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The Analysis of Stub on Coplanar-Fed of Single and Array Microstrip Antenna for Mobile Satellite Communication

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***Abstract*— The microstrip antenna has small, lightweight shape characteristics, and limit performances. It is necessary to increase the performances, especially the axial ratio (*Ar*) of the previous antenna configured in two layers accompanying the capacitive coupling between them. If length of feeding line and width-to-length ratio of radiating patch are not matched, it can decrease the *Ar* performance. This paper discusses about the analysis of previous antenna (two layers) and modified antenna (one layer), optimized modified antenna using stub on coplanar-fed both single and array microstrip patch antenna for mobile satellite communication, especially for receiver antenna, *Rx*. The Method of Moment (MoM) is used to analyze the antenna with an infinite ground plane and substrate. The antenna is made of a thin patch conductor and a microstrip-line. The microstrip-line is located on the same layer which has the thickness *h* = 1.6 *mm* and uses a conventional substrate (relative permittivity, ε_r = 2.17 and loss tangent, δ = 0.0009). The patch conductor is fed by a coplanar-fed with microstrip-line to obtain a conformal configuration. The dual-fed type is to generate a left-handed circular polarization (LHCP) which is combined with an equilateral triangle patch. In this case, one of the microstrip-line feeds is set longer than the other to introduce a 90^0 phase delay. Moreover, the simulation results discuss about the three varies size of stub embedded on coplanar-fed and compare among of them to confirm that the antenna satisfy the target. The results of single antenna using stub-fed, especially for bandwidth of axial ratio below 3-dB and gain above 5 dBic are about 0.02 GHz and 0.065 GHz, respectively. The results of array antenna, in the case of bandwidth of axial ratio below 3-dB and gain above 5 dBic are about 0.03 GHz and 0.3 GHz, respectively. In addition, the result for axial ratio of the modified antenna and the previous antenna at 2.5025 GHz are 0.27 dB and 1.02 dB, respectively. It is caused a coplanar-fed which connected directly to the radiating patch (one layer antenna).**

***Keywords*— one layer; stub; coplanar-fed; single and array microstrip patch; LHCP**

I. Introduction

The microstrip antenna has small and lightweight shape characteristics, low manufacturing cost, large operating frequency area between 400 MHz to 60 GHz, and can be integrated with the MIC (Microwave Integrated Circuit). Moreover, the microstrip antenna is also widely used in PCS (Personal Communication System), mobile satellite communication, DBS (Direct Broadcast Satellite), WLAN (Wireless Local Area Networks), and radar.

Meanwhile, the limit performance of the microstrip antenna is narrow impedance bandwidth. Pozar [1] shows that there are several ways to increase bandwidth microstrip antenna. Microstrip antenna bandwidth can be increased by increasing the thickness of the substrate, but this can increase the dominance of surface waves. Another way to increase bandwidth microstrip antenna is by multilayer configurations between the radiating element and the parasitic element, but it is quite difficult in the fabrication process of the antenna [2].

In practice, sometimes it is needed an antenna design that has the necessity emission characteristics. For example, the antenna with a radiation pattern that has a maximum radiation or minimum radiation in a particular direction, the antenna with a radiation pattern that has a low side lobe level, or the antenna has a radiation pattern with the desired shape. Design method to obtain the radiation pattern with a specific emission shape is called synthesis. Two steps for this synthesis are: (i) determine the analytical model of the desired emission beam, (ii) realize of the analytical model of the antenna design. The antenna with specific emission characteristics is typically used in mobile satellite communications systems, mobile communications, radars and communications systems engineering which requires modifications certain emission beam radiation in order to adjust resources and applications necessity.

In addition, mobile satellite communication using the geostationary satellite, that is remotely located (about 36,000 km) from the earth, yield very weak incoming wave. Consequently, it is required the receiver antenna for mobile satellite communication that has a high gain for performing large-capacity data communication. Furthermore, when the receiver antenna integrate to car, in the point of view of the car design, it is recommended the overall system to be light and compact.

Furthermore, the antenna that mentioned above need a feeding. The singly fed circularly polarized (CP) antennas have inherent limitation in gain, impedance, and axial ratio bandwidths. This is mainly caused by the resonant nature of the patch antenna which has a high unloaded Q-factor and the frequency-dependent excitation of two degenerative modes (TM_{01} and TM_{10}) when using a single feed [3].

