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Modified Compact H-Shaped Microstrip Antenna for Tuning Multi-Band Operation

Abdel Fattah Sheta*, Ashraf S. Mohra*, and Samir F. Mahmoud**
*EE Dept. Advanced Technologies Research Center (ATRC)r, King Saud University, P.O.Box 800, Riyadh 11421C Saudi Arabia
**EE Dept., Kuwait University, P.O.Box 5969, Safat 13060, Kuwait

Abstract

Modified H-shaped microstrip antenna configurations are introduced. Additional stubs or etching slots can be properly used to tune the desired band and leave little effect on others. Using the proposed approach, some modes can be tuned over 20% frequency range. The technique improves the flexibility in the design approach that allows the pre-selection of the resonant frequencies of the antenna. The approach is validated by the design of different modified H-shaped antennas for operation in quad band. The designed antennas are simulated by IE3D software. Good agreement with experimental results is demonstrated.

Keywords Microstrip antennas, Miniature antennas, H-shaped, Multi-band, Tunable antennas

I. Introduction

Multi-band microstrip antennas with a single feed have attracted much attention for new wireless communications applications. Generally speaking, reactive loading of a microstrip patch antenna at its radiating edges allows the reduction in resonance frequency and dual frequency operation. A rectangular microstrip patch loaded along its feed axis with two small length stubs has been used to control the resonance frequency and matching [1]. However, the dual frequency operation has been achieved by: (a) loading the rectangular patch at one end either by half wave short-circuited stub [2], or quarter wave open circuit stub [3], (b) loading the circular patch either with two equal angular stubs [4], or quarter wave stub located along its feed axis [5]. In the latter, the single frequency operation has been tuned over 9% frequency range for small stub length. These techniques increase the overall antenna size. An earlier investigation of compact H-shaped antenna showed the possible, dual, triple, and quad band operation [6].

In this paper, an extra degree of freedom to enable the control of the resonance frequencies of the H-shaped antenna is investigated. The frequency tuning can be achieved by either, extend the length of the current path, loading the patch by stubs or etching slots in an appropriate location. The analysis of such tuning is carried out, using the concepts of electric and magnetic walls placed at the planes of symmetry.

II. Resonant frequencies of H-structure

The resonant frequencies and radiation behavior of the H-shaped antenna have been described for multi-band operation [6]. As shown in Fig. 1, the resonance frequencies of the different modes depicted in Fig. 1a can be predicted from the possible current paths and distribution over the H-patch. Due to the symmetry of the structure about the X and Y axes, the concept of electric and/or magnetic walls placed at the two axes seems to be the most suitable approach to describe the nature of each mode and its radiation behavior. Placing electric and/or magnetic walls at the two axes results in the identification of four basic modes as shown in Fig. 1. These modes can be divided into two families as follows. Placing an electric wall at the Y-axis results in two modes with resonanant frequencies f_{E0} and f_{E1} depending on the type of wall on the X-axis as shown in Figs. 1(b) and (c). Similarly, placing a magnetic wall at the Y-axis results in modes with f_{H0}, and f_{H1} resonant frequencies as shown in Figs. 1 (d), and (e), respectively. The resonance frequencies have been calculated as functions of the mean current path of each. Here, we will study the influence of the geometry change on the resonance frequencies.

III. Effect of Geometry change on resonance frequencies

Since the resonance frequencies can be determined by the mean current path, any disturbance of the path can affect strongly the resonance frequency of the corresponding mode.

A. Consider first the patch in Fig 2(a). Without the stubs at the Y-axis, the extension of the line length at the end of the vertical arms will decrease the frequency of all the modes approximately by the same ratio. However, additional stub at the Y-axis will have little effect on the modes having electric wall at any of the two axes. This geometry can be used to decrease significantly f_{H1}, where there is no electric wall near the stubs added. However, the other modes have E-wall along X or Y axes, and the stub in this case have little effect on F_{E0} , F_{H0} , F_{E1}, and hence they can be tuned precisely. Instead of using a stub at the Y-axis, adding a stub in the vertical arms near the X-axis will decrease all the frequencies except f_{H1}, which corresponds to the mode with no electric wall. Transmission line equivalent circuit as described for each mode in [6], can be used to predict the variation in this case.

