Design of Triangular Microstrip Patch with Covered and Space Dielectric

Nivedita Kumar

Abstract — **This paper presents the effect on resonant frequency (f_r) of equilateral triangular patch due to cover and space dielectric. It is observed that as the superstrate dielectric constant and its thickness increases, the resonant frequency decreases. For space dielectric, as the air gap between patch and space dielectric increases the resonant frequency increases with incremental change in f_r < 0.4%. For large air gap, resonant frequency tends towards the simple microstrip antenna f_r. The accuracy in f_r of present and calculated from both FDTD and IE3D is ≤ 1%. The effects on co and cross polarization with respect to dielectric constant have also been calculated. The proposed design is very useful to design the equilateral triangular patch with wide bandwidth, high gain, to estimate the environmental effect on resonant frequency.**

Index Terms **— Resonant Frequency, Equilateral triangular microstrip patch, Substrate and Superstrate.**

I. INTRODUCTION

The microstrip antennas are widely used in microwave and millimeter wave applications starting from satellite to mobile hand sets due to its low profile, light weight, easily manufacturability and various other advantages [1-3]. However, the majority of the research in open literature reported in this area has been concentrated on the rectangular and circular patch antennas [4-9]. Present author has reported the effect on resonant frequency of Rectangular and circular patch in multilayer structure environment [10-11]. It is understood that equilateral triangular patch has radiation properties similar to that of the rectangular and circular patch. But equilateral triangular patch is physically smaller in comparison to rectangular and circular patch. This property of equilateral triangular patch is advantageous for being etched on curve surfaces and also for designing a compact array. Hassani et. al. [12] and Manotosh Biswas et.al [13] have reported the equilateral triangular patch with and without cover. As such no CAD model is available for equilateral triangular for with and without cover and to incorporate the effect of space dielectric and air – gap thickness on resonant frequency.

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In this paper, we proposes an simple design expression for equi-triangular microstrip patch in multilayered environment. This simple design expression can also estimates the effect on f_r due to intentional or unintentional air-gap with respect to their thickness. This design will be very useful for the design engineer. The calculated resonant frequencies have been compared with the measured results available and a good agreement is revealed.

II. DESIGN EXPRESSIONS

The multilayered microstrip structure is shown in Figure 1a. A simple more general expression for calculating resonant frequencies of TM_{nm} mode for equilateral triangular microstrip patch with and with air gaps, with and without superstrates can be written as

$$f_{rmin} = \frac{2C}{3\, S_{eff}\sqrt{\varepsilon_{reff}}}\,(n^2 + nm + m^2)^{1/2} \qquad (1)$$

Where c is free space velocity and ε_{reff} – effective dielectric constant of multilayered equilateral triangular patch. The S_{eff} effective side of equilateral triangular patch in presence of multilayered dielectric is given ;

$$S_{eff} = (2\pi/3)\, a\sqrt{(1+g)} \qquad (2)$$

Where g is the parameter determine the fringing field effect. One or more dielectric layers above a microstrip patch cause the change in the fringing fields between the patch and the ground plane and that effect is accounted by the effective dielectric constant $\mathcal{E}_{eff}$ (0). The general formulations for a circular patch [11] can be extended to calculate $\mathcal{E}_{eff}$ (0) of multilayered equilateral triangular patch (Fig. 1) by using the formulation

$$a = (3/2\pi)\, s \qquad (3)$$

where s is side length of equilateral triangular patch. Equation (2) is derived from an equivalence relation between a circular patch (radius = *a*) and a triangular patch with side length *s*. Equal circumference was considered as the basis of equivalence to account for equal static fringing fields. The effective dielectric constant $\mathcal{E}_{eff}$ (0) of multilayered equilateral triangular microstrip patch can be calculated by following expression

$$\mathcal{E}_{eff}(0) = \mathcal{E}_{r2}\, q1 + \mathcal{E}_{r2}\,(1-q1)2 \times [\mathcal{E}^2_{r3}\, q2\, q3 + \mathcal{E}_{r3}\mathcal{E}_{r4}\,(q2\, q4 +(q3+ q4)2] \times [\mathcal{E}^2_{r3}\, q2\, q3\, q4 + \mathcal{E}_{r2}\,([\mathcal{E}_{r3}\, q3 +\mathcal{E}_{r4} q4)(1-q1-q4)2+\mathcal{E}_{r3}\mathcal{E}_{r4} q4(q2q4+(q3+q4)2)]-1 \qquad (4)$$

