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An Extensive Judgment of Rectangular Microstrip Patch Antenna with Flexible Substrates

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Abstract: In this paper, the performance of U-slot Rectangular Microstrip Patch Antennas (RMSA) is analyzed by using different flexible substrates. The RMSA is designed to operate for a resonant frequency of 2.45 GHz with flexible substrate materials like Polydimethylsiloxane (PDMS), GML-1032 and Polyethylene. The antenna parameters like reflection coefficient, voltage standing wave ratio (VSWR), radiation pattern, bandwidth and cost are analyzed by keeping all the substrate height same and the value is 2.5mm. U-slot cutting is used in the patch to overcome the narrow bandwidth limitation in RMSA because U-slot tunes the higher order orthogonal mode resonance frequency of the patch with respect to fundamental mode to realize the wider bandwidth. The maximum bandwidth of 80MHz is achieved with the use of PDMS. The antenna is simulated using HFSS software.

Index Terms: HFSS, Reflection coefficient, RMSA, Substrate analysis.

I. INTRODUCTION

The S band frequency is popular for different applications like communication satellites, biomedical field, weather radar, and surface ship radar, multimedia, mobile TV and satellite radio etc, for its less susceptibleness to rain fading as compared to K and Ku band. In case of satellite, spacecraft, aircraft applications the limitations are size, lightweight and cost etc in terms of communication [1]. The solution to that is the use of microstrip patch antenna (MSA), which is smaller in size, lightweight with low fabrication cost. By using MSA dual and triple band frequency operation is also possible. The limitations of microstrip patch antennas are the narrow bandwidth, less efficiency and low gain. These issues can be addressed through the effective design of the antenna. The parameters of MSA like bandwidth, radiation pattern and efficiency can be effectively controlled by using suitable substrate, which has a significant role in designing antenna. There are three main properties of substrate materials such as substrate thickness, dielectric constant and loss tangent which are considered during the design of MSA [2]. There are various substrate materials present in the market but those are chosen according to the applications. To design an antenna, selection of substrate is more important and it must be a dielectric material. Substrate is required to design an antenna because it affects the electrical performance as well as it gives mechanical support to antenna for metallization. The antenna performances can be optimized by choosing proper substrate which includes the thickness of substrate, dielectric constant, loss tangent, flexibility, chemical stability and weather resistant etc. For designing of optimized MSA all the properties of substrate material should be considered together. If the height of the substrate increases the fringing field from the edge increases results in extension of length of patch causing the decrease in resonant frequency [3]. Material having less dielectric constant value considered as better insulator which can resist the absorption of electrons into it results in low return loss and higher bandwidth. In MSA if height of the substrate will less then there will be low loss but power send through it will less as the transmission line is made thinner for impedance matching. If heights of the substrate will more than the strip line then it will be wider for impedance matching. More power will pass through as It results in higher Q but the problem is more power is radiated from the transmission line. The better option in case of MSA is to design the antenna with the substrate having low permittivity for better radiation as it is required to enhance the fringing field [4]. The microstrip patch antenna consists of a dielectric substrate which is sandwiched between the conductive ground plane and a conductive patch on the top of the dielectric substrate and a U-shaped slot is cut up from the patch results in reduced size of the antenna. The reduction in the size of the antenna results in improved return loss and gain, wideband, multiband or frequency tuning operation of the antenna [5]-[6]. Therefore, the single U-shaped microstrip patch antenna has a broad bandwidth and can be used for wireless applications. The substrate can be classified depends upon which material is used. Different kinds of substrates are there like ceramic substrate, composite substrate, ferrimagnetic substrate, synthetic substrate, semiconductor substrate, flexible substrate, low loss, low cost etc.

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In this paper, the flexible materials are taken as the substrate material. In recent trends flexible electronic devices have its own importance for implantable and wearable application (mostly in medical application) as it is stretchable, low dielectric constant and low cost [7]-[8].

In this paper, three substrates with different dielectric constants have taken for the analysis of RMSA, which is mentioned in Table 1. The resonant frequencies of antennas are 2.45 GHz excited with the strip line feeding technique. For all the simulations a reasonable thickness of 2.5 mm substrate is used. A rectangular microstrip patch antenna with U-slot is cut up from the rectangular patch for bandwidth enhancement [9]-[10]. The given designs are optimized to get S_{11} value below -10dB. An analysis has been done based on the reflection coefficient, VSWR, radiation pattern, bandwidth and cost.

