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MULTI-WIDEBAND COMPACT PATCH ANTENNA WITH SEVEN-SEGMENT SLOTS

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A small size multi-wideband patch antenna with seven-segment slots is presented. The multi-wideband operation and size reduction are manipulated through the use of the slot loading technique. Etching seven-segment slots into the conventional patch antenna enhances its performance for multi-wideband applications. The geometry that is constructed by the slots controls the resonance frequencies and their bandwidths, of the antenna. The software IE3D is employed to analyze and simulate the proposed antenna. Some of the results are confirmed using the HFSS software. The results illustrate that the proposed antenna is capable to achieve return loss (RL) less than -10 dB and voltage standing wave ratio (VSWR) < 2 in up to eight frequency bands, in the frequency range 2 - 8 GHz.

1. INTRODUCTION

Microstrip patch antennas are widely used in wireless communication systems because they can provide low profile, medium efficiency, and mechanical reliability [1-3]. However patch antennas, especially in a compact form, have a narrow bandwidth. Enhancement of the antenna performance to cover the demanding bandwidth is necessary.

A few approaches can be applied to improve the microstrip patch antenna bandwidth. These include increasing the substrate thickness, introducing parasitic elements either in a coplanar or a stack configuration, and modifying the shape of a common radiator patch by incorporating slots. The last approach is particularly attractive because it can provide excellent bandwidth improvement and maintain a single-layer radiating structure to preserve the antenna's thin profile characteristic. Most of the previous studies in the literature focused on the microstrip patch antenna with a thick substrate (even over ~ 12 % working wavelength [1, 4]). Some work was done to enhance the operation bandwidth of the patch antenna with a thin substrate of less than ~ 1 % of the working wavelength [5]. However, the bandwidth of microstrip antenna may be increased using air substrate [6]. Also a dielectric substrate can be used for compact antenna with wide bandwidths operations [7]. Several approaches based on the slot loading technique are proposed for more bandwidth enhancement such as ultralow-profile patch antenna [1], patch antenna with switched slots [8], ground-slotted patch antenna using PIN diode switching [9], microstrip antenna with loaded slots and capacitances [10, 11], E-shaped patch antennas [12,13], H-shaped patch antennas [14, 15], U-slot patch antenna [16], V-slot patch antenna [17]. The main benefit with introducing the slot loading technique is that the multi-wideband performance can be enhanced with a smaller antenna volume compared to the conventional antenna.

In this paper seven segment slots constructing different shapes are introduced into the patch to control the resonance frequencies of the compact microstrip patch antenna. These shapes provide multi-wideband operations in the frequency range 2-8 GHz. The main idea of the proposed design is based on the slot loading technique. Here, we will study the influence of the geometry change of the slots on the resonance frequencies and on the performances of the antenna. The 3-D full wave method of moments (MoM) software package (IE3D) coded by zeland software [18] is applied to analyze and simulate the proposed antenna. Also some of the results are recomputed using the HFSS software which is based on the high-frequency finite-element simulation method to confirm our simulation. The description of the antenna design, analysis and simulation, and computed results are outlined in the following sections.

2. ANTENNA GEOMETRY AND DESIGN:

The geometry of the proposed antenna is shown in Figure 1. It consists of a conventional patch antenna which consists of a patch, substrate, and a ground plane. The dimensions of these elements as well as the thickness of the substrate and its relative permittivity are computed at central operated frequency of *2.4 GHz* [19]. The computed dimensions of the ground plane and the patch are *50.95x59* mm^2 and 41.35x49.41 mm^2, respectively. The dimensions are measured such that the length is in the x-direction and the width is in the y-direction. The substrate between the patch and the ground plane is considered from the dielectric material RT/ Duroid 5880 with relative permittivity $\varepsilon_r = 2.2$ which gives better efficiency and larger bandwidth. The thickness of the substrate is 1.6 mm. The antenna is fed by a 50-Ω coaxial feeding probe of radius 3.0 *mm*. The inner conductor is connected to the top surface of the patch antenna while the outer conductor is connected to the ground plane. The coordinate of the feeding point is (-6.35,0.0). In general, when this conventional patch antenna is simulated, a single resonant frequency band of *2.4GHz* is obtained, this single band can only cover one of the required applications. By utilizing the slot loading other bands of resonant frequencies can be introduced for multi-wideband operation. Therefore the patch antenna with loaded slots can be used for different applications.

