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A STUDY OF 15°-75°-90° ANGLES TRIANGULAR PATCH ANTENNA

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Abstract—In this paper, a triangular patch antenna (TPA) with 15°-75°-90° angles is studied. The simulation results, using the full wave simulator, IE3D, for this TPA shape are compared with those for the equilateral triangular patch antennas (ETPA), the right angle isosceles triangular patch antenna (RAITPA), the 30°-60°-90° TPA and 30°-30°-120° TPA. It is found that for the same resonant frequency, the 15°-75°-90° TPA occupies the least area among these triangular shapes. In an attempt to verify the simulation results, a 15°-75°-90° TPA operating at 900 MHz is designed, fabricated, and measured. The measured value for the resonance frequency is very close to the value obtained by simulation. Finally, a 15°-75°-90° TPA with a shorting pin is investigated. As expected, a miniaturized patch is obtained by loading a shorting pin at the tip of the patch.

1. INTRODUCTION

Patch antennas are based on printed circuit technology to create flat radiating structures on top of a ground-plane-backed substrate. The advantage of such structures is the ability of building compact antennas with low manufacturing cost and high reliability. However, it is in practice difficult to accomplish this while at the same time achieving high bandwidth and efficiency. Nevertheless, improvements in the properties of the dielectric materials and in design techniques have led to enormous growth in the popularity of microstrip patch antennas, and there are now a large number of commercial applications. Many shapes of patches are possible, with varying applications, but the most popular are rectangular, circular and thin strips [1].

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Among the shapes that attracted much attention lately is the triangular shaped patch antenna [2–8]. This is due to their small size compared with other shapes like the rectangular and circular patch antennas. In this paper, the triangular patch antenna (TPA) with 15°-75°-90° angles is studied. Up to our knowledge, this is the first time that this patch shape is considered. This paper is devoted to study the 15°-75°-90° TPA and compare it with other well-known triangular shapes like the equilateral TPA (ETPA), right angle isosceles TPA (RAITPA), 30°-60°-90° TPA and 30°-30°-120° TPA. Moreover, in order to obtain a miniaturized structure, shorting pin technique is applied onto this shape. The obtained simulation results are reported in this paper.

2. RESULTS AND DISCUSSION

Figure 1 shows several common shapes of triangular patch antennas (TPAs). Using the cavity model, and assuming perfect magnetic side walls, the resonant frequencies for these TPAs can be obtained using the following equations [9–11]:
For the ETPA:

$$f_{m,n} = \frac{2c}{3a\sqrt{\epsilon_r}}\sqrt{m^2 + mn + n^2} \tag{1}$$

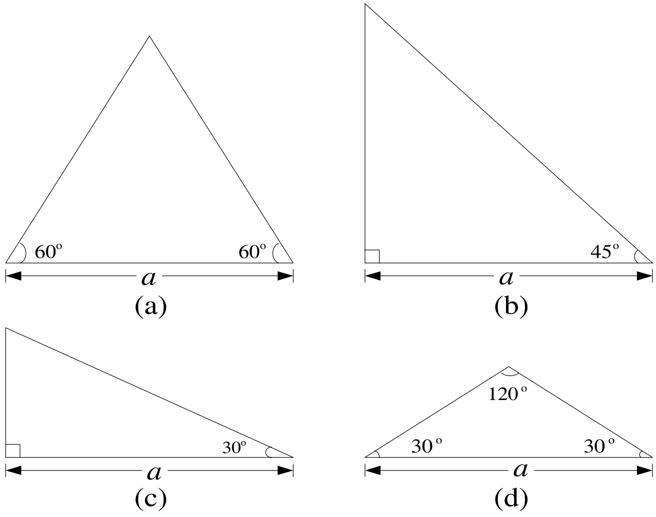

Figure 1. Common shapes of TPAs; (a) ETPA, (b) RAITPA, (c) 30°-60°-90° TPA, (d) 30°-30°-120° TPA.

For the RAITPA:

$$f_{m,n} = \frac{c}{2a\sqrt{\epsilon_r}}\sqrt{(m^2+n^2)} \tag{2}$$

For the 30°-60°-90° TPA:

$$f_{m,n} = \frac{c}{a\sqrt{3\epsilon_r}}\sqrt{(m^2+mn+n^2)} \tag{3}$$

For the 30°-30°-120° TPA:

$$f_{m,n} = \frac{2c}{a\sqrt{3\epsilon_r}}\sqrt{(m^2+mn+n^2)} \tag{4}$$

where c is the velocity of light in free space, m and n are integers (mode indices), and ϵ_r is the substrate relative permittivity.

