Gain Increase Modification Collinear Dipole Antennas for Secondary Surveillance Radar

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***Abstract*—In this research, an antenna design was developed using the wire-to-micros trip adaptation technique. The aim of developing the antenna is by modifying the change in position and shape of the antenna to get a large gain with a minimum value of 25 dB. This development is crucial for the use of Secondary Surveillance Radar (SSR). The design of the antenna used in this study is to improve the performance of modifying conventional dipole antennas to become collinear arrays. Collinear array antennas involve modifying dipole arms to form an array, incorporating a coupling effect on both the positive and negative arms, and strategically rotating the vertical placement by 180 degrees to maximize the resulting gain. The study involved three types of antenna arrays, each consisting of eight antennas: Mode A, unidirectional with opposite poles; Mode A, not unidirectional with opposite poles; and Mode B, unidirectional with opposite poles. Early research made comparisons of polar differences with polar similarities. For the results of a single polar difference antenna Mode A and B, where Mode A produces S11-26.884 dB with Gains 3.825 dB, Mode B produces S11-20.408 dB with Gains 2.364 dB, for research on array antennas, it was carried out in stages, with as many as 8 array antennas, without reflectors and with reflectors. In the final configuration, an antenna with an array of 112 antennas using reflectors to produce S11 for a frequency of 1.03 GHz of-15.53061 dB with Gain 26.52 dB and an Azimuth beam width of 0.9^{o} and for the frequency 1.09as big-20.73117 dB with Gain 25.6 dB and an Azimuth beam width of 0.8^{o}. These results indicate the successful achievement of improved antenna performance, including a reduction in reflection coefficient and an increase in gain. These findings contribute to the advancement of antenna design for SSR applications, showcasing the potential for substantial gains in signal strength and directionality.**

***Keywords*—Secondary Surveillance Radar (SSR, antenna, microstrip, array, gain, azimuth**

I. Introduction

Antenna is one of the crucial parts in the telecommunication system, especially in civil communication related to human life, especially communication in the world of aviation. Selection of the right antenna has a profound impact on the operational performance of the communication system [1]. Hence, antenna selection demands meticulous research, particularly for Secondary Surveillance Radar (SSR) communications. Within the SSR system, the ground segment comprises a transmitter/receiver, known as the interrogator, while the airborne segment encompasses the transponder, which operates as both a receiver and transmitter. The integration of these components is critical, especially in fighter aircraft applications. In the realm of aviation, the role of antennas extends beyond mere wireless communication. The efficiency and effectiveness of the SSR system hinge on the antenna's ability to transmit and receive signals accurately, enabling seamless interaction between ground control and aircraft. Just as antennas are vital in the broader context of global connectivity, in the aviation sector, they serve as a linchpin for ensuring the safety and security of flights [2]. The transmission interrogator is made at a frequency of 1030 MHz (approx. 29 cm) and is called a mode. At the interrogator receiving the signal in the mode that has been set, the transponder responds by transmitting on a frequency of 1090 MHz [3], this response is in coded form. On flights for military purposes, the integrator function is needed to detect and identify whether the aircraft is an enemy fighter or not. Then the ground station section can provide information to the weapons section to be able to anticipate when after the integrator the fighter does not respond. If the fighter aircraft responds, then the aircraft is a friend, by sending a squawk number code. The secondary radar works on the principle of sending pulses consisting of P1–P3 pulses over a certain distance. The secondary radar ground equipment is operated on the 1030 MHz frequency. If the interrogation signal is received by the aircraft transponder, the circuit. This pulse will be processed, and then the transponder will reply at a frequency of 1090 MHz [4], The interrogation pulses are called the Mode And the reply pulses are called the code. Furthermore, the reply from the aircraft received by the

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secondary radar antenna on the ground is processed and analyzed by the extractor device and computer to obtain the desired information. To achieve a long detection distance from the SSR radar to fighter aircraft, it is necessary to design an antenna that produces a high gain above 25 dB, with a beam azimuth below 1 degree. It is necessary to design an antenna with a minimum gain ratio of 316x with a minimum gain of 25 dB, the resulting gain is 25 dB, if the beam produces unidirectional, it can be ascertained that the azimuth beam produces a value below 1°. The antenna radiation pattern that is initially Omni, arrayed into 2 faces and a reflector is attached to concentrate in a certain direction, or a fan beam. To meet the demands of SSR communications, it becomes imperative to explore advanced antenna designs that not only offer directional capabilities but also address challenges related to space constraints and complex resonance patterns.

In this study, we aimed to elucidate a reliable Secondary Surveillance Radar where the main factor is the antenna design for 1.03 GHz and 1.09 GHz frequency. To our knowledge the Secondary Radar can be maximased by designing Colinear Dipole Array Antenna with variants of Mode A and Mode B. This study will then conduct the analysis through the optimization of characteristic on each Modes, then to assemble Colinear Dipole Array Planar with Array Methode and collect the required parameter as the result of final array antenna arrangement.

II. OVERVIEW OF SSR TECHNOLOGY

Currently, frequencies of 1.03 GHz are used for the interrogation path from ground to air path and 1.09 GHz for the reply path from air to ground, as shown in Fig. 1. The system, originally known as the military Mark X (Roman ten) was opened for civil use with mode 3 and A common to both. The interrogator transmitter transmits two 0.8 µs pulses with a power between 21 dBW and 27 dBW (about 125 W to 500 W) spaced according to the mode of interrogation in the main beam. The STANAG and ICAO pulse separations are listed in Table I [4].

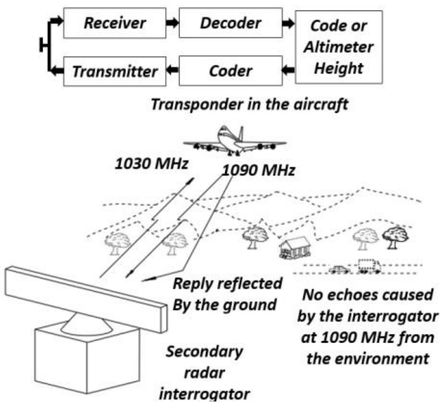


Fig. 1. A secondary radar interrogator and its environment [4].

Aircraft that use this system carry a combination of receiver and transmitter called a transponder. The pulses from the interrogator are decoded, and the code, if any, for the mode is sent to the coder. The coder sends two 0.45 µs bracket pulses with 20.3 µs spacing with up to 12 pulses carrying the code in between. The codes are generally set by the pilots on the instruction of the air controllers and are used to identify the aircraft. Mode C is reserved for the standard altimeter height, which obviates the need for civil three-dimensional radars. There are extra high security ciphered modes for military use, and the civil modes have been extended to mode S. Aircraft equipped with mode S reply normally to modes 1 to 3/A to D. Mode S has extra modes that are used to interrogate aircraft individually and transfer data [5]. The receiver operates at1090 MHz, while the echoes from the environment return at a frequency close to 1030 MHz; ensuring that there are no echoes are received to be mistaken with wanted replies. The aircraft antennas for the transponders are quasi omnidirectional, so there will be asynchronous replies in the receiver that come from interrogations from other sites [6].

