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Frequency Reconfigurable Antenna Based on Optically Tuned Multi-layered Substrate

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Abstract—*Reconfigurable Antennas (RA) have been considered as one of the favourable solutions for multi-frequency antennas as RA offers the agility in the resonating frequency. In this work, we propose an optically tuneable substrate material based frequency reconfigurable planar antenna with constant radiation pattern and polarization. The substrate material is designed as a multilayer substrate material containing Lead Sulfide (PbS), Plexiglas and glass epoxy (FR4) layers. The method to tune the antenna resonating frequency is based on the change of the dielectric constant of the substrate material upon the incidence of light of suitable wavelength on it. Photo conducting behaviour of Lead Sulfide is used to tune the material as with the incidence of the light dielectric constant of the layer changes. The dependence of antenna resonant frequency on the dielectric constant offers a shift of antenna resonant frequency by illuminating the PbS layer with a light source in the near infra-red region. The proposed antenna is verified by both simulations and experiments. The proposed antenna exhibits a frequency reconfigurability of ~ 0.16 GHz with a constant broad sight radiation pattern of ~ 60.0 ° (- 3 dB). Gain, efficiency, and cross polarization isolations are also in the acceptable range of around 7.2 dBi, 64.2 %, and -10 dB respectively.*

1. INTRODUCTION

Reconfigurable antenna (RA) has gained a lot of attention in recent years for applications in the wireless communications. RA has the ability to offer versatility in terms antenna resonating frequency, radiation pattern, and polarizations, thereby providing the additional performance enhancements [1]. Widely spread multi-standards wireless communications requires the service of antennas at different frequency bands. The accessibility of multiple frequency bands can be achieved by using a set of antennas or by a wide band antenna. However, in many cases these methods are may not be suitable due to some constraints like space limitations, system complexities etc [2, 3]. In such cases frequency, reconfigurable antennas can be considered as the alternative. In the recent years, various approaches are made to realize frequency reconfigurability in a single antenna. Most of these approaches involve the uses of electrical switching elements like RF-MEMS, PIN diodes, Varactor etc [4-6]. The ease of integration of these switches to the planar antennas makes them popular. However, they enforce some disadvantages also. These includes the high biasing voltages, interference due to the biasing lines, non-linearity, slow response time etc. and they may affect the antenna operating characteristics [1]. In another approach, the frequency of the planar antenna is reconfigured by altering the dielectric constant of the substrate material. The dielectric constant of the specially developed material is altered by applying an external electric or magnetic fields [7]. The method has some advantages over the electrically controlled technique as it is free from the effects of biasing lines and non-linearity shown by the switching elements.

In this work, we have investigated the shifting of resonating frequency of a planar microstrip patch antenna (MPA) fabricated upon a modified substrate material, which dielectric constant can be varied by the light illumination of the suitable frequency range. The modified substrate material designed as a multilayered substrate having layers of Lead Sulfide (PbS), Plexiglas and glass epoxy (FR4).

2. THEORY OF OPERATION

The developed reconfigurable antenna is based on the standard MPA, whose resonating frequency depends on the dielectric constant (ε_r) of the substrate material and length (L) of the radiating patch and it varies according to the equation 1 [8].

$$f_r = \frac{\upsilon_0}{2L\sqrt{\varepsilon_r}} \qquad (1)$$

In the designed antenna the substrate material is modified by creating multiple layers of lead sulfide (PbS), Plexiglas and glass epoxy (FR4). The photo-conducting behavior of PbS plays the key role in changing the dielectric constant of the modified substrate. The dielectric constant of PbS alters according to the following equation 2 because of its photoconductive nature in the mid-infrared regime [9].

$$\varepsilon_r = \varepsilon_L + \frac{ne^2}{m^*\varepsilon_0(-w^2 + j\frac{w}{\tau})} \qquad (2)$$

Where,

ε_r= Dielectric constant of the material under illumination

ε_L= Dielectric constant of the material without illumination

n=No of charge carriers

e= Electric charge

m^*= Effective mass

ε_0= Permittivity of free space

w= Applied frequency

τ= Collision time

With the illumination of the suitable frequency of light, the PbS layers change it states from non-conducting to conducting as the number of charge carriers increases. The dielectric constant of the PbS layers also changes with illumination. As the substrate material is developed by combining multiple layers of PbS thin films, the effective dielectric constant the modified substrate also changes with illumination. This alternation of dielectric constant leads to a shifting of antenna resonant frequency.

3. DESIGN AND FABRICATION

The proposed antenna is designed and fabricated in the following steps.

