2x2 Array Circular Microstrip Antenna Design for Altimeter Radar Antenna Applications

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Abstrak. *Radar Altimeter digunakan untuk mengukur jarak dari pesawat ke permukaan tanah atau permukaan laut yang bekerja pada frekuensi 4,2-4,3 GHz. Antena microstrip sebagai antena alternatif terdiri dari tambalan dan pesawat darat dengan Tembaga dan substrat menggunakan FR-4. Antena microstrip melingkar array 2x2 terdiri dari empat elemen antena melingkar tunggal yang dikombinasikan dengan teknik Wilkinson Power Divider. Optimalisasi array antena melingkar microstrip 2x2 pada 4,3 GHz sesuai dengan frekuensi operasi radar altimeter dengan kehilangan kembali -12,41 dB dalam rentang frekuensi 4,22 GHz hingga 4,36 GHz, bandwidth 144,1 MHz, VSWR 1,6, menghasilkan keuntungan 6.9 dB, serta menghasilkan pola radiasi lobus utama 7,34 dBi ke arah 20,0 deg dan beamwidth 26,3 deg. Hasil optimasi dibandingkan dengan antena microstrip melingkar tunggal, yang memiliki kehilangan pengembalian -16,19 dB dalam rentang frekuensi 4,27 GHz - 4,31 GHz, bandwidth antena ini adalah 48,4 MHz, VSWR 1,3, menciptakan keuntungan 4,3 dB, serta menghasilkan pola radiasi lobus utama 2,76 dBi ke arah 47,0 deg dan beamwidth 49,1 deg.*
Kata Kunci: *Microstrip, Power Divider, Singular Circular, Radiation pattern*

Abstract. *Altimeter radar uses to measure the distance from the aircraft to ground level or sea level working at a frequency of 4.2–4.3 GHz. Microstrip antennas as alternative antennas consist of patches and ground planes with Copper and substrates using FR-4. The 2x2 array circular microstrip antenna consists of four single circular antenna elements combined with the Wilkinson Power Divider technique. The optimization of microstrip circular antenna 2x2 array at 4.3 GHz according to the operating frequency of the altimeter radar with a return loss -12.41 dB in the frequency range of 4.22 GHz to 4.36 GHz, the bandwidth of 144.1 MHz, VSWR 1.6, resulting in a gain of 6.9 dB, as well as producing the main lobe gain radiation pattern of 7.34 dBi in the direction of 20.0 deg and beamwidth 26.3 deg. The optimization result compared with a singular circular microstrip antenna, which has a return loss of –16.19 dB in the frequency range of 4.27 GHz – 4.31 GHz, the bandwidth of this antenna is 48.4 MHz, VSWR 1.3, creating a gain of 4.3 dB, as well as producing the main lobe gain radiation pattern of 2.76 dBi in the direction of 47.0 deg and beamwidth 49.1 deg.*
Keywords: *Microstrip, Power Divider, Singular Circular, Radiation pattern*

1. Introduction

Radio Detection and Ranging or radar is a system used to detect and measure the distance, direction, speed of an object moving or still by utilizing the working principle of electromagnetic wave reflection (Zhou, Liu, Zuo, Zang & Hu, 2017). Some types of the radar in the world of aviation include *altimeter radar*. An *altimeter* radar is an instrument found on board used to measure the height or vertical position of an aircraft against the earth's surface or sea level (Choi, Jang & Roh, 2015). The working frequency limit of *altimeter* radars is 4.2 – 4.3 GHz with a *bandwidth* between 100 and 150 MHz (RamaDevi,2012). Altimeter radar can be used in civilian and military aircraft. One of the required components of the *altimeter* radar is the antenna. Antennas are used to transmit and receive radio waves. The *altimeter* radar antenna consists of a transmitter antenna and a receiver antenna (Rajkumar & Raj, 2019).

