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Electromagnetic Radiation in the Plasma Environment Around the Shuttle

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ELECTROMAGNETIC RADIATION IN THE PLASMA ENVIRONMENT AROUND THE SHUTTLE

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Abstract

As a part of the SAMPIE (The Solar Array Module Plasma Interaction Experiment) program, the Langmuir probe (LP) was employed to measure plasma characteristics during the flight STS-62. The whole set of data could be divided into two parts : I) low frequency sweeps to determine voltage-current characteristics and to find electron temperature and number density; ii) high frequency turbulence (HFT dwells) data caused by electromagnetic noise around the shuttle. The broadband noise was observed at frequencies 250-20,000 Hz. Measurements were performed in ram conditions; thus, it seems reasonable to believe that the influence of spacecraft operations on plasma parameters was minimized. The average spectrum of fluctuations is in agreement with theoretical predictions. According to purposes of SAMPIE, the samples of solar cells were placed in the cargo bay of the shuttle, and high negative bias voltages were applied to them to initiate arcing between these cells and surrounding plasma. The arcing onset was registered by special counters, and data were obtained that included the amplitudes of current, duration of each arc, and the number of arcs per one experiment. The LP data were analyzed for two different situations: with arcing and without arcing. Electrostatic noise spectra for both situations and theoretical explanation of the observed features are presented in this report.

1. Introduction

During the space shuttle flight STS-62 a broadband electrostatic noise was observed at frequencies 250-20,000 Hz. The measurements were performed in ram conditions by the Langmuir probe (LP) flown as a part of the SAMPIE package (*Ferguson et al., 1994*). The noise has almost a flat spectrum with a sharp decline near the lower hybrid resonance frequency f_{LH}, and the intensities are ranging from 0.1 to 5 mV/m (*Vayner & Ferguson, 1995*). It should be noted that such a noise was observed in ram conditions more than ten years ago (*Siskind et al., 1984*), but there is not a satisfactory explanation for mechanism of generation yet. An investigation of the plasma wave turbulence within the wide range of frequencies (from a few Hz to 200 kHz) was done by using the Plasma Diagnostic Package (PDP) during the SL-2 and STS-3 flights (*Murphy et al., 1986; Gurnett et al., 1988*) . It was established that the noise is electrostatic, the highest intensities occured in

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the region downstream of the spacecraft, and the intensities increased considerably after water dumps (*Pickett et al., 1989*). Two different processes were considered in attempting to understand the generation (instability) of the plasma turbulence caused by water release: the drift instability and the Ott-Farley instability caused by the ring distribution of the water ions. Model computations of the ion distribution function confirm the idea that this function is non-maxwellian (*Paterson & Frank, 1989*). Moreover, so called "ring distribution" was measured directly, and one may believe that the electrostatic broadband noise observed in the wake of the shuttle can be explained theoretically (*Kurth & Frank, 1990*). However, an additional analysis of electrostatic noise generation mechanism is needed because there are essential differences in plasma parameters between SAMPIE and PDP experiments. As it was mentioned above that all the measurements of electrostatic noise (HFT dwells) were performed in ram conditions. The LP uses a 5 cm diameter spherical sensor mounted on a fixed boom approximately 100 cm from the surface of the shuttle (*Hillard & Ferguson, 1993*; *Morton et al., 1995*), and fluctuations of electric current were measured by using the logarithmic amplifier with V-A characteristic shown in Fig. 1 (*Bozich, 1994*). Each dwell lasted for 4 ms, and experimental data were represented in digital form: 80 measurements of current with 50 μs intervals.

The spectra of fluctuations were computed by using the FFT procedure; thus, we are able to study the plasma turbulence within the narrow frequency interval Δf=250-10,000 Hz. According to the purposes of the SAMPIE, the samples of solar cells were placed in the cargo bay of the shuttle, and high negative bias voltages were applied to them to initiate arcing between these cells and surrounding plasma. It was shown that there is influence of arcing on the parameters of the electrostatic noise (*Vayner & Ferguson, 1995*), and we discuss this topic in the last chapter of the current paper.

2. Observations

Three examples of HFT dwells with their spectra are shown in Fig. 2-4. The background plasma parameters (electron number density and temperature) were obtained by using the V-A characteristic of the LP (*Morton et al., 1995*). As can be seen, there are no essential differencies among these graphs besides the amplitudes of fluctuations: the amplitude of the current reaches its magnitude $i_{max} \approx 0.1\,\mu A$ for dwell shown in Fig. 2, and the amplitudes are substantially higher for dwells shown in Fig.3 and Fig.4 ($i_{max} \approx 0.4\,\mu A$). But if we take into account difference in electron number densities for these three dwells, we may conclude that the level of fluctuations $\frac{\delta n_e}{n_e}$ is five times higher for the last dwell (Fig.4).

All spectra demonstrate sharp decline for frequencies $f \geq 6$ kHz. This fact could be considered as an argument in favor of the Ion Acoustic Waves hypothesis because such kind of waves can be excited within the frequency range $F_i < f < f_{LH}$ if the electron temperature T_e is much greater than the ion temperature T_i. (F_i is the ion gyrofrequency). HFT dwell that was recorded one minute before the dwell shown in

Fig.3 demonstrates almost the same signal shape and spectrum but the amplitude of fluctuations is about five times less (Fig.5).

One minute (60 seconds) is not a natural time scale for IAW because the calculations of the attenuation rate and instability increment for such waves show very short time intervals (τ=3-100 ms) (Fig.6). The duration of one dwell (τ_D=4 ms) is not long enough to observe any regular trend in amplitudes although one could believe that the decrease of the amplitude for time interval t>2 ms is caused by the real attenuation (Fig. 3 and Fig. 4).

Some measurements were done in plasma with relatively low electron number density (Fig.7). The pressure of neutral gas is about 20% less than for the dwells shown above but surprisingly the level of fluctuations is almost one order in magnitude higher. There are no essential differences in spectra between this dwell and other dwells .

For very low electron number density and low presssure of the neutral gas the instrument noise was registered only (Fig.8). The origin and the characteristics of the observed electrostatic noise are needed in theoretical explanation. We interpret these fluctuations in terms of the Ion Acoustic Waves travelling in low ionized plasma layer surrounding the shuttle.

3. Interpretation

The shuttle is surrounded by the gas cloud caused by many different processes accompanying the spacecraft operation: outgasssing of surfaces, leakages in valves, thrusters firing, etc. (*Paterson & Frank, 1989*). Molecules of the gas are moving at the thermal speed within the rest frame of the shuttle, and ionospheric ions and neutral atoms can be considered an inflow with an average speed V_S=7.8 km/s. If we suggest that the cloud is formed from water vapor (in the main part) with initial temperature $T_g \le 300K$, we may determine the number density of water molecules from measurements of the gas pressure near the shuttle:

$$n(H_2O) = \frac{p}{k_B T} = 6.4 \cdot 10^{10} \left(\frac{p}{2\,\mu Torr} \right) \cdot \left(\frac{T}{300K} \right)^{-1} cm^{-3} \qquad (1)$$

This value of the number density is few times more than the number density of the ambient atmospheric gas at flight altitudes (220-310 km). According to direct computations, the water vapor densities at distances about 50 m from the shuttle can be as large as $n(H_2O) = 2 \cdot 10^9\ cm^{-3}$, and this value reaches $4 \cdot 10^{10}\ cm^{-3}$ in the nearest vicinity of the spacecraft surface (*Paterson & Frank, 1989*). Now, we can estimate the mean free path for the water molecule. The thermal speed is equal to

$$V_T = \left(\frac{2k_B T}{m(H_2O)} \right)^{1/2} = 5.3 \cdot 10^4 \left(\frac{T}{300K} \right)^{1/2} \frac{cm}{s} \qquad (2)$$

