Multiband Concentric Ring Circular Microstrip Patch Antenna

Kanchan Usrete[1], Sunil Kumar Singh[2]

[1]PG Student, Dept. of Electronics & Communication Engineering, Jabalpur Engineering College, Jabalpur, M.P., INDIA

[2]Assistant Professor, Dept. of Electronics & Communication Engineering, Jabalpur Engineering College, Jabalpur, M.P., INDIA

Abstract - *In this paper, a multiband, easy to fabricate, high gain, concentric ring, circular patch antenna, using coaxial feed method & cavity model, is presented. Antenna resonant frequencies are 7.6 GHz, 8.2 GHz, 9.4 GHz, 10 GHz, 10.5 GHz & 12 GHz. Though antenna is specifically designed for X-band frequency 10 GHz, it is giving high gain & bandwidth for other bands to making it a useful multiband antenna. Substrate used is RTduroid 5880 with ε_r = 2.2 & maximum gain is approx. 7.5 dBi & maximum bandwidth is around 500 MHz*

Key Words: Multiband, Microstrip patch, Strip, X-band, concentric ring.

1. INTRODUCTION

In today's world, wireless communication has uplifted the standard of living of ordinary people. Applications of wireless communication ranges from mobile communication, satellite communication, radar technology, radio, television to automobiles, automated machines, wifi, Bluetooth technology etc. these applications require an antenna system to transmit & receive information effectively, ranging from low microwave frequency bands to high microwave frequency bands [1]. For this purpose, microstrip patch antennas are preferred because of qualities such as low profile, low cost, easy fabrication etc.

Such a wide range of applications of wireless communication require an antenna which is not only carrying low losses & high efficiency but also can perform effectively for different bands of microwave frequency, known as a multiband antenna [2]. Many designs & techniques have been studied & proposed in literature to achieve multiband property of a patch antenna with high gain, high bandwidth & high efficiency.

As in [3], a multiband double layered microstrip patch antenna is presented, consisting of two tri-slot elements, which are fed by a proximity coupling from a certain feeding structure located on another layer. The antenna works at four frequency bands, which is achieved through forming the antenna patch by three slots. Whereas low gain of approx. 1.13dBi makes it less applicable in practical use. In [4], a single microstrip G-shape antenna for multiband operations is proposed first & in order to increase its gain; an identical dual-element patch antenna is also proposed for the same band. The array elements are fed by only one feed network, which improves the impedance bandwidth of the two element G-shape microstrip antenna.

In [5], a frequency tunable dual-band Multi ring microstrip antenna fed by an L-probe with varactor diodes is proposed. In order to tune operating frequencies of the multi-ring microstrip antenna, two varactor diodes are mounted on each ring patch. An L-probe placed under the ring patches is used to feed them. In [6], a new microstrip monopole antenna with triple band coverage capability is proposed. To achieve multiband characteristics, ground plane & feed line has been modified. Finally, inserting PIN diodes on the ground plane of the antenna has led to three different desirable switchable bands of operation. In [7], a multiband MPA incorporating inverted L & T-shaped parasitic elements is proposed to cover 3 bands. Inverted L & T-shaped parasitic elements that resonate through perturbation & coupling with the MPA are used in this design.

In [8], DGS (Defective Ground Structure), which is composed of four arms spiral is introduced & produces 5 resonant frequencies. Inset feed is used as feeding technique for this antenna design. Maximum gain achieved is 4.5dBi. In [9], design of multiband microstrip antenna for ISM band applications is proposed. It utilizes a three arm radiating element with various arms lengths to create three different resonances. The maximum gain achieved is 4.91dBi. In [10], a compact multiband planar monopole microstrip antenna for modern mobile phone applications, is presented. Here, a combination of slots & strips, in the radiating patch & the ground plane, has been employed to achieve good radiation & multiband performance of the antenna.

In [11], multiband antenna array using 2*2 elements with multilayer structure & excited with probe feeding is being proposed. To improve the gain, the array structure is being proposed in this paper, & to achieve multiband operation, double U-slot is cut on every patch element. Maximum gain is 9.84dBi. In [12], an approach to implement an array of split ring resonators (SRR) as a part of antenna structure is presented for exciting multiband property of a single band microstrip patch antenna. It has been shown that the array of SRR & thin wires has contributed to produce the second & third resonant frequencies of proposed multiband printed antenna in the range of 1-3 GHz, while the first resonant frequency was generated by the square patch.

