Design of a 2*2 Microstrip Phased Array Antenna for Radar Applications

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Abstract: - Micro-strips patch antennae used in array configurations are more beneficial than single antenna element by augmenting the directivity (dB) radiation pattern, and lowering the substrate's permittivity to overcome its drawbacks, which include poor gain, low efficiency, narrow bandwidth limited directivity. It also facilitates beam-steering capability which is obtained by enabling phase difference(β) between the antennas. Beam scanning capability is used in radar and GNSS technologies. This paper proposes a 2*2 microstrip phased array antenna by using rectangular microstrip patch antenna on an FR-4 dielectric substrate for beam scanning. The resonant frequency of the antenna is at 2.52GHz frequency with a good Voltage Standing Wave Ratio (VSWR) value of 1.1325. The design has been simulated in Ansys HFSS software. The simulation results exhibit antenna better performance of the proposed antenna compared to state-of-art designs present in the literature. The compactly designed Rectangular Micro-strip Patch Antenna array shows a low S-parameter (–24.127858 dB), high gain (13.689104 dB), directivity (14.055125 dB), and efficiency of 91.917%.

Key-words: - Phased Array Antenna, beam scanning, directivity, efficiency, gain, VSWR, S-Parameter.

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1 Introduction

Nowadays, wireless communication has become an increasingly prevalent mode of communication, replacing traditional wired technology. The antenna device, which makes it possible to send and receive wireless signals, is at the heart of wireless communication. Since its inception as a massive metallic device, antenna design has seen numerous evolutions, driven by the diverse spectrum of wireless communication applications. In recent years there has been substantial increase in the popularity of microstrip Patch Antennae, in particular, due to their obvious advantages over conventional designs in terms of compact form factor, mechanical resilience, low cost, low power consumption, and ease of manufacture, [1]. Satellite communication requires higher gain so a single patch antenna cannot be used. An array antenna has to be employed to achieve a certain gain. However, beam steering must also be considered which scans a wide range of angles. Nowadays, phased array microstrips are widely employed in radar and satellite communication since they provide higher gain, beam scanning, etc. The array antenna is designed the energy radiated in the major or main lobe (ML) is high the direction can be manipulated by adjusting the signal phase fed to the antenna, [2]. These phased antennas are designed to provide accurate landing for the airplanes, as they can transmit data at required angles.

In this paper, a microstrip phased array antenna that resonates at 2.52GHz is designed and discussed. A single inset-fed rectangular patch antenna is designed with various parameters observed, which is then evaluated and designed to develop the 2*2 array acquired to obtain a good return loss. The gain and radiation pattern have been examined for varying degrees at 15.84dBi.

2 Microstrip Patch Antenna

A Rectangular Micro-strip Patch Antenna has three distinct layers, as shown in Figure 1. It consists of conducting ground and patch layers below and above the substrate plane. Substrate (dielectric) with less ε_r (dielectric constant) must be selected to get good performance. The h_s (substrate thickness) should be as low as it rises the surface wave affecting the entire performance. There are numerous forms of patches namely rectangular, square, circular, and so on, [3]. For some design limitations, a rectangular patch performs better than circular one. Numerous feeding techniques are available to insert electromagnetic energy into the antenna. The microstrip patch supports a variety of new application sectors because of its unique qualities, including mobile communication, computer network systems, radar applications, global positioning systems, smart IoT devices, and so on, [4].

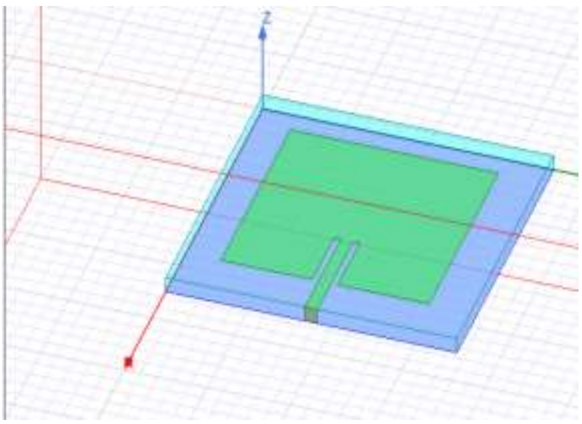


Fig. 1: Microstrip patch antenna

The major parameters namely VSWR, scattered parameter, and radiation pattern verifies the operation of an antenna. Energy transferred from source to load is measured using VSWR. A good antenna must have VSWR < 2, [5]. The radiation pattern is a graphical representation of the far field which has information about directivity, ML, and beam width. The input-output relation can be described using scattered parameters.

