Development of Wideband L-Probe Coupled Patch Antenna

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Abstract — The patch antenna fed by an L-shaped probe was proposed in 1998. This feeding method, and its modified version, the meandering strip, has led to the development of a new class of wideband patch antennas which can be operated in linear, circular or dual polarization with excellent performance characteristics. L-probe coupled patch antennas are simple in structure and low in material and production costs. Moreover, it can be designed with dual wideband performance which is very attractive for modern mobile communications. This paper presents a review of the general designs for linearly and circularly polarized L-probe patch antennas. Comparisons between measured and simulated results are presented. Methods for gain enhancement and cross polarization suppression are also introduced. The designs and performances of two dual-band wideband L-probe fed patch antennas are also described.

I. INTRODUCTION

In the last two decades or so, many methods have been developed to broaden the bandwidth of microstrip patch antennas. One way is to use the L-probe coupled feeding method. Since its introduction some seven years ago, a number of developments have taken place, including the designs for dual-band, dual-polarized and circularly polarized wideband patch antennas. The objective of this paper is to give an account of these developments.

The paper begins with a description of the context in which the method was developed, followed by a summary of the characteristics of the basic L-probe fed patch antenna and the characteristics of a twin L-probe fed patch antenna. It proceeds to describe the more recent developments, including a derivation of the L-probe, called the meander or M-strip feeding method. The design of a dual-band dual-polarized antenna array is then presented. The paper ends with some concluding remarks.

II. BRIEF REVIEW OF BANDWIDTH BROADENING TECHNIQUES OF MICROSTRIP PATCH ANTENNAS

The basic structure of a microstrip patch antenna consists of an area of metallization supported above a ground plane and fed against the ground at an appropriate location (Figure 1). The region between the metallic patch and the ground plane forms a resonant cavity. The patch geometry can take on a variety of shapes. Two common feeds are the coaxial probe and the microstrip line (Figure 2). The bandwidth of a patch antenna is governed by the impedance bandwidth, commonly defined as the range of frequencies for which the standing wave ratio (SWR) is less than or equal to 2. In general, for most frequencies of interest, the bandwidth increases with substrate thickness and also increases as the relative permittivity decreases. However, one cannot obtain wide bandwidth just by increasing the substrate thickness. For the coaxial fed case, the length of the probe is increased when the substrate thickness increases. The large inductance associated with a lengthy probe makes it impossible to match the antenna to the feedline. For the stripline fed case, the width of the line increases with substrate thickness, which increases the spurious radiation from the line and alters the resonant frequency of the antenna. Also, there is a lower bound on the value of the relative permittivity, namely, unity. The result is that narrow bandwidth (< 5%) is the major problem associated with the basic form of microstrip patch antennas fed by a coaxial probe or a microstrip line.

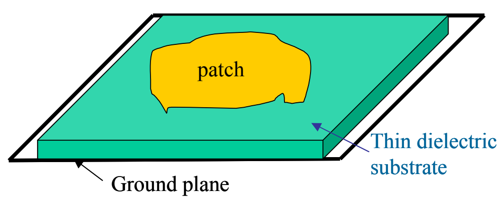


Fig. 1. Basic structure of a microstrip patch antenna.

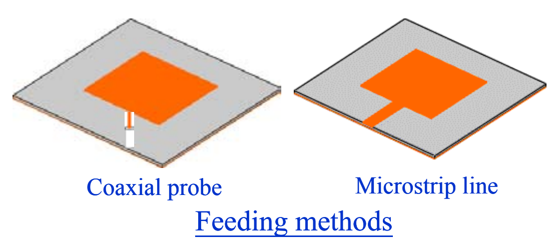


Fig. 2. Patch shapes and two common feeding methods.

In the last two decades or so, a number of bandwidth broadening techniques of microstrip antennas have been developed. Wideband designs use one or more of the following: (1) introduction of an additional resonance to the main patch resonance so that the overall response is broadband; (2) low permittivity substrates; (3) thick substrates and a scheme to overcome the mismatch problem.

Figure 3 shows three wideband coaxially fed patches. In Figures 3(a) and 3(b), parasitic patches are added either in the same layer (coplanar) or in another layer (stacked). The parasitic patches introduce an additional resonance. The coplanar design seldom exceeds 15% bandwidth, and it has the disadvantage of increasing the lateral size of the antenna [1]. The stacked geometry can achieve about 20% bandwidth [2]. Although it does not increase the lateral size, it introduces another layer.

