STS-3/OSS-1 PLASMA DIAGNOSTICS PACKAGE (PDP) MEASUREMENTS OF ORBITER TRANSMITTER AND SUBSYSTEM ELECTROMAGNETIC INTERFERENCE

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1.0 INTRODUCTION

This report is intended to present a quick-look analysis of the Plasma Diagnostics Package (PDP) electromagnetic spectral measurements on the STS-3/OSS-1 mission from March 1982. Further interpretation of the data is awaiting ancillary information on the operation of Orbiter subsystems, such as thrusters and on the detailed trajectory and attitude.

The PDP receiver system is described to identify the various antennas and to characterize the complement of receivers which cover the frequency range of 30 Hz to 800 MHz and S-Band at 2200 ± 300 MHz. Sample results are presented to show the variety of electromagnetic effects associated with the Orbiter and the time variability of these effects. The electric field and magnetic field maximum and minimum field strength spectra observed during the mission at the pallet location are plotted. Values are also derived for the maximum UHF transmitter and S-band transmitter field strengths. Finally, calibration data to convert from the survey plots to actual narrowband and broadband field strengths are listed.

Support for the PDP on the STS-3/OSS-1 Mission was provided through NASA/MSFC Contract NAS8-32807. OSS-1 Mission management was provided by NASA/GSFC.

2.0 DESCRIPTION OF RECEIVER SYSTEM

Sensors for the detection of magnetic and electric wave fields are identified in Figure 1. Two spheres of 8 inch diameter, separated by 1.2 meters make up the electric dipole antenna which is utilized from DC to 20 MHz in frequency. Calibration measurements at NASA/GSFC before flight indicated that the effective electrical length of this dipole was only 0.22 meters because of the proximity to the PDP. For higher frequency electric fields, a broadband single polarization horn antenna is utilized. It covers the range of 20 MHz through S-band at 2200 MHz. In addition, the searchcoil sensor is used to detect the magnetic field component of electromagnetic waves from 30 Hz to 178 kHz. The Langmuir Probe is sensitive to electrostatic plasma waves over the same VLF range of 30 Hz to 178 kHz.

A block diagram of the PDP sensors and associated receivers is shown in Figure 2. One VLF range receiver from the IMP program VLFR-IMP is switched between the electric dipole, the searchcoil and the Lagnmuir Probe sensors every 51.2 seconds to provide 16 channels of VLF spectra--30 Hz to 178 kHz. In addition, the waveform is preserved in the Wideband Receiver (WBR) and this analog data is included in the PDP data stream. Every 12.8 seconds the WBR switches 10 kHz bands sequentially covering 0-10 kHz, 20-10 kHz and 20-30 kHz for each sensor. The VLFR-HELIOS always is connected to the electric dipole antenna to give a peak and average spectrum every 1.6 seconds.

The electric dipole also drives the Medium Frequency Receiver (MFR) which covers 316 kHz to 17.8 MHz in 8 channels. This MFR shares a logarithmic detector with the High Frequency Receiver (HFR) which has four broadband channels spanning the range of 20 MHz to 800 MHz. Bandwidths for the VLFR and MFR are narrower at ± 15% and ± 30%, respectively. By mixing the S-band signal down to the HFR frequency range, the same log detector is used for the SBR by time multiplexing. Both peak and average spectra are obtainined each 1.6 seconds.

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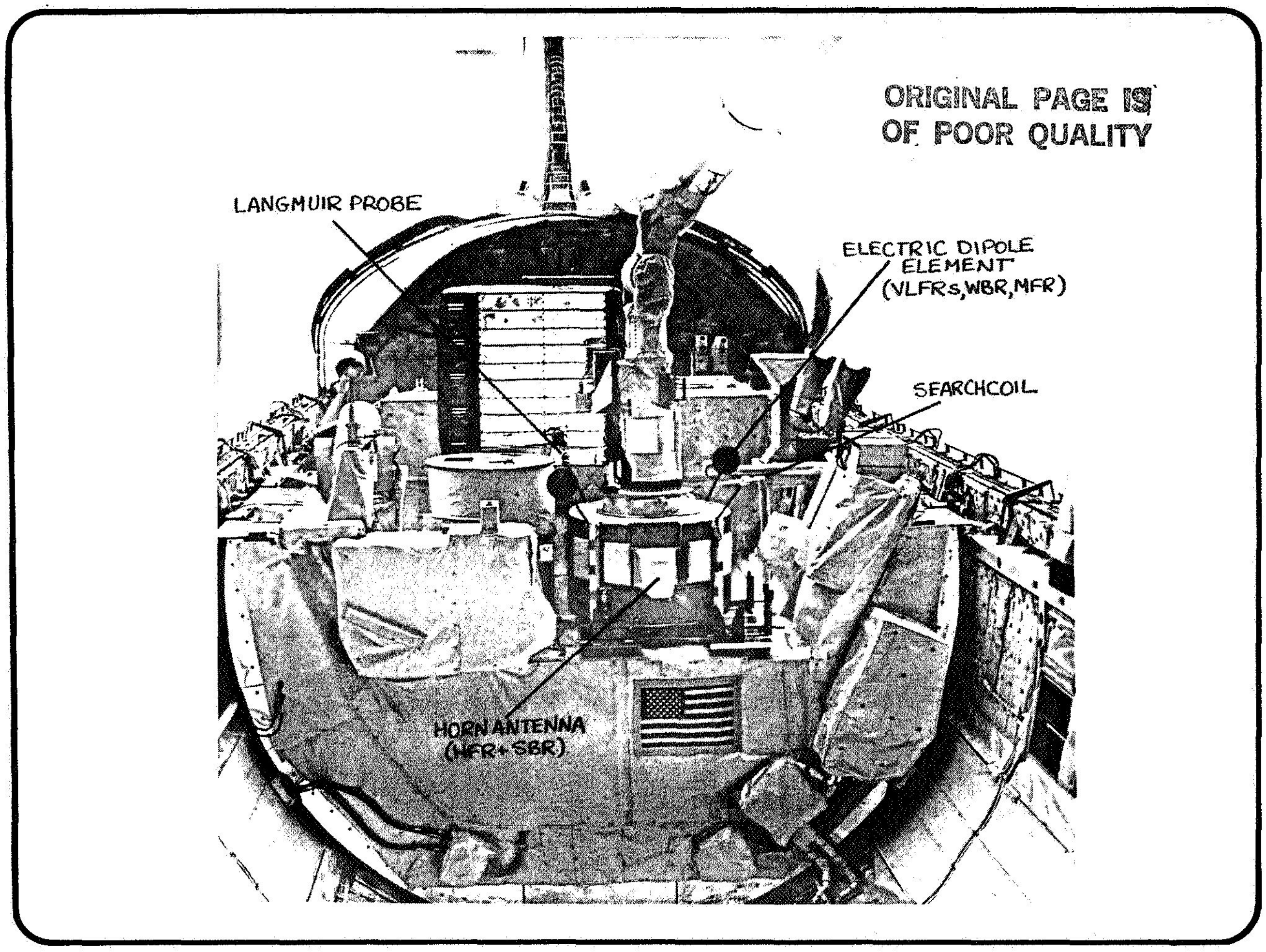
A summary of the receiver characteristics is given in Table 1. Detailed performance specifications for the receivers and the other PDP instrument are given in Table 2. Note that the stated field strength ranges are only approximate.



