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Modulated beam injection from the space shuttle during magnetic conjunctions of STS 3 with the DE 1 satellite

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An electron beam emitted from the Office of Space Sciences 1 pallet on STS 3 was pulsed with specially designed very low frequency (VLF) formats in an attempt to generate whistler mode waves. Modulated operations of the beam emitted by a fast pulse electron generator (FPEG) were initiated during times of magnetic conjunctions between STS 3 and the high-altitude DE 1 satellite equipped with broadband VLF receivers. Coordinated FPEG/VLF modulation and DE 1 wideband data acquisition were achieved in 12 different cases. No evidence of any waves generated by FPEG were detected on the DE 1 analog wideband data. However, it is shown that in all of the cases, either the STS 3 attitude was such that the emitted electrons struck the main body of the vehicle, or it was not possible for whistler mode waves to propagate from the STS 3 location up to the vicinity of the DE 1 satellite.

1. INTRODUCTION

In the last 14 years there have been more than 20 experiments involving the emission of particle beams from rockets and satellites. In addition there have been supporting experiments in large vacuum chambers (Bernstein et al., 1975, 1978, 1979; Banks et al., 1982; Raitt et al., 1982).

The space-borne particle beam experiments have been mainly directed at studies to produce artificial aurorae such as the Precede and Excede programs (O'Neil et al., 1978, 1982); to study magnetic and electric reflection such as the Echo program (Winckler, 1975, 1980, 1982) and Polar program (Maehlum et al., 1980); and a combination of the two studies in the Artificial Radiation and Auroras Between Kerguelen and the Soviet Union (ARAKS) (Cambou et al., 1980) and Kaui (Davis et al., 1980) programs.

Experiments on wave stimulation have been mainly limited to excitation of electrostatic waves due to the beam plasma interaction. These experiments on satellites include EXOS-B (Kawashima et al., 1982), SCATHA (Koons and Cohen, 1982) and ISEE-1 (Lebreton et al., 1982). Some experiments on sounding rockets have included beam modulation in the VLF range (Bernstein et al., 1982; Holzworth et al., 1982).

In this paper we report on modulated beam experiments performed on a recent flight of the space shuttle when attempts were made to detect waves propagating from the space shuttle to a magnetically linked satellite as a result of pulsing an electron gun at frequencies in the VLF range. The experiments were carried out successfully, but positive results were not obtained in the sense that no evidence of any beam-generated signals was observed on the satellite receivers. Although in this sense our results do not advance the state of knowledge, we have found it valuable to publish them as a primer for future efforts.

As part of the Vehicle Charging and Potential (VCAP) Experiment, the oFfice of Space Sciences (OSS 1) pallet on the third flight of the space shuttle (i.e.,

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Space Transportation System (STS) 3) included a fast pulse electron generator (FPEG) [Neupert et al., 1982; Banks et al., 1983]. This instrument was capable of emitting a 100-mA beam of nearly monoenergetic l-keV electrons. The pulse duration of the beam was adjustable from 600 ns (1.6 MHz) to 109 s (~0.01 Hz) under programmable microprocessor control. While the primary functional objective of the FPEG instrument was to change the electrical potential of the orbiter for vehicle charging experiments, the capability of pulsing the beam over a wide range of frequencies presented an opportunity for investigating the effectiveness of a pulsed electron beam in generating electromagnetic radiation . For this purpose a number of modulation sequences were preprogramed for pulsing the beam at frequencies up to 1 MHz. The primary instrument for detecting the possible radiation from the beam was the plasma diagnostic package (PDP) on the OSS 1 pallet [Neupert et al., 1983; Shawhan et al., this issue]. Even though the PDP instrument was on occasion moved away from the pallet using the remote manipulator system, it was at all times within ~20 m of the electron generator. Thus, in most cases, the PDP sensors were well within the "near" field in terms of any electromagnetic radiation that would be generated by the electron beam.

