Design of microstrip antenna C-band frequency for ground surveillance radar

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Abstract. This paper presents designing of a conformal antenna using a number of microstrip patches in C band frequency range 4 GHz to 8 GHz. The type of microstrip C-band antenna was chosen because it is suitable for use on portable surveillance radar systems. Single element patches antenna with a carved slit is used to obtain a horizontal polarization. In this paper, an microstrip patch antenna C-band frequency for 3-dimensional radar application was designed using CST Studio Suite 2018. The antenna operates at frequency 5.6 GHz, with 40.55 x 22.65 mm dimension using substrate Rogers RO-4350B (lossy) with thickness 1.524 mm and relative permittivity 3.66. The bandwidth obtained from the simulation is 200 MHz, the return loss values below -20 dB, VSWR less than 2, 5.6 dB gain, and has directional radiation pattern.

1. Introduction
Indonesia is a country that requires devices that can monitor land and waters throughout the country. One of the devices that can be used is Radar. Radar stands for Radio Detection and Ranging, this is a system for detecting objects that use Radio waves to determine the distance, altitude, direction, or speed of an object [1]. The radar system operates using radio wave transmission by detecting and translating echo signals reflected by the intended object. A portable surveillance radar system is needed because of the limited number of radars and the wide area that needs to be monitored [2].

In a wireless communication system, one component that plays an important role is the antenna. Rapid technological advances have brought antennas with light weight, affordable prices, and low profile while still being able to maintain high performance. In a radar system, it is also needed an antenna with low profile and lightweight characteristics, so that the current technology trend focuses a lot on the microstrip antenna design [3].

Radar Surveillance Ground is used as a detector of objects that move on land such as people, vehicles or aircraft that fly at a low altitude. This technology is designed using the Frequency Modulated Continuous Wave (FM-CW) technique, in which radar signals are transmitted continuously using two separate transmitting and receiving antennas. This technology requires a very low transmit power (≤ 10 Watt) so that it can be operated only by using a battery, but provides a wide monitoring area coverage [4,5].

The frequency range used for this surveillance radar is C-band. C-band is part of the microwave band of the electromagnetic spectrum for radio waves with frequencies between 4 to 8 GHz [6].

According to the definitions contained in the IEEE Standard Definitions of Terms for Antennas, the definition of an antenna is a device used to radiate or receive radio waves [7]. Microstrip antenna is a
metal conductor material attached to a ground plane. The microstrip antenna has several advantages, such as thin and small shape, has a light weight, easy to fabricate, easy to integrate with other electronic devices, and affordable price [8]. In general, microstrip antenna is shown in figure 1. Antenna polarization will greatly affect the performance of the radar. Antennas with horizontal polarization can reduce ground chaos rather than vertical polarization [2].

In this paper, a single microstrip antenna with horizontal polarization will be designed for ground surveillance radar. This antenna works on C-Band frequencies which are from the frequency range of 4-8 GHz and has an operating frequency of 5.6 GHz with a port impedance of 50 ohms. Horizontal polarization is obtained by making a slot on the antenna as shown in Figure 2.

![Microstrip antenna](image1)

**Figure 1.** Microstrip antenna.

![Microstrip antenna with a gap](image2)

**Figure 2.** Microstrip antenna with a gap.

2. **Researchs method**

The research was conducted through three stages namely design, simulation and optimization to get optimal results by using CST Studio Suite software. The design is done based on the desired antenna specifications. After the design is completed, it is simulated and if the results are not appropriate to the desired specifications, the optimization process is carried out by changing the values of each dimension until it meets the specifications.

3. **Results and Discussion**

This section explains three steps of research, that is the design, simulation and optimization of the arrangement of C-Band frequency microstrip antennas. The design step is carried out to determine antenna specifications such as geometry, dimensions, work frequency, VSWR, radiation patterns,
impedance, polarization and gain. The simulation step is done to find out the design results whether they are appropriate to the desired specifications, if not then it will proceed to the optimization step to get the desired results.

3.1. Design

Microstrip antenna is an antenna which is composed of three elements, that is: patch (radiating element), substrate, and ground. In designing this antenna, we use Rogers RO-4350 B (lossy) substrate which has the specifications listed in table 1. While the desired antenna specifications are listed in table 2.

