Analysis and Design of L-strip Proximity Coupled Circular Microstrip Antenna

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***Abstract*— An L-strip proximity coupled circular microstrip antenna is proposed. The structure is investigated using circuit theoretic approach and simulated using IE3D simulation software. The patch is designed on a thick substrate of thickness of 11 mm for a design frequency of 3.74 GHz and provides ultra wide band operation. The numerical results for input impedance, VSWR, radiation pattern, efficiency and gain are presented. Bandwidth is found to be dependent on length of horizontal part of L-strip. A bandwidth of 69.52% is achieved (for VSWR≤2) for y_0=0.112λ_0 and h_2=0.097λ_0. The beam of antenna rotates with operating frequency.**

***Index Terms*—**L-strip feed, Tunability, proximity coupled, wideband, radiation pattern, antenna gain, radiation efficiency, return loss, directivity.

I. INTRODUCTION

Microstrip patch antennas have been attracting the antenna designers because they offer the features of low profile, light weight, and compatibility with integrated-circuit technology. Recently, patch antennas have been receiving a great interest in various wireless communication systems since they can provide advantages over traditional antennas in terms of efficiency and electromagnetic coupling to the human head. In many applications, the requirements of bandwidth, tunability and physical size are quite important. Moreover, many efforts have been devoted to bandwidth widening techniques of microstrip antennas, including short-circuited termination for microstrip-fed slot antennas by Ching-Lieh Li, Pei-Ying Lin, and Chun-Kai Huang [1], dual slot loading by Amit A. Deshmukh and Girish

ISSN 2179-1074

Kumar [2], use of notch by Y. H. Ge, K. P. Esselle, and T. S. Bird [3], U-shaped ground plane by W. H. Hsu, and K. L. Wong [4]. For thick patch antenna, the coaxial feed is typically used. However, the probe inductance limits its impedance bandwidth to less than 10%. K.M. Luk, Y.X. Guo and K.F. Lee [5] used U-slot and L-probe feed, P.S. Hall [6] used probe compensation, C.L. Mak, K.F. Lee, and K.M. Luk [7] used T-shape probe for feed and T. Huynh and K.F. Lee [8] used L-shape probe to overcome band limitation problem. Many researchers have used L-shaped microstrip line as a feed line. M.K. Meshram used L-strip to to achieve a bandwidth of 56.67% [9] in rectangular microstrip antenna. Zhongbao Wang, Shaojun Fang, and Shiqiang Fu used modifies L-strip to 22% bandwidth with improved gain of 9 dBi [10].

In this paper, ultra-wideband proximity coupled L-strip fed Circular Microstrip Antenna (CSMA) has been presented. Using a foam layer of thickness 11 mm as a substrate, an impedance bandwidth of 69.52% and gain of upto 8 dBi has been achieved which is better than earlier reported results by T. Huynh and K.F. Lee [8]. No optimization was adopted in the design. The antenna is simulated using IE3D software. The computed results using circuit theoretic approach agree well with simulated data. The simulation for antenna efficiency, radiation efficiency, radiation pattern, gain and directivity has also been carried out.

II. THEORETICAL INVESTIGATION

The L-strip proximity coupled circular microstrip antenna is analyzed using circuit theoretic approach and cavity model. Broad banding is achieved by using thick substrate. But this reduces coupling between patch and microstrip feed. Various techniques have been used to counter this problem. The antenna given Y. X. Guo, K. M. Luk and K. F. Lee [11] is taken as reference for comparison. In the present analysis L-shaped micro-strip feed is used. The proposed structure is shown in fig. 1. The antenna structure contains a thick substrate of thickness H. An L-shaped strip line is designed to couple the power to patch electromagnetically. This L-shaped feed is connected to a standard microstrip feed which in turn is connected to source. The fig. 2 shows equivalent circuit of proposed antenna. The length of horizontal part of L-strip under patch is kept less than quarter wavelength because up to λ/4 length of an open circuited stub, the nature of impedance is capacitive. The capacitance thus introduced is suppressed by the inductance arising from vertical part of L-strip. Apart from these, a series resistance arises due to finite conductivity of copper used. The expressions of series resistance (R_s) and series inductance (L_s) as given by R. K. Huffman (1987) [12] are

$$\begin{aligned} L_s = 0.2h_2[\ln\{2h_2/(w_s+t_s)\} + \\ 0.2235\{(w_s+t_s)/h_2\}+0.5] \end{aligned} \ (\mathrm{nH}) \tag{1}$$

Brazilian Microwave and Optoelectronics Society-SBMO received 10 Oct. 2011; for review 14 Oct. 2011; accepted 15 June 2012
Brazilian Society of Electromagnetism-SBMag ISSN 2179-1074