PDP on Pallet: Antennas Identified

Figure 1

Figure 2

PDP WAVE INSTRUMENTATION

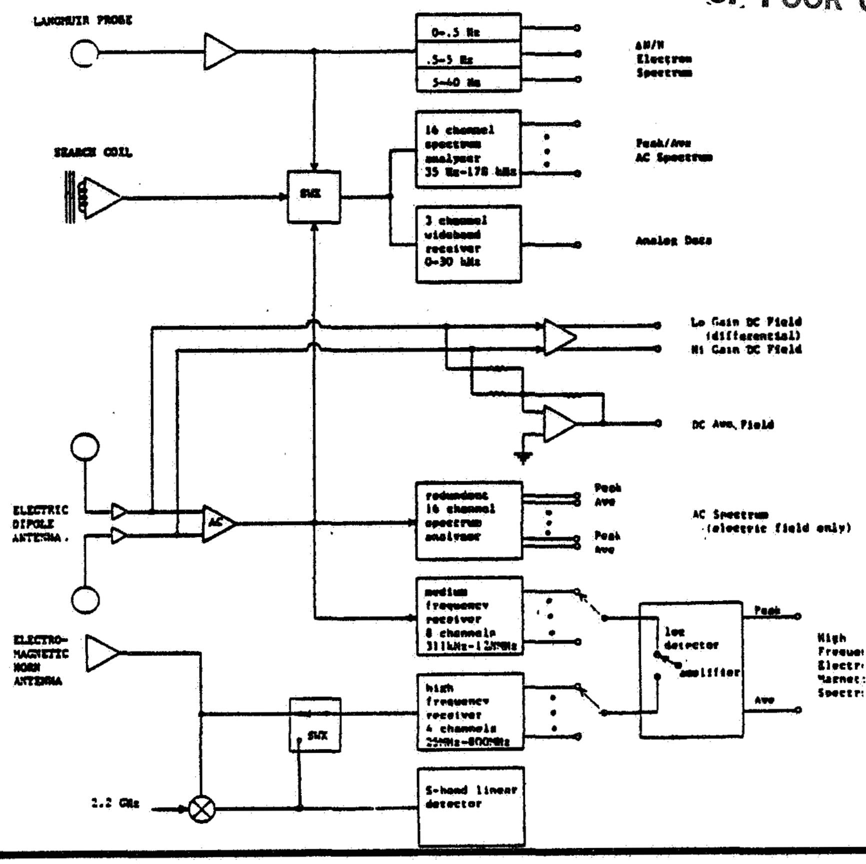


Table 1

STS-3/PDP RECEIVER CHARACTERISTICS

VERY LOW FREQUENCY (VLFR)

- 16 CHANNELS
- 30 HZ TO 178 KHZ

MEDIUM FREQUENCY RECEIVER (MFR)

- 8 CHANNELS
- 311 KHZ TO 17.8 MHZ
- 65 DB DYNAMIC RANGE

HIGH FREQUENCY RECEIVER (HFR)

- 4 CHANNELS
- 20 MHZ TO 800 MHZ

S-BAND RECEIVER (SBR)

- 4 CHANNELS WITH LOG DETECTOR
- 1 CHANNEL WITH LINEAR DETECTOR
- ~ 2200 MHZ ± 300 MHZ

Table 2

PDP SCIENTIFIC INSTRUMENTS PERFORMANCE SPECIFICATIONS

MEASUREMENT	TECHNIQUE	PARAMETERS	VALUE/RANGE
DC Magnetic Field	Triaxial Fluxgate Magnetometer	Dynamic Range Temporal Resolution	±12 milligauss to ±1.5 gauss each axis 10 samples/second each axis
DC Electric Field	1m Double Probe with Spherical Sensors	Dynamic Range Temporal Resolution	±2 mV/m to ±2 V/m (average and differential 20 samples/second
AC Magnetic Waves	Searchcoil Sensor; Wideband Receiver	Frequency Range Amplitude Range Duty Cycle	5Hz-1kHz & 0.65-10, 10-20, 20-30kHz 100db @ 0.4db resolution; 3mγ-300γ 12.8 seconds out of 51.2 sec.
	Searchcoil Sensor; VLF Spectrum Analyzer (IMP) VLFR-IMP	Frequency Range Frequency Resolution Amplitude Resolution Temporal Resolution Duty Cycle	16 channels 35.5 Hz to 178kHz ±15% bandwidth 100db @ 0.4dB resolution; 3×10^{-5} - $3\gamma Hz^{-1/2}$ (peak and average) 0.6 sample/second each channel 12.8 seconds out of 51.2 sec.
AC Electric and Electrostatic Waves	1m Dipole Antenna Wideband Receiver WBR	Frequency Range Amplitude Range Duty Cycle	5Hz-1kHz, 0.65-10kHz, 10-20kHz & 20-30kHz 100db @ 0.4db resolution; 3μV/m - 300 mV/m 38.4 seconds out of 51.2 sec.
	1m Dipole Antenna VLF Spectrum Analyzer (Helios) VLFR-HELIOS	Frequency Range Frequency Resolution Amplitude Resolution Temporal Resolution Duty Cycle	16 channels-31.2Hz to 178kHz ±15% bandwidth 100db @ 0.4dB resolution; 3×10^{-8} - $3 \times 10^{-3} V m^{-1} Hz^{-1/2}$ (peak and average) 0.6 sample/second each channel 100%
	1m Dipole Antenna, Mid Frequency Receiver MFR	Frequency Range Frequency Resolution Amplitude Resolution Temporal Resolution	8 channels-31.6Hz to 17.8 MHz ±30% bandwidth 70db @ 1dB resolution; 3×10^{-3} - 10 V/m (peak and average) 1.6 second/scan
VHF/UHF EMI Levels	Horn Antenna VHF/UHF Receiver HFR	Frequency Range Frequency Resolution Amplitude Resolution Temporal Resolution	4 channels—25-65, 65-160, 160-400, 400-800 MHz ±50% 70db @ 1db resolution; 10^{-2} - 30 V/m; (peak and average) 1.6 sec/scan
S-Band Field Strength Monitor SBR	Horn Antenna VHF/UHF Receiver + Mixer and L.O.	Frequency Range Amplitude Range Temporal Resolution	2000-2330 MHz .01 to 30 V/m (peak & average) 1.6 sec.
Suprathermal Particles	Low Energy Proton & Electron Differential Energy Analyzer (LEPEDEA)	Energy Range Energy Resolution Field of View Flux: Electrons Protons Temporal Resolution	2eV-50keV in 42 steps: electrons and ions 34% $6^\circ \times 162^\circ$ (7 detectors) $30-1 \times 10^7$, electrons/cm^2 sec sr eV $6-2 \times 10^8$ protons/cm^2 sec sr eV 1.6 sec for spectrum
	Electrometer	Flux Range Temporal Resolution	$10^9 - 10^{14}$ elect cm^{-2} sec^{-1} 10 samples/second
	Retarding Potential Analyzer/Differential Ion Flux Probe	Density Range Energy Range Velocity Range Temporal Resolution	$2 \times 10^1 - 1 \times 10^7$ ions cm^{-3} 0-16 eV 0-15km sec^{-1} 0.8 sec/scan; 51.2 sec/analysis
Thermal Electrons	Langmuir Probe, Density	Dynamic Range Temporal Resolution	$10^3 - 10^7$ electrons cm^{-3} 1 second sweep every 12.8 sec.
	Langmuir Probe, Density Irregularities	Scale Sizes Dynamic Range	10 meters to 100 km 80db @ 5db resolution; 10^2 - 10^8 cm^{-3}
Thermal Ions	Ion Mass Spectrometer	Dynamic Range Mass Range Temporal Resolution	$20-2 \times 10^8$ ions cm^{-3} 1-64 AMU @ < 1% overlap 1.6 seconds for mass scan
Ambient Pressure	Ionization Gauge	Pressure Range	10^{-7} to 10^{-3} torr

