Design and implementation of planar phase shifter for radar at frequency 2.9 GHz – 3.1 GHz as beam-steering

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Abstract. Nowadays in Indonesia, 3D Radar has been developed to perform a vertical scanning that has multi-functional benefits in telecommunication industry and defence. As a common practice, 3D radar system is frequently used to measure the distance of an object like the aircraft. Therefore, most important element in radar systems is the phase shifter that has a main role in steering the beam and replacing the rotator function. This final research will focus on the operation of simple Phase Shifter with concerning a 2.9 GHz – 3.1 GHz radar frequency. Phase shifter designed at 3 GHz as the centre frequency within a value return loss ≤ -15 dB, insertion ≥ -4 dB, coupling ≥ -4 dB, isolation ≤ -15 dB, phase difference 45°, 90°, 135°, phase error ≤ 15°, and realized by converting into Microstrip Quadrature Hybrid Coupler 90°. These particular phase shifter uses the type of substrate Rogers R04035B with dielectric constant values (\(\varepsilon_r\)) at 3.48, and the thickness of the substrate (h) of 1.524 mm. Simulations are performed using Computer System Technology (CST) software suite 2015 and assigned the average results each port to return loss value -37.290519 dB, insertion -3.154242 dB, coupling -3.164594 dB, isolation -32.714140 dB, with phase difference 45°, 89.09566°, 90.76276°, 134.85057° and phase error 0.00816°, 0.90434°, 0.76276°, 0.14943°. It is then subsequently realized and measured by Network Analyzer and return loss -30.078370 dB, insertion -3.229792 dB, coupling -3.146129 dB, isolation -42.651590 dB, phase difference 45.15190°, 86.38080°, 93.38538°, 134.36260° and phase error 0.15190°, 3.61920°, 3.38538°, 0.63740°.

1. Introduction

The rapid development of telecommunication technology with highly diverse services today demands to improve of quality. With good quality, communication technology can contribute to the development of society and can also help improve the quality in telecommunications and defense industries. Various manufacturing methods have also been developed in several ways with the emphasis in minimizing the size and enhancing the performance parameters of transmission line-based communication devices [1].

As the largest maritime nation in the world, currently in Indonesia a 3-dimensional radar (3D) for costal guards, which is able to perform vertical scanning is being develop. For the development of 3D radar, it requires a multi-beam antenna to scan electronically [2].

Current 3D radar technology uses an adjustable antenna array beam direction or the so-called beam forming antenna. Phase shifter act as a substitute of the rotator that moves the direction of transmit pattern. Phase shifter is a functional circuit used to shift or increase phase of transmitted signal, the antenna beam direction can be changed electronically without the need of changing its position [3]. By
shifting the phase of signal in array antenna beam direction will change automatically the continuous beam change periodically is called beam-steering. With beam-steering, scanning object on a 3D radar works electronically, without having to use a rotator or changing the position of radar antenna [4].

This final project will be designing phase shifter by using microstrip applied to radar that work at frequency 2.9 GHz - 3.1 GHz with phase difference between its output is 0°, 45°, 90° and 135° by using quadrature hybrid as its divider. This is simulated by the CST Studio Suite software and fabricated using the Roger 4350B Printed Circuit Board (PCB).

2. Literature review

2.1. Beam steering antenna array
If a group of antennas are assigned signals with the same phase, then the beam direction will be centred. Where in each direction of each patch of antenna array is the sum of all output signals with different directions [4]. To do beam-steering electronically, it takes a phase difference of \( \theta \) for each patch [4].

2.2. Quadrature hybrid 90°
If a hybrid 90° is supplied with an impedance of \( Z_0 \), then the impedance value of the shunt arm = \( Z_0 \) and the impedance value in the series arm = \( Z_0/\sqrt{2} \) the distance between arms \( \lambda / 4 \) is determined by the desired resonance frequency.

\[ \lambda_{\text{microstrip}} = \frac{60,412,209,333}{3,000,000} \text{ mm} \]

Figure 1. Size of series arm \( (Z_0 / \sqrt{2}) \) and shunt arm \( (Z_0) \) [5].

