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Simulation and experimental characterization of silver Nanofilm Microstrip patch antenna

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ABSTRACT

In this paper we report simulation and experimental characterization of microstrip antenna that employs silver nanofilm as radiating patch. The bulk silver is deposited to a thickness of 30 nm using physical vapor deposition system. In this work non-contacting feed aperture coupled patch antenna is used in order to avoid soldering problem between nanofilm (ultrathin) and bulk copper feed thickness of 17 micron. The experimental result of fabricated nanofilm antenna shows wide bandwidth response over bulk patch antenna. Using nanofilm, an optimum bandwidth of 12% is obtained which is 50% higher than bulk patch antenna. The nanofilm antenna resonates around 6.5 GHz finds application in 'C' band frequency.

Introduction

Microstrip patch antennas are the most common form of printed antennas used for applications in wireless communications ranging from satellite communication, Doppler and other radars, missile telemetry to environmental instrumentation and remote sensing [1]. They have attractive features of light weight, low profile, Omni-directional radiation pattern and low cost solutions that can be easily integrated with microwave circuits [2]. A narrow bandwidth is, however, the main drawback of the microstrip patch antennas [3-4]. Many practical applications demand bandwidth enhancement. Thus the bandwidth enhancement is becoming important design considerations for practical applications of patch antennas. Some approaches have been therefore developed for bandwidth enhancement [5-7]. Among those, one is to increase the height of the dielectric substrate while the other is to decrease the substrate dielectric constant. Certainly, the first one increases the size of the antenna, and the latter will induce the matching circuits to be impractical due to excessively wide lines designed.

Recently researchers are working on the nano material to increase the bandwidth and compactness of the antenna [8-9]. Nano material technique is the novel way to increase the bandwidth of the antenna in respect to the existing bandwidth enhancement techniques.

In this paper we focused on silver nano material deposited microstrip patch antenna as radiating element to increase the bandwidth at 6.5 GHz. To the best of our knowledge, there is limited amount of literatures are available on this novel work. Choice of conducting radiating element, deposition cost and application scope restrict the antenna structure.

Antenna Design

A microstrip patch antenna in its simplest form is a layered structure with two parallel conductors separated by a dielectric substrate and the conductor. The upper portion conducting pattern is a patch responsible for radiating the electromagnetic energy in free space. The radiating elements and the feed lines are usually photo etched on the dielectric substrate. The patch is generally made of conducting material such as copper or gold and can take any possible shapes like square, rectangular, thin strip, circular, elliptical, triangular or any other configuration are illustrated in figure 1 [2].

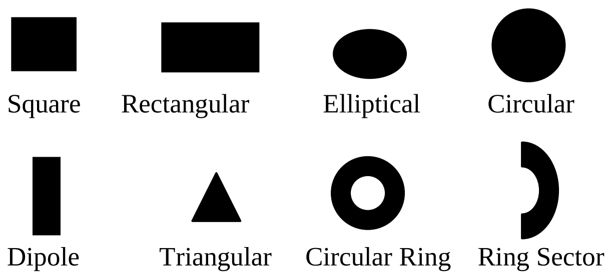

Figure 1. Various shapes of Microstrip Patch Antenna

For experimental characterization of silver nanofilm antenna, we have selected aperture coupled microstrip patch antenna (ACMPA). In aperture coupled microstrip antennas, the field is coupled from the microstrip line feed to the radiating patch through an electrically small aperture or slot cut in the ground plane of lower substrate. The coupling slot is usually centered under the radiating patch, providing low cross-polarization due to the symmetry. The shape, size, and location of the aperture decide the amount of field coupling from the fed line to the patch. The antenna design was undertaken through simulations using the IE3D software version 14.65 [10]. Figure 2 shows the arrangement of the ACMSA. The ACMPA offers two advantages over other antenna types. First, the coupling between nano thickness radiating film and bulk copper feedline will be taking place through electro-magnetic field, thus avoids reliable physical contact between nanofilm and copper bulk feed, and the second is ACMPA offers greater design flexibility through feedline, slot and patch dimensions [11].

