Implementation of Antenna System for Land Vehicle Mobile Satellite Application under Real Environment

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Abstract—**Implementation of a simple antenna system on vehicle-based mobile satellite communication is accomplished to realize mobile satellite applications. We develop the antenna system and establish an outdoor measurement for mobile communication through the satellite by designing a compact switchable-beam patch antenna that is covered by an industry standard plastic material (flat ABS radome), developing a satellite-tracking program by utilizing Global Positioning System (GPS) receiver or gyroscope sensor, and data acquisition program which utilizing spectrum analyzer. This paper provides a part of field measurement results that conducted in Japan to evaluate the propagation characteristics as well as the bit error rate of the vehicle-mounted antenna system. We carefully examine the measurement under two major environments to observe their propagation characteristics and bit error rate (BER) performance. We take sample data in areas either that satellite signal was dominantly direct received or it is shadowed by a number of vegetation in accordance with their density. The results are presented here to consider for improving a cost-effective implementation on mobile satellite applications in the forthcoming technology.**

Keywords—**Antenna system, bit error rate, mobile satellite communication, patch antenna, propagation characteristics**

I. Introduction

Terrestrial mobile communications infrastructure has made deep inroads around the world. Even rural areas are obtaining good coverage in many countries. However, there are still geographically remote and isolated areas without good coverage, and several countries do not yet have coverage in towns and cities. On the other hand, satellite mobile communications offers the benefits of true global coverage, reaching into remote areas as well as populated areas. This has made them popular for niche markets like news reporting, marine, military and disaster relief services. Until now, there has been global or regional-ranging adoption of mobile satellite communications to the mass market such as Iridium, Globalstar, ICO Global Communications, and Inmarsat to state some of them [1]. In order to benefit the great advantages of mobile satellite communications, the Japan Aerospace Exploration Agency (JAXA) launched the geostationary test satellite called Engineering Test Satellite (ETS-VIII) in the end of 2006. The ETS-VIII was conducted for various experiments in Japan and surrounding areas to verify mobile satellite communications functions [2]. In addition, the satellite communications system would help rescue efforts in disaster areas by allowing us to collect information more promptly, especially if ground communications facilities were damaged or in areas without advanced communications infrastructure such as rural and isolated areas. The satellite had three years mission test for field measurements. We were enrolled in the experimental use of the ETS-VIII, especially in land vehicle application.

This paper mainly concerns on measurement campaign that is conducted in Japan by utilizing our vehicle-mounted antenna system to verify its validity and confirm the quality of the received signal from the ETS-VIII satellite. In order to grasp the characteristics of received satellite signal impairment, we thoroughly examine the propagation characteristics under Ricean fading and shadowing environments. Meanwhile, its average bit error rate on each aforementioned condition is also observed. This paper will show us an implementation of simple antenna system in terms of field measurement results using satellite signal.

II. Realization of Antenna System

The antenna system is constructed by an active integrated patch array antenna that developed with no phase shifter circuit, realizing a light and low profile antenna system thus its reliable operation and high-speed beam scanning performance can be obtained. The antenna system has a simple tracking method controlled by a control unit as the vehicle's orientation is updated from a navigation system (i.e. GPS module) in real time. Then, the antenna system is installed on a vehicle to track the satellite during its traveling [3] as depicted in Fig. 1.

The array antenna configuration is 120º sequentially physical rotated and set with an equal distance between each element following a circular path on the same layer of the configuration. With such alignment, each element is fed in-phase allowing their relative phase is physically shifted. The feeding of each antenna element is successively turned off by controlling an onboard-switching circuit that installed on the beneath of the configuration, and thus the whole azimuth range can be scanned by step of 120º. Three beams are generated to cover all of the azimuth angles. The beam is generated in the azimuth plane at -90º from the element that is turned off. As a result, if each element i.e. element no. 1, 2 and 3 is turned off, the beam is generated in the direction Az = 0, 120º and 240º, respectively [4]. In addition, the satellite-tracking is conducted in the azimuth plane regardless the elevation direction owing to the antenna gain is quite enough to communicate with the geostationary satellite as predicted in the link budget [5].