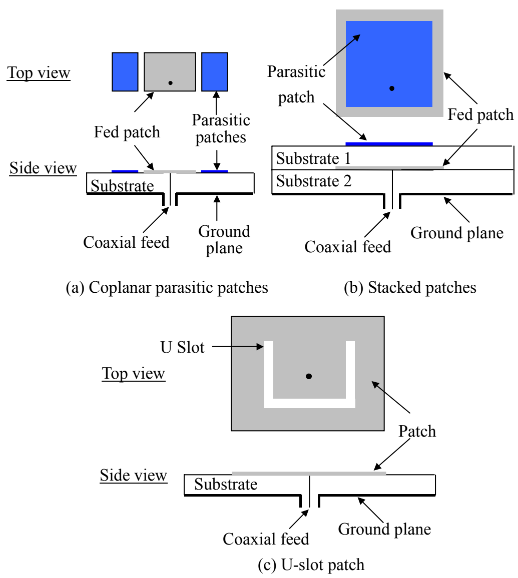


Fig. 3. Three broadband coaxial fed microstrip patch antennas.

Figure 3(c) shows a single-layer, single patch wideband microstrip antenna. In this design, a U-shaped slot is cut in the patch [3, 4]. The U-slot introduces a second resonance and provides a capacitance which tends to cancel the probe inductance, allowing the use of thick substrate. With a foam substrate thickness of about 0.08 free space wavelength, this antenna easily achieves 30% bandwidth. The main disadvantage is that the cross polarization radiation in the H-plane is quite high.

Another wideband design is feeding the patch by a microstrip line through an aperture (slot) [5] (Figure 4a). If the resonant frequency of the aperture (slot) is near the resonance of the patch, the effective bandwidth will be increased. Bandwidth of 10% can be achieved using a single patch. If a stacked patch geometry is used [6] (Figure 4b), 50% bandwidth has been reported. However, there is significant backlobe radiation due to the resonant slot.

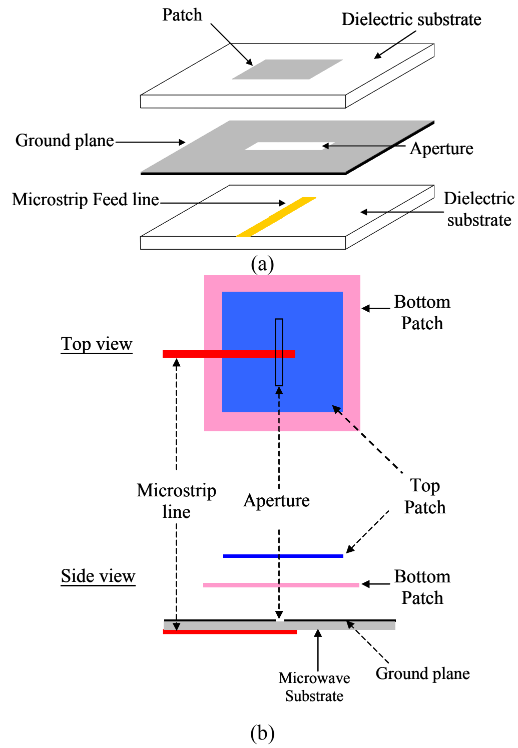


Fig. 4. (a) Aperture coupled patch, (b) Aperture coupled stacked patches.

III. THE L-SHAPED PROBE FEEDING MECHANISM

Shortly after the publication of the first paper on the U-slot single layer single patch wideband patch antenna, another wideband single layer single patch antenna was introduced. This design achieves wide band operation using an L-shaped probe feeding method. The geometry is shown in Figure 5 and a prototype of this antenna is shown in Figure 6. This design uses low permittivity substrate (air or foam) of thickness about 0.1 free space wavelength. The feed is a modified version of the coaxial probe. Instead of the center conductor extending vertically to the patch and connected to it, a portion of it is bent in the horizontal direction. The horizontal arm of the probe is approximately a quarter of a wavelength long. It provides a capacitance to counteract the inductance due to the vertical part. This design has only one patch and one layer but it achieves 30% or more bandwidth. This feeding method for patch antennas was first discussed in [7, 8].