If we adopt the cross section for molecular collisions $\sigma = 2\cdot 10^{-15}\,cm^2$ (*Kaplan & Pikel'ner, 1979*) and the number density of the neutral gas $n_g = 10^{10}\,cm^{-3}$, we will get a rough estimation for the mean free path:

$$l = \frac{1}{\sigma\cdot n_g} = 5\cdot 10^4\,cm = 0.5\,km \qquad (3)$$

that is much greater than the linear dimension of the spacecraft (L~10 m). The time interval between two collisions is equal to

$$\tau = \frac{l}{V_T} = 1\cdot\left(\frac{T}{300K}\right)^{-1/2} s \qquad (4)$$

These estimations allow us to write the radial dependence of the water molecules number density in the simple form (*Paterson & Frank, 1989*):

$$n(H_2O) = n_0\cdot\left(\frac{L}{L+R}\right)^2\cdot\exp\left(-\frac{R-L}{l}\right) \qquad (5)$$

The measurements of the electron temperature in the vicinity of the shuttle show the magnitudes inside the narrow interval T_e=(0.1-0.3) eV (*Morton et al., 1995*). For the IAW, the phase velocity is equal to

$$W_s = \left(\frac{k_B T_e}{m_i}\right)^{1/2} = 7.3\cdot 10^4\cdot\left(\frac{T_e}{0.1eV}\right)^{1/2}\frac{cm}{s} \qquad (6)$$

According to the dispersion relation for IAW, the wave length can be calculated as

$$\lambda = \frac{W_s}{f} = 73\cdot\left(\frac{f}{1kHz}\right)^{-1}\left(\frac{T_e}{0.1eV}\right)^{1/2}\quad cm \qquad (7)$$

where f is a frequency of fluctuations measured in the rest frame of the plasma.
Thus, within the framework of IAW hypothesis the wave length of fluctuations is less than 3 m for whole range of the observed frequencies. It means that we may consider the gas layer surrounding the shuttle as slightly non-homogenious because of the following inequalities:

$$S_{LP} \le \lambda_{max} << L << l \qquad (8)$$

In the relations (8) S_{LP} is equal to the distance of LP from the spacecraft surface.

Neutral water molecules that are ejected from the shuttle surfaces will be ionized by an electrical charge exchange with ions O^+ having the flow velocity V_0=- 7.8 km/s and temperature $T_+ \le 1000$ K:

$$O^+ + H_2O \rightarrow H_2O^+ + O \qquad (9)$$

Three more reactions should be added to the reaction (9) to write the chain of reactions correctly:

$$H_2O^+ + H_2O \rightarrow H_3O^+ + OH \quad (a)$$
$$H_2O^+ + e^- \rightarrow H_2O^* \rightarrow H + OH \quad (b) \qquad (10)$$
$$H_3O^+ + e^- \rightarrow H + H_2O \; and \quad OH + 2H \quad (c)$$

The kinetic equations for the reactions (9) and (10) were solved by using reaction rates tabulated in the work of Paterson and Frank (*1989*). For particular case

$n(O^+) = 2 \cdot 10^5\, cm^{-3}$,

$n(H_2O) = 6 \cdot 10^{10}\, cm^{-3}$,and $n_e = n(O^+) + n(H_2O^+) + n(H_3O^+)$

we obtain the ratio

$$x = \frac{n(H_2O^+)}{n(H_2O)} = 3.9 \cdot 10^{-6} \qquad (11)$$

As a result, the plasma comoving the shuttle can be characterized by the ion number density as large as $(2-3) \cdot 10^5\, cm^{-3}$. In the rest frame of the shuttle these ions are undergone of the influence of magnetic field $\boldsymbol{B}$ and induced electric field $\boldsymbol{E}$ that is perpendicular to both vectors $\boldsymbol{V_s}$ and $\boldsymbol{B}$, and the electric field strength is equal to

$$E = V_s \cdot B \cdot \sin\Theta = 0.23 \cdot \left(\frac{B}{0.3Gs}\right) \cdot \sin\Theta \quad \frac{V}{m} \qquad (12)$$

where Θ is the angle between the Earth magnetic field and the velocity of the spacecraft (Fig. 9).

It is well known that electrically charged particles will drift with speed $V_D = V_s \cdot \sin\Theta$ in the direction that is perpendicular to both electric and magnetic fields. The angle between the shuttle velocity and the magnetic field had been varying from Θ=-65° to Θ=90° during the experiments that are considered in the current paper. It means that the projection of drift velocity directed to the surface of the shuttle $V_\perp$ is always greater than the projection along the surface $V_{||}$:

$$\frac{V_\perp}{V_{//}} = |\tan\Theta| > 1 \qquad (13)$$

We can conclude that there are two streams of ions with relative velocity

$$V_r = -V_s - V_D \; . \qquad (14)$$

Thus, it is possible to use the dispersion equation for IAW that may be written in the following form (*Akhiezer et al., 1973*):

$$1 + \frac{1}{k^2\Lambda_1^2} + \frac{1}{k^2\Lambda_2^2} - \left(\frac{\omega_1}{\omega}\right)^2 - \frac{\omega_2^2}{\left(\omega - k \cdot V_r \cdot \cos\alpha\right)^2} = 0 \qquad (15)$$

where $\Lambda^2 = \frac{k_B T_e}{4\pi \cdot e^2 n_e}$ is the Debye length, $\omega_{1,2}$ are the ion plasma frequencies for oxygen and water ions respectively, and α is the angle between the wave vector $\boldsymbol{k}$ and the relative velocity V_r.

The fourth order equation (15) has complex roots (instability) if the following inequality can be fulfilled:

$$V_r^2 \cos^2 \alpha < W_s^2 \cdot \frac{\left(\omega_1^{1/3} + \omega_2^{1/3}\right)^3}{\omega_1 + \omega_2} \tag{16}$$

To obtain the inequality (16) we suggest $T_{e1} = T_{e2}$, and we take into account that masses of oxygen and water ions are almost equal to each other.

For the simplest example $\omega_1 = \omega_2$, the condition of instability (16) can be written in the form

$$|\cos\alpha| < 2 \cdot \frac{W_s}{V}, \tag{17}$$

where $V = V_s \cos\Theta$.

It is seen from the expression (17) that the cone of the instability is wide for the angle Θ near the right angle. But the dispersion relation does not have complex roots when angle $\Theta = \pi/2$. It is obvious because in this case the drift velocity is equal to the space shuttle speed exactly, and there is no any relative motion of two kinds of ions; thus, the two-stream instability does not work when the spacecraft velocity is directed perpendicularly to the Earth magnetic field.

Now we can consider some particular experiments. For example, angle between vectors V_s and B is equal to $\Theta = -66.4^\circ$ (Fig.2). It is easy to calculate the IAW phase speed $W_s = 8 \cdot 10^4$ cm/s and $|\cos\alpha| < 0.5$. The complex frequency (the growing mode only) can be determined from the Eq.(15):

$$\begin{aligned} \frac{\omega}{kW_s} &= 0.5 + i \cdot 0.34 \qquad (\cos\alpha = 0.25) \\ \frac{\omega}{kW_s} &= 0.9 + i \cdot 0.24 \qquad (\cos\alpha = 0.45) \end{aligned} \tag{18}$$

For different ion number densities $\frac{\omega_1}{\omega_2} = 2$ we obtain almost the same result:

$$\frac{\omega}{kW_s} = 0.6 + i \cdot 0.33 \qquad (\cos\alpha = 0.25) \tag{19}$$

During the experiment E_62-2/03 the electron temperature was substantially higher (Fig.3). IAW speed was equal to $W_s = 9.5 \cdot 10^4$ cm/s, and the relative velocity of the ion streams was equal to $V = 1.36 \cdot 10^5$ cm/s. It is seen that for this particular experiment "beam" velocity is almost equal (a little higher) to the IAW phase velocity. Such condition is optimal for the energy transfer from flux kinetic energy to fluctuations, and the rate of instability is high for all the magnitudes of angle between wave vector and stream velocity (see Eq. (17)). The result depends on the relation between ion number densities rather slightly:

$$\frac{\omega}{kW_s} = 0.5 + i \cdot 0.34 \quad \left(\cos\alpha = 0.5, \quad \omega_1 = \omega_2\right)$$

$$\frac{\omega}{kW_s} = 0.78 + i \cdot 0.25 \quad \left(\cos\alpha = 0.5, \quad \omega_1 = 0.1\omega_2\right) \tag{20}$$

$$\frac{\omega}{kW_s} = 0.22 + i \cdot 0.25 \quad \left(\cos\alpha = 0.5, \quad \omega_1 = 10\omega_2\right)$$

When the angle between the spacecraft velocity and the magnetic field is almost equal to 90° the relative speed is less than the IAW phase speed, and the conditions for the two-stream instability are broken in this case. The dispersion relation (15) has two real roots for any values ω_1 and ω_2:

$$\frac{\omega}{kW_s} = \pm 1 \tag{21}$$

Due to the IAW attenuation, we should not observe the electrostatic noise during the time interval $t \approx 5$ min which is needed to change the angle Θ from 85 to 95 degrees (Fig.10). However, fluctuations were observed even during the dwell recorded for $\boldsymbol{V_s \perp B}$ (Fig.4). Such situation was discussed by Pickett et al.(*1989*), and they suggested that a modified two-stream instability (MTSI) could explain the observational data obtained in their experiment for the wake of the shuttle. MTSI generates fluctuations with frequencies near the lower hybrid resonance frequency (few kHz), and some nonlinear processes should be considered to explain the observed spectrum that has significant amplitudes at frequencies as low as a few Hz.

