The ISEE-C Plasma Wave Investigation

F. L. SCARF, R. W. FREDRICKS, D. A. GURNETT, AND E. J. SMITH

***Abstract*—The ISEE-C plasma wave investigation is designed to provide comprehensive information on interplanetary wave-particle interactions. Three spectrum analyzers with a total of 19 bandpass channels cover the frequency range 0.3 Hz to 100 kHz. The main analyzer, which uses 16 continuously active amplifiers, gives two complete spectral scans per second in each of 16 filter channels. The instrument sensors include a high-sensitivity magnetic search coil, and electric antennas with effective lengths of 0.6 and 45 m.**

INTRODUCTION

THE ISEE-C plasma wave instrument will provide high-sensitivity measurements of interplanetary wave phenomena over the spectral range extending from below 1 Hz to 100 kHz. The wave electric-field and magnetic-field components are detected using a long body-mounted electric dipole (90 m, tip-to-tip), a short boom-mounted electric dipole (0.6 m, effective length), and a high-sensitivity magnetic search coil. The signal processing units in the plasma wave electronics box and in the dc magnetometer utilize three distinct spectrum analyzers that cover a total of 19 different frequency channels with varying time resolution. The main analyzer, with 16 continuously active channels, provides two complete spectral scans per second.

The primary scientific objectives of the ISEE-C plasma wave investigation can be summarized as follows:

1) to determine the roles that plasma waves play at interplanetary discontinuities and at stream-stream interaction fronts. Some wave energy must propagate away from the discontinuity, and this provides a nonlocal wave-particle interaction mechanism.

2) to analyze the basic interplanetary instabilities associated with thermal anisotropy and heat conduction that cause the solar wind to behave as an effective fluid even when the mean free path becomes large near 1 AU.

3) to study the energy loss and wave-wave conversion mechanisms for suprathermal electrons and protons by correlating particle distribution data with wave measurements. This study will involve effects associated with solar-radio bursts.

4) to determine the effective transport coefficients (heat conductivity, electrical conductivity, viscosity) associated with wave-particle scattering in the solar wind.

5) to search for local wave-particle acceleration processes in the solar wind.

We will also try to evaluate local plasma parameters by analyzing plasma wave data, search for interplanetary whistler-mode signals that should develop whenever $(T_\perp/T_\parallel)_e$ exceeds unity, and study the dynamical energy dissipation processes that can cause large amplitude MHD waves in the solar wind to steepen into collisionless shocks.

INSTRUMENT CHARACTERISTICS

The basic elements of the ISEE-C plasma wave instrument are shown in Fig. 1. The line drawing in the center depicts the spacecraft with all booms and antennas deployed. The 90-m, tip-to-tip, balanced dipole antenna along the U-axis has been designated as the primary long electric-field sensor for the plasma wave instrument, and the V-axis dipole antenna is the primary in-ecliptic sensor for the radio-astronomy investigation. However, these two wave instruments have been designed with a capability to operate together using

Manuscript received April 3, 1978.

F. L. Scarf and R. W. Fredricks are with TRW Defense and Space Systems Group, Redondo Beach, CA 90278.
D. A. Gurnett is with the Department of Physics and Astronomy, University of Iowa, Iowa City, IA 52242.
E. J. Smith is with Jet Propulsion Laboratory, Pasadena, CA 91103.

