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STUDY OF THE EFFECT OF AIR-GAP ON ARRAY MICROSTRIP ANTENNA PERFORMANCES FOR MOBILE SATELLITE COMMUNICATIONS

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ABSTRACT

This paper presents the design and performance analysis of stack-patch and pentagonal microstrip array antenna models based on simulation and measurement results. Both antennas use air-gap for enhancing bandwidth, gain, axial ratio and circular polarization. The paper first discusses stack-patch microstrip array antenna where the results at El=48° agree well with the calculated results of 5 dBic gain. Results also show that the 3-dB axial ratio beamwidth of the whole azimuth ranges about more than 120° for each beam coverage in the conical-cut direction satisfy for mobile satellite communications. Secondly, the paper examines the pentagonal microstrip array antenna model whose results demonstrate that the bandwidth of impedance, axial ratio, and gain at the resonant frequency of 2.4925 GHz are good mainly about 15.67 %, 4.11 % and 52.16 %, respectively. The results further yield the value of S-parameter, axial ratio and gain at 2.4925 GHz to be better about -15.03 dB, 0.06 dB and 8.74 dBic, respectively. Furthermore, performance characteristic especially bandwidth of axial ratio of both antennas mainly caused by a new shape of pentagonal antenna using air-gap and good selection of a feed position are satisfied.

Keywords: stack-patch, microstrip array, pentagonal, air-gap.

INTRODUCTION

Multimedia communications through geostationary satellites will be an essential part of future information infrastructure since the satellite-based communication provides "simultaneous" and "flexible" information network without large facilities. The future satellite networks will be tightly integrated with the terrestrial networks as an integral part of our future global information infrastructure. Space-based network which has survivability against disasters and flexibility will complementally work with mobile and fixed ground-based system in order to realize a reliable and mobile "ubiquitous" information society.

As geostationary satellites are remotely located (about 36,000 km) from the earth, the incoming wave is very weak. Consequently, it is required that the antenna for mobile satellite communications has a high gain in the case multimedia communications performing large-capacity data communication is aimed. Furthermore, when thinking of the integration to cars, from the point of view of the car design, it is recommended the overall system be light and compact.

Another consideration for designing the antenna system inside a car is that above where the antenna is located will require a feeding. This may me provided by a singly fed circularly polarized (CP) antenna which unfortunately has inherent limitation in gain, impedance and axial ratio bandwidths. Such limitations are mainly owing to the resonant nature of the patch antenna which has a high unloaded Q-factor and frequency-dependent excitation of two degenerative modes (TM01 and TM10) when using a single feed. To improve gain, impedance and CP bandwidth, several single-feed single element patch antennas may be used by utilizing an air-layer or foam substrate to minimize the unloaded Q-factor (F. S. Chang, 2003; C. Wang and K. Chang, 2000). Another way to increase the bandwidth of antenna is by using the stacked patches and electromagnetically coupled patch configurations as presented in (Q. L. Richard and L. Kai-Fong, 1990) and (N. C. Karmakar and M. E. Bialkowski, 1999)

In this paper, the method of enhancing the bandwidth of antenna by introducing an air gap in the stack-patch and the pentagonal antenna is presented. The effect of the air gap is investigated using a simple configuration setup for mobile satellite application as depicted in Figure 1. A model was then developed using a common technique for calculating the unknown current called the Method of Moments. The method discretizes the integral into a matrix equation which can then be solved. This discretization can be considered as dividing the antenna surface into a number of small elements. From the current distribution, the S-parameters, radiation pattern and any other parameters of interest can be obtained. Simulation of the model using the method of moments (via Ensemble version 8) was conducted and laboratory test setup of the model was constructed. Measurements from both simulation and hardware were taken whose results will be discussed in a later section.

METHODS

In this investigation, both the numerical simulation and measurement which related of the microstrip antennas were performed and the results of

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them are then compared. In particular, the analysis focuses on the study of the effect of air-gap on array microstrip antenna performances for mobile satellite communications, in the case of the stack-patch and the pentagonal array antennas.