To yield the aim of the multi-wideband operation seven-segment slots are introduced into the patch to give flexibility to construct various shapes of numbers and letters. The slots A, D, and G as in Fig. 1, have a dimension of *39.35x2.00* mm^2. The slots B, C, E, and F have a dimension of 2.00x15.71 mm^2. A 1.0 *mm* strip is made between the top, left, and right edges of the patch and the nearest slot. The y-dimension between the bottom edge of the patch and the slot D is 10.99 *mm*. The positions and dimensions of the slots are optimized by trial and error to yield the maximum number of resonance frequencies, wide bandwidths, and high gain. Specific slots are taken into consideration to construct a certain shape of a number or a letter. Some examples of these shapes and corresponding slots are illustrated in Table 1.

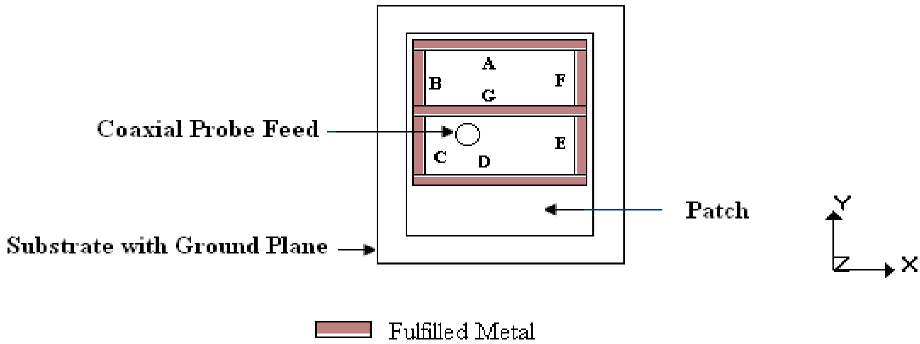


Figure 1. Geometry and parameters of the proposed antenna.

Since the resonance frequencies can be determined by the mean current path, any disturbance of the path by introducing slots can affect strongly the resonance frequencies. These resonance frequencies can be tuned by varying the length of the slots. Increasing the current path with the same physical length causes a downward shift in the resonant frequencies. This means that for an antenna with the same resonant frequency, the overall surface dimension can be decreased to a great amount. Various configurations of the slots create unequal lengths for different separated current paths. These current paths correspond to hybrid operating modes which result in wideband characteristics [19].

Table 1. Examples of specific slots and the corresponding shapes of some numbers and letters constructed by the slots.

Parameters shape	Corresponding slots	Parameters shape	Corresponding slots
0	A, B, C, D, E, and F.	1	F, and E.
2	A, F, G, C, and D.	3	A, F, G, E, and D.
8	A, B, C, D, E, F, and G.	9	G, B, A, F, E, and D.
A	A, B, C, E, F, and G.	b	B, C, D, E, and G.
C	A, B, C, and D.	d	C, D, E, F, and G

3. SIMULATION RESULTS AND DISCUSSIONS

The simulation of the proposed antenna is carried out using IE3D software [18]. The initial design of the antenna does not contain slots on the patch. For that case the optimum position of the feeding point was located at (X_f, Y_f) = (-6.35, 0). The computed result of the return loss, RL, as a function of frequency for that conventional antenna is shown in Fig. 2. When the slots are inserted to the patch more resonant frequencies become pronounced with RL less than −10 dB in the frequency range of 2 – 8 GHz. Those resonant frequencies depend on the configuration of the slots. For example the arrangement and specified dimensions for the state at which the slots construct letter C (consider only slots A, B, C, and D) are shown in Fig. 3. This construction corresponds to a pair of inverted L-shaped spaced with 2.0 *mm*. The first