The antenna system is mainly operated by a control unit (this time is a PC), hence the tracking-algorithm allows the antenna beam is automatically steered pursuing the satellite. The tracking-algorithm is simply developed regardless the signal of satellite for azimuthally-tracking. As for the beam-forming of the array antenna, the control unit provides three bias voltages to switch on and off the P-I-N diodes of the onboard-switching circuit (in Fig. 3.c of [4]) and thus two elements of the array are correctly fed and specified beam is created. For automatic beam-steering, by considering vehicle's orientation, an applet in the control unit selects the beam among three selectable-beams. As the satellite lies at southern from the Japanese archipelago, the beam is invariably controlled in the south direction [5]. The aforementioned antenna system description is illustrated in Fig. 1.

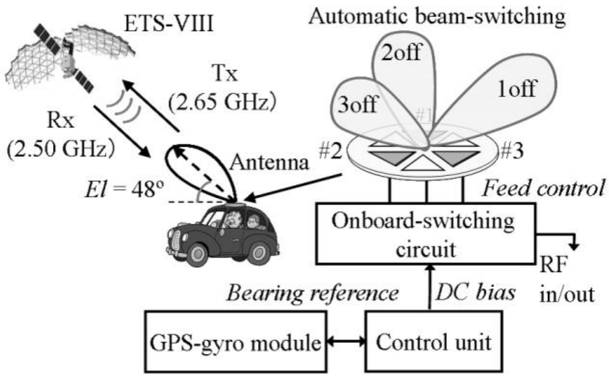


Fig. 1. Antenna system architecture.

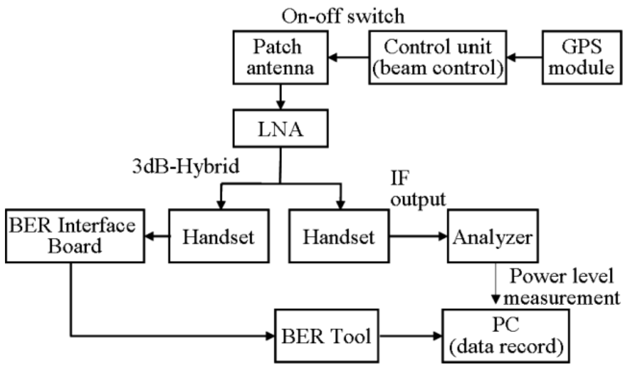
We have conducted a measurement campaign as an implementation of our developed antenna system by using a geostationary satellite in Japan. Due to trouble at the satellite for receiving signal from the ground station, our present measurement is assigned only for forward link namely from the fixed-earth station (transmitter) to vehicle (receiver) through the ETS-VIII satellite [6]. In this case, at the transmitter we amplify the transmitted signal by using a 22.40 dBi-gain parabola antenna. Afterwards, we simultaneously measure the received signal power and average BER at the receiver.

The measurement structure at the receiver is illustrated in Fig. 2. As described in Fig. 2(a), the patch antenna is connected with two handheld terminals by a power divider, and each received signal from the handheld terminals is measured by using a spectrum analyzer (Agilent E4403B) and a data transmission analyzer (Anritsu MD6420A) for received signal power measurement and average BER measurement, respectively. Even though the received signal measurement will decrease by 3 dB, however by adjusting attenuator of low noise amplifier (LNA), the decreased

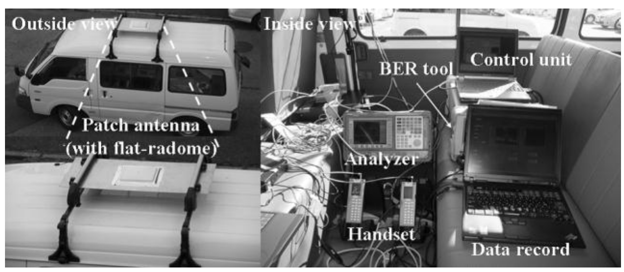
TABLE I
PARAMETERS OF EXPERIMENTAL SYSTEM

