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Performance Analysis of Co-planar Antenna in X-Band Range for Different Substrate Materials

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Abstract*— Antenna engineering acts as a center wing for the sophistification of communication systems.This paper emphasizes on the design of a aerial in X-Band range with the center frequency as 10GHz. The modelled radiator as a unique structure with repeated microscopic cylindrical slots. The outcome of this work has found its applications in UHF, VHF and microwave communication systems. FR4 Epoxy and Rogers RT Duroid 5880 are the insulating materials used in this design. The dimensions of the aerial for two different materials are determined by using same set of transmission line model equations. Out of the four available feeding techniques, microstrip edge feed has been chosen because of the ease of fabrication. Antenna attributes gain, directivity, Return loss and standing wave ratio were observed and compared. High Frequency Stuructural Simulator 15.0 is the software used to design the antenna.

Keywords*— Aerial, FR4 Epoxy, Rogers RT Duroid 588, Transmission line model equations, microstrip edge feed, HFSS.

I. Introduction

Different energy levels are defined in an electromagnetic spectrum both in terms of frequency and wavelength. Depending upon the range of frequencies, the entire spectrum has been sub divided into several bands namely C, S, X, K, Ku, Ka etc [1]. Band utilization varies for each frequency and for every band in the field of science and technology and communicarion systems and so on. Radar and Sonar are immensely being operated in the X-band i.e., 8GHz to 12GHz [2]. These systems which are used in this range are highly dependent on the feeding methodology. Hence high precision sources and detectors were deployed. X-band found number of applications in almost all the advanced scientific technologies because of the reason that it has high penetration, radiation intensity along with the spectroscopy [3].

The designing of an antenna in the X-band needs the high attention in the aspect such as interference of noise components into the radiated signal to the receiver. Here, in this work a group of conducting elements are arranged serially with each other and operated in the X-band to give the adverse characteristics [4].

In order to determine, how good the performance of the communication system, the antenna should display appreciable gain, directivity, impedance matching and bandwidth along with the radiation patterns. High gain, low physical size, broad bandwidth, versatility are the primary factors which are to be considered an antenna for any system and these factors can greatly compensate the involvement of antenna in many contemporary fields of engineering.

The other important parameters of an antenna are bandwidth and beamwidth. Bandwidth is an important factor through which the appropriate utilization of the spectrum can be determined. The antenna bandwidth can be defined for impedance, radiation and polarization [5]. Return loss is the basic consideration for any antenna design, which permits the maximum energy to be transferred from source to load. Maximum or minimum energy radiation along a specified direction can be ensured by radiation bandwidth. The loss in the radiation due to polarization mismatch can be reduced by a well defined polarization bandwidth.

II. Planar Antenna

An antenna can always be a radiator, hence in this context a planar radiator significantly equivalent to the planar antenna. The only discriminating factor between the coplanar and non coplanar antenna is the geometrical position of the ground i.e. whether the ground is placed above the substrate or below the substrate [6]. The feeding techniques and the method of analysis are always same for both the planar and non co-planar radiators.

The reason because planar antenna has grabbed the attention of researchers is, low manufacturing cost than the waveguide based technology and are considerably low weight and compact. The secondary reason is the planar nature of antenna makes the radiator ideal for array structure. The ease of integration with the microwave and millimeter circuit components is the important factor that makes the planar integrated antenna so desirable [7]. The ability of the transmission lines to integrate with 3 terminal devices makes possible to use for feeding both the planar and non co planar waveguides.

In air wave communication and space wave communication there is an obvious use of antenna but in order to make the system compact and flexible the antenna which is being installed in those systems should also posses the low profile features and miniaturized structure [8]. As the planar patch antennas are well known for their low weight, small size and compactness, these antennas are extensively being implemented in various research activities.

III. PROPOSED MODEL

The procedure for designing an antenna involves number of stages and the design can be accomplished using several platforms. Electromagnetic simulators can be used to simulate the antenna structure which gives the better perception to the designer. Here in this endeavor structure simulation software has been used. The structural representation of antenna includes substrate, patch, ground, feedline and a radiation box. One cannot confine to a particular order in defining and designing these objects.

