International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347 - 6435 (Online)) Volume 2, Issue 2, February 2014)

A Novel UWB Planar Cross Slotted Monopole with Complementary Split Ring Resonators for Multi Band Communication and Circular Polarization

[1]Swati Suryendu, [2]Sudha Nair
[1](Scholar) Department of ECE, R.K.D.F.I.S. & T. Bhopal, India;
[2](Prof.), Department of ECE, R.K.D.F.I.S. & T. Bhopal, India;

***Abstract*— Modern wireless systems is normally used as personal communication standards, continuously demands new antenna designing with better performance in order to increase wide bandwidth and, in some case, to allow multiband behaviour. In these very purpose a paper is presented here with design of an monopole antenna structure, its parameters, and its frequency domain analysis have been investigated to show its capability as an effective radiating element, where effect of asymmetrical rectangular cross slot, which is centred to monopole axis, for circular polarisation on its resonance frequency is studied, and approach of micro strip split ring resonators (SRR) has been incorporated in ground plane to improve directivity, return loss and band widths of a single layer, single probe-fed circular disc micro strip patch antenna. The design has been described as FR-4 substrate with thickness of 1.6mm, dielectric constant of 4.6 and loss tangent 0.02. It is demonstrated through simulation using IE3D that the designed antenna exhibit low return loss, high directivity in certain bands of interest between 3.1 to 10.6 GHz and while varying the antenna parameters attention is also paid to obtained good axial ratio.**

***Index Terms*- Circular disc monopole, Circular polarization, Directional UWB antenna, Multi band antenna, Multi notch antenna, Split (Complementary) ring ground plane resonator**.

I. INTRODUCTION

In the recent years, the area of UWB systems has received much attention from microwave engineers, especially after Federal Communications Commission (FCC) released its report in February 2002 [1] and permitting commercial use of UWB (3.1 – 10.6GHz). Few of them has well-established wireless standards are Bluetooth, Wi-Fi, and UWB (ultra wide band). Bluetooth (IEEE 802.15.1standard) is used for low-transmission-rate applications at 2.45 GHz, for near-user devices like cell phones, handheld terminals, printers, etc. Wi-Fi (IEEE 802.11x standard) simultaneously works within the 2.45-GHz and 5.5-GHz bands and is used in WLANs (wireless local area networks).

UWB is used for linking close devices (typically 10 m) with low cost and low energy consumption. Although omni directional antennas are commonly used in wireless personal communications, some particular applications are demanding antennas with specific characteristics of directional multiband.

Several techniques have been suggested to improve the antenna operating bandwidth. A radiator may be designed in different shapes [6]. A partial ground plane and feed gap between the ground plane and the radiator may be used to enhance and control the impedance bandwidth [7]. In addition, a notch cut from the radiator may be used to control impedance matching and to reduce the size of the radiator. Various different types of slot maybe inserted in the radiators to improve the impedance matching, especially at higher frequencies. In this paper a simple technique has been demonstrated to construct the monopole antennas for multi-band operation, small virtual size reduction and satisfactory gain improvement by loading rectangular slot centred at axis of the patch with changing radiation characteristics. It is found that the resonant frequency of a filter is reduced and structure size is significantly reduced simultaneously. The parameters that affects operations of antenna are also taken into account while optimization by simulation.

Circular polarization is very important in the antenna design as it eliminates the importance of antenna orientation in the plane perpendicular to the propagation direction. Single fed micro strip antennas are easy to manufacture, low cost and compact in structure and it eliminates the use of complex hybrid polarizer, which is very complicated to be used in antenna array [3, 5]. Single fed circularly polarized are simplest antennas that can produce circular polarization [7]. In order to achieve circular polarization using only single feed, two degenerate modes should be excited with equal amplitude and 90° difference. Since basic shapes micro strip antenna produce linear polarization there must be some changes in the patch design to produce circular polarization.

International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347 - 6435 (Online)) Volume 2, Issue 2, February 2014)

Perturbation segments are used to split the field into two orthogonal modes with equal magnitude and 90° phase shift. Here the circular polarizations requirements are met by introducing an asymmetrical cross slot. Cutting a slot in a micro strip patch is optimized as shape and the dimensions of the cut out slot also widen the bandwidth.

A general communication systems consists an antenna structure for every band to achieve good radiation in pass band and so as rejection achieved in between pass bands. So to form multi band characteristics and a micro strip resonator into a single module, SRR (split ring resonators) are studied as a planar structure and in coplanar waveguide technology (CPW) miniaturized stop band and band pass filter have been recently reported [14, 15]. CSRR (complementary split ring resonators) made as dual of SRR and being sub-wavelength resonators, their size are much smaller than the conventional micro strip resonators [17]. As a resonator, it has been observed that a single CSRR in the ground plane has a very high Q factor and gives a very high rejection in the stop band. The presence of ring leads to an effective negative valued permeability in a narrow band above resonance [14]. The parameters that affects operations of antenna are also taken into account while optimization by simulation.

