Design of a Dual Patch Triangular Microstrip Antenna

Dual patches offer wider bandwidth for wireless applications in the 2.4 GHz ISM band

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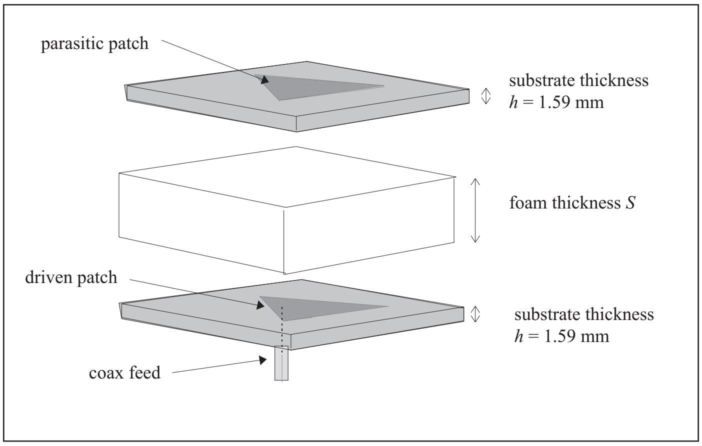
This paper investigates the design, measurement and characteristics of a probe-fed dual patch equilateral triangular antenna. A lossless foam material is sandwiched between the two patches to provide a mechanically stable and uniform height. It is shown that the separation height between the two patches plays a significant role in improving the impedance bandwidth of the antenna. A bandwidth of 13.2 percent is measured around a center frequency of 2.50 GHz. Measurements on gain and polar patterns are also presented. This antenna could find useful applications in the industrial, scientific and medical (ISM) frequency bands.



■ **Figure 1. Layout of the stacked triangular patch antenna.**

During the last two decades, a considerable number of papers have been published on the performance and applications of microstrip patch antennas [1-4]. Various patch configurations such as annular-ring, disk, rectangular and triangular have been investigated. These patch antennas possess many desirable features, such as low profile, light weight, low cost, direct integrability with microwave circuitry and the ability to conform to the surface of a host object. Such features make microstrip patch antennas useful for many applications in radar and wireless communication systems.

However, one of the principal limitations of such antennas is their very narrow bandwidth, which is on the order of a few percent. Many bandwidth enhancement techniques have been suggested and implemented in recent years, and one such technique is stacking patches either horizontally or vertically [5-7]. In this paper, we present an experimental investigation on broadbanding the impedance bandwidth of a vertically stacked equilateral triangular patch antenna. The equilateral triangular patch configuration is chosen because it has the advantage of occupying less metalized area on the substrate than other existing configurations.

A lossless foam material is used to control the distance between the two patches and to provide a mechanically stable height separation. In practice, it was found that the height separation plays a significant role in achieving the optimum impedance bandwidth of the antenna. The described antenna has an impedance bandwidth of 13.2 percent with the two ends of the frequency band being at 2.43 GHz and 2.76 GHz respectively. Measurements of antenna gain and radiation patterns are also presented.

Antenna design procedure

Figure 1 shows the configuration of the stacked triangular patch antenna that was considered in this paper. The design procedure starts with the determination of the sidelength of the driven patch using the resonant frequency formula. Several papers [8-13, 15] on the resonant frequencies of equilateral triangular patch antenna have been published. All of these papers agree on the basic equation for the resonant frequency given by

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

where m, n and l are the mode integers due to the electric and magnetic boundary conditions, c is the speed of light in free space, ε is the dielectric constant and a is the sidelength of the equilateral triangle.

However, several methods for correcting the sidelength due to the effect of the fringing fields have been discussed by various authors. The simplest correction was given by Dahele and Lee [8]:

$$a_{eff} = a + \frac{h}{\sqrt{\varepsilon_r}} \tag{2}$$

where a_{eff} is the effective sidelength, h is the substrate thickness and a is the actual sidelength of the equilateral triangle.

