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Miniaturization and Feeding Techniques of H-Shaped Antenna

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Abstract— **Rectangular Microstrip Antenna (RMSA) with a slot cut inside the rectangular patch at an appropriate position increases the surface current length and hence results in a compact RMSA like H-shaped MSA. This paper analyses the approximate equations to calculate the resonant length of the compact H-shaped MSA and discusses the technique for further miniaturization of the H shaped MSA by shorting one arm of the patch. Analysis of the antenna using FDTD method and different feeding techniques is also presented.**

***Keywords*—** Rectangular Microstrip Antenna, Electric Field and Current Distribution, Miniaturization.

I. Introduction

Rectangular Microstrip antenna (RMSA) with the slot cut at an appropriate position inside the MSA (RMSA) increases the surface current length thereby realizing a compact RMSA, like H-shaped MSA. The microstrip antennas are preferable over other types of radiating element due to its small size, low profile and lightweight. They can be made conformal and well suited to integration with microwave integrated circuit. In terms of fabrication, such system offers simplicity, so as to allow mass production and cost-effective manufacturing as well as high performance. The ever increasing demand for compact wireless communication equipment necessitates the research in compact antenna.

It has been noted that reactive loading such as shorting pin, stubs, slots, and capacitors lead to significant size reduction. Another approach based on the increase of electrical length by cutting slits in the radiating patch has also been used. H-shape antenna is one of the examples of this approach. However in the literature, only very few attempts have been made towards the complete analysis of H-shaped microstrip antennas. Results of an H-shaped microstrip patch for single-frequency operation was firstly published by Palanisamy and Garg [1]. They observed that the H-shaped patch antenna is smaller in size (about half), and is broadbeam but with narrow bandwidth. Singh et al [2] proposed an H-shaped patch antenna loaded with multiple shorting pins which will find application in MMIC design. This antenna occupies approximately one tenth of the substrate area of a half wavelength patch antenna. Gao et al [3] proposed a dual- frequency, compact antenna, which uses an H shaped microstrip patch with a shorting pin. Sheta et al[4] studied a multi-band compact H-shaped microstrip antenna. The resonant modes of the H-shaped structure were analyzed using the concept of electric and magnetic walls at the planes of symmetry. It was shown that dual, triple, or quad-band operation is possible by the proper location of a coaxial feed. Many methods have been developed to achieve the analysis of arbitrary shaped microstrip antennas such as: transmission-line model, cavity model and the moments method .However this paper presents the formulation for the H shaped antenna [5]. The technique to reduce the size of the antenna is analyzed using the shorting pins[6]. The performance of antenna is analyzed based on the feeding technique[7-8]and the antenna analysis is done by finding the electric field and current distribution and radiation pattern using FDTD method [9].

II. H-SHAPED ANTENNA

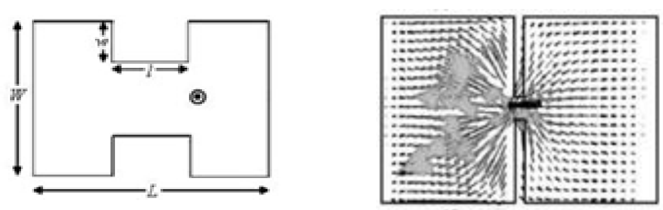
A. THEORITICAL FORMULATION

The H-shaped MSA is shown in Figure 1. For slot dimension of l =0.2 and w= 0.5 cm, L_e is obtained by averaging the length of the RMSA and the length along the slot as given in Eq. (1). W_e is calculated using following equations.

$$L_e=L+W \quad (1)$$

$$W_e= [W(L-l)+(W-w)l]/L \quad (2)$$

As w increases, the average length approaches the length along the slot as shown in Figure 1(b). A better approximation for these cases is obtained when the length along the slot is averaged with the length which does not entirely follows the slot but has some contribution in its value due to the slot as given in Eqs. (3)–(6).



(a) (b)

Figure 1(a)H-shaped Microstrip Antenna.(b)Electric Current Distribution for w=0.2cm, l=1.75cm.

