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Analysis of a Printed X-Shaped Monopole Antenna

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Abstract— **This paper presents a study of a printed X-shaped monopole antenna. The analysis has started from considering a strip fed conventional single band Rectangular Microstrip Antenna (RMSA) resonating at 2.45 GHz commonly used in WLAN applications. The antenna has been transformed to a monopole structure that has yielded a larger bandwidth.**

In the second part, triangular slots were introduced to the RMSA to obtain an X-shaped antenna and their effects were investigated. An X-shaped monopole structure presenting a bandwidth of 3.39 GHz (1.96 – 5.35 GHz) has been obtained. The analysis suggested a possibility of performing size reduction. This part resulted in a final X-shaped monopole printed structure with an enhanced bandwidth of 6.2 GHz (1.8– 8.0 GHz) and a significant external size reduction of 55.48 %.

The final antenna which can be used in various applications (WLAN, Wi-Fi, Wi-Max, LTE 4G, surveillance systems, medical imaging, etc.) has been fabricated and its reflection coefficient measured. Good agreement was noticed between the simulated and measured results.

Keywords-component: WLAN; Printed antenna; Size reduction; Bandwidth; Reflection coefficient

I. INTRODUCTION

Wireless communications have become the fastest growing segment of communication industry. The huge growth of the wireless systems such as cellular telephony, wireless local area networks, wireless sensor networks, smart home appliances and remote telemedicine has evoked a subsequent boost of wireless devices. A big part of it is the microstrip antennas which was introduced by Deschamps in 1953 [1] and realized in the 1970's by Munson [2] and Howell [3]. The main advantages of microstrip antennas are their low cost, light weight, single, dual and even multiband operation, mechanically robust, simple to manufacture, etc.

A patch antenna is fabricated by etching the antenna element pattern in a metal trace which is bonded to an insulating dielectric substrate such as a printed circuit board with a continuous metal layer bonded to the opposite side of the substrate known as a ground plane [4]. Different shapes of microstrip antennas can be used such as a square, rectangular, circular, elliptical and even more complicated geometry structures.

Miniaturization of microstrip patch antennas is a recent topic of interest. Two main techniques are usually used for that purpose: Defected Microstrip Patch (DMS) and Defected Ground Structure (DGS) and a variety of shapes have been proposed. These defects constitute an obstruction in the current path resulting in altering the microstrip structure performance. Important parameters that affect the performance of the microstrip structure are the slit or slot length, the width and the position [5-10]. Unfortunately, mathematical modeling for these parameters, even empirical formulas that allow having a pre-specified operation of the microstrip structure, are not available yet [11] due to the difficulty of analysis [5]. Some of the presented defects have been used for bandwidth enhancement purpose [11] and some of them for microstrip antenna size reduction [12].

This paper concerns analysis and size reduction of an X-shaped antenna obtained by introducing slots to an original RMSA.

The first step of this work consists on the design and analysis of a conventional rectangular microstrip patch antenna (RMSA) operating at a resonant frequency of 2.45 GHz used in Wireless Local Area Network (WLAN) using an empirical model [4] in conjunction with the electromagnetic (EM) full-wave simulator.

The second step consists on the modification of the RMSA by etching the ground plane and making it smaller to get a monopole structure that achieves a large bandwidth.

In the third step, slots were introduced to the original RMSA to obtain an X-shaped antenna.

The fourth step was to make the resulting X-shaped antenna monopole by etching its ground plane to make it able to operate in a large frequency range.

After that, size reduction was performed to the monopole X-shaped antenna yielding a larger bandwidth compared to the previous structure with a 55.48 % size reduction.

