modulo 30 so that details of the field can be shown on a fine scale.

This interval shows the beginning of a magnetic storm. Preliminary *Kp* values change from about 3^+ to 7^- at 0600 UT. A strong compression in the field at 0543 UT indicates a sudden storm commencement and wave activity is observed in the azimuthal *Y* component. Several hours later, major perturbations of the field are observed in all components and there is preliminary information that indicates that these perturbations are associated with observed particle and ion composition changes. These and other summary plots have already enabled the location of many interesting events in the CRRES data such as narrowband and broadband ion cyclotron waves, ULF waves, field line resonances, substorms, sudden impulses, and sudden storm commencements.

Acknowledgments

Many people have generously contributed, over many years, to the success of this experiment. We thank the following: C. T. Russell, R. C. Elphic, R. C. Snare, F. R. George, R. L. McPherron, M. G. Kivelson, M. H. Acuna, T. A. Potemra, D. J. Southwood, B. G. Ledley, W. J. Hughes, E. G. Mullen, N. C. Maynard, W. J. Burke, F. J. Rich, M. Smiddy, D. Moon, K. Kerns, K. Ray, M. Violet, K. Fredholm, R. Hayes, W. D. Dunham, C. R. Upton, C. A. Harris, and O. Palini.

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CRRES Electric Field/Langmuir Probe Instrument

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Introduction

THE CRRES electric field/Langmuir probe instruments consist of a main electronics package on the spacecraft body and two pairs of orthogonal sensors with tip-to-tip separations of about 100 m in the spin plane of the spacecraft. One pair of sensors is spherical probes and the other is cylindrical antennas. The instrument provides measurements of the quasistatic two-dimensional electric field in the spin plane of the spacecraft at a rate of 32 samples/s, a sensitivity of better than 0.1 mV/m, and a dynamic range of 1000 mV/m. The spherical probes can be periodically swept in either current or voltage to determine plasma density and temperature through ground analysis of the resulting Langmuir characteristic curve. The measurement is accurate for densities between 0.1 and 10^4 electrons/cm^3 and electron temperatures ranging from a fraction of an electron volt to 100 eV. The instrument also has a programmable burst memory which can provide selected high-time resolution data at cumulative rates up to 50,000 samples/s.

Scientific Objectives

The CRRES orbit, which extends in altitude from 358 km at perigee to 33,584 km at apogee, will allow extensive measurements, at all local times, throughout the radial extent of the plasmasphere, ring current, and radiation belts of the Earth. The spacecraft will also spend significant periods of time in the near-Earth plasma sheet during magnetically disturbed periods. The instrument will study electric fields associated with the large-scale convection of magnetospheric plasma driven by the solar wind and geotail substorm processes. It will also provide information on electric fields associated with injection of plasma sheet particles into the inner magnetosphere; the wave mode responsible for particle loss through precipitation into the ionosphere; the role of electric fields in radiation belt particle energization; and plasma processes which couple along the magnetic field line to produce acceleration of electrons to form auroral arcs at lower altitudes. This instrument provides measurements during both high- and low-altitude barium and lithium releases.

Comparison to Previous Instruments

A discussion of the physics of electric field probes under the variety of density and temperature regimes offered by space plasmas is presented in Ref. 1. Both spherical and cylindrical double-probe sensors are used on CRRES. Spherical double-probe sensors similar to those on CRRES have been flown at ionospheric altitudes on S3-2[2] and S3-3[3] and in the magnetosphere on ISEE-1[4] and GEOS-1 and -2.[5] The operation of the CRRES probes is similar to that of the ISEE-1 and the GEOS electric field instruments, in that these instruments incorporated current biasing to control probe floating potentials and to minimize the sheath impedance to allow measurements in low-density plasmas. In addition, the CRRES spherical probes have electrostatic guards which can be biased at ground-commanded potentials relative to the spherical probes to control the photoelectron flux to and from the spherical sensors to the guards and the spacecraft. This limits asymmetric charging effects which contributed to several millivolts/meters offsets in the electric field measurements on the ISEE-1 and GEOS spacecraft in low-density plasmas.[5] Unlike the spin axes of previous spacecraft, the axis of CRRES is nearly along the Earth-sun line so the solar illumination of the probes is approximately constant over a spin period. This minimizes variations of the photoemission from the probes as a function of spin angle and reduces the error signals from the booms by an order of magnitude.

