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Design and Simulation of Nanotechnology based Proximity Coupled Patch Antenna at X-Band

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Abstract: This paper presents design, modeling and simulated characterization of proximity coupled fed circular microstrip patch antenna (PCMPA) where the electromagnetic radiating patch is totally composed of nano thickness (nano meter) film. The nano film is excited through an electromagnetic coupling scheme also known as proximity coupler at 10 GHz. Antenna design and parametric studies have been executed through IE3D version 14.65 simulation software. Simulation result shows enhanced bandwidth and good return loss response of nano film patch antenna over traditional bulk thickness (micro meter) patch antenna. Since, the resonance frequency of this antenna is around 10 GHz; these antennas are suitable for X-band applications such as satellite communication, radar, medical, and other wireless systems.

Keywords: X-band, Patch antenna, nanotechnology, IE3D, proximity coupled patch antenna

I. INTRODUCTION

In recent years microstrip patch antennas (MPA) have been widely used in microwave frequencies for wide range of applications such as industry, military, and wireless systems etc. MPA offer the attractive advantage of low profile, low weight, simple fabrication, and easy integration with integrated circuits. The present day wireless communication system applications demand smaller antenna size and enhanced bandwidth. However, MPAs have disadvantage of narrow bandwidth, low gain and low power handling capacity [1].

There have been a lot of researches on MPAs to widen the band width. A part of them has focussed on employed antenna substrate. Magneto Dielectric (MD) substrates with permeability (μ_r) and permittivity (ε_r) values greater than one having favourable properties have been proposed as possible substrates for antennas in [2-3]. The MD material consists of some metallic or ferrite material so that permeability of substrate can be changed easily. The bandwidth for an antenna over a MD material substrate is approximately given by [4]:

$$BW \simeq \frac{96\sqrt{\mu_r/\varepsilon_r}\,\frac{t}{\lambda_0}}{\sqrt{2}\left[4+17\sqrt{\mu_r\varepsilon_r}\right]} \qquad (1)$$

where t is thickness of the MD material and λ_0 is the wavelength at resonant frequency. The term $\sqrt{\mu_r\varepsilon_r}$ is called refractive index or miniaturization factor n. Higher the value of n, the smaller the size of an antenna. It is seen that when $\mu_r=\varepsilon_r$, the characteristics impedance of MD medium is close to that of the surrounding medium, it allows ease of impedance matching over a wider bandwidth. The size of the antenna is unchanged because of refractive index n, the bandwidth can be broader by increasing the ratio between permeability and permittivity. However the use of MD substrate at GHz frequencies is limited by high magnetic loss ($\tan\delta_m$). The other problem with MD substrate is difficult to synthesize and fabricate material for $\mu_r=\varepsilon_r$.

The other part of researches on electrically small patch antenna is optimizing conductive parts of the antenna. Different techniques like meandering line technique; capacitive loading, inductive loading and employing parasitic stubs etc have been used in conjunction with the main antenna pattern to widen the bandwidth in addition to miniaturization [5-7]. However this arrangement reduces radiation efficiency. Also, MPAs at higher microwave band offer higher metallic losses there by reducing the bandwidth, radiation efficiency and gain.

Recently new technologies and nano materials have been developed to allow the fabrication of patch antennas. One of the technologies is to deposit required amount of conductive patch material on the dielectric substrate using nanotechnology tools like Physical (PVD) or chemical vapor deposition (CVD) method [8], instead of removing the unwanted metal from a fully covered dielectric substrate which uses conventional lithography. F. Urbani, D.W. Stollberg, and A. Verma have developed and demonstrated

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an aperture coupled microstrip patch antenna (ACMPA) that uses nano film as radiating patch [9]. Their demonstration clearly indicates the potential use of nano material as radiating patch for improving bandwidth of an MPA. Although their antenna demonstrates outstanding performance in terms of ultra wide band width (UWB), it has some disadvantages like very small coupling circular slot between ground plane and patch, high cost of substrates (RT Duroid and Silicon substrate), and ACMPA offers low bandwidth compared to PCMPA. In this paper we proposed modeling and simulation of a two layer FR4 rectangular patch antenna with proximity coupled feed line (PCMPA) at X-band that uses nano film as a radiating patch to study bandwidth performance.

