Multiband Antenna Design Using DMS (Defected Microstrip Structures) for Ship Radar

Bambang Bagus Harianto(✉), Dennys Aryo Herba Barani, Ade Irfansyah, and Lady Silk Moonlight

Politeknik Penerbangan Surabaya, Surabaya, Indonesia
bambangfarzardy@gmail.com

Abstract. Radio Detection and Ranging are used for object detection, distance and altitude measurement, and mapping. RADAR can be used in bad weather conditions and can see objects under the sea and in the air at great distances. Ship radar is one of the technologies in the shipping sector, especially in the marine sector navigation system. For that, we need an antenna that has a compact design, small size, wide bandwidth, and can be used to meet the operating frequency of the radar system. Microstrip antenna is a type of antenna that is currently widely used in several devices as an alternative because the manufacturing process is simple and inexpensive. Ordinary microstrip antennas work on one frequency (single band). By using DMS (Defected Microstrip Structures) the antenna can work in multiband. Therefore, the author tries to design a Multiband antenna using DMS for marine radar which is known to operate at the S-band (3 GHz) frequency, following the specifications of the radar antenna. The substrate used is FR-4. This research method uses CST 2019 simulation as simulation software. The simulation results at a frequency of 3.0046 GHz show a VSWR of 1.0764 and a return loss of −27.9 dB. From the simulation results, we can analyze that to get the characteristics of the antenna according to the desired specifications, namely working at a frequency of 3 GHz, VSWR 2, and Return Loss −10.

Keywords: Microstrip · Multiband · Rectangular Patch · DMS · Ship Radar

1 Introduction

Radar is the most important observation tool in air and sea transportation. Radar or radio detection and range are commonly used to measure distances and detect objects in the air [1].

Antennas are used to send and receive radio waves at the same frequency or frequency range. The antenna industry is constantly evolving, and various types of antennas are produced to keep up with the development of this increasingly advanced wireless communication technology. There are many types of antennas, one of which is a microstrip antenna. Specifics required by marine radar antennas include high gain, wide bandwidth, and excellent radiation patterns [2, 3].

B. Bagus Harianto et al. (Eds.): ICATEAS 2022, AER 217, pp. 211–222, 2023.
https://doi.org/10.2991/978-94-6463-092-3_19

Microstrip antennas are low-mass antennas that are easy to manufacture, their conformal properties allow them to be placed on several types of small surfaces compared to some other types of antennas. Due to their characteristics, microstrip antennas are very suitable for today's needs and can be embedded in other small telecommunications devices, but microstrip antennas have low gain, efficiency and efficiency dir, and narrow bandwidth [4, 5].

1.1 Maritime Radar

Maritime radar is a radar installed and used on ships that can detect and measure the distance between objects and ships near the ship. Maritime radar serves to detect the presence of other ships, weather, or clouds around the ship and avoid danger in front of the ship. For example Fig. 1 Maritime radar antenna [6].

1.2 Microstrip Antenna

A microstrip antenna is a metal conductor mounted on a ground plane with a dielectric in between. Below are the general forms of microstrip antennas in Fig. 2 [7].

Microstrip antennas are small, lightweight, easy to manufacture, and placed on almost any surface, therefore they are easy to apply to small communication equipment. A microstrip antenna consists of several structures, such as patches made of conductive materials, which serve to emit electromagnetic waves into the air. The transmitting element or patch is made of metal, has a certain thickness according to what is needed, and has the function of emitting waves of a predetermined thickness and serves to emit electromagnetic waves [8].

