Measurements of Electromagnetic Interference on OV102 Columbia Using the Plasma Diagnostics Package

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The Plasma Diagnostics Package (PDP) of the Office of Space Science-1 (OSS-1) payload included a complement of receivers covering the frequency range of 30 Hz to 800 MHz and S-band at 2200 ± 150 MHz to assess the intentional (transmitter) and unintentional (subsystem) electromagnetic interference (EMI) levels on the Space Shuttle Columbia's STS-3 mission. The following results were noted: at the pallet location, the uhf voice downlink transmitter field strengths did not exceed 0.1 V/m; on the remote manipulator system (RMS) arm the PDP measured less than 0.5 V/m; above 300 kHz Orbiter subsystem noise was not detected at the receiver noise levels (80 dBμV/m/MHz) which was well below the Interface Control Document (ICD) specification limits for the Shuttle; below 300 kHz the magnetic field noise was 30 dB pT ±20 db (due to power converters and clocklines) also below the worst-case specifications; below 300 kHz the electric field noise was broadband and variable over at least 60 dB depending on thruster firings and Orbiter attitude. This noise may have been generated by the Orbiter interaction with the ambient plasma; emissions stimulated by the OSS-1 fast pulse electron generator electron beam were ~20 dB above Orbiter associated levels at all frequencies <60 MHz.

Introduction

USERS of the STS Space Shuttle are concerned about the possible high levels of electromagnetic interference produced by the Orbiter subsystems. Interface Control Document curves for the worst-case electric field and magnetic field emissions are available in Ref. 1. Especially for space plasma investigations, which make use of sensitive plasma wave receivers,[2] emissions at the ICD specification limits would limit the dynamic range of the potential experiments. Because of these concerns, early measurements of the OV101 (Enterprise) EMI levels were carried out during the Orbiter's hardware development phase. Although the measurements were not complete in frequency range and did not include all on-orbit operating subsystems, the levels detected in the 10 MHz to 10 GHz range were significantly less than the proposed ICD worst-case specifications.[3] Consequently, the ICD specifications were revised downward in this frequency range.[1]

One of the primary objectives of the Office of Space Science-1 (OSS-1) Plasma Diagnostics Package on the third Shuttle mission was to measure the radiated EMI of the Orbiter Columbia on orbit, to interpret these measurements in terms of possible sources, and to compare these levels with the ICD worst-case specifications.[4] This report presents the results of an initial analysis of the PDP measurements from the STS-3 mission in March 1982. Some additional aspects of the Columbia EMI environment are available in other references.[5,6]

Received June 3, 1983; revision received Nov. 8, 1983.

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Description of PDP Receiver Systems

Sensors for the detection of magnetic and electric wave fields are identified in Fig. 1 which is an on-orbit picture of the OSS-1 pallet. Two spheres of 20 cm diameter, separated by 1.6 m, make up the electric dipole antenna which is utilized from dc to 20 MHz. For frequencies in the range 20-2300 MHz, a broadband single polarization horn antenna is used. 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 fluctuations in the electron density (plasma oscillations) over a frequency ranging from dc to 178 kHz.

A block diagram of the PDP sensors and associated receivers is shown in Fig. 2. One very low frequency (VLF) range spectrum analyzer from the NASA/IMP program is switched between the electric dipole, the searchcoil and the Langmuir probe sensors every 51.2 s to provide 16 channels of VLF spectra—30 Hz to 178 kHz. In addition, the waveform is preserved in the wideband receiver (WBR) and these analog data are included in the PDP data stream. The WBR switches 10 kHz bands sequentially covering 0-10, 10-20, and 20-30 kHz for each sensor. A second VLF receiver from the HELIOS spacecraft program (VLF-HELIOS) is always connected to the electric dipole giving a redundant peak and an average spectrum of the electric field every 1.6 s. Both spectrum analyzers have channels spaced logarithmically in frequency at four/decade with a 3.1, 5.6, 10, 17.8 center frequency sequence and a ±15% bandwidth.