In order to assess the feasibility of using electron beams for generating electromagnetic waves that would propagate away from the orbiter, a coordinated experiment attempting to detect the beam-generated radiation at ground-based sites and on existing free-flying satellites was conceived. Of particular interest for these experiments was the possibility of using the beam for radiating waves in the ELF/VLF frequency range. Several ground-based observatories with broadband VLF receivers were used for this purpose. While no obvious evidence of beam-induced radiation was observed, detailed analysis of the ground site overpasses of STS 3 is not complete and will be reported separately.

In terms of free-flying satellites, the Dynamics Explorer 1 (DE 1) satellite launched in 1981 [Hoffman, 1981] equipped with a broadband VLF receiver (Shawhan et al., 1981) presented a suitable platform for space observations. Thus, during the flight of STS 3 in March 1982, coordinated FPEG modulation and DE 1 observations were arranged during times of magnetic conjunctions of the two spacecraft. In this paper we report on the results of these experiments. To our knowledge they represent the first coordinated experiment of this type involving two spacecraft with independent orbits. In addition to the obvious constraint involving the spacecraft orbits and the geometry of the geomagnetic field, the experiments were further complicated by the fact that the DE 1 broadband VLF data could only be acquired with real-time telemetry by NASA ground stations around the globe, the same stations that were heavily involved in tracking and commanding the space shuttle (STS 3). In addition, the commands for the initiation of FPEG operation during magnetic conjunctions with DE 1 had to be uplinked to STS 3 in real time since, due to the uncertainty of the launch time of STS 3, the conjunctions could not be determined until after launch.

Since none of the preprogramed FPEG modulation sequences of the VCAP experiments was suitable for the STS 3/DE 1 experiments, special VLF beam modulation formats were designed and uplinked to the VCAP control microprocessor after launch. On DE 1, the wideband analog receiver operating in the 3 to 6-kHz range was used due to the need for high time resolution as well as for identification of any beam-induced radiation in the midst of a highly variable natural VLF background.

Coordinated FPEG VLF operations were also attempted during magnetic conjunctions of STS 3 with other satellites, namely the International Sun-Earth Explorer 1, 2 (ISEE 1, 2) and the ISIS 1, 2 satellites. Due to the orbital configuration of these spacecraft, very few conjunctions with STS 3 were physically possible. Also due to various operational constraints the acquisition of the satellite data in the desired modes was not possible in most of these conjunctions. For this reason, we limit our discussion in this paper to the STS 3/DE 1 experiments.

In the following we first describe the modulation formats and criteria used for determining the magnetic conjunctions of the two spacecraft. We then present the results of the experiments and ray-tracing computations to determine whether any waves generated at the location of STS 3 would be expected to reach the satellite. Finally, we present our conclusions and discuss the implications of the results for future experiments.

2. DESCRIPTION OF THE EXPERIMENT

In this section we discuss the DE 1 satellite instrumentation, the VLF modulation format for FPEG, and the criteria used for magnetic conjunctions of the two spacecraft. The FPEG instrumentation is described elsewhere [Banks et al., 1983] and is not repeated here.

DE 1 wave receiver description

The Stanford University linear wideband receiver (LWR) is integrated into the plasma wave instrument (PWI) on DE 1 [Shawhan et al., 1981; Inan and Helliwell, 1982]. The receiver measures the wave magnetic or electric field intensity and spectra selectively over the range of frequencies 1.5-3, 3-6, and 10-16 kHz. The LWR can be connected to a magnetic loop or a long electric dipole or it can be commanded to cycle between the two. For the STS 3/DE 1 experiments reported in this paper, the 3 to 6-kHz wide-band channel connected to the primary magnetic loop antenna with a threshold sensitivity of 6×10^{-7} $\gamma/\mathrm{Hz}^{1/2}$ at 6 kHz was used. The gain of the LWR can be set at 10-dB steps over a 70-dB range and can be varied automatically or can be commanded to remain at a fixed level. In the automatic mode that was used for the STS 3/DE 1 experiments, the gain is updated every 8 s. The receiver response is linear over a 30-dB dynamic range at any gain setting, thus facilitating accurate measurements of signal intensity and temporal growth rate. Also, the fact that the gain level remains fixed for 8 s enables the identification of relatively weaker signals in a background of much stronger but short-duration natural signals such as lightning-generated whistlers and emissions.

