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Present and Future Aspects of Japanese CS Program

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Japan's CS spacecraft was launched successfully in December 1977 and positioned at 135 deg east longitude in a geostationary orbit. After an initial on-orbit performance checkout, substantial communication and operation experiments were conducted starting in May 1978 as scheduled. Spacecraft attitude and position are being maintained precisely, and onboard mission equipment including the despun antenna and C-band (6 GHz/4 GHz) and K-band (30 GHz/20 GHz) transponders are working well except for two K-band transponders that had been excluded from the objectives of the experiments due to malfunctions that had occurred during the checkout period. After one year of experiments, it was concluded that the present CS-like system would be suitable for a future operational domestic satellite system in Japan. This paper will present typical first-year experiment results.

Introduction

THE CS is the first experimental communication satellite in Japan planned by the Ministry of Posts and Telecommunications.[1] The spacecraft was launched successfully from ETR on December 14, 1977. Nine days after the lift-off, the spacecraft was positioned at 135 deg east longitude in a geostationary orbit. The performance of the spacecraft was checked using ground facilities, assuring that all functions of the spacecraft were normal (except two K-band transponders). The spacecraft was then offered for use in communication experiments.

The CS is a spin-stabilized spacecraft weighing about 340 kg in orbit and has two C-band (6 GHz/4 GHz) and six K-band (30 GHz/20 GHz) transponders, labeled G_1, G_2, and F_1 through F_6 as shown in Fig. 1, and a shaped-beam mechanically despun antenna commonly used in both frequency bands. Telemetry Tracking and Command (TT&C) operations are carried out either in S band (2.1 GHz/2.3 GHz) or C band.

In Japan, C-band satellite communications are severely restricted because of potential interference problems with heavily distributed terrestrial networks, and it is quite important to analyze the frequency-sharing problems between space and terrestrial communications in this frequency band. Therefore, K band was adopted in the CS system notwithstanding difficulties such as rainfall attenuation, necessity of hardware development, and so forth in this new frequency region. Throughout the first year experiment period, valuable technical and operational data have been acquired.

Launch and Initial Check of CS Performance

Launch

The CS was launched by a Delta vehicle from NASA Kennedy Space Center, at 7:47 PM on December 14, 1977, and the spacecraft was accurately injected into the transfer orbit. After injection into the transfer orbit, determination of the spacecraft attitude, orbit, and functions was conducted using the telemetry and ranging data which were gathered by the ground stations.

Three maneuvers for the spacecraft attitude change were carried out before the apogee motor firing which took place near 133.8 deg east longitude over the equator near the 3rd apogee on December 16, at 12:25 (JST). Then the CS was injected into the drift orbit with orbital parameters very close to the planned values. During drift orbit, the satellite attitude was adjusted twice for setting the spin axis normal to the orbital plane and the despun antenna towards the south.

Finally, the CS was placed at the geosynchronous orbit position of 135 deg east longitude on December 24, 9 days after lift-off.

Initial Checkout

The initial operation and checkout of the CS system were carried out before starting communication experiments. The results of the bus equipment checkout were satisfactory in all functions and performances. During the first checkout, all communication subsystems, which consist of six K-band and two C-band transponders, a K-band beacon oscillator, and a despun antenna, functioned normally and satisfied all the requirements.

Two months after the launch, spurious signals were found in the downlink signal of one of the K-band transponders (F2). The cause of this failure was investigated by means of ground simulation tests. A probable cause of the failure was a change of characteristics of a resistance which was used in the frequency multiplier of the receiver local oscillator.

Another failure occurred three months after launch in another K-band transponder (F6) in which transmitting power suddenly vanished. From the telemetry data, it was found that the protection circuits in the TWT power supply tripped due to some trouble in the high-voltage circuit.

Characteristics of the Antenna and Transponders

The bandwidth of each communication transponder is about 200 MHz, and the nominal output powers are 4 dBW in K-band and 4.5 dBW in C-band, respectively. The AGC function of the first K-band transponder (F1) can be deactivated by command, and the C-band transponder (G2) has command-controlled step attenuators which range from 0 to

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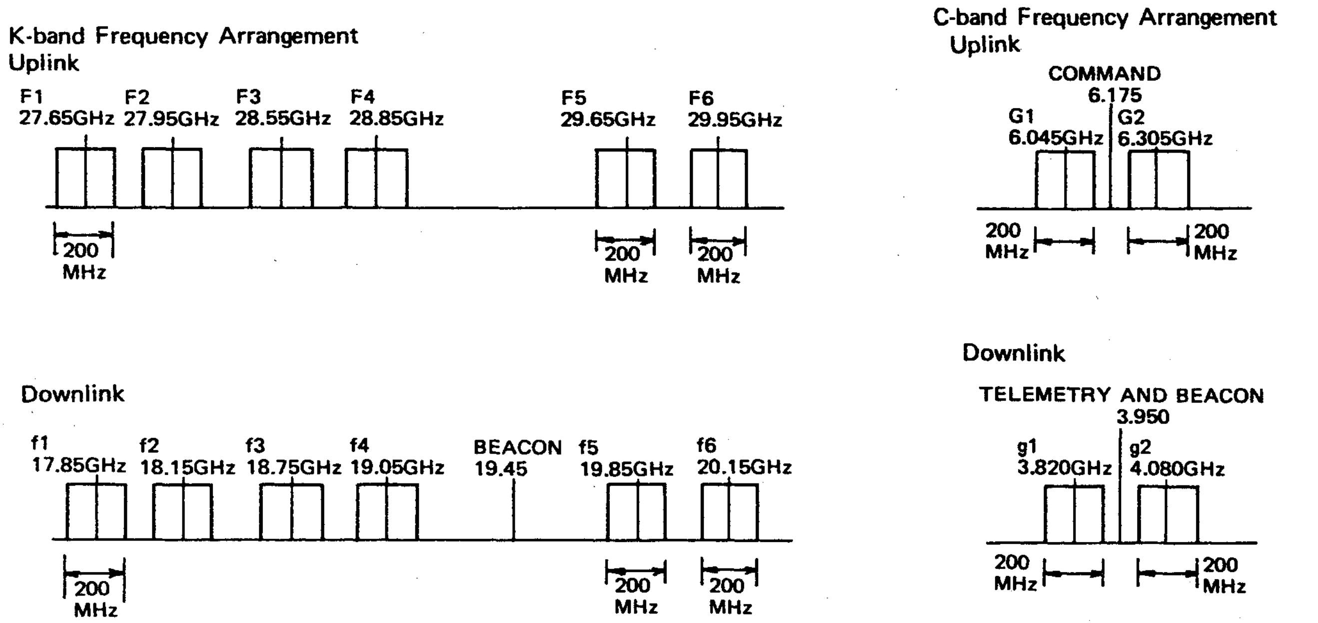

Fig. 1 Frequency assignment in the CS system.

