A Gap Coupled Stacked E-shaped Patch Antenna for Broadband Operation

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ABSTRACT

A gap-coupled stacked E-shaped patch antenna for broadband operation is proposed. The antenna is, theoretically, analyzed using circuit theory concept. The optimized antenna shows an operational frequency band of 207 MHz (impedance bandwidth of 40.43 % at center frequency 5.12 GHz). The antenna operates within its acceptable limit (<-10 db return loss) with gain of 7.5 dB and 3-db-beam width of 48.6^0. The theoretical results have been compared with IE3D simulated results.

1. INTRODUCTION

The demand for application of microstrip antenna in various communication systems has been increasing rapidly due to its small size, low cost, lightweight, ease of integration with other microwave components. But many of its applications require wide bandwidth, which is not provided by the conventional microstrip antenna. Therefore, many methods have been proposed in open technical literatures to improve the performance of the antenna. Among these methods, cutting of slots into the patch is a very significant advance in improving the inherent narrow bandwidth of the microstrip antenna [1]. By using an E-shaped patch, Yang et al [2] has realized a broadband operation with 30% impedance bandwidth. It may be mentioned that the bandwidth can also be improved by stacking a parasitic patch on the fed patch [3]. Therefore, in the present paper, an attempt has been made to enhance impedance bandwidth of a probe fed E- shaped patch antenna by adding a parasitic square patch vertically above the fed patch in the form of stacked structure. The antenna has been analyzed using modal expansion cavity model and circuit theory concept. The details of theoretical investigations are given in the following sections:

2. ANTENNA DESIGN AND FORMULATIONS

Fig. 1 shows the geometrical configuration of the proposed antenna. The lower E-shaped patch is like a rectangular patch of length L_d=35.6 mm and width W_d=24.6 mm with two identical slots incorporated in one of its radiating edge. Each slot of length L_S = 15 mm and width W_s = 2.75 mm, is positioned symmetrically with respect the feed point in such a way that P_s = 4.5 mm. The upper square patch of side $L_p = W_p$ = 16 mm, is gap-coupled tothe fed E-shaped patch. A coasial probe of diameter 1.29 mm feeds the lower patch. Air is used as dielectric substrate of constant $\varepsilon_{r1} = \varepsilon_{r2} = 1$ and thickness h_1 = 3.55 mm, h_2 = 3.75 mm for the fed and parasitic patches, respectively.

The proposed antenna behaves as an antenna having two resonators. One resonator is associated fed E-shaped patch and second resonator is associated with the parasitic square patch. Due to the presence of parasitic patch, dielectric substrate-2 acts as superstrate Due to the presence of superstrate the effective dielectric constant for the two resonators are changed that causes change in their resonance behaviors. For the first resonator, dielectric substrate-2 can be considered as a superstrate of E-shaped patch. Therefore, the effective dielectric constant for the first resonator is given as [4].

$$\varepsilon_{ef} = \varepsilon_{r1} q_1 + \varepsilon_{r2} \frac{(1-q_1)^2}{\varepsilon_{r2}(1-q_1-q_2)+q_2} \qquad ...(1)$$

where q_1 and q_2 are the filling factors.

The effective dielectric constant with superstrate can be represented as a single patch with semi-infinite superstrate of relative dielectric constant equal to unity and a single relative dielectric constant equal to ε_{rf} given as

$$\varepsilon_{rf} = \frac{2\varepsilon_{ef} - 1 + A}{A}; \quad A = \left(1 + \frac{2h_1}{W_d}\right)^{-1/2} \qquad ...(2)$$

Therefore, the resonance frequency of the first resonator is given as

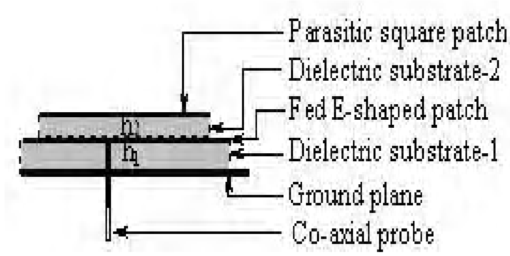
$$f_{r1} = \frac{c}{2(L_d + \Delta L_d)\sqrt{\varepsilon_{ef}}} \qquad ...(3)$$

where ΔL_d is the fringing length for the fed patch and c is the velocity of light in free space.

