

Design and simulation of low side lobe micro-strip array antenna at multiple frequencies

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Submitted: 17-09-2020

Revised: 27-05-2021

Accepted: 27-06-2021

ABSTRACT

In this paper, we present a simple design of a feed network for the antenna to achieve a lower side lobe level. Side Lobe Levels (SLL) are critical issues in the detection of an object. Higher side lobe levels can increase the false detection of objects in an autonomous vehicle system. The array is designed and simulated for four different frequencies, one at a time to make it a scalable design. The chosen frequencies are 10 GHz, 15 GHz, 20 GHz, and 24 GHz. The feed network design consists of eight patch elements with an equal power divider and CST studio software is used for simulations. From simulation results, it can be observed that VSWR is equal to 1.26, 1.16, 1.62, and 1.05 at respective frequencies. So, the radiation efficiency can be achieved as -1.14 dB, -0.92 dB, -0.46 dB, -0.41 dB. The results substantiate that proposed design can reduce the SLL more than -24.5 dB in the elevation plane and also it is greater than 14.4 dB at all the aforementioned frequencies.

Keywords: High gain; low side lobe; VSWR; CST; SLL.

INTRODUCTION

The facile fabrication, low profile, weight, and low-cost PCB manufacturing have made micro-strip patch antennas extremely significant antenna type of meeting many applications in the field of radar systems, aircraft, automotive applications, and others (Karimi & Maddahali, 2018). In autonomous vehicle (AV), the sensing module uses various sensor information (Radar, Lidar, and camera information), to indicate the obstacles on the path relevant to the driving scenario. Radar systems work in wideband frequencies from 300 MHz to 100GHz. The higher frequency in any radar system can be affected more by weather conditions such as rain or clouds. However, the higher the transmitted frequency, the better is the accuracy of the radar system (Rabbani & Ghafouri-Shiraz, 2017). In fact the most important thing is the matching the impedances of micro-strip patches which has been improved by using different unique matching networks (Anandkumar & Sangeetha, 2020; Rajeswari & Anbalagan, 2020; Sohail et al., 2018).

A large wideband array, containing twelve radiating elements with double-layer substrate integrated waveguide is presented in (Wang et al., 2018). Different kinds of power divider with unequal T-junction have been reviewed in (Ahn & Tentzeris, 2019; J. Ji et al., 2020; Quan et al., 2021) Taylor distribution is used for reducing the side lobe level, and achieve side lobe level of 23.9 dB in the E-plane and 20.5 dB in the H-plane at the center frequency. In (Liu et al., 2015), an array is presented to enhance the gain for millimeter-wave applications; the array evaluates the substrate height

for gain enhancement. The paper shows that a long feeding line can increase the loss, and thick substrate degrades the antenna gain. On the other hand, a relatively thin substrate can enhance the gain, but narrower bandwidth and higher side lobe levels are also introduced in the array antenna. (Oborzhytskyy & Prudyus, 2016) states that side lobe level ratios are essential to reduce false indications of objects in radars, and autonomous applications. So much research is being carried out on minimizing the side lobe levels. Many researchers such as (Gasztold, 2014) have proposed different solutions to eliminate the problems caused by SLL. Power divider feed networks have been mostly used for minimizing the side lobes levels. Various types of power dividers proposed with unequal and equal T-junction feed networks have been designed and reviewed in (Park et al., 2016).

In this paper, a patch array antenna is created and simulated for different frequencies, patch antenna constructed with a couple of slots near the radiating edges. After creating a patch, a uniform power divider is created for equal power distribution in the feed network. The detailed construction and mathematical expression are presented in the previous article (Jamshid et al., 2017). Here we modify the array to make it scalable for different frequencies. The array is simulated at four different frequencies, one by one, to make it a scalable design. The frequencies of 10 GHz, 15 GHz, 20 GHz, and 24 GHz are selected for simulation. The simulation shows that simulated VSWR we can calculate is almost equal to 1.26, 1.16, 1.62, and 1.05, and the radiation efficiency is equal to -1.14 dB, -0.92 dB, -0.46 dB, -0.41 dB at selected frequencies. Also, the SLL achieved is more than -24 dB

The remainder of the paper is organized as follows: Proposed array design is elaborated in the section 2. Section 3 demonstrates the simulation results at different scenarios of multiple frequencies. Finally, the conclusion along with the future work is drawn in section 4.

