P238

Development of electronically controlled array antenna system for ETS-VIII applications

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1. Introduction

The Japan Aerospace Exploration Agency (JAXA) has been developing ETS-VIII satellite mission technology, which is one of the largest geostationary S-band satellites in the world to meet future requirements of mobile communications. The ETS-VIII conducts various orbital experiments in Japan and surrounding areas to verify mobile satellite communications functions. The mobile communication technologies adopted by ETS-VIII are expected to benefit our daily life in the field of communications, broadcasting, and global positioning. Quick and accurate directions for example, can be given to an emergency vehicle by means of traffic control information via satellite in the event of a disaster [1]. In the end of 2006 year, ETS-VIII satellite has been successfully launched [2].

Up to now, various antennas for land mobile system have been developed aimed at ETS-VIII [3]-[5]. The performances of the antenna [4] have been experimented outdoor by use of a pseudo-satellite station. Moreover, the array antenna which is connected with a separated switching circuit has been experimented in indoor measurement to test the beam switching mechanism of the array antenna [5].

In this paper, we propose a configuration of antenna system for mobile ground terminal using GPS and gyroscope terminal unit as automatic-navigation system to track the ETS-VIII satellite. To miniaturize the antenna system we introduce an electronically tracking rather than mechanically by use of a developed control program. With this configuration the antenna system becomes light and low profile with more in reliability and high-speed beam scanning possibility. In this research, a left hand circularly polarized array antenna integrated with an onboard switching circuit is proposed. Measured results of return loss, axial ratio, elevation cut pattern and beam switching performance are presented.

2. Specifications and targets

Table 1 shows the specifications and targets required for an antenna to be used for land mobile satellite communication, in particular aimed at ETS-VIII applications, which are used in this paper. A gain more than 5 dBic (for a hundred kbps data rate) and an axial ratio less than 3 dB with a left-handed circular polarization (LHCP) should be considered to design the antenna. The antenna frequencies are set to 2.5025 GHz and 2.6575 GHz for the reception and transmission antenna, respectively, as shown in Table I. The direction of ETS-VIII seen from Japan has a certain elevation angle depending on the place. The beam of the antenna should cover the area from the northern to the southern part of Japan (El = 38° to El = 58°).

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Table 1:
Specifications and Targets on the Antenna for Mobile Satellite Communications (ETS-VIII)

Specifications		
Frequency bands	Transmission (Tx)	2655.5 to 2658.0 MHz
	Reception (Rx)	2500.5 to 2503.0 MHz
Polarization	Left-handed circular polarization for both transmission and reception	
Targets		
Elevation angle (*El*)		48° (Tokyo) ± 10°
Azimuth angle (*Az*)		0° to 360°
Minimum gain		5 dBic
Maximum axial ratio		3 dB

