Microstrip Antenna Design with Array Rectangular Patch 2x2 for Ship Radar at 2.2 GHz

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Abstract. This antenna uses FR4 substrate material with a substrate material thickness of 1.6 mm. The simulation results of the patch array microstrip antenna rectangular 2x2 elements with substrate material are FR4 able to work at a frequency of 2.2 GHz, with a frequency range of 2.1607 – 2.24 GHz, a return loss value of -18,086 dB with a bandwidth of 83.6 MHz, VSWR 1.284, the gain of 4.714 dB and beam width of 53.6 deg, these results will be compared with a single rectangular antenna and array antenna rectangular 1x2 that work at the frequency same of 2.2 GHz with range frequency of a single antenna 2.161 – 2.222 GHz, the return loss value - 13,934 with a bandwidth of 61 MHz, VSWR 1.502, a gain of 2.1988 dB and a beamwidth of 94.9 deg. As for the 1x2 array antenna, the value working range is of frequency a single antenna 2.164 – 2.247 GHz, the return loss value is -20.3717 with a bandwidth of 83 MHz, VSWR 1.21, a gain of 4.58 dB, and a beamwidth of 81.7 deg.

1. Introduction
Radar (Radio Detection and Ranging) is an electromagnetic wave system that is useful for detecting, measuring distances, altitudes, and mapping an object. Radar can be used to detect aircraft, ships, spacecraft, missiles, motor vehicles, weather, and so on. The way radar works, in general, is that the radar emits electromagnetic waves in a certain direction, then the waves are reflected by the object being observed. The reflected signal is then captured by radar [1]. The power level of the reflected signal received by the radar is very small because the attenuation obtained is very large, however, the signal can be detected because the radar system has a large gain [2].

According to the Radar’s range, the ship's radar functions to detect objects around the ship within a radius. The Radar unit is divided into two parts consisting of a monitor unit that is installed and can be read in the bridge room, the second unit is a scanner which is equipment that can rotate and is located above the bridge room or mounted on one of the ship's masts [3]. The radar system is divided into two main parts, namely the transmitter and the receiver. The results of radar detection will be displayed by the Display Unit, which processes the signal received from the receiver into an image that can be easily interpreted by the user. There is an antenna control that functions to adjust the movement of the antenna by the display on the screen from the Display Unit. The synchronizer serves to adjust the signals sent by the transmitter with the desired display on the Display Unit. One part of the radar system is an antenna that functions as a transformer. The antenna will transmit radio waves in the air and will convert electromagnetic waves into electric waves.

Microstrip antenna is one of the antenna materials consisting of 3 main components, namely: ground plane, substrate, and radiating elements (patch). Where the metal conductor is attached to the top of the substrate and the ground plane is at the bottom of the substrate. Because of the shape and
size of the compact antenna, causing the antenna is much in demand in the development of antennas for various applications [4] [5] [6].

The ship's radar works at the frequency S-band, several researchers have developed antennas at the frequency S-Band such as the design of a spiral antenna [7], research on designing a spiral antenna at a frequency of 2.68 to 4 GHz, rectangular patches 1x2 and 1x4 [8], research The discussion discusses the antenna design with a circular design at a frequency of 2.4 GHz as well as various studies others developed at the frequency S-Band. Then the application of 2 x 2 antenna arrays, many researchers have done antenna designs including [9][10].

From the results of research that has been developed by several researchers, we will design a 2 x 2 antenna at a frequency of 2.2 GHz rectangular patch whose analysis will be compared with antenna single patch and a 2x1 patch array at the frequency same, where the array feeding uses the N-Ways Wilkinson Combiner technique.

2. Antenna Calculation

The stages of the research carried out began with a literature study, using some literature in the form of textbooks and journals that were relevant to the problems studied and the software used. The next step is to determine the value of the parameters to be obtained according to the characteristics of the microstrip antenna, namely the working frequency of 2.2 – 4.3 GHz, the reflection coefficient (S11) below or equal to -10 dB, and the VSWR between 1-2. The next step is to determine the dimensions of the antenna, which is to calculate the dimensions of the patch, ground plane, substrate thickness, and placement feed point. Then the design of the antenna calculation will be simulated. The optimal simulation results are then made in the form of a prototype as an analysis material for comparison between simulations. Then determine the type of substrate used. In this case, using the FR4 Epoxy type. The results of this simulation are then determined whether it needs to be optimized or not. This optimization is in the form of setting the size of the substrate, patch, ground plane, and placement feed points. The next step is to compare the microstrip antenna and measure it based on the reflection coefficient (s11), VSWR, radiation pattern, and gain.

