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Land Mobile Satellite Communication System Using the Geostationary Platform

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If the geostationary platform (GPF) is available in the first decade of the 21st century, the demand on a voice communication base is expected to be about 800,000 Land Mobile Satellite Service (LMSS) terminals. To improve the frequency use of an LMSS over Japan, it is important to reuse the frequencies allocated to the Tokyo metropolitan area in the Osaka-Kobe-Kyoto region. An onboard multibeam antenna with beam intervals of 0.468 deg (L band 30-m class) for each of the 11 beams covering the main Japanese islands, cluster power feeding, and dual polarization can enable the reuse of frequencies at one-beam intervals. A deployable antenna is under development that is lightweight and has a high storage efficiency for launching. This will form the basis for an antenna with an aperture diameter of 30 m. Such a large antenna will be a key factor in reducing ground terminal size. This paper estimates the weight and power requirements of the mission payloads onboard the GPF, which include an LMSS, a millimeter wave personal satellite communication system, and a high-definition television/regional television satellite broadcasting service system. The total weight of this GPF would be approximately 4–5 tons.

Nomenclature

EOB	= edge of beam (Fig. 1)
erl/sub	= Erlang/subscriber (unit of traffic)
G/T	= gain-to-receiver-noise temperature, dB (receiver terminal performance index)

Introduction

EARLY in the 21st century, a geostationary platform (GPF),[1] a large-scale satellite that would be constructed by docking satellites or mission equipment with truss modules and that could be repaired and will compactly contain payloads used for point-to-point communications, broadcasting, radio location determination, and mobile satellite communication systems (MSS), is expected to be placed into orbit. The deployment or in-space erection of this GPF will be made possible by the progress achieved in satellite launching technology and space station activities.

Many countries are now conducting feasibility studies for land mobile satellite communication systems (LMSS). Well-known examples are the Canadian Mobile Communication Satellite (MSAT) and the American Mobile Satellite Consortium (AMSC), which will conduct mobile satellite communication service using the Canadian MSAT. Both of these systems are expected to be completed between 1992 and 1993.[2,3]

Another famous American project is NASA's Third-Generation MSS Concept. This project hopes to launch a mobile satellite system equipped with an 87-beam antenna having an aperture diameter of 55 m early in the next century.[4]

Japan is presently pursuing communication experiments using the ETS-V satellite. Several proposals have been made to produce mobile satellite systems by the late 1990s. Such a launch decision will be made after examining the results of ongoing experiments and ETS-VI's launching project, probably in 1993.[5]

Considering the peak forecast of future demand for LMSS, it will be necessary to develop a satellite equipped with a large multibeam antenna.[5] This paper deals principally with goals for the development of GPF-based LMSS, along with the concept of a GPF system.

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Demand for LMSS and Frequencies To Be Used

Demand for LMSS in the Early 21st Century

LMSS can offer service coverage of wide areas and supplement, in part, terrestrial mobile systems in sparsely populated areas where services are not economically viable. According to one estimate,[5] the potential demand for satellite mobile telephone service in the year 2000 will be 1 million terminals, and the demand for general business radio services, including multi-channel access (MCA, one of the terrestrial mobile communication services in Japan) will be 300,000 subscribers.

If geostationary 2-ton satellite-based mobile communications services first become available in the late 1990s, these demand estimates will come true around 2020, approximately 25 years after the MSS commercialization. In the same manner, the demand for voice communications, including motor-vehicle-mounted and portable telephones, is predicted to be 800,000 terminals in the year 2010. It is reasonable that satellite system capacity, however, should be designed to cover 1 million users to include demand for airplane and maritime mobile satellite voice communications services.

Frequency Resources

The demand for motor-vehicle communication and MCA has already begun to expand remarkably and is expected to reach a level of a million terminals by the year 2000.[5] Accordingly, in addition to the present uhf band, the development of a quasimicrowave band will be required.

At the World Administrative Radio Conference on Mobile Communications (WARC-MOB) 1987,[6] a pair of 7 MHz in the bands of 1.5 GHz (downlink) and 1.6 GHz (uplink) were allocated for LMSS use; additionally, an 11 MHz (uplink) or 15 MHz (downlink) was given for LMSS low-speed data transmission services on secondary basis. Frequency allocation for MSS services is to be reviewed at the next WARC.

