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A NOVEL HYBRID DESIGN OF PRINTED HEMI-CYLINDRICAL DIELECTRIC RESONATOR MONOPOLE ANTENNA WITH MULTI-BANDS OPERATION

M. Khalily and M. K. A. Rahim

Radio Communication Engineering Department
Faculty of Electrical Engineering
Universiti Teknologi Malaysia
UTM Skudai, Johor 81310, Malaysia

Abstract—A novel complex structure of Printed Dielectric Resonator Monopole Antenna (PDRMA) with multi-bands operation is presented and investigated. In the proposed structure, a printed fork-like stepped monopole antenna is used for exciting two new modified hemi-cylindrical dielectric resonators with a great relative permittivity of 80. A narrow medium substrate with a low permittivity is also applied between two mentioned dielectric resonators and the monopole antenna, to improve the matching, especially at the lower frequencies. By using this novel designed antenna applying two dielectric resonators with very high permittivity, many frequency wide bands for VSWR < 2 are practically measured and supported which are as follows: 1.54–3.25 GHz (GPS, GSM, PCS, UMTS 2000, 2.4 GHz-Bluetooth, WLAN, WiMax), 3.3–3.6 GHz (WiMax), 3.8–4.4 GHz (C-band), 4.8–6.2 GHz (5.2, 5.5 & 5.8 GHz-WLAN & WiMax). Experimental and numerical results are carried out and discussed, showing good agreement.

1. INTRODUCTION

Over the past few years, the planar-shaped dielectric resonator antennas (DRA) using microstrip line have received extensive attention, especially the complex, hybrid and modified forms of them. A major fraction of the recent studies concentrates on enhancing the impedance bandwidth of a DRA element in view of different applications. To this purpose, various techniques have been explored,

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Corresponding author: M. Khalily (mohsen@fkegraduate.utm.my).

which include a removed-air-volume from a cylindrical dielectric resonator [1], a modified cylindrical dielectric resonator excited with a slot [2–4] and microstrip-fed line [5, 6], a quarter-wave monopole loaded with an annular dielectric resonator [7, 8], and also using hybrid dielectric resonators excited by a simple monopole antenna [9, 10]. A hemispherical dielectric resonator (HDR) antenna excited with a thick slot at the short circuited end of waveguide is recently analyzed in [11] using the Green's function approach and the method of moments (MOM). Another MOM numerical study of split cylindrical dielectric resonator antennas on a conducting ground plane excited by a coaxial probe with a bandwidth of 35% is previously presented in [12]. In addition, the other analytical simulations on the various DRAs were presented in [13, 14]. In these studies, not only, the analyses on the DRA with multiband operation have been not done, but also, the majority of the used dielectrics have low permittivity which simplifies the design.

In this paper, a novel complex form of the DRA using two sliced cylindrical dielectrics excited by a new printed fork-like stepped monopole antenna is presented and studied. In this design, by using two high permittivity (= 80) dielectric resonators, the multiband operation between 1.5 and 7.5 GHz will be obtained. Therefore, many of wireless systems will be supported. In the following sections, the design of the proposed antenna is described, and then obtained results are presented and discussed.

2. COMPLEX ANTENNA CONFIGURATION AND DESIGN

The proposed complex antenna has three layers, which are shown in Fig. 1, respectively. The first layer is a printed fork-like monopole antenna which is seen in Fig. 1(a). Its optimal dimension is also presented in this figure. In this layer, a FR4-based substrate with thickness of 1.6 mm and dimension of $30 \times 40\,\mathrm{mm}^2$ is used. The width of the microstrip-fed line is about 2 mm for having an input impedance of 50 ohm. By using this novel modified stepped monopole antenna, a wide frequency bandwidth with poor matching is obtained. But, in this case the expected multi-band operation cannot be obtained. In addition, the quality factor of the antenna is very low. In order to eliminate these problems, two dielectrics with high permittivity and proper sizes, positions and shapes will be added to the antenna. In the next step of the design of the multi-layers antenna, a dielectric layer based on FR4 with thickness of 1.6 mm and dimension of $28 \times 30\,\mathrm{mm}^2$ is placed on top of the first layer [Fig. 1(b)]. Here, the ground plane of the monopole antenna is not covered.