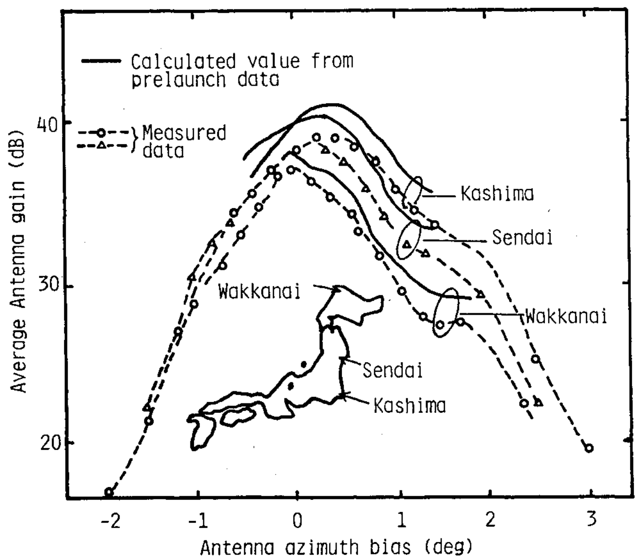

Fig. 2 Satellite K-band antenna pattern.

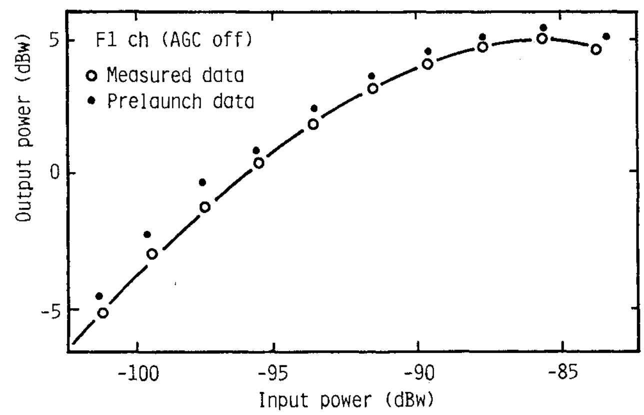

Fig. 4 Input-output characteristics of K-band transponder.

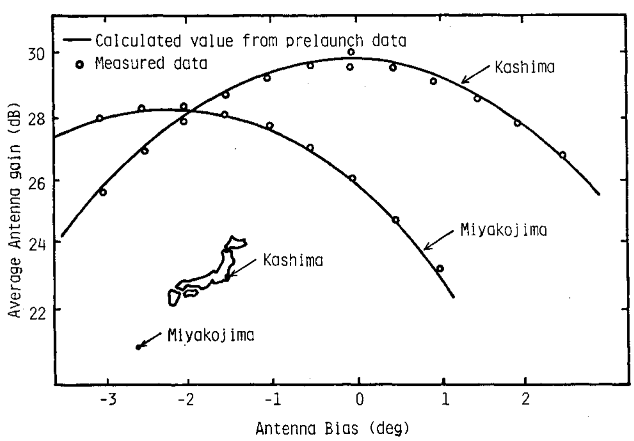

Fig. 3 Satellite C-band antenna pattern.

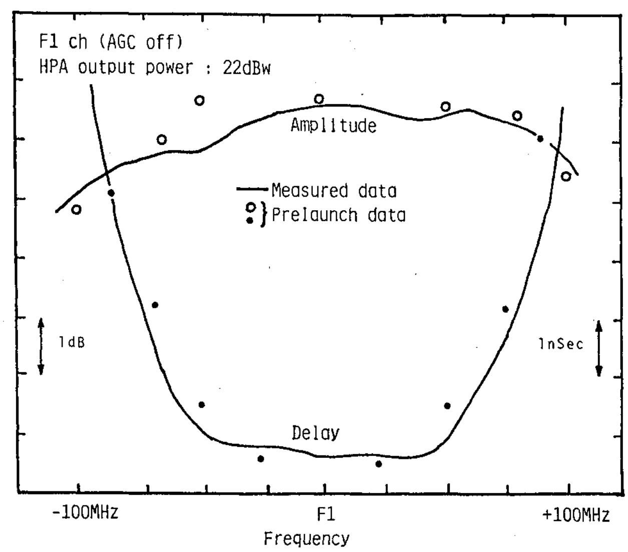

Fig. 5 Frequency-response and delay characteristics of K-band transponder.

10.5 dB with 1.5 dB steps. Owing to the troubles in two K-band transponders (F2 and F6), only four K-band transponders have been used in the various experiments.

The CS communication antenna was designed to cover mainland Japan with a 33-dB gain in the K band and Japan's entire territory with a 25-dB gain in the C band.

Patterns for the Communication Antenna

The communication antenna system consists of a shaped-beam horn reflector and waveguide assemblies to transmit and receive signals of circular polarization in both C and K bands. Only the azimuth pattern was measured by means of the despun antenna bias off-setting in order to minimize fuel consumption.

Figure 2 shows the K-band down-path antenna pattern data measured at several places on mainland Japan, and Fig. 3 shows the C-band down-path antenna pattern data at Kashima on the mainland and remote Miyako-jima island. The measured values are slightly lower than the calculated ones based on the antenna Acceptance Test data obtained on the ground before launch. These results may depend on the beacon output level decrease to some degree. In K band, there is a spin modulation of 2- to 4-dB depth at the antenna bias of 0 deg, and all measured data are of the averaged gain over the spin period.

Characteristics of the Transponders

Figure 4 shows the input-output characteristics of the K-band transponder (F1). The values of input power to the transponder were read out from telemetry data and the output power was calculated using link-budget data. Figure 5 shows the frequency amplitude and delay responses. The data shown in Figs. 4 and 5 are close to those of the pre-launch data, and there are no long-term characteristic variations.

Assuming that the transponder nonlinearity is expressed as AM/PM conversion and compression factors of input-output characteristics, these parameters are obtained from the unbalance two-tones method.[2] Table 1 shows these values. They are nearly equal to those of the pre-launch data.

Figure 6 shows the input-output characteristics of the C-band transponder (G2) when the ground transmitter power is changed. The range of input power of the transponder for obtaining the saturated output power of 4.8 dBW is from −94 to −104 dBW. They are the same as the pre-launch data. Also, the seven step attenuators are operating normally.