The Method of Moments (MoM) has been chosen in the numerical analysis for its asset of fast calculation. The software used was EnsembleTM version 8 from Ansoft. Owing to the software characteristics, the dielectric substrate and the ground plane are considered to be infinite. The usage of this software provides some advantages for industries and researchers when developing new and unproven telecommunication technologies such as the ability to conduct preliminary study of the new antenna design without having to build a hardware prototype. The performances are compared with measurements realized using a network analyzer HP 8510C in the radio anechoic chamber.

In this section, numerical simulation and measuremental results of the proposed antenna are shown, especially for *El*=48° at a particular area. The results of both type of antennas when utilizing the circular polarization can be simply obtained by properly adjusting the element parameters and using air gap. Furthermore, good results are also obtained on the performance characteristic, especially bandwidth of axial ratio of both of the antennas which is caused by a new shape of pentagonal antenna using air-gap and proper selection of a feed position.

ANTENNA CONFIGURATION

The stack-patch array antenna

Figures-1 and 2 illustrate the array antenna configuration aimed at mobile satellite communications (ε_r = 2.17, loss tangent 0.0009). The antenna is composed of three pentagonal patch antennas fed directly from the ground beneath the construction to radiating patch, instead of using three probe feeds. At the top of the construction lies three triangular patches as parasitic elements. The dimension of the construction is 160 mm and 6.4 mm in diameter and height, respectively. Three single patch antennas are arranged in 120° difference with respect to one another in the azimuth rotation to form the array antenna structure. The distance between two elements by viewing from the apex of patch antenna is about 0.5λ in order to generate a beam directed as desired. The radiation characteristics of such kind of array configuration were reported in (T. Tanaka, 2004), where the array antenna can produce three beams in different azimuth direction (Az = 0°, 120°, and 240°). Moreover, the distance between the tip of antenna element and center point of array composition is set in different length for radiating and parasitic element. By considering the axial ratio performance, their distance is set at 8.7 mm and 9.7 mm for fed and parasitic elements, respectively. The proposed array antenna is applied for reception purpose. With this composition, a dual band operation antenna with the reception and transmission antennas arranged in one dimension can be achieved. In addition, the array antenna is mounted on stacked-parasitic patch to enhance the gain and bandwidth. Moreover, when constructed this way, the loss of the switching circuit from beneath the array antenna may be compensated.

For a patch antenna, in case the radiating element is loaded with a parasitic element on its top, it is possible to obtain a higher gain and a wider bandwidth by using the multiple resonances generated by the radiating element itself and the parasitic element (T. Tanaka, 2004; R. Garg *et al.* 2001; H. D. Weinschel, 1975; V. Natarajan and D. Chatterjee, 2003; Y. Suzuki and T. Chiba, 1984; H. D. Chen and H. S. Chen, 2001). Figure 1 shows the configuration of the triangular patch array antenna with the parasitic element and Figure 2 shows the fabricated antenna. The circularly polarized radiation is simply obtained by the use of large truncation corner on the driven patch. This truncation corner can control the two orthogonal modes (mode #1 and mode #2 in Figure 3) on the patch (T. Tanaka, 2007). The area of the truncation corner is wider than a single layer because the Q of each mode is expanded by the parasitic patch; i.e. resonant frequency of each mode can be widely separated. Accompanied with the feeding location and to match the 50Ω matching input impedance, a 4 mm-air gap is inserted in the space between the radiating and parasitic elements. Moreover, the antenna can be fitted to the required frequency by varying a feed location, air gap thickness and antenna dimension. With this consideration the antenna resonates at 2.5025 GHz as a target frequency for reception antenna in mobile satellite applications. In addition, by setting the isosceles length of the parasitic element to be shorter with a ratio of 0.95 to other sides, a good axial ratio CP operation can be obtained (Basari, 2008).

In this configuration, the fabricated antenna is low profile, small, and lightweight to be mounted on the car-rooftop, and the generated-antenna beam is always directed to the east longitude of 146° where the mobile satellite is orbited.

