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Study of LEO-SAT Microwave Link for Broad-Band Mobile Satellite Communication System

Masayuki Fujise, Wataru Chujo, Isamu Chiba, Yoji Furuhama

Kazuaki Kawabata* and Yoshihiko Konishi**

ATR Optical and Radio Communications Research Laboratories

2-2, Hikaridai, Seika-cho, Kyoto

619-02, Japan

Tel +81-7749-5-1511

Fax +81-7749-5-1508

* Toshiba Corporation ** Mitsubishi Electric Corporation

INTRODUCTION

In the field of mobile satellite communications, a system based on low-earth-orbit satellites (LEO-SATs) such as the Iridium system has been proposed[1]-[3]. The LEO-SAT system is able to offer mobile telecommunication services in high-latitude areas. Rain degradation, fading and shadowing are also expected to be decreased when the system is operated at a high elevation angle. Furthermore, the propagation delay generated in the LEO-SAT system is less pronounced than that in the geostationary orbit satellite (GEO-SAT) system and, in voice services, the effect of the delay is almost negligible. We proposed a concept of a broad-band mobile satellite communication system with LEO-SATs and Optical ISL[4]. In that system, a fixed L-band (1.6/1.5GHz) multibeam is used to offer narrow band service to the mobile terminals in the entire area covered by a LEO-SAT and steerable Ka-band (30/20GHz) spot beams are used for the wide band service.

In this paper, we present results of a study of LEO-SAT microwave link between a satellite and a mobile terminal for a broad-band mobile satellite communication system. First, the results of link budget calculations are presented and, the antennas mounted on satellites are shown.

For a future mobile antenna technology, we also show digital beamforming (DBF) techniques. DBF, together with modulation and/or demodulation, is becoming a key technique for mobile antennas with advanced functions such as antenna pattern calibration, correction, and radio interference suppression[5]. In this paper, efficient DBF techniques for transmitting and receiving are presented. Furthermore, an adaptive array antenna system suitable for this LEO-SAT is presented[6].

SYSTEM CONCEPT AND LINK BUDGET

Table 1 outlines the system. The transmission quality of each link is expressed in terms of the bit error rate.

When the satellite altitude is 765 km and the minimum elevation angle is 30 degrees, the number of satellites in this system is 200, because 10 orbital planes are required to cover the entire earth. In this system, it is assumed that the aperture diameter of the mobile antenna is 50 mm and the transmission power of the mobile antenna is 1W for both L-band and Ka-band system.

Table 2 and Table 3 show the results of link budget calculations. In the calculations, the QPSK modulation scheme where BT=1.0 and half-rate punctured coding/Viterbi decoding FEC whose constraint length is 7 are assumed. As for the transmission quality, a bit error rate (BER) of better than 1×10^{-7} and the average annual time of 1% are also assumed. In this calculation, the user terminal antenna size for L-band and Ka-band links are set 50 mm.

SATELLITE ANTENNAS

L-band Multibeam Antenna

In our proposed system[4], a fixed L-band (1.6/1.5 GHz) multibeam is used to offer N-ISDN (64kbit/s) service to the mobile terminals in the entire area covered by a LEO-SAT. Two types of active array antennas are proposed for this system.

A. Low sidelobe multiple planar-array antennas

First, low sidelobe multiple planar-array antennas are presented. The antenna system is composed of 5 planar-array antennas with different broadside directions. One is a circular aperture array antenna, and the others are rectangular aperture array antennas. The constitution of them are presented in Fig.1 and Fig.2. This antenna system radiates 37 beams. In this system, the number of users is assumed to be 185. The beam coverages of each array antenna are shown in Fig.3. Because this multibeam antenna radiates low sidelobe pattern, then frequency is reusable. When the isolation level is above 30dB, the relation between allocated frequencies and beams is shown in Fig.4. In this system, 13 frequencies are needed.