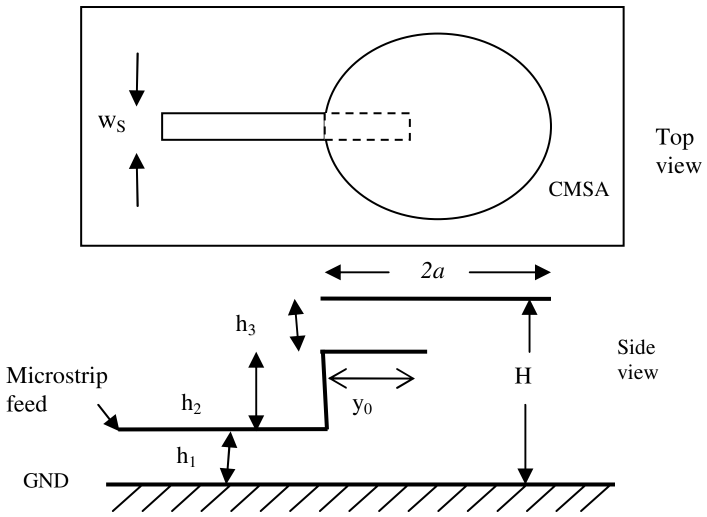


Fig 1. Structure of proposed antenna.

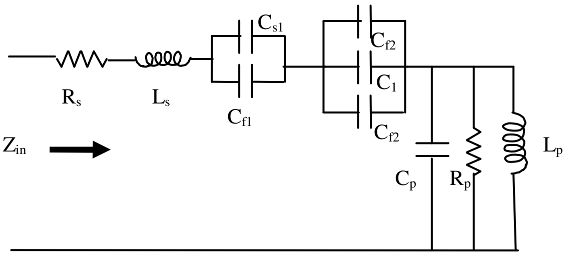


Fig 2. Equivalent circuit of L-strip proximity coupled CSMA.

$$R_s = 4.13 h_2 (w_s + t_s) \sqrt{f . \rho / \rho_0} \tag{2}$$

Where w_s is width and t_s is thickness of strip in mm, h_2 is height of L-strip, f is operating frequency in GHz, ρ is specific resistance of the strip (Ω cm) and ρ_0 is specific resistance of copper. All antenna metallization is taken as perfect except vertical portion. There is a capacitance (C_{s1}) arising due to vertical electric fields between horizontal part of L-strip and ground plane in series with above L_s and R_s and is calculated as

$$C_{s1} = \varepsilon_r \varepsilon_0 w_s y_0 / (h_1 + h_2) \tag{3}$$

Where y_0 is penetration of L-strip into patch ε_r is relative dielectric constant and ε_0 is dielectric constant of vacuum. There is a fringing capacitance between open end of L-strip and ground plane (C_{f1}), between open end of L-strip and patch (C_{f2}) and between radiating edge of patch and horizontal part of L-strip (C_{f2}). These capacitances are calculated by evaluating extended effective length of L-

Brazilian Microwave and Optoelectronics Society-SBMO received 10 Oct. 2011; for review 14 Oct. 2011; accepted 15 June 2012
Brazilian Society of Electromagnetism-SBMag ISSN 2179-1074

strip. The expression of extension in the length of an open ended microstrip line is given by T. C. Edward [13] and is given as

$$l_e = \frac{0.412h(\varepsilon_e + 0.3)(w_s / h + 0.264)}{(\varepsilon_e - 0.258)(w_s / h + 0.8)} \tag{4}$$

Where ε_e is effective dielectric constant of material buried under the microstrip line and ground plane. From T. C. Edward [13] the associated fringing capacitance is calculated as

$$C_f = l_e \sqrt{\varepsilon_{reff}} / cZ_0 \tag{5}$$

Where l_e is extension in length of L-strip feed, c is velocity of light in vacuum, Z_0 is characteristic impedance of feed and ε_{reff} is effective dielectric constant. The fringing capacitance between horizontal part of L-strip and ground plane (C_{f1}) is calculated by putting $h=h_1+h_2$ and the two capacitances between patch and horizontal part of L-strip (both C_{f2}) is calculated by putting $h=h_3$. Fringing capacitance between patch and L-strip is calculated using equations (4) and (5), ignoring curvature of patch. The capacitance due to vertical electric field between horizontal part of L-strip and patch is calculated as

$$C_1 = \varepsilon_r \varepsilon_0 y_0 w_s / h_3 \tag{6}$$

The equivalent circuit of L-strip fed circular microstrip antenna is shown in fig. 2. The structure contains a series RLC resonant circuit in series with a parallel RLC resonant circuit. The parallel RLC circuit is equivalent of circular microstrip antenna. The resonance resistance R_p of patch, antenna capacitance C_p and inductance L_p are calculated by Stuart A. Long, Liang C. Shen, Mark D. Walton and Martin R. Allerding [14] and is given as

$$R_p = J_n^2(k(a - y_0)) / [G_T J_n^2\{ka\}] \tag{7}$$

$$C_p = Q_T / \{2\pi f_{res} R_p\} \tag{8}$$

And $$L_p = R_p / \{2\pi f_{res} Q_T\} \tag{9}$$

Where Q_T is total quality factor, G_T is total conductance of patch of radius a incorporating radiation loss, conduction loss and dielectric loss [15] and f_{res} is resonant frequency of patch [16].

