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Revised

TRW PLASMA WAVE EXPERIMENT FOR THE IMP-H MISSION

by

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16. Abstract The IMP-H Plasma Wave Experiment is designed to extend knowledge of wave-particle interactions in the disturbed cislunar region, the distant geomagnetic tail, the upstream solar wind, and the flanks of the magnetosheath-shock interface. We expect to identify plasma instabilities, study particle acceleration and heating at collisionless shocks and other discontinuities, analyze turbulent conductivity and field line merging, and provide new information on dissipation processes for suprathermal particles.

Instrumentation for the plasma wave experiment is designed to measure local electric and magnetic field oscillations over the frequency range 10 Hz to 100 kHz. A 24" electric dipole, a 7" diameter air core search coil, and the associated preamplifiers are mounted on a spacecraft counterweight boom. The frequency range of 10 Hz to 100 kHz for both E and B is processed using an eight-channel spectrum analyzer located in the instrument main-body package (a standard "IMP" trapezoidal module, 3 inches high). Electric fields as small as 10-100 microvolts/meter and magnetic signals as small as 1-3 milligamma will be detected.

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PREFACE

1. OBJECTIVE

The purpose of this report is to summarize the performance of work in compliance with Article V of Contract NAS5-11384, entitled "Plasma Wave Experiment for IMP-H," dated February 11, 1971.

The objective of this contract was to provide a scientific instrument (hardware) for the study of solar wind phenomena on the IMP-H Mission. Briefly, the work included:

- Development, fabrication, and acceptance testing of one (1) flight instrument for the Plasma Wave Experiment
- Modification of one (1) GFE-supplied go-no-go test set
- Sustaining engineering, including field support engineering at GSFC during flight spacecraft integration and testing
- Field support engineering at the Eastern Test Range during pre-launch and launch activities
- Documentation of all technical aspects pertinent to the design, fabrication, and test and operation of the instrument and test set, with specific emphasis on assurance of Instrument-Test Set/ Spacecraft Interface compatibilities.

2. SCOPE OF WORK

In accordance with the contract, this report covers the hardware (instrument) development, fabrication, integration and testing activities from contract initiation through launch.

In addition to the discussion of hardware activities, this report also includes a brief description of the plasma wave instrument and its operation.

Detailed discussion of the scientific theory, its justification, or results of preliminary post launch data analysis are not within the scope of work performed under this contract, and are thus not reported herein. (See Reference 1 for preliminary report on in-flight performance.)

3. CONCLUSIONS

Because much of the TRF/IMP-H instrument utilized components and subassemblies designed and developed for previous TRW plasma wave instruments (OGO, Pioneer, OV2-5, etc.), no significant design or fabrication problems were encountered and work proceeded well. The instrument and GSE were delivered to NASA/GSFC on 22 June 1971, and integrated on the IMP-H spacecraft on 23 June.

The IMP-H spacecraft was launched on 22 September 1972 and, to date, the instrument has performed quite well.

4. SUMMARY OF RECOMMENDATIONS

Not applicable.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

1.0 INTRODUCTION

The IMP-H instrument payload was originally selected more than five years before launch, but at a very late stage an opportunity arose to provide a limited plasma wave instrument. At this late stage, several firm project and spacecraft restrictions naturally had to be satisfied, and these limitations strongly influenced the instrument design. Specifically, little time was avilable for overall design and fabrication, and there were firm limits on weight, power, and other resources. Authorization to start work on the wave instrument was received on 22 January 1971, and the flight unit had to be delivered before July 1, 1971; the boom package weight ceiling was 1.25 lbs; the main body limit was 3.5 lbs; and the power limit was set at 2.5 watts.

With these restrictions in mind, design of the IMP-H plasma wave instrument was based on the detailed building blocks (automatic gain control amplifiers, preamplifiers, filters, etc.) that had already been designed for the OGO-5 plasma wave detector and tested in space since 1968. In fact, some spare OGO-5 components, such as a magnetic loop antenna, were physically used in the IMP-H unit without internal modification. The only significant electronic circuit changes made in going from OGO-5 to IMP-H were those that had to be imposed because of the differences between the two spacecraft and the two sets of scientific instrument interface specifications. The major changes can be summarized as follows:

1.1 <u>Amplifier Response Time</u>

The OGO-5 spacecraft was three-axis stabilized, and it was appropriate to utilize simple amplitude detectors with rise time constants of the order of 20 milliseconds and decay time constants of about 400 milliseconds. The single most pressing redesign problem involved the need to shorten these time constants, because IMP-H had a planned spin period near one revolution per second. Accordingly, most of our redesign activities were devoted to this problem, and modified IMP-H amplitude detectors used in the VLF channels (center frequency equal to or greater than 600 Hz) have settling times between 10 and 20 milliseconds.