In present work, a circular patch antenna surrounded by concentric circular strips connected in between with each other, is proposed. The antenna has probe feed, a simple structure & small size. The substrate used is RT duroid 5880 having 2.2 as relative permittivity.

The basic circular patch is providing a resonant frequency band at 10 GHz, which is the resonant frequency. Concentric strips are generating remaining 5 bands, giving output return loss plot having 6 resonant frequencies on which, the antenna is working effectively with maximum gain around 9dBi & maximum bandwidth around 300MHz. paper.

2. DESIGN PRINCIPLE & CONFIGURATION

At first, a circular shaped patch antenna, based on cavity model for TM110 mode has been designed. For design & simulation purpose, Ansoft HFSS 13 has been used as simulation tool, the resonant frequency is taken as 10GHz, substrate used is RT duroid 5880 having relative permittivity (ε_r=2.2) & height of the substrate as 1.59mm. Figure 1, drawn below, shows the circular microstrip patch antenna.

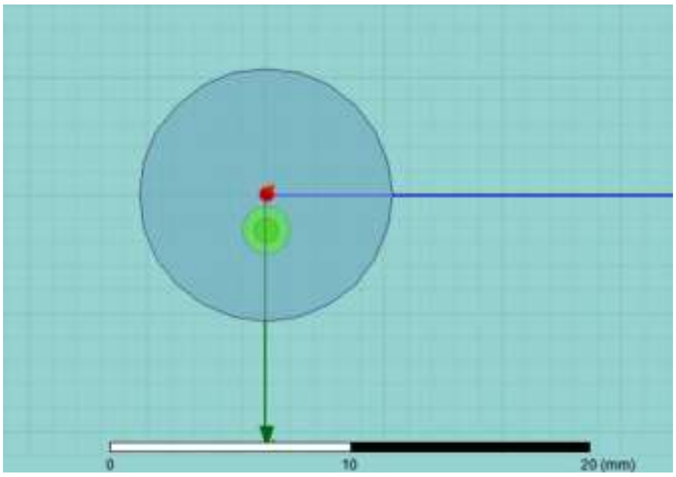

Fig -1: Circular Microstrip Patch Antenna

To draw this patch, following formula are used, for given values of f_r , h & ε_r:

Radius of the circular shaped patch is given by [2] :

$a = F/ (1+ \{2h/\pi\varepsilon_r F\}*[\ln(\pi F/2h)+1.7726])^{1/2}$

Here, F is in cm & is given by [1],

$F = (8.791*10^9)/ f_r(\varepsilon_r)^{1/2}$

The effective radius or the electrical radius, is calculated as [1],

$a_e = a *(1+ \{2h/\pi\varepsilon_r a\}*[\ln(\pi F/2h)+1.7726])^{1/2}$

Here,

h = height of the substrate in cm,

ε_r = relative permittivity of substrate,

a = radius of the patch,

fr = resonant frequency,

a_e = effective radius of the patch,

Here,

Resonant freq. (f_r)	10 GHz
Relative permittivity (ε_r) for RTduroid 5880	2.2
Height of substrate (h)	5.34 mm

Coaxial feed method is used to supply the patch. Pin, Probe & Coaxial covering of Coaxial cable is situated on x-axis at 1.602 mm distance from the center of the patch. Radius of Pin & Probe is taken as 0.5mm, while that of coaxial covering is taken as 1mm. Feed position is taken according to para-metrically varying feed from center to circumference, providing impedance is matched with 50 ohm coaxial cable.