3 Phased Antenna Array and Beam Steering

An arrangement of multiple single antenna elements constitutes an array. The antenna element, amplitude and Ø (phase excitation) of each antenna and geometry of the array are the factors controlling radiation pattern. When the radiation pattern of eeveryantenna adds up with na earby antenna to derive a major beam, it is referred ato s phased antenna array, [6]. The final electric field (E_t) is given by, [7]:

$$E_t = E_{se} * AF \quad (1)$$

Where $E_{se}$the single antenna field strength antenna and AF the array factor can be written as:

$$AF = \frac{1}{N}\left[\frac{\sin\frac{N}{2}\varphi}{\sin\frac{1}{2}\varphi}\right] \quad (2)$$

Here, $\varphi = k_0 d \sin\theta + \beta$ where d is the distance between array elements and β is the phase difference. The directivity can be increased by either increasing N or d. The first maxima occurs at n=0,

$$0 = k_0 d \sin\theta + \beta \quad (3)$$

By changing β, beam steering can be referred as the manipulation of the direction of the ML without disturbing the antenna where β varies from $-k_0 d$ to $k_0 d$.

4 Literature Review

Even though numerous significant research projects have been carried out since its inception, the last few years have seen an increase in the popularity of this issue among researchers as a result of the publication of numerous unique designs. A small compact lightweight Rectangular Micro strip Patch Antenna (RMPA) has been presented in, [8]. The proposed antenna operates at a 2.45 GHz ISM band suitable for Wireless LAN applications. The design is simulated using CST Studio Suite 2015 software. The proposed single-element RMPA shows low return loss (RL) and gain of – 47.20 dB and 3.18 dB respectively.

In [9], the impulse properties of the antennas used to play a crucial role in the very short-range radar systems performance such as antipersonnel landmine detection is achieved using ground penetrating radar. The radar typically uses two separate antennas, one for transmission and one for reception. These antennas are typically close together for mobility and proximity detectability reasons. To accomplish their wideband performance such as return loss, isolation, radiation patterns, polarization, and impulse creation, a variety of design strategies are applied. In [10], an RMPA with a sizable patch was introduced. Despite having a high directivity, it has a very low gain, a large return loss, and a low voltage standing wave ratio (VSWR). An alternative design with a taller form factor has been presented in, [11]. Despite having a better gain than, [10], their design has a worse directivity and a middling return loss.

Another RMPA with a large substrate, [12], and noticeably high directivity and gain was proposed by Shimu and Ahmed. However, it also exhibits minimal return loss, and 5 because of its greater dimension, its manufacturing cost would also be higher. A more compact RMPA design with a smaller patch size has been put forth in, [13]. The gain and directivity are high, and the return loss performance is also very good. Its VSWR performance, however, is rather poor, and there is a considerable gap between simulation and real-world performance.

In [14], a microstrip patch phased array antenna for GNSS augmentation has been proposed. The 2*3 phased array radiates at 1.278GHz which is the center frequency of Galileo E6 band with a VSWR of 1.253, scanning angle of 49° and a gain of 11dBi. The various parameters like S parameters, radiation pattern, beam scanning, etc. have also been measured.

In [15], designed a D-band phased array in proximity coupled fed at 130-160GHz using CST MWS software along with Ansys HFSS for equalization. The designed antennas had a high peak gain of 26.05dB; a high efficiency of 88.33%, and good steering angles in the range -13.5° to 13.7°. In [16], a tri-band slotted bowtie ultra-wideband antenna was designed on Sio2 laminate in Ansys HFSS software. The maximum gain obtained was 17.53dB with directivity 18.2dBi, bandwidth 68.13% and radiation efficiency of 71% with resonance frequencies as 7.1, 11.1, and 13.1 THz.