II. RECTANGULAR MICROSTRIP ANTENNA DESIGN

Microstrip patch antenna is becoming the most useful antenna as it can be easily printed on a circuit board. Although it has some disadvantage like narrow band width but it is low in cost, easy to fabricate and a low profile antenna. It consists of a conducting ground plane, above which substrate is there which is a dielectric material and a conducting rectangular shape patch with u-slot present over a substrate. Microstrip line feed technique is used to fed the RMSA and impedance is matched to 50 Ω. During design, the length and width of the patch, effective dielectric constant, substrate dimension etc. are necessary to calculate and these are calculated from the dielectric constant and height of the substrate, the resonant frequency, speed of light. The dielectric properties of PDMS (unfilled) have been measured over the range of 72-82 GHz and the dielectric constant value of the material has been measured: $\varepsilon_r = 2.68$ and tanδ = 0.04 [11]. The following parameters are important for the calculation of width and length of antenna.

A. Width of Patch (w)

To be an effective radiator the width of the patch should be taken as half of the wavelength and presented as

$$w = \frac{c}{2f_0\sqrt{\frac{(\varepsilon_r+1)}{2}}} \tag{1}$$

Where, c is the speed of light in free space and f_0 is the resonant frequency.

B. Effective dielectric constant (ε_{reff})

Effective dielectric constant is obtained related to the fringing field. Value of dielectric constant is more than effective dielectric constant because the fringing field around the patch is not limited within the substrate. So the following equation is given for the calculation of effective dielectric constant

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+\frac{12h}{w}\right]^{\frac{-1}{2}} \tag{2}$$

Where, ε_r(Fm^{-1}), w (mm) and h (mm) are the dielectric constant, width and height of the substrate respectively.

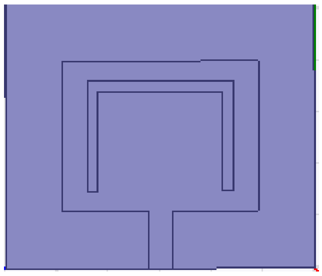

Fig. 1. Top view of Rectangular Microstrip U-slot Patch Antenna with strip line feed technique.

C. Length of patch (l)

The resonant frequency is determined by the length of the patch, so it is an important factor for narrowband patch. It is practically not possible to calculate the fringing field accurately as the result is not definite. The length of the patch is calculated as

$$l_p = l_{eff} - 2(dl) \tag{3}$$

Where l_{eff} is the effective length of the patch which is expressed as

$$l_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{reff}}} \tag{4}$$

and dl is the length extension because of fringing field and expressed as

$$dl = \frac{0.412h\,(\varepsilon_{reff}+0.3)\left(\frac{w}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{w}{h}+0.8\right)} \tag{5}$$

D. Substrate dimension (l_g and w_g)

Length and width of both substrate and ground plane are calculated from the following equations

$$lg = l + 6h \text{ and } wg = w + 6h \tag{6}$$

Table I. Substrate Materials

Substrate Type	Dielectric Constant (ε_r)	Loss tangent (tan δ)	Resonant frequency (GHz)	Height (mm)
PDMS	2.68	0.04	2.45	2.5
GML 1032	3.2	0.003	2.45	2.5
Polyethylene	4.4	0.02	2.45	2.5

III. SIMULATION RESULTS

Different substrate materials have taken and those are simulated by incorporation on the proposed design at 2.45 GHz. Fig. 2 shows the HFSS generated model for rectangular U-slot patch antenna. Parameters like reflection coefficient ($S_{11} \leq$ -10dB), VSWR, radiation pattern and bandwidth of the RMSA with different substrates have been analyzed. The simulation results of parametric analysis of the different substrate material have shown in Table II.

A parametric analysis for the parameters like the reflection coefficient ($S_{11} \leq$ -10dB), VSWR (in between 1-2), radiation pattern (for $\varphi = 0°$ and $90°$) and bandwidth for different substrates is done. The purpose of this work is to analyze the results based on the simulation.