0018-9413/78/0700-0191$00.75 © 1978 IEEE

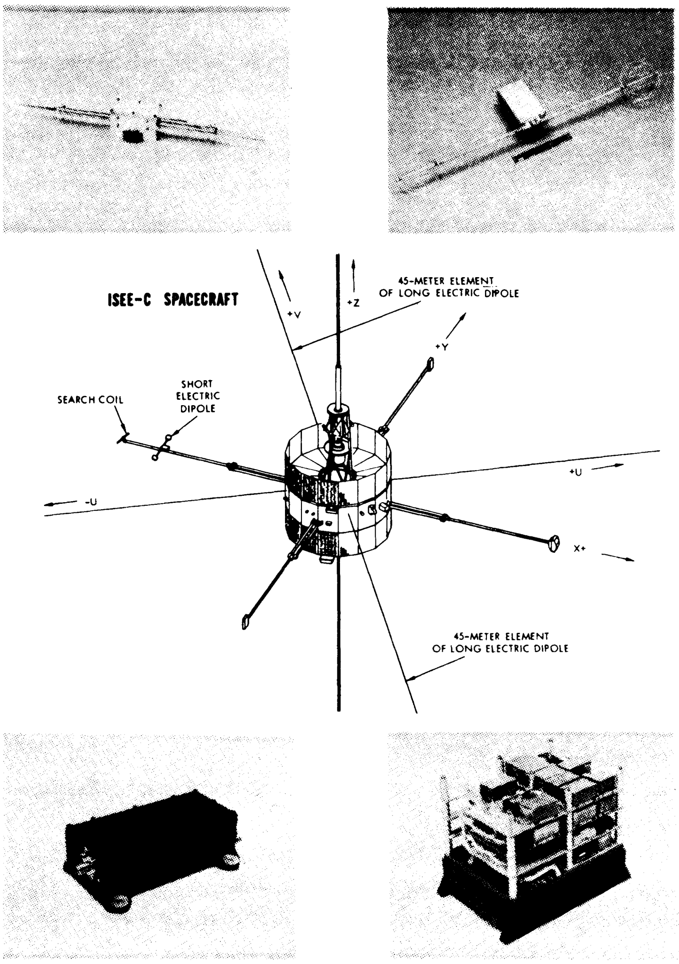


Fig. 1. Top: The magnetic search coil (left) and the short electric antenna (right). Center: Drawing of ISEE-C with all booms and antennas deployed. Bottom: One of the four identical unity gain preamplifiers used with the long wire antennas (left), and the main electronics unit (right).

TABLE I
ISEE-C PLASMA WAVE INSTRUMENT CHARACTERISTICS

Sensors:

Long electric dipole (90 meters, tip-to-tip); the U-axis antennas are assigned to the plasma wave investigation, but the radio astronomy (STH) and plasma wave (SCH) groups can share the U-or V-axis systems, if necessary.

Short electric antenna (0.6 meter effective length), on the minus X-axis hard boom.

Search coil, on the minus X-axis hard boom.

Electronics:

Sixteen-channel spectrum analyzer, 17 Hz to 100 kHz: 16 filters, 16 AGC amplifiers, 2 scans per second [E(long) or E(short) or B].

Eight-channel spectrum analyzer, 17 Hz to 1 kHz: 8 filters, one AGC amplifier, 1 scan per 16 seconds [E(short) or B].

Three-channel spectrum analyzer, 0.316 Hz to 8.8 Hz: using SMH electronics, 1 scan per 32 seconds [B only].

Mass:

Short Electric:	0.25 kg
Search Coil:	0.3 kg
Unity Gain Preamps:	0.09 kg (x4)
Main Electronics:	2.64 kg
Subtotal	3.55 kg

[Each motor-driven antenna element: 2.4 kg (x2)]

