Rectangular Notch Loaded Dual Band Annular Ring Patch Antenna

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***Abstract*— In this article, a dual band annular ring patch antenna is theoretically investigated using the equivalent circuit concept.Two symmetrical rectangular notches are etched in radiating ring patch with respect to feed point. It is observed that the resonant frequency is directly proportional to the notch width and notch length. The bandwidth of the antenna at lower and higher ends are 134 MHz(1.815-1.681GHz) and 212MHz (2.849-2.637GHz) respectively for given antenna specifications. The calculated results are compared with the IE3D simulation software and previously reported results based on Artificial Neural Network (ANN). The theoretical results obtained from the proposed analysis are in good agreement with the simulated and ANN based results.**

***Index Terms*—** Annular ring antenna, Cavity model, Notch loaded ring, dual band antenna

I. Introduction

Annular Ring Microstrip Antennas (ARMA) have received much attention because of their low profile, light weight and reduced size suitable for many portable wireless devices [1-2]. The size of the annular ring patch is smaller than circular or rectangular patch when it resonates in its fundamental TM_{11} mode. Annular ring antennas also exhibit broadband nature when operated near TM_{12} mode. The radiation efficiency of ring antenna is better than the circular patch antenna because in ring antenna, the edges at the inner and outer radii causes more fringing while in circular patch antenna, fringing occurs at the outer edge[3]. In annular ring antennas, the multiband characteristics can be easily obtained by adjusting the higher modes. A multiple- frequency antenna can reduce the installation space and provides advantage in cost and size. In the last two decades, many techniques for the design of patch antennas with multiple frequency operation have been reported such as single layer shorted pin microstrip antennas [4], gap couple annular ring antennas [5], loading of slots and notches in the radiating patch [6-9]. The incorporation of suitable dimensions of slot on the circular patch antenna does not introduce any mode but reduces the second order mode/resonance frequency. Thus, along with fundamental mode, such perturbed antennas show dualband as well as wideband behavior [10-12]. Similar properties are also observed in annular ring patch antennas.

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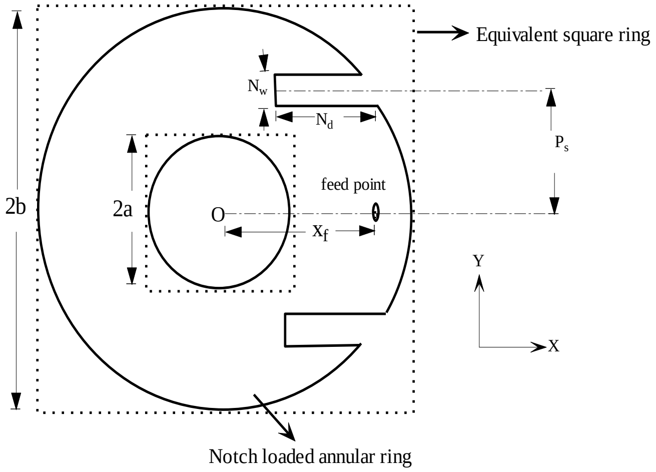
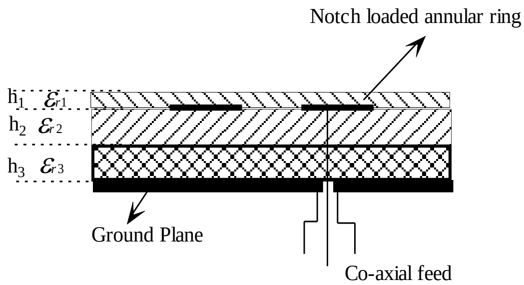
Therefore, in this paper, a dual band ARMA has been studied in which two notches are incorporated in the radiating patch with respect to the feed point. Circuit theory concept is used to analyze the various antenna characteristics such as impedance bandwidth, return loss,gain and radiation pattern. The effect of notch dimensions incorporated in the annular ring patch lowers the second order mode which reduces the separation between the dominant/fundamental and the second order resonating frequency and hence antenna exhibits a dual frequency nature. The effect of dimensions of rectangular notches on both upper and lower resonance frequencies has been studied theoretically. After optimizing the notched annular ring patch the proposed antenna can be used for Global Positioning System (GPS, 1.575 GHz) and Digital Multimedia Broadcasting (DMB, 2.62 GHz) simultaneously.

II. ANTENNA DESIGN AND ITS EQUIVALENT CIRCUIT

A two layered notch loaded ARMA configuration is shown in Fig.1 and further a superstrate is used to protect the radiating patch. Two rectangular notches of dimensions $N_d \times N_w$ are etched in the annular ring patch having inner and outer radii 'a' and 'b' respectively. In this analysis, for some calculation purpose, it is assumed that annular ring patch with inner 'a' and outer radii 'b' is equivalent to square ring patch with inner width '2a' and outer width '2b' (Fig. 1). It is because many characteristics of square ring patch are similar to annular ring patch [13-14]. Annular ring patch antenna is parallel LCR resonator for one resonant mode and the equivalent circuit can be given as shown in Fig. 2a.



