Experimental Study of a Microstrip Patch Antenna with an L-Shaped Probe

C. L. Mak, K. M. Luk, *Senior Member, IEEE*, K. F. Lee, *Fellow, IEEE*, and Y. L. Chow

***Abstract*—The L-shaped probe is shown to be an attractive feed for the thick microstrip antenna (thickness around 10% of the operating wavelength). A parametric study on the rectangular patch antenna is presented. It is found that the antenna attains 36% impedance bandwidth $(\mathrm{SWR} \leq 2)$ as well as gain bandwidth and about 7-dBi average gain. A two-element array fed by L-probes is also proposed. Experiments show that the array design can substantially suppress the cross polarization of the proposed antenna. Both the antennas have stable radiation patterns across the passband. Moreover, the measured resonant frequencies of the proposed antenna agree well with an existing formula and the L-probe does not have much effect on the resonant frequency.**

***Index Terms*—Bandwidth widening, microstrip patch antennas.**

I. Introduction

THE inherently narrow impedance bandwidth is the major weakness of a microstrip antenna. Techniques for bandwidth enhancement have been intensively studied in past decades. Several methods including the utilization of parasitic patches [1] and thick substrates [2] have been suggested in the literature. The stacked geometry resulting from the addition of parasitic patches will enlarge the size and increase the complexity in array fabrication, which is especially inconvenient for the coplanar case [3]. The technique of employing a thicker substrate in the coaxially fed method will not only cause a high level of cross polarization in the H-plane, but also limit the achievable bandwidth to less than 10% of the resonant frequency due to the increased inductance introduced by the longer probe required. It is found that the capacitance introduced by etching a small circular slot on the patch can cancel out a portion of the probe inductance [4], so that a 16% bandwidth can be achieved. By etching a U-shaped slot [5], the bandwidth can be substantially increased, typically to larger than 30%. Another method to compensate the probe inductance is the capacitive feeding technique [6]. A small capacitor patch, connected to the coaxial feed, excites the radiating patch through capacitive coupling. For the patch antenna with a thin dielectric substrate (thickness $< 0.05\lambda_0, \varepsilon_r = 3$), the bandwidth obtained is about 4% [6].

Recently, a novel feeding approach employing an L-shaped probe/strip has been proposed [7], [8]. It is already known that the L-probe has been applied successfully in other antenna designs [9]. We have discovered that the L-shaped probe/strip is an excellent feed for patch antennas with a thick substrate (thickness $\approx 0.1\lambda_0$). The L-probe/strip incorporated with the radiating patch introduces a capacitance suppressing some of the inductance introduced by the probe/strip itself. Compared with the capacitor patch [6] technique, which is based on similar principle of operation, the L-probe/strip avoids soldering the feed probe to the capacitor patch. Bending a straight probe/strip to an L-shaped probe/strip is easy in fabrication, especially in array design. With the use of a rectangular patch fed by the L-probe [7], the bandwidth and average gain achieved are 35% and 7.5 dBi, respectively.

In this paper, a comprehensive experimental study of the L-probe feed, for the rectangular patch antenna, is presented.