The amplitude and delay variations were measured to be within 0.8 dB/±50 MHz and within 3 ns/±50 MHz, respectively, at saturation region. When the ground transmitter output level decreases (to +10 dBW) for the transponder to be operated in a linear region, the linear first-order frequency response becomes within 1 dB/±50 MHz, even though the delay-characteristics are the same as the saturated operation case. In either case, they meet the specification values.

General Signals Transmission Characteristics

Telephone and TV Signals Transmission in FM[3,4]

The FM modem of RRL has wide-band characteristics suitable for modulating FDM telephony signals (24 to 1872 channels) or a composite color TV signal. Experiments have been conducted in both C- and K-band links, changing transmission parameters such as frequency deviation, channel frequency, emphasis on/off, receiver BPF bandwidth, and C/N_0 (carrier-to-noise power density ratio). Effects of spin modulation and rainfall attenuation in K-band links have been carefully investigated.

Figure 7 shows the results of the K-band noise loading test of 1872 channels with emphasis. Though the optimum loading level is about 6 dB above the nominal loading level (419 kHz rms/channel), 1872 channels of FDM telephony signals can be transmitted over the K-band links with signal quality better than 50 dB of $S/(N+D)$, (signal/thermal and intermodulation noise), at Kashima station. On a clear day, total link C/N_0 better than 100 dB-Hz can be kept for an EIRP of 86 dBW from the ground, and rain attenuation margins for uplink and downlink are measured as 11 and 7 dB, respectively, when the lower limit of $S/(N+D)$ is assumed to be 43 dB. Compared with the modem back-to-back test, degradation of $S/(N+D)$ within 0.5 to 2.5 dB is measured in the satellite links due to nonlinearities of the satellite-borne TWTA. Furthermore, it is found that the threshold C/N_0 in the K-band satellite link is about 1 dB larger than that in the modem back-to-back case. This effect

Table 1 Transponder characteristics by the unbalanced two-tones method

Item \ Channel	F1	F3	F4	F5	G1	G2
Suppression factor	1.0	0.9	0.9	1.0	0.9	1.0
AM/PM conversion coefficient (deg/dB)	2.9	4.7	3.2	4.0	2.1	3.3

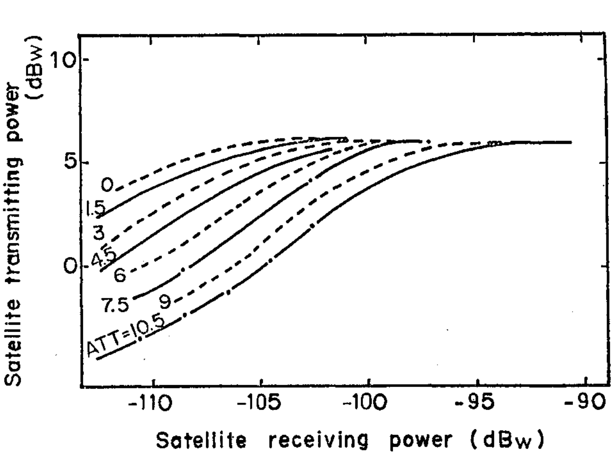

Fig. 6 Input-output characteristics of C-band transponder.

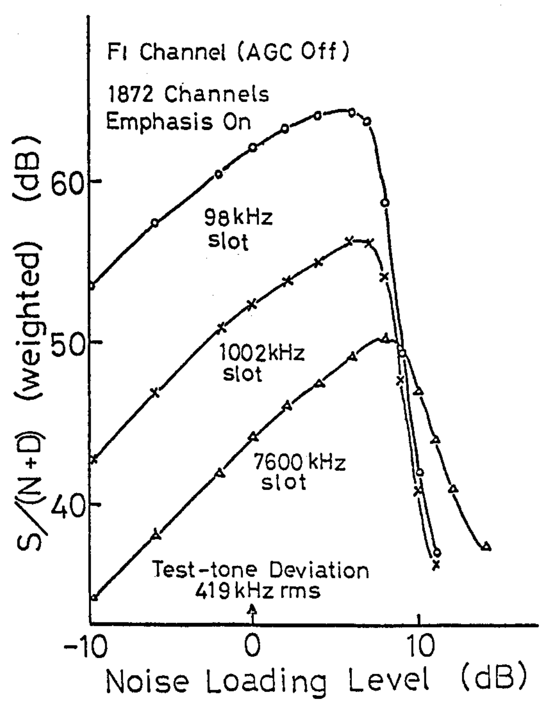

Fig. 7 Noise loading characteristics.

seems due to the spin modulation and the TWTA nonlinearities.

Figure 8 shows S/N vs C/N_0 characteristics of the FM-TV signal transmission at Kashima station through the K-band transponder. For a C/N_0 of 102 dB-Hz, unweighted S/N's of 59 and 53 dB are obtained for 50 and 20 MHz (p-p) frequency deviation, respectively. The threshold C/N_0 is also measured as 94 dB-Hz and 88 dB-Hz for each frequency deviation. Differential gain and differential phase were measured and almost identical values were obtained compared with the modem back-to-back cases.

Studies of the degradation of S/N due to rainfall attenuation in K-band satellite links are quite important, and long-term measurements of S/N, C/N_0, received beacon signal level, and other radio-wave propagation characteristics are being carried out during the rainy season. From the propagation data, a relationship between downlink (20 GHz) and uplink (30 GHz) rainfall attenuation, Ld and Lu, was determined statistically as follows.

$$\log \mathrm{Lu} = 2.1 \log \mathrm{Ld}$$

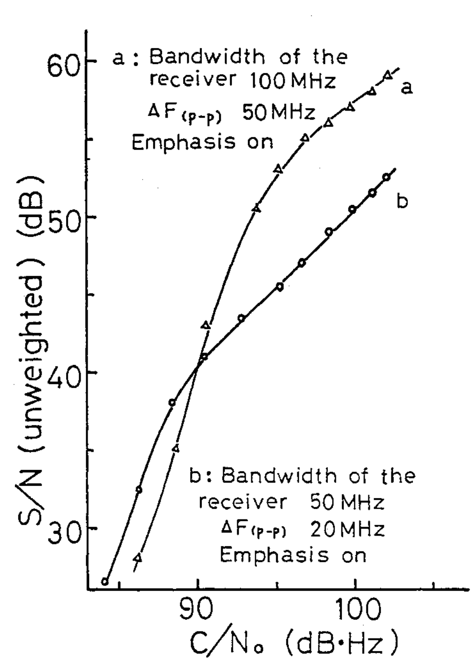

Fig. 8 S/N vs C/N_0 characteristics of FM-TV.

