Measurement on Simple Vehicle Antenna System Using a Geostationary Satellite in Japan

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***Abstract*—This paper provided a measurement campaign of simple antenna system mounted on a vehicle by utilising a Japanese geostationary test satellite called Engineering Test Satellite VIII (ETS-VIII). We developed an antenna system that was compact, light weight, and promising in low cost production. The antenna system was built by a 16-cm patch array antenna, which had simple satellite-tracking method that controlled by a control unit as the vehicle's bearing was updated from a navigation system in real time. A Global Positioning System (GPS) module was utilised for navigation system to provide accurate information of the vehicle's position and bearing during travelling. The control unit was used as the antenna-beam control and measured-data acquisition. The antenna system was thoroughly examined in the measurement under the line of sight (LOS) areas as well as the blockage areas in order to evaluate the propagation characteristics caused by utility poles, pedestrian overpasses and vegetation-covered road. In this measurement, received signal power and average bit error rate (BER) were simultaneously retrieved. Steadily received levels and BER were satisfactorily attained during satellite-tracking in LOS area. Moreover, the fade characteristics and BER performance were investigated while signal blockage happened. The measurement results were presented here to grasp their attenuations and effects on the bit error rate in terms of fade depth. With these results, we can consider to design a cost-effective mobile satellite application for future technology.**

I. INTRODUCTION

Mobile communications provided by satellite systems had widely developed in a range of operational systems either for domestic or global communications purposes. Mobile satellite 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 such as news reporting, marine, military and disaster relief services. In order to challenge the great advantages of mobile satellite communications, the Japan Aerospace Exploration Agency (JAXA) has launched the geostationary satellite called Engineering Test Satellite (ETS-VIII) in 2006. The ETS-VIII was conducted for various experiments in Japan and surrounding areas to verify mobile satellite communications functions [1]. 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 conducted in Japan by utilising our vehicle-mounted antenna system to verify its validity and confirm the quality of the received signal from the ETS-VIII satellite in several different environments.

The antenna system is constructed by an active integrated patch array antenna that developed with no phase shifter circuit, realising 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 travelling [2] as depicted in Fig. 1.

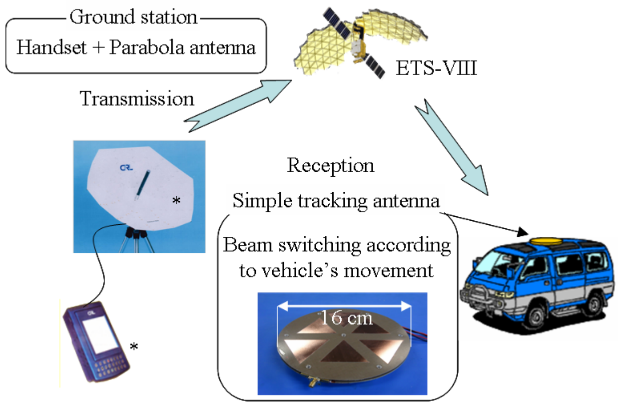

Figure 1. Experimental structure for antenna system measurement using the geostationary satellite. (* NICT Japan)

As for the array antenna configuration, it 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

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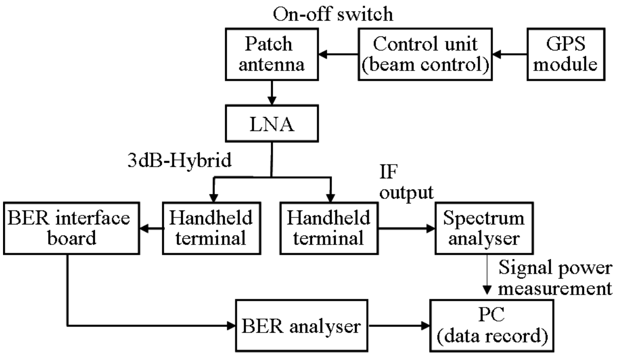
no. 1, 2 and 3 is turned off, the beam is generated in the direction Az = 0, 120º and 240º, respectively [3]. In addition, the satellite-tracking is conducted in the azimuth plane regardless the elevation direction owing to the antenna gain is quite enough to communicate with the geostationary satellite as predicted in the link budget [4].

