Nonlinear Interaction of Strong Microwave Beam with the Ionosphere
---- MINIX Rocket Experiment ----

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ABSTRACT. A rocket-borne experiment called MINIX was carried out to investigate the nonlinear interaction of a strong microwave energy beam with the ionosphere. The MINIX stands for Microwave-Ionosphere Nonlinear Interaction eXperiment and was carried out on Aug.29, 1983. The objectives of the MINIX is to study possible impacts of the SPS microwave energy beam on the ionosphere such as the Ohmic heating and plasma wave excitation. The experiment showed that the microwave with f = 2.45 GHz nonlinearly excites various electrostatic plasma waves, though no Ohmic heating effects were detected.

1. Introduction

One of the important issues of the Solar Power Satellite(SPS) is to make an assess of possible impacts of the SPS on the Earth's environment prior to the design of the SPS. The microwave-ionosphere interaction is one of such topics which need to be studied prior to the realization of the SPS. In order to meet such need, a rocket-borne experiment called MINIX was carried out by a Japanese S-520-6 sounding rocket on Aug.29, 1983. The MINIX stands for Microwave-Ionosphere Nonlinear Interaction eXperiment. One of the objectives of the MINIX is to measure plasma wave spectra during the microwave transmission and collect quantitative data of nonlinear excitation of plasma waves caused by the strong microwave energy beam. The other is to measure the possible electron heating and associated phenomena such as density depletion caused by the microwave transmission.

Both the plasma wave excitation and density modulation of the ionosphere by the SPS microwave may affect the short wave communications and may result in a strong modification of the natural ionospheric and magnetospheric plasma environment of the Earth. In order to obtain as quantitative data as possible on such effects, we transmitted a microwave energy beam with a frequency 2.45 GHz and a power density of the order of 230 watt/m^2. Those values are the same as the frequency and power density planned for the future SPS.

2. Experimental Instruments

The MINIX was performed by a mother-and-daughter rocket. The payload section is divided into two part, mother and daughter as illustrated in Fig.1 which shows a test scenery of the payload final check at the launching site at Kagoshima Space Center of ISAS located at Uchinoura in Kyushu island. The mother part contains the power supply composed of a DC-battery and DC-DC converter, the microwave transmitter composed of the magnetrons with a controller, two sets of truncated wave-guide antennas, a Langmuir probe for the measurement of electron temperature and density, wide band telemetry set, a neutral gas plume which is capable to emit a neutral nitrogen gas, and a TV monitor camera which was used to monitor the separation of the mother and daughter rocket. The configuration of these instruments is depicted in Fig.2. The mother section is below the plane denoted by "separation". The microwave transimission was made by one of the two truncated wave-guide antennas connected to magnetrons. The magnetrons used in the MINIX are those designed for a home-use microwave oven with a transmitting power of 830W. Most of the diagnostic instruments such as a VLF wide band receiver, an HF sweep frequency receiver, geomagnetic aspect meter, electron density and temperature meter and microwave detector are installed on the daughter section as illustrated in Fig.2.

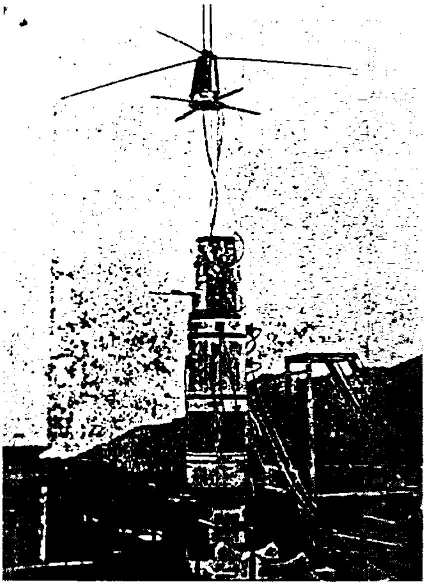

Fig.1 Test of payload at launching site. Daughter rocket is separated from the Mother.