This paper discuss and analysis the needs of low-power antennas at *S*-band for mobile satellite communication that located on the roof of cars, trains, ships, and others. The characteristics performance of this antenna is circular polarization, particularly a circular to the left, make it easier to transmit and receive signals to/from the satellite. This antenna is made by using the type of microstrip antenna that uniquely structured, so accordance with the technical specifications and the desired goal, especially as a receiver of mobile satellite communication application at the Kanto region (Japan) and its surroundings [4].

II. MATERIAL AND METHOD

In this investigation, only the numerical simulation related with the microstrip antenna is performed and the result is discussed. In particular, the analysis focuses on the study of previous antenna and modified antenna, optimized the modified antenna using stub-fed or the effect of stub-fed on single and array microstrip antenna for mobile satellite communication. In this case, the array antenna use the three element patches as receiver, *Rx* [4]-[5].

The Method of Moments (MoM) has been chosen for this numerical analysis to make fast calculation. The software used was Ensemble^{TM} version 8 from Ansoft [6]. According to the software characteristics, the dielectric substrate and the ground plane are considered to be infinite. The use of this software provides some advantages for industries and researchers when developing new telecommunication technologies, for instance the ability to conduct preliminary study of the new antenna design without having to build a hardware prototype.

In this paper, numerical simulation results of the proposed antenna are shown, especially for elevation, El = 48° at a particular area [4], [7]-[12]. The results of this antenna when utilizing the circular polarization can be simply obtained by properly adjusting the element parameters, feeding and stub-fed design. Furthermore, vary of the results are also obtained on the characteristic performances which affected by stub-fed, especially *S*-parameter, frequency characteristic, elevation and conical cut-plane, both of single and array antenna.

For ease discussion in this paper, we separate the explanation into three parts namely (i) single antenna (previous antenna and modified antenna), (ii) single antenna using stub-fed, (iii) array antenna using stub-fed. Firstly, we discuss about the antenna configuration of each part. Then in section III, we explain about the analysis and comparison of each part. In this section, we focus on the design of single and array triangle patch antennas for mobile satellite communication that use microstrip-line feed.

A. Single Antenna (Previous Antenna and Modified Antenna)

In microstrip antenna technology, it is necessary to make the manufacturing easy and to increase performances. In this case, the axial ratio (*Ar*) of the previous antenna configured in two layers that cause the capacitive coupling, the bandwidth difference, and various losses are embedded between the two layers. Therefore, it affect the current distribution on the patch surface decreasing the *Ar* performance.

Based on this idea, we can propose a new modified antenna as shown in Fig. 1. This figure shows the configuration of an equilateral triangle patch antenna with its parameters. There are two types of layer, two layers and one layer, using a conventional substrate (relative permittivity, ε_r = 2.17 and loss tangent, δ = 0.0009).

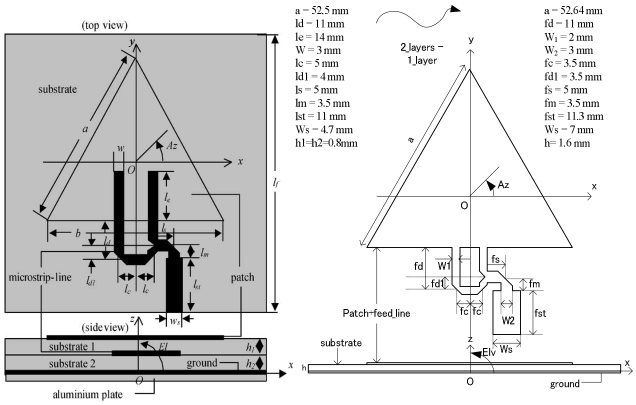

Fig. 1 Configuration of previous and modified antenna

B. Single Antenna Using Stub-fed

Fig. 2 shows the configuration of the equilateral triangle stub-fed antenna with use single layer. The various shapes of stub can be considered. The 3-models of stub that the stub position embedded on the right of microstrip-line as seen in Table I are investigated. Model-1 is the shape of antenna without use the stub. Model-2 and model-3 use the stub with Wa = 3 *mm* and Wa = 5 *mm*, respectively. However, all of them have similar characteristic performances, except the *S*-parameter and input impedance.