TABLE I. A SELECTION OF STANAG AND ICAO PULSE SEPARATIONS FOR SECONDARY RADAR

	Military mode	Civil mode	Pulse spacing (µs)
	1		3
	2		5
Military and civil (shared)	3	A	8
		B	17
Height reply		C	21
		D	25

III. ANTENNA DESIGN

A. Collinear Dipole

The next step is the design of the dipole collinear antenna. In this research step, the collinear dipole array antenna is designed using the same technique as the Collinear Franklin by applying it to the microstrip material adapted from the dipole antenna, with irradiation using a long field, with a length of 1/2 λ. Franklin antennas are commonly used for radio communications, such as HF and VHF and are made of wire and iron pipes. In the research the length of the antenna is doubled to see the maximum gain result of the antenna design to be used and microstrip antennas will be equipped with microstrip line feed rationing techniques. Coaxial feed or probe feed is a technique that is carried out by connecting the inner conductor of the coaxial cable to the radiating conductor, and the outer conductor of the coaxial cable connected to the ground using the antenna feed using a female SMA connector. However, this antenna has a different placement for the radiating part and the ground part. The Collinear franklin antenna only consists of 1 layer where the radiating and ground parts are in the same plane, while the Dipole array collinear antenna consists of 2 layers, of which layer 1 is for the irradiation field, layer 2 is for ground. In this research, many types of side sections will be made, to see the effect that occurs on the resulting parameter section. First the irradiation field and ground are equilateral, the two are different sides, and the third is the same side but the direction is different, the variants are Mode A, Mode B. Figs. 2 and 3 are the geometries of the research conducted where there are differences in the shape between the sides and layers, but the calculations are the same.

(a) (b)

Fig. 2. Collinear dipole antenna with two layers with different sides (Mode A), (a) front view, (b) bottom view.

(a) (b)

Fig. 3. Collinear dipole antenna with two layers with different sides (Mode B), (a) front view, (b) bottom view.

Based on calculations with a length of 1/2 λ and calculations made based on the calculation of the FR4 substrate material, with a value of εr = 4.40, h = 1.60 mm, the value of λ is 131.21 mm. So that the length of the antenna arm A is obtained is 65.60 mm and arm B is 32.80 mm. Fig. 4 illustrates detailed calculation results. For the equation to find Arm length (A) and Width (B) which are used as follows:

$$A = \frac{1}{2}\, x\, \lambda \quad (1)$$

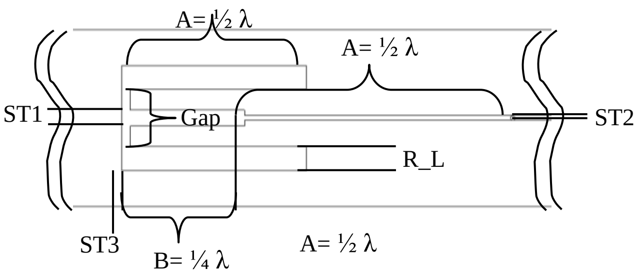
$$B = \frac{1}{4}\, x\, \lambda \quad (2)$$

For transmission channel width, use the following equation:

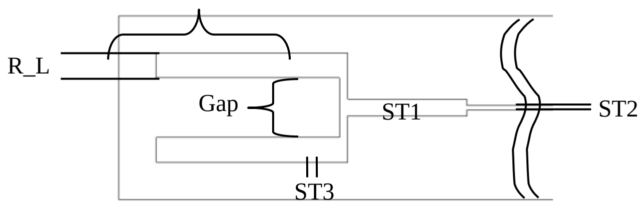
$$W_f = \frac{2 \times h}{\pi} \times \left[B - 1 - \ln(2B-1) + \frac{\varepsilon r - 1}{2 \times \varepsilon r} \times \left[\ln(B-1) + 0{,}39 - \frac{0.61}{\varepsilon r}\right]\right] \quad (3)$$

Where,

$$B = \frac{60 \times \pi^2}{Z_0 \times \sqrt{\varepsilon r}} \quad (4)$$



(a)

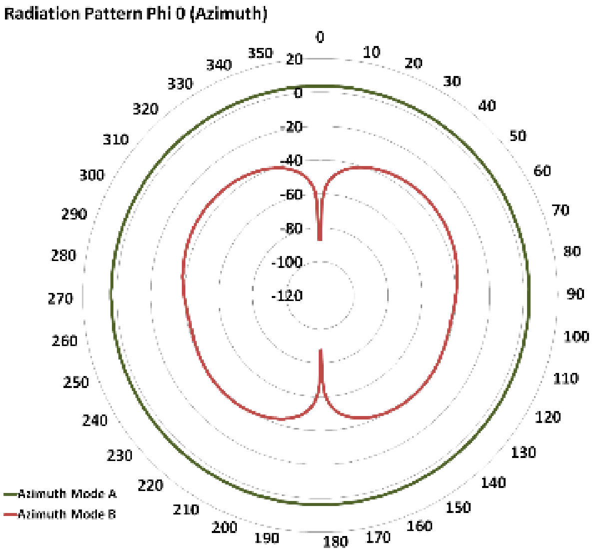


(b)

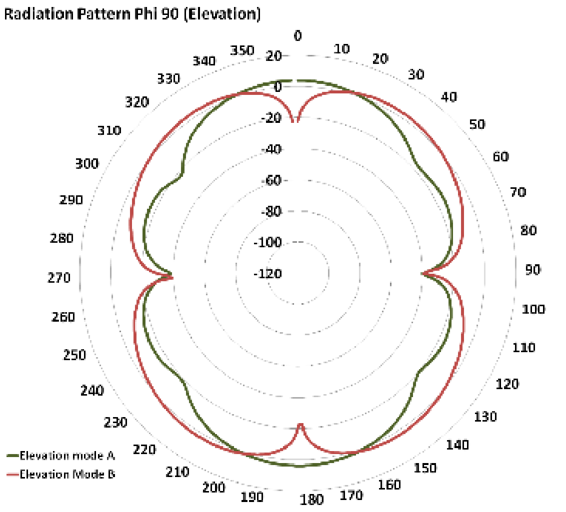
Fig. 4. Dimensional dimensions of the collinear dipole array antenna, (a) The inner side, (b) The outer side.

