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Compact Tripple U-Shaped Slot Loaded Circular Disk Patch Antenna for Bluetooth and WLAN Application

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***Abstract* -In the present paper a three U-shaped slot loaded disk patch antenna is analysed by using circuit theory concept. The antenna shows dual resonance. The resonance frequency of single layer patch is found to be 1.84 GHz and 2.61 GHz (simulated 1.80 GHz and 2.61 GHz) whereas for two layers dielectric antenna, it is 2.21 GHz and 3.14 GHz (simulated 2.20 GHz and 3.13GHz) respectively. The frequency ratio is found to be 1.41 (simulated 1.45) for single layer patch antenna and 1.42 (simulated 1.42) for two dielectric layers patch antenna. The bandwidth of single layer patch antenna is found to be 1.52% and 1.68 % for lower and upper resonance frequency respectively while for two layers dielectric antenna it is 1.10 % and 1.53 %. Introducing three U-slot in the circular disk 16.54 % of size reduction has been achieved. The theoretical results are compared with the simulated results obtained from IE3D which are in close agreement.**

***Index Term* - Patch antenna, U-slot loaded patch, dualband antenna and two dielectric layers**

I. INTRODUCTION

During the recent years there has been rapid development in dualband microstrip antenna due to its wide application in many communication systems. Some of the important applications of this kind of antennas are in Wireless Local Area Network (2.4-5 GHz), synthetic aperture radar (SAR), dualband GSM/DCS 1800 mobile communication system, Bluetooth and Global Positioning System (GPS). Dualband characteristics can be achieved with the same structure by exciting two different modes with suitable feed point [1], using stacked structures [2], loading reactive stub [3], slots [4], coplanar multi conductor structures [5] etc. The broadband characteristic of a rectangular, circular and stacked U-shaped slot microstrip patch antenna has been reported [6-9], in which two different but close resonant frequencies in a single patch are combined to give a wideband operation. On the other hand, if the excited resonant frequencies are far apart, a dual-frequency operation can be achieved with the U-slot antenna [10-13], wearable textile antenna [14], also give the dualband characteristics.

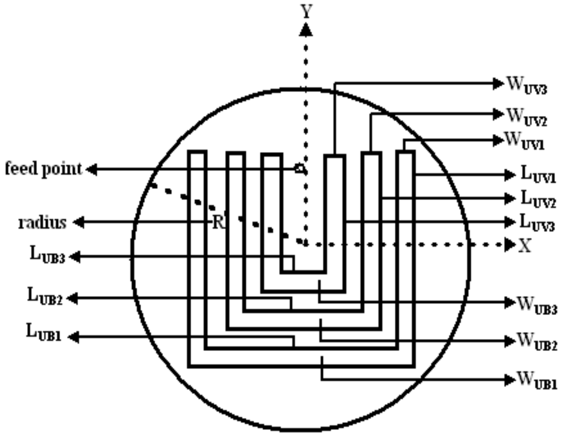
A slot antenna has special advantage because of its simple structure, such as wider bandwidth, less conductor loss [15-17]. A probe feed microstrip antenna with an internal U-shaped slot having large impedance bandwidth with broadside radiation pattern are reported [18-19].

In this article, a new type of three U-shaped slot loaded single and two dielectric layers circular disk patch antenna have been proposed for dualband applications using circuit theory concept based on modal expansion cavity model. The dimensions of three U-slot are chosen in such a way so that proposed antenna can exhibit dual frequency behaviour with good matching condition. Various antenna parameters are calculated as a function of frequency.