After validation check & analyzing the circular patch antenna, using HFSS 13.0 (simulation software from Ansys), return loss |S11| vs freq. plot of the circular patch antenna is calculated. As shown below in figure 2;

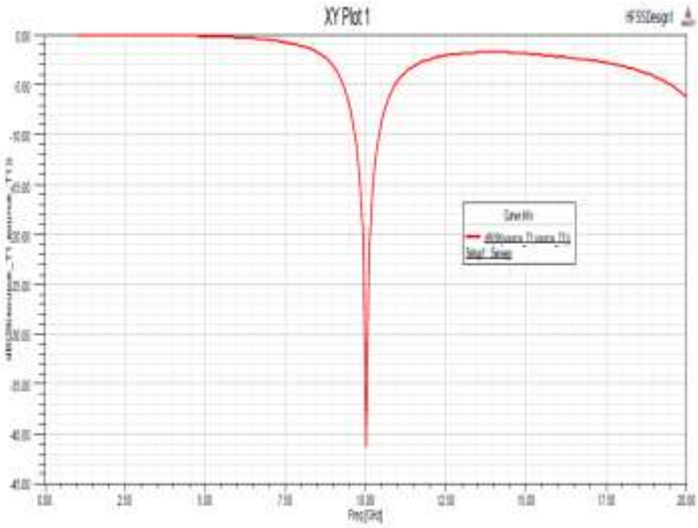

Fig -2: Return loss |S11| vs freq. plot of the circular patch antenna

Above figure indicates that |S11| at resonant freq. Of 10GHz is less than -35 dB, which is excellently showing proper impedance matching, with return loss bandwidth, greater than 1GHz, represented in table.1. The gain vs freq plot for this antenna gives very high gain of more than 10dBi. The problem with this antenna is, that it is not a multiband antenna. It is giving only one band, which is at 10GHz, means in X band.

Table 1: S11 & bandwidth for figure 2;

Resonant freq. (f_r) in GHz	Bands Covered	Return loss (dB)	Bandwidth (MHz)
10	X	-41.5	> 1GHz

To convert this antenna, to a multiband antenna, circular strips are added in the design, as strips provide inductive effect to the patch, while the gap between strips, and provide capacitive effect. This design provided in figure 3, gives as much as 4 resonant frequency terms in the |S11| vs freq plot.

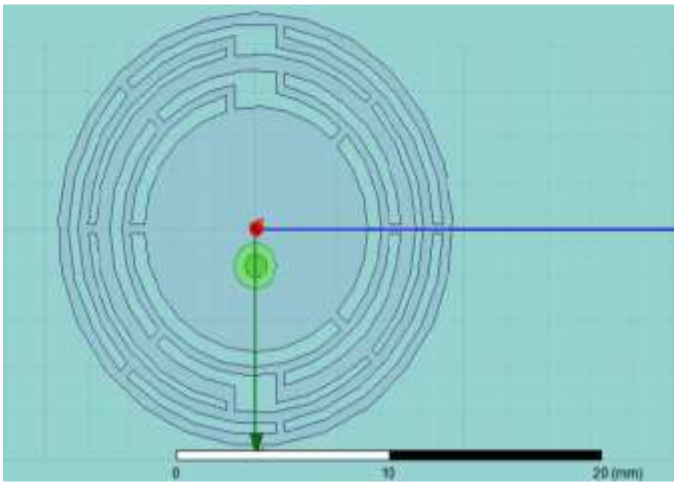

Fig -3: Updated concentric ring circular patch

The |S11| vs freq plot for figure 3, is shown in figure 4. It is explained in table 2.

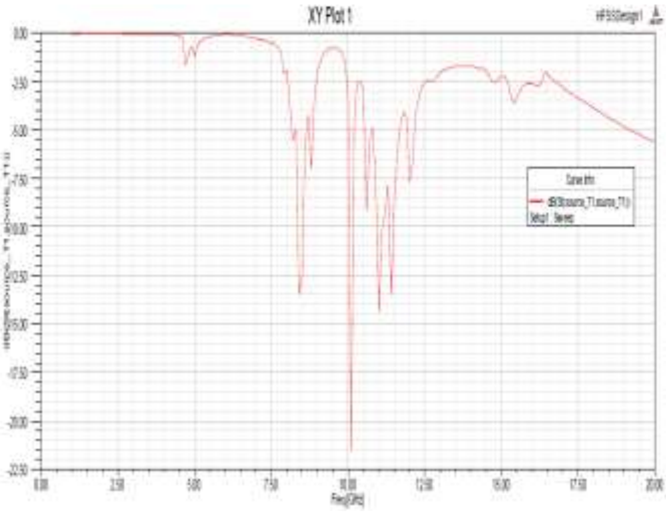

Fig -4: S11 vs freq plot of figure 3

Table 2: S11 & bandwidth for figure 3;

Resonant freq. (f_r) in GHz	Band	Return loss (dB)	Bandwidth (MHz)
8.4	X	-13	200
10.1	X	-22	130
11	X	-14	170
11.4	X	-13.5	140

To further increase number of bands, concentric strips are interconnected with each other, increasing inductive effect in the circuit. As shown in figure 5, the final design of concentric strips circular patch antenna is providing as many as 6 resonant frequency terms, ranging from C band to X band applications.

