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An Aperture Coupled Feed Approach to Gain and Bandwidth Enhancement of Microstrip Patch Array Antennas

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Abstract— Communication has become indispensable in the modern world and antennas, being the electronic eyes and ears of the world, have become an integral part of our communication technologies.
Among the various types of available antennas, Microstrip Antennas have been one of the most innovative developments in the era of miniaturization and are increasingly finding applications in a wide range of microwave systems.
The aim of this paper is to design and compare the performance of Rectangular and Circular Microstrip Patch array antenna using ADS (Advance Design System) Momentum. Microstrip Line feed is used to feed each element. The performance is further enhanced by replacing the Microstrip Line feed by Aperture coupling since aperture coupling eliminates the direct electrical connection between the feed and patch and allows independent optimization of both the feed and radiating patch, improving radiation pattern and bandwidth. These arrays are designed to operate at a frequency of 2.4 GHz.
Various parameters like the Return Loss, two dimensional and three dimensional radiation patterns, Gain and Directivity of the designed antenna are obtained using ADS Momentum for three designs, using different substrates. The purpose of this antenna is to obtain a high gain with better band width and reduced losses, to be especially used for WLAN applications.

Keywords-Circular patch, Rectangular Patch, Microstrip Line Feed, Microstrip Patch Array.

I.INTRODUCTION

Microstrip antennas, being light in weight and compact in nature, have found their way into a number of applications despite their narrowed bandwidth nature. Since these are capable of performing well over a wide range of frequencies, they are of great demand in the communication field.[1]

Patch Antennas could be excited by using Microstrip line Feed, Coaxial Cable, Aperture Coupling and Proximity Coupling. Microstrip Line feed is simple to fabricate and match, but has more spurious radiations and produces a narrow bandwidth.[2]On the other extreme, Aperture Coupling is difficult to fabricate, but easier to model and has moderate spurious radiations.

A Microstrip Line Feed uses a conducting strip, of smaller width, compared to the patch to feed the antenna. It is very simple to design, study and fabricate. Aperture coupled Patch Antennas, on the contrary use a layered structure, comprising of atleast 2 substrates, separated by a ground plane. The feed line on the bottom substrate is coupled to the patc on the top substrate, through a slot made in the ground plane.[3]This scheme is advantageous over Microstrip line feed as they:

1. demonstrate good impedance bandwidth
2. enable independent selection of patch and feed substrate.
3. possess a layered structure in which the ground shields the antenna from the feed.
4. provide good gain and directivity.[4]

The paper is organized in the following way. Section I gives an insight into Features of Microstripline feed and Aperture coupling and Section II describes the design of the various antennas. Section III comprises of the Simulation results and Discussions. Section IV concludes the paper.

II. ANTENNA GEOMETRY AND DESIGN

A. MICROSTRIP LINE FEED

For a rectangular patch, length L is usually $0.3333\lambda_0<L<\lambda_0$, where λ_0 is the free-space wavelength. Patch is usually very thin such that patch thickness t is very less than λ_0. The dielectric constant of the substrate ε_r ranges from 2.2 to 12. The thickness h of the dielectric substrate is usually in the range $0.003\lambda_0 \le h \le 0.05\ \lambda_0$.[5]

Based on the above constraints, the various dimensions of the Rectangular patch are calculated as follows.[6]

Width $W = \frac{1}{2f_r\sqrt{\mu_o \varepsilon_o}}\sqrt{\frac{2}{\varepsilon_r+1}}$ (1)

Effective Dielectric Constant

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2\sqrt{1+\frac{12h}{W}}} \quad (2)$$

Extended length

$$\Delta L = 0.412h\frac{(\varepsilon_{reff}+0.33)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \quad (3)$$

Actual length L

$$L = \frac{1}{2f_r}\frac{1}{\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\varepsilon_0}} \quad (4)$$

For a circular patch, Effective radius

$$a_e = a\{1+\frac{2h}{\pi a\varepsilon_r}\left[\ln\left(\frac{\pi a}{2h}\right)+1.7726\right]\}^{1/2} \quad (5)$$