Fig. 5 is the optimum simulation results obtained from several experiments, by changing the dimensions of the radiation and transmission lines. The collinear dipole array antenna, both Mode A and Mode B made from FR4, produces a reflection coefficient value of –16.01736 dB at a frequency of 1.03 GHz and – 16.51226 dB at a frequency of 1.09 GHz for Mode A and –20.41887 dB at frequencies of 1.03 GHz and–19.40287 dB at a frequency of 1.09 GHz for Mode B. Antenna Mode B produces an input reflection coefficient value than antenna Mode A. This is because antenna Mode B is more suitable than antenna Mode A. Antenna Mode B produces a more stable mutual coupling because both layers 1 and 2 have opposite geometries so that the coupling that occurs between irradiations is not too close and the positions of layers 1 and 2 are the same. So that the current marked positive (+) will flow or loop in the negative direction (–) according to the rules of dipole antenna theory, from Fig. 5 it is known that for the frequency response in Mode A the graph is orange, it can be seen that the bandwidth is narrower, but frequency response with a very small value, this is consistent with the single antenna theory. In contrast to Mode B, the dissimilarity in the cross-section’s configuration between the top and bottom sides of the antenna, featuring distinct poles, leads to a substantial leap in electromagnetic wave propagation. This, in turn, yields a frequency response with reflection coefficients extending to various frequencies, ultimately providing coverage for both 1.03 GHz and 1.09 GHz frequencies. For Mode B, the position between layer 1 and layer 2 is different. One side has a beam geometry that is facing each other and the other geometry has an opposite geometry, so that there is a difference in loops between the irradiation in the two layers 1 and layer 2. This also results in a difference in the resulting directional diagrams. The difference in the resulting directional diagrams can be seen in Figs. 6 and 7. In Antenna A mode, the resulting directional diagrams form a unified pattern, while the modes occur with maximum transmission differences. This happens because as explained earlier. The antenna width for Mode A is 79.902 MHz of frequency 1.023019–1.102921 GHz, while the antenna width for Mode B is194.299 MHz of frequency 1.008105–1.202404. The B Mode Antenna produces a wider bandwidth than the A Mode Antenna. This is in line with the theory of a sloping reflection coefficient, the greater the bandwidth produced, and the sharper the reflection coefficient, the smaller the resulting bandwidth (Table II).

Fig. 5. Simulation results of optimum reflection coefficient collinear dipole array mode A and mode B on microstrip.

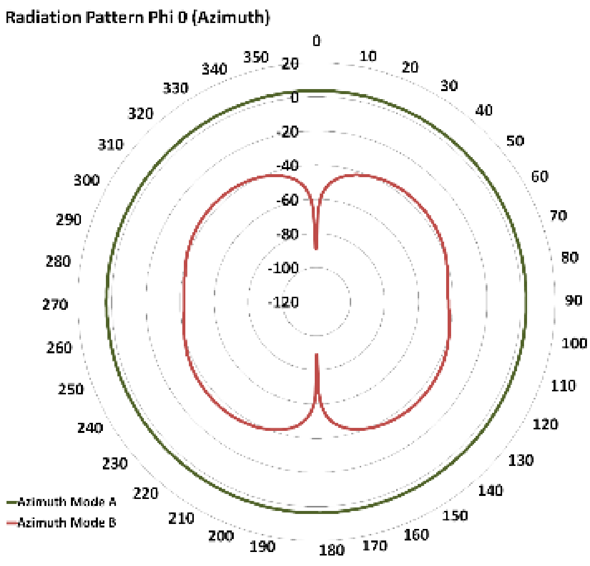


(a)

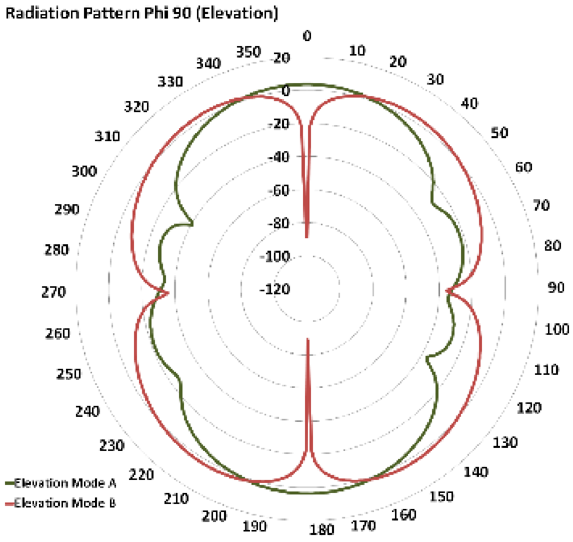


(b)

Fig. 6. Single antenna radiation pattern comparison frequency 1.03 GHz, (a) θ = 0˚, (b) θ = 90˚.



(a)



(b)

Fig. 7. Single antenna radiation pattern comparison frequency 1.09 GHz, (a) θ = 0˚, (b) θ = 90˚.

TABLE II. RESULTS OF THE PARAMETERS FOR OPTIMIZING THE DIMENSIONS OF THE COLLINEAR DIPOLE ARRAY ANTENNA

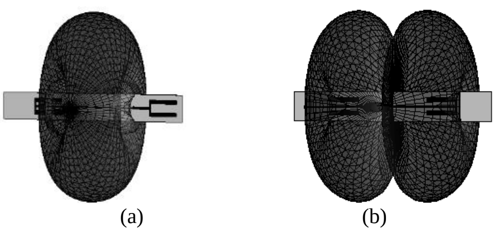
Parameter	**Mode A**	**Mode B**
s11 1.03 GHz (dB)	–16.01736	–20.41887
s11 1.09 GHz (dB)	–16.51226	–19.40287
VSWR 1.03 GHz	1.3758	1.2107
VSWR 1.09 GHz	1.3513	1.2399
Z (Ω) 1.03 GHz	68.61+J6.2	59.29+J6.5
Z (Ω) 1.09 GHz	38.46+J6.4	43.54+J8.5
Bandwidth (MHz)	79.902	194.299
Frequency range s11 -13.979 dB (GHz)	1.023019–1.102921	1.008105–1.202404
Gain 1.03 GHz (dBi)	3.779	3.107
Gain 1.09 GHz (dBi)	3.594	3.24
Azimuth 1.03 GHz	360°	55°
Azimuth 1.09 GHz	360°	50
SLL Azimuth (dB) 1.03 GHz	0	–4
SLL Azimuth (dB) 1.09 GHz	0	–0.7
Elevation 1.03GHz	38.9°	36.6°
Elevation 1.09 GHz	40.6°	35.5°
SLL Elevation (dB) 1.03 GHz	–18.7	0
SLL Elevation (dB) 1.09 GHz	–25.1	0

IV. SINGLE ANTENNA

Based on the results of the research conducted, the design of collinear dipole antennas with different sides and collinear dipole array antennas for Mode A and Mode B produces differences in characteristics that are not much different. However, the results of the different dimensions are significantly different. The resulting differences are due to the radiation size, transmission line, and antenna system aperture. Both types of antennas are modifications of the antenna on the pole, where the antenna produces a movement of electromagnetic waves like a dipole antenna starting from positive (+) flowing to negative (–). This can be seen in Figs. 6 and 7 for the collinear dipole array antenna. From this figure it can be understood when the signal is generated and flows through the source. In this case the supply that uses the antenna connector at phase 0° will move based on wave propagation in the material (λd). The difference in propagation will result in different parameter characteristics, both for Gain and radiation pattern (Fig. 8) and also for the overall shape of the beam. Comparison of the dimensions obtained in the design can be seen in Table III, Figs. 8(a) and 8(b) are 3-dimensional results of the shape of the beam or the resulting radiation pattern. From the design of the antenna, it can be seen that the resulting radiation pattern is different. It can be observed that the radiation generated is affected by the shape of the B arm of the collinear antenna design. The position of the placement of arm B has a very significant effect on the multiplication of the diagrams that occur so that when the position of arm B is on the same side. This causes the process of substitution and combination of antenna radiation into one unit so that it is not too broad. In contrast to the position of the B arm on a different side, this antenna produces a wide beam. This is due to the amount of emission produced by each arm B. In addition, the design of collinear dipole array antennas, Mode A and Mode B are greatly influenced by the radiation placement of each antenna. If layers 1 and 2 point at the same position, a similar multiplication diagram will be produced so that the beam becomes narrower, different from Mode B. In the opposite direction, or it is called a multi-beam, a multi-beam design like this is not suitable for use in SSR communication.