Cylindrical sensing elements have been flown on several earlier spacecraft including OGO-6[6] and DE-2[7] in the ionosphere, and ISEE-1[8] in the magnetosphere, where excellent measurements were reported in higher density regions of the orbit. The CRRES cylindrical sensor has an improved

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Received June 7, 1991; revision received Sept. 30, 1991; accepted for publication Oct. 9, 1991. Copyright © 1992 by the American Institute of Aeronautics and Astronautics, Inc. All rights reserved.

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performance at low plasma densities relative to earlier instruments because of the orientation of the spacecraft spin axis and because the cylinders are also current-biased, as is discussed below.

The CRRES instrument is improved over previous instruments in another respect. Advances in the technology of high-density RAM memory have allowed 192 kbytes of burst memory for high time resolution waveform analysis to be incorporated into the present instrument as compared to 256 bytes in the earlier ISEE-1 instrument.

Description of the Instrument

The CRRES elelectric field/Langmuir probe instrument has two different operating modes which are controlled by an onboard microprocessor. In the electric field mode, the sensors are current-biased and measure electric fields by determining the potential difference between opposing sensors. When the instrument is operated in the Langmuir probe mode, the spherical sensors are biased at fixed and stepped potentials relative to the plasma, and the current collected by the spheres is measured. The resulting Langmuir curve provides information on cold electron temperature and density.

The primary components of the spherical and cylindrical probe units are shown in Fig. 1. Inboard and outboard of the spheres are the previously discussed stub and guard sections. The surface of each sensor is connected to a high input impedance unity gain preamplifier (located inside each sphere and at the bases of the cylindrical wire antennas). The preamps have an input impedance $> 10^{11}\ \Omega$, which exceeds the dc source impedance of the plasma by more than two orders of magnitude. The sphere preamplifier bandwidth is about 100 kHz and the dc differential signal dynamic range is ± 100 V. The cylindrical probe preamplifiers have a frequency response from dc to >1 MHz and a dynamic range of ± 35 V. For low-frequency signals, the cylinders couple resistively to the plasma through the outer 10 m of bare wire whereas, for higher frequencies (about 10 Hz), capacitive coupling becomes important and the effective boom length shrinks with increasing frequency to one-half the physical length.

Electric Field Mode (Current Biasing)

As described already, the ability to inject an adjustable bias current from the sensors to the plasma is important for the accurate measurement of electric fields at low plasma densities. The bias current is injected by placing a processor-controlled voltage across the bias resistor (shown in Fig. 1) which is electrically connected to the sensor surface. Both the cylinders and the spheres on CRRES may be current-biased. The accuracy of the electric field experiment can be maximized by determining the impedance as a function of bias current, and by applying to the sensor the bias current that minimizes this impedance. This is done through ground analysis of on-orbit bias current sweeps of the probe. The sheath impedance of the plasma can thereby be reduced by one to four orders of magnitude to a value of about 10 MΩ for either spheres or cylinders. Since the dominant error voltages from the probes may be estimated as the product of the difference between the current flowing to the probes and the sheath impedance, measurement errors in the electric field are reduced by large factors when the sheath impedance is minimized.

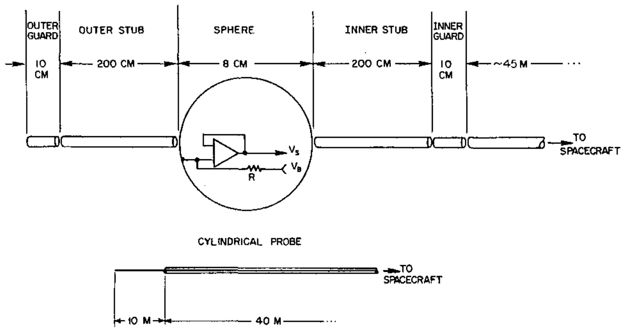

Fig. 1 CRRES spherical and cylindrical probes.