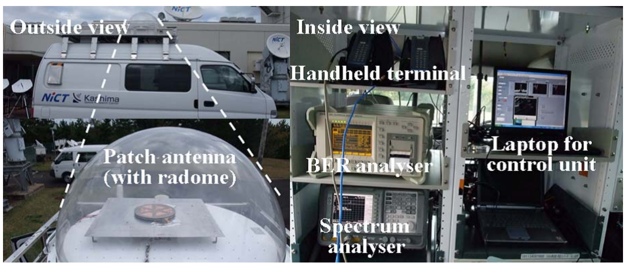
The antenna system is mainly operated by a control unit (this time is a PC), hence the tracking-algorithm allows the antenna beam is automatically steered pursuing the satellite. The tracking-algorithm is simply developed regardless the signal of satellite for azimuthally-tracking. As for the beam-forming 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 [3]) 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 [4].

II. MEASUREMENT STRUCTURE

The measurement structure is depicted in Fig. 1. As reported in [5], the large deployable reflector (LDR) antenna that installed on the ETS-VIII satellite cannot be used because of improper situation at power supply of low noise amplifier (PS-LNA), thus our measurement campaign is conducted by utilising the high accuracy clock (HAC) receiving antenna with lower gain 25 dBi instead of 43.80 dBi of the LDR antenna. Therefore, the present measurement campaign is assigned only for forward link namely from the fixed-earth station (transmitter) to vehicle (receiver) through the ETS-VIII satellite. In this case, at the transmitter we boost 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.



(a) Block diagram of measurement structure (receiver)



(b) External view of the measurement

Figure 2. Antenna system measurement structure

TABLE I
PARAMETERS OF EXPERIMENTAL SYSTEM

Parameter	Description
Satellite	Engineering Test Satellite (ETS-8)
Orbit	Geostationary (146º E)
Frequency	2.65/2.50 GHz
Polarisation	Left handed circular polarisation (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	Kashima (Ibaraki Pref.), Japan 35.97º N 140.63º E
Inclination from satellite	48º
Measurement sites	Rotary, open-field, public road, inclined 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, sometimes rain and fine weather

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 analyser (Agilent E4403B) and a data transmission analyser (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 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 the radome-covered patch antenna is mounted on vehicle's roof, as shown in Fig. 2(b).

Unmodulated and modulated continuous waves of left hand circular polarisation (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 [6]. 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 utilises a convolutional code (code rate R = 1/2 and input constraint length K = 7) with Viterbi decoding and no interleaver for error coding scheme [6]. To analyse the BER performance at the receiver, the BER analyser that we use for measurement generates a pseudo-random sequence 2^{23}–1 pattern that conforms to CCITT Recommendation O.151. The sequence synchronisation is manually established from an external applet, when pattern synchronisation loss is detected. At the measurement bit rate by 8 kbps, the pattern synchronisation will be lost either when there are 200 bit errors in the 512 bits of the analyser receive clock or the bit error ratio is equal or more than 0.2 during an integration interval of 1 second [7].

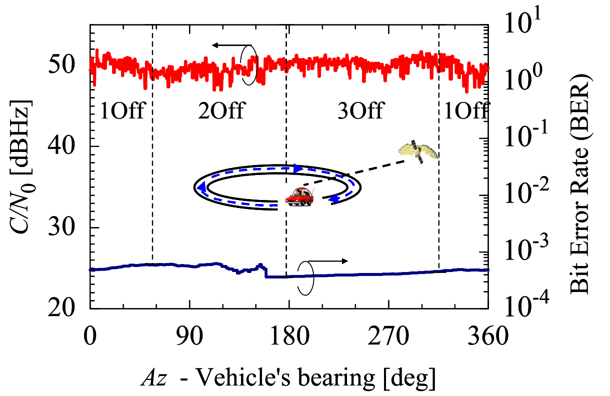


Figure 3. Carrier to noise density and BER performance for automatic satellite-tracking when vehicle turning round in circular path at LOS area.