TABLE III. COMPARISON OF THE DIMENSIONS OF THE COLLINEAR DIPOLE ARRAY ANTENNA

Parameter	Initial Value	Mode A	Mode B
A	65.605 mm	48.45 mm	48.9 mm
A_ST	65.605 mm	75 mm	75 mm
B	32.8 mm	31 mm	32 mm
Gap	3 mm	5.75 mm	5.75 mm
R_L	5 mm	6.7 mm	6.7 mm
ST1	3.05 mm	4.5 mm	4.5 mm
ST2	1.595 mm	1.3 mm	1.3 mm
ST3	1.595 mm	2.3 mm	2.3 mm
h	1.6 mm	1.6 mm	1.6 mm
Copper	0.035 mm	0.035 mm	0.035 mm
Total length	348.99 mm	333.5 mm	336.4 mm
Total width	36 mm	49.4 mm	49.4 mm



(a) (b)

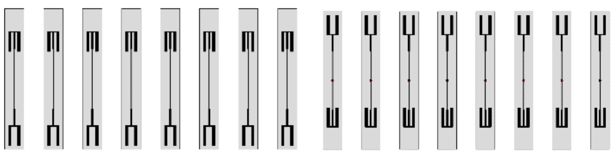
Fig. 8. Comparison of the 3-dimensional radiation pattern of the collinear dipole array antenna, (a) Mode A, (b) Mode B.

V. ARRAY METHODE

From the two antenna models carried out in the study, it was found that the most optimum radiation pattern is to use a collinear dipole array antenna Mode A (a) in Fig. 8(a). With a perfect 360-degree donut-shaped radiation pattern. With the resulting gain in Table III of 3.779 dBi at a frequency of 1.09 GHz and 3.594 dBi at a frequency of 1.09 GHz. Where for one antenna it produces the parameters needed to form an antenna array with a planar arrangement. Furthermore, the antenna is arranged as many as 112 units to form one planar plane which produces an elevation beamwidth of less than 1 degree for the resolution required by the SSR antenna.

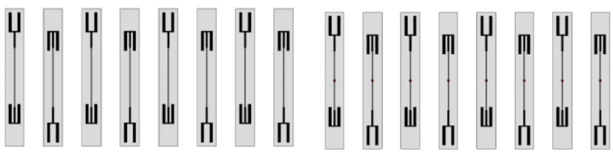
A. Collinear Dipole Array Planar

The assembled collinear dipole antenna is expected to produce a unidirectional radiation pattern with a beam elevation below 1 degree, so that the resulting resolution for the antenna sweep when rotating can be accurate and by producing a large gain the reception range can also be very far. The antenna arrangement is designed in a row towards the side with a total of 112-unit antenna units with the student antenna combining using a 16-way power combiner of 7 units and 1 unit of 7-way. In the early stages of antenna design, the number of antennas per module consisting of 8 antenna units was carried out, where the antenna was observed using a reflector and not using a reflector. The antenna arrangement is combined into 3 types of polar alignment for both the upper and lower layers, the first type with the name Mode A uses the same side antenna configuration with different poles, for the second type, namely modification of model A with different side shapes and different poles, and for the 3rd type of Mode B with the same sides and the same poles, what is different is the front and rear. Mode A is the same side with different poles in Fig. 9, Mode A is with different sides and different poles is Fig. 10, and Mode B is the same side and poles are also the same in Fig. 11 all without reflector. While Fig 12(a) is Mode A with the same side and different poles, Fig 12(b) is with different sides and different poles, and Fig 12(c) is Mode B is the same side and poles all with reflector.



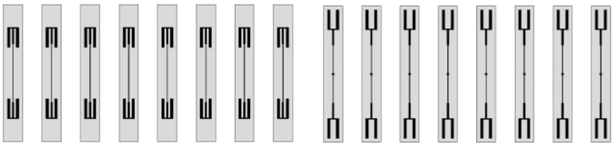
(a) (b)

Fig. 9. Sideways collinear dipole antenna array Mode A without reflector, (a) front view, (b) bottom view.



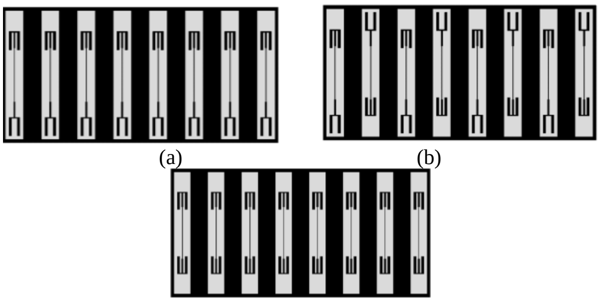
(a) (b)

Fig. 10. Collinear dipole antenna array Mode A with different side without reflector, (a) front view, (b) bottom view.



(a) (b)

Fig. 11. Collinear dipole antenna array B mode without reflector, (a) front view, (b) bottom view.



(a) (b) (c)

Fig. 12. Collinear dipole antenna array with reflector, (a) Mode A sideways, (b) Mode A different side, (c) Mode B.

From the results of the design of the 3 antenna modes, the parameters listed in Table IV are generated. In Table IV we can see that the most matching impedance parameter is in Mode B, where the reflection coefficient value obtained at the 1.03 GHz frequency is –20.86556 dB and there is the frequency of 1.09 GHz is –19.27911 dB where this value shows the smallest S11 value compared to the other 2 modes, this is because as explained in the single section, that the opposite antenna arms on the top and bottom sides produce long-distance loops of electromagnetic waves, because the pole arms are different with the same shape resulting in a constant addition of frequency response, resulting in a frequency response at other frequency points, so that the bandwidth will widen, the graphical representation of the S11 signal without reflection shows the bandwidth can be seen in Fig. 13 for the blue line indicates Mode B, and the width the bandwidth is 234.6663 MHz, compared to the two modes A, it can be seen that the resulting bandwidth is small, on the black and orange lines. The resulting bandwidth in the same side A mode is 58.872 MHz, and the different side A mode is 13.469 MHz. The graphical representation of the S11 signal with reflection also can be seen in Fig. 14 for the blue line indicates Mode B, and the width the bandwidth is 240.1829 MHz, compared to the two modes A, it can be seen that the resulting bandwidth is small, on the black and orange lines. The resulting bandwidth in the same side A mode is 128.162 MHz, and the different side A mode is 9.708 MHz. In this antenna study, the resulting main lobe radiation pattern leads to 2 sides, namely at ϴ = 0° and ϴ = 180°. In Table IV can see a striking comparison between the types of antennas, especially the gain section, where the gain of the A different side Mode Antenna is minus, while the A sideways Mode and B Mode Are positive, according to mathematical calculations.