In the 2.5/2.6-GHz band range, a 35-MHz band for MSS services (both up and down) has been given to the Asian and Oceanic Region. Since the frequency spectrum available for future LMSS services in Japan is not yet determined, research and development activities should take all potential bands (uhf, L, S) into consideration.

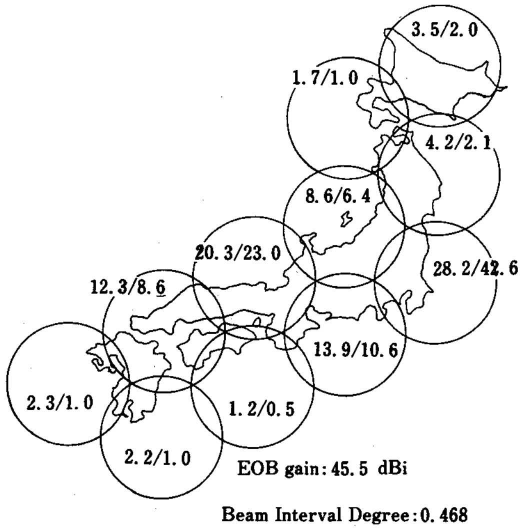


Fig. 1 Multibeam layout.

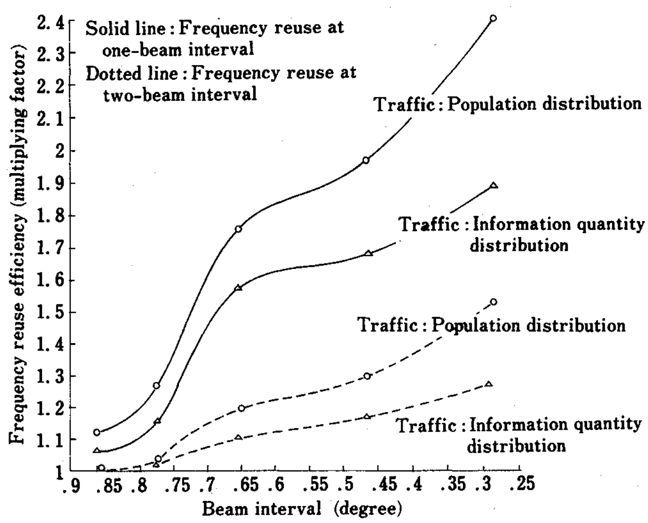


Fig. 2 Frequency reuse efficiency by beam interval.

Land Mobile Satellite Communication Systems

Multibeam Layout and Efficiency in Frequency Reuse

The frequency spectrum available for LMSS will undoubtedly be limited; therefore, frequency reuse via multibeam antennas will be mandatory to handle the high traffic volume. This requires a quantitative evaluation of beam layout and expected frequency reuse factor.

A typical beam layout with a given beam interval of 0.468 deg, where beam interval is the angle between beam centers in the multibeam layout, looking from geostationary orbit, is shown in Fig. 1. The numbers in each zone represent the share of population (%)/the share of information quantity (%). The Okinawa zone, which is not shown on the map, occupies 1% of the population and 0.5% of the information quantity. Satellite geostationary orbit is 125° E long. This beam layout is based on geographical considerations and the premise that the main Japanese islands and their surrounding waters should be covered by a hexagonal zonal arrangement.[7] Two numbers in each beam show the traffic rate in each zone, made on the assumption that future regional traffic growth will be proportional to the supply of information volume through public switched telephone, TV, and other data networks, or proportional to demographic shifts.

The frequency reuse factor in relation to beam intervals is shown in Fig. 2. This figure shows the frequency reuse efficiency as a multiplying factor. This multiplying factor is as follows: At first, the bandwidth is given for the traffic amount in the area covered by a beam, and total bandwidth is summed up all over the beams. Then the bandwidth is calculated for the cases when frequency reuse is done by a one-beam interval or a two-beam interval. Accordingly: Multiplying factor = [Total bandwidth in case of no frequency reuse]/[Total bandwidth in case of frequency reuse].