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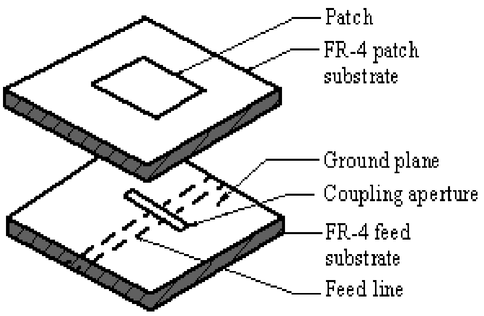
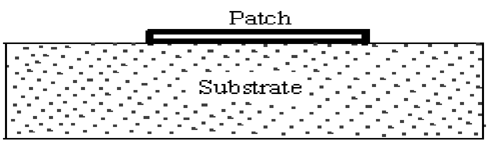


Figure 2. Geometry of Aperture Coupled Patch Antenna

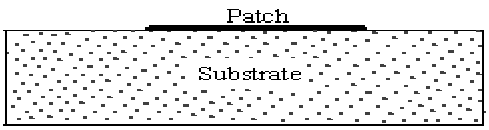
In this work we have selected 35x35 mm FR4 substrate with dielectric constant of 4.4, material loss tangent of 0.0245 and height of 1.6 mm. Since top FR4 substrate is placed on bottom substrate, the total height of the antenna substrate will be 3.2 mm. The antenna uses rectangular patch of size 14 mm by 10 mm, slot size of 8.5 mm by 1 mm, and feedline dimension of 27 mm by 3 mm to resonate at 6.38 GHz.

Antenna Simulation

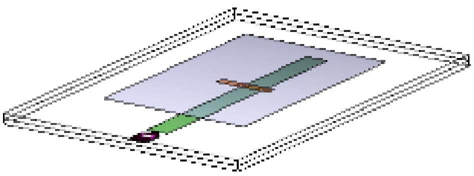
The ACMPA is simulated for both bulk silver patch antenna and nanofilm silver patch antenna using industry standard Zeland IE3D version 14.65 ver. from Mentor Graphics Inc, USA. For simulating bulk silver patch antenna, silver conductivity of 6.3×10^7 S/m is being used. And, for silver nanofilm antenna simulation, conductivity of 2.58×10^7 S/m is being used. According to [12], if thickness of silver film is less than its electron mean free path (57 nm for silver), its resistivity increases (conductivity decreases). In IE3D, the bulk silver patch is modeled using thick film, while nanofilm is modeled using thin patch model as shown below in figure 3(a-b). In case of thick film model the current flows on four sides of the patch considering skin depth, while in thin patch model the current flows on one single strip only, since thickness is less than skin depth of silver. The simulated ACMPA is shown in figure 3(c).



(a)



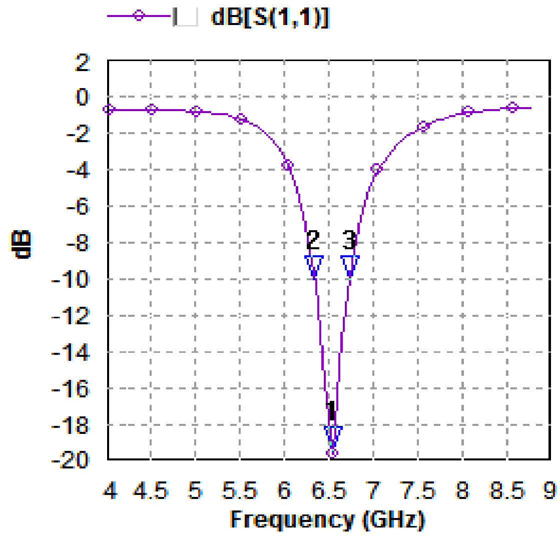
(b)



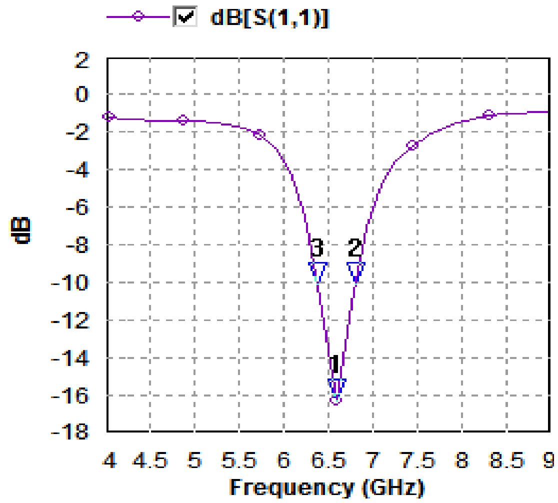
(c)

Figure 3. ACMPA (a) Bulk patch model (b) nanofilm thin patch model (c) simulated model

The ACMPA simulation is carried out for bulk patch and nanofilm patch antennas. The resonant frequency vs. return loss graphs are illustrated in figure 4. The radiation results in terms of resonant frequency (f_r), return loss (RL), and bandwidth (BW) are listed in table 1 for comparison with fabricated nanofilm patch antenna.