TABLE I
ANTENNA PARAMETERS

Parameter	Value of Model-1 (*mm*)	Value of Model-2 (*mm*)	Value of Model-3 (*mm*)
a	52.64	52.64	52.64
fd	11	11	11
fd1	3.5	3.5	3.5
fc	3.5	3.5	3.5
fs	5	5	5
fm	3.5	3.5	3.5
fsr	-	4	3
fss	-	7	7

fst	12	13.2	13
W_1	2	2	2
W_2	3	3	3
Wa	-	3	5
Ws	7	7	7

The antenna is made of a thin conducting patch that the radiating patch and microstrip-line located on the same layer whose thickness is h = 1.6 *mm* and using a conventional substrate (ε_r = 2.17 and δ = 0.0009) [4], [11], [12].

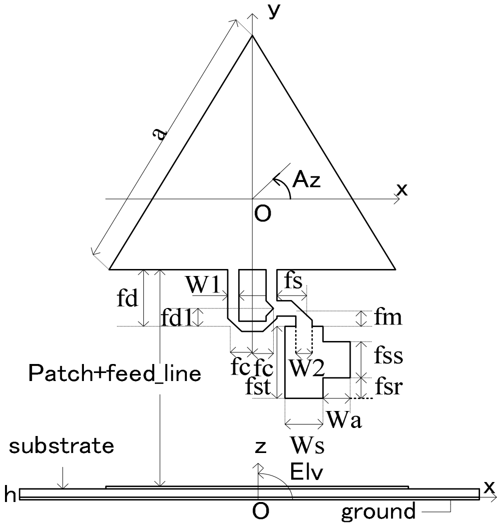

Fig. 2 Configuration of single antenna using stub-fed

C. Array Antenna Using Stub-fed

Fig. 2 also illustrates the configuration of the single patch equilateral triangle antenna for array antenna. The antenna parameters are almost the same with the model-2, only difference in parameter *fst* and *Wa* about 14 *mm* and 5 *mm* for array, respectively. The configuration of array antenna is same with single antenna but the number of element patches are three which rotated 120^0 each other, as shown in Fig. 3. There are three types of parameter size of single for array antenna, namely: without the use of stub with *fst* = 16 *mm* and *Wa* = 0 *mm*, the use of stub with *fst* = 14 *mm* and *Wa* = 3 *mm*, and the last ones is the use of stub with *fst* = 14 *mm* and *Wa* = 5 *mm*. In addition, the distance of the tip of the triangle to the central point, *lo* = 10 *mm*, the length of hexagonal ground g = 93.07 *mm*, and the angle between two adjacent patch seen from the central point, θ = 120^0. The array antenna is also made from a conventional substrate (ε_r = 2.17 and δ = 0.0009) with the substrate thickness h = 1.6 *mm*. The element patch of this antenna is supplied by coplanar-fed where the width *Ws* = 7.0 *mm* for receiver antenna, *Rx*. Singly-fed forked can generate two waves with different phase 90^0 to obtain left hand circular polarization (LHCP). In the same manner, the circular polarization wave to the right (RHCP) can be realized by exchanging the microstrip-lines on the *y*-axis. The usage of feeding technique is to get the ideal and stable current distribution on the surface of the element patch antenna by increasing performance that developed previously [4], [7], [8], [12], [13].

Some types of triangle circular polarization antenna has been developed previously, but hard to be designed and optimized, since the ratio between the two sides of the triangle (seen Fig. 1) affect the performance of axial ratio with a high level of sensitivity. Mechanical probe feeds are generally applied to produce circular polarization on a triangular patch antenna, but this technique is more difficult than coplanar-fed or microstrip-line in terms of the fabrication process [14], [15]. In addition, the feeding probe technique with a single-fed point will produce an unstable current distribution on each patch when the patches are composed of an array configuration. Therefore, coplanar-fed is used for an equilateral triangle patch antenna to design and fabricate the antenna easier without need to optimize the ratio between the two sides, as shown in Fig. 2 [16].