These data were obtained by calculating, for selected beam intervals, the traffic rates, which are proportional to population and information quantity, and by allocating corresponding bandwidths to each zone. Information quantity was counted as the total product of information, such as TV and radio broadcasting, newspapers, and various books, and is proportional to population, but information quantity also includes various one-way information supplies and the difference between the case of population shift and that of information quantity has been caused by the reason described above. The improvement of reuse factor in diverse beam intervals depends largely on whether the frequencies allocated to the Tokyo region can be reused in the Osaka-Kobe-Kyoto area, i.e., one beam interval use in Fig. 1.

The effective use of frequencies, therefore, requires a beam interval of approximately 0.65 deg or less and the reuse of frequencies at a one-beam interval.

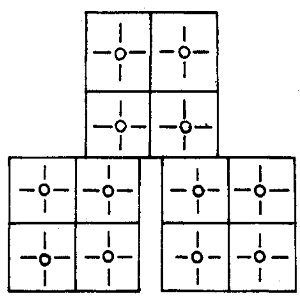
Technological Developments

Satellite Multibeam Antenna

Preliminary trade-off studies on lightweight structuring vs electrical performance, as well as the alleviation of passive intermodulation and aperture blocking, have identified that a pair of offset parabolic reflector antennas for separate transmission and reception would be the most promising design.

The beam configuration shown in Fig. 1, using a beam interval of 0.468 deg, makes it possible to reuse frequencies allocated to the Tokyo area in the Osaka-Kobe-Kyoto area as well. The reuse factor is estimated at 1.97 on a regional demographic distribution basis.

As a primary feed technique, two approaches are possible; a four-element cluster feed using cupped cross-dipole antennas (a dipole antenna put into a shallow rectangular box) and seven-element cluster feeding using microstrip array antenna.



(Four-element cluster feed)

Fig. 3a Cluster-feed arrangement using cupped cross dipoles. Three adjacent clusters are shown, and cluster interval is 1.7λ.

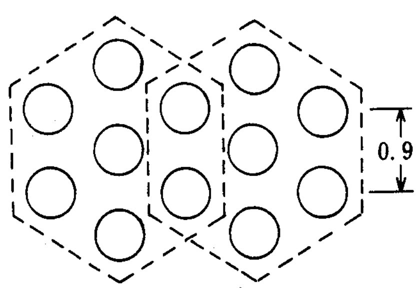


Fig. 3b Cluster-feed arrangement using a microstrip array. Adjacent clusters are shown in which the distance between the two elements is 0.9λ.

Diagrams of these two-feed systems are shown in Fig. 3. In this antenna design, beam allocation or beam crossover points were assumed to be the same.

Figure 3a shows a quadruple-radiating element cluster feed utilizing cupped cross-dipole antennas. No element shares its electrical current with adjacent clusters.

The same amount of electrical power is fed to all four elements. Given a focal length of 1.1 times the aperture diameter and a relative between-adjacent-beam deviation angle of 0.468 deg, the aperture diameter becomes 171λ [uhf (800 MHz): 43 m, L band: 25 m, S band: 15 m].

The minimum carrier-to-interference ratio (*D/U*) experienced at the zone edge would be 18 dB, if the same frequencies are used for a one-beam interval. If cross polarization is used between beams in which the same frequency is used, the interference levels will be less than or equal to the protection ratio of 20 dB.

Figure 3b diagrams a seven-element cluster feed using a microstrip antenna. The center element is the main radiating element and the six outside ones are commonly used with adjacent clusters.

