Fluxgate Magnetometer Instrument on the CRRES

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Introduction and Scientific Objectives

A PRIMARY objective of the CRRES mission is to examine the effects of the radiation belt environment on a variety of microelectronic components by making comprehensive and simultaneous environmental measurements. Other objectives include new static and dynamic models and descriptions of processes in the radiation belts. These objectives require knowledge of the Earth's magnetic field, and its variations, which are important for the study of all space plasma processes, including control of the source, loss, and energization of radiation belt particles. The fluxgate magnetometer makes the magnetic field measurements that are required to satisfy these major mission objectives.

CRRES was launched on July 25, 1990, at 1921 UT. In the initial CRRES orbit (period = 9 h 52 min, inclination = 18.2 deg, perigee = 350 km, apogee = $6.3R_e$, and initial magnetic local time of apogee = 8 MLT), the magnetometer must have a large dynamic range to measure magnetic fields from fractions of a nanotesla to about 45,000 nT (1 nT = 10^{-9} T). These measurements will be used 1) together with the look angles of the particle experiments to obtain the pitch angle of the measured particles; 2) as a diagnostic of global and local geomagnetic disturbances and current systems; 3) as a diagnostic of low-frequency waves in the ambient environment and to study wave-particle interactions; 4) to provide plasma gyrofrequencies; 5) to measure $v \times B$ electric fields; 6) to support chemical release activities; and 7) to provide a secondary source of spacecraft attitude information.

Instrument Operation

The CRRES triaxial fluxgate magnetometer sensors and analog electronics (model SAM-63B-15) were developed and built by Schonstedt Instrument Company in Reston, Virginia. The sensors are mounted in a single housing on a rigid Astromast boom built by Astro Aerospace in Carpinteria, California. The 6.1-m boom locates the sensors ~7.5 m from the center of the spacecraft to fulfill the requirement of having less than a few nanotesla of residual vehicle-generated magnetic field at the sensor location. The analog electronics to operate the sensors are mounted inside the spacecraft and connected to the Langmuir probe/electric field (LP/EF)[1,2] experiment for power, signal processing, and telemetry formatting. Table 1 lists the instrument characteristics.

Table 1 Instrument characteristics

Dynamic range	± 45,000 nT in low gain ~ ± 850 nT in high gain
Quantization	12-bit A/D converter
Quantization noise level	2×10^{-3} nT^2/Hz in high gain
Resolution	22.0 nT in low gain 0.4 nT in high gain
Range select (microprocessor controlled)	High-gain mode: 16 samples/1.024 s of high-gain data 2 samples/1.024 s of low-gain data Low-gain mode: 16 samples/1.024 s of low-gain data 2 samples/1.024 s of low-gain data
Data rate	704 bits/s
Sensor orthogonality	0.02 deg
Sensor mount	6.1 m Astromast boom

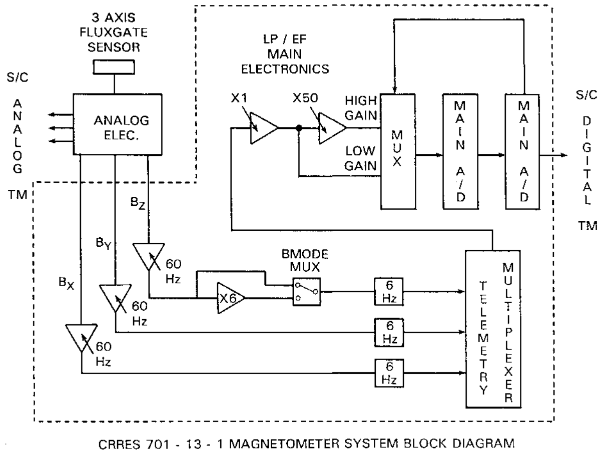

Fig. 1 Fluxgate magnetometer system block diagram.

The magnetometer system block diagram is shown in Fig. 1. Inside the LP/EF experiment, the analog sensor signals are filtered successively by 60- and 6-Hz low-pass filters. The purpose of the 6-Hz filter is to prevent aliasing from signals above the 8-Hz Nyquist frequency. After the filters, the telemetry multiplexer samples and separates each sensor analog signal into a low-gain, unamplified signal and a high-gain signal that is amplified by a factor of about 50. The analog signals are then examined by an onboard microprocessor to determine which gain range to use. If it is determined that the high-gain signal will not saturate the A/D converter, it is sampled and entered into the telemetry stream; otherwise, the low-gain sample is taken. The criterion that is used for switching between high and low gain can be modified on-orbit by uploading new commands to the LP/EF microprocessor.