The electric dipole also drives the medium frequency receiver (MFR) which covers 316 kHz to 17.8 MHz in eight channels also spaced logarithmically in frequency at four/decade with a ±30% bandwidth. This MFR shares a log detector video amplifier with the high frequency receiver (HFR) which has four broadband channels spanning the range 20-800 MHz. Both peak and average spectra are obtained from the MFR and HFR every 1.6 s. The HFR as well as the S-band receiver makes use of the horn antenna. This horn antenna is a broadband, folded, tapered dipole which was designed by the U.S. National Bureau of Standards in Boulder, Colorado. For redundancy purposes, S-band field

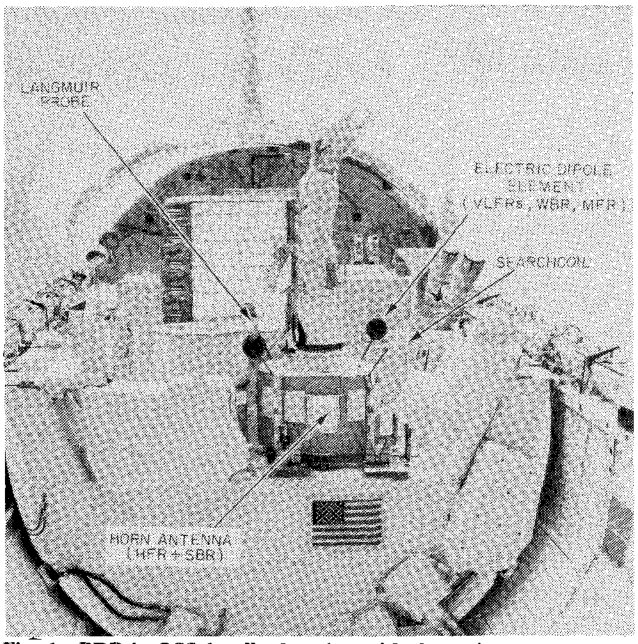

Fig. 1 PDP in OSS-1 pallet location with the various wave sensors identified.

strengths are also measured by a linear detector covering the range 1-72 V/m in a frequency band of 2200 ± 150 MHz. Details of the S-band receiver and results are given by Murphy and Shawhan.[7]

Overview of Orbiter ac Electric Field Environment

Figure 3 depicts in one 30-min time interval an example of the different types of electric field noise typically seen by the PDP. The 16 channels of the VLF spectrum analyzers are shown (VLFR-HELIOS), eight channels of the MFR, and four of the HFR. S-band results are discussed in detail in Ref. 7 and are not shown here. Note the scale is logarithmic in amplitude with 100 dB dynamic range for the VLFR and 80 dB for the MFR and HFR. Details such as minimum sensitivity level of each channel are given in Table 1 and are useful for getting an order of magnitude estimate of the field strength from the figure.

Several phenomena are evident in Fig. 3. The short bursts of noise at 04:37 and 04:39 result from attitude control thruster firings. The general decrease in noise at all VLF frequencies between 04:36 and 04:40 is a result of the PDP being situated in the Orbiter wake. The increase in noise at all VLF frequencies and the bursts of noise in the MFR between 04:40 and 04:51 illustrate the effect of firing the 100 W