Fig. 1. Ship Radar Antenna

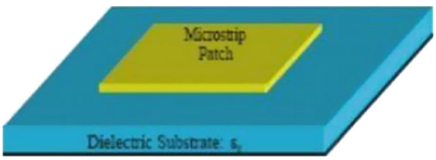

Fig. 2. Microstrip Antenna

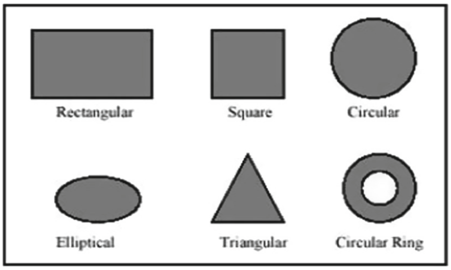

Fig. 3. Forms of Antenna Patches

1.2.1 Patch

The patch is on top of the entire antenna system. Microstrip antennas come in a variety of patch shapes, as shown in Fig. 3.

1.2.2 Substrates

The substrate is made of a dielectric material that serves as a medium for removing electromagnetic waves from the power supply. The substrate has properties that greatly affect the parameters of the antenna [9].

1.2.3 Ground Plane

A ground plane is the lower layer that functions as a reflector to reflect unneeded signals.

1.2.4 Transmission Channel

Transmission Line, that is, a useful channel for connecting the output of the feed line to the transmitting element [10].

1.3 Rectangular Antenna

Microstrip antennas with square patches are the most common forms that are commonly created because these shapes are the easiest to analyze. When designing a square patch microstrip antenna, the antenna dimensions are calculated as follows [11].

Use the formula to determine the width of the patch (W).

$$W = \frac{c}{2f_0\sqrt{\frac{\varepsilon_r+1}{2}}} \tag{1}$$

ioW is the patch width, c is the speed of light in the free space of 3 x 108 m/s, f_o is the resonance frequency of the antenna, and r is the dielectric constant of the substrate material [12]. The increase in the length of the ΔL due to the edge effect is formulated as:

$$\Delta L = \left(0,412h\frac{(\varepsilon reff\ +0,3)\left(\frac{W}{h}+0,264\right)}{(\varepsilon reff\ -0,258)\left(\frac{W}{h}+0,8\right)}\right) \tag{2}$$

where h is the thickness of the substrate and, ε the chorus is relatively effective mobility as the equation formula below,

$$\varepsilon_{reff} = \frac{\frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}}{\sqrt{1 + 12\frac{h}{W}}} \tag{3}$$

And according to the formula, the effective length of the patch,

$$Leff = \frac{c}{2f_0\sqrt{\varepsilon reff}} \tag{4}$$

Then get the patch length (L) of the formula,

$$L = Leff - 2\Delta L \tag{5}$$

1.4 DMS (Defected Microstrip Structures)

Defected Microstrip Structures (DMS), have been successfully used to reduce the size of rectangular DMS patch antennas, similar to structures called stubs, and as tuning techniques [9]. DMS also exhibited a greater slow wave effect due to more discontinuities and longer electromagnetic wavelength paths. At the same time, DMS also offers a larger stopband than the Spurline of the same size. Strain gauges can be used to increase the slow-wave factor (SWF) of the transmission line where strain gauges are introduced. This phenomenon can be used to reduce the size [13].

1.5 Antenna Parameters

Below are some of the important parameters commonly used when testing and measuring microstrip antennas.

1.5.1 Antenna Gain

Antenna gain is defined as the ratio of the maximum transmit power measured from an antenna to the maximum transmit power of an isotropic antenna as a reference when both antennas are supplied with the same power. Gain cannot be measured in physical units such as watts or ohms, but in comparisons where the unit used for gain is a decibel (dB), it is usually expressed in dBi or dB.

1.5.2 VSWR

Voltage Standing Wave Standing wave ratio is the ability of the antenna to operate at a frequency suitable for terminating the transmission line with an impedance that does not correspond to the characteristics of the transmission line without absorbing all the power at the termination. The ratio of the maximum voltage to the minimum voltage is called VSWR. The best VSWR condition is when the channels are completely matched and equal to 1, meaning that there is no reflection, but this condition is very difficult to achieve in practice. VSWR less than $(<)2$ is considered good [14].

1.5.3 Return Loss

Return loss is the ratio of the amplitude of the reflected wave using the amplitude of the wave to be transmitted. A good return loss value is −9.54dB or less, which is obtained in such a way that the reflective wave is not too large compared to the radiant wave [15].