The plasma wave instrument on DE 1 is also equipped with a wide-band receiver with automatic gain control over the frequency range 650 Hz to 10 kHz or 40 kHz. This receiver was not used in the present experiments since weaker signals would be suppressed by the relatively intense plasmaspheric hiss that is usually observed below 1 kHz. DE 1 wave data were also acquired using the digital output sweep frequency receiver (SFR), also part of PWI. The SFR has a 32 s time resolution and is thus not expected to be useful in detecting the VLF modulation format used for pulsing FPEG.

FPEG VLF modulation format

The VLF modulation format that was used to pulse FPEG during its magnetic conjunctions with DE 1 is shown in Figure 1. The format consists of frequency shift keying between two frequencies, 3.25 and 4.873 kHz, both within the 3 to 6 kHz band of the LWR on DE 1. Due to the fact that a fixed number of pulses (32K) was used for FPEG at any pulsing frequency, the duration of the modulation at the two frequencies is different. The main cycle of the FPEG/VLF format typically lasted ~92 s.

Magnetic conjunctions

A "magnetic" conjunction between the two spacecraft was assumed to occur when either of the two conjugate magnetic "footprints" of DE 1 was within 1500 km of an STS 3 footprint. In order to estimate the footprint, the orbital parameters of the spacecraft were used in conjunction with an Olson-Pfitzer model of the earth's magnetic field [Olson and Pfitzer, 1974]. With the criterion adopted here a typical STS 3/DE 1 conjunction lasted 4-5 min.

A computer code that computes the magnetic conjunctions of any two earth- orbiting spacecraft was developed at Stanford University for the purpose of the STS 3/DE 1 experiments. The inputs to the code are the state vectors (i.e., spatial and velocity components at a given time) of the two spacecraft and the distance criteria for defining a conjunction (in this case 1500 km). The output is a listing of the possible conjunctions in the specified time period and the orbital parameters of the two vehicles at the time of conjunction. Since the STS 3 orbit was not precisely known until after launch, the determination of the conjunctions was done after the launch of STS 3. Furthermore, the conjunction estimates were periodically updated as STS 3 orbit parameters changed slightly due to attitude maneuvers.

In the next section we present the results of the experiments and ray-tracing analysis to determine whether any FPEG-induced waves would be expected to propagate up to the location of the DE 1 satellite.

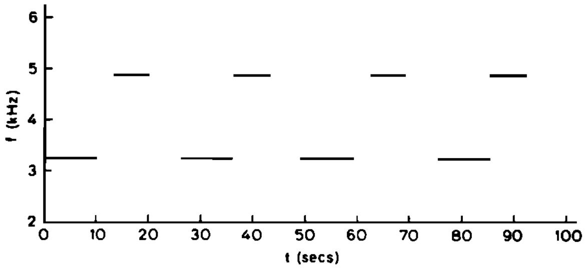

Fig. 1. The FPEG/VLF modulation format used in the STS 3/DE 1 experiments. The format consists of frequency shift keying between 3.25 and 4.873 kHz.

3. RESULTS

With the 1500-km criterion that was adopted for determining the magnetic conjunctions, in all there were 43 possible conjunctions during the flight of STS 3. Of these, the FPEG/VLF modulation sequences were utilized for 17 cases, whereas DE 1 wide-band data were acquired in 24 of the 43 possible conjunctions. The number of cases where both FPEG/VLF format was used and DE 1 data were acquired was 12. The various parameters of these cases are listed in Table 1. Shown in this table are the locations of STS 3 and DE 1 at the time of closest approach during the conjunction, the beam pitch angle and whether or not the beam escaped the vehicle (see below).

Beam pitch angle and PDP observations

In order to assess the effectiveness of the emitted electron beam for radiating whistler mode waves, it is first necessary to determine the beam voltage and pitch angle, modulation frequency and polar angle of observation with respect to the geomagnetic field [Harker and Banks, this issue]. Since the size of the STS 3 vehicle is comparable to the gyroradius of the ~1-keV electron beam, the emitted electron beam can collide with the vehicle for certain pitch angle ranges.

