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DISCUSSION ON THE PROGRESS AND FUTURE OF SATELLITE
COMMUNICATION (JAPAN)

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16. Abstract The current status of communications satellite development in Japan is presented. It is shown that beginning with research on satellite communications in the late 1950's, progress has been made continually in the areas of communications, remote sensing, and technology experimentation. The current status of communications satellites under development is presented, stressing development in the areas of CFRP construction elements, the use of LSI and MIC circuits, advanced multi-beam antenna systems, Ku and Ka band transmission systems, and the shift to small-scale earth stations. Methods for reducing costs and increasing transmission efficiency are shown. The technical specifications of all satellite projects currently being developed are given. Users of Japanese communications satellite are presented, including INTELSAT, ARABSAT, Japan Public Telegraph and Telephone Co., ITT and AUSSAT.			
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DISCUSSION ON THE PROGRESS AND FUTURE
OF SATELLITE COMMUNICATION (JAPAN)

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1. Introduction

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Satellite communication has steadily progressed, and now the number of communication and transmission satellites in stationary orbit exceeds 400 [1]. Since CS was launched in 1978, our country's satellite communications have shown a great increase as a system which bears the burden of one wing of advanced information communication. In this special edition, we shall emphasize not only the results of communications satellites and recent technological results in ground station development, but also prospects for future technological developments, developing technologies which will be the key to satellite development, and, further, diversified ground systems.

2. Developments in Satellite Communication within our Company

Our company began to develop artificial satellites in the late 1950's, and up to the present we have developed many artificial satellites and loading devices in such fields as observation, communication, and technology testing. In particular, with respect to our country's series of communication satellites, as a maker of communication satellites we were consistently in charge of development and worked to advance independent technology in accordance with national policy. The Number-3 communications satellites which we /409 are presently developing, and for which we have design

*Numbers in the margin indicate pagination in the foreign text.

TABLE 1
COMMUNICATION SATELLITES AND EXPERIMENTAL TEST
SATELLITES WITHIN OUR COMPANY

Satellite	Description	Lifespan (years)	Weight (kg)	Launch date	Authorized Agency	Responsibility	
Communications Satellites	CS (Sakura) Medium-capacity stationary communication satellite for experimental use	3	677	December 1978	Space Development Group	Main contractor	
	ECS-5, 5 (Ayame) Stationary Communication satellite for experimental use	1.5	260	February 1980 February 1981	Space Development Group	Main contractor	
	CS-2a, b (Sakura No. 2) Communication satellite No. 2	5	670	February 1984 August 1984	Space Development Group	Main contractor	
	CS-3a, b Communication Satellite No. 3	7	1,080	February 1986 (scheduled)	Space Development Group	Main contractor	
	ETS-II (Saku 2) Experimental test satellite, Type II	1.5	254	February 1978	Space Development Group	Main contractor	
	ETS-IV (Saku 3) Experimental test satellite, Type IV	1.0	638	February 1982	Space Development Group	Main contractor	
	ETS-III (Saku 4) Experimental test satellite No. III	1.5	385	September 1983	Space Development Group	- VHF transceiver - S band transceiver - Tape recorder - Heat control - Ion engine	
	ETS-V Experimental test satellite, Type V	1.5	1,080	August 1987 (scheduled)	Space Development Group	Main contractor	
	INTELSAT-III	- First stationary communication satellite using antenna despun system - 1,500 telephone channels, 4 TV channels	3	293	September 1969	INTELSAT/ TRW	- Power control device - Shunt unit - DC/DC converter
	INTELSAT-V	- INTELSAT's first triaxial communication satellite - 12,000 telephone channels, 2 TV channels	7	1,926	December 1981	INTELSAT/ Ford Aerospace	- 4/6 GHz-global antenna - Power control device - Telemetry unit - Command unit
ARABSAT	- Joint Arab communication satellite - 25-channel fixed CB communications - S/C band TV transmission on three channels	7	1,233	February 1985	ARABSAT/ SNTAK/ Ford Aerospace	- Power control device - Telemetry unit - Command unit	

authorization, have captured 80% of the domestic market. In addition, we are exporting loading equipment for organizations such as INTELSAT. The communications and experimental test satellites for which our company was responsible are shown in Table 1.

