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SPACE DEBRIS MEASUREMENTS IN JAPAN

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ABSTRACT

This paper describes the present status of space debris measurements in Japan, focusing on the recent achievements of existing systems and the design of new systems. Issues concerning the Leonids meteoroid storm in November 1998/99 will be also discussed.

INTRODUCTION

There have been several projects of space debris measurements in Japan. They have made significant contributions to research in this area from the viewpoint of new technologies. Unfortunately, no dedicated facility for that purpose has been established yet which can add new data to the space debris catalogue.

The MU-Radar which has the longest history of space debris measurements in Japan (Sato *et al.*, 1991), has recently been used jointly by the National Space Development Agency (NASDA) and Kyoto University to obtain basic data to determine the orbits of debris from a single pass (Tajima *et al.*, 1997). The bistatic radar of the Institute of Space and Astronautical Science (ISAS) which uses 20 and 64 meter diameter antenna for transmission and reception, respectively, is one of the first bistatic systems for debris observation in the world (Takano and Yajima, 1994). The recorded data were processed for correlation while compensating Doppler frequency (Murakami *et al.*, 1997). The Communication Research Laboratory (CRL) used a 1.5 m aperture telescope to observe satellites in GEO (Arimoto and Suzuki, 1997).

Now, several new plans are being studied. Systems still under preliminary study are a laser radar in ISAS (Takano *et al.*, 1995), and the laser communication and radar system of CRL which will be carried on the Japanese Experimental Module (JEM) of the Space Station (Arimoto *et al.*, 1998). NASDA is planning a radar and a telescope which could be used for space debris measurements for a substantial time. The details of the telescope will be described elsewhere (Isobe, 1998).

This paper presents the recent achievements of existing systems and the current design of new systems. The possibility to measure the Leonids meteoroid storm in November 1998 will be also discussed.

BISTATIC RADAR IN ISAS

Only a few radar stations exist which are fully equipped with transmission and reception capabilities. The construction of new stations is difficult due to high cost. On the other hand, large antennas for space communications or radio astronomy are distributed all over the world, and their number is increasing.

ISAS proposed a bistatic radar as shown in Figure 1. Using this configuration, we can form a space debris monitoring network with much freedom and flexibility. Also, the shape of a debris object may be estimated by processing information taken at several stations.

In the experimental system shown in Figure 1, Kagoshima Space Center with 10 m and 20 m diameter antennas and Usuda Deep Space Center with a 64 m diameter antenna, both of ISAS, are used as transmission stations and reception station, respectively. The distance between the Kagoshima and Usuda stations is about 1000 km. For system tests, real satellites in orbit are irradiated instead of space debris, because their orbits are known in advance. One of the test objects is Yohkoh, a scientific satellite in a circular orbit of 600 km altitude.

The satellite tracking station at KSC sends the up-link radio wave to a satellite. The radio wave is modulated by PN (Pseudo Noise) codes in PSK-PM (Phase Shift Keying-Phase Modulation) in ranging operation. The received radio wave at UDSC is amplified by a low-noise amplifier (LNA), and down-converted to the video-band of 0 to 2 MHz. The video signal is sampled by 4 MHz, one-bit-digitized, formatted and finally recorded on a magnetic tape. The receiver and recorder for VLBI (Very Long Baseline Interferometry) are diverted from a radio-astronomical use.

Data Analysis Improvement

The data analysis is based on correlation calculations. Earlier, a dedicated correlator for VLBI was used where the data are correlated in the time domain by changing the time delay of one of the two data sets. The problem is that the amount of time delay is limited by the total time lag, and the Doppler frequency compensation is not an easy task.

