FDTD SIMULATION AND RADAR EXPERIMENTS USING SCALE-DOWN MODEL FOR RADAR SOUNDING OF THE ASTEROID.
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Introduction: Internal structure of an asteroid tells us its history of accretion, metamorphism, differentiation impacts, disruption, and reassembly. Wilkison (2002) compared several models of formation and internal structure models for 433 Eros [1]. Based on the bulk porosity estimated from the mass and volume, and comparison of the sizes of the boulders and craters on the surface, 25143 Itokawa was suggested to be a rubble pile asteroid [2, 3]. Imaging of the asteroid internal structure is proposed in several studies. Simulation of radio wave propagation and internal structure imaging were performed by applying seismic migration technique and suggested that bistatic radar was more effective than monostatic radar [4, 5]. Several simulations of radio wave propagation and radar tomography were also performed based on the concept of a bistatic radar system installed on multiple cube satellites [6, 7, 8]. The purpose of this study is to perform the radar experiments of the radar sounding of the asteroid internal structures by using a scale-down model. For the preparation of reference data to be compared with radar experiment data, we performed Finite-Difference Time-Domain (FDTD) simulation.

Specifications of the radar: In order to perform imaging of asteroid internal structures, we assume a bistatic radar system. The first application of the bistatic radar system to a planetary mission was performed in the Rosetta mission for exploration of 67P/Churyumov-Gerasimenko comet nucleus [9]. In the Rosetta mission, transmitter and receiver was installed on the orbiter and transponder was installed on the lander. If we can install transponder on another orbiter, we would get large advantage in imaging of asteroid internal structure. The specifications of the radar assumed in this study are summarized in Table 1. The operation frequency range of the radar is from 50 to 150 MHz. The range resolution is therefore 1.5 m in vacuum. Transmitting peak power is 1 W. Assuming the loss tangent of ~0.01, the detection depth is estimated to be ~100 m.

Table 1. Specifications of the radar

Operation Frequency	50-150 MHz (Liner chirp)
Transmitting power	1W (peak)
Detection depth	100 m (S/C height: 15 km, loss tangent: ~0.01)

Scale-down model of the asteroid: It is difficult to perform radar experiments using a full-scale asteroid model on the ground. We, therefore, plan to perform radar experiments using a scale-down asteroid model. There are asteroids with various sizes. For example, the size of 25143 Itokawa is several hundred meters. We define a scale-down model with a diameter of 1 m for an asteroid with a diameter of 20 m. The operation frequency in radar experiment with 1/20 scale-down model is therefore selected to be 1-3 GHz, which is 20 times as high as radar for full-scale asteroids. The internal structure of the scale-down model consists of several rocks (for internal boulders) and sand surrounding them (for regolith).

FDTD simulation: For the preparation of the radar experiments, we performed FDTD simulation**.** In two dimensional 400×400 grids, the permittivity of the media was defined as shown in Fig.1. The permittivity of boulders (rocks) was in a range from 3 to 7 and that of regolith (sand) was 2. For simplicity, the first half of the radar pulse propagation, which was from the transmitter installed on the main orbiter to the receiver of the transponder installed on the sub orbiter, was simulated in this study. In the simulation box, the locations of the main and sub orbiters can be indicated by their azimuth angles ϕ_{TX} and ϕ_{RX} from reference direction. From calculated evolution of the electric field at sub orbiter, radargram along $0 < \phi_{RX} - \phi_{TX} < 2\pi$ could be obtained as shown in Fig.2. Several echo profiles are overlapped in it. The echoes labeled (1) indicate the arrival of diffracted pulses propagating outside of the asteroid. The echoes labeled (2) indicate the arrival of the pulses propagating inside of the asteroid, which is severely overlapped with the arrival of the diffracted waves due to the bulk permittivity range of the asteroid (~2). The echoes labeled (3) indicate the arrival of the pulses propagating inside the asteroid and reflected at permittivity contrasts in the asteroid, which is not much overlapped with other echo profiles. We, therefore, use the echo profiles labeled (3) for inversion analyses of the internal structures. For the initial trial, we applied Kirchhoff migration to radargrams obtained in $0 < \phi_{RX}$ - $\phi_{TX} < 2\pi$ and $0 < \phi_{TX} < 2\pi$ with an assumption of bulk permittivity of 2, and obtain the distribution of the reflectance in the asteroid as shown in Fig.3.

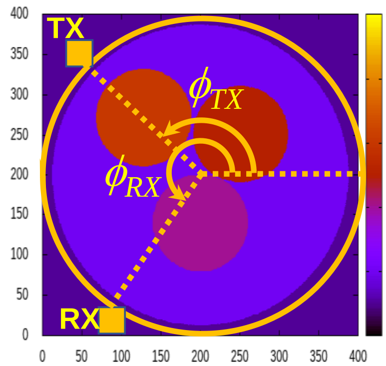

Fig. 1: Simulation box.

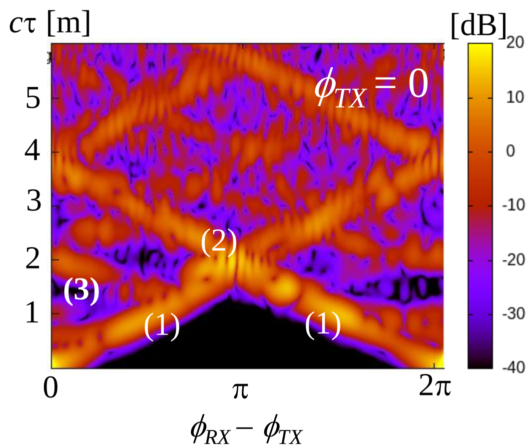

Fig. 2: Radargram along $0 < \phi_{RX} - \phi_{TX} < 2\pi$.

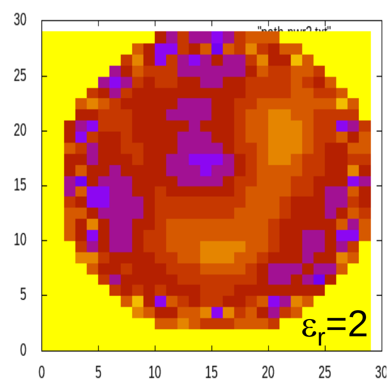

Fig. 3: Distribution of the reflectance in the asteroid obtained by applying Kirchhoff migration.

Radar experiments: Development of radar for experiment with scale-down model of the asteroid has been almost finished. We made antipodal Vivardi antennas on printed circuit board (PCB) for transmitting and receiving the pulse in a frequency range from 0.5 to 3 GHz. Transmitter and receiver of the radar were developed also as a bread-board model (BBM) of ground penetrating radar (GPR) operated in a frequency range from 0.5 to 3 GHz for exploration of the lunar subsurface ices. We are now starting test measurements of scale-down asteroid model, sand and rocks filling within a plastic bucket with a diameter of 1 m.

Summary: For the preparation of radar sounding of the asteroid internal structures in future missions, we are performing radar experiment and FDTD simulation with a scale-down asteroid model. In the radar experiment, 1m scale-down model is measured in a frequency range from 1 to 3 GHz for demonstration of radar sounding of 20-m asteroid in a frequency range from 50 to 150 MHz. In order to obtain reference data for the radar experiment, FDTD simulation was performed. Using echoes reflected from permittivity contrast within the scale-down asteroid model, we could obtain clear distribution of the reflectance in the asteroid.

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