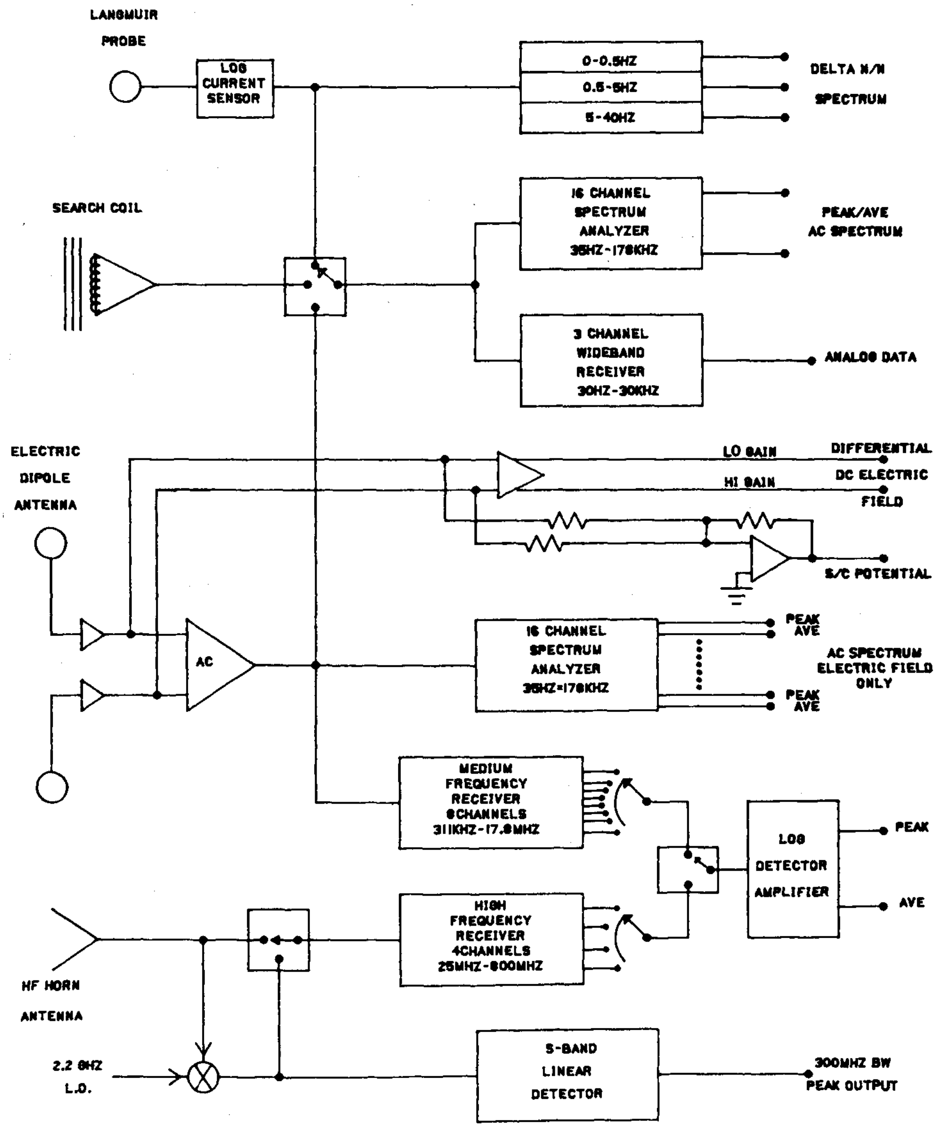

Fig. 2 Block diagram of the PDP wave sensors and receivers.

electron gun (FPEG) which was part of the vehicle charging and potential (VCAP) experiment. The PDP rotation which is evident by the change in magnitude of one magnetic field component plotted along the top of the figure shows that there is a certain degree of polarization to the waves in the MFR but less in the VLFR.

The uhf transmitter is detected when keyed on and registers in the 271 MHz channel. Only this uhf transmitter and an occasional ground transmitter are observed above the plasma frequency which is approximately 10 MHz for the ambient ionospheric plasma density at the Orbiter's altitude. The next figures and text section examine some of these observations in more detail.

Electric Field Details

Figure 4 illustrates further that the broadband electrostatic noise is extremely variable in amplitude. There is a 60-80 dB variation in intensity over a period of approximately 10 min. The noise seems most certain to be generated by the Orbiter as it flies through the plasma[9] and is strong, but variable as long as the PDP is not in the Orbiter's wake. When in the deep wake, the noise disappears entirely and it is encouraging to note that at this time no Orbiter subsystems, whose EMI may previously have been masked, are evident at any frequency.

Figure 5 presents data taken during a time when the payload bay doors were closed for several minutes. Note that the broadband electrostatic noise is gone and only very low level signals are seen, which is further evidence of the relative cleanliness of the vehicle from an EMI standpoint, and that the broadband electrostatic noise is generated externally.

Another important phenomenon in Fig. 5 is the high frequency of thruster firings. Figure 3 leads one to believe that attitude thruster events are infrequent; however, Fig. 5 presents data which is much more typical. These noise spikes actually last for several seconds and in a typical 10-min interval will occur from 1 to 10 times depending on the deadband setting of the autopilot. A detailed discussion of thruster plasma effects is available in Ref. 10.