The altimeter radar system working principle starts from generating radio waves at the frequency 4.3 GHz by the generator to be transmitted periodically by transmitter antennas to the earth's surface or sea level. Radio waves reflected by the earth's surface or sea level will be restored or received by the receiver antenna on the aircraft periodically with a delay time. The aircraft's position to the earth's surface or sea is determined by counting the difference between the transmitted and received signal in

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radio wave phases. The different phases of radio waves will be processed then produce several aircraft altitude values that will be displayed on the aircraft altimeter indicator (Saravanan & Rangachar, 2016). Altimeter radar antennas must provide directional beams, high *gain*, and wide *bandwidth*, have a light mass, small size, and are easy to install (Elkamchouchi & Salem, 2016). Altimeter *radars* generally use *horn* antennas that produce wide *bandwidth* and high *gain*. However, the disadvantages of *horn* antennas have considerable dimensions and

expensive manufacturing costs. The development of antenna technology in this period is inevitable. Researchers are racing to create antenna-making innovations in search of better quality antennas than ever before and gain more practical dimensions or physiques. Microstrip antennas are one type of antenna that work at very high frequencies, small shapes, lower production costs, and are easy to install on a particular tool or device (Gupta, Jain, Singh, 2014). Microstrip antennas are consisting of three layers, the top layer is named a patch, the middle part is a substrate, and the last one at the bottom is a ground plane. Microstrip antennas have several forms like rectangular, circular, triangular, and other forms. Some advantages of microstrip antennas include small and light dimensions, easily manufactured using a printed circuit board (PCB), and low budget. Another advantage is that they can work at very high frequencies (Wahab, Maslan, Muhamad & Hamzah, 2010). Besides having the advantage, singular microstrip antennas have disadvantages such as narrow bandwidth, poor directivity, and low gain (Muludi & Aswoyo, 2017). The fabricating process of microstrip antennas needs detailed dimension calculation for the patch, substrate, and ground because if the size is not appropriate it will affect the value of gain, VSWR, return loss, and radiation patterns of the antenna (Singh, Bhatia, Kuchroo & Sidhu, 2017). Microstrip antenna is one type of antenna that gives the specifications of making an altimeter radar antenna. The weakness of a single microstrip antenna can be overcome by using various methods, including array methods and defected ground structure (DGS) *techniques* (Hanaoui & Rifi, 2019). Array method is a way used to provide gain value by merging several patches of microstrip antennas through feed line (Sharma & Gupta, 2014), while to increase bandwidth, the ground antenna design uses defected ground structure (DGS) (Girase, Tiwari, Sharma & Singh, 2014).

In previous studies, several researchers have discussed the antennas design for altimeter radar under the title "Compact Microstrip Antenna for Radar Altimeter Applications" by A. Sudhakar, M. Sunil Prakash, M. Satyanaraya (Sudhakar, Prakash & Satyanarayana 2018) and research titled "Design of Compact C-Band Concave Patch Antenna for Radar Altimeter Applications" by Kanakavalli Harshasri, P.Vinod Babu, P.Narayana Rao (Harshasri, Babu & Rao, 2018) on the manufacture of microstrip antennas on the 4.3 GHz altimeter radar. In our research we had a novelty with a circular antenna 2x2 array, using defected ground structure (DGS), obtained a return loss value of -12.41 dB and antenna gain 6.9 dB at the working frequency of altimeter radar 4.3 GHz.

2. Literature Review

2.1. Antenna Design

The 2x2 array circular patch circular microstrip antenna for altimeter radar works at 4.2 GHz – 4.3 GHz. Patch and ground use Cooper material with a dielectric constant of 4.3 and 0.035 mm thickness, while the FR-4 material has a dielectric constant of 4.4 with a thickness of 1.6 mm used for the substrate part. An antenna will work well if conditions include VSWR = 1-2, return loss value ≤-10 dB, and gain ≥ 3 dBi.

2.2. The Design of Singular Circular Microstrip Antenna

A singular circular microstrip antenna is an antenna with small dimensions, light, and cheap in the manufacturing process that has a single circular shape. The design of this antenna uses the formula below The radius of the circular patch microstrip antenna can be known by using the following formula (Nayna, Baki & Ahmed, 2014) :

$$a = \frac{F}{\{1+\frac{2 \times h}{\pi \times \varepsilon_r \times F}[\ln\left(\frac{\pi \times F}{2 \times h}\right)+1{,}7726]\}^{\frac{1}{2}}} \quad (1)$$

$$F = \frac{8{,}791 \times 10^9}{f_r \sqrt{\varepsilon_r}} \quad (2)$$

a is the radius of the microstrip antenna, F is a function of the logarithm, h is the thickness of the substrate material, and that ε_r is the dielectric constant of the substrate, and f_r is the frequency of the of the antenna in Hz. The feedline is adjusted to the impedance value of the connector (Z). The feedline width can be determined through the following equation :

