The Array Microstrip Antenna for Mobile-Internet of Satellite Energy Communication

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Abstract: A simple Left-Handed Circularly Polarized (LHCP) proximity-fed equilateral-triangular array antenna with hole is proposed in order to support the mobile-internet of satellite energy communication covering the area of Japan (beam coverage elevation, *El* = 38° to 58°). In this paper, single-band LHCP triangular-patch array antenna is developed for receiver on ground applications. The targeted minimum gain of the antenna is set to 5 dBic at the central elevation angle (*El* = 48°), in Tokyo area, for applications using data-internet transfer of around hundreds kbps. The antenna consists of three equilateral-triangular patches with a hole for reception units operating at 2.50 GHz frequency bands. The antenna is simulated using the Method of Moments (MoM) analysis. The simulation results show that the frequency characteristics and the 3-dB axial ratio coverage in the conical-cut direction of the simulated antenna satisfy the target.

Key words: LHCP, proximity-fed, array antenna, mobile-internet of satellite energy communication.

1. Introduction

Nowadays, along with the spread of the internet and the miniaturized terminals such as mobile phones and the technetronic society, the mobile-internet of satellite energy communication is quickly developing. Then, the communications technology such as internet, data, voice, and video tend to spread in a populous urban region. The difference of communication environment (called digital divide) between cities and remote mountains or islands is questionable. As it became clear during the disaster, a big confusion is occurred in the communication network when the ground control stations cannot be used, which produces a great trouble to the rescue operation. Hence, it becomes urgent to develop a system which can perform the stable communication to provide the availability of energy via mobile-internet even during the disaster.

Therefore, it is meant that the mobile-internet of satellite energy communication does not use the ground communication network. It has the advantage of being able to cover a large area and attracts the attention for a convincing system towards future mobile-internet communication. Hence, along with the spreading of communication system, this system use the space satellite. It is thought that the reduction of the digital divide as well as the fast communication at the time of the disaster can be realized. In addition, the satellite communications can be expected to contribute in medical and education fields. For instance, in the education field, the use of satellite communication is by allowing a cultural exchange and online opinion exchange between universities and educational institutes in different countries through a communication network, or in medical field, it can be used by allowing a specialist in a remote city to order the most suitable medical prescription from long distance to handle the patients safely (telemedicine).

From such a background, with the aim of the development of a technology for mobile-internet communication, the Japan Aerospace Exploration Agency (JAXA) launched the Engineering Test Satellite VIII (ETS-VIII) in 2006 [1], [2]. The overview and system outline of ETS-VIII are shown in Fig. 1 and Table 1, respectively. The satellite, with a gross weight of around three tons and a diameter of 40 meters, has two Large Deployable Antenna Reflectors (LDAR) and two Solar Paddles (SP). One LDAR, with the size is about a tennis court, is the one of the world's largest geostationary satellites. Its size will enable direct communications with a geostationary satellite that covers all of Japan area (Fig. 2), making mobile-internet communication more reliable.

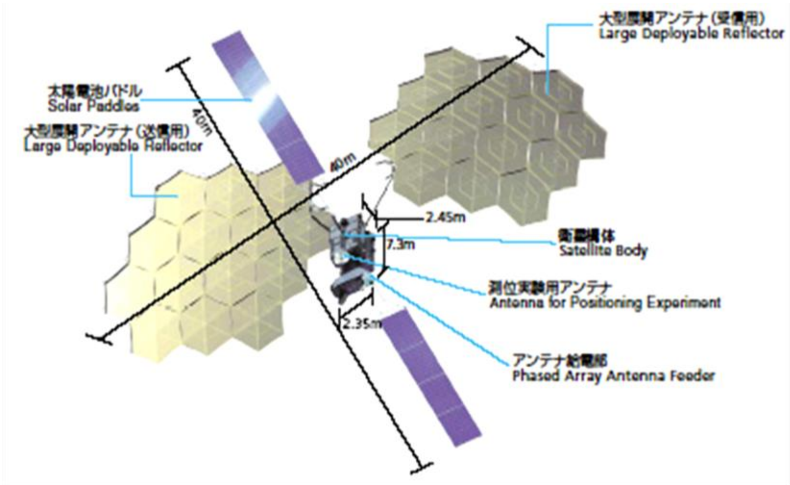

Fig. 1. External view of ETS-VIII [1].

