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High-Gain, High-Directivity 2x2 Array Microstrip Patch Antenna Design for RFID Reader Use

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Abstract- A "2x2 Array Microstrip Patch Antenna with High Gain and Directivity for RFID Reader Applications" is what this research is aiming to create and determine. Modern wireless communication systems rely heavily on microstrip antennas; they include healthcare, mobile communication, and radio frequency identification (RFID). In an effort to address the issue of low gain, a 2.5GHz microstrip antenna array with a single RT/duroid-5880 (ɑr1 = 2.2) and a second C-foam material substrate has been constructed. The C-foam substance has a dielectric constant value near to air, with a low value of 1.03 (ɑr2). To accomplish the parallel feed network with matching network having symmetric structure and co-axial probe feeding to match the array antenna, a T-type power distributor is used. With the help of HFSS software, we evaluate the suggested antenna's performance according to return loss, VSWR, gain, and directivity. With a bandwidth of 290 MHz and a relative bandwidth of 11.6%, the suggested antenna has a maximum gain of 14.34 dB in the simulation results.

Keywords - Microstrip Patch antenna, air substrate, RFID, High Gain

INTRODUCTION

Radio-frequency identification, or RFID, is a system that automatically identifies objects without the need for a human to physically touch the tag or reader. Automatically identifying and exchanging data contained on electronic tags is made possible by use of radio frequency signals. Typically, radio frequency identification (RFID) devices operate in one of four frequency bands spanning 120 kilohertz (kHz) to 10 gigahertz (GHz): low frequency (LF) 120 to 150 kHz, high frequency (HF) up to 13.56 MHz, ultra high frequency (UHF) 433 MHz, microwave 2.45 to 5.80 GHz, and ultra wide band 3.1 to 10 GHz. Electronic toll collection, access control, logistics systems, service sectors, animal monitoring, government agencies, and many more fields may benefit from RFID technology [1,2].

The two primary parts of an RFID system are the RFID tag (sometimes called a transponder) and the reader (also called an interrogator). The reader sends out a radio signal via the antenna to power the RFID system. Every passive transponder or electronic tag that comes into contact with this electromagnetic radiation becomes powered up and sends out all of the data stored on the tag [1,2]. As seen in figure 1, a predetermined protocol facilitates communication between the RFID tag and the reader.

ISSN: 1832-5505
Vol-11 Issue-02 June 2023

Figure 1 shows the RFID system components and operation [4].

The reader antenna is a critical component of an RFID system that influences the system's overall performance. Due to its low profile, tiny size, light weight, and ease of fabrication, the microstrip patch antenna has found extensive usage in the design of RFID systems. When attached to both flat and curved surfaces, these antennas provide excellent strength and flexibility. Microstrip antenna optimisation for communications needs in aerospace, military, and aviation applications has been the subject of several research. Low gain, poor polarisation purity, limited bandwidth, and dielectric material losses limit the applicability of microstrip antennas. Microstrip antennas typically have a gain of 6-8 dB.

This research aims to improve antenna gain and directivity by designing a 2x2 array microstrip patch antenna operating at 2.5GHz frequency. The primary focus of this research is on the use of a thick substrate with a low dielectric constant value in a multilayer construction using air as a substrate (specifically, C-foam material, which has a dielectric constant of 1.03), as well as the co-axial probe feeding approach. The research led to the development of an inexpensive antenna with respectable performance and a gain of 14.34 dB.

Literature Review

A basic 2x2 array antenna that operates at 2.45GHz was created by Du Yongxing [6]. A feeder consisting of a T-shaped structure is used by the antenna, which uses coaxial wire. The network is simple and impedance-matched. The highest gain that may be achieved is 13.9 dB.

A 4x1 array antenna working at 2.45GHz was created by O. Ouazzani [5]. It uses FR-4 material as its substrate and employs a quarter wave impedance matching approach. The antenna is fed via a 50 ohm microstrip line. The achieved gain is 8.36 dB. But the antenna is huge, and the gain isn't particularly good.

