4-5 Land Mobile Station for ETS-VIII Mobile Satellite Communications Experiments

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This paper describes the Land Mobile Station (LMS) developed for the mobile satellite communications experiments on the Engineering Test Satellite VIII (ETS-VIII). The LMS has a communications system consisting of terminal equipment, an up-converter (U/C) and a down-converter (D/C). These convert the signal frequency between 140 MHz and S-band (2.6/ 2.5 GHz). It also has a 50-W solid state power amplifier (SSPA) and a low noise amplifier (LNA). An antenna rotator capable of azimuth and elevation rotation and covered with a radome is installed on the LMS roof-top. An open-loop antenna tracking control by using the LMS attitude and a satellite direction is available. An S-band active phased array antenna and an S-band stairs type antenna were developed as the mobile antenna. This is a key component of the mobile terminal. The S-band active phased array antenna uses electronic beam-scanning to transmit and receive functions. It can track the satellite by using closed-loop control. The S-band stairs type antenna is a fixed-beam array antenna. This can track the satellite by using mechanical tracking in the azimuth direction. The antenna gain of these antennas is about 12 dBi. A gas-turbine generator supplies power to the equipment onboard the LMS. The LMS during the phase after the initial checkout of the satellite after launch will be dedicated to the mobile satellite communications experiments and the evaluation of the mobile antenna using the ETS-VIII.

Keywords
ETS-VIII, S-band, Land mobile station, Mobile satellite communications, Antenna tracking system, Mobile antenna

1 Introduction

The Engineering Test Satellite VIII (ETS-VIII) scheduled for launch in 2004 is being developed for the evaluation of mobile satellite communications and broadcast technologies in the S-band [1]. Planned experiments under the ETS-VIII project include those to evaluate personal mobile satellite communications technologies using large deployable antennas on board the satellite. To perform these experiments, the CRL has prepared a number of land mobile stations. The main focus of this paper concerns the configurations and the functions of the communications system, the antenna tracking system, and the developed antennas for the land mobile stations.

2 Equipment for the land mobile station

2.1 Overall system

Fig.1 shows the appearance of the land mobile station (LMS). An antenna positioner [two axes: azimuth (AZ) and elevation (EL)] is installed at the front of the roof carrier. (The figure shows an LMS mounted with an S-band stair-type antenna. The radome has been removed.). Fig.2 shows the configuration of the LMS. Terminal equipment with an interface frequency of 140 MHz may be mounted. The frequency conversion unit features an up converter (U/C) that converts the 140-MHz signals into the S-band (2.6-GHz band) and a down converter (D/C) that converts the S-band signals (2.5-GHz band) to 140 MHz. Table 1 shows the specifications of the frequency conversion unit. Figs.3 and 4 show level diagrams of the U/C and the D/C, respectively. The LMS also has a 50-W solid-state power amplifier (SSPA) and a low-noise amplifier (LNA) with a noise figure (NF) of 0.4 dB or less.

A directional mobile antenna requires antenna tracking control to locate the satellite. This LMS thus features an appropriate antenna tracking system. As shown in Fig.1, the system includes an antenna positioner (two axes: AZ and EL) and a semi-spherical

Fig.1 Appearance of the land mobile station (LMS). An S-band stair-type antenna is mounted on the antenna positioner. The radome has been removed.

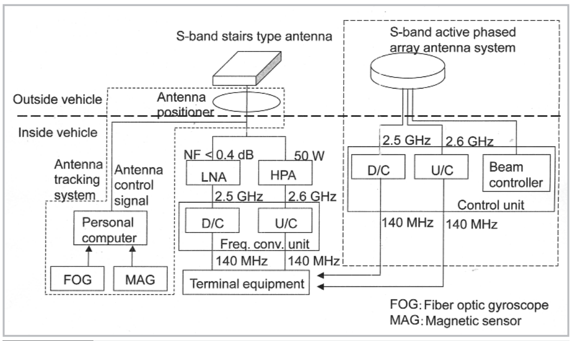

Fig.2 Schematic diagram of the LMS

Table 1 Specifications of the up converter (U/C) and the down converter (D/C)

