Design of Miniaturized Coaxial-Feed Patch Antennas with Air Cavity or Surface Integrated Resonator for UWB/WiFi/ Wireless /GPS

Mehdi Hamidkhani

Department of Electrical Engineering, Dolatabad Branch, Islamic Azad University

Isfahan, Iran

mehdi.hamidkhani@gmail.com

***Abstract*— Antenna miniaturization, which is a requirement of modern wireless communication systems, is usually concomitant with the reduction of impedance bandwidth. On the other hand, small antennas should also possess stable radiation patterns across a broad frequency band, such as in the UWB systems. In this paper, we propose a UWB antenna structure with a novel feeding system composed of an open cavity resonator. It has a wide relative bandwidth (of about 120%) particularly at the lower frequency limits. proposed antenna with the novel feed system is smaller and has a wider frequency bandwidth, as compared with other available UWB antennas in the literature. Furthermore, another antenna is proposed, which has a feeding system composed of a surface integrated resonator cavity, fabricated on a two layer microstrip structure. It has achieved better miniaturization and bandwidth enhancement, albeit somewhat lower gain. Three prototype models of the proposed antennas are fabricated and measured, of which the frequency response are in excellent agreement with computer simulation results.**

***Keywords*— Antenna Miniaturization, UWB, GPS, WiFi, Wireless, Surface Integrated Resonators, Patch Antenna.**

I. INTRODUCTION

The ultra wide band (UWB) communication systems in the allocated band 3.1 to 10.6 GHz find extensive commercial and military applications. They possess various advantages, such as low power consumption (which is a necessary condition for wireless communication systems and reduction of adverse effects on the human body), high security (which is required for secure communication and military systems), immunity to adverse interference (required for the maintenance of some signal level in a limited frequency band under the condition of severe noise in most parts of the band), desirable performance in multipath channels and capability of high signal penetration [1,2].

Microstrip antennas are inherently narrow band. There are several techniques to enhance their bandwidths, such as the increase of substrate height [4], low substrate dielectric constant [3], application of special feeding systems [5], implementation of impedance matching techniques [5], use of parasitic elements [4], employment of fractal geometries [4] and application of slot antenna configurations [6]. Furthermore, monopole, coplanar and slot structures have been used for UWB designs, which have lower radiation efficiency than the microstrip patch antennas [7].

The length of square patch is usually equal to ($\frac{\lambda}{2\sqrt{\epsilon_r}}$), where λ is the wavelength in free space and ϵ_r is the dielectric constant of substrate. Various techniques have been employed for the antenna miniaturization [8]. But they all have fundamental limitations, such as the decrease of impedance bandwidth due to the reduction of antenna size. In other word, the antenna size and impedance bandwidth are more or less proportional, but they have complicated relationship.

The implementation of substrate integrated waveguides (SIW) on printed circuit boards (PCB) have been used in the microwave and millimeter wave integrated circuits, such as filters, couplers, dividers, slot antenna arrays, circulators and multiport circuits [9]. The SIW configuration is shown in Fig.1, where the following relationships should hold [10, 11], which are required to remove any gap in the design frequency band, reduce scattering losses and to ensure ease of fabrication.

In this paper, we initially employ the techniques of appropriate feeding system, impedance matching and increase of substrate height for the objective of enhancing the antenna bandwidth and miniaturization. Furthermore, grounded shorting posts are used in the air substrate [12], of which the height may be readily adjusted [13], as shown in Fig.2. We then employ the SIW technique as shown in Fig.3, which is composed of two microstrip substrates, made of Rogers RT/Duroid 5880, with parameters ϵ_r =2.2, height h=125 mil and loss tangent tanδ=0.0009.

II. DESCRIPTION OF PROPOSED ANTENNA STRUCTURES

We use the antenna probe feeding through a coaxial cable, which has several advantages compared to a microstrip feeding system, such as lower feed line losses, less undesired radiation and adjustability of input impedance by the variation of probe position. In general, a microstrip patch antenna with a probe feeding has a narrow impedance bandwidth due to its high quality factor Q. The increase of substrate height leads to the reduction of Q and increase of its bandwidth.