II. PROPOSED ANTENNA STRUCTURE

As mentioned in the previous section, the first step consists on the design an RMSA that resonates at 2.45 GHz. This is done using the Hammerstad model [13]. For the used substrate having a thickness h=1.63mm, a dielectric constant $\varepsilon_r = 4.3$ and loss tangent $\tan\delta = 0.0017$, the rectangular patch dimensions are found to be: W=37.60 mm and L=29.24 mm. Using the EM tool to simulate the return loss of this structure, it has been found that the resonant frequency is 2.43 GHz which is less than the desired one (2.45 GHz). Indeed, empirical model calculations are not highly accurate compared to the full-wave model used by the EM tool. Accordingly, a slight adjustment consisting on the antenna length decrease has been performed to resonate at 2.45 GHz. The corrected length is: L=29.1 mm.

After that, the ground plane was etched and four slots where introduced to the RMSA to end up with a Monopole X-shaped antenna that has bandwidth of 3.39 GHz (1.96 – 5.35 GH). The current distribution on the antenna patch showed a large surface where current was very low. Hence, this surface can be removed resulting in a reduced size structure without considerably affecting the antenna performances. To this end, some modifications consisting were performed to end up with the reduced size X-shaped antenna shown in Fig.1.

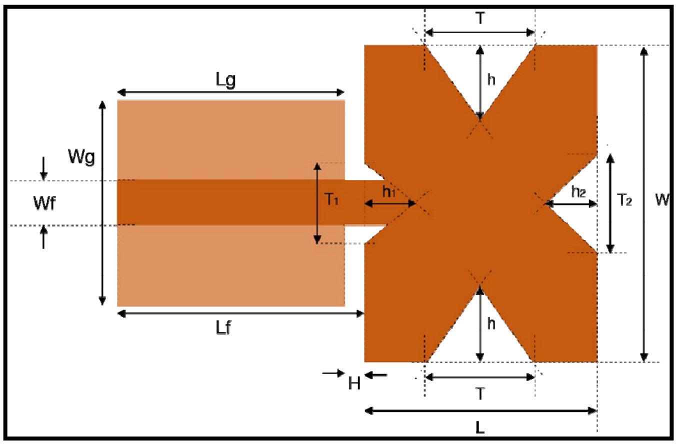


Fig.1 Geometry of the reduce size monopole X-shaped antenna

The structure illustrated in Fig.1 is obtained after removing parts of the antenna discussed earlier keeping the overall X-shape of the antenna. The ground plane dimensions have been decreased as well. The final dimensions are given in Table I.

Table 1 Dimensions of the reduced size Monopole X-shaped antenna (in mm)

L	W	T	T_1	T_2	h	h_1	h_2	Lf	Wf	H	Wg	Lg
17.6	23	8	6	7	5.5	3.8	3.8	20.1	3	1.4	15	17.1

III. RESULTS AND DISCUSSION

A. Effect of introducing slots

To illustrate the effect of introducing slots, these ones have been introduced separately one after the other as illustrated in Fig.2. Structures (a), (b) and (c) of Fig.2 were simulated and their reflection coefficients are shown in Fig.3 together with the original RMSA one.

From Fig.3, it can be noticed that the different slots affect the resonant frequency as follows:

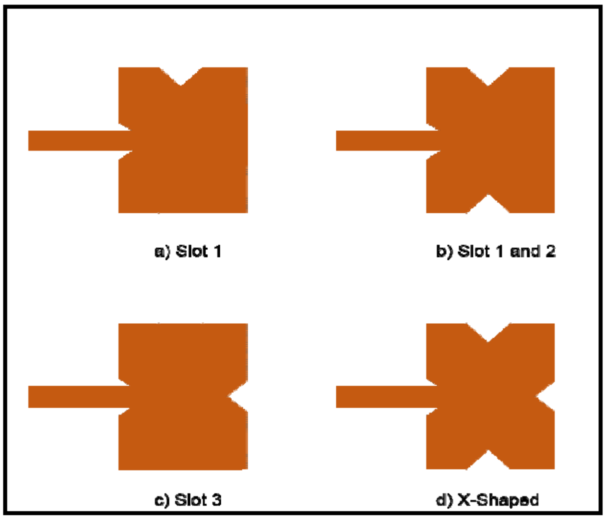


Fig.2 RMSA with slots

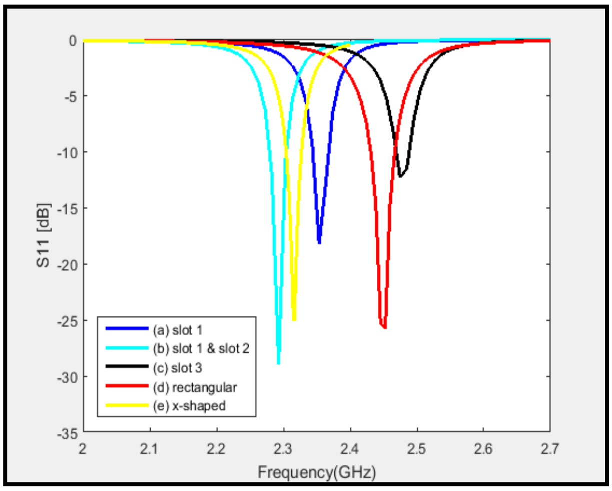


Fig.3 S11 (dB) versus Frequency of RMSA with slots

- **Effect of slot 1**

Because of the symmetry, introducing slot 1 or slot 2 at the opposite side is equivalent, thus there is no need to study the effect of slot 2 apart. It can be seen from Fig.3 that the frequency has decreased from 2.45 GHz to 2.35 GHz. This is due to the fact that the current takes a longer path, in other words the effective length of the antenna has been increased which is often referred to as a reactive loading of the patch.

- **Effect of slots 1 and 2**

When introducing slot1 and slot2 simultaneously, the frequency has decreased even more reaching a value of 2.29 GHz. As stated before, the introduction of the vertical slots results in a frequency shift toward lower region. This may also be regarded as size reduction.

- **Effect of slot 3**

  However, when introducing (the horizontal) slot 3, the frequency has increased from 2.45 GHz to 2.48 GHz. This is due to the fact that the current takes a shorter path along the central axis, in other words the effective length of the antenna has been reduced. Even though the horizontal slot does not contribute to size reduction, it plays a major role in making the bandwidth wider especially in with the monopole antenna as it will be seen later.

B. Perfomances of the monopole X-shaped antenna

The input reflection coefficient of the considered antenna is shown in Fig.4. This figure shows clearly that the final antenna presents a large bandwidth (2.4 - 6.44 GHz). The structure bandwidth is 4044 MHz corresponding to a percentage bandwidth of 91.4 %.

