



Multilayer microstrip log-periodic dipole antenna for C and X band communication

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ABSTRACT

A dual-band characteristic of multilayer aperture coupled microstrip log-periodic dipole antenna is studied. Further loading of patches is performed and its effects are investigated. It is a probe fed antenna for impedance matching with 50Ω coaxial cable. This antenna works well in the frequency range 4.3 GHz to 8.5 GHz. It is basically a low cost, light weight medium gain antenna, which is used for wireless communication. The multilayer microstrip antenna structure involves addition of multiple layers one over the other. When a microstrip antenna is stacked with a superstrate dielectric layer, its properties like resonance frequency, gain and bandwidth are changed, which may affect the system performance. With proper choice of the thickness of substrate and superstrate layers, significant increase in bandwidth and return loss can be achieved for practical applications. This structure uses stacked configuration of three different substrates. One dielectric substrate as a feeding plane, one dielectric substrate as aperture plane and a dielectric substrate as a LPDA. The simulated antenna yields -29.16 dB return loss with 33% bandwidth with a size of 14.80x16.89x6mm³. The proposed antennas present an excellent candidate for compact and low-cost microwave integrated systems.

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Introduction

Ultra wideband (UWB) wireless communication allows low power level and high data rate transmissions have embarked great research interests for wireless communications applications in the 3.1GHz –10.6GHz frequency band. High-performance UWB antennas require both good impedance matching and low signal distortion within the specified frequency bands. Microstrip patch antennas are widely used in wireless and cellular mobile communication systems because of their advantages, like low profile, light weight and ease of fabrication and LPDAs also have a reasonable gain with a very large bandwidth.

In the design we have used both the antennas as a combination, so that we can have the advantages of both the antenna. We have used stacked structure configuration. It consists of three substrates working as feed, coupling plane and director (an LPDA). The antenna simulated was based on patches, consisting of feeding plane, aperture plane and an LPDA. An array of three antenna elements was successfully used to achieve the required performances. The coaxial feed is used to feed the antenna.

In the paper, a novel compact antenna is simulated with the multilayer topology by stacking together the feeding layer, aperture layer and the top layer (an LPDA). The proposed design can provide so many advantages. First of all, the use of stacked configuration results in an effective reduction in size. Second, the dual polarization based design can be realised and coupling based feed mechanism can be deployed. Finally, high dielectric constant material can be utilized; thereby reducing spacing between the different layers can be reduced and hence can get better radiation characteristics.

Extensive research work is being carried out in the field of antennas. The development in the context of log periodic antenna is our focus area. The following review concentrates on the comparative study of four different research works based on log periodic antenna which analyses periodicity for input impedance of general finite log periodic array [1] and UWB PLPDAs with multiple notched bands in [3-4]. J. Yang [1] presented a method for input impedance of a general finite log periodic array antenna. This formula will help us in determining the input impedance at the higher frequencies by its value at lower frequencies with much less computation time.

Stable radiation patterns were experimentally confirmed within the whole working frequency bands by [2]. A section of HMSIW was integrated into the proposed antenna as an ultra-wideband balun in the feeding network and a reflector for the printed dipole array. The proposed PLPDAs with single and multiple notched bands were implemented simply by etching U-shaped slots on the antenna. Unlike the monopole antennas, the proposed PLPDAs radiate power in the end-fire direction. A compact UWB PLPDA with a notched band was presented by Tao Jiang et al. [3]. A section of HMSIW was integrated into the proposed antenna as an ultra-wideband balun in the feeding network. The size was reduced by folding the dipole arms and loading capacitive rectangular patches, and a notched band is generated by etching a U-shaped slot on the antenna. The antenna radiates power in the end-fire direction. Stable radiation patterns are confirmed within the whole working frequency band. A new band-notched UWB antenna in the category of directional antenna was successfully developed by Chao Yu et al. [4]. HMSIW was introduced as the feeding system. With the advantages of HMSIW and PLPDA, the antenna could easily earn mass production with a low cost. By combining the L-shape

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slot with the proposed UWB antenna, the narrow notch band near 5.5GHz can be created to avoid interferences from other narrow band communication systems in this frequency band. A new feeding technique for printed Log-periodic dipole arrays (LPDAs) was presented by Giovanni Andrea Casula et al. [5], it was used to design a printed LPDA operating between 4 and 18 GHz. The simulation results showed that the antenna can be used as an Ultra Wideband Antenna in the range 6-9 GHz.

