Design of array microstrip antenna with circular polarization for Broadband Tracking System Application

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Abstract. This paper proposes the design and simulation of microstrip array antennas with 4x1 elements that have circular polarization for Broadband Antenna Tracking System (BATS) applications. The proposed antenna is designed to work at a frequency of 11 GHz by using FR-4 type substrate with a dielectric constant 4.3, thickness (h) 1.6 mm and loss tangent (tan \(\alpha\)) 0.0265. Circular polarization with axial ratio \(\leq 3\) dB was obtained using the truncated corner technique while the 4x1 element array technique was used to increase the bandwidth of the proposed antenna. From the simulation results obtained return loss of -29.71 dB and VSWR 1.068 at the working frequency of 11 GHz. The bandwidth of the proposed antenna is 1663 MHz in the frequency range 10582 GHz - 12215 MHz. The axial ratio of the proposed antenna is \(\leq 3\) dB, which is 2.462 dB at the working frequency of 11 GHz. Based on the results obtained from the design and simulation process, the proposed antenna has worked in accordance with the specified working frequency and is suitable for the Broadband Tracking System application.

1. Introduction

Microwave radio communication systems have been widely used for long-distance and point-to-point communication. Based on regulations regulated by Cameron et al. [1] that the working frequency range for microwave radio is 10.7 - 11.7 GHz. One of the applications of microwave communication systems is Broadband Antenna Tracking System (BATS) [2]. BATS is used for radio communication systems in offshore oil drilling which serves to report the production of oil refineries on tankers in the ocean to platforms on land. Microwave radio communication systems require the accuracy of the transmitter antenna on the platform and the receiver on the tanker must always be in the line of sight position. For this reason, a microwave link radio system Broadband Antenna Tracking System (BATS) is used to control the azimuth of the antenna to keep it in line of sight. The movement of the antenna tracking depends on the received signal level on the receiving antenna on the tanker, if the reception is good, then the tracking is idle but if the reception is bad then tracking moves to find the best reception position. The type of antenna polarization used in BATS is vertical and horizontal. When the radio link uses horizontal polarization and the reception signal level decreases, the link will automatically use vertical polarization, and vice versa. This polarization transfer is generally found in the Indoor Unit (IDU) controller circuit as a protection switcher [3]. For this reason, an antenna that has circular polarization
is needed to overcome the problem of overlapping between horizontal and vertical polarization so that the reception signal level is more stable and uninterrupted.

One type of antenna that can be optimized to produce circular polarization is the microstrip antenna [4]. One of the advantages of microstrip antennas is the low cost, compact design and suitable for high frequency so that it is effective for use in the field [5]. But microstrip antennas have several disadvantages including narrow bandwidth, low gain and low directivity [6]. Based on previous research, it has been described to produce circular polarization with axial ratio ≤ 3 dB on microstrip antennas can use several methods including truncated corner [7-8], proximity coupling [9-10] and fractal [11-12]. While increasing bandwidth and gain can be used array [13-14], log-periodic [15-16] and parasitic [17-18]. In the previous study by Varghese et al. [19], a microstrip antenna has been investigated with four-element cross fed array method for 11 GHz working frequency with a return loss of -24.138, VSWR 1.1326 and bandwidth of 210 MHz but polarization is not circular with axial ratio ≤ 3 dB. While the research conducted by Muludi and Aswoyo [20] has successfully designed a microstrip antenna with circular polarization using truncated corner and four-element array using a T junction which produces a return loss of -17.742 dB, VSWR of 1.298, bandwidth of 79.9 MHz and the axial ratio of 2.697 dB.

In this paper, the truncated corner technique is used to produce circular polarization with an axial ratio ≤ 3 dB. To increase gain and bandwidth of the proposed antenna, an array method with 4 elements is applied by arranging the antenna in parallel which is connected with the microstrip line. The focus of this study is to produce microstrip antennas with circular polarization with axial ratio ≤ 3 dB, return loss ≤ -10 dB and gain ≤ 5 dB which works at 11 GHz for Broadband Antenna Tracking System applications.