(a) Top view



(b) Side view

Fig.1 Configuration of proposed antenna

The expression for the resistance R_1, inductance L_1 and capacitance C_1 can be given as [5,15].When two notches are etched in the ring patch with respect to feed point, the current length increases around the notch and hence the additional inductance ΔL and capacitance ΔC appear in the antenna structure which modify the initial equivalent ring circuit as shown in Fig. 2 b. Now the equivalent circuit for

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notch loaded ARMA can be given by adding a coupling capacitance (C_C) between two resonant circuits (Fig. 2c). Therefore, the present antenna shows a dual nature because both the resonant circuits give different resonant frequencies.

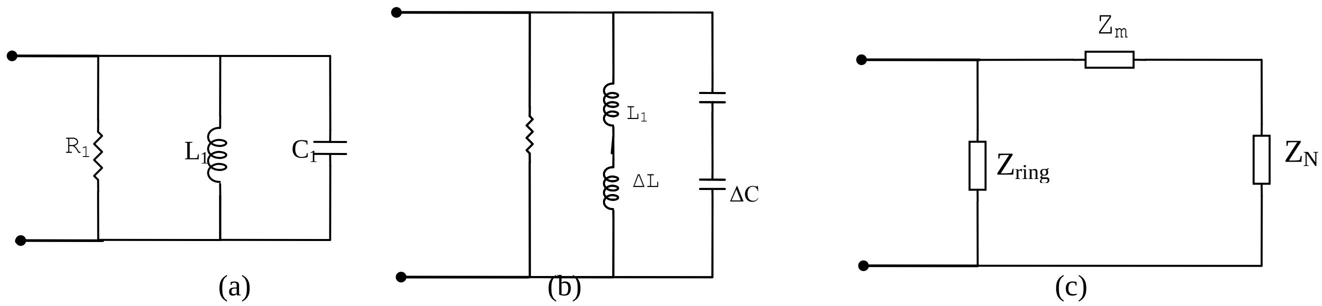

Fig. 2 Equivalent circuit of (a) ARMA (b) notched ARMA (c) Modified notched ARMA

This dual nature of antenna can also be explained by the current distribution on the ring patch obtained by the IE3D simulation software. Since etching a notch in the ring patch not only miniaturizes the antenna size but also reduces the resonance point of higher (TM_{12}) mode towards dominant (TM_{11}) mode (Fig. 3) and hence a dual band antenna response is observed.

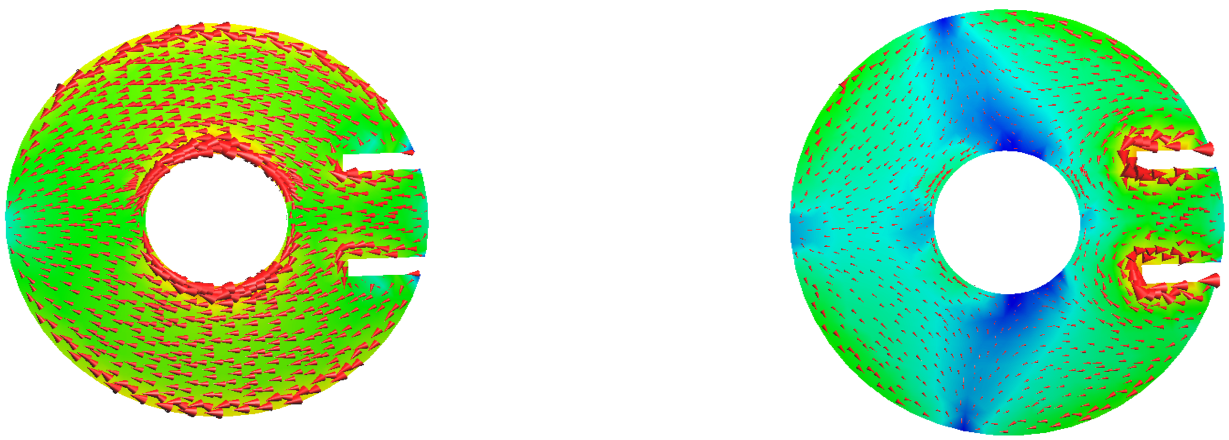

Fig.3 Current distribution on the patch at (a) 1.5 GHz (b) 2.68 GHz

The input impedance of the antenna can be calculated from the equivalent circuit shown in Fig. 2c.

$$Z_{in} = \frac{Z_{ring}(Z_N + Z_m)}{Z_{ring} + Z_N + Z_m} \tag{1}$$

here,

$$Z_{ring} = \frac{1}{\frac{1}{R_1} + \frac{1}{j\omega L_1} + j\omega C_1} \tag{2}$$