Choosing a material for the design and fabrication is the major task which includes lot of ground work. The change in material properties leads to the undesirable characteristics. A substrate material must always be a dielectric one with some dielectric constant (ε_r). Rogers RT/Duroid 5880 and FR4 Epoxy are the substrate material deployed for the designed antenna with a dielectric constant of 2.2 & 4 respectively. The patch is a conducting element which is responsible for the radiation of an antenna. Copper is the conducting element with the relative permittivity of unity.

Transmission line model is the best method to analyze the planar antenna and the microstrip antenna. In this method of analysis, the width 'W' and height 'h' of the patch and the substrate will be mentioned precisely [9]. For an antenna to be designed, the dimensions must be calculated using the model equations. The line model provides the equations to calculate the dimensions for length and width of patch, feedline, feed point and transmission line. The feedline can be either a inset feed or the edge feed with their own equations to calculate the dimensions.

The desired range of operating frequency for this antenna is X-band which extends from 8 to 12GHz. The central frequency can be anything in between that range and the dimensions of the antenna were dependent on the operating frequency. The following are the design equations using transmission line model [9].

Width of the patch is given by following relation.

$$W = \frac{1}{2 f_r \sqrt{\mu_0 \varepsilon_0}} \sqrt{\frac{2}{\varepsilon_r + 1}} = \frac{\lambda_0}{2} \sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

In the above equation, λ_0 is the operating wavelength.

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

Where 'h' is the height of the substrate material.

Extension in length due to fringing effect is given by following relation.

$$\frac{\Delta L}{h} = 0.412 \frac{\left(\varepsilon_{reff} + 0.300\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{W}{h} + 0.800\right)} \tag{3}$$

Actual patch length after including the extended length is

$$L = \frac{1}{2 f_r \sqrt{\varepsilon_{reff} \mu_0 \varepsilon_0}} - 2\Delta L = \frac{\lambda_0}{2\sqrt{\varepsilon_{reff}}} - 2\Delta L \tag{4}$$

By using the above formulae which were derived using transmission line model, the dimensions of the designed antenna has been tabulated as follows.

TABLE I
DIMENSIONS OF AN ANTENNA

S.No	Dimensions of the antenna		
	Object Name	**FR4 Epoxy**	**Rogers RT Duroid 5880**
1	substrate (length, width, height)	70mm, 200mm. 1.6mm	55mm, 172mm. 1.4mm
2	patch (length, width, height)	50mm, 170mm. 0.017mm	46mm, 158mm. 0.017mm
3	feedline (length , width, height)	3.29mm, 7.9mm. 0.017mm	3.29mm, 7.9mm. 0.017mm
4	ground (length, width, height)	70mm, 200mm, - 0.017mm	58mm, 200mm, - 0.017mm

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5	radiation box (length , width, height)	90mm, 200mm, 20mm	90mm, 200mm, 20mm
6	feed point (In XZ plane)	16.45mm, 6.72mm.	16.45mm, 6.72mm.
7	cylindrical Slots	Radius = 2mm Height = 1.6mm	Radius = 2mm Height = 1.6mm

The gain and directivity of an antenna can be concentrated in single direction and multiple directions based on which the antenna can be comes under the category of either Omni directional or isotropic. Gain of an antenna can be varied from far field to near field. Hence in order to provide discrimination between the near fields and far field the radiation box is always included in the antenna design [11]. The radiation box is always composed with air as a medium with dielectric constant of unity. Due to the change in the values of the relative permittivity between the device and the free space fringing effect will occurs which leads to change in the antenna dimension. While calculating the dimensions, the length of the patch should be taken as per fringing effect.

