# Design and Fabrication of Microstrip Patch Antenna on Flexible Epoxy Substrate Material

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## ABSTRACT
This paper deals with the fabrication and characterisation of microstrip patch antenna on a flexible substrate. The flexible planar antenna finds wide applications in defence, satellite, medical and automobile industries. Now days it is the most researched topics across the world. The flexible antenna gets conformal to the surface and can be used across curved surfaces. An antenna using room temperature vulcanizing silicone rubber compound is used as substrate on which the patch antenna is fabricated. Patch size was chosen such that the antenna resonates at 4.5 GHz. The substrate material used was characterised for its dielectric properties using Vector network analyzer (VNA). The resonant frequency does not show variation when the antenna is folded up to an angle of 30° from its centre feed location. The antenna with measured substrate properties was also simulated in High Frequency Structure Simulator (HFSS). Measured results for resonance frequency are in close approximation with that of simulated one. Slight variation in resonant frequency may be due to finite ground plane dimensions and variation of feed location. Silicone compound offers the flexibility of adding magnetic materials to alter the dielectric and magnetic properties, resulting in further miniaturisation. The simulation and measured results suggest that flexible substrate antenna can be successfully used for miniaturisation and with curved surfaces.

## Keywords
Microstrip antenna, Flexible, Substrate, HFSS, VNA.

## 1. INTRODUCTION
The miniaturization in the electronics and communication packages has put lot of constraints on antenna size [1]. Traditional rigid antennas are not flexible and non-conformal to curved spaces. Flexible antennas are, lightweight, gets conformal to any surface and can be used across curved surfaces. They can also withstand mechanical strains up to a certain extent depending upon the substrate materials properties. In order to make flexible antenna, rigid substrate materials are replaced by the flexible substrate materials like epoxies, polyurethane resin foam, liquid crystal polymer silicone rubber, paper, flexible FR4 etc. [2-4]. In last few years these conformal antennas are one of the most researched antennas. They find applications in defence, satellite, wearable electronics, medical field and automobile industry. The possibilities of using a microstrip patch antenna for wireless stain sensing applications have been analyses for different substrate materials [5]. For wideband communication application, research on wideband star shaped patch antenna with paper as the flexible substrate was done and bandwidth of 84% (2.45GHz to 6GHz) has been obtained [6]. In this paper, rubber, a natural polymer is chosen as the flexible substrate due to its good mechanical properties of forcibly retracts to its original dimensions after deformation. Previous research work on rubber as substrate material has been done in the ISM frequency band (2.4GHZ – 2.5GHz) [7].

The performance of the microstrip patch antenna using room temperature vulcanizing silicone rubber as the flexible substrate is fabricated and characterized. The antenna is designed and analyzed using Ansoft High frequency structure simulator (HFSS) software [8]. The performance parameters of the antenna are optimized to achieve reasonably wide impedance bandwidth, high gain and VSWR < 2. The fabricated patch antenna using coaxial feed with SMA connector is shown in Fig.1.

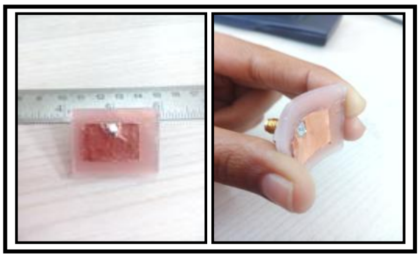

**Fig.1. Fabricated microstrip patch antenna on flexible substrate**

## 2. FEEDING TECHNIQUES
Feeding methods have great impact on the performance parameters of designed patch antennas. Feeding is used to provide input excitation power to the radiating patch. Four types of feeding techniques are commonly referred in the literature i.e. line feed, coaxial probe feed, proximity coupled and of aperture coupled type [9]. The feed technique can significantly change the structure and operation of the antenna. The feeding method that has been considered here is coaxial feed using a coaxial probe as shown in Fig. 1. This is due to its ease in fabrication, better impedance matching and low spurious radiation.

