A Wideband Co-Planar L-Strip Fed Rectangular Patch Antenna

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***Abstract*—The drawbacks of conventional L-probe fed antennas, namely multilayered structure and complicated fabrication process, are addressed in this letter by proposing a novel co-planar, modified/printed L-strip fed patch antenna. The achieved VSWR < 2 range with the proposed antenna is in the order of 41% from 5.09 to 7.7 GHz, which is wider than that of the conventional L-probe antenna with the dimensions on par with the proposed design. The realized patterns are also quite stable over the entire frequency range and the 3-dB gain bandwidth matches with the impedance bandwidth. The concept behind the wideband property of the printed L-strip antenna is explained in detail and the proposed antenna is numerically investigated to realize the effective impedance and radiation characteristics. A prototype of the antenna is also fabricated and successfully validated for its impedance and radiation characteristics.**

***Index Terms*— L-probe, modified L-probe, co-planar L-strip, rectangular microstrip patch antennas, wideband antennas.**

I. Introduction

OF all the standard feeding techniques for microstrip patch antennas (MPAs), the proximity coupling method yields a widest bandwidth range of around 13% [1]. Based on this technique, an L-shaped probe feed was proposed in [2] to excite thick MPAs. The realized VSWR < 2 range was as high as 36%. The L-probe fed, slotted-patch antennas provide much wider bandwidths [3] [4] as compared to its counterpart, SMA probe [5]. Such wide impedance and enhanced isolation characteristics find L-probe proximity feeds quite useful in realizing various radiation, impedance and isolation objectives [6]-[11]. However, the L-probe feeding technique does suffer from certain setbacks. For instance, the horizontal arm of the L-probe has to be precisely aligned in parallel to the radiating patch, otherwise resulting in diminished impedance matching and radiation characteristics. Moreover, compared to the other feeding methods, the fabrication is a bit more difficult, as the horizontal arm of the L-probe needs to be well supported in a separate layer usually by a non-conducting material with a dielectric constant close to unity. To overcome such drawbacks, modified L-probe feeding techniques [12]-[16] and capacitively-coupled feeds [17]-[24] were proposed. Impedance bandwidths up to 50% were realized with the aforementioned techniques at the cost of using either much thicker substrates or multilayered structures. Moreover, the additional non-integrated, feeding strip in the capacitively-coupled feeds [22], [23] would increase the lateral size of the antenna. This necessitates further research to modify the L-probe in integrated co-planar structures, while maintaining its attractive wide impedance matching characteristics.

In this letter, a wideband, co-planar printed L-probe fed patch antenna is proposed and investigated, which could potentially surmount the drawbacks of conventional L-probe patch antennas. That is, the L-probe now becomes an integrated part of the radiating patch, thus significantly alleviating the fabrication process. The proposed antenna generates stable broadside radiation patterns over a wide VSWR < 2 range of ~41% from 5.09 to 7.7 GHz, which is wider than that of the original L-probe fed patch antenna [2]. The thickness of the antenna is ~0.09λ_o, which is ~0.04λ_o smaller than that of the conventional L-probe design, where λ_o is the free space wavelength at the center frequency. The concept behind the co-planar L-probe feed along with the antenna geometry is discussed in Section II. The proposed antenna is investigated numerically using the full-wave Finite-Element EM solver, ANSYS HFSS [25]. The numerical results and the parametric investigation are provided in Section III. A prototype of the antenna is also fabricated and validated for its impedance and radiation characteristics, which are presented in Section IV.

