Realization of Simple Antenna System for ETS-VIII Mobile Satellite Communications

Basari#1, M. Fauzan Edy Purnomo#2, Kazuyuki Saito#3, Masaharu Takahashi#3, Koichi Ito#1

#1 Graduate School of Engineering, Chiba University #2 Graduate School of Science & Technology, Chiba University
#3 Research Center for Frontier Medical Engineering, Chiba University
1-33, Yayoi-cho, Inage-ku, Chiba-shi, Chiba, 263-8522 JAPAN
[1]basari@graduate.chiba-u.jp

***Abstract*— This paper presents a simple antenna system for land vehicle communication aimed at Engineering Test Satellite-VIII (ETS-VIII) applications. The developed antenna system which mounted into a vehicle is compact, light weight and simple satellite-tracking operation. Owing to low profile, a patch array antenna, which includes onboard-power divider and switching circuit for antenna feeding control, is applied at such system. A Global Positioning System (GPS) receiver is constructed to provide accurate information on the vehicle's position and bearing during travelling. The personal computer (PC) interfaces as the control unit and data acquisition, which specifically designed for this application, allow the antenna beam-switching control as well as the retrieving of the received power levels. Measured results of the received power levels as well as the bit error rate performance for satellite-tracking are discussed.**

I. Introduction

The Japan Aerospace Exploration Agency (JAXA) has launched satellite mission technologies called ETS-VIII in 2006. The ETS-VIII was conducted for various experiments in Japan and surrounding areas to verify mobile satellite communications functions [1]. Moreover, this satellite communications system will help rescue efforts in disaster areas by allowing us to collect information more promptly, especially if ground communications facilities are damaged or in areas without advanced communications infrastructure.

This paper provides a simple antenna system for land mobile satellite communications particularly aimed at ETS-VIII applications. Most of the recent developed antenna systems are huge, complex and weighty, either by use of electrical motors [2]-[3] or use phase shifters and feeding circuit controller to electrically deflect the beam [4]-[5]. Therefore, to minimize the bulky system, an active integrated patch array antenna was developed without phase shifter circuit, to realize a light and low profile antenna system with more in reliability and high-speed beam scanning possibility. The antenna system was built by an aforementioned antenna which its beam tracking characteristics was determined by the control unit as the vehicle's bearing from a navigation system (gyroscope or GPS receiver) was updated in real time. In this research, the antenna system was evaluated at the anechoic chamber for some basic measurements and beam-tracking. Yet, the outdoor measurement using ETS-VIII satellite was performed on a fixed testing-rig without any obstacles present. Furthermore, the antenna system was mounted on the vehicle and the received power levels as well as bit error rate (BER) for satellite-tracking were tested. Their results are discussed in this paper.

TABLE I
SPECIFICATIONS AND TARGETS OF THE ANTENNA

Specifications		
Frequency bands	Transmission	2655.5 to 2658.0 MHz
	Reception	2500.5 to 2503.0 MHz
Polarization	Left-handed circular polarization for both transmission and reception	
Targets		
Elevation angle *(El)*		48^o (Tokyo)
Azimuth angle *(Az)*		0^o to 360^o
Minimum gain		5 dBic
Maximum axial ratio		3 dB

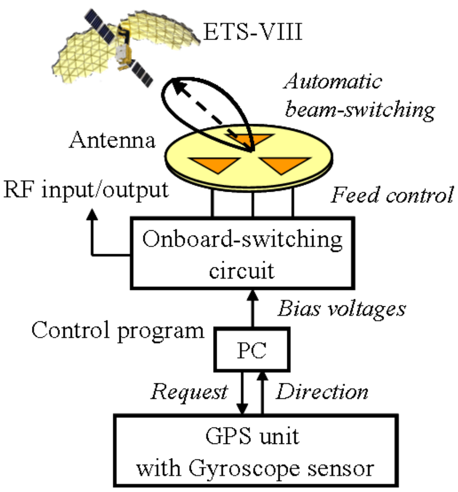

Fig. 1 Antenna system architecture aimed at land mobile satellite applications

II. Antenna System Description

A. Specifications and targets

The specifications and targets of the antenna are shown in Table I. The ETS-VIII was conducted at orbital experiments on mobile satellite communications and high-speed packets communications, providing voice/data communications with satellite mobile terminals in the S-band frequency. As this antenna was assumed to be used in Tokyo and its vicinity, the targeted elevation angle was set to 48º because it was the elevation angle of the geostationary satellite seen from the center of this city. In our system, the antenna beam was expected to be steered towards the satellite and cover the whole azimuth space by more than 5 dBic and less than 3 dB for the gain and the axial ratio, respectively.