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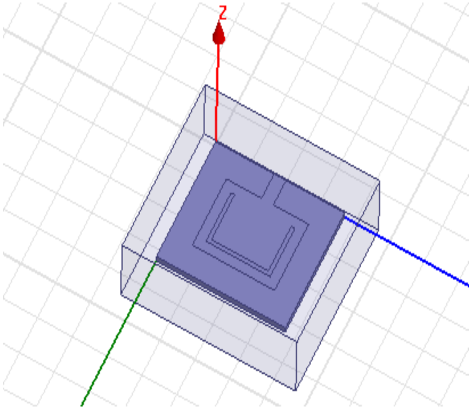
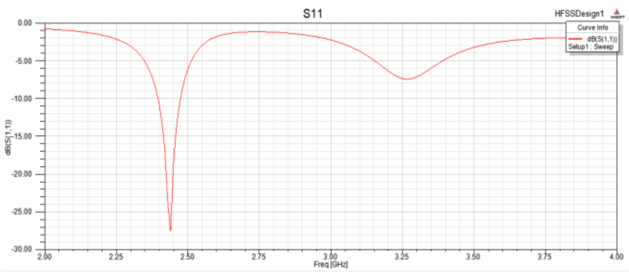


Fig. 2. Design of U slot Rectangular microstrip patch antenna using HFSS 13.0

A. Reflection Coefficient

The most convenient way to characterize the input and output of signal source is the return loss and it shows the amount of power that lost in the load. Fig. 3 explains the reflection coefficient graph for the different substrates and the maximum value of S_{11} is -27.54dB achieved for PDMS among the substrates taken because the permittivity of this substrate is lowest results in better radiation as it is required to enhance the fringing field [12].



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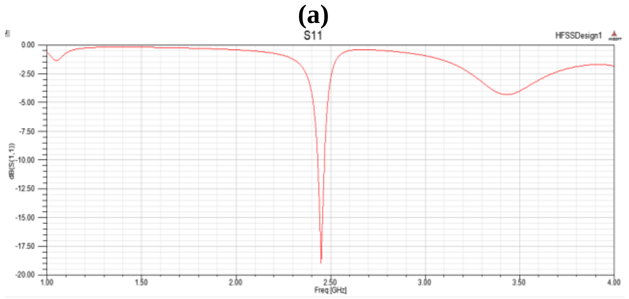

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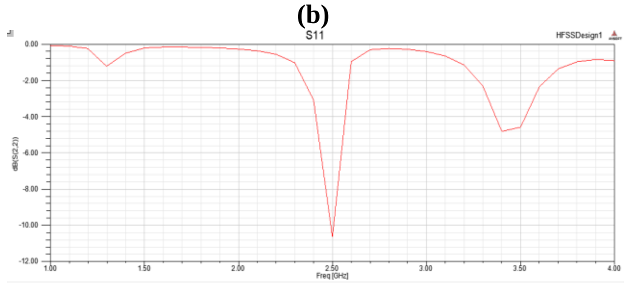

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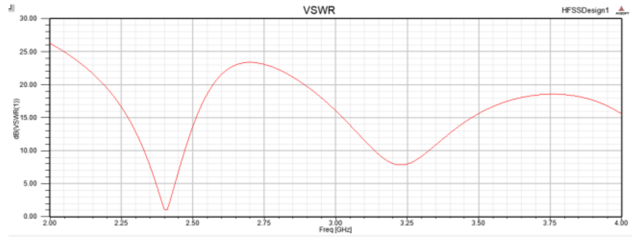
Fig. 3. Reflection coefficient versus frequency graph for the substrate PDMS (a) GML-1032 (b) and (c) Polyethylene

B. VSWR



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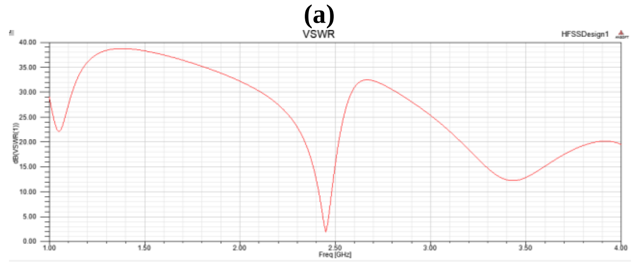

