation for the plasma wave experiment after the antenna extensions has been to have the sweep frequency receiver locked onto the WADA antenna and the multichannel analyzer cycling through all three antennas.

Figure 3 shows a plasma wave spectrogram for about a 2-h period on the inbound portion of orbit 143 on September 22, 1990. The spectrogram covers the frequency range from 5.6 Hz to 400 kHz. The data from 5.6–100 Hz are the measurements from the multichannel spectrum analyzer during the portions of its cycling when it is connected to the WADA antenna. The intensity of the waves are gray-scale coded with white being least intense and black being most intense. The dashed line labeled F_{CE} has been added to show the electron cyclotron frequency calculated from the fluxgate magnetometer experiment.[7] The F_{UHR} from which the electron number density can be calculated are clearly visible in the upper right portion of the spectrogram. Much variability in the F_{UHR} line indicates much structure in the plasma density. The time resolution above 6.4 kHz is one spectrum every 8 s, which is four times faster than the ISEE rate.

The plasmapause crossing occurs at about 2225 UT and intense low-frequency (5.6–100 Hz) electric field emissions are observed just at the outer edge. Plasmaspheric hiss (from about 300 Hz to 3 kHz) is evident here only inside the plasmasphere. An ELF hiss band (from about 50–200 Hz) is much more intense in a limited region outside the plasmapause than it is inside. Intense chorus emissions are predominantly outside the plasmapause but a weaker component of them does continue inside the plasmasphere. Outside the plasmapause, electron cyclotron harmonic (ECH) bands are apparent above the chorus and below the F_{UHR} line. The radiation from the F_{UHR} line up to about 70 kHz is trapped nonthermal continuum radiation. Weak auroral kilometric radiation emissions are visible above about 100 kHz outside the plasmapause. The striations apparent in some of the emissions are a result of the beating between the spin rate and the sampling rate. Please note the absence of any significant solar array interference at low frequencies that other spacecraft have experienced. This is due to the CRRES solar array always facing the sun and not being shadowed and to the very low spin rate.

The ability of the CRRES plasma wave experiment to detect a large variety of emissions over a large frequency range and a large dynamic range with high time resolution is clearly evident. In the data we have examined so far, many interesting features have been observed that, when analyzed along with the data from other CRRES instruments, should increase our understanding of the wave-particle interactions and plasma dynamics occurring in the inner magnetosphere.

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