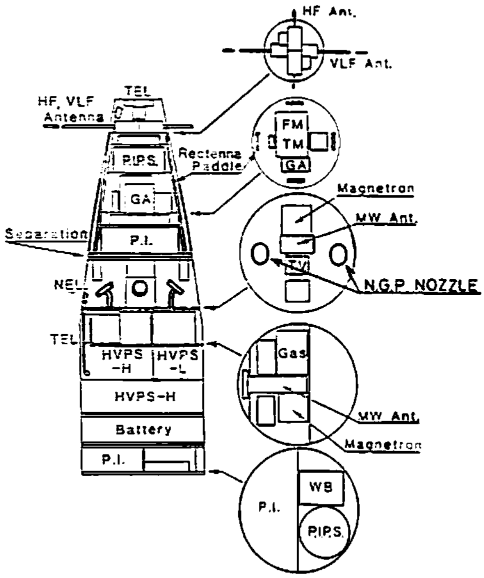

Fig.2 Configuration of instrumentation in the payload section onboard S-520-6 rocket.

The receiving antennas of the VLF and HF plasma waves are extended radially from the top portion of the daughter rocket as seen in Figs.1 and 2. Each antenna element is 2m in length and is used as a monopole antenna or is combined to form a dipole antenna. The HF sweep frequency receiver covered a frequency range of 0.1 MHz to 18 MHz with a sweeping time of 250 msec. The VLF receiver covers a frequency range of 60 Hz to 25 kHz. Three rectenna type antennas are installed at the bottom of the daughter rocket and extended radially to form four paddles as seen in Fig.1. One of the four paddle is used not as an antenna but as a mirror to view down the Earth by a TV monitor camera which is looking up to the daughter rocket form the mother rocket.

3. Experimental Time Sequence

Figure 3 shows the trajectory of the S-520-6 rocket and MINIX experimental Schedule along the orbit. The separation of the daughter rocket was made at t = 209 sec after launching at an altitude of about 220 km. The experimental period was divided into three categories. The first period (I) was mainly devoted to the study of the Ohmic heating. As the Ohmic heating requires a reasonable amount of electron-neutral collisions, a long duration (10 sec) transmission of the microwave was made during the period (I) when the rocket passes through the lower ionosphere where the collision frequency is high.

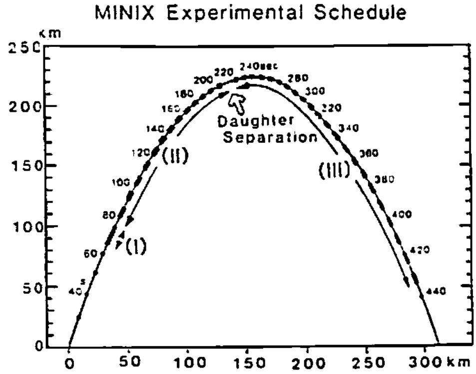

Fig.3 Trajectory of S-520-6 rocket and experimental time sequence.

In the second (II) and third (III) period, main focus is laid on the study of the nonlinear plasma wave excitation. The microwave was transmitted intermittently with 5 sec. transmission followed by 5 sec. pause. In the second phase, the dependence is studied of the nonlinear process on the ionospheric plasma parameters such as the electron density and the geomagnetic field which change with altitude. In the third phase after the daughter rocket separation, main interest was laid on the dependence of the nonlinear process of the plasma wave excitation on the distance between the mother and daughter rocket, i.e., the local intensity of the microwave field.

4. Main Results

The magnetron transmitter system which is reinforced against the rocket vibration and shocks worked perfectly during the flight. All the other diagnostic instruments were also perfect in their operation. A videotape was resumed by the resuming team. The tape contained the video information of the separation of the daughter rocket. It was taken by the monitor TV camera installed on the top of the mother rocket. Some of the video frame will be shown at the oral presentation.

The measurement of the electron temperature showed no temperature increase was detected both in the phase (I) and at the timing when an artificial neutral nitrogen gas was injected to increase the electron-neutral collisions. It turned out that the estimated temperature increase is of the order of 100 degrees which is not measurable by the temperature or Langmuir probes used in the MINIX. However, it should be noted that this result does not mean at all that the SPS microwave energy beam does not cause the Ohmic heating in the ionosphere. Even though the power density of the transmitted microwave from the rocket was the same as that of the SPS microwave, the effective time of exposure of the microwave to the ionospheric plasma was too short compared with the characteristic time of the Ohmic heating because the rocket passes through the ionospheric plasma too quickly.