B. Small size conformal-array antenna

In this LEO-SAT system, some tens satellites are needed. As the antenna size must be as small as possible, so a small size conformal-array antenna is proposed. Fig.5 shows the constitution of the conformal-array antenna fit into this LEO-SAT system. In this system, the number of users is assumed to be 9. The beam coverages of this conformal-array antenna are presented in Fig.6. The weight of this conformal-array is about 30% of the low sidelobe planar-array antenna. But the more frequencies are needed in this antenna than the low sidelobe planar-array antenna.

Ka-band Antenna

For a high bit rate users, the Ka-band(30.0/20.0 GHz) beams are used. In the present technology, due to the limitation of power consumptions and the efficiency of the high power amplifier or low noise amplifier, the expected maximum bit-rate of Ka-band is 15.5 Mbit/s. For this frequency band, a reflector antenna is proposed. The antenna configuration is presented in Fig.7.

The antennas mounted on the satellite is shown in Fig.8.

FUTURE MOBILE ANTENNA

Digital Beam Forming Technique

For a future mobile antenna technology, we show the digital beam forming (DBF) techniques[5]. The DBF can be applied to both L-band and Ka-band system. In this paper, the L-band DBF system is presented.

The basic block diagram of a digital beamformer for transmitting is shown in Fig.9, where digital PSK modulation is assumed. The configuration of the transmitting DBF antenna implemented by using multi-DSPs is shown in Fig.10.

The block diagram of a digital beamformer for receiving is shown in Fig.11, where digital PSK demodulation is assumed. The configuration of the receiving DBF antenna implemented by using multi-DSPs is shown in Fig.12.

Adaptive array antenna system

In a LEO-SAT system, the main beam should be directed to the direction of desired signal and nulls should be formed in the direction of interference signals. Then, the adaptive array antenna is useful as the mobile antenna. We propose a beam space CMA (BSCMA) adaptive array antenna. The constitution of the BSCMA is shown in Fig.13. In the BSCMA adaptive array, first, multiple beams are formed in the multibeam former, then the beams with receiving signals over a sufficient power are selected. The weights for these selected beams are optimized in an adaptive loop. The BSCMA is useful for a mobile satellite communication array antenna that consists of more than ten element antennas, because the number of interferences that need to be considered is smaller than the number of elements.

CONCLUSION

We have calculated the transmission parameters for mobile/satellite links in a mobile satellite communication system that offers not only narrow band service but also broad band service to users. Then, we have shown two types of satellite on-board phased array antennas for L-band fixed multibeam and we have also mentioned a reflector antenna for Ka-band steerable spot beam. Furthermore, we have discussed the digital beam forming and adaptive array for the mobile users antenna.

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Table 1 Features of the LEO-SAT system

Service Capability	Low-rate Channel (~64kbit/s) High-rate Channel (~15Mbit/s) Demand Assignment
Transmission Quality (BER)	1×10^{-7} (99% of the Year)
Minimum Elevation Angle	30°
User Type Small-class Large-class	 Car, Boat, Handheld Terminal, etc. Bus, Large Ship, Airplane, etc.
Satellite Orbit	Low Earth Orbit (765km in Height)
Number of Satellites	20/Orbit Plane x 10 Orbital Planes
Link Configurations -Mobile/Satellite Low-rate Channel High-rate Channel -Inter-satellite -Feeder Link	 L-band Fixed Multi-beam Ka-band Steerable Multi-spot Beam Optical Link TBD

Table 2 Mobile/satellite link budget (uplink)

Frequency	1.64GHz	30.0GHz
Transmission Rate	64kbps	15.0Mbps
Required Eb/No	7.5dB	7.5dB
Uplink C/No	55.6dB-Hz	89.4dB-Hz
EIRP of Mobile Antenna	0.0dBW	20.9dBW
Free-space Path Loss	159.3dB	184.5dB
Rain Degradation	0.0dB	5.3dB
Boltzman Coefficient	-228.6BW/K-Hz	-228.6dBW/K-Hz
Satellite G/T	-13.7dB/K	19.6dB/K

Table 3 Mobile/satellite link budget (downlink)