5 Proposed Antenna Design

The antenna array is done by designing a single rectangular patch with specific height and dielectric constant so that 2.52 GHz resonant frequency (f_r) can be achieved. For designing a rectangular patch antenna, length (L) and width (W) have to be calculated. The formula for calculating width and length can be written respectively as, [17] [18]:

$$W = \frac{c}{2}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{4}$$

$$\varepsilon_{ef} = \frac{\varepsilon_{rr}+1}{2} + \frac{\varepsilon_{rr}-1}{2}\left\{\sqrt{1+12\left(\frac{h_s}{W}\right)}\right\}^{-1} \tag{5}$$

$$\Delta L = h_s(0.412)\frac{\varepsilon_{ef}+0.3}{\varepsilon_{ef}-0.258}\frac{\frac{W}{h_s}+0.264}{\frac{W}{h_s}+0.8} \tag{6}$$

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{ef}}} \tag{7}$$

$$L = L_{eff} - 2\Delta L \tag{8}$$

Where ε_{ef} is the effective or efficient dielectric constant L_{eff} is the efficient length and c is the light speed. W_g (Width) and L_g (length) of the ground plane can be calculated as:

$$W_g = 6h_s + W$$
$$L_g = 6h_s + L \tag{9}$$

The inset-fed single microstrip patch antenna is designed on an FR-4 substrate for a good return loss. The various parameters used are listed in Table 1.

Table 1. Dimensions of microstrip patch antenna

Parameters	**Dimensions**
Dielectric constant, ε_r	4.4
Substrate thickness, h_s	1.6mm
Width of patch, W	71mm
Length of patch, L	54mm
Thickness of the patch, h_t	0.032mm
Width of the ground plane, W_g	220mm
Length of ground plane, L_g	203mm
Microstrip feed width, W_f	3.4mm

After analyzing the design of a single patch antenna, a 2*2 array is constructed where the spacing is equal between adjacent antennas. These antennas are provided with ground maintaining 50 ohm matching, [19], whereas some dimensions are slightly optimized to get better results. The 2*2 antenna array design is shown in Figure 2.

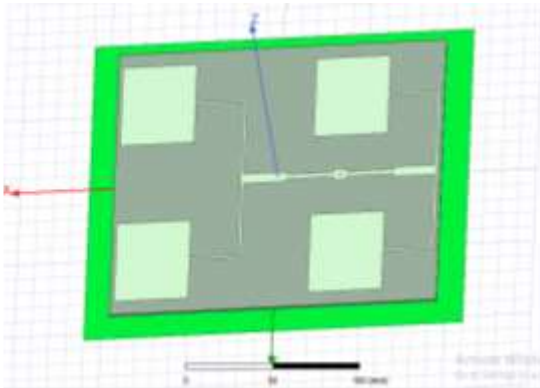


Fig. 2: Designed 2*2 phased array antenna

6 Results and Discussion

The patch array antenna is designed using Ansys HFSS software. Figure 1 shows the single patch antenna design which is designed and various parameters are observed. It resonates at 2.7638GHz frequency with an s parameter of -22.1541dB as observed from the graph shown in Figure 3. The VSWR value is illustrated in Figure 4 showing a value of 1.1693 at the resonant frequency.

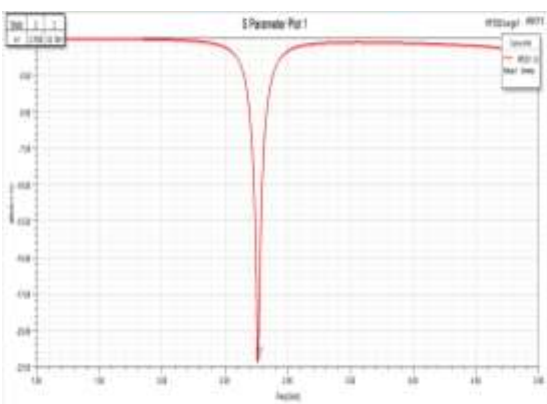


Fig. 3: S-parameter of single rectangular patch

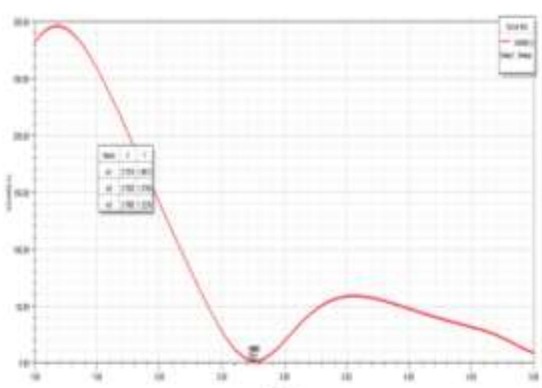


Fig. 4: VSWR of single rectangular patch

Figure 5 shows the single rectangular patch's radiation pattern which shows that the ML has a magnitude of 6.15dBi.

