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Up-to-date Communications System for Japanese Scientific Spacecraft

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Abstract

The Institute of Space and Astronautical Science (ISAS) has a plan to develop a lunar explorer and an interplanetary spacecraft as well as a near earth orbit satellites to perform various missions. In order to realize this plan, ISAS has been developing an onboard S-band transponder, S-band transmitter, S-band receiver and X-band transmitter for the newly developing X-band communications system employing new technologies. This paper presents an outline of the communications system and the corresponding onboard hardware.

1. Introduction

The communications system for Japanese scientific spacecraft has so far mainly utilized the VHF and UHF bands. Its roles have included tracking, telemetry and command (TTC) functions and mission data transmission for the satellites developed by ISAS. Recently, the communications system has become more sophisticated by adopting new technologies to satisfy increasing requirements for advanced missions. This paper describes the newly developed communications system for Japanese scientific spcecraft and outlines its future prospects.

2. Status of Communications System for Scientific Spacecraft

ISAS has placed a total of 17 spacecraft in orbit from the "OHSUMI", launched in 1970, to the "GINGA" in 1987. The frequency band used for the communication link for these spacecraft, as shown in Table 2-1, has shifted from the VHF band (148 MHz/136 MHz) and the UHF band (400 MHz) to the S-band (2.1 GHz/2.3 GHz). These changes have been made to : (1) increase the data transmitted (see Figure 2-1), (2) improve the radio propagation, (3) be compatible with NASA STDN (Satellite Tracking and Data Acquisition Network).

ISAS has been planning to launch various kinds of scientific spacecraft (See Table 2-2). These plans are becoming more sophisticated to realize the lunar explorer and interplanetary spacecraft. To cope with this, the following improvements are required in the communications system.

Table 2-1 Status of Uplink/Downlink Frequency Band

Name of S/C	Launch Date	VHF			UHF			S-Band		
		TRK	CMD	TLM	TRK	CMD	TLM	TRK	CMD	TLM
OHSUMI	Feb., 1970	○								
TANSEI	Feb., 1971	○	○	○	○		○			
SHINSEI	Sep., 1971	○	○	○	○		○			
DENPA	Aug., 1972	○	○	○	○		○			
TANSEI-II	Feb., 1974	○	○	○	○		○			
TAIYO	Feb., 1975	○	○	○	○		○			
TANSEI-III	Feb., 1977	○	○	○	○		○			
KYOKKO	Feb., 1978	○	○	○	○		○			
JIKIKEN	Sep., 1978	○	○	○	○		○			
HAKUCHO	Feb., 1979	○	○	○	○		○			
TANSEI-IV	Feb., 1980	○	○		○		○	○		○
HINOTORI	Feb., 1981	○	○		○		○	○		○
TENMA	Feb., 1983	○	○		○		○	○		○
OHZORA	Feb., 1984		○		○		○	○		○
SAKIGAKE	Jan., 1985							○	○	○
SUISEI	Aug., 1985				○		○	○	○	○
GINGA	Feb., 1987				○		○	○	○	○

Note: TRK: Tracking, CMD: Command, TLM: Telemetry

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1) Higher frequencies in S-and X-bands to achieve higher data rate transmission
2) New modulation techniques to meet the stringent power flux density requirements of the Radio Regulations
3) False lock protection for the highly sensitive PLL receiver to assure reliable satellite operation
4) Smaller and lighter communications subsystem to allow smaller satellites and more cost-effective scientific experiments
5) High gain antenna (approx. 2 m in diameter) for long range communication and high speed data transmission.
6) The standardization of convolutional coding and data compression in the data handling subsystem