II. Antenna Design

First step was to design a monopole disc to achieve impedance matching for ultra wide band range then etching out asymmetric pattern of crossed slots from the surface of a circular disc thus resonance frequency reduction, and compact size antenna is obtained then ground plane of the circular disc monopole antenna is shaped in complementary split ring resonator (CSRR) such as it can simultaneously satisfy the requirement of matching impedance with transmission line at most of pass bands for UWB radiation and also improve directivity.

A. Micro strip Planar Monopole Antenna

Planar monopoles in various radiator shapes such as circular, rectangular, elliptical, and pentagonal have been widely discussed and used [14]–[16]. It is defined as compact size, low spectral power density, wide stable radiation characteristics and easy to fabricate.

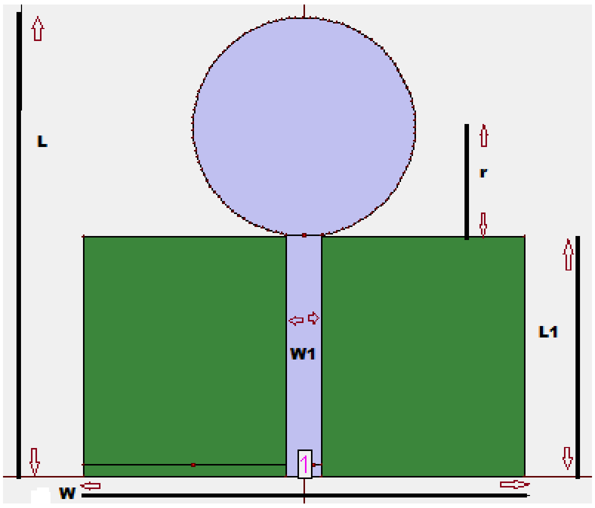

Fig.1. Geometry of the printed circular disc monopole

The BW of the Circular Monopole is larger than all the monopole antennas, because it can be interpreted in terms of various higher order modes of the circular resonator (characterized by the roots of the derivative of the Bessel function) which are closely spaced. Designed antenna assumed as a thin vertical wire mounted over the ground plane, whose BW increases with an increase in its diameter [23]. It can be equated to a cylindrical monopole antenna with a large effective diameter whose lower frequency corresponding to VSWR = 2 can be approximated by equating its area (in this case, a rectangular disc monopole) to that of an equivalent cylindrical monopole antenna of same height L and equivalent radius r as, $2\pi rL = WL$.

Here $L = 0.24F\lambda$ a slightly smaller length of the monopole is used (as input impedance of a l /4 monopole antenna is half of l /2 dipole antenna=$36.5 + j\ 21.25\Omega$, which is inductive). So calculations are:

$F = (L / r) / (1 + L / r) = L / (L + r)$

$\lambda = (L + r) / 0.24.$

Now calculating f_L as lower resonance frequency as

$f_L = c/\lambda = (30\times0.24)/(L + r) = 7.2/(L + r)$ GHz (1)

Above equation does not account for the effect of the probe length p, which increases the total length (L + r) of the antenna thereby reducing the frequency, if considered. For the circular monopole, the values L and r of the equivalent cylindrical monopole antenna are given by:

$L = 2a,\ r = a/4.$

Using above value and using equation (1), for $f \approx 3.1GHz$ & $p = 0.55mm$ (as taken in design)

We get $r = 9.1mm$ and diameter of disc = $18.2mm$.

International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347 - 6435 (Online)) Volume 2, Issue 2, February 2014)

Dimension of ground plane is shown in fig.1. Width of micro strip line feed is 3mm and feed point is optimized at (18,2) when lower left corner of ground is (0,0), to match with 50Ω impedance line and diameter of circular disc is 18.2 mm. The calculated structure designs parameters are in table below:

Table.1 Monopole structure parameter used to design

Dielectric Constant (εr)	= 4.6
Lower Resonance Frequency (fr)	= 3.1 GHz.
Dielectric Height (h)	= 1.60 mm.
Width of Feed strip line (W1)	= 3.0mm
Metallization Thickness	= 35µm
Loss Tangent (tan δ)	= 0.0021.
Radius of Circular Patch	= 9.1mm
Practical Ground Surface W×L_1 Imaginary Gnd. Surface W×L	36×20mm^2. 36×38.2mm^2.
Velocity of Light (c)	= 3×10^{-8}ms^{-1}.

.

B. Integrated Disc Antenna with ACS

Compared to the electrical antennas, slot antennas have relatively large magnetic fields that tend not to couple strongly with near-by objects which make them suitable for applications wherein near-filed coupling is required to be minimized [7]. By inserting a cross slot in a circular patch antenna as shown in Fig.2 circularly polarized compact size antenna is obtained. Increasing the slot length will decrease the resonant frequency hence decreasing the antenna size.