If we confront our LP data obtained for $\boldsymbol{B_x}=0$ (Fig.4) with data obtained for $\boldsymbol{B_x} \leq |\boldsymbol{B}|$ (Fig.3 and Fig.5), we may suggest that the nature of the turbulence is the same in all three cases because the shape of signals and their spectra do not have any considerable differences. One of the possibilities to explain the IAW instability is the gradient instability caused by electron and ion number densities gradient with a scale $a = \left(\frac{1}{n_i} \cdot \frac{dn_i}{dR}\right)^{-1} \approx 5m$ (see Eq. (5)). The dispersion relation can be written in the following form (*Timofeev,1964*):

$$\frac{1}{\Lambda_e^2} + k^2 - \frac{\omega_i^2}{\omega^2} \cdot k^2 \cdot \left(1 + \frac{1}{i \cdot k \cdot n_i} \cdot \frac{dn_i}{dR} \cdot \sin\varphi\right) = 0 \tag{22}$$

where φ is the angle between the wave vector **k** and the Earth magnetic field **B**.

Taking into account that the Debye length is much smaller than the wave length, we can represent the increment of instability in the following form:

$$\frac{\gamma}{\omega} = \frac{1}{2} \cdot \left|\frac{1}{k \cdot n_i} \cdot \frac{dn_i}{dR}\right| \tag{23}$$

where ω obeys the Eq. (21).

It should be noted that the Eq.(23) is valid when the angle between the wave vector ***k*** and the magnetic field ***B*** is not close to zero, but $\frac{k_y}{k_z} < 1, and \quad \frac{k_z}{k_z} < 1$ (k_y is the projection of the wave vector on the direction that is perpendicular to both vectors ***B*** and **grad** n_i.). The ratio (23) can be easily estimated for the considered frequency range: γ/ω= 0.005-0.1. The attenuation rate of IAW depends on the ratio of the electron temperature to the ion temperature (*Krall & Trivelpiece, 1973*) (Fig. 11). The electron temperature is measured for each dwell, and we can use these data for further calculations.

We can estimate the ion temperature working within the framework of our hypothesis that the main ion component of the plasma is water ions generated by charge exchange process. Thus, we can believe that T_i <300 K. Moreover, the IAW attenuation rate depends on the angle between the wave vector and the magnetic field (*Alpert, 1990*) (Fig.6). If we compare attenuation rates mentioned above with increment (23), we see that there is enough room for instability of IAW even in ram conditions with $\boldsymbol{V_s \perp B}$ if $\frac{T_e}{T_i} \geq 10$.

4.The Influence of Arcing

As it was mentioned above HFT data were obtained during the experiments when arcs occured. First of all, it is seen that there is a significant difference in amplitudes between signals with arcing and without them (Fig.12). For this particular dwell, the amplitude of current fluctuations is as large as 2 μA. The number of arcs, the maximum current for each arc, and the duration of arc were measured by the special counter. One example of data obtained during the experiment E_60-1/01 is shown in Fig. 13. It was established that there is a strong correlation between the number of arcs observed in an experiment and the amplitude of fluctuations (Fig. 14). All these facts show that there is an influence of arcs on HFT data. We believe that the large amplitude of LP current is caused by changes in the spacecraft potential due to arcing (*Vayner & Ferguson,1995*). However, this problem needs in more profound investigation. The measurements of the time interval between arc and HFT dwell would be very useful in this respect.

5. Conclusion

During the Solar Array Module Plasma Interactions Experiment (SAMPIE) fluctuations in the electron number density were observed in ram conditions. The amplitudes of these fluctuations were as large as 10^{-3} - 10^{-4} from the background density at frequencies f= 250-6500 Hz. The measurements of the Earth magnetic field allow us to show that this frequency range is inside the interval $F_i < f < f_{LH}$; thus, we might suggest that the Ion Acoustic Waves were observed. The additional argument in favor of the hypothesis of IAW is the inequality between ion and electron temperatures. From having measurements there was determined that the electron temperature was varying within the interval $0.1 \leq T_e \leq 0.3$ eV (*Morton et al.,1995*). According to Patterson and Frank (*1989*) the ion temperature should be substantially lower : T_i < 0.03 eV. This value of ion temperature is in accordance with the measurement of the pressure of neutral gas around the shuttle (Fig.15) and our estimations of the number density of water molecules (see also Eq.(1)). The facts named above allow us to adopt the basic model of the gas layer around the shuttle that was elaborated by Paterson and Frank (*1989*). Two kinds of instabilities were suggested for explanation of the origin of IAW: two-stream instability that works when the angle between the spacecraft velocity and the magnetic field is not too close to a right angle, and the gradient instability that works for situation when the magnetic field and velocity of the shuttle are perpendicular to each other. It should be noted that the last instability is weaker than the first one, and we could observe the transition between the two regimes if the dwell would last for several minutes at least. More measurements need to be done, particularly for frequency range 20-100,000 Hz, for understanding of the nature of the observed turbulence.

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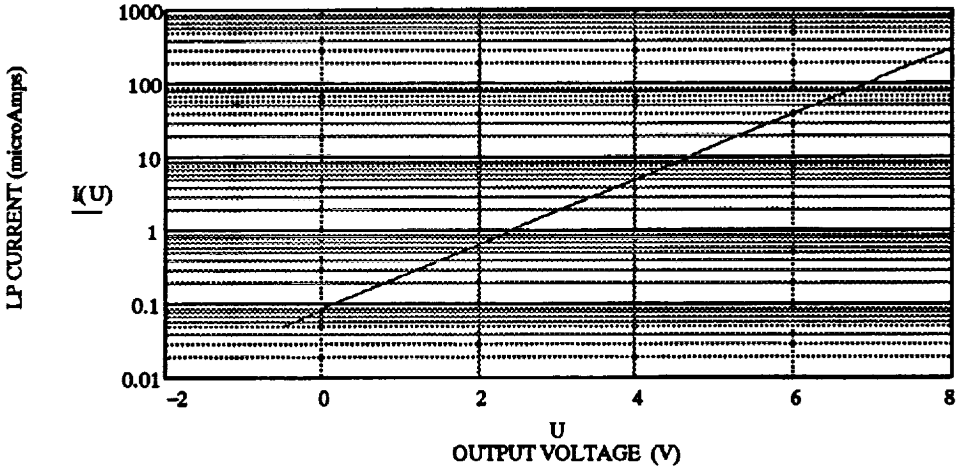

Fig.1 Voltage-current characteristic of the Logarithmic Amplifier.