Table IV for the different side A Mode Antenna in the Gain section it can be seen that the gain is worth –2.376 at frequency 1.03 and –2.055 at frequency 1.03, this is due to the radiation pattern that leads randomly to any angle, so the gain value will not be maximum, so it cannot be used as an SSR antenna that requires a unidirectional radiation pattern type in the direction certain. The shape of the 2D radiation pattern, either azimuth or ϕ = 0° in Figs. 15 (a), Elevation or ϕ = 90° in Fig. 15(b), azimuth or ϕ = 0° in Fig. 16(a), and Elevation or ϕ = 90° in Fig. 16(b) with respectfully the Fig. 15 is frequency 1.03 GHz and Fig. 16 is frequency 1.09 GHz. Image of an 8-unit array antenna with the addition of a reflector as seen in Fig. 12, with the aim of increasing the gain value, and making the antenna focus in a certain direction with a unidirectional fan beam radiation pattern. Adding a reflector using a copper plate with the width and length of the size of the placement of the array antenna, with an additional side of 10 mm on the side. The optimum reflector distance is 70 mm, or approx. (λd/2). In theory, the reflector is a reflection as well as reflection and multiplication diagram from ϴ = 180° in a certain direction to ϴ = 0°, so that apart from being a fan beam, the gain also increases.

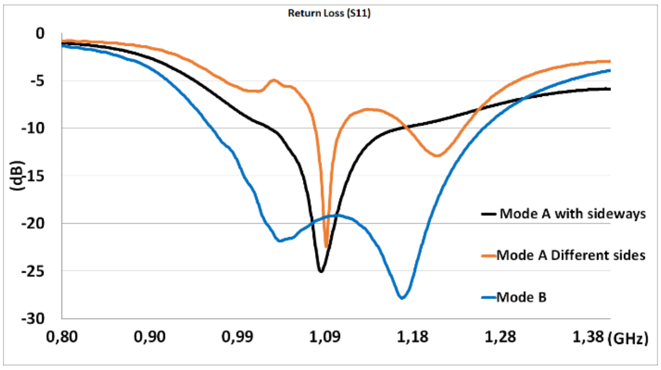


Fig. 13. Comparison of the values of S11 collinear dipole antenna array Mode A and Mode B without reflectors.

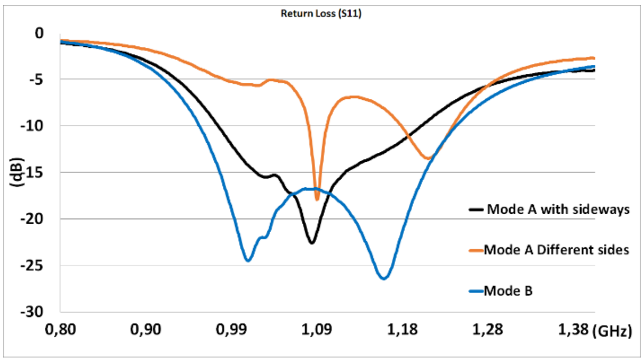


Fig. 14. Comparison of the value of S11 collinear dipole antenna array Mode A and Mode B with reflector

TABLE IV. RESULTS OF PARAMETER OPTIMIZATION OF ARRAY ANTENNA 8 WITHOUT REFLECTOR

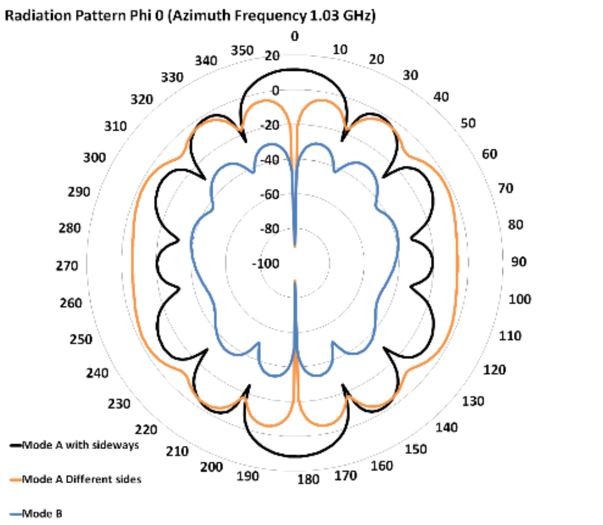
Parameter	Mode A		Mode B
	with sideways	Different sides	
s11 1.03 GHz (dB)	–10.16726	–5.005275	–20.86556
s11 1.09 GHz (dB)	–23.39728	–21.80382	–19.27911
Z (Ω) 1.03 GHz	54.78+ J335.8	44.35+ J301.7	56.1+ J351.5
Z (Ω) 1.09 GHz	49.33+ J352.5	59.41+ J357.2	41.34+ J355.3

VSWR 1.03 GHz	1.8994	3.5662	1.1990
VSWR 1.09 GHz	1.1451	1.1769	1.2438
Bandwidth (MHz)	58,872	13.469	234.6663
Frequency range s11-13.979 dB (GHz)	1.05989–1.1187	1.082527–1.095996	0.9943747–1.229041
Gain (dBi) 1.03 GHz	11.69	–2.376	11.42
Gain (dBi) 1.09 GHz	11.18	–2.055	11.81
Azimuth 1.03 GHz	18.3°	26.3°	11.9°
Azimuth 1.09 GHz	17.6°	20.3°	11°
SLL Azimuth (dB) 1.03 GHz	–13.8	–1,4	–0.7
SLL Azimuth (dB) 1.09 GHz	–13	-3.9	–0.6
Elevation 1.03GHz	42°	41.9°	35.9°
Elevation 1.09 GHz	42.7°	37.5°	34.7°
SLL Elevation (dB) 1.03 GHz	0	–6.2	0
SLL Elevation (dB) 1.09 GHz	–33.7	–4.3	–0.5