$$Wf = \frac{2 \text{ x } h}{\pi} \{B - 1 - \ln(2B - 1) + \frac{\varepsilon_r - 1}{2 \text{ x } \varepsilon_r} \left[(B - 1) + 0{,}39 - \frac{0{,}61}{\varepsilon_r}\right]\} \quad (3)$$

$$B = \frac{60 \text{ x } \pi^2}{Z\sqrt{\varepsilon_r}} \quad (4)$$

h is the thickness of substrate, π is constant value of 3.14, ε_r is a constant dielectric substrate, and Z is the impedance value of feed line. From the equations that have been described above, it can be known the importance of parameters to make the design of circular singular microstrip antenna as follows:

Table 1. Microstrip Patch Circular Singular Antenna Parameters

Parameter	Symbol	Starting Value	Optimizer Values
Ground Plane Width	Wg	50 mm	50 mm
Ground Plane Length	Lg	70 mm	70 mm
Ground Plane Thickness	t_g	0.035 mm	0.035 mm
Width of Substrate	Ws	50 mm	50 mm
Length of Substrate	Ls	70 mm	70 mm
Thickness of Substrate	h	1.6 mm	1.6 mm
Radius Patch	a	19.6 mm	20 mm
Patch Thickness	t_p	0.035 mm	0.035 mm
Width of Feed line 50 Ω	Wf_{50}	3 mm	3 mm
Length of Feed line 50 Ω	Lf_{50}	25 mm	25 mm

Once known all parameter values, researchers can create a singular circular patch microstrip antenna design as shown in figure 1.b.

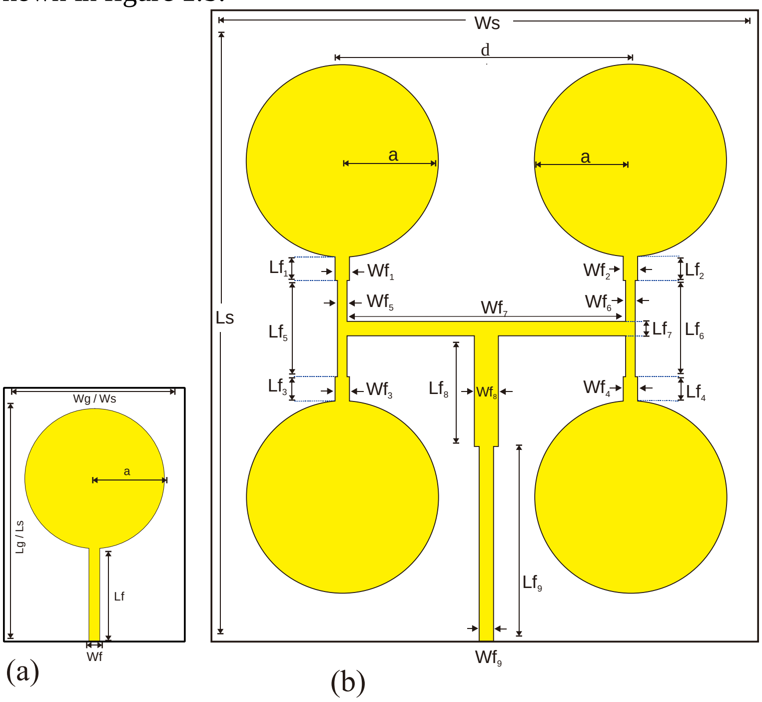

Figure 1. Microstrip Circular Antenna Design (a) Singular dan (b) 2x2 Array

Figure 1.b is a combination of patch design, substrate, and ground plane. The length and width of the ground plane are the same as the substrates but have different thicknesses. The ground plane

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element is 0.035 mm thick using Copper, while the substrate thickness is 1.6 mm using FR-4. The initial radius or radius of the singular circular antenna is 19.6 mm. Optimizer is done at the radius width or radius to obtain the desired gain, VSWR, and return loss values so that it becomes 20 mm.