A computer code was developed at Utah State University that uses the in-orbit attitude information for STS 3 in a model of the earth's magnetic field to determine not only the pitch angle of the beam at any given time but also whether or not the beam collided back onto the vehicle [Sojka et al., 1980]. For the case in hand, it was determined that in 11 of the 13 cases the emitted electron beam collided with the vehicle within one gyroradius and thus did not move away from the vehicle. This was confirmed with the measurement of the termination of the ~1-keV electron flux observed by the PDP [Shawhan et al., this issue].

While the radiation characteristics of a pulsed electron beam are not well known, the radiated electromagnetic field intensity is proportional to the physical length of the nondispersed portion of the beam [Harker and Banks, this issue]. Thus, it is expected that the fields radiated by a beam that does not leave

TABLE 1. Magnetic Conjunctions of STS 3 and DE 1 Satellites

Number	GMT dd/hhmm:ss	STS 3 Dipole Latitude	STS 3 Dipole Longitude	DE Dipole Latitude	Closest Footprint Distance	Pitch	Beam Escape
2	083/1630:59	-47.54	2.27	20.74	803.00	70.65	no
4	083/2059:08	-40.73	1.80	-13.97	879.50	71.06	no
5	083/2225:59	-32.76	1.46	-19.00	1177.60	66.20	no
17	085/1308:27	-43.94	2.00	-65.74	1141.10	76.43	no
20	085/1732:57	-46.89	2.22	40.18	875.40	68.70	no
22	085/2203:59	-38.14	1.68	13.05	1033.40	85.36	no
25	086/1117:31	-40.53	1.79	2.80	821.40	55.39	no
26	086/1252:54	-46.51	2.19	19.73	703.90	77.75	no
27	086/1425:45	-47.04	2.23	-48.00	818.80	76.60	no
29	086/1849:58	43.50	1.97	8.11	792.80	69.21	no
32	087/0939:30	-39.96	1.76	30.84	1402.30	149.27	possible
33	087/1109:30	-43.94	2.00	57.79	1178.40	149.68	possible

the immediate vicinity of the vehicle will be lower in intensity than those that would be radiated by a beam that propagates away. Data from the plasma diagnostic package (PDP) on the OSS 1 pallet for 4 of the 12 cases in Table 1 showed that both electric and magnetic fields were associated with the FPEG operation times discussed here. While these exhibited signatures of the FPEG-induced VLF modulation, such observations in the close vicinity of the beam cannot easily be used to determine whether or not any propagating waves were generated by the electron beam [Shawhan et al., this issue].

Ray-tracing analysis

Since the physical distance between DE 1 and STS 3 varied greatly during the magnetic conjunctions, ray-tracing analysis has been done to determine whether any VLF waves that might be generated at the location of STS 3 could propagate to DE 1. Here we present sample ray-tracing analyses representative of the conditions for the 12 cases listed in Table 1.

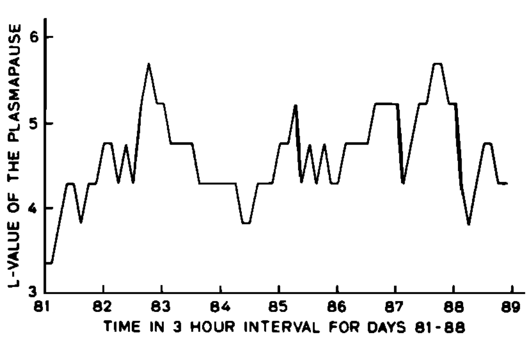

Fig. 2. The approximate L value of the plasmapause during the STS 3 mission estimated using the criteria, $L_p \simeq 5.7 - 0.47Kp$ where Kp is the maximum value of the Kp index in the preceding 12 hours [Carpenter and Park, 1973].

Theoretical analysis of modulated electron beam-induced radiation shows that the beam is expected to radiate waves over a broad frequency range, but with maxima at the modulation frequency and at the condition where the derivative of the ray angle with frequency is zero [Harker and Banks, this issue]. In our ray-tracing calculations, we have used initial wave normals $\psi < \pm\psi_r$, where ψ_r is the local resonance cone angle and where the wave propagation direction for $\psi = 0$ is the direction opposite to the motion of the electron beam.