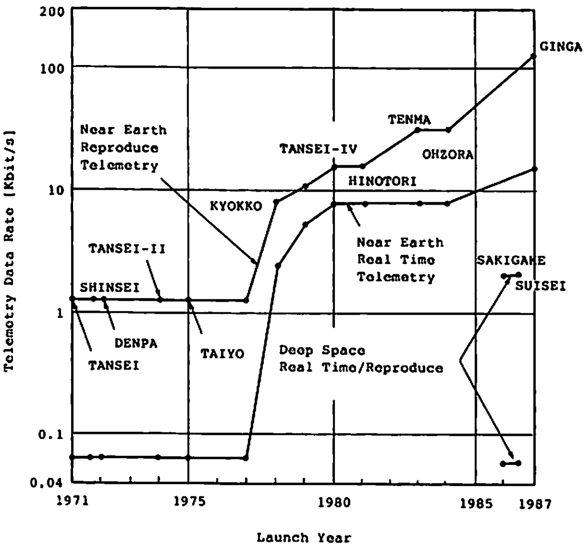

Fig. 2-1 Trend of Telemetry Data Rate

Table 2-2 Launch Plan for Scientific Spacecraft

Project	Launch Date	Orbit	Main Mission	Developments in Communications System
Exospheric Satellite (EXOS-D)	Feb.,1989	300 km ∿ 10,000 km Inclination: 76 deg.	o Observation of auroras in geomagnetic field	o Four levels of output power for S-band transmitter (to satisfy PFD specification) o False lock protection in S-band receiver.
Mu Space Engineering Satellite (MUSES-A)	Feb.,1990	Moon orbit plane Double lunar swing-by	o Practice of swing-by technique o Injection of very small satellite into orbit around the moon	o Development of X-band transmitter (to cope with high data rate for satellites after SOLAR-A)
SOLAR-A	Aug.,1991	600 km circular orbit Inclination: 31 deg.	o Observation of X-ray flares on the sun	
Geomagnetic Tail Satellite (GEOTAIL)	Aug.,1992	Sun synchronous, moon orbit plane, double lunar swing-by 51,000 km ∿ 160,000 km	o Investigation of energy flow and transformation in earth's magnetotail	
Astronomical Satellite (ASTRO-D)	Feb.,1993	600 km circular orbit Inclination: 31 deg.	o Observation of pulsar by X-ray reflecting telescope	
Space VLBI	Feb.,1993	10,000 km∿20,000 km Inclination: 31 deg.	o Precise measurement of celestial bodies	o Big deployable antenna o High speed data transmission
Lunar Exploration	First half of 1990's (2 sets launch)	100 km circular lunar orbit (around the moon)	o Observation of moon quake by penetrators o Remote probe	
Comet Sample Return	1994∿1995	TBD	o Capture of dust from Comet	o Electrical antenna
Venus Exploration	Sep.,1995 or Mar.,1997	300 km ∿ 13,300 km orbit around venus	o Investigation of tail of Venus	o 2mϕ despun hibh gain antenna o Date compression

3. X-band System

As the mission payloads (i.e. physical instruments) become large and more sophisticated the observation data sent to the earth station also increases. To transmit observation data to the earth at a higher rate, it is desirable to utilize the X-band with its wider frequency bandwidth than the S-band. The communications system of the present scientific satellite uses several frequency bands (from VHF to S-band) for data transmission in a redundant system. However, since the VHF and UHF bands are not appropriate for the high data rate transmission and their propagation characteristics are not always stable, S-band and X-band redundancy is required. The use of X-band redundancy is also indispensable for improving orbit determination accuracy, especially for swing-by of a planet in an interplanetary spacecraft mission. Furthermore, since the X-band is less restricted by the power flux density (PFD) of the earth's surface, it allows higher data rate transmission than the S-band and provides a more effective system. In addition, the use of X-band and S-band coherent carriers will allow radio wave experiments to verify the general relativity.

Based on the above, the UHF/S-band downlink system was adopted. From the MUSES-A project a new X-band downlink system will be added coherently to an S-band two way coherent communication system. Figure 3-1 is a block diagram of the latest scientific satellite tracking control network which is now being planned. The figure shows a new 20-m ø antenna which will be built at KSC (Kagoshima Space Center) in Japan to handle the S/X-band system for near-earth satellites and the interplanetary spacecraft. The necessity to have a new antenna came from the deterioration of the existing 18-m ø spacecraft tracking and control antenna. At UDSC (Usuda Deep Sace Center), new capability to handle the X-band system will be added to the existing S-band system for tracking interplanetary spacecraft.