Power: 3.8 Watts

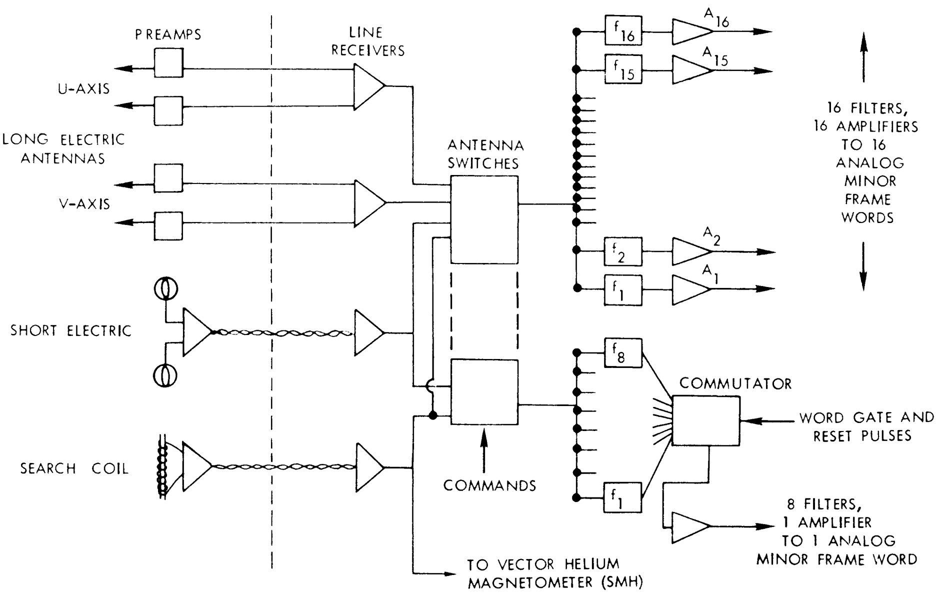
the V-axis or the U-axis dipoles in case one or more of the four individual 45-m wire antenna elements fails to deploy properly. This redundancy was achieved by designing separate radio-astronomy and plasma wave preamplifiers that can operate together on any individual antenna element. A set of these preamplifier pairs is mounted near the base of each 45-m antenna/motor unit. The photograph in the lower left shows one of the four long electric unity gain plasma wave preamplifiers, each of which is basically identical to the units built by the University of Iowa for operation on ISEE-A and ISEE-B [1]. The two additional sensors are the magnetic search coil (upper left) and the short electric antenna (upper right), which are mounted together on the 3-m minus-X boom, as indicated in the central drawing. A photograph of the main electronics unit for the plasma wave instrument is shown in the lower right, and the instrument specifications are in Table I.

Fig. 2 contains a simplified block diagram of the ISEE-C plasma wave instrument. The signals from the wave sensors are processed using three spectrum analyzers. The main 16-channel analyzer covers the range 17 Hz to 100 kHz with a separate continuously active automatic gain control (AGC) amplifier following each of the 16 bandpass filters. This spectrum analyzer provides essentially continuous information since the time between samples (500 ms) is comparable to the mean settling time of each AGC amplifier, and switching transients are absent. The 16-channel spectrum analyzer can be used with any of the wave sensors (long U, long V, short electric, or search coil).

The 8-channel analyzer covers the range 17 Hz to 1 kHz with a set of filters that correspond to the lower frequency ones in the main analyzer, but this secondary analyzer utilizes a single AGC amplifier. The commutator switches the amplifier from one frequency channel to another after every four measurements (covering 2 s) and the entire 8-channel scan is repeated every 16 s. This second spectrum analyzer is designed to be used with the magnetic search coil or the short electric antenna.

The third spectrum analyzer, which covers the range below 17 Hz, is located within the electronics unit of the Vector Helium Magnetometer [6]. A cable from the plasma wave instrument brings the output of the magnetic search coil to the SMH box, and the low-frequency spectrum is analyzed once per 32 s using three relatively broad filters that cover the range 0.316–8.8 Hz. The lowest of these channels is centered about the nominal ISEE-C spin frequency, and since the search coil is mounted at an angle to the boom, the 0.316-Hz output will provide a low-resolution backup measurement of the dc magnetic-field component in the plane perpendicular to the spacecraft spin axis.

The ISEE-C spectral coverage for plasma waves is summarized in the left-hand part of Fig. 3. This panel compares the response curves for the 15-percent bandwidth filters used in the two high-frequency analyzers with the spectral responses of the three wave channels in the Vector Helium Magnetometer unit. It can be seen that the full instrument will measure many aspects of E and B fluctuations over the complete range extending from 0.3 Hz to 100 kHz, although the ability of the instrument to perform highly comprehensive measurements does vary over this range. From 17 Hz to 1 kHz the capability is optimum since the 8 continuously active channels can be used to measure characteristics of short- or long-



ISEE-C PLASMA WAVE INSTRUMENT (SCH)

Fig. 2. Block diagram.