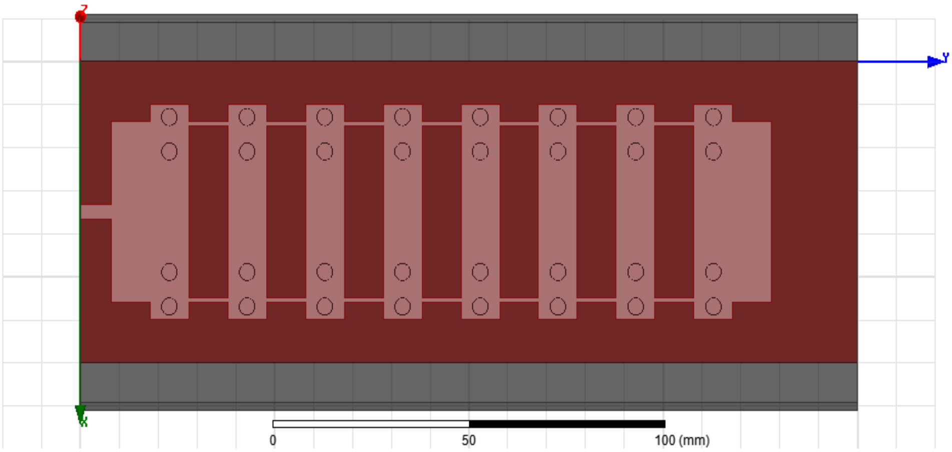

Fig. 1 Structure of planar antenna

Feeding an antenna is the next essential step. There are 4 types of feeding techniques depending upon their nature either contacting or non-contacting feed. Among the available feeding techniques microstrip edge feed is used because of its ease to implement and fabricate. A feed point is the port through which the excitation will be given. Here in this design a wave port is created to excite the antenna.

IV. RESULTS AND DISCUSSIONS

High frequency structure simulator software is the major tool to implement this work. Using the HFSS tool designer can analyze the antenna and it also helps in studying the parameters like Gain, Directivity, Axial Ratio, Impedance matching and Standing wave ratio.

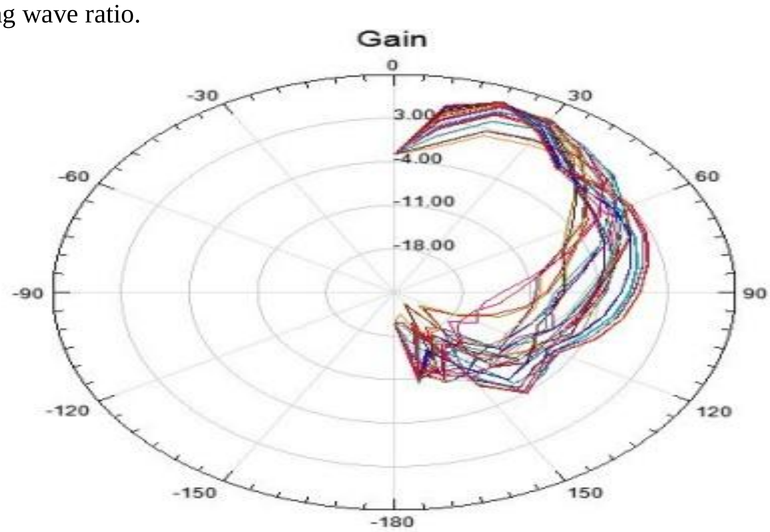

Fig. 2 Gain of planar antenna with FR4 epoxy as a substrate.