1.5.4 Antenna Bandwidth

Antenna bandwidth can be defined as the frequency range in which the performance of the antenna depends on several properties such as input impedance, gain, VSWR, efficiency, and return loss [16]. Antenna fractional bandwidth is a measure of antenna bandwidth. Fractional bandwidth values are:

$$\text{Fractional Bandwidth} = \frac{2(fh - fl)}{(fh + fl)} \times 100\% \tag{6}$$

Fractional bandwidth is a function of the middle range and frequency. Fractional bandwidth varies between 0 and 2 and is often expressed as a percentage (between 0% and 200%). The higher the percentage, the wider the range.

1.5.5 Radiation Patterns

Antenna directivity is a diagram that describes the radiation characteristics of antennas in distant terrain as a function of direction. The radiation diagram depicts the distribution of energy that the antenna emits into space. The distance between the transmitter and receiver must correspond to this long field distance for the wave propagation from the transmitting antenna to the receiving antenna to be practically successful [17].

1.6 CST Software Studio Suite

CST (Computer Simulation Technology) Studio Suite is software for designing, simulating, and optimizing electromagnetic systems such as antennas. The CST Studio Suite lets you use compute to optimize your results more accurately and efficiently. The software consists of tools for designing and optimizing devices that can operate on a wide frequency range from static to optical, and tools for manual analysis of design and mechanical effects [18].

2 Method

The method in this study is an antenna design method using the 2019 CST studio application, the process of making an antenna design starts by calculating the antenna dimensions in the formula listed to determine the dimensions of the patch, and ground created from microstrip antennas following the expected frequency.

2.1 Antenna Design Calculation

A microstrip antenna whose patch is square will be designed to be able to work at a frequency of 3 GHz. If it is known fr = 3 GHz, εr = 4.3, the speed of light (c) = 3.108 then:

$$W = \frac{c}{2f_0\sqrt{\frac{\varepsilon_r+1}{2}}} = \frac{3\times 10^8}{2\times(3000\,\text{MHz})\sqrt{\frac{(4.3+1)}{2}}} = 30.71\,\text{mm} \tag{7}$$

Then find the value of L (using Eq. 1) in the need for the effective value of constant dielectrics (εreff), Effective Length (Leff), and Length Extension (ΔL).

$$\Delta L = \left(0,412h\frac{(\varepsilon reff+0,3)\left(\frac{W}{h}+0,264\right)}{(\varepsilon reff-0,258)\left(\frac{W}{h}+0,8\right)}\right) \tag{8}$$

$$\varepsilon_{reff} = \frac{\frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}}{\sqrt{1+12\frac{h}{W}}} \tag{9}$$

$$Leff = \frac{c}{2f_0\sqrt{\varepsilon reff}} \tag{10}$$

From the formulas of Eqs. (2), (3), and (4) can be taken the value for the length of the patch (L) is

$$\begin{aligned} L = Leff - 2\Delta L &= \frac{c}{2f_0\sqrt{\varepsilon reff}} - 2\left(0,412h\frac{(\varepsilon reff+0,3)\left(\frac{W}{h}+0,264\right)}{(\varepsilon reff-0,258)\left(\frac{W}{h}+0,8\right)}\right)\\ &= \frac{3\times 10^8}{2x3000\sqrt{1.48719}} - 2\left(0,412x4.3\frac{(1.48719+0,3)\left(\frac{4.41275}{4.3}+0,264\right)}{(1.48719-0,258)\left(\frac{4.41275}{4.3}+0,8\right)}\right)\\ &= 27.07036\,\text{mm} \end{aligned} \tag{11}$$

Dimensional design for a ground plane
Ground plane length

$$\text{Lg} = 2\times\text{L} = 2\times 27.07\,\text{mm} = 54.14\,\text{mm} \tag{12}$$