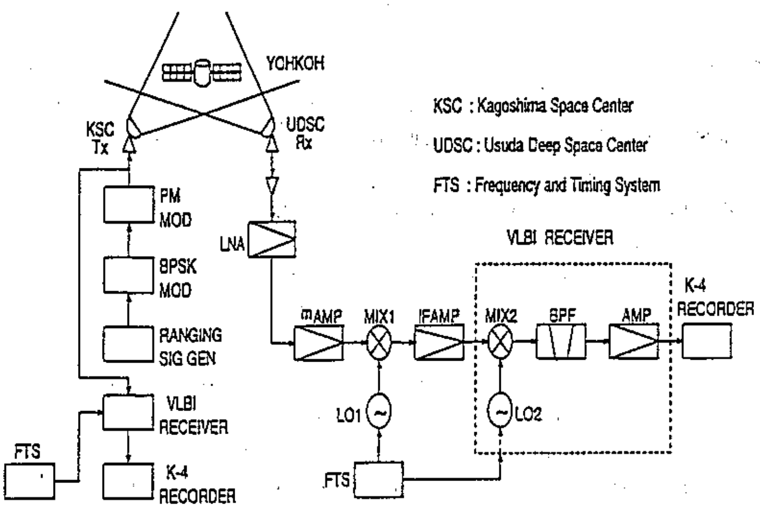


Fig.1. Configuration of the bistatic radar.

Recently, a special software has been developed which correlates the received wave with the transmitted wave in the frequency domain. The Doppler frequency can then easily be adjusted by shifting the frequency spectrum of the received wave before correlation calculation. Thick and thin lines in Figure 2 shows the correlated spectrum with nominal and adjusted Doppler frequencies, respectively. The peak value of the carrier is greatly enhanced. The carrier level changes according to the lapse of time as shown in Figure 3. The received wave can not be directly detected though the transmitted wave power is high and constant. The correlated received power with Doppler adjustment is increased seven times compared with nominal Doppler frequency.

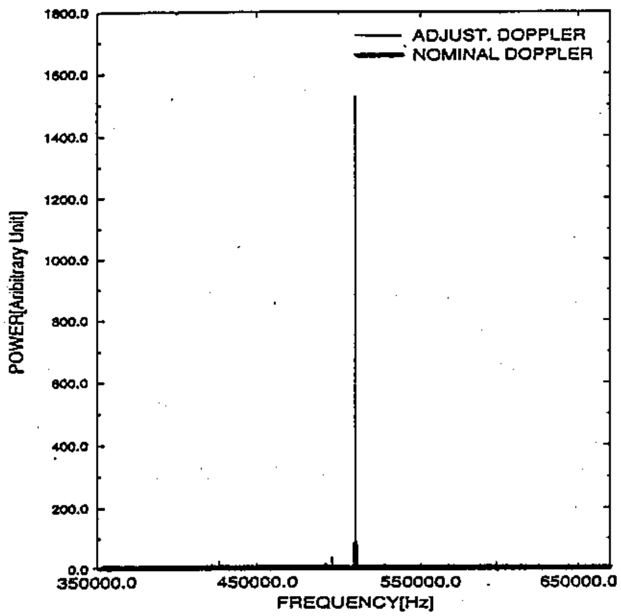


Fig.2. Correlated spectrum with/without Doppler compensation.

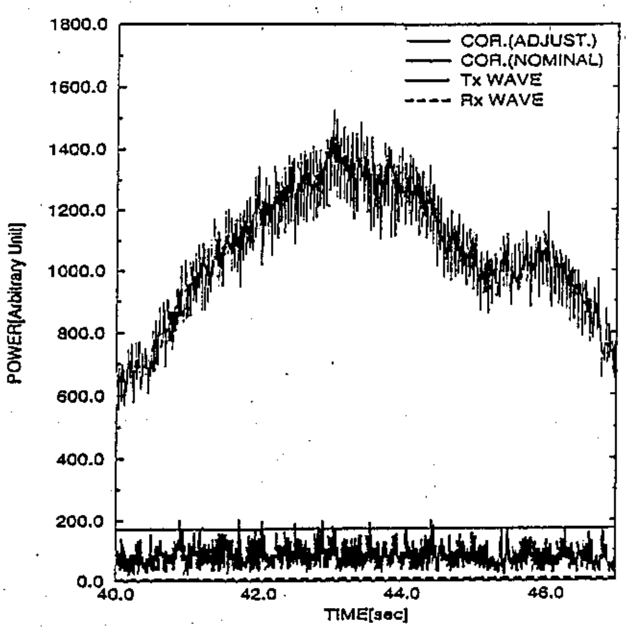


Fig.3. Time change of the carrier level.