Assuming $\epsilon_r = 1$ and a dominant mode (i.e., TM_{10} mode) resonant frequency of 3 GHz, the side lengths and areas corresponding to each shape can be calculated using the above equations, as shown in Table 1. It can be seen that the TPA with the least area is the 30°-60°-90° TPA. Now, the following question arises: what if another triangular shape is considered, say the 15°-75°-90° TPA (shown in Figure 2)?!

Using the full-wave simulator IE3D [12], simulation results were obtained for several designs of 15°-75°-90° TPA. Table 2 shows the obtained resonant frequency of the dominant mode for different designs. In the same table, the resonant frequency of 30°-60°-90° TPAs with the same "a" and substrate are also included. As shown in this

Table 1. Comparison between side lengths and corresponding areas for different shapes of TPAs operating at 3 GHz with $\epsilon_r = 1$.

Shape	Side length a (cm)	Area (in cm^2)
ETPA	20/3	19.25
RAITPA	5	12.5
30°-60°-90°	$10/\sqrt{3}$	9.6
30°-30°-120°	$20/\sqrt{3}$	19.25

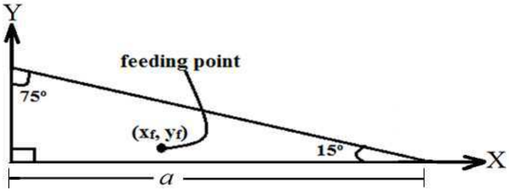

Figure 2. A probe-fed 15°-75°-90° TPA.

Table 2. Comparison between the resonant frequencies for the 30°-60°-90° and 15°-75°-90° TPAs.

Dimensions a (cm), ϵ_r, h (cm)	30°-60°-90° TPA resonant frequency (MHz)	15°-75°-90° TPA resonant frequency (MHz)	Ratio (30°-60°/15°-75°)
(10, 2.32, 0.159)	1127	1167	0.966
(14.66, 2.32, 0.159)	768	800	0.960
(4.1, 10.5, 0.07)	1332	1400	0.951
(9.5, 4.6, 0.16)	856	897	0.954

Table 3. Bandwidth, gain, and efficiency for several designs of both 30°-60°-90° and 15°-75°-90° TPAs.

Dimensions a (cm), ϵ_r, h (cm)	30°-60°-90° TPA			15°-75°-90° TPA		
	B.W. (MHz)	Gain (dBi)	Efficiency %	B.W. (MHz)	Gain (dBi)	Efficiency %
(10, 2.32, 0.159)	3.7	4.8	58.7	4.5	2.7	36.4
(14.66, 2.32, 0.159)	3	2.4	34.2	2	2.4	34.1
(4.1, 10.5, 0.07)	5	4.1	11	5	4.6	9.7
(9.5, 4.6, 0.16)	3.3	1.15	32	2.2	1.1	31.2

table, the same ratio (≈ 0.96) between the 15°-75°-90° TPA and 30°-60°-90° TPA dominant mode resonant frequencies exists for all the cases considered in the table. This is very interesting, and may help in estimating the resonant frequency of a 15°-75°-90° TPA since no formula exists, so far, to calculate its resonant frequencies. Table 3 shows the bandwidth, gain, and efficiency for several designs of both 30°-60°-90° and 15°-75°-90° TPAs. As shown in this table, both TPAs have low efficiency, low gain, and very low bandwidth, which are well-known characteristics of patch antennas.

Figure 3 shows the simulated reflection coefficient for the first case in Table 2. As shown in this figure, the resonant frequency of the dominant mode is 1167 MHz, which is very close to that for a 30°-60°-90° TPA (with the same a) dominant mode resonant frequency (1127 MHz), but with a reduction in area of more than 50% ($\tan 15/\tan 30$).