3.0 OVERVIEW OF ORBITER AC ELECTRIC FIELD ENVIRONMENT

In Figure 3 is presented a 30 minute summary plot of the PDP measured electric fields from 30 Hz to S-band for GMT DAY 85 20:30 to 21:00. Noted in the figure are the variety of phenomena which have been detected during the mission. Note that for each frequency, the vertical scale represents approximately 100 dB of dynamic range.

Very short bursts in the VLF range near 20:37 and 20:39 are assumed to be due to thruster firings. The changing VLF field strength from 20:30 to 20:37 has been identified as a broadband electrostatic noise which is Orbiter-attitude dependent--it peaks when the plasma is rammed into the payload bay (-Z axis parallel to velocity vector). Also very obvious in the VLF range is the increased intensity as the Fast Pulse Electron Generator (FPEG) emitts a 50 ma beam of 1 keV electrons. As the PDP is moved in and near the beam by the RMS (Remote Manipulator System), the noise is seen in the channels of the MFR. Probably these emissions occur near the electron gyrofrequency (~ 1 MHz) and the plasma frequency (3-10 MHz).

These FPEG generated plasma waves do not extend up into the HFR range, typically. At 271 MHz (165-400 MHz channel of the HFR) is seen the UHF downlink transmitter. Since the PDP is being rotated and positioned at various points just above the payload bay, it sees different S-band field strength levels as indicated.

Some of these effects are depicted in more detail in the next section.

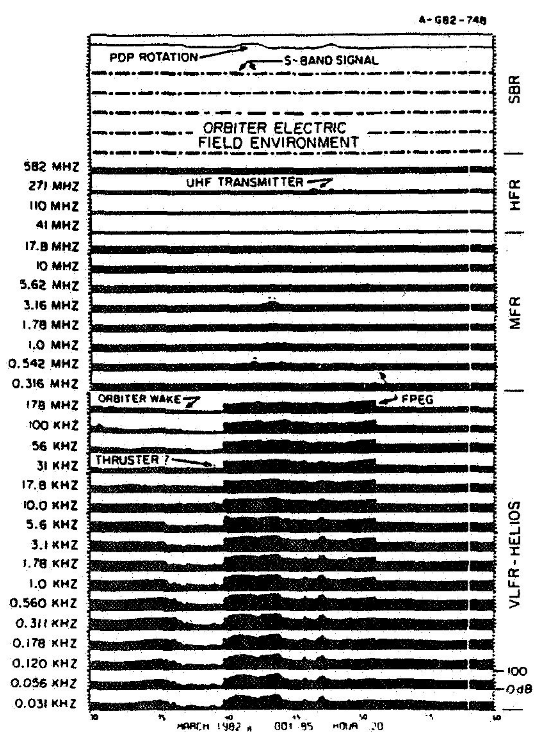


Figure 3

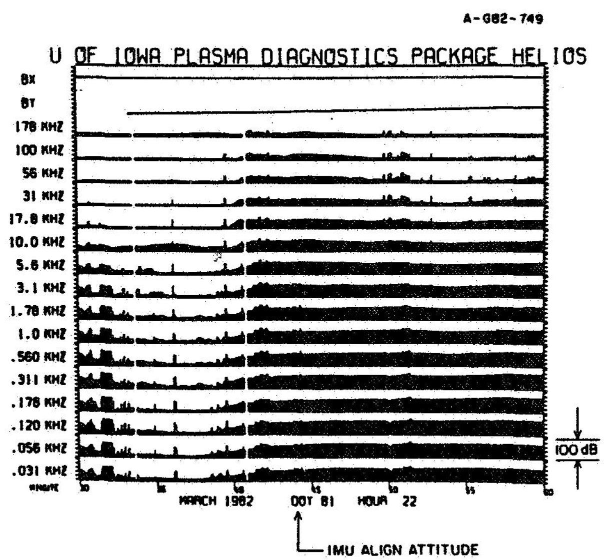
4.0 TIME VARIABILITY OF OBSERVED NOISE

The following series of figures illustrate the time variability of the VLF electric field noise from time scales of seconds to tens of minutes. Typically only the UHF and S-band transmitters are observed above 178 kHz because the receivers are less sensitive and plasma-related waves do not extend to frequency above 10 MHz. Thus waves at frequencies of a few hundred kilohertz to 20 MHz are not seen unless the FPEG is operating.

In Figure 4 is seen a ~ 60 dB overall amplitude change in the matter 10 minutes with short bursts of only seconds in duration. The overall trend is attributed to the Orbiter-attitude related electrostatic noise. Short bursts are most likely thrusters. For Figure 4, the PDP is stowed on the pallet whereas for Figure 5 the PDP is on the RMS. The overall levels are not much different but the levels do change with PDP rotation. This change indicates that the noise sources are either strongly polarized or what is more likely, localized on the Orbiter. Note that BX is a component of the earth's magnetic field which indicates the PDP rotation.