RELATED WORK

(Smolders & Visser, 2014) present a novel method for low side lobe and control of axial ratio of circularly-polarized (CP) phased array antennas. A novel random sequential rotation (RSR) provides the properties likely as randomly-spaced array antennas. Wider band is achieved, without the creation of grating lobes. In contrast, antenna gain improved using a uniform amplitude distribution. In fact, the interspacing of element is much higher than $\lambda/2$ but it well-controlled side lobes. In the diagonal-plane the measured cross-polarization level is down below -20db at a 20o scan angle.

(Yang et al., 2019) proposed a hybrid technique for 3D pattern synthesizing of antenna to achieve the low side-lobe level for truncated-cone arrays. For this technique, truncated-cone conformal phased arrays units were projected at a tangent plane of the cone. At that time, a 2 D optimization of Chebyshev amplitude distribution was used in 2 different direction of the tangent plane. In keeping with mind the position of the units, the amplitude of excitation current for every unit over the conformal design is originated reversely, after that the amplitude of excitation current is furtherly optimize by employing the genetic algorithm (GA). A study of side lobe level of 35 dB and 3-dimensional pattern is done by using this truncated cone with 8 by 8 units over it.

(P. Ji et al., 2020) presented an array of micro strip for 24 GHz frequency, with a single layer of substrate of electrically thin width to provide a solution regarding cost, enhanced impedance bandwidth etc. for automotive application. a prototype of array construct for a predefined side lobe level - 25 dB in E & H-plane. In contrast, the realized gain = 22.5 dBi, for central frequency and although more than -21 dBi for a 1Ghz band of frequency. At the end, the resultant side lobe in E plane is 20 dB and 18 dB for H-plane. (Shin et al., 2013) proposed a novel array antenna design for low side lobe. It is having a number of 18 elements, with gap coupled antenna to achieve a low radiation coefficient and is used for high radiation coefficient. Polarization of 450 is used to reduce the interference. The antenna has 20.8dBi gain and side lobe level of elevation direction is under -20dB.

PROPOSED ARRAY DESIGN

Construction of patch design, feed network design, and all related mathematical expression is describing in the previous article (Jamshid et al., 2017), some of them presented here. That paper also shows that SLL can be lower with increasing patch elements from four elements to eight elements.

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

$$\epsilon_{eff} = \frac{(\epsilon_r + 1)}{2} + \frac{(\epsilon_r - 1)}{2} \left[\frac{1}{\sqrt{1 + \frac{12h}{w}}} \right] \tag{2}$$

$$L = \frac{c}{2f_0 \sqrt{\epsilon_{eff}}} - 0.824h \frac{(\epsilon_{eff} + 3) \left(\frac{W}{h} + 0.264 \right)}{(\epsilon_{eff} - 0.258) \left(\frac{W}{h} + 0.8 \right)} \tag{3}$$

$$Z_0 = \frac{90(\epsilon_r^2 - 1)}{\epsilon_r \left(\frac{L}{W} \right)^2} \tag{4}$$

$$Z_{inr} = Z_0 \cos \left(\pi * \frac{R}{L} \right)^2 \tag{5}$$

Where W = patch width, f_o = operating frequency, L = patch length, h = substrate height or thickness, c = velocity of free space, Z_o = impedance with no inset-fed, Z_{inr} = impedance of inset-fed, and ϵ_{eff} = effective di-electric constant.

Now, this paper concentrates upon modification into the design to tune it at different frequencies. Initially, 24GHz is the operating frequency for autonomous vehicles radars. The only objective of choosing these frequencies is to check the scalability of the proposed antenna design. Here scalability means, this design can be modified and tuned at a range from 10 – 24 GHz as desired. We should recalculate the parameter's dimensions for the desired frequency. As we know from the literature, the operating frequency of a patch antenna depends upon the patch antenna length. Hence, the dimension of the presented array antenna for different frequencies is listed down in Table 1.