On command, the signal from the near spin axis, Y magnetometer sensor, can be amplified six times, in either the high-gain or low-gain mode, to provide better amplitude resolution at low field strengths near apogee. The increased sensitivity will facilitate the detection of high-frequency, low-amplitude waves, such as ion-cyclotron waves that interact strongly with the plasma environment.

A set of X, Y, and Z sensor signals are sampled by a 12-bit A/D converter at 16 times/1.024 s. The X, Y, and Z samples in each set are simultaneous to ~ 150 μs. Each data value has a one-bit gain indicator to specify if that sample is either high or low gain and a one-bit mode indicator to specify whether or not the Y magnetometer sensor has been amplified by the additional factor of 6. In addition, twice per second, the low-gain data value is included in the data stream to provide

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the opportunity for utilizing low-gain samples over the entire orbit and to intercalibrate low-gain and high-gain signals. The magnetometer data can also be sampled in a burst mode as described in the LP/EF instrument description.

The low-gain data covers the range approximately $\pm 45,000$ nT and high gain approximately ± 850 nT. Therefore, with a 12-bit A/D converter, the least-significant bit resolution is about 0.43 nT in high gain and 22 nT in low gain. During a typical CRRES orbit, all three magnetometer sensors will be taking data in the high sensitivity range about 75% of the time, i.e. when the satellite is beyond about $3.5R_e$. The quantization noise level in high sensitivity is $\sim 2 \times 10^{-3}$ nT^2/Hz. When the Y sensor is in its ($\times 6$) amplified mode, the least-significant bit resolution on that sensor is 0.07 nT in high gain and 3.3 nT in low gain.

Independent of the magnetometer LP/EF operational modes that have just been described, the sensor analog signals are provided directly to the spacecraft through 20-Hz cutoff low-pass filters in two ranges, $\pm 45,000$ nT and ± 1000 nT. These signals are then digitized by the spacecraft 8-bit A/D and entered into the telemetry stream. In the $\pm 45,000$ nT range, the sensitivity is ~ 350 nT/digital step and the data are sampled once per 4.096 s. In the ± 1000 nT range, the sensitivity is ~ 7.8 nT/digital step and the data are sampled once per 1.024s. In the event of a failure in the LP/EF experiment, a backup power supply will keep this operational mode of the magnetometer alive.

A unique feature of the magnetometer is that it provides a real-time signal to the low energy plasma analyzer experiment (LEPA)[3] to enable that instrument to determine which zone in the field of view of its detectors is observing nearly along the magnetic field direction. LEPA is then able to transmit high time-resolution data, a complete energy spectrum in 1/2 s, with about 1 deg pitch-angle resolution from the zone that is making observations near or within the particle loss cone.

Instrument Location and Coordinate System

Figure 2 shows the location of the magnetometer sensor package and the University of Iowa/Air Force Geophysics Laboratory single axis searchcoil magnetometer sensor.[4] The two detectors are mounted on opposite ends of a T-bar at the end of the Astromast boom. The magnetometer boom deployed to within a few inches of its full length, but the T-bar with the two magnetometer instruments is rotated ~ 15 deg about the y spacecraft axis from its intended orientation (dashed line indicates the planned orientation and solid line the actual orientation). The searchcoil and fluxgate instruments are separated by about 1 m on the T-bar. The purpose of the 2.5-deg rotation, shown in the side view in Fig. 2, was so that the near spin-axis sensor would have a component in the spin plane. This orientation provides a method for relating the gains of each sensor to a single sensor by measuring ratios

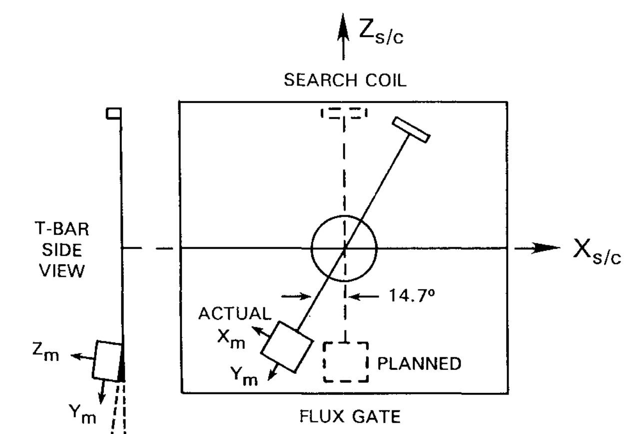

Fig. 2 Astromast boom and magnetometer sensor orientation in the approximate deployed position. (Dimensions are not to scale.)