B. Etching slot in the vertical arms (Fig. (2c))
In this case, the effective current path of all modes will increase and consequently, the resonance frequencies will decrease. Significant reduction can be achieved by increasing the depth of the etched slot.
C. Etching slots and extension of the length of the vertical arms (Fig. 2(d)
The mean current path now will increase significantly, and then a significant decrease in resonance frequencies is expected. This case should be considered as a way of decreasing further the antenna size. Appropriate transmission line model for each mode can predict its resonance frequency.

IV Design cases and experimental results

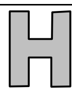
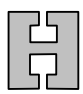
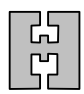
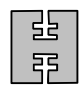
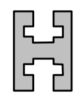
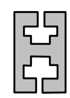
In this section, we demonstrate by simulations and experiment the effect of geometry modifications on the basic H-Shaped patch. The main H-shaped antenna presented in [6] will be used as the basic shape. The dimensions of the antenna implemented on Duroid RT/5880 with ε_r=2.2 and h=1.57 mm are L_1= 13.5 mm, W_1=8 mm, L_2 = 8 mm, and w_2 = 11 mm. (see Fig. 1(a)). A probe feed with radius 0.5 mm located in appropriate location for operation on dual, triple or quad mode, according to the excitation mechanism described in [6], is used to analyze the proposed structures. Length extension at the end of the vertical arms shown in Fig. 2(a) without the stubs along the Y-axis, decrease all resonance frequencies as shown in table 1 , 2nd shape from left (3rd column). The reduction ratio is maximum for f_{E1} (9%) and minimum for f_{H1} (6%). However, additional stubs of width(W=4mm) and length(L=5mm), at the Y-axis as shown in Fig. 2(a) increases the resonance frequencies of f_{E0} and f_{E1} by about 1.7% and 0.4%, respectively, and decreases f_{H0}, and f_{H1}, by 0.4% and 4.7%, respectively. This shows that fine tuning of modes having electric wall at any of the axes can be achieved with a very high precision by adding stubs at the Y-axis, since wide stubs achieve about 10 MHz frequency shift. The simulation results are shown in Fig. 4 (a). Now consider the case of the length extension and stubs in the vertical arms near the X-axis as shown in Fig. 2(b). The length is extended by a line of width 4 mm and length 3 mm, and the two other stubs have width = 3 mm and length = 3 mm. The addition of stubs near the X-axis decreases slightly the resonance frequencies of all modes except the f_{H1} (the mode has no electric wall) which is increased as shown in Table 1. The simulation and measurements of this case are shown in Fig. 3 (a). Etching slots of width 4 mm and depth 3 mm, as shown in Fig. 2(c), reduces the resonance frequencies f_{E0}, f_{H0} and f_{E1} by 2.3%, 3.8%, and 9%, respectively. The simulation and measurements of this structure are shown in Fig. 3(b). This shows that another mode appears in measurements at about 5 GHz, and does not appear in simulation. This may be attributed to the mounting inaccuracy of the connector which excites such mode. The last case is the extension of the vertical arms and etching slots in it as shown in Fig. 2(d). This achieves a reduction in resonance frequency of more than 20% and might be used as a way to reduce further the size of the H-antenna. The simulation results of this structure are shown in Fig. 4(b). This shows that, the two frequencies f_{H0} and f_{H1} are too close to each other.

This is so since f_{E1} which is highly affected by the changes in the shape, decreases faster than the f_{H0}. Fine tuning of the proposed structures with small stubs or slots will have little effect on the main H-shape antenna characteristics [6]. Table.1 is a useful to show the effect of the stubs added and slots etched on the resonance frequencies of each mode. Therefore, precise control of the resonance frequency of any mode can be adjusted by loading the structure with suitable stubs or slots according to Table.1. This would be achieved with the help of IE3D simulator. Simulations and measurements show fractional bandwidth less than 1% for approximately all cases. These results agree with the general concepts of compact microstrip antennas, when implemented on thin dielectric materials. The simulated radiation patterns, for E-phi and E-theta field, of the designed structure in Fig. 2b at the modes resonance frequencies are shown in Fig. 5.