Table 1. Component list with measurements

Detail of components	Symb ol used	Value (mm)			
		1 0GHz	1 5GHz	2 0GHz	2 4GHz
Length of line	L1	.05	.73	.92	.45
Width of line	WL1	.20	.20	.20	.20

Length of slot1	LS1	.4	8	.1	5	.8	3	.0	3
Length of slot2	LS2	.3	2	.7	1	.1	1	.70	0
Length of inset-fed	Li	.3	2	.1	2	.6	1	.25	1
Width of slot1	WS1	.6	0	.45	0	.32	0	.20	0
Width of slot2	WS2	.0	1	.8	0	.65	0	.40	0
Width of inset-fed	Wi	.6	0	.6	0	.60	0	.60	0
Slot position	Ps	.6	0	.4	0	.25	0	.20	0
Length of patch	LP	.5	9	.1	6	.6	4	.84	3
Width of patch	WP	5	1	0	1		8	.6	6

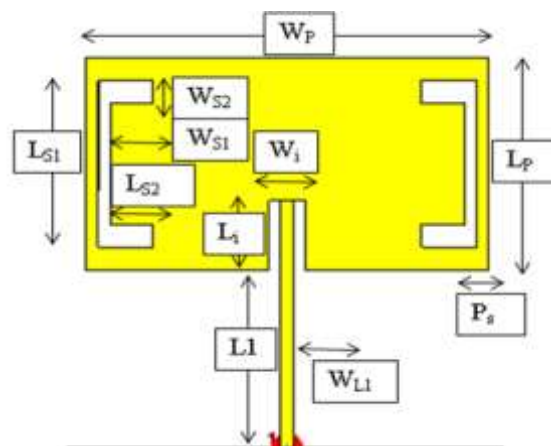


Fig 1. Proposed Inset-Fed Slotted Patch

Figure 1 shows the proposed patch antenna with the proper naming scheme. The length of line1 is a quarter wavelength transformer used to match the impedances. The length of slot 1 depends upon the patch length. It has approximately the difference of 0.80 to 0.90 from the length of the patch. The length of slot 2 is also approximately 0.70 to 0.85 times the width of the patch. Several iterations performed to achieve the best value, which is listed in the below table. Also, it is confirmed from the research articles that the input impedance decreases rapidly when the inset-fed is

moved toward the center. These parametric studies have been used to derive the formula to find the exact inset length (IL) to achieve 50-ohm input impedance for the commonly used thin dielectric substrate.

$$IL = \frac{0.001699\varepsilon^7 + 0.13761\varepsilon^6 - 6.1783\varepsilon^5 + 93.187\varepsilon^4 - 682.69\varepsilon^3 + 2561.9\varepsilon^2 - 4043\varepsilon + 6697}{2} \quad (2 \leq \varepsilon \leq 10) \quad (6)$$

The width of the inset is equally divided between the width of the inset line and the spacing form patch. Taylor synthesis (Li et al., 2017), one of the most appropriate techniques to reduce the side lobe level of the array. From Table 2 weighted values, we simulate the proposed antenna to verify the reduction in side lobe levels. We observe that best-weighted values are in case 1, which lower side lobe level more than -24.5 dB We apply the same Taylor weight values for all frequencies in the next section. The calculation of Taylor's weight function shown below.

$$f(\xi) = 1 + 2 \sum_{m=1}^{\bar{n}-1} g\left(m, A, \bar{n}\right) \cos m \xi \quad (7)$$

$$g\left(m, A, \bar{n}\right) = \frac{\left[\left(\bar{n}-1\right)!\right]^2}{(\bar{n}-1+m)!(\bar{n}-1-m)!} \prod_{k=1}^{\bar{n}-1} \left(1 - \frac{m^2}{\sigma^2 \left[A^2 + \left(k - \frac{1}{2}\right)^2\right]}\right) \quad (8)$$

$$A = \frac{1}{\pi} \operatorname{arch} \eta \quad (9)$$

$$\sigma = \frac{\bar{n}}{\left(A^2 + \left(\bar{n} - \frac{1}{2}\right)^2\right)^{\frac{1}{2}}} \quad (10)$$

Where A is the ratio of the main beam to SLL, \bar{n} is the number of Taylor weight. Generally, for Taylor distribution, \bar{n} is set to 4 to maintain the side lobe level between -20 to -30 dB.

Table 2. Weighted values for 1x8 array

Case No	Weight width (mm)					Side lobe level (dB)
	1 & w8	w & w7	w2 & w6	w3 & w4	w5	
1	2	1.	0.75	0.4	0.2	-24.5 dB

2	4	1.	1	0.6	0.2	-22 dB
3	1		0.6	0.4	0.2	-23 dB

SIMULATION AND RESULTS

At 10GHz

From Figure 2, we notice that the proposed array antenna is tuned at frequency 10GHz, and the reflected power loss is almost equal to -18.76 dB. We also find the reflection coefficient $\Gamma=0.11$ and VSWR = 1.26 from this figure.