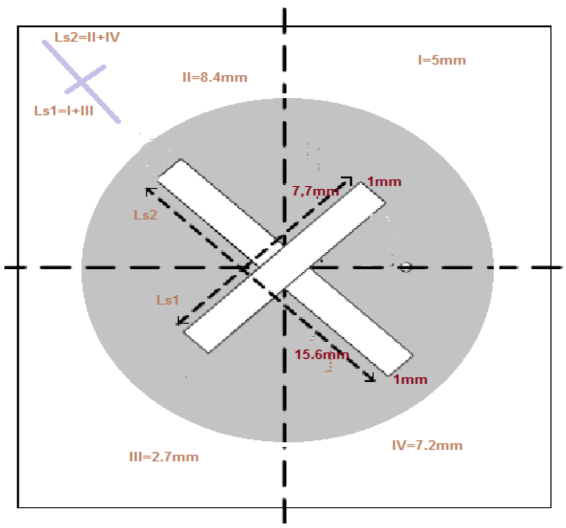

Fig.2. Geometry of the Asymmetrical Cross slot (ACS)

Two slots are formed on the radiating patch at an angle of ±45^0 with respect to micro strip feed line and 90^0 with each other. The slot lengths, widths and permittivity of the substrate determine the frequency of band of circular polarization as slot resonance frequency. It was observed the change in the value of Ls1 shifts the lower resonance frequency i.e., increasing Ls1 shifts the band on lower side and vice versa. Due to its shorter length Ls2 dominated higher resonance frequency. It was observed that increase in value of Ls1 shifts the band on upper side and vice versa [15]. For circular polarization the optimized geometry of cross slot is shown in fig. 2 with total lengths of the two slots $Ls_{1,}$ Ls_2 are not symmetrical to the centre of circular disc. Length was distributed with purpose of CSRR ring radius to be designed further. The length of $Ls_{1,}$ Ls_2 is again distributed in all four quadrants as

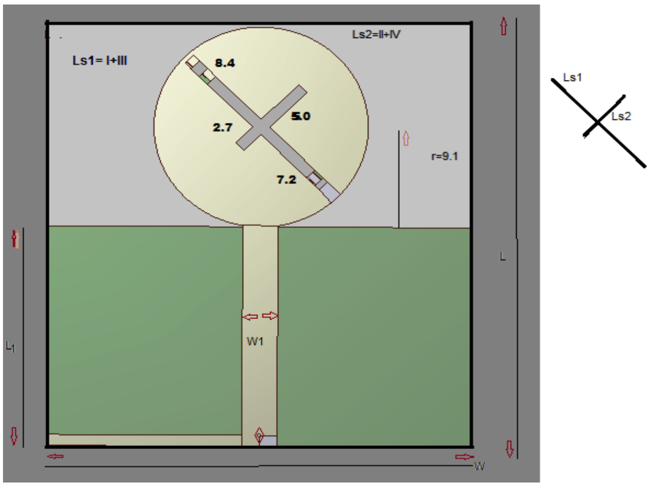

Fig.3. Geometry of proposed ACS loaded antenna (front view)

Ls_1= {5mm (1st quad) + 2.7mm (3rd quad)} = 7.7mm,
Ls_2= {8.4mm (2nd quad)+7.2mm (4th quad)} = 15.6mm.

Here in Fig. 3, the geometry of the monopole micro strip antenna integrated with asymmetric cross slots. For circular disc monopole, the ground plane serves as an impedance matching circuit. Other important design parameters that affect the antenna performance is the width of the ground plane [8] which is shown as the portion of the ground plane close to the disc acts as the part of the radiating structure. Consequently, the performance of the antenna is critically dependent on the width of the ground plane [8], [9]. However, when this type of antenna is integrated with printed circuit board, the RF circuitry cannot be very close to the ground plane. It has also been shown that first resonant frequency is associated with the disc dimension [6-8].

IJRDET
International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347 - 6435 (Online)) Volume 2, Issue 2, February 2014)

Actually, it is noticed in the simulations that the first resonance always occurs at close to the quarter wavelength for different W. Here disc radius r equals to 9.1mm furthermore, the diameter of the disc (i.e. 18.2 mm) is approximating the first frequency at 3.1 GHz with optimized design.

C. Integrated Disc Antenna with Complementary Split Ring Resonator (SRR):

Split Ring Resonator (SRR) has been introduced to provide a notch in the WLAN frequency band. Split Ring Resonator (SRR), originally proposed by Pendry [21], is a small sized high Q resonator which is used to produce Band Notched characteristics in a planar antenna monopole [6]. In a SRR, two similar split rings are coupled by means of a strong distributed capacitance in the region between the rings. The SRR is represented by an equivalent inductance L decided by average radius r and width of rings c, and capacitance C, the capacitance associated with SRR is given as $2\pi r C_a$ with C_a as capacitance per unit length between the two rings. The resonance frequency of the structure is given as

$f= (LC)^{-1/2}/2\pi$ [14].