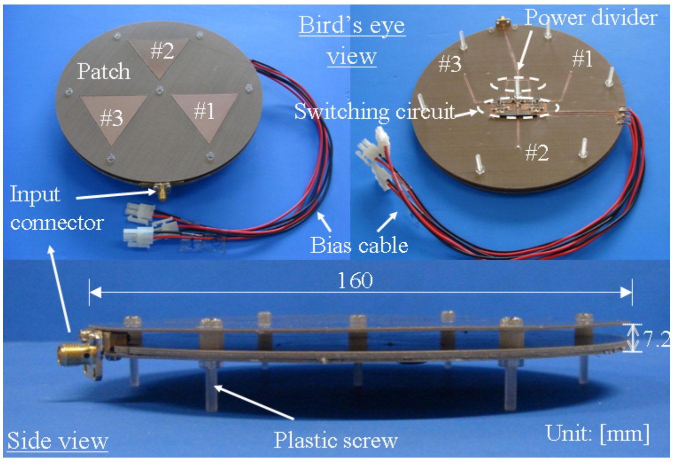

Fig. 2 Fabricated patch array antenna

B. *Antenna System Architecture*

In order for the beam-steering capability, the array antenna configuration was 120º sequentially physical rotated and set with an equal distance between each element following a circular path. With such alignment, in case each element was fed in-phase, by sequentially rotating them, their relative phase was physically shifted. Such a sequential rotation ensures the generation of circular polarization. As a result, a beam was generated in the elevation direction with the direction of the created beam being shifted in the azimuth plane by -90º from the element that was turned off. By successively turning off the feeding source of each antenna element, the whole azimuth range can be scanned by step of 120º. For example, when turning off element no. 1 located in Az = 90º, a beam is created in the azimuth direction Az = 0º. Similarly, if element no. 2 and no. 3 are turned off, the beam is generated in the direction Az = 120º, 240º.

Satellite-tracking system was created to provide a beam-steering capability for the array antenna. A designed tracking-algorithm for beam-steering of the array antenna is depicted in Fig. 1. The antenna system works associated with the control unit, hence the tracking-algorithm is expected allowing the antenna beam automatically steered. The tracking-algorithm was simply developed regardless the signal of satellite.

As for beam-forming of array antenna, the personal computer provides three bias voltages to switch on and off the P-I-N diodes of the circuit (switching circuit in Fig.2) and thus two elements of the array are correctly fed and specified beam is created. For automatic beam switching, by considering the orientation of the vehicle, a control program on a PC decides a correctly-generated beam among three selectable-beams. As the satellite lies at southern from Japan area, the beam was invariably controlled at the south direction.

C. *Array Antenna Design*

Structure of the developed array antenna is pictured in Fig.2. The array antenna was composed of three pentagonal patch antennas which excited directly from the feeding network on the beneath of the construction. In the top of the construction was put three isosceles triangular patches as parasitic elements to enhance bandwidth of the antenna. In order to match with 50Ω input feed, air gap was inserted at the area between the fed elements and the parasitic elements. The design makes possible the excitation of two near-degenerate orthogonal modes of equal amplitudes and 90° phase difference for left-handed circular polarization (LHCP) operation. Good axial ratio performance can be obtained by adjusting the feeding point, air gap height, and parasitic element dimension. Due to the satellite problem, this time, we developed and tested for reception only, however we also developed for transmission element which can be arranged by specified interval on the same layer for compactness. In order to make compactness and to minimize feeding losses, a power divider and a switching circuit embedded on the array antenna, which was mounted on the backside of the antenna.