2.3 The Design of 2x2 Circular Microstrip Antenna Array

One of the disadvantages of singular microstrip antennas is that they have a small gain. Microstrip array antennas use to increase the gain of singular microstrip antennas. Microstrip patch circular antenna 2x2 array consists of four singular circular antennas combined by the connecting channel with power divider technique. The radius (a) of the circular patch microstrip antenna can be known by using equations (1) and equations (2) that have been described previously the same as the radius of the singular circular microstrip antenna. The feedline combines four singular circular antenna elements to form a 2x2 circular patch microstrip antenna array. One of the ways used for matching impedance microstrip antenna arrays is generally using the Wilkinson power divider technique.

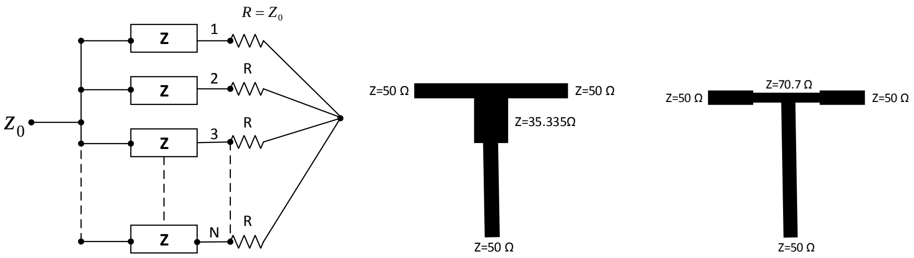
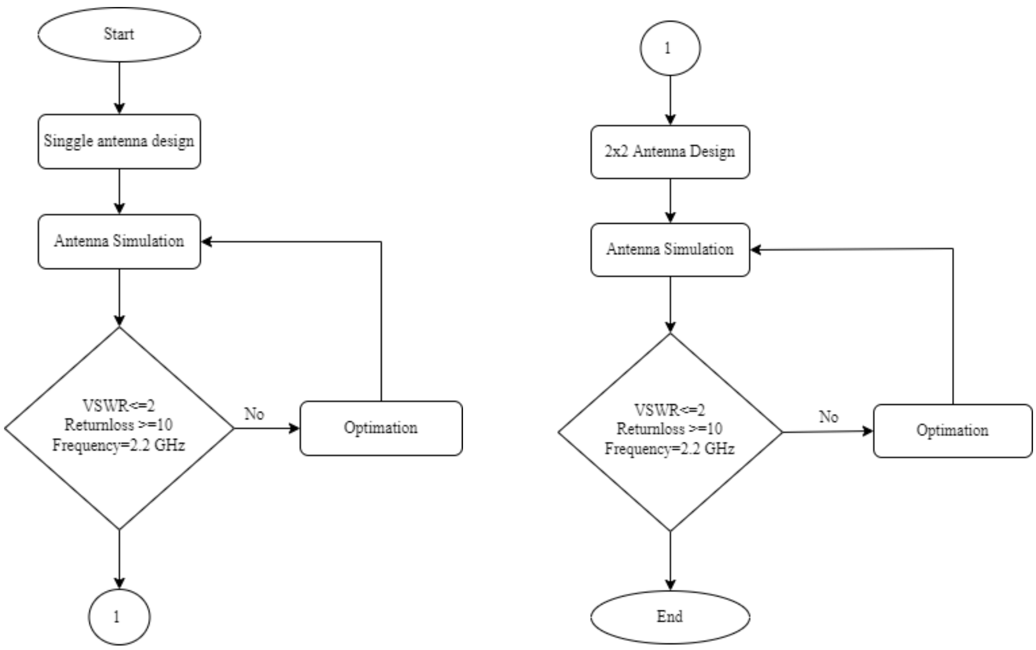


Figure 2. Wilkinson Power Divider Technique

3. Methodology

Figure 3 below is the flowchart design of the microstrip antenna. The design of the 2x2 antenna array comes from a single antenna design that already meets the VSWR criteria smaller equal to 2, the return loss value is greater than 10, and reaches a frequency of 2.2 GHz



(a) (b)

Figure 3 (a) Flowchart single antenna design (b) Flowchart array antenna design

The impedance value (Z) is obtained from the following equation:

$$Z = Z_0\sqrt{N} \quad (5)$$

The impedance values used in this study were other: 50 Ω, 35,335 Ω, and 70.7 Ω. The impedance of the connector (Z) can be known from equation (5). The feedline width is determined by equations (3) and (4) as described in the feedline width of the singular microstrip antenna. The distance between patches (d) is the distance that connects the midpoints of the patch. To find the width of the distance between patches is determined using the following equation:

$$d = \frac{\lambda}{2} = \frac{c}{2f} \tag{6}$$

where λ is the wavelength in meters, c is the speed of light with a value of $3x10^8$ m/s, and f is the frequency of antenna work in Hz units.