1.2 Extended Lower Frequency Limit

The IMP-7 spacecraft carries two 1.6 kilobit/second signal encoders, one of which was designed for use in a data system test. It was decided that the low frequency plasma wave E or B sensor response could be transmitted using the data system test encoder, and accordingly a wideband or waveform channel, covering the frequency range below about 150 Hz, was added.

2.0 INSTRUMENT DESCRIPTION

2.1 General Characteristics

The IMP-H Plasma Wave Experiment is designed to measure local electric and magnetic field oscillations over the frequency range 10 Hz to 100 kHz. A 24" electric dipole, a 7" diameter air core search coil, and the associated preamplifiers are mounted on the counterweight boom. The frequency range of 10 Hz to 100 kHz for both E and B is processed using an eight-channel spectrum analyzer. The low frequency range from 10 Hz to 150 Hz is analyzed by a specially-designed broad active filter channel. The remaining seven channels utilize high resolution UTC band pass filters to cover the rest of the range through 100 kHz. The band pass frequencies are nearly equally spaced on a logarithmic scale (actual center frequencies are selected to avoid known spacecraft interference tones). In the normal mode, the spectrum analyzer samples the output from one sensor in a fixed frequency channel for about one spin period. The other sensor is then sampled for a spin period, and the analyzer frequency changes every two spins. A complete polarization and frequency scna for both E and B sensors requires approximately 16 spin periods or twenty seconds. In the snapshot mode, the magnetic sensor is inhibited, and alternate spins are used for snapshots of our entire set of spectrum analyzers. The threshold sensitivities are somewhat frequency dependent. Electric fields as small as 10-100 microvolts/meter and magnetic signals as small as 1-3 milligamma can be detected.

In addition to the normal data channels discussed above, a low frequency waveform channel and its AGC level duplicating the data coverage of the low end of the spectrum is provided for an engineering test being made of a test data system on the IMP-H mission. If this system should operate, very high resolution coverage of the range from 10 Hz to 100 Hz will be obtained.

2.2 Detailed Description

The final IMP-H plasma wave instrument characteristics are summarized in Figures 1 and 2. The top part of Figure 1 shows the 1.2-pound boom-mounted package that includes the spare OGO-5 magnetic loop to measure B-components parallel to the spacecraft spin axis, a 24-inch wire grid electric dipole (similar to the OGO-5 Q, R, or S antenna; see Reference 2 for details) to measure E-components in the spacecraft equatorial plane, and the

