Dual Band Circularly Polarized Equilateral Triangular-Patch Array Antenna for Mobile Satellite Communications

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INTRODUCTION

The Japan Aerospace Exploration Agency (JAXA) will launch a geostationary satellite called Engineering Test Satellite VIII (ETS-VIII) in 2006. ETS-VIII will conduct orbital experiments on mobile satellite communications in the S-band frequency range. Mainly in support of the development of a technology for the transmission and reception of multimedia information such as voice and images for land mobile systems. In this research, a low profile dual-band satellite-tracking triangular-patch array antenna is proposed. Fig.1 shows the direction of ETS-VIII seen in Japan that is illustrated by the elevation angle (*El*) that the *El* of the beam of the developed antenna must cover from 38^o (Wakanai city at Hokkaido island) to 58^o (Naha city at Okinawa island) to maintain the multimedia service over all of Japan. The targeted minimum gain of the antenna is set to 5 dBic at the central elevation angle (*El*=48°) in the Tokyo area for data transfer applications of around one hundred kbps. The antenna should be designed as thin, compact, small and simple as possible, to allow it to be incorporated onto a car roof.

SPECIFICATIONS AND TARGETS

Table I shows the specifications and targets desired from an antenna for use with mobile satellite communications, in particular aimed at ETS-VIII applications, that are used in this research. In this research, the operating frequency of a single patch for reception (Rx) and transmission (Tx) are set to 2.5025 GHz and 2.6575 GHz, respectively, as shown in Table I. Both Rx and Tx are considered to work in left-handed circular polarization (LHCP) where the maximum axial ratio is 3 dB in the targeted direction (azimuth angle Az=0^o to 360^o and El=48^o).

ANTENNA CONFIGURATION

The antenna as single patch is discussed prior to the consideration of the array configuration. Fig. 2 shows the configuration of a single equilateral triangular-patch with its parameters. The antenna is fabricated using a conventional substrate (relative permittivity ε_r=2.17 and tan δ=0.00085). The elements are fed by novel type of proximity feeds with microstrip-lines whose widths w are 3.0 mm for each patch of Rx and Tx to obtain a thin configuration. A novel dual feed type is proposed for the generation of left-handed circular polarization (LHCP) by using equilateral triangular-patch, where one of the microstrip-line feeds is $\lambda/4$ longer than the other introducing a 90^o phase delay. The proposed feeding technique is designed to obtain an ideal and stable current distribution on the triangular-patch surface hence improving previously developed antenna [1]. In this research, the method of moment (MoM) was employed to simulate the model with a finite ground plane. The substrate thickness for the microstrip-line or feeding line (substrate 2) and triangular patch (substrate 1) are defined with the other implicit (h_1=h_2=0.8 mm). The lengths of microstrip-line inserted under the patch l_e are 14 mm and 10 mm for Rx and Tx, respectively and a quarter-wave transformer is used to obtain a matching impedance of 50 Ω for Rx and Tx, respectively. The detailed parameters of the microstrip-line (see Fig. 2) for Rx and Tx are l_s=5 mm, l_d=11 mm, l_{d1}=4 mm, l_c=5 mm, l_m= 2 mm, and l_{st}=11 mm.

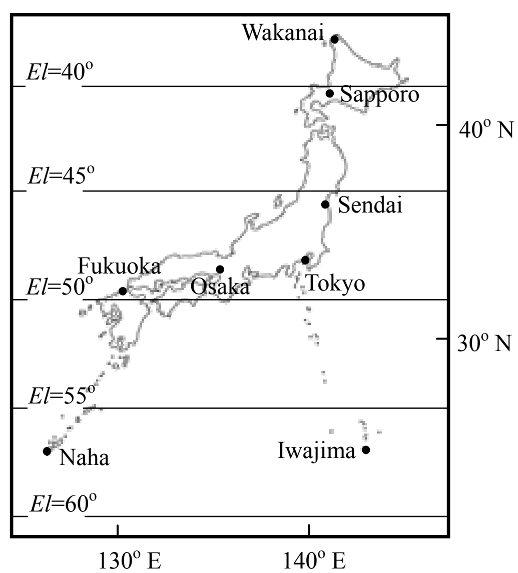


Fig. 1 Japan map: elevation angle of beam direction

Table I. Specifications 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 (LHCP) 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
maximum isolation		20 dB