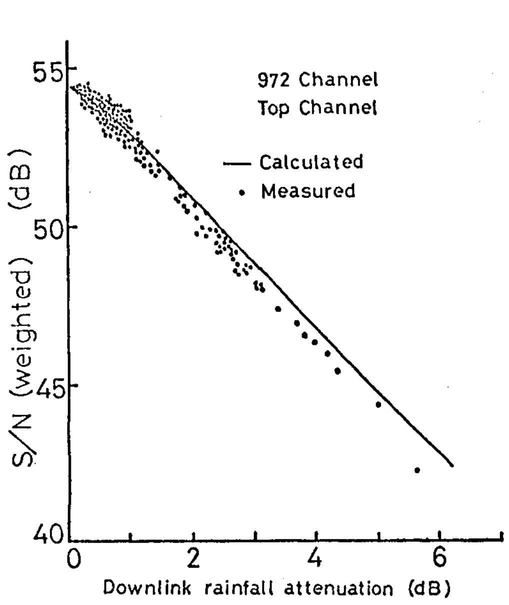

Fig. 9 S/N vs rainfall attenuation.

Figure 9 shows S/N vs downlink rainfall attenuation characteristics in the case of satellite loop-back test where uplink attenuation also occurs simultaneously. The figure shows that the experiment results agree with the calculated values.

PSK Signal Transmission

PSK signal transmission tests have been conducted at Kashima station for various kinds of digital signals such as PCM multiplexed telephony signals, DPCM television signals, and others with various transmitting parameters such as bit rate, modulation phase, energy dispersal, and so forth. The bit error rate (BER) performance is affected by rainfall attenuation, spin modulation and transponder nonlinearities. The variation in E_b/N_0 (energy per bit/noise power density) due to spin modulation in K band is observed to be 3 to 4 dB at Kashima station in the worst case. Bit errors occur mostly at the bottom portion of periodic spin modulation, and BER performance is degraded when referred to the E_b/N_0 value averaged over the spin modulation period. Figure 10 shows an example of BER performance in the K-band satellite link (F1) when the ground station transmitting power is changed within the range of the transponder's AGC function. BER performance in K band is worse by 1 to 2 dB than those in C band. Table 2 shows the degradation in BER performance compared with the modem back-to-back test as well as the uplink and downlink margins when the threshold signal quality is taken as 1×10^{-4}.

Figure 11 shows S/N vs BER characteristics of the PCM-TV and PCM-Telephone signals. In the PCM-Telephone signal transmission, weighted S/N increases with increasing E_b/N_0 up to 1×10^{-4} in BER, and it saturates at 42 dB, which satisfies CCITT REC G712, because of quantization noise. In the PCM-TV signal transmission, 50 dB of unweighted S/N is obtained at a BER of 1×10^{-4}, and the quality of the TV picture is estimated as excellent (5th grade in five-point scale of CCIR REC 500).

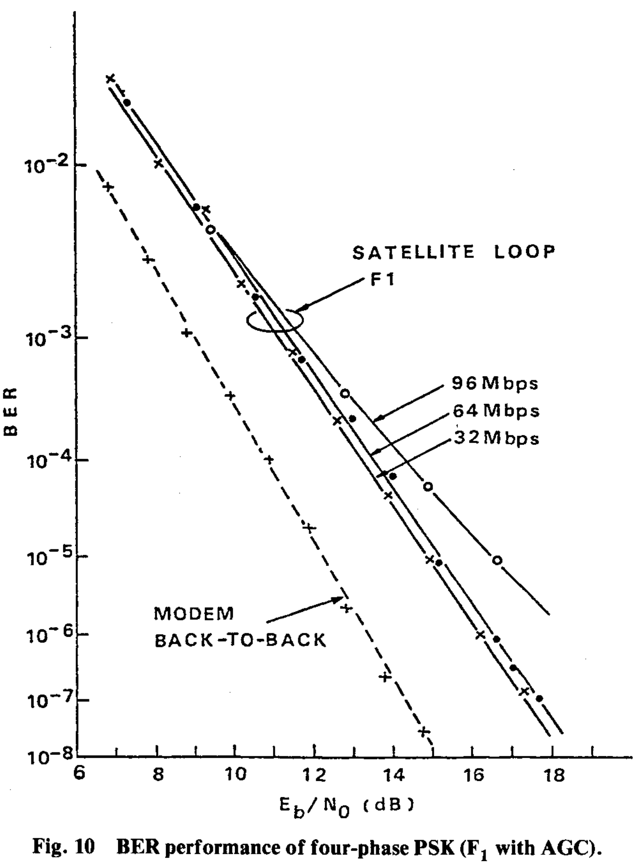

Fig. 10 BER performance of four-phase PSK (F_1 with AGC).

Table 2 Degradation from modem back-to-back test and link margin

Item	Degradation from modem back-to-back test at a BER of 1×10^{-4} (dB)				Link margin (dB)			
Link	Uplink[a]		Downlink[b]		Uplink		Downlink	
Band	K	C	K	C	K	C	K	C
32 Mbps 2-phase	–[c]	0.9	–	–	–	17.0	–	–
4-phase	2.7	0.9	2.1	–	18.4	16.6	16.8	–
8-phase	–	1.9	–	1.1	–	11.4	–	13.1
64 Mbps 4-phase	3.0	2.0	2.1	0.8	14.1	12.6	13.9	14.7
96 Mbps 4-phase	3.2	–	2.1	–	9.9	–	8.7	–

[a] Corresponds to uplink degradation of C/N_0 by varying transmitting power.
[b] Corresponds to downlink degradation of C/N_0 by adding noise at earth station receiver.
[c] Not measured.

