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Equilateral triangular microstrip antenna for circular polarization dual-band operation

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Experimental investigations were conducted on the equilateral triangular microstrip antenna to examine the radiation characteristic with two-layer triangular patch antenna. The two-layer triangular patch at both the frequencies 3.0 and 3.5 GHz radiate maximum power, VSWR, return loss, etc, which depended heavily on two-layer triangular microstrip patch antenna. It is shown to be possible to design two-layer equilateral triangular patch antenna for dual-band operation with reasonably good circular polarization.

Keywords: Microstrip antenna, Triangular antenna, Dual-band antenna, Circular polarization
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1 Introduction

A microstrip antenna (MSA) consists of a metallic patch radiator on an electrically thin-grounded dielectric substrate. The MSA has numerous unique and attractive features such as low profile, lightweight and conformable structure[1]. In many applications of such antennas on automobiles, aircraft and satellites, it is desired that MSA be used as a circularly polarized (CP) antenna. The CP antenna are classified into single-feed type and dual-feed type, depending on the number of feed points necessary to excite the circularly polarized waves[2]. The single-feed type is especially useful because it requires no external circular polarization such as the 90º hybrids. One of the most attractive features of the MSA is its ability to produce the CP waves easily with a single-feed. This is achieved by applying some perturbation or modification to a patch radiator having a standard geometry[3]. For example, according to the usual theories, the patch radiator of such a MSA has a nearly square geometry with a slot or cut-out on one diagonal line, a nearly circular (or elliptical) geometry or a circular geometry with a slot or cut-out on one diameter[4]. In these MSA the feed point is located near to two straight lines intersecting at an angle of +45º with respect to the symmetrical axis. In addition to the above MSA, a pentagonal MSA proposed by Weinschel is well known as a special example of a single-feed circularly polarized MSA. That apart the CP wave can also be produced from the single-feed equilateral triangular microstrip antenna[5,6]. Thus dual CP response may be useful on operating MSA as a CP antenna in dual frequency mode, e.g. transmitting and receiving modes.

2 Resonant frequency

The resonance frequency corresponding to various modes can be given[7] by

$$f_{\mathrm{r}} = \frac{ck_{\mathrm{mn}}}{2\pi\sqrt{\varepsilon_{\mathrm{r}}}} = \frac{2c}{3a\sqrt{\varepsilon_{\mathrm{r}}}}\sqrt{m^2 + mn + n^2} \qquad \dots (1)$$

where c is the velocity of light in free space and K_{mn} = wave number, given by

$$K_{\mathrm{mn}} = \frac{4\pi}{3a}\sqrt{m^2 + mn + n^2}$$

The expression for lowest order resonance frequency is

$$f_{\mathrm{r}} = \frac{2c}{3a\sqrt{\varepsilon_{\mathrm{r}}}} \qquad \dots (2)$$

In this relation end effects of fringing fields are not considered. The resonant frequency may be determined with better accuracy if ε_{r} and a in the above equation are replaced by effective dielectric constant $\varepsilon_{\mathrm{eff}}$ and a_{eff}, which are given by

$$\varepsilon_{\text{eff}} = \frac{1}{2}(\varepsilon_r + 1) + \frac{1}{4}\frac{(\varepsilon_r - 1)}{\sqrt{1 + \frac{12h}{a}}} \quad \ldots (3)$$

and

$$a_{\text{eff}} = a + \frac{h}{\sqrt{\varepsilon_r}} \quad \ldots (4)$$

respectively. Hence

$$f_r = \frac{2c}{3a_{\text{eff}}\sqrt{\varepsilon_{\text{eff}}}} \quad \ldots (5)$$

It is clear from Eqs (3) and (4) that for high dielectric constant substrates such as alumina, ε_r and a should be used in place of ε_{eff} and a_{eff}, respectively.