## 3. SYNTHESIS AND CHARACTERISATION
The flexible material chosen in this research work for the substrate is transparent room temperature vulcanizing (RTV) silicone rubber. Its dielectric properties were measured using vector network analyzer (VNA) (Model No. E5071C, make-Agilent). The silicone rubber is a flowable fluid and gets cured at room temperature. A toroidal pellet of cured silicone rubber was made having dimensions of 7mm outer diameter, 3mm of inner diameter and thickness of pellet 1.5mm. The pellet was loaded in a suitable test fixture and connected to VNA through 3.5mm connector cables. Transmission and reflection parameters of the sample were measured by VNA in the frequency range of 1-10GHz at equally spaced 201 point. The Nicholson–Ross-Weir (NRW) method was used to

obtained relative permeability and relative permittivity of the sample. Since, the material is pure dielectric, the relative permeability remains unity. The permeability and permittivity values were directly obtained from material measurement software, 85071of Agilent technology.

## 4. DESIGN CONSIDERATION

A microstrip antenna consists of conducting patch on a ground plane separated by dielectric substrate. Low dielectric constant substrate is generally preferred for maximum radiation. A rectangular shaped flexible microstrip patch antenna is designed and fabricated on the silicone rubber as the flexible substrate. The dimensions of the rectangular microstrip patch antenna were chosen to maximize the gain pattern and resonate at the desired 4.5GHz frequency. The geometry of antenna is shown in Fig. 2. Microstrip patch antenna dimensions are obtained using design equations [10].

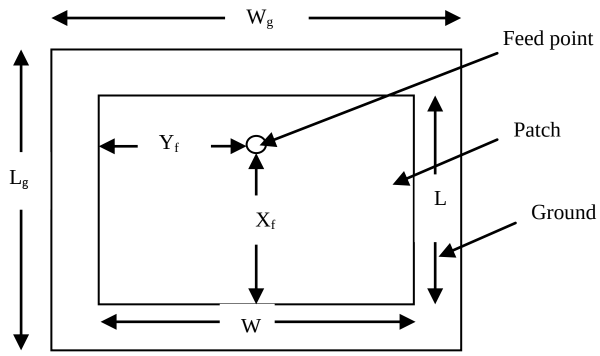


**Fig.2. Top view geometry of microstrip patch antenna**

### 4.1 Selection of substrate material

Physical and electrical characteristics of antenna substrate such as height, dielectric constant and loss tangent are variables. Hence, substrate material should be chosen accordingly. Dielectric constant of the substrate material controls the fringing field which is responsible for the radiations from microstrip patch antenna. Higher fringing field results into the better radiation and also high bandwidth and efficiency. Here flexible silicone rubber having dielectric constant of 2.7 was used as the substrate material.

### 4.2 Calculation of width

The width (W) of microstrip patch antenna, leading to good radiation efficiencies is given by eq. (1):

$$W = \frac{c}{2f_o}\sqrt{\frac{2}{\varepsilon_r+1}} \tag{1}$$

where c is free-space velocity of light, $\varepsilon_r$ is dielectric constant of material and $f_o$ is the resonant frequency of microstrip antenna.

### 4.3 Calculation of Effective dielectric constant

The value of effective dielectric constant is less than dielectric constant of the substrate due to the fringing fields. It is calculated using eq. (2)

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+12\frac{h}{W}\right)^{-1/2} \tag{2}$$

where h is the height of substrate of the antenna.

### 4.4 Calculation of resonant length

The resonant length (L) of the patch determines the resonance frequency thus it is a critical parameter for patch antenna. The drawn length differs from the calculated length due to fringing field and finite height of substrate. Actual (drawn) length of patch is calculated using eq. (3)

$$L = L_{eff} - 2\Delta L \tag{3}$$

where $L_{eff}$ is given by eq. (4)

$$L_{eff} = \frac{c}{2f_o\sqrt{\varepsilon_{reff}}} \tag{4}$$

$\Delta L$ is increase in length due to the fringing field, which can be calculated using eq. (5)

$$\Delta L = 0.412h\frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \tag{5}$$

Fringing field is a function of effective dielectric constant. It arises from the radiating slots (width) of patch. Due to fringing field the electrical length of patch is always larger than its physical length.