Parameter	Description
Satellite	Engineering Test Satellite (ETS-8)
Orbit	Geostationary (146º E)
Frequency	2.65/2.50 GHz
Polarization	Left handed circular polarization (LHCP)
Antenna and receiver	
Antenna type	6-patches array antenna (three patches is receive-use antenna)
Gain	> 5 dBic in all azimuth angles
Axial ratio	< 3 dB in all azimuth angles
Antenna tracking	Antenna beam switching by using open loop method with GPS module
C/N_0	48–50 dBHz at line of sight area
Campaign location	Chiba Prefecture, Japan 35.6º N 140.1167º E
Inclination from satellite	48º
Measurement sites	Direct-wave receive areas, public road and roadside tree areas
Communication link	
Access method	FDMA
Channel bandwidth	12.5 kHz
Modulated signal	BPSK
Transmitted data	PN-code
Transmission rate	8 kbps
Error coding	Convolutional codes with Viterbi decoding; without interleaver
Target BER	1×10^{-4}
Weather conditions	Partly cloudy and fine weather

signal is substituted so thus the carrier to noise density ratio C/N_0 is quite enough for carrying out the measurement. The measurement tools are installed inside vehicle and a flat ABS radome that covers the patch antenna is mounted on vehicle's roof, as shown in Fig. 2(b).



(a) Block diagram of measurement structure (receiver)



(b) External view of the measurement

Figure 2. Antenna system measurement structure

Unmodulated and modulated continuous waves of left hand circular polarization (LHCP) at 2.65 GHz are transmitted from the fixed-earth station to the satellite and received by the vehicle on which our antenna system is mounted. Two different channels are used for two transmitted signals (unmodulated and modulated signals) allowing two different measurements (i.e. signal power and BER measurement, respectively) are simultaneously conducted. At the receiver, the received signal power is retrieved from intermediate frequency (IF) output from a down-converter part of the handheld terminal. Meanwhile, the error rate of the data transmission is counted from the interface board that connected with the user interface part of the handheld terminal. We use the handheld terminal that developed by the NICT and Fujitsu [7]. With the personal computer (PC) the received signal power and average BER are recorded.

As for the bit error rate measurement, the binary phase shift keying (BPSK) modulation with coherent demodulation is adopted with symbol rate 8 kbps. It also utilizes a convolutional code (code rate $R = 1/2$ and input constraint length $K = 7$) with Viterbi decoding and no interleaver for error coding scheme [7]. To analyze the BER performance at the receiver, the BER analyzer that we use for measurement generates a pseudo-random sequence 2^{23}–1 pattern where it conforms to CCITT Recommendation O.151. The sequence synchronization is manually established from an external applet, when pattern synchronization loss is detected. At the measurement bit rate by 8 kbps, the pattern synchronization will be lost either when there are 200 bit errors in the 512 bits of the analyzer receive clock or the bit error ratio is equal or more than 0.2 during an integration interval of 1 second [8].

III. Measurement Results Analysis

A. Measurement in Ricean Fading Environment

The measurement is mainly conducted to verify the validity for satellite-tracking of our vehicle antenna system. We perform the measurement in location that the satellite direct-wave signal is a dominant component rather than the reflected or scattered waves. The vehicle moves by 10 km/hour in straight path, while the beam of the antenna is automatically steered to the satellite associated with vehicle's orientation. The averaged-50 dBHz of the C/N_0 is obtained to remain the BER in range of 1.2×10^{-4} to 5.4×10^{-5} as depicted in Fig. 3. Moreover, by comparing the obtained BER with the theoretical BPSK signal, the obtained BER is close to the ideal value even though some data are discrepant owing to the required C/N_0 to attain the target BER is higher by 1–3 dB. These values exist in the right-side of the target BER in Fig. 4. This indicates also imperfection in the filtering part at the BPSK signal detector. In addition, the multipath signal effects from the surroundings are also inevitable factors.

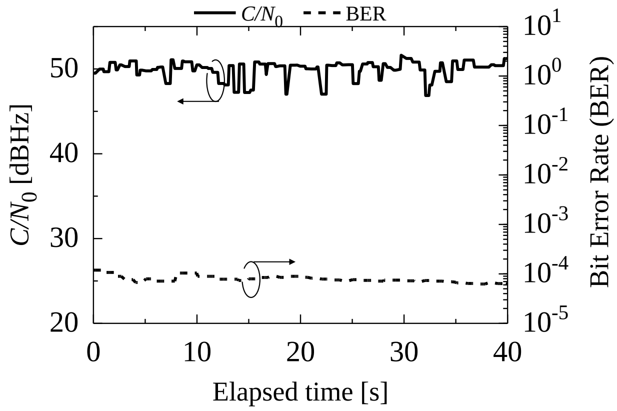


Figure 3. Carrier to noise density and BER performance for satellite-tracking when vehicle travels on the straight path lane at dominant direct-wave area.

