Development of Single Triangular Truncated Microstrip Antenna for CP-SAR Sensor

Muhammad Fauzan Edy Purnomo
Electrical Department of Engineering Faculty
Brawijaya University
Malang, Indonesia
mfauzan@ub.ac.id

Vita Kusumarsari
Mathematics Department, Faculty of Mathematics and Natural Sciences
Universitas Negeri Malang
Malang, Indonesia
vita.kusumarsari.fmipa@um.ac.id

Irawan Sukma
Research Center for Testing Technology LIPI
Jakarta, Indonesia
engineer.irawan@gmail.com

Rusmi Ambarwati
Electrical Department of Engineering Faculty
Brawijaya University
Malang, Indonesia
rusmi@ub.ac.id

Endah Budi Purnomowati
Electrical Department of Engineering Faculty
Brawijaya University
Malang, Indonesia
endah_budi@ub.ac.id

Akio Kitagawa
Electrical Engineering and Computer Science Department
Kanazawa University
Kanazawa, Japan
kitagawa@ece.t.kanazawa-u.ac.jp

Abstract— In this paper, we obtain the basic configuration of the Left-Hand Circular Polarization (LHCP) single triangular truncated microstrip antenna. Here, we discuss two types antenna, i.e. (i) triangular truncated proximity coupled feed antenna at target frequency, \( f = 1.25 \, \text{GHz} \), (ii) triangular truncated microstrip-line feed antenna at target frequency, \( f = 5.5 \, \text{GHz} \). Both of them are designed by using the Moments Method (MoM) for Circularly Polarized-Synthetic Aperture Radar (CP-SAR) sensor. The result of frequency characteristic performance and \( S \)-parameter for both of them at their target frequencies show 7.24 dBi and 7.28 dBi of gain, 0.11 dB and 1.25 dB of axial ratio, -19.73 dB and -13.45 dB of \( S \)-parameter, respectively. Moreover, the axial ratio bandwidth below 3 dB of these antennas are different around 15 MHz (1.2\%) of (i) and 360 MHz (6.55\%) of (ii).

Keywords—LHCP, proximity coupled feed, microstrip-line feed, MoM, CP-SAR

INTRODUCTION

Radar is an electronic device that utilizes a lot special technology, including signal processing, data processing, waveform design, detection, parameter estimation, and antenna propagation. The radar antenna transmits pulses of microwaves that bounce off any object in their path. The object returns a portion of the wave to the receiver which is in line of sight with the target [1].

Radar is a remote sensing system, which is widely used for monitoring, tracking and imaging applications. Remote sensing has been implemented for defense, disaster mitigation, earth and atmosphere observations, and mapping [2] [3] [4]. Remote sensing system use the side-looking images which are divided into two parts, i.e. real aperture radar (RAR) and synthetic aperture radar (SAR).

The backscattered SAR signal whose full characteristic can pass through the random objects both day and night, able to penetrate clouds, fog and smoke by using Circularly Polarized-Synthetic Aperture Radar (CP-SAR) sensor. In addition, the CP-SAR signal is also capable of capturing large amount of information from the image target [5] [6]. The technique to achieve Circular Polarization (CP) can be easily obtained by properly constructing feed, adjusting parameters of feed and patch antenna, and determining locus feed on the radiating patch and parasitic patch [7] [8] [9][10][11].

This paper presents the development of single triangular truncated microstrip antenna for CP-SAR sensor. The research constructs the triangular proximity coupled feed antenna (\( L \)-band) and the triangular microstrip-line feed antenna (\( C \)-band). These constructions use two layers or two substrates with low dielectric constant, modified radiating patch shape using microstrip-line feed to generate multi-resonant frequency and a circle-slotted parasitic patch for \( C \)-band CP-SAR sensor embedded on airspace.

To realize the numerical analysis with fast calculation, we choose the Moments Method (MoM) and CST 2016 to realize it. In this method, the antenna surface is divided into a small mesh [12]. So that, the integral is discretized into a matrix equation. The numeral simulation of the single triangular truncated microstrip antenna are shown in Section III (Results and Discussion), especially at the target frequency, \( f = 1.25 \, \text{GHz} \) for triangular proximity coupled feed antenna and \( f = 5.5 \, \text{GHz} \) for triangular microstrip-line feed antenna as basic configurations embedded on airspace for CP-SAR sensor both for transmitter (\( Tx \)) and receiver (\( Rx \)) with low power around 30 dBm. Table I shows the specification and the desired target for the CP-SAR airspace system [9] [13].