A 2x2 array antenna functioning at 10GHz has been developed by Yang Liufeng [8]. It makes use of MEMS technology, a double-layered silicon substrate with low and high resistivity silicon bonded together, and a defective ground. A gain of 10.9 dB is achieved.

A 4x1 array antenna has been developed by Norfishah Ab Wahab [10] using FR-4

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Vol-11 Issue-02 June 2023

material with a dielectric constant of 4.9, a quarter wave impendence matching mechanism, and feed

the microstrip line to 50 ohms. With such a huge antenna, the achieved gain of 5.732 dB is pitiful.

Using a network feed consisting of a T-shaped power divider with two substrate layers of RT/duroid-5880 and air, Chen jianjun [7] created a four-unit microstrip array antenna with two symmetrical angle cuts. This design achieves a gain of around 14.2 dB and uses a complicated antenna configuration.

Using a multi-layered substrate and a coaxial probe feeding approach, this research designs a simple 2x2 array antenna operating at 2.5GHz frequency. The antenna achieves a maximum gain of 14.34 dB and a minimum return loss of -34.10 dB.

ANTENNA DESIGN STRUCTURE

A Diaelectric material with permittivity values ranging from 2.2 to 12 is sandwiched between a radiating patch and a ground plane in a microstrip patch antenna. Due to its low profile, light weight, and conformability to both planar and non-planar surfaces, microstrip patch antennas are increasingly being used in RFID technology. When making microstrip patch antennas, dielectric materials are crucial. The structure dictates the form of the patch, which is a conducting substance often composed of gold or copper. The dielectric substrate is photoetched with the radiating patch [3].

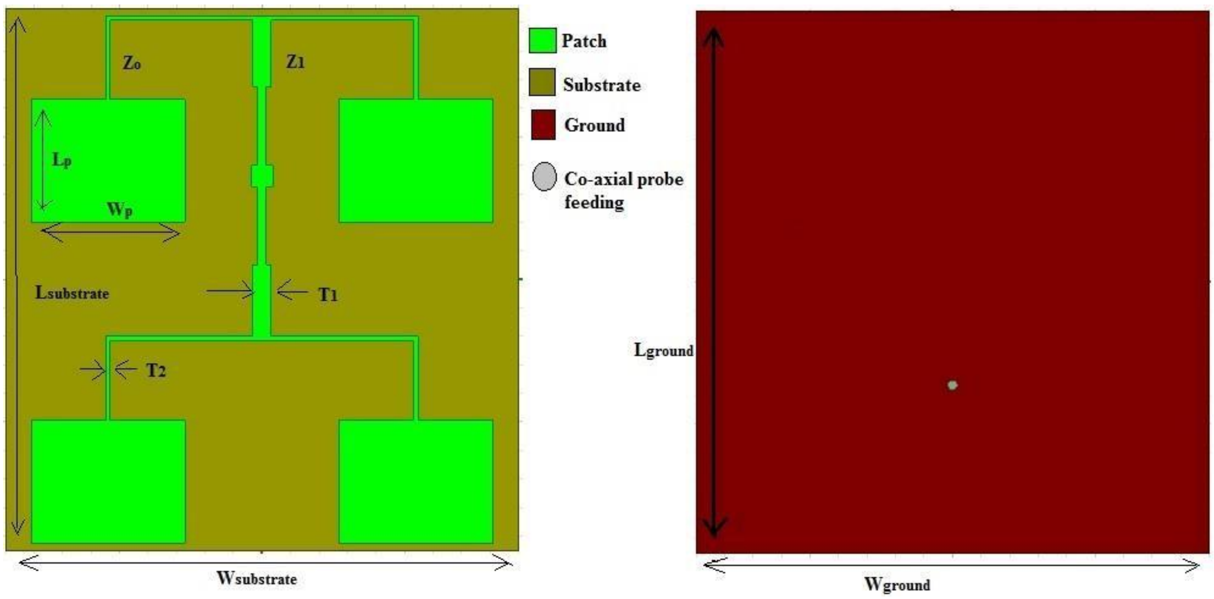

Fig: 2: Top and Bottom view of the designed antenna

The four rectangular patch pieces that make up the antenna design are laid out in a 2x2 pattern, as seen in figure 2. On one side of the dielectric substrate is where the patch is built, and on the other side is where it is ground.
Figure 3 shows the two components that make up the dielectric substrate, which has a thickness of 6.6 mm and is arranged in a stack. To begin with, there is an RT/duroid-5880 substrate underneath the patch. It has a relative permittivity of 2.2, a loss tangent of 9.10-4, and a thickness of 2.2 mm. In addition, the C-foam [12] material serves as a substrate and has little