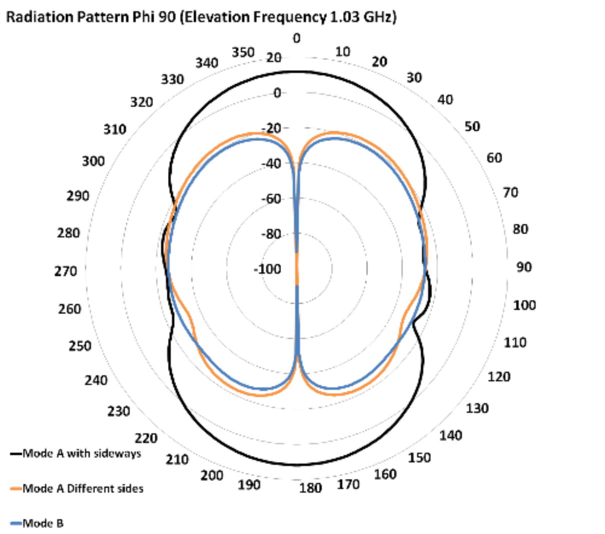
TABLE V. RESULTS OF PARAMETER OPTIMIZATION OF ARRAY ANTENNA 8 WITH REFLECTOR

Parameter	Mode A		Mode B
	with sideways	Different sides	
s11 1.03 GHz (dB)	–15.53061	–5.67655	–21.99171
s11 1.09 GHz (dB)	–20.73117	–17.10637	–16.83498
Z (Ω) 1.03 GHz	46.6+J358.3	37.78+J304,5	45.39+J353.7
Z (Ω) 1.09 GHz	61.05+J341.7	65.94+J354	39.3+J7.4
VSWR 1.03 GHz	1.4018	3.1684	1.1728
VSWR 1.09 GHz	1.2025	1.3243	1.3363
Bandwidth (MHz)	128.162	9.708	240.1829
Frequency range s11-13.979 dB (GHz)	1.00843–1.136592	1.083459–1.093167	0.9748971–1.21508
Gain (dBi) 1.03 GHz	14.44	–1.309	14.44
Gain (dBi) 1.09 GHz	14.52	–3.310	14.64
Azimuth 1.03 GHz	18.6°	24.3°	29.8°
Azimuth 1.09 GHz	18°	19.8°	23.8°
SLL Azimuth (dB) 1.03 GHz	–13.6	–0.9	–1.1
SLL Azimuth (dB) 1.09 GHz	–13.3	–0.9	–0.6
Elevation 1.03GHz	41°	39.4°	34.1°
Elevation 1.09 GHz	39°	32.4°	33.4°
SLL Elevation (dB) 1.03 GHz	–18.8	–5.5	–14.7
SLL Elevation (dB) 1.09 GHz	–13.9	–9.5	–15.3

Figs. 13 and 14 are the reflection coefficient values of the antenna array 8, where Fig. 13 is the antenna array graph without using a reflector, while Fig. 14 is the antenna array graph using a reflector. From Fig. 13 we can see both for A sideways mode, different sides produce a small bandwidth, especially sideways, while the parameter results obtained in Table IV show optimum results, such as Gain and the shape of the radiation pattern, even though the shape is still 2 directions from ϴ = 0° and from ϴ = 180°. Thus, the A different side antenna is not suitable for SSR applications as desired. For Mode B, it produces a good gain as well as Mode A sideways, the maximum value, but in Mode B the resulting radiation pattern is diffracted to many angles, which can be seen for 2D in Figs. 15–18 on the blue graph, and for the 3D radiation pattern can be observed in Figs. 19 and 20 section (b). So it is not suitable for SSR applications. Likewise for modifications using a reflector, where from the graph of Fig. 14, in A sideways graph mode the graph is black, indicating an increase in bandwidth width, this is because the reflection process seems to be 2 antennas, so that there is an additional frequency response at the same frequency. close to the main frequency, and makes the bandwidth wide, and as needed and limits the value of reflection coefficient for both the 1.03 GHZ and 1.09 GHz frequencies. The desired bandwidth limit is below s11 -13,979 dB or below VSWR 1.5, from the range 1.00843 - 1.136592 GHz, at 128.162 MHz. For the 1.03 GHz Frequency Gain it is 14.44 dBi and for the 1.09 GHz Frequency it is 14.52 on one module which consists of 8 antennas.

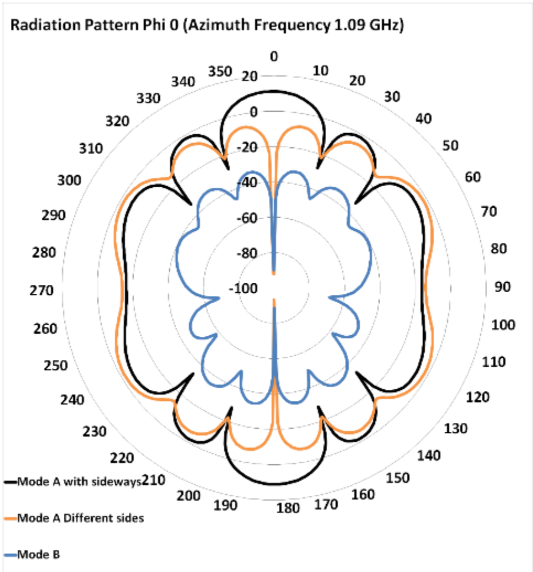


(a)

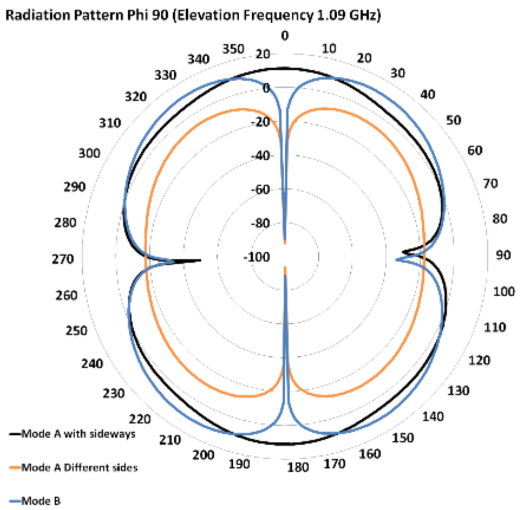


(b)

Fig. 15. Without reflector radiation pattern comparison Frequency 1.03 GHz, (a) θ = 0˚, (b) θ = 90˚.

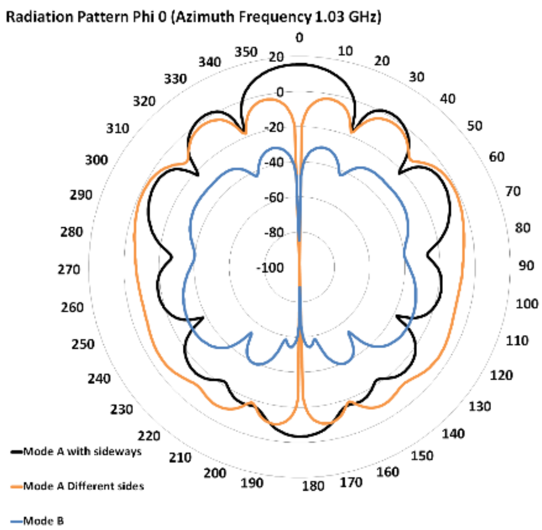


(a)

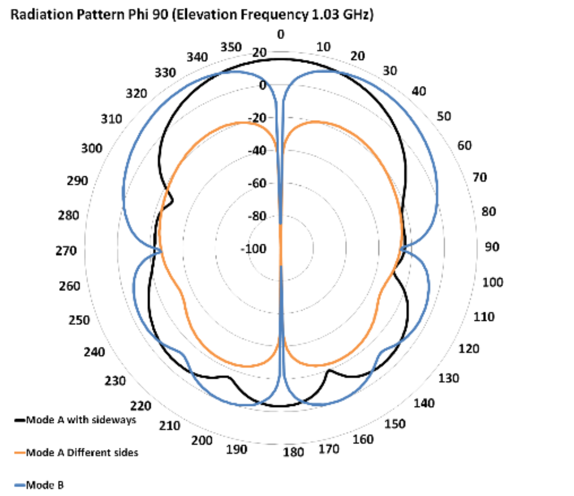


(b)

Fig. 16. Without reflector radiation pattern comparison frequency 1.09 GHz without reflector, (a) θ = 0˚, (b) θ = 90˚.