From the equations that have been described above, it can be known the values of parameters to make a design of microstrip antenna patch circular 2x2 array as follows:

Table 2. Microstrip Antenna Parameters Patch Circular 2x2 Array

Parameter	Symbol	Starting Value	Optimizer Values
Radius Patch	a	19.6 mm	20 mm
Width of Feed Line $_{1,2,3,4}$ 50 Ω	Wf_1=Wf_2=Wf_3=Wf_4	3 mm	3 mm
Length of Feed Line $_{1,2,3,4}$ 50 Ω	Lf_1 = Lf_2 = Lf_3 = Lf_4	5 mm	5 mm
Width of Feed Line $_{5.6}$ 70.7 Ω	Wf_5=Wf_6	2 mm	2 mm
Length of Feed Line $_{5.6}$ 70.7 Ω	Lf_5 = Lf_6	20 mm	20 mm
Width of Feed Line $_7$ 50 Ω	Wf_7	58 mm	58 mm
Length of Feed Line $_7$ 50 Ω	Lf_7	3 mm	3 mm
Width of Feed Line $_8$ 35.335 Ω	Wf_8	5 mm	5 mm
Length of Feed Line $_8$ 35.335 Ω	Lf_8	23 mm	23 mm
Width of Feed Line $_9$ 50 Ω	Wf_9	3 mm	3 mm
Length of Feed Line $_9$ 50 Ω	Lf_9	40.5 mm	40.5 mm
Patch Thickness	tp	0.035 mm	0.035 mm
Width of Substrate	Ws	120 mm	120 mm
Length of Substrate	Ls	130 mm	130 mm
Substrate Thickness	h	1.6 mm	1.6 mm
Width of Ground Plane $_a$	Wg_a	120 mm	120 mm
Length of Ground Plane $_a$	Lg_a	60 mm	60 mm
Width of Ground Plane $_b$	Wg_b	50 mm	50 mm
Width of Ground Plane $_c$	Wg_c	35 mm	35 mm
Length of Ground Plane $_c$	Lg_c	20 mm	20 mm
Ground Plane Thickness	tg	0.035 mm	0.035 mm

Once the entire parameter value is known, researchers can create a 2x2 circular microstrip antenna design array, as shown in figure 1.b above. Patch elements using Copper material have 0.035 mm thickness. The design of the 2x2 circular microstrip antenna patch element consists of 4 singular circular antenna elements. Feedlines use as patch connection with Wilkinson power divider technique methods. The patch design of the 2x2 circular microstrip antenna array has 19.6 mm initial radius. Then optimization is carried out to produce a radius to 20 mm at a frequency 4.3 GHz. Distance between patches $\frac{1}{2}\lambda$ is known to be 68 mm. Impedance used in feedlines is 50 Ω, 35.335 Ω, and 70.7 Ω. Feedlines with the impedance 50 Ω have a width of 3mm, the impedance 35.335 Ω has 5 mm width, and the impedance of 70.7 Ω has 2mm width. The higher the impedance, the smaller the width of the drain.

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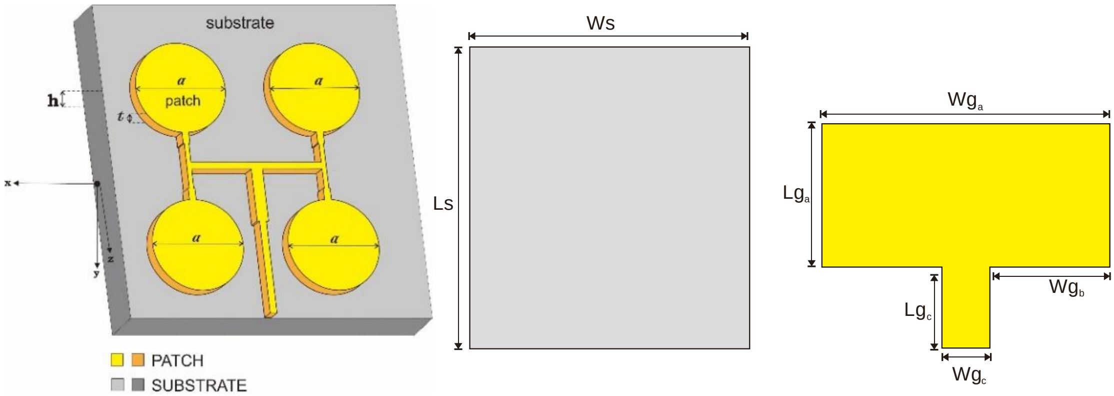


