COPPER NANOFILM ANTENNA FOR WLAN APPLICATIONS

Rajendra R. Patil¹, Vani R.M², P.V. Hunagund³

¹,³Department of Applied Electronics, Gulbarga University, Gulbarga-585106 India
²University Science Instrumentation Center, Gulbarga University, 585106 India

ABSTRACT

In this article we investigate the reliability of copper nanofilm as radiating patch on FR4 substrate for radiation properties. Pure copper is deposited through RF-sputter system at room temperature to a thickness around 100 nm on 1.6 mm height FR4 dielectric substrate to produce a 5.8 GHz nanofilm antenna. The effect of ultrathin copper metallization i.e. on antenna parameters such as resonant frequency, return loss, bandwidth and gain are investigated. The nanofilm antenna is compared with bulk copper patch of 17 micron thickness of antenna. It is found that nanofilm antenna presents wide bandwidth, higher return loss and slightly decreased gain over bulk patch antenna. The nanofilm antenna finds applications in, such as wireless LAN where short distance higher data rate transmission is required. The results encourage incorporating metallic nanofilm as a radiating element of an antenna for wide bandwidth improvement.

Keywords: Copper Nanofilm, Skin Depth, Patch Antenna, Wireless LAN.

1. INTRODUCTION

Microstrip patch antennas (MPAs) are widely used radio frequency/microwave passive devices in cellular communications, wireless sensor networks (WSN), wireless local area networks (WLAN), global positioning systems (GPS) etc. The MPAs have advantages such as low profile, light weight, low cost etc. The limitations of MPAs are narrow bandwidth, low gain, low efficiency and low power handling capacity. Nowadays, there is a continuous expansion of wireless system applications that demands higher bandwidth for high data rate transmission. The aim of this research is to discuss the usability of conducting ultra thin copper metal nanofilm (around 100 nm) radiating patch of antenna for bandwidth enhancement in wireless communication.

In this work, our study originates from previous work done in [1], where aperture coupled microstrip antenna with different nanofilm metals like Aluminum, Chromium, Titanium and Nickel patch were used. In this paper, we have considered other antenna structure with different metal nanofilm. We have designed, simulated, and fabricated bulk and nanofilm copper patch antennas...
with proximity feeding technique. This technique enables nanofilm metallic patch coupling to bulk microstrip feed line through electromagnetic radiation. This scheme also avoids having physical reliable contact between bulk and nano thickness metallic parts, like aperture coupled antenna. The proximity coupled antenna as described in [2], has the largest bandwidth as high as 13 percent, is easy to model and has low spurious radiation. However its fabrication is somewhat more difficult. The length and width of the feeding strip line, and width-to-line ratio of the patch is used to control the impedance match for a particular frequency resonance. The design and simulation was done by using IE3D simulator which is based on method of moment (MoM) [3].

2. THE DESIGNED ANTENNA

![Antenna Diagram]

**Figure 1**: Geometry of 5.8 GHz proximity coupled microstrip patch antenna. Top FR4 substrate dimensions: $25 \times 25 \times 1.6 \text{ mm}^3$; bottom FR4 substrate: $35 \times 35 \times 1.6 \text{ mm}^3$. The total height $h$ of FR4 substrates: 3.2 mm. Feedline dimensions $w_f \times l_f$ for 50 $\Omega$ impedance match: $3 \times 20 \text{ mm}^2$; Rectangular patch dimensions $W_p \times L_p$: $15 \times 10 \text{ mm}^2$

The proximity coupled antenna geometry is illustrated in figure 1. The antenna structure uses two layer substrate with the microstrip feed line on the bottom substrate and the rectangular metallic patch antenna on the top substrate. The microstrip feed line terminates in an open end underneath the centre of the rectangular patch. The coupling between the patch and the microstrip line is capacitive in nature [4]. Thus, this feeding technique is also known as “electromagnetically coupled” microstrip feed. The antenna dimensions shown in figure 1 are found by simulating the model antenna using IE3D simulator. The simulated results shows antenna resonates at 5.79 GHz with a return loss of -30 dB, and a bandwidth of 582 MHz. Figure 2 illustrates simulated results.

![Simulated Return Loss and Radiation Pattern]

**Figure 2**: Left: Simulated return loss characteristics; Right: Radiation pattern at 5.79 GHz
3. ANTENNA FABRICATION

3.1 Bulk Patch Antenna Fabrication

The bulk antenna is fabricated using photolithographic process. As per dimensions listed in figure 1, the copper clad (17 micron thickness) FR4 PCB is etched for microstrip feed line and ground. The bulk copper (17 micron thickness) antenna of $15 \times 10$ mm$^2$ is etched on top of upper FR4 substrate. The fabricated antenna is listed in figure 4.

![Fabricated Proximity coupled bulk patch antenna](image1)

**Figure 4:** Fabricated Proximity coupled bulk patch antenna; Left: Bottom substrate; Centre: bulk copper patch on top FR4 substrate; Right: The antenna structure with SMA connector

3.2 Nanofilm Patch Antenna Fabrication

Since, bottom FR4 substrate with bulk copper microstrip feed line and ground metallization is used for both bulk patch antenna and nanofilm patch antenna, we fabricate only nanofilm antenna on FR4 substrate. The copper nanofilm patch antenna is fabricated by RF-sputtered deposition (5) of pure copper for a thickness around 100 nm on FR4 substrate at room temperature. The average thickness of the deposited copper nanofilm on FR4 substrate is about 104 nm, confirmed by Scanning Electron Microscopy (SEM) [6] as shown in the figure 5.

