Microstrip Antenna Design with Patch Rectangular for Primary Surveillance Radar (PSR) L-Band Application

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Abstract. This research aims to design an inexpensive primary surveillance radar (PSR) antenna with high efficiency and works on the L-Band frequency by using a microstrip antenna, this antenna has advantages in terms of ease of design, light weight and low production prices. The design of the antenna design is made in a simulation that works at a frequency of 1.3 GHz, the substrate material is made of Fr-4 which has a dielectric constant value (εr) of 4.3, while the patch material is made of copper. The antenna has a patch size of 71 x 54 mm array 2x1, while the size of the ground plane is 222 x 124.8 mm. Antenna performance testing is done by looking at S-Parameter simulation and voltage standing wave ratio (VSWR). To get an accurate value at a frequency of 1.3 GHz, the sweep method is applied to the patch by changing the width and length of the patch. From the simulation results we get the S-Parameter value right at the frequency of 1.3 GHz with a return loss value of -35 dB while the value of VSWR of 1.29 indicates the antenna has a high efficiency. This research aims to create an antenna innovation that is based on inexpensive and has high efficiency.

1. Introduction

The ground radar system is divided into several groups based on its function, one of which is the PSR antenna (primary surveillance radar) which works using gamma void to detect targets [1]. PSR is a device to passively detect and know the position and target data around it, where the aircraft does not participate actively if exposed to the primary radar RF signal emission. The beam is reflected by the fuselage and can be received in the radar receiver system, where the RF energy emitted from the PSR antenna when it hits an In Line Target, the RF energy will be reflected and received again by this Radar System. The time needed by the RF energy when it is emitted until it is received back by the PSR will be converted in the form of a range. The emission direction and the direction of reflection of RF energy will be converted in the form of bearing information (Azimuth) [2].
Satellite communication with the earth station uses electromagnetic waves with frequencies above 100MHz because frequencies below 100MHz are reflected by the ionosphere or experience diverting from the actual signal direction [3]. The use of the frequency spectrum is regulated by the International Telecommunication Union (ITU) as shown in table 1. The L-Band signal is a relatively low frequency category so that it can easily process signals that do not require sophisticated RF equipment[4] In the L-band frequencies used in low-orbit satellite communication systems, military satellites to terrestrial wireless connections such as GSM cell phone signals. The L-Band signal is also used by the satellite TC frequency, namely the signal on the KU and KA bands and is converted into L-Band on the LNB antenna.[5].

Table 1. Frequency Allocation

| No | Band | Frequency (GHz) |
|----|------|----------------|
| 1  | L    | 1-2            |
| 2  | S    | 2-4            |
| 3  | C    | 4-8            |
| 4  | X    | 8-12           |
| 5  | Ku   | 12-18          |
| 6  | K    | 18-27          |
| 7  | Ka   | 27-40          |
| 8  | V    | 40-75          |
| 9  | W    | 75-110         |

Microstrip antennas made the development of antennas develop so rapidly starting in the 1950s that up to now there have been many papers and journals discussing these antennas [6]. This research aims to make a lightweight and low cost antenna that will be realized in the world of aviation, especially in Indonesia. Microstrip antennas consist of 3 main ingredients namely patches of a patch radiating on one side of the dielectric substrate which has a ground plane [7]. The shape of the patch on the microstrip antenna consists of various kinds including square, rectangular, elliptical and circular [8]. The feeding method in the microstrip antenna there are various methods which are divided into two namely contacting (connected) and non-contacting (not connected). In the contacting method (connected) RF power is directly channeled in the patch and will be emitted like a microstrip line while in the non contacting method the electromagnetic field coupling is done to transfer power between the microstrip lines and the patch that will radiate. The discussion this time will discuss 4 microstrip antenna methods, namely microstrip line feed, proximity fed microstrip probe microstrip feed, apart coupled microstrip [9]. In this study, we will use rectangular patches and the feeding method used is feed line. The most populous parameters on the microstrip antenna are; S-Parameters used to characterize high frequency circuits instead of impedances or reception parameters. This is used to model the N-port linear power
grid [10], while the feed line is used to connect between patches that function to receive or emit electromagnetic waves [11]. Micorstrip antennas have several advantages and disadvantages for more details, see the table below.