U/C unit	
IF IN	140 MHz±2.5 MHz, -10 dBm
RF OUT	2657.5 MHz±2.5 MHz, 0 dBm
Pass band ripple	< 1 dBp-p
BPF Isolation	> 50 dB
IM3	- 63 dBc (Two signal input: -10 dBm @ 1390 MHz, 141 MHz)
Output spurious	< -70 dBm
Phase noise	IN: 140 MHz, OUT: 2657.5 MHz, 300 Hz: -88 dBc/Hz
D/C unit	
RF IN	2502.5 MHz±2.5 MHz, -30 dBm
IF OUT	140 MHz±2.5 MHz, 0dBm
Noise figure	14 dB
Pass band ripple	< 1 dBp-p
LPF Isolation	> 50 dB
IM3	-64 dBc (Two signal input: -30 dBm @2501.5 MHz, 2503.5 MHz)
Output spurious	< -70 dBm
Phase noise	IN: 2502.5 MHz, OUT: 140 MHz, 300 Hz: -72.5 dBc/Hz
Ref. signal	10 MHz, 0 dBm
Unit size	W420 x D300 x H150 [mm]
Unit Weight	13.2 kg
Source voltage	AC 100 V
Power consumption	66 VA

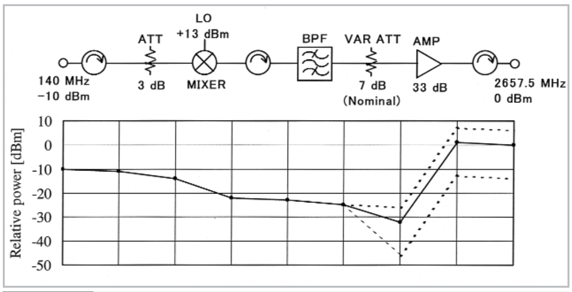

Fig.3 Level diagram of the U/C

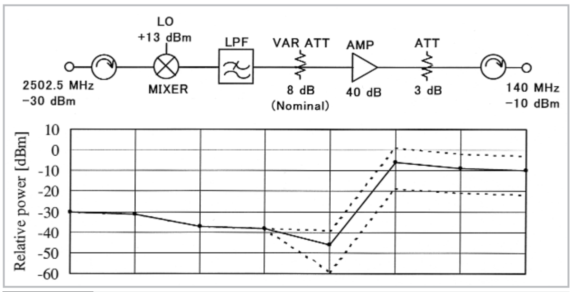

Fig.4 Level diagram of the D/C

radome to cover it; the entire apparatus is mounted on the roof carrier of the LMS. The speed of rotation is 30° per second at maximum for both the AZ and EL axes. For the interface with the car interior, the RF signals employ a rotary joint with a pass band of DC–50 GHz; a slip ring is used for the control signals. The automatic antenna tracking control method employed by the LMS is based on the open loop method, using information on vehicle attitude and satellite position. Specifically, this mobile satellite communications system, developed by the CRL, applies information supplied both by the fiber optic gyroscope (FOG) and by the magnetic sensor (MAG) to determine vehicle attitude [2] [3]. Table 2 shows the specifications of the antenna tracking system.

In addition to the antenna equipped with mechanical tracking, the LMS will incorporate an electronic beam scan S-band active phased array antenna (described in more detail in 2.2.1). This antenna system is connected to the terminal equipment at the 140-MHz terminals of the U/C and the D/C in the control unit, as shown in Fig.2. Further, in addition to the communication equipment described above, the LMS will also include specific communication equipment developed for the onboard processor (OBP) [4].

Power is supplied to the LMS from a gas-turbine generator (with an output power of 2.6 kVA).

Table 2 Specifications of the antenna tracking system

Antenna positioner	Two-axes mechanical pensioner (AZ and EL)
Operating angle range	AZ: 0 – 359.9 deg. EL: ±62.5 deg @ the zenith direction
Angular resolution	0.1 deg.
Rotation speed (MAX)	AZ: 30 deg./sec, EL: 30 deg./sec
Angle accuracy	AZ: ±0.1 deg., EL: ±0.1 deg.
RF cable	Rotary joint method
DC source supply	Slip ring method
Tracking control method	Open loop method, using information on vehicle attitude and satellite position

2.2 Mobile antennas

Mobile antenna technology is one of the key technologies underlying the development of mobile satellite communications systems. The CRL has developed mobile antennas for mobile satellite communications systems in connection with LMSs, airplanes, and helicopters [5]-[8]. As a part of the mobile communications experiment of the ETS-VIII project, the CRL is developing mobile-station antennas capable of communications at transmission rates of approximately 1 Mbps between the mobile station and the feeder-link station. The S-band active phased array antenna [9], an electronic beam scan antenna with a closed-loop tracking function, can be used both to transmit and receive signals. The S-band stair-type antenna [10], a fixed-beam antenna consisting of a low-profile stair-shaped array antenna, can also be used both to transmit and receive signals. It locates the satellite via mechanical tracking in the azimuth direction only. The antenna gain value for each of these antennas is approximately 12 dBi.