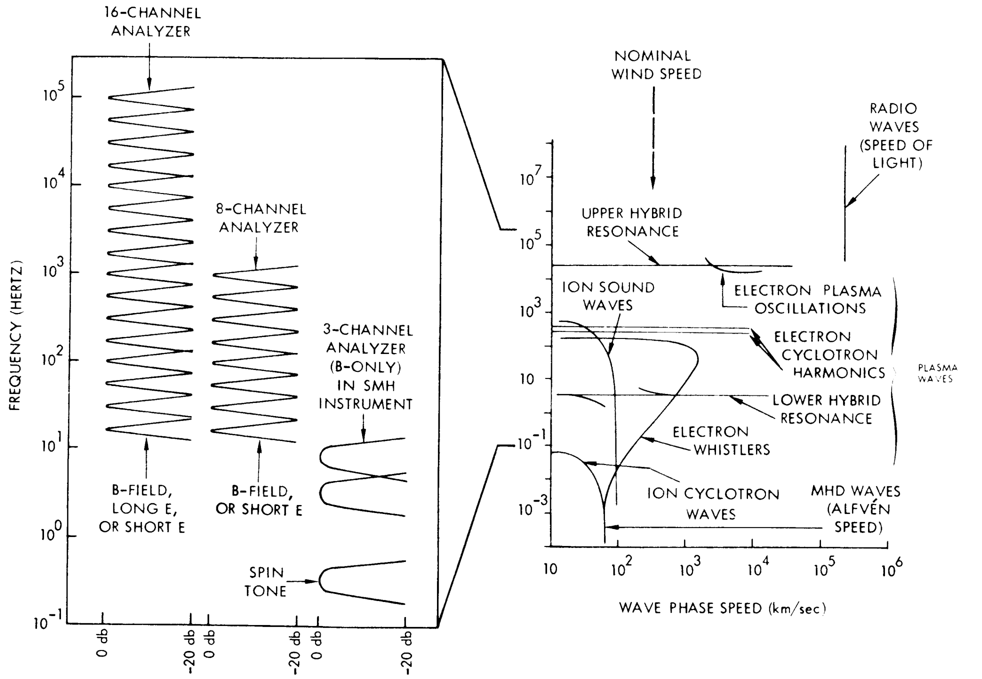


Fig. 3. Left: Filter response curves for the ISEE-C plasma wave investigation. Right: Some characteristic phase speed versus frequency plots for typical interplanetary conditions (B = 5 gamma, N = 5 protons/cm^3).

wavelength electric fields or magnetic fluctuations, while the second spectrum analyzer can be used to compare E and B measurements, or to compare long- and short-wavelength E-field observations. For the 8 continuously active channels covering the range 1.7 kHz to 100 kHz, there is still considerable flexibility, but the capability to compare outputs from various wave sensors is absent here.

The right-hand side of Fig. 3 contains frequency versus phase speed plots for many characteristic interplanetary wave modes (assuming $B = 5$ gamma, $N = S$ protons/cm^3). For a nominal solar wind speed near 400 km/s, it can be seen that many of the lower frequency modes have V(phase) $<$ V(wind), and hence Doppler shifts will have to be accounted for in the analysis of data obtained from the ISEE-C observing platform. However, in a very general sense, Fig. 3 does show that the ISEE-C plasma wave instrument will provide excellent coverage for all important local wave modes above the ion cyclotron frequency. Since electromagnetic ion cyclotron oscillations will be detectable in the magnetometer data, the full ISEE-C payload should provide valuable information for many new studies involving interplanetary wave-particle interaction phenomena.