This simple dielectric with low permittivity in middle layer is applied to adjust the total effective permittivity of the antenna and impedance matching. In the final step of the design, the main part of the antenna which is include of two new sliced cylindrical dielectrics with high permittivity of 80 is added to the structure, as shown in Fig. 1(c). The distance between these dielectrics and the bottom edge of the substrate is optimized and fixed at 16 mm. This parameter is a significant factor for having good impedance and radiation characteristics in all of the frequency bands. Finally, the exact dimensions of these dielectrics are illustrated in Fig. 1(d). In the next section, the effective parameters will be studied and the measured results also presented and compared in the last section.

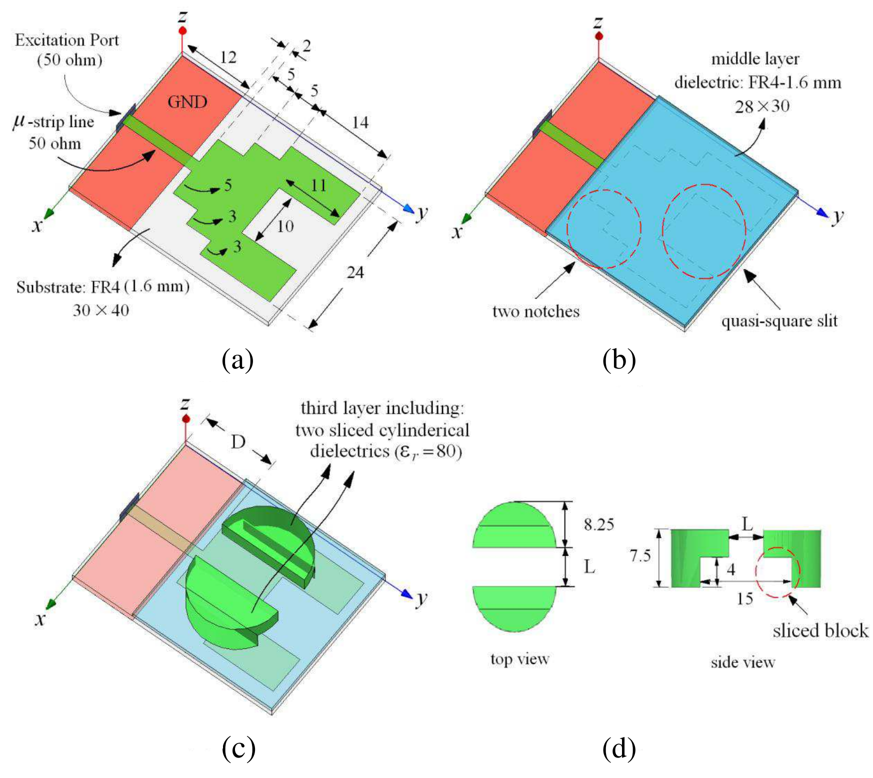

Figure 1. Configuration of the multi-layers complex antenna and its optimized dimensions, (a) First layer, (b) middle layer, (c) third layer and (d) dimension of the two sliced dielectrics.