II. Concept and Antenna Geometry

The underlying principle of realizing wide impedance bandwidth characteristics with the proposed printed L-strip antenna is the same as that of the conventional L-probe antenna, which is briefly reviewed here. As shown in Fig. 1, when the L-probe fed patch antenna is analyzed using the circuit theory approach, the vertical section of the L-probe L_v is modeled as a series combination of the resistance R_l and the inductance L_l induced by the probe. The open-ended horizontal section L_h with the length less than $\lambda_o/4$, on the other hand, is represented by a capacitor in series with the vertical section of the L-strip, whose capacitance (C_l) is determined by the heights h_1 and h_2 of Fig. 1. With the proper heights and the optimal horizontal (L_h) and vertical (L_v) arm dimensions, a resonance could be generated by cancelling out the inductance L_l with the capacitance C_l of the probe. When this resonance comes in proximity with the resonating frequency of the antenna's operating mode, a wide impedance

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bandwidth could be realized. Likewise, in the proposed design, the required capacitors to cancel out the probe inductors are realized by a rectangular ring separating it from the patch, as shown in Fig. 2a. On the contrary, herein the L-probe is now integrated within the radiating patch. This will in turn result in a co-planar structure, remarkably relaxing the fabrication process.

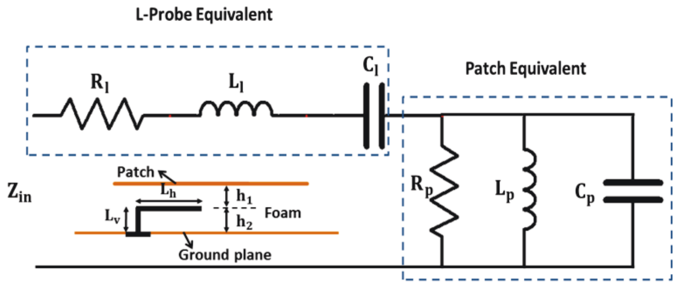


Fig. 1. Equivalent circuit model of the conventional L-probe antenna [2] along with its side view embedded into it.

The geometry of the proposed antenna is illustrated in Fig. 2. The radiating patch of 17 mm × 19.5 mm ($0.36\lambda_o \times 0.42\lambda_o$) and the ground plane of 55 mm × 55 mm ($1.17\lambda_o \times 1.17\lambda_o$) are printed on two identical 0.51mm-thick Rogers 5880LZ substrates ($\varepsilon_r = 1.96$). These two substrates are separated from each other by a distance of 3.5 mm, as shown in Fig. 2b. The two thin layers are used here for the proof of concept. Nonetheless, the proposed antenna can be readily fabricated in a single-layered structure, where the air gap between the layers is filled with a substrate material. The antenna is fed using a modified printed L-strip, which is designed such that its functionality matches the conventional L-probe, as described below. The SMA probe extending from the ground plane to the radiating patch forms the vertical section of the conventional L-probe. The 2D printed rectangular strip on the patch with the dimensions of $L_h \times L_w$ replicates the horizontal section of the L-probe, which is now integrated with the radiating patch. As noticed in Fig. 2a, the horizontal arm of the printed L-strip is open ended with the gaps g_1, g_2 and g_3 from the patch and its length L_h is less than $\lambda_o/4$. Thus, it acts as a capacitor according to (1) for open-ended transmission lines [26].

$$Z_{in} = -jZ_o cot(\beta l) \qquad (1)$$

where Z_{in} and Z_o are the input and the characteristic impedances, respectively, β is the phase constant, and l is the length of the transmission line. Thus, the proposed co-planar L-probe is modeled by a capacitor, determined by the gaps g_1, g_2 and g_3, in series with the inductor due to the vertical segment of the printed L-strip. By appropriately selecting the L_h, L_w, g_1, g_2 and g_3 values, a resonance from the printed L-strip could be generated by cancelling out the inductance of the vertical section with the capacitance of the horizontal section of the L-strip. When this resonance is properly coupled with the resonance of the radiating patch, a wide impedance bandwidth is realized.