L-shaped is constructed from the slots A, and B, and the second is formed from the slots C and D. The computed results of the RL as a function of frequency for some arrangements of slots forming shapes of numbers 0, 1, 2, 3, and letters A, b, C are shown in Fig. 4. As illustrated in Fig. 4(d) for the shape of letter C there are eight resonance frequencies at 2.41, 2.81, 3.21, 6.1, 6.8, 7.11, and 7.68 GHz with RL less than -10 dB.

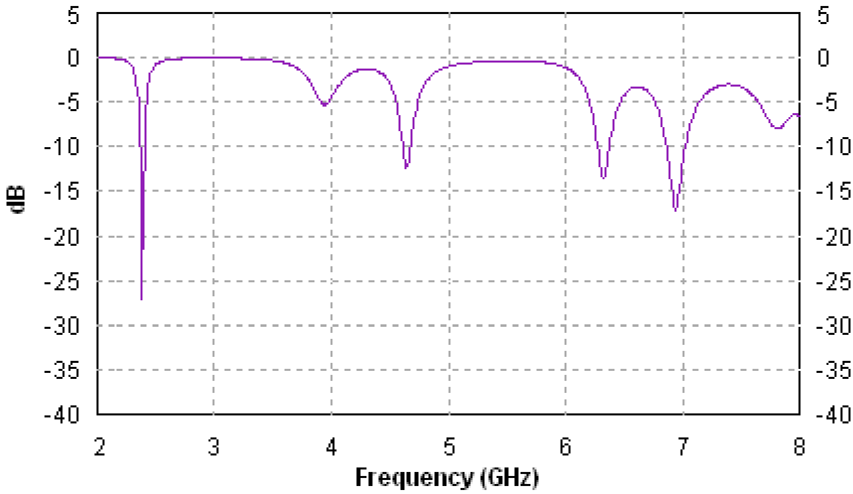


Figure 2. Simulated Return loss as a function of frequency for the conventional patch antenna.

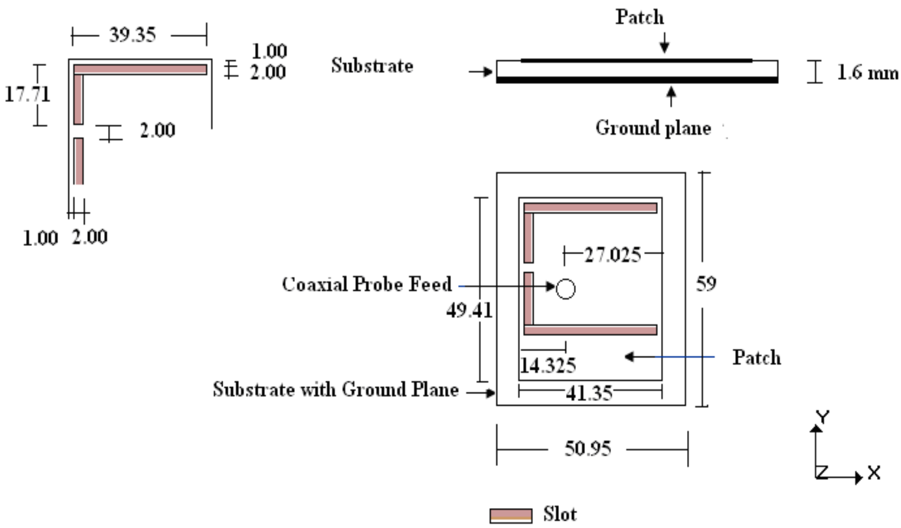


Fig. 3. Arrangement and dimensions of the slots constructing the shape of letter C. All dimensions by mm.