As to the nonlinear excitation of the plasma waves, the result was clearly positive. The HF receiver showed a clear difference in the frequency spectra of the plasma waves when the microwave transmission was on and off. One example of the dynamic spectrum of the measured plasma wave for the period from 120 second to 210 second after launching is shown in Fig.4. The second horizontal line from the top shows the on and off of the microwave transmission. The vertical axis is the frequency from 0.1 to 9 MHz. The horizontal axis show a time scale from 120 to 210 seconds. The dark and light bar on the line indicate the timings of the transmission and pause, respectively. The horizontal line appearing at the frequency 3.1 MHz is an interference from the beating of the two frequencies used for the telemetry.

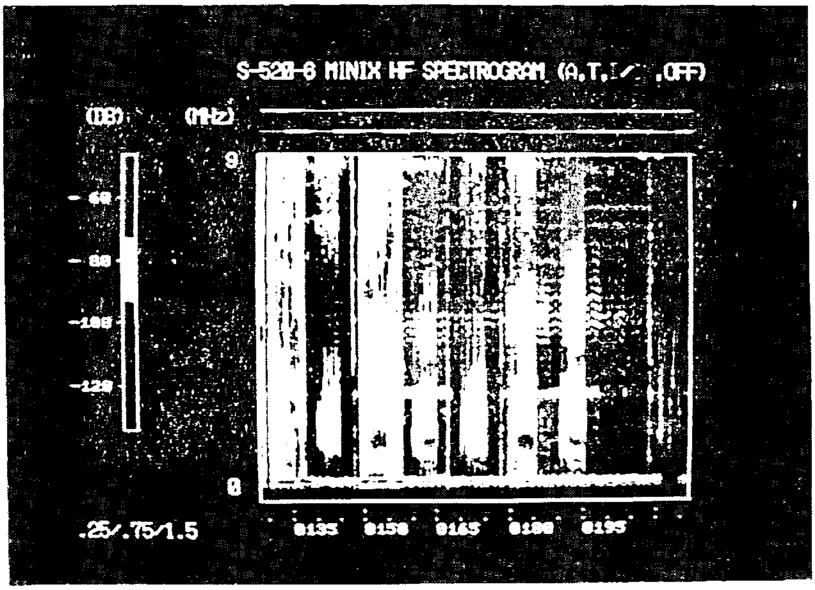

Fig.4 Dynamic spectrum of plasma waves observed by MINIX.

Two different types of strong waves are seen excited only during the periods of the microwave transmission. One is the waves around 1.5 MHz and its harmonics. The frequency does not change much but shows only a slight decrease in time i.e., with altitude. This wave turns out to be the electrostatic electron cyclotron harmonic waves judging from the comparison with the local electron cyclotron frequency. The second type of plasma waves excited by the microwave changes its frequency from 4 MHz to 6 MHz with altitude. The frequency of the wave turns out to be almost equal to the local electron plasma frequency. Thus this wave is supposed to be the electron plasma wave excited by the Raman scattering process of the transmitted microwave.

The present MINIX revealed that the strong microwave energy beam is subject to nonlinear decay instabilities and causes the nonlinear excitation of electron cyclotron and plasma waves in the ionosphere.

5. Conclusion and discussion

The MINIX was the first trial of transmission of high power microwave in situ the ionosphere. We carried out this experiment in a hope that a local effect of the high intensity microwave of the SPS microwave beam can well be simulated and examined by a rather small scale experiment such as the MINIX. The Ohmic heating and associated density depletion could not be measured showing that the heating effect is of large-scale and slow-time-scale phenomenon. However, it was demonstrated that various plasma waves are excited in the microwave beam column. This may not be important from a viewpoint of the energy loss because the loss of the energy transmission due to the excitation of the plasma waves is less than 1 %. However, the effect is significant in a sense that strong electrostatic waves are produced in the ionosphere and magnetosphere which may affect the high energy particle population through Landau and cyclotron resonances and diffuse them in both energy and pitch angles. Such secondary effect should be investigated in detail in the future before the realization of the SPS.

Support of the MINIX by the rocket and telemetry teams at ISAS and KSC is greatly acknowledged.