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$$Z_N = \frac{1}{\frac{1}{R_2} + \frac{1}{j\omega L_2} + j\omega C_2} \tag{3}$$

in which, $L_2 = L_1 + \Delta L$ and $C_2 = \frac{C_1 \Delta C}{C_1 + \Delta C}$

The additional inductance (ΔL) and capacitance (ΔC) can be calculated by [16-17]

$$Z_m = \frac{1}{j\omega C_c} \tag{4}$$

where, C_C is the coupling capacitance and given by [18]

$$C_c = \frac{-(C_1 + C_2) + \sqrt{(C_1 + C_2)^2 - C_1 C_2 (1 - 1/k_c^2)}}{2}$$

in which, $k_c = \frac{1}{\sqrt{Q_1 Q_2}}$

here Q_1 and Q_2 are the quality factors of both the resonators. The resonance resistance (R_2) of the modified configuration of the ARMA can be calculated from [19]. In the proposed antenna three layers of dielectric substrates are used, the effective dielectric constant of the structure can be calculated from [20]. The values of reflection coefficient and return loss can be calculated as:

$$\text{Reflection Coefficient } (\Gamma) = \left| \frac{Z_0 - Z_{in}}{Z_0 + Z_{in}} \right| \tag{5}$$

where Z_0= characteristic impedance of coaxial feed ($50\,\Omega$)

$$\text{Return loss} = -20 \log_{10} (\Gamma) \tag{6}$$

The radiation pattern for the antenna can be given by assuming it as conventional annular ring antenna [21].

$$E_\theta = \frac{j^n 2hk_0 E_0 e^{jk_0 r}}{\pi k_{nm} r} [J'_n(k_0 a \sin\theta) - \frac{J'_n(k_{nm} a)}{J'_n(k_{nm} b)} J'_n(k_0 b \sin\theta)].\cos n\phi \tag{7}$$

$$E_\phi = \frac{-j^n 2hk_0 E_0 e^{jk_0 r}}{\pi k_{nm} r} [\frac{J_n(k_0 a \sin\theta)}{k_0 a \sin\theta} - \frac{J'_n(k_{nm} a)}{J'_n(k_{nm} b)} \frac{J_n(k_0 b \sin\theta)}{k_0 b \sin\theta}].\cos\theta \sin n\phi \tag{8}$$

Here r is the distance of an arbitrary far field point, k_0 and k_{nm} are the propagation constants in free space and in dielectric medium in TM_{nm} mode respectively.

III. CALCULATION AND DISCUSSION OF RESULTS

TABLE 1. DESIGN SPECIFICATIONS FOR THE ANTENNA

Parameters	**Values**
Dielectric constant of material used for thickness h_1=6.1 mm	ε_{r1}=1.03
Dielectric constnat of material used for thickness h_2=6.05 mm	ε_{r2}=3.5
Dielectric constant of material used for thickness h_3=1.1 mm	ε_{r3}=1.04
Inner radius of the ring (a)	12.05 mm
Outer radius of the ring (b)	36.10 mm
Length of the notch (N_d)	15mm
Width of the notch (N_w)	3.0 mm
Feed location (x_0,y_0)	27.0,0 mm

The return loss for different values of notch depth is calculated using equation (6) and shown in Fig. 4. The variation of bandwidths at both the resonance frequencies is studied as a function of notch width and notch depth. It is found that for notch depth (N_d)=16mm, the bandwidth at upper and lower resonance frequencies are 280 MHz (3.284-3.004 GHz) and 162MHz(1.916-1.754GHz) respectively. It is also observed that both upper and lower antenna bandwidth decreases as the notch depth decreases. At lowest value of notch depth (N_d)=14mm, the bandwidth at upper and lower resonance frequencies are 221 MHz (2.785-2.564 GHz) and 129MHz(1.789-1.66GHz) respectively. But as the notch width (N_w) increases, both the bandwidths are decreasing. For notch width =2mm, the bandwidth at upper and lower resonance frequencies are 237 MHz (3.058-2.821 GHz) and 147 MHz (1.894-1.747GHz) respectively while at notch width =6mm, it is found to be 201 MHz (2.764-2.563 GHz) for upper side and 128 MHz (1.781-1.653GHz) for lower side respectively.

The higher resonant frequency (f_H) shifts from 3.13 GHz to 2.66 GHz and lower resonant frequency (f_L) shifts from 1.84 GHz to 1.73 GHz for the increasing value of notch depth (N_d). The similar effect is observed when notch width (N_w) increases (Fig. 5).

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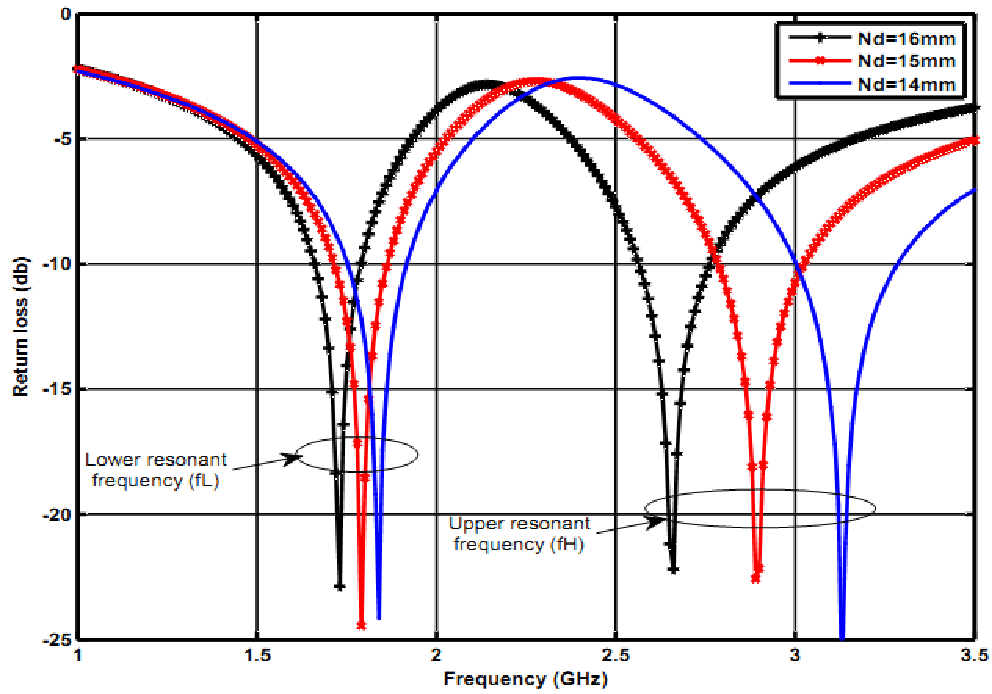

