PLASMA-INDUCED RADIO FREQUENCY INTERFERENCES FROM SPACE VEHICLE

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Abstract

Experiments on plasma-induced interferences from DC-DC converter to receiving antenna simulated for the REXS satellite was made in the presence of plasma in the space chamber of low density and low temperature. When the satellite is sunlit, interferences from DC-DC converter inside the spaceraft, to the receiving antenna via solar panel is found greatly to be enhanced due to the presence of plasma. Matal plate experiment simulated for solar panel showed that the presence of plasma increased the capacitive coupling when the matal plate as transmitter was positively or negatively DC biased, while the receiving antenna was not biased, and especially when the metal plate is positively biased at the space potential, conductive coupling was found to be superposed on this capacitive coupling. However, wavy coupling was not recognized.

1. Introduction

Recently there observed very intense radio noises, whose amplitude amounted to a few mV/m, in the VLF observations made on board of rockets and satellites (Scarf et al., 1965 ; Iwai et al., 1966), and these noises are considered to be electrostatic ion waves in the ionosphere. As electrostatic waves transport great energy, they strongly interact with charged particles, and they can propagate across the magnetic field etc., these noises attracted attentions of space physicists all over the world. On the other hand, a suspicion was cast as to whether these observed signals were caused by leaked noises from loaded instruments on board of spacecrafts. If this is so, we must consider how to suppress the interference noises from spacecrafts to such a level that their intensity being less than the sensitivity of radio wave measurement. For this purpose, Gurnett (1967) discussed the problem of reducing radio frequency interferences, and Osborne et al. (1967) made a simulation exeriment on plasma-induced coupling between converters and VLF receiver put in the spacecraft, However, above discussions did not refer to the nature of coupling. In order to know what kind of coupling, i. e., (1) capacitive coupling, (2) inductive coupling, (3) conductive coupling, (4) coupling due to electromagnetic waves, or (5) coupling due to electrostatic waves, will be most predominant, we made simulation experiment in the space chamber belonging to the Institute of Space and Aeronautical Science, University of Tokoy. This work will serve as the preliminary test of the instrument to be on board of REXS satellite.

2. Experimental arrangement and method of measurements

The simulation experiment was made using the space chamber belonging to the Institute of Space and Aeronautical Science, University of Tokyo. It was composed of a cylindrical stainless steel chamber ($2m\phi \times 3m$) with several ports and a 36″ diffusion pump. The plasma guns of back diffusion type are placed at both ends of the chamber. Tantalum was used as grid in the first exqerimental period (June 23-30, 1969), and we changed it to oxide coated grid in the second experimental period (July 14-21, 1969) because of the hardness. Then the density of plasma electrons and the pressure of He gas used amounts to 10^6 cm^{-3} and 10^{-4} Torr, respectively. The electron temperature is about a few thousand degrees in Kelvin. So the present chamber of low density and low temperature is a good simulator of the lower ionosphere.

The block diagram of experiments is shown in Fig. 1. The arrangement of solar panel and antenna was simulated for the REXS satellite during the first experimental period. At the same time, two kinds of metal (alminium) plate, one is covered with teflon sheets, the other uncovered, were prepared for the simulation of solar panel. The DC-DC converter system connected to the solar panel was set up outside the chamber. Also the metal plate can be biased negatively or positively, and the radio frequency signal of oscillator can appear on the plate through the transformer. The picked up signal by various antennas are displayed on the synchroscope or spectrum analyser.

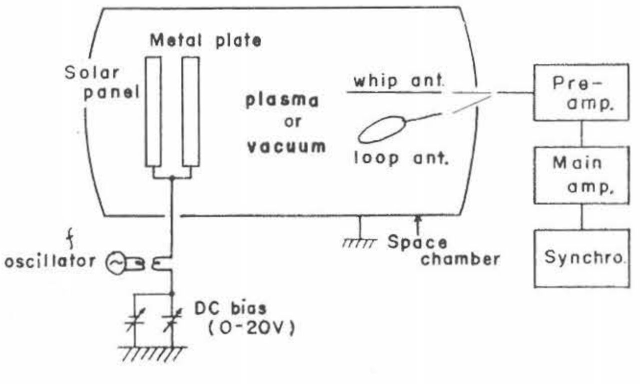

Fig. 1 Block diagram of experiments.