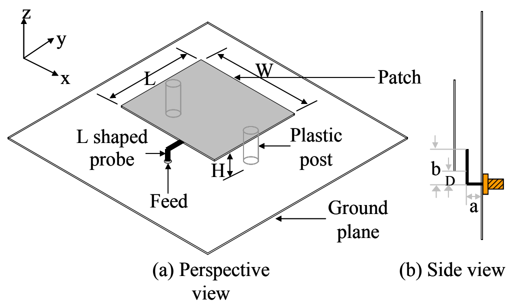


Fig. 5. Geometry of the L-probe coupled patch antenna.

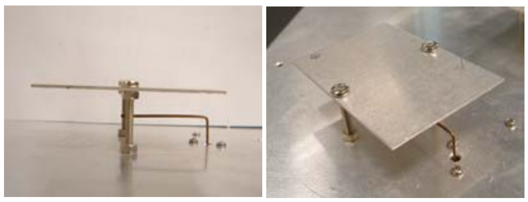


Fig. 6. Prototype of the L-probe coupled patch antenna.

To illustrate the characteristics of the basic L-probe proximity coupled patch antenna, consider a design with the dimensions given in the caption of Figure 7.

Figure 7 shows the simulated gain and SWR versus frequency for this antenna. The simulated radiation patterns are shown in Figure 8. It is seen that this antenna has an impedance bandwidth of 36%, an average gain of about 8.5 dB across the matching bandwidth, with stable broadside patterns. However, the cross polarization level at the edges of the band is high, due to radiation from the vertical arm of the probe. These characteristics are similar to the U-slot patch antenna.

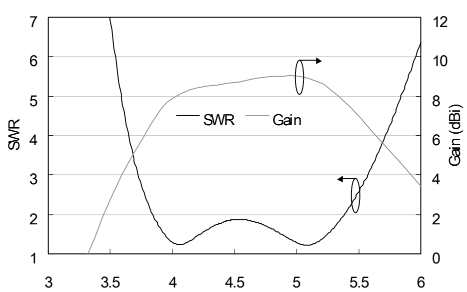


Fig. 7. Simulated SWR and gain versus frequency of the L-probe coupled antenna of Figure 6 with the following dimensions: W=30 mm,L=25 mm,H=6.6 mm, a=5.5 mm, b=10.5 mm, d=2 mm.

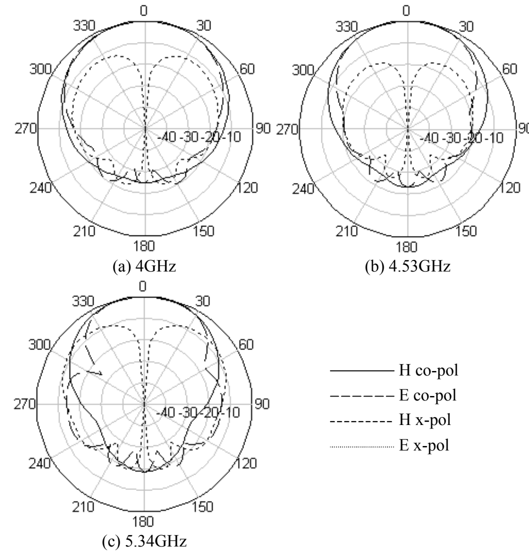


Fig. 8. Simulated radiation patterns of the L-probe coupled antenna with the dimensions shown in the caption of Figure 7.

In what follows, we describe various recent developments which show that the L-probe feeding method can be used to achieve a variety of performance characteristics.

IV. TWIN-L-PROBE FEEDING MECHANISM

By feeding the patch with twin L probes, the gain of the antenna is enhanced, accompanied by a reduction in the cross polarization radiation. The geometry is shown in Figure 9 [9]. The separation of the two L-probes is about half a wavelength and the width W of the patch is about 0.7 wavelength. The measured SWR and gain of this antenna are shown in Figure 10. The case of a single L-probe is also included. It is seen that the bandwidth for the twin L-probe is slightly smaller than the single L-probe, but the gain of the antenna is about 10 dBi for most of the passband. The maximum gain of the single L-probe is about 8 dB but it drops off rapidly in the upper half of the pass band. Figure 11 shows the measured radiation patterns. It is seen that the beamwidth is narrower than the single L-probe case. The cross polarization levels at the edges of the pass band are significantly reduced.

