MICROWAVE EMISSION EXPERIMENT WITH HYPERVELOCITY IMPACTS AND APPLICATIONS OF ITS RESULTS

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ABSTRACT

The experiments to detect microwave emission due to hypervelocity impacts have been carried out with significant improvements of time resolution. We can investigate waveforms up to 1 n sec so that the energy of the emitted microwave can be estimated. The emission is a random sequence of pulses which lasts more than 10 μ sec depending on the target destruction. The projectile is a nylon sphere of 0.21 gram, and is accelerated by a light-gas gun up to the velocity of 4 km/sec.

The timing and duration of the emission are strongly dependent on the material and thickness of a target. Especially, large delay of the emission was observed in the cases a projectile penetrates a target. Therefore, those informations seem to include key suggestions to destruction process as well as the emission amplitude. This phenomena can be applied to the impact detection on a large space structure like a space station. The generated microwave propagate in vacuum and may be diffracted so that impacts can be detected more easily and at more flexible locations than by a vibration sensor or an accelerometer.

1. INTRODUCTION

When a projectile collides a target with hypervelocity, we can observe a light flash. But in the past, few experimental results were presented concerning radio-frequency emission due to hypervelocity impacts. There was a report of magnetic field detection via wires at several hundreds kHz[1], but the experiment seems to have much ambiguity and uncertainty. We already succeeded to detect the emission using direct detection and heterodyne detection schemes[2].

This time, the experiment system has been greatly upgraded. Especially, time resolution is improved upto 1 n sec. The experimental parameters are changed: The material and thickness of targets, projectile speed, time resolution, detected period, and detection polarization. But this paper focuses on the measurements on an aluminum and iron GHz and 2GHz. The details of the experiment systems and obtained results will be given together with an application example.

2. SYSTEM CONFIGURATION FOR EXPERIMENTS

The total system for the experiment is shown in Fig.1, which is composed of the followings:

(a) Projectile and target
(b) Accelerator
(c) Detection devices
(d) Recording devices.

A projectile flies in vacuum to strike a target so that the accelerator is equipped with a vacuum chamber the size of which is 350 mm diameter. The triggering device detects the ignition of the accelerator, and generate a trigger pulse to the recorders.

The projectile was a nylon sphere of 0.21 gram with 7 mm diameter. The projectile is accelerated by a light-gas gun to get the speed of 4km/sec. The speed of a projectile is measured in the mid-course by using a light chopper. The target is an aluminum plate with thickness of 2mm, 8mm and 22 mm, respectively.

To detect sharp pulses, detectors with wide frequency bands are required. The detectors are as follows:

(1) Heterodyne receiver with a low noise amplifier and a pyramidal horn: 22 GHz, IF (Intermediate Frequency) output of 4 MHz to 1 GHz

(2) Heterodyne receiver with a log-periodic antenna: 2 GHz, IF output of 10 MHz

The configuration of the detector at 22 GHz is shown in Fig.2(a). The microwave signal is picked up by the pyramidal horn and amplified by the low noise amplifier (LNA) and the microwave amplifier. The signal is mixed with the local frequency to generate the IF signal, which should be stored. In the direct detection scheme shown in Fig.2(b), a diode detector is used instead of a mixer in Fig.2(a) to detect the envelope of the microwave waveform.,

Recording devices are also important to confirm the

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digital oscilloscope with a floppy disc. The maximum sampling frequency is 2 GHz. The trigger to the recording system should be paid much attention to, in order to pick up the short time around an impact and to obtain many sample points on the generated pulse. We used a cut-wire trigger device located in front of the target. The time resolution of 1 n sec is obtained so that the energy of the emitted microwave can be estimated.

3. OBTAINED WAVEFORMS AND TARGET DESTRUCTION

When a projectile with a speed of 4 km/sec collided a target of an aluminum plate with 2 mm thickness, a hole of 20 mm diameter was made as shown in Fig.3. The waveform of microwave emission is shown in Fig.4. At 22 GHz in Fig.4(a), there are many pulses at 6 μ sec after the impact lasting for 5 μ sec, and at 21 μ sec after the impact lasting for more than 25 μ sec. At 2 GHz in Fig.4(b), there are smaller number of pulses. The pulses at 2GHz are correspondent in time to those at 22 GHz. The polarity is always negative because the diode output is a direct current of negative sign.

In the case of a target of an 8 mm thick aluminum, the plate was made a crater on the front and a hump on the back as shown in Fig.5. The emission waveform at 22 GHz in Fig.6(a) is calmer than that in Fig.5(a). The first emission occurred at the same timing after the impact and duration, but the second emission is closer to the impact and composed of much smaller number of pulses. The pulses at 2 GHz in Fig.6(b) has coincident in time with those at 22 GHz in Fig.6(a).