On the other hand, longer probes lead to the increase of their inductive effects which limit the antenna bandwidth. Several methods have been proposed to overcome such effects, such as folded-patch-feeds. Now in this paper, we propose to decrease the substrate thickness at the probe feed section, whereas the substrate thickness under the patch is kept high. Consequently, the inductive effect of the probe is kept low and the antenna bandwidth remains high. Furthermore, the proposed feeding system increases the effective length of patch, while its physical length is kept constant. Consequently, the antenna is effectively miniaturized. Two types of antenna configurations are designed, fabricated and measured. The first antenna type is shown in Fig.2 and photograph is shown in Fig.12, 13 respectively, where its detailed geometrical configuration is indicated. Two versions of this configuration are considered, which are called Antenna 1 and Antenna 2. The geometrical dimensions of these two antennas are given in Table 1. The second antenna type is shown in Fig.3 and photograph is shown in Fig.14. One version of its configuration is fabricated, which is called Antenna 3. The geometrical dimensions of antenna 3 are given in Table 2. The first antenna type has a smaller size and wider bandwidth relative to other comparable antennas in the literature. The air spacing under the patch has a height oh h_2, whereas the feed probe length (h_1) is shorter. In order to further decrease the antenna size, three shorting pins are installed between the patch and ground plane. The diameters of these pins are optimized to the value of 0.7mm (see Fig.2).

The second antenna type applies a substrate integrated resonator (SIR) to the first antenna type, as shown in Fig.3. It consists of two substrates. Its feed consists of a coaxial probe in the lower substrate connecting to a small patch on the interface between the lower and upper substrates. Then this small patch is connected to the upper larger patch on the upper substrate by some pins, in the form of a substrate integrated resonator (SIR), which is equivalent to the open cavity in the feeding system of the first antenna type. Also three shorting pins are connected between the patch and ground plane. Observe that the feed probe is connected to the center of the lower patch. The height of the upper patch to the ground plane is 250mil and that of the middle patch is 125mil. A photograph of the fabricate version of this antenna is shown in Fig.3. It is observed that its efficiency may be degraded due to the losses in metallic pins.

III. Simulation Results and Measurement Data

Firstly, we consider two versions of the first proposed antenna type, denoted as antennas 1 and 2. We then study the second proposed antenna type denoted by antenna 3.

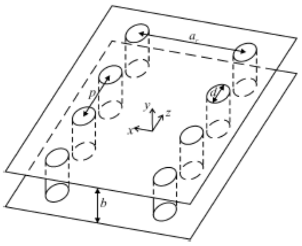
Antenna 1 is designed for the frequency band 2.8 to 11.1 GHz, which is an UWB antenna. The dimensions of antenna 1 are given on Table 1. Its size at the lowest frequency is $0.186\lambda_{\mathrm{fmin}} \times 0.186\lambda_{\mathrm{fmin}} \times 0.098\lambda_{\mathrm{fmin}}$. Its impedance bandwidth (for SWR⩽2) is about 119%, which is better than three times the bandwidth obtained by the common E shaped patch antenna [10]. Fig.4 shows the SWR versus frequency for antenna 1 with and without shorting pins as obtained by the simulation results (by HFSS version 12) and measurement data. The results are in a good agreement.

To show the degree of miniaturization of the proposed antenna 1, we compare it with the antenna in [9] with the size $0.198\lambda_{\mathrm{fmin}} \times 0.198\lambda_{\mathrm{fmin}} \times 0.093\lambda_{\mathrm{fmin}}$ which has obtained a bandwidth of 73.8% in the frequency band 3.96 to 8.59 GHz. Observe that the bandwidth of antenna 1 has increased by 45.2% and its size has decreased by 11.8%. The gain of antenna 1 is drawn in Fig.5. The maximum gain is 5 dB, which is obtained at 6 GHz. The measurement radiation patterns of antenna 1 in the XZ plane are shown in Fig.6, which is seen to be stable across the bandwidth.