In this paper, we use the target frequency because especially in the \( C \)-band, the frequency that produces the best frequency characteristic and radiation pattern performance is at \( f = 5.5 \, \text{GHz} \). This is consistent with Table I that the \( C \)-band frequencies allocated for the design of single and array antenna are in the range of 5.0 - 5.5 GHz.

TABLE I. TECHNICAL SPECIFICATION OF AIRSPACE SYSTEM

<table>
<thead>
<tr>
<th>No</th>
<th>Antenna Parameters</th>
<th>Specification for Airspace</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Target Frequency (Center) (GHz)</td>
<td>( L )-band: 1.0 - 1.5 GHz; ( C )-band: 5.0 - 5.5 GHz</td>
</tr>
<tr>
<td>2.</td>
<td>3-dB Axial Ratio Bandwidth (MHz)</td>
<td>( \geq 10 )</td>
</tr>
<tr>
<td>3.</td>
<td>Axial Ratio (dB)</td>
<td>( \leq 3 )</td>
</tr>
<tr>
<td>4.</td>
<td>Antenna Efficiency (%)</td>
<td>( \geq 80 )</td>
</tr>
<tr>
<td>5.</td>
<td>Gain Antenna (dBiC)</td>
<td>( \geq 10 )</td>
</tr>
<tr>
<td>6.</td>
<td>Azimuth Beamwidth (( ^\circ ))</td>
<td>( \geq 1.08 )</td>
</tr>
<tr>
<td>7.</td>
<td>Elevation Beamwidth (( ^\circ ))</td>
<td>( \geq 2.16 )</td>
</tr>
<tr>
<td>8.</td>
<td>Antenna Size in array (m)</td>
<td>( 2 \times 4 ) (( L )-band) ( 0.5 \times 1 ) (( C )-band)</td>
</tr>
<tr>
<td>9.</td>
<td>Polarization (( Tx/Rx ))</td>
<td>RHCP + LHCP</td>
</tr>
</tbody>
</table>
The configuration of Left-Handed Circular Polarization (LHCP) single triangular truncated microstrip antenna without parasitic patch and using proximity coupled feed with the parameters known as previous antenna is shown in Fig. 1. Next, Fig. 2 depicts the design of LHCP single triangular truncated microstrip antenna including radiating patch which is directly fed by microstrip-line feed and using parasitic patch with it parameters knowns as modified antenna.

The equilateral triangular patch in Fig. 1 has a length, \( p + 2t = a + t + h \) and a permittivity relative, \( \varepsilon_r = 2.17 \) and dissipation factor, \( \delta = 0.0005 \). The parameters length of truncated-tip of \( t \) is 1.5008 mm and \( h \) is 7.64 mm as the key that the antenna is LHCP or Right-Handed Circular Polarization (RHCP) or linear polarization function. For example, if \( t = h \), the antenna only obtain a linear polarization. If \( t > h \), as the proximity coupled feed is placed on the right side of antenna then RHCP is obtained. Otherwise, if \( t < h \), the feeding put on the left side of antenna then LHCP is occurred [9]. In the previous results of the previous antenna with \( lst = 15.87 \) mm, already achieved the real impedance matched 50 ohm [14], but this result only for single element, when the antenna applied for array configuration, the basic configuration of single element must be optimized to enhance the array performance characteristic. Actually, based on the principle of single antenna that if the size of parameter feeding antenna increasing, especially the parameter \( lst \) of the feeding antenna, the performance characteristic, especially real impedance become higher.

Fig. 2 depicts the configuration of the substrate modified antenna. The antenna is constructed by stacking two substrates, with 1.6 mm thickness \((h_1 \text{ and } h_2)\), 2.17 of \( \varepsilon_r \), 0.035 mm of copper cladding thickness, and 0.0005 of \( \delta \). To expand the impedance bandwidth (IBW), the modified antenna employs a thick substrate with low permittivity relative. The antenna design having a triangular patch with curve corner-truncation \((tr = 1 \text{ mm})\) and without it \((tr = 0 \text{ mm})\) is adopted as radiating patch in lower layer that is fed by a microstrip-line. It is placed below a triangular parasitic patch having circle slot as upper layer in order to improve the axial ratio bandwidth (ARBW) and gain rather than using slot or slot embedded on triangular parasitic patch [15] [16]. These references explain that the slit or slot above the triangular microstrip patch antenna that radiates circular polarization can obtain lower resonant frequency that capable of decreasing the quality factor of triangular patch thus increasing the antenna ARBW.