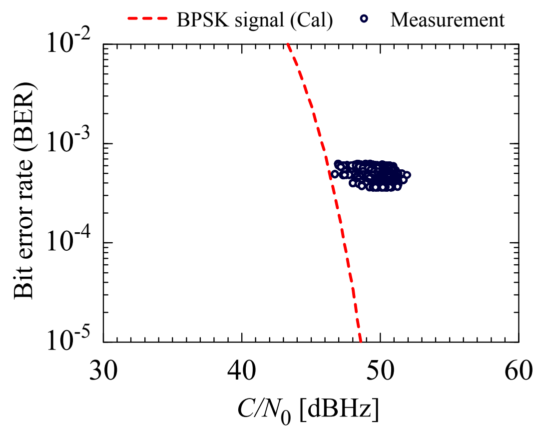


Figure 4. BER performance of automatic satellite-tracking in LOS area while performing beam-switching in circular path.

According to the predicted link budget [4], the communication between transmitter and receiver through the ETS-VIII satellite can be approximately established by 45.83, 44.31, and 41.84 dBHz of C/N_0, for target BER 1.0×10^{-4}, 1.0×10^{-3} and 1.0×10^{-2}, respectively, at 8 kbps transmission rate. In real environment, however, the channel exhibits some form of compound behaviour that consists of a mixture of burst and random errors due to multipath fading and shadowing. Nevertheless, by adopting the error coding, the decreasing of link margin can be reduced. In order to summarise our measurement campaign, the description of the measurement parameters is listed in Table I.

III. Measurement Results

The measurement campaign is conducted in Kashima city, Ibaraki Prefecture, Japan (El = 48º). We carry out the measurement in some different areas i.e. in LOS area and blockage (such as utility poles and vegetation) area. The measurement results are presented in the following subsection.

A. *Measurement in line of sight areas*

The measurement in line of sight areas is mainly conducted to verify the satellite-tracking performance of our vehicle-mounted antenna system. While the vehicle is travelling by a circular path, the beam of the antenna is electronically steered pursuing the satellite associated with vehicle's orientation. Three antenna beams are smoothly switched to the satellite for each beam-coverage in the azimuth direction, as depicted in Fig. 3. Sufficient C/N_0 is obtained to remain the fluctuated-BER in range of 3.5 to 6.5×10^{-4}. Moreover, by comparing the obtained BER with the theoretical BPSK signal, the obtained BER is worse than the target due to the required C/N_0 to attain the target BER is higher by 1–4 dB. This result is shown in Fig. 4 where the measured-BER exists in the right-side of the target BER which indicates also imperfection in the filtering at the BPSK signal detector [8]. Besides, multipath signal effects from the surroundings are also considered.

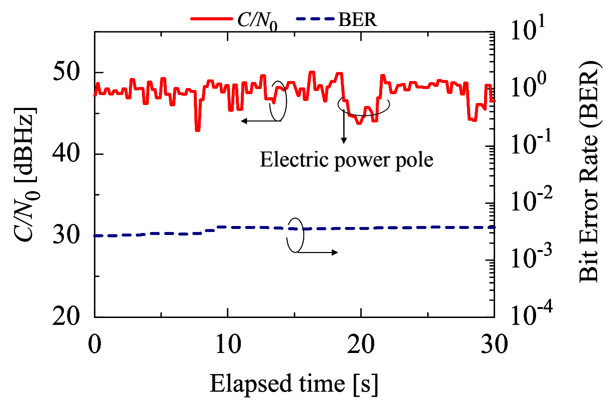


Figure 5. Carrier to noise density and BER performance when signal is blocked by a single pole.

B. *Measurement in blockage areas*

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 buildings [11] by using low gain omnidirectional antennas or diversity antennas. In addition, the BER measurement results using the satellite were very few reported. Therefore, this paper tried to provide some BER performances as well as the fade percentage distribution when the blockage happened.