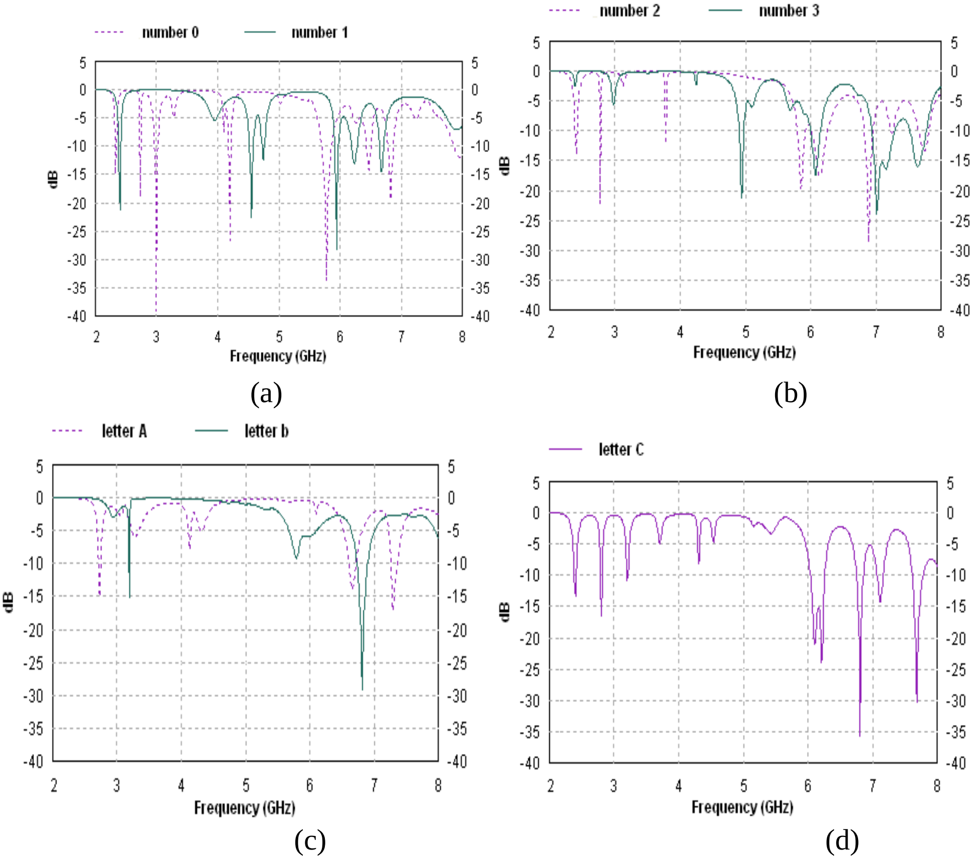
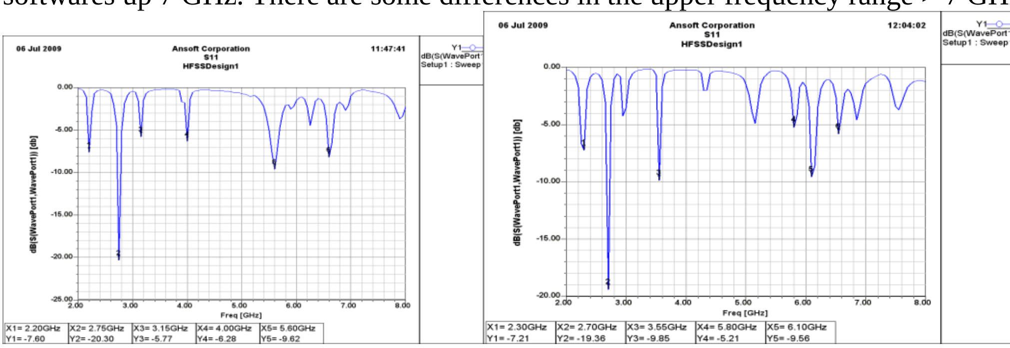


Figure 4. Return loss as a function of frequency for the proposed antenna when the arrangement of the slots construct the shape of (a) numbers 0,1; (b) numbers 2,3; (c) letters A, b; (d) letter C.