While, to decrease undesirable of electromagnetic field radiation is generated by microstrip-line feed then in upper layer besides circle slot is covered by copper. The ground plane is a copper sheet placed at the bottom layer of the antenna. The dimension of the circle slot has not significantly affected the performance of Axial Ratio (AR), but in turn, it has changed the Return Loss (RL) characteristic of the antenna. The IBW and ARBW are also affected by changing the circle slot diameter. Also, the circle slot does not significantly affect either the resonant frequency response or the surface current distribution direction of the parasitic patch [17] [18]. Therefore, for higher resonant frequency the antenna construction is described on Fig. 2.

Fig. 3 to Fig. 8 show the result of single triangular truncated previous and modified antennas, those are S-parameter, input impedance, and frequency characteristic. We are known that the using single-feed has inherent limitation in gain, impedance and axial ratio bandwidths thus the bandwidths of antennas are relative small [19] [20] [21] [22] [23].

Fig. 3 and Fig. 4 show the graphs between the S-parameter (S-11) and the frequency for the simulation Tx/Rx triangular truncated previous and modified antennas. From these figures, we can see that the value and the bandwidth of S-11 both previous antenna, \( f = 1.25 \) GHz and modified antenna, \( f = 5.5 \) GHz are about \(-19.73 \) dB and 33 MHz (2.64%), and \(-13.45 \) dB and 660 MHz (12%) for \( tr = 1 \) mm and \( tr = 0 \) mm, respectively. Moreover, the minimum value of S-11 for modified antenna at resonant frequency, \( f = 5.61 \) GHz, \( tr = 0 \) mm is \(-20 \) dB and \( f = 5.88 \) GHz, \( tr = 1 \) mm is \(-27 \) dB.
The input impedance characteristic of $Tx/Rx$ both previous and modified antennas are depicted in Fig. 5 and Fig. 6. These figures show that at the target frequency of 1.25 GHz and 5.5 GHz, the value of real-impedance approach to 50 $\Omega$. The imaginary-impedance both antennas close to 0 $\Omega$ including modified antenna with $tr = 1$ mm and $tr = 0$ mm. However, the characteristic impedance graph patterns both previous and modified antennas are different. Especially for modified antenna, due to the influence of the circle slot dimension, the double stack and the modified radiating patch shape using microstrip-line feed that generate multi-resonant frequencies.

Fig. 3. S-parameter for previous antenna, $lst = 24.49$ mm

Fig. 4. S-parameter for modified antenna

Fig. 5. Real-imaginer-impedance of previous antenna, $lst = 24.49$ mm

Fig. 6. Real-imaginer-impedance of modified antenna

The values of gain and axial ratio ($Ar$) for single triangular truncated previous and modified antennas at the direction of $\theta = 0^\circ$, target frequency, $f = 1.25$ GHz and $f = 5.5$ GHz consecutively are about 7.24 dBi and 7.28 dBi of gain for both $tr$, and 0.11 dB and 1.25 dB of axial ratio as an average of $tr$ that shown in Fig. 7 and Fig. 8. Moreover, the axial ratio bandwidth less than 3 dB are around 15 MHz (1.2%) of previous antenna and 360 MHz (6.55%) of modified antenna. Here, we use the single triangular truncated antennas thus the axial ratio bandwidth are narrow. Then, it is insufficient for the airspace with a target specification of $\geq 10$ MHz (see Table I). Our future work will need more considerations to extend axial ratio bandwidth by using array antenna.