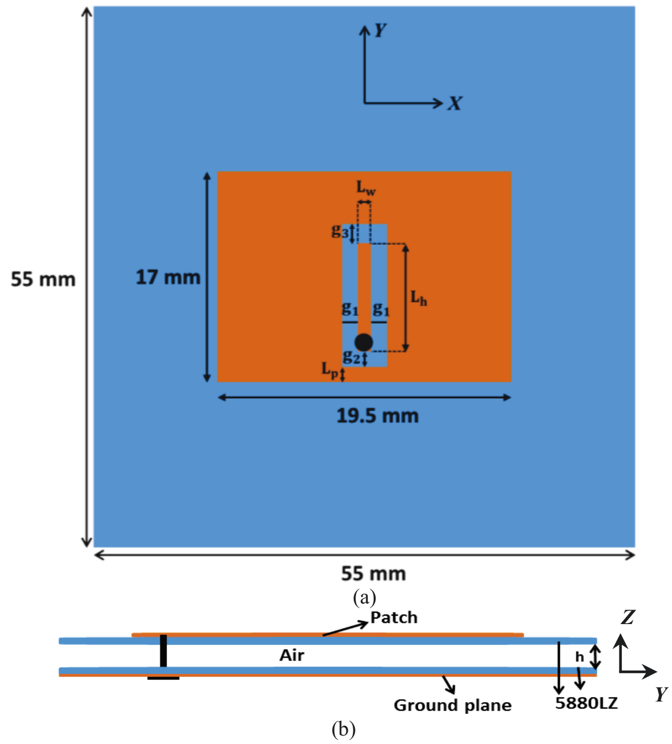


Fig. 2. (a) Top view, (b) Cross-sectional view of the proposed antenna with the modified printed L-probe, L_h = 7.5, L_w = 0.7, L_p = 1.5, g_1 = 0.54, g_2 = 0.37, g_3 = 1.13 and h = 3.5. All values are in mm.

III. Parametric Investigation and Numerical Results

The impact of the patch length and width on the impedance matching has been well established in the literature and is not repeated here for brevity. Instead, the printed L-strip parameters L_p, L_h, L_w, g_1, g_2 and g_3 are investigated, which play a major role in widening the impedance bandwidth. Fig. 3a shows the VSWR characteristics of the antenna with varying L-strip position, denoted by L_p in Fig. 2a. The widest VSWR < 2 bandwidth of 41% is achieved when L_p = 1.5 mm. The smaller values of L_p result in a dual-band behavior, whereas a good coupling between the resonance frequencies of the L-strip and the radiating patch with reduced bandwidth range is observed at the larger values of L_p. For instance, per Fig. 3a, with L_p as 2.5 mm, the impedance bandwidth range reduces to 35%. The length of the horizontal section of the printed L-strip L_h has a nontrivial role in determining the operating frequency range of the antenna. Based on the concept discussed in Section II, the value of L_h has to be less than $\lambda_o/4$ to generate a resonance from the L-shaped strip of the antenna. Thus, when this couples with the resonance of the dominant mode of the radiating patch, a wide impedance bandwidth is realized. The value of L_h is numerically finalized as 7.5 mm, which is ~$0.13\lambda_o$ at the lowest operating frequency 5.09 GHz and ~$0.19\lambda_o$ at the highest frequency 7.7 GHz. L_h is varied from 6.5 mm to 8.5 mm with a step of 1 mm and its impact on the VSWR characteristics of the antenna is presented in Fig. 3b. As observed, with all the L_h values, a second resonance is formed in addition to the actual resonance of the radiating patch. However, a wide bandwidth range is only obtained when L_h = 7.5 mm. In the other two cases, a dual-band behavior is attained. The impact of the width of the printed L-strip L_w on the VSWR of the antenna is more or less same as that of the length of the printed L-strip L_h. That is, with the lower and the higher values of L_w, a dual-band behavior is observed. A wide impedance matching is realized when L_w is 0.7 mm. These results are omitted here for brevity.