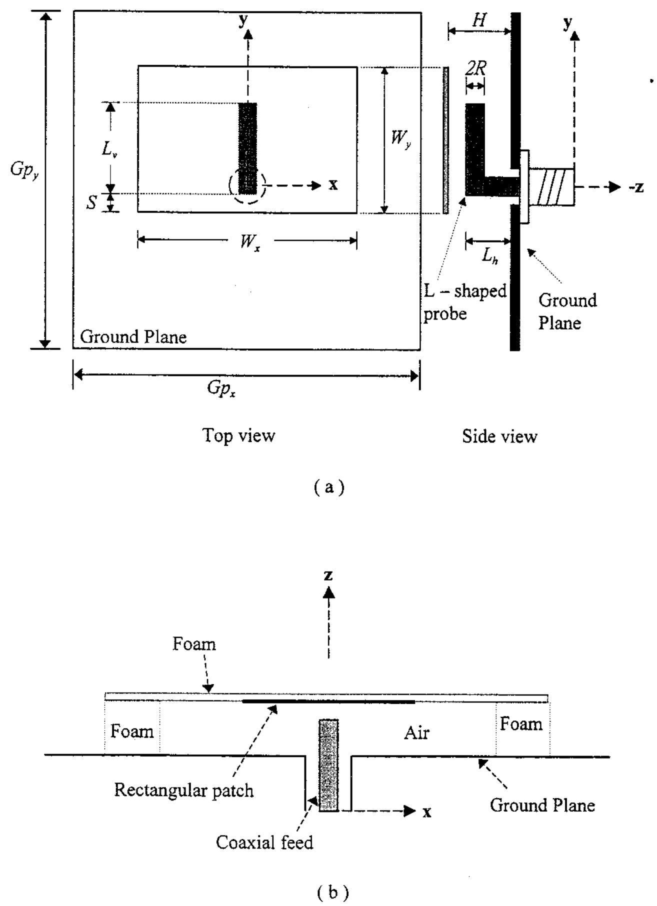

Fig. 1. Basic geometry of the L-shaped probe fed patch antenna and the coordinate system.

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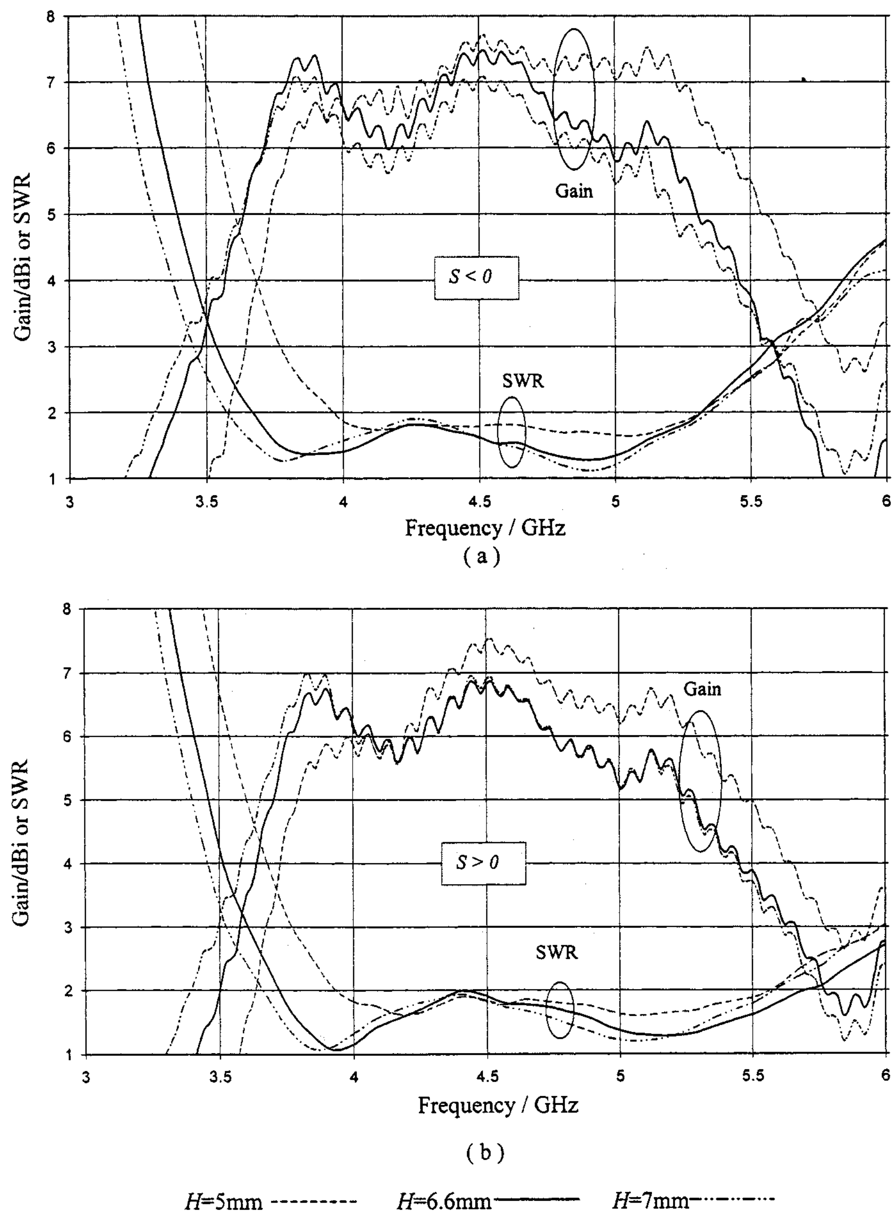