(a) (b)

Figure 4 (a) Substrate Patch 3D view (b) 2D view of substrate and ground plane

Figure 3 is a patch, substrate, and ground plane view of the antenna microstrip circular 2x2 arrays. Figure 3.a is an image of patch design and substrate seen from above. Figure 3.b shows an antenna substrate made of FR-4 epoxy has a width of Ws 120 mm, length or Ls of 130 mm with a material thickness of 1.6 mm and a dielectric constant of 4.3, the ground design of the 2x2 array antenna after undergoing optimization and defected ground structure (DGS). Ground plane elements are made of Copper material with a material thickness of 0.035 mm, the same as patches. Ground plane width Wg_a is 120 mm, ground plane length Lg_a is 60 mm, width Wg_b 50 mm, width Wg_c 35 mm, and length Lg_c 20 mm.

4. Antenna Simulation Results

Microstrip antenna design 2x2 circular patch array for altimeter radar application must meet several specifications and requirements to work correctly, such as : circular patch dimension, altimeter radar operating frequency 4.3 GHz, resulting in return loss value less than -10 dBi with gain more than 3 dBi, has VSWR value of 0 to less than equal to 2, and vertical polarization.

Return loss is a comparison of the wave level reflected against the sent 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 equal to –10 dB for the antenna to be used. The smaller or the minus the return loss value of an antenna, the better the antenna is designed. The return loss reading on the singular circular microstrip antenna at an intermediate frequency of 4.3 GHz is -16,192. The return loss value of –10 dB is at the upper frequency of 4,271 GHz and the lower frequency of 4,319 GHz resulting in a bandwidth of 48 MHz. Then the singular microstrip antenna is connected by a feed line using an array method thus forming a 2x2 patch. On a 2x2 array circular microstrip antenna, the return loss value at the intermediate frequency of 4.3 GHz is -12.41 dB, at frequencies below 4,223 GHz and upper frequencies of 4.3671 GHz the return loss value is –10 dB so that bandwidth can be obtained at 144 MHz.

Return loss is a comparison of the wave level reflected against the sent 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 equal to –10 dB for the antenna. The smaller or the minus the return loss value of an antenna, the better the antenna is designed. The return loss reading on the singular circular microstrip antenna at an intermediate frequency of 4.3 GHz is -16.192. The return loss value of –10 dB is at the upper frequency of 4.271 GHz and the lower frequency of 4.319 GHz resulting in a bandwidth of 48 MHz. Then the singular microstrip antenna is connected by a feedline using an array method, thus forming a 2x2 patch. On a 2x2 array circular microstrip antenna, the return loss value at the intermediate frequency of 4.3 GHz is -12.41 dB. At frequencies below 4.223 GHz and upper frequencies of 4.3671 GHz, the return loss value is –10 dB, so bandwidth obtain to 144 MHz.