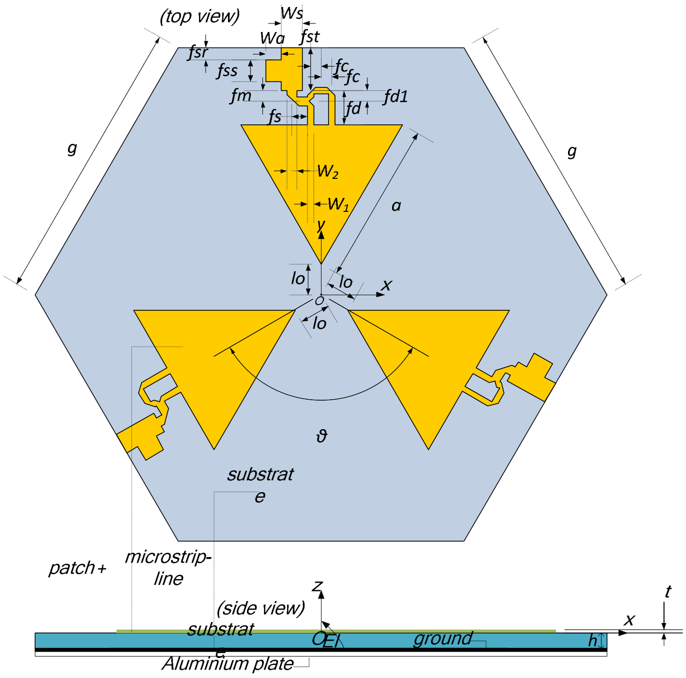

Fig. 3 Configuration of array antenna using stub-fed

III. Results and Discussion

A. Single Antenna (Previous Antenna and Modified Antenna)

Fig. 4 and Fig. 5 show the increasing of axial ratio (*Ar*) when parameters configuration of previous antenna are changed partially. The changing of this parameters are the dimension of width *W*, length of *lc* and ld_1. For instance, the width of previous antenna, *W* = 3 *mm*, is changed become two parts in modified antenna, namely W_1 = 2 *mm* and W_2 = 3 *mm*. In the same manner, the length of *lc* = 5 *mm* is changed to *fc* = 3.5 *mm*, also ld_1 = 4 *mm* become fd_1 = 3.5 *mm* to achieve smooth LHCP with good result of *Ar*. These changing are due to the influence of the edge effect in microstrip-line feed and proximity coupled feed. The advantages of microstrip-line feed or coplanar feed are easy to feeding technique and fabrication, also simplicity in modelling as well as impedance matching that can avoid undesirable cross polarization effects. In other hand, the disadvantages are the thickness of the dielectric substrate increases, surface waves and spurious feed radiation also increases, which hampers the bandwidth of the antenna. Moreover, the advantages of proximity coupled feed are has the largest bandwidth and low spurious radiation. Other than that, its disadvantages are difficult to fabricate, using length of feeding line and width-to-length ratio of radiating patch to control the match.

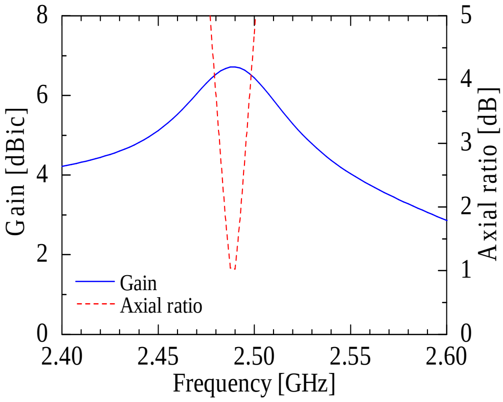

Fig. 4 Frequency characteristic of previous antenna

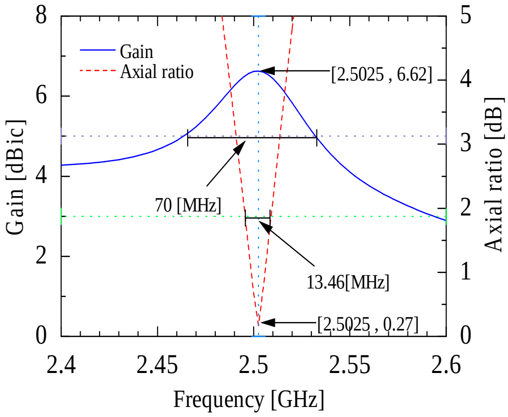

Fig. 5 Frequency characteristic of modified antenna

Fig. 6 shows the *S*-parameter of previous antenna has impedance bandwidth larger than modified antenna in Fig. 7. In this figure, the *S*-parameter decreases strongly at the resonant frequency caused by the loci of feeding antenna differences between two layers and one layer. Moreover, to increase the *S*-parameter of modified antenna in one layer, we change the width of antenna, Ws = 4.7 *mm* become 7 *mm* (seen Fig.1), but this way is just a little bit increasing of *S*-parameter. Hence, the next discussion is about optimized of modified antenna using stub-fed to increase the performance of antenna, especially *S*-parameter.