3. PARAMETRIC STUDIES AND DISCUSSIONS

In this study, the performances of the presented two dielectrics with different positions and sizes is more considered. Because, employing this form of the dielectrics with very high permittivity for supporting the multiband operation is the main novelty of this paper. Moreover, the effects of using of these three layers will be studied. The proposed complex antenna is simulated by High-Frequency Structure Simulator (ver. 11) software. First, the bottom layer is studied. The significant parameters of the monopole structure are two rectangular notches at two bottom corners of the patch which their dimensions are seen in Fig. 1(a). Fig. 2 shows the VSWR of the only monopole antenna with and without two notches and a quasi-square slit in top edge of the patch with dimension of $10\times11\,\mathrm{mm}^2$ [see Figs. 1(a) & (b)]. It is seen from this figure that when two notches are not used, the matching of the antenna is entirely degraded. The optimal performance is obtained when both two notches and the square slit are employed, simultaneously. Moreover, it is discover from this figure that without using the quasi-square slit on the patch the impedance matching between 1.8 and 2.5 GHz is degraded. In addition, it is noted that by using the slit, two independent microstrip arms are specified for exciting each of the sliced dielectrics. In the next step, the effects of the positions of the two dielectrics are studied. In this case, the second layer, including a simple dielectric layer, is added and considered. The simulated VSWRs

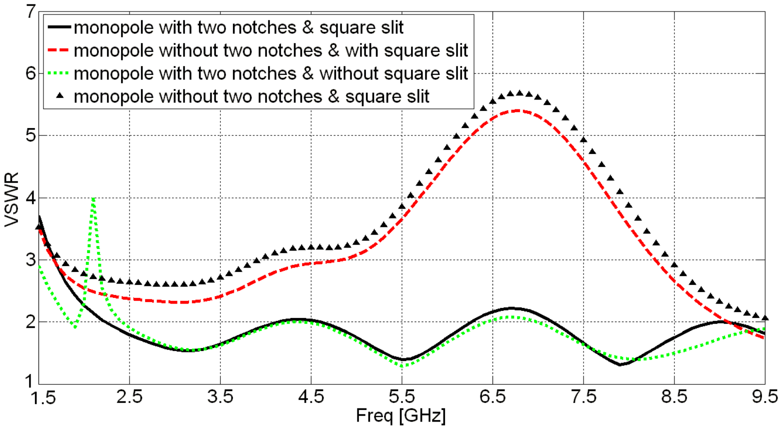

Figure 2. Simulated VSWRs of the monopole antenna in first layer for four cases of two notches and quasi-square slit, cut from the patch edges [Fig. 1(a)].

of the antenna including two sliced dielectrics and the middle layer for different values of D and L are shown in Figs. 3 and 4, respectively. These results show that the optimized values of D and L are 16 and 7 mm, respectively.

By helping of a parallel process, the optimum values of the other parameters are achieved [see Fig. 1(d)]. As shown in Fig. 3, by decreasing D or nearing the dielectrics to the bottom edge of

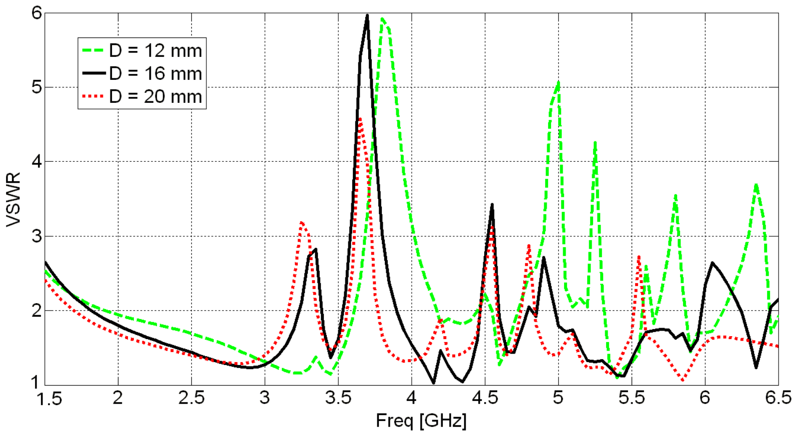

Figure 3. Simulated VSWRs of the antenna in different values of D ($L = 7\,\text{mm}$).