![SEM micrograph showing deposited copper in nanometer thickness on FR4 substrate](image2)

**Figure 5:** SEM micrograph showing deposited copper in nanometer thickness on FR4 substrate surface
The complete proximity coupled copper nanofilm antenna structure is illustrated in figure 6.

Figure 6: Left: Copper nanofilm deposited on top FR4 substrate; Right: Copper nanofilm based proximity coupled microstrip patch antenna with microstrip feed line connected to SubMiniature Version A (SMA) connector

4. RADIATION MEASUREMENTS

The Rhode-Schwarz make vector network analyzer model ZVK 1127.8651.60 is used to measure the experimental resonant frequency, return loss, bandwidth and gain of bulk patch and nanofilm patch antenna. The experimental results are listed in Table 1.

4.1. Bulk Patch Antenna characterization

Figure 7 shows variation of return loss versus frequency graph of bulk patch antenna. From RL vs. \( f_r \) graph it is seen that the antenna resonates at 5.8 GHz frequency with -13.84 dB return loss. The experimental impedance bandwidth over return loss less than -10 dB is computed using

\[
\text{BW(\%)} = \left( \frac{f_h - f_l}{f_r} \right) \times 100 \%
\]

where \( f_h \) and \( f_l \) are lower and upper cut-off frequencies of the resonating bands when their return loss reaches -10 dB return loss points, and \( f_r \) is the resonating centre frequency of \( f_h \) and \( f_l \). From eq. (1) the bandwidth is found to be 350 MHz or 6 %. Similarly, co-planar and cross-polar radiation patterns of an antenna are measured at 5.7 GHz is shown in figure 7.

Figure 7: Left: Variation of RL vs. \( f_r \); Right: Radiation pattern of bulk copper patch antenna at 5.8 GHz
The gain of the bulk thickness patch antenna is calculated using absolute method is given by the relation [4]

\[ G(\text{dB}) = 10 \log \left( \frac{P_r}{P_t} \right) - (G_d) \text{ dB} - 20 \log \left( \frac{\lambda_0}{4\pi R} \right) \text{ dB} \]  

(2)

Where \( P_t \) and \( P_r \) are transmitted and received power, \( R \) is the distance between transmitting pyramidal antenna and receiving antenna under test. The peak gain is found to be 16 dB.

4.2. Nanofilm Patch Antenna characterization

The variation of return loss and frequency is shown in figure 8. From this figure it is seen that, the antenna resonates at 5.64 GHz for a return loss of -37.58 dB. From equation (1) the calculated bandwidth is found to be 810 MHz or 14.36%. Similarly, co-polar and cross polar radiation patterns are measured at 5.64 GHz frequency. Measured radiation pattern in H-plane at 5.64 GHz is shown in figure 8, right side. The peak gain for nanofilm is calculated from equation (2) is found to be 13.59 dB. The results are summarized in Table 1.

![Figure 8: Left: Variation of RL vs. f_r; and Right: Radiation pattern at 5.64 GHz frequency](image)

**Table 1:** Experimental result for f_r, RL, BW and gain of bulk patch and nanofilm antenna

<table>
<thead>
<tr>
<th>Antenna Type</th>
<th>f_r (GHz)</th>
<th>RL (-dB)</th>
<th>BW (MHz)</th>
<th>BW (%)</th>
<th>Gain (dB)</th>
</tr>
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<tbody>
<tr>
<td>Bulk</td>
<td>5.79</td>
<td>13.84</td>
<td>350</td>
<td>6.00</td>
<td>16.08</td>
</tr>
<tr>
<td>Nanofilm</td>
<td>5.64</td>
<td>37.54</td>
<td>810</td>
<td>14.36</td>
<td>13.59</td>
</tr>
</tbody>
</table>

5. DISCUSSION

The measured results for resonant frequency, return loss, bandwidth and gain are presented in Table 1. As shown in the Table 1, the copper nanofilm patch antenna resonates at 5.64 GHz against the simulated and experimental values of bulk patch antenna. The difference in resonant frequency may be attributed to the nanofilm fabrication process tolerances. Since the little change in mask dimensions along the length of the antenna may change slight variation in resonant frequency. The nanofilm antenna shows good 50 \( \Omega \) impedance matching between feedline and ultra thin patch compared to bulk patch antenna. Similarly the impedance bandwidth of nanofilm patch antenna is 56.79% more over bulk patch antenna. This increase in bandwidth is attributed to higher surface resistance of the film around 100 nm. When metal depositions on FR4 substrate are thinner than skin depth \( \delta_{sk} = \sqrt{2/\sigma\mu} \) (skin depth: 0.871 micron at 5.64 GHz), the surface resistance increases as a function of thickness t [7], compounded by the doubling of the surface resistance. This doubling of the surface resistance decreases ‘Q’ of the antenna and thereby increasing the bandwidth. Thin film
depositions smaller than skin depth create severe skin effect losses that deeply influence antennas at microwave frequencies. The gain measurement shows lesser gain in nanofilm patch than bulk patch antenna. This may be attributed due to more conductor losses (due to higher surface resistance), dielectric losses of the material used, and surface waves exist (thick substrate).

6. CONCLUSION

In this paper, a copper metal nanofilm based microstrip patch antenna is proposed for wireless LAN applications. The antenna is designed, fabricated and measured. The nanofilm antenna gives wide bandwidth and increased return loss. There is not much deterioration in the radiation characteristics of nanofilm antenna. It is closer to bulk patch antenna radiation. However there is decrease in the gain in the nanofilm antenna. The nanofilm antenna finds application in Wireless LAN, where high data rate transmission is required.

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