To check that the presented results are correct the return loss is recalculated using the HFSS software for the cases of slots configurations corresponding to the shapes of O and C. That software is designed by Ansoft Corporation. The results are presented in Fig. 5. There are good agreements for the results computed by the two softwares up 7 GHz. There are some differences in the upper frequency range > 7 GHz.



(a) (b)

Fig. 5. Return loss for two cases of slots constructions using HFSS Software; (a) number O shape, (b) letter C shape

The current distributions are calculated at the resonant frequencies for the state of slots arrangement constructing the shape of the letter C (as that specified in Fig. 3). The calculated results are shown in Fig. 6. The results show that the current concentrates on the strip around the slots that satisfying the boundary condition.

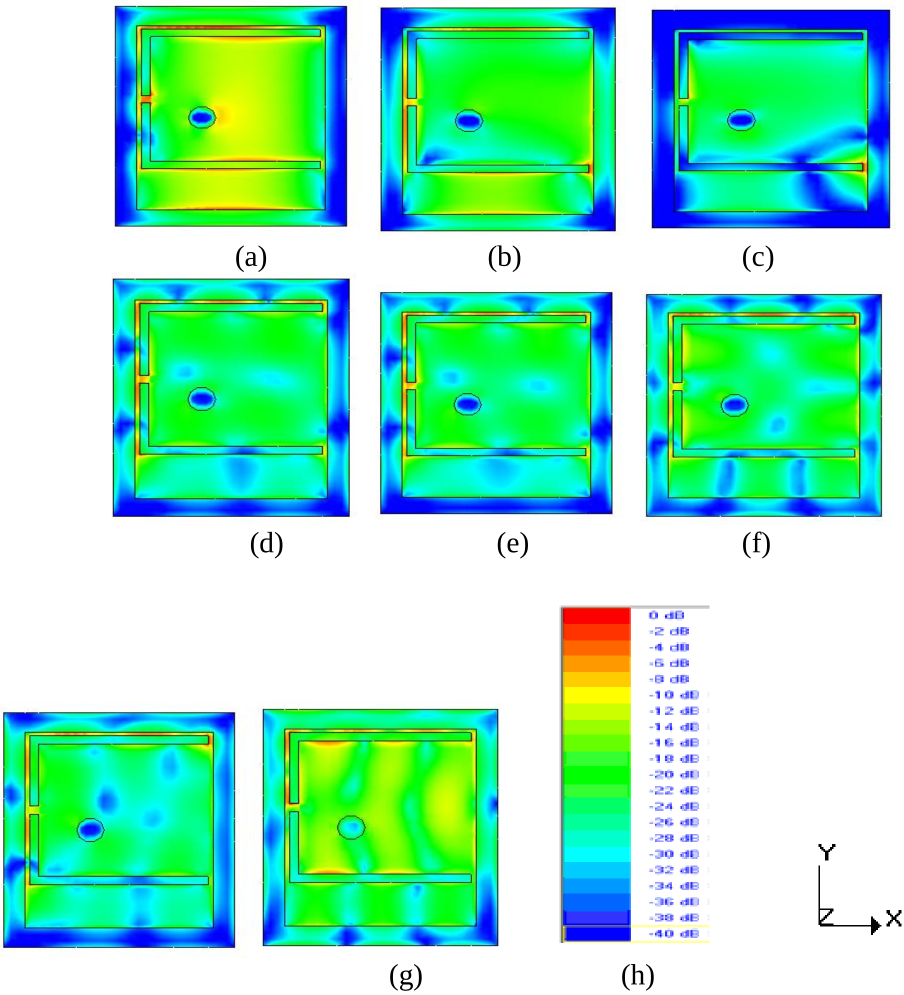


Figure 6**.** Surface current distributions for an arrangement of the slots that construct the shape of letter C at the resonant frequencies (a) f_r = 2.41GHz, (b) f_r = 2.81GHz, (c) f_r = 3.21GHz, (d) f_r= 6.10GHz, (e) f_r = 6.21GHz, (f) f_r = 6.80GHz, (g) f_r = 7.11GHz, and (h) f_r = 7.68 GHz.

Figure 7 shows the simulated radiation patterns of the electric field ***E*** in the $\varphi = 0^o$ and $\varphi = 90^o$ planes at different resonant frequencies for the same state as that in Fig. 3. The results illustrate that at some resonance frequencies wide variations of the radiation pattern with small back radiation are obtained. The advantage of reducing radiation to the back is that minimizing the electromagnetic power radiated back to the heads of the headsets users if the antenna is used in the mobile communication.