M. Mehranpour et al. [6] proposed a novel printed monopole antenna for ultra wide band applications with dual band-notch function. The antenna consisted of a square radiating patch with a pair of L-shaped slits, and an E-shaped slot and a ground plane with a V-shaped protruded strip, which provides a wide usable fractional bandwidth of more than 140% (2.89–17.83 GHz). In order to generate single band-notch characteristics, two L-shaped slits in the radiating patch were used. By adding an E-shaped slot in the centre of the radiating patch, a dual band-notch function is achieved. Also, by inserting a V-shaped protruded in the ground plane, additional resonances were excited, and hence much wider impedance bandwidth could be produced, especially at the higher band. The measured results reveal that the presented dual band-notch monopole antenna offers a very wide bandwidth with two notched bands, covering all the 5.2/5.8-GHz WLAN, 3.5/5.5-GHz WIMAX and 4-GHz C-bands. The designed antenna has a small size area of mm, which has a size reduction of 35% with respect to the previous similar antenna. Radostin S. Pavlov et al. [7] demonstrated log-periodic antennas that exhibit broadband directivity as a result of the self-similar relation between the lengths, separations and widths of the elements. Numerical simulations showed that the log periodic designs have a considerable potential for improvement of both directivity and operation bandwidth over classical Yagi-Uda designs and the influence of geometrical parameters on angular performance and local field enhancement to arrive at optimum values. It demonstrated that introducing a gap in the dipole array architecture can provide at least a ten-fold enhancement of the emitted power. Radostin S. Pavlov et al. [7] also presented an optical zigzag antenna capable of both broader spectral response and even higher directivity. An antenna with the notched frequencies of 1.03 GHz, 1.28 GHz, 1.72 GHz, 2.24 GHz and 2.51 GHz is designed, fabricated, and measured by Tian Haiyan in [8].

Antenna model was established on the substrate of FR4 and feed by a strip line. The simulation results show that the antenna can achieve an impedance wide bandwidth from 0.89 to 2.58 GHz with return loss less than -10 dB and exhibit stable antenna gain.

A compact planar antenna operating at a frequency range of 3–16 GHz was presented by Rezaul Azim et al. [9] for wideband applications. This antenna composed of a square patch fed by a microstrip line and a partial ground plane with a rectangular slot. The flat antenna had a compact structure and the total size was 29 mm×22 mm. The result shows that the measured impedance bandwidth ($VSWR \leq 2$) of the proposed antenna is 3.2–15.44 GHz, with a notch from 4.7 to 5.8 GHz. The effects of the structure parameters on impedance bandwidth were also investigated.

A comparison was carried out between different material of pad, calculation of parameters and method of simulation by Ping Li et al. [10]. Through selection, A Printed Log-Periodic Antenna was made using the material of TB-73. The antenna could be used in the channel of 700MHz to 3GHz from the

results of actual measurement, the average of Gain was found to be better than 9dB, and the VSWR was less than 1.2 from 700MHz to 2GHz. Adding covering, which was made of PEI and changing the feed structure were also measured and analysed. From the results, the operating frequency became narrow after adding covering, and the bandwidth in high frequency points dropped 200MHz. With the change of feeder, VSWR was higher than 2 in high frequency points and reduce to less than 1.2 in low frequency.