Resonant Frequency

$$(f_r)_{110} = \frac{1.8412v_0}{2\pi a_e\sqrt{\varepsilon_r}} \quad (6)$$

Where v_0 is the velocity of light $= 3X10^8$ m/s

Radius a

$$a = \frac{F}{\{1+\frac{2h}{\pi aF}\left[\ln\left(\frac{\pi a}{2h}\right)+1.7726\right]\}^{1/2}} \quad (7)$$

$$\text{where } F = \frac{8.791X10^9}{fr\sqrt{\varepsilon_r}}$$

The dielectric substrate used is RT DUROID with ε_r of 2.2 Based on thesedesign equations, a single rectangular patch antenna is designed. Table I shows the specifications.

TABLE I
PARAMETERS TO DESIGN A SINGLE RECTANGULAR PATCH ANTENNA

Parameters	Specifications
Patch Length (L)	41 mm
Patch Width (W)	49 mm
Width of Feed (W_f)	4.8 mm
Height of Substrate (h)	1.588 mm
Input impedance	50 Ω
Frequency of Operation	2.4 GHz
Type of feed	Microstrip Line Feed

Figure 1 shows the designed single rectangular patch antenna.

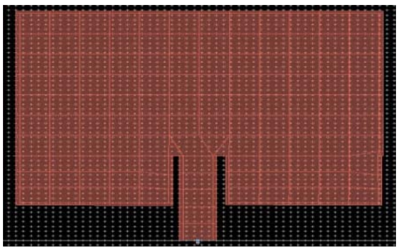

Fig.1. Single Rectangular patch Antenna

Using the same dimensions and a spacing of 70 mm between the patch elements, an array of 2 and 4 rectangular patches are designed. Following this, a circular patch antenna is designed according to Table II

TABLE II
PARAMETERS TO DESIGN A SINGLE CIRCULAR PATCH ANTENNA

Parameters	Specifications
Patch radius (R)	22.6 mm
Width of Feed	2.1 mm
Input impedance	50 Ω
Distance of feed from center of patch	7 mm
Height of Substrate (h)	1.588 mm
Frequency of Operation	2.4 GHz
Type of feed	Microstrip Line Feed

Figure 2 shows a single circular patch antenna.

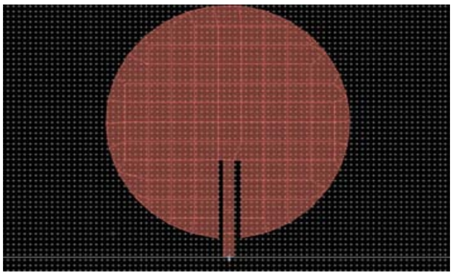

Fig.2. Single Circular patch Antenna

With a spacing of 70 mm between the patch elements, an array of 2 and 4 Circular patches are designed.

B. APERTURE COUPLED FEED

The aperture coupled microstrip antenna involves over a several material and dimensional parameters like those shown in Table III:

TABLE III
INFLUENCE OF VARIOUS DIMENSIONS ON APERTURE COUPLED ANTNNA PERFORMANCE

Parameters	Features
Slot Width	i) affects coupling level
Patch substrate	i) Affects Bandwidth ii) low ε_r gives wide impedance Bandwidth iii) Preferred thick
Feed Width	i) controls characteristic impedance ii) preferred thin
Feed Substrate	i) controls spurious radiation ii) Preferred thin
Tuning Stub Length	i) tune excess reactance
Patch radius	i) Determines resonant frequency
Slot Length	i) determines coupling and backlobe radiation level

Based on these above constraints, 3 designs were simulated using 3 substrates and their performances were studied. Table IV shows the specifications.

TABLE IV
PARAMETERS TO DESIGN APERTURE COUPLED PATCH ANTENNA

Design		Design I	Design II	Design III
Specifications				
Substrate	Patch	FR 4(ε_r=4.5)	RT DUROID 5880(ε_r=2.2)	RT DUROID 5880
	Feed	FR 4	RT DUROID	Alumina(ε_r=9)

		5880	
Radius (mm)	15.4	21	22
Frequency f_0 (GHz)	2.41	2.407	2.38
Length of feed (mm)	55.14	57.4	44.6
Width of feed (mm)	2.5	4.3	3.3
Length of stub (mm)	15.7	16.1	5.5
Length of Slot (mm)	14.44	20.3	17.5
Width of slot (mm)	2.5	3	2.8

Figure 3 shows the Design I Aperture coupled Patch Antenna.