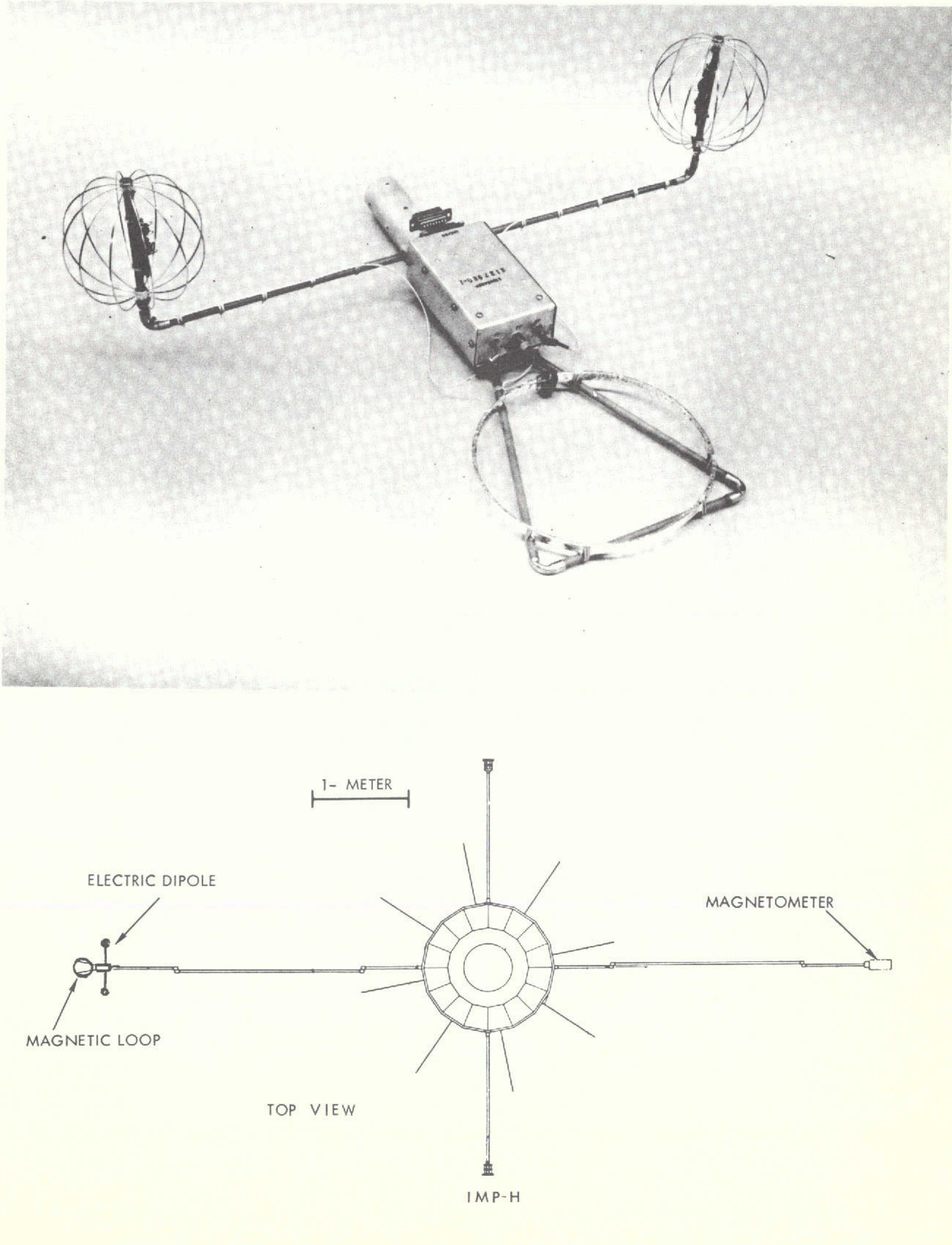
1- METER
ELECTRIC DIPOLE
MAGNETOMETER
MAGNETIC LOOP
TOP VIEW
IMP-H

Figure 1

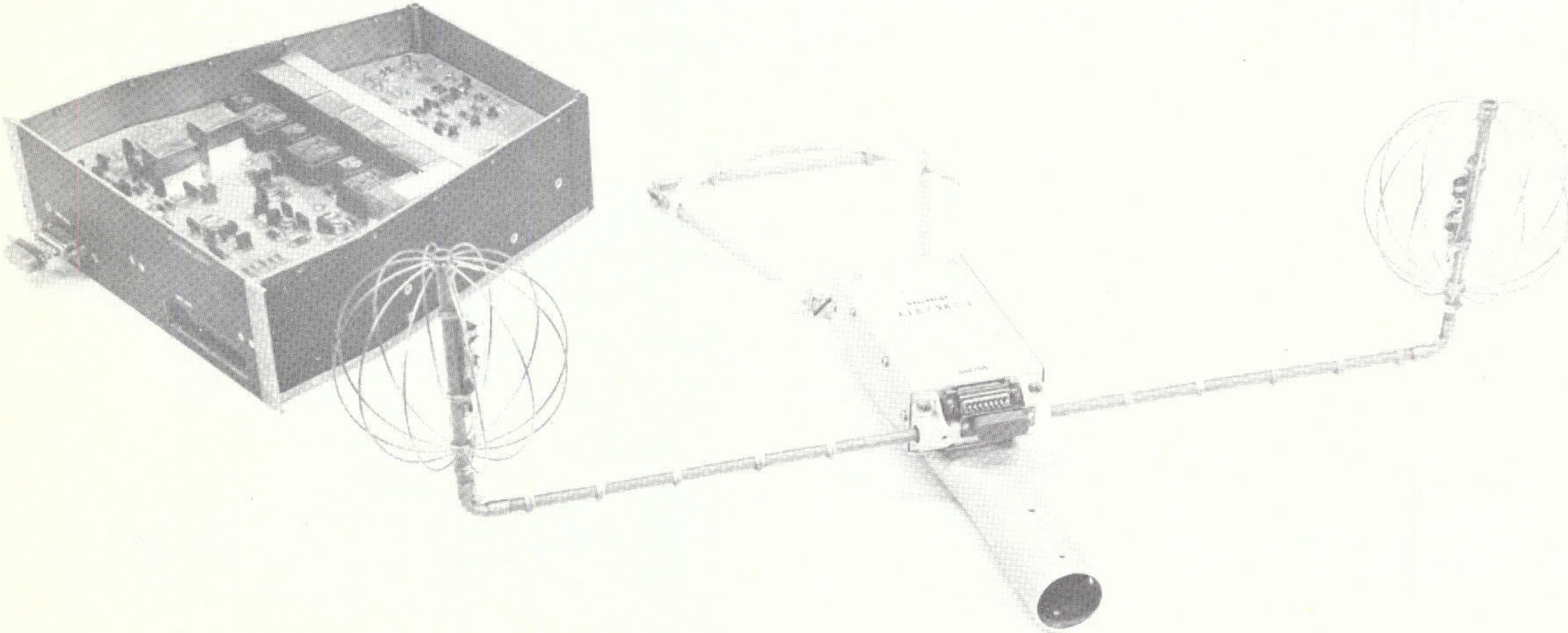

Figure 2

associated preamplifiers. The bottom part of Figure 1 shows the mounting of this boom package, as seen from the top of IMP-7.

The wideband E and B signals are processed in the main body package shown in Figure 2 (with top cover removed). A simplified block diagram for this unit is shown in the top of Figure 3. The E or B broadband signals are transmitted to the data system test telemetry as analog waveforms. In addition, the plasma wave signals are processed by an eight-channel spectrum analyzer that consists of the automatic gain control (AGC) reading from the waveform channel, plus amplitude measurements from seven narrowband filter-fast amplitude detector channels. The instrument has four modes of operation, because the waveform analyzer and associated AGC reading can be switched to E or to B, and the seven higher frequency channels in the spectrum analyzer can independently be used in two modes; that is, the seven upper channels can be used to obtain either full E and B frequency and polarization scans, or a succession of E-field spectral snapshots, alternated with E-field polarization scans in the individual frequency channels.