Frequency	1.54GHz	20.0GHz
Transmission Rate	64kbps	15Mbps
Required Eb/No	7.5dB	7.5dB
Downlink C/No	55.6dB-Hz	89.4dB-Hz
G/T of Mobile Antenna	-26.5 dB/K	-8.5dB/K
Free-space Path Loss	158.7dB	181.0dB
Rain Degradation	0.0dB	2.8dB
Boltzman Coefficient	-228.6dBW/K-Hz	-228.6dBW/K-Hz
Satellite EIRP/ch	12.2dBW	43.0dBW

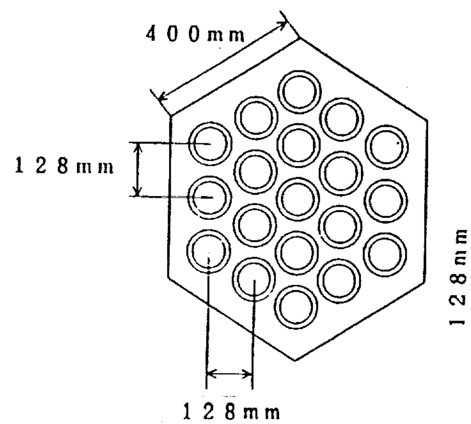


Figure1. Constitution of the low sidelobe planar-array antenna (Circular aperture array).

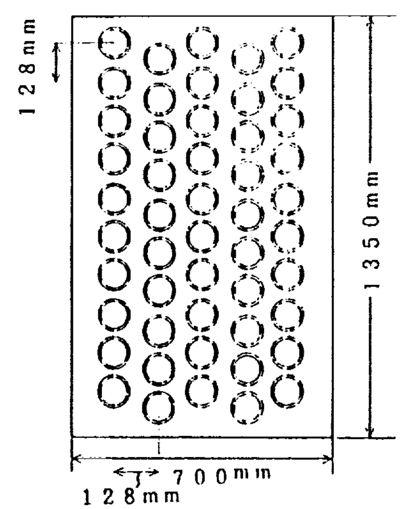


Figure2. Constitution of the low sidelobe planar-array antenna (rectangular aperture array).

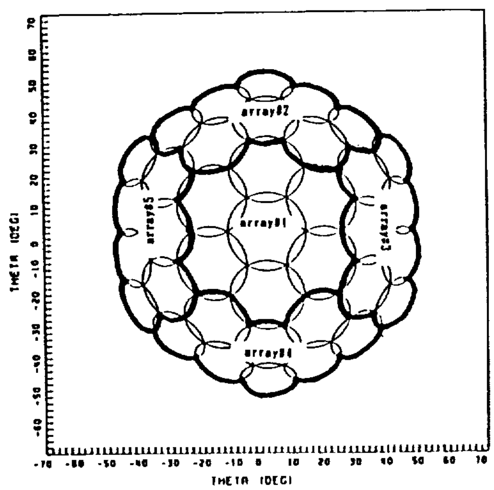


Figure3. Beam coverage of the low sidelobe planar array antenna.

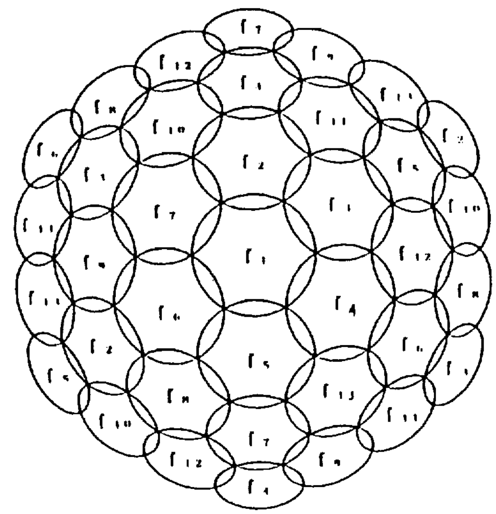


Figure4. The relation between frequencies and beams.