Fig. 2. SWR and gain curves for the six cases in Table I.

A two-element array fed by two different L-probes is proposed for suppressing the cross polarization caused by the feed. The measured resonant frequencies are compared with theoretical results based on an existing formula available in the literature.

II. L-Shaped Probe-Fed Patch Antenna

A. Geometry and Fabrication

The basic geometry of the antenna is shown in Fig. 1. A copper ground plane with dimension $Gp_x \times Gp_y = 100 \times 120$ mm^2 $(1.5\lambda_0 \times 1.8\lambda_0)$ and thickness 2 mm is used. A 0.07 mm thick rectangular copper patch (3M product, foil shielding tape no.: 1181—copper foil) with width $W_x = 30$ mm $(0.45\lambda_o)$ and length $W_y = 25$ mm $(0.375\lambda_o)$ is used for the parametric studies. As shown in Fig. 1(b), the copper patch is taped on the bottom side of a 1-mm-thick foam $(\varepsilon_r \approx 1.06)$, which is supported by two small cubic foams $(\varepsilon_r \approx 1.06)$ located at a distance from the patch. The L-probe with $2R = 1$ mm diameter is connected to the 50-ohm SMA launcher. λ_o refers to the wavelength of the operating centre frequency f_0, 4.5 GHz. The L-probe excites the TM_{01} mode of the radiating patch by proximity coupling. A series of extensive measurements has been carried out in order to optimize the performance of the antenna.

B. Measurements

1) Impedance Bandwidth and Gain: Three different values of height H $\{5\text{ mm }(0.075\lambda_o), 6.6\text{ mm }(0.099\lambda_o)$ and $7\text{ mm }(0.105\lambda_o)\}$ are used. For broad-band operation, two

TABLE I
BANDWIDTH AND GAIN OF THE L-SHAPED PROBE FED PATCH ANTENNA WITH DIFFERENT VALUES OF PARAMETERS

Set	H/mm	L_v/mm	L_h/mm		S/mm	Bandwidth (SWR ≤ 2)	Average Gain
1	5 ($0.075\lambda_o$)	10.42 ($0.1563\lambda_o$)	4.44 ($0.0666\lambda_o$)	$S<0$	-1.5 ($-0.0225\lambda_o$)	28%	7dBi
2	6.6 ($0.099\lambda_o$)	10.5 ($0.1575\lambda_o$)	5.68 ($0.0852\lambda_o$)	$S<0$	-3 ($-0.0450\lambda_o$)	36%	7dBi
3	7 ($0.105\lambda_o$)	9.88 ($0.1482\lambda_o$)	6.2 ($0.0930\lambda_o$)	$S<0$	-1 ($-0.0150\lambda_o$)	39%	6.5dBi
4	5 ($0.075\lambda_o$)	7.64 ($0.1146\lambda_o$)	4.8 ($0.0720\lambda_o$)	$S>0$	+1.5 ($0.0225\lambda_o$)	32%	6.5dBi
5	6.6 ($0.099\lambda_o$)	5.18 ($0.0777\lambda_o$)	6.48 ($0.0972\lambda_o$)	$S>0$	+2 ($0.0300\lambda_o$)	42%	6dBi
6	7 ($0.105\lambda_o$)	6.98 ($0.1047\lambda_o$)	6.68 ($0.1002\lambda_o$)	$S>0$	+1 ($0.0150\lambda_o$)	42%	6dBi