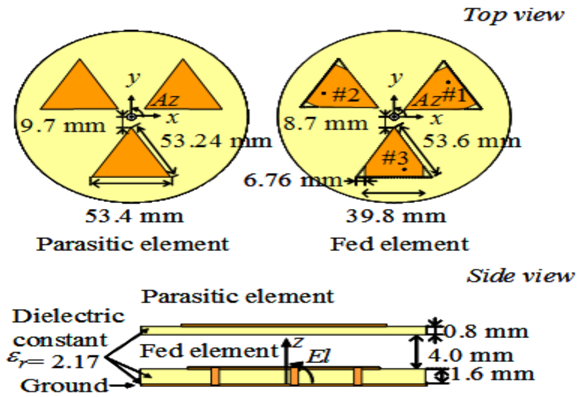

Figure-1. Stack-patch array antenna configuration.

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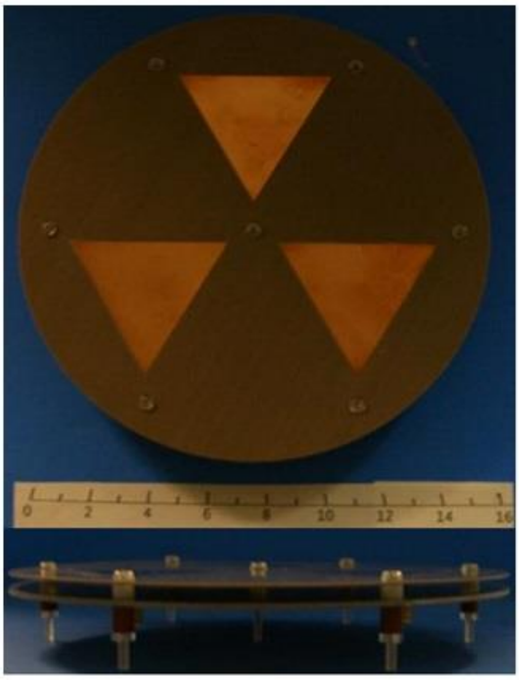

Figure-2. Fabricated of the stack-patch array antenna.

The pentagonal array antenna

Figure-4.and Figure-5 depicts the configuration of antenna design for single and array pentagonal antenna, respectively. Both of antennas are using a conventional substrate (relative permittivity 2.17 and loss tangent 0.0009) and fed by a coaxial probe to avoid the degradation of elliptic by unwanted radiation from the feed network.

Figure-4.shows the single model designed of pentagonal antenna using air-gap whose angle $\angle\theta$ is 45^0.

The shape of such a pentagonal shape can be prescribed completely by two parameters c/a and b/a. The pentagon becomes a rectangle when c/a = 0, an isosceles triangle when c/a = 1. It is important to consider that for enhancing the bandwidth, the c/a position should be 0 < c/a < 1, or in other words the patch shape should combine two or more shapes in becoming one (pentagon = triangle + rectangle). In this case, however, the combination of two shapes for getting the wide antenna bandwidth is not enough. For matching a 50 Ω impedance, smooth axial ratio and gain are added to the dimension of the antenna with b/a > 1.

The air gap and feed location must also be chosen correctly as illustrated in Figure-4.

The combined two shapes is then used to excite more than one mode where each mode degenerates two close frequencies; and hence most of the current paths around this area move to y direction and x direction which are perpendicular to each other. As a result, the bandwidth of axial ratio is increased.

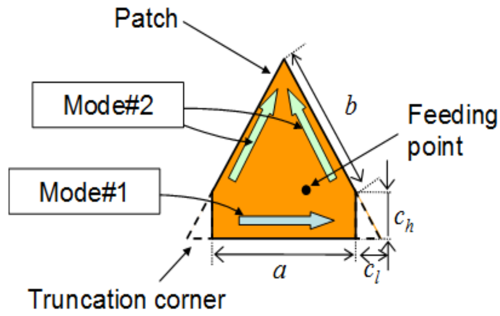

Figure-3. The two orthogonal mode with truncation corners.

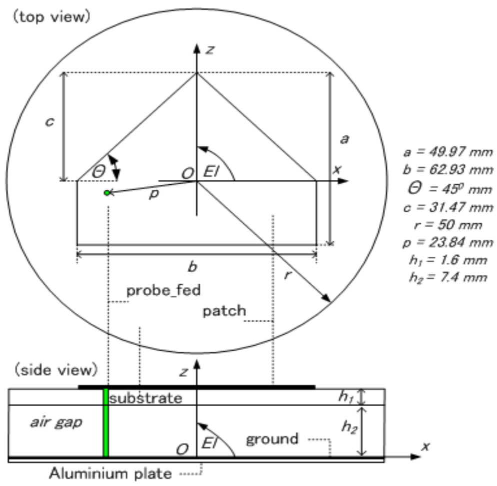

Figure-4. Single pentagonal antenna configuration.