Fig.4 Variation of return loss with frequency for different notch depth (N_d)

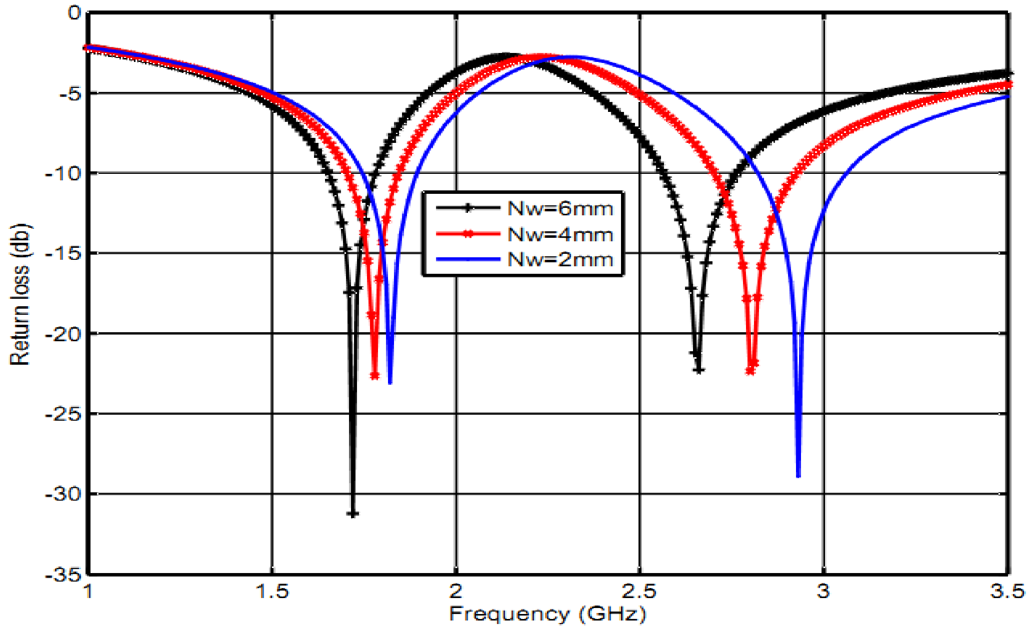

Fig.5 Variation of return loss with frequency for different notch width (N_w)

From Fig. 6 it is observed that the frequency ratio f_L/f_H is inversely proportional to the notch depth and notch width. It is noted that the effect of notch depth on both the resonant frequencies is more significant as compared to notch width.

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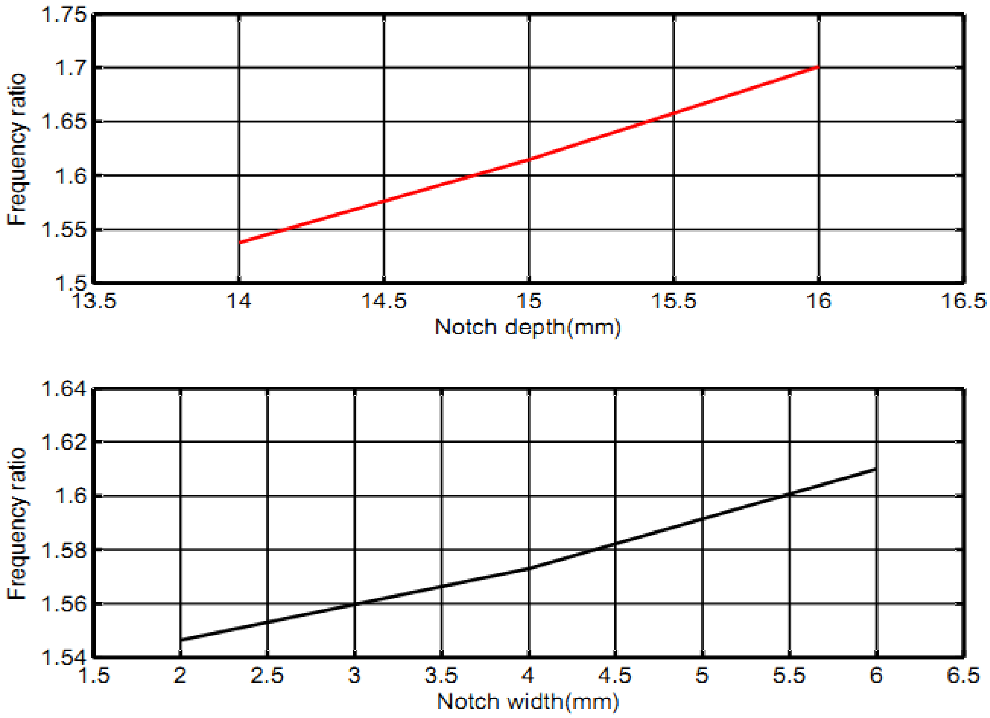