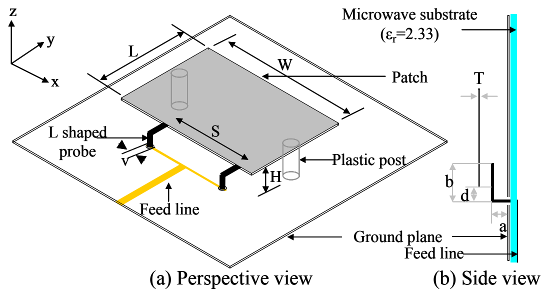


Fig. 9. Geometry of the twin-L-probe fed patch antenna.

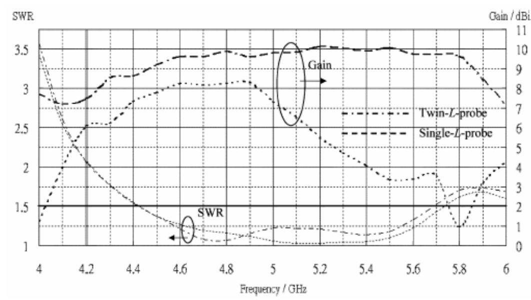


Fig. 10. Measured SWR and gain of the twin-L-probe coupled patch of Figure 9 with the following dimensions: L=22 (0.367λ), H=6 (0.1λ), W=44 (0.733λ), T=0.3 (0.005λ), a=4.5 (0.075λ), b=12 (0.2λ), v=2(0.033λ), d=0(0λ), s=28.6(0.477λ). The case of single L-probe coupled patch is also shown for comparison. (From Mak et. al. [9], c 2005 IEEE)

V. WIDEBAND DUAL FREQUENCY L-PROBE FED PATCH ANTENNA

There are many applications in wireless communications that involve two or more distinct frequencies. It is sometimes possible that a broadband microstrip antenna can cover the frequencies of interest. However, the disadvantage of using a broadband antenna is that it also receives nondesired frequencies unless some kind of filtering network is introduced to reject such frequencies. On the other hand, the advantage of a dual-frequency design is that it focuses only on the frequencies of interest and is thus more desirable. Dual-frequency microstrip antennas can be designed by using a single-element, stacked patches, patch with reactive loading, or patches with slots. When these are fed by the conventional coaxial probe, the resulting bandwidths are narrow. The bandwidths in the two bands can be considerably enhanced by means of L-probes. Two designs are described below.

A. Dual-Band Patch Antenna Fed by Two Separate L-Probes

One such design is shown in Figure 12 [10]. It consists of two stacked patches, with the smaller one on the top layer. Each patch is fed by a L-probe. Figure 13 shows the simulation and measurement results of the return loss and antenna gain at the lower and upper bands. It appeared that the simulation results missed two high Q resonances in the lower band and one high Q resonance in the upper hand. The impedance bandwidth is 26.6% and 42.2%, respectively, at the lower and upper bands, while the peak gains are 8.4 dBi and 8 dBi within these two bands. The simulated and measured radiation patterns at 0.89 GHz and 2.4 GHz, respectively, are shown in Figures 14 and 15, respectively. All simulations in this paper are performed with the Zeland IE3D software.

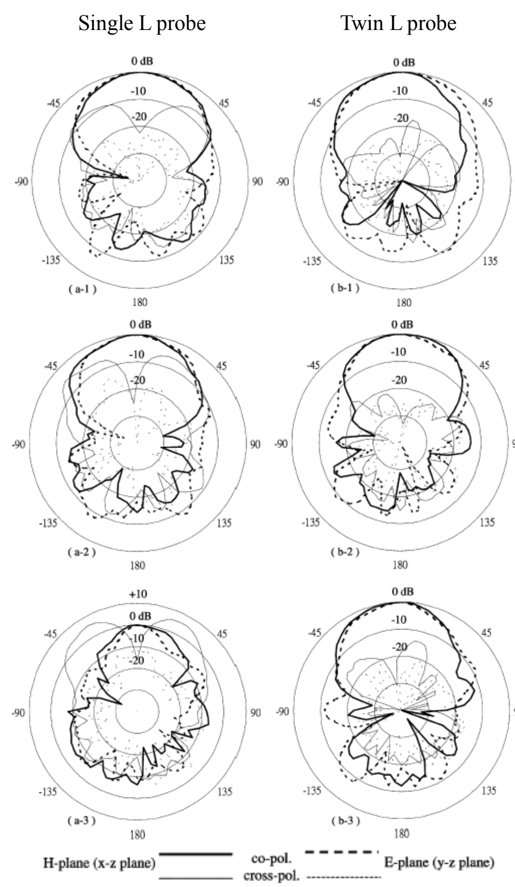


Fig. 11. Measured radiation patterns of the single L-probe and twin-L-probe coupled patch antennas. (From Mak et. al. [9], c 2005 IEEE)