The individual filter response characteristics are shown in the bottom panel in Figure 3. The six highest frequency filters are UTC minifilters of the type used in the OGO-5 detector; the 30 kHz and 70 kHz channels have 30 percent bandwidth, and the filters with center frequencies at 1.3, 2.3, 5.4, and 10.5 kHz have 15 percent bandwidths. The broader filter below 1 kHz is an active one with center frequency of 500 Hz, effective 45 percent bandwidth, and 1- db falloff points at 270 and 810 Hz. A steep notch filter at 1 kHz is also inserted to minimize any electric field interference that could be associated with the AC modulation on the MIT Faraday cup plasma probe. The

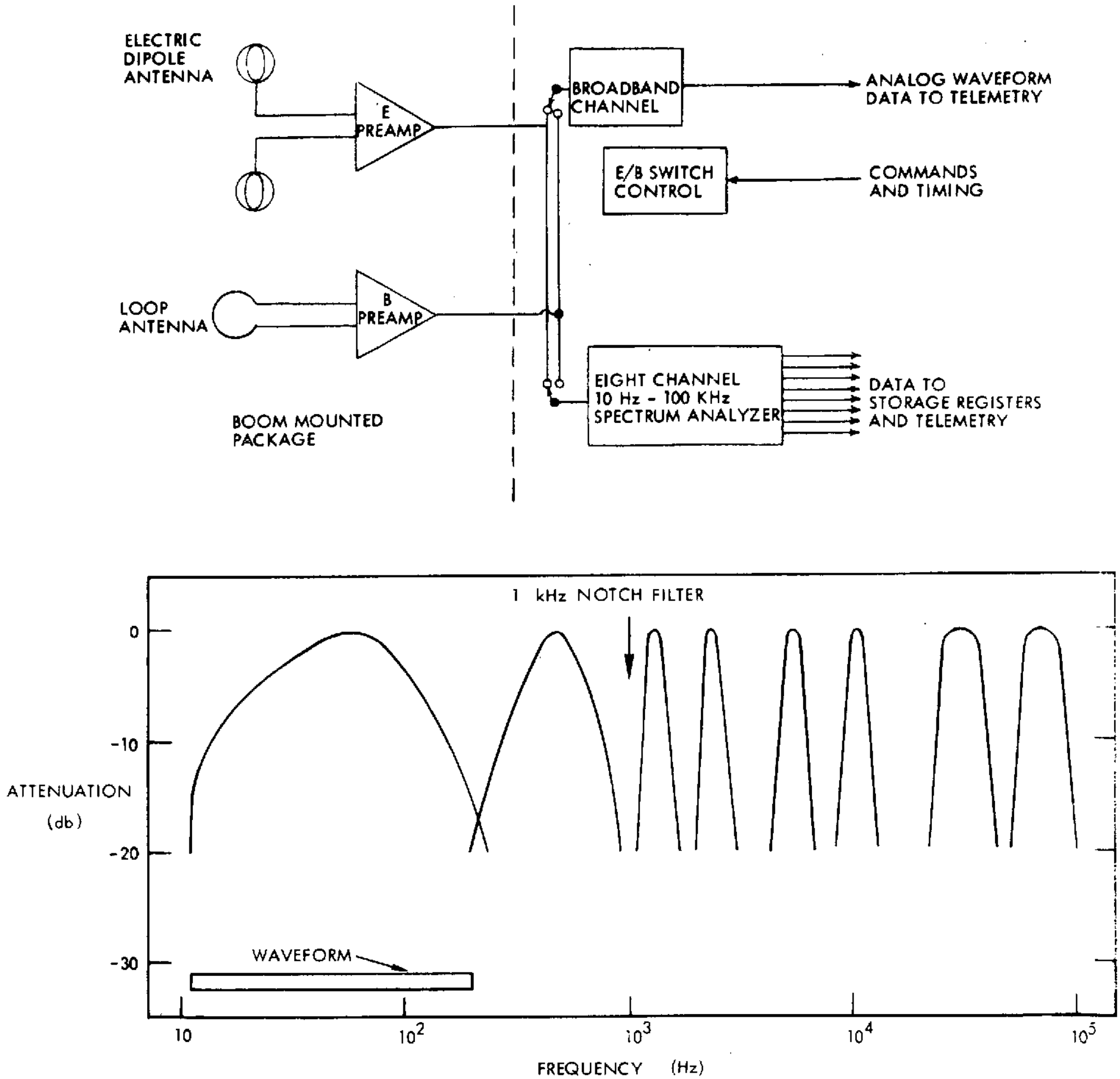
ELECTRIC DIPOLE ANTENNA
E PREAMP
LOOP ANTENNA
B PREAMP
BOOM MOUNTED PACKAGE
BROADBAND CHANNEL
ANALOG WAVEFORM DATA TO TELEMETRY
E/B SWITCH CONTROL
COMMANDS AND TIMING
EIGHT CHANNEL 10 Hz - 100 KHz SPECTRUM ANALYZER
DATA TO STORAGE REGISTERS AND TELEMETRY
1 kHz NOTCH FILTER
0
-10
-20
-30
ATTENUATION (db)
WAVEFORM
10
10^2
10^3
10^4
10^5
FREQUENCY (Hz)