Fig.6 Variation of frequency ratio with different notch depth (N_d) and notch width (N_w)

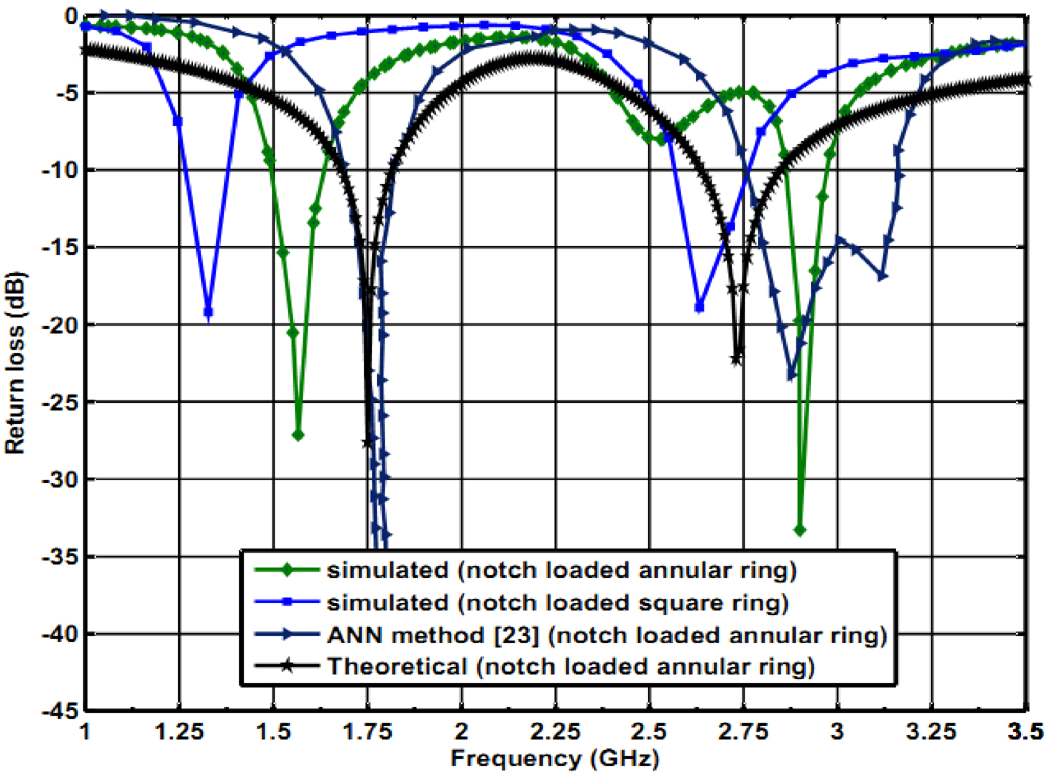
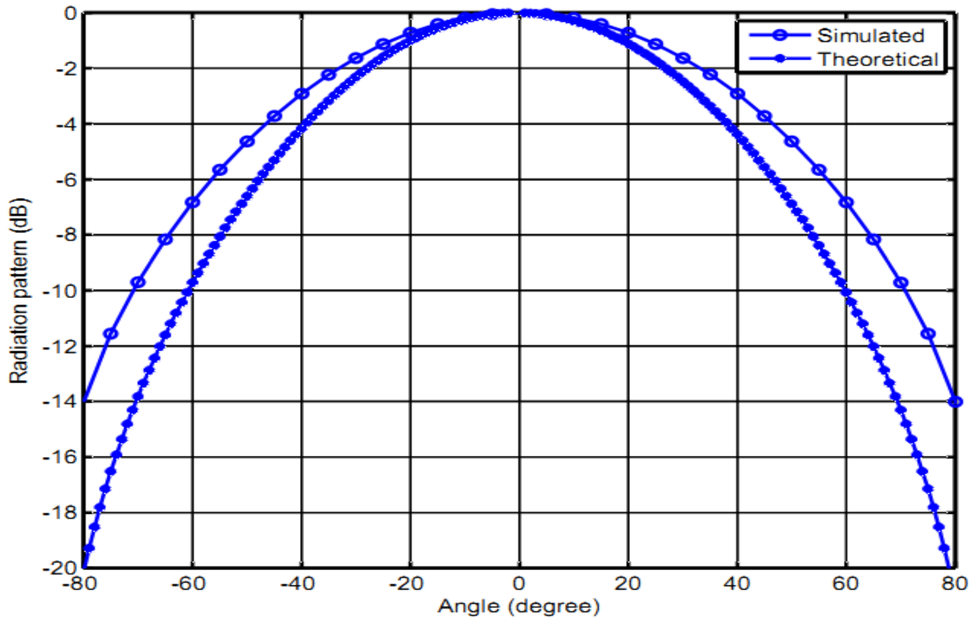
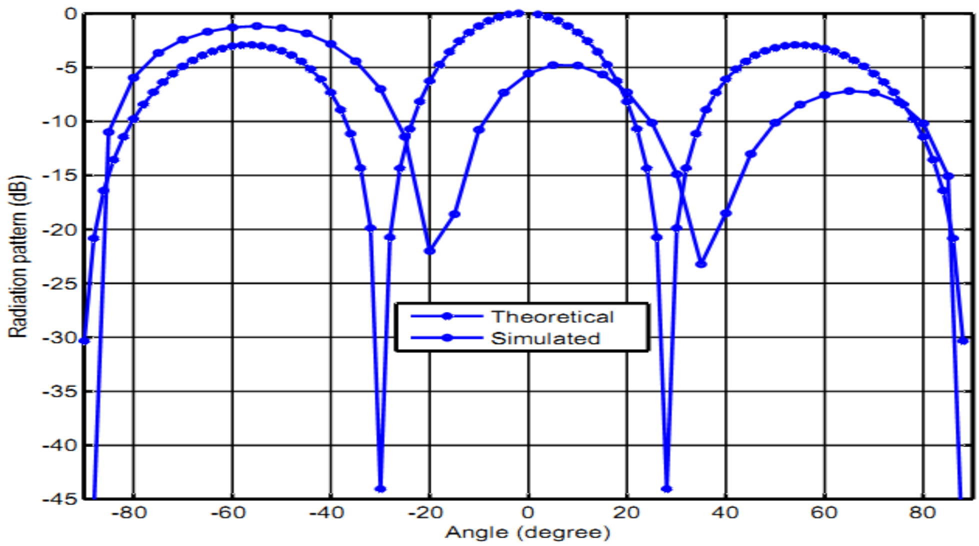