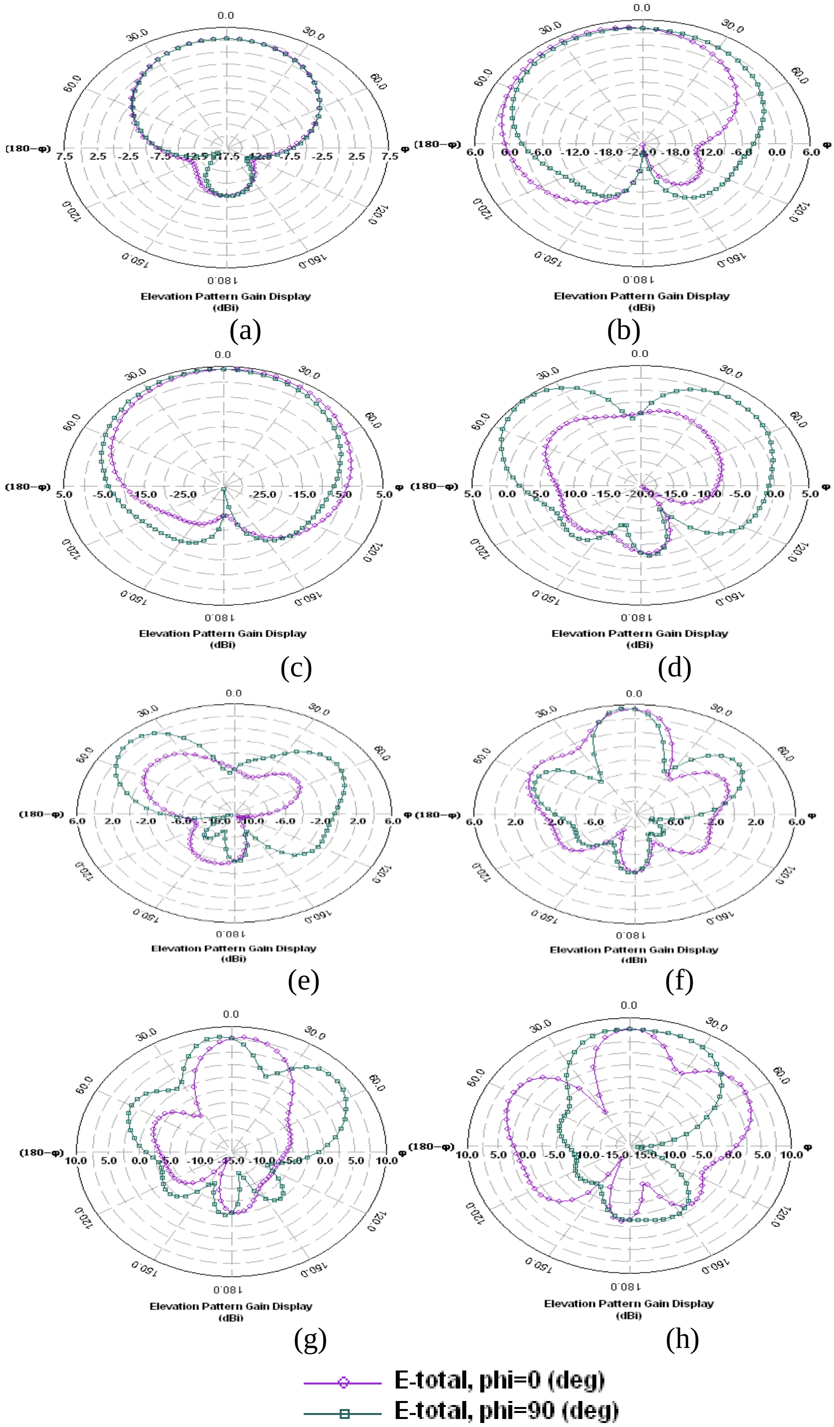


Figure 7**.** Simulated Radiation pattern of ***E***-fields in the $\varphi = 0^{o}$ and $\varphi = 90^{o}$ planes at different resonant frequencies for an arrangement of the slots that construct the shape of letter C, (a) $f_r = 2.41$GHz, (b) $f_r = 2.81$GHz, (c) $f_r = 3.21$GHz, (d) $f_r = 6.10$GHz, (e) $f_r = 6.21$GHz, (f) $f_r = 6.80$GHz, (g) $f_r = 7.11$GHz, (h) $f_r = 7.68$GHz.

The simulated gain of the antenna at the resonant frequencies for the state of the slots constructing letter C is given in Figure 8. It is clear that the gain has peak values of 4.5, 4, 2, 6, 6, 6, 7, and 7.5 dBi at the corresponding frequencies 2.41, 2.81, 3.21, 6.1, 6.21, 6.8, 7.11, and 7.68 GHz respectively. The behaviors of the