The dimensions of the second version of antenna type 1 (namely antenna 2) are given in Table 1. Its SWR is drawn in Fig.7. Its impedance bandwidth (defined for SWR⩽2) is 115.5% in the frequency band 0.86 to 3.21 GHz. Observe that the proposed feed system may be applied to any patch size and shape to obtain wide bandwidth. The current distributions on the structure of antenna 1 at the lower and upper limits of the frequency band are shown in Fig.8. It extends over the whole structure at the lower frequency limit, but it is concentrated at the pin locations at the higher frequency limit.

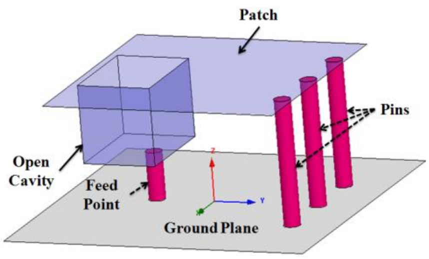
We then consider the proposed antenna type 2, denoted as antenna 3. Its dimensions are given Table 2. The curves of SWR versus frequency as obtained by computer simulation and measurement for the two cases of with and without substrates are drawn in Fig.9 (The case of absence of substrate is actually antenna type 1). This antenna can radiate effectively in the band 5.1 to 11.9GHz for SWR⩽2. Its impedance bandwidth is about 80%. The lower bandwidth of the antenna with no substrate is due to the inappropriate impedance matching, which may be remedied by increasing the height of space under the patch. The impedance matching and bandwidth of antennas for the case of inclusion of substrates may also be improved by increasing the height of substrates. The gain of antenna 3 is drawn in Fig.10, which has decreased across the band due to the losses of substrate. The advantages of antenna 3 relative to antennas type 1 are the reduction of its size without the increase of its substrate height and its higher bandwidth. Its disadvantage is the reduction of its gain.

The current distribution on the patch of antenna 3 at the lower frequency limit extends over the whole structure of antenna and at the upper frequency limit is located at the pins. The two dimensional radiation patterns in the XZ plane as obtained by measurements are drawn in Fig.11.

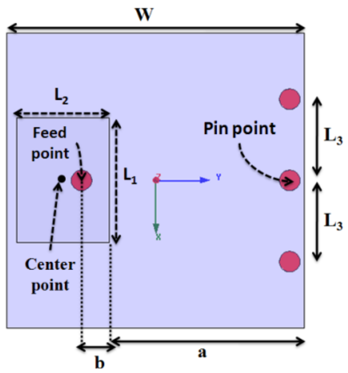


$$p > d \qquad \frac{\alpha_l}{k_0} < 1 \times 10^{-4}$$
$$\frac{p}{\lambda_c} < 0.25 \qquad \frac{p}{\lambda_c} > 0.05.$$

Fig. 1



(a)



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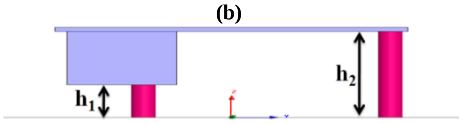
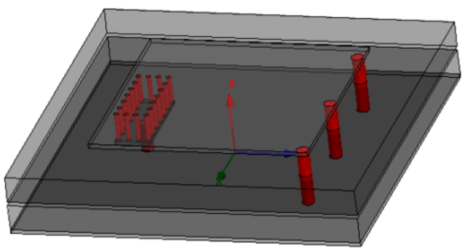


(c)

Fig. 2 Definition of parameters used in design of the first antenna type.