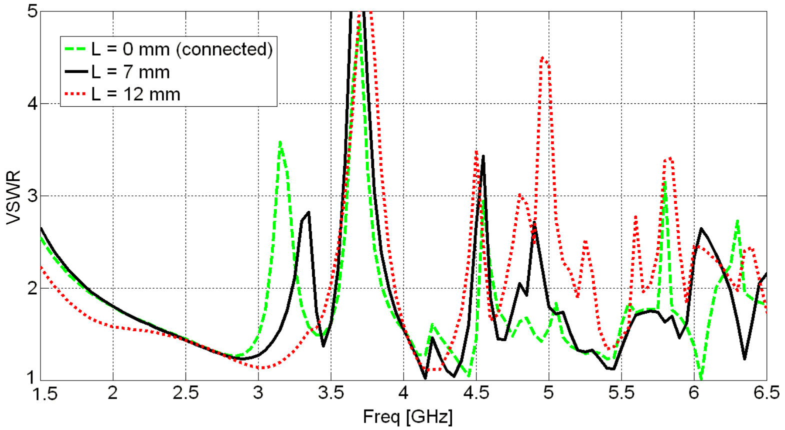

Figure 4. Simulated VSWRs of the antenna in different values of L ($D = 16\,\text{mm}$).

the substrate, the magnitudes of the discontinuities are improved. Therefore, the matching at high frequencies is degraded. Similarly, Fig. 4 presents that by decreasing L, the matching at high frequencies is again degraded. In this design, it is tried to adjust the positions of the two dielectrics for fully covering the microstrip discontinuities (i.e., the common areas between two notches and the square slit) in first layer. In these areas, the values and directions of the surface currents are greatly changed.

The effects of non-existence of middle layer and the sliced blocks in comparison to the presented antenna are clarified in Fig. 5. When these elements are not used, the matching at low frequencies, especially between 2.5 and 3.2 GHz is very low. Also, the resonance of 3.5-GHz WiMax is not separately supported. In these cases, the mentioned multi-bands operation is not obtained.

Finally, as expected, it is clearly discovered from Fig. 6 that by decreasing ε_r, the multi-bands case is degraded and also the ultra-wideband case is improved. It is also noted that because of the using two dielectrics in active areas on the microstrip exciter with very high permittivity, the many sudden discontinuities in Figs. 3–6 are detected. By controlling these discontinuities in different frequencies the multi-band performance has been achieved.

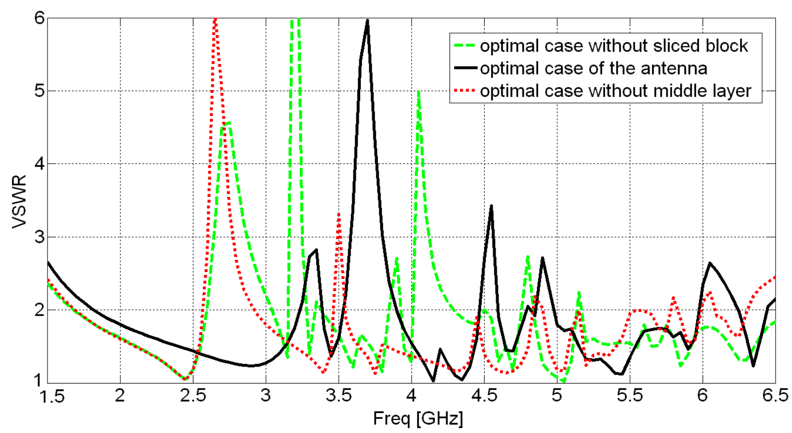

Figure 5. The comparison between the optimal antenna and the antenna without sliced block and middle layer.