The experimental CS medium-capacity stationary communications satellite, our country's first communications satellite, was begun in 1974 and was developed by the Space Development Group. This satellite was a genuine 350-kg communications satellite in a stationary orbit and, without any precedent in the world, used the standard millimeter wave band (the Ka band). It was a developmental product of Japan Public Telegraph and Telephone. In addition to reaching the expected objectives of standard millimeter wave experiments and establishing techniques for practically applying satellite communication systems, the satellite continued its normal functions even after its designed lifespan and collected a great quantity of data for a long period of time.

The communications satellites CS-2a and CS2b [2] now in use were of about the same capability as the CS and were launched from the Tanegashima Space Center. At present they are being used not only by the Japan Public Telegraph and Telephone Corporation (Ltd.) and municipal agencies, but also in planned pilot experiments by the Ministry of Postal Services.

More than just being able to continue the service of the CS-2 and deal with increased and diversified communication demands, the No. 3 communications satellites CS-3a and CS-3b are able to further present development. These satellites weigh 550 kg and occupy a stationary orbit. Their communication capabilities and capacities have been increased on a large scale based on the CS-2. They have the greatest capacity of their class for carrying communications equipment. They use new

technology such as gallium arsenate solar cells [3] and CFRP (carbon fiber reinforced plastic) lightweight construction.

As the main contractor we were responsible for the development of ETS-II, Japan's first stationary satellite, and ETS-IV, Japan's domestic large-scale satellite, each of which collected important data. Further, we are now promoting, as the main contractor, the development of ETS-V, the first domestic stationary triaxial satellite. The ETS-V will be developed by independent technology using such important technology as the high-stability triaxial position control system [4], lightweight CFRP solar paddles, lightweight CFRP body construction, and large-capacity heat control systems. It also anticipates things that will facilitate development of the next generation of high-efficiency, large-scale satellites.

We began developing communications satellites for export in the late 1960's, though we were already supplying loading equipment to INTELSAT III. Further, our company, along with all the European countries, participated in INTELSAT V, the latest large-scale triaxial satellite ordered by America's Ford Aerospace Co., and we were in charge of the antenna, electrical power control devices, telemetry units, and command unit. This led to ARABSAT's order for loading equipment.

For future communications satellites, we envision things which will promote capacity growth in response to communication's demands for growth, diversification, and economizing. There is a multi-beam satellite communication system which will efficiently advance the growth in satellite capacity. As for technical problems related to this system's communications, there are small multi-beam antennas, SS-TDMA technology, and technology for reducing size and weight such as equipment "LSI-izing" and "MIC-izing". Also, in the satellite housing, lightweight large-body construction, lightweight high-powered solar cell paddles, lightweight long-life

batteries, and high-capacity, high-efficiency heat control systems are important.

3. Satellite Communication Earth Stations in our Company

Since our firm delivered its first antenna for International Telegraph and Telephone's (Ltd.) Ibaraki Satellite Communication Station in 1974, we have delivered equipment relating to many earth stations all over the world. If these are generally classified according to use, there are those for international communication, those for domestic and regional communication, and our country's domestic communication (CS and BS response), and satellite tracking and control. Including equipment that will be delivered in 1985, the total number of deliveries comes to 150. The main deliveries are outlined below.

For an earth station for international communication, there are, for example, 6/4 GHz large-model stations (standard A-model), 6/4 GHz small-model stations (standard B-model), and 14/12 GHz large-model bureaus (standard C-model). Including the 7 delivered to International Telegraph and Telephone (Ltd.), we have delivered 34 standard A model stations (21 of which included antenna equipment). Among those, however, some such as the following deserve special mention.

(1) The Ibaraki number 3 antenna delivered to International Telegraph and Telephone (Ltd.) in 1972 established a four-reflector beam transmitting system and standards for wheel-drive, large-scale earth station antennas.