| Number | Advantage | Disadvantage                        |
|--------|-----------|-------------------------------------|
| 1      | Light     | Less efficient                      |
| 2      | Simple    | Low gain                            |
| 3      | Thin / small | Wide ohm loss in array techniques |
| 4      | Does not require cavity back | Low power capacity                  |
| 5      | Linear and Circular Polarization | Surface wave excitation             |
| 6      | Can be dual and triple frequency | Pure polarization is hard to come by |
| 7      | Network matching lines can be fabricated simultaneously | The structure of complex feed techniques requires high array configurations |

Dielectric constant of substrates affects the antenna performance. The table 1 is given below in which values for different parameters are given for all five substrates considered indicating the performance analysis of the substrates. The return loss for Roger RO4003 shows maximum value & its maximum value of gain is noted down[13]

| Parameters          | RT Duroid | Taconic TLC | RO4003 | FR-4 | Bakelite |
|---------------------|-----------|-------------|--------|------|----------|
| Dielectric constant | 2.2       | 3.2         | 3.5    | 4.4  | 4.8      |
| Return Loss (dB)    | 25.02     | 26.26       | 31.06  | 20.6 | 30.68    |
| VSWR                | 1.26      | 1.61        | 1.68   | 1.28 | 1.78     |
| Gain (dB)           | 3.429     | 5.11        | 5.2    | 1.89 | 3.286    |

Furthermore impedance matching is one of the significant applications that plays an important role in improving system performance. To ensure maximum power is transferred between the source and sink of a system it is ensured that they match correctly [14]. Patch length calculation using the formula[15]:

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

Patch length calculation using the formula[16]:

\[ \epsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2} \sqrt{1+\frac{12\mu}{W}} \quad (2) \]

\[ L_{eff} = \frac{c}{2 \nu \epsilon_{eff}} \quad (3) \]

\[ L = L_{eff} - 2 \Delta L \quad (4) \]

Feeding method on microstrip antennas there are various types such as microstrip line, coaxial line, aperture coupled and proximity coupled which have advantages and disadvantages of each for more details see the table below.
Table 4. Comparison of various feeding technique [17–19]

| Characteristic         | Microstrip line | Coaxial line | Aperture coupled | Proximity coupled |
|------------------------|-----------------|--------------|------------------|-------------------|
| Spurious feed radiation| Many then other  | Many         | Less             | Minimum           |
| Reliability            | Better          | Poor due to soldering | Good            | Good              |
| Easy of fabrication    | Easy            | Soldering and drilling needed | Alignment required | Alignment required |
| Impedance matching     | Easy            | Easy         | Easy             | Easy              |
| Bandwidth              | 2-5%            | 2-5%         | 2-5%             | 13%               |

Like the table above one of which is the feed line method, namely connecting the patch with the edge of the substrate with a line (feed line) with the same material and thickness as the patch. This type is divided into 4 types of variations including non radiating, quarter feed gap coupled feed and the last insert feed gap. In this study using line feed with gap feed type, for more details see in Figure 2 below.

Fig. 2. Microstrip Feed line

The advantages of microstrip line feeds are that it is easy during fabrication, matching and easy to make but has the disadvantages of having a narrow bandwidth, cross polarization. To calculate the feed line used the equation below. Previous research that used feed line was a study entitled "Compact Multiband Rectangular Microstrip Antennas for UWB Applications", this journal discusses microstrip antennas with patches that translate to protected ground structure or what we call (DGS) with ultra wide band frequencies or UWB[20].

$$W_f = \frac{7.48 \times h}{\varepsilon \left(\sqrt{2\varepsilon + 1} \frac{1}{h}\right)} - 1.25 \times t$$