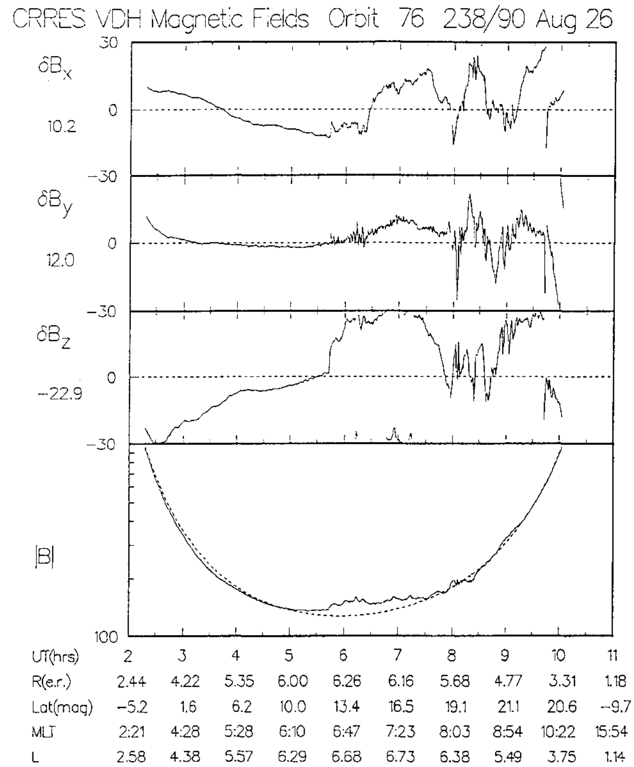

Fig. 3 Magnetometer summary plot for orbit 76, August 26, 1990.

of the sine-wave signals from each sensor on the rotating spacecraft.

Calibration, Testing, and Initial Operations

Initial calibrations of the instrument, including sensor orthogonaltiy, linearity, gain, and noise levels were performed at the Schonstedt Instrument Company in Reston, Virginia. Final calibrations of instrument offsets, gains, and linearity were performed at the Goddard Space Flight Center Magnetic Test Facility in Greenbelt, Maryland. The ground-based calibrations showed that the instrument is linear to about 1 part in 2^{12} and the temperature dependence of the instrument offsets in high gain mode is less than 0.2 nT/°C.

The CRRES spacecraft dc magnetic field was not measured; however, the magnetic moment of each instrument and spacecraft package was measured and magnetic compensation was used if any package had a moment greater than 100 G-cm^3. During testing, it was discovered that a few nanotesla offset would be observed in space during the operation of the power amplifier for the spacecraft transmitter. Other than this effect, which has now been observed on-orbit, it does not appear that the spacecraft has a large enough dc moment to be observed by the magnetometer at the end of the boom.

Figure 3 shows an example of the CRRES magnetometer data. It is a summary plot for orbit 76, August 26, 1990. One-minute averaged data are shown during the interval that the magnetometer is in high gain (about 8 h out of the 9 h 55 min CRRES orbit.) The field is shown in VDH coordinates where Z is antiparallel to the magnetic dipole axis, X is radially outward in the magnetic equatorial plane, and Y is eastward completing the orthogonal right-handed coordinate system. In the bottom panel, the dashed line indicates the total magnetic field from the Olson-Pfitzer 1977 model. The solid line shows the magnitude of the observed field. The log scale begins at 100 nT at the bottom of the plot. The CRRES apogee is near the middle of the plot and these observations are near dawn local time. The top three panels show the difference between the observed field and the Olson-Pfitzer model field in VDH coordinates. The scale is in nanotesla and the value in the left margin indicates the value of the first point plotted. If the data amplitude excedes the plot scale limits, the data wraps 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.

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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