V. Conclusions

New configurations designed from the H-shaped patch antenna are shown to allow the control of its resonance frequencies.. It has been found that, according to the geometry of the modified-H shape, the mode resonance frequencies can be controlled from 0.4% to more than 20% change The Simulations have been performed using the IE3D software. Good agreement between the simulations and measurements has been achieved on various variations of the basic H-antenna. All the implemented antennas have the same overall dimensions , but different shapes.

Table 1 Comparison between different H-shaped and modified H-shaped structures

Modified H Struct.									
Freq. (GHz)	Sim	Meas	Sim.	Sim.	Sim	Meas	Sim.	Meas.	Sim.
F_{E0}	2.18	2.19	2.025	2.06	1.985	2.04	2.12	2.13	1.85
F_{H0}	2.75	2.748	2.545	2.535	2.495	2.52	2.645	2.625	2.264
F_{E1}	2.92	2.93	2.66	2.67	2.6	2.66	2.655	2.655	2.283
F_{H1}	5.02	5.05	4.75	4.525	4.78	5			

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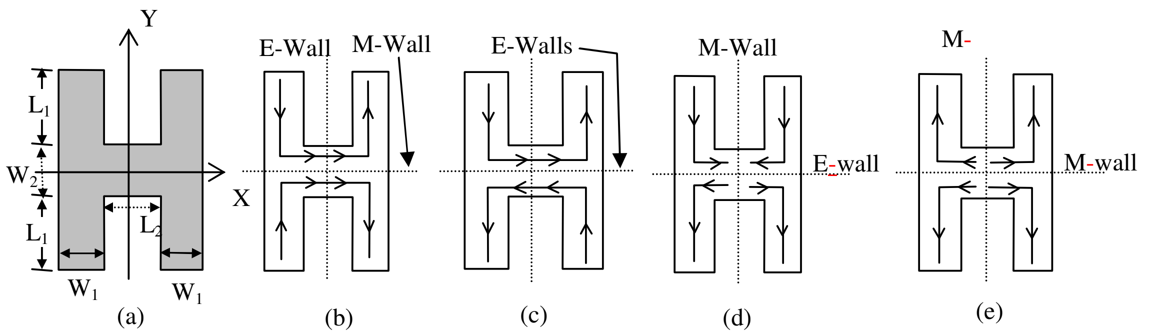


Fig. 1 Current paths of possible modes with electric walls along the X- and Y-axes
(a) H-shape structure and its dimensions
(b) Current path of the first mode. The resonance frequency of this modes is denoting f_{E0}
(c) Current path of the second mode with E-walls along Y and X-axes (fr = f_{E1})
(d) Current path of the first mode with a M-Wall along the Y axis and E-Wall along the X-axis (fr = f_{H0})
(e) Current path of the second mode with a M-wall along the Y and X-axes (fr = f_{H1})