Propagation paths of whistler mode waves in the magnetosphere are governed by the gradients of the static magnetic field and the cold plasma density in the anisotropic medium within which the rays are refracted. As the density model we have assumed a diffusive equilibrium model of the cold plasma density inside the plasmasphere and an r^{-4} model outside the plasmapause [Angerami and Carpenter, 1966]. For the static magnetic field a centered dipole approximation is used [*Helliwell*, 1965]. To determine the location of the plasmapause we have used an approximate criterion given by Carpenter and Park, [1973], i.e., that the L value of the inner edge of the plasmapause is given by $L_p \simeq 5.7 - 0.47Kp$ where Kp is the maximum Kp in the preceding 12 hours. Figure 2 shows a plot of L_p as a function of time during the STS 3 mission. According to this plot, the plasmapause during this period was in the range $L_p=4$ to 5.

To compute the ray paths, we have used the Stanford University VLF ray-tracing program described by Burtis, [1974]; and Inan and Bell, [1977]. Figure 3 shows the equatorial cold plasma density profile for which the ray paths were determined. The plasmapause location was taken to be $L_p = 4.5$.

Figure 4 shows typical ray trajectories in a magnetic meridional plane for a wave frequency $f = 4$ kHz propagating inside the plasmasphere. We have chosen 4 kHz since it is roughly the average of the two discrete frequencies used in the FPEG/VLF format. As the injection latitude we have taken $\lambda_m = -45°$, again representative of the average λ_m for the STS 3 locations during the conjunctions listed in Table 1. Also shown in Figure 4 are the locations of the DE 1 satellite during the same 12 conjunctions as identified by the conjunction numbers. The trajectories shown are for rays with wave normals $\psi < \pm\psi_r$ and spaced at 10° intervals injected at the STS 3 altitude ($\sim$240km). The dashed lines indicates the $L = 4.5$ field line.

The ray paths shown in Figure 4 indicate that in 10 of the 12 cases listed in Table 1, it was not possible for any VLF waves generated in the vicinity of STS 3 to reach the location of the DE 1 satellite. In these cases, the DE 1 satellite was typically outside the plasmapause and at too high a latitude or altitude to be intercepting waves generated at the STS 3 location with any initial wave normal. For example, in the two cases where the electron beam did leave the vehicle (conjunctions 32 and 33) the satellite was too far north at latitudes $\lambda_m > 30°$. In the cases of conjunctions 4 and 25, the satellite position was within reach of any FPEG-generated waves with initial wave normals in the range. However, as seen in Table 1, in both cases the FPEG-generated electrons collided with the main body of the STS 3 vehicle within one gyroradius.

DE 1 linear wideband receiver data

In this section we show sample wave data acquired on DE 1 using the LWR during conjunction 4, one of the two conjunctions when the DE 1 satellite is believed to have been within the plasmasphere. Figure 5 shows frequency-time spectra in the 2 to 7-kHz range (the nominal receiver bandwidth in the mode used was 3 to 6-kHz) at two different times, both within a minute of the time of closest "magnetic" approach of STS 3 and DE 1 at 2059:08 UT on March 24, 1982. The top panel shows lightning-generated whistlers that may have arrived at the satellite through direct or reflected paths [Edgar, 1976], much like those shown in Figure 4. In this case, however, the lightning-generated impulses must have entered the magnetosphere at magnetic latitudes higher than the $\lambda_m = \pm 45°$ used to represent the injection point of any FPEG-induced waves. The presence of whistlers with distinctly different dispersion indicates that they arrive at the satellite on at least two different paths. Also, the whistlers may be generated by different lightning flashes in the two hemispheres.