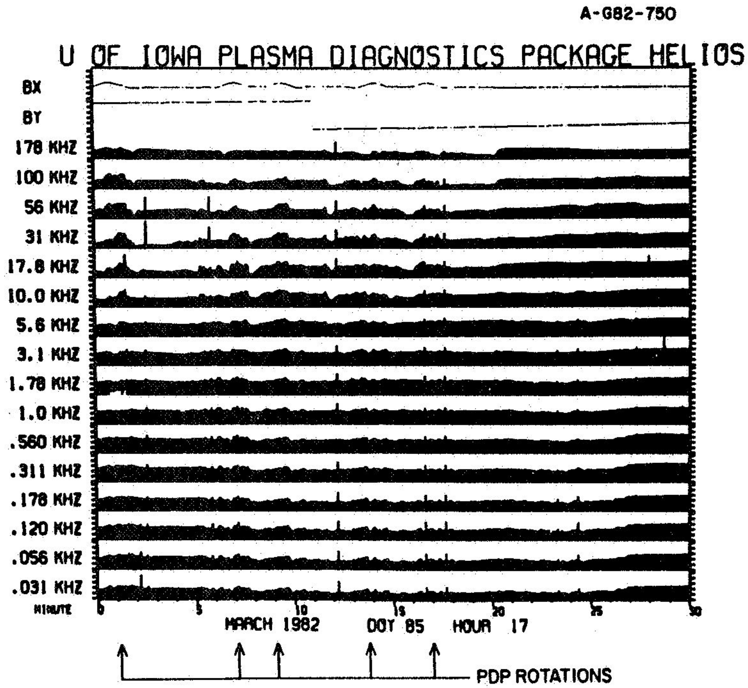
Experiment and Orbiter systems can definitely affect the signal strengths. When the FPEG operates, levels increase by ~ 20 dB. In the one case of a Primary Reaction Control System (PRCS) jet firing at GMT DAY 85 14:36, the noise actually decreases at the higher frequencies. The momentary gas output may moderate the Orbiter interaction with the plasma which produces the broadband electrostatic noise.

Evidence that the broadband electrostatic noise is not due to an Orbiter subsystem or instrument is presented in Figure 7 at the time of a payload bay door closing. During this three minute interval, the noise dropped below the receiver noise levels at all frequencies. Consequently, the noise does not originate inside the bay; it is shielded by the doors. When the doors are opened, the noise returns. If this noise is a significant problem to payload instrumentation, it can be minimzed by directing the bay away from the velocity vector.



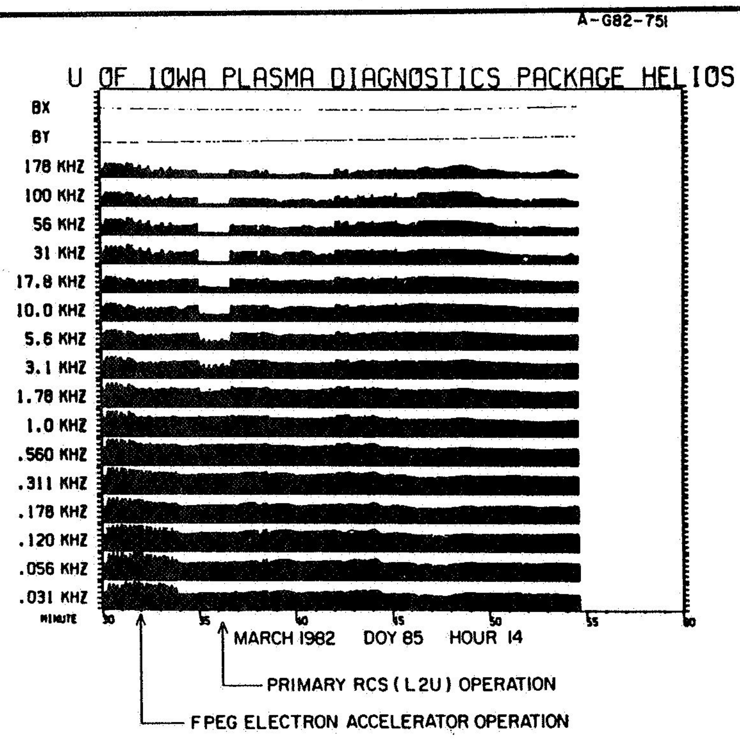
NOISE TIME VARIABILITY WITH THRUSTERS

Figure 4



SIGNAL STRENGTH VS PDP ROTATION

Figure 5



BACKGROUND NOISE MODULATION

Figure 6

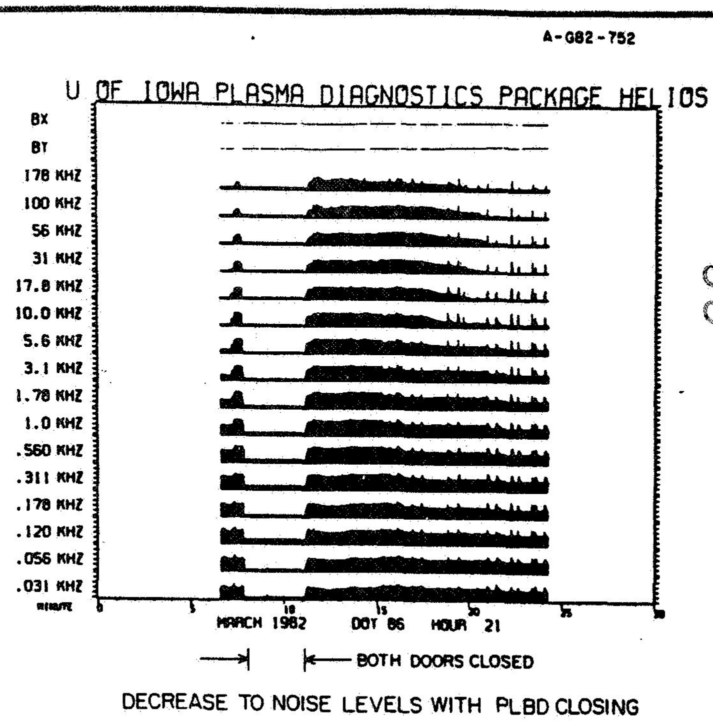


Figure 7

5.0 SPECTRUM OF ELECTROMAGNETIC NOISE

Use has been made of the Wideband Analog Receiver (WBR) to determine the spectral nature of the electric field and magnetic field noise. Spectra covering 0 to 30 kHz for several minutes of time are shown in Figure 8. The magnetic field noise shows intense lines with spacings of Hz, kHz, 10's kHz, and harmonics. Further work is in progress to identify the exact frequencies and their change with time. It is surmized that these lines are associated with data clocks and power converters.