$W_x \times W_y = 30 \times 25\text{mm}^2$, $R = 0.5$mm.

sets of values (L_h, L_v, S) are found for each value of H. Fig. 2 shows both SWR and gain, measured by a HP8510C Network Analyzer and a compact range with a HP85301C Antenna Measurement System, for the six sets of parameters. The geometric parameters, bandwidth and average gain are tabulated in Table I. It is checked that the error of all the dimensions measured are within 1–2%.

2) Radiation Pattern, Input Impedance and Effect of Variations of L_v, L_h and S: From Table I, set 2 seems to give an antenna close to the optimum broad-band operation. It attains a 36% impedance bandwidth $(\text{SWR} \leq 2)$ and 7-dBi average gain. The radiation pattern of the antenna using the parameters of set 2 is measured and is found to be stable across the passband. Furthermore, it is also found that the cross polarization is lower at the middle part of the passband. Fig. 3 shows the patterns at 4, 4.53, and 5.34 GHz. The cross polarization in the H-plane is quite high especially at $\theta \approx 30°$, it is about -15 dB at 4.53 GHz. The input impedance of the same antenna is shown in Fig. 4. The measured resonant frequency is 4.45 GHz.

As seen in Table I, when the whole L-probe is covered by the patch (i.e., $S > 0$), the gain is slightly lower in comparison with the case when $S < 0$, using the same thickness H. Based on the parameters used in set 2, it is found that a small variation in either value of L_v or L_h will significantly narrow the achievable bandwidth. Moreover, Fig. 5 shows the SWR curves with different values of S of this antenna, and Table II shows the bandwidth obtained together with the corresponding value of S.

III. L-SHAPED PROBE-FED TWO-ELEMENT PATCH ANTENNA ARRAY

A. Geometry

Fig. 6 shows the geometry of a series-fed two-element antenna array. The vertical portion of the two L-probes is pointing at opposite directions. For the copolarization to be re-inforced