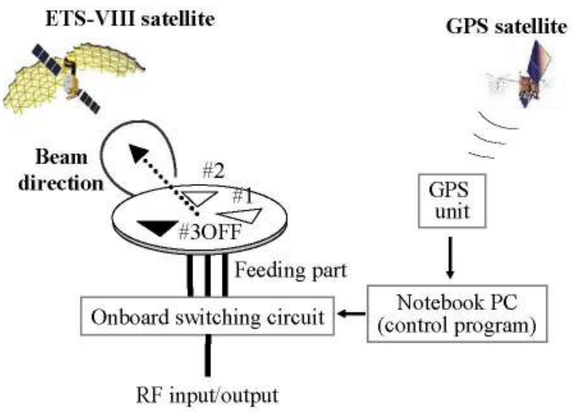

Figure 1: Configuration of the antenna system aimed at ETS-VIII experiment

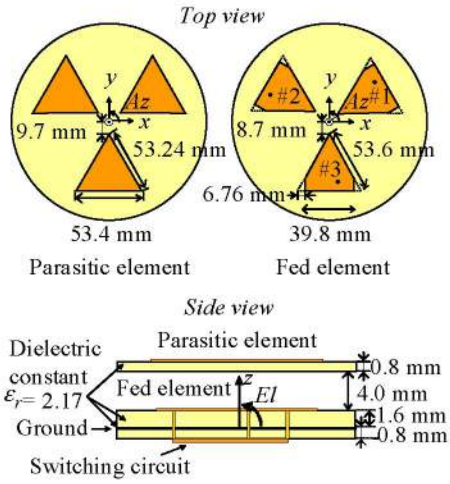

Figure 2: Geometry of the antenna integrated with switching circuit

3. Antenna system configuration and experimental set-up

3.1 Antenna system configuration

Figure 1 depicts a proposed antenna system configuration for outdoor experiment aimed at land vehicle communications using ETS-VIII satellite. In this configuration, GPS data from the navigation system is retrieved via serial port of the computer. Then, the GPS sentence data is processed in the computer by use of the developed control program to generate three bias voltages. These bias voltages control the onboard switching circuit thus the switching circuit is biased according to the beam mechanism's rule of the control program. In this case, each of antenna elements is electronically fed. With this mechanism each of antenna elements is easily able to be switched ON or OFF. So, the generated-antenna beam is always directed to the east longitude of 146° where the ETS-VIII satellite is orbited. The construction gives a simply connection of the antenna system because the devices construction is possibly connected and independently removed.

3.2 Experimental set-up

To prepare the outdoor experiment using ETS-VIII satellite, the antenna system is needed to be evaluated in the indoor experiment. This paper demonstrates the array antenna performance in the indoor measurement. To set up the indoor measurement, three main components are used namely the array antenna with switching circuit, GPS unit with gyro sensor, and application program to control the switching circuit from the notebook computer.

3.2.1 Geometry of array antenna

Geometry of the antenna is shown in Figure 2. The antenna is composed of three pentagonal patch antennas which fed directly from the switching circuit on the beneath of the construction. In the top of the construction is laid three triangular patches as parasitic elements. With this geometry the antenna becomes simple, compact and low loss, because no need a power divider to distribute power signal to the antenna element. The dimension of the construction is 160 mm and 7.2 mm in diameter and height, respectively.

3.2.2 GPS unit

The gyro sensor data of the GPS is acquired and processed in the application program to yield the bias voltages by which the performance of the switching circuit can be controlled. The acquired gyro sensor data is a direction of the GPS bulk unit. To simplify the circumstance of the measurement, the direction way is regarded same as the azimuth angle *Az*.

3.2.3 Application program

In the experiment, an application program is used to control the switching circuit in the antenna system. This applet is made to perform easily the experiment and to control automatically the beam of the antenna.

4. Experiment results

The developed array antenna was fabricated and measured by a vector network analyzer in indoor measurement. The measured antenna gives the impedance bandwidth ($|S_{11}| < -10$ dB) about 10.8% and the 3 dB axial ratio bandwidth 1.6% in the target frequency 2.5025 GHz as shown in Figure 3 and 4, respectively. The worth feature of the antenna is the beam of the antenna can be generated towards a certain azimuth direction electronically by ON-OFF switched method. This work provides the performance of the antenna not only covering the gain and the axial ratio in the whole of azimuth angles as well as the beam can be controlled smartly orientated to the transmitting antenna.