antenna and radiation efficiencies are presented in Figure 9. The computed results in Figures 8 and 9 illustrate that the proposed antenna for the slots arrangement constructing the letter C provides a high gain. Its radiation efficiency is higher than 98 % over the operating frequency range. The radiation efficiency is high because there are no high dielectric losses and small surface wave losses. The high gain and radiation efficiency make the antenna suitable for wireless communication systems. Moreover, the antenna provides more enhancements of multi-wideband operation.

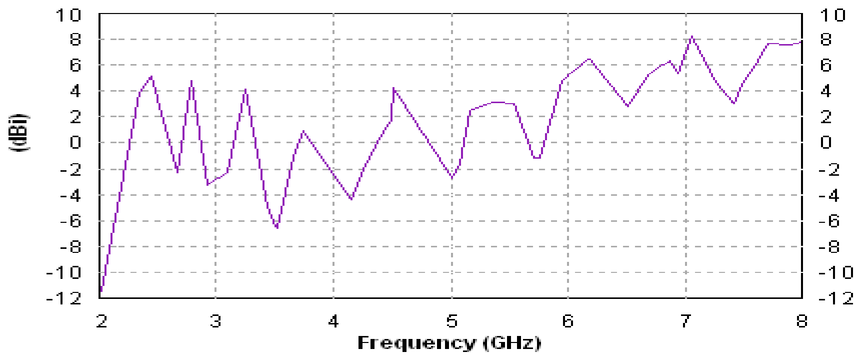


Figure 8. Simulated gain as a function of frequency for the antenna for an arrangement of the slots that construct the shape of the letter C.