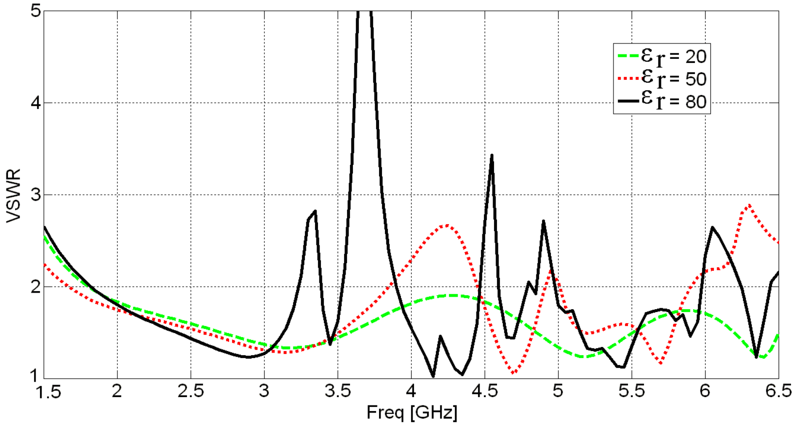

Figure 6. Simulated VSWRs of the antenna in different values of ε_r of two modified dielectrics.

4. MEASUREMENT RESULTS

The realized complex multi-layers dielectric antenna in different views is illustrated in Fig. 7. Considering the many design, manufacturing and measurement problems of this multi-layers complex antenna, the optimized structure was successfully constructed and measured. The measured and simulated VSWRs of the antenna are simultaneously shown in Fig. 8, for comparison. It is clearly seen from this figure that the results are in good agreement and the mentioned multi-bands operation is obtained. Therefore, the antenna can support the many wireless systems which are as follows: 1.54–3.25 GHz (GPS, GSM, PCS, UMTS 2000, 2.4 GHz-Bluetooth, WLAN, WiMax), 3.3–3.6 GHz (WiMax), 3.8–4.4 GHz (C-band), 4.8–6.2 GHz (5.2, 5.5 & 5.8 GHz-WLAN & WiMax). Moreover, two simulated results with HFSS and CST (ver. 2010) are simultaneously presented in Fig. 8 for more comparison and confirming the accuracy of the results and design. It is found out from these results that by using this form of the dielectrics exciting by the modified fork-like monopole, different resonance modes (hybrid modes) are excited. It is also interesting to notice that in comparison with the presented wideband dielectric antenna in [15], the proposed multi-layer antenna uses the substrates with high permittivity which further complicates the design. Moreover, unlike [15] the proposed antenna presents both wideband and multiband operations, simultaneously.

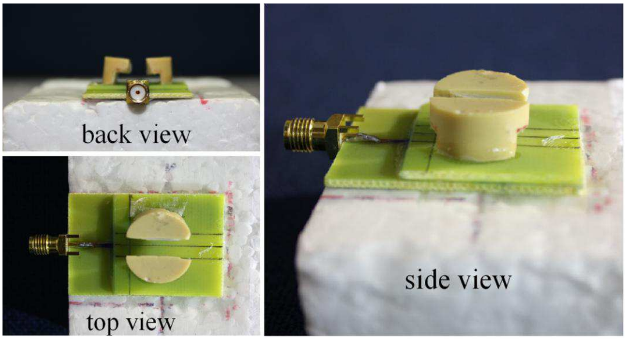

Figure 7. Photograph of the realized multi-layers dielectric antenna in back, side and top views.

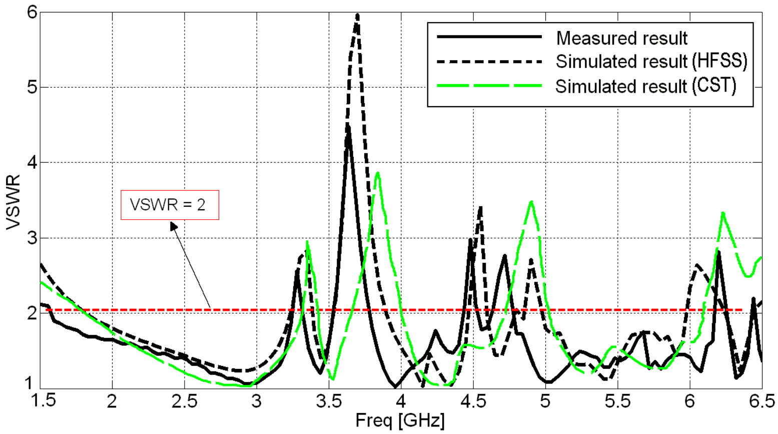

Figure 8. Measured and simulated (with HFSS & CST) VSWRs of the realized antenna.