Table 3-1 shows the main performance of the X-band system in KSC and UDSC.

Table 3-1 Performance of X-band System

Parameters	Performance	
	KSC	UDSC
Receiving frequency range	8.4 ~ 8.5 GHz	8.4 ~ 8.5 GHz
Receiving input level	-55 ~-155 dBm	-85 ~-182 dBm
Receiving Subsystem noise temperature	55 K	55 K
Coherent turnaround frequency ratio		
·Near Earth System	900/221	900/221
·Deep Space System	880/221	880/221
Maximum doppler shift	±12 km/s	±30 km/s
Ranging method	PN code method	Sequential code method
Ranging minimum input S/No	27 dB·Hz	8 dB·Hz
Telemetry signal demodulation type	PCM, PCM-PSK PCM-CONV PCM-CONV-PSK	PCM, PCM-PSK PCM-CONV PCM-CONV-PSK

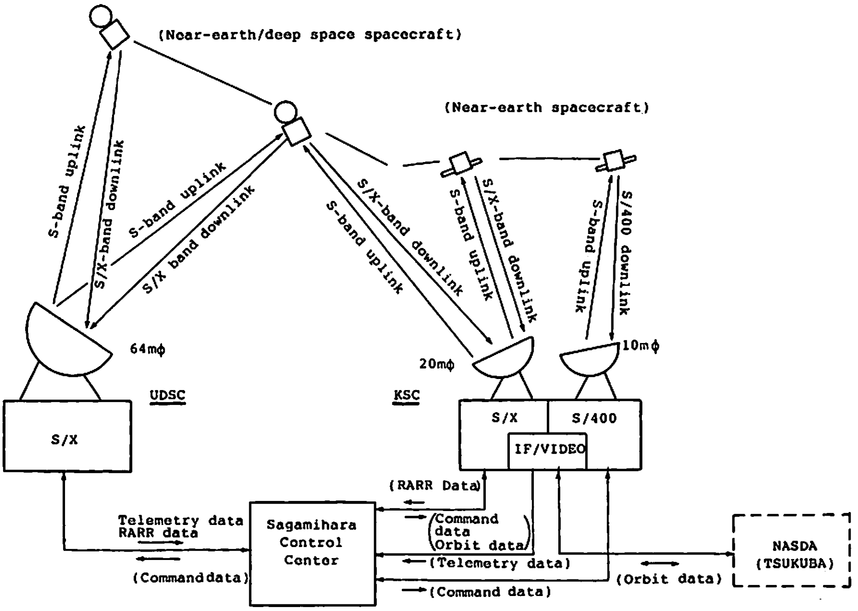

Fig. 3-1 TTC Control Network for ISAS Scientific Spacecraft

4. Hardware Technology

4.1 EXOS-D S-Band Transmitter

The power of the onboard satellite transponder has recently been increased to allow high rate transmission. However, in case of the satellites with high orbit eccentricity, the large difference between apogee and perigee altitudes forces to overcome the restriction on the earth's PFD. This problem has been solved for the EXOS-D S-band transmitter (TMS) by changing the power level control system from two levels to four levels. The following is a functional description of the system.

The EXOS-D requires transmission power over a range as wide as 24 dB, from 10 dBm to 34 dBm. This is realized by the power control system shown in Figure 4-1. In this system, the LOW AMP outputs 10 dBm and the HI AMP outputs three levels of 20 dBm, 27 dBm and 34 dBm by changing the power supply voltage of the HI AMP in the control circuit. The S-band signal from the DRV AMP is split into two by the HYB. One signal is amplified to 10 dBm by the LOW AMP. The other is amplified by the HI AMP and a part of the output is fed back through the following P MON to CNT as a power monitor voltage. The CNT contains differential amplifiers whose reference voltages are switched to control the power supply voltage of the HI AMP according to the output levels required. Power level control is accomplished by comparing the reference voltage with the monitor voltage.