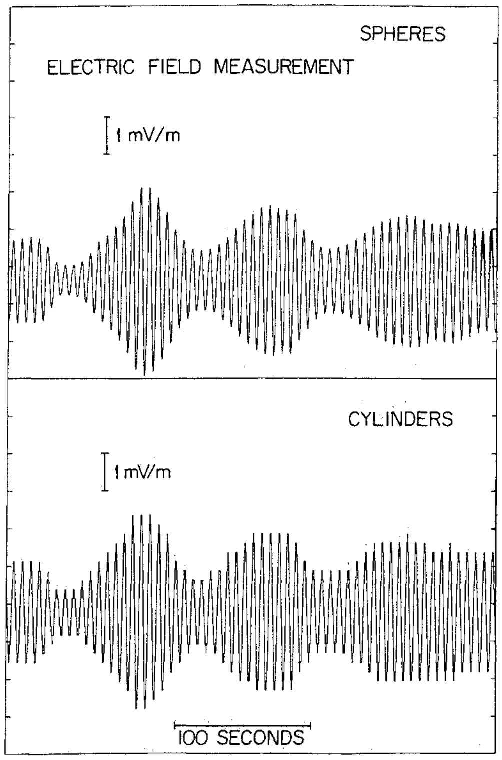

Fig. 2 Comparison of electric field measurements by cylindrical and spherical probes.

The potential differences between each of the four sensors and the spacecraft are also measured and transmitted to provide measurements of the spacecraft potential which responds to plasma thermal electron currents. By adding the spacecraft-probe potential difference measurements from opposing probes, the contribution from the electric field is cancelled, and the spacecraft floating potential $(V_{sc})^{3-5}$ is obtained, providing a measure of the plasma thermal current, $V_{sc} - V_0 \ln [I_e/I_\gamma]$, where I_e is the thermal electron current density from the plasma incident upon the spacecraft, I_γ the saturation photocurrent from the spacecraft due to solar illumination (about 1.5 nA/cm^2), and $-V_0$ the photoelectron e-folding energy (about 1 V). This quantity is useful for detecting plasma boundaries and rapid thermal plasma variations associated with waves.

Figure 2 shows a comparison of the electric field measured by the spherical sensors and the cylindrical antenna at $L = 4$ while the density was about 100 cm^{-3}. This comparison occurs during a slow variation in the large-scale field associated with a magnetic pulsation event with a period of 90 s. The spacecraft rotation during its 6-s spin period results in a sine-wave output signal from the electric field booms. The amplitude of this wave varies with slow changes in the magnitude of the pulsation electric field. The amplitudes measured by the cylinders and spheres agree to within 5%, and the waves are 90 deg out of phase, as expected for orthogonal booms.

To demonstrate instrument sensitivity, Fig. 3 presents a measurement near $L = 4$ of bursts of 10-Hz ion cyclotron waves measured by the spherical sensors. The magnitude of the 10-Hz signal, superimposed on the spin-period sine wave, is less than 50 μV/m, indicating the sensitivity provided by the CRRES instrument design, which is an order of magnitude better than that obtained from previous instruments.

Langmuir Probe Mode (Voltage Biasing)

In the Langmuir probe mode of operation, the spheres are biased at controlled voltages and the collected currents are

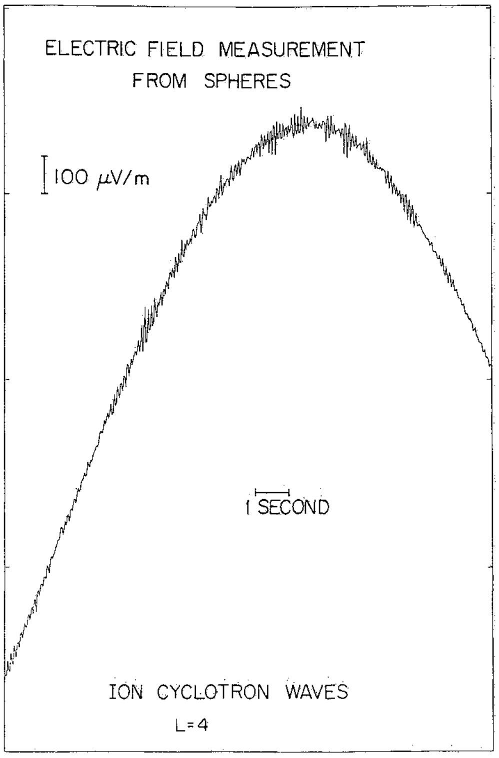

Fig. 3 Electric field measurements from spherical probes of small-amplitude (50-μV/m), 10-Hz ion cyclotron waves.

measured. The voltages may either be held constant to provide measurements of current fluctuations, or be stepped to produce the characteristic Langmuir curve. Langmuir curves and thermal current measurements are obtained simultaneously from opposing sensors to allow elimination of the electric field as a differential contaminant to the common mode signal. Langmuir curves are obtained every 2 min and are analyzed on the ground to provide measurements of density ranging from 0.1 to 10,000 cm^{-3}, and of energies ranging from a fraction of an electron volt to 100 eV. Measurements taken while the probes are biased at fixed voltages are used for studying rapid thermal current fluctuations associated with electrostatic plasma structures propagating past the spacecraft.