In blockage areas, we thoroughly evaluate the effect of obstacle objects i.e. a single pole, vegetation includes its foliage density, pedestrian overpass and inclined-road, 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 blocked by a single electric power pole, sparse-foliage vegetation and dense-foliage vegetation, respectively. As shown in Fig. 5, the pole attenuates signal whereas the BER remains stable since its received signal fluctuation is very short compared with the retrieved-time of the BER. The average BER is steadily kept in 2.7–3.8×10^{-3}.

As for the shadowing by trees, the received signal is slightly attenuated longer causing more fluctuation in signal and the error rate gets worse. In this measurement, we concern on vegetation density effect on the received satellite signal. Therefore, two cases i.e. sparse foliage vegetation (Fig. 6) and dense foliage vegetation (Fig. 7) are evaluated. The results can be obviously seen that density of tree's foliage gives different degree of attenuation allowing the different BER performance. As depicted in Fig. 6, in case of the sparse foliage shadowing, the average BER remains approximately within 10^{-3} even though the C/N_0 gradually gets worse. In contrary, dense foliage trees attenuate the received satellite signal deeper than sparse foliage ones as described in Fig. 7. The average BER suddenly drops in significant value to be approximately 10^{-2}. In fact, besides the density of foliage, the average BER is also affected by the distance between tree and vehicle, and vegetation type as well.

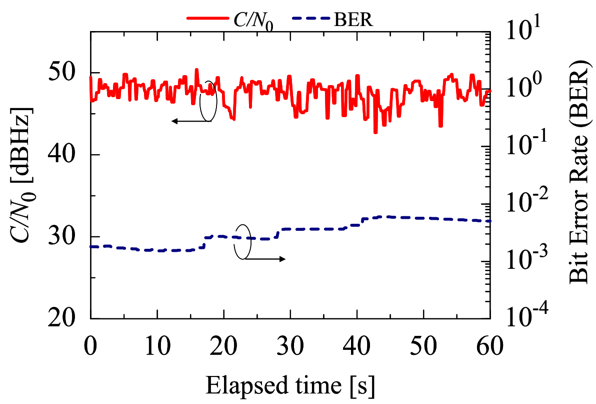


Figure 6. Carrier to noise density and BER performance in sparse foliage environment.

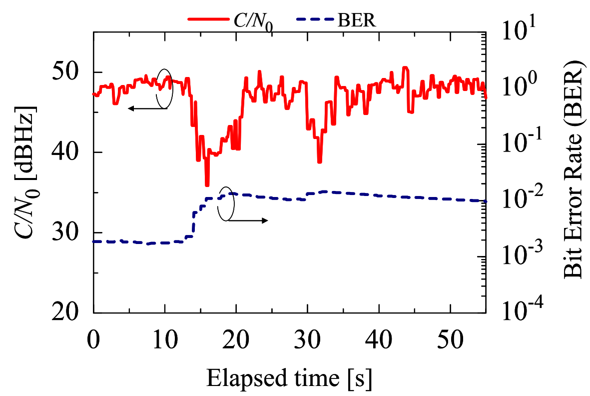


Figure 7. Carrier to noise density and BER performance in dense foliage environment.

The amount of signal attenuation can be determined by expressing in cumulative fade distribution. Figures 8 and 9 show the fade percentage distribution of each blockage signal with respect to the received signal power. As shown in Fig. 8, the fade level increases as the blockage is present. It is clearly shown by the blockage signal curve moves to the left side. The 10% exceedance of fades is about 7 dB of sparse foliage blockage and 11 dB of dense foliage blockage. The pole blockage is quite similar with the sparse foliage one, which means the most of the fades in sparse foliage environment are contributed by branches and twigs.