3. Experimental results and discussions

3. 1. Results of the experiment made with solar panel

a) Test in vacuum. In the case when the solar panel was exposed to the light such that its induced voltage attained to the prescribed level, we cleary observed harmonics of 34 kHz in the frequency range between, about 200 kHz, and 3 MHz on a whip antenna directed along chamber axis separated about 5 cm underneath the solar panel, where 34 kHz is the chopping frequency of DC-DC converter connected to the solar panel. In this experiment, both solar panel and receiving whip antenna were not biased. Lower order of harmonics such as fundamental, second etc., were not detected although they were expected to be coupled with the antenna. The reason is that the input impedance of the receiver takes such low value as 50 Ω and the frequency characteristic of the whip antenna of 1 m length is not enhanced in that frequency range. A shielded loop antenna of 30cm ϕ of 21 turns about 15cm away from the solar panel could not detect these harmonics, too. Next in the case when the light was not impressed on the solar panel, we could not observe the harmonics.

b) Test in plasma. The same experiment was carried out when the chamber was filled with plasmas. When the satellite is sunlit, we detected harmonics of 34 kHz in the frequency range from about 400 kHz as in the test in vacuum. Compared with the results of test in vacuum where harmonics appeared from about 200 kHz, lower frequency harmonics from about 400 kHz in plasma were thought to be masked by the increased noise level due to the presence of plasmas by about 10 dB. The peak value of the harmonics around 600 kHz is found to be about 10 dB above noise level. When the solar panel was not exposed to the light, the harmonics were not coupled to the whip antenna, as being similar to the test in vacuum. Of course, the loop antenna could not detect harmonics.

c) Conclusion. From the above experiments, the following facts can be concluded. When the satellite is sunlit, the possibility of plasma-induced interferences from DC-DC converter to the receiving antenna vis solar panel is greatly high. The fact that the shielded loop antenna did not respond to these interferences, suggests that the coupling between DC-DC converter and the antenna is electrical, and not magetic. These inteferences are explained qualitatively using Fig. 2. When the satellite is sunlit, the harmonic frequency waves due to chopping action of DC-DC converter can appear on solar panel, because the diode is forward biased so that the ac voltage of approximately 0.5 V on the main power bus can propagate through the diode. On the other hand, in the case the satellite is in darkness, high impedance of the diode prevents the ac voltage from appearing on the solar panel,

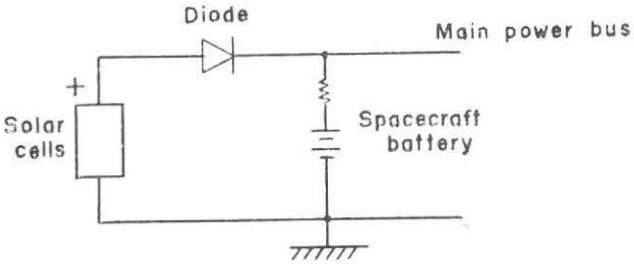

Fig. 2 Qualitative explanation of plasma-induced interference.

3. 2. Simulation experiments of solar panel using metal plates

In order to make clear the coupling, we arranged two kinds of metal plates in addition to solar panel. One is exposed directly to plasma or vacuum (abbreviated as M. U.), and the other is covered with teflon sheets (abbreviated as M. C.). As it is shown in Fig. 1, these plates can be biased negatively or positively and high frequency (20-100 kHz) AC voltage 1 volt from oscillator can be applied to the plates through the transformer. Sensor arrangement is shown in Fig. 3. Considering the increased plasma noise encountered during the first experimental period, the antenna