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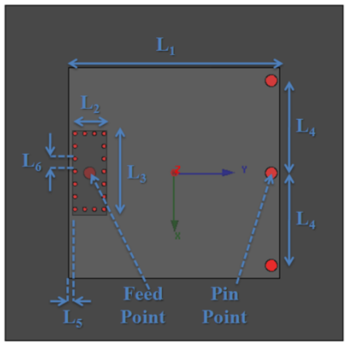

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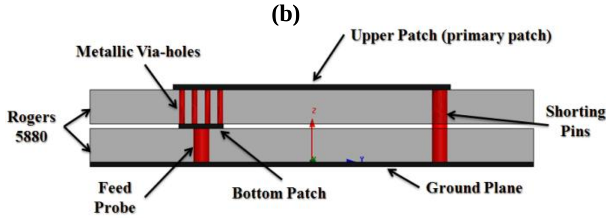

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Fig. 3 Definition of parameters used in design of the second antenna type.

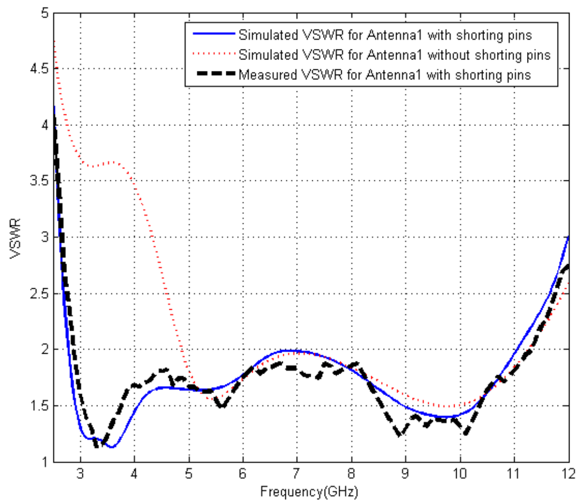


Fig. 4 Simulated and measured VSWRs of Antenna 1 with and without shorting pins.

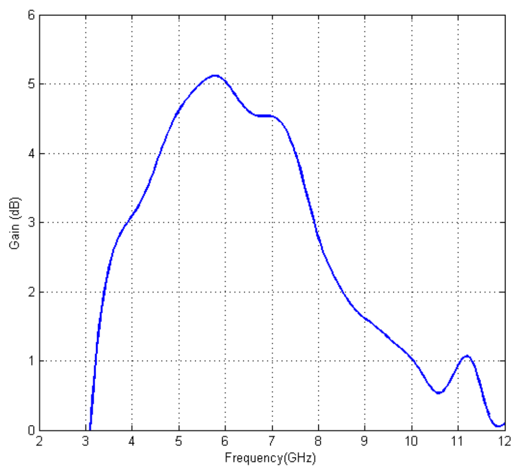


Fig. 5 Simulated gain of Antenna 1.

TABLE 1
dimensions of the first proposed antennas (units in mm).

	L_1	L_2	L_3	W	h_1	h_2	Pin Point	Feed Point	Center Point
Antenna.1	8.4	6.2	5.5	20	4	10.5	(0, 9)	(0,-5)	(0,-6.2)
Antenna.2	32.6	4.6	15	70	5.6	30	(0,32)	(0,-21.8)	(0,-21.8)