The thickness h2 is 4.4 mm and the dielectric constant (αr2) is 1.03. Because it has a dielectric constant very near to air, C-foam is

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Vol-11 Issue-02 June 2023

chosen as the material. In other words, this dielectric substance is like air.

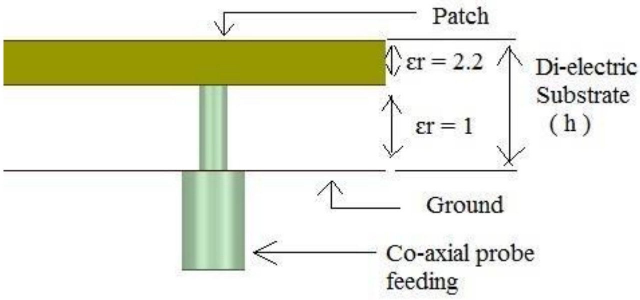

Fig:3: Side view of the designed antenna

The designed antenna dimensions are calculated using the standard formulae [3]. Single patch dimensions width (w) and length (L) of the patch are calculated using equations (1) and (5).

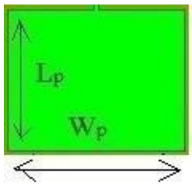

Fig 4 single patch antenna

$$w = \frac{c}{2f}\sqrt{\frac{2}{\epsilon_r+1}} \qquad (1)$$

$$\epsilon_{reff} = \frac{\epsilon_r+1}{2} + \left(\frac{-1}{2}\right)/\left(\sqrt{1+\frac{12h}{w}}\right) \qquad (2)$$

$$L_{eff} = \frac{c}{2f\sqrt{\epsilon_{reff}}} \qquad (3)$$

$$\Delta L = 0.412h\left(\frac{(\epsilon_r+0.3)\left(\frac{w}{h}+0.264\right)}{(\epsilon_r-0.258)\left(\frac{w}{h}+0.8\right)}\right) \qquad (4)$$

$$L = L_{eff} - 2\Delta L \qquad (5)$$

$$L_{substrate} = 6h + L \qquad (6)$$

$$w_{substrate} = 6h + w \qquad (7)$$

$$L_f = \frac{L}{2\sqrt{\epsilon_{reff}}} \qquad (8)$$

$$Z_o = \frac{60}{\sqrt{\epsilon_{reff}}}\ln\left[\frac{8h}{w_f} + \frac{w_f}{4h}\right] \qquad (9)$$

Where w = Width of the patch

L = Length of the patch

ISSN: 1832-5505
Vol-11 Issue-02 June 2023

ϵ_r	=	Dielectric constant value of the substrate
h	=	Thickness or Height of the Substrate
ϵ_{reff}	=	Effective Dielectric constant value
ΔL	=	Extension in Length due to fringing effect
L_{eff}	=	Effective Length
$L_{substrate}$	=	Length of the Substrate
$w_{substrate}$	=	Width of the Substrate
L_f	=	Length of the feed line
Z_o	=	Impendence
f	=	Resonant Frequency
c	=	Speed of Light

The calculated patch and substrate dimensions are as shown in Table 1.

Table 1: dimensions of the designed antenna

Variables	Values (in mm)
Lp	47
Wp	36
Lsubstrate	190
Wsubstrate	180
T1	6.5
T2	1.5
Lground	190
Wground	180
H	6.6
h1 (εr1 = 2.2)	2.2
h2 (εr2 = 2.2)	4.4

The four patch components in the antenna design are spaced appropriately apart from each other. Figure 2 shows a symmetrical construction with a parallel feed network, with Zo = 100 ohm and Z1 = 50 ohm, and this is accomplished with the help of a T-type power distributor. The antenna performance may be simulated and analysed with the help of the High Frequency Structure Simulator (HFSS) software by using the co-axial probe feeding approach [11].