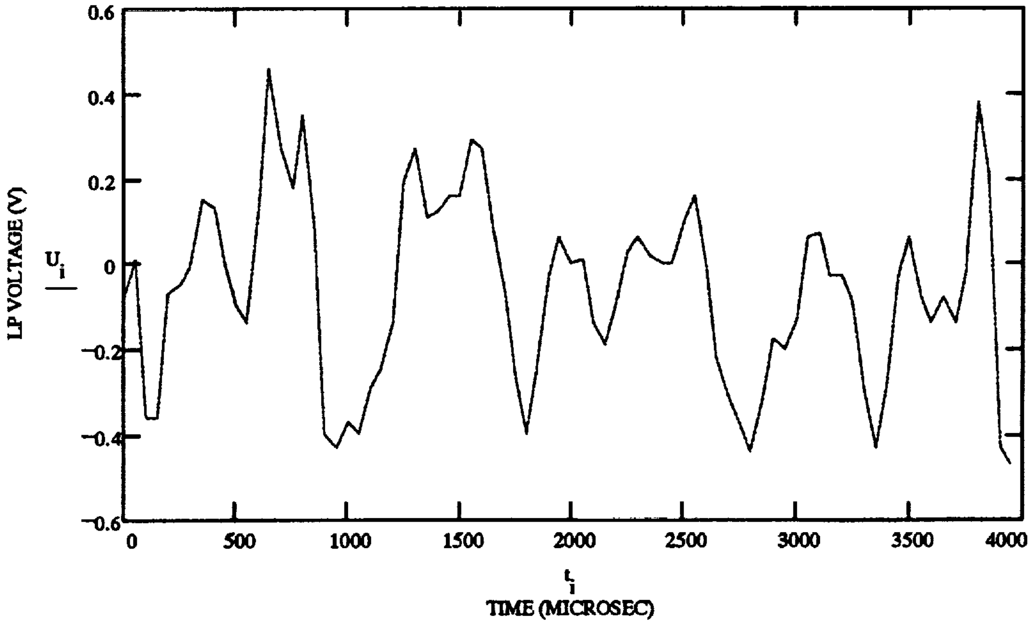

Fig. 2a HFT dwell recorded during the experiment E_44-2/01. MET 7/15:43, electron number density $5.4 \cdot 10^5$ cm^{-3}, electron temperature 0.12 eV, and neutral gas pressure 2.27 microTorr.

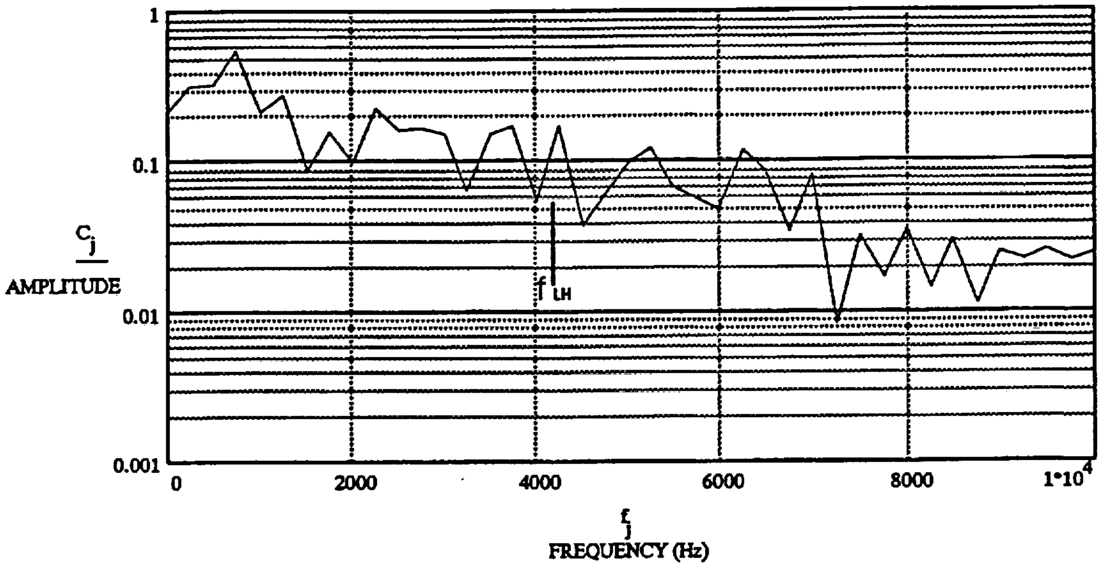

Fig. 2b The spectrum of signal shown above. Magnetic field strength B=0.25 Gs, and angle between B and the velocity of shuttle Θ=-66.4 degrees.

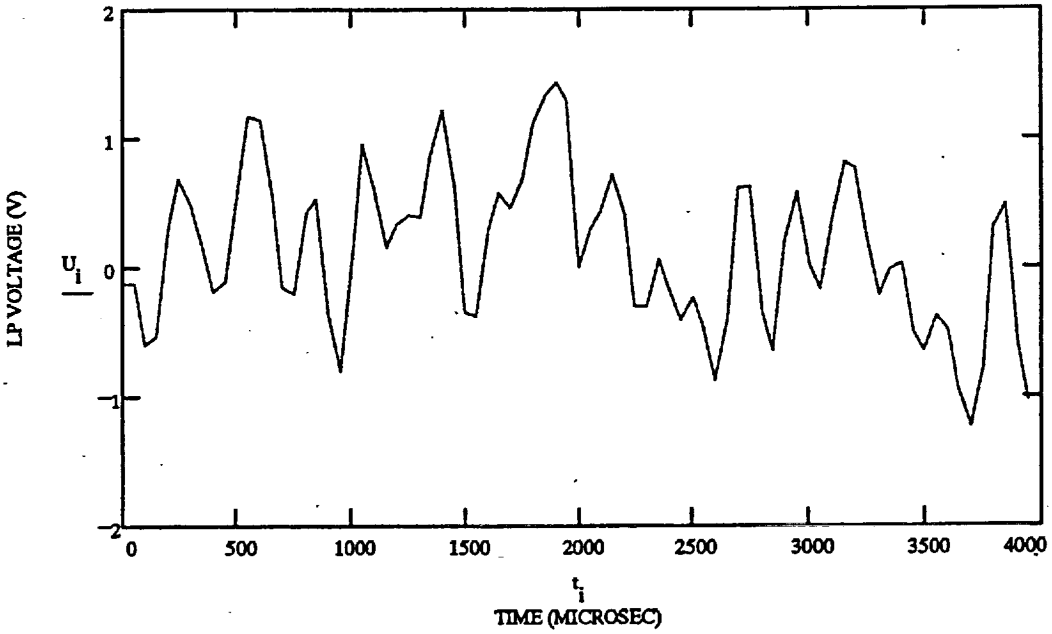

Fig.3a Experiment E_62-2/03. MET 7/23:40, $n_e=4.7\cdot10^5$ cm^{-3}, T_e=0.17 eV, and p=2.1 μTorr.