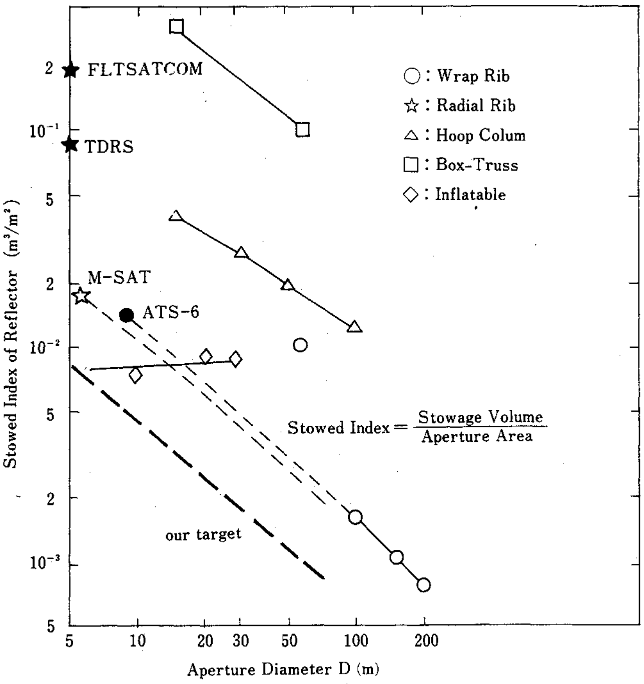


Fig. 4 Stowed index vs aperture diameter. Filled-in symbols indicate values already realized, and outlined symbols indicate values under development.

This feed technique obtains a larger *D/U* compared to that of the cross-dipole feed; however, there would be a thermal problem in feeding more than 100 W to each element. Also, the aperture size for obtaining a beam separation angle of 0.468 deg is 212λ (nominally aperture size is 230λ and was shortened considering sidelobe level allowance). Considering these two points, the cupped cross-dipole feed is the optimum system.

A deployable satellite antenna requires a high stowage efficiency, lightness, and high rigidity. The stowage indices of various deployment methods, the ratio of payload density to aperture size, is shown in Fig. 4. Surface density related to aperture size is shown in Fig. 5 for these same deployment methods. The reference indices for an antenna having a diameter in the range of 30 m are 0.005 m^3/m^2 for the stowage index, 0.4 kg/m^2 for the surface density, and 0.5–1 Hz, or higher, in the number of natural vibrations for the rigidity.[8] Various types of deployable antennas are reviewed in the Appendix.

Given that the aperture diameter of the main reflector is 171λ, as mentioned above, the reflector diameter should be 20.5–33.0 m for the 1.55/2.5-GHz bands. Fundamental studies on the structural and mesh surface performance of deployable reflectors are being carried out, targeting the 30-m class antenna system.

The Appendix includes several photographs of antenna models and details of their features.[8]

Transponder Development

A solid-state power amplifier (SSPA) in multicarrier operations must have good linearity performance and high efficiency. The performance of the SSPA to be used for MSAT, for example, is reportedly as an output power level of 100 W (output backoff: 4.8 dB) with a carrier-to-intermodulation noise ratio (*C/IM*) of 19 dB at an efficiency of 27%.[9] Progress in circuit configuration technology provides good prospects for bettering the efficiencies up to around 50%.[10]

System Considerations

Network Configuration

A conceptual network configuration is illustrated in Fig. 6. The feeder link, composed of a single beam, consists of three types of Earth stations: 1) a network control station that identifies the location and conditions of land mobile Earth stations (referred to as mobile terminals) and also allocates and con-

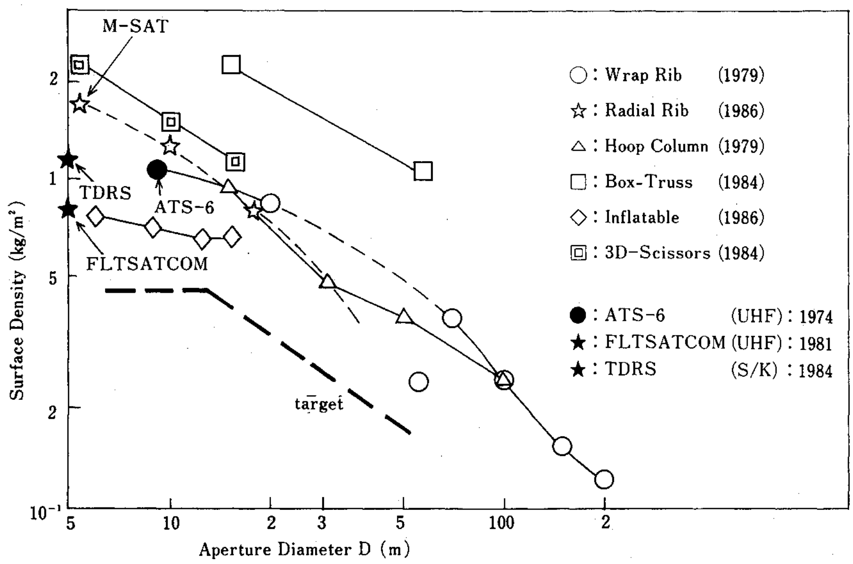


Fig. 5 Relationship of surface density to aperture diameter. Filled-in symbols indicate values already realized, and outlined symbols indicate values under development.