Table 1. Substrate specifications.

| Substrate type | Rogers RO-4350 B (lossy) |
|----------------|--------------------------|
| Relative dielectric constant (\(\varepsilon_r\)) | 3.66 |
| Dielectric Loss tangent (\(\tan \delta\)) | 0.0037 |
| Substrate thick (h) | 1.524 mm |

Table 2. Antenna specifications.

| Parameter      | Value         |
|----------------|---------------|
| Working Frequency (F0) | 5.6 GHz       |
| VSWR            | < 2           |
| Bandwidth       | 200 MHz       |
| Impedance (Z₀)  | 50 Ω          |
| Gain            | > 5 dB        |
| Radiation pattern | Directional |
| Polarization    | Horizontal    |
| Return Loss     | <-10dB        |

3.1.1. Antenna type. The antenna form used was a modification of the journal references Paramayudha [9], Kuo F Y and Hwang [10]. There is a modified geometry shape as shown in figure 3. In this antenna design, there is a gap or slot to get horizontal polarization. Horizontal polarization occurs because of changes in the direction of surface current that flow on the patch. Before inserting a gap in a patch, the surface current flow vertically. With the gap in the patch, the surface will flow horizontally.

Figure 3. Modified antenna type.

3.1.2. Antenna design. For the initial design of the antenna dimensions, we use dimensional calculations for rectangular microstrip antennas as shown in table 3. This antenna uses the microstrip feeding rationing technique.
Table 3. Calculation of basic parameters for microstrip antennas.

| No | Dimension | Formula and results | Value |
|----|-----------|---------------------|-------|
| 1. | Patch width | $W = \frac{c}{2f_0\sqrt{\varepsilon_e + \frac{1}{2}}} = 17.547 \text{ mm}$ | 17.547 |
| 2. | Patch Length | a. $\varepsilon_e = \varepsilon_{RF} + \frac{1}{2} + \varepsilon_{RF} - \frac{1}{2} \left(1 + \frac{2h}{W} \right) - \frac{1}{2} = 3.260 \text{ mm}$ | |
|    |           | b. $\Delta L = 0.412 \left(\varepsilon_e + 0.3\right) \left(\frac{W}{h} + 0.264\right) = 0.7114 \text{ mm}$ | |
|    |           | c. $L = \frac{c}{2f_0\sqrt{\varepsilon_e}} - 2\Delta L = 14.652 \text{ mm}$ | |
| 3. | Substrate width / ground | a. $W_s = 6h + W = (6 \times 1.524) + 17.547 = 26.691 \text{ mm}$ | |
|    |           | b. $L_s = 6h + L = (6 \times 1.524) + 14.835 = 23.979 \text{ mm}$ | |
| 4. | a. Feed Channel Width | a. For get B, value, use the equation $B = \frac{\phi_0 \varepsilon_e}{2\varepsilon_0 \sqrt{\varepsilon_e}} = 6.1844$ and get the $W_e$ value using the equation $W_e = 2\varepsilon_0 \pi \left(1 - 1 + \frac{1}{2} \left(\varepsilon_e - 1\right) + \frac{\varepsilon_e - 1}{2\varepsilon_e} \left(\varepsilon_e + 1\right) + 0.3\varepsilon_e - \frac{\varepsilon_0 \varepsilon_e}{\varepsilon_e} \right)^2 = 3.33 \text{ mm}$ | |
|    | b. Length of Feed Channels | b. $L_e = 7 \text{ mm}$ | |
|    | c. Width and length of matching impedance | c. $W_e = 1.813 \text{ mm}$ | |
|    | d. W50 length and width | d. $L_{50} = 8 \text{ mm}$ | |
|    |       | d. $W_{50} = 3.33 \text{ mm}$ | |
|    |       | L50 = 7.9 mm | |
| 5. | Relative Dielectric Constant ($\varepsilon_{reff}$) | To get the $\varepsilon_{reff}$ value, use the equation below, In this case $W_e/h \geq 1$, $\varepsilon_{reff} = \frac{\varepsilon_e + 1}{2} + \frac{\varepsilon_e - 1}{2} \left(1 + \frac{h}{w}\right)^2 = 2.72$ | |

3.2. Simulation

After the calculation step, the simulation process is carried out using CST Studio Suite 2018. At this step, the optimization process is carried out, by changing the dimensions of the antenna, to obtain the desired specifications.

3.2.1. Initial design. The initial design list parameters are listed in Table 4. Antenna simulation results using initial design parameters, are not met all the desired specifications. The operating frequency is 4.35 GHz instead of 5.6 GHz, the antenna impedance is 33.56 ohms instead of 50 ohms, polarization is not horizontal and gain is less than 5 dB. Return loss and VSWR values, -14.8 dB and 1.4 respectively, are already met the desired specifications.

