The University of Iowa HELIOS Solar Wind Plasma Wave Experiment (E 5a)

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This document describes the University of Iowa solar wind plasma wave experiment for the HELIOS missions (Experiment 5a). The objective of this experiment is the investigation of naturally occurring plasma instabilities and electromagnetic waves in the solar wind. To carry out this investigation, the experiment consists primarily of a 16-channel spectrum analyzer connected to the electric field antennas. The spectrum analyzer covers the frequency range from 20 Hz to 200 kHz and has an amplitude dynamic range which extends from · 3 μV/m to 30 mV/m per channel. This spectrum analyzer, the antenna potential measurements, the shock alarm system and the supporting electronics are discussed in detail.

Dieser Bericht beschreibt das Solarwind-Plasmawellen-Experiment der Universität Iowa für die HELIOS-Mission (Experiment 5a). Aufgabe dieses Experimentes ist die Untersuchung der auftretenden Plasma-Instabilitäten und der elektromagnetischen Wellen im Solaren Wind. Um diese Messungen durchführen zu können, besteht das Experiment hauptsächlich aus einem Spektral-Analysator mit 16 Kanälen, der mit den Antennen zur Messung des elektrischen Feldes verbunden ist. Der Spektral-Analysator deckt einen Frequenzbereich von 20 Hz bis 200 kHz ab und hat eine Amplitudenweite von 0,3 μV/m bis 30 mV/m pro Kanal. Der Spektral-Analysator, die Messungen des Antennenpotentials, das Stoßwellen-Alarmsystem und die dazugehörige Elektronik werden im Detail diskutiert.

1. SCIENTIFIC OBJECTIVES

The University of Iowa solar wind plasma wave experiment for the HELIOS missions has been jointly planned with the University of Minnesota [P. Kellogg] and GSFC [R. Weber and R. Stone] so that the combined experiments provide complementary measurements.

The objective of this experiment is the investigation of naturally occurring plasma instabilities and electromagnetic waves in the solar wind. In the solar wind a wide variety of electromagnetic and electrostatic wave phenomena can be expected in the frequency range from a few tens of Hz to several hundred kHz. These phenomena may include Type III radio noise bursts and associated longitudinal electrostatic waves down to the solar wind plasma frequency (from about 20 kHz at 1 AU to 100 kHz at 0.3 AU), intense (30 mV/m) electrostatic waves of the type observed by Scarf **et al.** [1] with the Pioneer 8 spacecraft, electrostatic waves associated with interplanetary shock waves and solar particle emissions, and whistler-mode instabilities related to anisotropic solar wind electron distributions ($T_{II}/T_{\perp} > 1$). Figure 1 summarizes the frequency range and characteristics of various plasma wave phenomena which could be expected in the solar wind and FIG. 2 illustrates the expected radial variation of the solar wind electron plasma frequency, ion plasma frequency, electron gyrofrequency, and lower-hybrid resonance frequency from the Earth to 0.3 AU.

Wave-particle interactions can lead to many important effects in the solar wind. Of particular interest on this mission is the investigation of instabilities which make the solar wind behave like a fluid. If the solar wind had no collective effects, the ratio $T_{II}/T_{\perp}$ for the protons would be 100 to

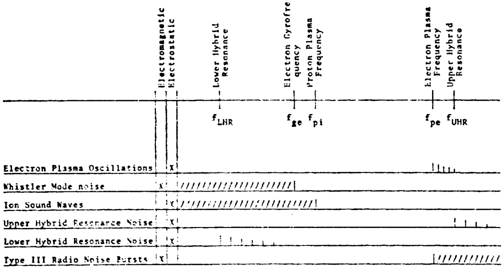

FIG. 1: Frequency range and characteristics of various plasma wave phenomena which could be expected in the solar wind