III. Measurement Results

Having designed and manufactured the components of the system, we thoroughly tested each one before it was incorporated into the overall design. The first testing performed involved the array antenna. As for basic performance of the array antenna the measurement was tested at the anechoic chamber. It involved S parameter, axial ratio and radiation pattern measurements. The measured results of the antenna were reported in [6] which was satisfied the requirements. Once all the required components of the system were developed and individually examined, testing of the completed array antenna was performed in the anechoic chamber. The beam of the antenna was generated by a mechanism that consists of switching off one of the radiating elements. Having performed a manual beam measurement, an automatic-tracking was decided so thus the gain can be switched automatically at the specified azimuth angles and the axial ratio for each beam satisfied below 3 dB as expected to cover 360º of conical-plane.

Since the antenna system would be tested on car roof, thus the array antenna was covered by a radome and mounted on a ground plate to surely make the antenna tightly installed. With this configuration environment hindrance like wind, rain, and snow could be reduced. It was reported that the characteristics of antenna did not change drastically when the radome and ground plate were employed [7].

A. *Outdoor Measurement on the Testing-Rig*

The antenna system was also examined in the outdoor measurement using ETS-VIII satellite as depicted in Fig.4. The antenna system was tested in Chiba area (El = 48º) at the rooftop of building for considering unobstructed-area to receive the satellite signal. In this measurement, a spectrum analyzer (Agilent E4403B) was used to measure the received power signal from the satellite signal. In order to compensate the weak satellite signal, an amplifier (Agilent 83017A) was associated with the array antenna and thus the signal level could be increased to achieve an enough C/N_0. Measured result showed that C/N_0 was 47.30 dBHz with link margin 1.45 dB where sufficiently to make the satellite-tracking measurement.

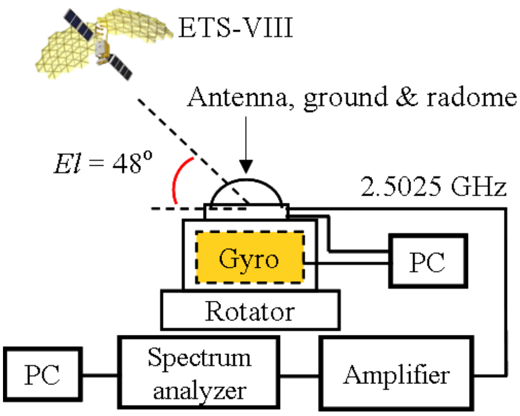

Fig.3 Outdoor measurement configuration on a testing-rig

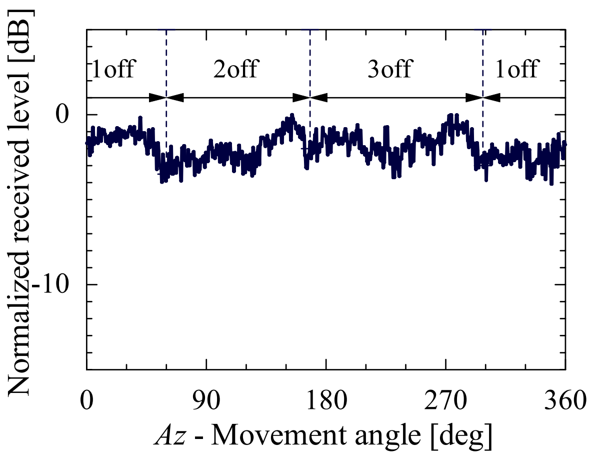

Fig.4 Received power levels of satellite-tracking on a testing-rig

B. Land Vehicle Outdoor Measurement

Table II shows the link budget for land vehicle aimed at ETS-VIII application. The link budget was made according to the report [8] that the Large Deployable Reflector (LDR) antenna of ETS-VIII satellite could not be used due to improper situation at Power Supply of Linear Noise Amplifier (PS-LNA). For that reason, the present experiment was performed by using High Accuracy Clock (HAC) receiving antenna with gain 25 dBi instead of 43.80 dBi of LDR antenna.