In the case of a target of a 22 mm thick aluminum, the plate was made a crater with 5 mm depth on the front without any change on the back as shown in Fig.7. The microwave emission occurred right after the impact in a smaller amplitude, and no emission was observed 15 μ sec after the impact at both of 22 GHz and 2GHz, as shown in Fig.8.

Then, the argent is changed to an iron plate with 20 mm thickness. As the material is harder than aluminum, the damage due to impact is much smaller as shown in Fig.9. A small and shallow crater is formed on the front. In the case 1 of Fig.10 (a), the first emission occurred at the same timing as the case of thick aluminum shown in Fig.8(a), at about 6 μ sec after the impact lasting for 5 μ sec, but composed of very fewer pulses.. The second emission is almost gone. In the case 2 of Fig.10 (b), the first emission is delayed by 15 μ sec, and followed by several pulses until 35 μ sec after the impact.

4. CONSIDERATION OF THE WAVEFORMS

From the obtained waveforms, we can conceive three different types of factors:

(1) White Gaussian noise with a random waveform, which occasionally raise a large amplitude with a probability of Gaussian distribution.

(2) A group of isolated pulses with direct current.

(3) A group of isolated pulses with many frequency components in correspondence to the detector frequency band.

The observed waveforms shown in Figs.4, 6 and 8 show the feature of the type (2) or (3) rather than the type (1). If the emission occurs due to blackbody radiation with occasional instances, the waveform should be of the type (3).

The expanded pulse with the amplitude of-0.7 V in Fig.8 (a) is sampled by three points so that the pulse width is 2 n sec. The peak value of the waveform corresponds to 2×10^{-8} m W.

Daring to integrate the curve of the pulse, we obtain the amount of work to be 3×10^{-17} Joule. This integration should represent the maximal value of the pulse energy. Therefore, the emitted energy at 22 GHz and within the 1 GHz bandwidth is calculated to be 5×10^{-15} Joule taking the aperture area of the horn and its distance from the target into consideration.

As the total kinetic energy of the projectile is 1.7×10^{3} Joule, 3×10^{-18} of the amount was converted to the microwave energy of the above frequency per puluse.

5. CONCLUSIONS

Microwave emission due to a hypervelocity impact has been detected. with fairly good repeatability. The strength and time delay of the emission are highly dependent on the degree of target destruction. This phenomena is probably caused by localized heating due to impacts, heat conduction and black-body radiation[3]. Therefore, we could use the characteristics of the phenomena to study destruction mechanism due to study hypervelocity impacts[4] or to sense space debris collisions to spacecraft.

Fig.11 shows an application of impact detectors installed on the center tower of the space station. Three systems monitors all part of the structure surface.

6. REFERENCES

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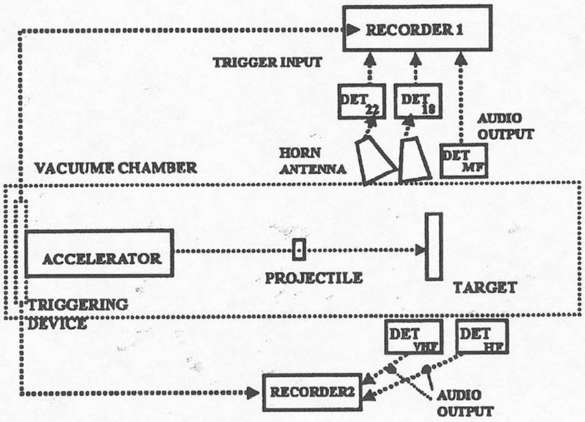
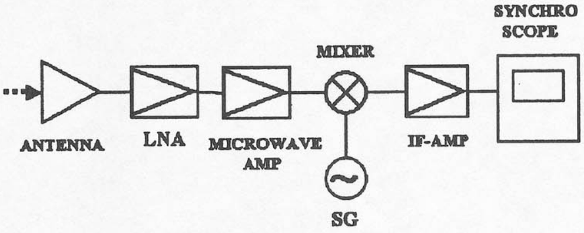