Applied GIS

ISSN: 1832-5505
Vol-11 Issue-02 June 2023

I. SIMULATION RESULTS

Here we will show you the simulation results of the antenna that was constructed, which is a 2x2 array microstrip patch antenna that operates at 2.5GHz. Using HFSS software, we analyse the data for Return Loss, VSWR (Voltage Standing Wave Ratio), Gain, and Directivity.

a. Return Loss (S_{11}):

The term "return loss" describes the power drain that occurs when a signal encounters a break in the transmission line or optical fibre. The signal's strength may be preserved by keeping the return loss to a minimal. The intended antenna has a return loss of -34.1029 dB, as illustrated in figure 5. This demonstrates that the antenna's return loss is minimal.

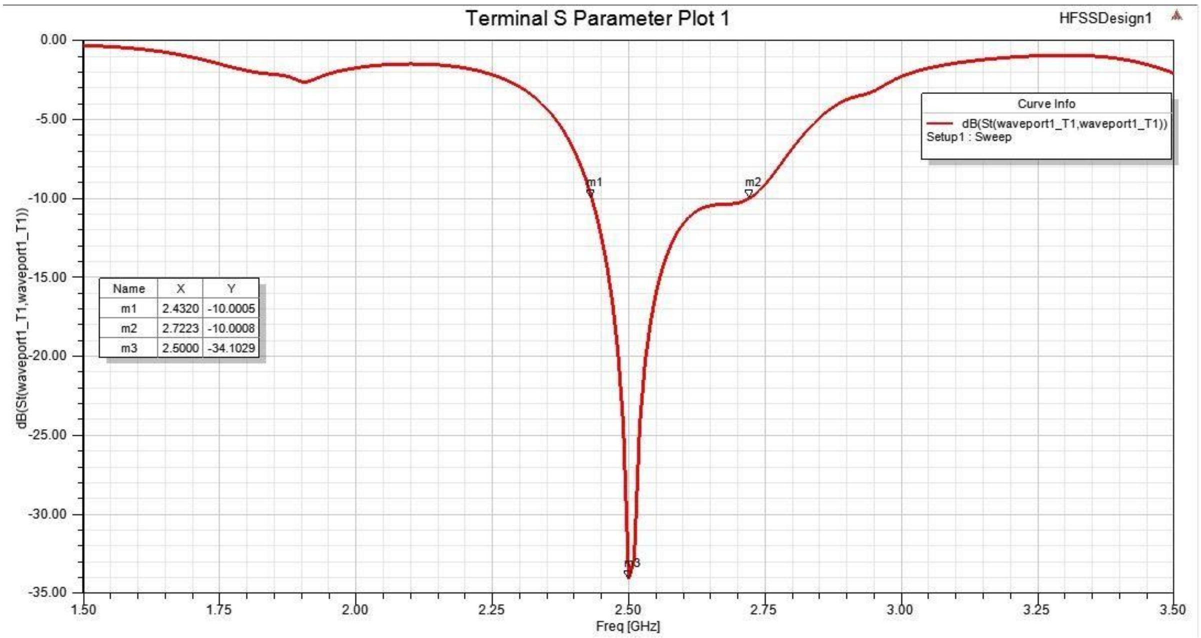

Fig 5 Return Loss or S_{11} plot of designed antenna

The bandwidth of the designed antenna is calculated using (10) at -10dB which is indicated in the figure 5. The bandwidth is 290 MHz for this antenna.

Bandwidth (BW) = (max) – (min) at -10dB (10)

b. Voltage Standing Wave Ratio (VSWR):

The adaptation quality of an antenna is defined either by its input impendence or VSWR Value. The antenna operates at the resonant frequency, only when the VSWR Value is less than 2. The VSWR graph is shown in the figure 6. The resultant value at 2.5GHz is 0.3426. This proves that there is good adaptation between the antenna array and coaxial probe input.