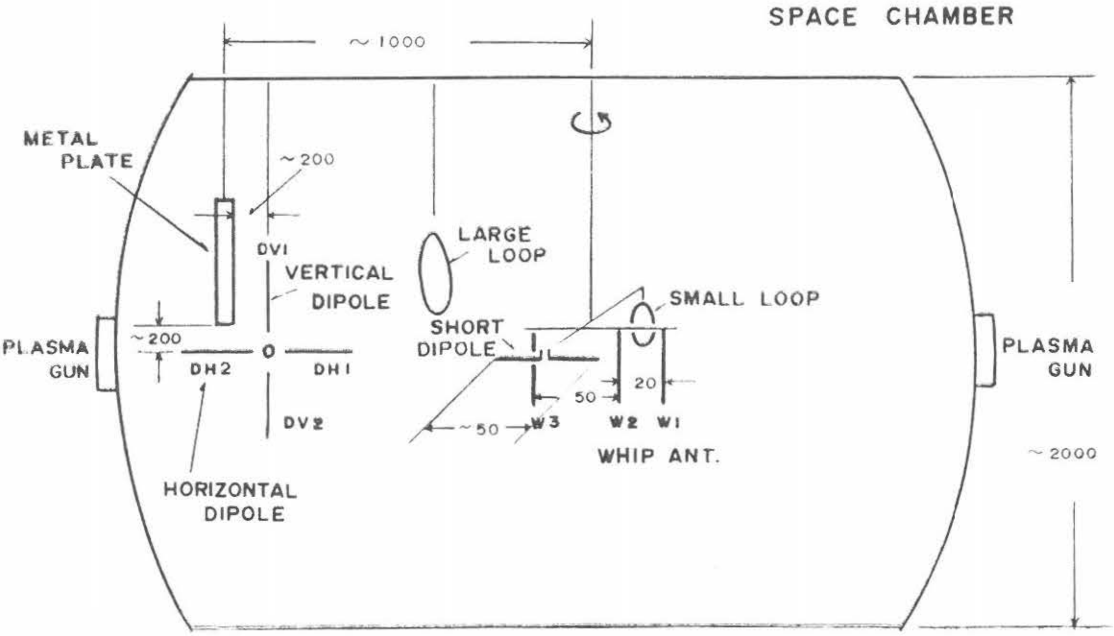

Fig. 3 Sensor arrangement in the chamber.

output was introduced to the receiver through a differential amplifier just outside the frange of the chamber.

a) Test in vacuum. Coupled signal strength picked up by vertical and horizontal antennas is found not to depend on the DC bias voltage of metal plate as well as of receiving antenna. This fact suggests that the coupling of high frequency signal to antenna in vacuum is capacitive.

b) Test in plasma. Quite different from the results of the test in vacuum, the intensity of high frequency coupled signal is much dependent on DC bias of M. U. Also it is influenced by the DC bias of receiving antenna. An example of this is plotted in Fig. 4. In the experiment shown in Fig. 4, DV1-2 dipole antenna of 50cm in tip to tip was used as a receiving antenna and was not biased. The plasma conditions during this experiment was $N_e \sim 1.2 \times 10^6$ cm^{-3}, $T_e \sim 4300$°K and $p \sim 10^{-4}$ Torr. The following facts were understood.

(1) Clearly seen in the figure, when the M. U. is negatively biased, is that the value of the coupled signal intensity is relatively flat, i. e., the signal strength is out of influence of DC bias of M. U. Also this phenomenon is recognized when positively biased at above +6 volts.

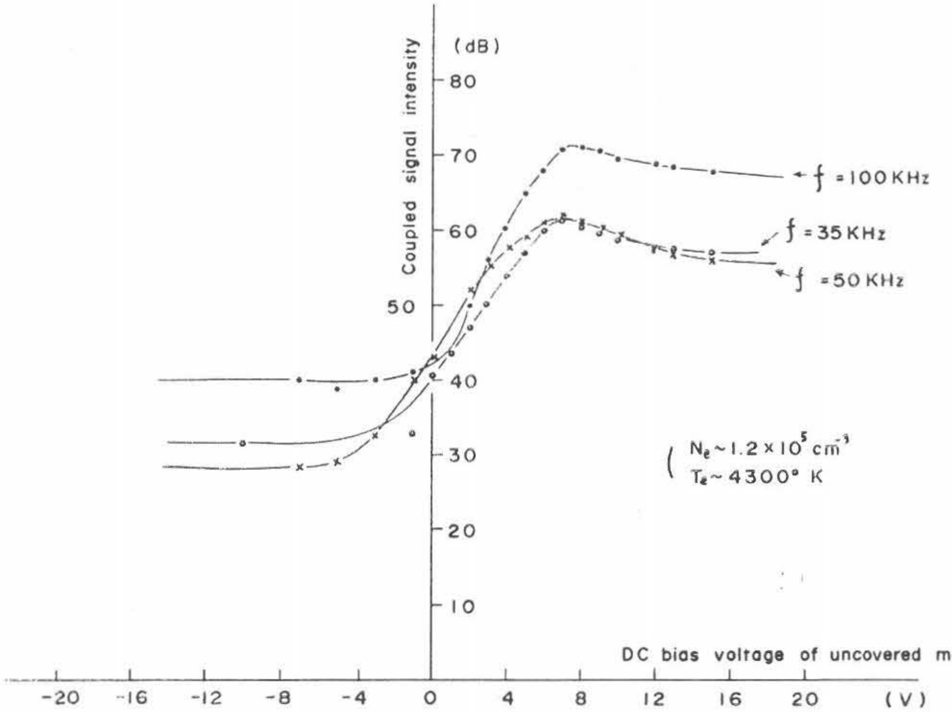

Fig. 4 Coupled signal strength vs. DC bias voltage of M. U.