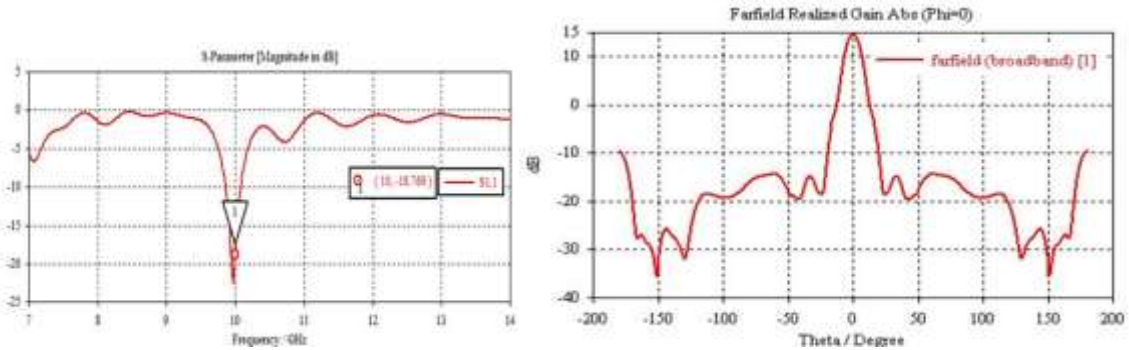


Figure 2 Proposed Antenna Frequency Response at 10 GHz **Figure 3** Side Lobe Levels 10 GHz

Simulation results also exhibit the amount of power accepted and radiated of the array antenna. The amount of power accepted by antenna array is -3.0 dB, which is 0.49w in linear-scale, also power radiated by the antenna is -4.2 dB (0.37w in linear scale). In Figure 3, the frequency is set to 10 GHz, Main Lob Magnitude = 14.6 dB, main lobe direction=0.06 deg, angular width (3 dB) = 10.7 deg, side lobe level=-24.2 dB. Furthermore, Figure 3 shows the Cartesian representation of the radiation pattern and exhibits some information about side lobe level, tuning frequency, main lobe magnitude, and direction. We observe that a side lobe level of -24.2 dB is achieved with a gain of 14.6 dB.

Figure 4 shows the graphical result of radiated efficiency and total efficiency at frequency 10GHz. The radiated efficiency of this array is -1.14 dB (76%) and total efficiency is -1.2 dB (75%). Figure 5 is the 3D radiation pattern plot of array antenna, and from this result, we also see the realized gain, which is 14.9 dB at 10 GHz frequency.

Il simulation results are shown that the presented array antenna shows a good radiation pattern along with the efficiencies, powers, and gain, which are the critical features of any antenna. These parameters will justify the effectiveness of antenna in practical usage. In the next section, we perform simulation at 15 GHz and check all these parameters to verify the scalability of the design.

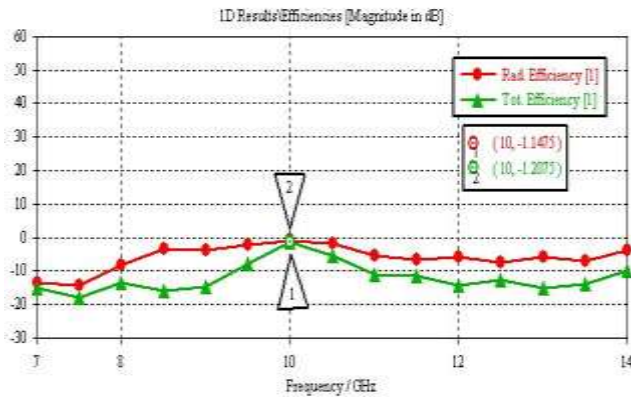


Fig 3. Efficiencies of Proposed Antenna Array

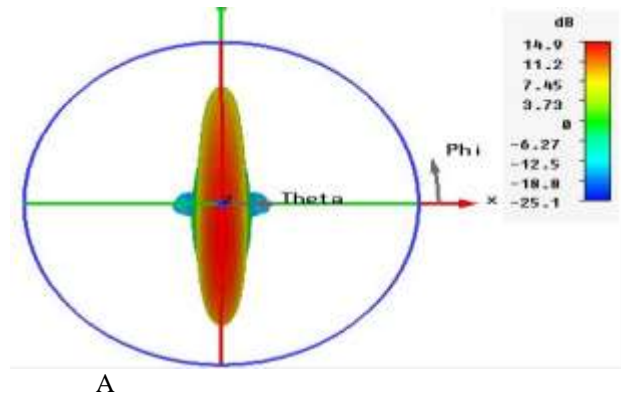


Fig 4. Proposed Antenna Array Radiation Pattern

At 15GHz

From Figure 6 we notice that the proposed array antenna is tuned at frequency 15GHz, and the reflected power loss is almost equal to -22.5dB. We also find the reflection coefficient $\Gamma=0.074$ in linear scale and $VSWR = 1.16$ from this figure.