The second panel shows similar spectra except for a noise burst that is observed beginning at $\sim$2059:52 UT. The "bullet shaped" front end of the noise burst is consistent with a distant generation region and dispersion

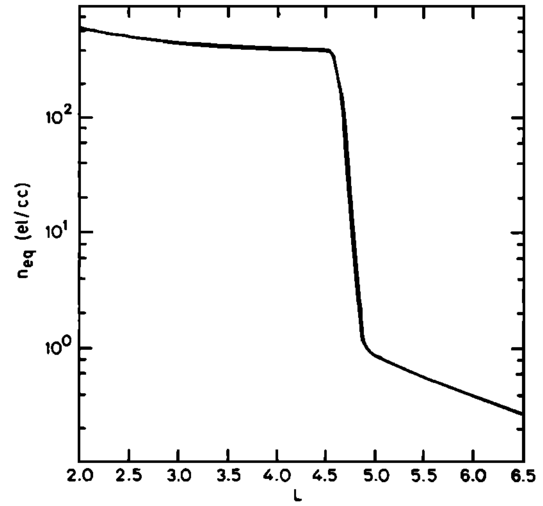

Fig. 3. The equatorial cold plasma density profile used for the ray-tracing calculations.

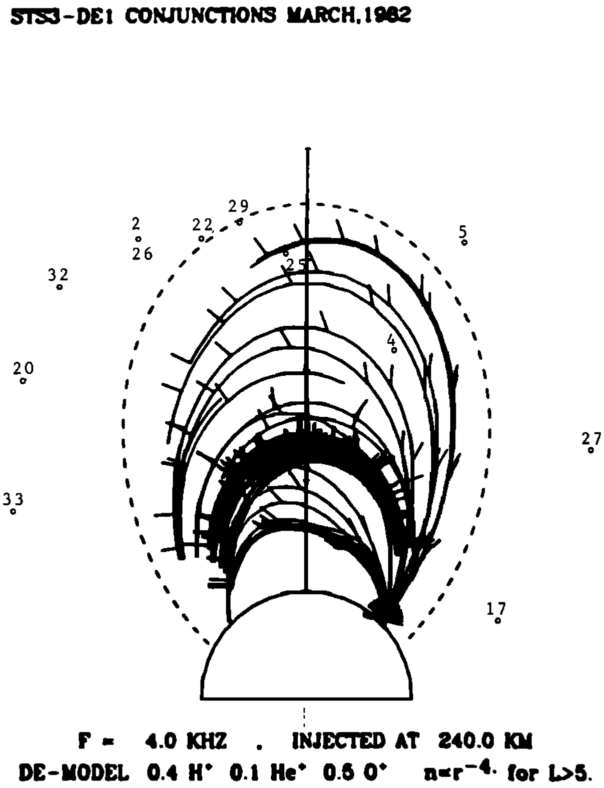

Fig. 4. Ray paths for $f = 4$ kHz rays injected at a geomagnetic latitude of $\lambda_m \simeq -45°$ with the cold plasma model being as shown in Figure 3. Rays with initial wave normals between $-\psi_r$ and $+\psi_r$ at 10° spacings are shown. Also shown are the locations of the DE 1 satellite during the 12 conjunctions of Table 1.