Thus total input impedance of the circuit is given as

$$Z_{in} = R_s + j\omega L_s + \left\{ \frac{1}{j\omega C_{total}} \right\} + \frac{1}{(1/R_p) + j\omega C_p + (1/j\omega L_p)} \tag{10}$$

where C_{total} is total capacitance arising due to L-strip (i. e. C_1, C_{s1}, C_{f1}, and C_{f2}) and is calculated as

$$C_{total} = \frac{(C_1 + 2C_{f2})(C_{s1} + C_{f1})}{(C_1 + 2C_{f2} + C_{s1} + C_{f1})} \tag{11}$$

The reflection coefficient of the antenna is given as

$$\Gamma = \frac{Z_{in} - Z_0}{Z_{in} + Z_0} \tag{12}$$

and the VSWR is calculated as

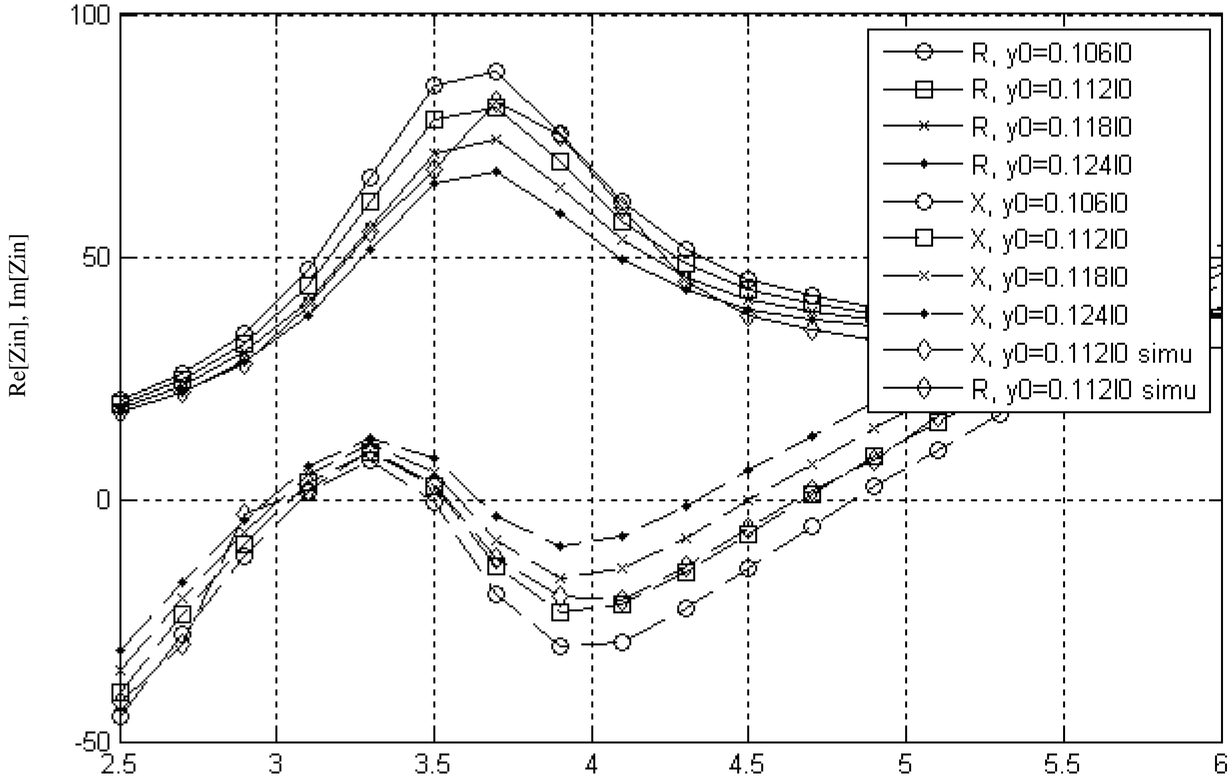
$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|} \tag{13}$$

III. DESIGN PARAMETERS

The basic design parameters of the proposed antenna are same as taken by Y. X. Guo, K. M. Luk and K. F. Lee [11] for comparison purpose. The radius of patch (a) is 17 mm, total height (H) of substrate is 11mm, and dielectric constant is 1.07 (foam layer). The parameters which are new for the design are - height of microstrip feed (h_1= 1.6 mm or 0.02λ_0), height of L-strip (h_2= 7.8 mm or 0.097λ_0) and gap between circular patch and horizontal part of L-strip (h_3= 1.6 mm or 0.02λ_0). The width and length of L-strip are 5mm and 9.5 mm (0.097λ_0) respectively. The design frequency of the antenna is 3.74 GHz (λ_0= 80.2 mm). A 50 ohms microstrip line on 1.6 mm thick substrate was taken to feed the power to L-strip (w_s= 5 mm).

IV. RESULTS AND DISCUSSIONS

The L-strip proximity coupled microstrip CMSA is analyzed and the results are compared with the ones obtained by Y. X. Guo, K. M. Luk and K. F. Lee [11]. The variation of input impedance with frequency for different horizontal length of L-strip of proposed structure is shown in fig. 3. The capacitive nature of antenna increases with horizontal length of L-strip. The resonance resistance decreases as open end of L-strip moves towards center of patch. This indicates that open end is working as feed point. The variation of VSWR with frequency for different horizontal length of L-strip is shown in fig. 4. The fig. shows that matching improves with the horizontal length of L-strip. At the same time, bandwidth decreases due to increased quality factor of the structure. The bandwidth for different y_0 is given in Table I. it is clear that bandwidth decreases with increase in y_0 at constant value of h_2. The simulated result is also given in the table which shows a close resemblance with calculated bandwidth. Fig. 5 shows variation of input impedance at various heights of L- strip for fixed horizontal length of L-strip (y_0=0.112λ_0). With the height of L-strip the inductive



Frequency(GHz) [R—real part, X---Imaginary part]

Fig 3. Variation of input impedance with frequency for different L-strip lengths h_2=0.097λ_0.