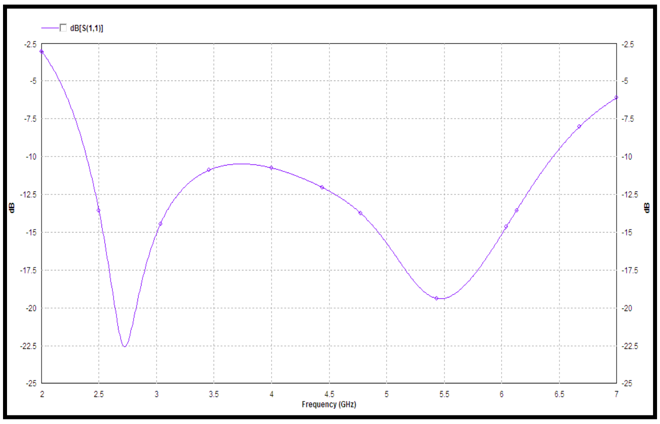


Fig.4 Return Loss versus Frequency

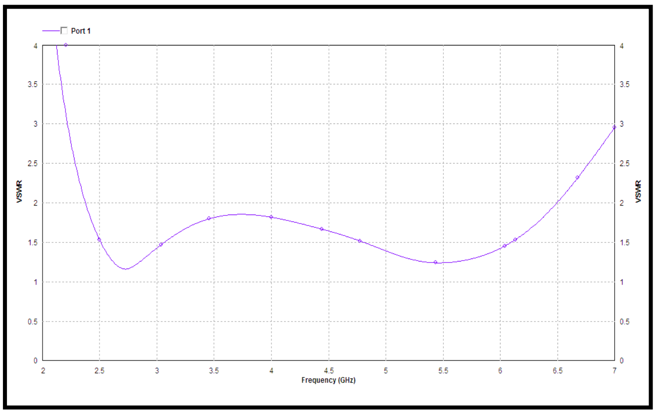


Fig.5 VSWR versus Frequency

The antenna VSWR is illustrated in Fig.5 which shows that in the band [2.40 -6.44 GHz] this ratio is between 1 and 2 with a minimum value of 1.16 at 2.73 GHz.

The current distribution of the considered antenna at 2.45 GHz, 2.73 GHz and 5.50 GHz is shown in Fig.6.

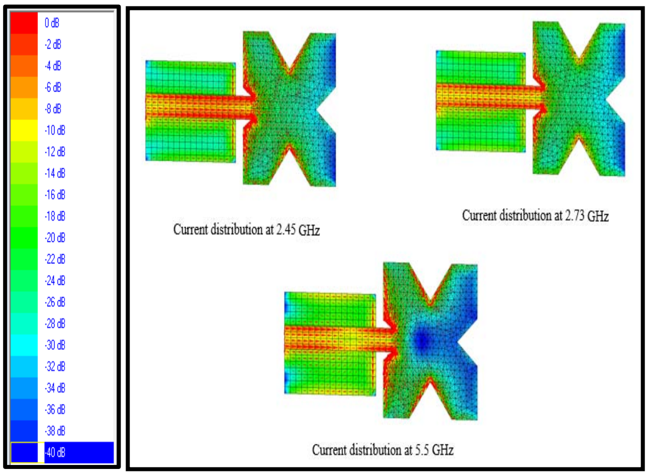


Fig.6 Current Distribution of the reduced size X shaped antenna

The first frequency corresponds to the frequency of interest of the original RMSA whereas the two others are selected because they achieve best power matching as shown in Fig. 4.

From this figure, we see that the current densities at 2.45 GHz and 2.73 GHz are similar. They are low at the right (radiating) edge of the patch and particularly dense at the central vertex of the lateral triangular slots. Whereas, at 5.50 GHz the current density is concentrated only at the edges of the lateral slots and its low level extends from the right edge of the patch to its center.

The following figures show the radiation pattern for the antenna at the selected frequencies in both E and H-planes.