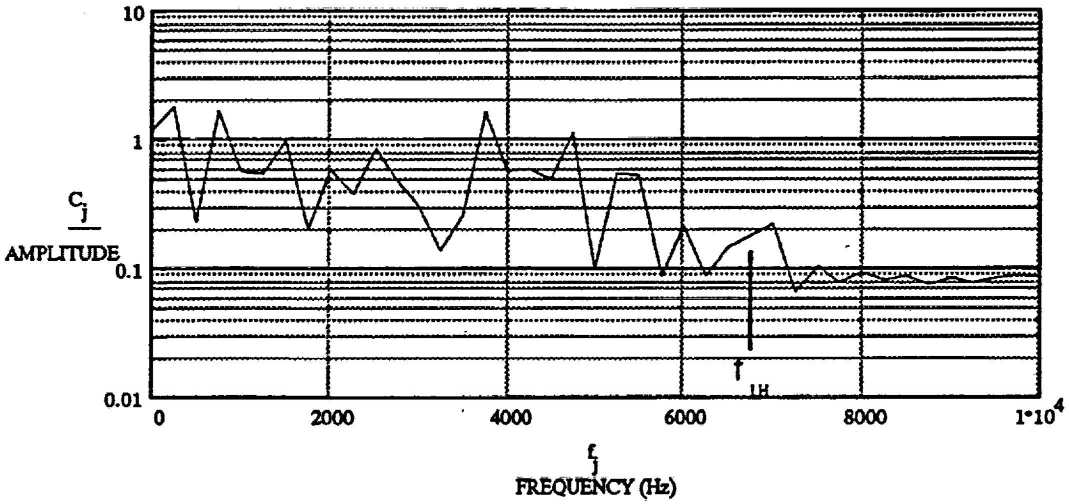

Fig. 3b The spectrum of the signal shown in Fig.3a. B=0.46 Gs, and Θ=-80°

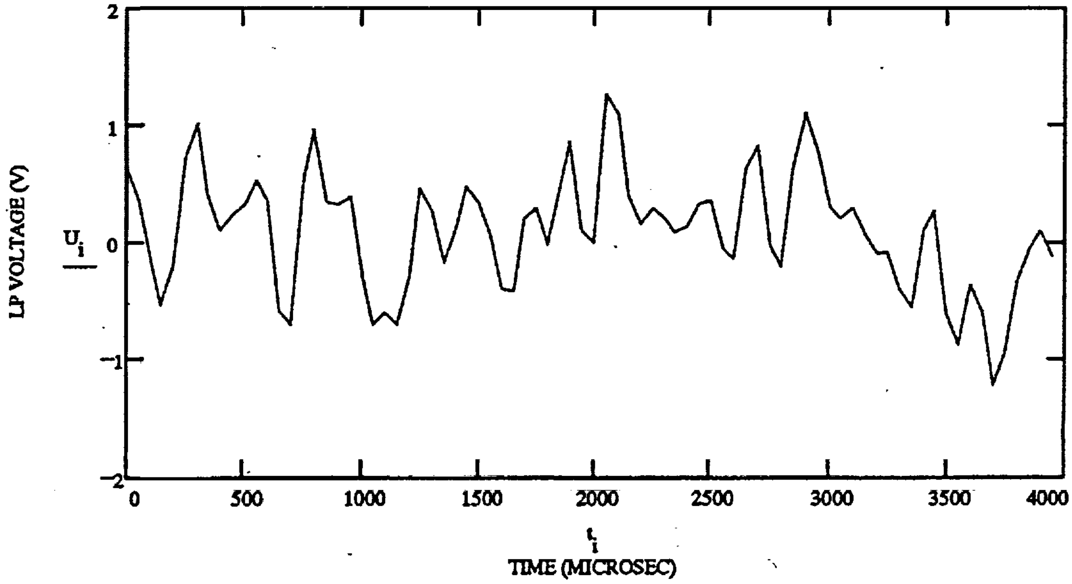

Fig. 4a Experiment E_48-2/01. MET 7/22:54, n_e=6·10^5 cm^{-3}, T_e=0.1 eV, and p=1.86 μTorr.

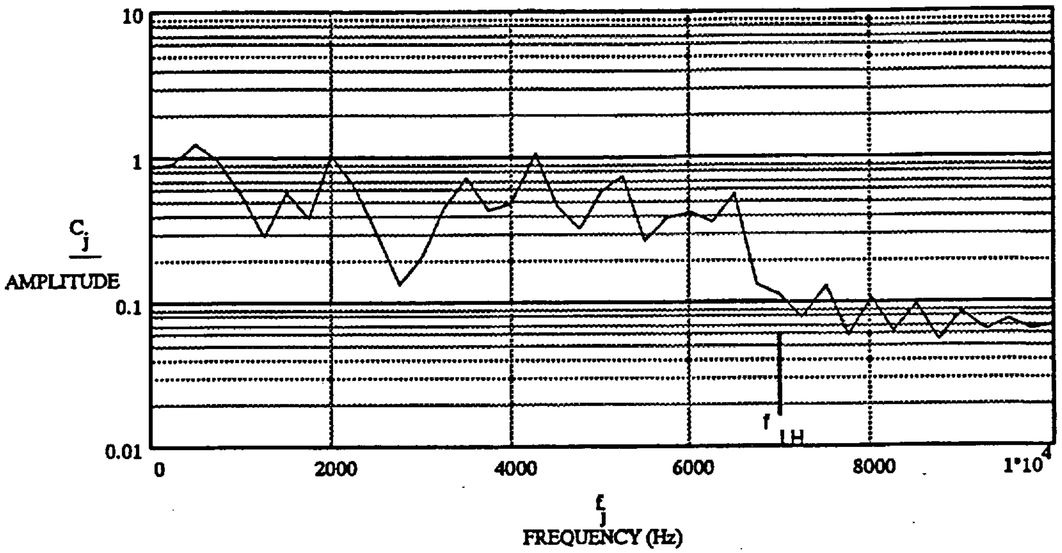

Fig. 4b. The spectrum of the signal shown in Fig. 4a. B=0.52 Gs, and Θ=90°.

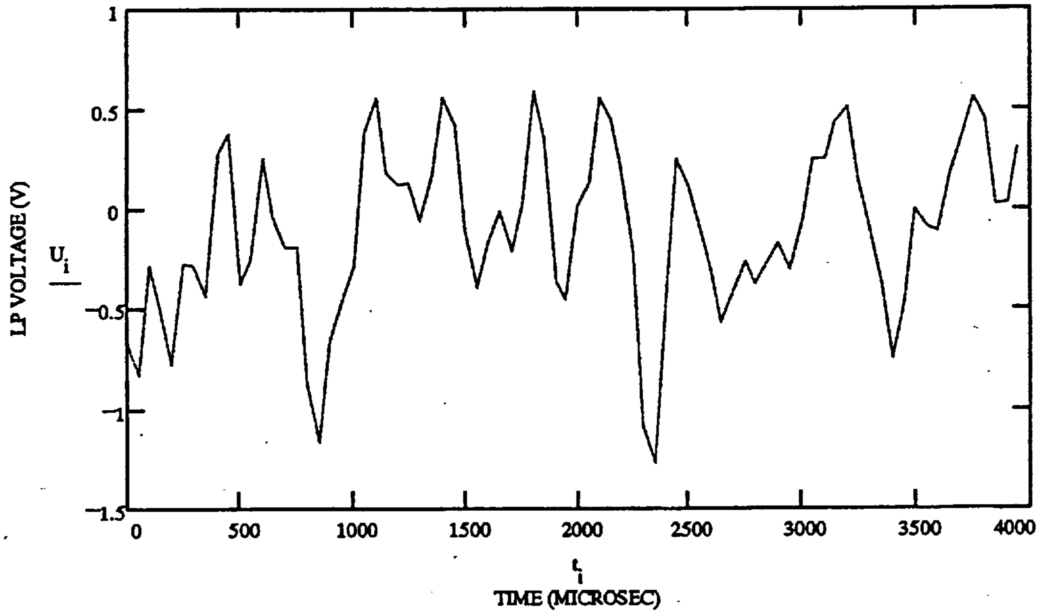

Fig. 5a Experiment 62_2/02. MET 7/23:39, n_e=3.8·10^5 cm^{-3}, T_e=0.17 eV, and p=2.2 μTorr. All parameters are almost the same as in Fig. 3, but the amplitude of fluctuations is about five times less.

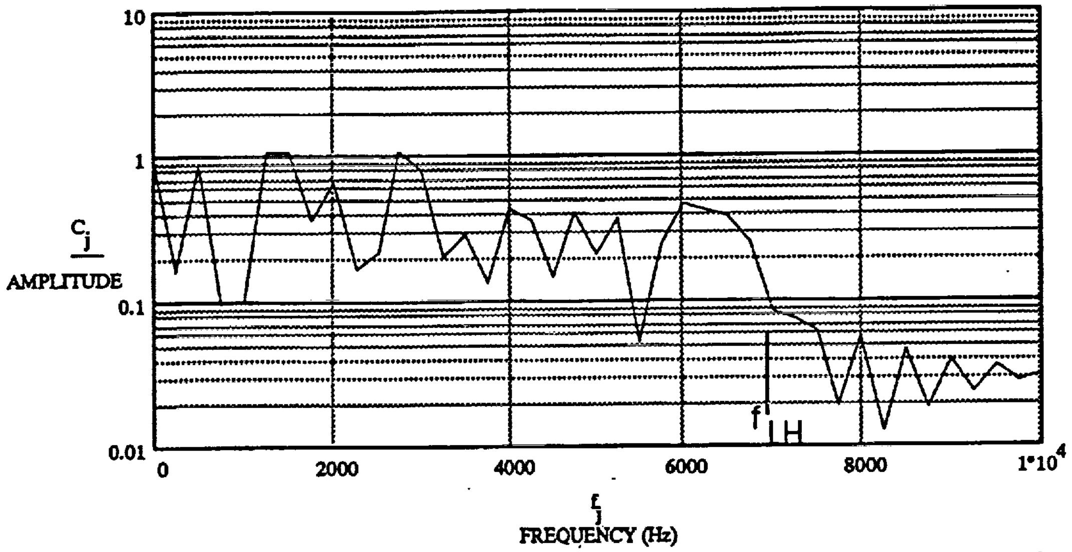

Fig. 5b. This spectrum demonstrates very sharp decline for frequencies $f \geq f_{LH}$.