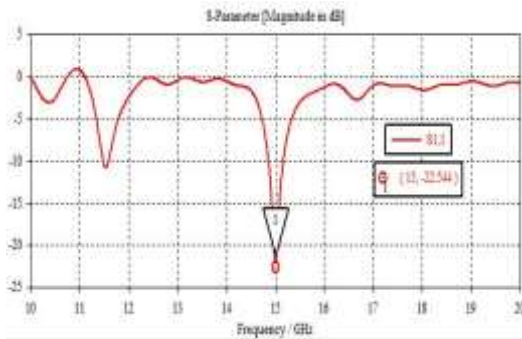


Fig 5. Frequency Response at 15 GHz

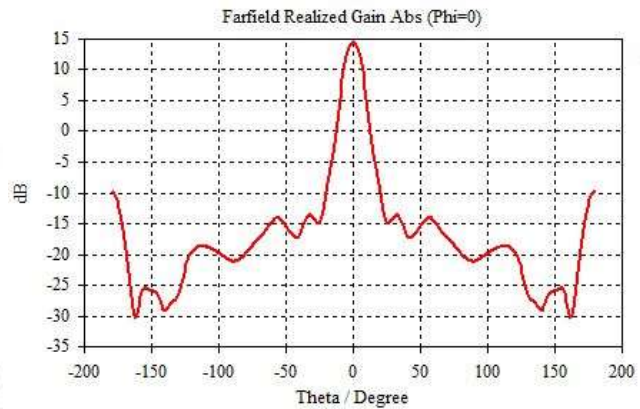


Fig 6. Side Lobe Levels at 15 GHz

From simulation results, we also measure power accepted and power radiated of the array antenna. The amount of power accepted by antenna array is -3.0 dB, which is 0.49w in linear-scale, also power radiated by the antenna is -3.9 dB (0.40w in linear scale). In Figure 7, the frequency is set to 15 GHz, Main Lob Magnitude = 14.4 dB, main lobe direction=0.0 deg, angular width (3 dB) = 11.5 deg, side lobe level=-24.3 dB. Furthermore, Figure 7 is the Cartesian representation of the radiation pattern and exhibits some information about side lobe level, tuning frequency, main lobe magnitude, and direction. We observe that a side lobe level of -24.3 dB is achieved with a gain of 14.4 dB.

Figure 8 shows the plot of radiated efficiency and total efficiency of the antenna array at frequency 15GHz. The radiated efficiency of this array is -0.92 dB (80.8%) and total efficiency is -0.94 dB (80.3%).

Figure 9 is the 3D radiation pattern plot of the array antenna, and from this result, we also see the realized gain, which is 14.4 dB at a frequency of 15 GHz.

All simulation results shown previously proves that the presented array antenna shows a good radiation pattern, as well as the efficiencies, powers, and gain, which is also acceptable, which is the critical feature of any antenna. These simulation results will justify the effectiveness of the design. Now we modify the design to operate at 20 GHz.