A method to form a notch band was presented by The-Nan Chang et al. [11]. Complementary split-ring resonators in the T-stub region of a CPW-feed ultra wideband (UWB) antenna were etched. Due to limited space in this region, two resonators were connected together so that they would have a common slot edge. Compared with two separated CSSRs, this new design not only occupied less space but also yielded high mismatch losses. It was found that high mismatch losses and deep suppression level can be obtained at the desired notch band. Constant radiation characteristics over a decade bandwidth are required for some of wide band applications, for example, feeds for reflector antennas in radio telescope [12]. Jian Yang [12] presented an analysis on condition for constant radiation characteristics over wide bandwidth for a log-periodic array antenna was presented.

Joseph R. Mruk et al. [13] proposed three band rejection techniques integrated with a multi-octave wideband planar log-periodic antenna. Antennas were designed to operate between 1.8 and 11 GHz with rejection at 6 GHz. Demonstrated band-rejection techniques include the removal of resonant teeth also referred to as aperture rejection, integration of a dual band filter, and combination of the two above techniques. Aperture rejection is shown to produce greater than 25 dB realized gain reduction. Integrated filter and combined methods achieve over 30 dB and 55 dB rejections, respectively. Antennas were fabricated on a 0.508 mm RT/Duroid 6002 substrate and excellent agreement between theory and measurements was obtained.

Three types of ultra wideband (UWB) antennas with triple notched bands were proposed and investigated by Yan Zhang et al. [14]. The proposed antennas consist of a planar circular patch monopole UWB antenna and multiple etched slots on the patch and/or split ring resonators (SRRs) coupled to the feed line. Shih-Yuan Chen et al. [15] presented coplanar waveguide-fed uniplanar log-periodic slot antenna suitable for use in the ultra-wideband radio systems. The in-band impedances and radiation performances were quite stable and satisfactory. Rejected narrow frequency band was obtained by inserting a pair of metallic stubs into two vertical slots of the proposed antenna. The stub pair provides significant attenuation in the desired notched band but has little effect on the antenna operation outside of the notch. The time-domain characteristics of the proposed antennas are also investigated.

Jian Yang et al. in [16] presented a new compact design of a 1.2–10 GHz Eleven antenna, as a feed for reflector antennas by re-arranging the geometry of the outermost elements of the antenna. The new compact eleven feed has only a 40% volume of the original standard eleven feed. A design was proposed to achieve Maximum bandwidth in multilayer patch array in [17]. A new wideband stacked patch antenna was successfully fabricated on microwave substrates using micromachining and micro-assembly methods in [18]. In [19] a compact single-feed stack antenna consisting of a square loop radiator with perturbation, an aperture-coupled structure and a straight-strip feed line was proposed for circular polarization (CP) and

unidirectional radiation applications. Tamer Güdü and Lale Alatan in [20] presented asymptotic waveform equation/pade approximation techniques to analyse structures with periodic implants. A new compact microstrip antenna was designed for ultra wideband applications in [21]. Due to its compact design, structure also finds its application in mobile communication. Bandwidth about 50% was achieved with maximum gain about 7.5 dB.

The configuration of the multilayer antenna consists of three different planes; feeding plane, aperture plane and an LPDA. feeding plane and aperture plane using patch on the substrate but in this design an LPDA designed on the top layer which acts as director. In the proposed design, we will investigate the effect of loading of patches onto the director (LPDA).

In this paper, the configuration of the proposed multilayer Microstrip LPDA antenna is described in detail. Design specifications are discussed, considering the effects of different dimensions on antenna performances. The proposed antennas as described in Fig. 1 is Simulated with the IE3D version 9.0, and the work is finally concluded.