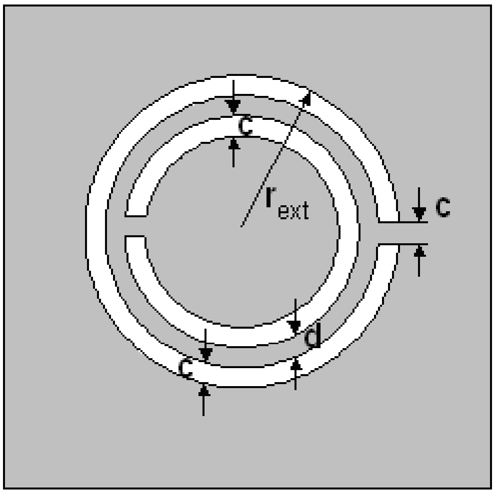

Fig.4. Geometry of the split ring resonator at patch radiator

A perfect dual behaviour of SRR (resonant magnetic dipole) is obtained by CSRR (resonant electric dipole) excited by respective axial field formed by etching negative image of SRR in ground plane of micro strip underneath the conductor, a narrow stop band appears at approximately the resonance frequency of SRR of identical dimension etched at radiator patch [15]. CSRR essentially behaves as an electric dipole that can be excited by an axial electric field. The CSRR behaves as an externally driven parallel LC resonant circuit [18].

A SRR consisting of a pair of concentric annular rings with splits at opposite ends is considered in this project to implement the band notch characteristics (Fig. 4). The resonant frequency of SRR is given by [14] where r is average radius of the SRR, r_1 is outer radius of outer ring, r_2 is inner radius of inner ring. As shown in Fig.5 the radius of outer and inner ring is *r1=9.0mm, r2=6.0mm.* The CSRR structure is placed in the ground plane exactly below the centre of a micro strip circular disc. The dimensions of the CSRR structure chosen for this frequency of UWB are *rext*= 9.0 mm, *c*=1.0 mm and *d*=1.0 mm respectively as seen by Fig.4. The dependence on the dimensions of the CSRR structure on the resonant frequency is observed as follows: with the increase of external radius (*rext*), resonant frequency decreases and with the increase of the ring width (*c*) and gap width (*d*), resonant frequency increases. The required width (w1) of the micro strip feeding line is calculated for a characteristic impedance Z_0=50Ω.

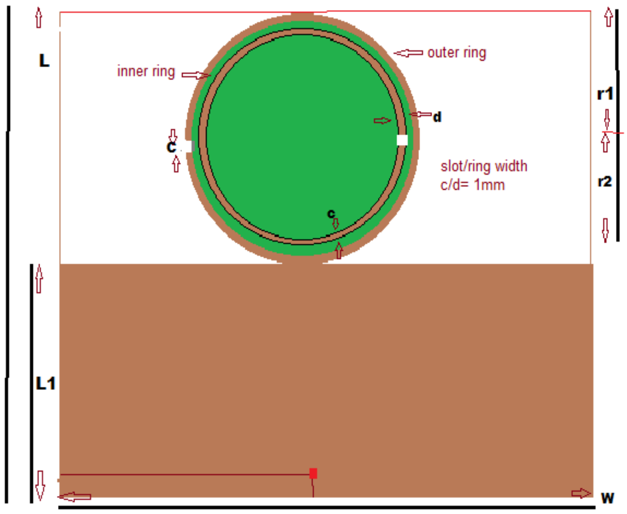

Fig.5. Geometry of CSRR loaded antenna (back view)

$W1/h=2/\pi[B-1-\ln(2B-1)+(\varepsilon r-1/2\varepsilon r)\{\ln(B-1)+0.39-0.61/\varepsilon r\}]$ where $B= 377\pi/2 Z_0\sqrt{\varepsilon r}$

Where radius of outer ring rext (for f_L) decided by:

$rext=F/\{1+(2h/\pi \varepsilon rF)[\ln(\pi F/2h)+1.7726]\}^{1/2}$

Here $F=8.791\times 10^9/f_r\ \varepsilon r$

And fr= Resonant Frequency, εr = Dielectric Constant of the Substrate, h= Height of the Substrate.

In fig. 6 the geometry of the monopole circular micro strip antenna with asymmetric cross slots and CSRR in the ground plane is shown. All the designs are simulated using Zeland IE3D software [19].

IJRDET
International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347 - 6435 (Online)) Volume 2, Issue 2, February 2014)

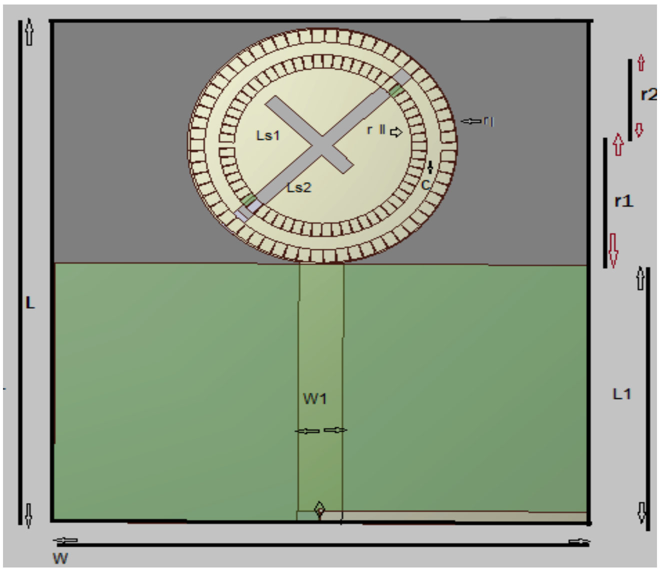

Fig.6. Geometry of ACS+CSRR (final) antenna (back view)

III. Result And Discussion

The radiation properties of the various stage of the proposed antenna are described in this section. The simulation is carried out on IE3D which incorporates the industry's only Full-Wave 3D Method-of-Moments (MoM) EM simulation implementation. The MoM provides full 3D capability in the frequency domain, treating both planar and 3D high frequency structures in a multilayer environment. Antenna characteristics are shown here as improvement approach (CSRR/ACS (dotted/dashed dotted) or both) in designing method. The term final antenna (solid lines) is used for CSRR built ACS loaded monopole disc.