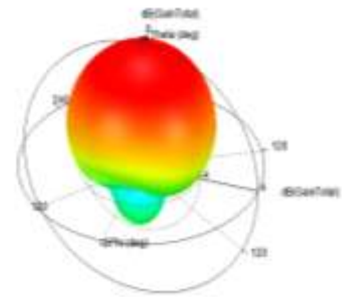


Fig. 5: Radiation pattern of the single rectangular patch antenna

The antenna array is designed where all the ports are given simultaneous excitation without any phase change. All the antennas must resonate at the same frequency. The S-parameter of the antenna is -24.1279dB and is shown in Figure 6.

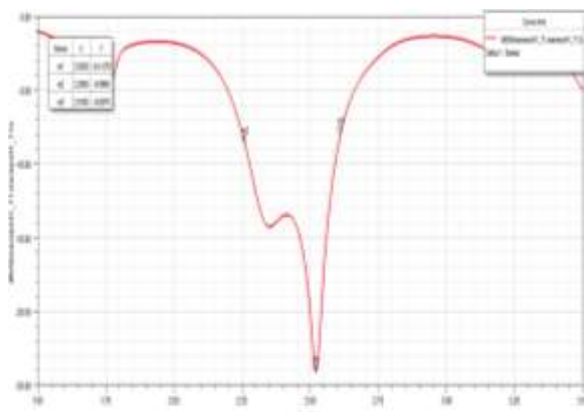


Fig. 6: S-parameter of the 2*2 array antenna

From Figure 6, it is inferred that the antenna array resonates at 2.52GHz. The 2*2 array antenna's polar representation of radiation pattern without phase manipulation is shown in Figure 7 indicating that the ML magnitude is 11.35dBi and the direction of ML is 0°.

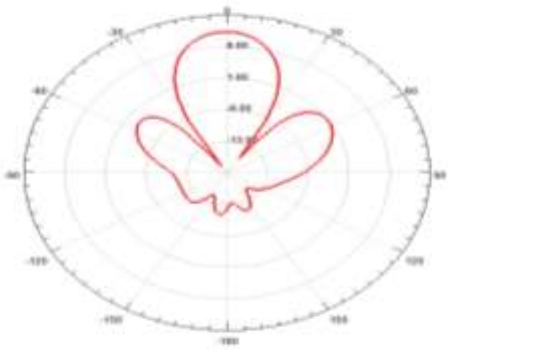
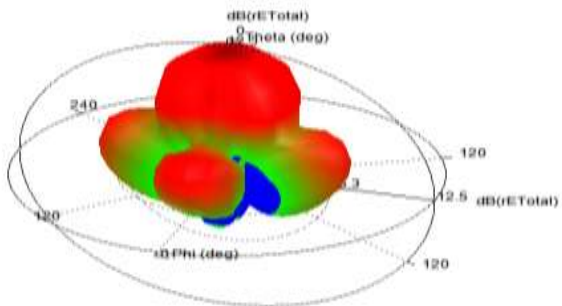
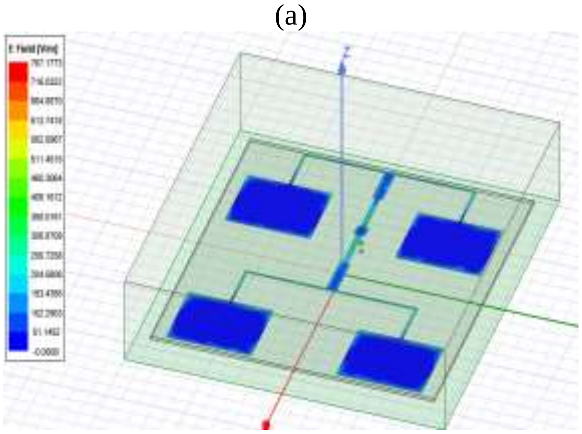


Fig. 7: Radiation pattern of array antenna

The gain and current distribution for the 2*2 array antenna are shown in Figure 8 with the gain value of 13.689dB at 2.52GHz.