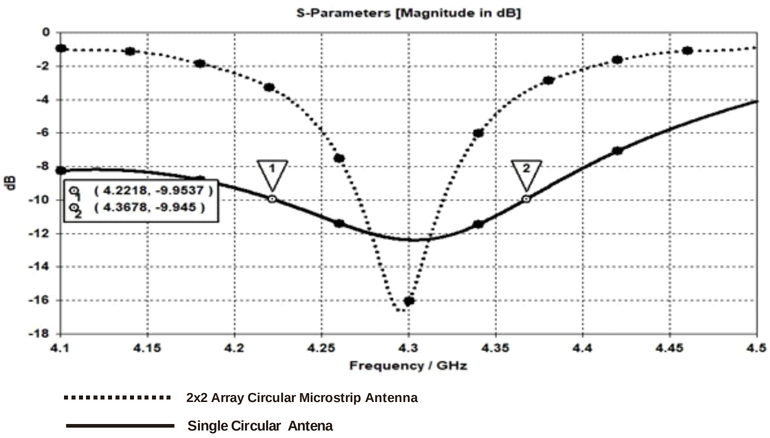
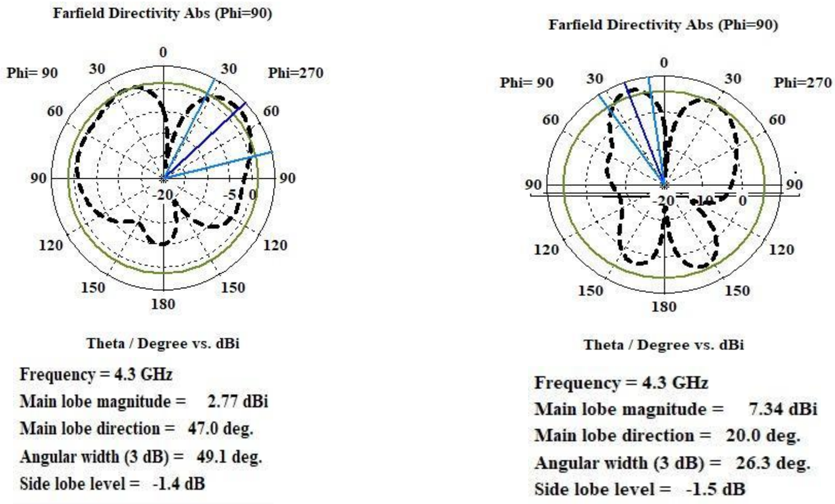


Figure 5. S-Parameter Chart

Voltage Standing Wave Ratio (VSWR) compares maximum voltage with minimum voltage calculated at the time of reflection coefficient at the end of the transmission and load line. The VSWR value of the antenna must be between 0 and less than 2 for the antenna to work correctly. At best, the VSWR value is equal to 1. The voltage standing wave ratio (VSWR) value of the singular microstrip antenna at 4.3 GHz is 1.36, while the VSWR value of a 2x2 microstrip antenna array at the same frequency is 1.6. The value is sufficient to meet the minimum VSWR specification of an antenna. Gain is the comparison of output voltage with input voltage. The singular microstrip circular antenna gains reading in the 4.3 GHz altimeter radar frequency read 4.3 dB, while the 2x2 circular microstrip circular antenna gain reading of the same frequency array reads 6.9 dB. This proves that the antenna array method will increase the antenna's gain. Directivity is the direction of the radiation pattern of an antenna. The higher the antenna's directivity, the narrower the main beam so that the antenna beam is more focused.



(a) (b)

Figure 6 Directivity Results of Microstrip Circular Antenna (a) Singular (b) 2x2 Array

Figure 5.a is a directivity of singular circular microstrip antennas at altimeter radar frequency 4.3 GHz altimeter resulting in the main lobe gain of 2.76 dBi at 47.0 degrees and beamwidth 49.1 degrees. Figure 5.b directivity of the 2x2 array circular microstrip antenna at a frequency of 4.3 GHz resulted in the main lobe gain of 7.34 dBi at 20.0 degrees and beamwidth at 26.3 degrees.

5. Conclusion

The test results of singular microstrip antennas design at a frequency of 4.3 GHz for altimeter radar resulted in a return loss of -16.19 dB, VSWR 1.36, gain 4.3 dB and bandwidth 48 MHz. The gain of singular microstrip antennas for small altimeter radars and narrow bandwidth makes the antenna not work optimally. Therefore it is necessary to innovate or develop such particular microstrip antennas. The design of 2x2 array circular microstrip antennas using defected ground structure (DGS) increases antenna gain and bandwidth. The 2x2 array circular antenna innovation consists of 4 singular circular antenna patch elements connected by 50 Ω, 35.355 Ω, and 70.7 Ω. The simulation test result of designing a 2x2 array circular microstrip antenna resulted in return loss of -12.41 dB, VSWR 1.6, 6.9 dB gained, and bandwidth of 144 MHz. The gain increased by 2.6 dB (60%) and 96 MHz (200%) increase in bandwidth.

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