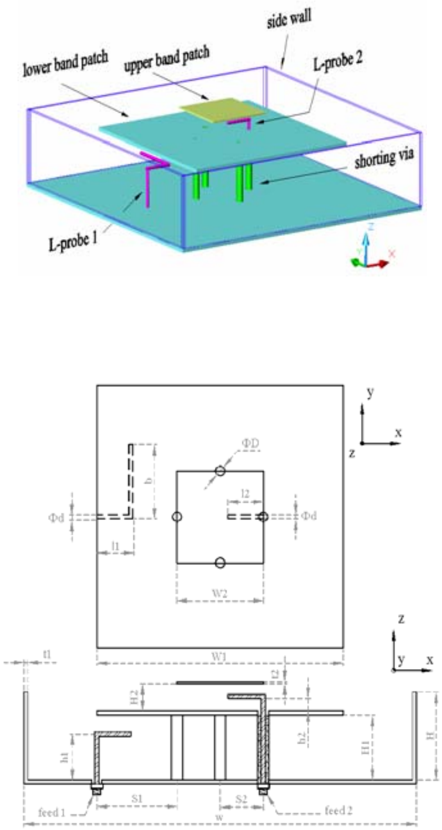
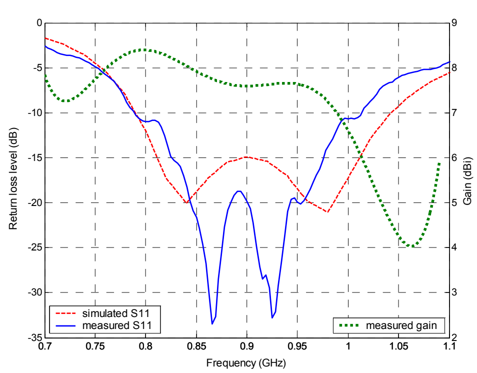
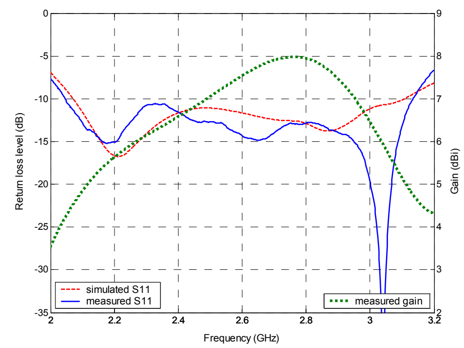


Fig. 12. Geometry of the two-layer dual-band L-probe coupled patch antenna. W=243.6 mm($0.72\lambda_1$), H=47 mm ($0.139\lambda_1$), W1=125.6 mm ($0.37\lambda_1$), H1=33 mm ($0.098\lambda_1$), l1=20.5 mm ($0.061\lambda_1$), h1=24.8 mm ($0.074\lambda_1$), b=33.5 mm ($0.1\lambda_1$), W2=44 mm ($0.36\lambda_2$), H2=13 mm ($0.106\lambda_2$), l2=19 mm ($0.155\lambda_2$), h2=9.5 ($0.077\lambda_2$), t1=2 mm, t2=1 mm, D=4.6 mm, d=2 mm, S1=62.8 mm, S2=22 mm. (From Li et. al. [10], c 2005 IEEE)



(a) Lower band



(b) Upper band

Fig. 13. Simulated and measured return loss and gain of the antenna in Figure 12 at the lower and upper frequency bands. (From Li et. al. [10], c 2005 IEEE)