TABLE I. BANDWIDTH FOR DIFFERENT y_0 AT h_2=0.097 Λ_0.

Result	y_0	f_H(GHz)	f_L(GHz)	Δf(GHz)	%BW
Calculated	0.106λ_0	5.65	2.85	2.8	74.86
	0.112λ_0	5.45	2.85	2.6	69.50
	0.118λ_0	5.30	2.85	2.45	65.5
	0.124λ_0	5.10	2.85	2.25	60.1
Simulated	0.112λ_0	5.5	2.90	2.6	69.5

Brazilian Microwave and Optoelectronics Society-SBMO received 10 Oct. 2011; for review 14 Oct. 2011; accepted 15 June 2012
Brazilian Society of Electromagnetism-SBMag ISSN 2179-1074

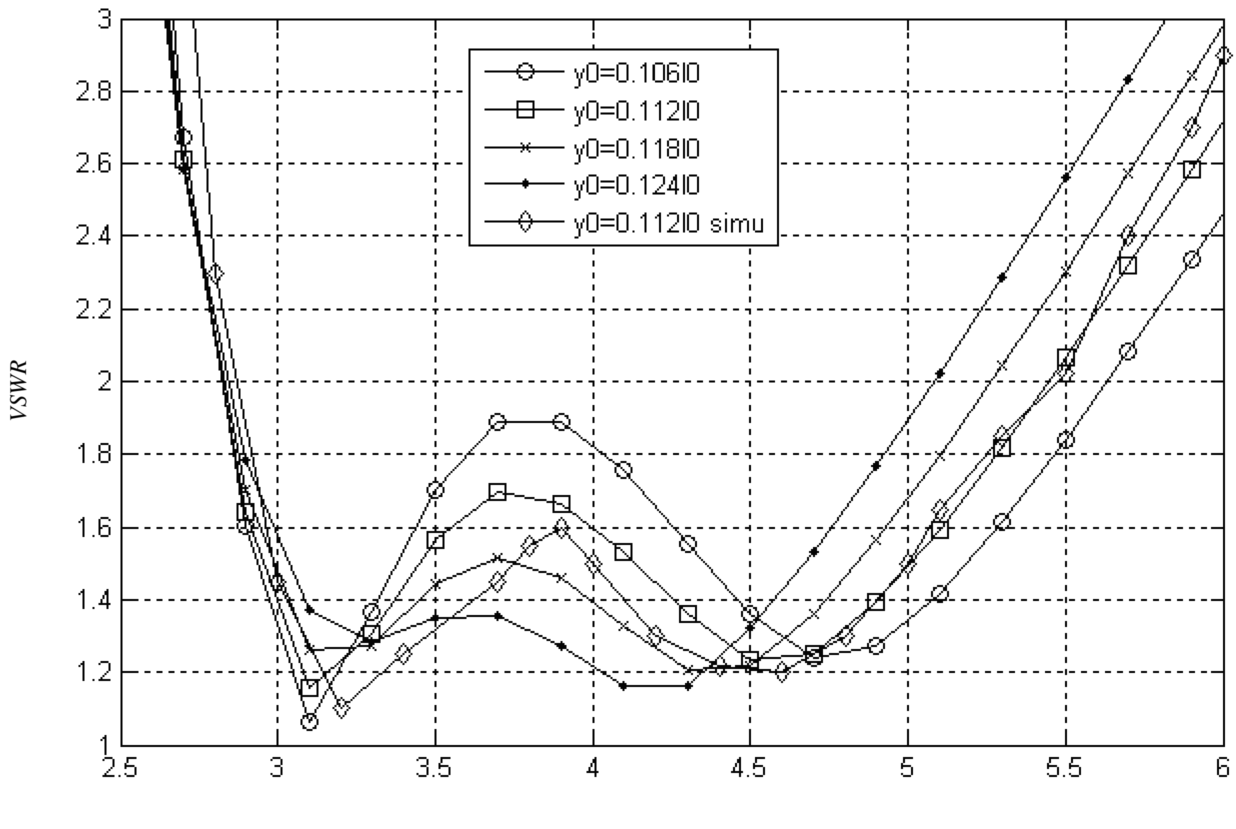


Fig 4. Variation of VSWR with frequency for different horizontal length of L-strip at h_2=0.097λ_0.