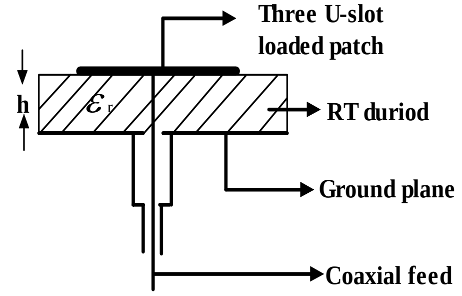
II. CONFIGURATION AND ANALYSIS

A. *Analysis of three U-shaped slot loaded Single layer patch antenna*

U-slot can be considered as combination of three slot as shown in Fig.1. Among these, two vertical slot are the arms of the U-slot having dimension ($L_{UV} \times W_{UV}$) and the third one is base of the U-slot and it is horizontal ($L_{UB} \times W_{UB}$).The equivalent circuit of a narrow slot comprises a series combination of radiation resistance (R_s) and the reactive component (X_s) [20-21] as shown in Fig.2,



(a) Top view



(b) Side view

Fig.1. Geometry of three U- shaped slot loaded single layer patch antenna

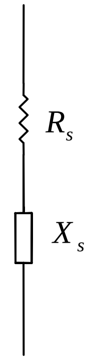


Fig.2. Equivalent circuit of slot

Therefore the impedance of the vertical slot can be given as [22]

$$Z_{UV} = R_{UV} + jX_{UV} \tag{1}$$

where

$$R_{UV} = 60\left\{\begin{array}{l} C+\ln(kL_{UV})-C_i(kL_{UV})+\frac{1}{2}\sin(kL_{UV})[S_i(2kL_{UV}) \quad 2S_i(kL_{UV})]+\frac{1}{2}\cos(kL_{UV}) \\ \left[C+\ln\left(\frac{kL_{UV}}{2}\right)+C_i(2kL_{UV})\text{-}2C_i(kL_{UV})\right] \end{array}\right\}$$

and

$$X_{UV} = 30\cos^2\alpha\left\{\begin{array}{l} 2S_i(kL_{UV})+\cos(kL_{UV})[2S_i(kL_{UV})-S_i(2kL_{UV})-\sin(kL_{UV})] \\ \left[2C_i(kL_{UV})-C_i(2kL_{UV})-C_i\left(\frac{2kW_{UV}{}^2}{L_{UV}}\right)\right] \end{array}\right\}$$

in which C is Euler's constant=0.5772, k is the propagation constant in free space and functions S_i and C_i are the sine and cosine integrals defined as

$$S_i(x) = \int_0^x \frac{\sin(x)}{x}dx$$

and $$C_i(x) = -\int_x^\infty \frac{\sin(x)}{x}dx$$

Similarly the impedance of the base slot can be given as [22]

$$Z_{UB} = R_{UB} + jX_{UB} \qquad (2)$$

where

$$R_{UB} = 60\left\{\begin{array}{l} C + \ln(kL_{UB}) - C_i(kL_{UB}) + \frac{1}{2}\sin(kL_{UB})\left[S_i(2kL_{UB}) \quad 2S_i(kL_{UB})\right] + \\ \frac{1}{2}\cos(kL_{UB})\left[C + \ln\left(\frac{kL_{UB}}{2}\right) + C_i(2kL_{UB}) - 2C_i(kL_{UB})\right] \end{array}\right\}$$

and

$$X_{UB} = 30\cos^2\alpha\left\{\begin{array}{l} 2S_i(kL_{UB}) + \cos(kL_{UB})\left[2S_i(kL_{UB}) - S_i(2kL_{UB}) - \sin(kL_{UB})\right] \\ \left[2C_i(kL_{UB}) - C_i(2kL_{UB}) - C_i\left(\frac{2kW_{UB}^{\ 2}}{L_{UB}}\right)\right] \end{array}\right\}$$

where L_{UV} = length of vertical slot, L_{UB} = length of base slot and W_{UV} = width of vertical slot, W_{UB} = width of the base slot

Hence the input impedance for U-shaped slot can be calculated from Fig.3.