Fig.7 shows return loss (S_{11}) of simple monopole antenna, CSRR loaded antenna and proposed antenna. It may be observed that the operating frequency for simple monopole antenna ranges from 2.38 to 12.5GHz, while for CSRR loaded antenna the multiband characteristics is observed. The band notched characteristic is observed when both cross slot and CSRR is employed in the antenna. It is noticed that for simple monopole antenna the radiation pattern is omni directional all frequency range (2.38-12.5) GHz which covers UWB range. The antenna with CSRR only range contains one wideband from 2.59 GHz to 4.61GHz along with 4 narrow bands 5.45- 6.14GHz, 6.65GHz to 7.43GHz, 7.74GHz to 7.9GHz and 11GHz to 11.41GHz. As evident, the two notch bands for S_{11} < -10dB are 4.62 GHz – 5.44GHz (S_{11}<-5dB for 4.95 – 5.23GHz) and 6.15 – 6.64GHz (S_{11}<-5dB for 6.33 – 6.54GHz) respectively.

Two band of notch one narrow and wide each can be seen to shifted to lower range at (4.48-5.30 GHz) and (5.83-7.23 GHz). So it is showing multiband characteristics which are applicable to satellite communications.

The antenna gain, efficiency (radiation) and directivity, is shown in Fig.8, Fig.9 and Fig.10 respectively as a comparison of CSRR and CSRR+ACS structures. All these radiation parameter are improved by CSRR so variation from this structure to final antenna is shown only. Fig.8 is shown as results about gain characteristics. A sharp fall in the antenna gain is found for CSRR only around the notch frequency of 4.6 GHz. At pass band frequencies, the antenna gains with notch filters are similar to those without notch filters. The gain decreases sharply below 0dB for the notched frequency bands (-0.55 dB at 4.2 -6.4 GHz), also for (-0.3dB at 8.2GHz and -1.0dB at frequency greater than 9.1GHz). For final antenna, variation of gain is also shown as fall occurs at 4.45 GHz and from 2.5dBi to -2.1dBi in the second band occurs which goes till 7.3 GHz. At higher frequency (>7.3 GHz) final antenna gain is always more positive than CSRR only. The gain may be improved by using the array of CSRR or ACS.

The radiation efficiency characteristics of the antenna have been studied and presented in Fig. 9. The efficiency is high at lower frequency while it decreases with frequency, indicating increased dielectric and conductor losses at higher frequency. Radiation efficiency of CSRR loaded structure varies less within UWB range than to final antenna radiation efficiency.

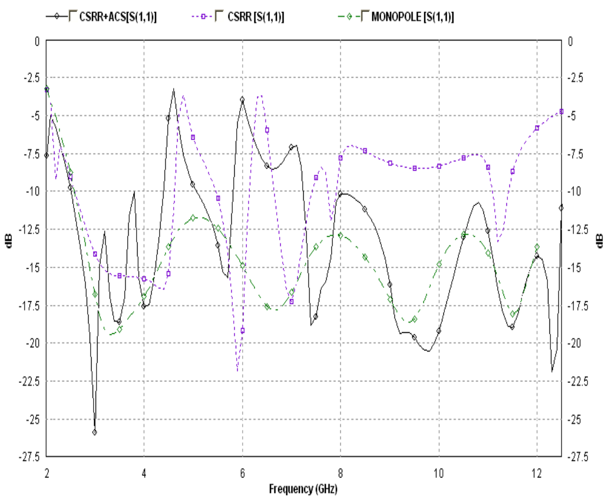

Fig.6. Variation of antenna return (S_{11}) loss with frequency

IJRDET
International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347 - 6435 (Online)) Volume 2, Issue 2, February 2014)