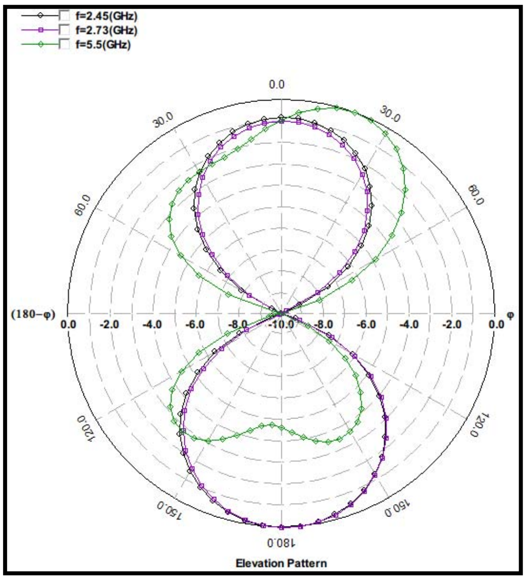


Fig.7 Co-polar component for the E-plane

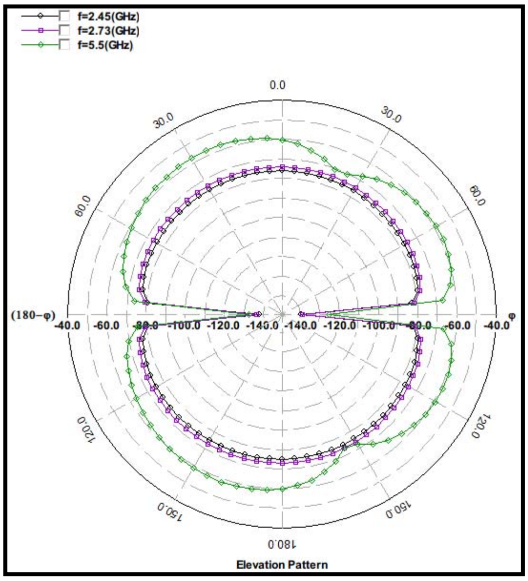


Fig.8 Cross-polar component in the E-plane

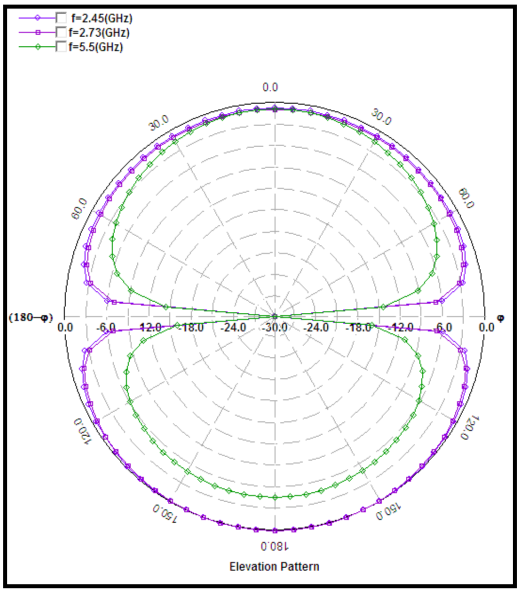


Fig.9 Co-polar component in the H-plane

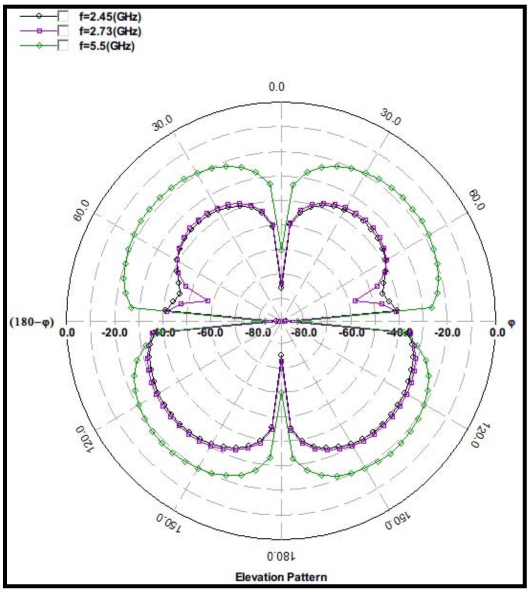


Fig.10 Cross-polar component in the H-plane

As expected, the 3-D radiation patterns illustrated in Fig.11-13 show two hemispheres as a consequence of removing the ground beneath the patch (almost omnidirectional pattern with an exception that there is no radiation in the plane including the patch).