Ground plane width

$$\text{Wg} = 2\times\text{W} = 2\times 30.71\,\text{mm} = 61.42\,\text{mm} \tag{13}$$

Length of Feed Line Insert (Table 1)

$$\begin{aligned} &\text{Fi} = 10 - 4(0.001699\times 4.37 + 0.13761\times 4.36 - 6.1783\\ &\times 4.35 + 93.187\times 4.34 - 682.69\times 4.33 + 2561.9\times 4.32\\ &-4043\times 4.3 + 6697) = 1.\frac{1.78}{2}6\,\text{mm} \end{aligned} \tag{14}$$

Logger Width

$$W_f = \frac{7.48\times h}{3.9484} - 1.25\times t = 2.89\,\text{mm} \tag{15}$$

Table 1. Specifications of 3 GHz Microstrip Antennas

No.	Part	Symbol	Size
1.	Patch Width	W	30.71 mm
2.	Patch Length	L	27.07 mm
3.	Width Catalyst Channel	Wf	2.89 mm
4.	Ground plane length	Lg	54.14 mm
5.	Ground plane width	Wg	61.42 mm
6.	Feedline Length	Fi	1.6 mm
7.	Gap width	Gpf	1 mm

Table 2. Final Design of Multiband Antennas

No.	Part	Symbol	Size
1.	Patch Width	W	59 mm
2.	Patch Length	L	23.3 mm
3.	Ground plane Width	Wg	131.6 mm
4.	Ground plane length	Lg	52.8 mm
5.	Length of Feed line	Fi	7.6 mm
6.	Gap Width	Gpf	1 mm
7.	Feed Length	Lw	3 mm
8.	Feed Width	Fw	22 mm
9.	Crop Length	Lc	7.6 mm
10.	Width Crop	Wc	5 mm
11.	Subtract Thickness	St	1.6 mm
12.	Ground and Patch Thickness	Ct	0.0035 mm

3 Antenna Design

After obtaining the size value of the square patch microstrip antenna to be designed and fabricated, the microstrip antenna began to be designed using CST Studio 2019 software. The square microstrip antenna that has been designed and simulated in the CST Studio 2019 software has a different size from the previous calculation because the antenna size according to the calculation has not met the specifications expected when simulated. After simulation and re-measurement of the antenna's dimensions again, the following size was obtained (Fig. 4 and Table 2).

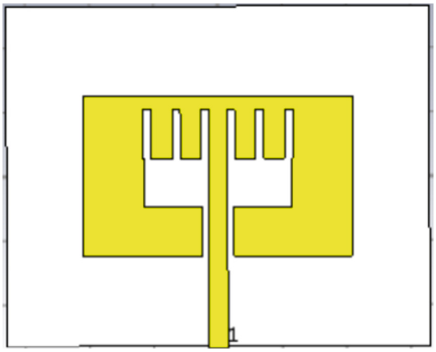

Fig. 4. Multiband Antena with DMS (Defected Microstrip Structures)

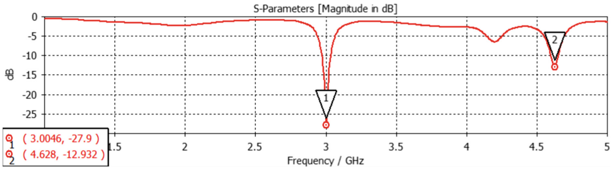

Fig. 5. Return loss results on CST

4 Results and Discussion

The simulation results for the antenna parameters are presented in a graphic image provided in the CST Studio 2019 software. The author also attached some data in the form of a parameter photography chart which is the result of testing return loss, VSWR, bandwidth, and directivity (Fig. 5).

4.1 S-Antenna Parameters

Return Loss results using CST simulation on a rectangular antenna with the DMS (Defected Microstrip Structure) method get 2 frequencies results

- 3 GHz of −27,9 dB
- 4.63 GHz of −12,932 dB

4.2 VSWR

The CST simulation results on the 3 GHz frequency antenna are at point 1.0763 and 4.63 GHz frequency antenna are at point 1.5828. VSWR enters the author's expectation of <2 (Fig. 6).