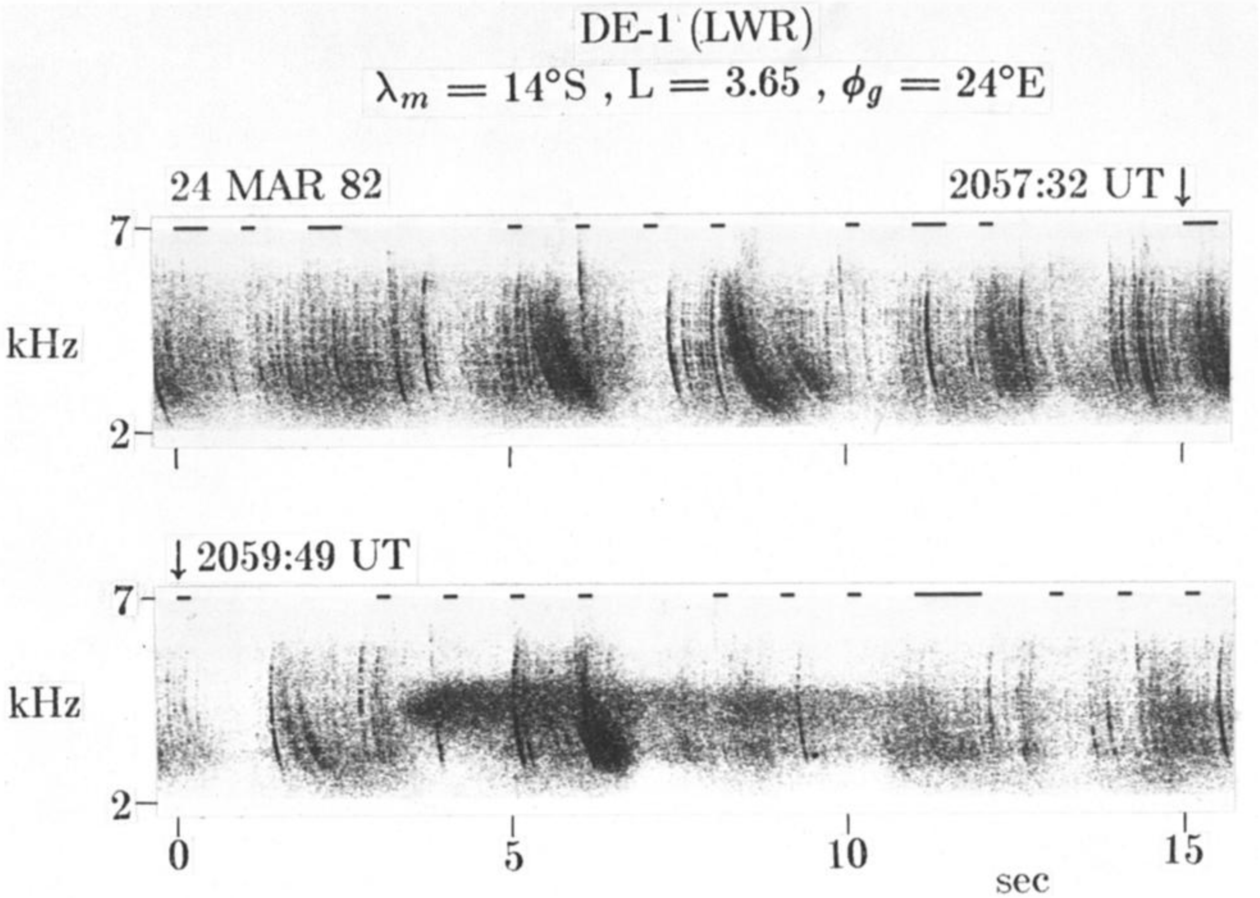

Fig. 5. Example of DE 1 LWR data acquired during conjunction 4 on March 24, 1982. The upper panel shows lighting generated whistlers with distinctly different dispersion. The lower panel shows the same plus a noise burst observed at 2059:52 UT. The tail end of this noise burst lasted until 2100:15 UT.

along the path of propagation from there to the satellite. The characteristics and the frequency range ($\sim$ 3-5 kHz) of this event warrant consideration for possible generation by FPEG/VLF modulation. However, the timing of the burst observation seems to rule out this possibility. According to the STS 3/OSS 1 data, the FPEG was pulsed with a VLF format between 2059:08 to 2059:40 UT, and no electrons were emitted from 2059:40 to 2100:10 UT. Since the one-hop whistler mode time delay on the field lines $L < 4$ inside the plasmasphere is typically 2-5 s, it does not seem possible that a noise burst like the one shown, observed over times that are 12 to 24 s after the time at which the FPEG was turned off, could be induced by the emitted electron beam. In fact, the tail end of the noise burst lasted up to 2100:15 UT, well beyond the time corresponding to the rightmost edge of the bottom panel of Figure 5. Also, observation of natural noise bursts of the kind shown in Figure 5 is not uncommon [Dingle and Carpenter, 1981].

Thus, there seems to be no conclusive evidence that any FPEG-induced waves were observed by the DE 1/LWR during conjunction 4, consistent with the fact that, as shown in Table 1, the emitted electron beam did not leave the immediate vicinity of the STS 3 vehicle during this magnetic encounter. While we have not shown DE 1 LWR data acquired during the rest of the 12 conjunctions of Table 1, we note here that no significant wave activity was observed in the 3 to 6-kHz band during most of these remaining 11 conjunctions. Since the satellite was outside the plasmapause during these times, no significant whistler activity was observed as would be expected [Carpenter et al, 1969]. Observations of chorus emissions during some of these conjunctions were also consistent with earlier satellite observations outside the plasmapause [Burtis and Helliwell, 1975].

