Simulation Characterization of Patch Antenna using Ultra Thin Conductors for Wireless LAN Applications

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ABSTRACT
This paper reports simulated performance analysis of microstrip patch antenna with conducting/radiating patch thickness less than one skin depth (SK) in terms of antenna bandwidth. For performance analysis antenna is designed and modeled for 5.8 GHz applications like WLAN, for which conducting metal copper's fraction of skin depth lies in the nano thickness (1 to 100 nm) range. In this study IE3D industrial standard electromagnetic simulator is used. The fractional skin depth thickness radiating patch is excited through a feeding mechanism known as electromagnetically coupled or proximity feed. The simulation result shows increased bandwidth. The improvement in bandwidth makes antenna more tolerant to variations in fabrication without compromising the operation of the antenna.

Keywords
Microstrip patch antenna, skin effect depth, nano film, bandwidth, nanotechnology

1. INTRODUCTION
Microstrip Patch Antennas are commonly used passive microwave devices in wireless communication systems. These antennas have become popular due to their low profile, light weight and compact size. One of the main limitations of the patch antennas are narrow bandwidth and low radiation efficiency [1]. There have been a lot of good research and development on patch antennas to widen the bandwidth and improving radiation efficiency. One of them is optimizing radiating or conductive element of the antenna. Electrical elements like matching stubs, capacitive loads, meander lines etc. have been used along with the conductive antenna pattern to widen bandwidth [2-3].
Recent advances in material engineering and nanotechnology made utilization of nano materials as radiating patch to enhance radiation properties of patch antenna [4]. This paper reports fraction of skin depth thickness copper metal as conducting patch at 5.8 GHz. At 5.8 GHz frequency the thickness of copper reduces to micro meter thickness (0.850 micron). The performance of antenna that utilizes fractional skin depth thickness conducting patches is compared with one that uses bulk thickness of 17 micron conducting patch.

2. BACKGROUND
The skin effect is the high frequency crowded current density near surface of a conductive material, there by effectively increasing the resistance of the conductive material at microwave frequencies [5]. The skin depth, δ_s of any conducting material is a measure of the skin effect penetration of electromagnetic fields attenuate very rapidly as they penetrate into conductors[6]. The depth δ_s through which current density or electromagnetic fields decreased to e^{-1} factor or 36.8% of its surface value is defined as the skin depth [7]. The relationship between skin depth and frequency is defined by

$$\delta_s = \sqrt{\frac{2}{\omega\,\mu\,\sigma}} = \sqrt{\frac{\rho}{\pi\, f\,\mu}} \qquad (1)$$

where:

μ = permeability of the metal $\left(4\pi * 10^{-7}\ \text{H/m}\right)$

π = pi

δ_s = skin depth (m)

ρ = resistivity ($\Omega * \text{m}$)

ω = radian frequency=$2\pi * f$ (Hz)

σ = conductivity (S/m)

From equation (1), we can deduce three key conclusions that surround the fabricating process of the antenna:

1) The higher the frequency (in this particular case, 5.8 GHz), the smaller the skin depth

2) The higher the conductivity (in this particular case, conductivity of copper is $5.8*10^7$S/m), the smaller the skin depth.

3) The higher the permeability (in this particular case, 1. In case it is not that high, which needs high attention while printing process), the smaller the skin depth.

A conductive material having a thickness equal to its skin depth functions as a high dielectric constant material at frequencies below the resonant frequency that defines the skin depth [6]. The quality factor, Q, of an antenna is given by

$$Q = 2\pi \frac{\text{Time-average energy stored at a resonant frequency}}{\text{Energy dissipated in one period of this frequency}} \qquad (2)$$

The quality factor 'Q' is a measure of the bandwidth of the antenna, where

$$Q = \frac{f_r}{\text{bandwidth}} \qquad (3)$$

where f_r is the resonating frequency. All antennas including microstrip patch antenna have much lower quality factor due to radiation losses. Hence stored energy is lower as are radiating currents and resistive losses. The low 'Q' of patch antenna is caused by losses due to antenna radiation. In addition, resistive and dielectric losses in antenna produce small decrease in the 'Q' of the antenna. Further, losses in the skin depth thickness conductor decreases quality factor 'Q' of the antenna thereby increase in the bandwidth [6].