3.1 Synthesis of PbS Thin Films

The photoconductive films of PbS are deposited on FR4 substrates using chemical bath deposition. The bath contains equimolar solutions of lead acetate and thiourea. The deposition temperature, pH value are maintained at 300 deg centigrade and 10 for 45 minutes. The deposited films are then washed with deionized water and deposition process is repeated two more times to obtain the thickness of about 300 nm. Finally, the deposited films are air annealed at 348 K for about 8 hours [10].

3.2 FR4|PbS|Plexiglas Sandwich Fabrication

Deposited PbS films are used to fabricate the FR4|PbS|Plexiglas sandwich as shown in Fig. 1. Plexiglas layers are used as the transparent medium to carry required illumination from the sources to the PbS films. FR4 layers are used as the supporting layers.

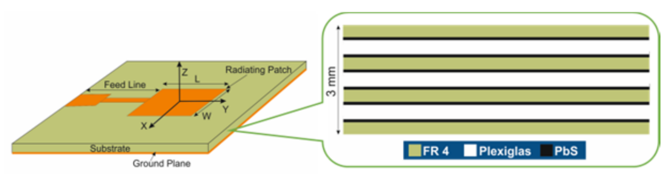

Fig. 1: Schematics of the designed antenna and multilayered substrate

3.3 Fabrication of the MPA

A standard MPA is fabricated on the developed multilayered substrate. The antenna is designed to resonate at 6.0 GHz in unilluminated condition.

4. RESULT AND DISCUSSION

The microstructure of PbS thin film is studied by an X-ray diffractometer (Rigaku Mini Flex 2000) and shown in Fig. 2. The interplanar distances (d) calculated from 2θ of the XRD lines are 0.3391, 0.2946 and 0.2029. They are in good agreement with standard (JCPDS: 05-592) interplanar distances of 0.3429, 0.2969, 0.2099 respectively, corresponding to (111), (200), (220) planes of cubic PbS.

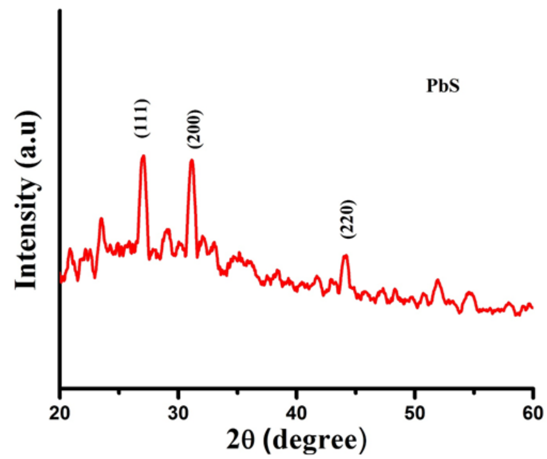

Figure 2. X-Ray diffractogram of PbS

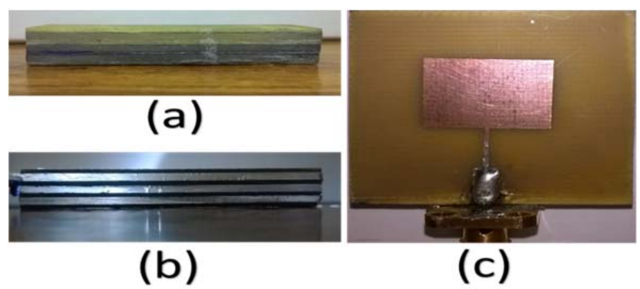

Figure 3. (a) Multilayered substrate without illumination (b) Multilayered substrate with illumination (c) Fabricated antenna

The prototype antenna is studied by both simulation and experimental tools. Simulation studies are done by using CST MW Studio and experimental measurements are carried out Agilent VNA (E8362C) and Antenna Measurement Setup from Diamond Engineering, U.S.A. The dielectric constants and loss tangents of the fabricated substrate are measured using in touch dielectric measurement technique [11] for both illuminated and unilluminated conditions and results are given in Table 1.

Table 1: Dielectric constants and loss tangents

Condition	Dielectric constant	tan δ
Without illumination	4.19	0.032
With illumination	3.84	0.038

4.1 S11 parameters

The simulated and measured S11 parameters of the prototype antenna is shown in Fig. 4. The antenna resonates at 5.96 GHz in unilluminated condition, while in the illuminated condition the resonant frequency shifts to 6.12 GHz. The simulated and measured results are in good agreement. However, small variations resulted due to fabrication tolerances. The antenna can be reconfigured to two different resonate frequency by altering the status of light illumination.