In summary, electric field spectral characteristics are always dominated by noise from an Orbiter-plasma interaction or attitude control system thruster firings.

Magnetic Field Observations

Figure 6 is a reproduction of the WBR data from dc to 30 kHz. Note again evidence that a typical pallet measurement of electric field noise is "white" even with the payload bay doors closed. Only at very low frequencies is there any spectral content evident and then only when the automatic gain control has turned on maximum receiver gain. The magnetic component however indicates the "line spectra" nature of emissions detected by the searchcoil. Some, but not all lines have been identified and are invariably associated with instrument power converters or the 400 Hz ac Orbiter bus. The frequencies that are present change as instruments and

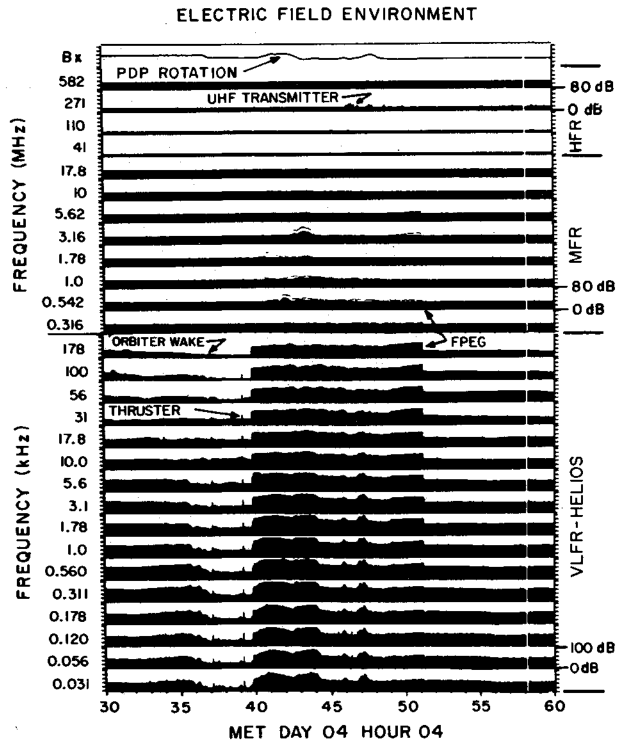

Fig. 3 Overview of the STS-3 Orbiter electric field environment as detected with the PDP.

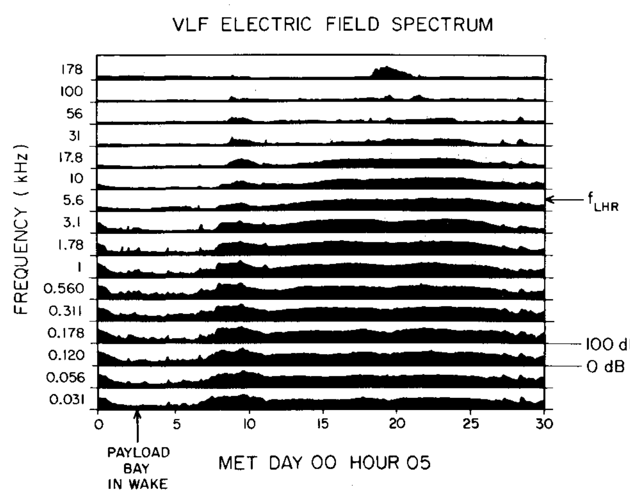

Fig. 4 Variability of electrostatic noise with plasma wake associated decrease.

Table 1 PDP wave receiver characteristics

Receiver	Center frequency	Bandwidth	Saturation level, dB μV/m (at 5 V out)	Sensitivity, dB/V
VLFR	1, 1.78, 3.1, 5.6 in log sequence from 31 Hz to 178 kHz	±15%	120	20
MFR	1, 1.78, 3.1, 5.6 in log sequence from 311 kHz to 17.8 MHz	±30%	150	16
HFR	40 MHz	25-65 MHz	172	16
	100 MHz	65-165 MHz	161	
	250 MHz	165-400 MHz	153	
	600 MHz	400-800 MHz	152	

systems cycle on and off. The next section discusses the amplitude of these emissions.