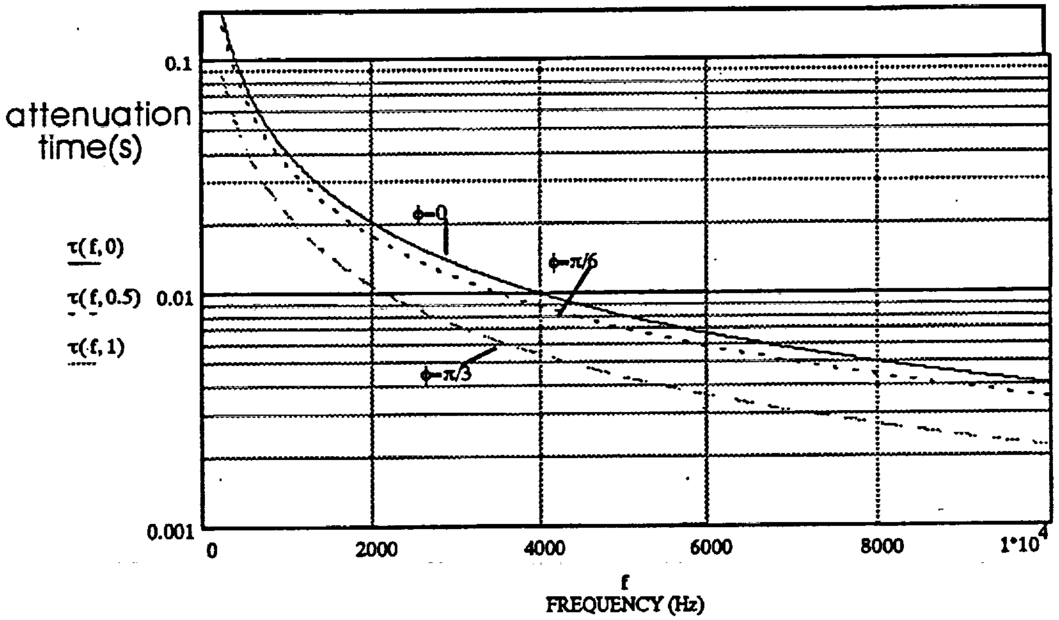

Fig. 6 IAW attenuation time vs. frequency for three magnitudes of angle between the Earth magnetic field and the wave vector (φ). ($T_e/T_i=15$)

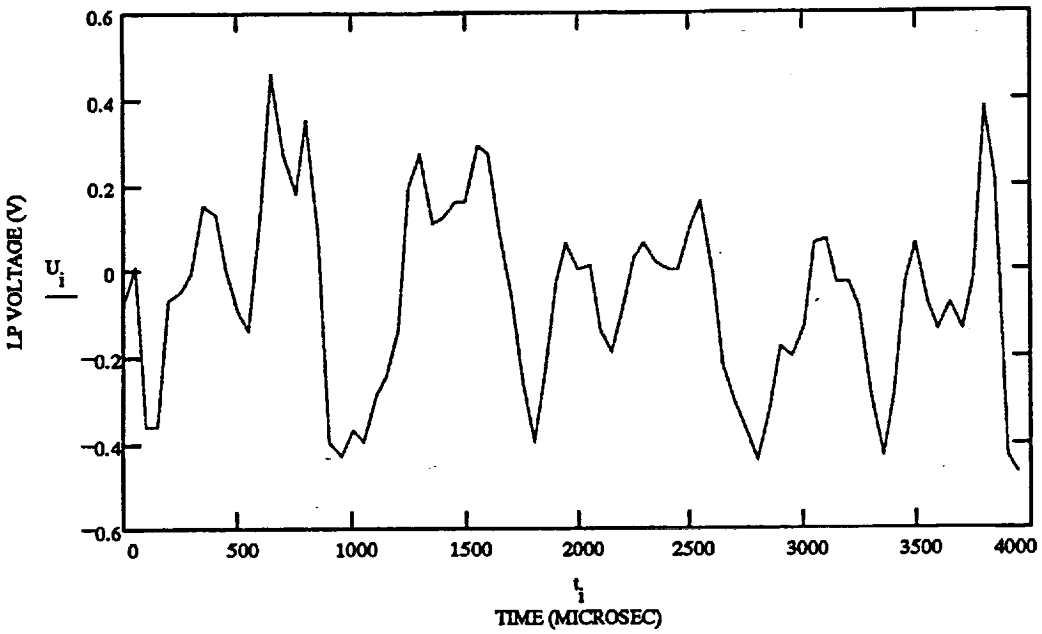

Fig.7a **Experiment E_46-1/01. MET 7/15:57, $n_e=4.3\cdot10^4$ cm^{-3}, T_e=0.14 eV, and p=1.85 μTorr.**

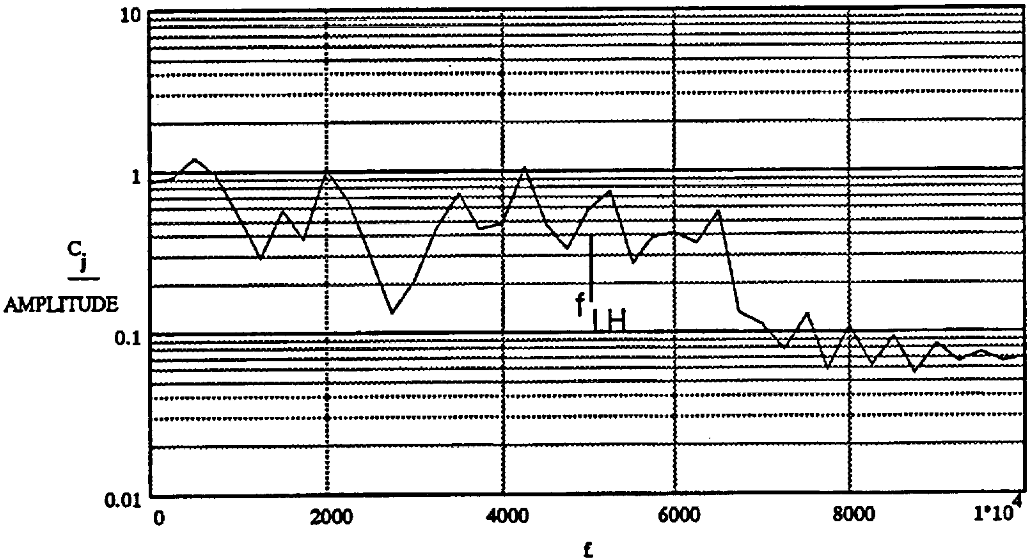

Fig. 7b The spectrum of the signal shown in Fig. 7a. B=0.33 Gs, and Θ=74°.