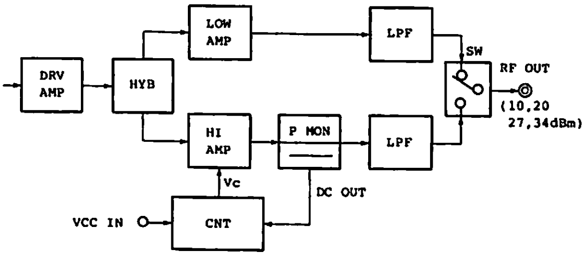

Fig. 4-1 EXOS-D TMS Four Levels Power

4.2 False Lock Protection

EXOS-D employs two S-band antennas(SBA's) and two S-band receivers (SBR's). Each SBA is connected to the corresponding SBR. When one of the SBA/SBR pairs is operated until the phase lock of the SBR is released due to a spacecraft attitude change, another SBR is ready to acquire the uplink signal. However, it is possible that the SBR will lock on the command subcarrier which always presents in the uplink signal, and the signal frequency is sometimes lost.

To solve this problem and ensure continuous spacecraft operation, a receiving system with false lock protection was developed.

Figure 4-2 shows the receiving system with false lock protection. A beat signal between two voltage-controlled local oscillators (VCXO's) of the SBR's is generated by the beat DET and the lock/unlock mode of each receiver is detected by the signal DET. When an input signal is received by either SBR-A or SBR-B (the figure shows the case, in which SBR-A is receiving the signal), the signal from the signal DET is sent to the LOGIC, which sets the switch to PLL loop for the SBR which is receiving the signal. The beat signal of the VCXO generated in the Beat DET is sent from the switch to the loop filter (LOOP FIL) of the SBR which is not receiving the signal. This pulls the local frequency of the SBR without receiv-

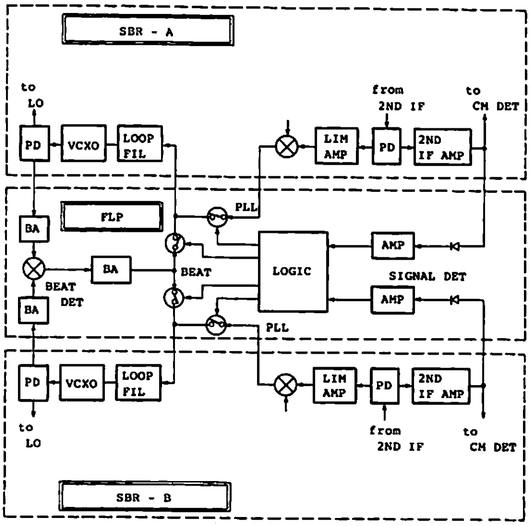

Fig. 4-2 False Lock Protection System

ing signal onto the local frequency of the SBR with receiving signal, and keeps it in that mode until the lock-in level signal is received. When this signal is received, the switch is turned over to recover the PLL loop. In other modes, the receivers hold their own PLL loops and operate as independent receivers.

4.3 X-Band Transmitter

As described in Section 3, the spacecraft will employ X-band transmitters (TMX) following to the MUSES-A project, to handle the sophistication of the mission payloads. The TMX transmits the telemetry and ranging signals by the X-band wave to earth. Its features of TMX are direct generation of 8.5 GHz PLO by a dielectric oscillator and automatic level control (ALC) power amplifier for X-band. Figure 4-3 shows the block diagram of the TMX and its main performance is shown in Table 4-1.