For LHCP (Left Hand Circular Polarization), the feeding is located on the left side from null potential. This happened on three modes at the operating frequencies of 2.4925 GHz, 4.5 GHz and 6.8 GHz. However, a good radiation characteristic occurred only in the first mode at 2.4925 GHz. This sets the dominant modes (TM01 and TM10) owing to the perturbation shape (pentagonal) using air-gap. The effective excited patch surface current path in the y direction is slightly shorter than that in the x direction, which in turn gives the y-directed resonant mode a resonant frequency slightly larger than that of the x-directed resonant modes of equal amplitudes, and 90^0 phase difference at the left side of pentagonal for the LHCP operation.

Figure-5.depicts the design of simulated array of the pentagonal antenna that consists of three pentagonal patch antennas which is fed directly from the switching circuit beneath the construction. Figure 6 shows the array geometry of the fabricated antenna that is made by a microstrip material (ε_r = 2.17, loss tangent 0.0009) without the parasitic elements. With this geometry the antenna becomes simple, compact and low loss, because there is no need for a power divider to distribute power signal to the antenna elements. The dimension of the construction is 190 mm and 7.2 mm in diameter and height, respectively.

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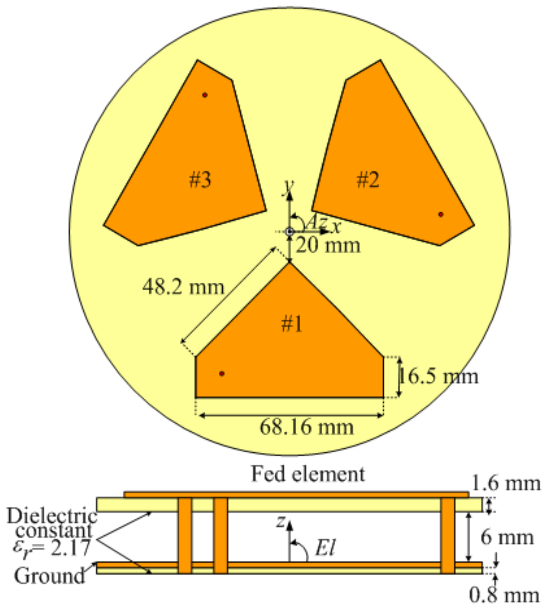

Figure-5. Calculated of the pentagonal array antenna.

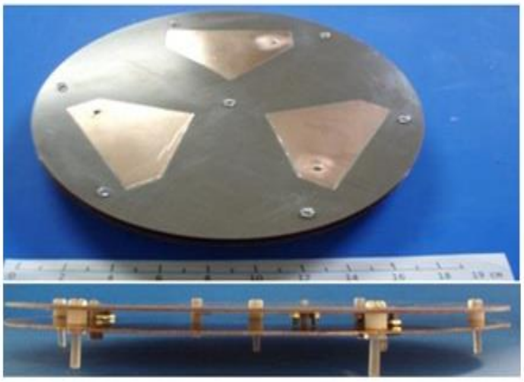

Figure- 6. Fabricated of the pentagonal array antenna.

PERFORMANCE ANALYSIS RESULTS

The stack-patch array antenna

Figures-7 to 12 illustrate the results from both calculation and measurement in terms of S-parameter, input impedance, axial ratio characteristic, and radiation pattern. The difference between the simulation and measurement that appears in the results is due to the fact that a finite ground is used in the measurement while it is infinite in the simulations.