Fig.7 Comparative results of return loss with frequency of the ARMA for proposed, simulated and ANN method



(a)



(b)

Fig. 8 Radiation pattern for the proposed antenna (a) at 1.75 GHz (b) at 2.74 GHz

Theoretical results obtained by the cavity model are compared with the IE3D simulated results [22] and the result obtained by ANN method [23]. The results predicted by theory are in good agreement with the simulated as well as ANN results. However, some deviation in the theoretical result is seen because the analogy between square ring and annular ring differs in the patch area which causes the shift in resonance frequency. For a given dimension the area of an annular ring is smaller than square ring due to which both the resonant frequencies of the square ring move towards lower side as shown in Fig. 7. The radiation pattern of the antenna is calculated using equations (7) and (8) at lower (1.75 GHz) and upper (2.74 GHz) resonance frequencies.

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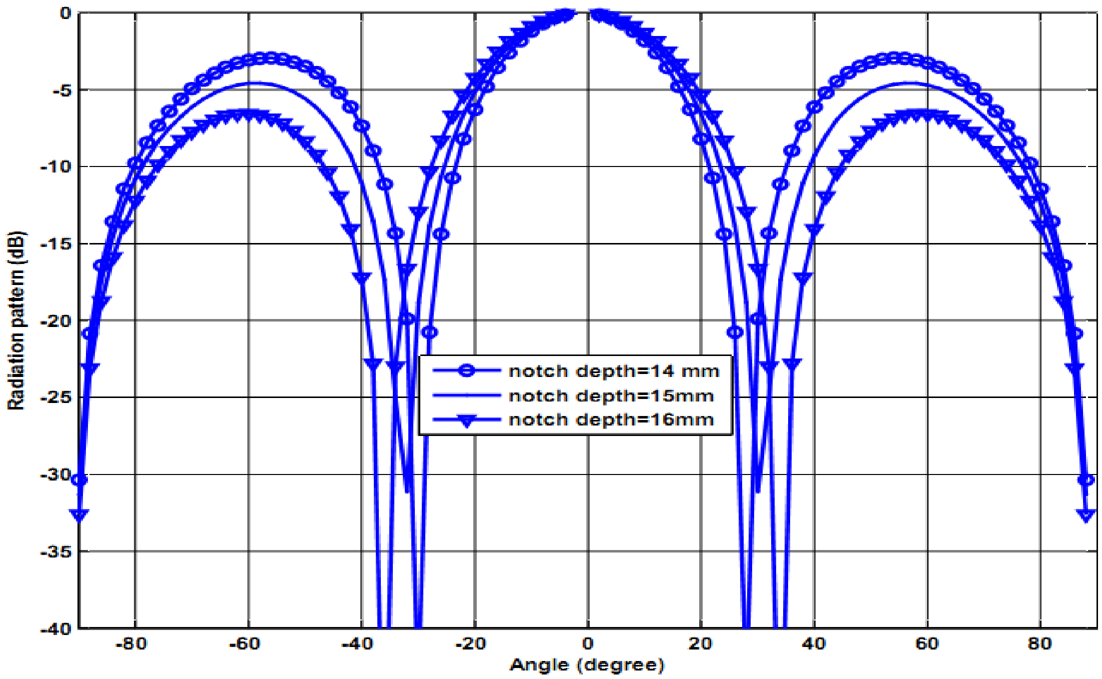