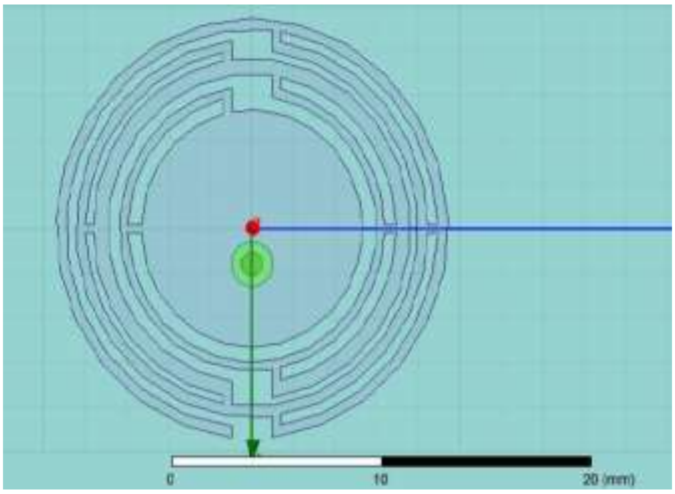

Fig -5: Final design of concentric ring circular patch

The |S11| vs freq plot of the final design is shown in figure 6, presented in table 3. The gain (dBi) plot of the final design is shown in figure 7. As we can see that the maximum gain is greater than 7.6 dBi, at central resonant frequency of 10GHz. 2D radiation pattern of gain at resonant frequency is shown in figure 8. The 3D polar plot of gain is shown in figure 9. The radiation pattern for directivity at resonant frequency is shown in figure 10.

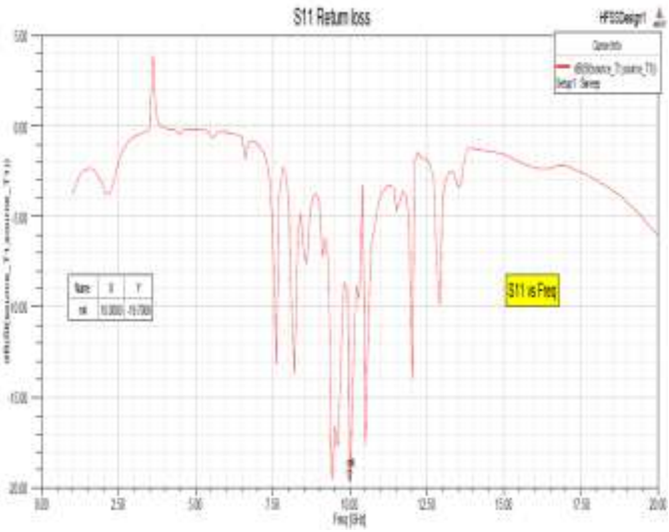

Fig -6: S11 vs Freq plot of the final design

Table 3: S11 & bandwidth for figure 6;

Resonant freq. (f_r) in GHz	Bands Covered	Return loss (dB)	Bandwidth (MHz)
7.6	C	-13	83
8.2	X	-13.8	147
9.4	X	-19.5	450
10	X	-20	180
10.5	X	-18	110