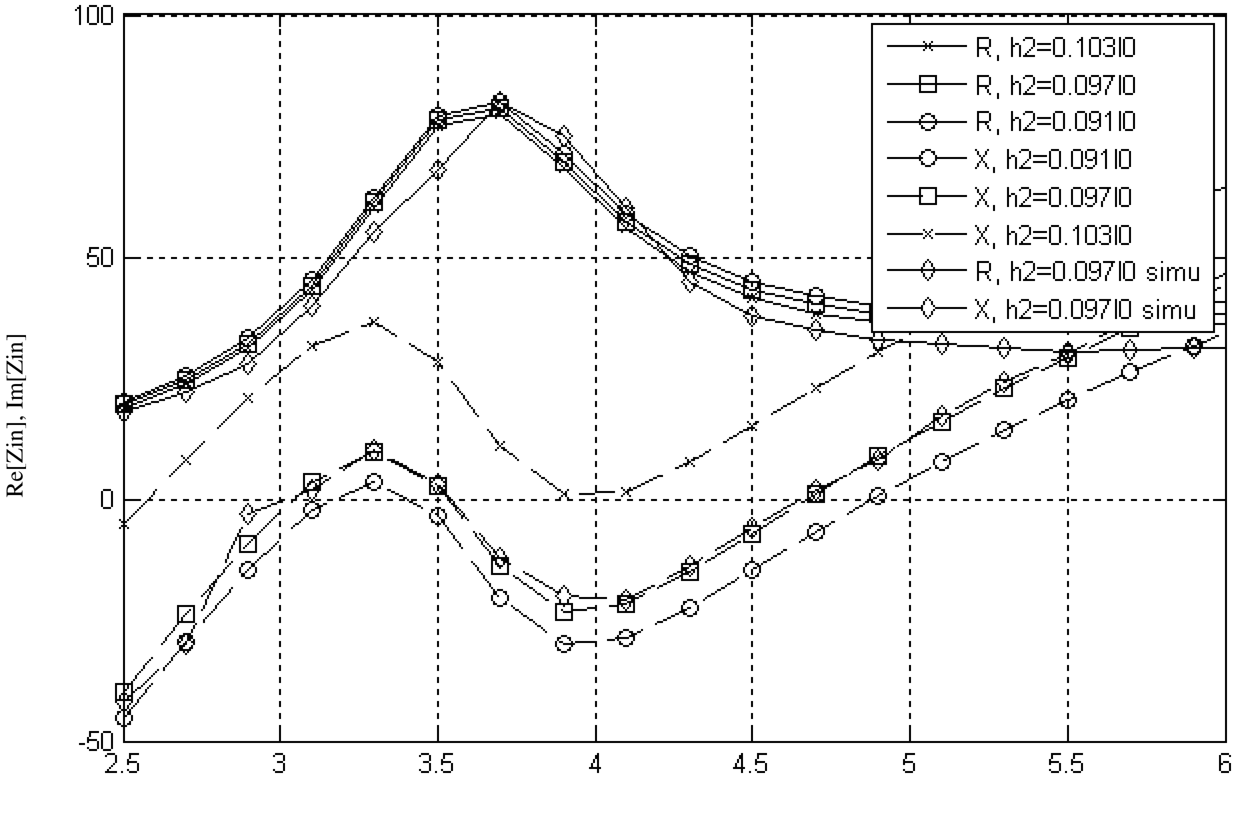


Fig 5. Variation of input impedance with frequency for different height of L-strip at y_0=0.112 λ_0.

Brazilian Microwave and Optoelectronics Society-SBMO received 10 Oct. 2011; for review 14 Oct. 2011; accepted 15 June 2012
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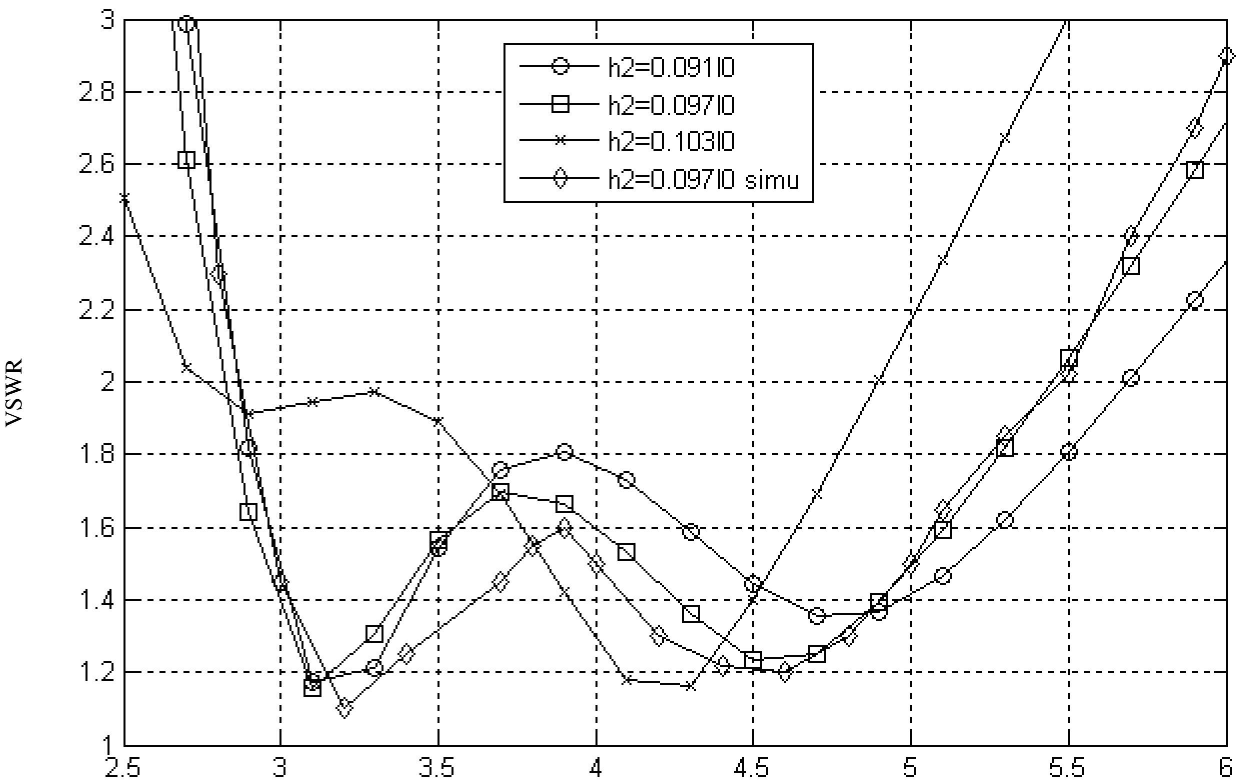
nature increases which is obvious. The variation of VSWR with frequency at different height of L-strip is shown in fig. 6. The bandwidth for different height of L-strip is given in Table II. The bandwidth decreases with height of L-strip. It is very similar to bandwidth variation with length of horizontal part of L-strip (y_0). Again the simulated and calculated results are in good agreement. The antenna was simulated on Zealand IE3D v 14.0 software [17]. The variation of VSWR and input impedance at y_0=0.112λ_0 and h_2=0.097λ_0 are shown in figs. 3, 4, 5 and 6. The calculated results using circuit theoretic approach and simulated results were in good agreement.