| Table 1. Antenna Specifications |
|---------------------------------|
| Specification                  | Description |
| patch                          | rectangular |
| frequency                      | 2.2 ghz     |
| return loss                    | >=10 db     |
| vswr                           | <=2         |
| impedance                      | ±500Ω       |
| dielectric constant            | 4.3 εr      |
| patch thickness                | 0.035 mm    |
| substrate thickness            | 1.6 mm      |
| substrate material             | fr-4        |
| patch material                 | copper      |

Based on the purpose of this design, we will design a microstrip antenna with a working frequency of 2.2 – 4.3 GHz, VSWR value 2, Channel impedance 50 ohms, and using connectors 50 ohms. The substrate on the microstrip antenna affects the bandwidth, quality factor, and efficiency of the antenna. Microstrip antennas with thicker substrates will have wider bandwidth but lower quality and efficiency factors.

The permittivity of the substrate will affect the dimensions, bandwidth, quality factor, and efficiency of the microstrip antenna. The larger the permittivity value, the smaller the dimensions of the antenna produced and the smaller the permittivity value, the larger the antenna will be, a large permittivity will result in bandwidth a narrower, small efficiency, and a large quality factor. In this
antenna design using a substrate Epoxy FR4 with Relative Permittivity of 4.3, dielectric thickness 1.6 mm and conductor thickness 0.035 mm.

The use of Epoxy FR4 as a substrate by the authors is based on the purpose of designing a smaller antenna but the impact on lower antenna efficiency and wide bandwidth antenna. This is due to the relatively large value of the relative permittivity and thickness of the dielectric and the easily available materials.

Figure 1 shows the design of a rectangular patch antenna with the insert feeding method. The calculation has been done using formulas 1 and 2 to get the desired frequency value, while the width of the feed line uses formulas 3 and 4 with the results as shown in table 2. The arrow lines indicate the dimensions in designing the antenna which is symbolized by the letters listed in Figure 1.

Table 2. Antenna specifications and optimization

| No | Part                  | Symbol | Specification (mm) | Optimization (mm) |
|----|-----------------------|--------|-------------------|-------------------|
| 1. | patch diameter        | Lpa    | 39.2              | 38                |
| 2. | line width            | Wfa    | 3                 | 3                 |
| 3. | ground plane length   | Lg     | 48                | 48                |
| 4. | width of ground length| Wg     | 57                | 57                |
| 5. | insert feeding length | Wifa   | 9                 | 5                 |
| 5. | gap width             | Gpf    | 1                 | 1.5               |

Table 2 is the specifications and optimization of the antenna. The length of the patch/radiating element is symbolized by (Lpa), with a calculated value of 39.2 mm. after optimizing the Lpa value to 38 mm. The feeding length (Lfa) is 23mm, the feeding width (Wfa) is 3 mm, the size of the feeding width indicates that the antenna has an impedance of 50 ohms as is used in most antennas according to the calculations in formulas 3 and 4. In this design the antenna uses insert feeding aims to maximize the return loss value. The width of the insert feeding (Wifa) is 1 mm and after optimization it becomes 1.5 mm and has a length of insert feeding (Lifa) of 5 mm. While at the bottom of the substrate there is a ground with a ground length (Lga) of 48 mm and a ground width (Wga) of 57 mm.

Below is the formula for designing the antenna, which includes [10]:

Patch Radius

\[ F = \frac{8.791 \times 10^9}{f_r \sqrt{\varepsilon_r}} \]  

\[ Lp = \frac{F}{\left(1 + \left(\frac{2h}{\pi f r}\right)\ln\left(\frac{F}{2h}\right) + 1.7726\right)^{0.5}} \]
$F$ is a parameter whose value depends on the resonant frequency, while $f_r$ is the desired working frequency in designing the antenna and $\varepsilon_r$ is the value of the permeability of the material. Then in formula 2 are $L_p$ which is the radius of the rectangular antenna, a patch antenna radius value depends on $h$ which is a substrate height.