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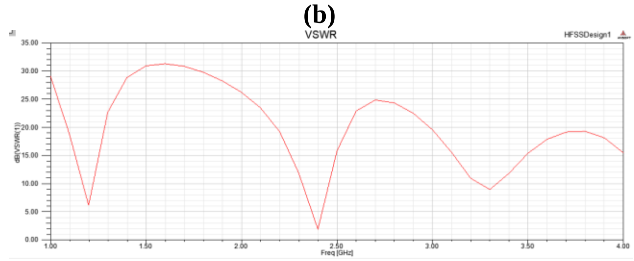


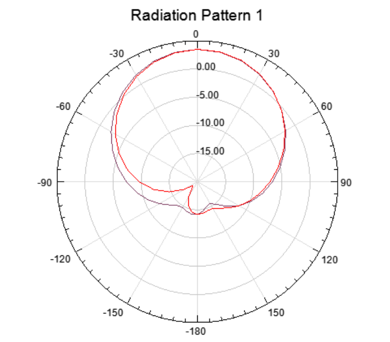
(c)

Fig. 4. VSWR versus frequency graph for the substrate PDMS (a), GML-1032 (b) and (c) Polyethylene

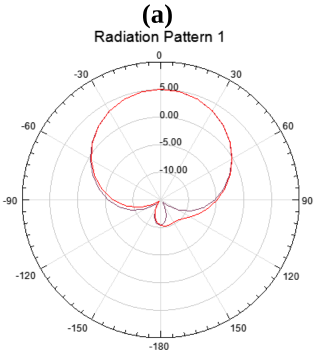
The ratio between the maximum voltage and minimum voltage in the transmission line is known as the VSWR. Basically VSWR measure the impedance mismatching between the feed line and the antenna. VSWR is the function of reflection coefficient which shows the power reflected from antenna [13]. The ideal value of VSWR is 1, which shows no power is reflected from antenna. Fig. 4 shows the VSWR versus frequency graph for various substrates. VSWR of PDMS is 1.05, which is very close to ideal value shows almost no power reflected from antenna as the impedance is matched properly [14]-[15].

C. Radiation Pattern

Radiation pattern is the graphical representation of the antenna radiation properties as a function of position. Polarization of an antenna is represented by its polarization pattern, which is the distribution of polarization of a field vector radiated by an antenna over its radiation sphere. Co-polarization shows the polarization that the antenna is expected to radiate where cross polarization shows polarization that is orthogonal to a particular polarization [16]. So co-polarization should always greater than cross-polarization. All the substrates taken are showing more co-polarization than cross polarization. It means all the substrates show stable radiation pattern.



(a)



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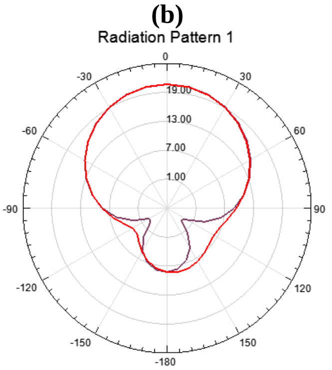

(c)

Fig. 5. Antenna radiation pattern for the substrates PDMS (a), GML-1032 (b) and (c) Polyethylene $\boldsymbol{at\ phi = 0^0\ and\ 180^0}$**.**

Table II. Substrate comparison

Substrate	Reflection coefficient(dB)	VSWR	Bandwidth (MHz)
PDMS	-27.54	1.05	80
GML-1032	-18.95	1.96	30
Polyethylene	-10.62	1.91	10

IV. CONCLUSION

In this paper, the parametric analysis of a rectangular MSA using three different flexible substrates has been presented and the fundamental parameters are modeled with the equations and estimated with HFSS software. The microstrip patch antenna is designed for operating in S-band region and mostly for biomedical application. The simulation result shows very good performance with PDMS substrate with an enhanced bandwidth of 80MHz, reflection coefficient of -27.54dB and stable radiation pattern. It is also possible to adjust the relative permittivity of the PDMS substrate by doping according to the applications. Our results show that narrow band issues of rectangular microstrip patch antenna are solved by cutting U-slot on the patch. In conclusion our analysis shows that PDMS has the most potential among the taken substrates for use in flexible microstrip patch antenna.

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