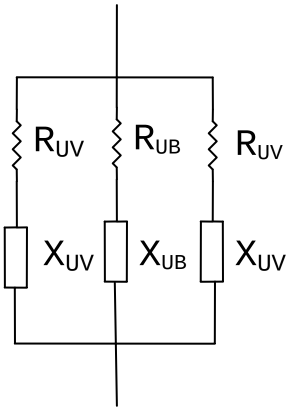


Fig. 3. Equivalent circuit of U-shaped slot

where

R_{UV} = Radiation resistance of vertical slot

R_{UB} = Radiation resistance of base slot

X_{UV} = Reactive component of vertical slot

X_{UB} = Reactive component of base slot

$$Z_U = \frac{Z_{UV} + 2Z_{UB}}{Z_{UV}Z_{UB}} \qquad (3)$$

in which

Z_{UV} = Input impedance of vertical slot

Z_{UB} = Input impedance of base slot

A disk patch can be analyzed as the parallel combination of resistance, inductance and capacitance as shown in Fig.4, [23].

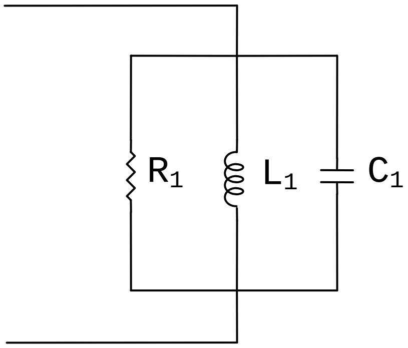


Fig.4. Equivalent circuit of circular disk patch antenna

where
$$C_1 = \frac{Q_T}{2\pi R_1 f_r} \qquad (4)$$

$$L_1 = \frac{R_1}{2\pi f_r Q_T} \qquad (5)$$

and
$$R_1 = \frac{h^2 E_0^2 j_n^2(kx_0)}{2P_T} \qquad (6)$$

in which

$J_n(kx_0)$ = Bessel functions of order ‘n’

x_0 = feed location from the center of the disk patch

h = thickness between ground plane and fed patch

Q_T = total quality factor of the resonator

p_T = total power loss in the cavity

The resonance frequency of the disk patch antenna can be approximately determined from the equation [24].

$$f_r = \frac{k_{nm}\,c}{2\pi R_e\sqrt{\varepsilon_r}} \qquad (7)$$

in which

k_{nm} = mth zero of the derivative of Bessel function of order ‘n’

c = velocity of light

R_e = effective radius of the circular disk [23]

ε_r = dielectric constant of the substrate.

Therefore, the impedance of the patch without U-slot can be derived as

$$Z_P = \frac{1}{\frac{1}{R_1} + j\omega C_1 + \frac{1}{j\omega L_1}} \quad (8)$$

Hence the total input impedance of proposed antenna can be calculated from Fig. 5 as

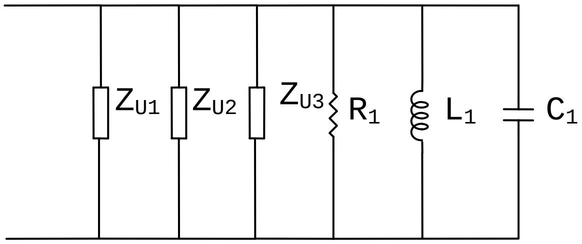


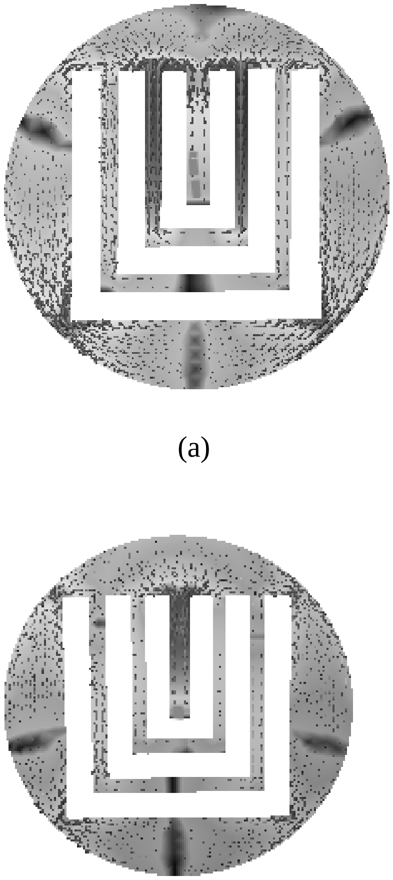
Fig.5. Equivalent circuit of three U-shaped slot loaded circular disk patch antenna