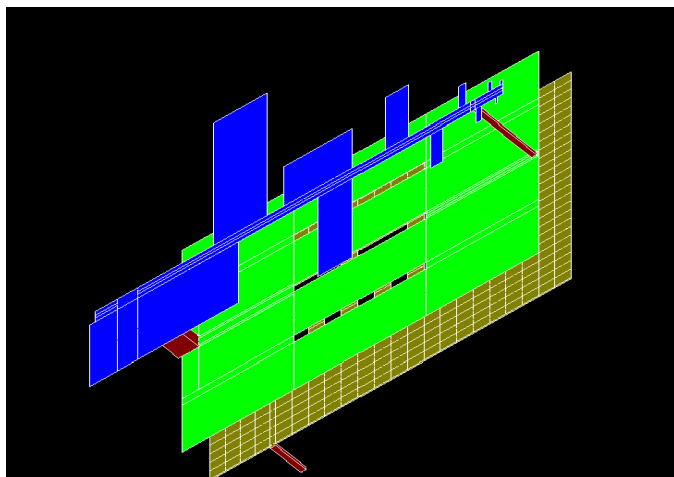
Antenna Design Consideration

The configuration of multilayer Log-periodic antenna shown in Fig.1 is based on the stacked configuration design. It consists of feeding plane, aperture plane and an LPDA on the top layer. The feeding technique used in the proposed design is probe feeding on the bottom layer at $X_f = -4.825$ and $Y_f = -8.445$. Feeding patch is designed with the dimensions $L = 14.80$ mm, $W = 16.89$ mm is shown in Fig. 2. The dielectric constant for the bottom layer (feeding plane) is chosen to be $\epsilon_r = 3.38$ (RO4003) with the height $h = 1.5$ mm. the location of the feeding point is obtained from the equation given below;

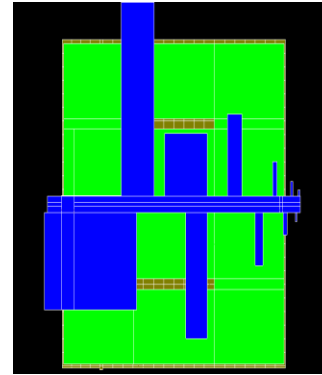
$$X_f = \frac{L}{2\sqrt{\epsilon_{\text{reff}}}} \quad \text{and} \quad Y_f = \frac{W}{2}$$

For the designing of patch certain calculations have been done with the help of following equations;
Width and Length of patch is given by;

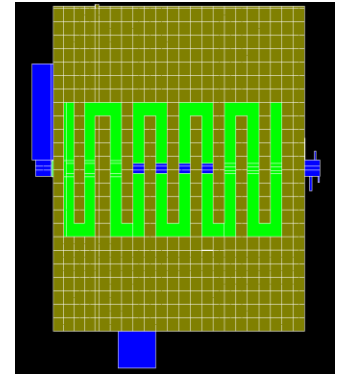
$$W = \frac{V_0}{2*f_r} \sqrt{\frac{2}{\epsilon_r + 1}}, \quad L_{\text{eff}} = \frac{V_0}{2*f_r \sqrt{\epsilon_{\text{reff}}}}$$



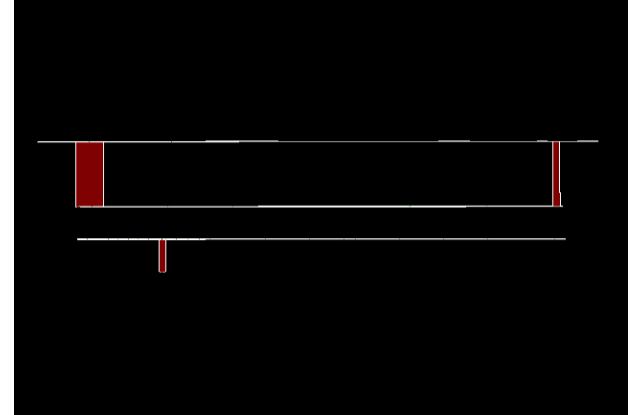
(A). Whole view of antenna



(B). Top view of antenna



(C). Bottom view of antenna



(D). Side view of antenna

Fig. 1 (A) Whole view of antenna, (B) Bottom view of antenna, (C) Top view of antenna, (D) Side view of antenna