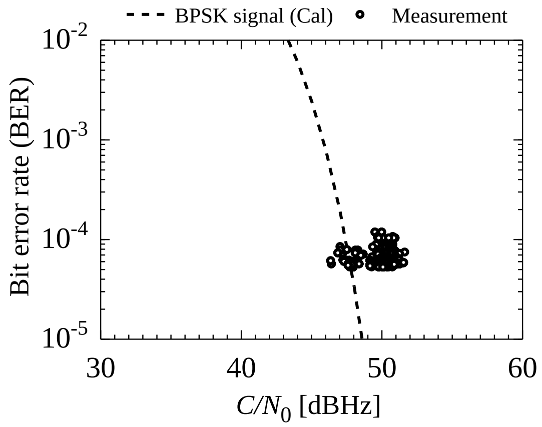


Figure 4. BER performance vs C/N_0 of satellite-tracking at dominant direct wave area.

B. Measurement in Shadowing Environment

Some measurements of mobile satellite communication have been investigated especially for evaluating the attenuation signals due to the blockage such as shadowing of trees [9], [10] and blocking of buildings [11] by using low gain omnidirectional antennas. However, the propagation characteristics combined with the BER performance in mobile state measurement by utilizing the satellite signal was not reported yet. Therefore, this paper tried to provide simultaneous BER value while simultaneously evaluating the propagation characteristics. It also provided fade percentage distribution in shadowing environment.

In shadowing areas, we thoroughly evaluate the effect of obstacle objects i.e. electric poles and evergreen vegetation includes their population or distribution, on the received signal and link qualities of the antenna system. Figures 5, 6, and 7 show the instantaneous received signal power defined in C/N_0 with respect to the BER performance, when the signal is shadowed by far-distance with small number of vegetation and several electric power poles present, several of vegetation and dense vegetation distribution, respectively. As shown in Fig. 5, the poles attenuate signal gradually allowing the BER get slightly worse especially when huge pole exists. The average BER is kept in range 4.0×10^{-4} to 9.6×10^{-5}. In this case, the trees do not affect the BER significantly since they are situated far enough from vehicle with small distribution.

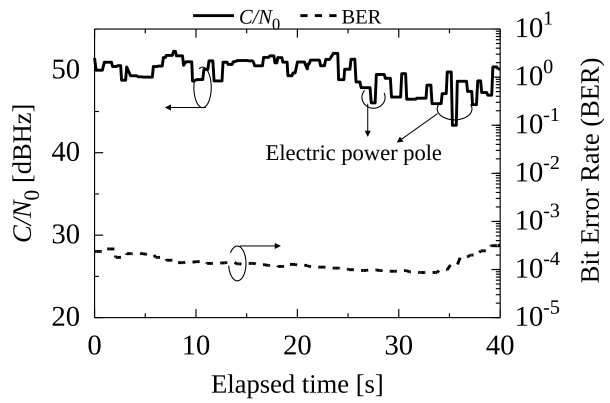


Figure 5. Carrier to noise density and BER performance when signal is shadowed by small number of trees at 6 m and several poles at distance 2 m.

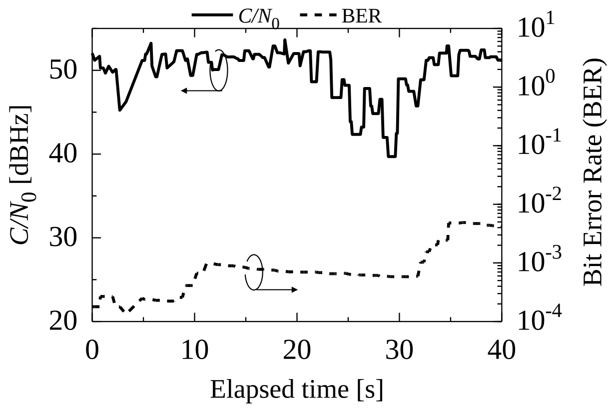


Figure 6. Carrier to noise density and BER performance when signal is shadowed by several roadside-trees at distance 2 m.