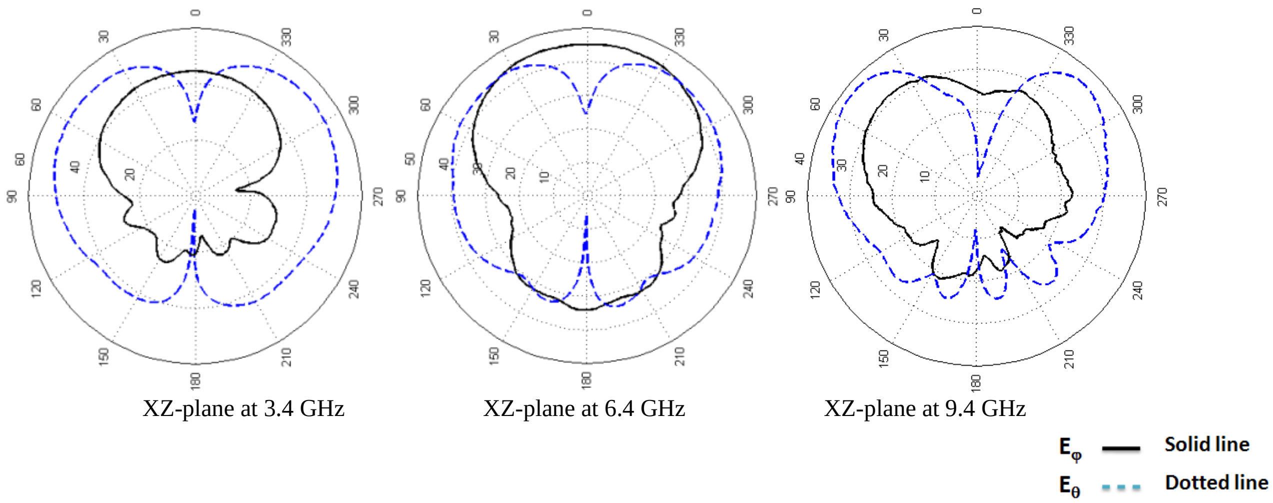


Fig.6 Measured radiation pattern of the antenna (1) in the XZ-plane (E-plane).

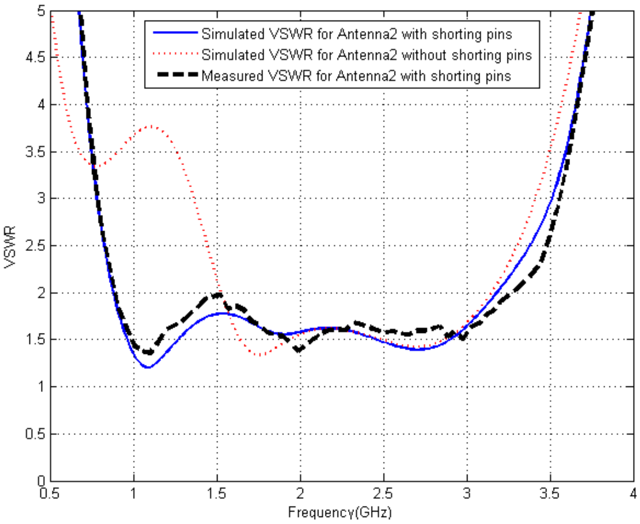
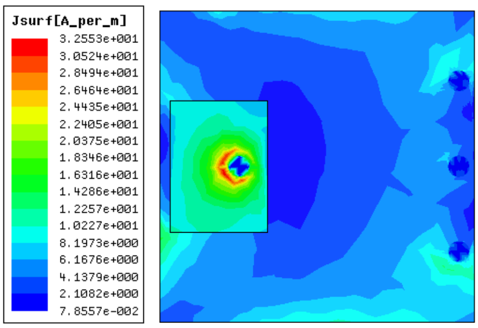


Fig. 7 Simulated and measured VSWRs of Antenna 2 with and without shorting pins.