3 Determination of patch dimensions

Let a be the side length of the equilateral triangular MSA and the used substrate material is bakelite. The various parameters used for the design of the antenna are given below:

Relative dielectric constant ε_r	= 4.78
Substrate thickness h	= 0.15 cm
Thickness of the copper foil t	= 0.0018 cm
Loss tangent tan δ	= 0.03045
Design frequency for bottom triangular patch	= 3.0 GHz
Design frequency for top triangular patch	= 3.5 GHz

Thus according to Eq.(2) for f_r = 3.0 GHz the length of the side for the bottom triangular patch is given as

$$a_1 = \frac{2c}{3f_r\sqrt{\varepsilon_r}} = \frac{2\times 3\times 10^{10}}{3\times 3\times 10^{9}\times\sqrt{4.78}} = 3.05 \text{ cm}$$

and

for f_r = 3.5 GHz the length of the side for the top triangular patch is given as

$$a_2 = \frac{2\times 3\times 10^{10}}{3\times 3.5\times 10^{9}\times\sqrt{4.78}} = 2.61 \text{ cm}$$

4 Location of feed point

The feed point location is calculated using a cavity model, in which a magnetic wall surrounds the triangle. For simplicity coaxial feeding is used, since the coaxial cable impedance in general is 50 Ω. Here, a point is to be found out on the patch conductor where impedance is 50 Ω. There are a large number of points inside the patch having 50 Ω impedance. These points constitute a locus, called as 50 Ω locus. Feeding at any of these points results in maximum radiation because of perfect matching.

The input impedance is obtained using the field equations given as[8]

$$E_z = A_{1,0,-1}\left[2\cos\left(\frac{2\pi x}{\sqrt{3}a} + \frac{2\pi}{3}\right)\cos\frac{2\pi y}{3a} + \cos\frac{4\pi y}{3a}\right] \quad \ldots (6)$$

$$H_x = -jA_{1,0,-1}\xi_0\left[\cos\left(\frac{2\pi x}{\sqrt{3}a} + \frac{2\pi}{3}\right)\sin\frac{2\pi y}{3a} + \sin\frac{4\pi y}{3a}\right] \quad \ldots (7)$$

$$H_y = j\sqrt{3}A_{1,0,-1}\xi_0\left[\sin\left(\frac{2\pi x}{\sqrt{3}a} + \frac{2\pi}{3}\right)\cos\frac{2\pi y}{3a}\right] \quad \ldots (8)$$

where, $\xi_0 = 1/120\,\pi$ (mhos)

Input impedance (Z_{in}) is calculated by

$$Z_{in} = \frac{2E_z}{H} \quad \ldots (9)$$

where $H = \sqrt{H_x^2 + H_y^2}$

Here, for different feed points (x, y) the values of E_z, H_x, H_y and finally the input impedance Z_{in} is in the range of 48-50 Ω. A coordinate system of triangular patch antenna is shown in Fig. 1. An equilateral-triangular-patch of area S is etched on the metallic

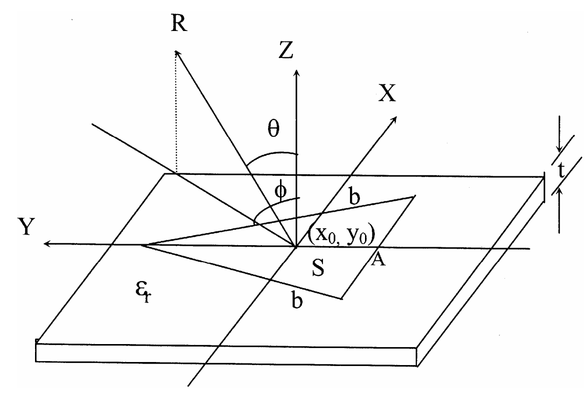

Fig. 1—Coordinate system for equilateral-triangular microstrip antenna

constant ε_r. Usually the patch is fed either by a microstrip feed line or by a coaxial probe. To get good CP wave from an MSA with a single feed, the patch must be generally fed at an optimum feed location (x_0, y_0). The loci of 50 Ω input impedance for the triangular patch are shown in Fig. 2[(a) and (b)] for operating frequencies 3.0 and 3.5 GHz, respectively.