Figure-7 demonstrates that the measured S11 tends to meet the calculated value. The impedance bandwidth (S11 < -10 dB) is about 6.93%. The isolation is more than 25 dB which is above the target isolation of 20 dB. Figure 8 depicts the input impedance characteristic of Rx. This figure also shows that both calculation and measurement results are a little bit shifted relative to each other to the lower and higher frequency of approximately 0.2%. In this case, the real part of measurement is closed to 50Ω or about 35.90 – j0.95 Ω. The mismatch between the two results is contributed from fabrication error, connector, coaxial cable, aluminum block and plastic screws to support the substrate to be flat (C.A. Balanis, 1997; Sri Sumantyo, J.T. *et al.* 2005; Otero, M.F., and Rojas, R.G., 1995; Lier, E., and Jacobsen, K., 1983; Delgado, H.J. *et al.* 1989; Iyer, S.M.V., and Karekar, R.N., 1991; Maci, S., and Borselli, L., 1996;Maci, 2000). Empirically, these are very sensitive to the performance of the antenna, especially the input impedance.

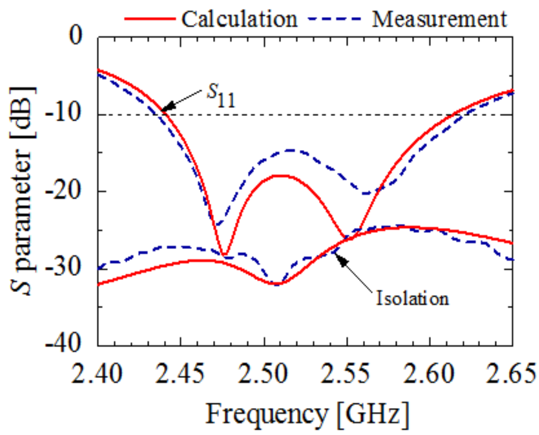

Figure-7. S-parameter.

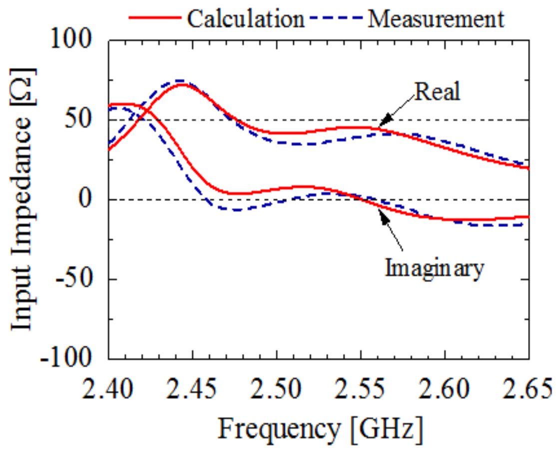

Figure-8. Input impedance.

Figure-9 illustrates that the measured result of axial ratio increases to 1.0 dB at frequency 2.5025 GHz and El = 48°. Moreover, the 3 dB axial ratio bandwidth gets about 1.7%. The measurement result is worse than the calculated result due to the variation in the measurement during the fabrication process. In order to match between measurement result of fabricated antenna and the calculation result, the antenna was optimized until the measurement result suits the target for mobile satellite applications. Here, the result satisfies the target although a little bit decreased.

The axial ratio satisfies the target less than 3 dB and the gain is more than 5 dBic at elevation angle El = 38^0 – 58^0 as shown in Figure-10. This condition was achieved by having one of three ports switched OFF, and the others

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biased ON. This mechanism produces a beam that could be directed at the desired target.

The beam of the antenna is generated by a simple ON OFF mechanism (Basari, 2008) that consists of one out of three radiating elements being turned off. For that reason, there are three OFF state beam switching mechanisms: #1 OFF, #2 OFF, and #3 OFF. By considering the mutual coupling between fed elements, their phases and distances, the beam direction can be varied. Furthermore, the two fed elements theoretically will generate a beam shifted of -90° in the conical-cut direction from the element which is switched OFF. For example, when element #1 located at Az=30° is switched OFF, the beam is directed towards the azimuth angle Az=-60° or 300° (Muhammad Fauzan Edy Purnomo *et al.* 2008) as shown in Figure-1.

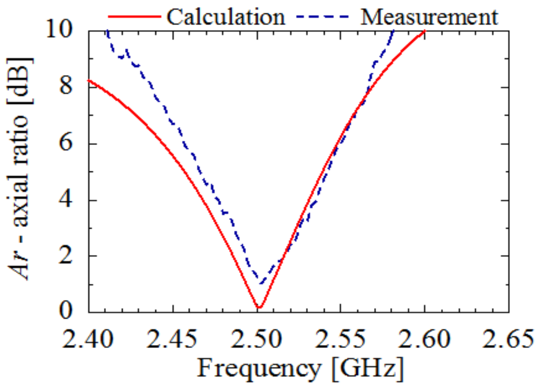

Figure-9. Axial ratio vs frequency.