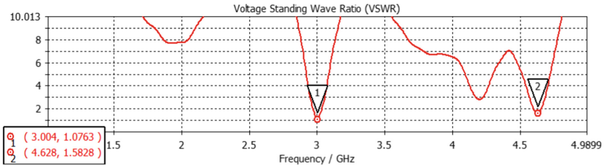

Fig. 6. VSWR Results on CST

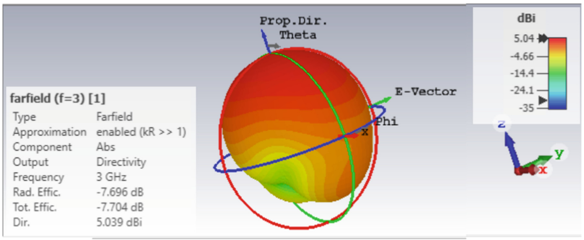

Fig. 7. Radiation Patterns on CST

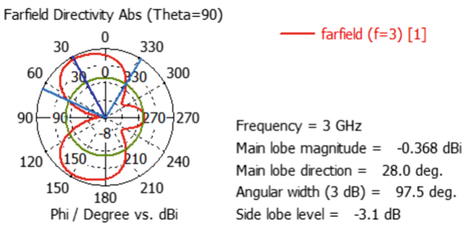

Fig. 8. Radiant Pattern on CST

4.3 Farfields

The 2019 CST simulation radiation pattern can be calculated for distant field antennas with maximum gain marked in red and minimum gain marked in blue. You can see the antenna radiation in this 3D view (Fig. 7).

4.4 Antenna Directivity

The figure above is the main beam of the antenna of −0.368 dBi located at 28° and the width of the beam area is up to 97.5° with a side lobe of –3.1 dB (Fig. 8).

Table 3. Comparison of CST Parameter Results

Parameters	Specification	Rectangular	Rectangular DMS
Frequency	3 GHz		
VSWR	≤ 2	1.38	1.08
Profiteering Methods	Microstrip Line		
Return Loss	≤ -10 dB	-15.9dB	-27.9dB
Patch/Ground	Copper		
Substrate	FR-4 lossy		
Gain	> 0	-2.85	1.93
Impedance	$\pm 50\ \Omega$	$50\ \Omega$	$50\ \Omega$

5 Conclusion

The results of spesification antenna, rectangular antenna parameters, and Rectangular DMS antenna parameters, can be seen in the following table by comparing with the antenna specifications made (Table 3).

In this final project, the author tried to design, fabricate and simulate a Multiband Antenna using DMS (Defected Microstrip Structure) at frequencies of 3 GHz and 4.63 GHz for radar ships. From the data from the analysis and measurement results, several conclusions were obtained as follows:

- The DMS (Defected Microstrip Structure) structure allows the antenna to work multiband.
- The multiband antenna shape design using DMS (Defected Microstrip Structure) is a new form.
- DMS (Defected Microstrip Structure) allows getting better VSWR and Gain.

References

1. P. Bezousek, M. Chyba, V. Schejbal, and J. Pidanic, “Dual frequency band integrated antenna array,” 2013.
2. B. B. Qas Elias, “A new reduced size multiband fractal microstrip patch antenna for microwave applications,” *Elektrotehniski Vestnik/Electrotechnical Review*, 2018.
3. L. Wang, J. Tang, and Q. Liao, “A Study on Radar Target Detection Based on Deep Neural Networks,” *IEEE Sens Lett*, vol. 3, no. 3, Mar. 2019, doi: https://doi.org/10.1109/LSENS.2019.2896072.
4. K. Nallely, O. Nuñez, R. Stack, and M. Arteaga, “Diseño, Modelado y Caracterización de Arreglo de Antenas Microstrip para Aplicaciones del Internet de las Cosas,” 2019.