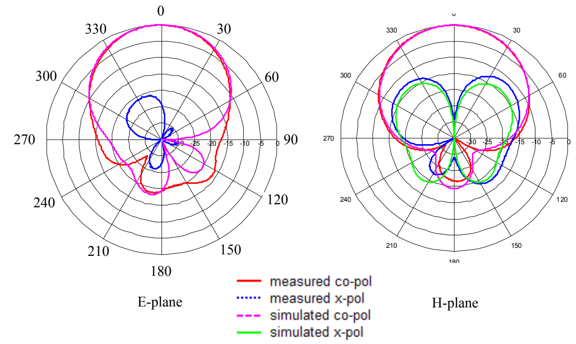


Fig. 14. Simulated and measured radiation patterns at 0.89 GHz of the antenna in Figure 12. (From Li et. al. [10], c 2005 IEEE)

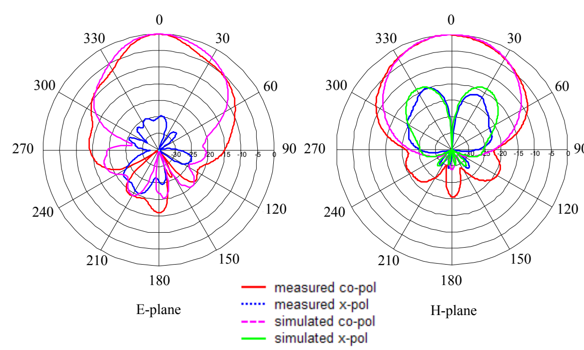


Fig. 15. Simulated and measured radiation patterns at 2.45 GHz of the antenna in Figure 13. (From Li et. al. [10], c 2005 IEEE)

B. Dual-Band Patch Antenna Fed by Two Combined L-Probes

Another design of dual-band patch antenna [11] fed by L-probes is shown in Figure 16. Instead of using two distinctly different feeds, as in the case shown in Figure 12, the two probes are combined together to form a single feed structure. Two slots are etched from the radiation edge of the lower-band patch to suppress the excitation of the TM_{20} mode that would influence the upper-band radiation pattern. The performance of the antenna is simulated by IE3D ver. 10. Figure 17 shows the simulated return loss for the antenna of Figure 16, with dimensions shown in the captions. The antenna operates at 900 MHz (λ_1, lower-band operation) and 1.8 GHz (λ_2, upper-band operation). The impedance bandwidth of 21% and 11% was found for the lower and upper bands, respectively. It is wide enough to cover GSM 900 and 1800 cellular phone systems. The maximum gain of 8.7 dBi was found in the upper band. The simulated radiation patterns are shown in Figures 18 and 19. The 3 dB beamwidths of lower and upper bands are 71^o and 83^o in the H-plane and are 51^o and 57.5^o in the E-plane. The cross polarizations is -10 dB and -13 dB in the lower and upper bands, respectively. The measured results agree with the simulation. Results can be found in [11].

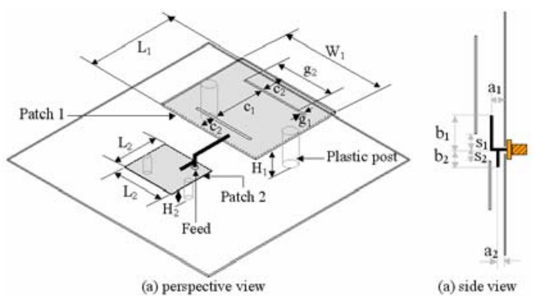


Fig. 16. Geometry of the dual-band patch antenna with combined dual L-probe feed.

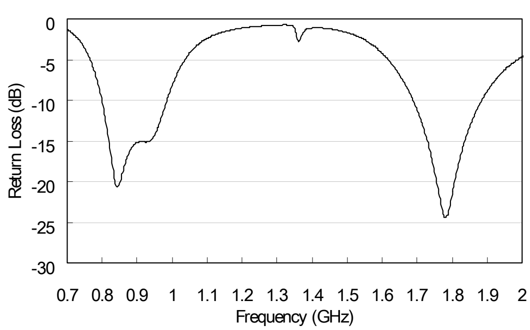


Fig. 17. Simulated return loss of the antenna shown in Figure 16 with the following dimensions: L_1= W_1 = 102 mm ($0.324\lambda_1$), H_1=45.5 mm ($0.145\lambda_1$), b_1=51 mm ($0.162\lambda_1$), a_1=31 mm ($0.098\lambda_1$), S_1=4 mm ($0.0127\lambda_1$), g_1 = 2 mm ($0.0064\lambda_1$), g_2=90 mm($0.286\lambda_1$), c_2 = 25.5 mm ($0.081\lambda_1$) L_2=37 mm ($0.22\lambda_2$), H_2=24 mm ($0.128\lambda_2$), b_2=31 mm ($0.184\lambda_2$), a_2=13 mm ($0.077\lambda_2$), S_2 = 4 mm ($0.0238\lambda_2$).