trols the radio link with one station; 2) gateway stations that interface with terrestrial networks [approximately the same number as regional stations in a conventional public service telephone network (PSTN); and 3) joint-subscribing Earth stations (approximately one per prefecture) for closed user groups.

The mobile link is arranged by beams, as shown in Fig. 1. Both Single Channel Per Carrier/Frequency Division Multiple Access (SCPC/FDMA) for uplink and narrow-band Time Division Multiplex Access/Time Division Multiplex (TDMA/TDM) for downlink are feasible; however, SCPC/FDMA is assumed to be preferable by reducing mobile terminal equivalent isotropically radiated power (EIRP), which affects mobile vehicle costs, and because of the uncertainty of selective fading in TDMA/TDM transmission channels.

Mobile Earth Terminals

For popularization among the public, mobile terminals must be available at significantly lower costs and smaller in size. With these constraints, it might not be appropriate to use tracking middle/high-gain antennas. If large onboard antennas become available, a nontracking antenna of several decibels can be adapted for mobile vehicles. Conical beam antennas whose takeoff angles are approximately equal to satellite elevation angles are also promising, an example of which is the circularly polarized microstrip antenna (MSA). The MSA is practical for transceiving right-hand circular polarization (RHCP) and left-hand circular polarization (LHCP) by switching hybrid forward error correction (HYB) feeder terminals, as shown in Fig. 7.

Propagation and Modulation/Coding

Continued technological development will result in highly efficient speech coding and will contribute to the efficient utilization of frequency resources and satellite power. It is expected that in the future a 4.8 kilobit per second (kbps) speech compression will be improved to near-toll quality. Transmission over the LMSS channel is susceptible to multipath fading and shadowing.

Through propagation tests conducted in the United States and the ETS-V experimental program,[11,12] results have been obtained similar to the Rician fading channel, i.e., the direct wave/reflected wave power ratio (*C/M*) is equal to 10–20 dB.

Forward error correction (FEC) coding techniques primarily offer improved power performance in the fading channel.

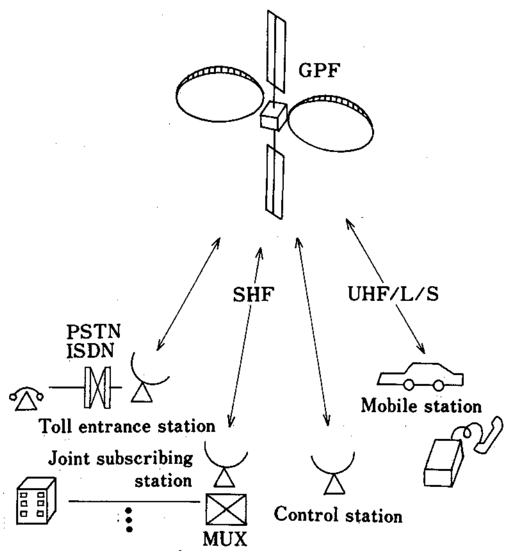


Fig. 6 Network concept. The control station, toll entrance stations, and joint subscribing stations use SHF, the so-called Ku band. Communication routes are from mobile terminals to satellite and toll entrance stations connecting the ground PSTN network.

In addition to this feature, a combined modulation/coding scheme is noteworthy because of its enhanced spectral efficiency. At NASA, for example, development is proceeding on trellis-coded differentially detected 8-phase shift keying (TCM/D8-PSK) schemes with interleaving techniques to transmit 4.8 kbps digital speech signals on MSS channels of 5-kHz spacing.[13] The adoption of this modulation/coding scheme is practicable for LMSS.

