Wideband printed patch antenna on low cost epoxy resin polymer substrate

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In this study, the design and prototyping of a compact planar antenna is presented for a wideband application. The designed transmission line fed antenna constitutes with dual elliptical patches radiator with two circular parasitic elements and a partly ground plane printed on both sides of a 1.6-mm thick epoxy resin reinforced with a woven glass dielectric material. The structure of the antenna is planar, and the design is easily fabricated. In comparison to the other substrate materials, the proposed antenna on epoxy resin woven glass material can achieve a wider bandwidth and is less expensive. Experimental findings reveal that the designed antenna is able to gain an impedance bandwidth of 7.78 GHz (reflection coefficient ≥ -10dB) from 5.42 GHz to 13.2 GHz (2.42: 1, 83.56%). Moreover, the antenna has meaningful gain and demonstrates radiation patterns that are stable within the operating band. The details of the proposed antenna are described and discussed in detail.

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1. Introduction

The necessity of wide and multi-band antennas is growing fast based on the requirement to support additional users and to offer information with a higher rate of data transmission in the wireless communication technology. Due to such characteristics as compact size, lightweight, cost effectiveness and easy fabrication [1], microstrip antennas are some of the most suitable structures for modern communications. Planar microstrip antennas that are partly printed on the circuit board have become popular in modern wireless communication because it is easy to embed it into wireless devices and to integrate it with other RF circuits.

Various antennas have been studied and various techniques have been proposed to meet the demands of the wideband applications. A variety of dielectric materials has been used for designing and prototyping these antennas. A dielectric material used for the design of wideband antennas is preferably needed to feature a higher permittivity and lower dissipation factor [2]. Lower permittivity materials are good insulators for signals of a lower frequency that require high isolation in the circuits that are densely packed, as in mobile communications. On the other hand, materials with higher dielectric constant have higher ability to create wider electromagnetic fields and for charges storage but have limited isolation between the conductors [3]. Moreover, by using a material with higher permittivity, a compact antenna can be designed that is capable of achieving a very wide operating band. A miniaturized modified circular patch antenna was designed on a ceramic-polytetrafluroethylene (PTFE) composite material [4]. With an overall size of $0.22\lambda \times 0.29\lambda \times 0.03\lambda$, the proposed antenna achieved multi-band characteristics. Nevertheless, the antenna was not successful in fulfilling the requirements of the wideband antenna that has triple operating bands of 5 - 6.3 GHz, 9.1 - 9.6 GHz, and 10.7 - 11 GHz. A printed wide-slot antenna designed and prototyped on the available low-cost polymer resin composite material was fed by a microstrip line with a square slot that is rotated for enhancement of bandwidth and a defected ground structure for gain enhancement [5]. In [6], a wideband pentagon-shaped planar microstrip slot antenna was designed on an epoxy resin composite material. The antenna obtained an impedance bandwidth of 124% by combining the pentagon stub, pentagon-shaped slot, and the feed line. Nevertheless, its utilization in communication devices that are portable has limitations given the wide ground plane. A double L-shaped multi-band patch antenna on the polymer resin substrate material had been proposed [7]. By introducing two L-shaped slots in the rectangular patch, the designed antenna could achieve dual operating band centered at 4.85 GHz and 8.1 GHz and thus not suited for broadband wireless communication. A circular patch antenna was proposed for X-band operation (8 to 9.5 GHz), where the metal disk laid on the foam-like substrate constructs the microstrip antenna's circular patch and the antenna diameter was 32 mm [8]. A bow tie antenna was presented in [9] for simultaneous operation of C and X-band with the size of 29 mm × 30 mm. The proposed antenna was printed on a high dielectric Rogers RT/Duroid 6010/6010 LM substrate whose cost is high compared to an epoxy resin substrate. Satellite applications using the slotted triangular shape C and X band patch antenna have been suggested with the high dielectric and costly material [10].