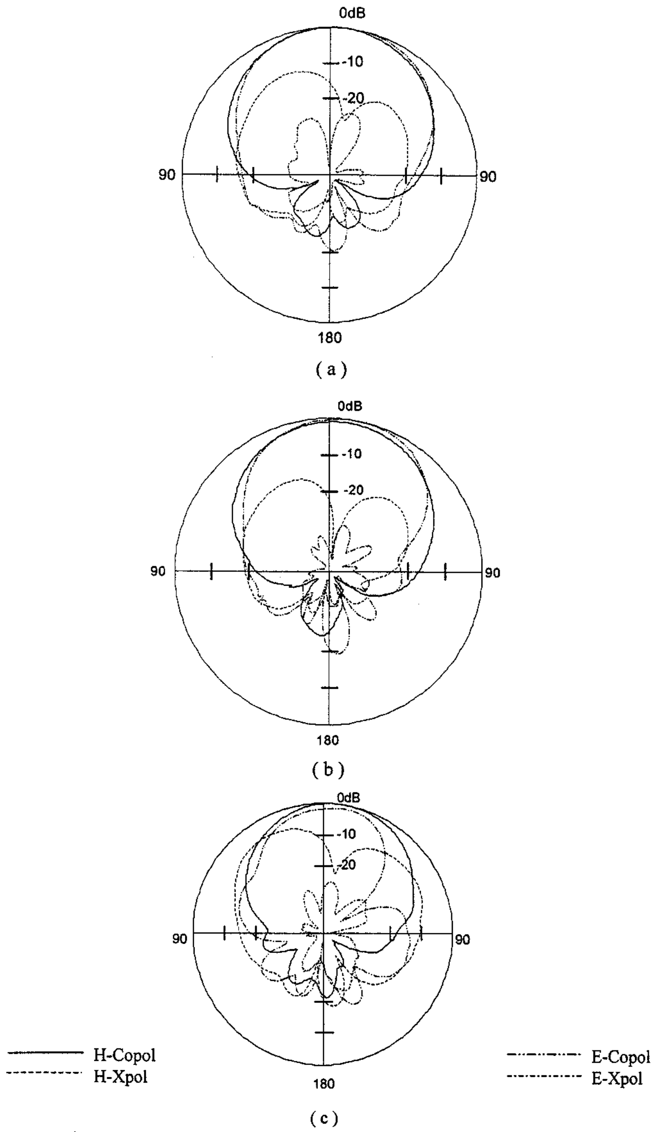

Fig. 3. Radiation patterns of the antenna using parameters in set 2 at (a) 4 GHz; (b) 4.53 GHz; and (c) 5.34 GHz.

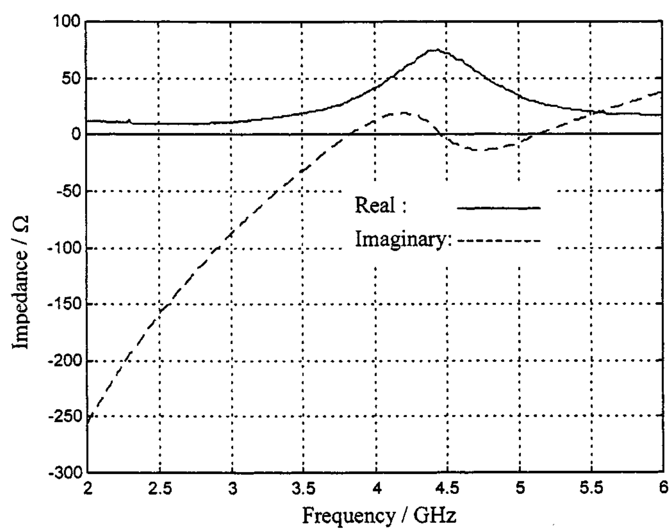

Fig. 4. Input impedance curves of the antenna using parameters in set 2.

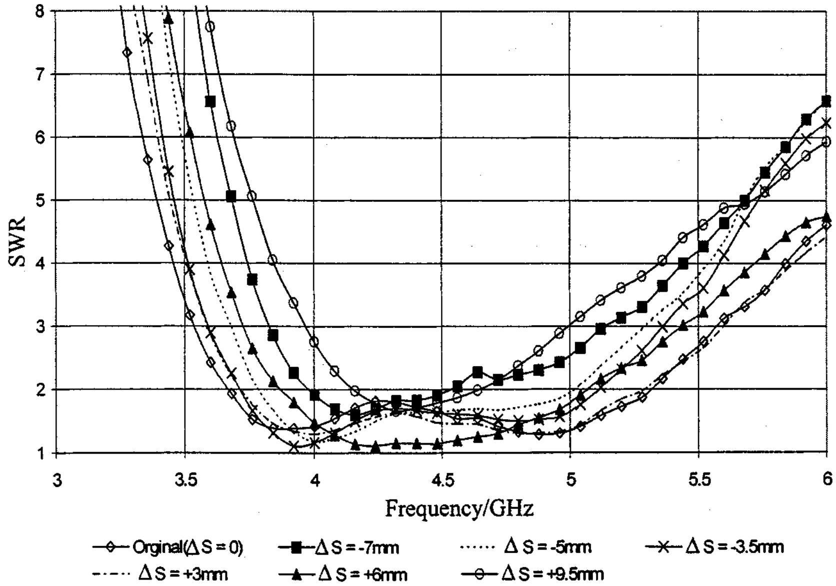

Fig. 5. SWR curves of the antenna using parameters in set 2 but with different values of S.

TABLE II
BANDWIDTH OF THE L-PROBE FED PATCH ANTENNA WITH DIFFERENT VALUES OF S

ΔS / mm	Bandwidth (SWR ≤ 2)
-7	13%
-5	30%
-3.5	32%
0	36%
+3	35%
+6	27%
+9.5	12%

Besides S, other parameters are same as set 2.