The length $L_1$and L_2 has some contribution due to the slot. This is valid for w = 1.0 cm, or for w > 0.25*W.

$$L_1 =L +2w \quad (3)$$

$$L_2 = L +2w_x \quad (4)$$

$$w_x =w -1.0 \quad (5)$$

$$L_e =(L_1 + L_2)/2 \quad (6)$$

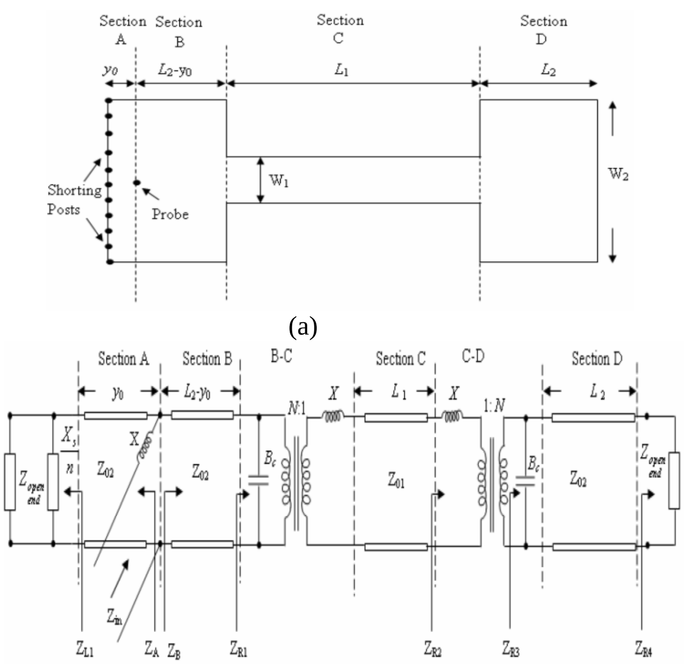
The surface current distribution for the slot of dimension l = 0.2 and w = 1.75 cm is shown in Figure 1(b). Here the average current length is along the slots. Therefore the L_e is modified and is given by Eq. (7). This reduces the error for larger slot dimensions of w > 0.8 * (W/2).

$$L_e = L + 2w \quad (7)$$

Thus, in all the slotted compact MSAs, for smaller w, the L_e is obtained by averaging the patch length with length along the slot. For larger w, H-shaped MSAs, the L_e approaches the length along the slot.

B. MINIATURIZATION BY INDUCTIVE LOADING TECHNIQUE

The theoretical analysis of shorting posts loaded H-shaped planar antenna is presented. A study of resonant frequency, return loss and saving in patch area of the antenna are discussed based on the transmission line model. It is found that resonant frequency, return loss and saving in patch area of the designed antenna are very sensitive to the dimensions of middle section of the patch. Figure 2(b) shows the equivalent circuit of the shorting post loaded H-shaped microstrip patch antenna.



(a)

(b)

Figure 2.(a) Shorting port loaded H-shaped microstrip patch antenna.(b)Equivalent circuit of shorting pin loaded patch antenna.

The antenna consists of an H-shaped microstrip patch, supported on a grounded dielectric sheet of thickness h and dielectric constant ε_r. The H-shaped patch can be divided into three parts consisting of a center conductor strip with length L_1 and width W_1 and two identical conductor strips with length L_2 and width W_2 on its two sides. One of the radiating edges of the patch is shorted by n numbers of equidistant shorting posts. r_s is radius of shorting posts and the feed point is located at the central line of the H-shaped patch, at a distance of y_0 from the shorted radiating edge. The important parameters for analysis are:

A. Resonant Frequency

$$f_r = \frac{kc}{4\pi\sqrt{\varepsilon_r}} \quad (8)$$

B. Return Loss

$$\text{return loss} = 10\log\frac{1}{\rho^2} = -20\log\rho \quad (9)$$

C. Patch Area:

$$A_H = 2W_2L_2 + W_1L_1 \quad (10)$$

$$A_R = \left[\frac{c}{2f_r\sqrt{\varepsilon_{eff}}} - 2\Delta l\right]W_2$$

Variations of Resonant Frequency and Return Losses:

i. Variation of resonant frequency with W_1/W_2 for the patch loaded with n= 10 (shorting posts):
It is observed that the resonant frequency of the patch decreases as W_1/W_2 decreases. The possible reason of deviation of resonant frequency for lower values of W_1/W_2 is negligence of mutual coupling between all the radiating edges.

ii. Variation of return loss with frequency for different width of middle section and n = 10:
The Return Loss first increases and then keeps falling with increase in the width.

iii. Variation of resonant Frequency with L_2/L_1 for different width of Middle section and n=10:
It is observed that lowest possible resonant frequency is obtained when W_1=1 mm and L_2/L_1=0.23. It is also observed that the point of lowest resonant frequency is shifted towards lower values of L_2/L_1 for higher values of W_1.