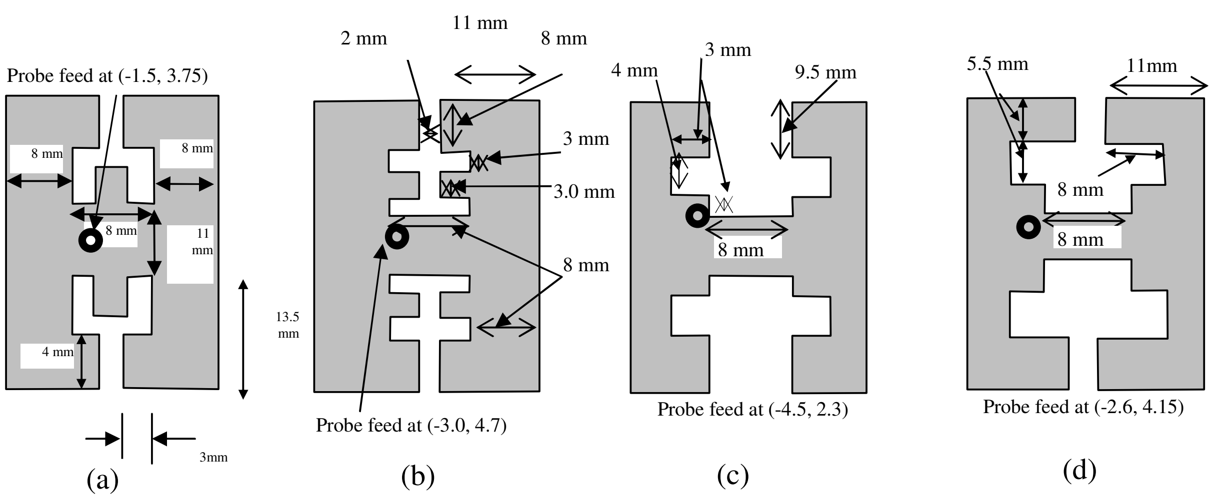


Fig. 2 Modified H-shape structures
(a) Stubs at the Y-axis used to tune precisely the resonance frequencies
(b) Stubs in the vertical arms reduces the resonance frequencies up to 10%
(c) Etched slots in the vertical arms reduces f_{E1} by about 10% and the other by about 2-3%
(d) Etched slots and extended length of the vertical arms decreases the resonance frequencies by more than 20%

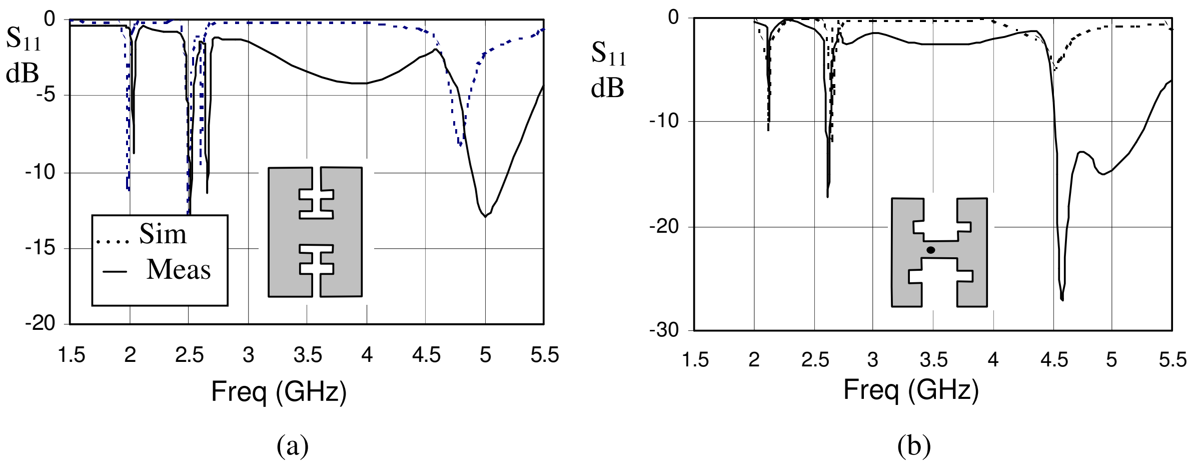


Fig. 3 Simulated and measured results of Modified H-shaped antennas fed to operate on four-band f_{E0}, f_{H0}, f_{E1} and f_{H1},