II. Antenna Design And Modelling

The main objective of this paper is to model, design and study the bandwidth characteristics of a circular disk PCMPA that uses nano film thickness radiating patch for X-band applications. The advantage of a circular disk microstrip configuration, compared to its rectangular geometry for an identical design is that the circular disk patch occupies less space. Thus, in applications, such as arrays, circular structures are preferred.

The circular PCMPA structure consists of a defined metallic circular patch on the top side of a FR4 top substrate and metallic ground plane placed on other side of FR4 bottom substrate. The circular PCMPA is fed by electromagnetically coupled microstrip feedline placed between two FR4 dielectric substrates. The geometry of the proximity coupled patch antenna is shown in Fig. 1. The feedline is centered with respect to the centre of the radiating patch of an antenna. The two substrates may be of different

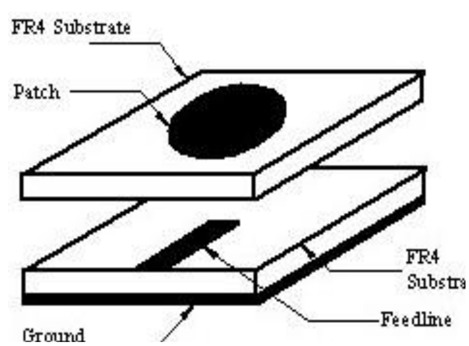

Fig. 1 Proximity coupled Microstrip Patch Antenna

thickness and permittivity, but in this report we modeled for same thickness. The impedance match for resonance is controlled by length of feedline, and radius of radiating patch. A cavity model formulation has been proposed as efficient analysis and design method [10]. This modeling is known as simplest tool for designing circular microstrip patch antenna. This modeling approach promise a very good antenna performance in terms of bandwidth and radiation efficiency. In microstrip antenna design, dielectric substrate is one of the important considerations. The resonance frequency f_r for the dominant mode of propagation is given by

$$(fr)_{110} = \frac{1.8412}{2\pi r\sqrt{\mu\varepsilon}} = \frac{1.8412 v_0}{2\pi r\sqrt{\varepsilon_r}} \qquad (2)$$

where v_0 is the speed of light in free space, r is the actual radius of the patch and ε_r is dielectric constant of the substrate. The resonant frequency of Eq. 1 does not take into account fringing. Fringing makes the patch look electrically larger and it was taken into account by introducing a length correction by using an effective radius r_e to replace the actual radius r is given by

$$r_e = r\{1 + \frac{2h}{\pi r \varepsilon_r}\left[\ln\left(\frac{\pi r}{2h}\right) + 1.7726\right]\}^{1/2} \qquad (3)$$

The modified equation of the resonant frequency of Eq. 1 for the dominant mode TM^z_{110} is given by

$$(f_r)_{110} = \frac{1.8412}{2\pi r\sqrt{\mu\varepsilon}} = \frac{1.8412 v_0}{2\pi r\sqrt{\varepsilon_r}} \qquad (4)$$

A first order approximation to the solution of Eq. 2 for r is to find r_e using Eq. 3 and to substitute that into Eq. 2. This leads to

$$r = F/\{1 + \frac{2h}{\pi r \varepsilon_r}\left[\ln\left(\frac{\pi r}{2h}\right) + 1.7726\right]\}^{1/2} \qquad (5)$$

where
$$F = \frac{8.791 \times 10^9}{f_r\sqrt{\varepsilon_r}} \qquad (6)$$

and h is height of the substrate in cm. The 50Ω characteristic impedance Z_0 of feedline can be computed from the equations 7 and 8, given below:

$$Z_o = \frac{60}{\sqrt{\varepsilon_{eff}}}\ln\left(\frac{8h}{W_f} + \frac{W_f}{4h}\right)\Omega \quad \text{if } \frac{W_f}{h} < 1 \qquad (7)$$