Table 1. System Outline [1]

Specifications	Explanations
Launch	2006 (Fiscal Year) and after / by H-IIA Launcher
Design life	Satellite Bus: 10 years, Mission: 3 years
Location	146 °E (Provisionally)
Weight	Approx. 3,000 kg (Initial in Orbit)
Electric power	Approx.7,500 W (EOL, Summer Solstice)
Postural stabilization system	Three axis attitude control
Main characteristics	Large-scale Deployable Reflector, Antenna Feeder, Transponder, Onboard Processor, High Accuracy Clock, Feeder Link Equipment

The mission of ETS-VIII, shown in Fig. 3, is not only to improve the environment for mobile-phone-based communications, but also to contribute to the development of technologies for a satellite-based energy of multimedia broadcasting system for mobile-internet devices. It will play an important role in the provision of services and information, such as the transmission of CD-quality audio and video; more reliable voice and data-internet communications; global positioning of moving objects such as cars, broadcasting; faster disaster relief, etc. Experiments in the fundamental technology for satellite-positioning, using a high-precision clock system, would be conducted between ETS-VIII and Global Positioning System (GPS), through the reception of signals transmitted from the clock [3].

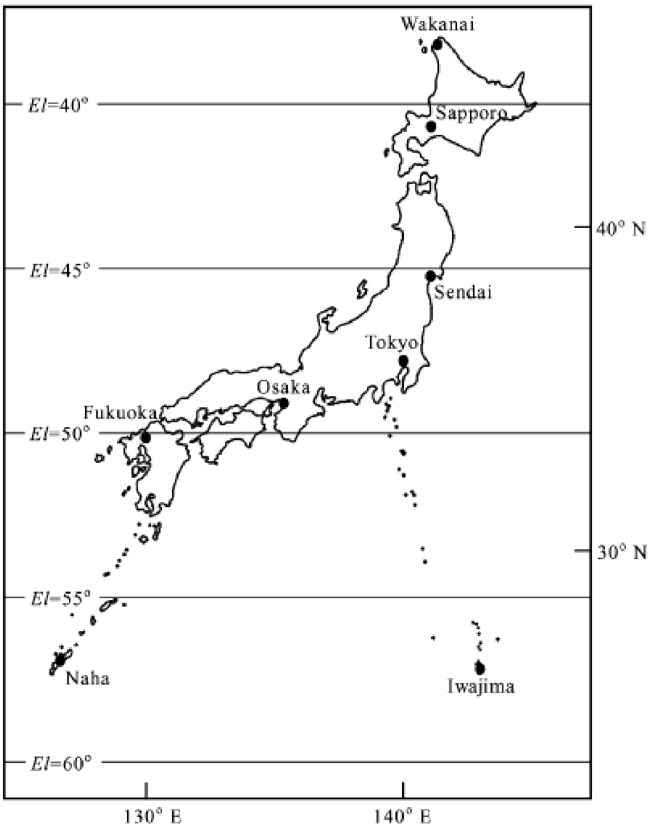

Fig. 2. Japan map: elevation angle of beam direction [4].

In addition, based on the spreading of the GPS or the Electronic Toll Collection (ETC) at this time, the vehicular communication systematization is remarkable. From this phenomenon, in the near future, the systems for mobile-internet of satellite energy communication using the internet environment will be generalized and the demand for on-board mobile-internet of satellite energy communication systems as well as antenna is expected to increase. Anticipating this, we enrolled in the council operation for the experimental use ETS-VIII and develop, jointly by the National Institute of Information and Communications Technology (NICT), an on-board antenna system for mobile-internet of satellite energy communication.