Table 4. Initial design list parameters.

| Name       | Expression | Value  | Description          |
|------------|------------|--------|----------------------|
| pw         | 17.547     | 17.547 | Patch width          |
| feed_length| 7          | 7      | Feeder length        |
| Lsli       | 5          | 5      | Slit length          |
| Lp1        | 6.1        | 6.1    | Slit to patch bottom distance |
| Wsli       | feed_width | 6.1844 | Slit width           |
| feed_width | 6.1844     | 6.1844 | Feeder width         |
| f_shit     | 2          | 2      | Feeder shift         |
| sub_width  | 1.524      | 1.524  | Substrate thickness  |
| lw         | 14.835     | 14.835 | Patch length         |
Figure 4-9 shown respectively, the return loss, antenna impedance, VSWR, polarization, gain, and radiation pattern of initial design result.

Figure 4. Initial design s-parameters.  
Figure 5. Impedance of initial design.  
Figure 6. Initial design VSWR.  
Figure 7. Initial design polarization.  
Figure 8. Initial design gain.  
Figure 9. Initial design radiation pattern.

To get a design that fits the desired antenna specifications, optimization must be done by changing the antenna dimension values. Table 5 shown the optimization results using parameters sweep.
Table 5. Optimization result using parameters sweep.

| No. | Pw (mm) | Feed Width (mm) | Lp1 | L slit | Feed Length (mm) | Freq. (GHz) | Imp (ohm) | Return Loss (dB) | Gain (dB) | Polarization | VSWR |
|-----|---------|-----------------|-----|--------|-----------------|-------------|-----------|-----------------|-----------|--------------|------|
| 1   | 17.547  | 6.18            | 6.1 | 5      | 5               | 4.3         | 33.5      | -14.8           | 4         | Vertical     | 1.4  |
| 2   | 16      | 6.18            | 6.1 | 5      | 7               | 4.8         | 33.5      | -13.2           | 4.8       | Vertical     | 1.4  |
| 3   | 16      | 5               | 6.1 | 5      | 7               | 4.72        | 38.9      | -13.6           | 6.5       | Vertical     | 1.5  |
| 4   | 9.75    | 0.66            | 3   | 5      | 5               | 7.12        | 105       | -8.6            | 3.6       | Vertical     | 2.1  |
| 5   | 12.65   | 0.66            | 3   | 5      | 7               | 7.64        | 106.7     | -6.4            | 5.5       | Vertical     | 2.4  |
| 6   | 12.65   | 0.66            | 3   | 7      | 25              | 5.68        | 106.8     | -6.0            | 5.6       | Horizontal   | 2.9  |
| 7   | 12.65   | 0.66            | 4.5 | 7      | 25              | 5.68        | 106.7     | -5.8            | 5.5       | Horizontal   | 3.05 |

The optimization using the sweep parameter, as in table 5, have not yielded satisfactory results. From the fifth experiment, only the gain meets the specifications. In the sixth experiment, we expanded the feed length and Lslit value to obtain horizontal polarization. The addition of LP1 in seventh experiment did not give better results yet. Next, we added a matching impedance by put in a new parameter, W50 (width of matching impedance) into the simulation as shown in table 6, and produces an antenna with the desired specifications.

Table 6. Optimization results using matching impedance.

| No. | Pw (mm) | W50 (mm) | Feed Width (mm) | Lp1 | L slit | Feed Length (mm) | Freq. (GHz) | Imp (ohm) | Return Loss (dB) | Gain (dB) | Polarization | VSWR |
|-----|---------|----------|-----------------|-----|--------|-----------------|-------------|-----------|-----------------|-----------|--------------|------|
| 8   | 12.65   | 3.0375   | 0.75            | 4.5 | 7      | 25             | 5.6         | 50.11     | -37             | 6.08      | Horizontal   | 1.02 |
| 9   | 12.65   | 3.04     | 0.75            | 4.5 | 7      | 25             | 5.6         | 50.08     | -37.05         | 6.08      | Horizontal   | 1.02 |
| 10  | 12.65   | 3.0429   | 0.75            | 4.5 | 7      | 25             | 5.6         | 50.05     | -37.1          | 6.08      | Horizontal   | 1.02 |
| 11  | 12.65   | 3.048    | 0.75            | 4.5 | 7      | 25             | 5.6         | 50.00     | -37.18         | 6.08      | Horizontal   | 1.02 |
| 12  | 12.65   | 3.048    | 0.75            | 4.5 | 7      | 20             | 5.6         | 50.00     | -20            | 6.2       | Horizontal   | 1.2  |
| 13  | 12.65   | 3.048    | 0.75            | 4.5 | 7      | 15             | 5.6         | 50.00     | -22            | 6.16      | Horizontal   | 1.17 |
| 14  | 12.65   | 3.048    | 0.75            | 4.5 | 7      | 12             | 5.6         | 50.00     | -26.1          | 5.9       | Horizontal   | 1.1  |
| 15  | 12.65   | 3.048    | 0.75            | 4.5 | 7      | 7              | 5.6         | 50.00     | -26.8          | 5.6       | Horizontal   | 1.09 |