Otherwise

$$Z_o = \frac{120\pi}{\sqrt{\varepsilon_{eff}}} \cdot \frac{1}{\left(\frac{W_f}{h} + 1.393 + 0.677 \ln\left(\frac{W_f}{h} + 1.449\right)\right)}\ \Omega \qquad (8)$$

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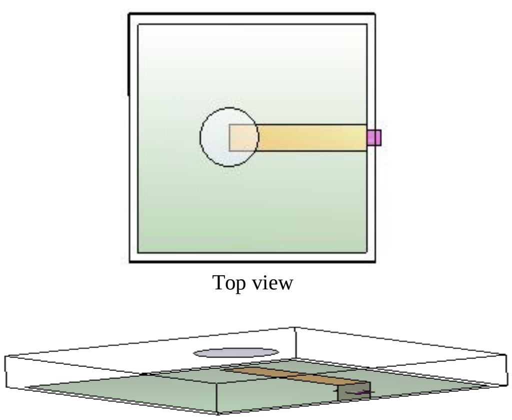
TABLE I. SPECIFICATIONS OF PCMPA AT 10 GHZ

f_r (GHz)	ε_r	h (mm)	μ_r	tan δ_m
10 GHz	4.4	1.6	1	0.0245

where ε_{eff} and W_f are effective dielectric constant and width of feedline in mm. Design specifications of circular PCMPA are listed in Table I.

III. SIMULATION OF ANTENNA MODEL

Equation 4 is used to compute the dimensions of PCMPA and it gives bigger than the actual size (3.6 mm). IE3D version 14.65 simulator is used to calculate best design parameter for circular patch to radiate at 10 GHz [11]. IE3D is a full-wave, method-of-moments (MoM) based EM tool for the design of general 3D and planar structures like microstrip patch antenna and 2D inductors. It solves Maxwell's equations in integral form and its solutions include the wave effects, discontinuity effects, coupling effects, and radiation effects. The radius of simulated size of PCMPA radiating patch is 3.2 mm that resonates at 10.1 GHz. The simulated PCMPA model is illustrated in Fig 2.



Top view

Side view

Fig. 2 Simulated Model of circular disk PCMPA

The modeled antenna is simulated for bulk radiating patch thickness of 17 µm, 10 µm, and 1 µm, and nano thickness radiating patches of 100 nm, 50 nm, and 10 nm thicknesses respectively. For each thickness, conductivity value of 38 MS/m (Aluminum) is used [12]. For all the patch types the computed feedline dimensions W_f and L_f are 3 mm and 15 mm with respect to 50Ω characteristic impedance. The antenna is simulated for infinite ground.

IV. RESULTS AND DISCUSSION

The modelled antennas are simulated for the frequency range from 7 GHz to 15 GHz. Table 2 lists antenna radiation parameters return loss (RL) and bandwidth for different patch thicknesses. The bandwidth of the antenna is defined by:

$$BW(\%)=100\left[\frac{f_{max}-f_{min}}{f_r}\right] \quad (9)$$

f_{max} and f_{min} are determined at -10dB and f_r is the resonant frequency for different patch thicknesses.

Return loss (RL) versus resonant frequency and radiation pattern characteristics of antennas are shown through Fig 3-5.From Table II, it is observed that the percentage bandwidth of nano film antenna (49.65 %) is 65 % higher than that of bulk thickness patch antenna (17.24 %). It is observed that as thickness of radiating patch decreases to 10 nm thickness, bandwidth increases without much change in return loss. This increase in bandwidth may be attributed due to decrease in eddy current loss in the ultra thin nano conducting patch, lesser antenna losses and lesser scattering and diffraction effect on ultra thin patch. In bulk patch, surface irregularities and diffraction contribute more antenna losses.