2. Design of antenna

2.1. Design of single patch of antenna

In this research, the initial design of a single patch of antenna uses a rectangular shape that works in the working frequency of 11 GHz. The proposed antenna is realized on a single layer substrate with relative permittivity (ε_r) of 4.3, substrate thickness (h) of 1.6 mm and loss tangent (tan δ) of 0.0265. The dimension of the rectangular microstrip antenna obtained using equations (1) until (4). The feed line used from the proposed antenna is microstrip line with an input impedance of 50 Ohms. The dimensions of the microstrip line are obtained using equations (5) and (6) [21].

\[
W = \frac{C}{2f\sqrt{\varepsilon_r + \frac{1}{2}}} \quad (1)
\]

\[
L_{eff} = \frac{C}{2f\sqrt{\varepsilon_{reff}}} \quad (2)
\]

\[
\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left[1 + 12\frac{h}{W}\right]^{-1} \quad (3)
\]

\[
\Delta L = 0.412h\frac{(\varepsilon_{reff} + 0.3)(W + 0.264)}{(\varepsilon_{reff} - 0.258)(W + 0.8)} \quad (4)
\]

\[
B = \frac{60\pi^2}{2h\varepsilon_{reff}} \quad (5)
\]

\[
W_z = \frac{2h}{\pi}\left\{B - 1 - \ln(2B - 1) + \frac{\varepsilon_r - 1}{2\varepsilon_r} \left[\ln(B - 1) + 0.39 - \frac{0.61}{\varepsilon_r}\right]\right\} \quad (6)
\]
After calculating using equations (1) and (2), the dimensions of W is 7.6 mm and L is 6 mm, while the dimensions of the channel width (Wz) are 0.7 mm. The initial design of a single element microstrip antenna can be seen in Figure 1.

![Design of microstrip antenna with rectangular patch](image)

**Figure 1.** Design of microstrip antenna with rectangular patch.

Figure 1 shows that the dimensions of the substrate on a single element microstrip antenna are X = 10 mm and Y = 10 mm. Furthermore, a rectangular microstrip patch antenna has dimensions of Width (W) is 7.6 mm and Length (L) is 6 mm with dimensions of width (Wz) and length of microstrip line (Lz) is 0.7 mm and 3.5 mm.

2.2. **Design of truncated corner microstrip antenna with array 4 element**

To produce circular polarization on a single element microstrip antenna, a truncated corner method is required. The truncated corner method is carried out by cutting the edge of a single element patch antenna so that it occurs on the edge effect of the microstrip antenna. The biggest current flowing on the microstrip antenna is on the edge of the patch so that if the part is deformed it will have an impact of shifting the working frequency and produce circular polarization. The dimensions of the pieces on the edge of a single patch antenna element can be obtained using equation (7) while the cutting angle is 45 degrees with respect to the flat plane of the patch antenna [21].

$$\Delta L = \frac{1}{8} \times L$$  (7)

From equation (6) the dimensions of the pieces obtained on the patch edge of the microstrip antenna (ΔL) are 1.3 mm which are applied by cutting the upper and lower left edges of the single element antenna patch. In this paper, four patches linear array microstrip antenna technique is used for improving bandwidth and gain. The distance between patches antenna and its related length can be obtained using equation (7) and (8) below [22].

$$d = \frac{\lambda}{2}$$  (8)

$$d_{array} = d - L$$  (9)

The design of a single element antenna with the truncated corner technique and array with four elements can be seen in Figure 2.
Figure 2 shows the design of the proposed antenna that has been developed using an array with four elements. Each patch antenna is separated by distance $d_1$ and $d_2$. This spacing arrangement between patches is done to prevent interference between the radiating elements. The overall dimension of the proposed antenna can be seen in Table 1.

Table 1. The dimension of proposed antenna.

| Parameter | Dimension (mm) | Parameter | Dimension (mm) |
|-----------|----------------|-----------|----------------|
| $X$       | 51.5           | $L_2$     | 25.4           |
| $Y$       | 20             | $L_3$     | 22             |
| $W$       | 7.8            | $L_4$     | 10             |
| $L$       | 5.1            | $W_z$     | 0.7            |
| $\Delta l$| 2.5            | $d_1$     | 5.9            |
| $L_1$     | 4.5            | $d_2$     | 8.4            |

Table 1 shows the overall dimensions of the proposed antenna. After optimization and trial error using AWR Microwave Office, the distance $d_1$ 5.9 mm and $d_2$ 8.4 mm. To produce the best axial ratio, the proposed antenna is given 3 slices on the edge of the patch.