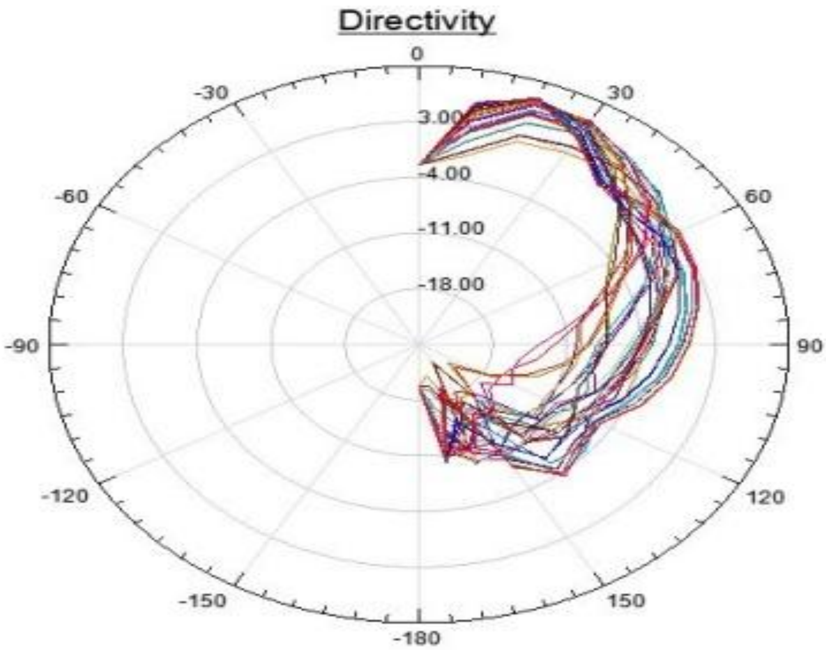

Fig. 3 Directivity of planar antenna with FR4 epoxy as a substrate.

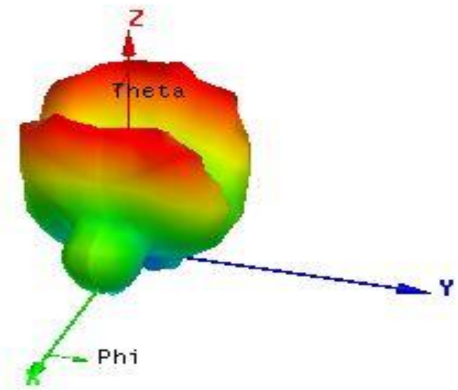

Fig. 4 Polar plot of planar antenna with FR4 epoxy as a substrate.

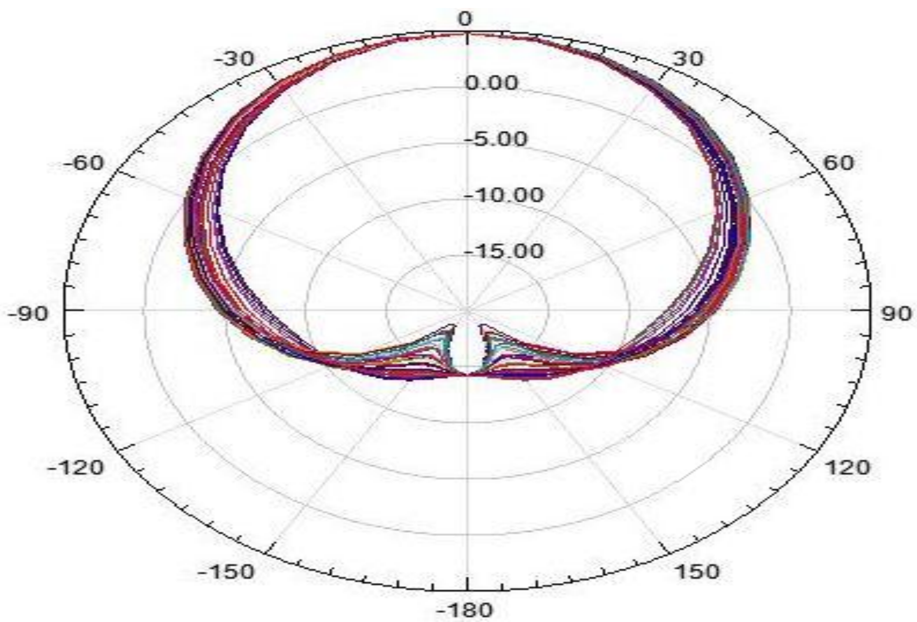

Fig. 5 Gain of planar antenna with Rogers RT duroid 5880 as a substrate.