Comparison to ICD Specifications

By searching the periods of time while the PDP was stowed on the pallet, values for the minimum (solid circles) and the maximum electric field (open circles) noise levels have been obtained and are displayed in Fig. 7. These values are calibrated in microvolts per meter and normalized to a 1 MHz bandwidth. The receiver channels and dynamic ranges are also indicated by the vertical boxes. Also plotted for comparison are the broadband electric field limits for the Shuttle itself and for a payload. Extrapolations are shown below the 14 kHz spec limit. When the FPEG is not operating, the maximum level (open circles) does not exceed the payload limit above 14 kHz. When the FPEG operates with the PDP manipulated by the RMS to be in the beam, the levels are increased by ~20 dB in the VLF range as indicated by the triangles. This situation of course would not occur in a typical mission.

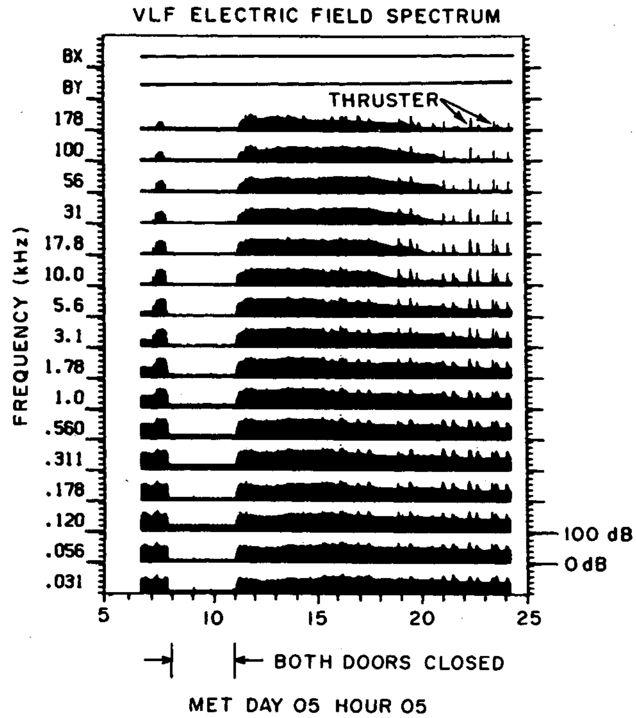

Fig. 5 Electrostatic noise disappears when the payload bay doors are closed and is more intense during thruster firings.

Narrowband magnetic field strengths are much less variable (±10 dB) from the minimum (solid circles) to maximum (open circles) observed levels as seen in Fig. 8. These levels are not Orbiter-attitude dependent and unlike the electric field emissions, the levels were higher with the payload bay doors closed. It is surmised that the magnetic field levels are due to Orbiter subsystems which should be slightly time dependent as systems turn "on/off." All subsystem and payload levels fall well below the Orbiter specifications limit up to 50 kHz.

When the FPEG operated, the magnetic levels did increase by as much as 30 dB in the frequency range 1-100 kHz. However, these emissions were due primarily to the wave stimulation which produced induction fields in the kHz range and at harmonics. Only at 30 kHz and above did these fields exceed the specification limits.

One filter channel of the PDP HFR covered the band of 165-400 MHz which included the 295 MHz frequency of the uhf voice downlink transmitter. As discussed previously, when this transmitter was keyed "on" and connected to the Orbiter upper antenna, a signal was detected by the PDP (Fig. 3). These measured peak field strengths were always below 0.5 V/m with the PDP on the RMS at 8 m from the radiating antenna and below 0.1 V/m at the PDP pallet location which was 13 m from the radiating antenna. These levels are well below the 2 V/m radiated susceptibility field strengths anticipated in this frequency range.