In this study, a simple planar antenna that is able to achieve a profile with a physically compact planar that has enough impedance bandwidth and a radiation pattern that is stable is proposed for wideband applications. The antenna has two elliptical radiating patches with T shaped feed and a partly ground plane. It also consists of two slotted circular parasitic elements to enhance the bandwidth. The transmission line-fed radiating patch is printed on one side of the epoxy matrix reinforced woven glass material and the other side is printed with the partly ground plane. The observation reveals that the radiating patch of the design proposal has a strong coupling with the ground plane and the antenna designed on a polymer resin composite material is able to support multitude of resonance modes. These overlapping multitude resonance modes lead to the wideband characterization ranging from 5.42 GHz to 13.20 GHz. The simple structure, ease of fabrication, low cost, wide operating band, and stable radiation patterns enables the proposed antenna to be applicable for utilization in WiMAX, WLAN, C-band, UWB, and X-band applications.

2. Antenna design

The optimized design layout of the proposed antenna is presented in Fig. 1. On the top side of the substrate, two elliptical patches with major axis *R1* and minor axis *R2* and *L1*×*W1* rectangular element are printed. The elliptical patches are fed by *Lf*× *Wf* feed line with 50Ω input impedance. To initially achieve a wide bandwidth, *d1*slot is introduced in both elliptical patches and then, the *d2* slot is introduced in the left elliptical patch, which suppresses the electric currents. Two external parasitic elements are added in the lower portion of the top side; one is a circular parasitic element of *R3* radius and another is an annular ring slot with a *d3* dimension. On the bottom side of the substrate, a horizontal rectangular element of *L3*×*L* with a vertical rectangular element of *L2*×*W2* is embedded. The radiation from the ground plane cannot be avoided, as the electric current will be distributed on both the radiating elements. The antenna specifications are shown in Table 1. The antenna that was proposed was fabricated on a FR-4 substrate with 1.6 mm height and dielectric constant of 4.6. The overall dimension of the designed wideband antenna is optimized to a compact size of 20 mm × 20 mm, which is much smaller than the antennas proposed in [7, 9-12] and suitable to be integrated in portable communication devices.

Table 1. Antenna dimension specifications.

Parameter Name	Values (mm)	Parameter Name	Values (mm)
L	20	*R1*	5
L1	10	*R2*	4.45
L2	9.5	*R3*	2
Lf	10	*d1*	0.2
W1	0.9	*d2*	0.2
W2	4.1	*d3*	1
Wf	1.5	*W2*	2.9

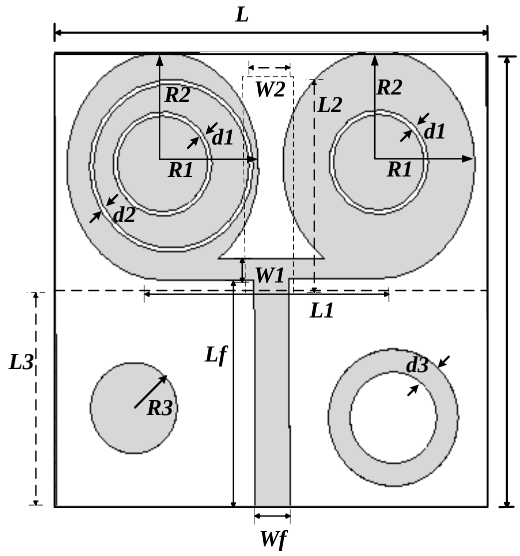

Fig. 1. Geometric layout of the antenna.

3. Antenna performance with Epoxy Resin Polymer substrate

The proposed planar microstrip patch antenna was designed and examined with the Finite Integration Technique (FIT) domain based CST microwave studio. The designed antenna was fabricated on a recently available 1.6 mm thick low-cost durable polymer resin substrate utilizing a circuit board (PCB) prototyping machine that was printed in lab. The substrate material consists of an epoxy matrix reinforced by woven glass. This composition of epoxy resin and fibreglass varies in thickness and is direction dependent. One of the attractive properties of polymer resin composites is that they can be shaped and reshaped repeatedly without losing their material properties [13]. Due to the lower manufacturing cost, ease of fabrication, design flexibility, and market availability of the proposed material, it has become popular for use as a substrate in patch antenna design. The composition ratio of the material is 60% fibreglass and 40% epoxy resin. Fig. 2 shows the steps involved in constructing the epoxy resin polymer substrate (FR4) material substrate.