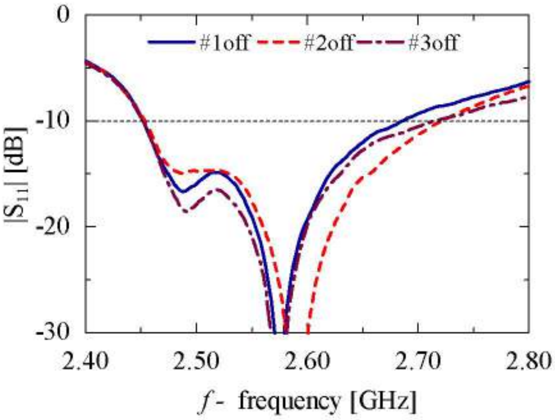

Figure 3: |S| parameter performance of the antenna

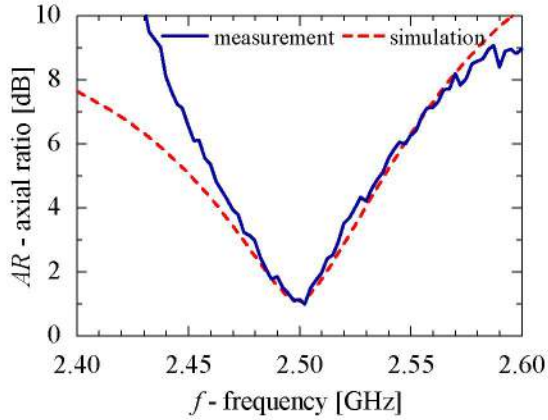

Figure 4: Axial ratio of the antenna

The beam of the antenna is generated by a mechanism that consists of switching OFF one of the radiating elements. By considering the mutual coupling between fed elements, their phase and distance, the beam direction can be varied. Theoretically, the generated beam is shifted of -90° in the conical-cut direction from the element that is switched OFF, in the case of a LHCP antenna. For example, when Rx element #1 (refers to Figure 2) placed at $Az = 90°$ is switched OFF, the beam is theoretically directed toward the azimuth angle $Az = 0°$. The other two beams can be generated in the same manner, switching each element OFF successively (Rx_2 and Rx_3 is switched OFF, each beam is directed to $Az = 120°$ and 240°, respectively).

Figure 5 describes the elevation cut pattern of the antenna when element #1 is switched OFF at the target elevation angle $El = 48°$. The 5 dBic gain and 3 dB axial ratio meet the target in the range of elevation angle $El = 38°$ - 58°. As discussed aforementioned, the antenna generated the beam in three states to cover the whole of the azimuth angles. Figure 6 depicts the beam switching performance of the antenna at $El = 48°$ in the target frequency 2.5025 GHz. By switching each beam separately (Figure 6, dot-line) the gain and the axial ratio meet the target more than 5 dBic and 3 dB, respectively, for the whole of the azimuth angles. To examine the tracking performance, the beam antenna electronically switched in order to cover the whole of the azimuth angles with the gain more than 5 dBic and the axial ratio less than 3 dB. It is shown in Figure 6 (solid-line) that the variation of the gain value more than 5 dBic and the axial ratio less than 3 dB in the azimuth direction is confirmed.

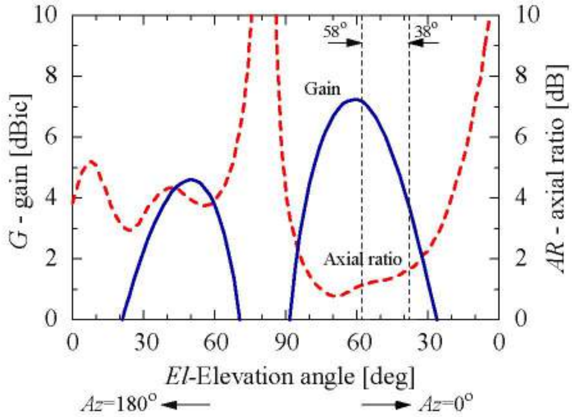

Figure 5: Elevation cut plane for each switched-OFF element

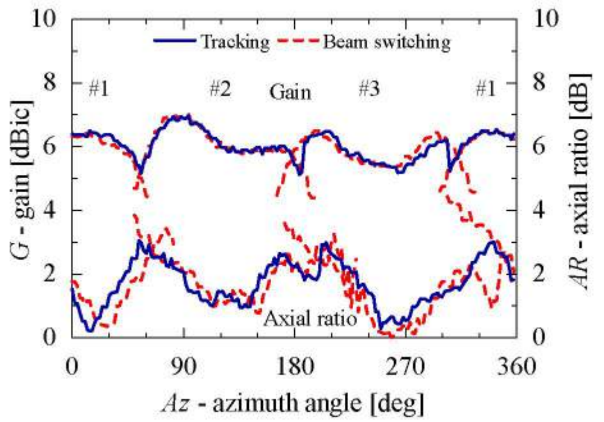

Figure 6: Beam switching performance manually & electronically switched beam

5. Conclusion and future work

Configuration of antenna system for land vehicle communications aimed at ETS-VIII applications was proposed. The configuration of antenna system uses a gyroscope sensor of the GPS unit as an automatic-navigation system was presented. The proposed antenna system consists of an array antenna loaded with switching circuit onto which controlled by a developed program. In addition, the array antenna is experimentally performed in the indoor measurement. The measured impedance bandwidth ($|S_{11}| < -10$ dB) and the 3 dB axial ratio bandwidth are about 10.8% and 1.6%, respectively. For an elevation angle El = 48° (as assumed in Tokyo area), three beams are electronically created in the azimuth direction with a minimum gain more than 5 dBic and an axial ratio less than 3 dB. Moreover, the 5 dBic gain and 3 dB axial ratio meet the target in the range of elevation angle El = 38° - 58°. In the next step, an outdoor experiment using ETS-VIII satellite will be performed with a radome package in the whole system.

Acknowledgments

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