(2) Delivery of a direct bipolarization joint-use antenna for use in the INTELSAT V satellite to British Electronic Mail Public Corporation in 1977

(3) Delivery of a C-band (6/4 GHz) TT&CM/IOT 32m antenna to International Telegraph and Telephone's (Ltd.) Yamaguchi satellite communication station in 1980 [6].

(4) The Yamaguchi number 2 antenna which was delivered to International Telegraph and Telephone's Yamaguchi satellite communication station in 1981 delivered a) correction in the properties of the wide angle-side lobe that took into account reflection from the auxiliary reflector support mirror and b) a device that compensates for the deterioration of cross polarization characteristics due to rainfall.

(5) Delivery of a common-use C-band antenna to British Telecommunications International in 1984.

(6) Delivery of an entire TDMA/DSI system for use with INTELSAT to International Telegraph and Telephone's (Ltd.) Yamaguchi satellite communication station.

(7) Delivery of 2 complete TDMA/DSI systems to Sweden's Tanama Station and one complete system to Australia's Sedeuna Station [7]

The standard B-station is a SCPS-PCM/PSK system with a 13-11-m antenna and is used in countries with relatively little traffic and in developing countries. Our company has delivered 4 of these [8].

As for domestic and regional satellite communication systems placed in other countries, in 1976 we delivered 4 SCPC-supplied 2 standards and inspection stations for the TDMA and a

station for joint use by all Nordic countries. In the case of Australia's domestic satellite communication system, AUSSAT, our company received orders for twelve main line stations that are currently being built by the eight states and capital territories. They have now entered the final stages of construction aimed at inaugurating television broadcasting in October 1985. These stations adjust antennas to 18 m in areas of heavy rainfall and 13 m in areas of light rainfall to compensate for decreases in rainfall. EUTELSAT's Nordic station is the same, but the earth stations of advanced countries are set up as computer-controlled, unmanned operations, capable of remote control. In the AUSSAT system the other 11 stations are controlled by the Sydney station. Also, the small station (2.4- and 3.7-m antennas) which can be used by established communications lines of small towns and villages scattered throughout Australia have begun in-use testing due to competition from three other domestic and foreign companies.

In the field of Japan's domestic satellite communications, we have delivered various earth station-related devices to such groups as Japan Telegraph and Telephone Public Corporation, the Space Development Group, the Communication and Broadcasting Satellite Organization, and the Japan Broadcasting Association, but recently we have delivered small-scale Ka-band (30/20 GHz) earth stations to many private users as a link with the CS-2 association and satellite-use pilot plan.

We have delivered a great deal of experimental equipment to the Japan Telegraph and Telephone Public Corporation's Yokosuka Electrical Communications Research Facility since the early days of satellite communication, including a multi-frequency common-use antenna already completed in 1973, the first in the world. After that came the CS, Cs-2 period when many Ka- and C-band antennas for use as part of public circuit satellite

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TABLE 2
 REPRESENTATIVE SATELLITE COMMUNICATIONS EARTH STATIONS

Wave frequency band (GHz)	Antenna diameter (m)	G/T(dB/K)	EIRP (dBW)	Communication System	Use
6/4	32	40.7	79.2 (132 CH) 61.5/CH 67.5/CH 15.4	FDM/FM, TDMA SCPC/PCM/PSK (4 ϕ) SCPC/PSK (4 ϕ) FM-TV	INTELSAT standard Type A station Telephone, TV relay
6/4	11	31.7	61.5/CH 67.5/CH 85.0	SCPC/PCM/PSK (4 ϕ) SCPC/PSK (4 ϕ) FM-TV	INTELSAT standard Type B station Telephone, TV relay
6/4	8	28.2	57.8/CH	SCPC/ Δ M/PSK	Domestic communication using INTELSAT satellite's transponder Telephone, data
14/11	18	39.6	87.5 87.5	120 Mbps TDMA/DSI FM-TV	European region's satellite communication Telephone, TV relay
14/11	3.3	25.0	72.5	F/CM/PSK (4 ϕ)	IBS (International Business Service)
14/12	2.4	23.0	48.7/CH	SCPC/CFM	Australia's domestic satellite communications Small-capacity communications stations
30/20	5	32.4	73.6	SCPC-FM SCPC-PCM-PSK	Domestic satellite communications earth station Telephone, facsimiles, data, communication conferences
30/20	2.4x1.7 (elliptical)	24.0	53.0	SCPC-FM SCPC-PCM-PSK	Domestic satellite communications earth station Telephone, facsimile, data, photographs

communications were delivered. Among these are the first mirror-correcting offset cassegrain antennas in actual use anywhere in the world.