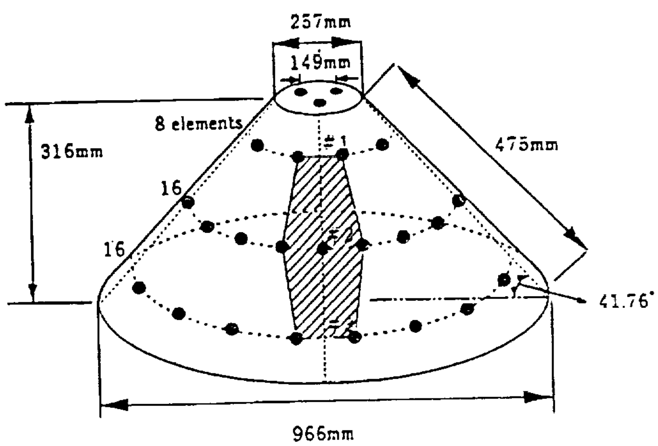


Figure5. Constitution of the small size conformal array antenna.

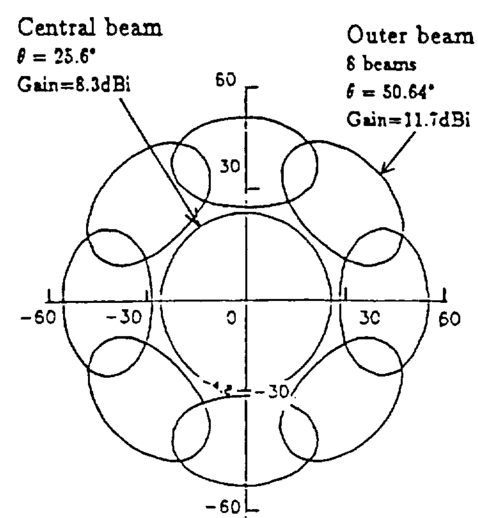
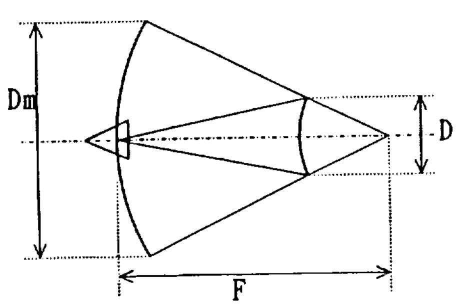


Figure6. Beam coverage of the conformal array antenna.



Cassegrain antenna

Dm = 1200 mm
F = 720 mm
Ds = 288 mm

Figure7. Constitution of the Ka-band antenna.

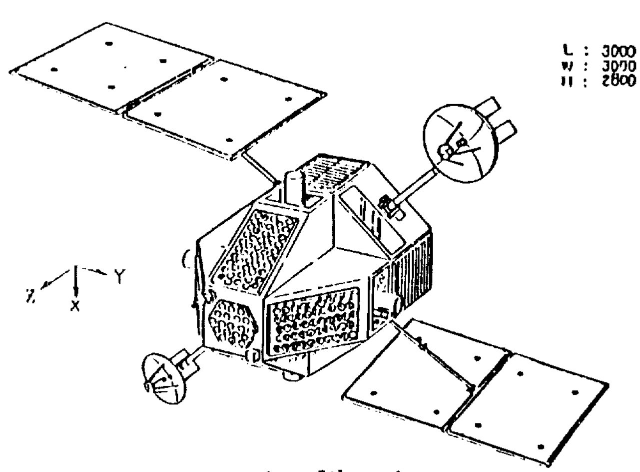


Figure8. Configuration of the antennas mounted on the LEO-SAT.

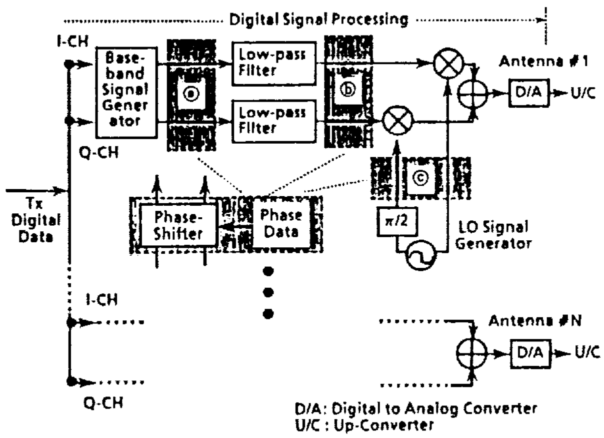


Figure9. Basic block diagram of a transmitting DBF processor.