MU RADAR EXPERIMENT OF ORBIT DETERMINATION BY A SINGLE TRACK

The MU (Middle and Upper atmosphere) radar of Kyoto University, Japan, is a powerful VHF radar operating at 46.5 MHz. The main target of this radar is the earth's atmosphere, or more precisely, weak backscatter from the refractive index irregularities of the air caused by the atmospheric turbulence. Since this atmospheric echo is weak, scientists have been bothered by strong 'undesired' echoes from various objects such as space debris. They found that these previously discarded echoes could be converted to valuable data, and started a statistical study of space debris in 1988. Large output power of 1 MW and the antenna size of 100 m compensate for the reduced sensitivity at this frequency. The radar has a sensitivity roughly equal to the radars used by the US Space Surveillance Network (Sato *et al.*, 1991).

The antenna of the MU radar consists of 475 Yagi antennas which form an active phased array. The advantage of this type of antenna is that it can observe different directions almost simultaneously by electronically switching multiple antenna beams.

Use for Space Debris Measurements

In the special observation mode developed for debris observations (Sato *et al.*, 1994), 8 antenna beams are arranged as shown in the left panel of Figure 4, so that objects passing through this region can be observed by at least three overlapping beams simultaneously. The abscissa and the ordinate show the east-west and the north-south angles from the zenith in degree. Solid and dashed circles denote the half-power width of the beam and its effective coverage of 3 degrees from the center, respectively. Small circles overlaid on Figure 4, show a path of the target, which is the Japanese MOS-1b satellite in this case. The straight line shows the linear fit to these points with plus symbols indicating the location of the object for every 1 sec time step.

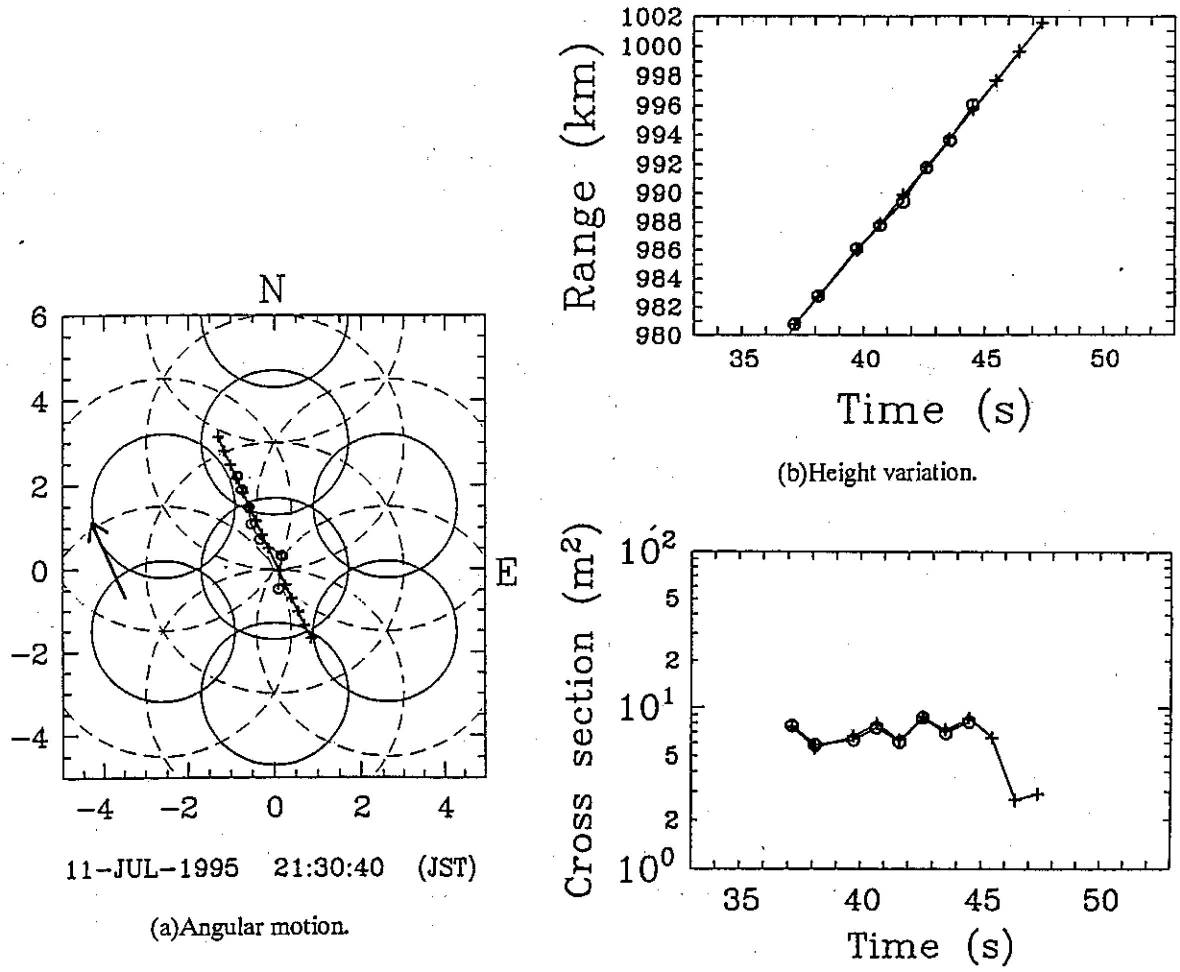
It is then possible to roughly determine the orbit of the target from a single observation. A conventional radar with a large parabolic antenna has a single and sharp beam. Therefore, the beam should be fixed waiting for the passage of an orbital object, or it should track the target with the aid of orbit prediction data. In order to obtain accurate orbital elements, it is necessary to track the object for a long duration. Since the number of beams used for a single observation is limited by various requirements such as the S/N (Signal-to-Noise) ratio, the angular coverage of each observation is limited to about 8 degrees as shown in Figure 4a, resulting in an observation period of only about 10 sec.