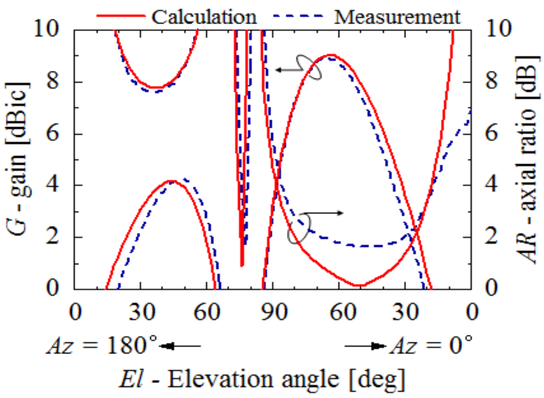

Figure-10. Elevation cut-plane.

The measured results of gain and axial ratio characteristics of the beam switching in the azimuth plane are shown in Figure-11 and Figure-12.The tendency of the measurement results is same as the calculated ones. The measured results show that at the center beam, the gain of each beam is averaged about 0.2 - 0.5 dB less than that of the calculation results. The axial ratio increases for each OFF condition, but the 3-dB axial ratio coverage of the measured result can cover 360° in the conical-cut plane at El = 48°. Moreover, the beam is possibly switched at minimum gain of 6.3 dBic. Also, although the axial ratio is shifted from the switched point, to cover 360° conical-plane the minimum axial ratio below 3 dB is possible to obtain. This elevation is applied at a particular area.

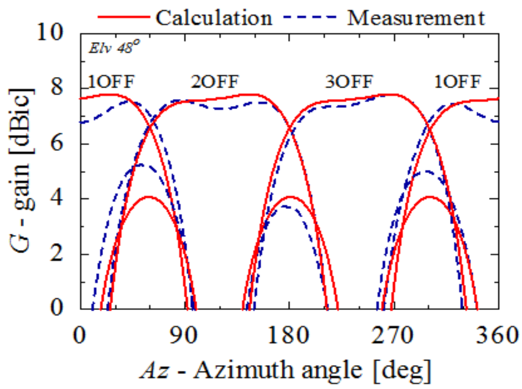

Figure-11. Conical cut-plane: Gain vs Azimuth.

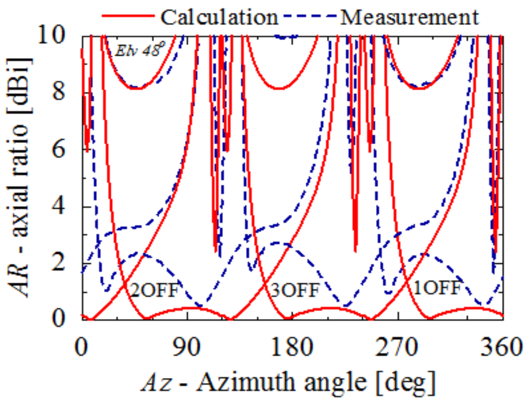

Figure-12. Conical cut-plane: Axial ratio vs Azimuth.

The pentagonal array antenna

Figure-13 to Figure-15 show the simulation results for both single element and array pentagonal antennas in terms of frequency characteristic, S-parameter, and input impedance.

Figure-13 shows that the values of gain and axial ratio (Ar) at the resonant frequency of 2.4925 GHz are about 8.74 dBic and 0.06 dB, respectively. In addition, the bandwidth of axial ratio of the antenna is about 4.11%.

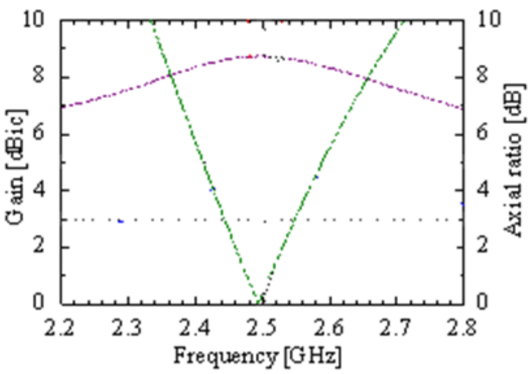

Figure-13. Gain and axial ratio vs. frequency.