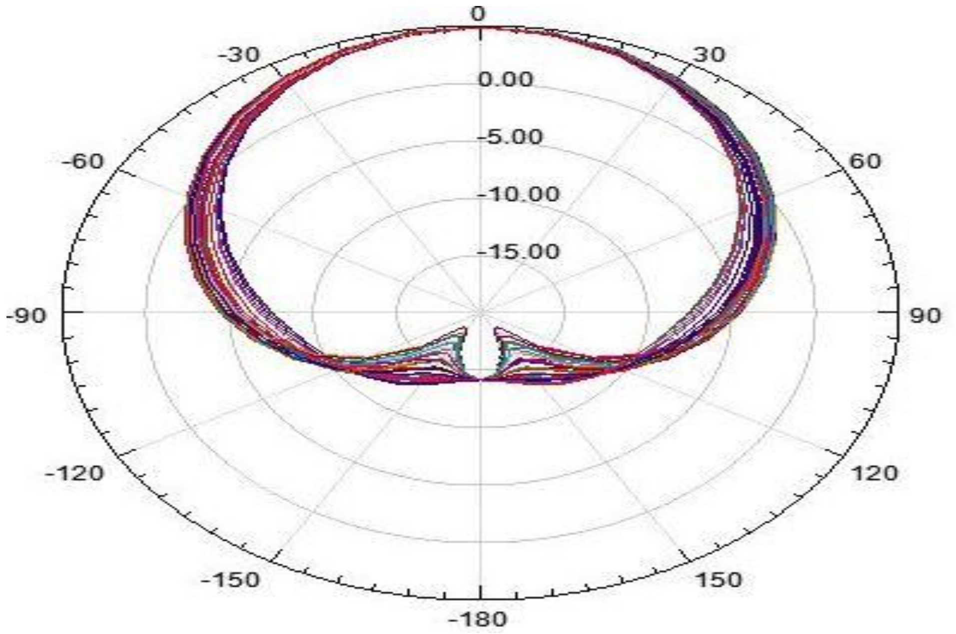

Fig. 6 Directivity of planar antenna with Rogers RT duroid 5880 as a substrate.

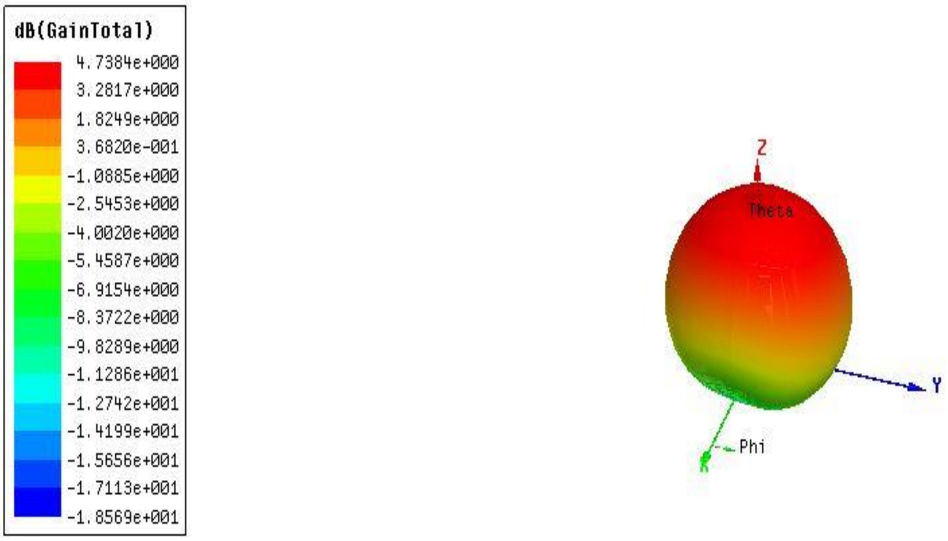

Fig. 7 Polar plot of planar antenna with Rogers RT duroid 5880 as a substrate.