ISSN: 1832-5505
Vol-11 Issue-02 June 2023

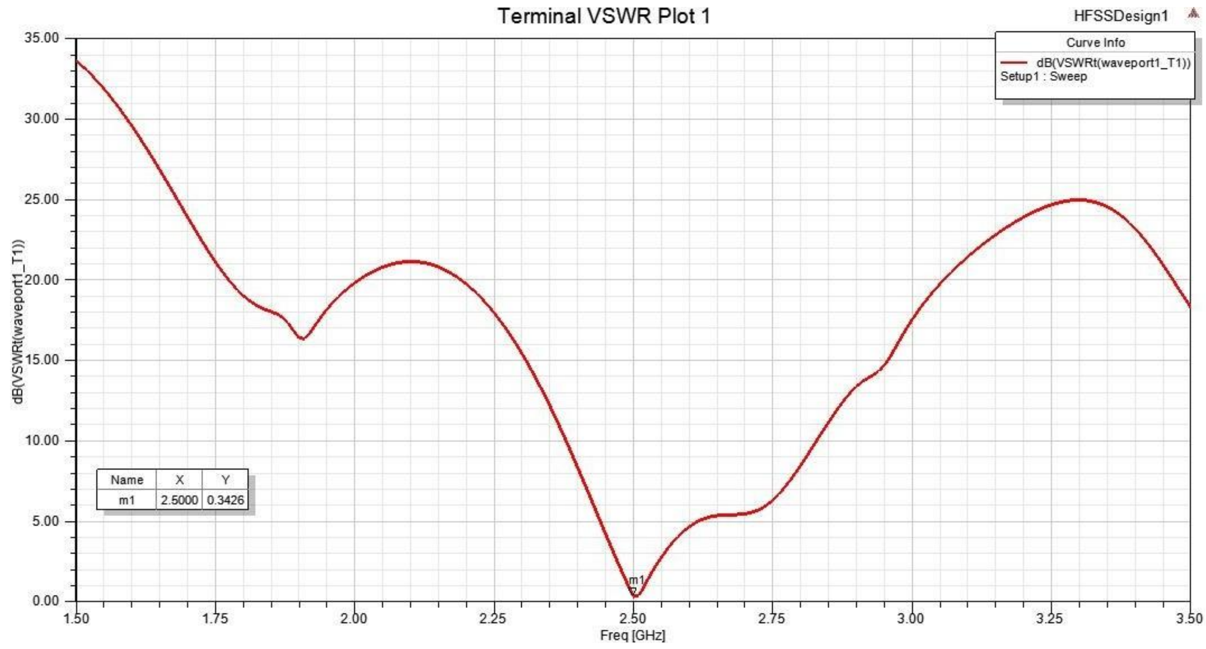

Fig 6 VSWR plot

c. Gain and Directivity:

Gain represents the directionality of the antenna. An isotropic antenna radiates energy in all directions but practical antenna radiates energy in some direction only. The gain plot in 2D and 3D representations are shown in the figure 7. The gain obtained for the designed antenna is 14.3450 dB.