3. Planar phase shifter design

3.1. Transmission channel design
The planar phase shifter is planned to have a working frequency between 2.9 to 3.1 GHz. Based on the frequency range the middle frequency of 3 GHz can be calculated. The material used is Roger4350B which has a dielectric constant value of \( \varepsilon_r \) 3.48 and substrate thickness of \( h \) 1.524 mm. Using the obtained:

\[ w = \frac{3,396,774,17}{3,000,000} \text{ mm} \]

3.2. Phase shifter design
To determine the phase shifter length (Ps), the effective dielectric constant must the determined first by using the obtained:

\[ \varepsilon_{\text{reff}} = 2.74 \]

With the centre frequency of 3GHz and the value of electromagnetic wave propagation in free space is \( c = 3\times10^8 \text{ m/s} \), then \( \lambda_{\text{microstrip}} \) can be calculated:

\[ \lambda_{\text{microstrip}} = 60,412,209,333 \text{ mm} \]

The phase shifter being used is 45°, the channel length (Ps) is calculated:

\[ Ps = 7,551,526,16 \text{ mm} \]
3.3. Design of quadrature hybrid
In constructing a hybrid quadrature, some calculations such as shunt arm calculations, series arms and port channel length are required.

To determine the length and width of the shunt arm are used:

\[ \begin{align*}
    w_{sh} &= 3,39677417 \text{ mm}, \quad L_{sh} = 15,10305233 \text{ mm}, \\
    w_{se} &= 5,72182255 \text{ mm}, \quad L_{se} = 14,8208616 \text{ mm}
\end{align*} \]

Then the length and width of the series arm are calculated, it is then obtained:

And for port length or Lp not more than \( \lambda / 4 \), then for Lp length is used 6 mm. Initial dimensional simulation gives less optimum parameters, optimization process is required. Based on experimental results, variables of hybrid dimensions are obtained in optimum sizes as illustrated in the following figure.

![Figure 2. Quadrature hybrid optimization results.](image)

And the optimization results can be seen in the following figure.

![Figure 3. Results of quadrature hybrid optimization.](image)

3.4. Planar phase shifter design
Planar phase shifter is designed by using the value of optimization results in phase shifter and quadrature hybrid simulation before and on the dimension of mitred bend using the results from calculation. Here is table of parameter values and the layout of the planar phase shifter design.
Figure 4. Planar phase shifter layout.

Initial dimension simulation produces less optimal parameters because of that optimization process is required. From optimum optimization results obtained data with average value on each port:

- **Return Loss** \((S_{11}, S_{22}, S_{33}, S_{44}) = -37.292686\) dB
- **Insertion** \((S_{21}, S_{12}, S_{43}, S_{34}) = -3.1540642\) dB
- **Coupling** \((S_{31}, S_{42}, S_{13}, S_{24}) = -3.1629035\) dB
- **Isolation** \((S_{41}, S_{32}, S_{23}, S_{14}) = -40.192566\) dB

And phase difference is:

- **Port 1** \(|S_{31} - S_{21}| = 45.007913°
- **Port 2** \(|S_{42} - S_{12}| = 89.095661°
- **Port 3** \(|S_{13} - S_{43}| = 90.762741°
- **Port 4** \(|S_{24} - S_{34}| = 134.8508°

4. Results

After obtaining the dimensions in accordance with the specifications of the simulation phase, the next step is the realization or fabrication planar phase shifter to the material PCB Roger 4350B. The results of manufacturing can be seen in the following figure.

Figure 5. Fabrication result planar phase shifter.

Measurement result of planar phase shifter manufacturing is done by using the ADVANTEST R3370 network analyzer with S-Band frequency range of 2 GHz - 4 GHz. Because the phase shifter is using a hybrid coupler, the measurement is done by each port.

In port 1 the following results are obtained.
Table 1. Port 1.

| Name            | Frequency (GHz) | Return Loss (dB) | Insertion (dB) | Coupling (dB) | Isolation (dB) | Phase Difference |
|-----------------|-----------------|------------------|----------------|---------------|----------------|------------------|
|                 | 2.89            | -28,417670       | -3,213151      | -3,172687     | -32,714140     | 45,15190°        |

In port 2 the following results are obtained.