Dahele and Lee also reported that, when a_{eff} is used to replace the value of a in Equation (1), this correction would give a 2 percent error on the calculated resonant frequency. Gang [9] proposed another version of a_{eff} which keeps the same expression as that given in Equation (2) but uses the effective dielectric constant given by the following formula:

$$\varepsilon_{eff} = \frac{1}{2}(\varepsilon_r + 1) + \frac{1}{2}(\varepsilon_r - 1)(\alpha_t) \tag{3}$$

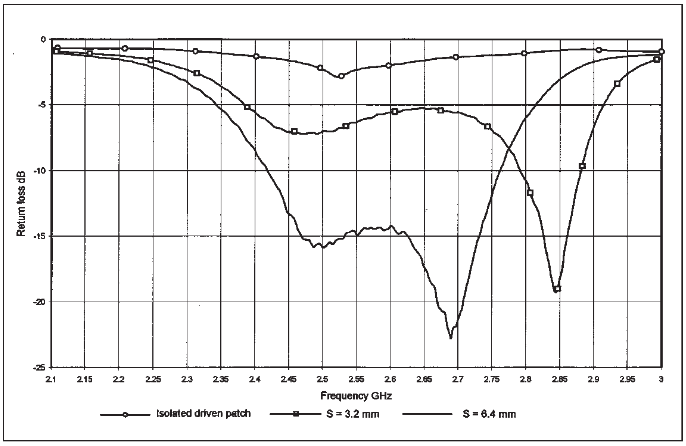
where

$$\alpha_t = \frac{\sqrt{(A+H)H} - A\ln\left(\sqrt{H} + \sqrt{(A+H)}\right)}{H} + \frac{A\ln(A)}{2H} \tag{4}$$

$$A = 6\sqrt{3}h \text{ and } H = \sqrt{3}\frac{a}{2} \tag{5}$$

For thin substrates — that is, for small h/a — the accuracy of Equation (2) with ε_r replaced by ε_{eff} is not much better than that of Dahele and Lee [8] because ε_{eff} is approximately equal to ε_r.

Garg and Long [10] put forward the idea that the fringing fields for an equilateral triangular microstrip patch can be considered equal to that of a disk having the same metalized area. The equivalent radius of the disk is given by



■ **Figure 2. Return loss vs. frequency.**

$$a_{eq} = \sqrt{\frac{S}{\pi}} \tag{6}$$

where a_{eq} is the equivalent radius and S is the actual area of the equilateral triangle.

It was accepted that the effective radius of the disk takes into account the fringing effect is given by

$$a_{eff.disk} = a_r\sqrt{1 + \frac{2h}{\pi\varepsilon_r a_r}\left(\ln\left(\frac{\pi a_r}{2h}\right)\right) + 1.7726} \tag{7}$$

where $a_{eff.disk}$ is the effective radius of the disk and a_r is the actual radius of the disk.

Substituting a_{eq} into equation (7) gives

$$a_{eff1} = a_r\sqrt{1 + \frac{2h}{\pi\varepsilon_r a_{eq}}\left(\ln\left(\frac{\pi a_{eq}}{2h}\right)\right) + 1.7726} \tag{8}$$

Garg and Long [10] also suggested that the effective sidelength calculated from Equation (8) should be used to replace the value of a in Equation (1) while keeping ε_r constant. Suzuki and Chiba [11] put forward a formula that took into account the effect of fringing field for an arbitrary shape patch. Based on this formula, Singh, De and Yadava [12] proposed that the effective sidelength be given by

$$a_{eff2} = a\left(\frac{a_{eff1}}{a_{eq}}\right) \tag{9}$$

where a_{eq} and a_{eff1} are calculated using equations (6) and (8) respectively. Another formulation for the effective sidelength was given by Kumprasert and Kiranon [13], which was derived from an expression for the capacitance of a disk patch antenna given by Chew and Kong [14]. The formula for a_{eff} is given by

$$a_{eff\,3} = a\left[1+\frac{2h}{\pi\varepsilon_r a_{eq}}\left[\ln\left(\frac{a}{2h}\right)+\left(1.41\varepsilon_r+1.77\right)+\frac{h}{a}\left(0.268\varepsilon_r+1.65\right)\right]\right]^{\frac{1}{2}} \quad (10)$$

Also, a paper was published by Guney [15], who proposed another expression for the effective sidelength. In that paper he used the term ε_{eff}, given by Equation (3), and a formula for a_{eff} given by

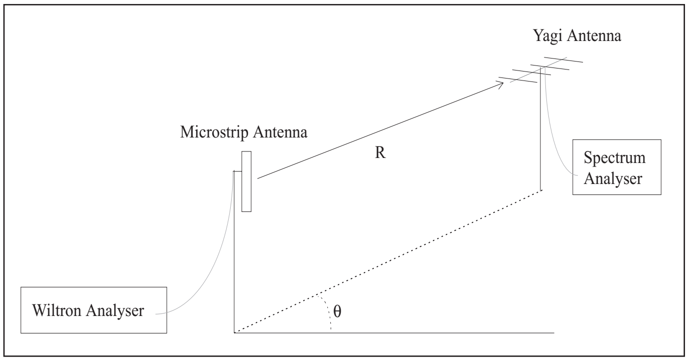
$$a_{eff\,4} = a + \frac{h^{0.6}a^{0.38}}{\sqrt{\varepsilon_{eff}}} \quad (11)$$