$$Z_T = \frac{Z_P Z_U^{\,*}}{Z_P + Z_U^{\,*}} \quad (9)$$

where

$$Z_U^{\,*} = \frac{Z_{U1} Z_{U2} Z_{U3}}{Z_{U2} Z_{U3} + Z_{U1} Z_{U3} + Z_{U2} Z_{U1}}$$

where Z_{U1}, Z_{U2}, Z_{U3} are the total input impedance of the three U-shaped slot respectively. The current distribution for proposed single layer dualband antenna is shown in Fig.6. There are two currents flowing in the patch, one is in the initial patch and another is around the slots, which are responsible for the dual band behavior.



(a)

(b)

Fig.6. Current distribution in three U-shaped slot loaded single layer circular disk patch antenna for lower and upper resonance frequency (a) fr_1=1.80 GHz (b) fr_2=2.61GHz

B. Analysis of three U- slot loaded patch antenna with two dielectric layers

The side view geometry of the proposed antenna in two dielectric layers is shown in Fig.7.

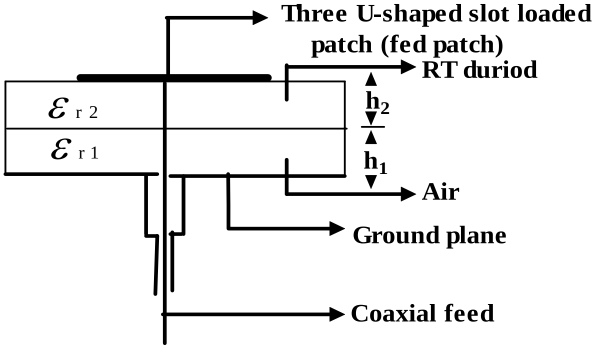


Fig.7. Side view geometry of three U-slot loaded microstrip patch antenna with two dielectric layers

The effective permittivity for driven patch for this antenna is given as [23].

$$\varepsilon_{e1} = \frac{\varepsilon_{re}+1}{2} + \frac{\varepsilon_{re}-1}{2}\left[1+\frac{10\,h_e}{L}\right]^{-\frac{1}{2}} \qquad (10)$$

where $h_e = h_1 + h_2$

in which h_1 and h_2 are thickness for two dielectric layers

and $$\varepsilon_{re} = \frac{\sum_{i=1}^{2} h_i}{\sum_{i=1}^{2} \frac{h_i}{\varepsilon_{ri}}}$$

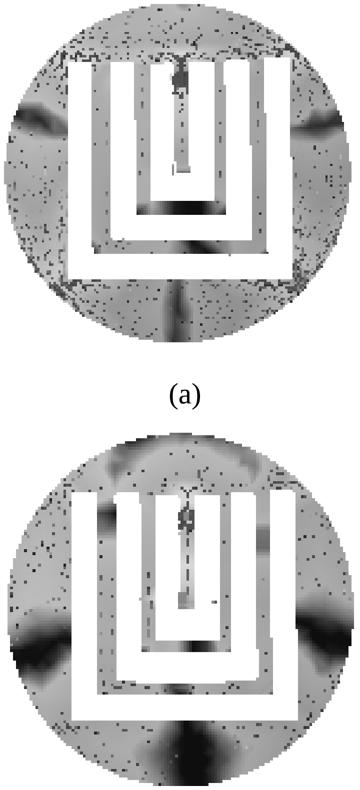
Now the value of R, L and C for this configuration can be obtained by replacing the value of effective permittivity (ε_r) and thickness (h) with ε_{e1} and h_e in equations (4), (5) and (6). The total input impedance of this geometry can be calculate as