Hence, the inductively loaded H-shaped microstrip patch antenna shifts the resonant frequency to lower side by (i) increasing the number of shorting posts, (ii) decreasing W_1/W_2 and (iii) optimizing the value of L_2/L_1, which presents its potential for size reduction and suitability for wireless communication.

C. FEEDING TECHNIQUES

i. Capacitive feeding

In the Capacitive Feeding of the antenna, there are two patches in which the larger patch act as radiator and small one serves as a feed strip which couples the energy to the radiators by capacitive means.(Figure.3) The antenna substrate is placed above the ground plane at air gap g with a substrate having dielectric constant=3, loss tangent=0.0013, and thickness h=1.56mm. Such an antenna operates at the frequency of 5.1 GHz . VSWR bandwidth of 46% is obtained at 5.1GHz. Specification of the antenna for 5.1 GHz are length(L) 15.5mm, width(W) 13.12mm, length of feed strip(s) 3.7mm, width of feed strip(t) 1.8 mm, length of slot(W_1) 8.2, width of slot 1.55mm, separation of feed strip 0.75mm, air gap(h) 6mm and probe diameter of 0.8 mm.To avoid spurious radiation and to let the radiations goto non- radiating edges there is a slot at the corner.

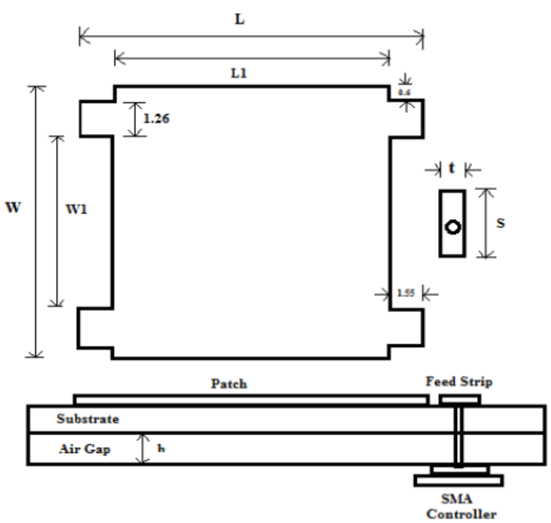


Figure 3 Capacitive feed H Patch antenna

- **Effect of Air Gap**
  It has been observed that as air gap increases the bandwidth decreases.
- **Effect of Probe Diameter**
  It has been observed that, there is an enhancement in the VSWR bandwidth if the probe diameter is changed as it reduces the inductance effects. But the variation will lead to increase or decrease in bandwidth with slight variation in diameter of probe.
- **Effect of the separation distance between Feed Strip and Radiator Patch**
  VSWR bandwidth increases by increasing the separation distance between radiator patch and feed strip.
- **Effects of the dimensions of Feed Strip**
  The bandwidth reduction caused by increasing the strip width (t) can be restored to a great extent by decreasing its length. The variation of changing the feed strip width, antenna input resistance increases and the input reactance decreases with an increase in the length of the feed strip.

However, the drawback of the feed strip is that it causes the asymmetry in radiation characteristic at the higher frequency because of spurious radiation along the non-radiating edges of the patch.

ii. CPW Feed

H-shaped narrow slot antenna fed by a coplanar waveguide (CPW) is analyzed. The antenna operates in the 2.4 GHz band and is used for WLAN applications. It has a bandwidth of 13.5%, and the radiation pattern measured at resonance is very close to Omni-directional in the H-plane. It is designed on FR4 substrate of thickness h=1.6 mm and relative permittivity ε_r=4.2.