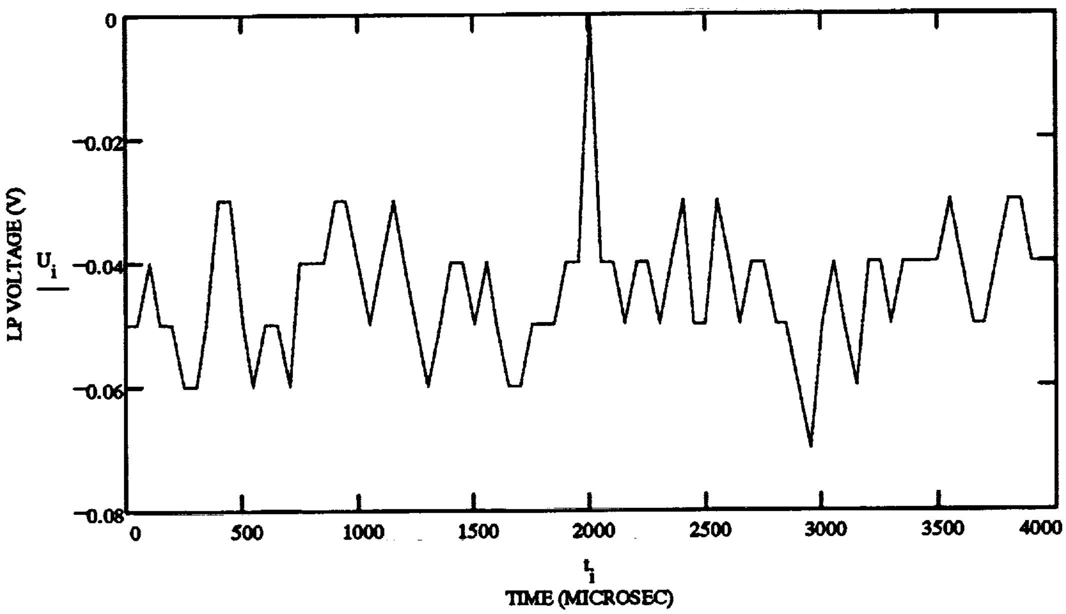

Fig. 8 Experiment E_52-12. MET 10/06:27, $n_e = 3 \cdot 10^4$ cm^{-3}, $T_e = 0.1$ eV, and p= 0.665 μTorr. The instrument noise is registered for low electron number density and low pressure of the neutral gas.

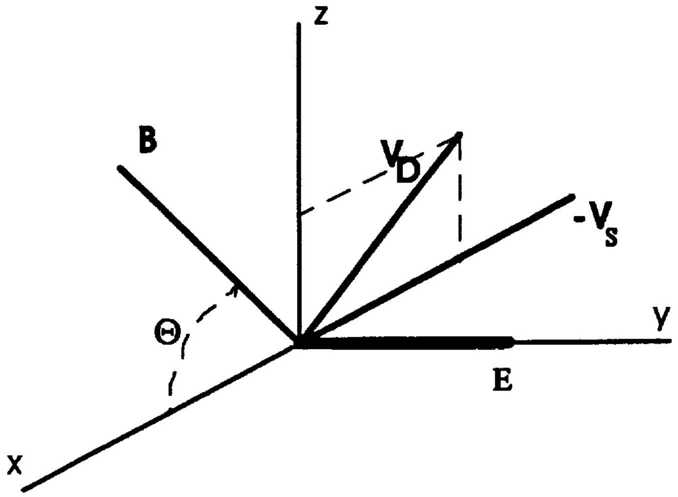

Fig. 9 The spacecraft velocity is directed along x axis. The vector of magnetic field is placed on xOz plane, and the induced electrical field is perpendicular to both vectors B and V_s. The vector of drift velocity V_D is perpendicular to both vectors B and E.

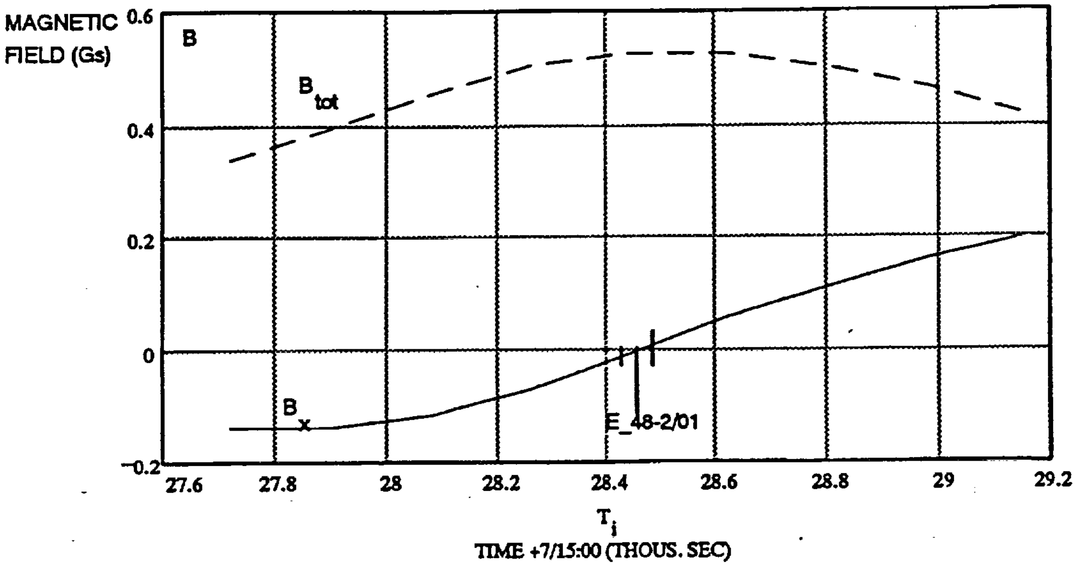

Fig. 10 The mafnetic field strength vs. time started at MET 7/15:00.

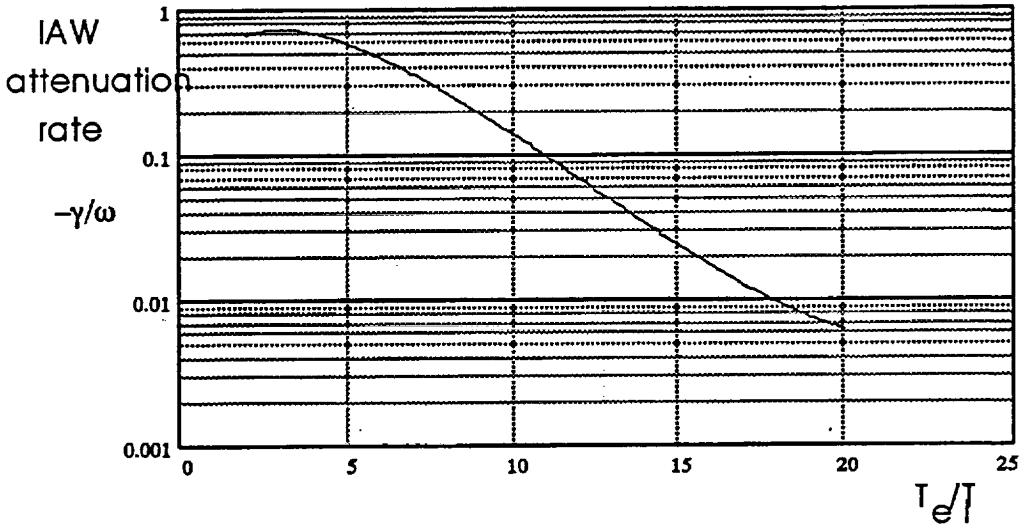

Fig. 11 The IAW attenuation rate vs. the ratio of electron and ion temperatures.