5. D. Cristallini, I. Pisciottano, and H. Kuschel, "Multi-Band Passive Radar Imaging Using Satellite Illumination," in *2018 International Conference on Radar (RADAR)*, Aug. 2018, pp. 1–6. doi: https://doi.org/10.1109/RADAR.2018.8557260.
6. A. Brown and D. Anderson, "Trajectory optimization for high-altitude long-endurance UAV maritime radar surveillance," *IEEE Trans Aerosp Electron Syst*, vol. 56, no. 3, pp. 2406–2421, Jun. 2020, doi: https://doi.org/10.1109/TAES.2019.2949384.
7. Td. Kumar, "28 GHZ PRINTED ANTENNA FOR 5G COMMUNICATION WITH IMPROVED GAIN USING ARRAY," 2020.
8. C. Mohan and S. E. Florence, "Miniaturised Triangular Microstrip Antenna with Metamaterial for Wireless Sensor Node Applications," *IETE J Res*, vol. 68, no. 2, pp. 1177–1182, 2022, doi: https://doi.org/10.1080/03772063.2019.1643266.
9. M. N. E. Temmar, A. Hocini, D. Khedrouche, and M. Zamani, "Analysis and design of a terahertz microstrip antenna based on a synthesized photonic bandgap substrate using BPSO," *J Comput Electron*, vol. 18, no. 1, pp. 231–240, Mar. 2019, doi: https://doi.org/10.1007/s10825-019-01301-x.
10. M. Darsono and A. R. Wijaya, "Design and simulation of a rectangular patch microstrip antenna for the frequency of 28 GHz in 5G technology," in *Journal of Physics: Conference Series*, Feb. 2020, vol. 1469, no. 1. doi: https://doi.org/10.1088/1742-6596/1469/1/012107.
11. A. Abbas *et al.*, "A rectangular notch-band UWB antenna with controllable notched bandwidth and centre frequency," *Sensors (Switzerland)*, vol. 20, no. 3, Feb. 2020, doi: https://doi.org/10.3390/s20030777.
12. Mamdouh EI-Sayed, Nasr Gad, Mostafa EI-Aasser, and AshrafYahia, "Slotted Rectangular Microstrip-Antenna Design for Radar and 5G Applications," 2020.
13. C. Ding, Y. J. Guo, P. Y. Qin, T. S. Bird, and Y. Yang, "A defected microstrip structure (DMS)-based phase shifter and its application to beamforming antennas," *IEEE Trans Antennas Propag*, vol. 62, no. 2, pp. 641–651, 2014, doi: https://doi.org/10.1109/TAP.2013.2290802.
14. N. Mohamed, S. Banu, M. Ramkumar Prabhu, U. T. Sasikala, P. Student, and A. Prof, "Design A Square Microstrip Patch Antenna for S-Band Application," *IOSR Journal of Electronics and Communication Engineering Ver. IV*, 2015, doi: https://doi.org/10.9790/2834-10242430.
15. H. Werfelli, K. Tayari, M. Chaoui, M. Lahiani, and H. Ghariani, "Design of rectangular microstrip patch antenna," 2016. doi: https://doi.org/10.1109/ATSIP.2016.7523197.
16. A. Kumar, N. Gupta, and P. C., "Gain and Bandwidth Enhancement Techniques in Microstrip Patch Antennas - A Review," *Int J Comput Appl*, vol. 148, no. 7, pp. 9–14, Aug. 2016, doi: https://doi.org/10.5120/ijca2016911207.
17. L. Yao *et al.*, "Fabrication and characterization of microstrip array antennas integrated in the three dimensional orthogonal woven composite," *Compos B Eng*, 2011, doi: https://doi.org/10.1016/j.compositesb.2011.01.006.
18. J. Chen *et al.*, "Modulating dielectric loss of mesoporous carbon fibers with radar cross section reduction performance: Via computer simulation technology," *Inorg Chem Front*, vol. 8, no. 3, pp. 758–765, Feb. 2021, doi: https://doi.org/10.1039/d0qi01237h.