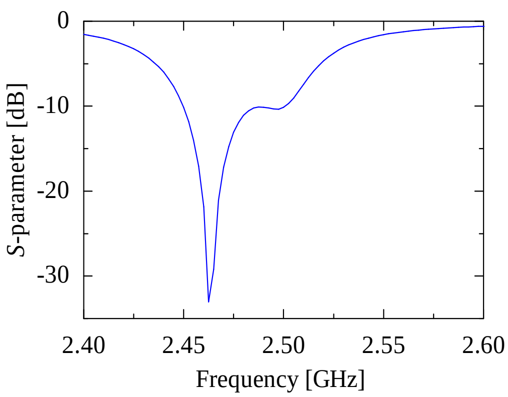

Fig. 6 *S*-parameter of previous antenna

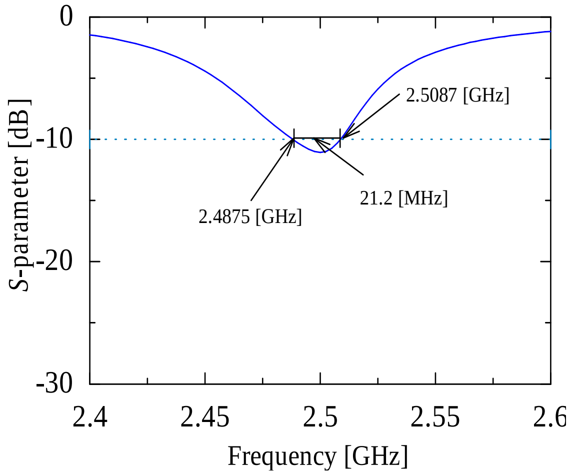

Fig. 7 *S*-parameter of modified antenna

B. Single Antenna Using Stub-fed

Fig. 8 shows the frequency characteristic that not difference for all model, only a little bit shifting in the case of gain to up-down on the begin and end of the wave as function of frequency. It is similar type of the radiation pattern in Fig. 11 and Fig. 12.

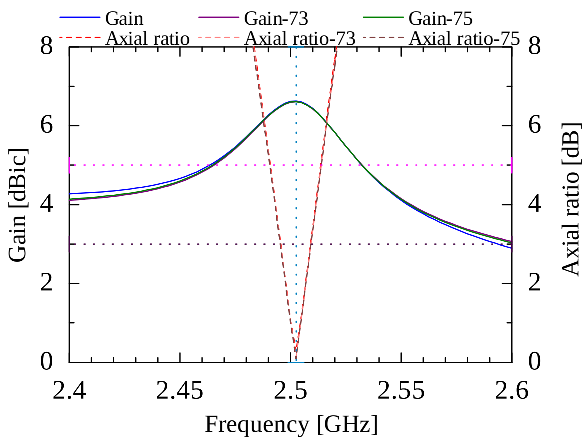

Fig. 8 Frequency characteristic of single antenna using stub-fed

Otherwise, Fig. 9 depicts the strongly effects of stub. It is caused by the function of stub that decreasing the signal which absorbed by the antenna. Hence, the coefficient reflection become lower. In other word, the losses energy is less than without use the stub. This figure show that the sizes of stub affect toward *S*-parameter. In general, if the parameter of Wa or fss is set be higher, then the result of *S*-parameter is better than before. In this case, it is important to obtained the optimize results among *S*-parameter, input impedance, and the interesting shape of antenna. If the size of stub is similar or bigger than the microstrip-line, it is not good for designing the antenna.

Fig. 10 describes about the characteristic of input impedance. It seem that the fixed real impedance occur at 50 Ω, while the tip of signals at the resonant frequency tend to decreases, seen from the increasing of the stub sizes. So, the stub antenna has to set about Wa = 5 *mm* and fss = 7 *mm*. In this case, the real and reactance impedance at f = 2.5025 GHz occur about 47.92 Ω and 0.96 Ω, respectively.