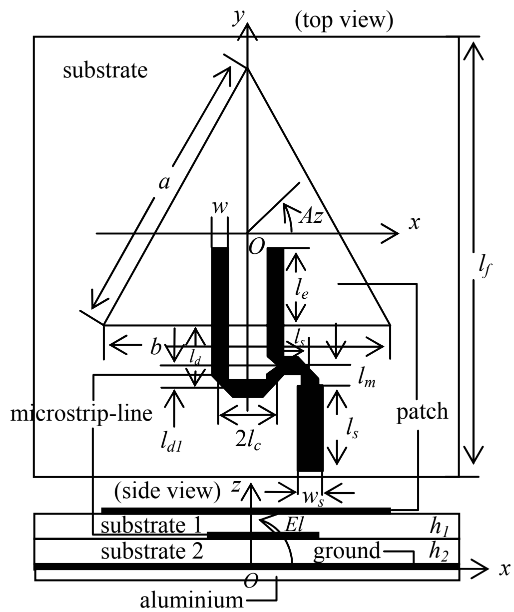


Fig. 2 Configuration of single triangular patch antenna

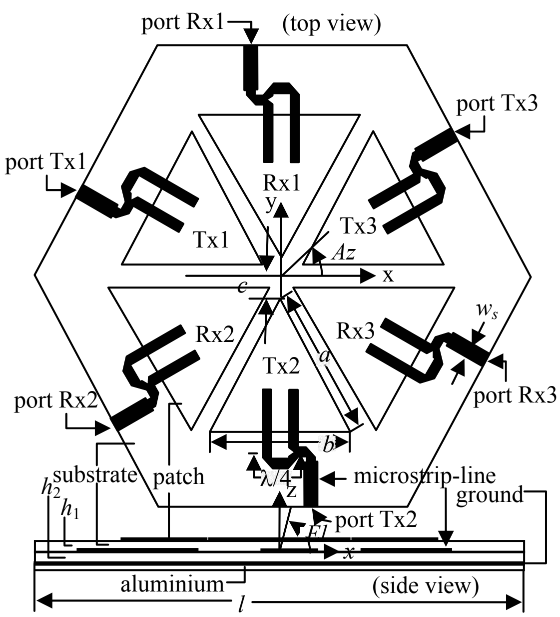


Fig. 3 A dual band equilateral triangular-patch array antenna

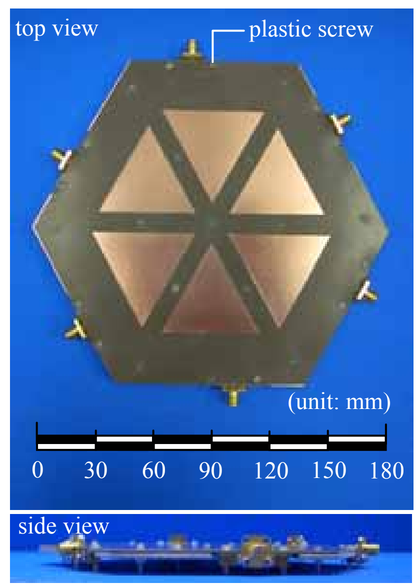


Fig. 4 Fabricated antenna

The width of the input microstrip-line w_s for Rx and Tx are 4.7 mm and 4.0 mm, respectively. The patch length parameters (for a=b) obtained are 52.5 mm and 49.4 mm for Rx and Tx, respectively. Fig. 3 shows the configuration of the triangular-patch array antenna; the Tx and Rx sections are composed of three triangular elements each. This configuration is used to minimize space usage. The fabricated triangular-patch array antenna is shown in Fig. 4 from the top and side. An aluminium plate with thickness 2 mm is used to support the substrate.

PERFORMANCE OF THE ANTENNA

Fig. 5 shows the S-parameters obtained from the simulation model and the measurement for element no. 1 of the Rx and Tx, shown in Fig. 3 as Rx1 and Tx1. Then Fig. 6 shows the input impedance characteristics of patch Rx1 and Tx1. These figures show that the simulation results for both Rx and Tx are shifted 0.7% and 0.5% respectively to lower frequencies from the measurement result. It is considered that the measurement systems (i.e. cable, connectors, plastic screws etc) affect the characteristics of the antenna. In case of input impedance, the real part of measurement at the Rx and Tx target frequencies (center frequency of Rx 2.5025 GHz and Tx 2.6575 GHz) is 50 Ω providing a good match.