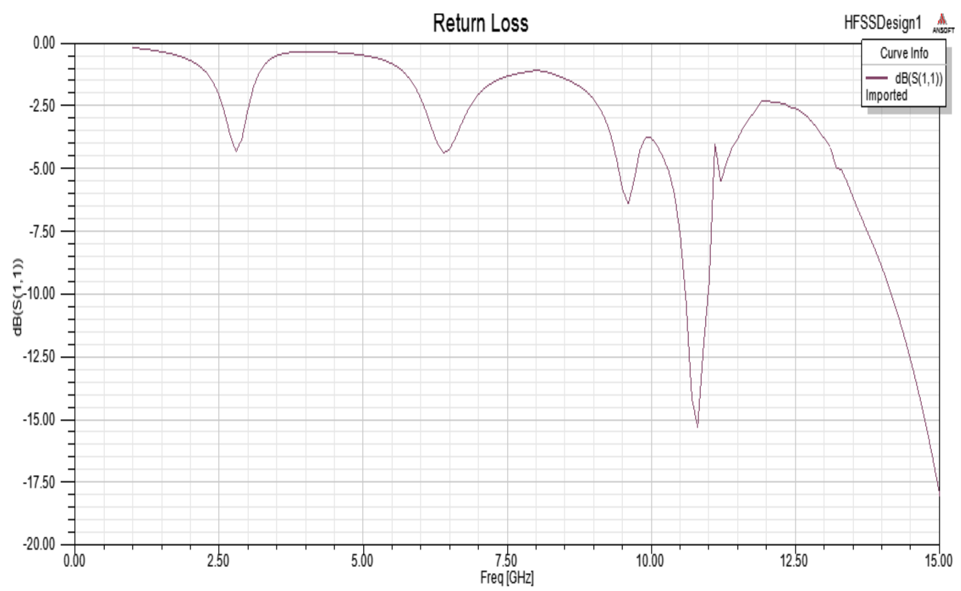

Fig. 8 Return loss curve of planar antenna for both substrate materials.

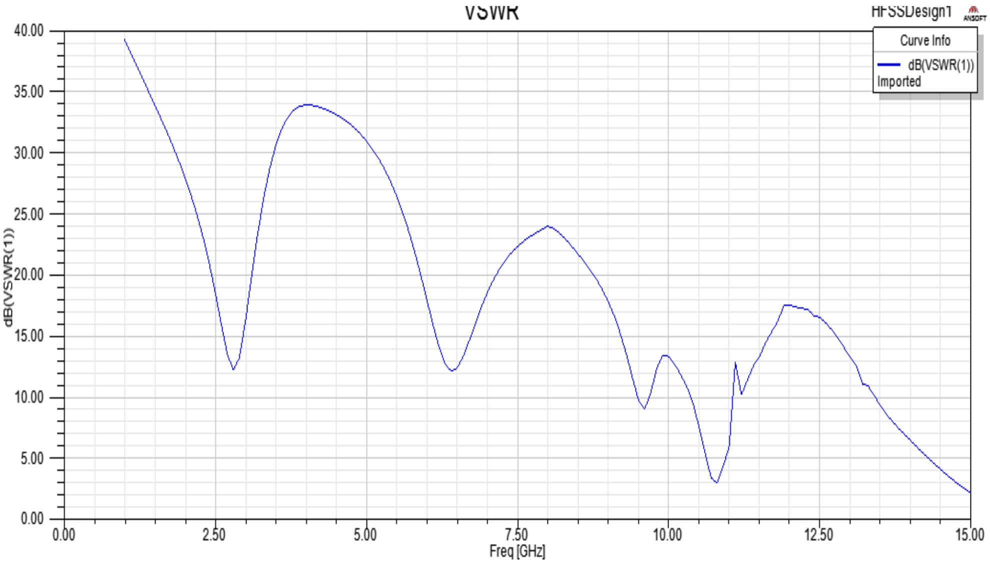

Fig. 9 Standing wave curve of planar antenna for both substrate materials.

TABLE III
EFFECT OF DIFFERENT SUBSTRATE MATERIALS ON PLANAR ANTENNA

S.No	Performance Analysis		
	Parameter	**Rogers RT Duroid 5880**	**FR4 epoxy**
1	Resonating frequency	10.4GHz	10.4GHz
2	Gain in dB	7.6dB	4.73dB
3	Directivity in dB	7.75dB	5dB
4	Return loss in dB	-15dB	-15dB
5	VSWR	1.8	2.1

From the above tabular data it can be easily depicted that the central frequency is around 10.4GHz which is lies in the X-band. The designed aerial is performing better for the Rogers RT Duroid 5880 material when compared to the FR4 Epoxy material.

V. CONCLUSIONS

The designed planar radiator is meeting the microstrip technology requirements which substantial values of parameters. Resonating frequency is 10GHz which has found the immense applications in almost all the UHF and VHF applications. The fabrication of the antenna can be done and the working can be determined by using a network analyzer.By introducing stub matching or varactor diode, the same antenna can be operated under circular polarization which can be considered as the future scope of this work.

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