2.2.1 S-band active phased array antenna [9]

In the S-band active phased array antenna, the amplifiers are placed directly below the antenna elements. In contrast to a passive phased array antenna, in which the amplifiers are situated at the input terminal of the combiner, the active phased array antenna can reduce the power distribution per amplifier under constant power, thus providing greater power efficiency. Since G/T is determined mostly by three factors—gain, loss, and noise temperature (from LNA to antenna element), the active phased array antenna, in which LNA is situated directly after the antenna element, can realize a high G/T.

Fig.5 shows the appearance of this antenna system, Fig.6 shows the relevant block diagrams, and Table 3 shows the electrical performance specifications. This antenna system consists of an antenna mounted outside the vehicle and a control unit stored inside the vehicle. The antenna is an 18-element self-diplexing antenna with integrated transmission and reception functions. The isolation between the transmit and the receive antenna element is 20 dB or greater. The transmission frequency is 2655.5–2658.0 MHz, and the receiving frequency is 2500.5–2503.0 MHz. The beam scan range for the elevation angle is from 45 to 90 degrees with the direction of the antenna face defined as 90 degrees. The beam scan range for the azimuth angle is 360 degrees. The design values for antenna gain are 12 dBi or greater for both transmission and reception within the range of the beam scan. The measured values are 12.3 dBi for the transmitting antenna and 14.5 dBi for the receiving antenna at an elevation angle of 45 degrees. Based on a link design calculated to realize a transmission rate of 1 Mbps, the design value for the equivalent isotropically radiated power (EIRP) is set to 25.01 dBW or greater and that for the G/T is set to −14 dB/K. Measured values reflect these design values.

This antenna system employs an analog phase shifter with a double-balanced mixer [11]. This phase shifter can independently set the phase and the amplitude of the input RF signals by applying a control voltage.

A personal computer connected to the control unit controls and monitors the status of the antenna system. The control unit controls automatic tracking based on the closed loop method using the receiving antenna. Two methods of automatic tracking are prepared for comparative evaluation: rough tracking, which uses a summed signal, and fine tracking, which uses a difference signal. The speed of tracking is 30℃ per second or more in the azimuth angle direction, the initial acquisition time upon system startup is one second or less, and the re-acquisition time after loss of the reception radio signal (e.g., due to blocking) is one second or less. Here, the tracking of the transmitting antenna follows that of the receiving antenna. To prevent radiation in directions other than toward the satellite, the transmitting antenna operates only when the receiving antenna locates the satellite. This antenna system can also perform automatic tracking based on the open-loop method using the information on azimuth and elevation angles calculated by the LMS antenna tracking system.

Table 4 shows the physical specifications of the antenna system. The antenna unit is 440 mm in diameter and 117 mm in height. It weighs 18.7 kg. The unit is waterproof and is mounted on a roof carrier attached to the experimental vehicle. A finned heatsink is attached to the side of the antenna unit. The antenna unit connects to the control unit inside the vehicle via the following cables: three RF signal cables (one each for the transmission signal, the reception summed signal, and the reception difference signal), two control signal cables (one for transmission and one for reception), and DC power supply cables. The control unit is designed to fit within the 19-inch rack. This antenna unit operates at AC 100 V, with a power consumption of approximately 354 W.