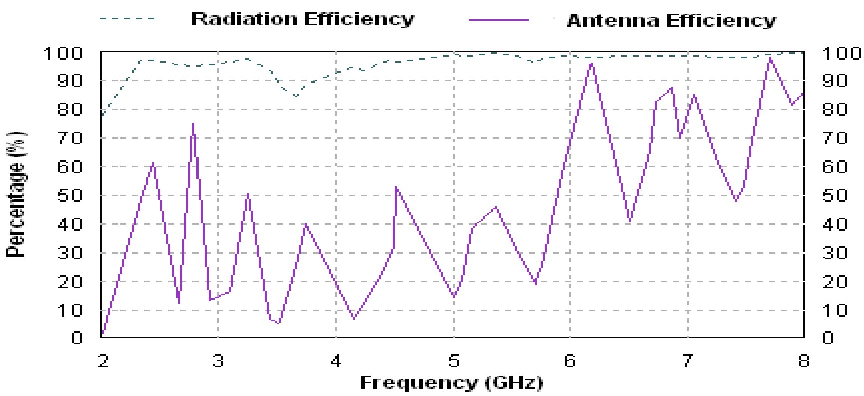


Figure 9**.** Simulated antenna and radiation efficiencies of the antenna as a function of frequency for an arrangement of the slots that construct the shape of the letter C.

5. CONCLUSION

In this paper a suggested design of a compact patch antenna for multi-wideband applications is presented. The antenna is designed to operate at frequency range 2-8 GHz. The antenna contains seven segments slots introduced into the patch to define number of the resonant frequencies and to enhance the bandwidths. Some of these slots can be taken into consideration to construct a certain shape of a number or a letter. Number of the resonant frequencies and their locations are dependent on the shape of the constructed slotted patch model. It is found that the resonance frequencies can be controlled through choosing the positions and dimensions of the slots. For example if the slots are chosen such that the shape of the letter C is constructed the antenna will provide up to eight widebands resonance frequencies. These multi-wideband resonances make the same antenna applicable for different applications. Also the designed antenna model gives higher gain and radiation efficiency than the traditional one.

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هوائي الشريحة المتناهية الصغر ذات السبعة مجارات والمتعدد النطاقات لترددات رنين واسعة

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تم عرض تصميم لهوائي شريحة متناهية الصغر حفر بها سبع مسارات كل منها مستطيلة الشكل. والهوائي ذات نطاقات ترددات رنين متعددة ومتسعة المدى. ويمكن التحكم في عدد النطاقات الترددية للرنين ومدى أتساعها عن طريق تشكيل السبعة مسارات لتأخذ أشكال معينة من أرقام أو حروف. ولقد أستخدم برنامجIE3D لعمل نمذجة للتصميم المقدم. وتم أيضا حساب بعض النتائج باستخدام برنامج HFSS وذلك للتأكد من النتائج المستخلصة من البرنامج IE3D.

وضحت النتائج أن التصميم المقترح يقدم فقد رجوع أقل من −10 ديسيبل في نطاقات ترددية لرنين متسعة ومتعددة. وعلى سبيل المثال لو نظمت المسارات لتأخذ شكل الحرف C على الشريحة لوجد أن هناك ثمانية ترددات رنين متسعة النطاق لها فقد رجوع أقل من −10 ديسيبل في المدى الترددي من 2 الى 8 جيجاهرتز. ولقد تم حساب توزيعات التيار الكهربي على الشريحة وتبين أن التيار مركز حول المسارات المحفورة على الشريحة. وتبين أيضاً أن التصميم المقترح للهوائي له معامل كسب عالي وكفائة كبيرة. بالأضافة أن الهوائي المقترح له انعكاس موجي صغير في الخلف مما يكسب الهوائي ميزة عدم انعكاس الموجات الكهرومغناطيسية ذات الترددات المتناهية الصغر الى رأس المستخدم للتليفون المحمول في حالة تركيب هذا الهوائي في التليفون. وحيث أن هذا الهوائي لة عدة نطاقات رنين لذا يمكن أستخدامه في أكثر من تطبيق من التطبيقات العملية.