(a)



(b)

Fig. 8: Radiation pattern of the array antenna (a) 3D gain (b) current distribution

To find the scan angle's range, the ports are excited at the same amplitude with different phase combinations. While simulating, the ML magnitude and direction are examined from various angles. The results show that the directivity and gain are maximum at 14.055dB and 13.689dB respectively. The gain plot for various angles is given in Figure 9.

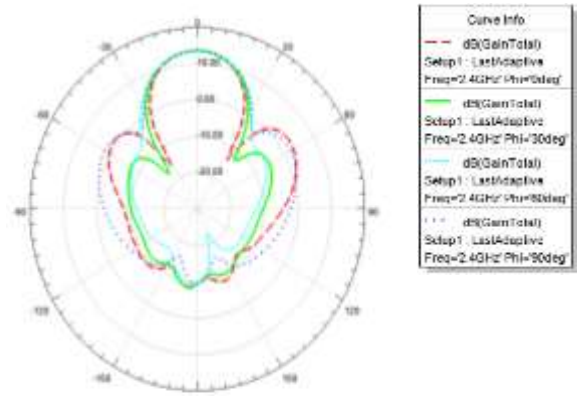
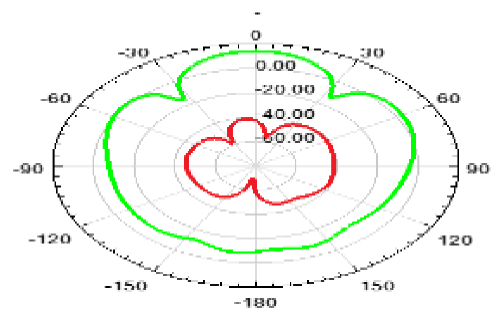
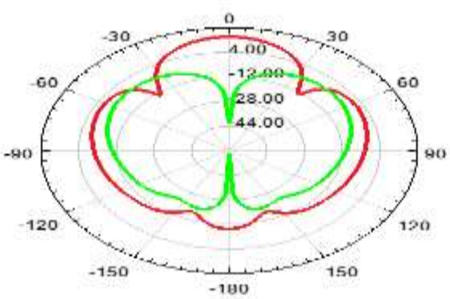


Fig. 9: Polar gain plot for 2*2 array Antenna

The E-field and H-field pattern for the 2*2 array antenna is shown in Figure 10. From the shown simulation results, it is proven that for particular phase combinations, the antenna's main beam steers to a particular direction up to a scanning range.



(a)



(b)

Fig. 10: (a) E-field pattern (b) H-field pattern of 2*2 array antenna

Table 2 gives the performance comparison of the proposed antenna with the state of the art, [20], [21], [22] and [23]. The gain of the antenna is improved. Whereas the efficiency is less than the circular patch proposed in [19] but better than other works available in the literature.

Table 2. Comparison with the state-of-art

	VSWR	Gain	Efficiency %
Khattak[19] (circular patch)	1	13.5 dB	98
Zhang[20] (MIMO DRA)	1.244	7.02 dBi	85.5
Jebabli[21] (1*4)	1.278	13 dB	86.73
Benlakehal[22] (1*2)	-	11.77 dBi	87.63
Hrudananda[23](circular patch)	-	10.26 dBi	84.16
Proposed (2*2)	1.133	13.69 dB	91.91

7 Conclusion and Future Work

As in various communication fields like radar, and satellites, beam steering not only increases the integrity of the overall system but provides high performance. In this paper a 2*2 phased array antenna using microstrip patch with a scan angle of 47degrees is designed. The array antenna resonates at 2.52GHz with a VSWR of 1.1325. The S-parameter values are below -10dB which is a threshold value indicating a good resonance. Other parameters like radiation pattern, gain, and directivity are also evaluated for a better understanding of the antenna's performance. These antennas can be used as radars as it has an efficiency of 91.91%. It can also be used for ensuring accurate landing for airplanes. The performance of the antenna can be further increased by enhancing the number of antennae. Further, studies will be done to improve the scan angle's range as well as gain, efficiency, and other operational parameters.

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- Mridula S. carried out the design, Simulation, and Manuscript writing.
- Shantha Selva Kumar. R, guided in Problem formation, Troubleshooting, and Manuscript organization.

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