At S-band, the 150 W data downlink transmitter (2287.5 MHz) can produce fields which are modeled to be 49.6 V/m/R (with R distance in meters) in the beam of the selected "quad" antenna.[7] 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. A detailed report on these measurements and models is given by Murphy and Shawhan.[7]

Summary

Receivers on the Plasma Diagonostics Package covering the frequency range from a few hertz to 2 GHz for electric fields and from a few hertz to 200 kHz for magnetic fields monitored the Orbiter Columbia and the OSS-1 payload on

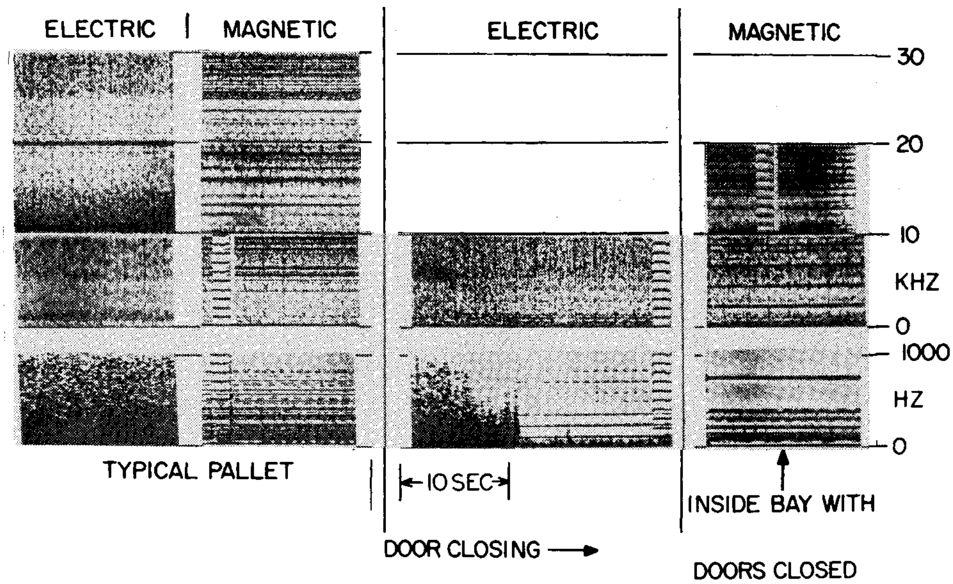

Fig. 6 Detailed spectra of electric and magnetic field noise in the frequency range of 0-30 kHz.

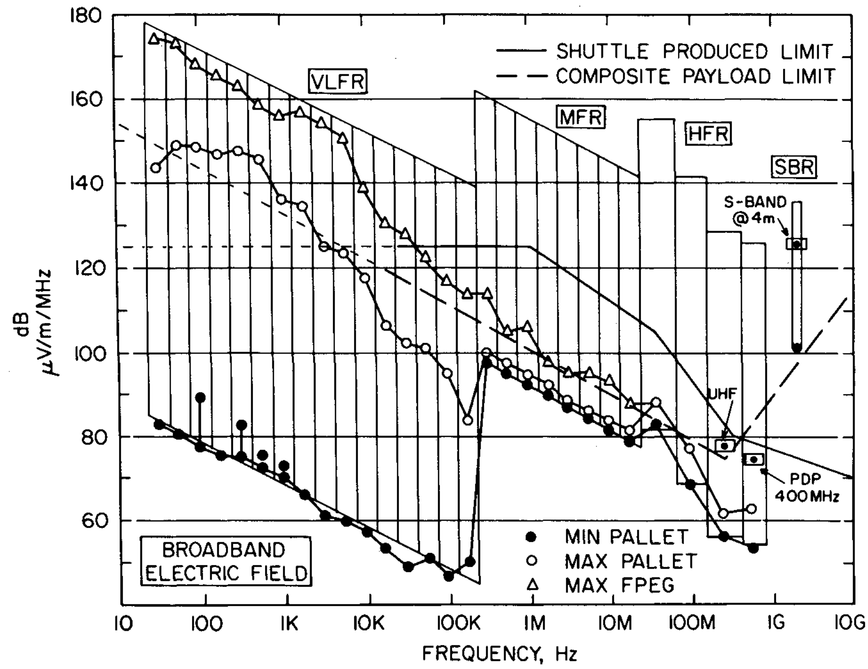

Fig. 7 Minimum and maximum electric field noise levels for PDP at pallet location.