ΔS = 0 is used for reference.

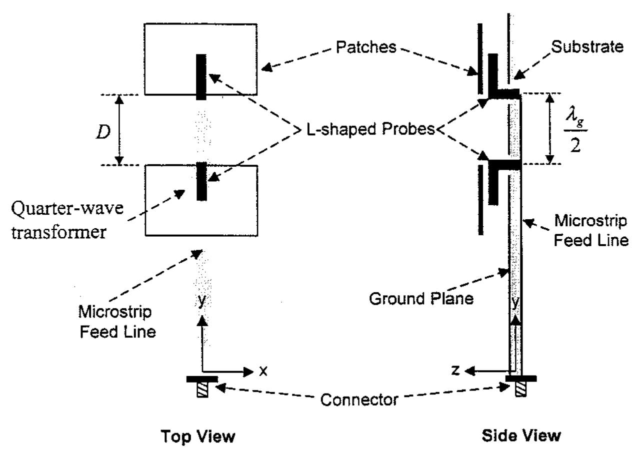

Fig. 6. Geometry of the L-shaped probes fed two-element antenna array and the coordinate system.

in the broadside, the two probes are fed out of phase. This geometry has the advantage of canceling the cross-polarization radiation [10]. The physical dimensions of each antenna element are same as stated in set 2. In other words, the distance between the edge of the two patches is $D = 28.8$ mm (element spacing $\approx 0.88\lambda_0$). A quarter wave transformer in the microstrip feed line is designed at 4.5 GHz. Another single-element antenna, with the L-probe connected to the stripline via the ground plane, is also made for comparison.

B. Measurements

Fig. 7 shows measured results of SWR, copolarization gain and cross-polarization gain of both antennas. The bandwidth $(\mathrm{SWR} \leq 2)$ is 33% for the single-element antenna and is 30% for the antenna array. The average gain is 6.5 dBi for the single-element antenna and is 9 dBi for the antenna array. It is clearly seen that the cross polarization is lower at the center region of the passband. The gain of this single-element antenna is slightly less than that of the antenna studied in Section II. The discrepancy is due to the additional microstrip line loss and backlobe radiation loss. Most importantly, the proposed antenna array attains a cross polarization of -20 dB within most of the passband. Table III tabulates the obtained results. The radiation patterns for both antennas are stable within the passbands, and Fig. 8 shows the patterns of the array at 4, 4.5, and 4.8 GHz.

IV. DETERMINATION OF RESONANT FREQUENCY

The following formulas [11] are employed to compare the measured results of resonant frequencies