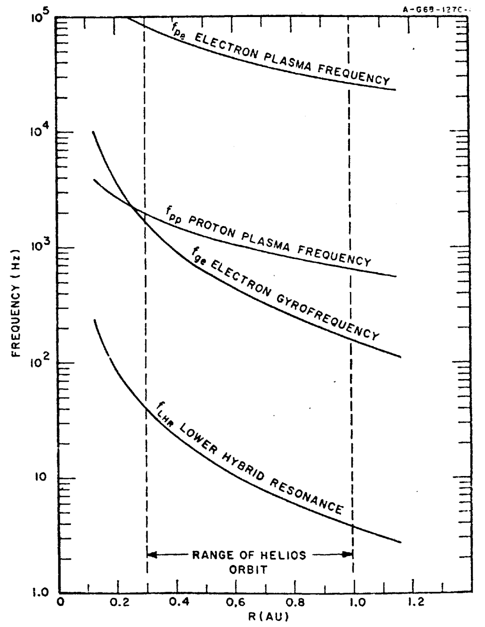

FIG. 2: The expected radial variation of the solar wind electron plasma frequency, ion plasma frequency, electron gyro-frequency, and lower-hybrid resonance frequency from the Earth to 0.3 AU

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1 or more at the Earth, contrary to observation. It is generally believed that a plasma instability, possibly the whistler-mode, alters the proton pitch angle distribution. Because of the large radial variation in the solar wind properties (density, magnetic field, $T_{\|}/T_{\perp}$, etc.) from the Earth to 0.3 AU, the stability criteria and wave phenomena occuring in the solar wind at 0.3 AU may be quite different compared to near the Earth. The spatial distribution of instabilities may influence the propagation of solar and galactic cosmic rays, slowing down times for super thermal particles can be drastically modified, waves generated in shocks can carry energy and momentum away from the shock region, and many more examples can be cited. Also of great importance is the direct observation of the electron plasma oscillations which are believed to give rise to Type III radio noise bursts through non-linear effects.

The frequency range of this experiment, nominally 20 Hz to 200 kHz, has been chosen to include most of the characteristic frequencies for plasma waves in the solar wind (see FIGs. 1 and 2). The upper frequency limit (200 kHz) is approximately the maximum electron plasma frequency (f_{pe}) expected and was chosen to provide some overlapping frequency coverage with the radio astronomy experiment (26 kHz to 3 MHz). The lower frequency limit for the plasma waves experiment (20 Hz) is influenced by the spacecraft spin rate (1 rev/second). Since strong electric field signals are expected at harmonics of the spacecraft spin rate, due to the asymmetrical photoelectron sheath around the spacecraft, the lower frequency limit of this experiment has been chosen to be well above the frequencies of the expected spin rate interference.

2. TECHNICAL DESCRIPTION OF THE EXPERIMENT

2.1 Electric Field Antenna

FIG. 3 shows a sketch of the electric field/radio astronomy antenna used on the HELIOS spacecraft. The antenna is an extendible cylindrical dipole 32 meters tip-to-tip, similar to the antennas used on the Alouette, OGO, IMP, and RAE satellites. In order to reduce the capacity between the antenna and the spacecraft photo-electron sheath to an acceptable value, an insulating sleeve approximately 2.0 meters long is placed over the antenna where the antenna passes through the spacecraft photoelectron sheath region. The antenna diameter is as small as possible (0.635 cm) in order to minimize the ratio of resistive-to-capacitive coupling to the surrounding plasma.

The electric field antenna and associated erection mechanism are provided by the spacecraft for this experiment. The antenna erection mechanism is designed to minimize the antenna to erection mechanism capacitance. This capacitance does not exceed approximately 30 pf in the extended configuration. Also, special consideration has been given to electrostatically shielding the antenna from spacecraft related interference, such as through the erection motor, deployment length indicators, etc.

2.2 Electric Antenna Preamplifier

Each element of the electric dipole is connected to three preamplifiers which provide signals to the respective University of Iowa, University of Minnesota, and GSFC experiments.

2.3 Main Electronics Package

A block diagram of the main experiment electronics is shown in FIG. 4. The main elements of the experiment electronics consist of (1) a differential amplifier, (2) a 16-channel spectrum analyzer, (3) an antenna potential monitor, (4) a shock alarm, and (5) a power supply.