Also, for the sake of comparison, we simulated a 15°-75°-90° TPA with $a = 14.66$ cm, which has the same area as the 30°-60°-90° TPA considered in the first case in Table 2 ($a = 10$ cm). Compared to 1127 MHz, which is the resonant frequency of the 30°-60°-90° TPA,

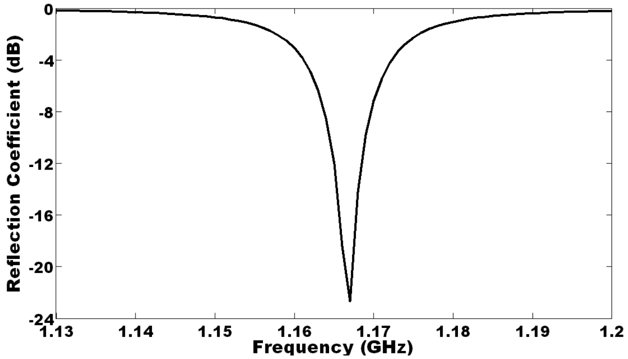

Figure 3. Simulated reflection coefficient (in dB) of a 15°-75°-90° TPA with $a = 10\,\text{cm}$, $h = 0.159\,\text{cm}$, $\epsilon_r = 2.32$, fed at (4.23, 0.2) cm.

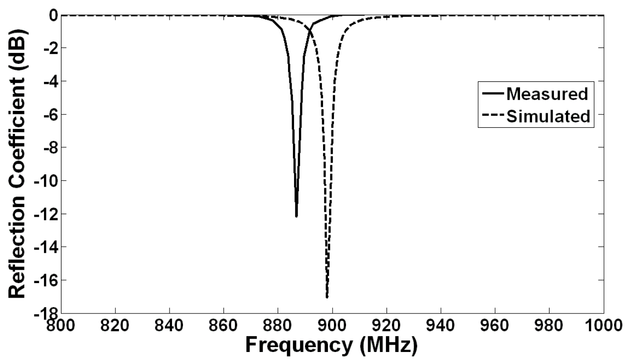

Figure 4. Measured and simulated reflection coefficient (in dB) of a 15°-75°-90° TPA with $a = 9.5\,\text{cm}$, $h = 0.16\,\text{cm}$, and $\epsilon_r = 4.6$.

the obtained resonant frequency for the 15°-75°-90° TPA was 800 MHz; thus, achieving 29% reduction in the resonant frequency.

Table 2 shows also the resonant frequency of a 15°-75°-90° TPA with $a = 4.1\,\text{cm}$, $h = 0.07\,\text{cm}$, $\epsilon_r = 10.5$, fed at (1.8, 0.2) cm (third case in Table 2). The resonant frequency is almost 1400 MHz, which is also close to the resonant frequency of a 30°-60°-90° TPA with the same dimension "a" (1332 MHz), but again with more than 50% reduction in area.

A resonant frequency of 897 MHz, which is close to the operation frequency of GSM (900 MHz), can be obtained using a 15°-75°-90° TPA with $a = 9.5\,\text{cm}$ and FR4 substrate having $h = 0.16\,\text{cm}$ and $\epsilon_r = 4.6$ (fourth case in Table 2). Figure 4 shows both measured and simulated reflection coefficient for this case. The measured results were obtained using a Spectrum Analyzer with a built-in tracking generator. As shown in this figure, the measured value of the resonant frequency is 886 MHz which is very close to the simulated value (897 MHz). The measured return loss at the resonant frequency is 12 dB, while it is 17 dB in the simulation. This difference could be due to the feed position, BNC connector, and fabrication and measurement error. Figure 5 shows the fabricated 15°-75°-90° TPA along with the 30°-60°-90° TPA, both designed to operate at 900 MHz. The size reduction is clearly seen.

Lastly, Figure 6 shows the simulated radiation pattern for the 15°-75°-90° TPA studied in the first case in Table 2. It can be noted that the pattern is in the broadside direction at the resonant frequency of

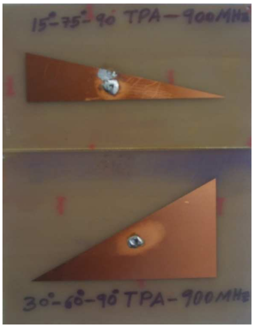

Figure 5. Two fabricated TPAs operating at 900 MHz; the upper one is the 15°-75°-90° TPA and the lower one is the 30°-60°-90° TPA.

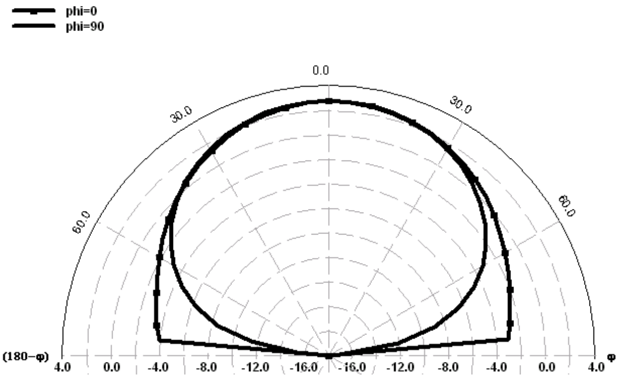

Figure 6. The simulated radiation pattern of a 15°-75°-90° TPA at 1167 MHz with $a = 10\,\mathrm{cm}$, $h = 0.159\,\mathrm{cm}$, $\epsilon_r = 2.32$, fed at $(4, 3)\,\mathrm{cm}$.