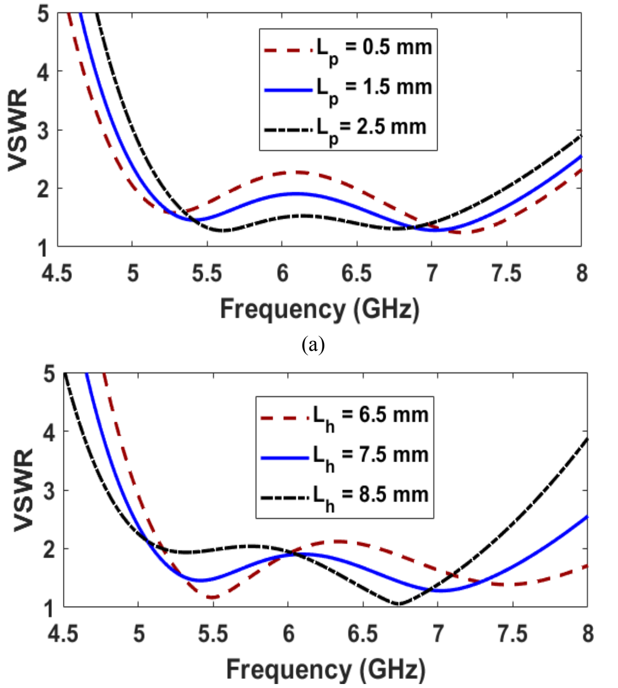


Fig. 3. Impact of the printed L-strip parameters on the VSWR characteristics (a) position of the co-planar L-probe (L_p), (b) Length of the L-strip (L_h).

The gaps between the printed L-strip and the radiating patch along the *X*- and *Y*-axes are labeled by g_1, g_2 and g_3 in Fig. 2a. The capacitance of the printed L-strip section depends on these gaps, which determines the operating bandwidth range of the antenna. The impact of the gap g_1 on the impedance matching of the antenna is shown in Fig. 4a. The value of g_1 with which a widest bandwidth range is achieved is 0.54 mm. It should be noted that the diameter of the SMA probe used is 1.27 mm, which is greater than the width of the L-strip section L_w (0.7 mm). Therefore, the value of g_1 cannot be less than 0.3 mm. Thus, it is varied from 0.34 mm to 0.74 mm with a step of 0.2 mm. As observed, with all the g_1 values, the resonances of both the L-strip and the radiating patch remain almost unchanged. However, the VSWR trace is pushed beyond the threshold value of 2 with the values of g_1 of 0.34 and 0.74 mm. As illustrated in Fig. 2a, the bottom and the top edges of the printed L-strip are separated from the radiating patch by gaps g_2 and g_3, respectively, along the *Y*-axis. The variation of the VSWR with g_2 is shown in Fig. 4b. As noticed, the value of g_2 is very critical in determining the overall bandwidth range of the antenna. Even a minor change in g_2 has a drastic impact on the impedance matching characteristics. With smaller values of g_2, the resonance from the L-strip hardly exists. On the other hand, the antenna exhibits a multi-band behavior with the larger values of g_2. The top-edge gap g_3 has a negligible impact on the impedance bandwidth of the antenna. Overall, larger values of g_3 depreciate the peak gain of the antenna and its smaller values impact the overall 3-dB gain bandwidth range. Considering these two factors, the value of g_3 is chosen as 1.13 mm. For brevity, these results are omitted here.