As geostationary satellites are remotely located from the earth about 36,000 km, the incoming wave is very weak. Consequently, it is required that the antenna for mobile-internet of satellite energy communication having a high gain in the case multimedia communications performing large-capacity data communication is aimed. Furthermore, to be integrated in the cars, in the point of view of the car design, it is recommended the overall system to be light and compact. However, among the antennas for mobile-internet of satellite energy communication proposed so far [4], [5], it is necessary to embark phase shifter, motor, etc., especially for the antenna systems equipped with satellite-tracking function [6], which produce a problem in terms of the size and the cost.

In this paper, a modified model of antenna is proposed in order to simplify and miniaturize the antenna. The antenna consists of a dual-fed equilateral-triangular patch antenna with a hole for Left-Handed Circular Polarization (LHCP). However, although the feed-line design has already been developed [4], [7], [8], its design was for patch without hole. Here, design for an array fed by microstrip-line aiming at ETS-VIII is discussed. The design of a simple LHCP dual proximity fed equilateral-triangular array antenna with a hole is studied in order to support the mobile-internet of satellite energy communication using ETS-VIII.

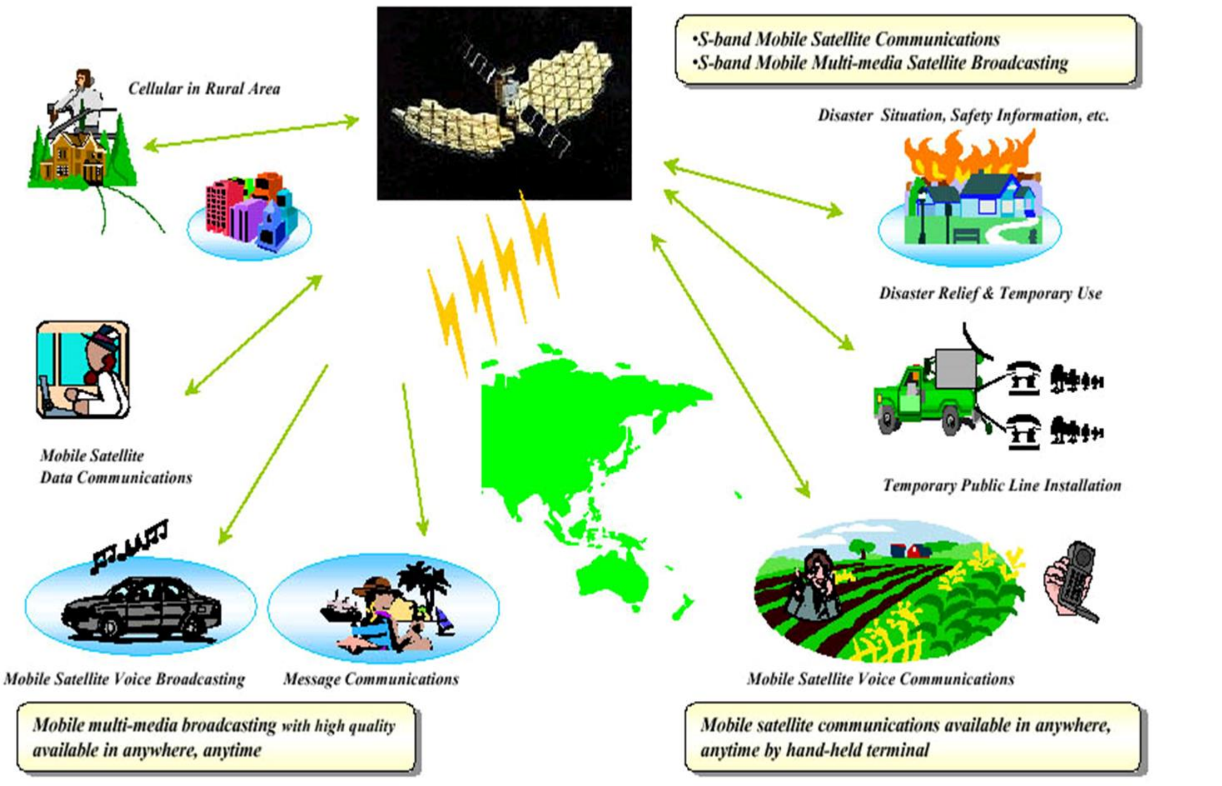

Fig. 3. Conceptual chart of mobile-internet of satellite energy communication system [5].

2. Specifications and Targets

Specifications and targets of the antenna for mobile-internet of satellite energy communication aimed at ETS-VIII applications are shown in Table 2. Here, a thin miniaturized antenna designed for hundreds kbps data-internet transfer (gain 5 dBic) is analyzed by numerical simulations. In addition, the measurements are assumed to take place in the center of Tokyo. As a result, the targeted elevation angle (*El*) is set to 48°. Furthermore, the operating frequency is fixed to 2.5025 GHz for reception frequency [9]-[11].

Table 2. Specifications on the Antenna for Mobile-Internet of Satellite Energy Communication System (ETS-VIII)

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

3. Structure of the Antenna