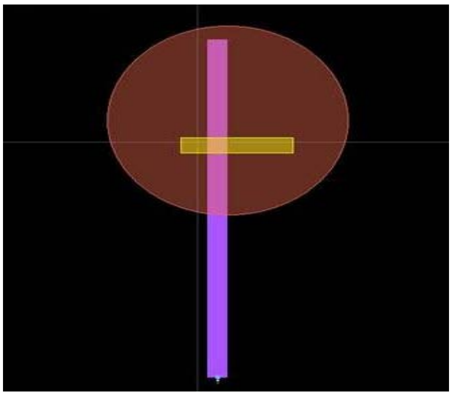

Fig.3 Design I of Aperture Coupled Patch Antenna

Figure 4 shows the Return Loss performance of the 3 Designs.

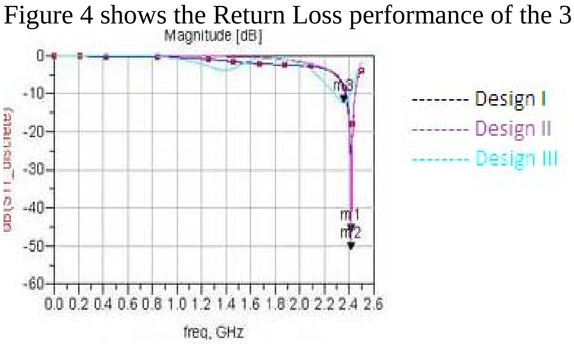

Fig. 4 Return Loss comparison of 3 Designs

III. SIMULATION RESULTS AND DISCUSSIONS

The designs are simulated using ADS Momentum, at a frequency of 2.4 GHz. Table V compares the performance of Rectangular and Circular Patch Antennas.

TABLE V
PERFORMANCE COMPARISON OF RECTANGULAR AND CIRCULAR PATCH ANTENNA

Patch Shape	Rectangular			Circular		
No. Of Elements	1	2	4	1	2	4
Parameters						
Return Loss (dB)	-16	-24	-25	-0.25	-9.8	-13
GAIN (dB)	6.9	8.5	11	7	8.8	11.25
Directivity (dB)	7	9.7	12	7.4	9.7	14.63

Table VIshows the performance of the 3 designs, designed using Aperture coupling.

TABLE VI
PERFORMANCE COMPARISON OF 3 DESIGNS MADE USING APERTURE COUPLING

Parameters	Design I		Design II		Design III	
	Single	Array	Single	Array	Single	Array
S_{11} (dB)	-46.417	-35.03	-51	-33.66	-12.4	-10
Gain (dB)	2	12.5	7	13.3	5.5	10.7
Directivity(dB)	6.2	7.27	7	10	8	8
BW (MHz)	76	77	83	84	121	123
%BW	3.1	3.1	3.44	3.5	5.5	5.6
VSWR	1.01	1.036	1.01	1.04	1.63	1.8

IV. CONCLUSION

Circular Patch Antenna, compared with rectangular Patch antenna has shown considerable increase in Gain and Directivity.[7] Comparing the performance of Rectangular and Circular, the narrow bandwidth feature of Microstrip Line feed has been overcome by Aperture coupling. There has been a significant improvement in the Bandwidth Out of the 3 designs, RT DUROID performs exceptionally well, providing a bandwidth of over 83 MHz, at a resonant frequency of 2.407 GHz. It also provides greater Gain and Directivity compared to the other 2 designs. However design III provides the highest bandwidth. Overall, Aperture coupling reduces backlobe radiation, improving Bandwidth, Gain and Directivity, with reduced losses. Such antennas designed using RT DUROID perform exceptionally well and can be used to form arrays.

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