Experimental Results

Our approach was to direct the beams toward the point where the satellite enters the visible region of 30 degrees from the zenith. The first observation lasted for about 10 sec, and then the beams were switched to a direction where the satellite exits from the visible region. The second observation was made again for about 10 sec. The time span between the two observations is 1 to 2 min depending on the orbit of the satellite. The rapid increase of the observed range in Figure 4b is because the beam center was pointed 24 degrees off the zenith.

The predicted orbital elements using this set of data were compared with those determined from a routine tracking system as is shown in Table 1. It is found that the location of the satellite is determined with an error of about 5 km using a single observation by the MU radar, which satisfies the condition that the next appearance of the same satellite should be predicted accurately.

Similar experiments have been repeated with NASDA satellites. They confirmed that a single radar with a steerable antenna can be used to determine a satellite's orbit without using data of another radar.



(a)Angular motion.

(b)Height variation.

(c)RCS variation.

Fig.4. MU radar observation data of MOS-1b.

Table 1. Comparison of Orbital Elements Determined by the MU Radar Experiment and by the Routine Tracking (MOS-1b on July 11, 1995)

	NASDA determination	MU radar data
a (km)	7290.383	7285.677
e	0.0014	0.0017
i (deg)	98.992	98.803
Ω (deg)	261.379	261.255
ω (deg)	103.429	135.536
M (deg)	289.680	257.600
ϕ (deg)	33.109	33.136

LASER RADAR ONBOARD JEM OR THE SPACE STATION

A laser communication experiment is planned around the year 2003 between JEM on the Space Station and a ground station. It is based on adaptive optics which compensates atmospheric turbulence effects by using real time feedback control. The bit-rate of the link is 2.5 Gbps, which will demonstrate the capability of a high speed optical downlink from the manned Space Station to the ground. On this occasion, a preliminary measurement of space debris will also be performed using mainly existing equipment.

Experiment Details

Figure 5 shows the configuration of the onboard devices. A high power pulsed laser is used for space debris measurement. Table 2 shows system parameters applicable to the debris measurements.