On the other hand, the electric field spectra show a "white noise" characteristic which does not change much with time. During the payload bay door closing, weak spectral lines were evident since the external broadband noise was screened out. Note that the WBR has an automatic gain control so that the amplitude variations of Figure 4, for example, are not evident.

By searching over extended periods while the PDP was stowed on the pallet, values for the minimum and the maximum noise levels have been obtained and displayed in Figure 9. These values are calibrated in volts per meter and normalized to a 1 MHz bandwidth. The electric scales as 20 log (electric field), whereas, the bandwidth scales as 10 log (bandwidth) as the data are presented. Also plotted for comparison are the broadband electric field limits for the Shuttle itself and for a payload. When the FPEG is not operating, above the 14 kHz cutoff, the maximum level (open circles) does not exceed the payload limit. When the FPEG operates with the PDP in the beam, the levels are increased by ~ 20 dB in the VLF range.

Narrowband magnetic field strengths are much less variable (< ± 10 dB) from the minimum to maximum observed levels. These levels are not Orbiter-attitude dependent and in fact, the levels were above the maximum door-opened levels with the payload bay doors closed. It is surmized that these levels are due to Orbiter subsystems which should be slightly time dependent as systems turn ON/OFF. During FPEG operations, levels in the 1-100 kHz range are increased.