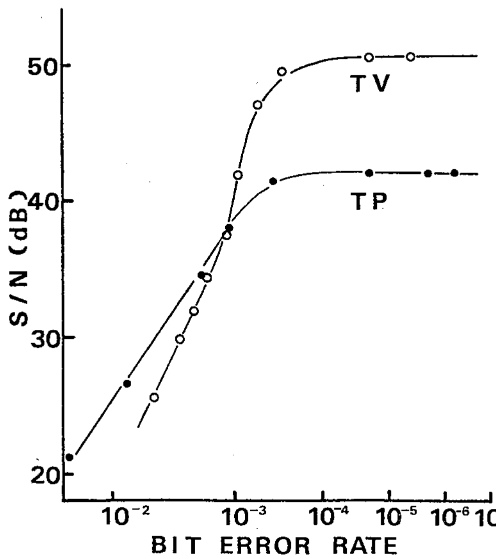

Fig. 11 *S/N* **vs BER characteristics of PCM-TV (unweighted) and PCM-Telephone (weighted).**

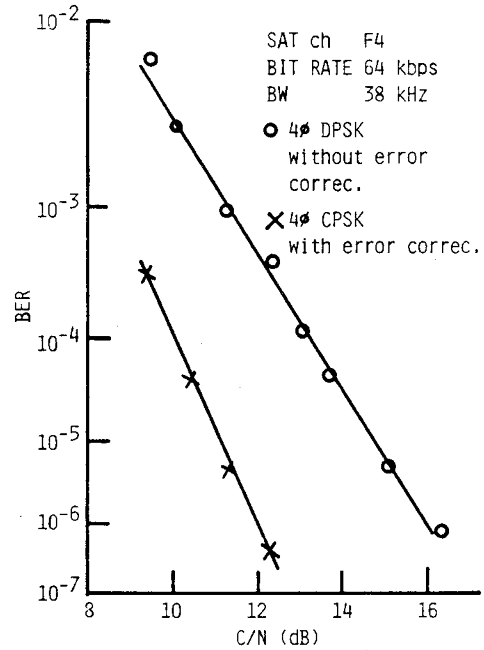

Fig. 12 BER characteristics of SCPC system.

SCPC and SSRA Signals Transmission

SCPC (Single Channel Per Carrier) and SSRA (Spread Spectrum Random Access) equipments have been developed[5] for small traffic, multiple-access communications (between a main Earth station and small-sized stations through the CS K-band transponders). The small-sized K-band station consists of a 2-m dish Cassegrain-type antenna of *XY* mount and indoor modem units. The antenna gains are 53.5 dB in 30 GHz and 50.0 dB in 20 GHz, and an IMPATT diode transmitter with 2-W output power and a GaAs FET receiver with 800 K noise temperature are mounted in the back structure of the antenna. The SCPC system can transmit and receive 64 kbps, 4-phase, DPSK voice signals or equivalent multiplexed data signals. The voice signal is encoded with bit rate of 48 or 64 kbps in an adaptive delta modulator. A 3/4 error correcting coding can be applied to any baseband signal of bit rate lower than 48 kbps. Figure 12 shows the BER characteristics of this system. On a clear day, C/N of about 25 dB could be obtained at the small station. The figure shows that a coding gain of about 2.8 dB can be expected at BER of 10^{-3}.

Application of spread-spectrum techniques to the satellite communication systems is quite attractive because of their excellent characteristics such as interference insensitivity, code division multiple access, information security, ranging capability, and so forth. They will provide a powerful means to solve frequency-sharing problems. Reflecting the experiences of ATS-1 communication experiments, a new SSRA system was developed which would exhibit superior performance over the former one. Improved items include 1) an increase in the number of coexisting channels by adopting coding techniques in the baseband; 2) quick initial synchronization by applying supplemental FSK signals during acquisition period; 3) an increase of identification numbers for user stations by allotting carrier frequencies of the FSK signals; and 4) channel multiplexing by use of the delayed PN codes.

Experiments in the satellite links have not yet started, but preliminary in-house test results promise the expected performances.

Propagation Characteristics

Rainfall Attenuation

At Kashima station, various kinds of propagation data such as K- and C-band beacon levels, cross-polarization component level, rainfall rate, receiving system noise temperature, radar reflectivity of rain, and telemetry data of the CS are collected and processed by a mini-computer system. Figure 13 shows the cumulative distributions of the K-band beacon signal (19.45 GHz) attenuation and the rainfall rate at Kashima. The beacon signal attenuation and rainfall rate are 12 dB and 40 mm/h, respectively, for 0.01% of the time.

The site diversity effect between the Yokosuka and Sugita stations, which are aligned in a north-south direction with about a 21-km separation, is being measured. Figure 14 shows the cumulative distribution of rainfall attenuation on a 19.45-GHz beacon signal at these stations and the diversity effects.

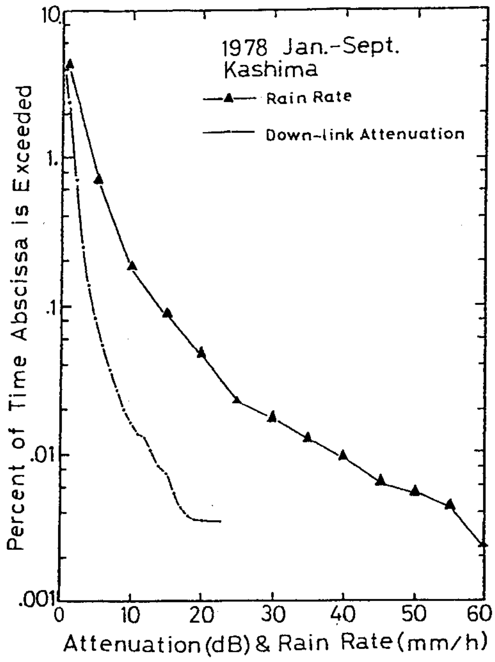

Fig. 13 Cumulative distribution curves of downlink (19.45 GHz) attenuation and rainfall rate.

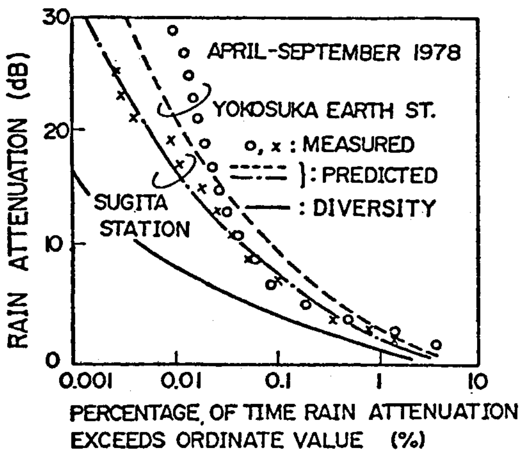

Fig. 14 Cumulative distribution of rain attenuation and diversity effect.