Table 4-1 Performance of TMX

Parameters	Performance
Transmitting frequency	8474.66 MHz
Coherent turnaround ratio	900/221
Output power (HI power)	0.80 W
(LO power)	0.16 W
Modulation type	PM
Modulation ratio (TLM)	1.20±0.20 rad 0-P
(RNG)	0.90±0.15 rad 0-P
Power consumption	
(HI power)	11.6 W
(LO power)	5.3 W
Weight	1.2 kg
Size	158 x 178 x 35 mm

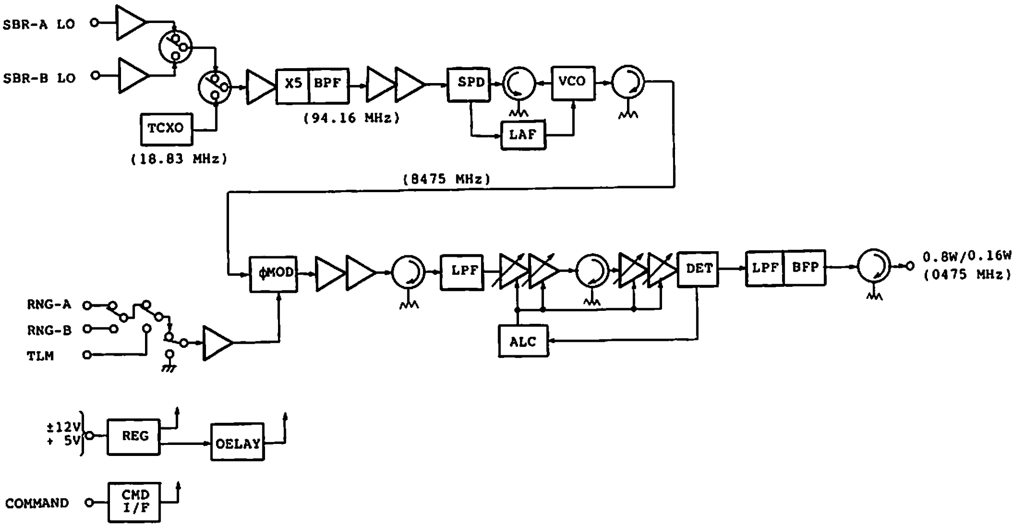

Fig. 4-3 Block Diagram of TMX

4.4 Small S-band Transponder

The weights of the VHF and UHF transmitters and S-band transponder (comprising S-band transmitter and receiver and S-band diplexer) used for the satellite have been gradually decreasing. Recently, however, further compactness has become necessary for the MUSES-A lunar orbiter system and other small satellite systems. To satisfy these requirements, a compact S-band transponder is in development using the technologies shown in Table 4-2. This S-band transponder has the main functions of (1) receiving and demodulating command signals, (2) modulating and transmitting telemetry signals, and (3) relaying ranging signals. The block diagram and main performance of the transponder are shown in Figure 4-4 and Table 4-3 respectively.

Table 4-2 Miniaturization

Item	Description
Single super-heterodyne receiver	Existing double superheterodyne receiver is changed to single superheterodyne type.
SAW VCO	Surface Acoustic Wave Voltage Controlled Oscillator (SAWVCO) with stable oscillation at about 300MHz is employed as the master oscillator for the local signal.
HIC	Hybrid integrated circuit (HIC) technology is applied to LF amplifier for command/ranging signals, and DC amplifier/low pass filter for AGC and PLL circuits.
MMIC	Monolithic microwave integrated circuit (MMIC) is employed for S-band and IF linear amplifier.
SAW Filter	SAW filter is employed for IF narrow band filter instead of existing crystal filter.
Greater Compactness	Whole construction reviewed to eliminate useless space as much as possible

Table 4-3 Performance of Compact S-band Transponder

Parameters	Performance
Receiving Parameters	
·Frequency	2084.40 MHz
·Type	Phase-lock , Coherent Phase
·Tracking range	±120 KHz
·Tracking rate	20 KHz/sec
·Dynamic range	-110 ~ -50 dBm
·Noise figure	8 dB
Transmitting Parameters	
·Frequency	2283.60 MHz
·Output power	50 mw
·Modulation type	PM
Transponder Parameters	
·Coherent turnaround ratio	240/221
·Weight	820 gr
·Power Consumption	4.4 w
·Size	180 ×130 ×50 mm