$$Z'_T = \frac{Z_{path} Z^*_{slot}}{Z_{path} + Z_{slot}} \qquad (11)$$

where

$$Z^*_{slot} = \frac{Z_{U1} Z_{U2} Z_{U3}}{Z_{U2} Z_{U3} + Z_{U1} Z_{U3} + Z_{U2} Z_{U1}}$$

in which Z_{patch} is the input impedance of microstrip patch antenna with two dielectric layers and Z^*_{slot} is the total input impedance of three U-shaped slot with two dielectric layers. Using equation (9) and (11) one can calculate the various antenna parameters. The corresponding current distribution for three U-shaped slot loaded for two dielectric layers are shown in Fig.8.



(a)

(b)

Fig.8. Current distribution in two dielectric layers patch antenna (a) fr$_1$=2.20GHz (b) fr$_2$=3.13GHz

III. RADIATION PATTERN

The radiation pattern for three U-shaped slot loaded circular disk patch antenna is calculated by considering the proposed antenna as circular disk patch [22]

$$E(\theta) = J^n k_0 R V_0 e^{jk_0 r_1} [J_{n+1}(k_0 R \sin\theta) - J_{n-1}(k_0 R \sin\theta)].\cos n\phi \qquad (12)$$

$$E(\phi) = J^n k_0 R V_0 e^{-jk_0 r_1} [J_{n+1}(k_0 R \sin\theta) - J_{n-1}(k_0 R \sin\theta)].\cos\theta \sin n\phi \qquad (13)$$

where

V_0 = radiating edge voltage

= $hE_0 J_n(R)$

r_1 = distance of an arbitrary far-field point

R = radius of fed disk patch

For two dielectric layer microstrip patch antenna

$$k = k_0 \sqrt{\varepsilon_{re}}$$

where ε_{re} is the effective permittivity for driven patch. Substituting the value of k and thickness (h_e) in equation (12) and (13) one can calculate the radiation pattern for two dielectric layers patch antenna.

IV. DESIGN AND SPECIFICATIONS

Table 1. Design specifications for the three U-shaped slot loaded single layer patch antenna

Substrate material used	RT duroid
Relative permittivity of the substrate (ε_r)	2.32
Thickness of the dielectric substrate (h)	1.5 mm
radius of the circular disk patch (R)	30 mm
Length of the vertical slots $L_{UV1}, L_{UV2}, L_{UV3}$)	38 mm,31mm,24mm
Length of the base slots ($L_{UB1}, L_{UB2}, L_{UB3}$)	30mm,16mm,2.0mm
Width of the vertical slots ($W_{UV1}, W_{UV2}, W_{UV1}$)	4.0 mm
Width of the base slots ($W_{UB1}, W_{UB2}, W_{UB3}$)	4.0mm
Feed location (x_0 , y_0)	(-0.32 mm,16.22 mm)

Table 2. Design specifications for the three U-shaped slot loaded patch antenna with two dielectric layers

Relative permittivity of the first substrate (ε_{r1})	1.0 (air)
Thickness of the first dielectric substrate (h_1)	1.0 mm
Radius of the circular disk patch	30 mm
Length of the vertical slots ($L_{UV1}, L_{UV2}, L_{UV3}$)	38mm, 31mm, 24mm
Length of the base slots ($L_{UB1}, L_{UB2}, L_{UB3}$)	30mm,16mm,2.0mm
Width of the vertical slots ($W_{UV1}, W_{UV2}, W_{UV3}$)	4.0 mm
Width of the base slots ($W_{UB1}, W_{UB2}, W_{UB3}$)	4.0mm
Relative permittivity of the second substrate (ε_{r2})	2.32 (RT duroid)
Thickness of the second dielectric substrate (h_2)	1.5 mm
Feed location (x_0 , y_0)	(-0.32mm,16.22mm)