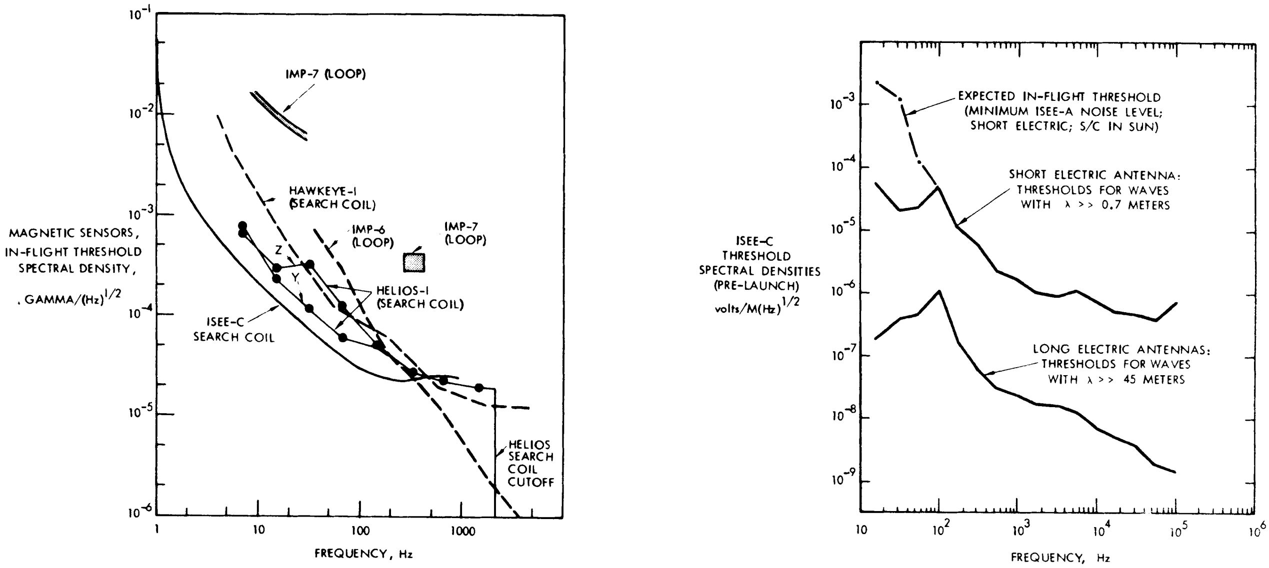


Fig. 4. Anticipated threshold sensitivities of the ISEE-C plasma wave investigation.

Sensor Characteristics and Anticipated Sensitivities

The Search Coil

The ISEE-C search coil is a high sensitivity version of the magnetic sensor designed for ISEE-A, -B [1]. The flux concentrating core, made of high permeability nickle-iron alloy, is 39.4 cm in length, with a square cross section (0.48 cm on a side). The coil has 80 000 turns of AWG 47 wire and the effective loop area is 2100 m^2 for signals below 500 Hz. The entire unit is 40.6 cm long, the coil constant is 13 μV/gamma/Hz, and the rolloff above 500 Hz is approximately 6 dB per octave.

The anticipated in-flight sensitivity of the ISEE-C search coil is plotted as a function of frequency in the left side of Fig. 4. The other curves shown here are adapted from a drawing in a recent report by Neubauer *et al.* [3]. The comparisons indicate that the ISEE-C search coil will be at least as sensitive as any magnetic sensor flown previously, and if the spacecraft noise levels are sufficiently low, the ISEE-C instrument will be able to detect very low wave levels with the magnetic sensor.

Short Electric Antenna

The short electric antenna is designed to provide well-defined measurements of signal amplitudes for modes, such as ion acoustic oscillations, which can have very short wavelengths. The minimum wavelength is nominally taken to be $2\pi\lambda_D$ where λ_D [$= (\kappa T/4\pi Ne^2)^{1/2}$] is the Debye length, but this cutoff is not well defined and in principle, waves with $\lambda < (2\pi\lambda_D)$ can also be generated; in fact, Scarf [5] presented evidence that waves with $\lambda \simeq (2\pi\lambda_D)/2$ were detected by the IMP-7 plasma wave instrument at the September 15, 1974 interplanetary shock, when λ_D was approximately 6 m. Since small values of λ_D are commonly expected near interplanetary stream interfaces and shocks, an E-field sensor with l(eff) = effective length $\ll \lambda$(min) is used to provide comprehensive coverage.

The ISEE A-, B-, C-short electric antennas are physically similar to the IMP-7 E-field sensor [4], but several electrical and mechanical changes have been incorporated for ISEE. The most important of these improvements involve: a) the use of low-noise, high-impedance field-effect transistors in the input circuits; b) the use of an input capacitive voltage divider that greatly reduces the effect of any sheath fluctuation on the sensor response; c) the use of grounded metallic tape wrap around each fiberglass antenna stem, to satisfy the ISEE electrostatic cleanliness specification.