In the present investigation, the formula given by Kumprasert and Kiranon [13] is used because the correlation achieved between the theoretical and experimental values of the resonant frequency is the most accurate. The sidelength of the equilateral triangle was calculated to be L= 52.1 mm at the designed resonant frequency of 2.50 GHz. The lower and upper patches have similar dimensions and were constructed using RT/Duroid 5880 substrates with height h = 1.59 mm and dielectric constant ε_r = 2.2. The lower patch was probe-fed and the position of the feed point was chosen on the median line and located at a distance of one-third of the length down from the apex. This location of the feed point was deliberately chosen to obtain a strong mismatch between the input impedance of the isolated driven lower patch and the coaxial cable feeding it. The upper patch was electromagnetically coupled to the lower patch. The former is used to tune out the impedance mismatch over a wider frequency range by altering the height separation between the two patches. The layout of the stacked equilateral triangular microstrip antenna is shown in Figure 1.

Measurements

Initial measurements carried out on the isolated driven patch, using a Wiltron Network Analyser System, showed that the return loss was -2.88 dB at a resonant frequency of 2.523 GHz. The discrepancy between the design and measured frequencies is less than 1 percent. Figure 2 illustrates the dependence of the return loss on the frequency for various values of height separation between the two patches. It is evident from Figure 2 that, for the isolated driven lower patch, the value of the return loss obtained is a measure of the existing strong mismatch between the 50 Ω feeding cable and the input impedance of the patch. An optimum impedance bandwidth of 330 MHz was measured for S = 6.4 mm with the two ends of the frequency band being at 2.43 GHz and 2.76 GHz respectively.

The antenna gain and polar patterns were measured at these frequencies using the set-up shown in Figure 3. In the antenna gain measurement, the Friis transmission formula and a standard Yagi antenna were used in the following experimental procedures. First, the total



■ Figure 3. Antenna gain and polar pattern measurement setup.

power radiated from the transmitting antenna P_t must be established and kept constant. Then, readings for the power received P_r by the second antenna are taken, at various separations R between the two antennas as shown in Figure 3. The Friis transmission formula has the form $y = m(x)$ when R^2 and the ratio P_t/P_r are made the variables. The relationship is as follows

$$R^2 = \left[\left(\frac{\lambda}{4\pi}\right)^2 G_t G_r\right]\frac{P_t}{P_r} \quad (12)$$

Frequency	Wavelength	Spacing	Reflector Length	Driver Length	Director length
1	30.00	7.50	14.31	13.53	13.26
1.1	27.27	6.82	13.01	12.30	12.05
1.2	25.00	6.25	11.93	11.28	11.05
1.3	23.08	5.77	11.01	10.41	10.20
1.4	21.43	5.36	10.22	9.66	9.47
1.5	20.00	5.00	9.54	9.02	8.84
1.6	18.75	4.69	8.94	8.46	8.29
1.7	17.65	4.41	8.42	7.96	7.80
1.8	16.67	4.17	7.95	7.52	7.37
1.9	15.79	3.95	7.53	7.12	6.98
2	15.00	3.75	7.16	6.77	6.63
2.1	14.29	3.57	6.81	6.44	6.31
2.2	13.64	3.41	6.50	6.15	6.03
2.3	13.04	3.26	6.22	5.88	5.77
2.4	12.50	3.13	5.96	5.64	5.53
2.5	12.00	3.00	5.72	5.41	5.30
2.6	11.54	2.88	5.50	5.20	5.10
2.7	11.11	2.78	5.30	5.01	4.91
2.8	10.71	2.68	5.11	4.83	4.74
2.9	10.34	2.59	4.93	4.67	4.57
3	10.00	2.50	4.77	4.51	4.42
3.1	9.68	2.42	4.62	4.36	4.28
3.2	9.38	2.34	4.47	4.23	4.14
3.3	9.09	2.27	4.34	4.10	4.02
3.4	8.82	2.21	4.21	3.98	3.90
3.5	8.57	2.14	4.09	3.87	3.79
3.6	8.33	2.08	3.98	3.76	3.68
3.7	8.11	2.03	3.87	3.66	3.58
3.8	7.89	1.97	3.77	3.56	3.49
3.9	7.69	1.92	3.67	3.47	3.40
4	7.50	1.88	3.58	3.38	3.32
4.1	7.32	1.83	3.49	3.30	3.23
4.2	7.14	1.79	3.41	3.22	3.16
4.3	6.98	1.74	3.33	3.15	3.08
4.4	6.82	1.70	3.25	3.08	3.01
4.5	6.67	1.67	3.18	3.01	2.95

■ Table 1. Physical dimensions of the Yagi antenna, with frequency given in GHz and dimensions in centimeters.