V. RESULTS AND DISCUSSION

The variation of return loss with frequency for three U-shaped slot loaded single layer patch antenna is shown in Fig.9 along with simulated results using IE3D [25]. It is observed that the antenna resonates at two frequencies (fr_1=1.84 GHz, fr_2=2.61GHz, simulated fr_1=1.80 GHz and fr_2=2.61GHz) and -10dB bandwidth is found to be 1.52% for lower resonance and 1.68 % for upper resonance frequency. Calculated frequency ratio of upper to lower resonance frequency (fr_2/fr_1) is 1.41. The theoretical results are in good agreement with simulated one.

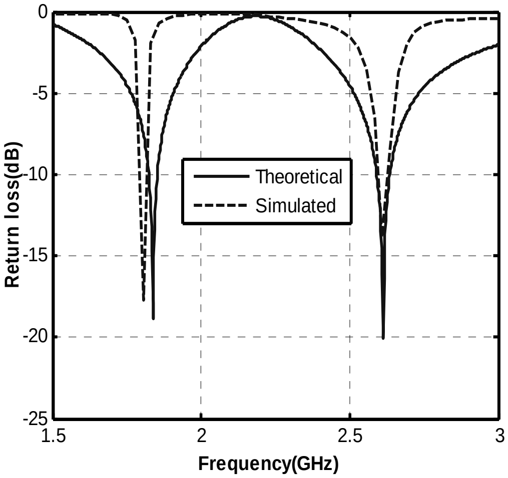


Fig. 9. Variation of return loss with frequency for single layer patch antenna along with simulated results (ε_r=2.32, h=1.5mm, R= 30mm)

Similarly for two dielectric layers patch antenna two resonance frequencies are obtained as shown in Fig.10. i.e. lower resonance frequency is 2.21 GHz and upper resonance frequency is 3.14 GHz. (simulated 2.20GHz and 3.13GHz). In this case the bandwidth is 1.10% and 1.53 % for lower and upper resonance frequency respectively. The ratio of the resonance frequencies of two layer patch is found to be higher (1.42) as compared to single layer patch antenna (1.41). It can be observed that both theoretical and simulated bandwidth is in good agreement at upper resonance frequency whereas there is slight deviation at lower resonance frequency.

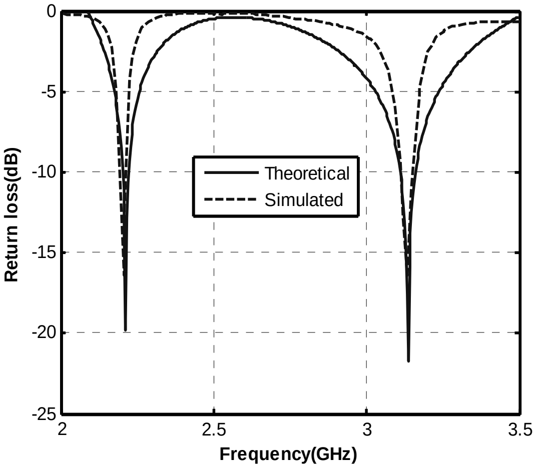


Fig.10.Variation of return loss with frequency for two dielectric layers patch antenna along with simulated results(ε_{r1}=1.0, ε_{r2}=2.32, h_1=1.0mm, h_2=1.5mm, R=30mm)

Radiation pattern for single layer microstrip patch antenna is shown in Fig.11. The theoretical results show good agreement with the simulated results of lower resonance however, there is small deviation in maximum power in case of upper resonance frequency as shown in Fig. 12.