During most of the 12 conjunctions the 3 to 6-kHz spectra were very quiet and uniform with no detectable wave activity.

4. SUMMARY AND DISCUSSION

In summary, we conclude that no detectable evidence of any FPEG-induced waves were observed on the DE 1 satellite. However, it should be noted there were no cases where the STS 3/DE 1 experiments were optimally carried out in the sense of emitting an electron beam that propagates away from the vehicle during a conjunction where it is possible for beam-induced waves to propagate up to the satellite location. Thus, the results from the STS 3/DE 1 experiments are essentially inconclusive; in other words, we cannot, on the basis of these experiments, determine whether or not an electron beam with the characteristics of FPEG (in terms of current level and modulation frequencies) can generate electromagnetic radiation in the form of propagating whistler mode waves at a level detectable by presently available satellite based wave receivers. This determination would be an important goal of future experiments involving space-based electron generators such as those planned for Spacelab 1 and 2 and ground- or satellite-based wave receivers.

In the immediate future, there exist at least two opportunities for carrying out experiments similar to those reported in this paper. The flight of Spacelab 1 (STS 9) in September 1983 will carry the Space Experiments with Particle Accelerators (SEPAC) package, involving an electron generator that can emit a 1.7-A beam of $\sim$7-keV electrons, thus operating at $>$50 times higher power level than the FPEG. While the modulation capability of SEPAC is limited, a 5-kHz pulsing frequency is planned to be used in an attempt to generate electromagnetic waves. In addition, the OSS 1 VCAP experiment is scheduled to be flown again on Spacelab 2 in March 1985 with the plasma diagnostic package (PDP). In this flight the PDP will be released from the orbiter, permitting it to measure any FPEG-generated radiation at distances of many wavelengths from the vehicle.

In both the Spacelab 1 and 2 experiments, the potential also exists for coordinated experiments with existing free-flying satellites as well as ground stations equipped with wave receivers. The criteria used for defining a magnetic conjunction in such experiments should be chosen in the light of the ray-tracing result given in Figure 4. While the criterion outlined in section 2 above was utilized for STS 3/DE 1 experiments in order to reduce the number of conjunctions in the limited time available, other criteria may also be used. For example, while it is important for the two satellites to be close in geomagnetic longitude, the nonducted ray paths of Figure 4 indicate that closeness in latitude is not that critical. In fact, almost any latitude to the north of the STS 3 location in Figure 4 would have been satisfactory for the case shown.

Acknowledgments. The STS 3/DE 1 experiments, representing the first active coordinated experiment of its kind involving two spacecraft with independent orbits, could not have been carried out without the help and cooperation of many people. These experiments were conceived of only a few months prior to the STS 3 mission, and the fact that data were successfully acquired is a tribute to the many people involved and especially the project personnel at Goddard Space Flight Center and the payload support team at the Johnson Space Center who made it possible to carry out active real-time scientific experiments in space. In addition, we would like to acknowledge the major effort made by C. Gustafson of the Dynamics Explorer project for his help in acquiring the DE 1 wide-band analog data. The support provided by the personnel in the Orbiting Satellites Division of the Goddard Space Flight Center in providing up-to-date state vectors for the DE 1 and ISEE 1 satellites is also appreciated. For their help in carrying out the FPEG experiments we acknowledge the support we have received from Jack Sevier and other personnel of the Universities Space Research Associations' Lunar and Planetary Laboratory in Houston, Texas. For developing, building and testing the FPEG we acknowledge the contributions of A. B. White of Utah State University. We also acknowledge discussions we have held with our colleagues in the STAR Laboratory. The STS 3/DE 1 experiments were supported by the National Aeronautics and Space Administration under contract NAS-25688 for DE 1 data acquisition and analysis (U. S. I.), under contracts NAS5-24455 at Utah State University and NAGW-225 at Stanford University for VCAP experiments and data analysis (M. P., P. M. B., P. R. W., W. J. R.) and under contract NAS8-32807 for PDP operations and data analysis (S. D. S.).

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