Feed line width (35.5, 50 $\Omega$, 70.7 $\Omega$)

$$B = \frac{60\pi^2}{Z_0\sqrt{\varepsilon_r}}$$  

$$W1 = \frac{2h}{\pi} \left\{ B - 1 - \ln(2B - 1) + \frac{\varepsilon_r - 1}{2\varepsilon_r} \left[ \ln(B - 1) + 0.39 - \frac{0.61}{\varepsilon_r} \right] \right\}$$  

Distance between patch elements

$$d = \frac{\lambda}{2}$$  

Array factor

$$AF = 2\cos\left[\frac{1}{2}(kd\cos\theta + \beta)\right]$$  

The or feedline is adjusted to the value impedance $Z_0$ connector to be used. The width of the feed line or feedline can be determined through the following equation 4. $h$ is the thickness of the substrate material, which $\pi$ is a constant that has a value of 3.14, $\varepsilon_r$ is the dielectric constant of the substrate, and the value of $B$ which is the value of the impedance material is obtained from equation 3.

Development of an array antenna design

Figure 2, is the development of the antenna array design development of a single patch antenna. In Figure 2.a is a 1x2 antenna design and in Figure 2.b is a 2x2 antenna design for feeding the two antennas using the N-Ways Wilkinson Combiner technique.

$$Z = Z_0\sqrt{N}$$

Where N is the number of branches on the microstrip array antenna and $Z_0$ is the input impedance. By applying the results of this calculation, there are 2 T-Junction methods that are used to produce an impedance value of 50 Ohms as shown below.

![Design of 1x2 and 2x2 Array Antenna](image-url)

(a.) (b.)

**Figure 2.** Design of 1x2 and 2x2 Array Antenna

After the calculation is done, the simulation software design is carried out and the calculated value is entered, but the calculation still does not get the result frequency desired working according to the parameter value, then the next step is to perform optimization with the values listed in table 3 and table 4.
### Table 3. Optimization of 1x2 array antenna

| Part                        | Symbol | Optimization |
|-----------------------------|--------|--------------|
| patch length                | Lpb    | 31.38 mm     |
| feeding 1st length          | Lfb1   | 23.5 mm      |
| feeding 2nd length          | Lfb2   | 10 mm        |
| feeding 3rd length          | Lfb3   | 12 mm        |
| width 1st feeding           | Wfb1   | 1 mm         |
| width 2nd feeding           | Wfb2   | 2 mm         |
| width 3rd feeding           | Wfb3   | 67 mm        |
| width 4th feeding           | Wfb4   | 3 mm         |
| width of insert feeding     | Lifb   | 5 mm         |
| length of insert feeding    | Wifb   | 1.5 mm       |

In table 3, Patch Length of 1x2 antenna element is symbolized by (Lpb), after optimization the Lpb value is not equilateral, but there is a difference in length, namely 31 and 38 mm. Feeding 1st length (Lfb1) is 23.5 mm, length of 4th feeding (Wfb4) is 3 mm, the size of the feeding width indicates that the antenna has an impedance of 50 ohms as is used in most antennas. In this design, the antenna uses insert feeding, which aims to maximize the return loss value. The width of the insert feeding (Wifb) is fixed at 1.5 mm and the length of the insert feeding (Lifb) is 5 mm. The next step is compiling the antenna array feeding, the width 1st feeding (Wfb1) is 1 mm, the width 2nd feeding (Wfb2) is 2 mm, then the width 3rd feeding (Wfb3) is 67 mm while the width 4th feeding (Wfb4) is 3 mm.

### Table 4. Optimization of 2x2 array antenna

| Part                        | Symbol | Optimization |
|-----------------------------|--------|--------------|
| patch length                | Lpc    | 31.5, 43 mm  |
| feeding 1st length          | Lfc1   | 16 mm        |
| feeding 2nd length          | Lfc2   | 20.5 mm      |
| feeding 3rd length          | Lfc3   | 33.5 mm      |
| width 1st feeding           | Wfc1   | 2 mm         |
| width 2nd feeding           | Wfc2   | 66 mm        |
| width 3rd feeding           | Wfc3   | 5 mm         |
| width 4th feeding           | Wfc4   | 3 mm         |
| width of insert feeding     | Wifc   | 1 mm         |
| length of insert feeding    | Lifc   | 11 mm        |

In table 4 is the specification of the antenna array 2x2 patch length (Lpc) is 31.5 and 43 mm. The feeding 1st length (Lfc1) is 16 mm, feeding 2nd length (Lfc2) is 20.5 mm, the feeding 3rd length (Lfc3) is 33.5 mm. For the width, the width 1st feeding is (Wfc1) is 2 mm, width 3rd feeding (Wfc2) is 66 mm, width 3rd feeding (Wfc3) is 5 mm, then for width 4th (Wfc4) is 3 mm. Then for the specifications of the Insert Feeding Length (Wifc) is 1 mm, and also the size of the Insert Feeding Width (Lifc) is 11 mm.