The differential amplifier provides AC signals proportional to the potential difference between the antenna elements. It provides a high order of common mode rejection to reduce the response to interference signals present on both antenna elements. The differential amplifier is followed by a narrow band notch filter which provides approximately 30 db of attenuation at frequencies of 20 kHz, 40 kHz, and 60 kHz (harmonics of the power supply frequency).

The 16-channel spectrum analyzer is the basic element of the University of Iowa experiment. This analyzer is to provide relatively coarse frequency coverage and rapid temporal resolution with essentially continuous coverage of all frequencies (20 Hz to 200 kHz) and all times (using peak detectors). The nominal frequency response of the various spectrum analyzer channels is shown in FIG. 5. The lowest 8 frequency channels use active filters spaced with four filters per decade of frequency. The highest 8 frequency channels use passive filters spaced with four filters per decade. The detector and log compressor in each channel will rectify and log compress signals from the filter and produce an output proportional to the logarithm of the noise intensity in each filter channel. The dynamic range of the compressors extends from 10 μV to 1 V rms. The log compressor output is used to provide three outputs: (1) a peak output (P). (2) an average output (A), and (3) a short time constant output (S).

The peak output provides a voltage (0-5 volts) proportional to the logarithm of the peak signal since the preceding reading. The peak detector is reset after readout by a signal from the Data Processing Unit (DPU).

The average output provides an RC average output with either (1) a time constant τ which depends on the bit rate and science format mode or (2) a forced short time constant, τ_s. Which time constant is used is determined by the shock alarm channel number.

The short time constant outputs provide short-time-constant field strength voltages to the shock mode memory. One channel of short time constant outputs is continuously available in the science data. This channel is determined by the shock alarm channel number. The output from this channel is sampled 16 times in one spacecraft revolution by the DPU and stored for later readout.

The DPU provides a Shadow Blanking Pulse to the experiment to open the input to the 8 lowest frequency compressors for 4 sectors twice per revolution to reduce the

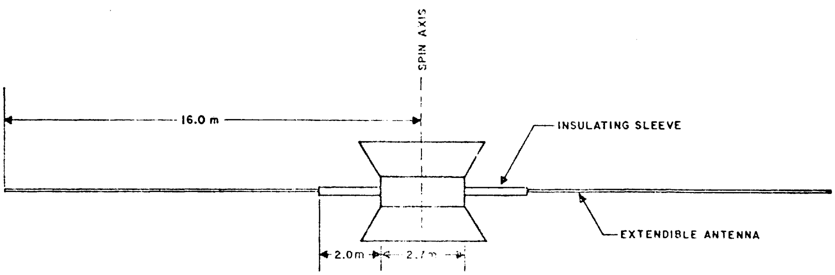

FIG. 3:
Sketch of the electric field/radio astronomy antenna used on the HELIOS spacecraft