This expression for effective permittivity can be used to calculate the resonant frequency of multilayered equilateral triangular microstrip patch i.e. spaced dielectric ETMP for intentional or unintentional air-gap. The filling fractions q1, q2, q3, q4 are given in [11]. The multilayer microstrip structure is shown in Fig. 1a can be made equivalent to single layer microstrip structure shown in Fig. 1b by using single layer reduction technique applied by [13,14]. In this, effective dielectric constant $\mathcal{E}_{eff}(0)$ calculated by equation (4) of multilayered microstrip structure will be equivalent to effective dielectric constant of single layer microstrip structure with equivalent relative permittivity $\mathcal{E}_r$ of single layer structure and radius of patch which provides width of the patch calculated from the side length of ETMP, which is replaced by effective width and substrate height $h_1 = h_{11} + h_{12}$ and $h_2 = h_3 + h_4$

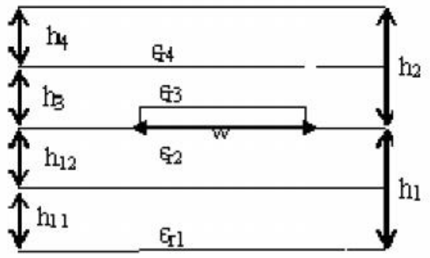

Figure 1 a Multilayered Microstrip Patch Antenna

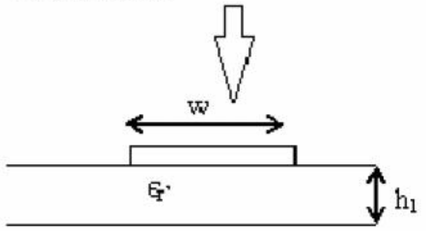

Figure 1b Equivalent Equi-trianglur Microstrip Patch

III. RESULTS AND DISCUSSION

A. Equilateral Triangular Microstrip Patch Antenna Fig. 1 shows equilateral triangular microstrip patch in multilayer media along with its equivalent single microstrip equilateral triangular patch. This is achieved using the single layer reduction technique [14]. Simple equilateral microstrip antenna can be made by substituting $\mathcal{E}_{r11} = \mathcal{E}_{r3} = \mathcal{E}_{r4} = 1$, $h_{11}=0$ $h_3=0$ $h_4=0$ .Table 1, compares the effect on fr due to various values of side length of equilateral triangular patch. As side length s increases the f_r decreases. The experimental resonant frequency is in good agreement with the present method. The accuracy is less than 0.5%.

TABLE 1
COMPARISON OF RESONANT FREQUENCY OF VARIOUS EQUILATERAL TRIANGULAR PATCH

$\varepsilon_{r12} = 4.3$, $h_{12} = 1.53$ mm, $h_{11}=0$		
Side length(mm)	Exp. f_r (GHz)	PM f_r (GHz)
58.0	1.6412	1.6467
55.0	1.732	1.7349
45.0	2.137	2.1118
35.0	2.6905	2.6965
16.0	5.65	5.6581

B. Equilateral Triangular Microstrip Antenna with cover dielectric

The equilateral triangular microstrip patch with cover can be achieved by substituting $\varepsilon_{r1} = \varepsilon_{r4} = 1$, $h_{11} = h_4 = 0$ in multilayered structure shown in Figure 1. In Table 2, effect of superstrate on the resonant frequency has been tabulated for various superstrate dielectric constant ε_{r2}. The resonant frequency calculated by present method has been compared with f_r calculated from FDTD method [14], SDA [12] method and others [13]. As the dielectric constant of superstrate increases the resonant frequency of equilateral triangular microstrip patch decreases. The incremental % change in resonant frequency in comparison to simple equilateral triangular microstrip patch is 2.177%, 3.421% and 5.13% respectively for $\mathcal{E}_{r3} = 1.5$, 2.5 and 3.2.

TABLE 2
COMPARISON OF THE EFFECT SUPERSTRATE DIELECTRIC CONSTANT ON FR WITH PRESENT METHOD

$\varepsilon_{r2} = 2.5$, a = 37mm, $h_{12} = h_2 = 1.59$mm				
ε_{r3}	FDTD [16]	PM	[13]	SDA [12]
1.0	3.215	3.2606	3.156	3.3
1.5	3.145	3.1084	3.133	3.245
2.5	3.105	3.0819	3.0955	3.165
3.2	3.050	3.065	3.0712	3.12

Table 3, shows the effect on resonant frequency due to superstrate thickness of different dielectric constant for equilateral triangular microstrip patch. From the table 3, it is clear as the thickness of the supersterate increases, the resonant frequency decreases. But the incremental % change in f_r reduces as thickness increases. The maximum incremental % change occurs between the equilateral triangular patch without substrate and with superstrate. The incremental % change increases as dielectric constant of superstrate increases. But decreases as the thickness of superstrate decreases. It can been seen that the experimental resonant frequencies are in very close agreement with the resonant frequencies calculated by present method. Fig. 2 shows the resonant frequency due to various dielectric constant and their thickness.