1167 MHz. It is worth mentioning that the polarization is linear which is similar to the polarization of other patch shapes.

3. 15°-75°-90° TPA WITH A SHORTING PIN

Compact microstrip antennas have recently received much attention due to the increasing demand of small antennas for personal communication equipment. It has been demonstrated that, loading the microstrip patch with a shorting pin can effectively reduce the required patch size for a given operating frequency [13, 14]. Using this technique, the diameter of a shorting pin-loaded circular microstrip patch [13] or the linear dimension of a shorting pin-loaded rectangular microstrip patch [14] can be as small as one-third of that of a corresponding conventional microstrip patch without a shorting pin at the same operating frequency. This patch size reduction is mainly due to the shifting of the null-voltage point at the center of the rectangular patch (excited at TM_{01} mode) and the circular patch (operated at TM_{11} mode) to their respective patch edges, which makes the modified patches resonate at a much lower frequency.

In [15], it was predicted that at a given operating frequency, the required triangular patch dimensions can be significantly reduced by employing a shorting pin, and the reduction in the patch size is limited by the distance between the null-voltage point in the patch and the patch edge. To verify this prediction, the 15°-75°-90° TPA loaded with a shorting pin is simulated and compared with the conventional 15°-75°-90° TPA. Figure 7 shows the configuration of the 15°-75°-90° TPA loaded with a shorting pin at its tip. Figure 8 shows the reflection coefficient for a shorting pin-loaded 15°-75°-90° TPA along with that for a conventional one (i.e., without a shorting pin). As shown in the figure, by loading a shorting pin at the tip, the resonant frequency decreases from almost 900 MHz to 217 MHz; a reduction of more than 75%. It is worth mentioning that better reflection coefficient can be obtained by changing the feed location for the shorted patch.

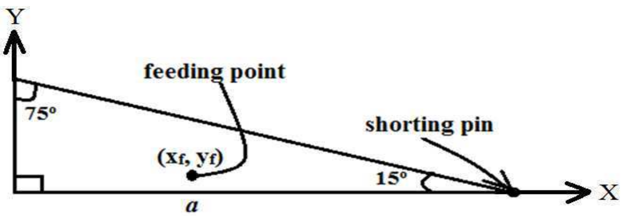

Figure 7. Geometry of a shorting pin-loaded 15°-75°-90° TPA.

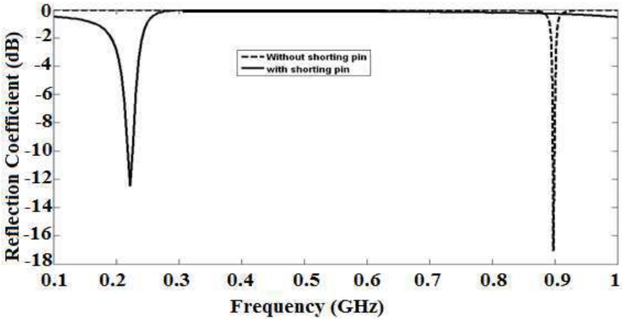

Figure 8. Simulated reflection coefficient of a 15°-75°-90° TPA with $a = 9.5\,\mathrm{cm}$, $h = 0.16\,\mathrm{cm}$, and $\epsilon_r = 4.6$. The conventional patch is fed at $(4, 0.3)$ cm, while the patch with a shorting pin is fed at $(8.4, 0.16)$ cm.

4. CONCLUSION

A simulation study of the 15°-75°-90° TPA was performed. Comparison between the 15°-75°-90° TPA and other TPA shapes was also included. The results show that the same resonant frequency can be obtained using this shape with smaller area compared to other shapes. For verification purposes, a 15°-75°-90° TPA was fabricated and measured. The measured resonant frequency agrees well with the simulated one. Moreover, the 15°-75°-90° TPA with a shorting pin at the tip was studied. It was shown that, a reduction of more than 75% in the resonant frequency can be obtained by shorting the tip. Up to our knowledge, no theoretical analysis of the 15°-75°-90° TPA exists in the literature.

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