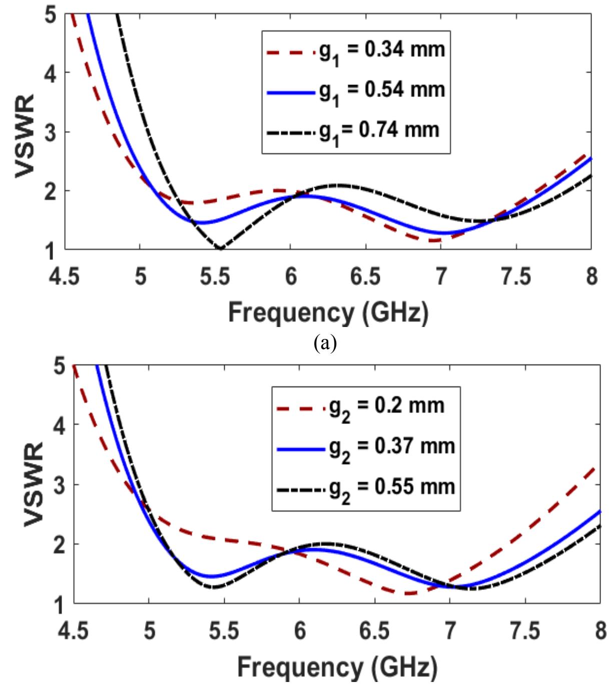


Fig. 4. Impact of the gaps on the VSWR characteristics of the antenna: (a) g_1, (b) g_2.

IV. MEASURED RESULTS AND RADIATION CHARACTERISTICS

A prototype of the proposed antenna shown in Fig. 2 was fabricated and tested for its impedance and radiation validation in practice. The measured and simulated VSWR characteristics of the antenna are shown in Fig. 5, exhibiting good agreement between them. The operating frequency range of the fabricated antenna is from ~5 to ~7.6 GHz, thus validating the 41% of impedance bandwidth (VSWR< 2). Minor oscillations are observed in the measured VSWR trace due to the uneven patch and the ground layers. These two layers were separated from each other at the height of 3.5 mm, using plastic screws. For reference, a photograph of the fabricated antenna is also embedded into Fig. 5.

To measure the 3dB gain bandwidth, the simulated and measured peak gain of the antenna is plotted in Fig. 5. As observed, the results are well aligned over the entire frequency range. The peak gain of the antenna is ~9.5 dBi at the frequency 6.3 GHz. Moreover, the 3dB gain bandwidth range matches with the operating frequency range of the antenna. The simulated and measured co-pol and the cross-pol radiation patterns of the proposed antenna at the low (5.1 GHz), center (6.4 GHz) and the high (7.7 GHz) frequencies along the principal E- and H- planes are shown in Fig. 6, showing good agreement between the measured and simulated results. The radiation patterns are quite symmetric along the H-plane. However, a minor tilt is observed in the E-plane patterns, which is due to the asymmetry caused by the co-planar L-strip along the E-plane. The efficiency of the proposed antenna is also investigated and found to be about 90% throughout the frequency range of operation.

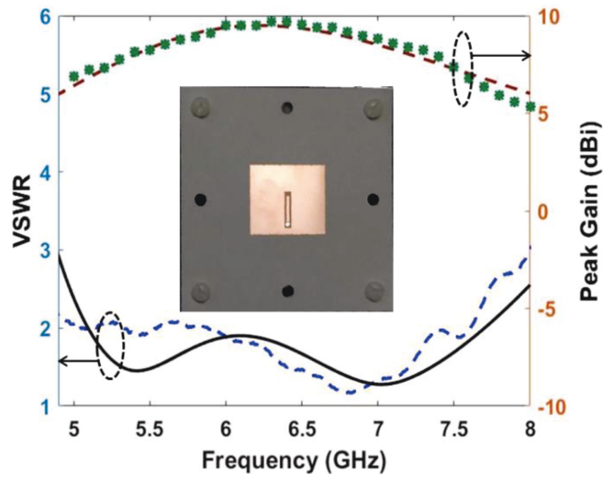
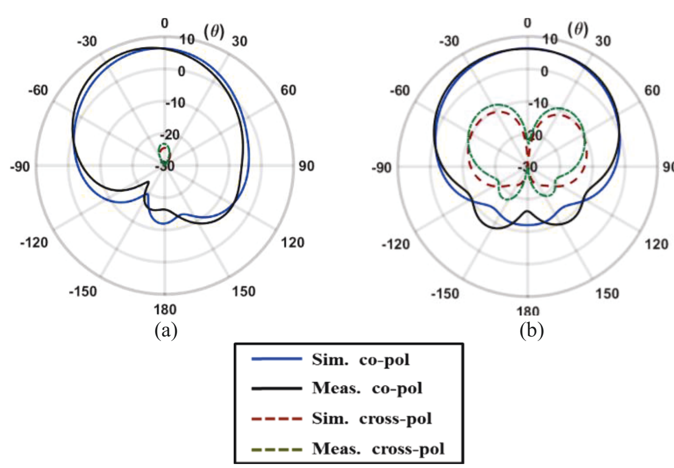