Where \( t \) has a value of 0.035. While the patch length can be calculated using the equation below.

$$F_l = 10^{-4}(0.001699 \times \varepsilon_f^7 + 0.13761 \times \varepsilon_f^6 + 6,1783 \times \varepsilon_f^5 + 93,187 \times \varepsilon_f^4 - 682 \times \varepsilon_f^3 + 2561.9 \times \varepsilon_f^2 - 4043 \times \varepsilon_f + 6697) \times \frac{L}{2}$$

In a previous study that discussed microstrip antennas with rectangular patches, namely the title “Design of Rectangular Microstrip Patch Antennas”, this study discusses microstrip antennas at frequencies of 3.1 GHz – 5.1 GHz that use substrates made from FR4 [21]. The difference from this research is the use of simulation software, the research is using the advance design system momentum software or what we call ADS. The next research is microstrip antenna research entitled “Design, simulation and analysis of a microstrip antenna using PU-EFB substrate”. This study uses a substrate made from PU-EFB which has a dielectric value of 2.3 for constants [22]. Subsequent research using a
microstrip antenna entitled “A Low-Profile Aperture-Coupled Microstrip Antenna with Enhanced Bandwidth under Dual-Resonance”. This journal uses a type of aperture-coupled microstrip patch feed model where the ground on the antenna is flanked by 2 substrates used in the TM10 and TM30 models which are useful for increasing the impedance bandwidth. Simulated and measured results are found in good agreement with each other and illustrate that the antenna achieves a wide impedance bandwidth of about 15.2% in fraction or 2.32-2.70 GHz under |S11| < -10 dB[23].

2. Antenna Calculation

The antenna calculation starts from the calculation of the patch calculation with a frequency of 1300 MHz and uses Cooper material which has a dielectric constant value of 4.3 while the thickness of the patch uses 0.035 mm. The thickness of the substrate uses a thickness of 1.6 mm which is made from FR-4 which has an impedance value of ± 50 Ω while the ground has the same length and width with the size of the substrate but has the same thickness as the patch that is equal to 0.035 mm. The results obtained are as in table 2 below.

| No | Symbol | Information       | Result  |
|----|--------|-------------------|---------|
| 1  | W      | Width of Patch    | 74 mm   |
| 2  | L      | Length of Patch   | 53.2 mm |
| 3  | Ws     | Width of Substrate| 140 mm  |
| 4  | Ls     | Length of Substrate| 110 mm |
| 5  | Wg     | Width of Ground   | 140 mm  |
| 6  | Lg     | Length of Ground  | 110 mm  |

Table 5. Specification Dimension of Antenna Microstrip 1300 MHz

After being included in the equation the feed line length is obtained as below. To get better efficiency of the antenna performance, it is very important to determine where should be the feed point for perfect impedance matching between the radiating patch and feed line, Feed line width and inset length have been calculated with the following formulas [24].

\[ W_f = \frac{2h}{\pi} \left( B - 1 - \ln(2B - 1) + \frac{\varepsilon_r - 1}{2\varepsilon_r} \ln \left( \frac{B - 1}{B + 1} \right) + 0.39 - \frac{0.61}{\varepsilon_r} \right) \]  \hspace{1cm} (6)

\[ B = \frac{60\pi^2}{Z_0\sqrt{\varepsilon_r}} \]  \hspace{1cm} (7)

\[ y_f = \frac{L_p}{\pi \cos^{-1} \left( \frac{Z_0}{\sqrt{R_{in}}} \right)} \]  \hspace{1cm} (8)

Where \( W_f \) is microstrip line feed width, \( y_f \) is insert length \( Z_0 \) is input impedance and \( R_{in} \) is input resistance, so the value obtained is like the table below.

| No | Symbol | Information   | Result |
|----|--------|--------------|--------|
| 1  | Wf     | Width Feed line | 2.9 mm |
| 2  | Lc     | Length Crop  | 4.9 mm |
| 3  | Gpf    | Width of Gap | 1 mm   |

Table 6. Specification of Feed line

Gap is a feeding technique that separates between feed line and patch antenna. This is done because it can increase the value of antenna bandwidth [25]. For more details, see the picture below the gap antenna in the image below is marked in red which has a distance of 1 mm.
Fig. 3. Gap Antenna

In the picture above shows the microstrip antenna image consisting of patches, ground and substrate and added a gap that has been explained its function in the previous explanation.