Table 2. Port 2.

| Name            | Frequency (GHz) | Return Loss (dB) | Insertion (dB) | Coupling (dB) | Isolation (dB) | Phase Difference |
|-----------------|-----------------|------------------|----------------|---------------|----------------|------------------|
|                 | 2.89            | -24,922970       | -3,317630      | -3,172687     | -54,274670     | 86,38080°        |

In port 3 the following results are obtained.

Table 3. Port 3.

| Name            | Frequency (GHz) | Return Loss (dB) | Insertion (dB) | Coupling (dB) | Isolation (dB) | Phase Difference |
|-----------------|-----------------|------------------|----------------|---------------|----------------|------------------|
|                 | 2.89            | -31,211930       | -3,166852      | -3,172687     | -50,985130     | 93,38538°        |

In port 4 the following results are obtained.

Table 4. Port 4.

| Name            | Frequency (GHz) | Return Loss (dB) | Insertion (dB) | Coupling (dB) | Isolation (dB) | Phase Difference |
|-----------------|-----------------|------------------|----------------|---------------|----------------|------------------|
|                 | 2.89            | -35,760910       | -3,221536      | -3,119571     | -32,632420     | 134,36260°       |

5. Conclusion
From the research and writing of this Final Project some conclusions can be drawn about the design and realization of Planar Phase Shifter, these includes as follows:

- From the Planar Phase shifter simulation result according to the desired specification by doing Nine times optimization on the simulation. On the nine optimization of the frequency obtained corresponding at 3 GHz with the average return loss value of each port -37.290519 dB, the average insertion value of each port is -3.154242 dB, the average coupling value of each port for - 3.164594 dB, the average isolation value of each port is -32,714140 dB, with phase
difference 45.00816°, 89.09566°, 90.76276° and 134.85057° and phase error of 0.00816°, 0.90434°, 0.76276° and 0.14943°. The result is in accordance with the specified planar phase shifter specification i.e. return loss ≤ -15 dB, insertion ≥ -4 dB, isolation ≤ -15 dB, phase difference 45°, 90°, 135°, and phase error ≤15°.

- From the Planar Phase Shifter measurement result using the Network Analyzer the obtained frequency shifted 110 MHz from the desired frequency, with the middle frequency 2.89 GHz. On the result of measurement of return loss parameter obtained by -30.078370 dB, insertion equal to -3.229792 dB, coupling equal to -3.146129 dB, isolation equal to -42.651590 dB, phase difference equal to 45.15190°, 86.38080°, 93.38538°, 134.36260° and phase error of 0.15190°, 3.61920°, 3.38538° and 0.63740°. The result parameters are in accordance with the specified planar phase shifter specification i.e. return loss ≤ -15 dB, insertion ≥ -4 dB, coupling ≥ -4 dB, isolation ≤ -15 dB, phase difference 45°, 90°, 135°, and Phase error ≤ 15°. The shift experienced in the working frequency remains within the S-Band radar working frequency of 2 GHz - 4 GHz.

- In the results obtained from the realization of differences with the simulation. The difference between the two is due to several factors, such as the temperature and humidity factors that can influence measurement the accuracy of the manufacturing tool, where the resonance frequency is closely related to the length of the transmission line, the process of soldering the port less carefully, the losses due to coaxial cable on the network Analyzer used during process measurement and loss of conductor owned by PCB material.

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References
[1] Ahmad E, Hamidi Z, Utami U S, Ismail N and Munir A 2018 Compact SIW Power Divider with CSRRs for WLAN Application 2018 Prog. Electromagn. Res. Symp., 1108–1111
[2] Vswr L and Vswr L return loss Vs . VSWR table of return loss vs . voltage standing wave ratio 111
[3] Selvaraj J 2012 Phase shifter design Research study and verification of wide band phase shifter circuits
[4] Radar S, High V and Vhf F 2014 Faktualita 9(4) 9–11
[5] Douville R J P and James D S 1978 Experimental Study of symmetric microstrip bends and their compensation IEEE Transactions on Microwave Theory and Techniques 26(3) 175-181