TABLE 3
EFFECT OF SUBSTRATE THICKNESS ON RESONANT FREQUENCY OF EQUILATERAL TRIANGULAR PATCH

a = 58 mm, ε_{r2} = 4.3, h_{12} =1.53mm,					
ε_{r3} = 4.3			ε_{r3} = 2.2		
h_3 mm	Exp. f_r GHz	PM f_r GHz	h_3 mm	Exp. f_r GHz	PM f_r GHz
0.0	1.641	1.6467	0.0	1.6412	1.6467
1.53	1.582	1.5609	0.787	1.6224	1.6419
3.06	1.562	1.5534	1.574	1.6172	1.6397
4.59			2.361	1.613	1.6382

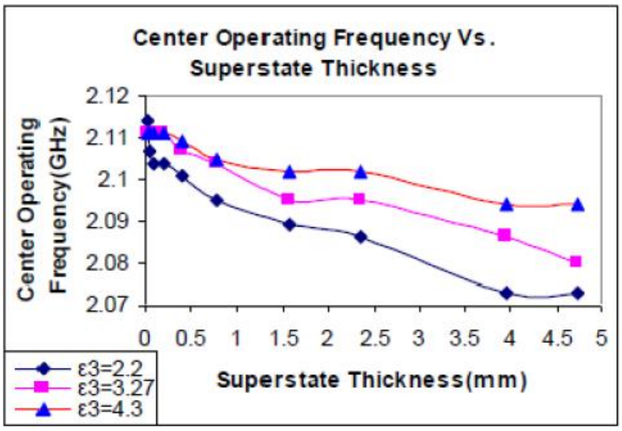

Fig. 2. Variations of the center operating frequency with superstate thickness for h_2= 0.024 mm , h_{12}=1.53 mm ,L = 45 mm

C. Equilateral Triangular Microstrip Antenna with Spaced Dielectric

The equilateral triangular microstrip patch with spaced dielectric can be achieved by substituting h_{11} = 0.0, $\mathcal{E}_{r1}$ = 1 in multilayered structure shown in Fig. 1. Table 4, calculates the effect on resonant frequency of a spaced dielectric thickness with variable intentional or unintentional air-gap. The effect on resonant frequency due to various air-gaps with 1.53 mm thickness spaced dielectric of $\mathcal{E}_{r4}$ = 4.3 has been compared with the calculated resonant frequency from FDTD and Present method which are in good agreement. As the air-gap increases the resonant frequency increases and tends towards the resonant frequency of simple ETMP. The % change in resonant frequency for h_3/h_4 =0.5 to 2.05 is 0.76% and incremental % change is less than 0.41%. The average and maximum deviation in resonant frequency is less than 0.31% and 0.56 % respectively. For small air-gap the change in f_r is maximum but as the air-gap increases the incremental % change in f_r decreases beyond i.e at h_3/h_4 = 2, the % incremental change is less 0.07 %. It is observed as the dielectric constant of spaced dielectric increases the resonant frequency decreases for fixed air-gap. If the thickness of spaced dielectric increases with the fixed air-gap, the resonant frequency decreases.

The equilateral triangular patch antenna has been simulated using commercial software based on method of moment. Figure 3 shows the return loss versus frequency for with and without dielectric cover and space dielectric.

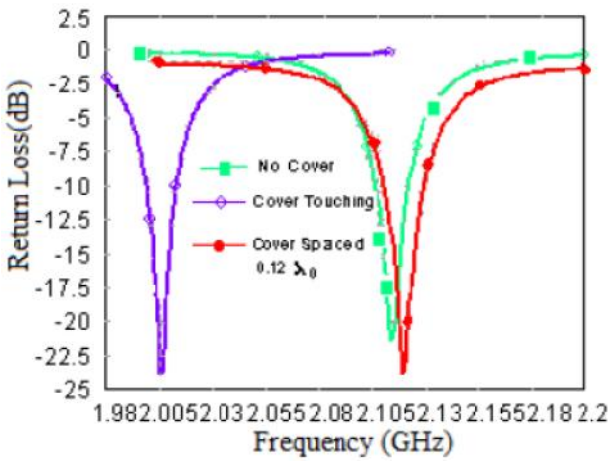

Fig. 3. Effects of with and with dielectric cover and spacing dielectric height for h_3= 1.53 mm , h_4 =1.53 mm , ε_{r1} = 4.3 , ε_{r2} = 1.0 , ε_{r3} = 4.3 , L = 45 mm