Table 2. System Parameters Relevant to the Laser Radar

Optical antenna		Cassegrain telescope
Antenna diameter		15 cm
Acquisition and tracking system	Coarse tracking	Two-axis gimbals with DC servomotor, Si-CCD detector
	Fine tracking	Quadrant photo-detector and two-axis fine tracking mirror
Acquisition and tracking FOV		0.6 deg
Gimbals angle		Az: -30~210 deg., El: -30~120 deg.
Tracking error		<1 μ radian. (using the vibration isolator)
Required optical power		-60 dBm
Debris detector		Pulsed laser (energy: <10 mJ, wavelength: 1.9 μ m) and InGaAs heterodyne receiver
Detectable debris size		1 cm at 2 km distance from the ISS
Vibration isolation		less than 1/10 (at 100 Hz)
Total mass		about 100 kg

Tasks to be performed in this demonstration are as follows:

(1) Demonstration of laser communication

The communication system consists of an optical antenna with an aperture of 15 cm, a precise and sensitive acquisition, tracking and pointing (ATP) sub/system, an optical transmitter with a bit-rate of 2.5 Gbps, an optical receiver with a bit-rate of 2 or 50 Mbps, and a vibration isolator which reduces the tracking disturbance from the space station. Data of high-definition videos generated at the Space Station will be down-linked to the ground stations using the laser communication link.

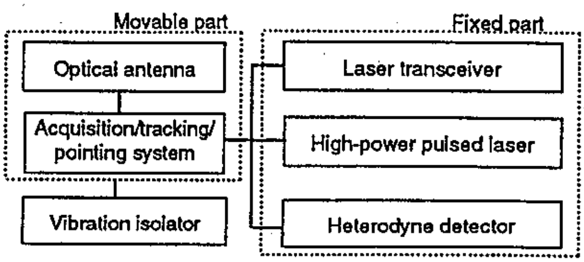


Fig.5. Optical/mechanical part of the onboard transponder.

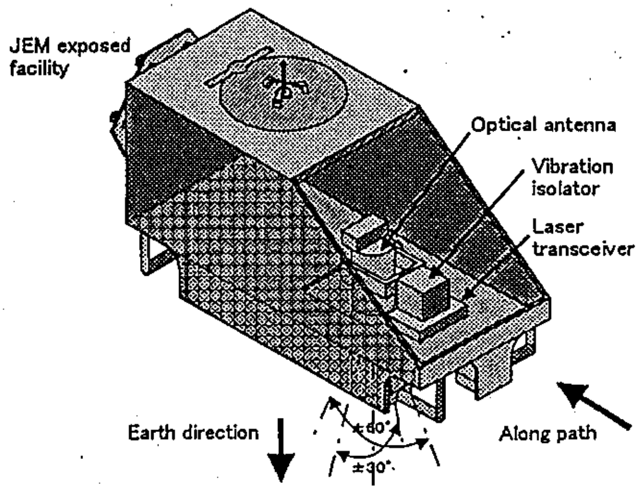


Fig.6. Configuration of the laser communication equipment for JEM.

(2) In-space evaluation of laser communication device
High-speed logic integrated circuits (IC), laser diodes, opto-electric modulators, and fiber-amplifiers will be operated and tested for about one year in the space environment. After the communication experiment is completed, the devices can be retrieved to the ground for evaluation.

(3) Detection of space debris
A preliminary experiment to detect small sized debris (from 0.1 cm to 10 cm in diameter) around the space station will be performed by using a small-sized but high-power pulsed laser transmitter and a heterodyne receiver. The ATP subsystem for the laser communication is applicable when the debris is illuminated by the sun and comes into the field of view of the acquisition sensor. The narrow beam from the pulsed laser transmitter can be pointed to the debris, and the reflected light can be received at the heterodyne receiver. The distance between the debris and the space station can be measured by analyzing the delay of the reflected light. The relative velocity of the debris can be obtained by measuring its Doppler shift.

The onboard laser communication equipment on JEM is shown in Figure 6. The earth stations will be accessed via a small window in the lower panel. Though the link duration downward to the earth station is about 2 minutes, a target upward in zenith direction such as a geostationary satellite can be seen for more than 10 minutes.

The basic study of this mission will be conducted by CRL and the development will be carried out by NASDA. The Engineering Model test will be finished in 2000. The experiment on board will be performed for about one year beginning in 2003.