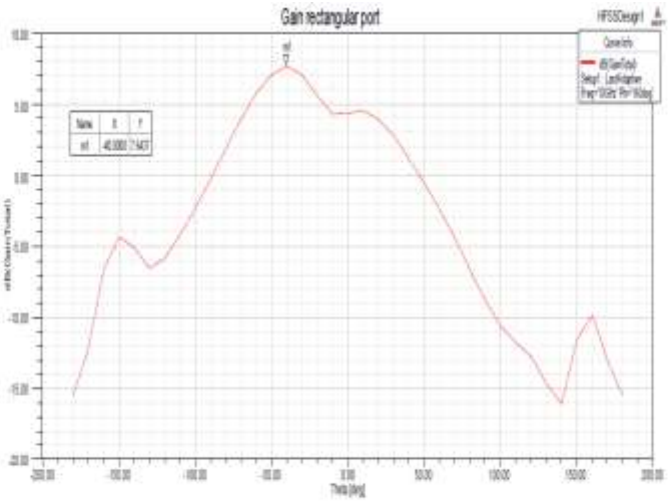

Fig -7: Gain rectangular plot of the final design

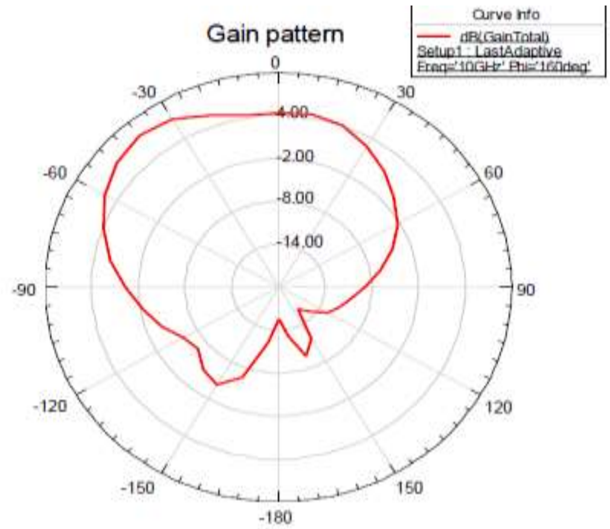

Fig -8: 2D radiation pattern of gain of the final design

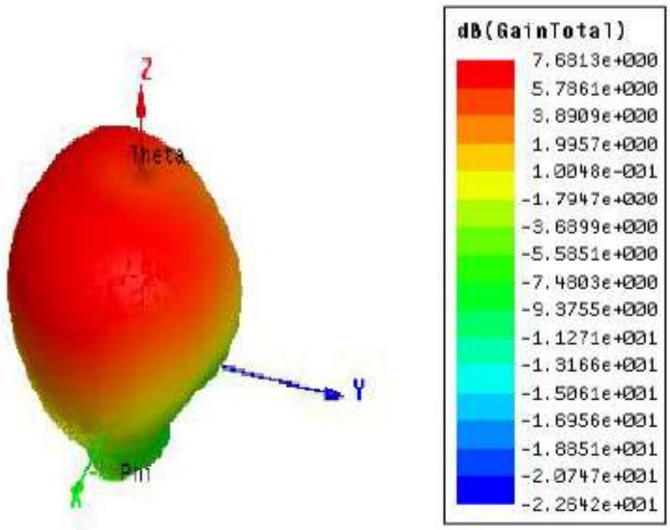

Fig -9: 3D Gain polar plot of final design

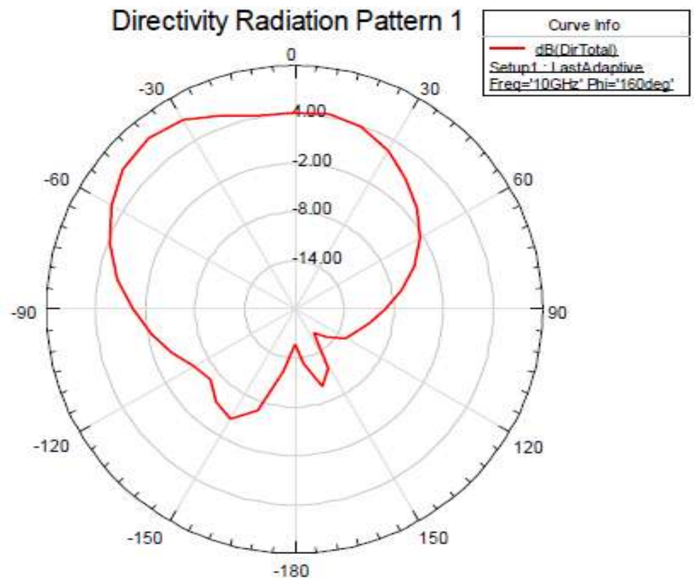

Fig -10: Radiation pattern for directivity at resonant frequency 10 GHz

Here, it should be clear that the antenna gain is defined as the ratio of maximum power density radiated by the antenna (that is being used practically) to the maximum power density radiated by an isotropic antenna, when both antenna have equal input powers. While, directivity is a measure of the concentration of radiation in the direction of the maximum. In other words, the ratio of maximum radiation intensity of the subject antenna to the radiation intensity of an isotropic or reference antenna, is termed as directivity. It is maximum gain obtainable in a particular direction [2].