The plot of R^2 on the y-axis against P_t/P_r on the x-axis gives a straight line with slope equal to

$$\left[\left(\frac{\lambda}{4\pi}\right)^2 G_t G_r\right]$$

Since one of the antennas is a standard Yagi antenna, whose gain (i.e., either G_t or G_r) is known, the gain for the equilateral triangular patch antenna can be readily calculated. The five element standard Yagi antenna was designed using the method of moments, and the dimensions at various frequencies are given in Table 1. The same experimental procedures were used to measure and calibrate the gain of a pair of similar standard Yagi antennas.

In the present investigation, it was found that the antenna gain at 2.43 GHz and 2.76 GHz was 8.7 and 8.8 dB respectively. The E- and H-plane radiation patterns were also measured these frequencies (i.e. at the two ends of the frequency band). These are illustrated in Figure 4. The corresponding half-power beamwidths are:

2.43 GHz: E-plane = 66 degrees
H-plane = 83 degrees

2.76 GHz: E-plane = 66 degrees
H-plane = 82 degrees

It is evident that there is no significant change in the polar pattern at these frequencies.

Conclusions

A vertically stacked, probe-fed equilateral triangular microstrip antenna having a wide impedance bandwidth has been investigated experimentally. The experimental technique employed in this design was to locate the position of the input feeding probe on the median line of the lower patch in such a way as to produce a strong mismatch between the feeding probe and the input impedance of the lower patch. The upper patch was then used to tune out the impedance mismatch over a wide frequency range by varying the height separation between the two patches. An optimum impedance bandwidth of 13.2 percent is achieved centered around a frequency of 2.50 GHz. ■

Acknowledgment

The authors wish to express their grateful thanks to John Hendricks of Rogers n.v., Gent, Belgium for supplying the RT/Duroid substrates used in this research work.

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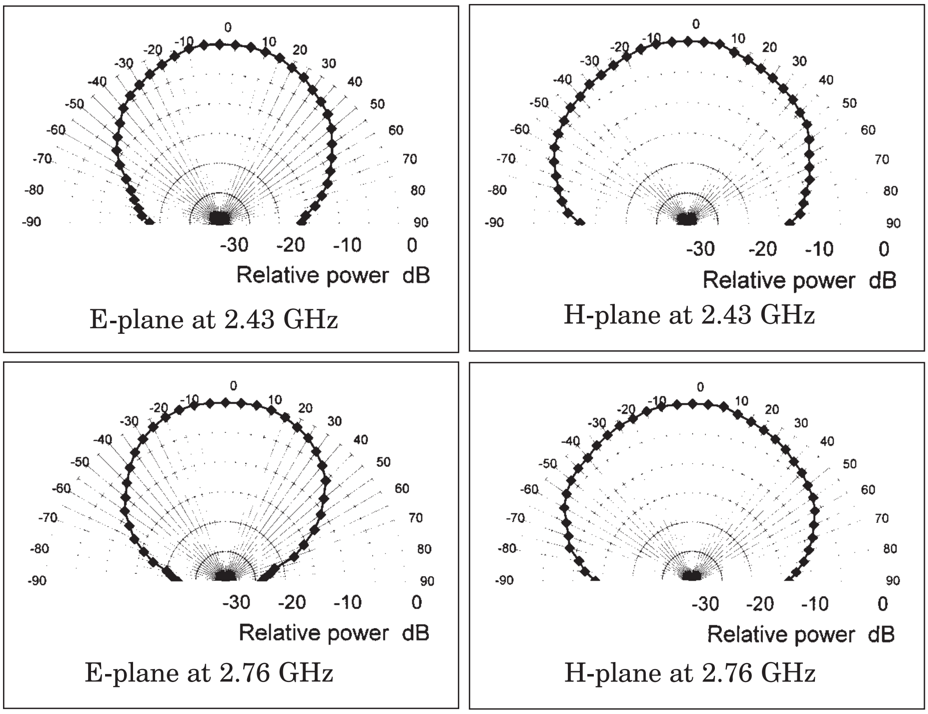

■ **Figure 4. Radiation patterns at the two ends of the frequency band.**

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