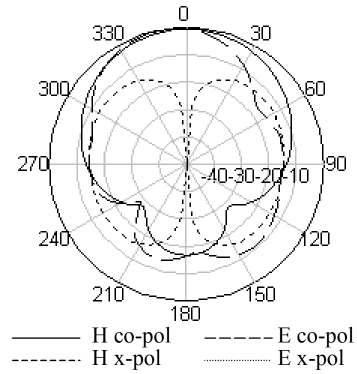


Fig. 18. Simulated radiation pattern of lower band at 953 of the antenna shown in Figure 16, with the dimensions given in the caption of Figure 17.

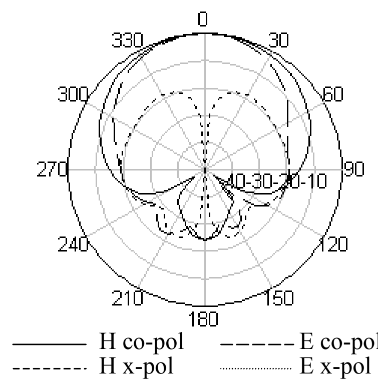
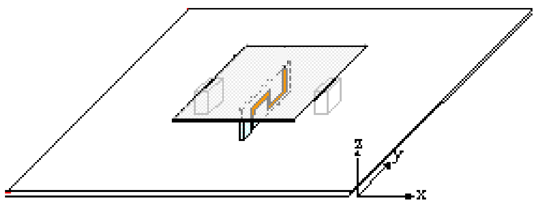


Fig. 19. Simulated radiation pattern of the higher band at 1.786 GHz of the antenna shown in Figure 16, with the dimensions given in the caption of Figure 17.

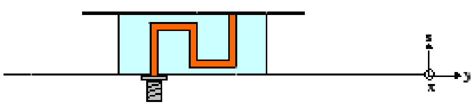
VI. MEANDERING STRIP FED PATCH ANTENNA

The L-probe patch antenna has a cross-polarization level of about -15 dBi which may be too high in some applications. Phase cancellation technique can be employed to suppress the cross-polarization as described in [12]. This method can suppress the cross-polarization effectively but it requires a wideband matching network to feed the two oppositely oriented probes which are 180 degrees out of phase with each other, thereby increasing the complexity of the antenna structure. In addition, the E-plane pattern of the L-probe patch antenna is not symmetrical with respect to the broadside direction. This may affect the performance in antenna array design.

As a modification of the L-probe patch antenna technique, a patch antenna fed by a meandering strip has been invented recently [13]. As shown in Figure 20, the L-shaped probe is replaced by a strip feed which has a meandering form. The strip looks like a combination of one L-shaped probe and one inverted L-shaped probe. It is formed by bending a metal strip so that it has 3 portions normal to the ground plane and patch, and 2 portions parallel to the ground plane and patch. For an appropriate length of the strip, the phases of the current in the vertical portions of the strip are such that their radiations in the far-zone cancel, resulting in the suppression of cross polarization.



(a) Perspective view



(b) Side view

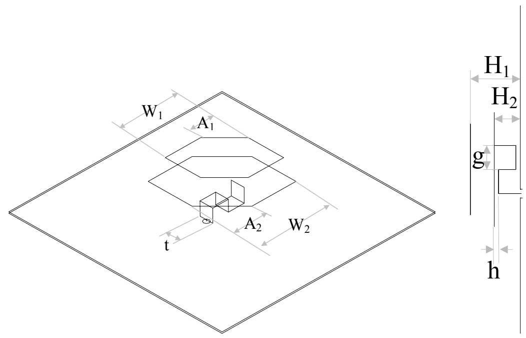
Fig. 20. Geometry of the printed meandering strip fed patch antenna.