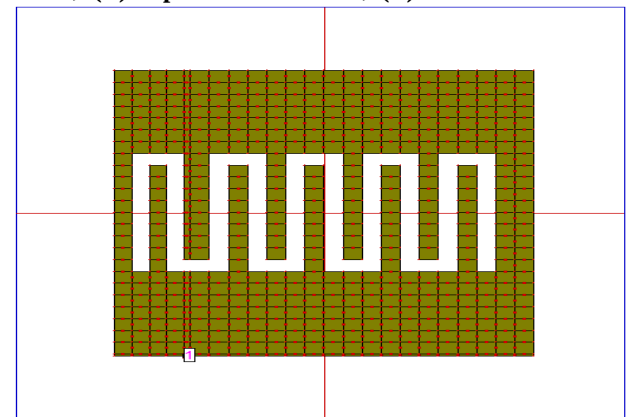


Fig. 2 feeding layer structure

Effective dielectric constant is given by;

$$\epsilon_{\text{reff}} = \left(\frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \right) * \frac{1}{\sqrt{1 + \frac{12h}{w}}}$$

Practical approximate relation for normalized extension of length;

$$\frac{\Delta L}{h} = 0.412 \frac{(\epsilon_{\text{reff}} + 0.3) \left(\frac{W}{h} + 0.264 \right)}{(\epsilon_{\text{reff}} - 0.258) \left(\frac{W}{h} + 0.8 \right)}$$

Actual length of the patch is given by;

$$L_{\text{eff}} = L + 2\Delta L$$

Three similar slot have been designed on the aperture plane having length and width as 5.375, 0.5375 respectively. The aperture plane is shown in Fig. 3. When 2nd substrate is stacked

on the bottom layer, the ϵ_{eq} (equivalent dielectric constant) is calculated from the equation given below;

$$\epsilon_{eq} = \frac{\epsilon_{r1} * \epsilon_{r2} (h_1 + h_2)}{\epsilon_{r1} * h_1 + h_2}$$

An air gap of 1mm is introduced in between feeding layer and aperture layer. Aperture plane is designed with the 0.5 mm thick RT/duroid/5870 having dielectric constant $\epsilon_r = 2.33$. The radiation coming from the feeding layer is coupled to upper layer through these slots. There is a slot designed on the feeding plane for impedance matching purpose. Finally the director has been designed using LPDA structure. The designed LPDA has 9 elements. All the dimensions for the designing of LPDA are tabulated in Table. 1.

Table. 1. Design parameters of LPDA

Tau=0.65, Sigma=0.155, $\epsilon_r=2.33$, h=1mm, Alpha=29.5°, cotα=1.77			
S.no	Length of dipole (mm)	Width of dipole (mm)	Spacing b/w elements(mm)
1.	9.975	2.177	5.985
2.	6.483	1.415	3.890
3.	4.214	0.919	2.528
4.	2.739	0.517	1.643
5.	1.780	0.388	1.068
6.	1.157	0.252	0.694
7.	0.752	0.164	0.451
8.	0.488	0.106	0.293
9.	0.317	0.069	0.190

The dimension of LPDA such as Length (L_n), Width (W_n) and Spacing (S_n) can be calculated from the equation given below;

$$\frac{1}{\tau} = \frac{L_{n+1}}{L_n} = \frac{W_{n+1}}{W_n} = \frac{S_{n+1}}{S_n}$$

LPDA is designed with $\tau = 0.65$, $\delta = 0.15$. Substrate used for designing of LPDA is 1mm thick RT/duroid/5870 having $\epsilon_r=2.33$. An air gap of 2mm is also introduced in between aperture layer and director. The LPDA structure is shown in Fig. 5.

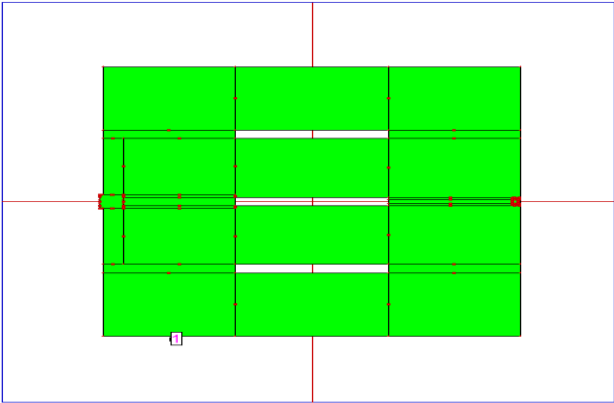


Fig. 4 aperture layer structure

In this paper we load two extra patches onto the LPDA structure thereby improving the results. We have investigated the results by changing dimensions of patches.