Figure 9 shows the measured and simulated H & E planes radiation patterns at three selected frequencies, 2.4, 4 and 5.5 GHz. The cross-polarized fields in both E & H planes are sufficiently low compared to the co-polarized peak level. These results for the patterns are acceptable. Half power beam widths (HPBW) measured from the radiation patterns in the H-plane at 2.4, 4 and 5.5 GHz are 80, 65 and 60 deg, respectively, which are suitable. Finally, the simulated 3D Gains of the antenna at four selected frequencies, 2.4, 3.45, 4 and 5.5 GHz are presented in Fig. 10. The omni-directional and stable form in these 3D patterns are nearly detected. It is seen from this figure that the simulated peak gains of the antenna in direction of $z = 0$ deg are

1.016 dB (at 2.4 GHz), 2.12 dB (at 3.45 GHz), 2.36 dB (at 4 GHz) and 4.1 dB (at 5.5 GHz). In this case, the measured peak gains in direction of $z = 0$ deg are 0.9 dB (at 2.4 GHz), 1.89 dB (at 3.45 GHz), 2.16 dB (at 4 GHz) and 4.22 dB (at 5.5 GHz), as illustrated in Fig. 11. Figures 10 & 11 show the acceptable agreement between the simulated and measured gain results. The small degree of asymmetry in the patterns and 3D gains is due to the effects of the SMA connector and feed cable on one side of the antenna as well as the non-accuracy of the fabrication. It is noted that the proposed antenna has a fully complicated structure. Therefore, the process of the design, implementation and measurement is a hard work.

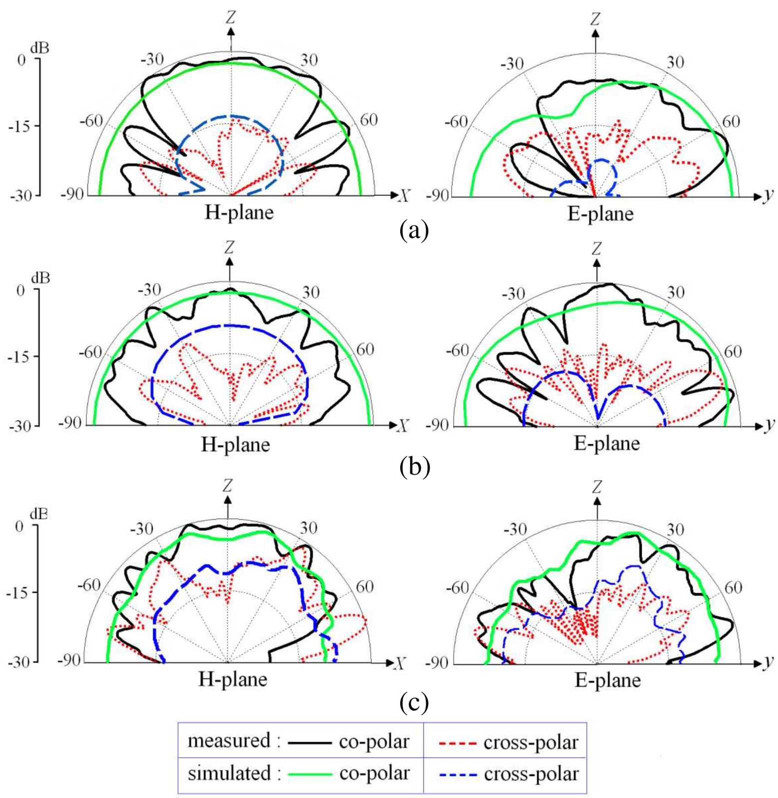

Figure 9. Measured and simulated H & E planes radiation patterns of the realized antenna in normalized form, at: (a) 2.4 GHz, (b) 4 GHz, and (c) 5.5 GHz.