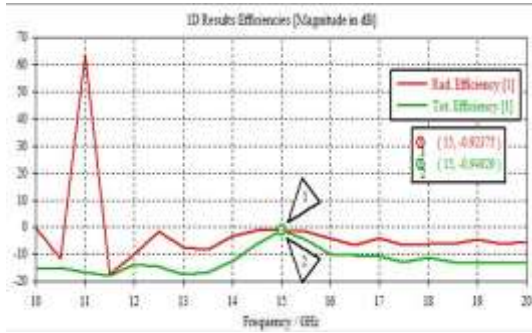


Fig 7. Efficiencies of Antenna Array

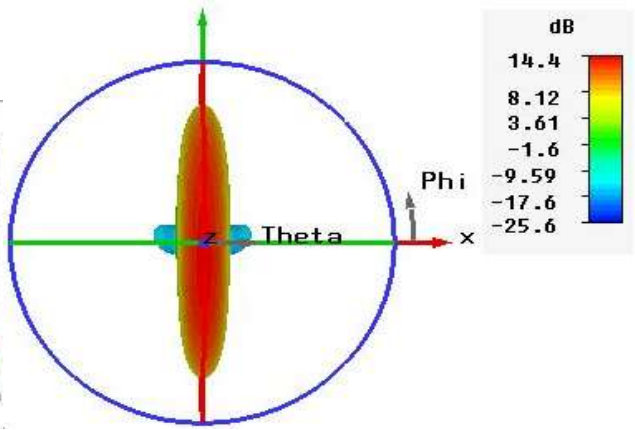


Fig 8. Proposed Antenna Array Radiation Pattern

At 20GHz

From Figure 10, we notice that the proposed array antenna is tuned at frequency 20GHz, and the reflected power loss is almost equal to -14.77 dB. We also find the reflection coefficient $\Gamma=0.18$ in linear scale and VSWR = 1.4.

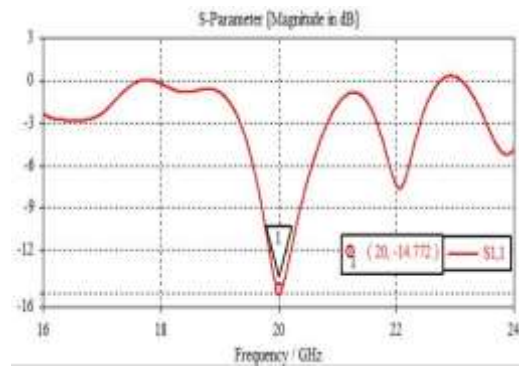


Fig 9. Frequency Response at 20 GHz

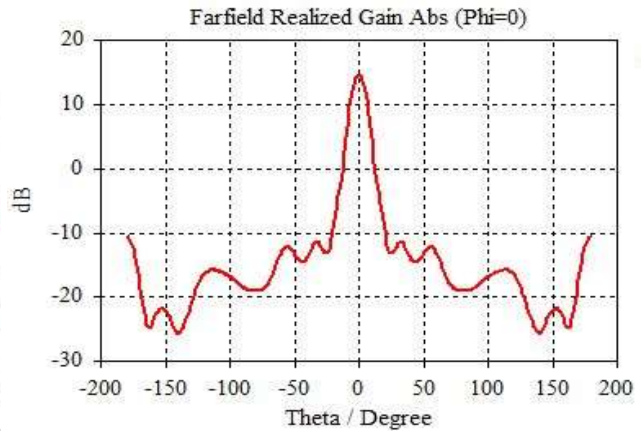


Fig 10. Side Lobe Levels at 20 GHz

From simulation results, we also measure power accepted and power radiated of the array antenna. The amount of power accepted by antenna array is -3.16 dB, which is 0.48w in linear-scale, also power radiated by the antenna is -3.8 dB (0.41w in linear scale). In Figure 11, the frequency is set to 20 GHz, Main Lob Magnitude = 14.5 dB, main lobe direction=0.0 deg, angular width (3 dB) = 11.1 deg, side lobe level=-25.1 dB. Furthermore, Figure 11 is the Cartesian representation of the radiation pattern and exhibits some information about side lobe level, tuning frequency, main lobe magnitude, and direction. We observe that a side lobe level of -25.1 dB is achieved with a gain of 14.5 dB.

Figure 12 shows the plot of radiated efficiency and the total efficiency of the antenna array at 15 GHz

frequency. The radiated efficiency of this array is -0.64 dB (86%), and total efficiency is -0.79 dB (83%). Figure 13 is the 3D radiation pattern plot of the array antenna, and from this result, we find the realized gain, which is 14.4 dB at a frequency of 20 GHz.