3. Antenna Simulation

The antenna measurement starts at a simulation of the working frequency at 1300 frequency in a microstrip antenna with a feed line. S-Parameter measurement or what we commonly call return loss is the ratio between the amplitude of the reflected wave and the amplitude of the transmitted wave [26]. The following is an S-Parameter description with specifications as in table 2 above.

Fig. 4. S-Parameter

Seen in the picture above shows the antenna does not work at the desired frequency so we need to change the antenna dimensions by sweep the antenna, sweep the antenna is done at the patch length starting from 5.5 - 5.32 mm. The results obtained antenna works at a frequency of 1300 by using an antenna length of 5.32 mm, for more details, see in Figure 5 below.
Fig. 3. S-Parameter Sweep Antenna

From the results of Figure 5 above shows the middle frequency is at 1300 MHz with a return loss value of -20 dB. Based on these values the antenna design results meet the antenna eligibility standard with a value of <-10dB. The next measurement is the measurement of VSWR, VSWR is the reflection power that is generated if the impedance of the transmission line does not match the transceiver [27]. VSWR can be searched by manual formula like the formula below

$$s = \frac{V_{\text{max}}}{V_{\text{min}}} = \frac{1+|\tau|}{1-|\tau|}$$ (9)

Where Vmax is the maximum voltage, Vmin is the minimum voltage, \( \tau \) is the reflected coefficient.

Next is the VSWR antenna results shown in Figure 6 below.

Fig. 4. VSWR Result

Based on the simulation results in Figure 6 above obtained a VSWR value of 1.3 at a frequency of 1300 MHz. This value meets the antenna eligibility requirements that have been set that VSWR must be more or equal to 0 and less or equal to 2. The next test is the bandwidth test, bandwidth is the frequency range of the antenna with some characteristics in accordance with predetermined standards, Bandwidth values can be searched manually using the equation below [23].

$$Z = \frac{4\pi A_e}{\lambda^2} = \frac{4\pi f^2 A_e}{c^2}$$ (10)

Where G is the antenna gain, Ae is the effective area, f is the carrier frequency, c is the speed of light and \( \lambda \) is the carrier wavelength Bandwidth measurement results are 0.04 GHz. The next test is the antenna gain test, the gain is the ratio between the radiation intensity of an antenna in a utena direction with the radiation intensity of an isotropic antenna [28]. The gain test results can be seen in Figure 7 below which has the simulation results n gain value of 1.14 dBi.
The next simulation is testing the radiation pattern, the radiation pattern that is a mathematical function or a graphical representation of the radiation properties of the antenna as a function of space coordinates. Radiation patterns on antennas are usually represented by 3-dimensional patterns, 3-dimensional antenna patterns are usually formed from two radiation patterns in the form of elevation patterns and azimuth patterns. The test results can be observed in the image below.

The next simulation is an increase in the efficiency of the antenna such as a decrease in the value of s-parameters, VSWR, Gain. Improvements were made using an antenna array design with specifications as the table below.