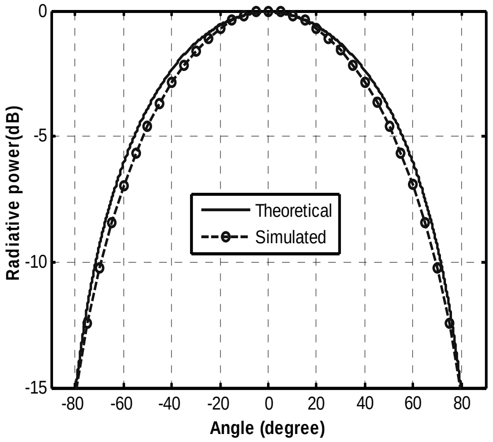


Fig. 11. Radiation pattern for single layer dielectric patch antenna for lower resonance frequency (fr_1=1.86GHz)

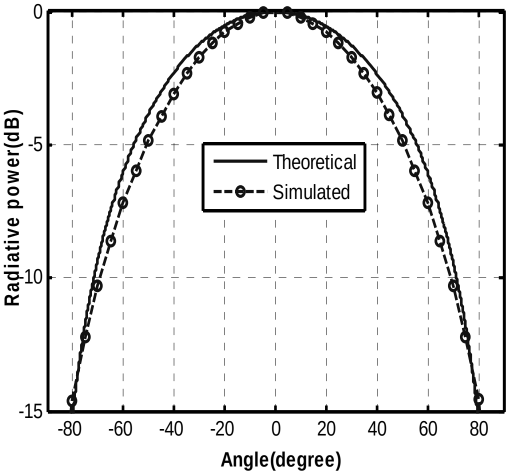


Fig.12. Radiation pattern for single layer dielectric patch antenna for upper resonance frequency (fr_2= 2.61GHz)

Radiation pattern for proposed antenna with two dielectric layers at lower and upper resonance frequency is shown in Fig.13 and Fig.14. In this case also the theoretical results are in good agreement with the simulated one.

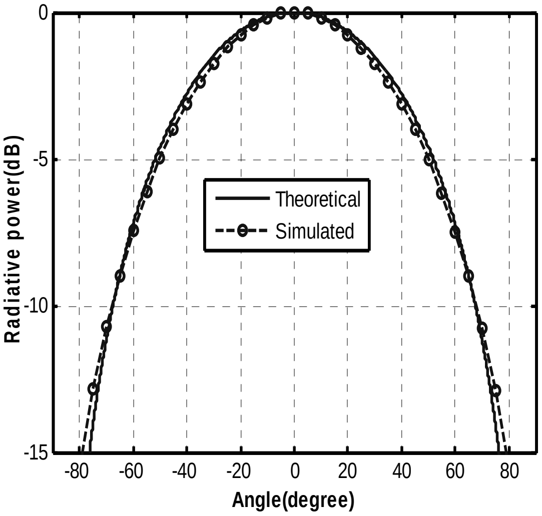


Fig.13. Radiation pattern for two dielectric layers patch antenna for lower resonance frequency (fr_1=2.21GHz)

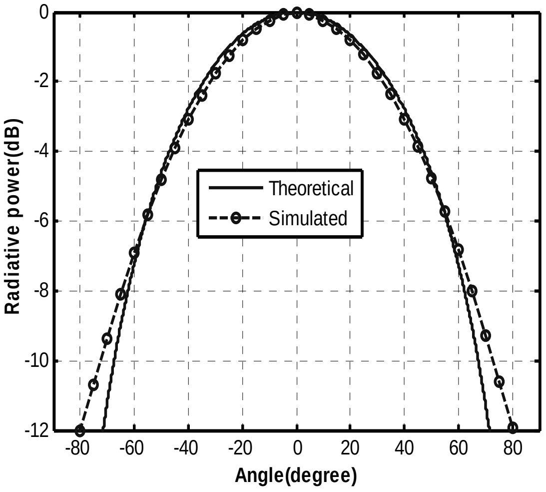


Fig. 14 Radiation pattern for two dielectric layers patch antenna for upper resonance frequency (fr_2=3.14GHz)

VI. CONCLUSION

From the analysis it is concluded that three U-shaped slot loaded patch can operate at two resonance frequencies. Hence this antenna can be used for dualband operation in which separation of resonance is controllable with the dimensions of the slot.

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