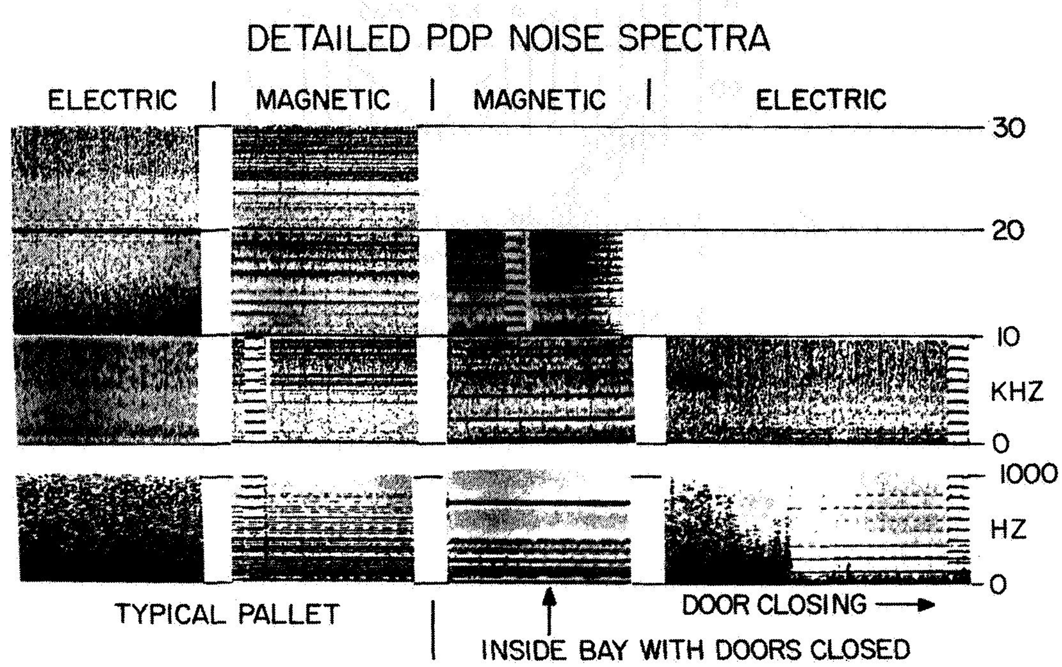


Figure 8

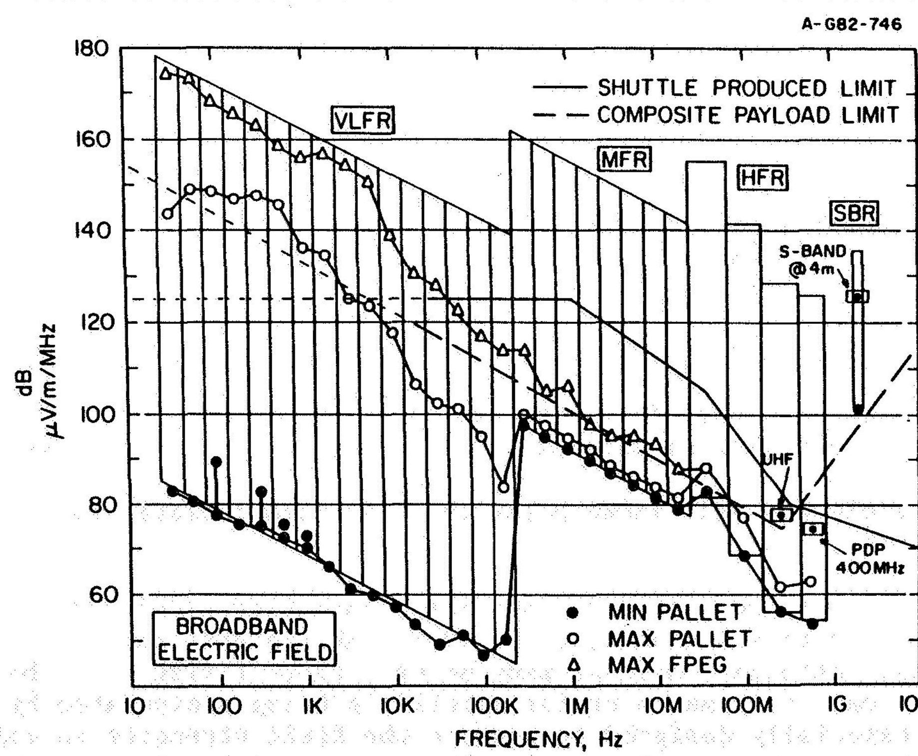


Figure 9

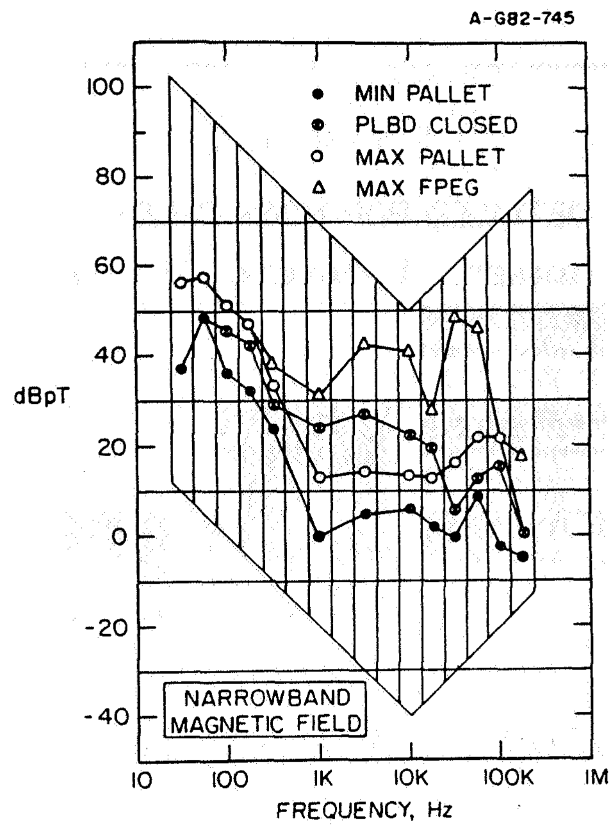


Figure 10

6.0 UHF AND S-BAND TRANSMITTER FIELD STRENGTHS

One filter channel of the PDP HFR covered the band of 165-400 MHz which includes the 295 MHz frequency of the UHF voice downlink transmitter. When this transmitter was keyed ON and connected to the upper antenna, a signal was detected by the PDP as shown in Figure 3. These measured field strengths were always below 0.5 V/m with the PDP on the RMS and below 0.1 V/m at the PDP pallet location. Average and peak field strengths are given in the following table:

Location/Field Strengths ± 2dB	Average	Peak
PDP on Pallet at 13 meters from Antenna	.05 V/m	0.08 V/m
PDP on RMS at 8 meters from Antenna	.23	.44

These levels are well known below the suggested radiated susceptibility field strengths.

At S-band, the 150 watt data downlink transmitter (2287.5 MHz) can produce fields which are modeled to be 49.6 V/mR (meters) in the beam of the selected "quad" antenna. Even at many meters, these fields could be at damage level for payload instruments or for satellites being manipulated by the RMS. The SBR was especially designed to measure the field strengths in and around the payload bay as shown in Figure 3. These measured levels were about 5 dB ± 2 dB higher than the modeled values but comparable to a crude theoretically calculated value as follows:

	Field Strengths Relations (V/m)
Predicted Field Strengths	49.6 /R (meters)
Measured with PDP (± 2 dB)	90.3 /R (meters)
Calculated @ (150 Watts)	94.9 /R (meters)

The calculated value assumes that all of the power is emitted into a hemisphere (2 π steradians) with 100% efficiency.

In the antenna beam, the fields exceed 20 V/m inside of 5 meters. However, with the PDP on the pallet at a range of 13 meters off the edge of the beam, the fields were not observed at the threshold of 2 V/m whereas the in-beam prediction would be 7V/m. Consequently, payload bay instrumentation is not subjected to damage levels.

7.3 HFR

Because of the variety of bandwidths, the dynamic range is listed in the following table:

Center Freqency	Bandwidth	Minimum	Maximum	Slope
40 MHz	20 - 65 MHz	-40 dBV/m	+32 dBV/m	16 dB/V
100	65 - 165	-40	+32	16
250	165 - 400	-31	+41	16
600	400 - 800	-22	+52	16

dBV/m ~ Maximum dB + 16 dB V/m * Output Voltage -80 dB

7.4 SBR

Only the linear detector on the S-band system operated. An RF relay failure prevented the S-band signal from getting to the log-detector. Using calibrations at GSFC and Iowa before flight and re-calibration after flight, it is determined that the linear response is

V/m = 5.7 * Output Voltage at 2287.5 MHz Boresight

giving a fit to the field with range of about

$$V/m = \frac{90\ V/m}{R\ (meters)}$$

where R is the distance from the S-band quad antenna in the nominal beam.

8.0 COMMENTS

Comprehensive sets of Orbiter noise spectrum measurements have been obtained. It is found that the noise levels do not exceed the worst case predictions for the Orbiter. Consequently, the receivers really need to be more sensitive to obtain the science and the EMI data on Spacelab-2 especially since the PDP measures the Orbiter at 100 meters range. It is hoped that these improvements in sensitivity can be made for Spacelab-2.

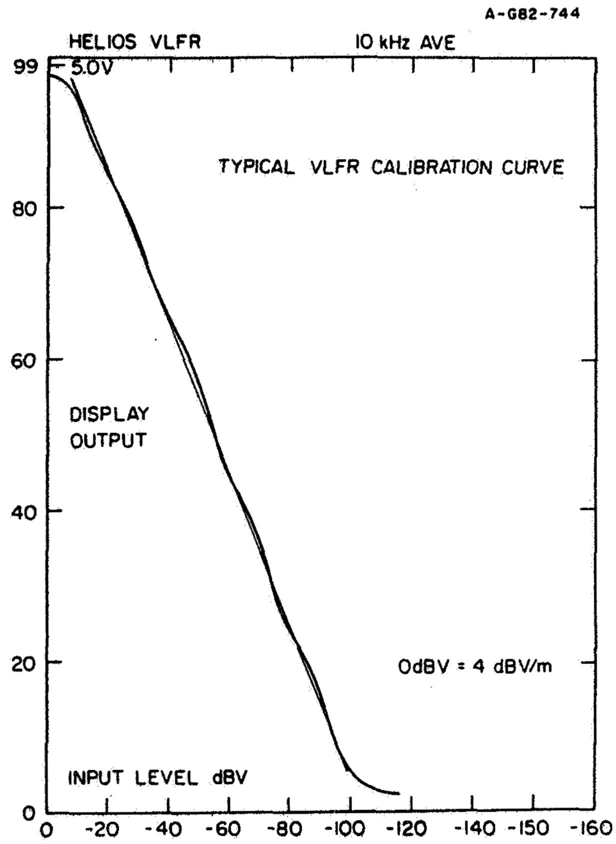

A-G82-744
HELIOS VLFR
10 kHz AVE
99
5.0V
TYPICAL VLFR CALIBRATION CURVE
80
60
DISPLAY
OUTPUT
40
20
OdBV = 4 dBV/m
INPUT LEVEL dBV
0
0
-20
-40
-60
-80
-100
-120
-140
-150
-160

Figure 11

ADDITIONS TO
DR. S. SHAWHAN
PRESENTATION

TABLE 4

STS-3/PDP RECEIVER CHARACTERISTICS

VERY LOW FREQUENCY (VLFR)

- DOUBLE SPHERE ANTENNA FOR ELECTRIC FIELD
- SEARCH COIL ANTENNA FOR MAGNETIC FIELD
- 16 CHANNELS (x2 SYSTEMS)
- 30 HZ TO 178 KHZ
- WIDEBAND RECEIVER 30 HZ TO 30 KHZ

MEDIUM FREQUENCY RECEIVER (MFR)