As shown in table 6, the addition of matching impedance can match the antenna impedance to 50 ohms line impedance. By reducing the feed length value as in 15th experiment, the VSWR will be smaller. Reduction in feed length as shown in 15th experiment, giving the desired antenna specifications.

3.2.2. Final design. After optimization, the antenna meets the specified specifications. The final dimension is shown in table 7.

Table 7. Final design parameters list.

| Name       | Expression | Value | Description               |
|------------|------------|-------|---------------------------|
| sub_add    | 5          | 5     | Substrate width addition  |
| pw         | 12.65      | 12.65 | Patch width               |
| feed_length| 7          | 7     | Feeder length             |
| Lslit      | 7          | 7     | Slot length               |
| Lp1        | 4.5        | 4.5   | Slot to patch bottom distance |
| Wslit      | feed_width | 0.75  | Slot width                |
| feed_width | 0.75       | 0.75  | Feeder width              |
| f_shift    | 4          | 4     | Feeder shift              |
| sub_width  | 1.524      | 1.524 | Substrate thickness       |
| w50        | 3.048      | 3.048 | Matching impedance        |
The results obtained from the final optimization are as shown in figure 10-15:

**Figure 10.** S-Parameter final design.

**Figure 11.** Final design impedance.

**Figure 12.** Final design VSWR.

**Figure 13.** Final design polarization.

**Figure 14.** Final design gain.

**Figure 15.** Final design radiation pattern.

### 4. Conclusion

A C-Band microstrip antenna for the Surveillance Ground radar has been designed. The desired antenna specifications have been reached, for the return loss value of -26.8 dB, 1.09 VSWR, 50 ohm impedance, directional radiation pattern, horizontal polarization due to patch loopholes, 200 MHz bandwidth and gain of 5.6 dB. All parameters affect work frequency, so accuracy is needed in analyzing and determining dimensions.
References

[1] Molchanov P, Gupta S, Kim K and Pulli K 2015 Short-range FMCW monopulse radar for hand-gesture sensing 2015 IEEE Radar Conference (RadarCon) (pp. 1491-1496) IEEE

[2] Briggs J N 2004 Target detection by marine radar 16 Iet.

[3] Beenamole K S 2009 Microstrip Antenna Designs for Radar Applications DRDO Science Spectrum 84-86

[4] Klugmann D 2016 FMCW radar in the digital age 2016 IEEE International Geoscience and Remote Sensing Symposium (IGARSS) (pp. 7370-7373) IEEE

[5] Boskovic N, Jokanovic B, Oliveri F and Tarchi D 2015 High gain printed antenna array for FMCW radar at 17 GHz 2015 12th International Conference on Telecommunication in Modern Satellite, Cable and Broadcasting Services (TELSIKS) (pp. 164-167) IEEE

[6] Samudrala S and Palle H C 2016 Rectangular microstrip patch antenna array for C-band scatterometer and MBI 2016 IEEE Annual India Conference (INDICON) (pp. 1-4) IEEE

[7] Monebhurrun V 2018 Use of Standard Definitions of Terms for Antennas & Propagation: IEEE Std. 145 & IEEE Std. 211 2018 IEEE Conference on Antenna Measurements & Applications (CAMA) (pp. 1-2) IEEE

[8] Balanis C A 2016 Antenna theory: analysis and design (John wiley & sons)

[9] Paramayudha K, Amrullah Y S and Wahyu Y 2016 X-band antenna design for Indonesian ground surveillance man pack radar 2016 2nd International Conference of Industrial, Mechanical, Electrical, and Chemical Engineering (ICIMECE) (pp. 1-3) IEEE

[10] Kuo F Y and Hwang R B 2014 High-isolation X-band marine radar antenna design IEEE Transactions on Antennas and Propagation 62(5) 2331-2337