In this link budget, the system was built for forward link from the transmission (earth fixed-station) to the reception (land mobile) through the ETS-VIII satellite. In the same manner, the return link could be calculated in the same results. As a result of the link budget, the targeted antenna gain for 8 kbps of data transmission rate should be more than 5 dBic. Additionally, the link was inserted loss in the reception due to the feeding and tracking loss by 1.7 dB and 3 dB, respectively. The switching circuit and power divider circuit were attached on the antenna to control each feeding part of the antenna, thus the circuit loss was considered less than 1 dB. With the total C/N_0 47.64 dBHz and required C/N_0 45.83 dBHz, communication between transmitter and receiver through the ETS-VIII satellite can be established with margin 1.81 dB. This time, we performed the outdoor measurement without correction-code transmission, thus the margin was decreased to be 0.31 dB. However, the quality of communication channel at the reception (land mobile) was sufficiently designed at 64.77 dBHz.

TABLE II
LINK BUDGET OF THE LAND VEHICLE EXPERIMENT

Link Parameter	Earth Fixed-Station →Land mobile	
Up Link		
Up link frequency (GHz)	Earth Fixed-Station	2.6575
Tx power (Watt)		1.00
EIRP (dBW)		20.90
Received level/total (dBW)		-172.48
Satellite Rx Antenna gain (dBi)	ETS-VIII Satellite	25.00
Satellite G/T		-8.40
Signal power/total (dBW)		-150.08
C/No up link (dBHz)		47.72
Down Link		
Down link frequency (GHz)	ETS-VIII Satellite	2.5025
Tx power (Watt)		40.00
EIRP (dBW)		55.02
Received level (dBm)		-137.91
Antenna gain	Land Mobile	5.00
Land mobile G/T		-22.92
Signal power (dBW)		-137.61
C/No down link (dBHz)		64.77
Calculation Results		
C/No total (dBHz)		47.64
Bit rate (kbps)		8.0
Eb/No (dB)		8.60
Coding gain		1.50
Threshold (BER = 1.0E-4) Eb/No (dB)		8.30
C/No required (dBHz)		45.83
Margin (dB); uncoded		0.31
Margin (dB); coded		1.81

Fig.5 Photograph of outdoor measurement circumstance

In this measurement, we measured the received power level of the array antenna at some different areas for direct wave area and obstructed areas like buildings, towers and foliages. The received power level was measured from intermediate frequency (IF) output from handset terminal. The measurement circumstance is described in Fig. 5. The land vehicle measurement was mainly tested to evaluate the satellite-tracking of antenna system. The result is shown in Fig. 6. While the vehicle was travelling the beam of the antenna electronically steered pursuing the ETS-VIII satellite associated with vehicle's orientation. Three antenna beams were smoothly switched to the satellite for each beam-coverage in the azimuth direction. Additionally, measured results of the received signals showed that C/N_0 was averaged by 47.70 dBHz and thus the link margin achieved 1.87 dB.