Raw glass materials are melted in a furnace and extruded to shape the fibreglass filaments that are integrated into strings of multiple fibre yarn. After that, the yarns are weaved to make the fibreglass cloth. A coupling agent, which is normally an organosilane, is coated on the fabric to enhance the adhesion between the inorganic glass and the organic resin. Resin is derived by processing petrochemicals and in its purest form (uncured) is known as the A-stage resin. Additives, for example curing agents, flame retardants, fillers, and accelerators, are mixed into the resin to manage the board’s performance. A 60% glass fabric impregnated with the semi-cured (B stage) 40% epoxy resin is used to fabricate a prepreg. Multiple prepregs are pressed thermally to achieve a laminate or a core (C-stage resin). After that, a copper foil is normally electro-deposited to achieve a copper-clad laminate. Thus, a final product of FR4 material substrate has come to the market. Epoxy matrix reinforced woven glass material is a popular and versatile high-pressure thermo set plastic laminate grade with low dissipation factor. Epoxy matrix reinforced woven glass material is the most commonly used electrical insulator that possesses good mechanical strength and nearly zero water absorption coefficient.

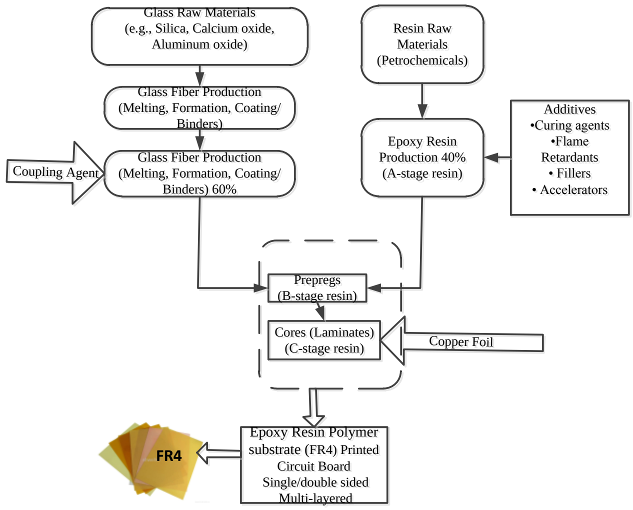

Fig. 2. FR4 material construction [5].

Fig. 3 demonstrates the impact of the various substrate materials on the return loss of the antenna that has been proposed. It is clearly observed that the proposed antenna offers a wider bandwidth and acceptable return loss value compared to the three other reported materials. The dielectric constant and loss tangent of Epoxy Resin Fibre is comparatively low; therefore, the bandwidth is increased. Although the antenna with a ceramic-PTFE composite material substrate gives a lower frequency return loss value because of the higher dielectric, the desired resonances are shifted and it is extremely expensive compared to the proposed material. Table 2 shows the dielectric properties and the achieved bandwidth from the proposed design with different materials. Fig. 4 shows the effect of the reflection coefficient for different steps of the antenna to the final design. It can be clearly stated that when the d1 slot was introduced in the right elliptical patch, the four resonances (less than -10 dB) in the reflection coefficient were found at 5.5, 6.5, 11.5, and 13.2 GHz, respectively. On the other hand, when d1 slot was etched from the left elliptical patch, the three resonances (less than -10 dB) in the reflection coefficient were found at 5.8, 6.7 and 11.5 GHz, respectively. Finally, when the d1 slot was cut from both the elliptical patches, a wide bandwidth of reflection coefficient was achieved from 7.7 GHz to 10.1 GHz. The effect of the d2 slot from the left elliptical patch exhibits a wide bandwidth of 3.15 GHz, from 7.2 GHz to 10.35 GHz. After adding two external parasitic elements, the bandwidth increased to 7.78 GHz, from 5.42 to 13.2 GHz.

Table 2. Dielectric properties of substrate materials.