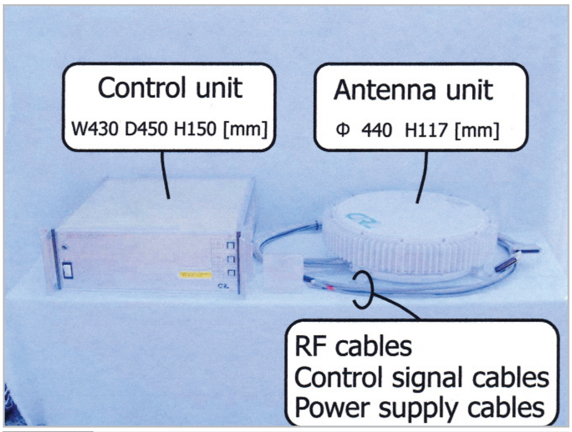

Fig.5 Appearance of the S-band active phased array antenna

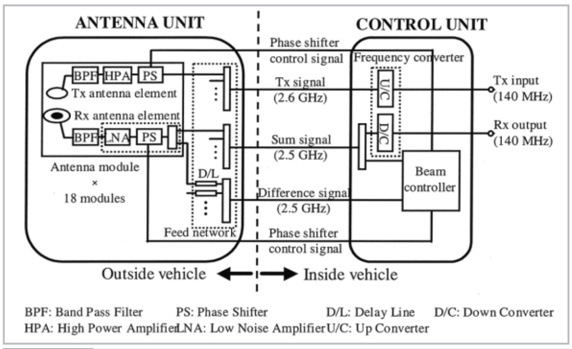

Fig.6 Block diagram of the S-band active phased array antenna

The SSPA transmission power of this antenna is approximately 20 W. In accordance with the Telecommunications Technology Council's reported safety requirements applicable to the transmission of radio waves, the antenna must be placed at least approximately 3 m from the human body when transmitting. [A power flux density of 1 mW/cm2, the guideline safety value for radio-wave radiation at 1.5–300 GHz, is applied toward the antenna face (with an antenna gain value of 17.6 dB), providing maximum power flux density.]

Table 3 *Electrical performance specifications of the S-band active phased array antenna*

Frequency	Tx: 2655.5 – 2658.0 MHz Rx: 2500.5 – 2503.0 MHz
Polarization	LHCP for both Tx and Rx
Beam scan range	AZ: 0 – 360 deg. EL: 45 – 90 deg.
Gain	> 12 dBi (Desired value*) Tx: 12.3 dBi (Measured value**) Rx: 14.5 dBi (Measured value**)
Beamwidth	Tx: 30 deg., Rx: 28 deg. (Measured value**)
Axial ratio	Tx: 1.5 dB (Measured value**) Rx: < 0.5 dB (Measured value**)
G/T	> -14 dB/K (Desired value*) -12.3 dB/K (Measured value**)
EIRP	> 25.01 dBW (Desired value*) 26.3 dBW (Measured value**)

*: Desired value within beam scan range
**: Measured value at EL = 45 deg.

Table 4 *Physical specifications of the S-band active phased array antenna*

Antenna unit	
Radiating element	Two-layer Self-diplexing antenna Upper layer: circular patch (Tx) Lower layer: ring patch (Rx)
Number of elements	18
Element allocation	Triangular
Element spacing	72 mm (0.64λ for Tx, Rx: 0.6λ for Rx)
HPA	20 W for eighteen elements
LNA	HEMT (NF: 0.94 dB)
Phase shifter	Endless phase shifter (double balanced mixer type)
Unit size	φ440 x H117 (mm) (including radome)
Unit weight	18.7 kg
Control unit	
Unit size	W430 x D450 x H150 (mm)
Unit weight	15.0 kg
Power consumption	354 W with AC 100 V

This antenna system features a frequency converter unit for transmission (U/C) and a frequency converter unit for reception (D/C) in the control unit at an inter-frequency (IF) of 140 MHz to provide an interface with the terminal equipment. The maximum allowable IF input level for the U/C is −20 dBm. (At this value, the SSPA operates in the nonlinear region and the EIRP is 26.3 W.) If the input level exceeds this value, the SSPA will overload and may be damaged. The standard IF output level for the D/C is −10 dBm (when the receiving power at the antenna feed point is −124 dBW).

2.2.2 S-band stair-type antenna [10]

We have developed a small, lightweight, low-profile S-band stair-type antenna as one of the antennas designed for use with the LMS in mobile satellite communications. This antenna is highly wind-resistant and is easy to mount on the LMS. Fig.7 shows the appearance of the S-band stair-type antenna. The antenna consists of 16 elements in a 4×4 array with the antenna elements arranged in sequential manner. The two front rows constitute the transmitting antenna and the rear two rows constitute the receiving antenna. Each element is tilted 48° according to the elevation angle of the ETS-VIII at Tokyo. The phases of both the foremost row for transmission and the rearmost row for reception are adjusted for co-phase feeding in the direction of the satel-

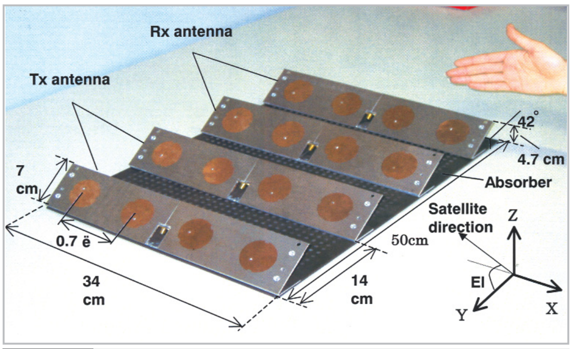

Fig.7 *Appearance of the S-band stair-type antenna*

lite. The aluminum ground plane is covered with a 3-mm-thick radio-wave absorber to improve the axial ratio. The antenna is 50 cm long, 34 cm wide, and 5 cm high.