3. Results and discussion

After the design process is complete, the next step is to do the simulation process using the AWR Microwave office. The simulated parameters are return loss, VSWR, axial ratio, gain and radiation pattern. Comparison of simulation results from the proposed antenna is shown in Figure 3 until Figure 8. The working frequency of the antenna observed in this paper is 11 GHz according to the frequency for the BATS application. Simulation is done by trial and error method using the AWR Microwave Office.

Figure 3. Comparison simulation result of return loss.
Figure 3 and Figure 4 show a comparison of the simulation results of return loss and VSWR from the proposed antenna. The design of a single element antenna produces a return loss $-21.87$ dB, VSWR of $1.175$ and bandwidth $392$ MHz whereas after being optimized with an array of 4 elements the return loss increases until $-29.71$ dB and VSWR increase become $1.068$. The bandwidth of a 4 element array antenna increases to $1663$ MHz or $324 \%$ compared to a single element antenna. Comparison of the simulation gain and axial ratio results is shown in Figure 5 and Figure 6.
Figure 5 shows the simulation results of the gain of the proposed antenna. Single element antenna produces gain 5.6 dB while after optimizing the array it decreases becomes 2.941 dB at the working frequency of 11 GHz. The decrease in gain occurs because the bandwidth of the proposed antenna has increased significantly. Wide bandwidth produces smaller gain compared to a narrow bandwidth. This is shown when the antenna is designed with a single element, a narrower bandwidth with a higher gain is obtained. Figure 6 shows the simulation results of the axial ratio of the proposed antenna. The use of truncated corners in 4 element array antennas produces circular polarization with axial ratio 2.14 dB while on the antenna the single element axial ratio is still above 3 dB. Comparison of the overall simulation results from the proposed antenna can be seen in Table 2.

Table 2. Comparison of simulation result.

| Condition                        | Parameter       | Return Loss | VSWR | Bandwidth | Gain   | Axial Ratio |
|----------------------------------|-----------------|-------------|------|-----------|--------|-------------|
| Single Element                   |                 | -21.87 dB   | 1.175| 392 MHz   | 5.6 dB | -           |
| Truncated Corner With Array 4 Element |                 | -29.71 dB   | 1.068| 1663 MHz  | 2.941 dB| 2.941 dB    |

Table 2 shows the overall comparison of simulation results from the proposed antenna. Return loss and VSWR generated from antenna arrays with four elements increased by 35.94% and 9.10% compared to single element antennas. In addition, the bandwidth of the array antenna also increased by 324% compared to a single element but a decrease occurred for the gain of the antenna. The decrease in gain on the proposed antenna is due to the impact of increasing the bandwidth of the antenna significantly so that the antenna has a wider frequency range. The radiation pattern of the proposed antenna can be seen in Figure 7 and Figure 8. Figure 7 shows the radiation pattern of a single element antenna which has a narrow direction while Figure 8 shows a radiation pattern from an antenna array with four elements that have a wider directional angle. The red line is the electrical field (Ephi) and the black line is the magnetic field (Etheta) from the radiation pattern of the proposed antenna. From the whole simulation process, it can be concluded that the proposed antenna has produced circular polarization and has met the criteria for working at the 11 GHz working frequency for the BATS application with a minimum bandwidth of 1 GHz with a gain of 2 dB.
4. Conclusion
In this paper, the microstrip antenna with rectangular patch developed using truncated corner with a four elements array has been successfully designed and investigated. From the simulation results obtained return loss -29.71 dB, VSWR 1.068 with bandwidth 1663 MHz. The gain generated from the proposed antenna is 2.94 dB while circular polarization is indicated by an axial ratio of 2.941 dB at the working frequency of 11 GHz. Return loss and VSWR generated from antenna arrays with four elements increased by 35.94% and 9.10% compared to single element antennas. In addition, the bandwidth of the array antenna also increased by 324% compared to a single element but a decrease occurred for the gain of the antenna. The decrease in gain on the proposed antenna is due to the impact of increasing the bandwidth of the antenna significantly so that the antenna has a wider frequency range. The future work of this research is to increase the gain by increasing the array to 16 elements and manufacturing and testing antennas in the laboratory.

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