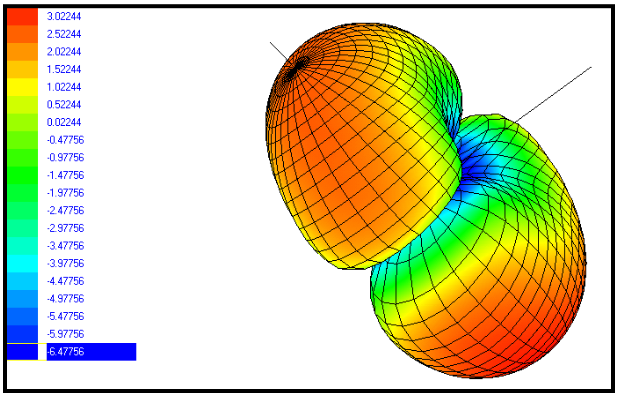


Fig.11 3-D Radiation Pattern at 2.45 GHz

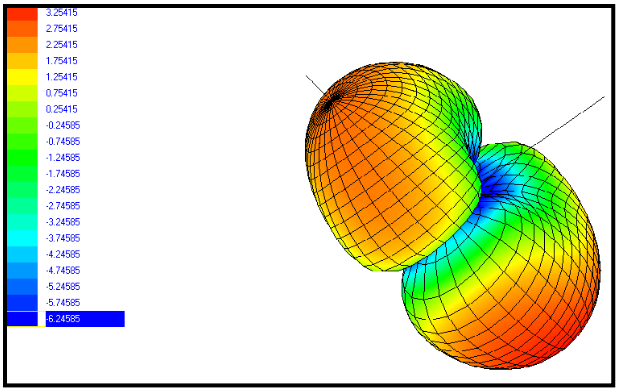


Fig.12 3-D Radiation Pattern at 2.73 GHz

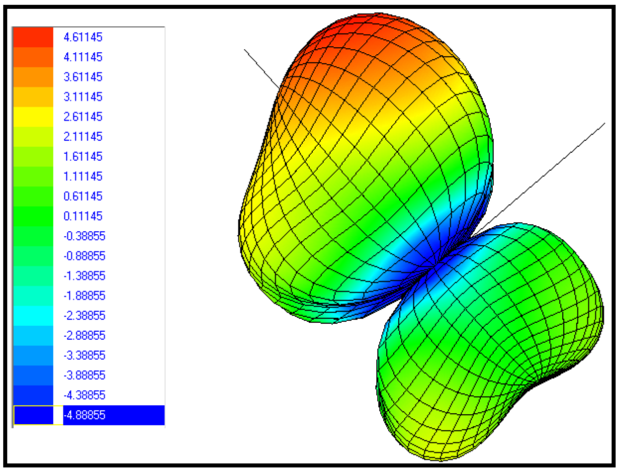


Fig.13 3-D Radiation Pattern at 5.5 GHz

The radiation pattern characteristics at these frequencies are summarized in Table 2.

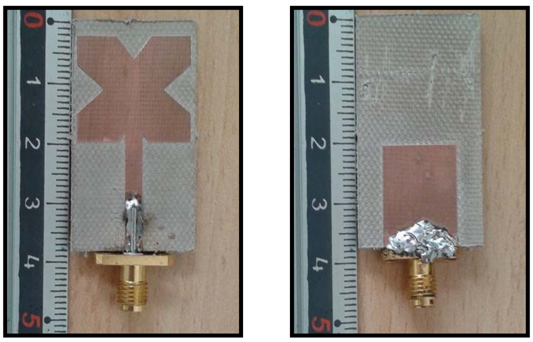
Table 2 *Radiation Pattern Characteristics of the Reduced Size Monopole X-shaped Antenna*

Frequency (GHz)		2.45	2.73	5.5
E-plane	Maximum direction of propagation (**θ**)(°)	180	180	20
	Beamwidth (θ^{E}) (°)	86.56	85.63	99.79
H-plane	Maximum direction of propagation (**θ**)(°)	180	180	0
	Beamwidth (θ^{H}) (°)	161.2	158	121.36
Max Directivity (dB)		3.022	3.25	4.63
Polarization Purity (dB)	E-plane	75.88	73.78	60.68
	H-plane	75.88	73.78	60.68

From this table, it is observed that:

- The presented antenna has good polarization purity in both E- and H- planes at the selected frequencies.
- As the frequency increases, the directivity increases.
- The maximum direction of propagation has remained the same for the two low frequencies (180° in both planes) whereas at 5.5GHz it is in the direction of 20° in the E-plane and 0° in the H-plane.
- The -3dB beamwidths in both planes at the selected frequencies are relatively high.
- The maximum directivity at the selected frequencies are relatively small denoting the broadside nature of the antenna.