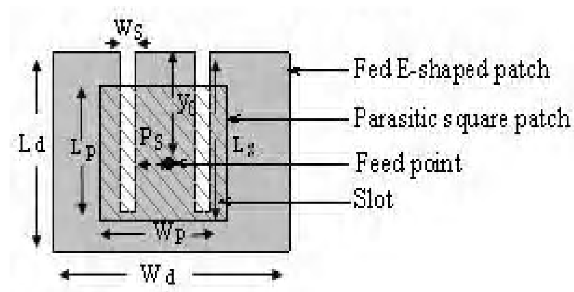
The impedance and resonance characteristics of the parasitic patch are affected by the two layers of the substrate below it (excluding patch metallisation of the E-shaped patch). Therefore, the effective dielectric constant for the second resonator can be given as [5].

$$\varepsilon_{ep} = \frac{\varepsilon_{re2}+1}{2} + \frac{\varepsilon_{re2}-1}{2}\left(\frac{10\sum_{i=1}^{2} h_i}{L_p}\right) \qquad ...(4)$$

$$\text{where } \varepsilon_{re2} = \frac{\sum_{i=1}^{2} h_i}{\sum_{i=1}^{2} \frac{h_i}{\varepsilon_{ri}}}; \quad i = 1,\ 2$$



(a)



(b)

Fig. 1: Geometrical configuration of the proposed antenna (a) Top view and (b) Side view

Therefore the resonance frequency of the second resonator is given as

$$f_{r1} = \frac{c}{2(L_d + \Delta L_d)\sqrt{\varepsilon_{ef}}} \qquad ...(5)$$

According to the modal expansion cavity model [6], each resonator can be represented by a parallel *R* - *L* - *C* circuit. Therefore the equivalent circuits of the two resonators are shown in Fig. 2 (a-c). From these figures, their impedances can be derived as

$$Z_E = \frac{(Z_1 - j\omega C_c) Z_2}{Z_1 + Z_2 + j\omega C_c} \qquad ...(6)$$

$$Z_S = \frac{j\omega L_2 R_2}{R_2 - \omega^2 L_2 C_2 R_2 + j\omega L_2} \qquad ...(7)$$

where Z_1 and Z_2 are the impedances of the center and side wings of E-shaped patch, C_C is coupling capacitance between these wings. R, L, C and R_1, L_1, C_1 characterize the center wing and side wing of the E-shaped patch, respectively. These are calculated as [7]. R_2, L_2 and C_2 are the resistance, inductance, and capacitance of the square patch calculated as [6]. These two resonators electro-magnetically couple together so that the equivalent circuit of the proposed antenna becomes as shown in Fig. 2(*d*). Therefore, the input impedance of the antenna can be derived as

$$Z_{IN} = X_P + \frac{Z_E\,(Z_C + Z_S)}{Z_E + Z_C + Z_S} \qquad ...(8)$$

where $X_P = j\omega\, L_P$ and

$X_C = j\omega L_M / (1 - \omega^2 L_M C_M)$, L_P is the inductance due to the co-axial probe. L_M and C_M are the mutual inductance and capacitance respectively.

The return loss (*RL*) of the antenna is given as

$RL = 20 \log_{10} |\ \Gamma\ |$

where $\Gamma = (Z_{IN} - Z_0) / (Z_{IN} - Z_0)$, Z_0 is the characteristic impedance of the coaxial feeding line of 50 ohm.

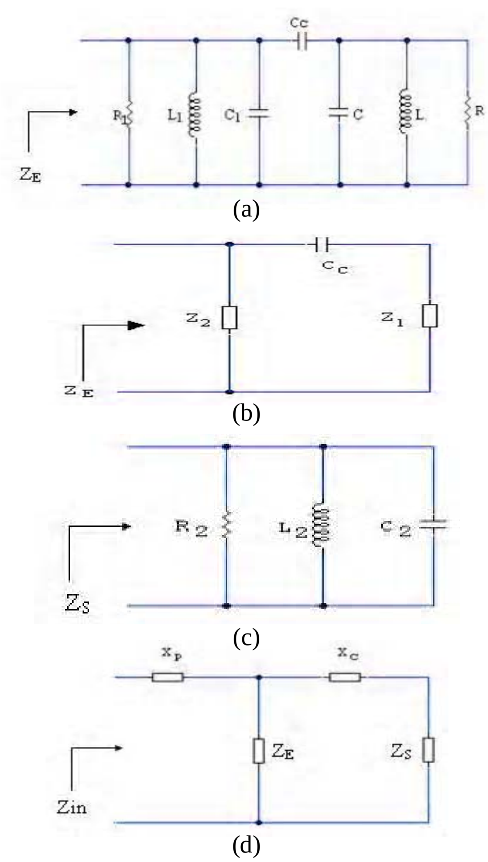


Fig. 2: Equivalent circuits of (a) E-shaped patch, (b) E-shaped patch (modified), (c) Square patch and (d) Proposed antenna

The E-plane radiation pattern for the rectangular patch is given as [8]

$$E(\phi) = \frac{jkW_d V_O e^{-jkr}}{\pi r} \left[\frac{\sin\left(\frac{kh\,\cos\phi}{2}\right)}{\frac{kh\,\cos\phi}{2}} \right]$$

$$\cos\left(\frac{kL_d\,\sin\phi}{2}\right) -\frac{\pi}{2} \le \phi \le +\frac{\pi}{2}$$

where V_O is the radiating edge voltage, r is the distance of an arbitrary far-field point and k is the propagation constant in the dielectric medium.