Figure 3

wide lowest frequency filter is primarily designed to define the limits of the broadband waveform channel, and it has restricted value as an element of the spectrum analyzer whose output appears on the conventional scientific encoder-transmitter data link. In terms of conventional "narrowband" filter characteristics, this lowest frequency or AGC channel on IMP-H has a bandwidth of 67 Hz, and the 10-db falloff points are at 17 Hz and 150 Hz.

The spectrum analyzer output is read out once per 80 milliseconds, and in the E-B switching mode the format is such that the output from a given sensor is processed in a fixed-frequency channel long enough for sixteen amplitude readings to be transmitted. This 16-point sequence takes 1.28 seconds and since the spacecraft spin period is just over 1.3 seconds, an individual sequence lasts for almost one complete revolution of IMP-H, with the plasma wave instrument in a fixed frequency channel for a given sensor. The E-B switching mode has sixteen such sequences that make a full spectral and polarization scan, and these sequences are arranged as follows: 70 kHz - E → 70 kHz - B → 30 kHz - E → .... 600 Hz - B → AGC - B → AGC - B → 70 kHz - E. [There is no automatic switching of the 17-150 Hz or AGC channel from E to B, because this low frequency channel necessarily has a long settling time; the AGC channel switching is accomplished by ground command only.] The complete scan thus involves a total of 256 measurements made with two field sensors, eight frequency channels, and sixteen azimuthal positions of the plasma wave boom, and it is repeated every 20.5 seconds.

2.3 Summary Characteristics

The "as delivered" characteristics of the instrument are summarized in Tables 1, 2, and 3.

Table 1. IMP-H Plasma Wave Instrument Summary
Characteristics - Physics & Electrical

Main Body Package Weight: 2.9 pounds

Main Body Package Height: 3 inches

Boom-Mounted Package Weight: 1.18 pounds

POWER SUMMARY

Average input:	2.5 watts
Peak input:	2.5 watts
Duty cycle:	Continuous

THERMAL RESTRAINTS

	Facet Card	Boom-Mounted Package
Non operating	+60°C -60°C	+60°C -60°C
Operating	+50°C -20°C	+60°C -60°C

HUMIDITY RESTRAINTS

Non operating	50%	50%
Operating	50%	50%

High Voltage Operating Restraints: None

Turn-On Operating and Test Temperatures:

	+50°C -20°C	+60°C -60°C

INTERNAL POWER SUPPLIES

Name and Type: DC-DC Power Converter - Magnetic Multivibrator

Voltage: 28 VDC Input
± 9 VDC Output
+5 VDC Output

Frequency: 20 kHz ± 3%
Efficiency: 55%
Duty Cycle: 100%

Table 2. IMP-H Plasma Wave Instrument Summary Characteristics - Telemetry Command Description

COMMAND OFF: EXPERIMENT POWER OFF

Analog performance parameter 1 (APP-1) will show 0 VDC

COMMAND ON: EXPERIMENT POWER ON

Analog performance parameter 1 (APP-1) reads converter voltage status and will have a minimum value of 1.0 VDC

COMMAND 1: LOW FREQUENCY WAVEFORM E/B SWITCH

This command toggles the broadband channel between the E and B modes. Digital performance parameter 1 (DPP-1) will indicate the mode.

"1" - +7.75 to +5 VDC - E mode ⟵ Nominal
"0" - -4 to +0.5 VDC - B mode

COMMAND 2: NARROW BAND a_1 INHIBIT SWITCH

This command toggles the narrow band channels between the a_1 switching of the E and B modes and the a_1 inhibited or E only snapshot mode. Digital performance parameter 2 (DPP-2) will indicate the mode.

"1" - +7.75 to +5 VDC - E/B mode ⟵ Nominal
"0" - -4 to +0.5 VDC - E only snapshot mode

COMMAND R: RESET TO NOMINAL

This command resets the experiment to the nominal modes discussed above under Command 1 and Command 2. (After each POWER ON command, the experiment should be commanded into the mode indicated above as nominal.)

Table 3. IMP-H Plasma Wave Instrument Summary Characteristics - Telemetry Performance Parameters and Outputs

DIGITAL PERFORMANCE PARAMETERS

1. E/B SWITCH (DPP-1)

DPP-1 gives the mode of the "low frequency waveform E/B switch."

"1" - +7.75 to +5 VDC - E mode ⟵ Nominal
"0" - -4 to +0.5 VDC - B mode

2. A_1 INHIBIT SWITCH (DPP-2)

DPP-2 gives the mode of the "narrow band a_1 inhibit switch."

"1" - +7.75 to +5 VDC - E/B mode ⟵ Nominal
"0" - -4 to +0.5 VDC - E only snapshot mode

ANALOG PERFORMANCE PARAMETERS

1. OFF/CONVERTER VOLTS (APP-1)

APP-1 will be at 0 VDC for POWER OFF and will read the converter voltage for POWER ON. The range of output indicating the state of health of the power converter will be from a minimum of 1 VDC to a maximum of 4.5 VDC.

2. BOOM MOUNTED PACKAGE TEMPERATURE (APP-2)

APP-2 will give the temperature of the boom-mounted package (thermistor).

ANALYZER CHANNEL OUTPUTS

Eight outputs, 0 to 5 VDC.

3.0 HARDWARE ACTIVITIES

3.1 Project Recap

The first formal proposal(1) for the TRW Plasma Wave Experiment (TRF/IMP-H) for the IMP-H mission was submitted on 8 July 1970 to Dr. L. Kavenaugh of NASA as a substitute for an experiment previously assigned to Facet 13 on the IMP-H spacecraft. Initially, one flight instrument, one spare, plus ground support equipment were proposed. Additional requirements of the IMP project ultimately resulted in two revisions(2,3) to the original proposal.

The contract per Revision 2 of Proposal 17557.000 was negotiated on 11 February 1971, thus formalizing the start of project activity. In order to meet the contractual delivery date of 1 July 1971, however, authorization(4) was obtained to begin work on 21 January 1971.

A schedule of the IMP-H Plasma Wave instrument hardware activities is shown in Figure 4.

4.0 DESIGN AND DEVELOPMENT CONCEPTS

Because of the tight schedule and budget, certain methods and concepts employed to reduce lead times and costs for the project may be worthy of review here.

From the start, a basic ground rule for the project was that new design be kept to a minimum. Thus, much of the "design" phase consisted of merely updating or modifying and re-issuing drawings from previous projects. In some instances, even spare components "left over" from previous projects