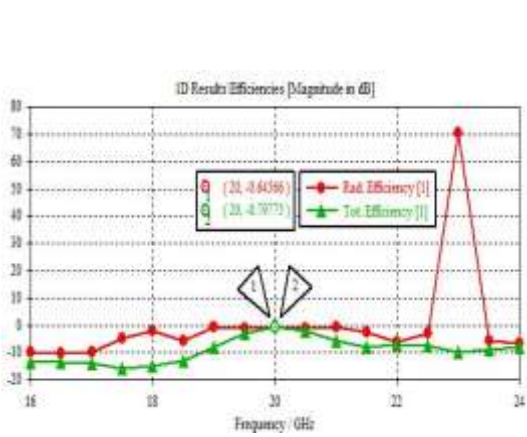


Fig 11. Efficiencies of Antenna Array

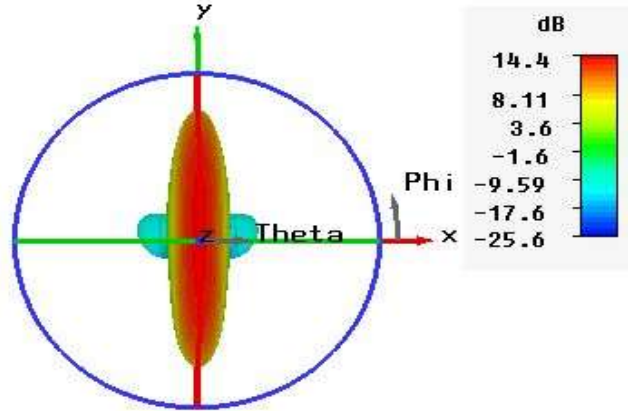


Fig 12. Proposed Antenna Array Radiation Pattern

Similarly, the simulation results prove that the presented array antenna shows a good radiation pattern, efficiencies, powers, and gain, which are the fundamental parameters of any antenna. Now we modify the design to operate at 24 GHz.

At 24GHz

From Figure 14, we notice that the proposed array antenna is tuned at frequency 24GHz, and the reflected power loss is almost equal to -30.9 dB. We also find the reflection coefficient $\Gamma=0.028$ in linear scale and VSWR = 1.05 from this figure.

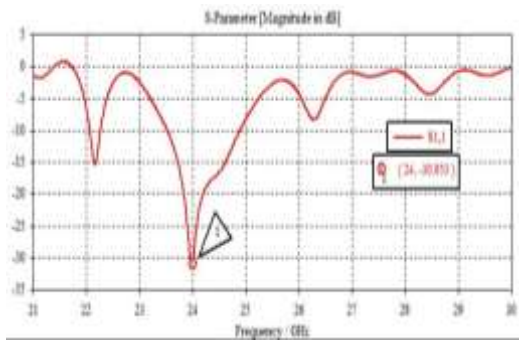


Fig 13. Frequency Response at 24 GHz

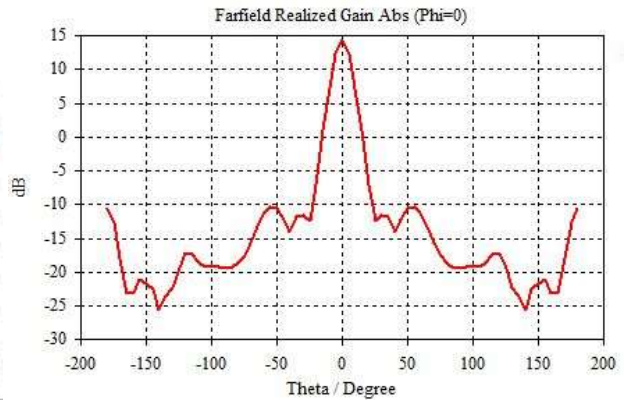


Fig 14. Side Lobe Levels at 24 GHz

Simulation results also exhibit the amount of power accepted and radiated of the array antenna. The amount of power accepted by antenna array is -3.0 dB, which is 0.49w in linear-scale, also power radiated by the antenna is -3.4 dB (0.44w in linear scale). In Figure 15, the frequency is set to 24 GHz, Main Lob Magnitude = 14.4 dB, main lobe direction=0.0 deg, angular width (3 dB) = 11.9 deg, side lobe level=-24.7 dB. Furthermore, Figure 15 is the Cartesian representation of the radiation pattern and exhibits some information about side lobe level, tuning frequency, main lobe

magnitude, and direction. We observe that a side lobe level of -24.7 dB is achieved.

Figure 16 shows the plot of radiated efficiency and total efficiency of antenna array at frequency 15GHz. The radiated efficiency of this array is -0.41 dB (90%), and total efficiency is -0.48 dB (89%).