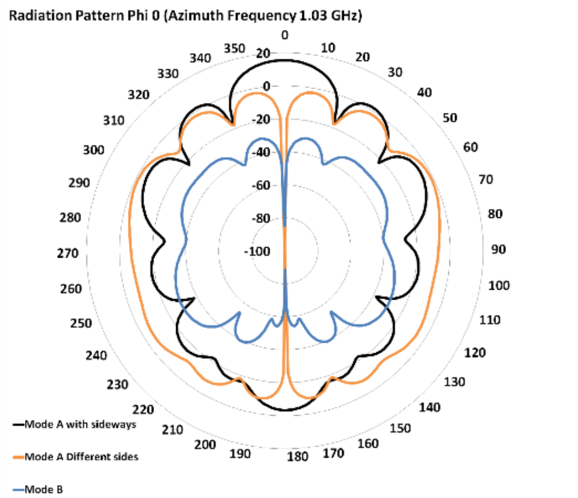


(a)

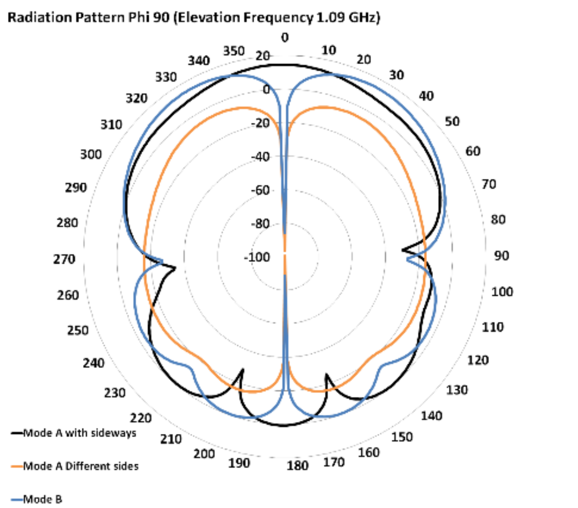


(b)

Fig. 17. With reflector radiation pattern comparison frequency 1.03 GHz, (a) θ = 0˚, (b) θ = 90˚.



(a)

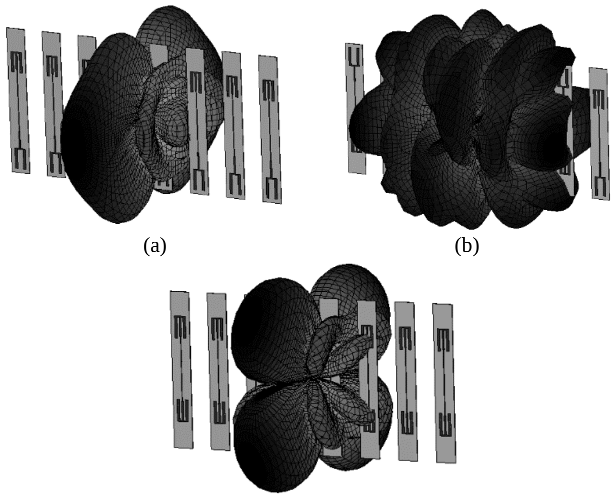


(b)

Fig. 18. With reflector radiation pattern comparison frequency 1.09 GHz, (a) θ = 0˚, (b) θ = 90˚.

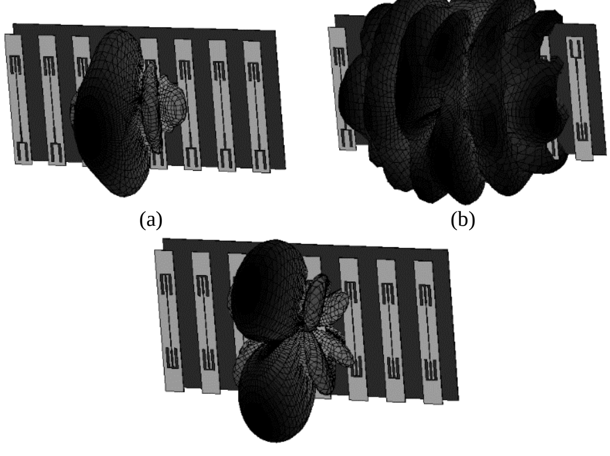
Fig. 15 is a comparison of 3 modes of radiation pattern or 2D direction diagram of an antenna array of 8 units without a reflector at a working frequency of 1.03 GHz where the radiation pattern 3D can be seen in Fig. 19. In the other hand Fig. 16 is the results of a radiation pattern/direction diagram at a frequency of 1.09 GHz, (a) is the angle ϴ = 0° or azimuth , and (b) ϴ = 90° or elevation for both the 1.03 and 1.09 GHz frequencies, the shape of the radiation pattern does not change much, both A sideways mode, A different ways Mode And Mode B. which differ significantly are each of these modes. The radiation pattern from the antenna array Mode A sideways produces a unidirectional radiation pattern at a certain angle, but if a reflector is not added, it will produce 2 opposite directions, Fig. 19(a). For the antenna array Mode A different side ways, the radiation pattern is broken into many angles, this is because the array antenna array is not uniformly continuous, but on different sides or on different poles, so that the multiplication diagram produced between each single antenna becomes messy and lumps together. Each direction from a different angle. Can be seen in Fig. 19(b). whereas for the antenna array Mode B, the antenna array per layer is symmetrical with different polar directions, but the direction of the arm is inward, so that the electromagnetic wave loop goes to the supply source, while the layer 2, or bottom layer, the arm goes to the side of the antenna , so that the movement of electromagnetic waves goes to the outside or the outside of the antenna, so that if there is a process of multiplication diagrams, the direction diagram becomes 2 poles per side of the screen, or is called directional I, this can be observed in Fig. 19(c). of the three antenna array models that were carried out by research and then developed using a reflector, with the aim of reversing the direction of the radiation pattern on one side or corner to be towards the main aperture of the antenna. In the research on observing the array diagram on the antenna, the most ideal Mode A is modified using a reflector, with the results of a 2D radiation pattern which can be seen in Fig. 17 for a frequency of 1.03 GHz, and Fig. 18 for a frequency of 1.09 GHz.

Fig. 20 is the result of a 3D radiation pattern using or adding a reflector to an antenna array of 8 antenna units, we call it 1 antenna module. In the figure it can be seen, the results for the A Mode Antenna in Fig. 20(a) sideways show the most optimum results, with a unidirectional radiation pattern towards the front of the antenna aperture cross section, while the other 2 modes cannot be used as utilization for SSR applications [7]. With a gain value of 1 antenna module at a frequency of 1.03 GHz of 14.44 dBi, and for a frequency of 1.09 GHz 14.52 dBi. For other parameters obtained, can be observed in Table V. The next process is to unite the antenna modules into a series of antenna arrays or arranged horizontally. In this study, the optimum number of modules obtained was 14 antenna array modules. For an overview of the SSR antenna as a whole, it can be seen in Fig. 21, with a length of 11.17 meters. In this study, the standard for antenna length is based on the azimuth angle, which is expected to be at least 1 degree. The concern is the resolution of the antenna catch, if the resulting angle is below 1 degree, then the angle accuracy will be more accurate [8]. Antennas that have been arranged as many as 14 modules will be placed above the SSR radar pedestal, as a function of the integrator and transponder of the SSR system. For an overview of the placement of the antenna can be seen in Fig. 22. For the height of the tower, adjusted to the needs of the detection area.