DEVELOPMENT OF THE SPACE DEBRIS MEASUREMENT SYSTEM OF NASDA

NASDA studied space debris measurement systems from 1994 to 1997. In the first two years of the conceptual study phase, the current debris observation activities in the world and new technologies were surveyed focusing on the detection capability of 1 cm diameter debris. In the next two years, more attention was paid to beam agility. Specifications were issued of a space debris measurement system with an active phased array radar which can detect 1m diameter debris in a 300 km-altitude orbit.

Based on these studies, NASDA proceeds to the development phase of an experimental space debris observation system. The development will take six years from 1998 to 2003. The following development program describes the measurement system for experimental purposes.

Purpose of the Program

The purpose and significance of the space debris measurement program are well understood as part of NASDA's space activities:

(1) As one of the nations conducting space development programs, NASDA is willing to investigate the space debris environment resulting from Japan's international space activities since 1957.

(2) Japan has launched over 70 satellites, and left many operational debris in orbit in each launch operation. After successful launch and operations, several satellites were re-orbited into disposal orbits. NASDA, as one of debris generating organizations, has a duty to maintain the space environment by taking appropriate actions.

(3) NASDA considers a space debris measurement system as an infrastructure for manned space activities. Therefore, NASDA identified the necessity to develop technologies for debris observation, and to realize a debris observation system with sufficient capability.

Space Debris Observation System for the Experimental Purpose

(1) Configuration: The configuration of the space debris measurement system is shown in Figure 7. This system consists of the following subsystems.

a) Radar subsystem: The radar is based on an active phased array antenna which includes radiators and transmitter/receiver/phase-shifter modules. The antenna is associated with a signal processor to obtain the information from the received signal, and a beam controller to send the phasing signal to the phase shifters. The radar places six beams in space simultaneously, and can shift each beam electronically.

b) Orbit computation subsystem: The computer carries out calculations for debris orbit determination and prediction using observation data.

c) Management subsystem: The computer monitors and controls the whole system, and plans observation schedules based on the orbit prediction.

(2) Functions:

a) A debris object is detected by multiple beams. By analyzing the data, azimuthal and elevation angles are obtained. This system can determine the orbit of the debris from data of a single pass, with sufficient accuracy to acquire the same debris 24 hours later.

b) This system can track more than 5 debris objects simultaneously with six beams arranged in space.

c) The purpose of this system is to show the effectiveness of a multiple beam radar with a limited detection capability. A 1m diameter object can be detected at a slant range of 600 km.

d) This system has a capability to automatically execute orbit determination, prediction and observation planning.

The main characteristics of this radar are still under study in order to satisfy performance requirements. Provisional data are shown in Table 3. The fabrication of the system will begin in 2000, and will be completed in 2003. The system will be installed in the Okayama prefecture in the western part of Japan.