TABLE 4
EFFECT ON RESONANT FREQUENCY OF SPACE DIELECTRIC W. R. TO AIR-GAP

a = 58 mm, ε_{r2} = 4.3, h_{12} =1.53mm, ε_{r3} = 1

ε_{r4} = 4.3, h_4 = 1.53 mm					ε_{r4} = 2.2, h_4 = 0.787			
h_3 mm	Exp. f_r GHz	PM f_r GHz	Incr. % change	% dev.	Exp. f_r GHz	PM f_r GHz	Incr. % change	% dev.
0.0	1.5820	1.5609		1.33	1.6224	1.6419		-1.2
0.787	1.6168	1.6259	2.1299	-0.56	1.6316	1.6354	0.56	-0.23
1.574	1.6234	1.6286	0.4065	-0.32	1.6334	1.6369	0.11	-0.21
2.361	1.6280	1.6308	0.2825	-0.17	1.6351	1.6381	0.1039	-0.18
3.148	1.6292	1.6326	0.074	-0.208	1.6356	1.6390	0.03	-0.207

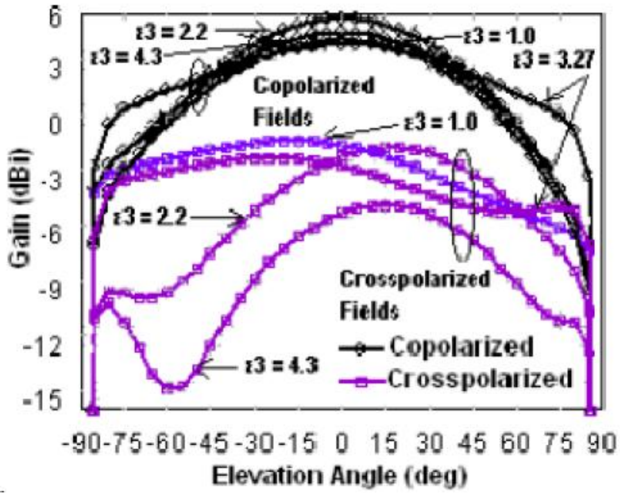

Fig. 4. Co and Cross polarized patterns cover dielectric for h_3= 0.0 mm; h_4= 1.53 mm , h_{12} =1.53 mm , ε_{r1} = 4.3 , ε_{r2} = 1.0, L = 45 mm.

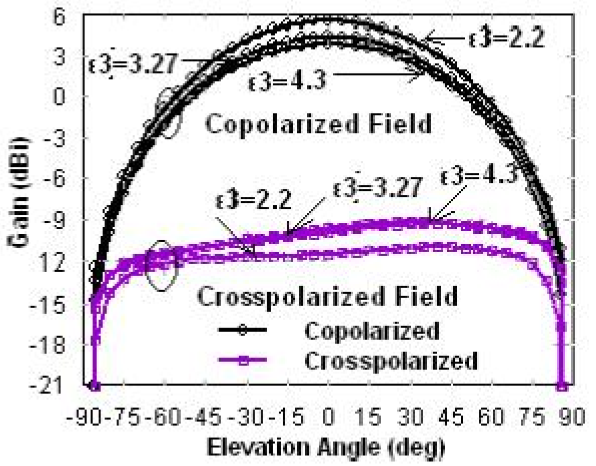

Fig.5. Co and Cross polarized pattern for Space dielectric h_3 = 0.024mm,h_4 =1.53 mm,h_{12} = 1.53mm,$\mathcal{E}_{r1}$=4.3,$\mathcal{E}_{r2}$= 1.0, L=45mm

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Fig. 4 shows the effect on co and cross polarization due to covered dielectric. As the cover dielectric constant varies the cross and co polarisation of antenna is also varies. Fig. 5 shows the co and cross polarization effect due to various space dielectric.

IV. CONCLUSIONS

An accurate simple design methodology for equi-triangular patch has been presented for multilayered media. The accuracy of this proposed method is in the close agreement with full wave and experimental values.

Such design study is very useful for designing the high gain antenna and calculating the effect of environment on resonant frequency. The effect on the co and cross polarization has also been estimated due to cover and space dielectric. The design method is efficient and suitable for CAD.

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