Sample Link Budget

A sample link budget is shown in Table 1. The spectrum presently allocated in the L band for LMSS will undoubtedly be limited. This frequency band, however, is assumed to be used. It is estimated that this LMSS service would attract 800,000 users on a voice-grade basis by the year 2010. The required channels would number more than 10,000 in order to handle that traffic volume (0.01 erl/sub, 80% circuit efficiency). Required frequency spectrum would roughly amount to 30 MHz (26 MHz nominally plus guard band), if we assume a channel spacing of 5 kHz and a reuse factor of 2. This system would be realized in the 2.5/2.6-GHz band. As for the *C/No*, 47.8 dB is required since the *Eb/No* is 11 dB ($BER = 10^{-3}$), at a *C/M* equal to 10 dB.

The effective output power of the transponder totals 1 kW, estimating that the carrier activation rate is 0.4 by voice activation. For the Kanto beam, having the heaviest traffic loading due to Tokyo area, the required output power is 280 W. A 100-W level (output back off 3 dB) SSPA[10] feeds power to each of four cluster-fed horns.

GPF Scale in the Initial Stage and Its Conceptualization

A system summary and technological developments have been presented for the LMSS. In the case of onboarding this mission payload to GPF, weight and required power become 1100 kg (800 kg for twin antennas and 300 kg for transponders) and 2.5 kW, respectively.

Besides the LMSS described above, two other satellite service systems, millimeter wave personal satellite communica-

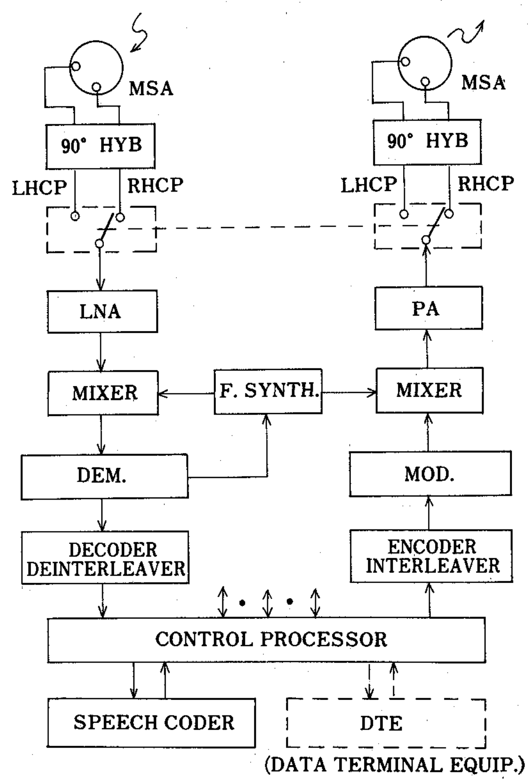


Fig. 7 One of the configurations for mobile stations. This system uses dual polarized microstrip antenna (MSA) and chooses one polarization of higher level in a service area.

Table 1 Link budget (an example)

	FES-to-mobile		Mobile-to-FES	
	Uplink	Downlink	Uplink	Downlink
Frequency, MHz	14,000	1555	1657	11,700
TX power/ch, dBW	−6.0	−6.0	−3.0	−10.0
TX feeder loss, dB	3.0	2.0	2.0	3.0
TX antenna gain, dBi	47.0	45.5	6.0	36.0
EIRP/ch, dB	38.0	37.5	1.0	23.0
Free space pass loss, dB	207.0	187.9	188.4	205.4
RX antenna gain, dBi	36.0	6.0	45.5	45.4
RX feeder loss, db	3.0	2.0	2.0	3.0
Noise temperature, dBK	28.4	25.5	26.4	25.1
G/T, dB/K	4.6	−21.5	17.1	17.4
C/No, dBHz	64.2	56.7	58.2	63.6
C/IMo, dBHz	80.0	56.0	56.0	80.0
C/Iduo, dBHz		56.0	56.0	
C/(No+Io), dBHz	64.1	51.5	51.9	63.5
C/(No+Io) total, dBHz		51.2		51.6
C/(No+Io) required, dBHz		47.8		47.8
Margin, dB		3.4		3.8