Fig. 4 depicts the configuration of a single and an array equilateral triangular-patch with a hole, using a conventional substrate (relative permittivity 2.17 and loss tangent 0.0009). The antenna is fed by proximity feed with microstrip-lines which the width *W* is 3.0 mm for *Rx* to obtain a thin configuration. A novel dual feed type with a hole is proposed for the generation of a compact LHCP using a compact equilateral triangular-patch, where one of the microstrip-line feeds is longer than the other introducing a 90° phase delay. In the same manner, a Right-Handed Circular Polarization (RHCP) could be realized by swapping the microstrip-lines with respect to the *y*-axis. The proposed feeding technique is designed to obtain an ideal and stable current distribution on the triangular-patch surface hence it improve the previously developed antennas [3].

In this paper, the method of moment (MoM) (IE3D Zeland software) is employed to simulate the model with a finite ground plane. We consider that the efficient thickness of the antenna (see Fig. 4) allowing either the substrate thickness for the microstrip-line or feeding line (substrate 2) and triangular patch (substrate 1) are defined implicitly as $h_1 = h_2 = 0.8$ mm. The length of microstrip-line inserted under the patch l_e is 11 mm and a quarter-wave transformer is used to obtain a matching impedance of 50 for *Rx*. The detailed parameters of the microstrip-line (see Fig. 4) for *Rx* are $l_s = 5$mm, $l_d = 11$ mm, $l_{d1} = 4$ mm, $l_c = 3$ mm, $l_m = 2$ mm, $l_{st} = 11$ mm, $r = 7$ mm. The width of the input microstrip-line W_s and patch length parameters (for $a = b$) are 4.90 mm and 46.15 mm, respectively [12]. In the case of array antenna, the distance between the tip of patch antenna *c* is 5 mm, and the length of array antenna configuration *l* is 153.64 mm. In addition, a hole with dimension of radius $r = 7$ mm is embedded in the patch which hole center is at the null voltage point of the fundamental TM_{10} mode of the simple triangular microstrip antenna without a hole. Then, it is expected that the current path or guide wavelength λ_g of the TM_{10} mode with hole is longer than the current path without hole, thus the frequency operation can be decreased. Also, by adjusting the radius hole *r* and the length of l_e and l_c, two orthogonal resonant modes can be equal amplitudes and 90° phase difference and a compact Circular Polarization (CP) operation on the target frequency at 2.5025 GHz can be achieved, with the reduction percentage of length patch is about 12.60 % ($a = 52.80$ mm to $a = 46.15$ mm) [12], [13].