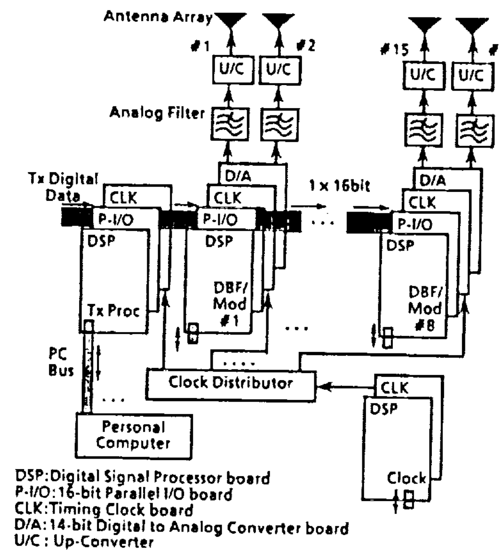


Figure10. Configuration of a transmitting DBF antenna.

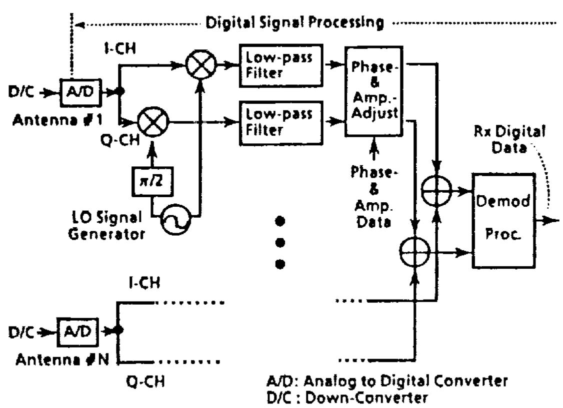


Figure11. Block diagram of a receiving DBF processor.

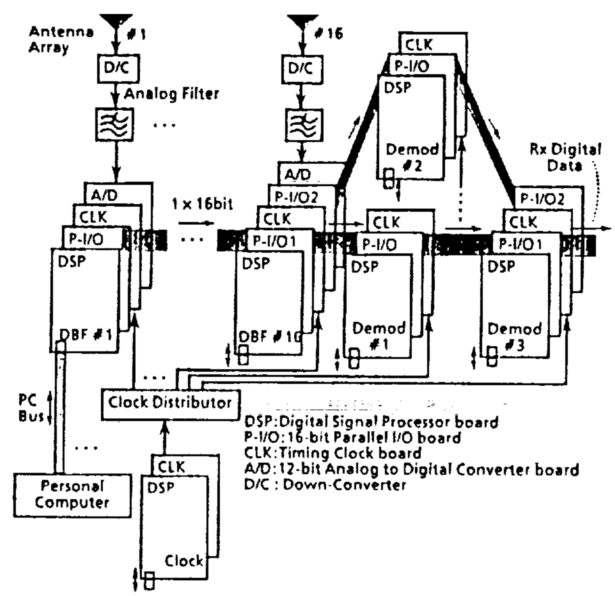


Figure12. Configuration of a receiving DBF antenna.

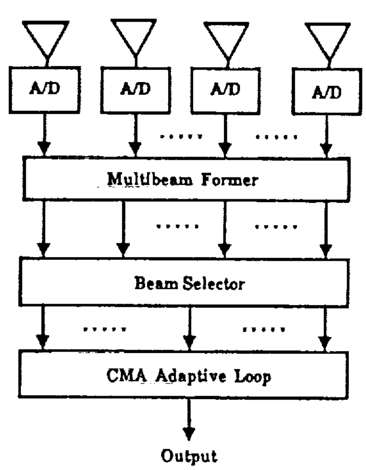


Figure13. Consitution of the BSCMA.