Table 2 shows an outline of some things representative of what our company has delivered up to now.

Attached to this special edition are four papers on the following subjects which form a treatise on communications satellites: the EUTELSAT traffic station, the earth station with the TDMA/DSI mechanism, computer-controlled unmanned system delivered to Sweden, the Gurnhealy number 6 antenna which was a joint-use C/Ku-band antennas delivered to British

Telecommunications International, the small-type Ka-band earth station which introduced the DAMA system delivered to the Fire-fighting Bureau, and the Mitsubishi small-scale earth station which was an example of a trial participation earth station.

4. Technical Problems and the Outlook for the Future

Satellite communications grew smoothly in response to the occasional demands of both the space components, which include the communication satellite and their launch rockets, and the earth components, which include satellite communication earth stations and satellite control and use stations. The new situation is that modern "communications" has diversified remarkably, and the role that should be attained by the field of satellite communications has become greater and greater. Here we want to try to review the true technical nature of satellite communication.

4.1 Characteristics of Wireless Communication Circuits

When we consider circuits coming down from the satellite and about their performance, in particular their signal-to-noise ratio, we should point out that satellite EIRP is proportional to the area of the earth station antenna, and the system's transmission speed is inversely proportional to the degree of static of the earth station. Therefore, assuming a certain transmission speed (pulse rate) required by the system, the more you raise the satellite's EIRP, the smaller you can make the earth station antenna and the more you can utilize a less expensive receiver. This is the most direct method of bringing down costs and increasing earth station efficiency (generally listed using G/T).

Because EIRP is the product of antenna size and transmission output, increasing a satellite's EIRP requires increasing either the satellite antenna diameter or the satellite

transmission output. This is the primary reason why we seek the early development of the efficient multi-beam antenna. To load large-diameter antennas into rockets, it is essential to develop the technology for large-scale housing construction as well as to develop lightweight components. Technological developments that permit folding up the antenna at launch time and extending it in orbit are also essential. Furthermore, since beam directional accuracy must be higher as the beam becomes more acute, the satellite posture control must also be extremely precise.

Increasing a satellite's transmission output is another important technical problem. Because the TWT is good at ultrahigh frequencies and high output, in the future much effort will be poured into developing the TWT for transmission satellites which we want to have over 100 W of power. We must also realize that power consumption, heat generation, and reliability are the greatest difficulties in handling high frequencies and high outputs. In communications satellites for which about 20 W of output is sufficient, we can continue to switch gradually from the relatively low-frequency 4 GHz band to semiconductors. An FET amplifier for the 30/20 GHz-band has recently been developed and, with respect to increasing transmission output, this is the beginning of an era.

One cannot forget the important point that with wireless circuits there is radio wave interference. No matter what is said, the circuit signal coming down from a satellite, because of its weakness, encounters severe static from ground-based microwave circuits. Also, because the pathway up to the orbit for stationary satellites is getting more crowded, interference with the circuit going up to the satellite is significant as well. Because the radio beam sent out from the transmission antenna becomes acute in proportion to the antenna diameter and wave frequency, interference necessarily limits the reduction in ground-based antenna diameter and accelerates the move to high

regions of the used wave frequency bands. At present the C band, Ku-band, and Ka-band are allotted to fixed satellite circuits, but the overall move from C to Ku and from Ku to Ka is mainly for this reason. Because in Japan land is scarce and microwave lines have grown in number, interference is a 411 special problem. In fact, the C-band and even the Ku-band are already overcrowded with ground lines, and as long as no interference reduction plan is implemented, things will become worse.