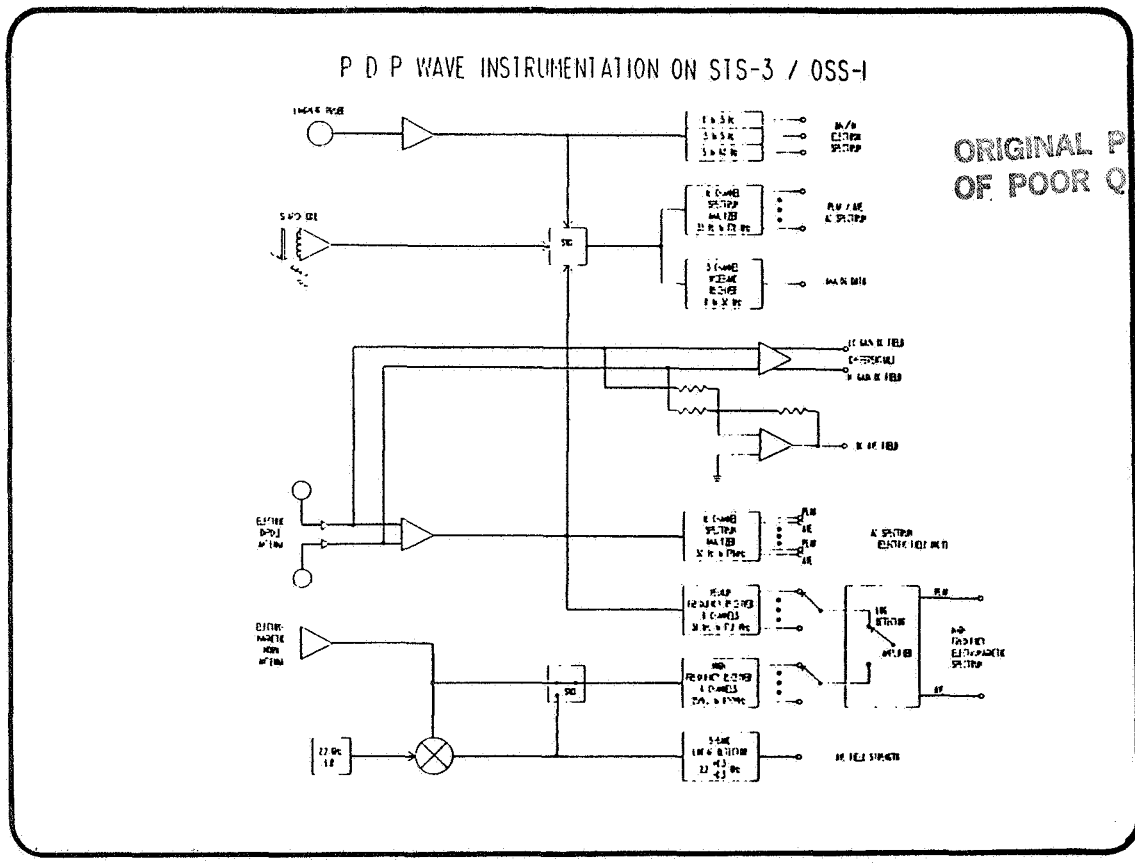
- 8 CHANNELS
- 311 KHZ TO 17.8 MHZ
- 65 DB DYNAMIC RANGE

HIGH FREQUENCY RECEIVER (HFR)

- 4 CHANNELS
- 20 MHZ TO 800 MHZ

S-BAND RECEIVER (SBR)

- 4 CHANNELS WITH LOG DETECTOR (FAILED)
- 1 CHANNEL WITH LINEAR DETECTOR
- ~ 2200 MHZ ± 300 MHZ


P D P WAVE INSTRUMENTATION ON STS-3 / OSS-1

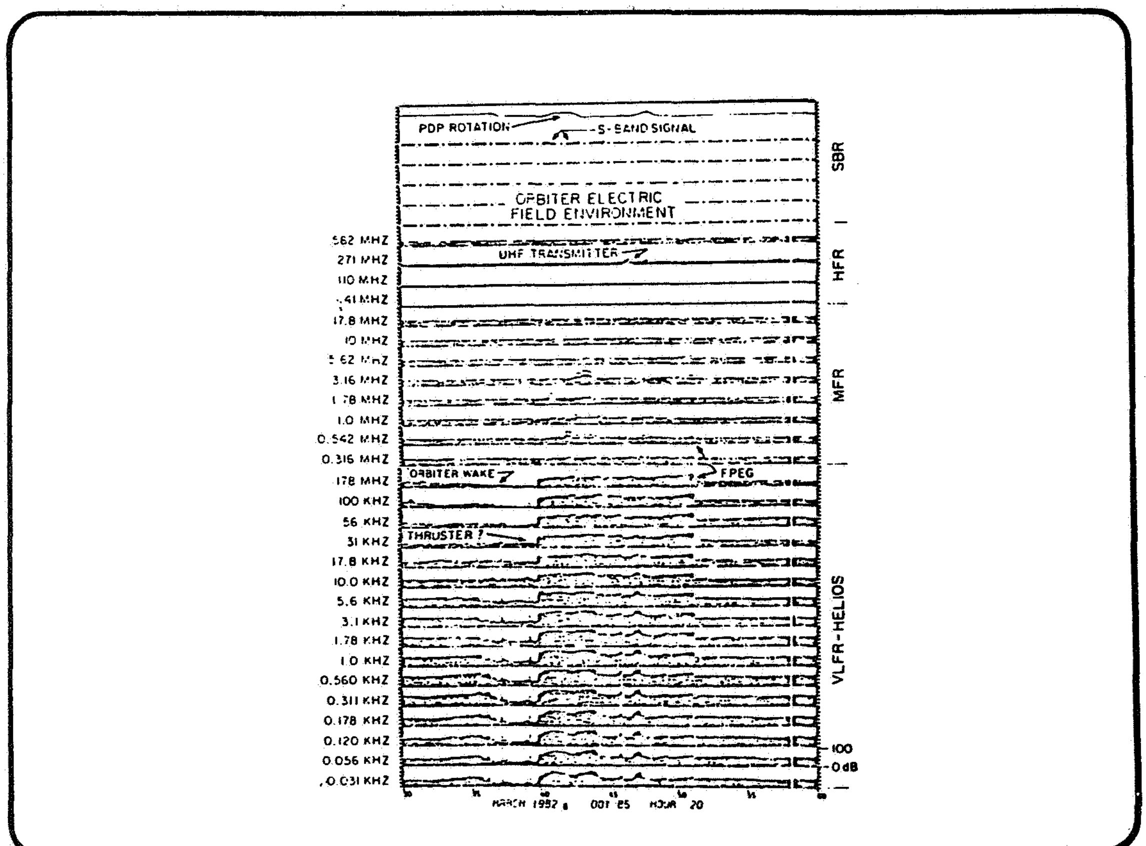

PDP ROTATION
S-BAND SIGNAL
SBR
ORBITER ELECTRIC
FIELD ENVIRONMENT
UHF TRANSMITTER
HFR
MFR
ORBITER WAKE
FPEG
THRUSTER ?
VLFR-HELIOS
562 MHZ
271 MHZ
110 MHZ
17.8 MHZ
10 MHZ
3.16 MHZ
1.0 MHZ
0.542 MHZ
0.316 MHZ
100 KHZ
56 KHZ
31 KHZ
17.8 KHZ
10.0 KHZ
5.6 KHZ
3.1 KHZ
1.78 KHZ
1.0 KHZ
0.560 KHZ
0.311 KHZ
0.178 KHZ
0.120 KHZ
0.056 KHZ
0.031 KHZ
100
0 dB
MARCH 1982
HOUR 20