There exists coupling between the E-shaped patch and the parasitic element; therefore, the resultant radiation is contributed by the coupling between them. For the far-field E-plane radiation of the proposed antenna, following assumptions can be made

1. E-shaped patch can be approximated as a rectangular patch for small slot width.
2. The slot voltage induced in the parasitic element is C_C times the slot voltage of the main patch.
3. The radiations from the two patches are in the same phase as the gaps between the fed patch and parasitic patch are very small as compared to the far-field point.

Hence the radiated far-field of the proposed antenna in the E-plane can be written as

$$E(\phi) = \frac{jkW_d V_O e^{-jkr}}{\pi r} \left[\frac{\sin\left(\frac{kh_1\,\cos\phi}{2}\right)}{\frac{kh_1\,\cos\phi}{2}} \right] \cos\left(\frac{kL_d\,\sin\phi}{2}\right)$$

$$+2C_C \frac{jkW_P V_O e^{-jkr}}{\pi r} \left[\frac{\sin\left(\frac{kh_2\,\cos\phi}{2}\right)}{\frac{kh\cos\phi}{2}} \right] \cos\left(\frac{kL_p\,\sin\phi}{2}\right) \qquad ...(10)$$

3. CALCULATIONS AND DISCUSSION OF RESULTS

The calculations for return loss of the antenna were carried out using equation (9) to obtain the optimum conditions. The variation of return loss with frequency for the optimized antenna is shown in Fig. 3. It is observed that the antenna has two resonance frequencies in which upper one is associated with parasitic square patch and lower one is associated with the fed E-shaped patch. The lower resonance frequency appears at 5.32 GHz and higher one at 6.58 GHz. On the other hand, the simulated results show the resonance at 5.41 GHz and 6.51 GHz, respectively. The theoretical frequency band of the antenna is obtained between 5.10 GHz and 7.17 GHz with bandwidth of 40.43% at center frequency of 5.12 GHz, whereas the simulated result shows 38.48 % impedance bandwidth. Thus simulated results along with theoretical results justify the veracity of the proposed method.

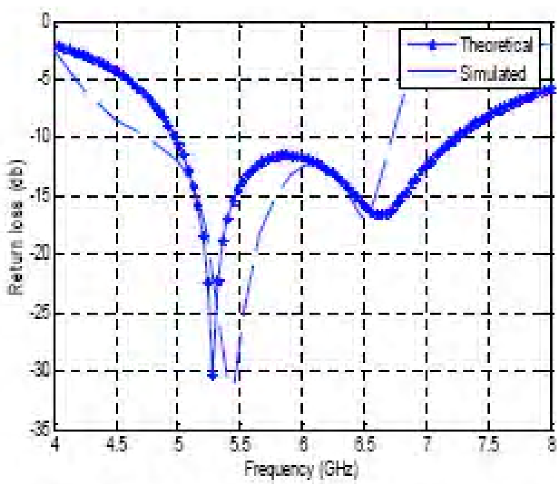


Fig. 3: Variation of return loss with frequency

The calculations for E-plane radiation pattern of the antenna were accomplished using equation (10), the resulting data are shown in Fig. 4, for frequency 5.28 GHz. It depicts that direction of maximum radiation is shifted by 6^0 from the broadside direction. The antenna shows a 3-dB beam width of 48.6^0 with gain of 7.5 dB.

4. CONCLUSIONS

It is, therefore, concluded that due to dual resonance nature the proposed antenna shows a broadband characteristic. It is noted that the antenna operates in

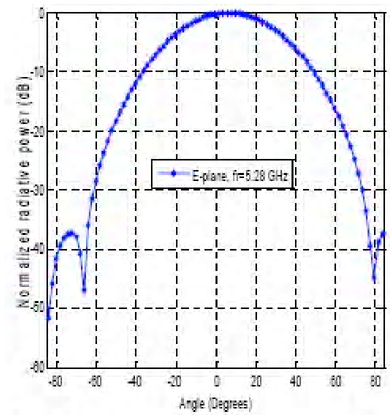


Fig. 4: E-plane radiation pattern at frequency 5.28 GHz

acceptable limit (< -10 db return loss) from 5.10 GHz to 7.17 GHz (frequency band of 207 MHZ) with impedance bandwidth of 40.43 % that can be applied in various communication systems.

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