3. METALLIC THICKNESS MODELING

The conducting metal patch thickness of the antenna is modeled using IE3D electromagnetic simulator, for both bulk and fractional skin depth nano thickness on FR4 substrate of 1.6 mm thickness [8]. In IE3D there are two ways to model metallic thickness. One is the finite thickness model where the current flows on the four sides of the patch as illustrated in figure 1(a). The other way is to use infinitely thin strip to model the patch, where the current is assumed on one single strip only as shown in figure 1(b). The bulk thickness patch is modeled using finite thickness model and fractional skin depth thickness is modeled using infinite thickness model. In this work we modeled copper metal for the proposed microstrip patch antenna. The copper metal is having the advantage of hardness and high electrical conductivity.

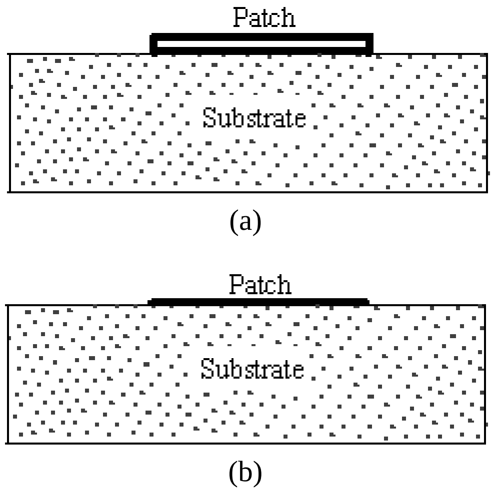


Figure 1: IE3D metal thickness model (a) finite (thick) thickness (b) infinite (thin) thickness

The electrical parameters of copper metal are listed in Table 1.

Table 1. Modeled Metal Patch Electrical Specifications

Metal	Conductivity (σ)	Resistivity (ρ)	Permeability (μ)
Copper	$5.8*10^7$ S/m	6.34 $\Omega*10^{-8}$m	1

The proposed antenna is designed for WLAN application with resonant frequency of 5.8 GHz. The bulk thickness of the conducting patch is taken as 17 micron. Substituting table 1 electrical parameters in to equation (1) computes skin depth thickness of conducting patch to 0.85 micron.

4. ANTENNA DESIGN AND MODELING

In the present research work non contact feeding method is opted for microstrip antenna. This overcomes the problem of reliable connection between bulk metallic microstrip feedline and nano thickness (fractional skin depth thickness) conducting patch. The antenna configuration is known as proximity or electromagnetically coupled antenna. In proximity coupled microstrip antenna configuration, the radiating patch fabricated on a top dielectric substrate, is fed by a microstrip feedline on another bottom substrate, as illustrated in figure 2. Proximity coupling has the advantage of allowing patch to exist on a relatively thick substrate for improved impedance bandwidth while the feed line sees an effective thinner substrate which reduces spurious radiation and coupling [9].

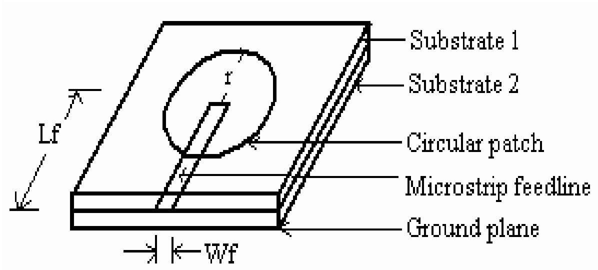


Figure 2: Structure of the circular proximity coupled microstrip patch antenna

The circular patch is fed by proximity coupled microstrip line placed between two dielectric substrates. The proximity coupled patch adds an extra degree of freedom to the design. A good impedance match can be obtained by selecting proper value of the feedline width and by adjusting radius of the patch. The advantage of a circular patch antenna configuration compared to its rectangular counterpart for an identical design is that the circular patch occupies less space. In applications, such as arrays, circular structures are preferred. The antenna was designed to operate at resonant frequency of 5.8 GHz and input impedance of 50Ω. Table 2 shows the design parameters for substrates.