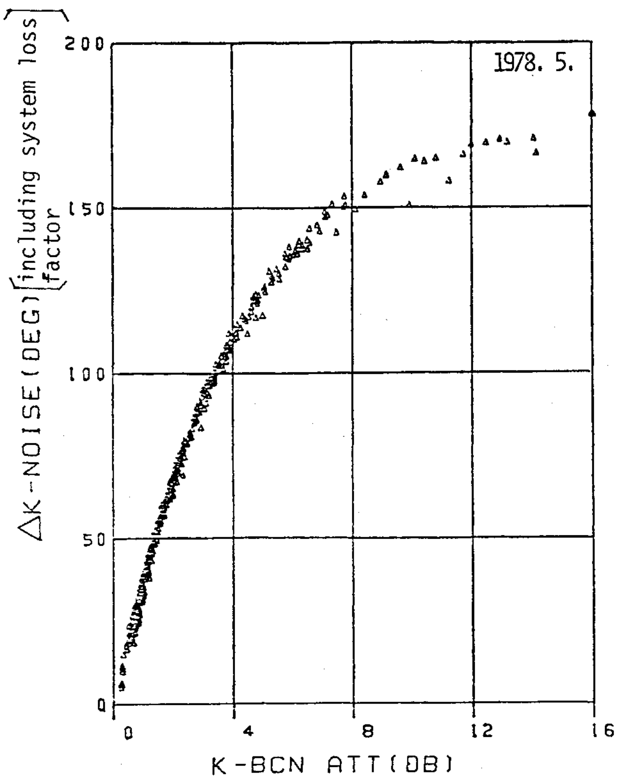

Fig. 15 K-band excess noise temperature vs K-band beacon attenuation.

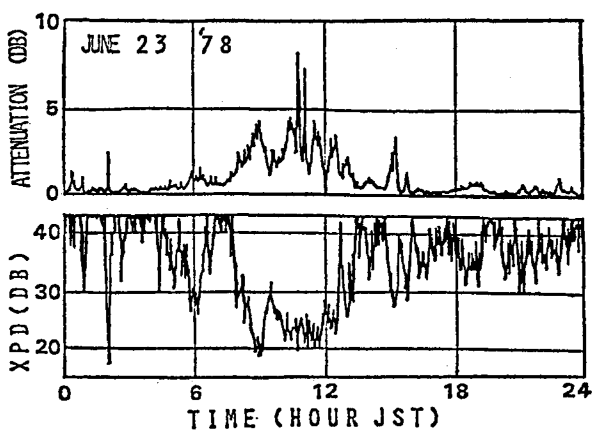

Fig. 16 Degradation of XPD characteristics and rain attenuation.

Excess Noise Temperature due to Rain

At Kashima station, receiving system noise temperature is being measured continuously at 18.40 GHz, the outband frequency of the transponders. When it rains, system noise temperature increases along with the attenuation. Figure 15 shows the relation between the excess noise temperature beyond the clear day's system noise temperature and the rainfall attenuation. As expected, there is a very good correlation between them.

Other Propagation Effects

Cross-polarization discrimination, XPD, is degraded by the rainfall. Figure 16 is a sample of XPD and attenuation records of the K-band beacon signal on a rainy day. Of course, some correlation between degradation of XPD characteristics and rainfall attenuation exists, but the relation is not sufficiently simple to be explained by assuming a raindrop structure model. Analysis of the accumulated data is being made.

Weak scintillations have been often observed in the C-band beacon. The scintillation phenomena are believed to be due to electron density irregularities in the ionosphere.

Relative propagation delay between C- and K-band satellite links has been measured precisely, and it was recognized that the daily changes of the delay agreed well with the change of the total electron content along the path through the ionosphere. These relative propagation delays between different frequency bands would have to be taken into consideration when a communication system is designed with the requirement to keep time synchronization between links of different frequency bands.

Communication System Operation Experiments

Experiments by the C-Band Small Transportable Earth Station[6]

The Small Transportable Earth Station (STES) can be transported to any place in Japan and can make a satellite link between STES and the Fixed Earth Station (FES). Fundamental K-band STES-FES satellite link characteristics were obtained between STES and FES located at Yokosuka Laboratory. After the initial experiments, STES was transported to Miyako-jima, a southern-most remote island, located at the fringe of the CS C-band antenna pattern in order to affirm transmission capability all over Japan.

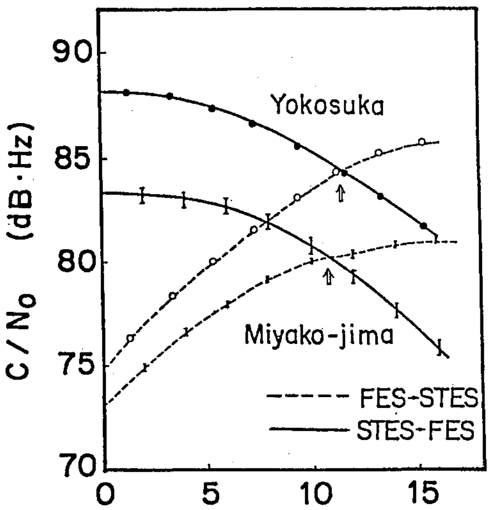

Fig. 17 C/N_0 as a function of FES's TX power (STES's TX power: 20 dBW const).

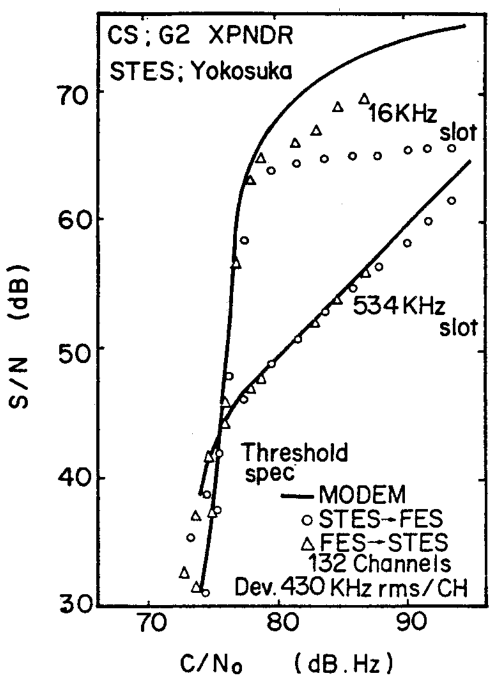

Fig. 18 Satellite link threshold characteristics.

Two-way STES-FES satellite link is made through a single transponder, and required transponder output power to FES is far less than to STES. Figure 17 shows the C/N_0 of the satellite link measured at Yokosuka and Miyako-jima island.

In this case, the transmitting power of STES has a fixed value of 20 dBW and the transmitting power of FES is changed from 0 to 17 dBW. Subsequently, the FES transmitting power was adjusted to the value needed to produce the same C/N_0 values in two ways.