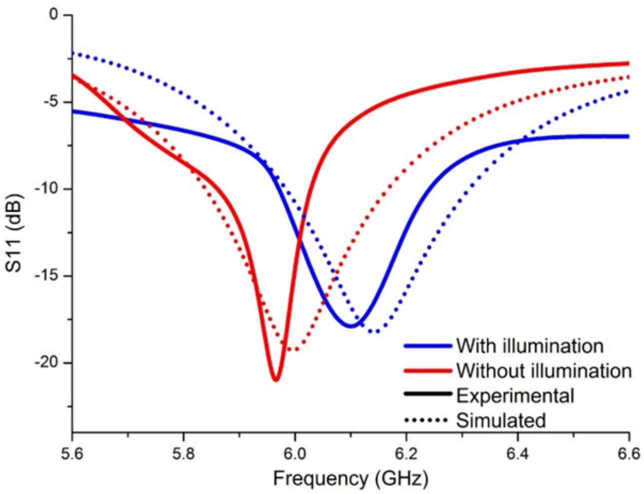

Figure 4. S11 parameters of the designed antenna

4.2 Radiation Pattern

The radiation pattern of the prototype antenna is simulated and measured for both the illuminated and unilluminated conditions. Co and cross-polarization radiation patterns for the unilluminated condition in XZ and YZ planes are shown in Fig. 5. (a) and (c) respectively. Fig. 5. (b) and (d) shows the radiation patterns of illuminated conditions in XZ and YZ planes respectively. The antenna radiation patterns in both the conditions and both the planes exhibit consistency and have a 3 dB beam width of about 60 deg and main lobe direction at 0 deg. The antenna also offers a good cross polar isolation of minimum -10 dB at both the operating conditions.

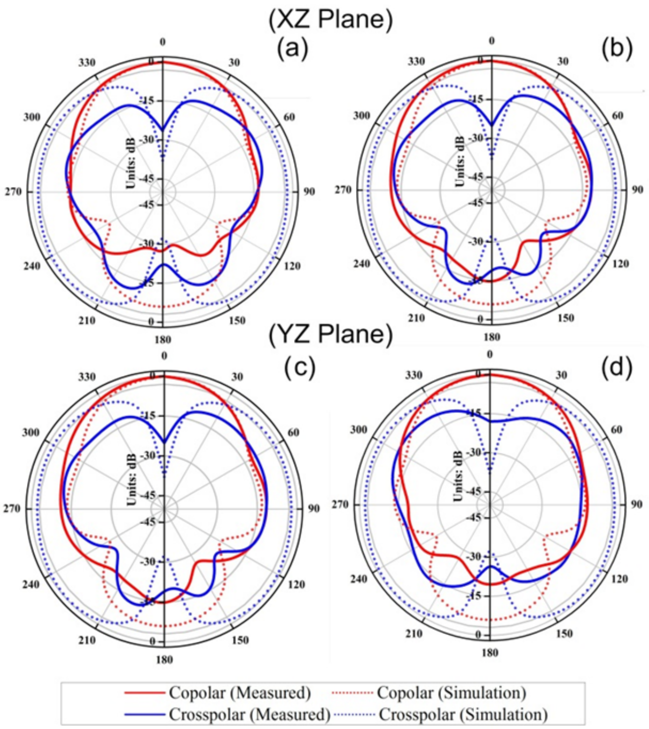

Figure 5: Radiation patterns of the designed antenna (a), (c) without illumination (b), (d) with illumination

4.3 Directivity, Gain, and Efficiency

The measured directivity, gain and efficiency of the antenna at both the accessible frequencies are given in Table 2. At frequency 5.96 GHz the antenna radiates with a directivity of 10.92 dB and gain of 7.24 dBi. The antenna also exhibits comparatively constant directivity (10.86 dB) and gain (6.98 dBi) at 6.12 GHz. The efficiency of the at both the conditions are 66.30 % and 64.27 %. The observed result shows that the antenna can reconFig. to both the frequencies without any significant changes in the antenna radiation characteristics.

Table 2: Directivity, gain and efficiency of the designed antenna

Condition	Directivity (dB)	Gain (dBi)	Efficiency (%)
Unilluminated	10.92	7.24	66.30
Illuminated	10.86	6.98	64.27

5. CONCLUSION

The work presents a modified substrate based frequency reconfigurable antenna. The modified substrate is a multilayered substrate having layers of photoconductive PbS. The dielectric constant of the substrate can be altered by illuminating light of suitable frequency and thus the antenna resonate frequency. The designed antenna offers frequency reconfiguration between two frequencies having values 5.96 GHz and 6.12 GHz with constant radiation characteristics. The antenna radiates with an almost constant gain of ~ 7.2 dBi and efficiency ~ 64.27 % in the both the states. The antenna may find its potential application in scenarios where frequency reconfigurability with constant radiation characteristics is required.

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