Fig. 5. Simulated and measured VSWR and the peak gain of the antenna along with a photograph of the fabricated antenna (——, - - - simulated; – – , ✱ measured)

From the characterisitcs demonstarted above, it could be concluded that the proposed antenna outperforms the conventional L-probe fed antenna in terms of impedance bandwidth, structural rigidity and fabrication simplicity, to name a few. To further demonstarte its effectiveness, the antenna characteristics are compared with those of the traditional L-probe antenna of [2] in Table I.

TABLE I. COMPARATIVE STUDY WITH THE CONVENTIONAL L-PROBE ANTENNA

	VSWR BW	Patch Dimensions(λ_o)	Height of Antenna(λ_o)	3-dB Gain BW
[2]	~36%	0.375 × 0.45	~0.13	~36%
Proposed Antenna	**~41%**	**0.36 × 0.42**	**~0.09**	**~41%**
	Co-planar Structure	Structural Rigidity	Fabrication Simplicity	
[2]	✗	✗	✗	
Proposed Antenna	✓	✓	✓	



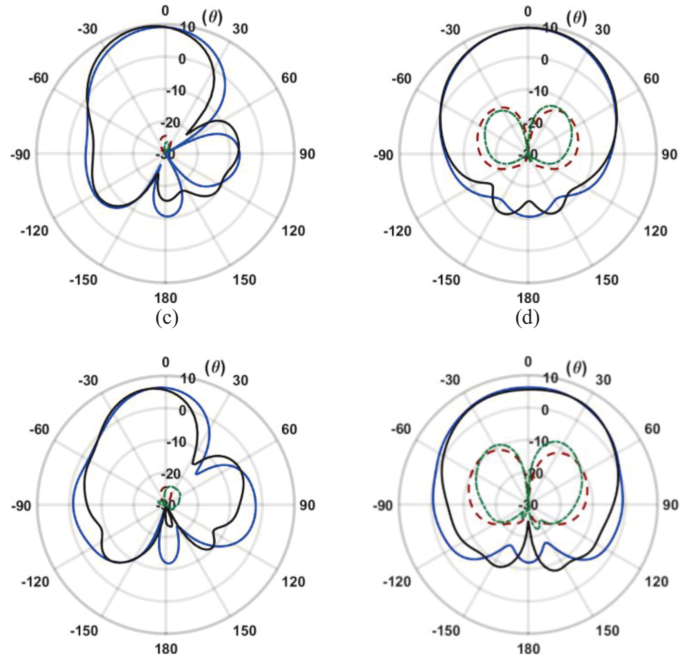


Fig. 6. Measured and simulated radiation patterns in the principal E- and H-planes (a) (b) 5.1 GHz; (c) (d) 6.4 GHz; (e) (f) 7.7 GHz. Left and right figures are the E- and the H-planes, respectively.

V. CONCLUSION

A modified co-planar wideband printed L-strip fed patch antenna, which could surpass the drawbacks of the conventional L-probe antenna, was proposed. The achieved impedance bandwidth (VSWR<2) was in the order of 41% from 5.09 GHz to 7.7 GHz. This is much wider than that of the conventional L-probe antenna. The proposed antenna was thoroughly investigated in terms of its impedance and radiation characteristics. A prototype of the designed antenna was fabricated and successfully tested in practice. Good agreement between the numerical and experimental results is observed. The realized radiation patterns are stable over the entire operating frequency range and the 3dB gain bandwidth range matches with that of the impedance bandwidth range with the peak gain of ~9.5 dBi at 6.3 GHz.

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