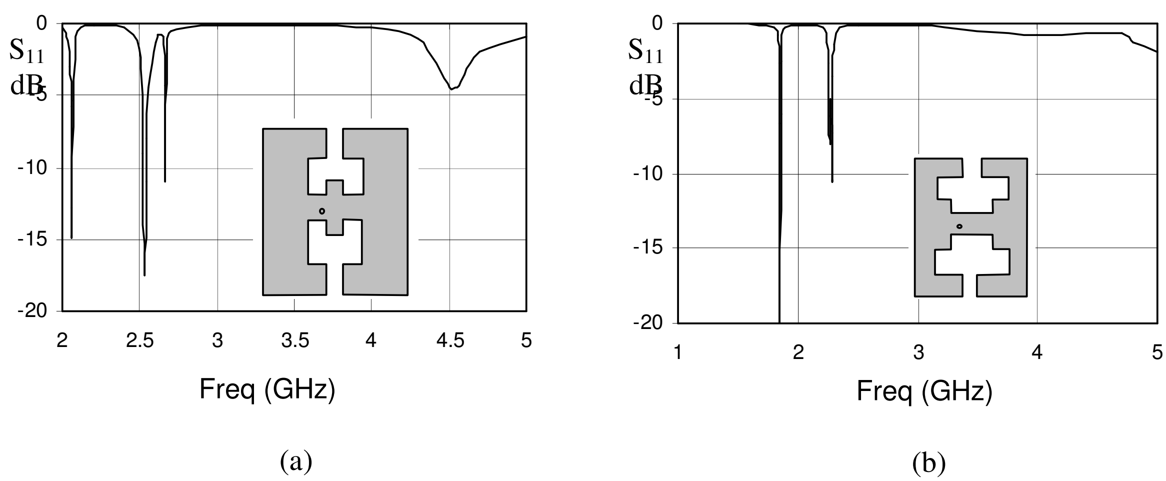
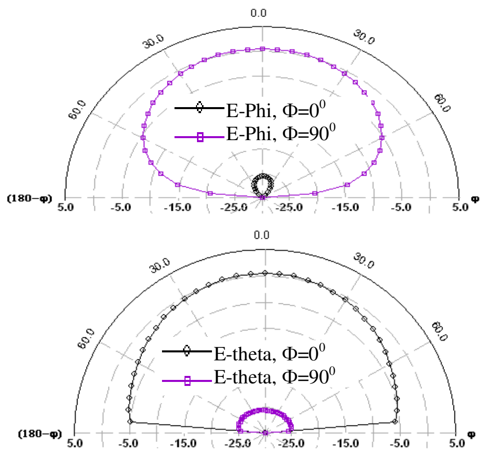
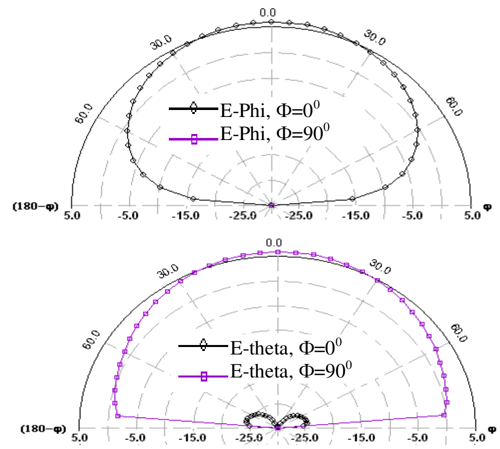


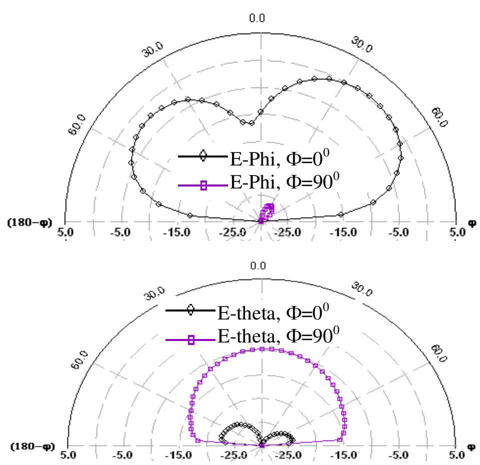
Fig. 4 Simulation results of Modified H-shaped antennas fed to operate on four-band f_{E0}, f_{H0}, f_{E1} and f_{H1}, Simulation has been performed using IE3D



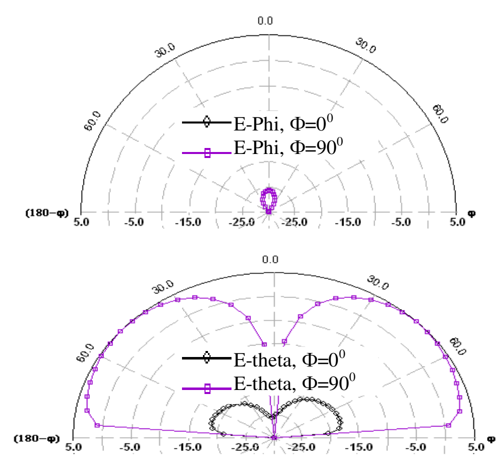
(a)



(b)



(c)



(d)

Fig.5 the simulated radiation patterns of Fig. (2b) at modes resonance frequencies
(a) F=1.985GHz (b)F=2.495GHz (c)F= 2.6GHz (d) F=4.78 GHz