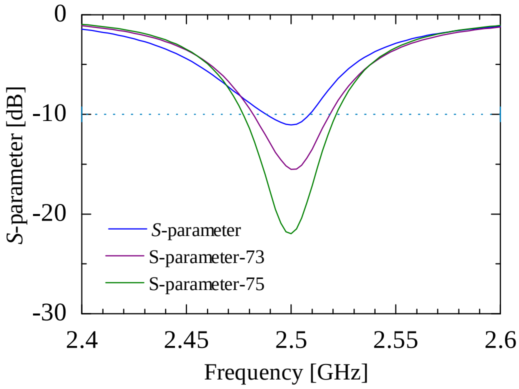

Fig. 9 *S*-parameter of single antenna using stub-fed

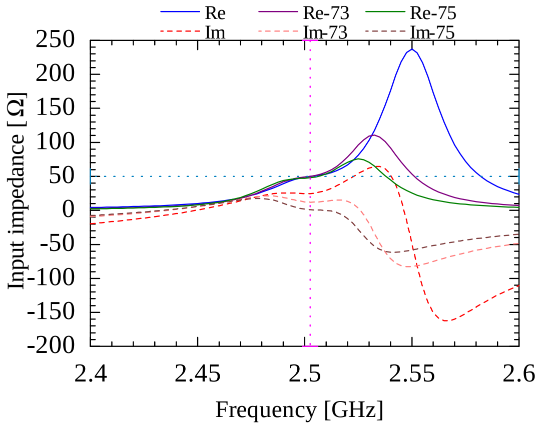

Fig. 10 Input impedance of single antenna using stub-fed

TABLE II
PERFORMANCES OF THE STUB ANTENNA at $f = 2.5025$ GHz

Model	S-parameter (dB)	Real-Z (Ω)	Imaginer-Z (Ω)
1-stub-00	-10.99	50.05	24.72
2-stub-73	-15.48	50.07	12.04
3-stub-75	-21.49	47.92	0.96

Fig. 11 and Fig. 12 depict the relationship between gain and elevation angle at azimuth, Az = 0^0 and 90^0. At the elevation 90^0 the maximum gain and the minimum axial ratio are about 6.62 dBic and 0.27 dB in both of azimuth angle, respectively. The effect of using stub in case of the elevation plane is little different than without stub.

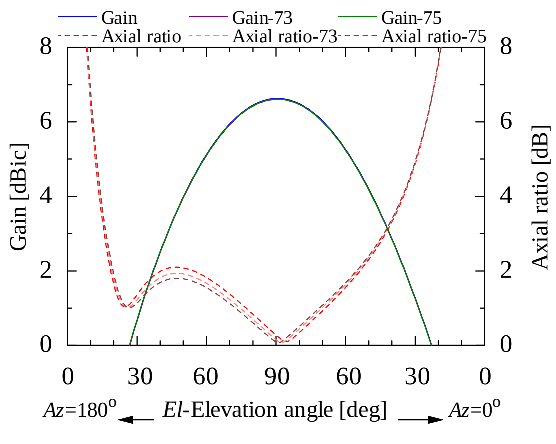

Fig. 11 The elevation of *x-z* plane of single antenna using stub-fed

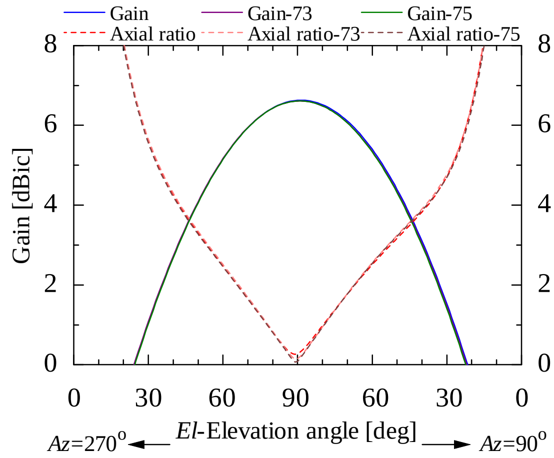

Fig. 12 The elevation of *y-z* plane of single antenna using stub-fed

C. Array Antenna Using Stub-fed

Fig. 13 to Fig. 15 show the simulation results of antenna array, such as frequency characteristics, *S*-parameter, and impedance input. While Fig. 16 and Fig. 17 are specific to the performance of the antenna array, namely the vertical and the horizontal radiation patterns.