(a)



(b)

Figure 4. ACMPA simulated f_r vs. RL graph (a) Bulk patch (b) nanofilm patch antenna

Antenna Fabrication Process

Antenna fabrication consists of two parts. One is to fabricate bottom FR4 substrate of thickness 1.6 mm with a bulk copper (17 micron) feedline of dimensions 27 mm by 3 mm on bottom side, and etching a slot of size 8.5 mm by 1 mm in ground on top side.. The bottom substrate is fabricated using gum tape and ferric chloride solution.

Second, the top patch radiator, 14 mm by 9 mm, is fabricated by depositing a bulk silver of 99% purity to a thickness of 30 nm on a 0.3 mm plastic paste which is pasted on top of FR4 substrate of thickness 1.6 mm with non-conductive araldite standard epoxy adhesive, which is easily available in local market, using Physical Vapor Deposition (PVD) system [13]. The deposited silver nanofilm thickness is monitored by digital thickness meter attached to PVD system through quartz crystal inside the PVD system. The fabricated ACMPA is shown in figure 5.

(a)

(b)

Figure 5. Fabricated ACMPA (a) Slot in ground plane on top of lower FR4 substrate, right: Silver nanofilm on top of upper FR4 substrate (b) feedline on downside of bottom FR4 substrate, right: bottom side of top FR4 substrate

Antenna Experimental Characterization

The fabricated ACMPA antenna with silver nanofilm was experimentally characterized for f_r, RL and BW using Rhode-Schwarz vector network analyzer model ZVK 1127.8651.60. The frequency is swept from 500 MHz to 16 GHz. The graph of resonant frequency vs. return loss is illustrated in figure 6. The experimental results are listed in table 1 along with simulated results for comparison.

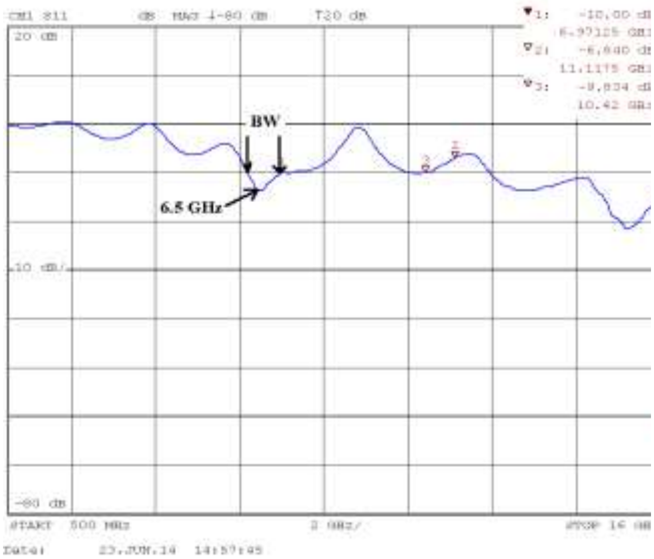


Figure 6. Experimental graph of f_r vs. RL

Table 1. Simulated and Fabricated Antenna Result

Antenna Patch Type	Antenna Radiation Parameters			
	f_r (GHz)	RL (-dB)	BW (MHz)	BW (%)
Bulk, Simulation	6.50	19.57	394	6.0
Nanofilm, Simulation	6.58	16.18	421	6.39
Nanofilm, Fabricated	6.50	13.82	780	12.0

Results and Discussion

The modeled and designed antennas with bulk patch and nanofilm are simulated and experimentally characterized using IE3D simulation software and vector network analyzer. The bandwidth response in each case is listed in table 1. The percentage bandwidth of an antenna is given by

$$BW\,(\%) = 100\left[\frac{f_{max} - f_{min}}{f_r}\right] \quad (1)$$

From table 1 it is observed that the antenna resonates around 6.5 GHz for both simulated and fabricated. This signifies variation in thickness of patch does not alter the resonant frequency i.e. resonant frequency is independent of variation in patch thickness. In case of return loss, as patch thickness decreases to ultra thin level, the impedance match between bulk feedline and nanofilm increases, hence decrease in return loss. However, in case of bandwidth, as thickness of patch reduces to ultrathin level, the 'Q' of patch decreases thereby increases in bandwidth. The enhancement in bandwidth from 6% to 12% through patch height reduction contributes an increase of 50% bandwidth of nanofilm antenna over bulk patch antenna. Another important parameter that is compared between bulk patch and nanofilm antenna is radiation pattern. The radiation pattern of simulated bulk patch is same as simulated nanofilm antenna. The significance is patch thickness variation does not affect radiation pattern of an antenna, as shown in figure 7(a-b). This makes antenna more tolerant to fabrication variation without compromising antenna operation.