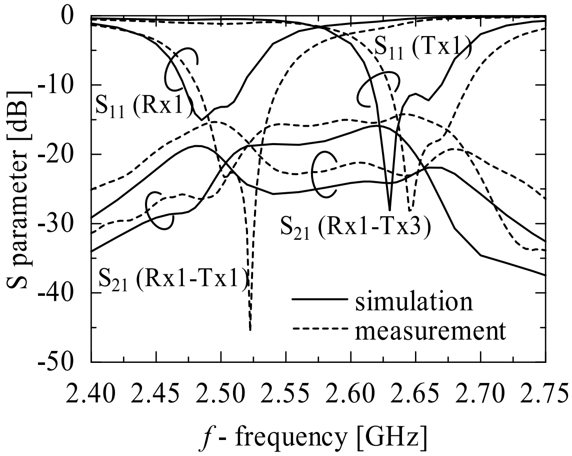


Fig. 5 S-parameter vs frequency

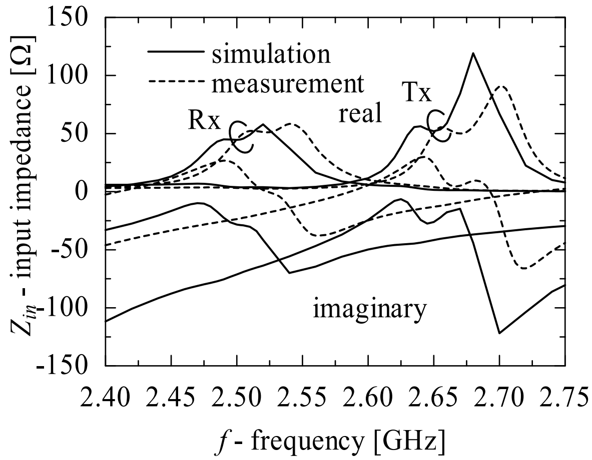
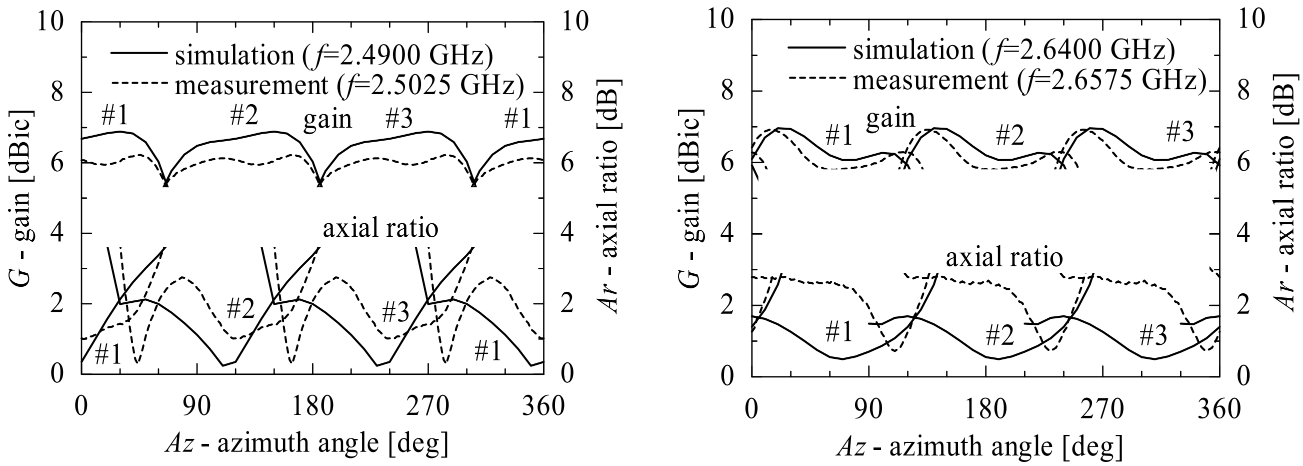
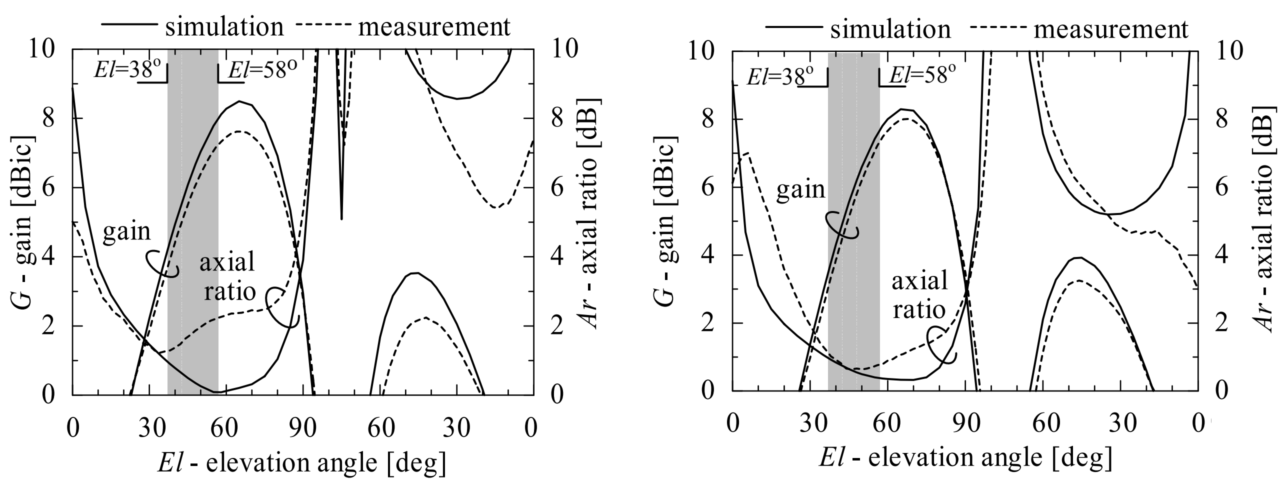