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Figure-14 shows the relationship between the reflection coefficient (S-parameter) and frequency for the simulated antenna. From this figure, it can be seen that the bandwidth of S-parameter has enough width of about 15.67%. This is potentially caused by the new shape of perturbation antenna, likely a pentagonal, where the area square is relatively large at about 2154.3 mm^2. In addition, it is also caused by the effect of air-gap and location of feeding that matches with the configuration of antenna to yield the satisfied targets. Moreover, the value of S-parameter at the resonant frequency is good at around -15.03dB.

Figure-15 depicts the input impedance characteristic with well satisfied real and reactance parts as indicated by the close to 50 Ω for the real value, and close to 0 Ω for the reactance value.

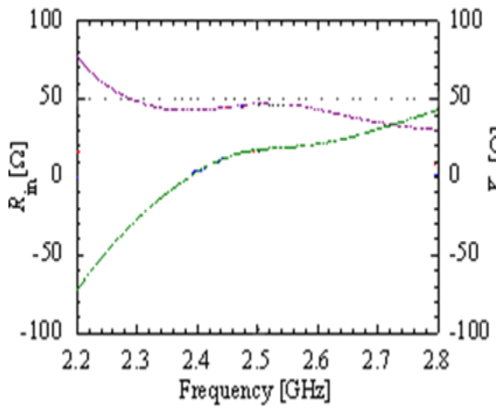

Figure-15. Input impedance.

For coaxial-fed antennas, the resonant frequency, axial ratio, S-parameter and input impedance can be slightly affected and is dependent on the feed position. By properly choosing the feed position, an effective match between the antenna and the transmission line can be obtained.

Figure-16 shows the frequency characteristics from the simulation and measurement results conducted on array antenna. As indicated, the results disagree with each other as usually the measurement antenna shifts to higher frequency, but here the shift is to lower frequency. This again may be contributed from variation during fabrication and measurement error. The resonant frequency for the simulation is located at 2.48 GHz while the measurement yields a location at 2.43 GHz (Iyer, S.M.V., and Karekar, R.N., 1991). The reason for this anomaly is still being investigated. Furthermore, to analyze radiation pattern, this antenna is operated at 2.5 GHz.

It is necessary to have a traveling wave current distribution which has constant amplitude and a linearly changing phase for a pentagonal antenna to radiate a circularly polarized wave. In the general antenna theory, a circularly polarized wave can be radiated by means of loading a reactance of an appropriate value. However instead of doing so, a very simple method may be used that incorporates air gap. By introducing such air gap with a certain size of pentagonal antenna and feeding the antenna with a coaxial probe, a traveling-wave current distribution could be excited, and as a result, a circular polarization can be achieved.

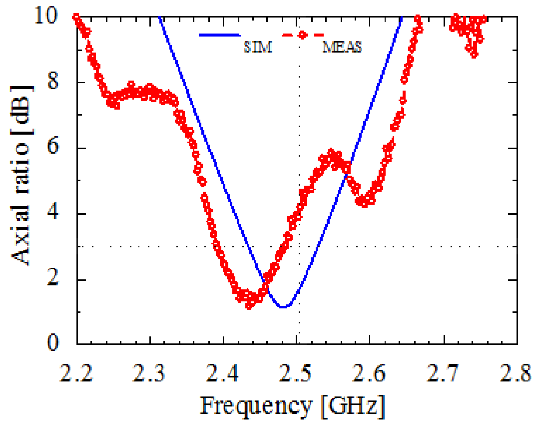

Figure-16. Frequency characteristics at El = 48°.

Figure-17 describes the elevation cut-plane with antenna performance at the elevation angle of El = 38°-58°. The results generally are the same between simulated and hardware measurements for the array antenna, especially the gain. However, axial ratio in the measured results is considerably affected by the shape of ground (considering that simulation used infinite ground and measurement used finite ground with a circle-shape), and also affected by conductivity (σ) and permittivity (ε_r) of ground. Hence, the axial ratio at the elevation direction from 38° - 58° does not satisfy the targets yet. These dependencies are caused by error during fabrication, especially when soldering a feed on the ground is still not optimized.