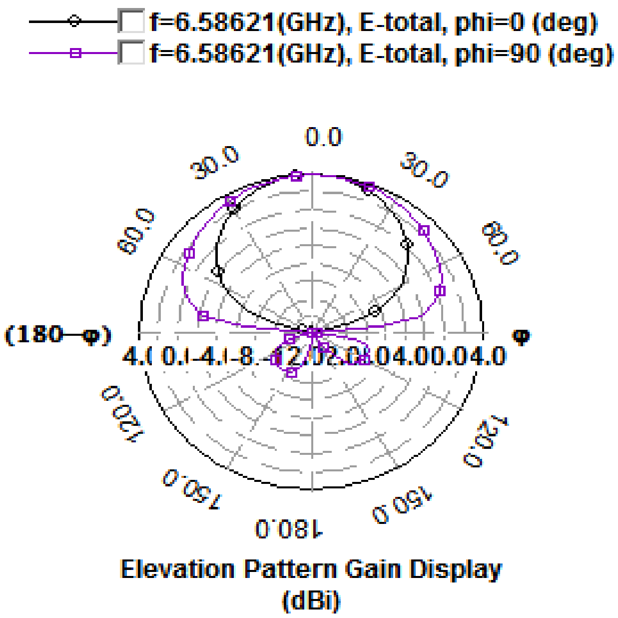


Figure 7(a). Radiation pattern of bulk patch antenna

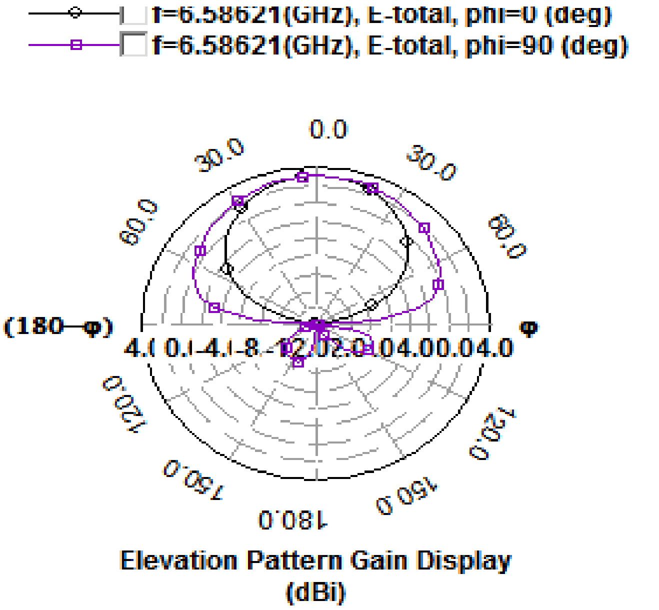


Figure 7(b): Radiation pattern of nanofilm patch antenna.

Conclusion

A simulated and fabricated ACMPA antenna is presented with bulk and silver nanofilm thickness. The research shows increase in bandwidth due to reduction of radiating patch height from 17 micron thickness to 30 nm thickness. There is no change in other radiation parameters like radiation pattern and return loss between bulk and nanofilm patch antennas. The increase in surface resistance of nanofilm plays important role in increasing the bandwidth, since it decreases the 'Q' level of patch. The bandwidth of the antenna can be changed by varying the thickness of radiating patch below metals electron mean free path. A simulated result of the proposed nanofilm ACMPA is verified with experimental results. The proposed antenna can be used in 'C' band frequency applications. With recent technological advances in material science and engineering it is possible to deposit and save noble metals like silver and copper by PVD system, whereas in conventional lithographic fabrication, a lot of material is being removed and wasted. In this research work we have selected aperture coupled microstrip patch antenna, since patch is excited through aperture in the ground through magnetic coupling, since maximum coupling occurs when the aperture is centred below the patch**,** where the magnetic field is maximum [11], without having reliable physical contact between them.

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