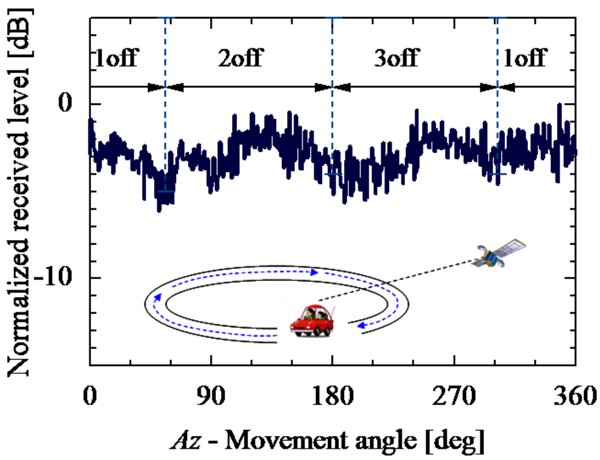

Fig. 6 Received signal levels of satellite-tracking

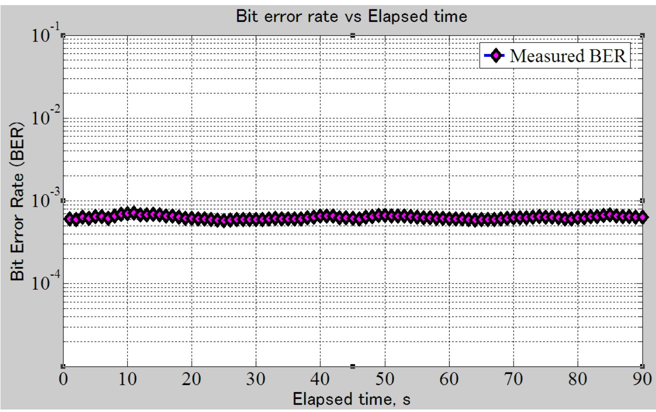

Fig. 7 Bit error rate performance of satellite-tracking

Additionally, bit error rate (BER) measurement was performed during satellite-tracking as shown in Fig. 7. In this case, we transmitted a pseudorandom noise sequence (PN sequence) onto binary phase shift keying (BPSK) modulation. By use of a data transmission analyzer (Anritsu MD6420A) at the receiver, the BER performance could be obtained. As a result, it can be stated that BER performance was kept stable in range 6 to 7 x 10^{-4} yet the beam-switching was happened.

IV. CONCLUSIONS

Realization of simple antenna system for land mobile satellite applications has been experimentally tested, was presented. Antenna system components discussed include the array antenna integrated by a switching circuit and a satellite-tracking system, which mounted into vehicle. Following the antenna system measurement in anechoic chamber, which satisfactory performances have been recorded, and antenna system has been examined on testing-rig using signal from ETS-VIII satellite for immobile-state. Without any obstacles present, the system was able to correctly track the satellite by considering the orientation of rotation of the antenna.

Furthermore, we tested the antenna system in outdoor environment for land vehicle measurement. Unobstructed-area measurement was performed to grasp the satellite-tracking performances. As a result, the satellite-tracking performed well with good received signal, was confirmed. Moreover, the measured bit error rate was satisfied within 10^{-4} level for 8 kbps as the targeted design.

ACKNOWLEDGMENT

This work was supported in part by the Strategic Information and Communications R&D Promotion Programme (SCOPE) for Grant-in-Aid for Scientific Research (Project no.061203004). The authors wish to thank to the National Institute of Information and Communication Technology (NICT) and the Japan Aerospace Exploration Agency (JAXA) for Research Collaboration.

REFERENCES

[1] JAXA Homepage, "Engineering Test Satellite (ETS-VIII)," http://www.jaxa.jp/projects/sat/ets8/index_e.html.

[2] J. Huang and A.C. Densmore, "Microstrip yagi array antenna for mobile satellite vehicle application," *IEEE Trans. on Antennas and Prop.*, vol. 39, pp. 1024-1030, Jul. 1991.

[3] P.C. Strickland, "Planar arrays for MSAT and INMARSAT land mobile satellite communications," *Proc. of IEEE Antennas and Propagation Society International Symposium*, Newport Beach, CA, USA, vol. 3, pp.1388-1391, Jun. 1995.

[4] S. Ohmori, K. Tanaka, S. Yamamoto, M. Matsunaga, and M. Tsuchiya, "A phased array tracking antenna for vehicles," *Tech. Rep. IEICE*, AP 90-75, SANE 90-41, pp. 33-40, Oct. 1990. (in Japanese).

[5] J.I. Alonso, J.M. Blas, L.E. Garcia, J. Ramos, J. de Pablos, J. Grajal, G.G. Gentili, J. Gismero, and F. Perez, "Low cost electronically steered antenna and receiver system for mobile satellite communications," *IEEE Trans. on Microwave Theory and Techniques*, vol. 44, pp. 2438-2449, Dec. 1996.

[6] Basari, M. Fauzan E.P, T. Noro, T. Houzen, K. Saito, M. Takahashi, and K. Ito, "Development of electronically controlled array antenna system for ETS-VIII applications," *Proc. of the International Workshop on Antenna Technology 2008 (iWAT2008)*, pp.414-417, Chiba, Japan, Mar. 2008.

[7] Basari, M. Fauzan E.P, T. Noro, T. Houzen, K. Saito, M. Takahashi, and K. Ito, "Simple switched-beam antenna system for mobile satellite applications," *Proc. of 2008 IEEE AP-S International Symposium and USNC/URSI National Radio Science Meeting*, pp.323-326, San Diego, CA, USA, July 2008.

[8] NICT Homepage, "Engineering Test Satellite (ETS-VIII) Project," (http://www2.nict.go.jp/p/p463/ ETS8/ETS8.html).