Analog Electronics

The potential differences on each axis which determine the electric fields, the outputs of bandpass filter banks, the potentials of each sensor, data from the three-component measurement of the fluxgate magnetometer,[9] and high-frequency measurements from the search coil magnetometer[10] are fed through a network of programmable and fixed antialiasing filters and into the telemetry and burst multiplexors. The electric field signals for the main telemetry are sampled at 32 samples/s and filtered at 10 Hz with two-pole fixed filters. The fluxgate magnetometer is sampled at 16 samples/s and filtered at 6 Hz.[11] The electric, magnetic, and search coil signals are filtered for burst telemetry using four-pole programmable filters set at the Nyquist frequency. Each multiplexor has a dedicated 12-bit analog-digital (A-D) converter. For signals that fall below an amplitude threshold, a gain multiplication of 50 is automatically imposed on the signal. Lists of digitizable quantities, for both the main and burst telemetries, are given in Table 1. The electric field/Langmuir probe instrument provides electric field measurements in an analog form to the low energy plasma analyzer (AFGL 701-6) for onboard correlation with particle measurements, and also shares the electric field booms with the passive plasma sounder (AFGL 701-15).[10]

Microprocessor Control

The electric field/Langmuir probe instrument has two microprocessors. One microprocessor is responsible for telemetry formatting, command reception and execution, sensing burst conditions, boom deployment, current and voltage sweeps, gain decisions, and other control functions. The second microprocessor controls the burst memory. Both microprocessors contain sufficient RAM memory to allow for substantial ground reprogramming.

The data rate, the length of time required to fill the memory, and the sequence of quantities fed into the memory are controlled by ground command uplinked to the burst processor. A separate 12-bit A-D converter is used for burst data collection. Any subset of the 16 quantities defined in the burst section of Table 1 may be sampled at cumulative rates up to 50,000 quantities/s and recorded in the burst memory. A typical example of high time resolution electric and magnetic field data sampled at 1000 samples/s through the burst memory is provided in Fig. 4. In this case, the duration of the recordings is 1 s, and the recording is played back every 3 min. The strong correlation between the electric and magnetic field components indicates the wave is an electromagnetic whistler propagating with a phase velocity of about 15,000 km/s along the ambient magnetic field direction. The top panel provides an indicator of the plasma thermal fluctuations through measurement of variations in spacecraft potential. Note that using the expression for spacecraft potential, we have $\delta V_{sc}/V_0=\delta I_e/I_e$ for small perturbations. This panel shows that the whistler pulses are imbedded in 20% decreases in the thermal plasma current density. These plasma thermal current variations are probably due to previously unresolved small-scale density variations.

Table 1 Telemetry quantities

Main		
1) Electric field (V_{12}, V_{34})	2 components	10 Hz
2) Spacecraft potential (V_1, V_2, V_3, V_4)	4 probes	1 Hz
3) Wide band filters (BP1, BP2, BP3)	Center frequency 32, 256, 2048 Hz	1-2 samples/s
4) Fluxgate magnetometer (Bx, By, Bz)	3 components	6 Hz
5) Langmuir sweeps (I_1, I_2)	Density and temperature	1 sweep/3 min
6) Thermal current fluctuations (I_1, I_2)	Alternate with sphere E-field	8 Hz
Burst (maximum total rate: 50 k samples/s)		
1) Electric field (V_{12}, V_{34})	2 components	12 kHz max
2) Spacecraft potential or thermal fluctuations (V_1, V_2, V_3, V_4)	4 probes	6 kHz max
3) Iowa search coil (SC)	1 component	300 Hz to 10 kHz
4) Fluxgate magnetometer (Bx, By, Bz)	3 components	64 Hz max
5) Thermal current fluctuations (I_1, I_2)	4 probes	12 kHz max