Radiation characteristics of bulk thickness and nano thickness patch antennas are also studied. Compared to bulk thickness patch radiation characteristics as shown in fig. 4, the nano thickness patch antenna has similar radiation pattern illustrated in fig. 5. From this observation, we can conclude that the patch thickness variation does not affect the radiation behavior of an antenna.

TABLE II. SIMULATED RESULT

Patch thickness	f_r (GHz)	RL (-dB)	BW (GHz)	BW(%)
17 µm	10.09	20.05	1.74	17.24
10 µm	10.10	20.08	1.74	17.22
1 µm	10.11	20.08	1.75	17.30
100 nm	10.15	20.01	1.81	17.83
50 nm	10.10	20.01	1.89	18.71
10 nm	10.25	20.42	5.09	49.65

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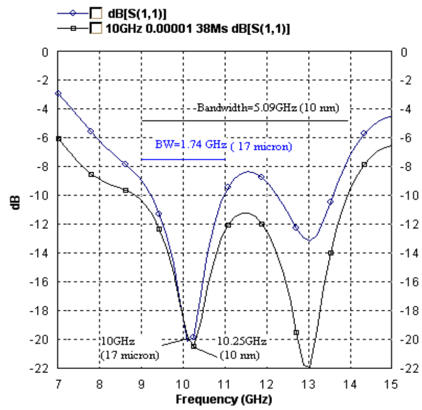

Fig. 3. Simulated result for RL vs. Frequency of 17 micron and 10 nm thickness radiating patches PCMPA

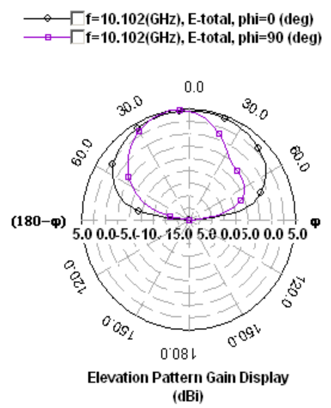

Fig. 4 Simulated radiation pattern of 17 micron thickness radiating patch PCMPA

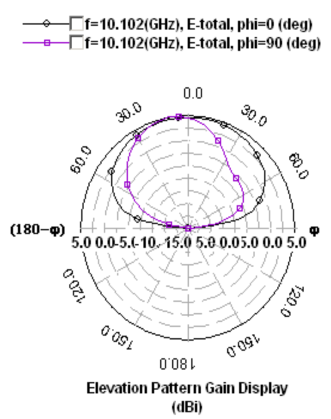

Fig. 5 Simulated radiation pattern of 10 nm thickness patch PCMPA

V. Conclusion

A comparative simulation characterization of bulk thickness radiating film PCMPA and nano thickness radiating film PCMPA is carried out. The nano film antenna shows excellent performance in terms of bandwidth. The enhancement in bandwidth provides higher data rate transmission for WLAN applications. In this work, simulation characterization of proximity fed patch antenna is selected as it offers large band width over other types of antennas like aperture coupled patch antennas etc. It also offers contactless feeding mechanism and electromagnetic coupling between radiating nano film and bulk feedline. This ensures response of patch is not depending on the reliability of the electrical contact between them. It must also be noted that the bulk conductivity value used in this simulation may be different for fabricated nano thickness patch. Hence, it is necessary to investigate fabricated radiating nano patch in terms of skin effect, resistivity and conductivity for RF performance at X-band.

This paper has presented the primary effect of nano film radiating patch on the antenna resonant frequency and bandwidth. Although the effect of nano film widens the bandwidth without change in frequency and return loss, there are still some issues that need to be addressed are radiation efficiency, gain and directivity of the antenna.

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BIOGRAPHY

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