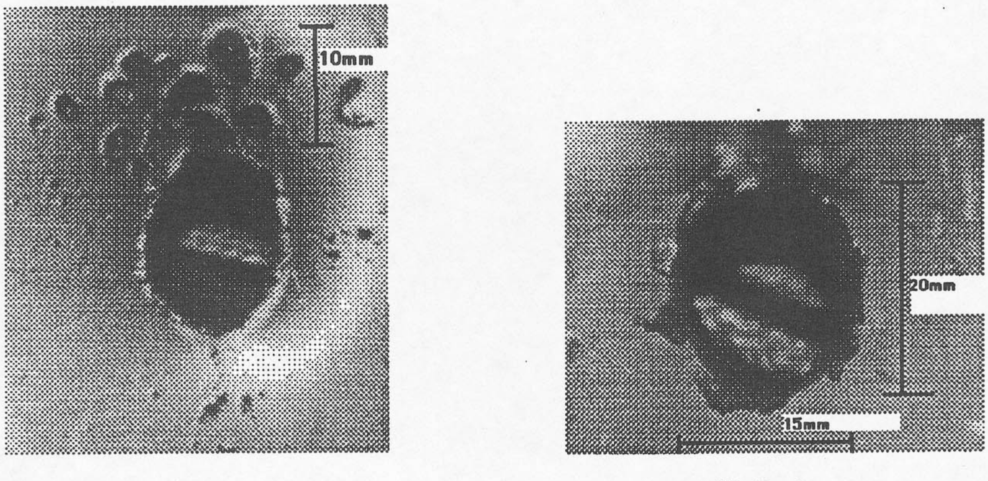
Fig.1 Total system configuration



(a) Hterodyne detection at 22 GHz

(b) Direct detection at 2 GHz

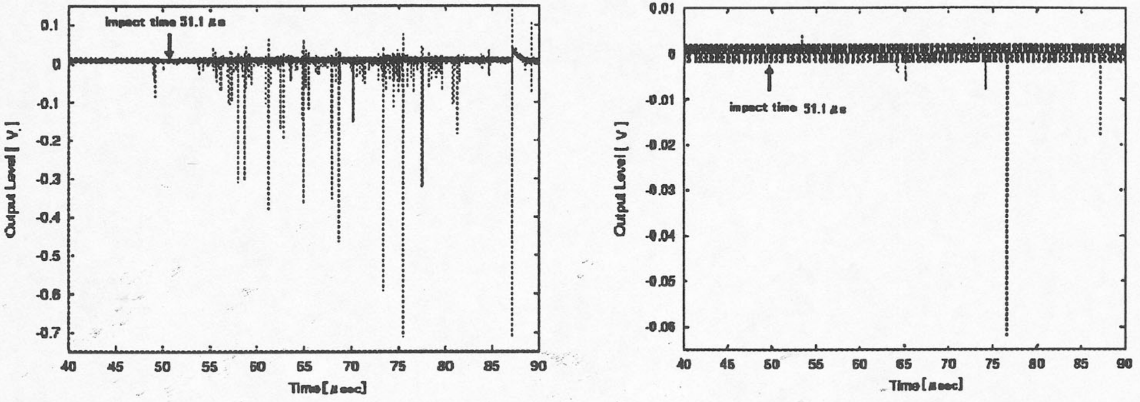
Fig.2 Configuration of the detector



(a) Front

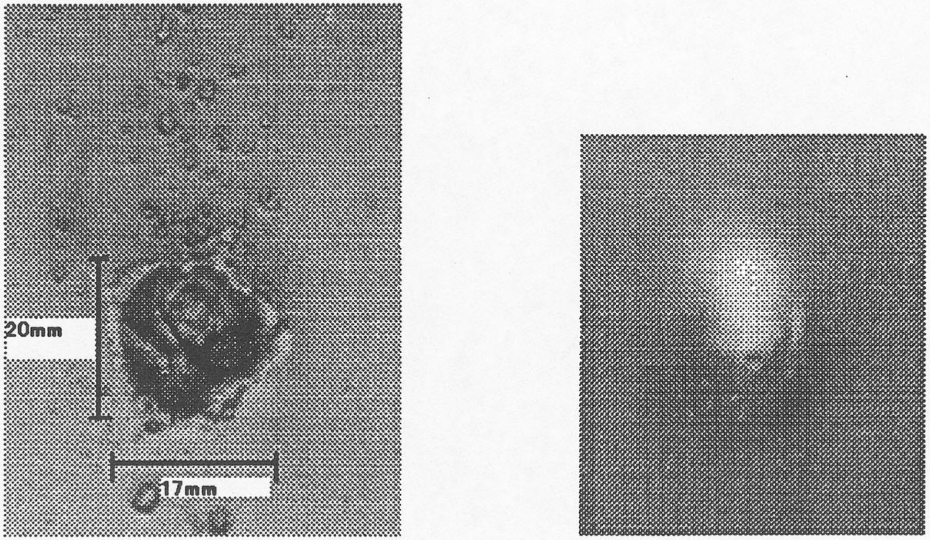
(b) Back

Fig.3 Destruction of a 2mm thick aluminum plate.



(a) 22 GHz (b) 2 GHz

Fig.4 Response in the case of a 2mm thick aluminum plate.