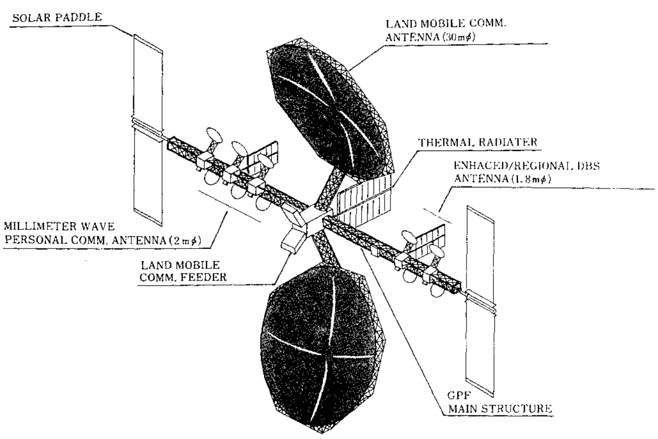


Fig. 8 SCR-GPF configuration concept.

tions systems using 50/40-GHz and 22-GHz satellite broadcasting services, were considered. For millimeter wave personal satellite communications, a projected system was designed using 27 small beams to cover the Japanese islands with a 2-m antenna, and 2000 voice channels are exchanged with baseband satellite switching.[14,15] As for 22-GHz satellite broadcasting, eight channels and higher than 250-W power transmitters are necessary and six multibeam services are provided by 2–3 m antennas.[16] Many kinds of services, such as high vision, sports, education, and local channels, will be broadcast.

Taking these two additional services onboard the GPF, the mission payloads weight becomes about 2 tons and required power is about 10–13 kW.

Accordingly, the GPF that includes all three services weighs about 4–5 tons. This GPF configuration concept is shown in Fig. 8.

Conclusions

The characteristics of an LMSS using a GPF are as follows. By mounting two large multibeam antennas, it is possible to utilize frequencies efficiently and make mobile stations smaller, thus offering communication services to many users. Proceeding principally from this viewpoint, the expected reuse rate can be clarified in terms of local traffic distribution and multibeam layouts. In addition, voice communication service for 800,000 users is feasible by employing small mobile terminals ($G/T = -21.5$ dB/K).

With the addition of millimeter wave personal and 22-GHz band enhanced broadcasting mission payloads, figures for the initial stage GPF weight and required power, along with a possible GPF design with these three missions, have been presented. Further research will be conducted on network-control methods, nonvoice communication methods, and costs in LMSS.

Appendix: Research on Several Mock-Up Models of a Large Deployable Antenna in SCR

Until now, various types of deployable antennas have been designed, and some of them, such as those for ATS-6 or TDRS, have been launched and used for practical satellite communications. These are shown in Table A1.[17,18] Considering these developments, SCR started research on deployable antennas for future mobile satellite communications in 1987.

Several mock-up models of a large deployable antenna have been designed, in order to develop a large multibeam antenna capable of being mounted on a geostationary platform-like satellite in a mobile communications system. This development will make small and economical ground mobile equipment possible by an efficient frequency utilization and the improvement of satellite communications transmitting and receiving techniques.

To achieve this goal, research has been conducted on the development of a large (30-m class) deployable antenna. The offset parabolic antenna is very promising because of its simple construction. For the reflector, a mesh device that can form an antenna surface is desirable because it offers the advantages of lightness and good stowage for rocket launching.

An investigation has been undertaken on reflector structures, focusing on surface accuracy and rigidity. Three truss configurations have been devised and tested. The modularized hoop frame in Fig. A1 is a structure in which many hexahedral hoop frames are combined two-dimensionally to facilitate the development of a large diameter antenna, with improved rigidity and stowage.

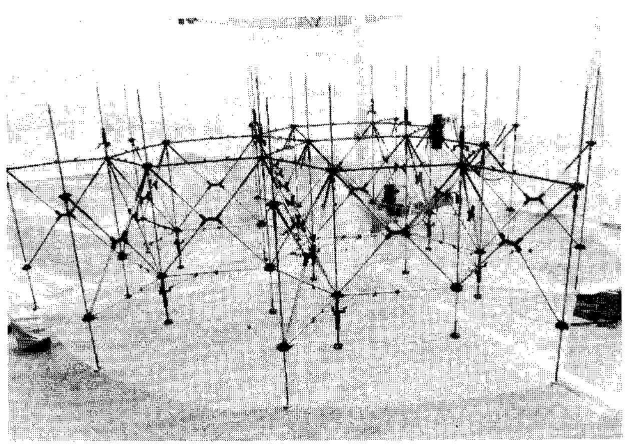


Fig. A1 Modularized hoop frame.