$$f_r = \frac{c}{2(W_y + 2\Delta w_y)\sqrt{\varepsilon_{\mathrm{re}}}} \tag{1}$$

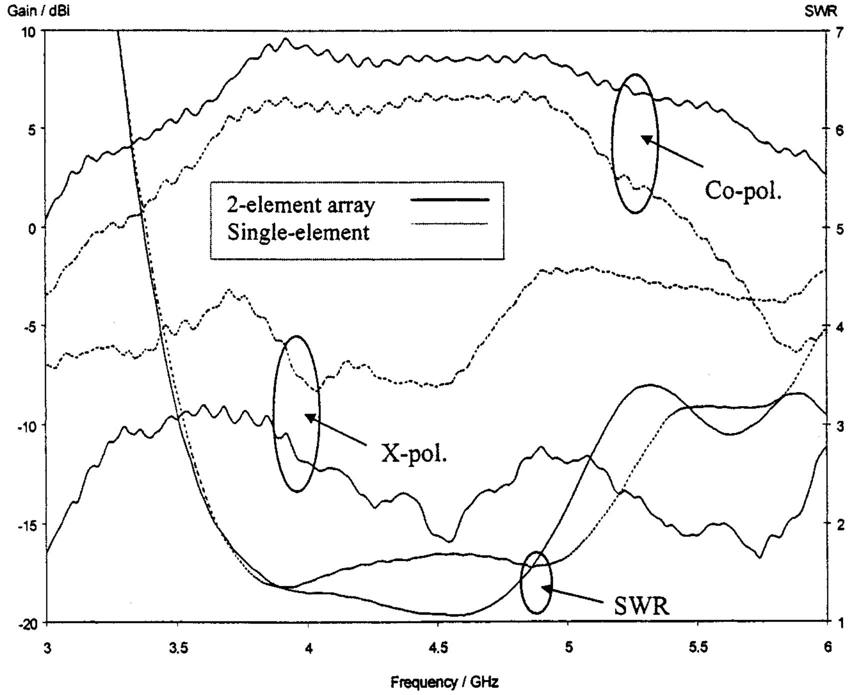

Fig. 7. SWR copolarization gain and cross-polarization gain of the antenna array.

TABLE III
COMPARISON BETWEEN THE SINGLE-ELEMENT ANTENNA AND THE TWO-ELEMENT ARRAY ANTENNA

L-probe feed Antenna	Bandwidth (SWR ≤ 2)	Gain	Cross-polarisation within most of the passband
Single-element	33%	6.5dBi	down 15dB or more
Two-element	30%	9dBi	down 20dB or more

The L-probes are directly connected to the microstrip feed-line via the ground plane.

TABLE IV
COMPARISON BETWEEN THE MEASURED f_r AND CALCULATED f_r USING DIFFERENT GEOMETRY

Case	Patch $W_x \times W_y$ mm²	H mm	f_r / GHz Meas.	Cal.	Parameters used L_v/mm	L_h/mm	S/mm	BW. SWR≤2
1	40×25	6.6	4.415	4.442	9.68 (0.1452λ$_o$)	5.52 (0.0828λ$_o$)	-3 (-0.045λ$_o$)	34%
2 *(set2)*	30×25	6.6	4.45	4.471	10.5 (0.1575λ$_o$)	5.68 (0.0852λ$_o$)	-3 (-0.045λ$_o$)	36%
3	25×25	6.6	4.5	4.492	9.62 (0.1443λ$_o$)	5.8 (0.0870λ$_o$)	+1.5 (0.0225λ$_o$)	38%
4	40×25	5	4.60	4.722	8.16 (0.1224λ$_o$)	4.68 (0.0702λ$_o$)	-3 (-0.045λ$_o$)	32%
5 *(set4)*	30×25	5	4.62	4.741	7.64 (0.1146λ$_o$)	4.8 (0.0720λ$_o$)	+1.5 (0.0225λ$_o$)	32%
6	25×25	5	4.672	4.756	10.14 (0.1521λ$_o$)	4.2 (0.0630λ$_o$)	+3 (0.045λ$_o$)	28%

The measured f_r for case 2 is shown in Figure 4.

$$\varepsilon_{\rm re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{10H}{W_x}\right)^{-\frac{1}{2}} \tag{2}$$

$$\Delta w_y = 0.412 \frac{(\varepsilon_{\rm re} + 0.3)\left(\frac{W_x}{H} + 0.264\right)}{(\varepsilon_{\rm re} + 0.258)\left(\frac{W_x}{H} + 0.813\right)} H \tag{3}$$

where

- c — 3×10^8 m/s;
- f_r — resonant frequency;
- $\varepsilon_{\rm re}$ — effective dielectric constant;
- Δw_y — resonance edge extension of the patch.

Three different patches ($40\times$ 25 mm^2, $30\times$ 25 mm^2 and $25\times$ 25 mm^2) are considered for demonstrating the usefulness of the above equations. Results are tabulated in Table IV. It is found that for a given value of H, the dimensions of the L-probe (i.e., L_v and L_h) will not change very much even if the size of the patch is varied by a large amount. Note that space between the radiating patch and the ground plane is occupied by air ($\varepsilon_r = 1$). In addition, the 1-mm-thick foam ($\varepsilon_r \approx 1.06$), which is used as a superstrate has less effect on the resonant frequency of the antenna. Thus, the effective dielectric constant in (1) is selected as unity, i.e., $\varepsilon_{\rm re} = 1$.