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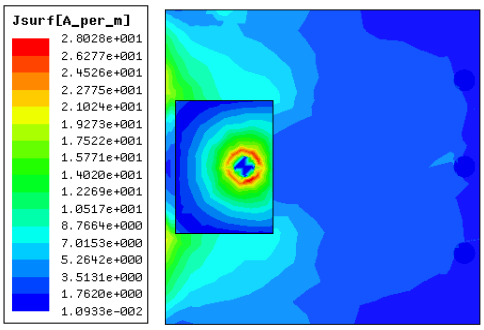
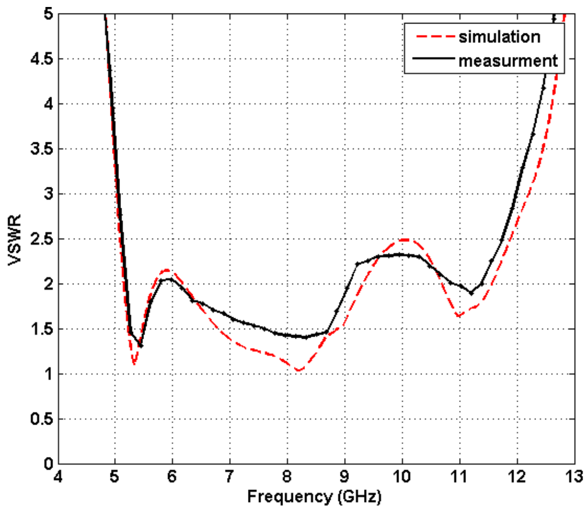


(b)

Fig. 8 Current distribution on antenna 1 at different frequencies; (a) Current distribution at 2.8 GHz, (b) Current distribution at 11.1 GHz.



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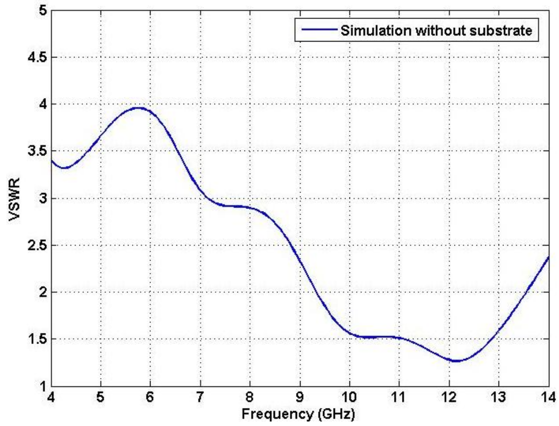


(b)

Fig. 9 Simulated and measured VSWRs of Antenna 3 with and without substrate.

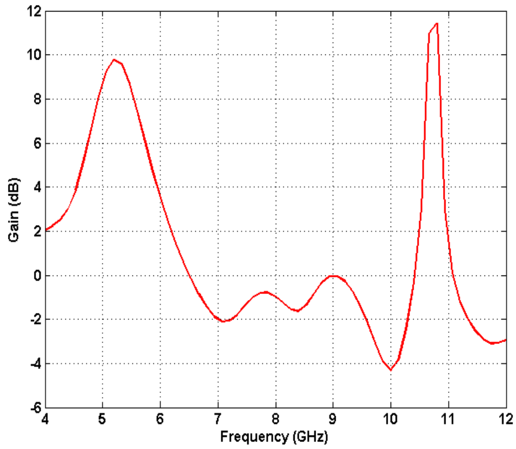


Fig. 10 Simulated gain of Antenna 3.

TABLE 2
dimensions of the antenna 3 (units in mm).

L_1	L_2	L_3	L_4	L_5	L_6	Pin point	Feed point
25	4	10	11	0.5	1	(0,11.5)	(0,-10)