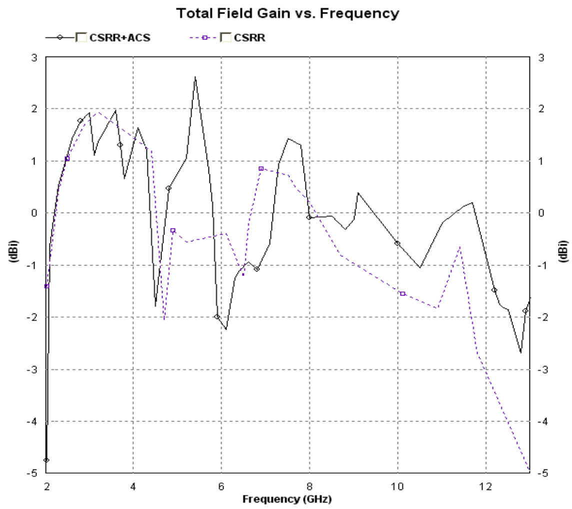

Fig.7. Variation of antenna Gain with frequency

The fig. 10 shows variation of directivity with frequency. In the first band the directivity starts from 3.3dBi and attains a maximum of 4.24dBi while the directivity in second band improves further in both. The third band directivity shows (minima of 4.23dBi and maxima of 6.7dBi) of CSRR than to (5.1dBi to 7.4dBi) for final antenna. The directivity of the antenna is low in the first band where both antennas behaves like omni -directional wide band monopole disc while it improves as frequency increases and it is seen to get maximum directivity in the 3rd band.

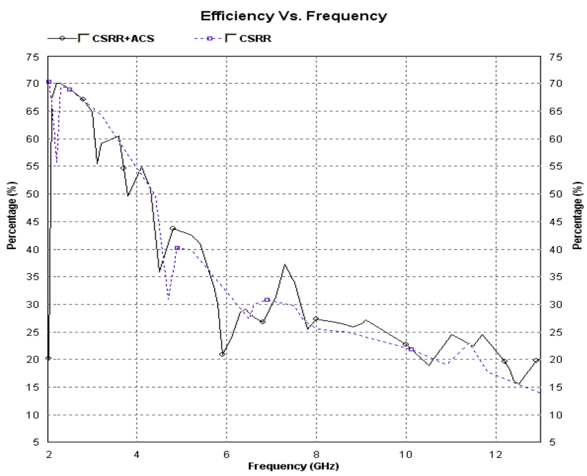

Fig. 8: Variation of radiation efficiency with frequency

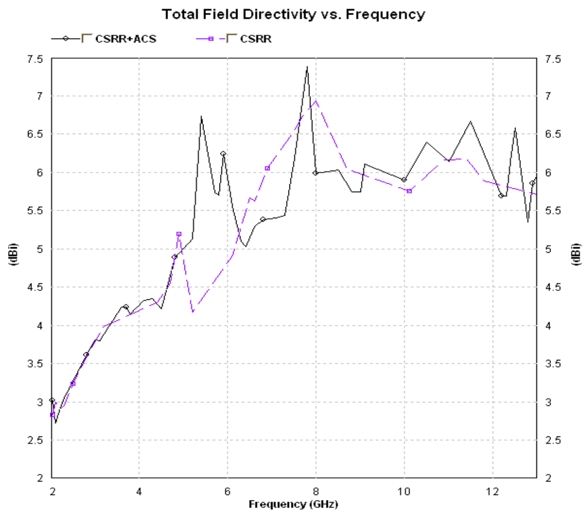

Fig 9: Variation of directivity with frequency

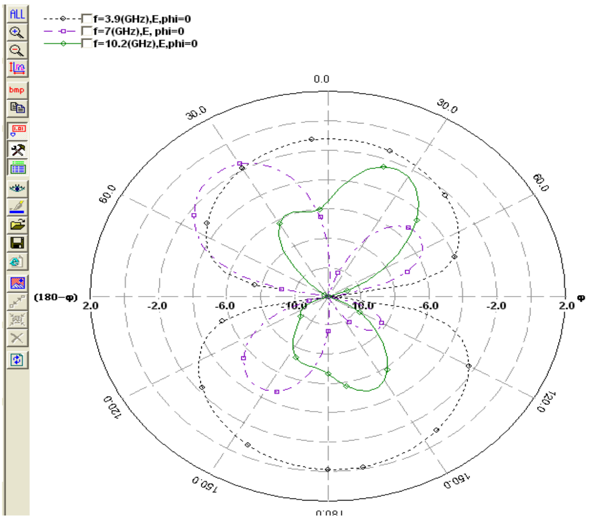

Fig.10. radiation pattern of ACS at various frequencies

The simulated normalized radiation patterns at 3.9, 7.0, and 10.2 GHz are plotted in Fig.11. Frequencies are taken at random for pass band and notch band ranges. The E -plane patterns are obtained in the simulation. It is noticed that the E-plane pattern is omni-directional at lower frequency (≈3.9 GHz) and is directional at higher frequencies (≈7 and 10.2 GHz). The pattern can be seen to increasing from broadside to end-fire direction as the frequency increases.