Because a given satellite's EIRP is relatively small and the transmission speed required by a system is relatively large, it is simply inevitable that we will create large-scale earth stations with systems which handle large volumes of information. Because of this kind of thing, in the early days of satellite communications, in order to relay TV, a 30-m-diameter class, large-scale antenna with helium-cooled receiver and a kilowatt class transmitter was used. Earth stations with large, stable output are gradually becoming small scale. Particularly in the case of earth stations whose systems consist of data transmission, there is the possibility that they can become so small that they will be just like the existing 60-cm antennas.

4.2 Properties of Communications Networks

The relationship between the three factors of satellite EIRP, earth station G/T, and transmission speed are, as stated above, relatively simple. Since hitherto TV signals and large bundles of public communication circuits were the main load of transmitted information, a system's highest rate of transmission needed to be about 100 Mbps, and earth stations' G/T was matched to this. As wireless technology advances, EIRP and G/T plans become relatively more free, and the information that has to be transmitted diversifies, we will probably tend to think mainly

of the transmission speed of a system and in turn of communications networks.

Without touching on the problems relating to there being no wires, efficient use of wave frequencies demands compression of information transmission bands. Simply digitalized TV signals demand a high transmission speed of 64 Mbps; using recent technology [11], however, just 768 Kbps is sufficient for TV conference use, and also, depending on the use, one can transmit images using just 64 Kbps, the same as a telephone. Meanwhile, regarding computer data transmission speed, we envision high-speed data using just 48 Kbps, much less than that used by TV and multiplex telephone. As stated previously, if the speed of transmission is low, it is all right if just that part of the earth station is small and an increase in a satellite's EIRP will further spur the down-scaling of earth stations.

If earth stations come to be small, many so-called compound systems will be built from the many small-scale earth stations. The communications network that satellites will create looks disjointed, but actually it makes up a net-like circuit. The fact that a perfect network is formed naturally is a satellite communications network's best quality. Thus, a network constructed in this way has the characteristic that there is essentially no difference between international communications which span continents and a network within a city 50 km in diameter.

When a system's transmission rate is relatively low, there is a drive for a computer network that can adequately manage a satellite using small-scale earth stations. The packet exchange system recognized by data communication is compatible with existing communication satellite systems, and the growth of this so-called satellite packet network is expected. Propagation delay as a particular problem for wireless satellites is a frequent topic of conversation. However, if one takes

propagation delay into account from the start of system planning which includes protocols, it is actually not a big problem. Because satellite communication control mechanisms are able to work with existing transmission control procedures used by earth-bound circuits, using things that were developed from this sort of viewpoint, they are very useful.

The TDMA system that has continued to be developed rapidly in recent years is close to the general idea of the satellite packet network mentioned above. Using the TDMA (Time Multiplexing) system, one transmitting earth station can instantly occupy one satellite relay, rather than get rid of reciprocal modulation which is a problem using FDM (Frequency Dividing). Moreover, besides increasing transmission capacity, the TDMA has extremely high flexibility in network construction.

The SS/TDMA (Satellite Switching Time Multiplexing) system is the first switching TDMA system finally introduced from INTELSAT IV after a long period of technical development. This switching allows association between satellite relay devices by microwave and, further, it advanced SS/TDMA research which carried out relays as an advanced system and which was based on beam scanning. Because it is possible to do such things as exchange signals that are on the time spindle, if one comes back to the bass band using the satellite, it is possible to build a system which can constitute a flexible system, which can change allocations as needed in response to special traffic demands, and which is extremely practical.

The advance of semiconductors and the completion of software also accelerated the creation of advanced systems. The creation of systems like those mentioned above which used relays and ultra-high-speed switching, at least in theory, looked quite distant. Recently, however, high-reliability, small-sized, lightweight "LSI-ization" has allowed advanced simulations by

systems tests without worrying about the environment of space. Therefore, we can say that what should be called the ideal of satellite communication, the creation of on-board processing, is near at hand.

If a signal is reconstituted within the satellite, it will differ from existing transit type devices and will be able to exclude much of the heat static and interference static involved with transmitting up to satellites. Therefore, including frequency choice and circuit preparation and adding degrees of freedom to circuit plans in turn brought about reforms in system construction.