(a) (b) (c)

Fig. 19. Array 8 polarization without reflector, (a) Mode A with sideways, (b) Mode A different sides, (c) Mode B.



(a) (b) (c)

Fig. 20. Polaradiasi array 8 with reflector, (a) Mode A with sideways, (b) Mode A different sides, (c) Mode B.

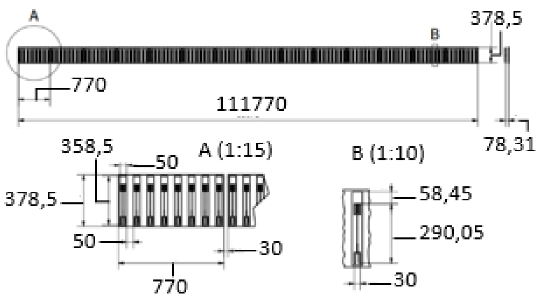


Fig. 21. SSR antenna final dimensions for 1.03 GHz and 1.09 GHz frequencies.

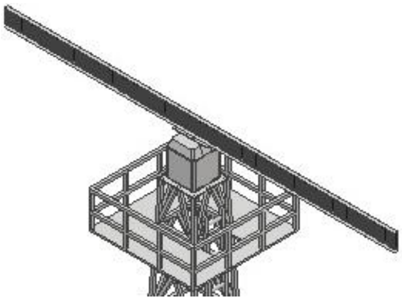


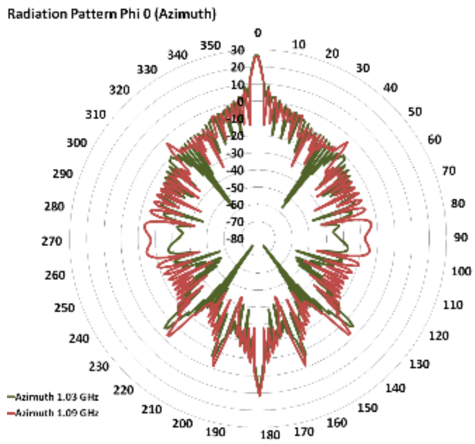
Fig. 22. Placement of the SSR antenna that has been made is placed on the tower.

To see the results of the final array antenna arrangement, it can be seen in Table VI, where the optimum parameter values obtained are close to the desired main specs according to SSR applications, both for 1.03 GHz and 1.09 GHz frequencies, for integrator and transponder applications. The bandwidth that is obtained is 128,162 MHz. What is crucial in this antenna design is the addition of the gain and also the azimuth angle that is obtained, because in the requirements of an SSR antenna, the antenna design must be a fan beam, which forms a fan-like shape that rises vertically, while thin in the horizontal section. The gain obtained in the final antenna is 26.52 dBi at a frequency of 1.03 GHz and 25.6 dBi at a frequency of 1.09 GHz. In terms of system requirements, a minimum gain value of 25 dBi, or 316 x the gain generated from an antenna. The azimuth beam obtained is 0.9° for the 1.03 GHz frequency and 0.8° for the 1.09 GHz frequency, with a side lobe level (SLL) of –17.9 dB for the 1.03 GHz frequency and –13.9 dB for the 1.09 GHz frequency. In the design of the system, it is expected that the minimum SLL value is –13 dB, or what usually occurs in uniform distribution arrangement type antennas. Whereas in this study, the Azimuth SLL is even lower than the standard required, which means it is better, then for the elevation section of the antenna it produces a beam of 41 degrees at a frequency of 1.03 GHz, and 39 at a frequency of 1.09 GHz, with an SLL in the elevation plane of = 18.8 dB for frequencies 1.03 and –13.9 dB. Just like the azimuth, the SLL that is produced is also in excess of what is needed, which means it is already good. Why is the SLL needed to be smaller than –13 dB, this is because, the smaller the SLL, the farther the distance between the main beam or main lobe and the side lobe, the farther this will avoid detection errors which are caused by the detection not coming from the main lobe, but from side lobes. If the SLL distance is large, it means that the side lobe is almost the same, maybe even bigger than the main lobe, and results in ambiguity in target detection.

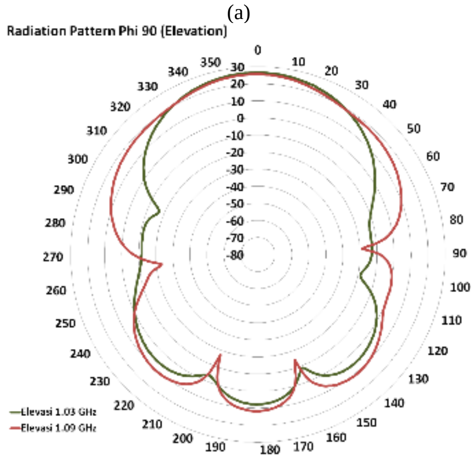
For the direction chart graph that has been outlined in Table VI and the characteristic results have been explained, in terms of the graph it can be seen in Fig. 23, for part (a) is an azimuth graph, and (b) an elevation graph. The green line is a frequency graph of 1.03 Hz, the red graph is a frequency of 1.09 GHz. In other words, the results of this research demonstrate significantly better performance in terms of gain, which is the primary parameter for evaluating antenna design quality when compared to previous research findings [9–11]. The proposed antenna design demonstrates its superiority by achieving optimal performance in the dipole collinear array configuration. The most advantageous arrangement is the lateral positioning of antennas, resulting in an optimized radiation pattern. This configuration, when combined with a reflector on the rear layer, enhances the antenna's unidirectional radiation pattern towards the front [12–13].

TABLE VI. RESULTS OF PARAMETER OPTIMIZATION OF ARRAY ANTENNA FOR SSR

Parameter	**Frequency**	
	1.03 GHz	**1.09 GHz**
s11 (dB)	–15.53061	–20.73117
VSWR	1.4018	1.2025
Z (Ω)	46.6+J358.3	61.05+J341.7
Bandwidth (MHz)	128.162	
Frequency range s11-13.979 dB (GHz)	1.00843–1.136592	
Gain (dBi)	26.52	25.6
Azimuth	0.9°	0.8°
SLL Azimuth (dB)	–17.9	–13.9
Elevation	41°	39°
SLL Elevation (dB)	–18.8	–13.9



(a)



(b)

Fig. 23. Final azimuth radiation pattern comparison Frequency 1.03 GHz and 1.09 GHz, (a) θ = 0˚, (b) θ = 90˚.

VI. CONCLUSION

From the designed antenna, it can be concluded that the most optimal antenna arrangement in this dipole collinear array technique is a sideways antenna arrangement, where the optimum radiation pattern is obtained in this mode, with the addition of a reflector on the back layer, so that the radiation pattern becomes unidirectional towards the front of the antenna section. Both the 1.03 GHz and 1.09 GHz frequencies gain 26.52 dBi and 25.6 dBi, with azimuth angles of 0.9^{o} and 0.8^{o} and elevation angles of 41^{o} and 39^{o}, where the SLL value is below –13 dB.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Y.P.S, M.K, D.P, and A.H designed the study. Y.P.S and M.K performed the experiment and simulation. M.K and A.H analysed the data and verified the result of simulation. Y.P.S and D.P drafted the manuscript and wrote the manuscript with input from all authors.

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