Substrate material	**Relative Permittivity (ϵ_r)**	**Dielectric Loss tangent**	**Fraction achieved bandwidth (%)**	**Antenna Dimension**
Glass microfiber reinforced PTFE	2.33	0.0012	24.5	
Epoxy resin-fibre glass	4.60	0.02	83.56	Proposed Antenna
PTFE Ceramic	10.20	0.0023	No resonance found	
Teflon	2.10	0.01	33.6	

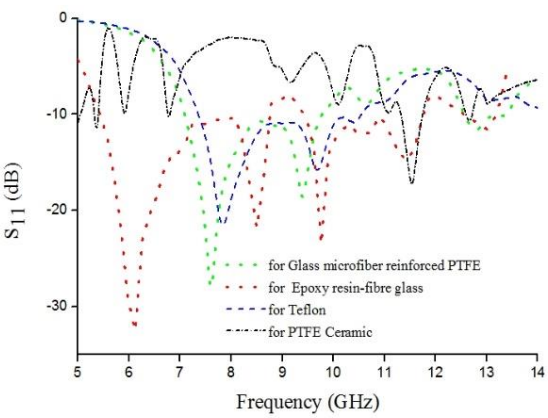

Fig. 3. Effect of Reflection coefficient for different substrate materials.

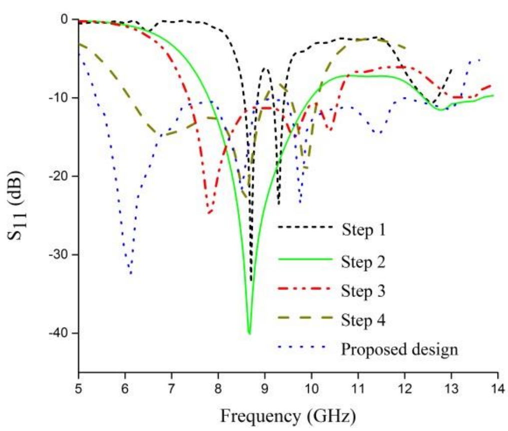

Fig. 4. Effect of Reflection coefficient for different step of antenna to final design.

4. Experimental verification

The design and simulation of the antenna that has been proposed have been carried out by utilizing the Computer Simulation Technology (CST) Microwave Studio software package that is commercially available. An Agilent TE8362C network Analyser and an anechoic chamber was used to measure the reflection coefficient, radiation pattern, gain, phase, and the Smith chart of the presented antenna.

Subsequently, the antenna was prototyped for verification of the experiment as revealed in Fig. 5. The simulated and measured return loss curves are shown in Figure 6. The simulated -10 dB reflection coefficient bandwidth are from the ranges of 5.42 GHz to 13.2 GHz, which are equivalent to a bandwidth fraction of 83.56%. This wideband feature of the proposed planar antenna is affirmed in the measurements. Even though, there is a disparity between the simulated and measured resonances that can be possibly attributed to the manufacturing tolerances and to the effects of imperfect soldering of the SMA connector, the frequencies of the measured resonance are almost identical to the frequency that has been simulated. This mismatch may also be due to the effects of the RF feeding cable that has been utilized in the measurements but have not been taken into consideration during the simulation. The ripples observed in the measured result may be caused by the current drain from the conducting ground plane to the outer shield of the RF feeding cable, which is not presumed during simulation.

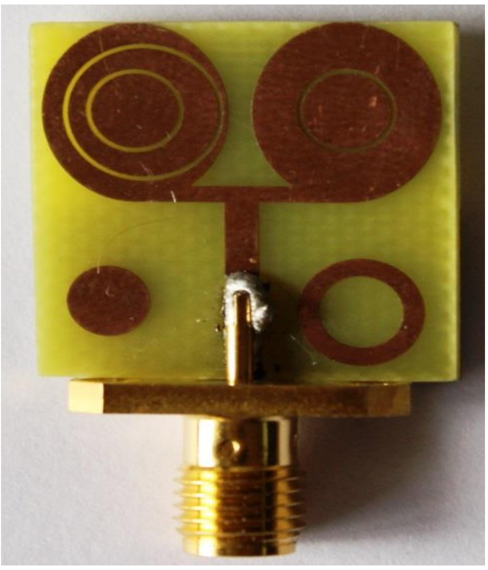

Fig. 5. Photograph of the fabricated antenna.