TABLE II. BANDWIDTH FOR DIFFERENT h_2 AT y_0=0.112 λ_0.

Result	H_2	f_H(GHz)	f_L(GHz)	Δf(GHz)	%BW
Calulated	0.091λ_0	5.70	2.90	2.80	74.86
	0.097λ_0	5.47	2.80	2.67	71.39
	0.103λ_0	4.90	2.70	2.20	58.8
Simulated	0.097λ_0	5.25	2.95	2.30	69.52



Frequency(GHz)

Fig 6. Variation of VSWR with frequency for different heights of L-strip y_0=0.112 λ_0.

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The return loss of an antenna shows how well antenna port is matched with source. A good return loss or VSWR alone is not measure of a good antenna as it does not tell how well the radiation is taking place. Hence investigation of Directivity, radiation efficiency, antenna efficiency and antenna gain is required. Radiation efficiency of an antenna is defined as ratio of power radiated to power given to antenna excluding return loss at antenna port. However, the antenna efficiency is defined as ratio of radiated power to actual power fed to antenna (includes return loss at port). For a good antenna high gain, high efficiency is desirable. The variation of directivity at different operating frequency is shown in fig. 7. It is clear that directivity is maximum (8.4 dBi) at the design frequency and it remains above 6 dBi for the entire range. The fig. 8 shows variation of maximum antenna gain

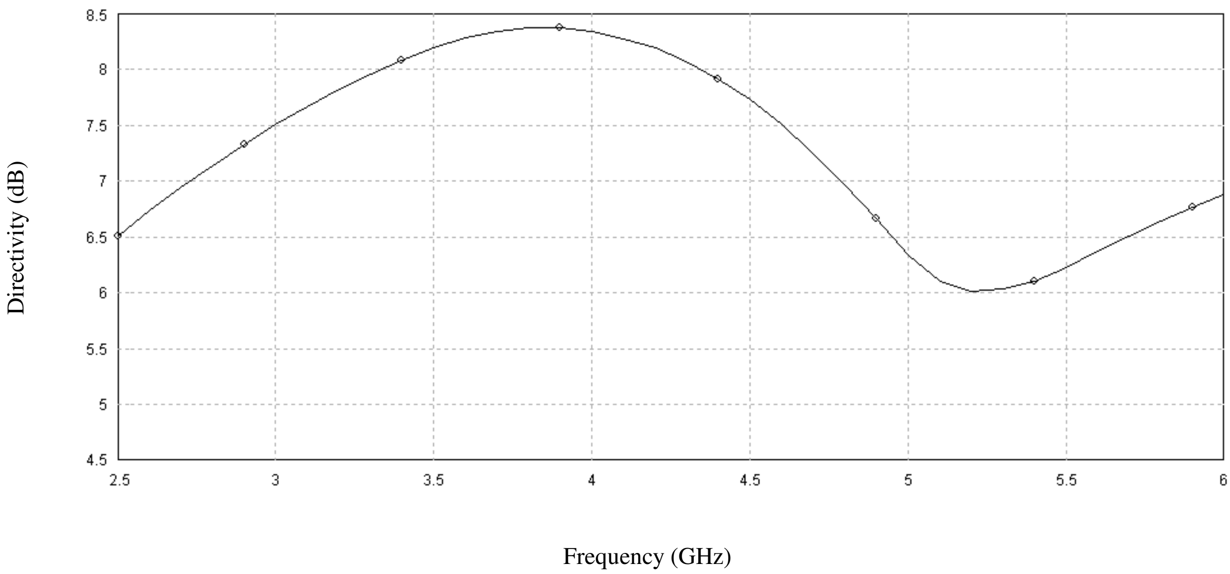

Fig 7. Variation of maximum field directivity with frequency.