Further, the plot of bandwidth of the antenna, around resonant frequencies in the |S11| vs freq plot is shown in figure 11. As we know that usual drawbacks of a microstrip patch antenna are its low gain & low bandwidth. Here, in this antenna, gain is high, reaching up to 9dBi & bandwidth is approximately 300 MHz around resonant frequency of 10 GHz & more than 100 MHz around other resonant frequencies.

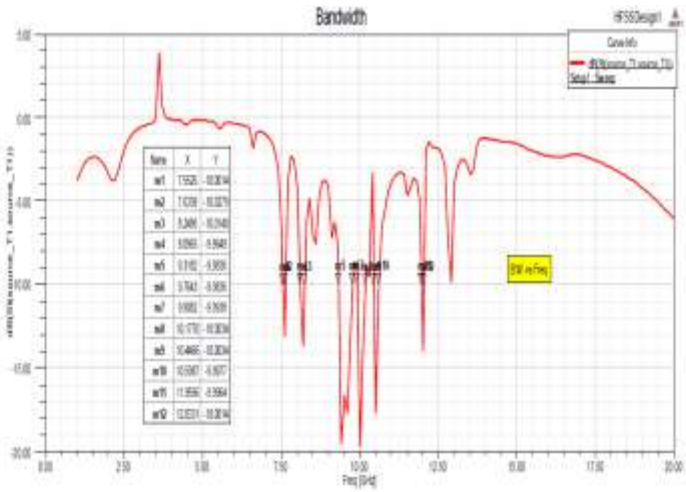

Fig -11: Bandwidth plot for final design

The VSWR plot, which is the analogous plot of |S11| vs freq plot & gives information about impedance matching level of the antenna & feed, at resonant frequency is shown in figure 12.

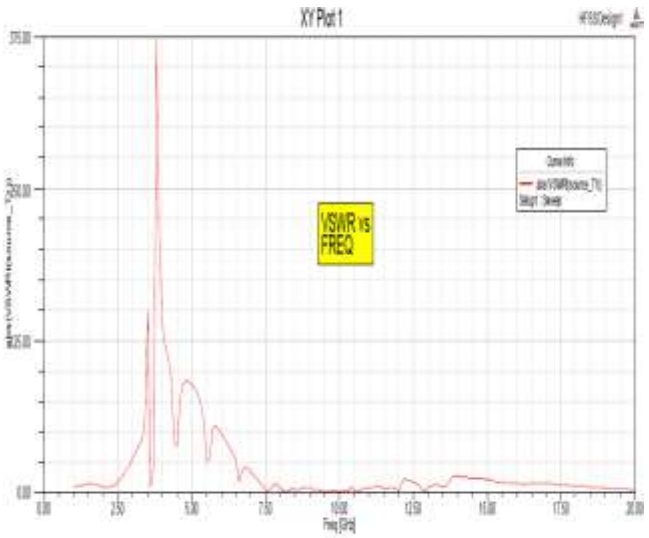

Fig -12: VSWR vs freq plot of final design

Figure 13 represents the smith chart for the antenna representing impedance matching. It is a plot, which is used to visualize complex valued quantities such as impedance, admittance etc & to calculate mapping between them. Before plotting the smith chart, we should be aware of the fact that, it represents normalized values of impedance, because the behavior of antennas & transmission line depends up on load impedance as well as characteristic impedance.