Fig. 13 shows the value of the gain and axial ratio (*Ar*) for the three types of simulation well-fed antenna without stub-fed and with stub-fed in different sizes at the frequency target 2.5025 GHz. The value of each gain almost same, around 6.93 dBic and also this case occur for each axial ratio, roughly 2.43 dB. In addition, the gain-bandwidth-5dBic of the three types of antenna is also almost same, around 2.59%. While the axial ratio-bandwidth-3dB for the three types of antenna is approximately 0.7%.

Fig. 14 shows the relationship between the *S*-parameters and frequencies for simulation of receiver antenna (*Rx*). In this figure, it can be seen that the *S*-parameter (S_{11}) of the three types of antenna (without stub-fed, stub-fed$_{73}$ and stub-fed$_{75}$) at the frequency target 2.5025 GHz about -11 dB, -15 dB, and -20 dB, respectively. Then, the *S*-parameters (S_{22}) of the three types of antenna are almost same, roughly -33 dB.

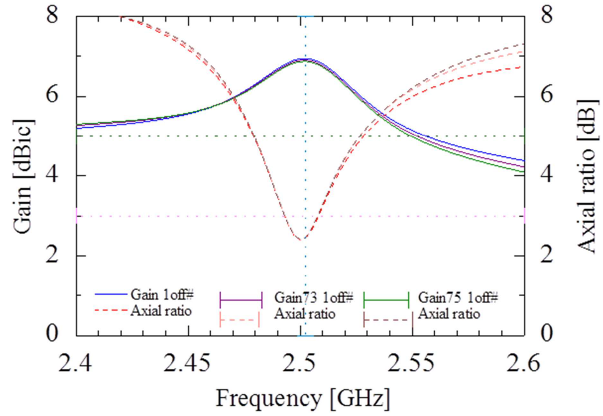

Fig. 13 Frequency characteristic of array antenna using stub-fed

Fig. 15 illustrates the characteristics of the input impedance of *Rx*. This figure shows that the real parts of the simulation have similar results at the frequency target 2.5025 GHz that is equal to 50 Ω. However, if there is any different model probably this is beyond the frequency target.

But the reactance parts of the simulation are vary depend on the frequency target, that are consecutively of the antenna without a stub-fed, stub-fed$_{73}$ and stub-fed$_{75}$, i.e. 30 Ω, 15 Ω and 0 Ω. Furthermore, the impedance bandwidth (below -10 dB) of the three types of antenna (without stub-fed, stub-fed$_{73}$ and stub-fed$_{75}$) are about 20 MHz, 35 MHz and 60 MHz, respectively.