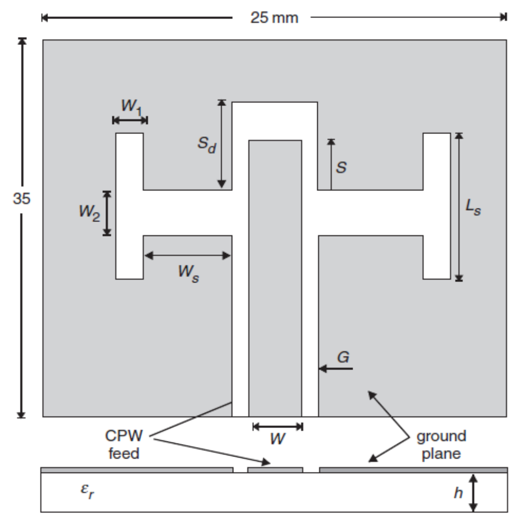


Figure4.Geometry of CPW-fed capacitive H-shaped slot antenna

The design parameters are: W_s=7 mm, W_2=3 mm, L_s=11 mm, W_1=1.2 mm, S_d=5 mm and S=6 mm. The width of the strip and slot of the 50 ohm CPW feed line, W and G, are chosen to be 3.7 and 0.4 mm, respectively. In addition, the total length of the perimeter of the H-shaped slot is about 1.02 λ_s (~101.8 mm) where λ_s is about 99.5 mm and λ_s is the guided wavelength in the slot determined to be about 0.8 λ_0 by considering the presence of different dielectric substrates on the two sides of the slot. The gain of antenna is 2.5 dBi .It is observed that the radiation patterns are similar to a half wavelength dipole antenna in the two radiating planes and the patterns in the H-plane are more omni-directional when compared to the conventional slot antenna because the H-slot is narrower than the conventional, and because of different electric field distribution in the H-shape slot.

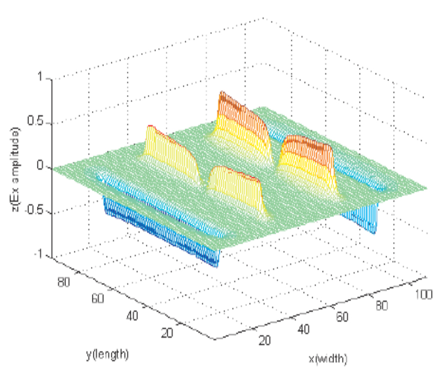
Hence capacitive fed antenna provides 46% of bandwidth on a substrate with ε_r =3 and operates at 5.1GHz and the CPW fed antenna operates at 2.4GHz and has a bandwidth of 13.5% on the substrate with ε_r=4.2. .

D. METHOD OF ANALYSIS USING FDTD METHOD

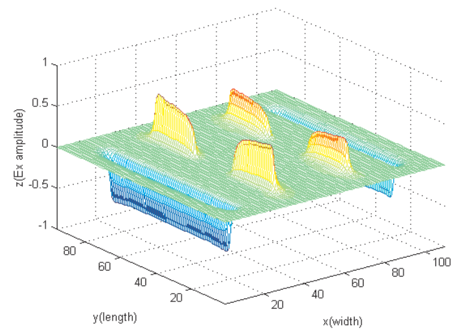
Finite-difference time-domain (FDTD) algorithm is used for the theoretical analysis as it is very simple to understand and can be used for antennas of much complexity. The first important thing in designing an antenna is to grid up the object. The grid size must be small enough so that the fields are sampled sufficiently to ensure accuracy. Once the grid size is chosen, the time step is determined such that numerical instabilities are avoided, according to the stability condition. A Gaussian pulse voltage with unit amplitude is excited in the probe feed. For the feed probe, a series resistor Rs with the voltage generator is used to model the current in the feed probe. To get the electric current distributions on the patch and the ground plane, a sinusoidal excitation at the probe feed is used, which is given by V (t) = sin $2\pi f_0 t$, where f_0 is the resonant frequency of interest. The field distributions are recorded at one instant of time after the steady state has been reached.

i. Electric Field Distribution

The distributions of electric field components E_x, E_y and E_z in the H-shaped patch are quite different from those of the conventional rectangular patch. Figures 5(a) ,(b) &(c) shows the distributions of the electric fields component E_z in the case when the parameters of the H-shaped patch antenna are W_2 (total patch width) = 33mm, L_2 (side strip length) = 14.3mm, L_1 (center strip length)= 26mm, ε_r = 2.5, h = 1.59 mm, and (center strip width) W_1 is changed to 2mm, 10 mm and 33 mm respectively(Figure2(a)).The distributions of electric fields also vary with the change of the center strip width. The results show that for the H-shaped patch antennas, the distribution of the electric field component E_z is anti symmetrical in the patch length direction (along the x axis here). The electric fields E_x, E_y and E_z are generated at all edges of the H-shaped patch. These fringing fields are the radiating sources in the H-shaped patch antenna.