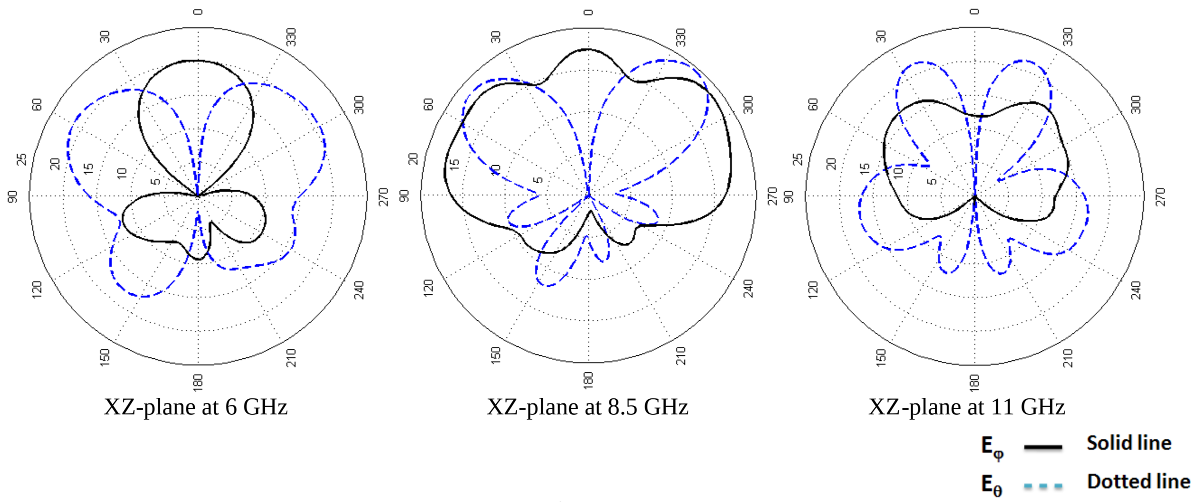


Fig. 11 Measured radiation pattern of the antenna (3) in the XZ-plane (E-plane).

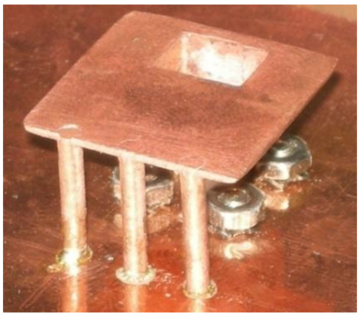
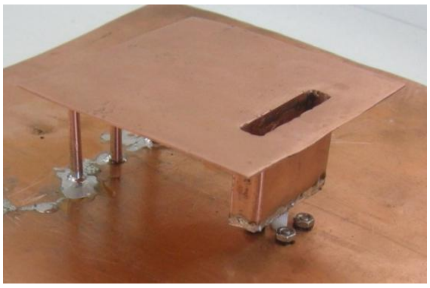
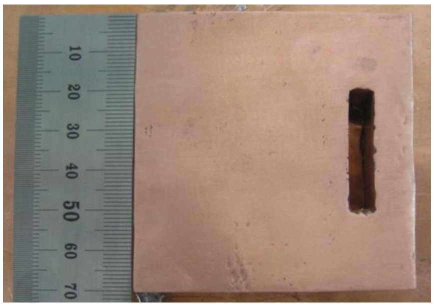


Fig. 12 Photograph of the antenna 1.



(a)



(b)

Fig. 13 Photograph of the antenna 2.

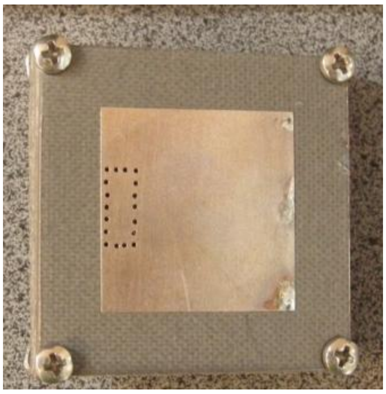


Fig. 14 Photograph of the antenna 3.

IV. CONCLUSION

In this paper, two novel feeding systems are proposed for the miniaturization and realization of wideband performance of microstrip antennas, namely an open cavity resonator (in an air substrate) and a surface integrated resonator (in a dual dielectric substrate), both fed by a coaxial probe. Three prototype models are fabricated and measured, namely two patch antennas with three shorting pins with an air cavity, one for operation in UWB (3.1-10.6 GHz) and the other for GPS (1.5-1.8 GHz), WiFi (2.1-2.6 GHz) and Wireless (3.1-3.8 GHz). A third patch antenna with a SIR cavity is fabricated for UWB. The level of miniaturization and ultra wide band performance are better than what have been achieved by other comparable techniques reported in the literature.

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