(2) The coupling is greatly enhanced when the bias voltage of M. U. is around +6 volt.

(3) Another noticeable point is that the coupled signal is not dependent on DC bias voltage when the plate is changed from M. U. to M. C. The level of coupled signal from M. C. is comparable to that when M. U. is negatively biased.

3. 3. Generation of harmonics

Generation of harmonics are very important in relation to the nonlinearity of plasma sheath around the antenna as well as plasma nonlinearity. In our experiment these harmonics generation was found to depend on DC bias voltage of transmitter and that of receiving antenna. During this experiment, M. U. was used as the transmitter, the probes W1 and W3 as receiving antenna, and 100 kHz AC voltage of 5.8 V was impressed on M. U. (see Fig. 3). The experimental results are summarized in the following.

(1) When the DC bias voltage of both transmitter and receiving antenna was in the range $-18\sim-4$ volts, fundamental wave of 100 kHz was detected with intensity of$\sim$40 dB (noise level$\sim$30 dB), whereas the second harmonic could not be detected. When the both DC bias voltage exceded -4 volts, the second harmonic began to be observed in addition to the fundamental. So the boundary of DC bias for harmonics generation is found to be -4 volts on M. U. as well as on antenna.

(2) When M. U. is biased at -15 V and the receiving antenna at $+15$ V, we could not observe the second harmonic, whereas the fundamental was detected.

(3) In the case of M. U. being biased at $+15$ V and the receiving antenna being biased at -15 V, the second harmonic was observed in intensity of 4o dB. From the above results, the most influential factor of harmonics generation is found to be DC bias voltage of transmitter. And the effect of DC bias of receiving antenna is secondary.

4. Discussions

In section 3. 1. the plasma-induced coupling is concluded to be electrical. We will consider all kinds of electrical coupling mentioned in the introduction. The results (1) and (3) in section 3. 2. are considered to be due to the increased capacitive coupling because of the presence of plasma, considering the coupled signal strength of M. C. and of M. U. negatively or positively biased except at around the space potential being not dependent on DC bias. The difference in capacitive coupling level when M. U. as transmitter is negatively or positively biased is due to the difference in sheath formation, i. e., ion- and electron-sheath, respectively. In this case around the receiving antenna is formed ion sheath since the antenna is not biased. Superposed on this capacitive coupling, the coupling term dependent on DC bias with peak at aronnd +6 volt bias, was detected, and this is taken to be due to conductive coupling with considerable loss on account of frequent collisions. Coupling due to the radiation of electromagnetic waves in such low freauency range as 20-100 kHz is not expected from the metal plates. Assume the coupling due to electrostatic waves. As the used frequency is less than the ion plasma frequency, the most acceptable mode is ion acoustic waves. For ion acoustic waves, the wavelength at a frequency about a few tens of kHz becomes very short such as a few tens of cm in the He gas plasma with $T_e \sim 4000°$ K. However as the frequency approaches the ion plasma frequency, larger Landau damping results in. Under this condition the whip and short dipole antennas become near tuned to ion waves, and great output is expected in spite of low input impedance of the receiver and the increased plasma noise. However, this expectation was not noticed.

5. Conclusion

Experiments on plasma-induced interferences from DC-DC converter to receiving antenna was made in the presence of plasma in the space chamber. When the satellite is sunlit, interferences from DC-DC converter inside the spacecraft to the receiving antenna via solar panel is found to be greatly enhanced due to the presence of plasma. Metal plate experiment simulated for solar panel showed that the presence of plasma increased the capacitive coupling when the metal plate as transmitter was positively or negatively DC biased, while the receiving antenna was not biased, and especially when the metal plate is positively biased at the space potential, conductive coupling was found to be superposed on this capacitive couping. However, no wavy coupling was recognized.

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References

Gurnett, D. A., Reducing radio-frequency-interference from spacecrafts in the frequency range from 20 Hz to 200 kHz, Department of Physics and Astronomy, Univ. of Iowa (1967).

Iwai, A., J. Outsu and Y. Tanaka, The observation of ELF-VLF radio noise with sounding rockets L-3-2, K-9M-6, Proc. Res. Inst. Atmospherics, Nagoya Univ., **13**, 1-22 (1966).

Osborne, F. J. F., F. H. C., Smith, R. E. Barrington and W. E. Mather, Plasma-induced interference in satellite v. l. f. receivers, Can. J. Phys., **45**, 47-56 (1967).

Scarf, F. L., G. M. Crook and R. W. Fredricks, Preliminary report on detection of electrostatic ion waves in the magnetosphere, J. Geophys. Res., **70**, 3045-60 (1965).