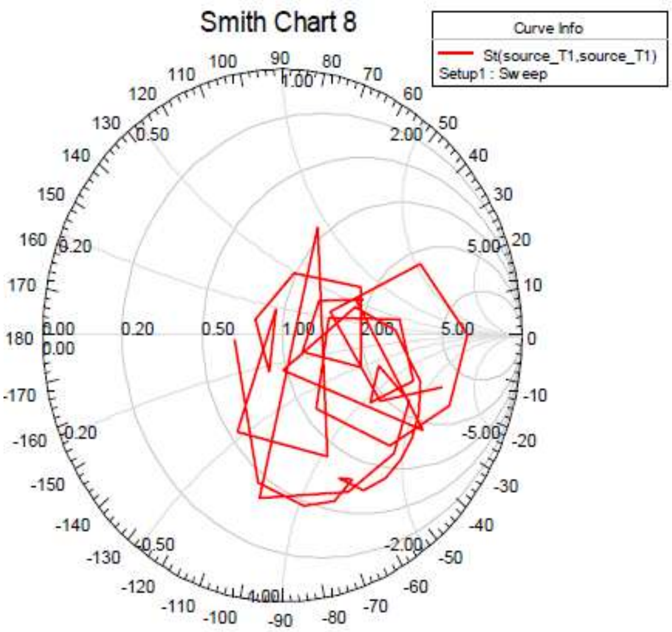

Fig -13: Smith chart for S11 of the final design

Normalized impedance = Z_L / Z_0 ;

Here, Z_L remains a complex number, as Z_L = RL+ jXL ; & Z_0 remains constant, which is taken as 50 ohm, for coaxial cable, feeding the antenna. Smith chart represent antenna properties in terms of reflection coefficient too, which is represented as (Γ), & is given as:

$\Gamma = (Z_L - 1)/(Z_L + 1)$;

With Z_0 taken as 50 ohm;

Here, in the smith chart, the horizontal line represents, the normalized resistance & the normalized reactance is shown on the outer edge of the circles.

3. PERFORMANCE COMPARISON & APPLICATIONS OF PROPOSED ANTENNA

Ref.	No. of Bands & Resonant freq. (f_r) in GHz	Peak Gain (dBi)	Max. Bandwidth (MHz)	Appli-cations
[3]	4, S- band (3.1 GHz), C-band (5.8 GZz & 7.4 GHz), X-band (9.8 GHz)	1.1	≥ 500	WiMAX, Wi-Fi
[4]	3, S-band (3.7GHz), C-band (5.2GHz & 5.8 GHz)	5	100	WiMAX, Wi-Fi
[5]	2, S- band (3.6 GHz) & C-band (5 GHz)	1	500	WiMAX, Wi-Fi
[6]	3, S-band (2.3 GHz & 3.4 GHz) & C-band (5 GHz)	1.6	150	Bluetooth , WiMAX, WLAN
[7]	3, S-band (2.0175 GHz, 2.45 GHz & 3.5 GHz)	3.6	255	LTE, WLAN, WiMAX
[8]	3, S-band (2.5 GHz & 3.8 GHz) C-band (5.25 GHz)	4.5	50	Bluetooth , Wi-Fi
[9]	3, L-band (0.9 GHz), S-band (2.4 GHz), C-band (5.2 GHz)	4.9	307	ISM Band, WLAN, Bluetooth
[10]	5, L-band (0.824 GHz & 1.85 GHz), S- band (2.4 GHz & 2.5 GHz), C-band (5.1 GHz)	5.9	600	GSM, WLAN, WiMAX

[11]	6, L-band (1.64 GHz, 1.74 GHz & 1.9 GHz), S- band (2.3 GHz, 2.6 GHz & 2.9 GHz)	9.8	80	WiMAX, Bluetooth, Wi-Fi
[12]	3, L-band (1.4 GHz), S- band (2.4 GHz & 2.8 GHz)	2	330	GPS, WLAN
Proposed Antenna	6, C-band (7.6 GHz), X-band (8.2 GHz, 9.4 GHz, 10GHz, 10.5 GHz & 12 GHz)	7.6	460	Satellite comm., RADAR, Air traffic control

4. CONCLUSION

A coaxial feed, Multiband, Concentric ring, Circular Microstrip Patch Antenna, with easy design geometry, high gain (Approx. 7.5 dBi) & high bandwidth (Approx. 500 MHz) is proposed here. Proper approach towards final result is fully analytical & explained step by step. Number of bands have been increased using the concept of strips & slots, equating circuit model of inductors & capacitors respectively. Further improvement in gain & bands is achievable by using Metamaterials, Split ring resonators, Dielectric resonators etc. The proposed antenna is efficient enough for applications such as RADAR communication, satellite communication, air traffic control, speed detection of road vehicles.

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