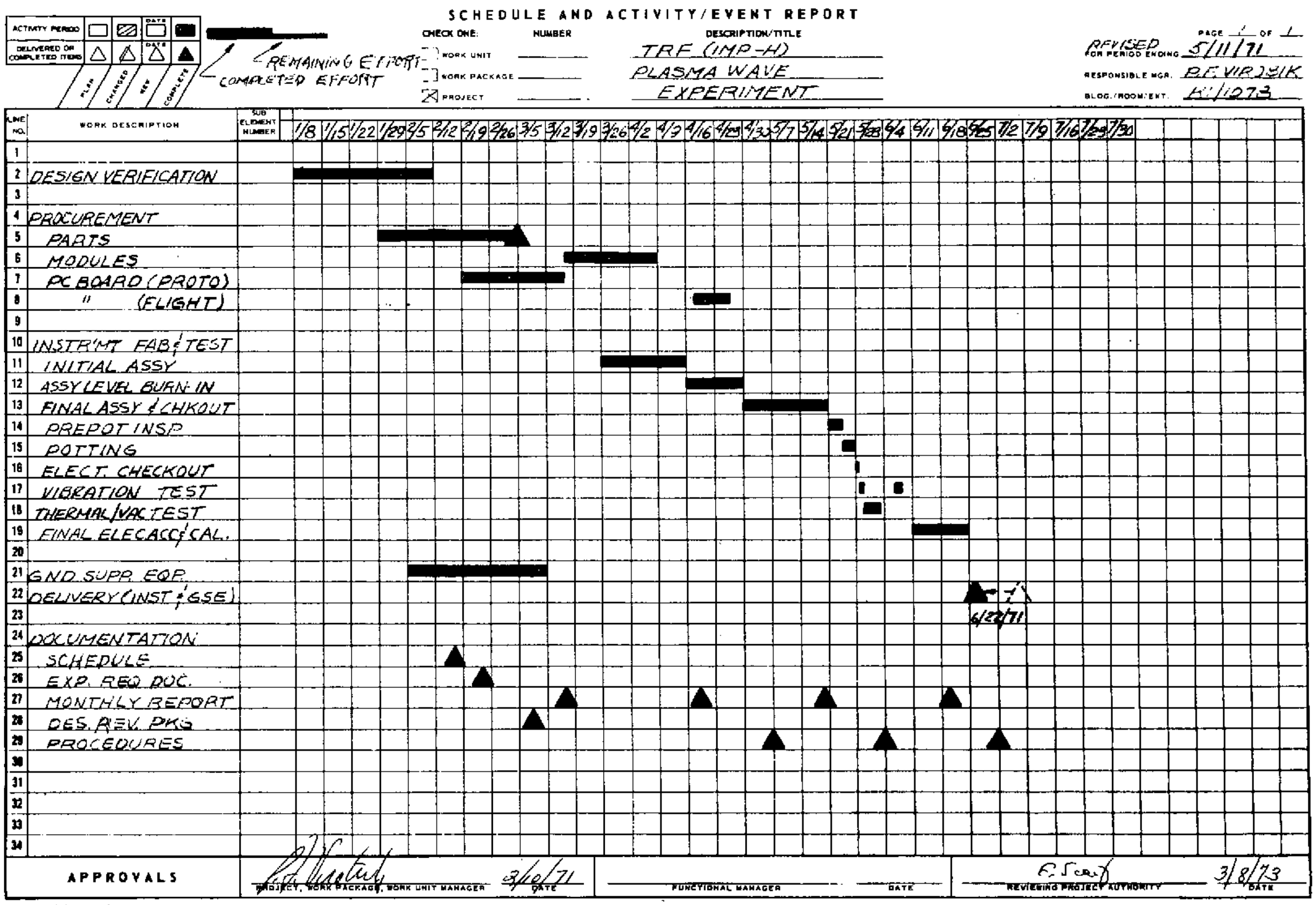
SCHEDULE AND ACTIVITY/EVENT REPORT
ACTIVITY PERIOD
DELIVERED OR COMPLETED ITEMS
PLAN
CHANGED
REV
COMPLETE
REMAINING EFFORT
COMPLETED EFFORT
CHECK ONE:
NUMBER
WORK UNIT
WORK PACKAGE
PROJECT
DESCRIPTION/TITLE
TRF (IMP-H)
PLASMA WAVE
EXPERIMENT
PAGE 1 OF 1
REVISED FOR PERIOD ENDING 5/11/71
RESPONSIBLE MGR. R.F. VIRZYIK
BLDG./ROOM/EXT. K/1273
LINE NO.
WORK DESCRIPTION
SUB ELEMENT NUMBER
1/8 1/15 1/22 1/29 2/5 2/12 2/19 2/26 3/5 3/12 3/19 3/26 4/2 4/9 4/16 4/23 4/30 5/7 5/14 5/21 5/28 6/4 6/11 6/18 6/25 7/2 7/9 7/16 7/23 7/30
2 DESIGN VERIFICATION
4 PROCUREMENT
5 PARTS
6 MODULES
7 PC BOARD (PROTO)
8 " (FLIGHT)
10 INSTR'MT FAB & TEST
11 INITIAL ASSY
12 ASSY LEVEL BURN-IN
13 FINAL ASSY & CHKOUT
14 PREPOT INSP
15 POTTING
16 ELECT. CHECKOUT
17 VIBRATION TEST
18 THERMAL/VAC TEST
19 FINAL ELEC ACC & CAL.
21 GND SUPP EQP
22 DELIVERY (INST & GSE)
6/22/71
24 DOCUMENTATION
25 SCHEDULE
26 EXP. REQ DOC.
27 MONTHLY REPORT
28 DES. REV. PKG
29 PROCEDURES
APPROVALS
PROJECT, WORK PACKAGE, WORK UNIT MANAGER
3/10/71
DATE
FUNCTIONAL MANAGER
DATE
REVIEWING PROJECT AUTHORITY
3/8/73
DATE