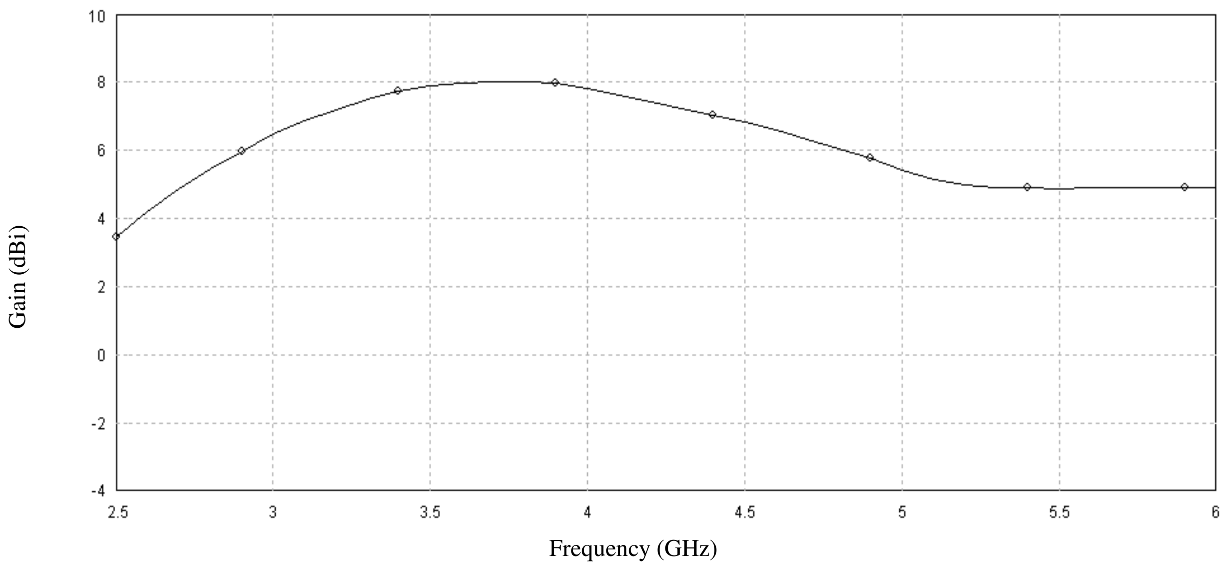

Fig 8. Variation of Gain of the antenna with frequency.

with frequency. The gain of the antenna remains more than 4 dBi for the entire range of operation (2.9-5.5GHz).Total antenna efficiency and radiation efficiency is shown in fig. 9. The antenna efficiency remains above 80% for the entire range. Total antenna efficiency is above 70%. The radiation pattern of the proposed antenna using IE3D at 3.1 GHz, 3.8 Ghz and 4.5 GHz is shown in Fig. 10. It is also observed that beam rotates with frequency of operation. The radiation achieves its peak

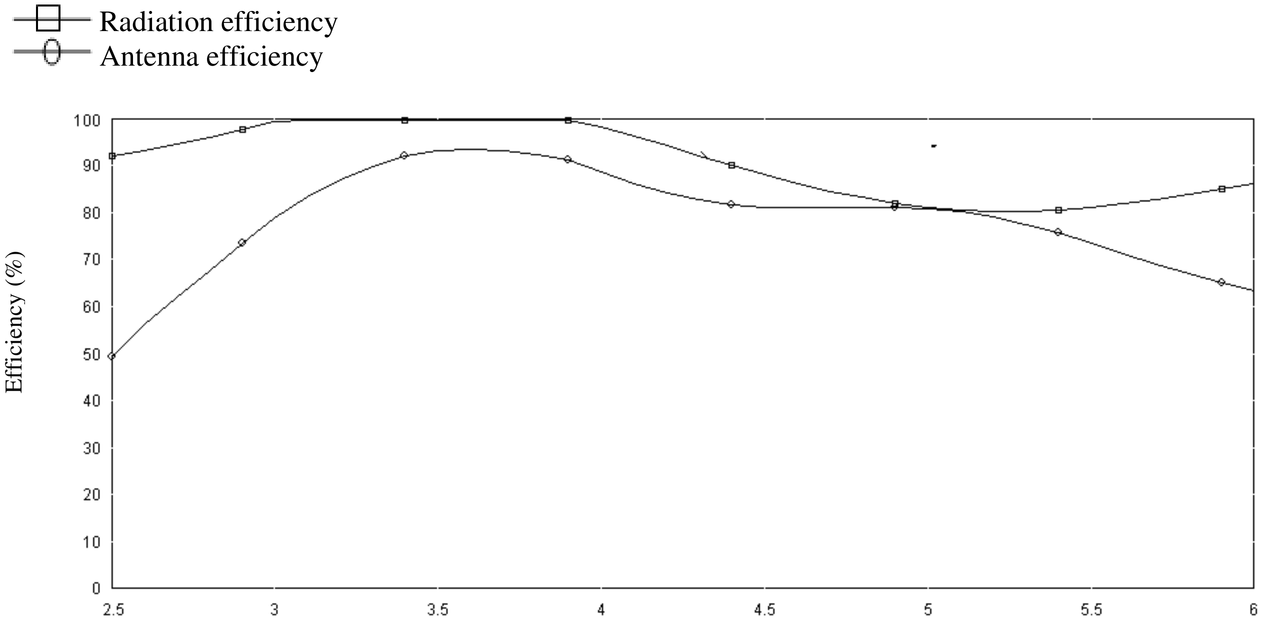

Fig 9. Variation of efficiency with frequency.