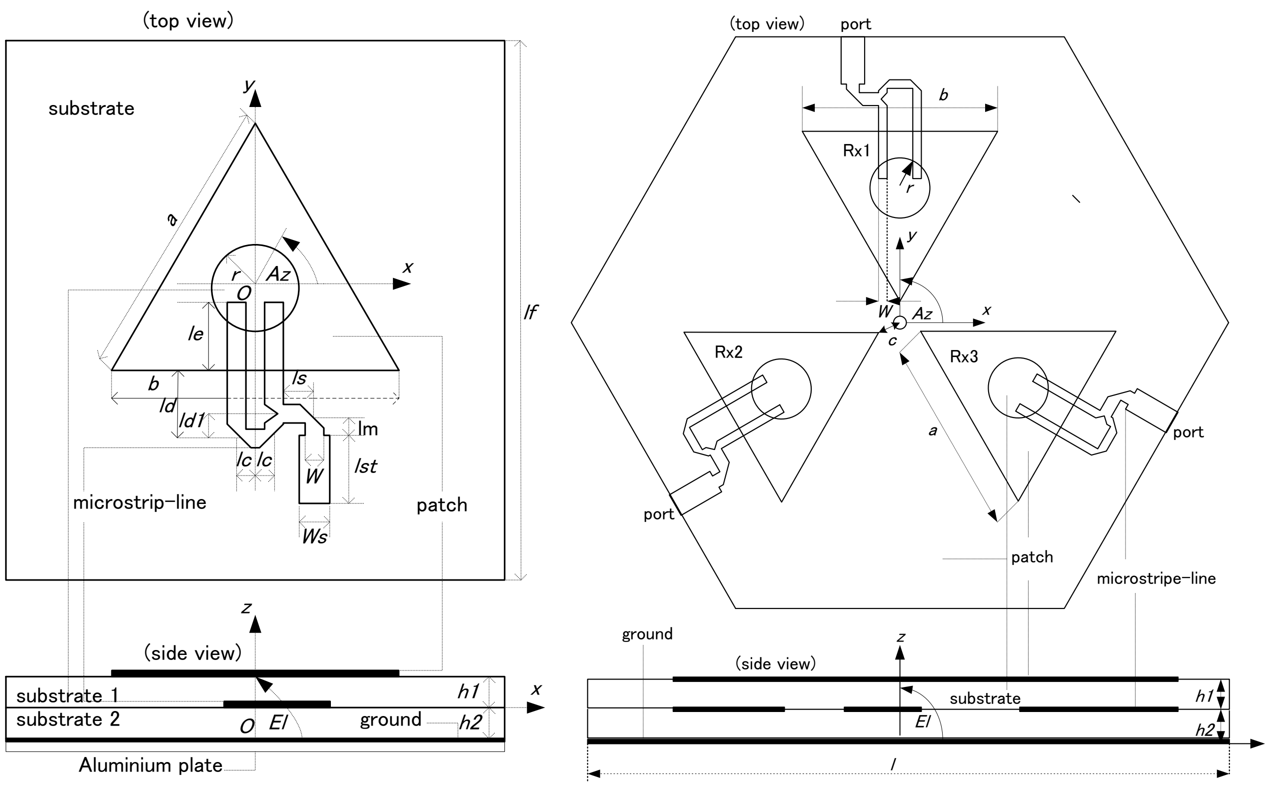

Fig. 4. Configuration of antenna: single patch and patch array antenna for reception (Rx).

4. Simulation Results

Fig. 5 and Fig. 6 represent of the *S*-parameter and input impedance, in the case of array antenna using a hole whereas single element 1off#, 2off#, and 3off#. Fig. 5 shows that 2off# is the best result of *S*-parameter compared with the others. It is caused by the mutual coupling between fed elements, their phase and distance and affected by finite ground system. Fig. 6 depicts the input impedance characteristics both for resistance (real) and reactance (imaginary). The efficient value for antenna performance is obtained at a frequency around 2.5025 GHz. Fig. 7 shows the frequency characteristic, in the case of single element 1off#, the gain and axial ratio tend to shift slightly to the below frequency at elevation angle 48°.