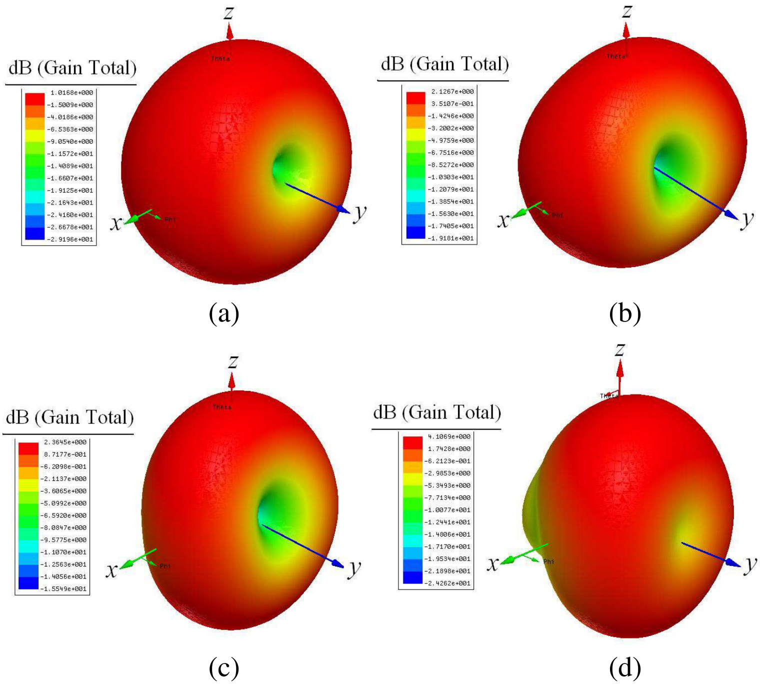

Figure 10. Simulated total 3D-Gain of the antenna at: (a) 2.4 GHz, (b) 3.45 GHz, (c) 4 GHz and (d) 5.5 GHz.

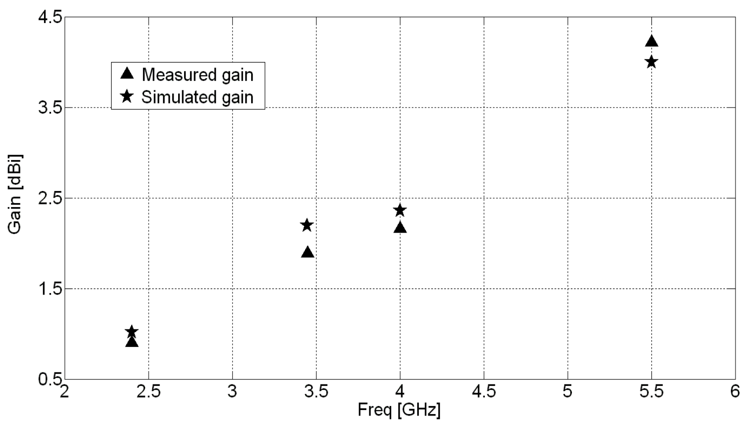

Figure 11. The measured and simulated gains of the realized antenna at 2.4 GHz, 3.45 GHz, 4 GHz and 5.5 GHz.

5. CONCLUSION

In this paper, a novel complex antenna for supporting the multi-bands operation has been presented. In this design, three connected different layers including a new modified fork-like monopole antenna with two separated microstrip arms for exciting the two novel sliced hemi-cylindrical dielectric resonators and a middle dielectric layer for improving the matching have been employed. By using these novel modified dielectrics with great permittivity of 80, the many of wireless systems between 1.5 and 6 GHz such as GPS, DCS, PCS, UMTS, Bluetooth, WLAN, WiMax and Wi-Fi are supported, simultaneously. The good agreement between the measured and two simulated (HFSS & CST) results was presented. In addition, suitable radiation pattern and gain characteristics over the four wireless bands are obtained. As a result, the proposed antenna is attractive and can be practical for various multifrequency systems.

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