4.3 Cost Effectiveness

The fact that one is fully utilizing the cost effectiveness of a satellite when one implements satellites in networks is becoming more and more important. That is, people have decided to build systems which make the most of the characteristics of satellites and maximize satellite utility. As for the bottom line in cost effectiveness, namely "a cost is a cost," it is necessary to investigate each case on the basis of the terms agreed upon.

The most effective way to minimize the cost of machinery, and this is not limited to satellites, is to mass produce the items whose development is complete. Figure 1 is extremely rough, but it shows that costs (unit costs) decrease in response to quantity produced (one can see this roughly by date). Line 1 is the cost reduction curve for the space components (communications satellites and launch rockets and tracking/control). (The reduction rate from the INTELSAT satellite is 0.6). Viewed in this way, the technical progress of communications satellites is spectacular, and, therefore, cost reductions are phenomenal. Line 2 is the earth part (earth stations) cost curve; while it is not spectacular,

it shows the same or greater price reduction than earthbound wireless systems.

Meanwhile, there were many existing communications networks combining the space and earth parts which seldom used mainly large-scale communication satellite stations. In other words, there were mostly stations which sent and received messages using large-scale earth stations which used the large capacity, long distance cables, the satellites hung in the sky. However, in addition to recognition of the utility of satellite communications and the diversification of their use, component systems which use small-type earth stations continue to increase in number. As was stated before, in order to make the earth components simple, the space components will probably be made even larger (curved lines 1' and 2'). In this way the so-called rooftop earth stations are springing up one by one.

However we cannot in the least ignore the future competition for public resources. That will promote efficient use of radio waves (wireless frequencies and bands) and stationary satellite orbits. The development of essential interfaces to be able to combine satellites into existing networks will also become important. Thus, the demand for these things will gradually become severe. (curved line 3)

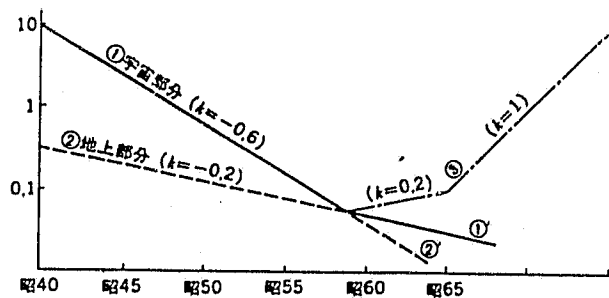


Figure 1. Cost History
 Vertical scale: Relative cost;
 Horizontal scale: 1961 1966
 1971 1976 1981 1986;
 1. Space components; 2. Earth
 components; 3. Cost for
 effective use of orbits and
 electrical waves, for network
 interfaces, etc.

Because of facts like these, high cost effectiveness /412 will be demanded of future satellite communication systems: a) In the field of public communications, we can probably continue progressive development of systems centered on large-size communications satellites and aimed at establishment of a large-capacity wide-band region (a highway) of transmission pathways. b) Also, for commercial use, in addition to using the lowest cost communications satellites whose development is already complete, feedback into the planning of communication satellites in order to build the most efficient network will also become a major theme. c) Further, the use of satellite communications as the most efficient tool for radio station networks will inevitably increase.

5. Conclusion

In the preceding, after we looked at the history of communications satellites and satellite communications within our company, we explored 1) satellite communications with wireless circuitry and 2) the technical problems involved with communications satellites which form networks with special features.

Satellite communications were extended from international communications. This was done using primarily the matchless characteristics of satellites, least of which is their long-range transmitting ability. We may say that recently it has finally been realized that satellite circuits are a unique and indispensable tool for the construction of high-speed information communication networks.

Our country's communications satellites are working in a stable way. The Ka-band, which we led the world in introducing, has proved itself in use and opened the road to the future efficient use of the whole spectrum of wave frequencies. There is an extreme abundance of choices in earth stations. However,

maximizing the efficiency of satellites will be controlled by future systems and construction. What we need to do is solve detailed technical problems while broadly concerning ourselves with hardware, software, cost, and efficiency. Finally we would like to express our gratitude to everyone involved who provided us with continued guidance, and we hope that the use of satellite communications continues to grow.

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