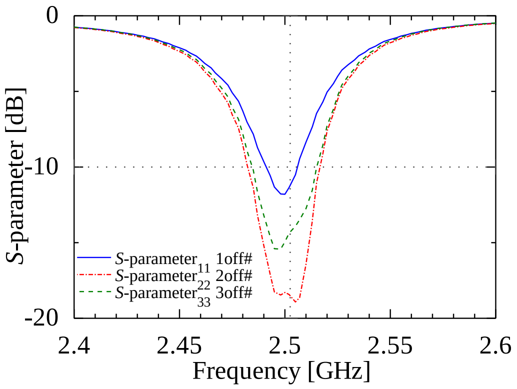

Fig. 5. S-parameter vs frequency.

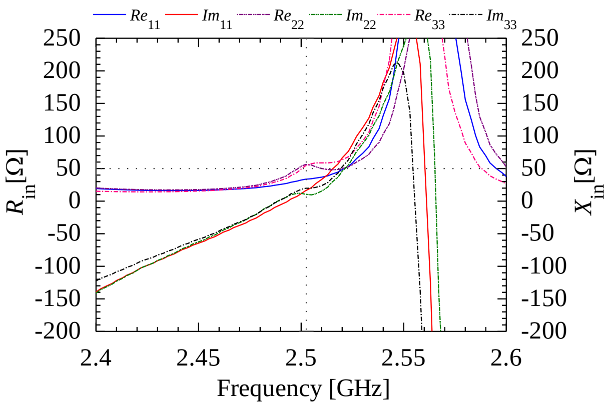

Fig. 6. Input impedance.

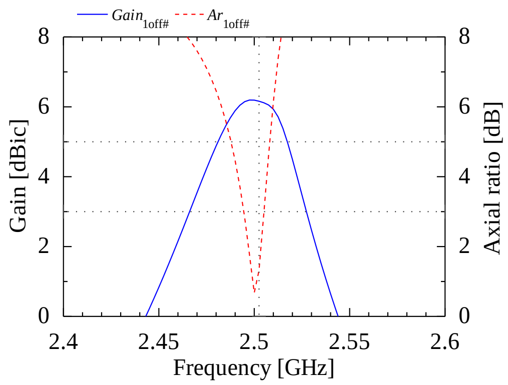

Fig. 7. Gain and axial ratio vs frequency at *El* = 48° (1off#).

The beam of the antenna is generated by a simple mechanism that consists of switching 1off# of the radiating element of reception shown in Fig. 4. By considering the mutual coupling between fed elements, their phase, and distance, the beam direction can be varied. Hence, the two fed elements theoretically will generate a beam shifted of -90° in the conical-cut direction from the element which is switched OFF, in the case the antenna configuration shown in Fig. 4. For example, when element #Rx1 is switched OFF, the beam is directed towards the azimuth angle *Az* = 0° [5], [14], [15]. Then, the current and its vector distribution are shown in Fig. 8.

Fig. 9 describes the radiation characteristics in the elevation-cut plane angle when element #Rx1 is switched OFF. It is assumed that from northern to southern Japan the elevation angle is 38° to 58° towards the satellite position. According to this figure, the axial ratio satisfies the targets although the gain at the lowest target elevation angle is less than 5 dBic. Fig. 10 represents the radiation characteristics in the conical-cut direction. This figure shows that the peak gain and the axial ratio is around 6.82 dBic and 0.66 dB respectively in the theoretical beam direction. The gain is satisfied the target above 5 dBic in the 120°

coverage for each beam. In addition, the axial ratio satisfies less than 3 dB. However, the bandwidth of *S*-parameter, gain, and axial ratio are still not good enough yet. Hence, it will be considered in the next research in order to improve the bandwidth performances [16].