Table 2. Design data for FR4 substrates

Substrate thickness (h)	Permittivity (ε_r)	Permeability (μ_r)	Loss tangent (tan δ)
1.6 mm	4.4	1	0.0245

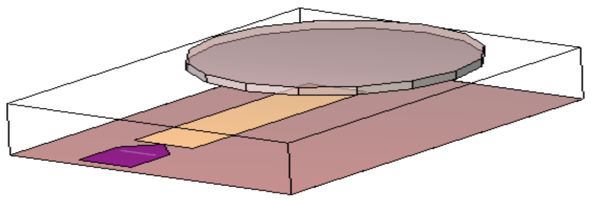
Good impedance matching is obtained using IE3D software by selecting the proper value of the microstrip line width and by adjusting the length under circular resonator. The circular patch is designed using cavity model and optimized using IE3D simulator. For 5.8 GHz, the dimension detail of proximity coupled patch antenna is given in table 3.

Table 3. Dimensions of patch antenna at 5.8 GHz

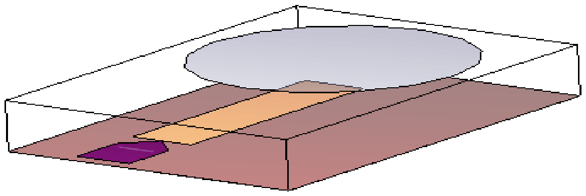
Radius of patch	Total substrate height (h)	Feedline width(W_f)	Feedline length(L_f)
6.2 mm	3.2 mm	3 mm	12 mm

5. ANTENNA SIMULATION

IE3D version 14.65 electromagnetic simulator is used to calculate the best design parameter for circular patch to radiate at 5.8 GHz. IE3D simulator is a full wave, method of moments (MOM) based electromagnetic tool used for the design of general 3D and planar structures like patch antennas. It solves Maxwell's equation and its solutions include discontinuity effects, wave effects, coupling effects, and radiation effects. The simulated proximity coupled circular patch antenna model for bulk thickness and thin thickness patch is shown in figure 3. The modeled antenna is simulated for radiating patches of bulk thickness (17 micron), and, the thickness between $2\delta_s$ and $0.01\delta_s$ where δ_s is skin depth thickness (850 nm) at operating frequency of 5.8 GHz. For all patches, the antenna is simulated for infinite ground in order to avoid any back lobes.



(a)



(b)

Figure 3: Simulated proximity coupled circular patch antenna using IE3D models (a) bulk patch (b) thin patch

6. RESULTS AND ANALYSIS

The modeled antennas are simulated for the frequency ranges 4 GHz to 7 GHz. Table 4 shows the simulation results of bulk thickness and fractional values of skin depth thickness in terms of return loss and bandwidth. The bandwidth of an antenna is given by

$$BW(\%) = 100\left[\frac{f_{max} - f_{min}}{f_r}\right] \quad (4)$$

It is seen that as thickness decreases from bulk to fractional skin depth, there is an increment in bandwidth (BW) from 8.75% to 11.6%, i.e. overall 24.5% improvement of $0.01\delta_s$ thickness patch over 17 micron bulk thickness patch. In addition to bandwidth, there is an improvement in return loss (RL) from -23.5 dB to -28.9 dB. Figure 4(a-b) illustrates return loss vs. frequency plot for bulk and fractional skin depth patch antennas.