Fig. 6 Input impedance vs frequency



(a) reception (b) transmission

Fig. 7 Radiation characteristics in the conical-cut plane for an elevation angle $El = 48^{o}$



(a) reception (b) transmission

Fig. 8. Radiation characteristics in the elevation-cut

BEAM SWITCHING TECHNIQUE

The beam of the antenna is generated by a simple mechanism that consists of switching OFF one of the radiating elements shown in Fig. 3. By considering the mutual coupling between fed elements, their phase and distance, the beam direction can be varied. Hence, the two fed elements theoretically generate a beam shift of -90^o in the conical-cut direction from the element that is switched OFF, in the case of a LHCP antenna. For example, when Rx element 3 placed at Az=330^o is switched OFF, the beam is theoretically directed towards the azimuth angle Az=240^o (see Fig. 7 (a), beam no. 3 shown as symbol #3 in the graph). The other two beams of reception can be generated in the same manner, switching each element OFF successively (Rx2 and Rx3 in Fig. 3 and each beam shown as symbol #2 and #3 in Fig. 7 (a), respectively).

The simulation and measurement results of gain and axial ratio characteristics of the beam switching in the conical-cut plane are shown in Figs. 7 (a) and (b) for Rx and Tx respectively. The figures show that the maximum gain is 5.4 dBic for both the simulation and the measurement of Rx, and 5.9 dBic and 5.8 dBic for both the simulation and measurement of Tx. From these results, both simulation and measurement results are better than the targets in Table 1 (minimum gain 5.0 dBic and maximum axial ratio 3 dB) and cover the whole azimuth angle. The 5-dBic beam coverage is more than 120^o, and the 3-dB axial ratio coverage of the simulation and measurement results covers 360^o in the conical-cut plane at *El*=48^o.

The measurement results of Rx and Tx (Fig. 7) show a saddle-shape scalloping occurs for both the main beam gain and axial ratio. The scalloping in the main beam becomes more apparent when the distance between the center of the antenna and the apex of patch is reduced [1] or the distance decreased. This effect is also considered to decrease the performance of the antenna, especially its axial ratio. This is due to the influence of the edge effect that generates an oscillation of current distribution on the surface of the patch with finite ground plane and the change in antenna characteristics as the substrate surface is reduced, in particular the resonant frequency and radiation pattern [2].

Figs. 8 (a) and (b) show the radiation characteristics in the elevation-cut for Rx and Tx, respectively. If the antenna is put on the car roof and must cover the area of Japan (see Fig. 1), considered to be ±10^o in elevation with center at *El*=48^o, the gain and axial ratio in this range must satisfy the targets (minimum gain 5 dBic and maximum axial ratio 3 dB).

Fig. 8 (a) shows that the gain of simulation result, between *El*=40^o and 58^o is higher than 5 dBic, and the measurement result can cover from *El*=42^o to 58^o. The axial ratio of both simulation and measurement from *El*=38^o to 58^o are lower than 3 dB, showing that the axial ratio of Rx satisfies the targets. At this point the gain at low elevation angles needs to be improved by around 2^o and 4^o for simulation and measurement respectively, to meet the desired targets. Then Fig. 8 (b) shows the gain of the simulation result, between *El*=43^o and 58^o is higher than 5 dBic, and the measurement result can cover from *El*=45^o to 58^o. The axial ratio of both simulation and measurement from *El*=38^o to 58^o are lower than 3 dB, showing that the axial ratio of Tx satisfies the targets. At this point the gain at low elevation angles needs to be improved by around 5^o and 7^o for simulation and measurement respectively, to meet the desired targets.

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