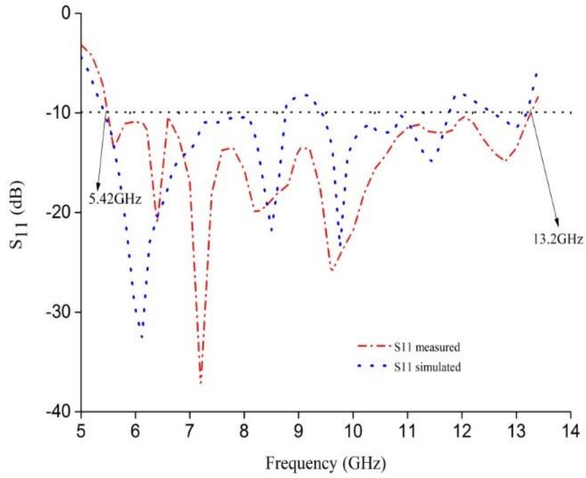

Fig. 6. Measured and simulated and reflection coefficient value of the proposed antenna.

The surface current distribution of the proposed antenna for 7 GHz and 9 GHz are presented in Fig. 7. As shown in Fig. 7(a), at 7 GHz maximum current shows on the junction of elliptical patches and microstrip feed line. Figure 7(b), at 9 GHz shows the most current on the left elliptical patch and junction of left elliptical patch and microstip feed line. This characteristic agrees with the measured reflection coefficient and radiation patterns for the theses frequencies.

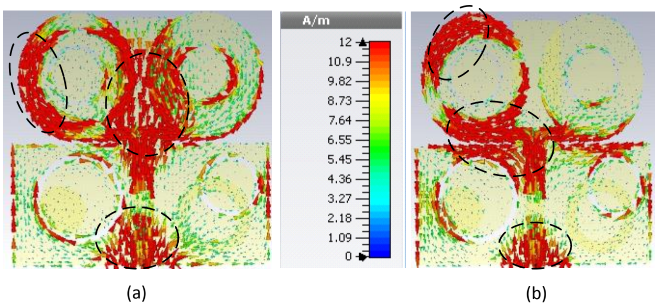

Fig. 7. Surface current distribution at (a). 7 GHz (b). 9 GHz.

The *E*-and *H*-plane radiation patterns of the proposed antenna at 7 and 9 GHz are depicted in Fig. 8. At 7 GHz, the antenna exhibits a bi-directional radiation pattern for the *E* plane co-polarization and H-plane cross-polarization. At 9 GHz, the antenna exhibits approximately omnidirectional radiation pattern for both E and H plane. The antenna radiation patterns of the proposed antenna shown in Fig. 8 are measured. According to Fig. 10, a non-linearity in phase variation is observed, which indicated generation and an out of phase excitation of surface waves. Theses surface waves radiate in in opposite phase of the main radiating waves, which generate high cross polarization level, especially in higher frequency [14].