Table 4. Simulation results

SK Model	Patch thickness	f_r (GHz)	RL (-dB)	BW (MHz)	BW (%)
$20\delta_s$	17 µm	5.79	23.5	507	8.75
$2\delta_s$	1.70 µm	5.79	22.9	512	8.84
δ_s	0.85 µm	5.79	22.9	513	8.86
$0.5\delta_s$	0.42 µm	5.79	22.9	515	8.89
$0.05\delta_s$	43 nm	5.79	24.6	550	9.49
$0.01\delta_s$	10 nm	5.79	28.9	677	11.6

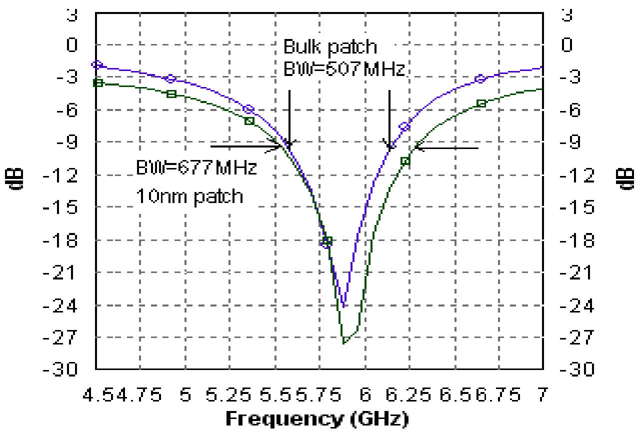
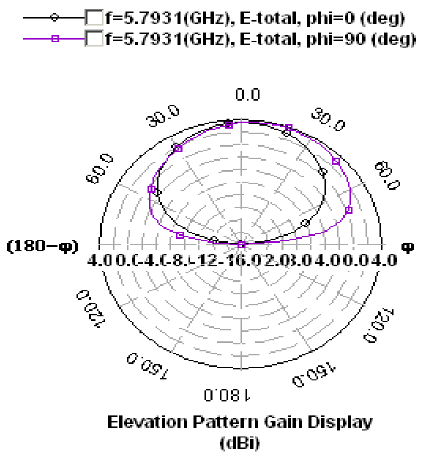
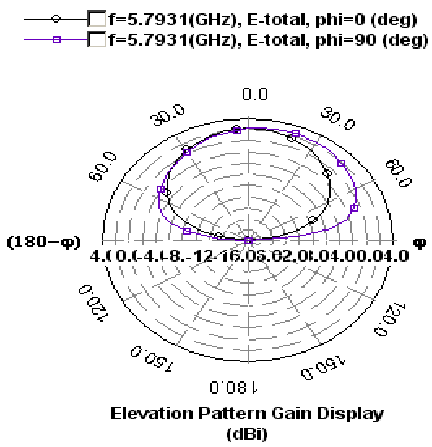


Figure 4. Simulation plot between return loss vs. frequency

Another important observation made is radiation pattern for bulk patch and fractional skin depth thickness patch. Fractional skin depth thin patch antenna has same radiation pattern as bulk thickness patch antenna. It is clear that change in thickness from bulk to fractional skin depth thickness does not affect radiation pattern of an antenna. Figure 5(a-b) illustrates radiation pattern for both type of antennas.



(a)



(b)

Figure 5. Simulated radiation pattern (a) bulk thickness (17 micron) patch, (b) ultra ($0.01\delta_s$: 10 nm) thin patch

7. CONCLUSION

This paper has discussed and presented modeling and effect of skin depth thickness on performance of electromagnetically coupled microstrip patch antenna. The skin depth and its fractional thickness are modeled using infinite (thin) model, and bulk thickness is modeled using finite (thick) model, using IE3D simulator. The skin depth is modeled between δ_s and $0.01\delta_s$. The fractional skin depth patch thickness (10 nm) forms ultra thin conductor. Compared to bulk thickness conductor antenna, ultra thin conducting patch antenna shows increased return loss and improvement in bandwidth. The increased bandwidth allows higher data rate transmission for wireless LAN applications at 5.8 GHz. With recent advances in material engineering and nanotechnology, it is possible to deposit metal in nano thickness on substrates. This type of deposition allows us to save conducting metals during fabrication of antennas, where as in conventional lithographic fabrication, excess metal is being removed.

8. ACKNOWLEDGMENTS

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