TABLE 17

ORBITER-GENERATED ELECTROSTATIC NOISE

- OBSERVED CHARACTERISTICS

Δ SPECTRAL EXTENT	- 30 HZ TO 178 KHZ
Δ SPECTRAL PEAK	- 0.1 V/M @ 0.3 KHZ
Δ VARIABILITY	- 70 DB OVER ORBIT
Δ MAGNETIC COMPONENT	- NONE DETECTABLE OVER ORBITER MAGNETIC FIELD EMI
Δ LOCATION	- COMPLETELY DISAPPEARS WITH PAYLOAD BAY DOOR CLOSED; IMPLIES EXTERNAL TO ORBITER
	- NO SIGNIFICANT DIFFERENCE WITH PDP ON RMS: IMPLIES GENERATED IN LARGE VOLUME
Δ THRUSTER RESPONSE	- HIGH FREQUENCIES (> 10^4 KHZ) ARE ATTENUATED DURING FIRINGS
	- LOW FREQUENCIES ENHANCED IF NOT ALREADY PRESENT
Δ ORBITER ATTITUDE DEPENDENCE	- MAX INTENSITY ~ RAM
	- MIN INTENSITY ~ WAKE
	- SEE LOW FREQUENCY AT ALL ATTITUDES EXCEPT EXACTLY WAKE
	- SEE HIGH FREQUENCY ONLY ~ RAM

- TENTATIVE INTERPRETATION

Δ WAVE MODE	ION ACOUSTIC
Δ PHASE/GROUP VELOCITY	$V \sim 2 \times x\ 10^3$ M/SEC
Δ MINIMUM WAVELENGTH	λ (MIN) ~ $2\pi\lambda$ (DEBYE)
	λ (MIN) ~ 0.02 METERS
Δ MAXIMUM DOPPLER SHIFT FREQUENCY	F (MAX) ~ V/λ (MIN) ~ 100 KHZ
Δ MAXIMUM WAVELENGTH	λ (MAX) ~ 10 LARMOR RADII
Δ MINIMUM FREQUENCY	F (MIN) ~ V/λ (MAX) ~ 30 HZ

- POSSIBLE ORBIT ENERGY DISSIPATION

Δ ENERGY DENSITY (STIX)	$W = \frac{\pi i^2}{\omega^2} \bullet \left\{\frac{1}{2} \bullet \varepsilon_o \bullet E^2\right\}$ (MKS)
	$W \sim \left(\frac{50\ \text{kHz}}{300\ \text{Hz}}\right)^2 \bullet \frac{1}{2} \bullet 9 \times 10^{-12} \bullet (0.1\ \text{V/M})^2$
	$W \sim 1 \times 10^{-9}$ Joules/m^3
Δ VOLUME ESTIMATE	$V \sim (10$ LARMOR RADII$)^3 \sim (R_i)^3$
	$V \sim 2.2 \times 10^5\ m^3$
Δ TOTAL ENERGY/VOLUME	$W.V \sim 3 \times 10^{-4}$ Joules
Δ POWER	$P = \frac{W.V}{10R_i} \bullet$ Velocity
	$P \sim 4 \times 10{-}2$ WATTS

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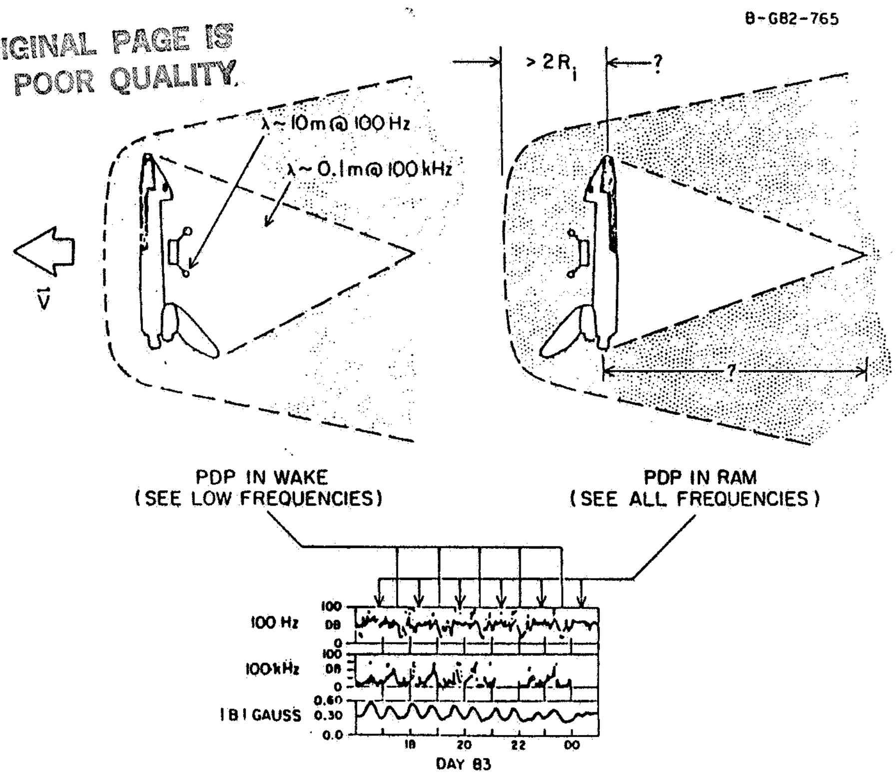

TABLE 9A

UHF/S-BAND TRANSMITTER FIELD STRENGTHS

UHF VOICE LINK (165-400 MHZ)

- PALLET LOCATION: < 0.1 V/METER
- RMS SCANS: < 0.5 V/METER

S-BAND COMMUNICATIONS LINK (2200 ± 300 MHZ)

	V/M @ 1M
• MEASURED WITH PDP (± 2 DB)	90.3
• EXPECTED @ 150W	49.6
• CALCULATED @ 150W (100% INTO HEMISPHERE)	94.9