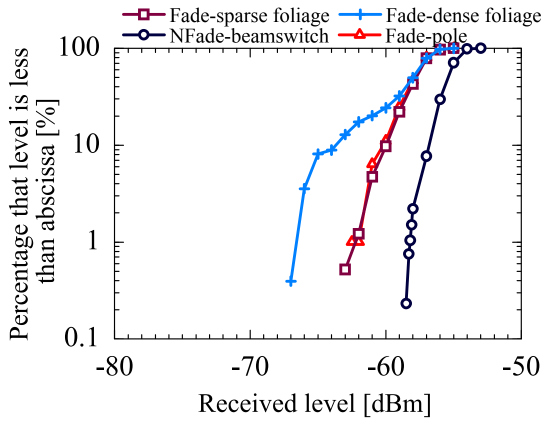


Figure 8. Fade percentage distribution due to vegetation and pole compared with the non-fade signal.

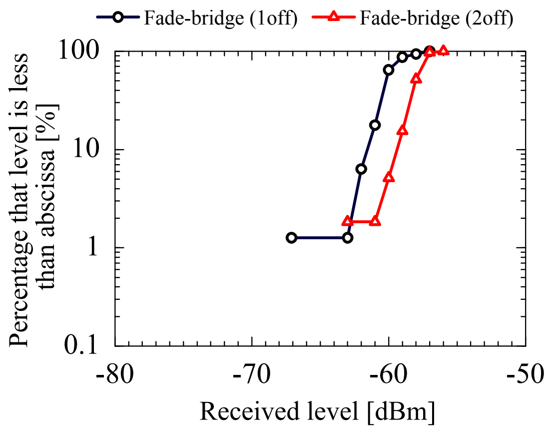


Figure 9. Fade percentage distribution due to pedestrian bridge.

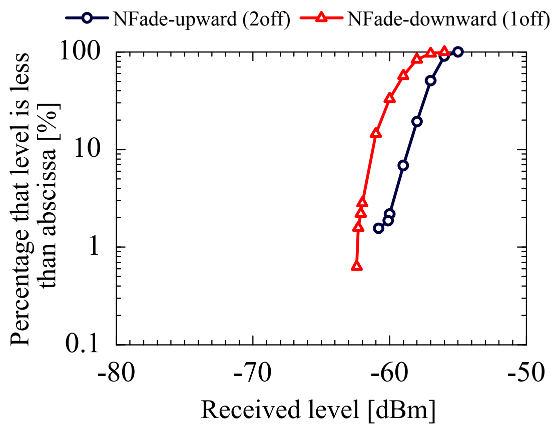


Figure 10. Fade percentage distribution due to road elevation in inclined path.

Figure 9 shows the fade percentage distribution when the blockage occurs due to the pedestrian bridge. The measurement is conducted in two different lanes on the road (as described by 1off and 2off antenna beam). The fade level for 1off antenna beam is higher 2 dB for probability 2–60%, since the vehicle is situated closer to the surrounding obstacles during travelling. However, the key point from this figure is the bridge attenuates signal in deep attenuation shortly. It is shown by the exceedance of the fades is less than 2% as a horizontal curve.

Finally, we also test the inclined-road effect on the received signal as shown in Fig. 10. The upward motion of vehicle gives 2 dB higher signal rather than the downward motion. The reason is as increasing elevation (upward motion), the antenna gain increases, hence the received signal power increases as well.

IV. Conclusions

The measurement campaign of simple antenna system that mounted on a vehicle by utilising a geostationary satellite was conducted for verifying its validity in real environment. We have confirmed the antenna system could establish the link well through the satellite. In this paper, we mainly examined the received signal power as well as the average BER performances of our antenna system in several areas i.e. in LOS area and blockage area (such as poles and vegetation). The steadily received level was obtained as well as the satisfactory BER of satellite-tracking in LOS area. As for the measurement in blockage areas, from the fade characteristics and BER performance it was shown that different environment gave different degree of attenuation and effect in terms of fade depth and average error rate. In addition, these measurement results will help us to design a costly-effective land-mobile satellite communication system. Finally, the overall our developed antenna system is simple, compact and promising low cost, for contribution in the future mobile satellite communications.

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