**Table 1. Design parameters of rectangular microstrip patch antenna**

| Parameters | Value |
|---|---|
| Resonance Frequency ($f_o$) | 4.5GHz |
| Dielectric constant of substrate | 2.7 |
| Height of dielectric substrate(h) | 3.1mm |
| Length of patch (L) | 18.2mm |
| Width of patch (W) | 24.5mm |
| Length of ground ($L_g$) | 36mm |
| Width of ground ($W_g$) | 43mm |

### 4.5 Calculation of ground dimensions

The ground and substrate dimensions were taken 3 times the height of the substrate on either side of length and width of patch. This was taken to avoid finite ground effect.

### 4.6 Feed location ($X_f$, $Y_f$)

The feed point was placed along the centre line of one dimension of the antenna ($Y_f$ = 12.25mm) to give linear polarization. Feed location was optimized for proper impedance matching, such that Real (Z) ≈ 50Ω and Imaginary (Z) ≈ zero. The resulting feed position ($X_f$) was 14.4mm from the edge of the patch.

## 5. RESULTS AND DISCUSSION

The values of relative permittivity and relative permeability of silicon rubber from the measurement using material measurement software with VNA were 2.7 and 1 respectively. The value remains constant in the entire measured frequency band from 1-10 GHz. The practical analysis of antenna performance was performed using vector network analyzer as shown in Fig.3. The performance parameters of microstrip patch antenna resulted from the simulation in HFSS software was compared with the results taken from the measurement of antenna using VNA and are tabulated in Table 2.

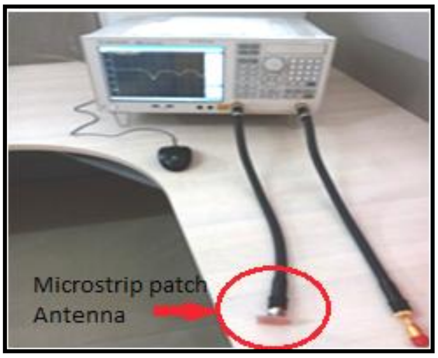


**Fig.3. Measurement of Return loss ($S_{11}$) of the microstrip patch antenna using Vector network analyzer**

The simulation results of antenna from HFSS were verified practically by using Vector network analyzer. There is a slight frequency shift in the resonating frequency of microstrip patch antenna, when measured with the VNA. This may be attributed to finite ground plane dimensions and variation in feed location during fabrication. The small variation in effective electrical dimension of patch antenna may also be the reason for shift in resonating frequency. [11]. The results for Return loss (S11), VSWR and impedance Real (Z) are shown in Fig. 4, Fig. 5 and Fig. 6 respectively.

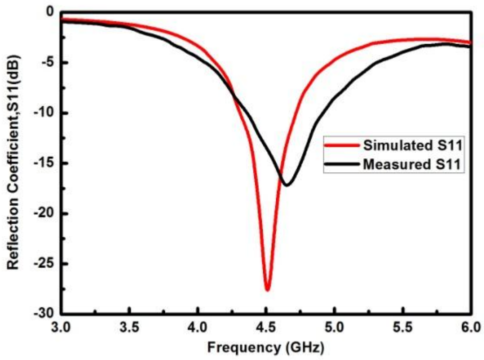


**Fig.4. Comparison of simulated and measured return loss plot of microstrip patch antenna**

**Table 2. Performance parameters of microstrip patch antenna with flexible substrate**

| Parameters | Simulation results | Measurement results |
|---|---|---|
| Resonating frequency (GHz) | 4.5 | 4.64 |
| Return loss (dB) | -30.59 | -17.5 |
| VSWR | 1.04 | 1.1 |
| Impedance, Real (Z)(Ohm) | 52.8 | 45.8 |