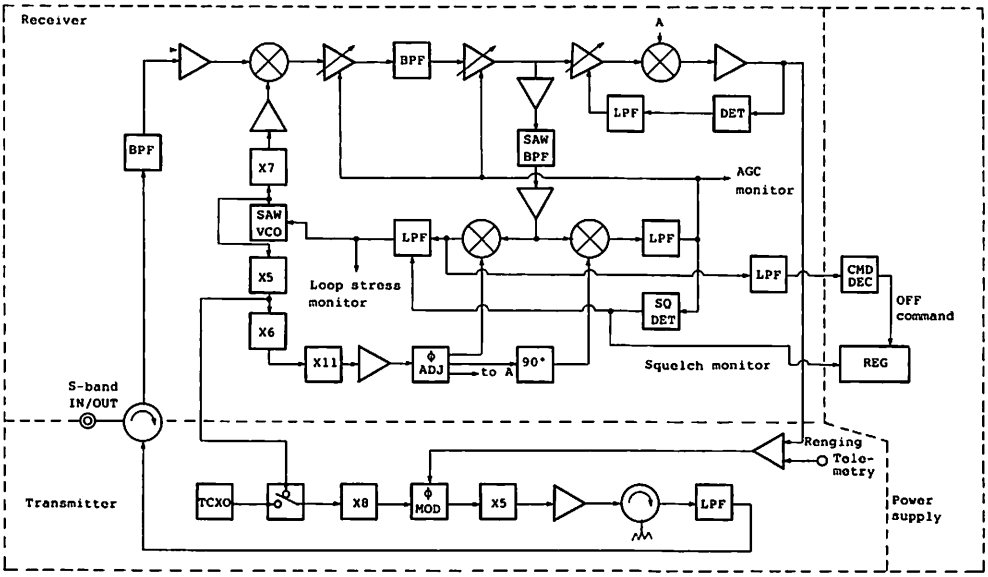

Fig. 4-4 Block Diagram of a Compact S-band Transponder

5. Conclusion

The remarkable variety of recent scientific spacecraft systems has raised the importance of communications systems for the success of these missions. For future scientific spacecraft, it will be important to continuously develop more sophisticated communications systems beyond those designed for the EXOS-D satellite to be launched in 1989 and the MUSES-A satellite in 1990.

For instance, to overcome the PFD which restricts transmission of higher data rates to earth stations, it will be neccessary to adopt a modulation system employing the spread spectrum technique, in addition to the existing system. In the present simple phase modulation system, the residual carrier signal itself conflicts with the PFD limit on many occasions. Therefore, if the carrier power could be spread over a wide frequency range, it would be possible to satisfy the PFD criteria per 4 kHz bandwidth as specified. In this case, the onboard equipment can easily be realized, but some complexity will be needed for the receiving system of the earth station.

When satellite operation is to be performed with real time collection of a large quantity of data, it will be difficult to manage by only reproducing telemetry data with an ordinary tape-recorder or by sequential command control with a program-timer. To solve this problem, it will be useful to make a communication link via a geostationary communication satellite. NASA is now constructing TDRS (Tracking and Data Relay Satellite) system. NASDA and ESA are also separately studying their own data relay satellite systems which will start their service by the middle of the 1990's. Therefore, it would be possible that scientfic satellites will be able to utilize these data relay satellites, and the real-time performance of satellite tracking control would be greatly improved by the development of onboard communications equipment compatible with the new system.

6. Acknowlegments

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References

(1) T. Hayashi, et al., "Communication and Data Processing Techniques for Scientific Satellites", The Journal of IECE Vol. 10, 1985.
(2) T. Hayashi, et al., "Feasibility study on the Ultra-Small Launch Vehicle", IAF-86-109.