The shadowing by several trees in road-line is depicted in Fig. 6. The result can be obviously seen that distribution of roadside-trees gives longer duration of shadowing that worsening C/N_0 as well as the average BER performance. The average BER remains within the worst value by 4.8×10^{-3} even though the C/N_0 immediately gets worse. In addition, as for dense vegetation trees attenuate the received satellite signal longer and deeper than other distribution as described in Fig. 7. The average BER get drops longer duration to be approximately 6.4×10^{-2}. In fact, besides the distribution of roadside-trees, the average BER is also affected by the distance between tree and vehicle, density of foliage and vegetation type as well.

The amount of signal attenuation is usually determined by expressing in cumulative fade distribution. Figure 8 shows the fade percentage distribution of each shadowing signal with respect to the received signal power compared with line of sight received signal. The fade level increases as the population or distribution of roadside-trees increases. It is noted that the shadowing signal curve moves to the left side. The 10% exceedance of fades is about 3 dB of small distribution roadside-trees shadowing, 6 dB of several roadside-trees and 8 dB of dense distribution of vegetation. It is clear that high populated vegetation gives longer attenuation and decreases BER performance in significant value.

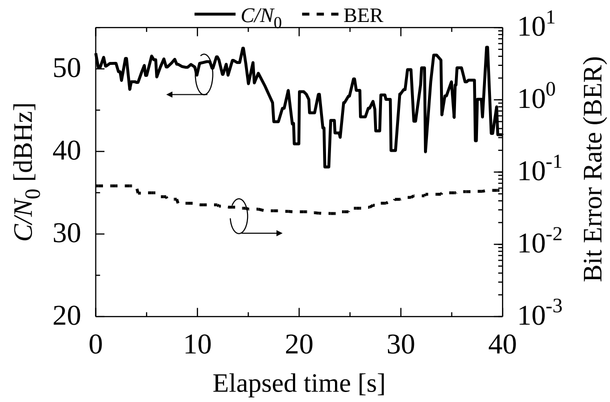


Figure 7. Carrier to noise density and BER performance when signal is shadowed by trees with dense canopy at distance 2 m.

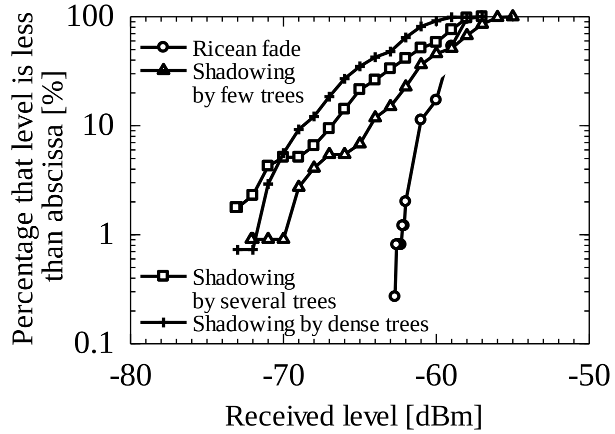


Figure 8. Fade percentage distribution due to vegetation density compared with the Ricean-fade signal.

V. Conclusion

The implementation of simple antenna system for vehicle satellite communication was realized by conducting a measurement campaign that used a geostationary satellite for verifying the validity of system in real environment. We have confirmed the antenna system could establish the satellite link with sufficient C/N_0. This paper mainly examined the received signal power as well as the average BER performances during mobile measurement in two major areas i.e. in Ricean fading environment and shadowing area (such as poles and or evergreen vegetation). The steadily received level was obtained as well as the satisfactory BER of satellite-tracking in Ricean fading environment. Unlike in Ricean fading, measurement in shadowing areas, from the fade characteristics and BER performance it was shown that different distribution of vegetation gave different degree of attenuation and effect in terms of fade depth and average error rate. Therefore, by these results will expect us to design more costly-effective antenna system that good performance. Ultimately, the overall our current developed antenna system is simple, compact and promising in low cost, for contribution in the forthcoming land mobile satellite communications.

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