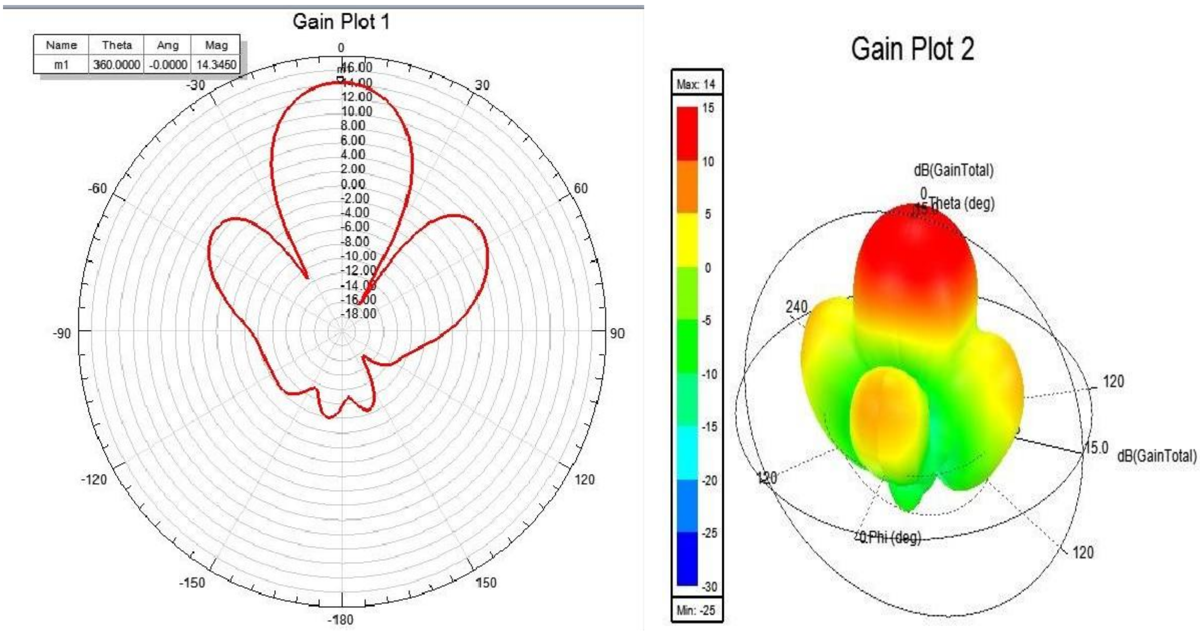

Fig 7 Gain plot in 2D and 3D representation for designed antenna

One measure of antenna performance is its directivity, which is defined as the ratio of the averaged radiation intensity in all directions to the intensity in a specific direction. The directivity of an antenna is a three-dimensional model of its radiation, and its gain is calculated from a two-dimensional slice of this model. Figure 8 shows the directivity plot, with a maximum value of 14 dB.

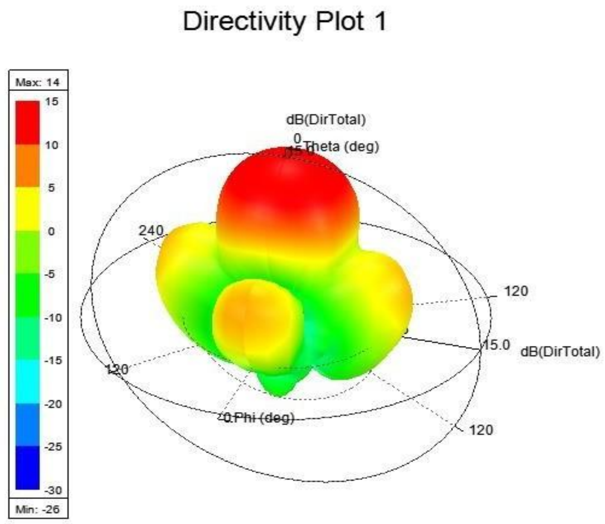

Fig 8 Directivity plot of array antenna

The gain and directivity values for the designed antenna shows that the array antenna has obvious advantages compare to other works in table 2. It can be seen that the designed antenna is simple in structure and has significant gain and good adaptation.

Table 2: comparison with other works

Parameters / article	Du Yongxing [6]	In this Proposed article
Design	2x2 array antenna	2x2 array antenna
Return loss	-23.7 dB	-34.1029 dB
VSWR	VSWR< 2.0: 1	VSWR = 0.3426
Gain	13.9 dB	14.3450 dB

II. CONCLUSION

A 2x2 array microstrip patch antenna operating at 2.5 GHz frequency with a basic construction was the primary focus of the current work. A T-type power distributor and coaxial probe feeding comprise the parallel feed network in this simple design. Using HFSS software, the planned antenna's performance is evaluated in relation to gain, directivity, return loss, and VSWR. The planned antenna's maximum gain is 14.34 dB, bandwidth is 290 MHz, and relative bandwidth is 11.6%, according to the simulation results. This demonstrates that the suggested antenna is structurally simple, has a high gain, and is adaptable well, all of which contribute to its potential for use in RFID systems.

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