The short electric antenna has an effective length of 0.61 m, and the intrinsic sensitivity is given by the solid upper curve on the right side of Fig. 4. Early post-launch data from ISEE-A, -B indicate that low-frequency spacecraft-associated noise is always detected on the electric antennas except when each ISEE is in the earth's shadow. This noise is most likely to be coupled to the plasma through the current systems that flow in the illuminated solar panels, and we expect similar low-frequency spacecraft interference to be present on ISEE-C. Thus the actual in-flight threshold will probably be elevated at low frequencies as given by the dashed line, which is based on actual ISEE-A measurements in the quiet solar wind. On the basis of achievable thresholds from previous interplanetary missions that used solar-panel spacecraft, these in-flight interference levels are not at all unexpected. For instance, on Helios-2, with an antenna-effective length of 16 m, the 30-Hz in-flight threshold was near 2×10^{-4} V/m(Hz)$^{1/2}$. The ISEE-A minimum level at 30 Hz is a factor of 10 higher than the Helios-2 level, as would be expected if comparable voltage ripples were present, and we therefore anticipate that the ISEE-C noise environment will also be roughly comparable (in voltage ripple) to that found on Helios.

Long Electric Antenna

The long electric antenna is designed to provide optimum E-field sensitivity for the long-wavelength electromagnetic modes (solar radio bursts, whistler-mode signals, etc.). The ISEE-C sensors are shorter versions of the wire antennas provided for the direct-current electric-field investigation on ISEE-A [2].

The lower solid curve on the right side of Fig. 4 shows the intrinsic sensitivity of the ISEE-C instrument, using the large electric antennas. This assumes that no solar array noise effects are present and that the waves have $\lambda >> 45$ m. In fact, the early ISEE-A measurements indicate that some finite solar panel noise is also detected on the long electric antennas, although the voltage interference effect is less significant because the antenna length is so much longer. Moreover, it appears that for the long antennas on ISEE-A, the noise rolls off more rapidly with frequency than for the short antennas. Since we do not yet know how to scale these effects as functions of varying antenna length, we do not show an anticipated spacecraft noise effect in connection with the long electric antenna curve of Fig. 4; it is likely that the effect will be small, in comparison with the in-flight noise enhancement shown on the upper curve.

Acknowledgment

P. Virobik, the TRW Project Manager for the ISEE-C Plasma Wave Instrument, was the leader of a large effort involving a number of cooperating institutions. The authors are very grateful for his dedicated efforts and they especially thank J. Atkinson, E. Vrem, and I. Green (all of TRW), D. Odem and R. Shaw (of the University of Iowa), and A. Frandsen and J. van Amersfoort (of JPL) for their invaluable assistance with the design, fabrication, integration, and pre-launch data reduction tasks. They are indebted to S. Mosier of Goddard Space Flight Center for representing their interests with the wire antenna design, procurement, and integration. They are also very grateful for the outstanding support and continuing cooperation of the many members of the ISEE Project Staff, and their associates at Fairchild Space and Electronics Company.

References

[1] D. A. Gurnett, *et al.*, *IEEE Trans. Geosci. Electron.*, this issue, pp. 225-230.

[2] J. P. Heppner, *et al.*, *IEEE Trans. Geosci. Electron.*, this issue, pp. 253-257.

[3] F. M. Neubauer, G. Musmann, and G. Dehmel, "Fast magnetic fluctuations in the solar wind," *J. Geophys. Res.*, vol. 82, p. 3201, 1977.

[4] F. L. Scarf, R. W. Fredricks, I. M. Green, and G. M. Crook, "Observations of interplanetary plasma waves, spacecraft noise, and sheath phenomena on IMP-7," *J. Geophys. Res.*, vol. 79, p. 73, 1974.

[5] F. L. Scarf, "Wave-particle interaction phenomena associated with shocks in the solar wind," in *Proc. of the DeFeiter Symp. on Study of Traveling Int. Phenom.*, Noordwijk, The Netherlands: Reidel Publishing Company, pp. 259-275, 1977.

[6] D. A. Gurnett, *et al.*, *IEEE Trans. Geosci. Electron.*, this issue, pp. 225-230.