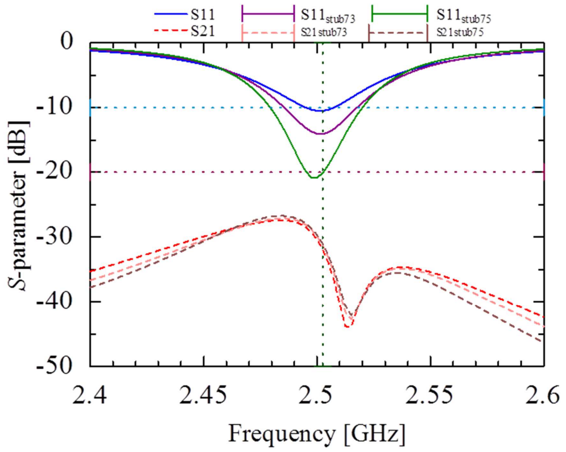

Fig. 14 *S*-parameter of array antenna using stub-fed

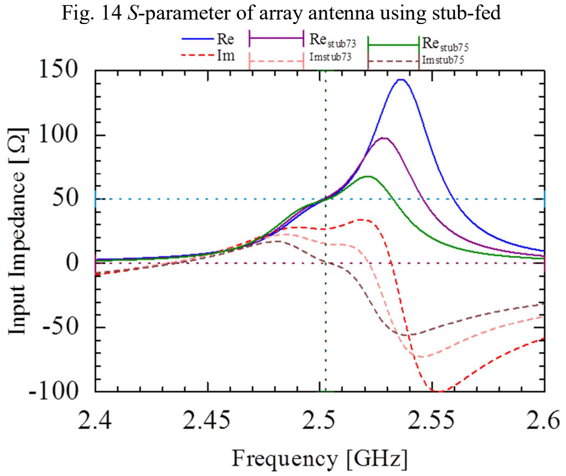

Fig. 15 Input impedance of array antenna using stub-fed

Fig. 16 shows the relationship between the characteristics of the radiation (gain-axial ratio) in the part of $Az = 0^0$ and elevation angle when the one of three patches antenna is switched OFF and the others switched ON. The results indicate that from the northern tip to the southern tip of Japan elevation angle of 38^0 to 58^0 relative to the satellite position (above the equator) for the three types of antenna mentioned above, yield the desired target (as shown in Fig. 16).

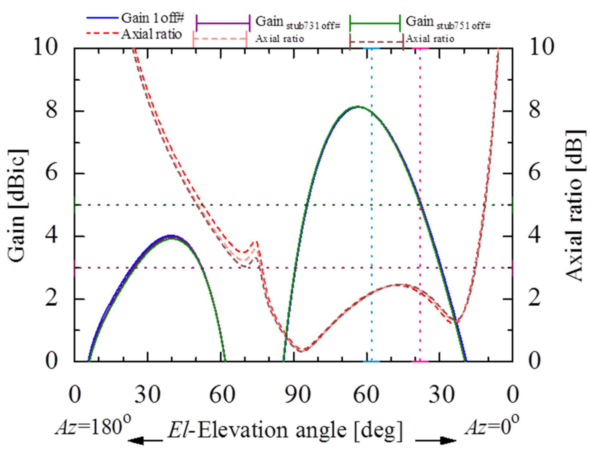

Fig. 16 Elevation cut plane of array antenna using stub-fed

Fig. 17 describes the characteristic of conical pieces radiation in the *El* = 48° area. In this figure is seen that the peak of the gain and axial ratio for the three types of antenna are almost same, around 7.56 dBic and 0.13 dB, respectively. In addition, the values of the gain and axial ratio beamwidth meet the target for beam coverage of 120^0.

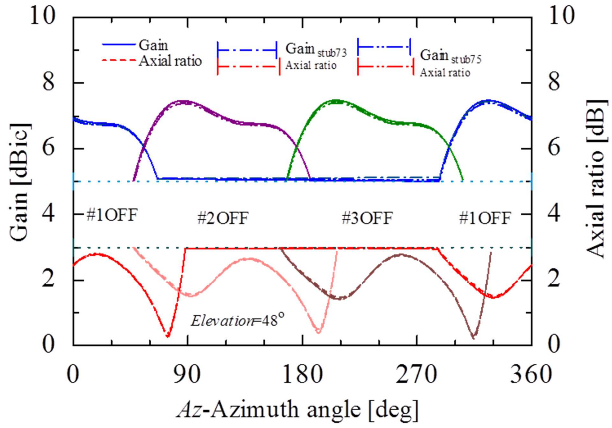

Fig. 17 Conical cut plane of array antenna using stub-fed

IV. Conclusions

The analysis of previous antenna (two layers) and modified antenna (one layer), optimized modified antenna using stub on coplanar-fed both single and array antenna have been discussed. The result for axial ratio of the modified antenna and the previous antenna at 2.5025 GHz are 0.27 dB and 1.02 dB, respectively. It is caused a coplanar-fed which connected directly to the radiating patch (one layer antenna). The use of stub can increase *S*-parameter, about more than -10 dB. The results of single antenna, especially for bandwidth of axial ratio below 3-dB and gain above 5 dBic are about 0.02 GHz and 0.065 GHz, respectively. Furthermore, the results of 5-dBic-gain and the 3-dB-axial ratio beamwidth are consecutively about 60^0 and 120^0, respectively. The results of array antenna, in the case of bandwidth of axial ratio below 3-dB and gain above 5 dBic are about 0.03 GHz and 0.3 GHz, respectively. Moreover, the results of 5 dBic-gain and the 3 dB axial ratio beamwidth for elevation cut plane are about 48^0 and 87^0, respectively. Moreover, gain over 5 dBic and axial ratio less than 3 dB can be obtained according to the desired target, the beam coverage area of them are 120^0 and elevation angle of them are from 38^0 to 58^0.

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