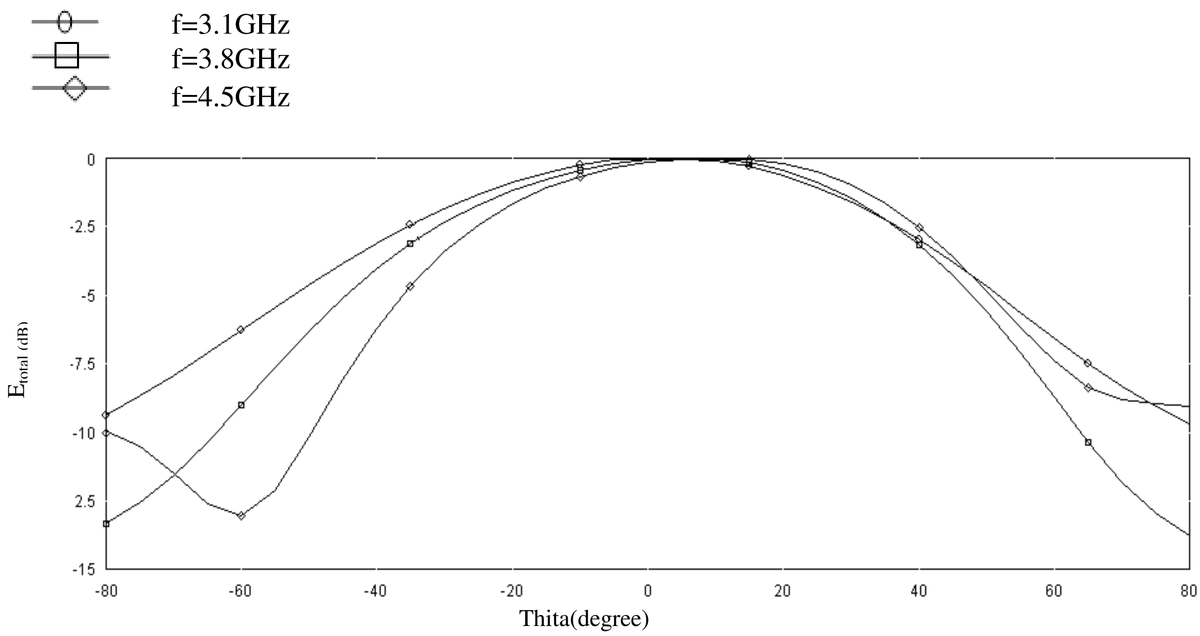

Fig 10. Radiation pattern of proposed antenna.

at 0.46^0, 5.07^0, and at 10.24^0 for 3.1GHz, 3.8 GHz and 4.5GHz frequencies respectively. The variation of beam width and its direction shift is shown in table III. The wave takes definite time to reach at the

Brazilian Microwave and Optoelectronics Society-SBMO received 10 Oct. 2011; for review 14 Oct. 2011; accepted 15 June 2012
Brazilian Society of Electromagnetism-SBMag ISSN 2179-1074

feed end and get coupled to the patch. This time delay causes phase difference which in turn affects the total field in the far field zone. Hence antenna beam rotates for different frequency of operation.

Table III. Beam Rotation at Different Operating Frequency.

Operating frequency	First half power point (θ_1)	Maximum radiation point (θ_0)	Second half power point (θ_2)	Beamwidth ($\Delta\theta = \|\theta_1-\theta_2\|$)
3.1GHz	-39.2^0	0.46^0	39.95^0	79.15^0
3.8GHz	-34.2^0	5.07^0	39.00^0	73.2^0
4.5GHz	-27.77^0	10.24^0	42.00^0	70.01^0

V. CONCLUSION

A novel L-strip fed circular microstrip antenna has been presented for ultra wideband application. An equivalent circuit was given for the structure and calculations were carried out for circular patch of 11 mm thickness. Various antenna properties were investigated using circuit theoretic approach and results were verified with simulation. The proposed antenna has an operating frequency range from 2.85GHz to 5.45GHz (2.9GHz to 5.5GHz simulated) and bandwidth of 69.52% which is better than earlier reported bandwidth (35%) and gain (8 dBi). It may also be concluded that the input impedance is very sensitive to variation in horizontal length and height of L-strip feed. The beam of antenna is rotating with the frequency of operation.

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Brazilian Microwave and Optoelectronics Society-SBMO received 10 Oct. 2011; for review 14 Oct. 2011; accepted 15 June 2012
Brazilian Society of Electromagnetism-SBMag *ISSN 2179-1074*