Fig. 9 Variation of radiation pattern at upper resonace frequency for different values of notch depth (N_d)

The results are also compared with the simulated results as shown in Fig. 8 (a and b). It is observed that 3dB beam width (66^0) at lower resonant frequency is greater than the beam width (32^0) at upper resonant frequency. It is due to (i) incorporation of the notches in ring patch (ii) higher ratio of inner and outer radius of annular ring and (iii) some assumptions in the theory which change the broadside nature of the radiation pattern and hence the symmetry of the radiation pattern deviates at upper resonant frequency. The sidelobes in radiation pattern at upper resonance frequency can be reduced by optimizing the notch dimensions as shown in Fig. 9.

The antenna gain obtained at upper and lower resonace frequencies are 4.25 dB (at 2.74GHz)and 6.6dB (1.75 GHz) respectively (Fig.10). Variation of radiation efficiency as a function of frequency is shown in Fig.11.From the figure it is clear that at upper and lower resonance frequencies the efficiency of the proposed antenna is 75% and 80% respectively .

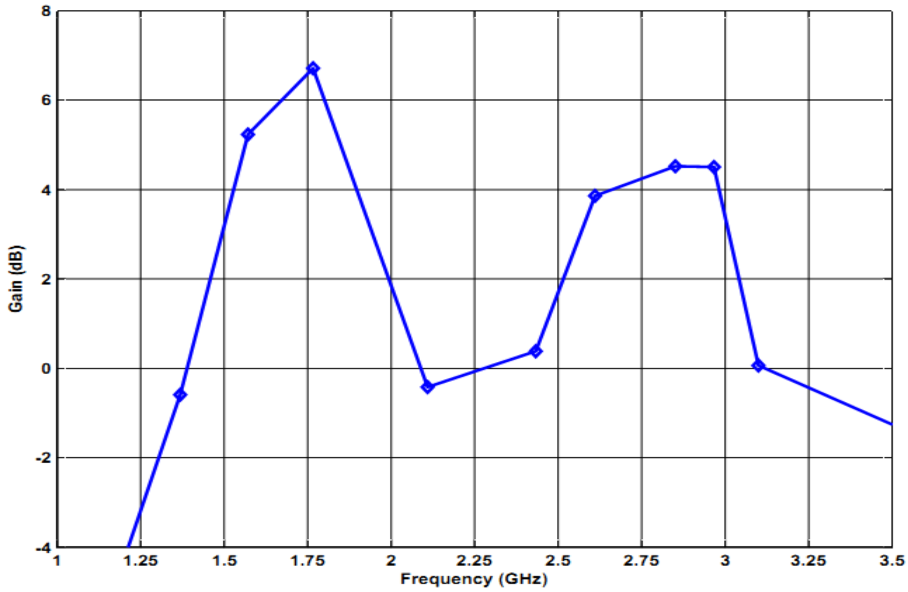

Fig. 10 Variation of Gain as a function of frequency

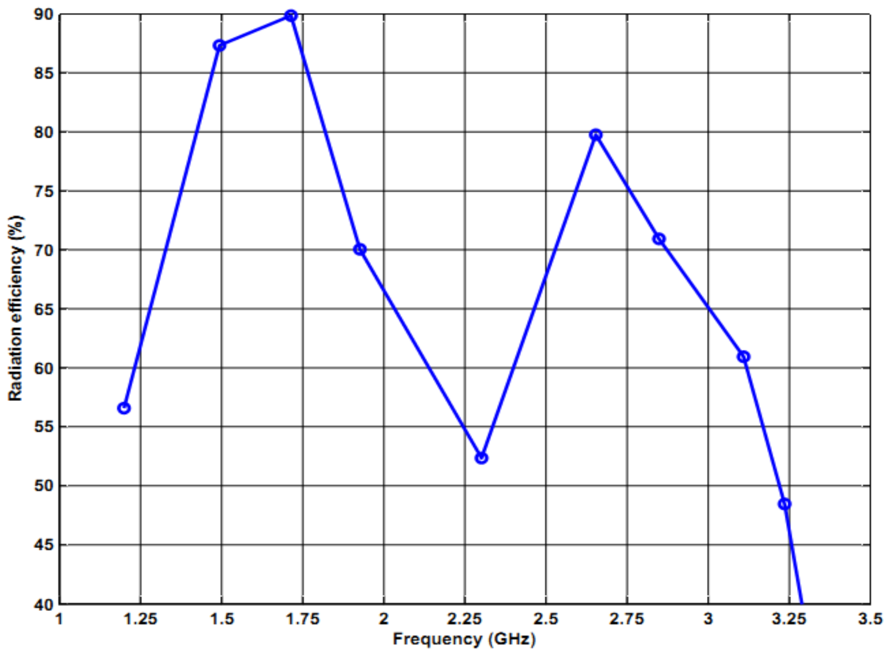

Fig. 11 Radiation efficiency of the proposed antenna

IV. CONCLUSION

In this work, circuit theory concept is implemented to design a notch loaded annular ring antenna. The equivalent circuit model has successfully verified the earlier reported results. The resonant frequencies of the proposed antenna calculated by the present theory agree well with the reported results. However, no considerable change in the bandwidth is observed by the variation of notch dimensions. Further the resonant frequency ratios can be tuned by varying the dimensions of the notches for the various applications such as GPS and DMB.