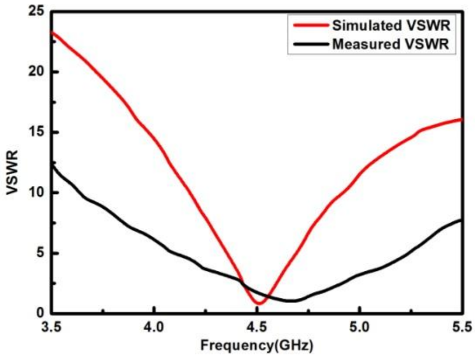


**Fig.5. Comparison of simulated and measured VSWR plot of microstrip patch antenna**

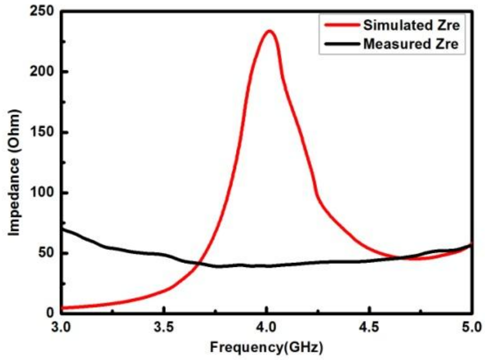


**Fig.6. Comparison of simulated and measured Impedance plot of microstrip patch antenna**

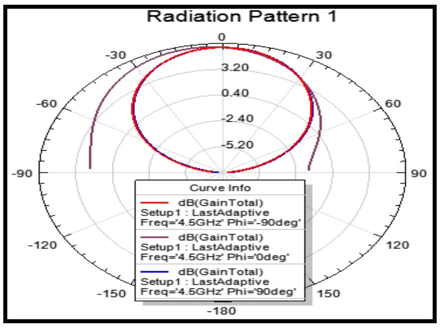


**Fig.7. 2D Radiation pattern of microstrip patch antenna**

The 2D radiation pattern of designed antenna structure is shown in Fig. 7 for different values of phi (0°, 90° and -90°).

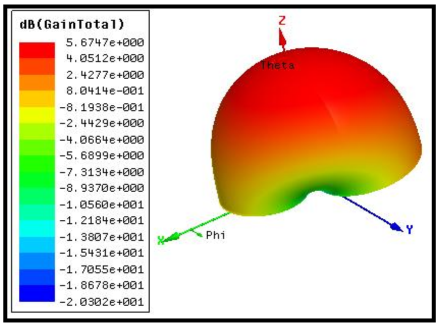


**Fig.8. 3D Gain Total (dB) of microstrip patch antenna**

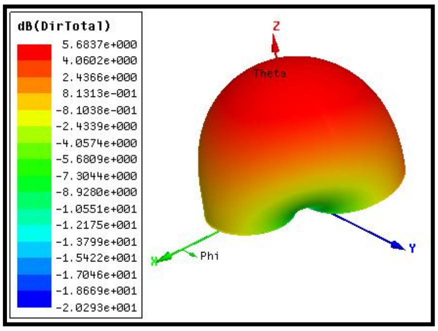


**Fig.9. 3D Directivity Total (dB) of microstrip patch antenna**

The 3D polar plots of total gain (dB) and total directivity (dB) of the designed microstrip patch antenna are shown in Fig. 8 and Fig.9 respectively. Gain of 5.67dB and total directivity of 5.68dB was obtained from the designed microstrip patch antenna.

Microstrip patch antenna was also analysed in fold condition and it show no variation in the resonating frequency of antenna when folded up to an angle of 30° from the center feed location [12].

## 6. CONCLUSION

This paper represents the design of a flexible microstrip patch antenna, resonates at 4.5 GHz frequency. The design parameters of microstrip patch antenna were optimized to achieve 8.5% bandwidth (≈ 400MHz for VSWR < 2) with a stable radiation pattern. The design antenna exhibits a good Impedance matching of 52Ω at the center frequency and return loss of -30.59dB at the resonating frequency. The flexible epoxies material such as silicone rubber also offers flexibility of doping magnetic materials to alter its electromagnetic properties. Since magneto-dielectric materials when used as substrate for patch antenna are very effective in miniaturisation [13-15]. The flexible silicon rubber used in this research can be further reduce the size and increase the bandwidth.

## 7. ACKNOWLEDGEMENT

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