Finally, the antenna has been fabricated and its reflection coefficient measured.



(a) Top view (b) Bottom view

Fig.14 The fabricated reduced size X-shaped monopole antenna

Fig.15 displays a comparison between the simulated and the measured results

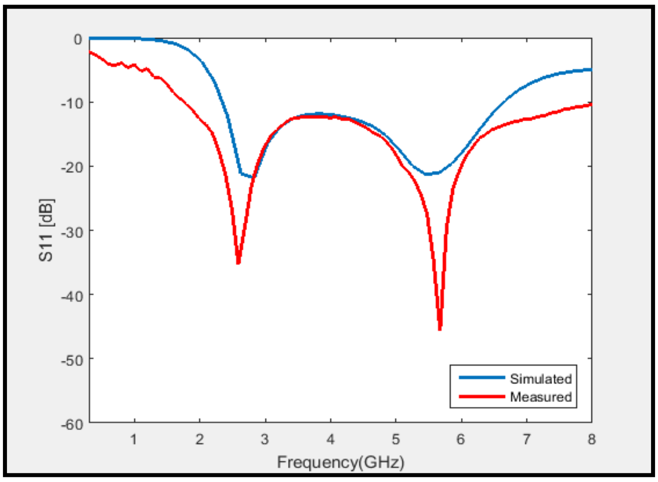


Fig.15 Measured and Simulated input reflection coefficient

Table 3 Simulated and measured frequency bands limits and bandwidths

	High Frequency (GHz)	Low Frequency (GHz)	Center Frequency (GHz)	% BW
Simulated	6.44	2.4	4.42	91.4
Measured	8	1.8	4.9	126.53

We notice a small negative shift of the measured results compared to the simulated ones at the lower band limit and a positive shift at the high band limit. Also, both simulated and measured bands show that the developed X-shaped monopole antenna exhibits a wide band feature. Although the difference in the reflection coefficient at the resonant frequencies, Fig.15 shows that the simulated and measured graphs are similar. The difference is attributed to various factors such as substrate characteristics and realization accuracies.

IV. CONCLUSION

The purpose of this work concerns the analysis of a printed monopole X-shaped antenna. The work has been started from considering a reference structure which is a conventional Rectangular Microstrip Antenna (RMSA) designed to operate at WLAN application (2.45 GHz) for which modifications have been introduced to end up with the desired configuration. This has been carried-out following successive steps.

In the first step, a conventional strip fed RMSA has been designed using an empirical model. Its dimensions have then been readjusted to resonate at the desired frequency. After that, the ground plane has been partially etched so that the antenna becomes a monopole structure which exhibits wideband feature (1.99 - 3.17 GHz; %BW= 45.74 %) and radiates in both sides of the plane containing the antenna.

In the second step, slots producing the X-shape have been introduced separately to original RMSA to investigate their effects. It is noticed that slots lateral to the feed current main direction contribute in frequency decrease whereas the ones normal to this direction contribute in bandwidth enhancement.

The obtained configuration exhibits a bandwidth of 3.39 GHz (1.96 - 5.35 GHz; BW = 92.75%). Investigations on current distribution on the patch suggested that size reduction can be performed. This task has ended up with the final reduced size X-shaped monopole antenna which presents a larger bandwidth of 6.2 GHz (1.8 GHz - 8 GHz; BW = 126.53%). Furthermore, a significant antenna total size reduction of 55.48 % as compared to the previous structure is achieved.

The final structure has been fabricated and its reflection coefficient measured. A good agreement is observed between the simulated and measured results thought the slight deviation attributed to various factors mainly related to substrate characteristics and realization accuracies.

Finally, the obtained reduced size wide-band monopole antenna can be used in several wireless applications (WLAN, Wi-Fi, Wi-Max, LTE 4G, surveillance systems, medical imaging, etc.).

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