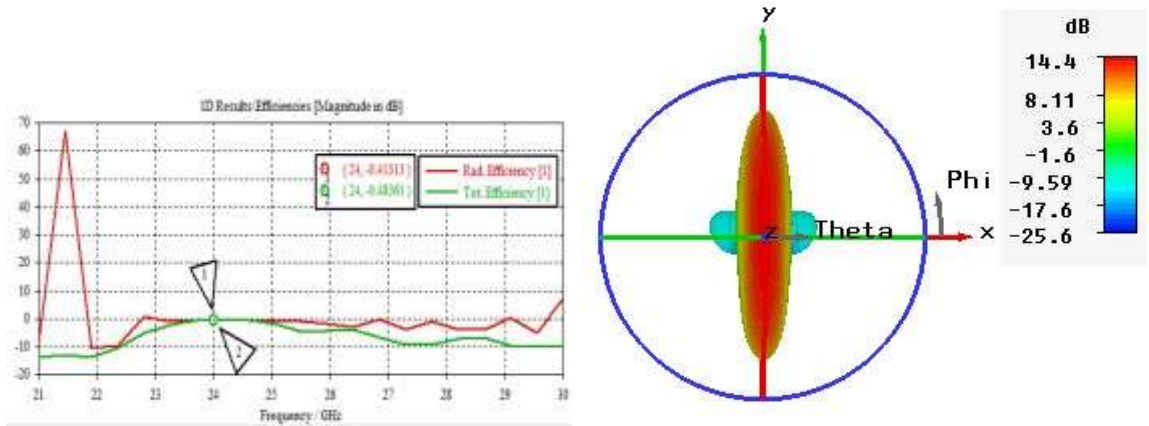


Fig 15. Efficiencies of Antenna Array

Fig 16. Proposed Antenna Array Radiation Pattern

Figure 17 is the 3D radiation pattern of the array antenna, and from this result, we find the realized gain, which is 14.4 dB at a frequency of 24 GHz.

All simulation results are showing that the presented array antenna shows a good radiation pattern along with the efficiencies, powers, and gain, which are the critical parameters of any antenna. These parameters will justify the effectiveness of the antenna. All the above results and parameters are summarized in Table 3 for easy understanding.

Table 3. TABULATED SIMULATION RESULTS

Parameters	10GHz	15GHz	20GHz	24GHz
Reflected Power Loss	-18.76 dB	-22.5 dB	-14.77 dB	-30.9 dB
Reflection Coefficient	0.11	0.074	0.18	0.028
VSWR	1.26	1.16	1.4	1.05
Power Accepted	490mw	490mw	480mw	490mw
Power Radiated	370mw	400mw	410mw	440mw
Radiated Efficiency	76%	80.8%	86%	90%

Realized Gain	14.9 dB	14.4 dB	14.4 dB	14.4 dB
Side lobe level	-24.2 dB	-24.3 dB	-25.1 dB	-24.7 dB

In Table 4, we present a comparison of proposed feed network SLL to the recently proposed design. Different techniques are proposed in these researches as discussed in introduction, with number of antenna elements used for reduction of side lobe. The proposed patch antenna and feed network gives better results by using four elements with simple power divider and weight.

Table 4. comparison table

Methodology	Operating frequency (GHz)	Array elements	Side lobe level
(Smolders & Visser, 2014)	3.5 – 4.5	4x4	≤ -12.3 dB
		8x8	≤ -17.8 dB
		16x16	≤ -23.4 dB
		32x32	≤ -29.5 dB
(Yang et al., 2019)	24	8x8 planner array antenna	≤ -21 dB in both planes
(P. Ji et al., 2020)	24	8x8 planner array antenna	E-plane ≤ -20 dB H-plane ≤ -18 dB
(Shin et al., 2013)	28	1x8 element	Azimuth plane ≤ -20 dB
Proposed Method	Multiple frequencies (10, 15, 20, 24)	1x8 element	≤ -24.2 dB ≤ -24.3 dB ≤ -25.1 dB ≤ -24.7 dB

CONCLUSIONS

This unique and simple array antenna was created and simulated for four different frequencies. Patch antenna and an equal power divider are designed to make it is a cost-effective solution in the field of automotive application. A

couple of slots in scratch near the edges of the patch and then creating a uniform power divider to distribute power in the feed network equally. To further verify simulation results, an array is simulated at four different frequencies, selected one by one to make it is a scalable design. The SLL achieved is more than -24.5 dB at all frequencies in the elevation plane, which is important to minimize false target indication in radars. The results also show that simulated VSWR is equal to 1.26, 1.16, 1.62, and 1.05 and the radiation efficiency is equal to -1.14 dB, -0.92 dB, -0.46 dB, -0.41 dB at selected frequencies. All simulation results show that the proposed array antenna has a good radiation pattern at all selected frequencies along with the radiated efficiency, radiated power, and gain, which are the fundamental parameters of any antenna. These simulations will justify the effectiveness and scalability of the design. This design can be enhanced to suppress the side lobe level as per requirement. Due to its compact and feasible size, it can be used as a radar antenna in autonomous vehicle technology.

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