For ease of fabrication, the meandering strip can be printed on a printed circuit board. For a typical design, the impedance bandwidth is similar to the L-probe patch antenna, while the cross-polarization is lower than -20 dBi over the operating band. Very symmetrical radiation patterns in the E-plane and H-plane are observed. Due to the suppression of cross-polarization, a higher gain of about 8.5 dBi can be achieved, which is about 1 dBi higher than the L-probe patch antenna.

It was discovered that the impedance bandwidth of the meandering strip patch antenna can be increased to over 60% with acceptable performance in other electrical parameters. This is achieved by increasing the width of the meandering strip to about 0.25λ. This antenna represents the state-of-the-art wideband patch antenna technology.

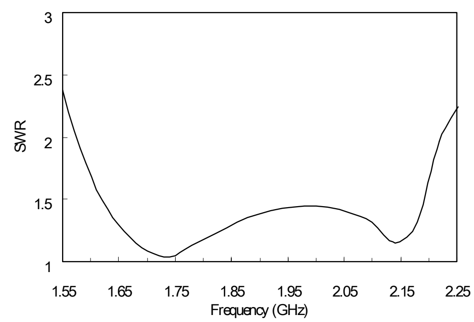
VII. CIRCULARLY POLARIZED STACKED PATCH ANTENNA FED BY A MEANDERING PROBE

Both the L-probe and the meandering strip feeding method can be used for circularly polarized patch antenna. Figure 21 shows one such design using two truncated stacked patches fed by a meandering strip. This arrangement generates two pairs of orthogonal modes, resulting in wide impedance bandwidth (34%, SWR<2) as well as wide 3 dB axial ratio bandwidth (14%). The simulated results are shown in Figure 22.

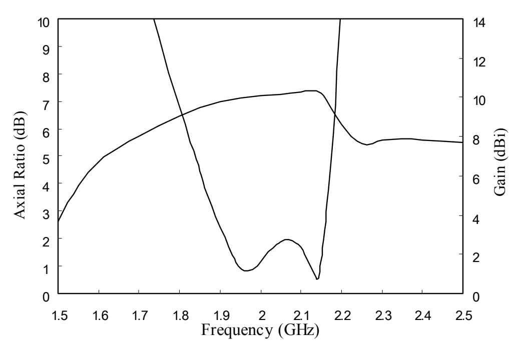


(a) perspective view (b) side view

Fig. 21. Geometry of the meandering strip fed stacked patches with truncated corners for circular polarization.



(a)



(b)

Fig. 22. (a) Simulated SWR (b) simulated AR and gain of the antenna shown in Figure 21 with the following dimensions: W_1=56 mm ($0.378\lambda_0$), W_2=66 mm ($0.445\lambda_0$), A_1=17 mm ($0.115\lambda_0$), A_2=23.5 mm ($0.159\lambda_0$), H_1 = 18.5 mm ($0.125\lambda_0$), H_2=11.5 mm ($0.078\lambda_0$), t = 16 mm ($0.108\lambda_0$), g=1.45 mm($0.01\lambda_0$), h=9.3 mm($0.063\lambda_0$).

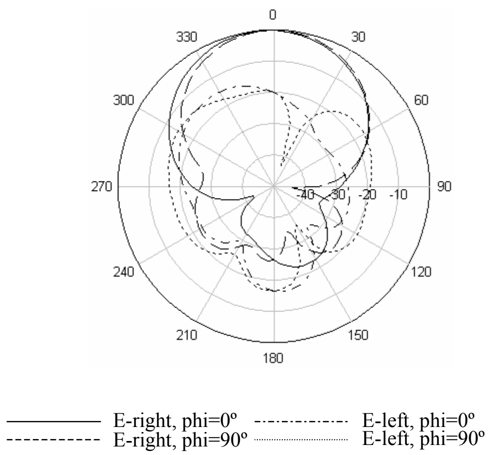


Fig. 23. Simulated radiation pattern of the higher band at 2.036 GHz of the antenna shown in Figure 21, with the dimensions given in the caption of Figure 22.

VIII. CONCLUDING REMARKS

In conclusion, a class of wideband patch antennas, in the form of L-probe and the M-strip proximity coupled patch antennas, have been described. These antennas can be designed to yield wide bandwidth, high gain, and low back radiation. They can also be designed for dual-band and/or dual-polarized applications. It is relatively simple in structure and low in production cost.

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