When the two triangles are matched keeping the center point o common for the two cases and considering the feed location loci T_1 and T_1' for the two triangular patches, it is seen that the loci are overlapping even though the dimensions of the patches are different, because of different design frequencies. The overlapping of curves in Fig. 2(b) ensures that if the feed is chosen on the curve then two-layer antenna can be operated at two different frequencies, radiating circularly polarized waves.

5 Experimental set-up

For the experimental set-up the source of microwave signal was a S-band klystron, which could deliver a power of 12 mW. The output of the source was fairy constant during the measurement. The frequency of the signal was 3.5 GHz. The source of the microwave power was quite stable and frequency variations were negligibly small. An isolator with an isolation of 30 dB was used to avoid the reflection from the antenna system and, therefore, the source was interference free during the experimentation. The transmitting antenna was a pyramidal horn having an aperture of 9.2 × 5.3 cm. The developed microstrip antenna was used for receiving purpose. It was fixed on a turntable kept on a wooden stand, which provided the necessary rotation to the antenna in azimuth plane. The turntable was calibrated in terms of angle. The square law detector was used for measuring the received power.

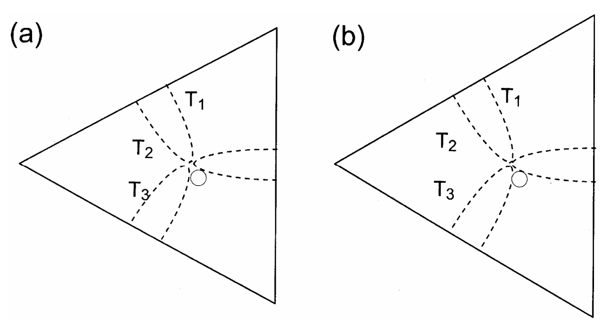

Fig. 2—Loci of 50 Ω input impedance for the triangular patch at (a) 3.0 GHz and (b) 3.5 GHz

6 Experimental measurements

The set-up used for measuring the radiation pattern of the patch antenna in two orthogonal planes is shown in Fig. 3 [(a) and (b)]. During the experiment the output of the source was fairly constant. The source of the microwave power was quite stable. Isolator was used to avoid the reflection from the antenna. The receiver system was kept in far zone, i.e. $R = (2d^2/\lambda)$. Using the setup the radiation patterns of the antenna were measured at frequencies 3.0 and 3.5 GHz, separately. Using the set-up shown in Fig. 3(b) the VSWR and return loss for the patch antenna at source frequencies from 2 to 4 GHz were also measured.

7 Discussion of results

(i) From the examination of radiation pattern Figs 4(a) and (b) it is observed that radiated power of two-layer triangular patch at the two frequencies 3.0 and 3.5 GHz radiate maximum power along the on-axis direction, both for co-polar and cross-polar case (the polarization orthogonal to a reference polarization). The radiated power degrades in the off-axis directions. The on-axis axial ratio[9] indicates good circular polarization. However the axial ratio degrades in the off-axis direction, indicating that the circular polarization degrades in the off-axis direction and the axial ratio is almost 3 dB.