V. CONCLUDING REMARKS

In this paper, a novel L-shaped probe is shown to be an excellent feed for thick ($\approx 0.1\lambda_o$) microstrip patch antennas. The performance of this new feeding technique is quite similar to that of the U-shaped slot patch antenna [5], in the

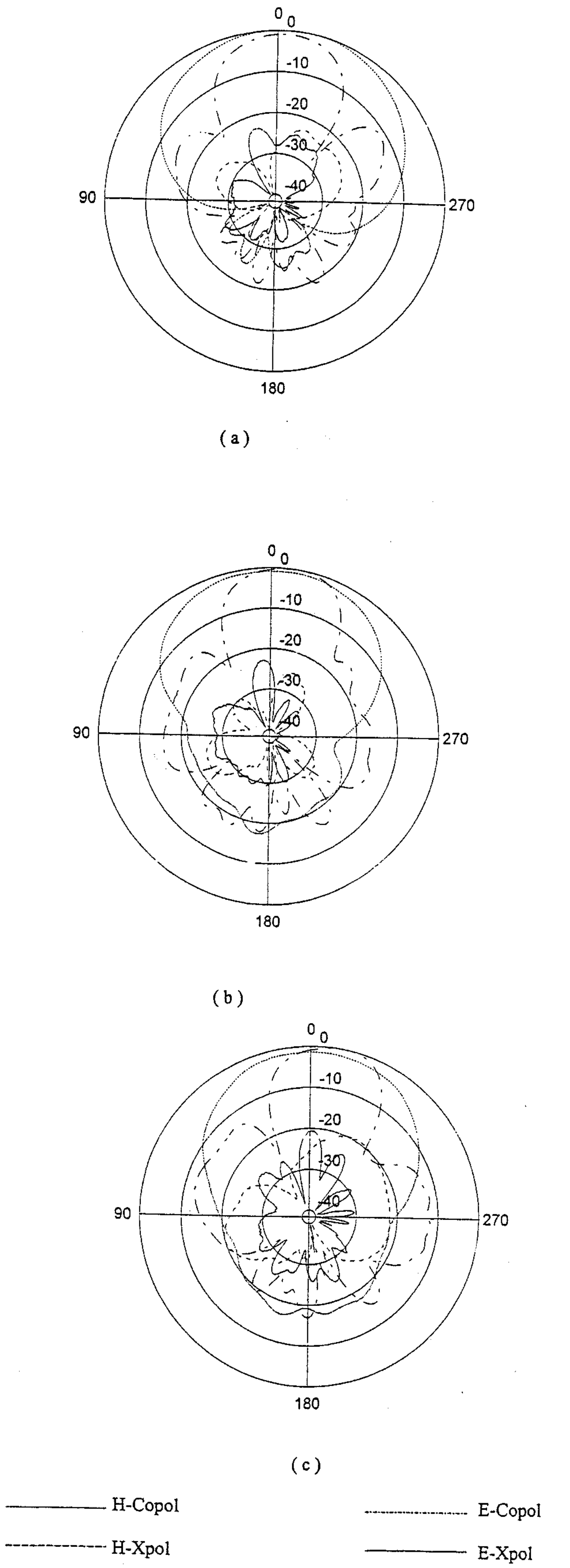

Fig. 8. Radiation pattern of the antenna array at (a) 4 GHz; (b) 4.5 GHz; and (c) 4.8 GHz.

sense that both exhibit broad-band and high-gain characteristics. The bandwidth and gain of the proposed antenna are 36% and 7 dBi, respectively. A parametric study of the L-probe is presented. A two-element array, which attains 33% bandwidth and 9 dBi gain is proposed for suppressing the cross polarization. It is also demonstrated that the resonant frequencies have a good agreement with the existing formula.

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Y. L. Chow, biography and photograph not available at the time of publication.