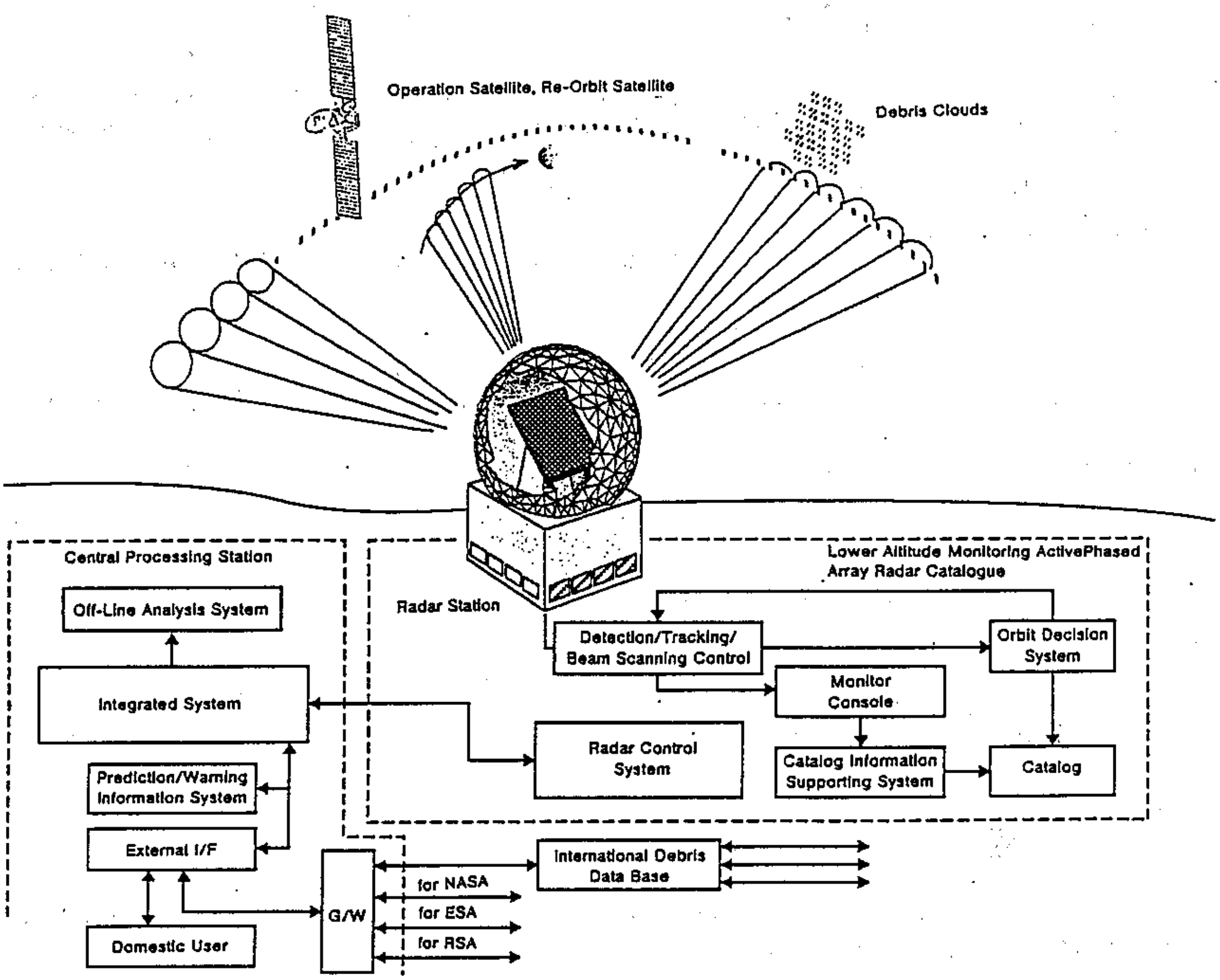


Fig.7. Concept of the space debris radar of NASDA.

Table 3. Major Parameters of the NASDA Radar

Item	Data
Antenna type	2-dimensional electronically scanning active phased array
Frequency	S-band
Peak power	90 kw
Pulse width	300 μ sec (compressed to 1.5 μ sec)
Diameter	3 m x 3 m
Beam width	Azimuth: 2 deg., Elevation: 2 deg.
Beam scanning Electronic Mechanical	 Azimuth: 45 deg., Elevation: 15-75 deg. Azimuth: 0-360 deg.
Angle accuracy	0.3 deg.rms
Ranging accuracy	30 m
Doppler accuracy	20 Hz

LEONIDS METEOROID MEASUREMENT

The Leonids meteor shower has been gathering much attention in the space community in Japan due to concerns partly raised by space debris specialists. ISAS organized meetings to discuss the following topics:
(1) details on the Leonids,
(2) probable hazards to the satellites which are operated by ISAS,
(3) possible measures against Leonids.
Several participants in the meeting are responsible for satellite mission operations and checked the safety of their own satellites. NASDA also examined the safety of their satellites.

Considering the potential hazard caused by the Leonids, and also considering the good opportunity to study meteoroids, another meeting on operational implications of the Leonids measurements was arranged. The topics are :
(1) relevant organizations or personnel,
(2) measurement data and measuring methods,
(3) possibility to collaborate with different organizations using different measuring methods.

Probable sensors to participate in the Leonids measurement campaign include:
(1) MU radar (Kyoto University),
(2) Fish-eye camera (NAO, amateur meteoroid associations, ISAS),
(3) Schmidt camera (ISAS),
(4) Meteor communication system (Shizuoka University).

CONCLUSIONS

It has been shown that the research and development of space debris measurement systems has expanded in this decade in Japan. A full-scale measurement system will be further studied in the next step. Data processing and modeling will also be addressed.

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