Figure 4

were used. Such as the case for the magnetic ("B") field coil (developed for the OGO-5 Plasma Wave Detector) which simply required a different connector.

The "minimum new design" concept was probably carried to the ultimate for the test set (GSE). A test set unit, previously built for the TRW/Pioneer Electric Field Experiment and no longer in use, was transferred to and modified for the IMP-H project. While not an original idea, perhaps, the modification and re-use of otherwise obsolete equipment _is_ possible and, in this instance, represented a considerable cost savings.

The only item requiring new design was the printed wiring board. As finally negotiated, the contract called for delivery of only _one_ instrument, thus posing a problem: with no prototype instrument as a test bed, how was the integrity of the printed wiring board and component layout to be determined? The solution to this problem might be called the "Mock Prototype."

Essentially the printed wiring board was procured in two phases. In Phase 1, a "prototype" board was designed and fabricated. Then all of the (flight) electronic components (modules, transistors, resistors, etc.) were attached to the board in their respective places with the exception that the component leads were not trimmed to length but, rather, left "standing" above the board on long leads. Thus, it was possible to perform a complete electrical checkout of not only the printed wiring board, but all of the components and the complete system as well. After the "prototype" board layout was corrected and verified, the artwork changed as necessary, the "flight" board was ordered and, in final assembly then, all components were transferred to the flight board -- this time trimming the leads to proper length.

As it turned out, the "Mock Prototype" not only solved the design verification problem (two layout errors were found), but also aided in the parts screening program which was accomplished on the entire "Mock Prototype." With all flight components installed, the assembly was exposed to 96 hours (each) at +75°C and -50°C, with system electrical tests preceding and following each exposure. Thus, the parts were screened as a "system" - rather than individually - at a considerable saving in costs and time.

5.0 FAILURES AND MALFUNCTION

Except for RFI, the instrument passed all of the required electrical, magnetic and environmental tests. In the RFI bench test, the instrument exceeded the specification limits for radiated (magnetic and RF) fields and for conducted susceptibility portions of the test. Review of this data, the instrument RFI design, and test methods, however, did not yield any clearcut direction regarding necessary corrective action. Consequently, resolution of the RFI problem was deferred until the spacecraft RFI tests were completed. Results of the spacecraft RFI test, which provided a more representative test environment for the TRF instrument, indicated that the out-of-specification conditions would not significantly degrade operation of either the spacecraft or the instrument. Thus, the instrument was accepted by the IMP Project Office with no corrective action taken.

Although not a test failure, the fragile "B"-field sensor coil was inadvertently damaged during spacecraft test and required replacement.

No other test, component, or functional failures were experienced.

6.0 CONCLUSION

In conclusion, the TRF project was quite successful, modest in scope and cost and yet, from a cost-effectiveness standpoint, will provide a high return in scientific value.

7.0 NEW TECHNOLOGY

Because of the "minimum new design" philosophy employed throughout the project, no new technology was generated under this contract.

8.0 REFERENCES

(1) "A Preliminary Report on IMP-7 Plasma Wave Investigation: Instrumentation and In-Flight Performance," F. L. Scarf, R. W. Fredricks, I. M. Green, and G. M. Crook, TRW Systems Group Technical Report No. 22751-6001-000, March 1973.

(2) Crook, G. M., F. L. Scarf, R. W. Fredricks, I. M. Green, and P. Lukas, IEEE Trans. Geosci. Elec., GE-7, 2, 120, 1969.

(3) TRW Proposal No. 17557.000, "Proposal for a Plasma Wave Experiment for IMP-H," dated 26 June 1970 (submitted 8 July 1970).

(4) Revision 1 to TRW Proposal 17557.000, dated 17 September 1970 (submitted 18 September 1970).

(5) Revision 2 to TRW Proposal 17557.000, dated (and submitted) 17 November 1970.

(6) Contract Authorization per "Notice of Work Without Contractual Coverage," dated 21 January 1971.