Figure 18 shows the threshold characteristics of the satellite link. Differences from the modem characteristics at 16 kHz is due to the noise of the Earth station up/down converters. From this figure, it is shown that for 132 telephone channels transmission, the required C/N_0 is about 76 dB-Hz at threshold ($S/N=43$ dB). Therefore, Fig. 17 shows that the threshold margin at Miyako-jima island is about 4 dB for 132 telephone channels transmission.

Experiments by the K-band Small Transportable Earth Station[7]

At the beginning of the CS experiments, the K-band STES was locted at Yokosuka and fundamental STES-FES satellite

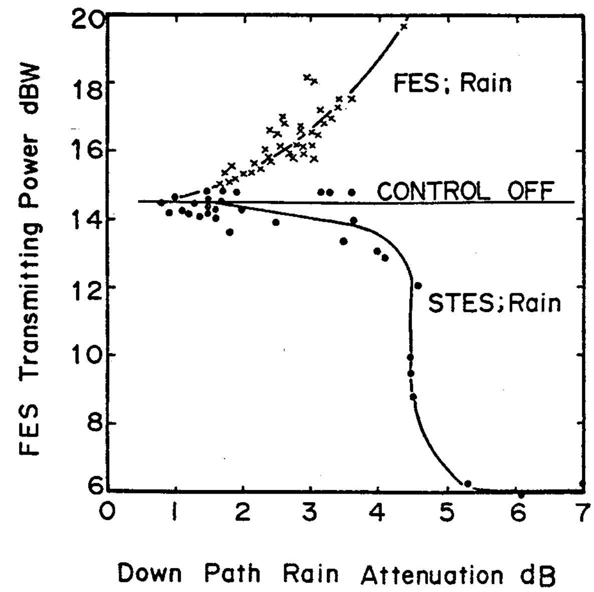

Fig. 19 Controlled FES TX power as function of down-path rain attenuation.

link characteristics were obtained. Later, STES was transported to Kyoto, Owase, Nagoya, Tokyo, and Aomori, thus covering the central to northern part of Japan, for experiments. Initial tracking of CS at each place was made easily using a magnetic compass.

For the K-band STES-FES communication, a new FES transmitting power control method was developed to reduce unavailable time of the satellite link caused by precipitation. Figure 19 shows the controlled FES transmitting power as functions of down-path rain attenuation. By this control method, C/N_0 improvement effects of about 3 to 4 dB for rain at FES and about 1.5 to 2 dB for rain at STES were obtained. The two-way communication link C/N_0 was about 87 dB-Hz, which agreed well with the predicted value.

Experiments in TDMA System

There are two different TDMA burst synchronization techniques in CS experimental system. One is the noncoherent system, the other is the clock coherent system.[8] We will now discuss some results of K-band and C-band TDMA of the latter system.

The TDMA-100M system, whose bit rate is 106.88 Mbps, was designed for communications between the mainland of Japan and some remote islands. It has the simultaneous transmission capacity of 384 one-way telephone channels and two 32-Mbps color TV channels.

The TDMA-60M system has the bit rate of 64.136 Mbps and transmission capacity of 960 one-way telephone channels. This system was designed for communications among K-band fixed Earth stations to be constructed in several main cities in Japan.

Figures 20 and 21 show the K-band TDMA and C-band TDMA BER performances, respectively, which were measured through the CS satellite links. Both performances are almost the same as the predicted values except for the K-band spin-modulation degradation.

The equivalent degradation of E_b/N_0 at BER of 1×10^{-4} was 1.8 dB from the theoretical value. This is the sum of the 1F loop degradation of 1 dB and the satellite transmission path degradation of 0.8 dB. The 1F loop degradation is mainly caused by intersymbol interference due to band-limiting effect of filter.

Figure 22 shows the relation between BER and spinning time. BER changes with the satellite spin period and depends on the antenna pointing azimuth bias value. Therefore, the average BER vs average C/N_0 during the spin period shifts to the worst BER. If the degradation is improved, the BER

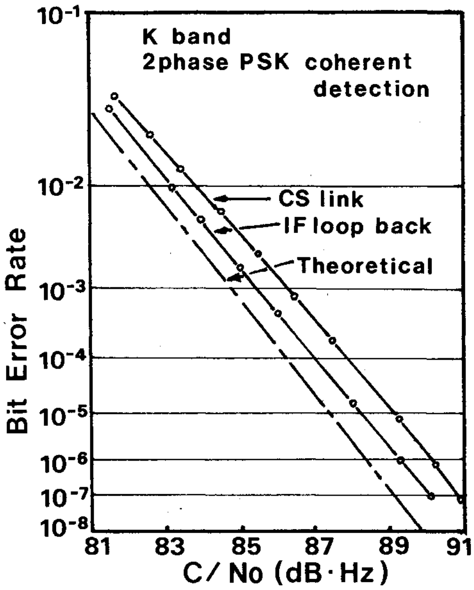

Fig. 20 BER performance (TDMA-60M system).

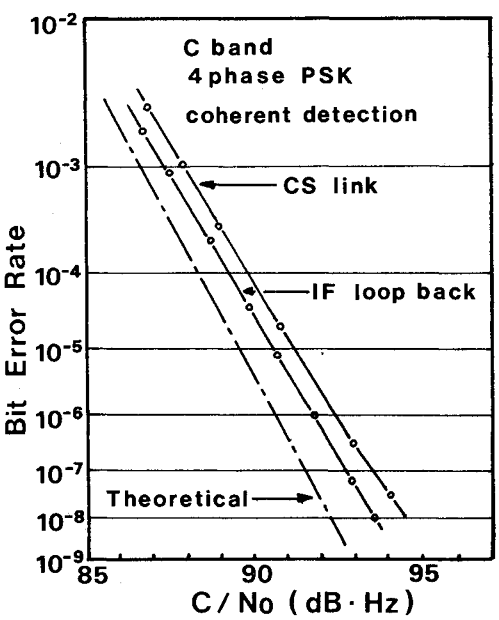

Fig. 21 BER performance (TDMA-100M system).

performance will be close to IF loop characteristics of the Earth station.

Figure 23 shows the error correction performance in C-band TDMA. This uses rate 7/8 convolutional coding and threshold decoding with a two-error correction capability within its constraint length. The measured values are very close to the calculated values and the coding gain of the forward error correction (FEC) codec was 3.8 dB in E_b/N_0 at BER of 1×10^{-7}.