(a)



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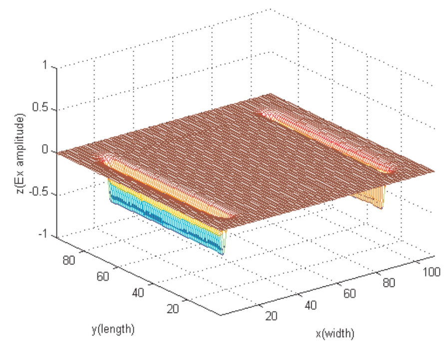
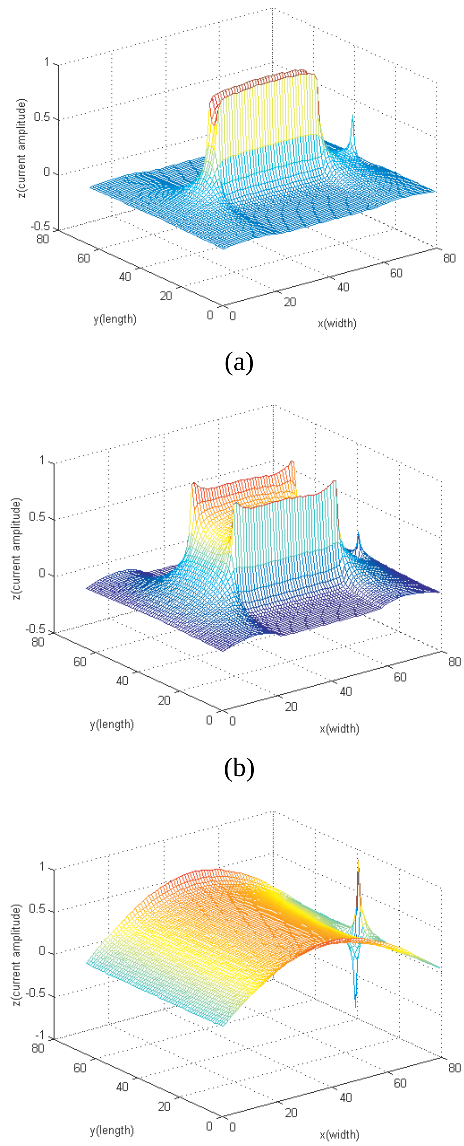


(c)

Figure 5. Electric Field Distribution E_z with (a)W_1=2mm(b) W_1=10mm(c) W_1=33mm

ii. Current Distribution

The distributions of the surface currents at resonance on both the patch and the ground plane are presented in Figures6(a),(b)&(c).The pointy parts of the currents in the figure correspond to the feed point. For the case of W_1= 33 mm, the current distribution of J_x follows the sin(x) distribution along the x axis and approximately the $\sqrt{1-y^2}$ distribution (i.e., edge conditions) along the y axis. Compared with Figure6 (a), it is seen that the electric current distributions are strongly affected by the H shape. Hence, the electric current distributions lead to the decrease of the resonance frequency. Very large currents J_x are obrtained on the H-shaped patch and ground plane; consequently, these current distributions are considered to excite the inner electric and magnetic fields between the patch and the ground plane. The current J_x of the H-shaped patch has the largest amplitude upon the center strip area, which is much narrower than the side strips. This phenomenon is physically understandable in accordance with the continuity of current. It is noted that for the H-shaped patch, the current J_x upon the center strip is non-uniform along the y axis, with the maximum values at the patch edges along y axis. J_x, i.e., the copolar current component, is symmetric with respect to the center point and is in phase on entire surface except in the vicinity of the feed point and J_y, i.e., the cross polar current component, is also symmetric with respect to the patch center, but out of phase on two sides It is also interesting to note that the current distributions on the ground plane seem to be just the image of the current distributions on the patch.



(a)

(b)

(c)

Figure 6:J_x on patch of the antenna with(a)W_1=2mm(b) W_1=10mm (c) W_1=33mm

iii. Radiation Patterns

The radiation patterns of the H-shaped patches with different center strip widths is analyzed and it is seen that when the center strip width W_1 decreases, the radiation patterns are broadened in the E plane. Accordingly, slightly broadening of radiation pattern in the H plane is also found. However, the extent of broadening is so small in the H plane that they seem to coincide. It is found that the patterns in both the E and H planes will be broadened with the increase of center strip length , or the decrease of side strip length , or the decrease of side strip width .

III. CONCLUSION

The results obtained clearly indicate the main factors that affect the Resonant frequency and Return loss of H-shaped RMSA are the center conductor strip width, center strip length and the side strip width. Resonant frequency decreases with the decrease in the center strip width and increase in the center strip length. Hence, it is shown that both the length and the width of the center strip affect the resonant frequency significantly. Thus, it is concluded that the reduction of the center strip width is an effective way of reducing the antenna size and by increasing the dielectric constant for the same height of the substrate, the capacitive feeding gives a better bandwidth than the CPW Feed.

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