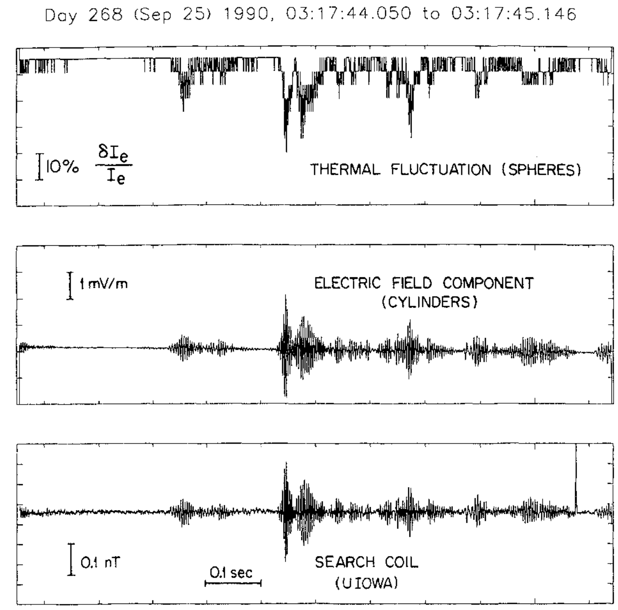

Fig. 4 High time resolution measurement from burst memory of a modulated whistler wave.

Acknowledgments

This instrument was designed, fabricated, and tested under Air Force Geophysics Laboratory Contract F19628-87-K-0016. The authors would like to acknowledge the engineering efforts of E. Bielecki, the programming efforts of J. Vernetti and J. Caron, and the copyediting efforts of M. Currie. We would also like to thank W. Burke, M. Kelly, and R. Torbert for contributions to the early phases of instrument design. The fabrication of the main instrument box and the power supply took place at the Analytyx Corporation through the efforts of K. Fredholm and R. Hayes.

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NRL-701 LASSII/QIMS Quadrupole Ion Mass Spectrometer on CRRES

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THE quadrupole ion mass spectrometer (QIMS) on the CRRES is one of the three instruments that make up the low altitude satellite studies of ionospheric irregularities (LASSII) investigation. Along with the other LASSII instruments, the goals of QIMS are to investigate the dynamics of naturally occurring irregularities in the equatorial ionosphere (e.g., spread-F plumes) and to diagnose the low altitude chemical releases from the CRRES satellite.

QIMS measures the identities and relative concentrations of ionospheric positive ions, both ambient and those produced by photoionization of the released chemicals. The mass spectrometer is designed to be sensitive to thermal ions in the stationary ionosphere and to the ions formed following chemical releases. These ions have energies in the range of 0–100 eV in the instrument's frame of reference. This is a very different operation regime than the other ion mass spectrometers onboard CRRES. For example, the ONR-307-3 low energy ion mass spectrometer measures the fluxes of radiation belt ions in the energy range of 500 keV to 100 MeV.

The design of the QIMS mass spectrometer was adapted from similar instruments that have been flown successfully on many sounding rockets.[1-3] QIMS consists of a sensor and an electronics box. The sensor, shown in Fig. 1, incorporates a circular, motor-driven cover that maintains a high vacuum in the instrument during ground testing and is opened by command once the satellite is in orbit. Immediately underneath the cover is the aperture plate that is biased at -10 V to draw ions into the instrument, and the quadrupole rods, which run down the axis of the cylindrical front part of the sensor. The electron multiplier, the high voltage power supply, the radio frequency (rf) amplifier, and the logarithmic current amplifier for the aperture plate are contained in the back half of the sensor package. The electronics box contains the low voltage power supplies, programming circuitry, pulse counter, and command and telemetry systems. The sensor is 14 in. long, the electronics box is a 6-in. cube, and the weight of the instrument is 28 lb.

The mass range of the spectrometer is 4–155 amu. All ambient ions (with the exception of H^+) and all ions derived from the chemical releases fall into this range. The resolution of the instrument was adjusted to give the mass peaks a full width at half-maximum of ~ 2 amu across the entire mass range. This is sufficient resolution to separate the two O^+ isotopes at masses 16 and 18, to separate the ambient molecular ions at masses 28, 30, and 32, and to differentiate between all of the metal ions (Li^+, Sr^+, Ca^+, Ba^+, and Eu^+) derived from the chemical releases. Because the total ion density is measured by the aperture plate and the LASSII P^3 Langmuir

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Received June 6, 1991; revision received March 21, 1992; accepted for publication March 22, 1992.

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