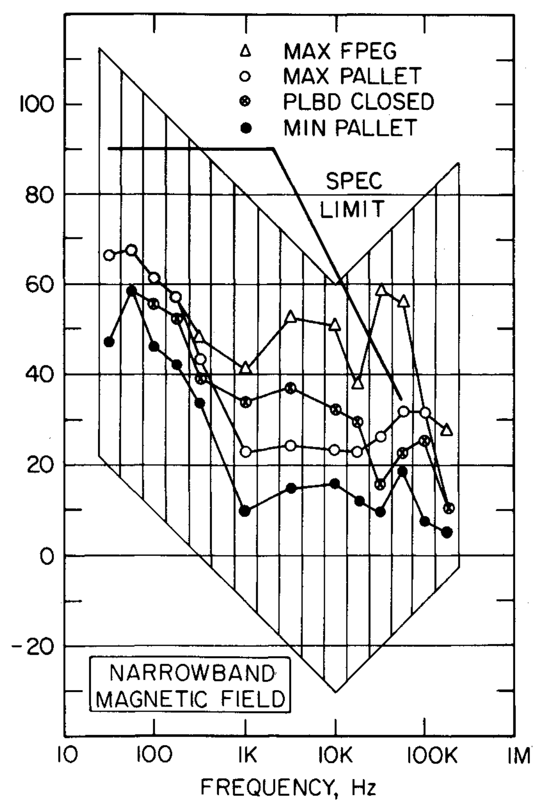

Fig. 8 Minimum and maximum values of the narrowband wave magnetic field strength at the PDP pallet location.

the STS-3 Shuttle mission. Under nominal operating conditions, the Orbiter and payload systems emissions did not exceed the ICD worst-case specification limits. When the 100 W fast pulse electron generator was operated, emission levels increased by 20-30 dB probably due to induction fields from the electron beam. Even these intentional emissions were within acceptable limits.

A broadband electrostatic noise with fields up to 10 dB V/m/MHz in the range from 30 Hz to 100 kHz was discovered to be generated by the Orbiter's motion through the ambient ionospheric plasma and dominated electric field spectra.

The Plasma Diagnostics Package is scheduled for a reflight in 1985 as part of the Spacelab-2 mission on STS-24. It will make measurements at its pallet location, on the RMS, and as a free-flying satellite. Several upgrades are being implemented. A Ku-band has been added to measure the field strength in and around the payload bay at ranges of 100 m to 2 km from the Orbiter. Within the Ku-band transmitting antenna beam fields up to 275 V/m are predicted. The S-band receiver is to have a dedicated horn antenna and a wider dynamic range receiver. The high frequency receiver is to be eliminated in order to improve the time resolution and the sensitivity of the medium frequency receiver. Both the MFR and the two VLF receivers will have improved sensitivities since the dipole antenna will have a tip-to-tip length of approximately 4 m when the PDP is in the free-flyer configuration. The MFR will also have a 20 dB gain preamp which will increase its sensitivity further.

Many of the STS-3 measurements will be repeated to verify the general results, to determine differences in EMI levels with the Spacelab payload, and to explore hypotheses about the noise sources. In addition, more comprehensive measurements of emission from the FPEG electron beam will be made out to a range of 2 km from the Orbiter.

Acknowledgments

The authors wish to thank our co-investigator, Dr. Donald Gurnett, for providing the flight spare VLF receivers from the HELIOS and IMP spacecraft programs. We also thank our engineers Daniel Odem, Allen Huneke, Michael Miller, Miles Bailey, and Kerry Neal for carrying out the necessary receiver design and refurbishment. Receiver calibration was carried out at NASA Goddard Space Flight Center by Gerry Taylor. Thanks to Arthur Reubens of NASA Johnson Space Center and Theodore Pumphrey of Rockewell International for their advice on the interpretation of the measurements.

Support for the PDP on the STS-3/OSS-1 mission was provided through NASA Marshall Space Flight Center Contract NAS8-32807. OSS-1 mission management was provided by NASA Goddard Space Flight Center.

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