Mechanical tracking of the satellite is assumed for the azimuth angle. The tracking of the elevation angle is omitted. (The tracking errors due to the vibration of the vehicle are absorbed by expanding the radiation pattern in the direction of the elevation angle.) The design value for gain within the elevation angle (EL = 48°) ± 10° is 12 dBi or greater, the same value applicable to the S-band active phased array antenna discussed in 2.2.1. Figs.8 and 9 show the radiation patterns for transmission and reception, respectively. The obtained transmitting antenna gain in the direction of the satellite (EL = 48°) ± 10° is 12.6 dBi or greater, and the obtained receiving antenna gain is 12.0 dBi or greater. The axial ratio is suppressed at 1 dB or less. The isolation between transmission and reception is 40 dB or greater between a transmission frequency of 2.6575 GHz and a reception frequency of 2.5025 GHz. Table 5 shows the specifications of the S-band stair-type antenna.

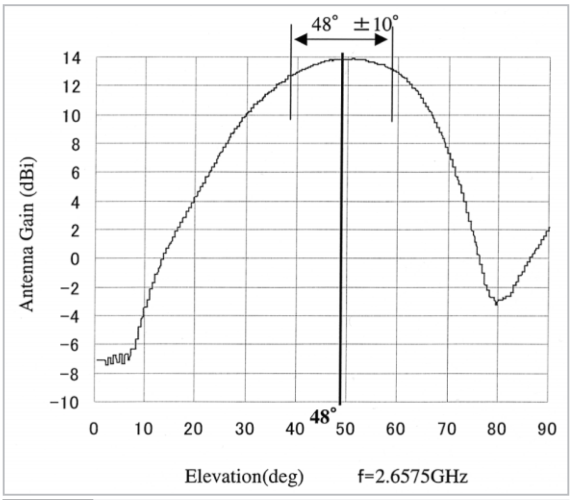

Fig.8 Transmission pattern of the S-band stair-type antenna

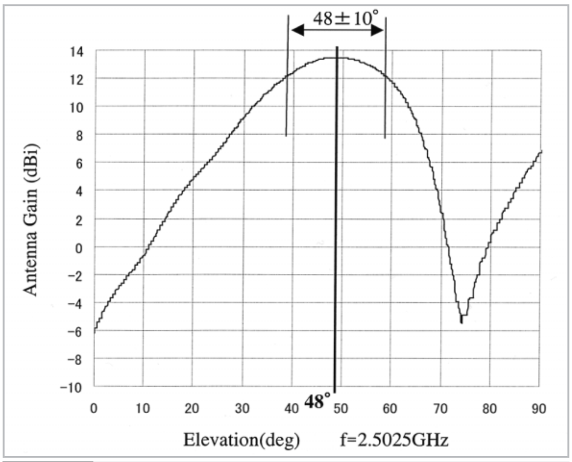

Fig.9 Receiving pattern of the S-band stair-type antenna

Table 5 Specifications of the S-band stair-type antenna

Frequency	Tx: 2655.5 – 2658.0 MHz Rx: 2500.5 – 2503.0 MHz
Polarization	LHCP for both Tx and Rx
Gain	Tx: > 12.6 dBi, Rx: >12.0 dBi (within EL = 48 deg.±10deg.)
Elements spacing	84 mm (Tx: 0.74λ, Rx: 0.7λ)
Feed loss	< 1.0 dB
Antenna element	Circular patch,
Antenna type	The antenna consists of 4 rows of sequentially rotated 1 x 4 element arrays
Antenna size	W340 x D500 x H50 (mm)
Weight	< 4.0 kg

3 Summary

We have presented an outline of a land mobile station (LMS) for use in ETS-VIII mobile satellite communications experiments. During the basic experimental phase following initial post-launch satellite verification, the LMS will be used for various types of mobile satellite communications experiments and for overall evaluation of the mobile antenna in conjunction with the ETS-VIII.

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