Table A1 Deployable satellite antenna types suitable for use in the 1-3-GHz region

Structure	Category	Construction and aperture deployment method	m	Frequency limit, GHz	Notes and references
Ribs with mesh surface	Radial rib	Umbrella like	4.5	12	TDRS
	Wrap-rib[a]	"Carpenter tape" ribs unwrapped from central column	9	6	ATS-6
	Cable-catenary	Mesh supported radial booms and catenary cables	4.9	0.2	FLTSAT
	Fan-rib	Ribs, open like a fan, to form segment of a circular aperture	4.5	6	
Hoop with mesh surface	Hoop-column hoop-frame	"May-pole" structure	15	0.8[b]	
Truss with mesh surface	Tetra-hedral[a] (i.e., "box") truss	Multiplicity of connected cubes with mesh supporting stand-offs of appropriate length (box deployed by energy stored in "carpenter-tape" hinges)	4.6		
	Quadrature aperture	Hoop-column concept forming four, independent apertures	3.5 each	(model only)	
	Geodesic truss	Triangular pyramids (element of classical geodestic structures)	5	12	
	Prism	(Details not available)	10	1	
	Tension truss structure	Cable-stiffened mesh support	20	2–20	Conceptual model
Inflatable	Multi-layer fabric	Positive gas pressure throughout life, or inflated structure, rigidized by solar heat	3.5		

[a]Discussed in Report 955-2.
[b]Technique applicable to much higher frequencies.

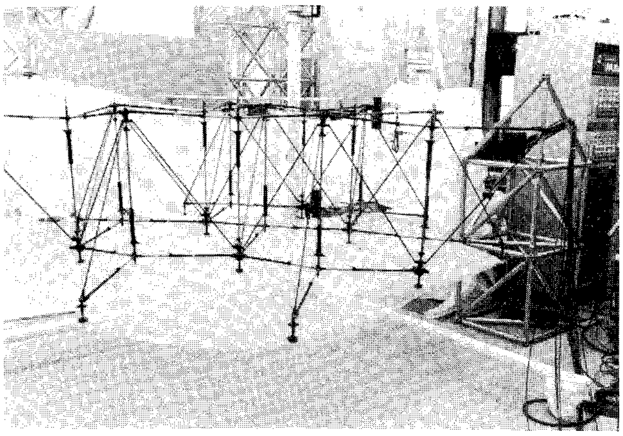


Fig. A2 Tetra-rib truss.

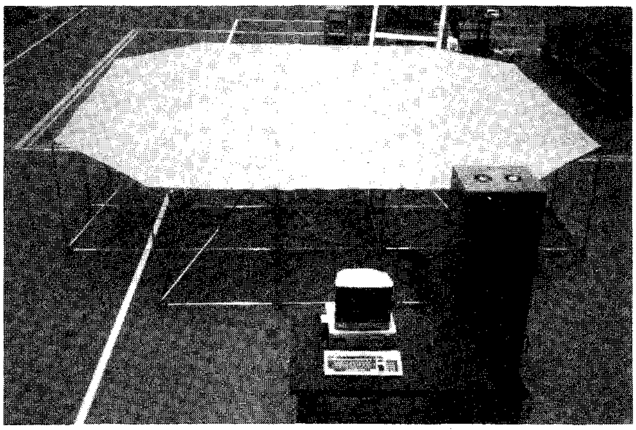


Fig. A3 Variable-structure truss.

In a tetra-rib truss (Fig. A2), wire is used for one part of a tetrahedral truss, which is a fundamental concept of the reflector structure and provides a degree of tension to the structure. This eliminates the undesirable play in joints that is peculiar to the deployment structures. As a result, both lightness and rigidity can be realized.

In a variable-structure truss (Fig. A3), each diagonal member of the hexahedral truss unit is made elastic to actively deal with the problem of thermal deformation. A motor and springs are used as the drive mechanism.

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