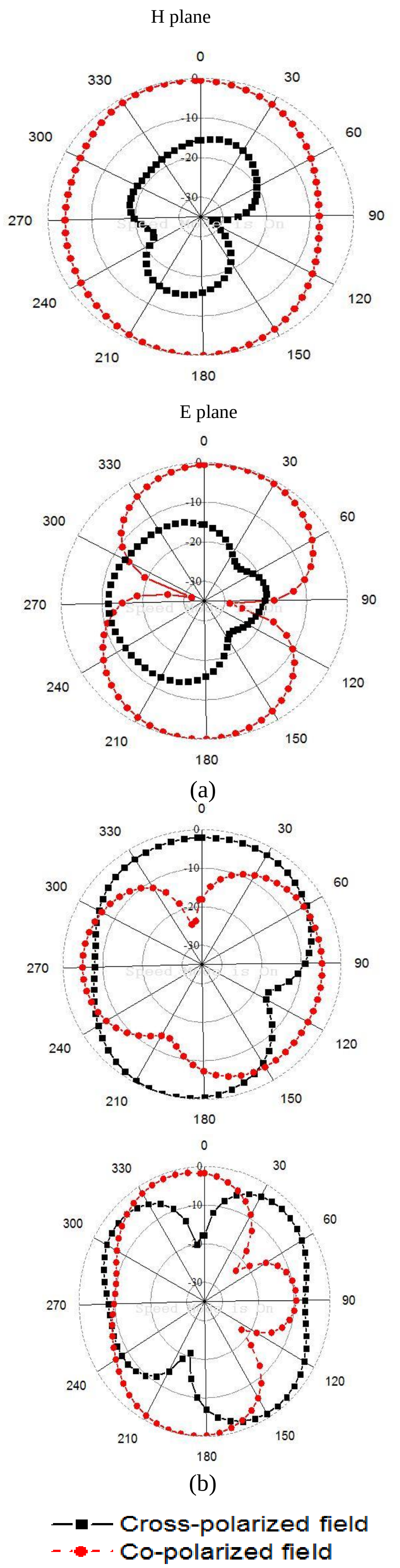

Fig. 8. Radiation pattern of the proposed antenna for at (a). 7 GHz and (b). 9 GHz.

Fig. 9 reveals the calculated peak gain of the proposed antenna. The figure shows that the measured antenna gain level exhibits 2.5 dB to 4.9 dB in the range of 5.4 GHz to 13.2 GHz. Moreover, a peak gain average of 3.7 dB has been achieved. The antenna's measured phase difference is reflected in Fig. 10. From Fig. 10, it is observed that the change of phase across the whole band is linear, which indicates that the entire frequency components of signal have a similar delay, causing a similar pulse distortion.

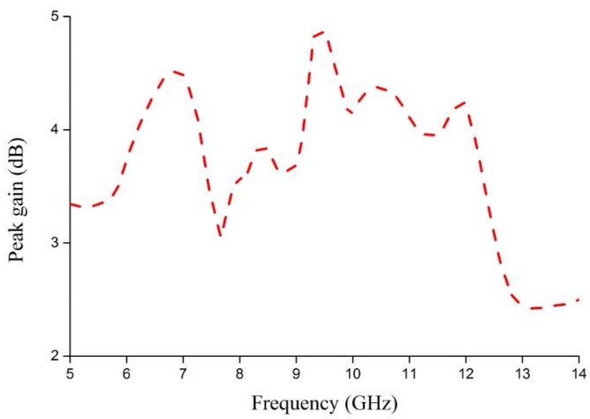

Fig. 9. Measured Gain of the proposed antenna.

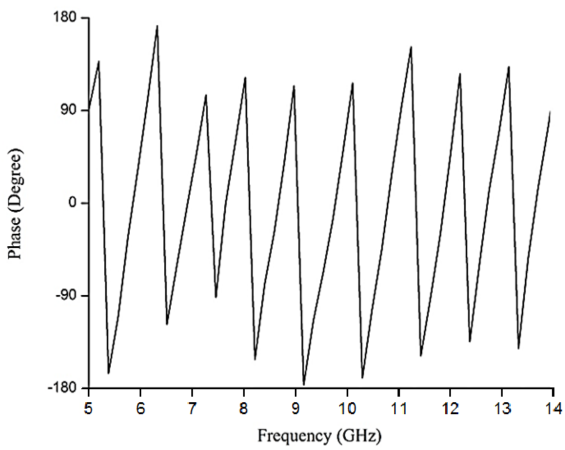

Fig. 10. Measured phase of the input impedance.

5. Conclusions

A compact printed microstrip line-fed elliptical patch antenna has been proposed with a prototype for wideband applications. The antenna is designed and fabricated on an epoxy matrix reinforced woven glass material with a 20 mm×20 mm overall size. Experimental findings reveal that the proposed antenna is able to gain an impedance bandwidth ranging from 5.52 to 13.20 GHz (2.42, 83.56%) for return loss ≤ -10dB. Compared to the other dielectric materials, the proposed antenna with an epoxy matrix reinforced woven glass material exhibits better bandwidth, returns, radiation patterns, and gain performance. In addition, the antenna achieved a good gain and stable radiation patterns. All these features of the proposed epoxy resin material based antenna make it a worthy candidate for wideband applications in portable communication devices. Therefore, the proposed antenna can be a suitable for WiMAX, WLAN, C-band, UWB, and X-band operating frequency applications.

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