Fig. 7. Frequency characteristic for previous antenna, $lst = 24.49$ mm

Fig. 8. Frequency characteristic for modified antenna

Graphs depicting gain/axial ratio versus elevation or $\theta$-angle of the single triangular truncated both previous and modified antennas at $f = 1.25$ GHz and $f = 5.5$ GHz are indicated in Fig. 9, Fig. 10, Fig. 11, and Fig. 12. Fig. 9 and Fig. 10 are for $\phi = 0^\circ$ (positive-0) and $\phi = 180^\circ$ (negative-0) or $x$-$z$ plane. Fig. 11 and Fig. 12 are for $\phi = 90^\circ$ (positive-0) and $\phi = 270^\circ$ (negative-0) or $y$-$z$ plane. The maximum gain and the average axial ratio values of the single triangular truncated both previous and modified antennas consecutively are about 7.24 dBi and 7.28 dBi for both $tr$, and 0.11 dB and 1.25 dB as the average of $tr$ in both the azimuth angle ($\phi = 0^\circ$ and $\phi = 90^\circ$) that occur at the elevation, $El = 90^\circ$ or $\theta = 0^\circ$. Furthermore, the axial ratio elevation-beamwidth less than 3 dB at $\phi = 0^\circ$ and $\phi = 90^\circ$ both previous and modified antennas are similar about 150° and 80°, respectively.

The characteristic of azimuth-cut $x$-$y$ plane generated by the single triangular truncated both previous antenna using proximity coupled feed and modified antenna using microstrip-line feed in the area of $El = 90^\circ$ or $\theta = 0^\circ$ at the both target frequency are described on Fig. 13 and Fig. 14. Here, we can see that the values of axial ratio azimuth-beamwidth less than 3 dB cover perfectly the whole of 360°.
IV. CONCLUSION

The performance results both (i) Left-Handed Circular Polarization (LHCP) previous antenna at frequency, \( f = 1.25 \text{ GHz} \) and (ii) LHCP modified antenna, \( f = 5.5 \text{ GHz} \) using low power around 30 dBm for CP-SAR sensor have been presented. The values of S-11 = -19.73 dB of (i), S-11 = -13.45 dB of (ii), Gain = 7.24 dBi of (i), Gain = 7.28 dBi of (ii), axial ratio, \( AR = 0.11 \text{ dB} \) of (i), \( AR = 1.25 \text{ dB} \) of (ii). The axial ratio bandwidth less than 3 dB were different around 15 MHz (1.2%) of (i) and 360 MHz (6.55%) of (ii). The values of axial ratio elevation-beamwidth less than 3 dB at \( \phi = 0^\circ \) and \( \phi = 90^\circ \) of (i) and (ii) were the same about 150°.

Fig. 9. Elevation-cut x-z plane, \( f = 1.25 \text{ GHz} \), \( \phi = 0^\circ \) (positive-0), \( \phi = 180^\circ \) (negative-0) for previous antenna, \( lst = 24.49 \text{ mm} \)

Fig. 10. Elevation-cut x-z plane, \( f = 5.5 \text{ GHz} \), \( \phi = 0^\circ \) (positive-0), \( \phi = 180^\circ \) (negative-0) for modified antenna

Fig. 11. Elevation-cut y-z plane, \( f = 1.25 \text{ GHz} \), \( \phi = 90^\circ \) (positive-0), \( \phi = 270^\circ \) (negative-0) for previous antenna, \( lst = 24.49 \text{ mm} \)

Fig. 12. Elevation-cut y-z plane, \( f = 5.5 \text{ GHz} \), \( \phi = 90^\circ \) (positive-0), \( \phi = 270^\circ \) (negative-0) for modified antenna

Fig. 13. Azimuth-cut x-y plane, \( f = 1.25 \text{ GHz} \), \( \theta = 0^\circ \) for previous antenna, \( lst = 24.49 \text{ mm} \)

Fig. 14. Azimuth-cut x-y plane, \( f = 5.5 \text{ GHz} \), \( \theta = 0^\circ \) for modified antenna

Fig. 15. Radiation efficiency for previous antenna, \( lst = 24.49 \text{ mm} \)

Fig. 16. Radiation efficiency for modified antenna

Fig. 15 and Fig. 16 show the antenna efficiency which is the radiation efficiency 91.39% of triangular truncated proximity coupled feed antenna and 96.3% of triangular truncated microstrip-line feed antenna for both \( tr \) on a target frequency, \( f = 1.25 \text{ GHz} \) of previous antenna and \( f = 5.5 \text{ GHz} \) of modified antenna.
and 80°, respectively. The values of axial ratio azimuth-beamwidth of (i) and (ii) were covering the whole of 360°. The antenna efficiency which was the radiation efficiency about 91.39% of (i) and 96.3% of (ii).

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