### 3. Antenna Simulation

Return loss is the ratio of the reflected wave level to the transmitted wave level. The return loss value will occur due to a mismatch between the transmission line and the load. The return loss value of the antenna must be less than -10 dB for the antenna to be used. The smaller or minus the value of return loss of an antenna, the more efficient the antenna is designed [11] [12].

From the simulation results that have been carried out, the return loss value is obtained as shown in Figure 3. Return Loss or also called reflected coefficient is the value of the antenna efficiency when emitted. Value antenna working visits of the acquisition value of the return loss below 10 dB, which
means that only 10 percent of the power of the transmitter is returned while 90 percent of the power transmitted via the antenna.

![Figure 3. The return loss of antenna, single an array of 1x2 and 2x2 arrays](image)

Figure 3 is a combination chart return loss value which consists of a single patch antenna, 1x2 array antenna, and 2x2 antenna array. The single patch is symbolized by a dotted line with a circle style marker, while the 1x2 patch array antenna return loss uses a dotted line with a rectangular style marker and a full line 2x2 patch array with a triangle style marker. S11 single patch works at a frequency of 2.164 – 2.247 GHz with a bandwidth of 83 MHz and a return loss value of -13,934 dB, for a 1x2 patch array antenna, the frequency range starts from 2.161 – 2.222 GHz with a bandwidth of 61 MHz and a return loss value of -13,934 MHz, while the 2x2 patch array antenna works from a frequency of 2.1607 GHz – 2.24 GHz with a bandwidth value of 83.6 MHz and a return loss value of -18,086 dB.

Figure 4. below shows a graph of the frequency against the gain value in dB units. In the graph, there is a triangle that shows the frequency value and the amount of gain.

![Figure 4. The gain of the 2x2 antenna](image)

The center frequency in the antenna design for the ship’s radar of 2.2 GHz. With gain value of 4.714 dB. While the frequency of the bottom there is a triangle number 1 rated frequency 2.159 GHz while the value gain of 4.128 dB then the highest frequency that is equal to 2.239 GHz with a value of
4.446, after passing through the working frequency of the highest value of the gain is likely to go down to the frequency of observations at 2.5 GHz.

Figure 5. Shows a graph of the radiation pattern of the far field directivity theta/Degree antenna to the amplification of isotropic radiation, then the Fairfield directivity Phi/Degree to the amplification of isotropic radiation.

In Figure 5a, the radiation pattern of 2.2 GHz shows the main lobe magnitude of 6.08 dBi, then the main lobe direction of 1 degree. Angular width (3dB) of 94.9-degree side lobe level of -12.9 dB. In Figure 5 b, the value of the main lobe magnitude is 8.79dBi, while the main lobe direction is 10 deg. While the angular width is 81.7 dB and the side lobe level is -13 dB. Then in figure 5c. The value of the main lobe magnitude is 8.51 dBi while the main lobe direction is 42 deg and the angular width is 53.6 deg.

The results of the analysis of the three designs above can be compared with the design of a single patch, 1x2 patch array, and 2x2 patch array including values of return loss, VSWR, bandwidth, gain, and beamwidth. The results of the comparison of values can be seen in Table 5 below.

Table 5. Comparison of antenna parameter values

| No | Parameter     | Single Patch | Array Patch 1x2 | Array Patch 2x2 |
|----|---------------|--------------|-----------------|-----------------|
| 1  | Frequency     | 2.2 GHz      | 2.2 GHz         | 2.2 GHz         |
| 2  | S-Parameter   | -13.934 dB   | -20.371 dB      | -18.086 dB      |
| 3  | VSWR          | 1.502        | 1.211           | 1.284           |
| 4  | Bandwidth     | 61 MHz       | 83 MHz          | 83.6 MHz        |
| 5  | Gain          | 2.144 dB     | 4.58 dB         | 4.714 dB        |
| 6  | Beamwidth     | 94.9 deg     | 81.7 deg        | 53.6 deg        |

From table 5 above it can be concluded that the best efficiency value is in the 1x2 patch array antenna design worth -20.371 dB, and the lowest VSWR value is 1.211 then the lowest bandwidth is 61 MHz and the highest bandwidth is 83.6 MHz there is no significant difference in the highest bandwidth value of 83.6 or a difference of 6 kHz. The highest gain value is 4.714 dB and the lowest beamwidth is 53.6 deg.
4. Conclusions
Based on the results in chapter 3, it can be concluded that increasing the number of patches on the antenna affects the bandwidth and gain values but reduces the beamwidth.

5. Reference
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