International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347 - 6435 (Online)) Volume 2, Issue 2, February 2014)

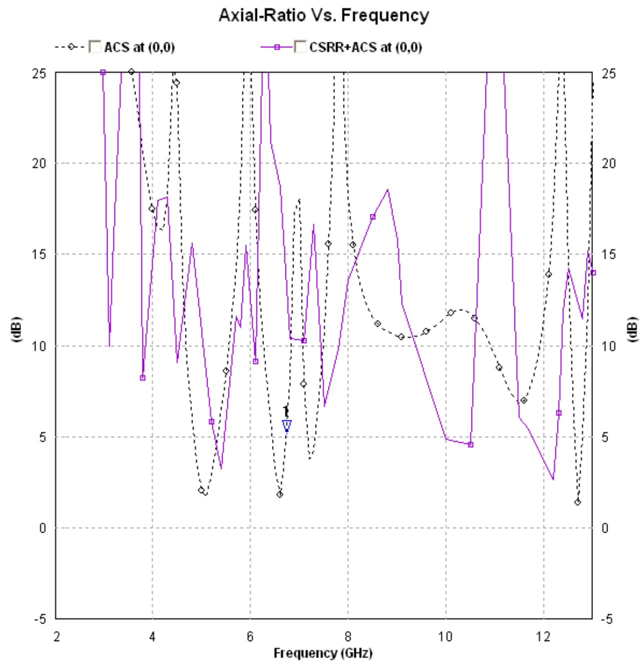

Fig. 11: Variation of Axial ratio with frequency

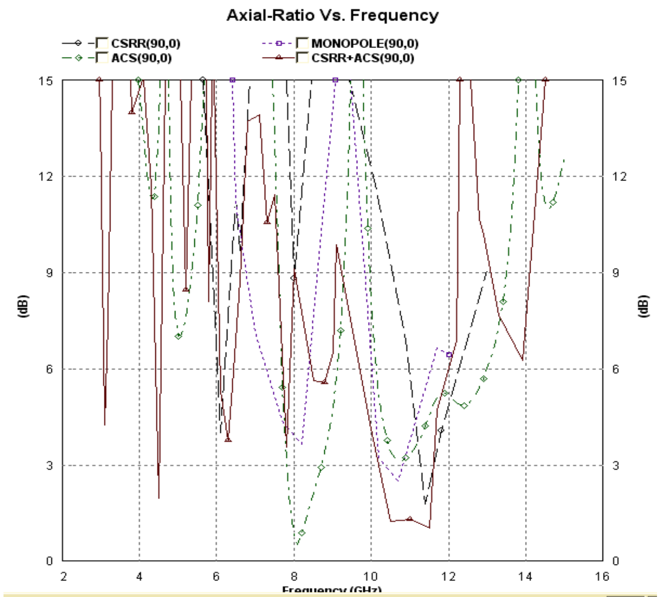

Fig. 12: Variation of Axial ratio with frequency (broad-side)

Axial ratio is analysed for circular polarisation measurement, where ACS was implemented for generating circular polarization on disc monopole so ACS and CSRR+ACS (final antenna) are compared. The axial ratio characteristics of the antenna are depicted in Fig.11.

From the Fig.11 in ACS only structure it may be noted that the circular polarization Operation (AR≤ 3dB) is in between in three different bands which are lying in our first and third band of analysis till now. In third band axial ratio reaches as low as 1.75dB. In the second band of operation the antenna shows two regions with circular polarization – first from 4.94GHz to 5.2GHz (AR≤ 1.9dB) and second from 6.5GHz to 6.66GHz (AR≤ 1.88dB). In the third band of operation a very small axial ratio bandwidth is obtained ranging from 12.672GHz to 12.745 Ghz (AR≤ 1.75dB). This all corresponds to an axial ratio bandwidth of 6.1% if UWB (3.1-10.6GHz) is considered as band of operation. The final antenna gives (AR≤5dB) in second band of analysis. As seen in Fig.12 the final antenna has circular polarization in the broadside direction in the second (AR≤2dB) and third band of operation and in higher band a wide range (10.15-11.9 GHz) of circular polarization (AR≤3dB) occurs.

IV. Conclusion

The printed circular disc monopole antenna fed by micro strip line with multiple circular polarization bands is investigated in this paper. It is described with reference paper that the proposed printed circular disc monopole can yield the FCC defined UWB frequency band for Omni-directional over the entire band of operation. A further structural improvement of asymmetrical cross slot has been optimally designed. It is seen that simulation results as ACS loaded circular patch micro strip antenna can produce circular polarization and at the same time gives good impedance matching high gain better radiation pattern and return loss. Improvements in directivity and antenna radiation efficiency, in multiple bands as stated earlier, has been created by imposing CSRR on its ground plane. Single CSRR particle in the ground plane gives a very narrow stop band at its resonant frequency. By combinations of these structures a multi-band frequency notched antenna has been implemented in this study and a small profile monopole antenna has been designed which works in the Bluetooth and UWB frequencies. Since there is no external 90 degree hybrid coupler for generating the circular polarization, this antenna can be also used as an element of phased array antenna. Due to their compactness the proposed antennas are suitable for application on mobile wireless nodes and also to operate in some band for circular polarization mode. This proposed antenna can be used for mobile satellite communication.

International Journal of Recent Development in Engineering and Technology
Website: www.ijrdet.com (ISSN 2347 - 6435 (Online)) Volume 2, Issue 2, February 2014)

REFERENCES

[1] "Federal Communications Commission Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems", FCC, 2002, First Report and Order FCC, 02.V48.

[2] D. M. Pozar, "Microwave engineering", 3rd ed. New York: Wiley, 2005.