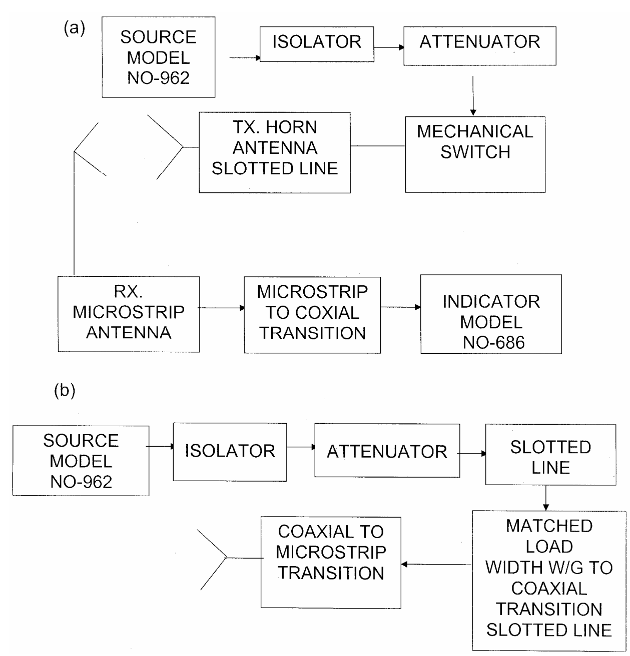

Fig. 3—Set-up for (a) radiation pattern and (b) VSWR measurement

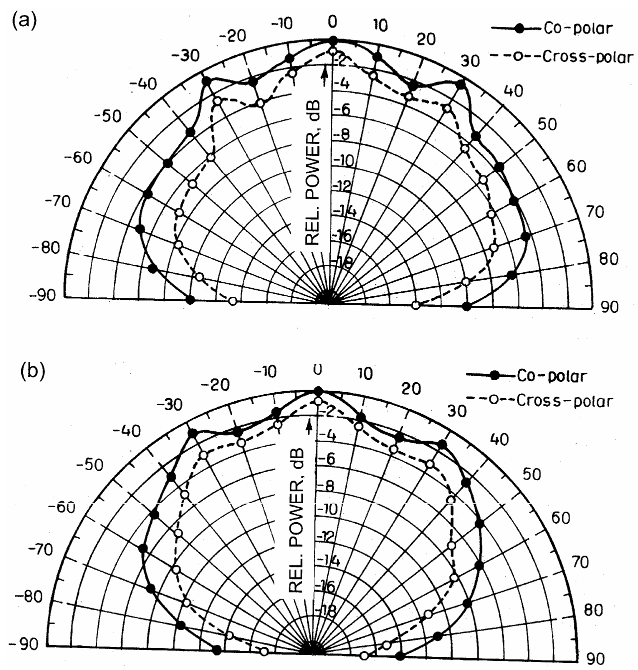

Fig. 4—Radiation pattern in two orthogonal plane at (a) $f = 3.0$ GHz and (b) $f = 3.5$ GHz

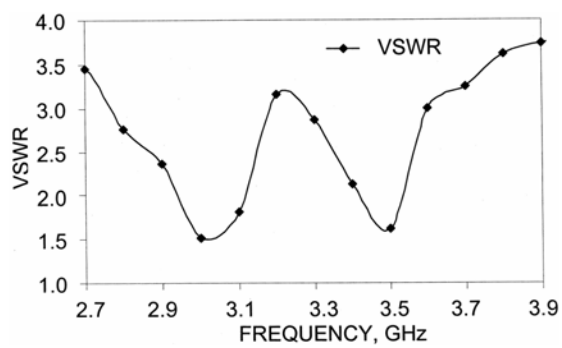

Fig. 5—Variations of VSWR with frequency (GHz)

(ii) Variation of VSWR with frequency is shown in Fig. 5. It is observed that the developed antenna shows two resonance frequencies 3.0 and 3.5 GHz, for which the antenna is designed. This also indicates the accuracy of the design for the dual band antenna.

(iii) From the return loss variation with frequency it is found that the antenna can be operated within the frequency band 2.92-3.12 GHz, i.e. within a bandwidth of 0.20 GHz, at the first resonance frequency 3.0 GHz, considering the return loss as 10 dB. The antenna can be operated within the frequency band 3.42-3.52 GHz, i.e. within a bandwidth of 0.10 GHz for the second resonance frequency 3.5 GHz, considering the same return loss.

(iv) This shows that it is possible to design two-layer equilateral triangular patch antenna for any dual band operation with reasonably good left circular polarization.

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