(a) Front (b) Back

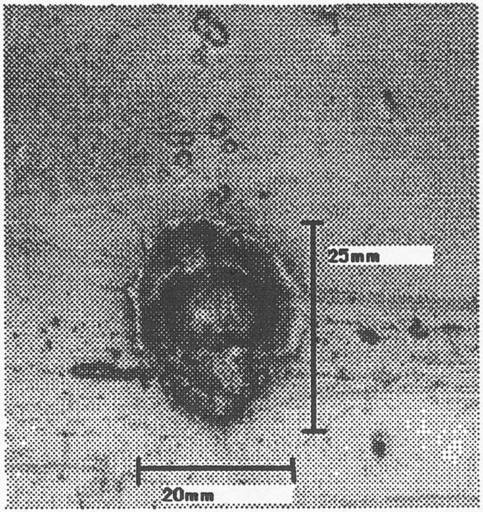
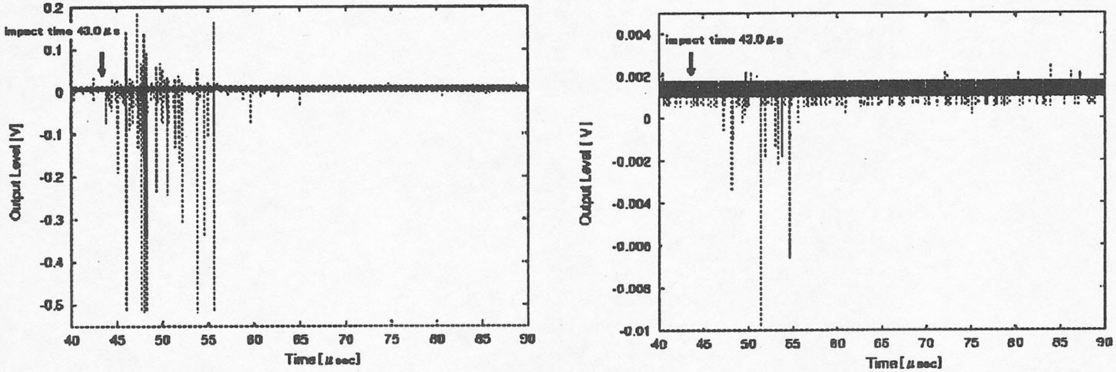
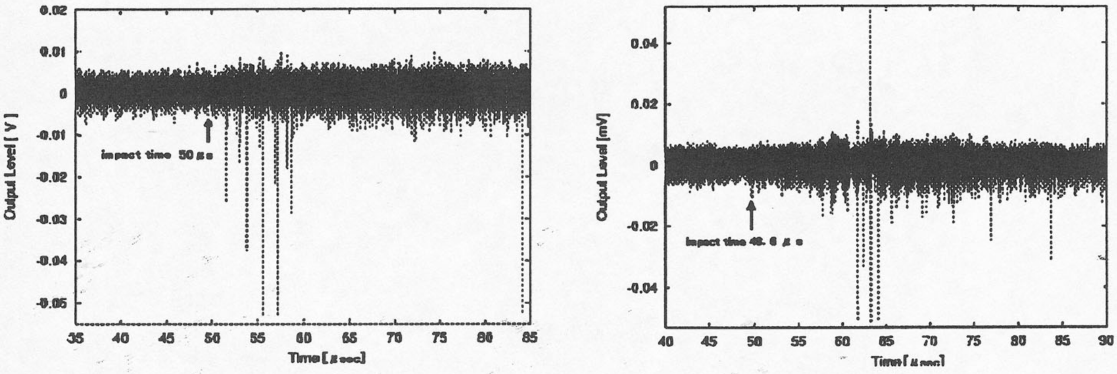


Fig.7 Destruction of a 22mm thick aluminum plate (Front).



(a) 22 GHz (b) 2 GHz



(a) Case 1

(b) Case 2

Fig.10 Response at 22 GHz in the cases of a 20mm thick iron plate.

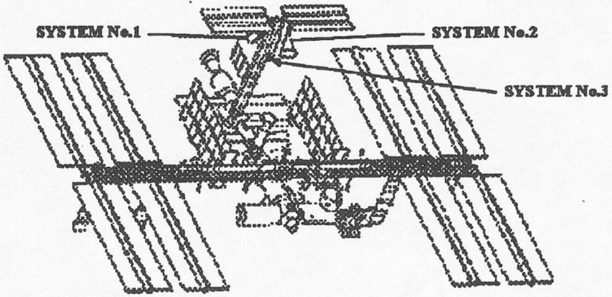


Fig.11 Application of impact detectors on a space station