[3] C. A. Balanis, "Antenna Theory—Analysis and Design", 3rd ed. New York: Wiley, 2005.

[4] K.Chang, L.H.Hsieh, Microwave Ring Circuits and Related Structures, 2nd ed., John Wiley & Sons, New Jersey, 2004.

[5] J.-S. Row, C.-Y. Ai "Compact Design of Single-Feed Circularly Polarised Microstrip Antenna" IEEE Electronics Letters, vol.40, issue: 18, 2004, pp. 1093- 1094.

[6] J. Liang, C. C. Chiau, X. Chen, and C. G. Parini, "Analysis and design of UWB disc monopole antennas," in Proc. Inst. Elect. Eng. Seminar on Ultra Wideband Communications Technologies and System Design, Queen Mary, University of London, U.K., Jul. 2004, pp. 103–106

[7] Wen-Shyang Chen, Chun-Kun Wu, Kin-Lu Wong, "Compact Circularly-Polarised Circular Microstrip Antenna with Cross-Slot and Peripheral Cuts," IEEE Electronics Letters, vol. 34, issue 11, 1998 , pp.1040-1041.

[8] New Planar Dual-Mode Filter Using Cross-Slotted Patch Resonator for Simultaneous Size and Loss Reduction Lei Zhu, Pierre-Marie Wecowski, and Ke Wu IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, VOL. 47, NO. 5, MAY 1999.

[9] "Printed circular disc monopole antenna for ultra wideband applications," Electron. Lett., vol. 40, no. 20, Sep. 2004

[10] Equivalent circuit model for split ring resonators and complementary split ring resonators coupled to planar transmission lines, Juan Domingo Baena, jordi Bonache, Richard Marques Silero, Member, IEEE, IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, VOL. 53, NO. 4, APRIL 2005

[11] K. Chang and L. H. Hsieh, Microw. Ring Circuits and Related Structures, 2nd ed. New York: Wiley, 2004.

[12] Y. Zhang, W. Hong, C. Yu, Z.-Q. Kuai, Y.-D. Don, and J.-Y. Zhou, "Planar ultra wide band antennas with multiple notched bands based on etched slots on the patch and/or Split ring resonators on the feed line," IEEE Antennas Propag. Mag., vol. 56, pp. 3063–3068, 2008.

[13] Integrated Planar Monopole Antenna With Micro strip Resonators Having Band-Notched Characteristics Dong-Zo Kim, Wang-Ik Son, Won-Gyu Lim, Han-Lim Lee, and Jong-Won Yu, Member, IEEE, IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 58, NO. 9, SEPTEMBER 2010

[14] F. Martin, F. Falcone ,J. Bonache, T. Lopetegi, R. Marques,and M. Sorolla, "A new spilt ring resonator based left hand coplanner waveguide",Appl, .Phys.Lett., vol.83, pp. 4652-4654,2003.

[15] F. Martin, F. Falcone ,J. Bonache, T. Lopetegi, R. Marques, M. Sorolla, "Miniaturized coplanar waveguide stopband filters based on bi-layer multiple tuned split ring resonators", IEEE Microw . Wireless Compon. Lett., vol 13, no.12, pp. 511-513, Dec.2003.

[16] Electrically Small Resonators for Planar Meta material, Microwave Circuit and Antenna Design: A Comparative Analysis .Miguel Durán-Sindreu, Jordi Naqui, Ferran Paredes, Jordi Bonache and Ferran Martín Appl. Sci. 2012, 2, 375-395; doi:10.3390/app2020375 applied sciences ISSN 2076-3417

[17] RAKHESH SINGH KSHETRIMAYUM, SRIDHAR KALLAPUDI AND S S KARTHIKEYAN, IETE Technical Review Vol 24, No 6, November-December 2007, pp 463-474

[18] J D Beana, J Bonache, F Martin, R Marques, F Falcone, T Lopetegi, M A G Laso, J Garcia-Garcia, I Gil, M F Portillo & M Sorolla, Equivalent-Circuit models for Split-Ring Resonators and Complementary Split-Ring Resonators coupled to planar transmission lines, IEEE Trans Microwave Theory and Tech, vol 53, no 4, Apr 2005.

[19] IE3D version 10.2, Zeland Corp., Freemont, CA, USA

[20] Lin Dang, Zhen Ya Lei, Yong Jun Xie, Gao Li NIng, and Jun Fan, "A Compact Microstrip Slot Triple-Band Antenna for WLAN/WiMAX Applications," IEEE Antennas and Wireless Propagation Letters, Vol.9.,2010

[21] J. B. Pendry, A.J.Holden,, Magnetism from conductors and enhanced nonlinear phenomena, IEEE Transmission on Microwave Theory and Techniques, vol. 47, no.11, 2075-2084, November 1999.

[22] Pradeep Kumar Dixena,ECE Dept.,IISc BangaloreStudy and design of Directional Ultra Wideband antenna in planar technology

[23] J. Hong and M. J. Lancaster, Micro strip Filters for RF/Microw. Applications. New York: Wiley, 2001.