The phase ambiguity of the recovered carrier is removed by the carrier recovery circuit by detecting the unmodulated carrier phase, which is transmitted at the top of TDMA burst. The measured cycle slipping occurrence of the recovered carrier phase was negligibly small, and finally the full capacity of the FES codec was obtained.

These K-band and C-band TDMA systems adopted the network clock synchronization system through clock-coherent operation. In this system the transmitting symbol's clock timing of nonreference stations is synchronized in phase on the satellite transponder to the timing of the reference station. The burst-time position can be synchronized within one

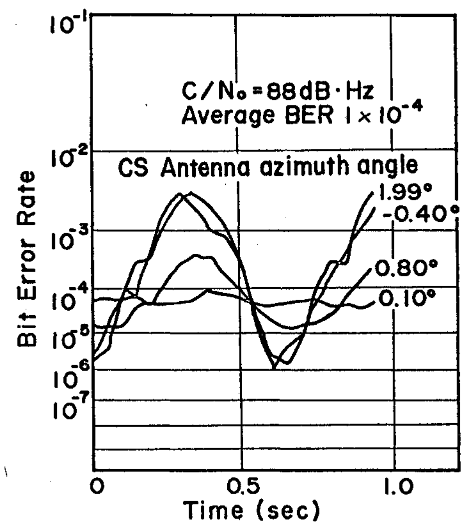

Fig. 22 BER performance vs CS antenna spinning time.

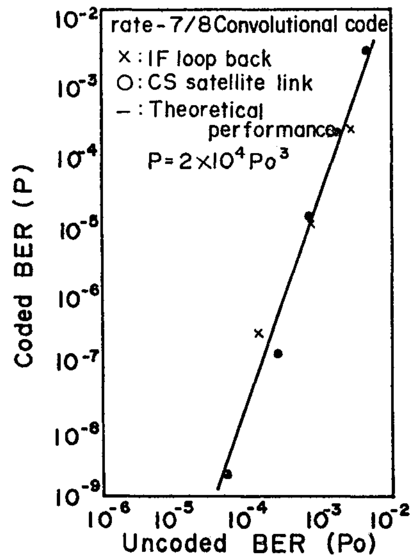

Fig. 23 FEC performance.

symbol accuracy. Figure 24 shows the phase error of the transmitting clock timing of a nonreference station. The phase jitter is within 10 deg (p-p). It is possible for the automatic phase control to compensate for the phase error caused by the frequency variation of the transmitting clock timing oscillator. This result satisfies the design value of ± 6 deg.

The lower-level transmitting PN synchronization is used for the initial acquisition. The transmitting power of the acquisition signal is decided by the allowable interference level to the normal signal and the acquisition probability. Figure 25 shows the range of the transmitting power in C-band TDMA. The allowable acquisition range is between 11 and 18 dB lower than the normal signal level. In this case, the BER of normal signal is better than 1×10^{-4} against the interference caused by acquisition and the detection miss probability of the acquisition is less than 1×10^{-2}.

Spacecraft Operation and Control

The system is composed of Okinawa and Katsuura Tracking and Control Stations which are linked to Tsukuba Space Center, Tracking and Control Center.

The orbital position and attitude of the CS have been kept within an accuracy of ± 0.1 deg, and the beam pointing of the despun antenna for communication has also been kept within ± 0.3 deg. The attitude control is executed about every 3

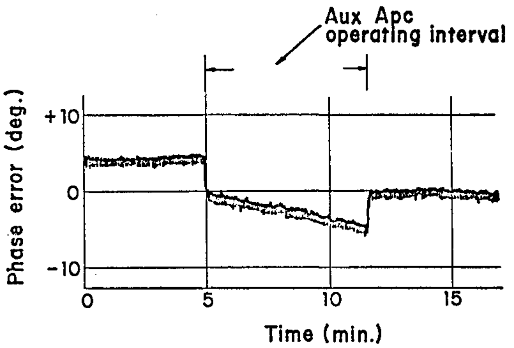

Fig. 24 TX clock timing phase error performance.

weeks, and east-west and north-south orbital control are executed about every 3 and 10 weeks, respectively.

Over a two year period, which includes three eclipse seasons, the CS has operated smoothly and shown good performance.

Future Experiment Plans

The experiments have been conducted according to the predetermined schedule based on the three-year spacecraft design life. At present, however, it is anticipated that the experiment period could be extended at least one year longer, and additional experiments are now being prepared.

Typical new experimental items are as follows: 1) experiments on satellite K-band computer networks; transmission of random burst signals and evaluation of link-level protocol; 2) experiments on K-band FM-SCPC communication system using a very small-sized Earth terminal having a 1-m dish antenna; 3) experiments on a K-band MCPC (Multiple Channels Per Carrier) communication system using small-sized Earth terminals having 2-m dish antennas with digital multiplexed voice channels; 4) total system experiment connected with terrestrial communication network; 5) small-capacity communication experiments between many C-band small stations and the fixed station; and 6) high-speed data, facsimile, television conference, and packet switching experiments using the new type K-band small Earth station.

Furthermore, many organizations will join the experiments for cultivating their communication means via satellite.

Conclusion

During the first-year experiments, useful results have been obtained in the CS program. Fundamental technically oriented experiments including K-band propagation studies will be continued further. Expecting that the satellite life can be extended, some applications of socially oriented experiments will be added in the latter half of the experiment period.

Responding to the proposal of Ministry of Posts and Telecommunications, the Space Activities Communication had decided last year that an operational communication satellite, CS-2, should be launched in 1983 from Tanegashima Space Center by a N2-type rocket. The CS-2 will be similar to the present CS with respect to its scale and functions. The results of development and experiments in the CS program will be fully reflected on the CS-2 program.

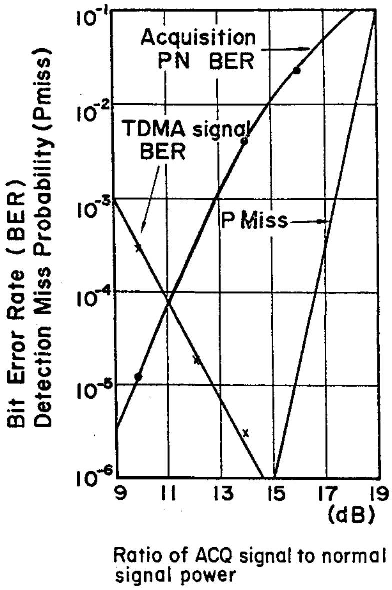

Fig. 25 Acquisition performance.

Acknowledgments

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