| Antenna Design                  | Symbol        | Calculation | Optimizer |
|---------------------------------|---------------|-------------|-----------|
| Width Ground                    | Wg            | 222 mm      | 222 mm    |
| Length Ground                   | Lg            | 124.8 mm    | 124.8 mm  |
| Width Patch                     | Wp            | 71 mm       | 71 mm     |
| Length Patch                    | Lp            | 54 mm       | 53.2 mm   |
| Standing Width feeding 100 ohm  | Wf_{1,2}100Ω | 1 mm        | 1 mm      |
| Standing Length feeding 100 ohm | Lf_{1,2}100Ω | 23 mm       | 23 mm     |
| Flat Width feeding 100 ohm      | Wf_{1}100Ω   | 132 mm      | 132 mm    |
| Flat Length feeding 100 ohm     | Lf_{1}100Ω   | 1 mm        | 1 mm      |
| Width feeding 70.7 ohm          | Wf 70.7 Ω    | 2 mm        | 2 mm      |
| Length feeding 70.7 ohm         | Lf 70.7 Ω    | 13.8 mm     | 13.8 mm   |
| Width feeding 50 ohm            | Wf 50 Ω      | 3 mm        | 3 mm      |
Antenna array is an antenna consisting of several interconnected elements and arranged in a regular structure to form into one antenna [29]. There are several types of antenna array configurations including linear, planar and circular. In this design using the linear array configuration shown in the image below.

| Antenna Design           | Symbol | Calculation | Optimizer |
|--------------------------|--------|-------------|-----------|
| Length feeding 50 ohm    | Lf 50 Ω| 24 mm       | 24 mm     |
| Width insert feeding     | Wif    | 1 mm        | 1 mm      |
| Length insert feeding    | Lif    | 17 mm       | 10 mm     |
| Length between patch     | ds     |             |           |

Fig. 5. Antenna Array 2x1

Seen in Figure 9 above has 2 patches which both have gaps and are connected to the feedline. This antenna will be simulated using parameters including s-parameters, VSWR and antenna gain. The first simulation is the s-parameter simulation shown in Figure 10 below.

Fig. 6. S-Parameter Array Antenna Calculation

In the s-parameter simulation the return loss value is at -35 dB which in the previous simulation has a value of -20 dB. The next simulation is the VSWR simulation shown in Figure 11 below.

Fig. 7. VSWR Array Antenna Calculation
In the above simulation, the VSWR value shown above has a value of 1 while the previous simulation has a value of 1.3. In the next simulation the gain shown in Figure 12 below.

![Fig. 8. Gain Array Antenna Calculation](image)

In Figure 12 below it appears to have a gain value of 3.389 while the previous simulation has a gain value of 1.1. The next simulation is the antenna radiation pattern on the antenna array shown in the figure below.

![Figure 9. Radiation Pattern Array Antenna](image)

Figure 13 above shows that the main lobe magnitude has a value of 9.15 dBi and the main lobe direction has a value of 6.0 degrees, while the angular width has a value of 85.8 db and the side lobe level has a value of -12.9 dB.

4. Conclusion

From the results of simulations that have been carried out on an antenna with a coaxial feed with a frequency of 1300 MHz can be seen in table 3 below.

| No | Parameter   | Result      |
|----|-------------|-------------|
| 1  | Frequency   | 1300 MHz    |
| 2  | S-Parameter | -20 dB      |
| 3  | VSWR        | 1.3         |
| 4  | Bandwidth   | 230.7 MHz   |
| 5  | Gain        | 1.1 dB      |

Based on table 3 above we can draw some conclusions including:

a. In the simulation process the rectangular antenna can simulate operate at a frequency of 1300 MHz with an S-Parameter value of 20 dB

b. The simulation process also measures VSWR and bandwidth as well as gain which have values of 1.3, 230.7 MHz and 7,054 dBi, respectively.
After adding antennas, the array value of the parameter value changes to the previous one and will be compared in table 8 below.

**Table 9. Comparison Between Two Simulation**

| No | Parameter   | First Simulation Result | Array Antenna Result |
|----|-------------|-------------------------|----------------------|
| 1  | Frequency   | 1300 MHz                | 1300 MHz             |
| 2  | S-Parameter | -20 dB                  | -35 dB               |
| 3  | VSWR        | 1.3                     | 1                    |
| 4  | Bandwidth   | 0.04 GHz                | 0.04 GHz             |
| 5  | Gain        | 1.1 dB                  | 3.2 dB               |

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