We have loaded two patches corresponding to L_9 and L_8 . Length of the patches is kept $L/2$ and then variation in width of first patch is observed while the width of second patch is kept constant ($2 * \text{Width of } L_9$). Due to gradual change in width, it has been observed that return loss of the antenna is improving and together with this bandwidth is also getting improved.

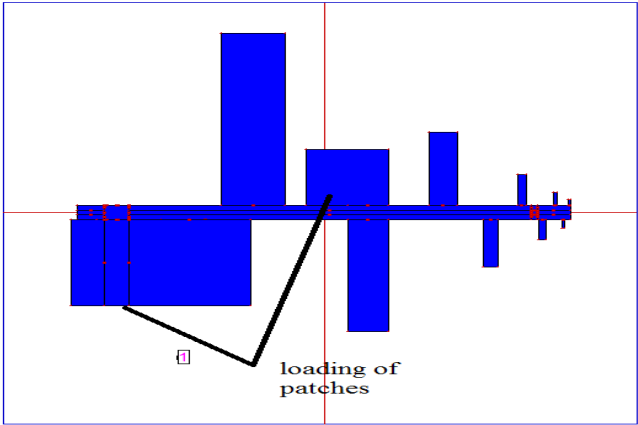


Fig. 5 LPDA structure

On the other hand on increasing the length of the loaded patch output suddenly deteriorates. Results are tabulated in table. 2.

Table. 2. Change in width of loaded patch & its result.

S.no.	Length (mm)	Width (mm)	Return Loss(dB)	Bandwidth (%)
L= 9.975mm and W= 2.177mm				
1.	L/2=4.9875	2xW=4.354	-29.12	33
2.	4.9875	2.2xW=4.789	-30.35	30
3.	4.9875	2.4xW=5.224	-32.16	31
4.	4.9875	2.6xW=5.660	-33.65	32
5.	4.9875	2.8xW=6.095	-36.16	32.5

From the table, it is clear that on increasing width of the loaded patch we are getting much better return loss and considerable bandwidth.

Conical via holes are implemented in between the aperture plane and LPDA structure. This causes the sudden increment in current distribution to the LPDA structure. Air gap is very beneficial in stacked configuration geometries, since it increases the bandwidth. A comparative graph is shown in Fig. 6. This shows the validation of the proposed work.

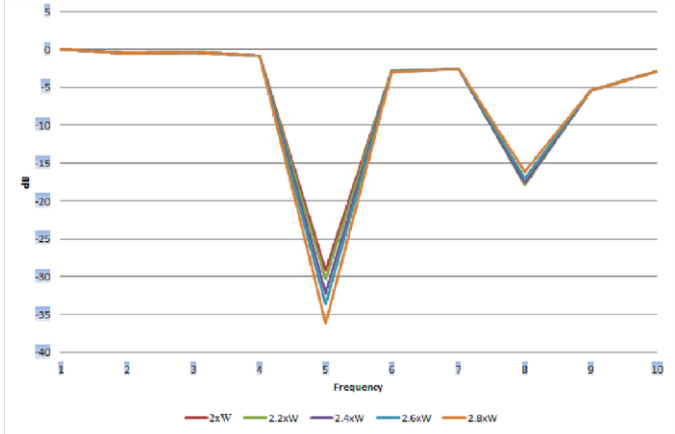


Fig. 6 comparative graph for different patch width & their results

Results And Discussion

The antenna is based upon the multilayer configuration is designed using IE3D version 9.0. Three different substrates are used to design stacked antenna. RO4003 ($\epsilon_r=3.38$) and RT/Duroid/5870($\epsilon_r =2.33$) substrates of 1.5mm, 0.5mm and 1mm are used for feeding plane, aperture plane and LPDA respectively. Probe feed is used for feeding purpose is shown in Fig. 1. A comparative graph is generated for different patch width shows the effect of variation in width of the first patch. Patch width of 6.095 mm size results in improved return loss -