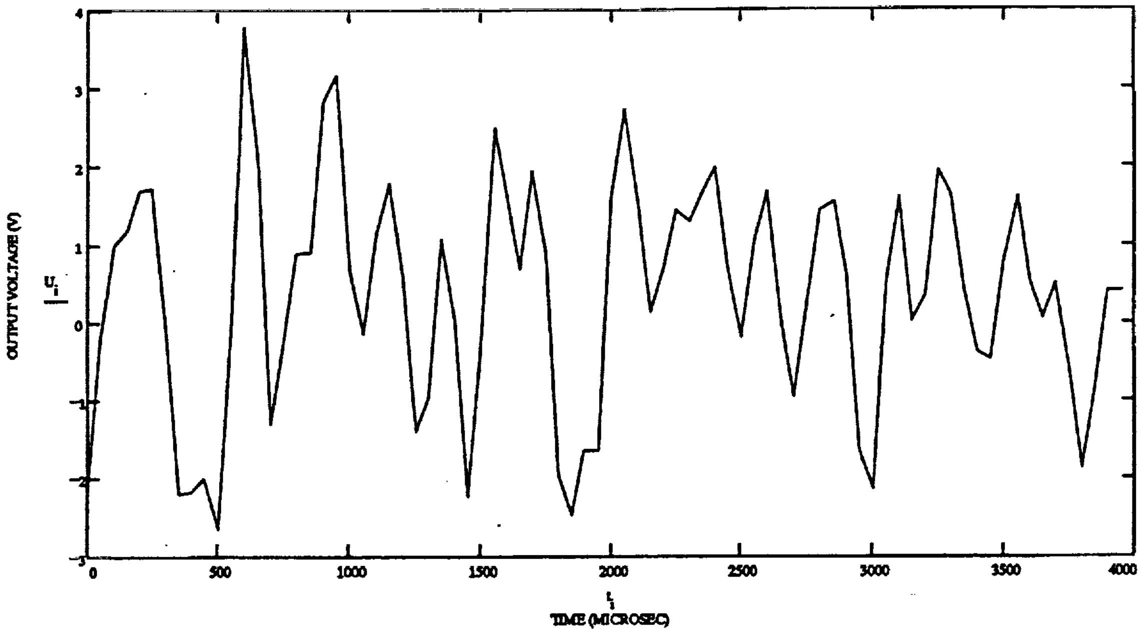

Fig.12 LP output voltage fluctuations measured during the dwell in ram conditions when arcing occurred (MET 7/17:21). This plot demonstrates the large amplitude caused by arcing.

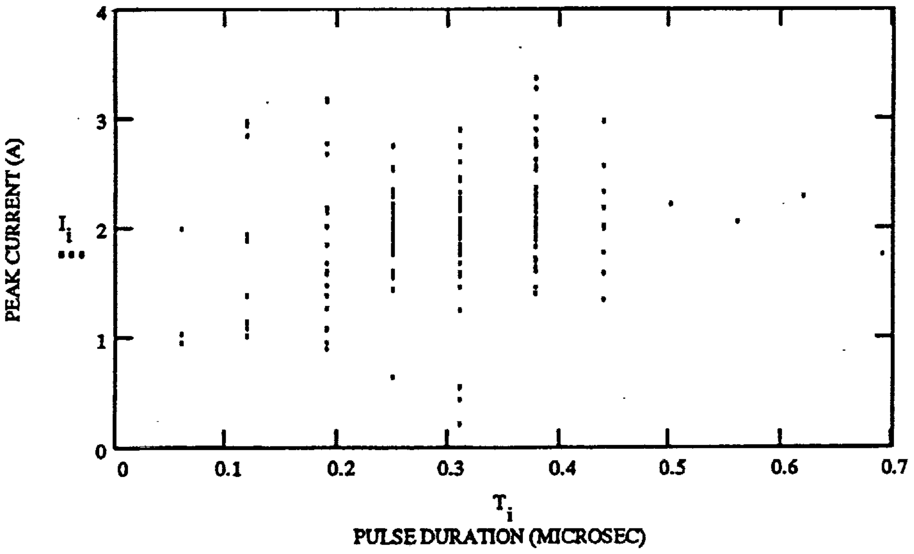

Fig. 13 Data from the Experiment #60-1/01. The bias voltage V=-400 *V*, and 181 arcs were registered.

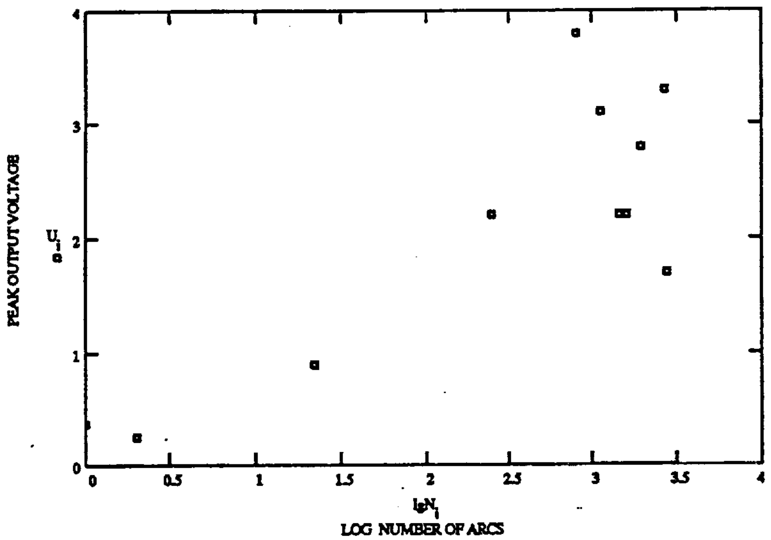

Fig. 14. LP peak voltage vs. the number of arcs per one experiment. Twelve dwells are used to draw this chart. No correlations were found between the peak voltage and the distance of the LP from biased solar cell samples.

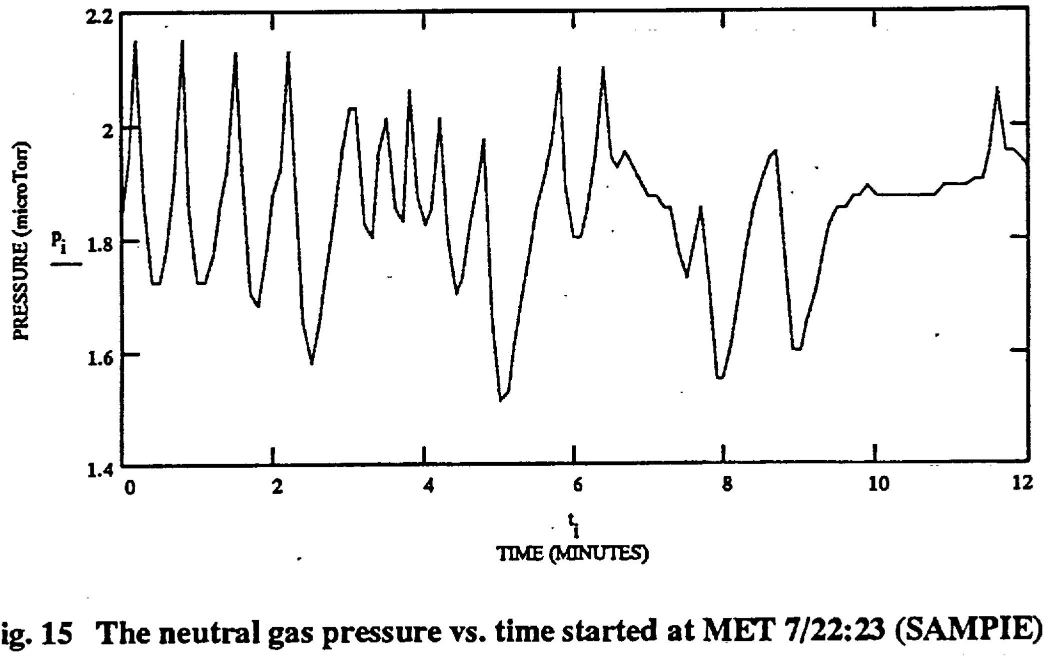

Fig. 15 The neutral gas pressure vs. time started at MET 7/22:23 (SAMPIE)

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13. ABSTRACT ***(Maximum 200 words)***

As part of the SAMPIE (The Solar Array Module Plasma Interaction Experiment) program, the Langmuir probe (LP) was employed to measure plasma characteristics during the flight STS-62. The whole set of data could be divided into two parts: i) low frequency sweeps to determine voltage-current characteristics and to find electron temperature and number density; ii) high frequency turbulence (HFT dwells) data caused by electromagnetic noise around the shuttle. The broadband noise was observed at frequencies 250-20,000 Hz. Measurements were performed in ram conditions; thus, it seems reasonable to believe that the influence of spacecraft operations on plasma parameters was minimized. The average spectrum of fluctuations is in agreement with theoretical predictions. According to purposes of SAMPIE, the samples of solar cells were placed in the cargo bay of the shuttle, and high negative bias voltages were applied to them to initiate arcing between these cells and surrounding plasma. The arcing onset was registered by special counters, and data were obtained that included the amplitudes of current, duration of each arc, and the number of arcs per one experiment. The LP data were analyzed for two different situations: with arcing and without arcing. Electrostatic noise spectra for both situations and theoretical explanation of the observed features are presented in this report.

14. SUBJECT TERMS
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