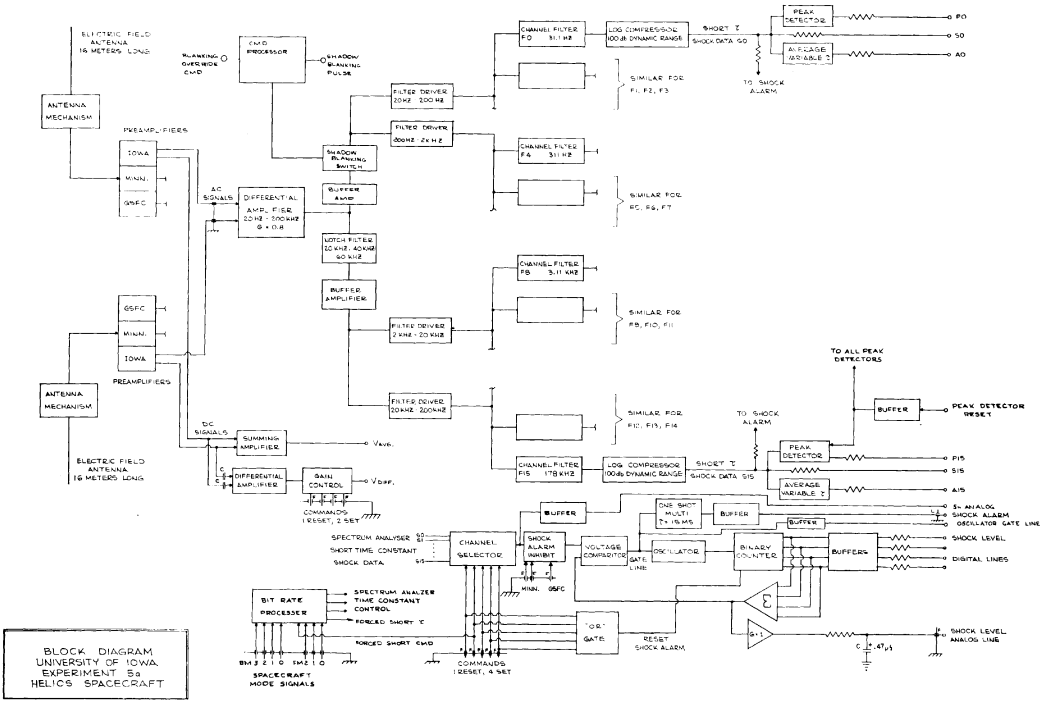

FIG. 4: **Block diagram of the University of Iowa HELIOS solar wind plasma wave experiment**

effects of the large voltage pulses generated as the antennas sweep through the spacecraft shadow. This blanking pulse can be eliminated by command.

The average potential, V_{avg} and the difference potential, V_{diff}, between the antenna elements are measured with operational amplifiers in the main electronics package. The frequency range of the V_{diff} measurement is from 0.2 to 10.0 Hz. The dynamic range of the V_{diff} measurement can be controlled by command to be either ± 8.0, ± 2.0, ± 0.5, or ± 0.125 volts. The dynamic range of the V_{avg} measurement is ± 20.00 volts. These data are needed for a complete understanding of the antenna operation in the plasma surrounding the spacecraft.

A shock alarm signal is to be sent to the spacecraft when the electric field experiment senses noise associated with an interplanetary shock wave. The shock alarm circuit will permit the selection of any one of the 16 spectrum analyzer channels, by command, for shock identification. The threshold field strength required to trigger the shock alarm has 16 levels and is controlled by a 4 bit binary counter. The shock threshold level is reset whenever any shock channel command is received. After reset, the threshold is advanced upward every time the threshold is exceeded, in each case the new threshold level is set to the peak value of the electric field strength observed. This procedure, therefore, results in the storage of the "best" event observed over the shock search interval.

The experiment power supply provides regulated voltages of ± 6 volts and ± 12 volts to the experiment electronics. The power supply operates at a frequency of 20 kHz and is synchronized by a 40 kHz synchronization signal provided by the spacecraft.

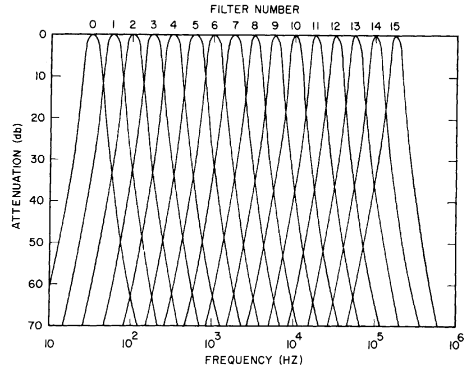

FIG. 5: **Frequency response curves for the 16 spectrum analyzer channels**

2.4 Data Processing Unit

The Data Processing Unit (DPU) for the Plasma Waves Experiment is separate from the main experiment electronics and is provided by GSFC through an industrial contractor. The purpose of the DPU is to (1) provide interface connections between the experiment and the spacecraft, (2) provide A/D conversion of all scientific analog data, (3) provide buffer storage, as necessary, to adapt to the spacecraft data transmission format.

REFERENCE:

[1] SCARF, F. L., G. M. CROOK, I. M. GREEN and P. F. VIROBIK: Initial results of the Pioneer 8 VLF electric field experiment, **J. Geophys. Res., 73,** 6665, 1968.