36.16 dB and 32.5% bandwidth at 5GHz shown in Fig. 7. By using multilayer-stacked substrates, this design allows compact size realization and achieves good performance at the demonstrated frequency of 5 GHz. VSWR less than 2 is achieved at 5 GHz and 8 GHz is shown in Fig. 8.

The variation in width of patch results in mutual inductance minimization. as we gradually increase the width of first patch by keeping width of second patch constant, the mutual coupling between first two dipoles, after loading the patch gets reduced thereby increasing the radiation.

The proposed geometry can also be designed with a ground plane, this will further decreases the mutual coupling and therefore we can achieve much better radiation from the same geometry.

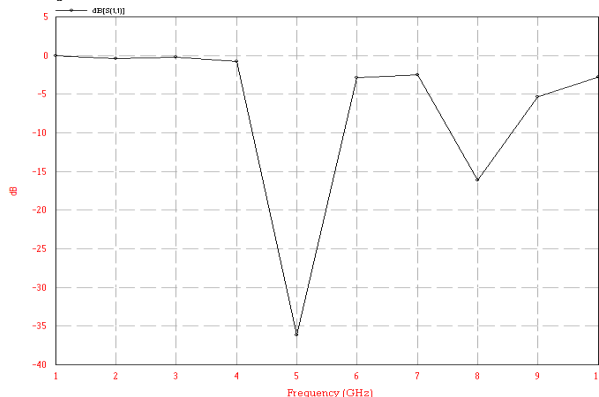


Fig. 7 Return Loss

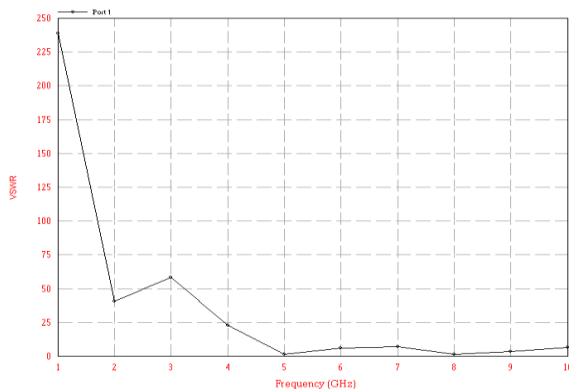


Fig. 8 (A) VSWR

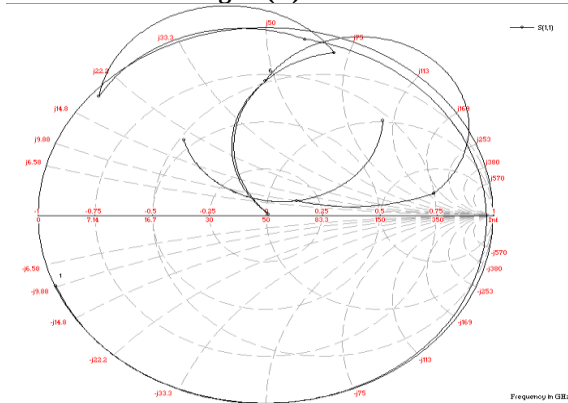


Fig. 8 (B) Smith Chart

Conclusion

In this paper multilayer aperture coupled antenna is presented. Probe feeding is used in this structure as a feeding mechanism. By using multilayer-stacked configuration, we can achieve size reduction and achieve good performance at the

demonstrated frequency of 5 GHz. By varying width of patch of the LPDA we can have better return loss and hence bandwidth. It is also helpful in reducing mutual inductance between the dipoles of the antenna, which causes the reinforcement of the radiation through antenna.

In future this can be proved as a good candidate of mutual inductance reduction.

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