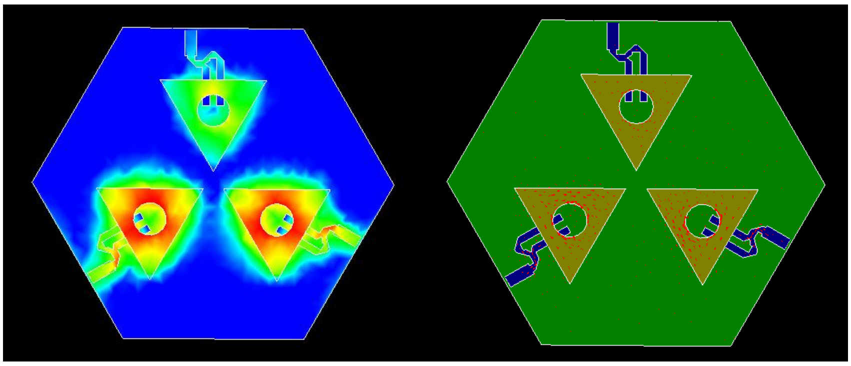

Fig. 8. Current and its vector distribution when element #Rx1 is switched OFF.

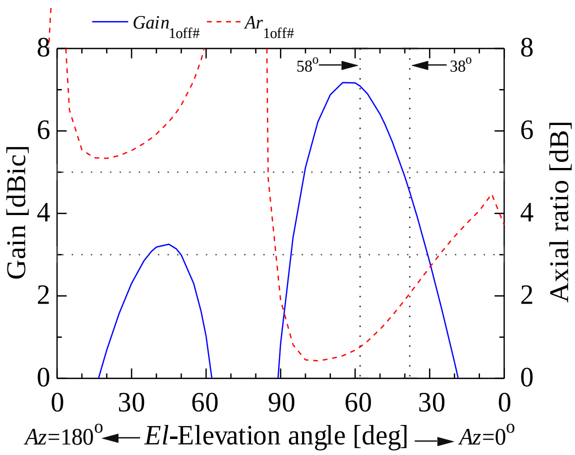

Fig. 9. Radiation characteristics in the elevation-cut plane for reception (Rx).

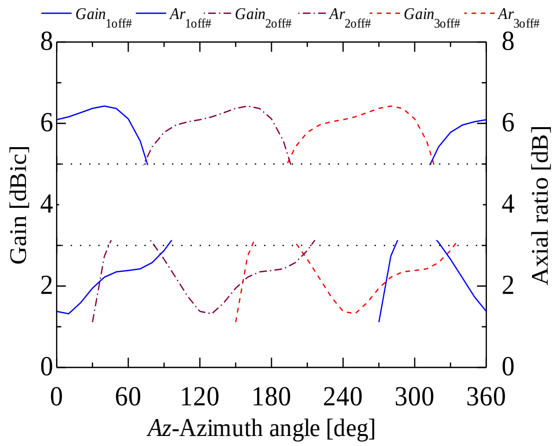

Fig. 10. Radiation characteristics (gain and axial ratio) in the conical-cut plane on the elevation angle El = 48° for reception (Rx).

5. Conclusion

The design of a simple Left-Handed Circular Polarized (LHCP) dual proximity fed equilateral-triangular array antenna with a hole has been studied in order to support the mobile-internet of satellite energy communication using Engineering Test Satellite VIII (ETS-VIII). The performances analysis of the antenna have been discussed. *S*-parameter, input impedance, and frequency characteristic are affected by the mutual coupling between fed elements, their phase and distance, and finite ground system. The target of the gain and axial ratio were satisfied namely above 5 dBic and less than 3 dB, respectively, at the 120° coverage for each beam and in the elevation angle of 48°. In the future work, integrating the array microstrip antenna could be applied on mobile-internet of satellite energy communication system to support the communication technology for smart grid.

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