REFERENCES

[1] R. Garg and V. S. Reddy, "Edge feeding of microstrip ring antennas," *IEEE Transactions on Antennas and Propagation*, vol.51, no.8, pp.1941-1946, 2003.

[2] D.M. Kokotoff , J. T. Aberle and R. B. Waterhouse, "Rigorous analysis of probe fed printed annular ring antennas," *IEEE Transactions on Antennas and Propagation*, vol. 47, no.2, pp.384-388, 1999.

[3] Ouarda Barkat, "Full-Wave Spectral Analysis of Resonant Characteristics and Radiation Patterns of High Tc Superconducting Circular and Annular Ring Microstrip Antennas" in Advancement in Microstrip Antennas with Recent Applications, InTech Publication, Croatia, pp. 57, 2013.

[4] S. C. Pan and K. L. Wong, "Design of dual-frequency microstrip antennas using a shorting-pin loading," *IEEE International Symposium*, vol.1, pp.312-315, 21-26 June, 1998.

[5] B.K. Kanaujiya and A.K. Singh, "Analysis and design of gap-coupled annular ring Microstrip antennas," *International Journal of Antennas and Propagation,* doi:10.1155/2008/792123, 2008.

[6] Y. M. M. Antar , A. I. Ittip Iboon and A. K. Bhattachatyya, "A dual-frequency antenna using a single patch and an inclined slot," *Microw. and Opt. Technol. Lett.*, vol. 8, no.6, pp.309-310,1995.

[7] K. F. Lee, K. M. Luk, K. M. Mak and S. L. S.Yang, "On the use of U-slots in the design of dual-and triple-band patch antennas," *IEEE Transactions on Antennas and Propagation*, vol.53, no.3, pp.60-74,2011.

[8] J. S. Chen, " Multi-frequency characteristics of annular-ring slot antennas," *Microw. Opt. Technol. Lett.*, vol.38, pp.506–511,2003.

[9] X.C. Yin, C.L. Ruan, S.G. Mo, C.Y. Ding, and J.H. Chu, "A compact ultra- wideband microstrip antenna with multiple notches," *Progress In Electromagnetics Research* , vol. 84, pp.321332, 2008.

[10] A.A. Deshmukh, K.P. Ray, T. Sonawdeker, S. Warawalla and R. Kataria, " Formulation of resonance frequency for multiband circular Microstrip antennas," *Int. Journal of Microw. and Optical Technology*, vol. 5, no.5, pp. 248-256,2010.

[11] R. Azim, M. T. Islam, J. S. Mandeep and A. T. Mobashsher, "A planar circular ring ultra-wideband antenna with dual band-notched characteristics", *Journal of Electromagnetic Waves and Applications*, vol. 26, nos. 14–15, pp. 2022–2032, 2012.

[12] R. Azim, M. T. Islam and N. Misran, "Printed circular disc compact planar antenna for UWB applications", *Telecommunication Systems*, vol. 52, no. 2, pp. 1171-1177, 2013.

[13] S. H. Chen, J. S. Row and C. Y. D. Sim, "Single-feed square- ring patch antenna with dual-frequency operation," *Microwave and Optical Technology Letters*, vol. 49, pp. 991-994, 2007.

[14] S. Behera and K. J. Vinoy "Resonance characteristics of non-uniform width square ring antennas," *Progress In Electromagnetics Research C*, vol. 31, pp.54-66, 2012.

[15] A. K. Bhattacharyya and R. Garg, " A Microstrip array of concentric annular rings," *IEEE Transactions on Antennas and Propagation*, vol.33, no. 6, pp.655-659, 1985.

[16] X. X. Zhang and F. Yang, "Study of a slit cut on a microstrip antenna and its applications," *Microw. Opt. Technol. Lett.*, vol. 18, pp. 297-300, 1998.

[17] I. J. Bahal, " *Lumped elements for RF and microwave circuits*," Artech House, Boston, pp. 456-459, 2003.

[18] V. K. Pandey and B. R. Vishvakarma, " Analysis of an E-shaped patch antenna," *Microw. Opt. Technol. Lett.*, vol. 49,no.1, pp. 4-1,2007.

[19] C. A.Balanis, " Antenna theory analysis and design," 2nd edition, New York, Wiely, pp. 728-746,1997.

[20] S. Jiri, "Analysis of multilayer microstrip lines by a conformal mapping method," *IEEE Trans Microw. Theory and Tech*., vol. 40, pp.769-772,1992.

[21] R.Garg, P. Bhartia, I. Bahl and A. Ittipiboon, "Microstrip Antenna Design Handbook," Artech House, Norwood, MA,2001.

[22] IE3D simulation software, Zeland, *version 14.05,* 2008.

[23] K. Siakavara, "Artificial Neural Network employment in the design of multilayered microstrip antenna with specified frequency operation," *PIERS Online*, vol. 3, pp.1278-1282, 2007.

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