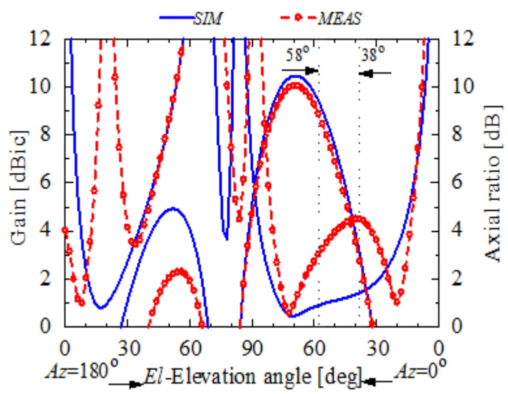

Figure-17. Elevation cut-plane 2.5 GHz.

Figure-18 depicts the conical cut plane for El=48°at the frequency f = 2.5 GHz from the measurement results. This means it is possible to evaluate the antenna system without circuit switching as far as how good performances could occur with a new shape of antenna and how they are affected using a ground antenna (Muhammad Fauzan Edy Purnomo *et al.* 2008).

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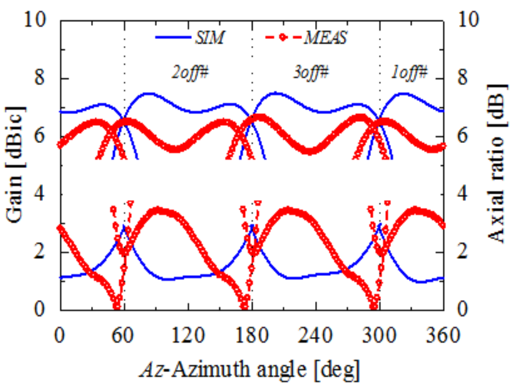

Figure-18. Conical cut-plane at f = 2.5 GHz.

Further inspection of Figure-18 demonstrates that the cutting of beam angle between the axial ratio and gain in simulation is the same. This happens probably owing to the same phase of modes used for both the gain and axial ratio in the simulation. On the contrary, this observation does not occur in the measurement results. One explanation of this is that the ground is not optimized especially in terms of its conductivity (σ) and permittivity (ε_r) that are not matched with the radiating antenna. The strong effect of the ground could be seen in the gain measurement, as the gain decreases significantly compared with the gain obtained in the simulations. Therefore, the cutting of beam angle in measurement is different between axial ratio and gain (Kawakami, H. *et al.* 1997). Another reason is probably due to the variation in fabricating the antenna. For example, the soldering between feed and ground may not be be good that the current distribution on the patch radiating of antenna could not flow normally. In addition, the discrepancies may be contributed from the effect of power divider and semi-rigid that are not optimized. More specifically, a phase of semi-rigid circuit to connect two of three feed beneath the construction of the antenna is not same, hence the axial ratio could not be obtained satisfactorily because the axial ratio is very sensitive to the difference in phase.

CONCLUSIONS

To conclude, the measurement results for the stack-patch array antenna demonstrate that wide impedance bandwidth, low axial ratio, and radiation characteristics are satisfied in the azimuth direction at the target frequency of 2.5025 GHz for elevation angle El = 48°at a particular area. Compared to the pentagonal antenna, the beam switching characteristics show that gain and axial ratio are more than 5 dBic and less than 3 dB, respectively. In addition, the gain above 5 dBic and the axial ratio below 3 dB can be obtained at elevation angles between 38° - 58°.

The results of the pentagonal array antenna show that the bandwidth of impedance, axial ratio, and gain at the resonant frequency of 2.4925 GHz are 15.67%, 4.11% and52.16%, respectively. Moreover, the value of S-parameter, axial ratio and gain at 2.4925 GHz are -15.03 dB, 0.06 dB and 8.74 dBic, respectively.

By properly adjusting the element parameters and using air gap, both antennas can produce circular polarization. Furthermore, good performance of axial ratio bandwidth of both antennas which are characterized especially by a new shape of pentagonal antenna using air-gap and good selection of a feed position.

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