International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:12, No:1, 2018

12x12 MIMO Terminal Antennas Covering the Whole LTE and WiFi Spectrum

Mohamed Sanad, Noha Hassan

***Abstract*—**A broadband resonant terminal antenna has been developed. It can be used in different MIMO arrangements such as 2x2, 4x4, 8x8, or even 12x12 MIMO configurations. The antenna covers the whole LTE and WiFi bands besides the existing 2G/3G bands (700-5800 MHz), without using any matching/tuning circuits. Matching circuits significantly reduce the efficiency of any antenna and reduce the battery life. They also reduce the bandwidth because they are frequency dependent. The antenna can be implemented in smartphone handsets, tablets, laptops, notebooks or any other terminal. It is also suitable for different IoT and vehicle applications. The antenna is manufactured from a flexible material and can be bent or folded and shaped in any form to fit any available space in any terminal. It is self-contained and does not need to use the ground plane, the chassis or any other component of the terminal. Hence, it can be mounted on any terminal at different positions and configurations. Its performance does not get affected by the terminal, regardless of its type, shape or size. Moreover, its performance does not get affected by the human body of the terminal's users. Because of all these unique features of the antenna, multiples of them can be simultaneously used for MIMO diversity coverage in any terminal device with a high isolation and a low correlation factor between them.

***Keywords*—**IOT, LTE, MIMO, terminal antenna, WiFi

I. Introduction

MIMO technology has achieved a great increase in the capacity of communication and greatly improved the communication quality. The capacity of the communication systems can be increased by the MIMO systems when channels are independent and identically distributed [1], [2]. The number and spacing of antennas are the key parameters of the MIMO antenna. The more the number of MIMO antennas are, the better the MIMO performance is. However, in the small mobile terminals, with multiple MIMO antennas, spacing between the antennas is not enough to ensure to reach high isolation between antennas. If the isolation within the multi-antenna system is insufficient, system performance is reduced due to the coupling between antennas [3].

In this paper, a broadband resonant terminal antenna will be presented. The antenna can be implemented in smartphone handsets, tablets, laptops, and notebooks. It is also suitable for IoT and vehicle applications. It is independent on the terminal type and size and its performance does not get affected by the environment. The antenna can be used in 2x2, 4x4, 8x8, and 12x12 MIMO configurations with a high isolation and a low correlation coefficient between the MIMO antennas. Each antenna covers the whole LTE spectrum plus the WiFi band besides the existing 2G and 3G bands (700-5800 MHz) without using any matching/tuning circuits. Matching circuits are frequency dependent and, therefore, they reduce the bandwidth. The losses in matching circuits significantly reduce the efficiency, which also results in reducing the battery lifetime. The antenna is self-contained and does not need an extended ground plane. It has a thin and narrow size and it is manufactured from a flexible material that can be bent or folded and shaped in any form.

Mohamed Sanad and Noha Hassan are with the Faculty of Engineering, Cairo University, Giza, Egypt (e-mail: msanad@amantantennas.com, nhassan@eng1.cu.edu.eg).

This research was fully financed by and assigned for Amant Antennas (www.amantantennas.com).

II. A Single Resonant Antenna For the Whole LTE and WiFi Spectrum

A broadband antenna technology was developed before by the authors of this paper where two antennas were used together to cover the whole LTE band (700-3800 MHz) [4]-[6]. The first antenna was covering the low band LTE spectrum starting from 698 MHz up to 960 MHz while the second one was covering the high band portion of the LTE spectrum starting from 1.42 GHz to 3.8 GHz. A third antenna was added to cover the WiFi band [7]. Each antenna consisted of two narrow printed metallic arms connected together by a shorting metallic strip. Each arm had a set of slots having different configurations. The shapes, locations, and dimensions of the slots were optimized in order to maximize the bandwidth. The antennas of the dual antenna configuration were completely self-contained and they did not need any additional ground planes or any other components.

In this research, the low and high band antennas of the above dual antenna configuration have been combined together in a single resonant antenna configuration as shown in Fig. 1. The antenna covers the whole LTE band plus the WiFi band (700-5800 MHz). It consists of three arms; two of them are directly fed while the third arm is fed by coupling as shown in Fig. 2 [8]. The three arms may be parallel to each other or may have any angle between them. They can be shaped in different ways in order to optimize the antenna performance. Each arm has a set of slots having different configurations. The length of the antenna determines its operating frequency. The other design parameters such as the width and the thickness of the antenna are all optimized together in order to enhance the antenna performance such as the bandwidth, the peak gain, and the efficiency. The optimized antenna dimensions can be scaled for any application at any frequency band.

The antenna is self-contained and it does not need to use a part of the handset as an extended ground. Hence, it can be mounted anywhere inside or outside any terminal. Furthermore, the antenna is made of a flexible material and can be bent and/or folded in different forms in order to fit any available space inside or outside the terminal.

Fig. 1 The wideband antenna

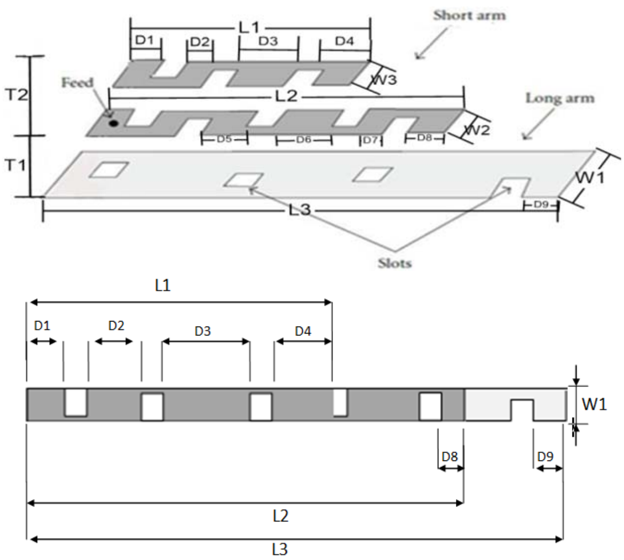

Fig. 2 Geometry of the wideband antenna

The performance of the antenna was numerically analyzed with the moment method using IE3D software from Zeland. The dimensions of the three arms were optimized together in order to increase the overall bandwidth of the antenna. A sample configuration of the single antenna technology is selected, optimized, manufactured and tested. The return loss was measured using a vector network analyzer while the efficiency and the radiation patterns were measured using a Satimo Compact Range [9]. The dimensions of the antenna are: L1=7.2 cm, L2=10.4 cm, L3=16 cm, T1=2 cm, T2=1 cm, D1=D8=D9=0.7 cm, D2=D7=0.5 cm, D3=D4=1.5 cm, D5=1.3 cm, D6=2.1 cm, and W1=W2=W3=0.3 cm. So, the overall length of the selected antenna configuration is 16 cm when it is not bent or folded. The overall width of the antenna is 0.3 cm and the overall thickness is 0.3 cm. Thus, the antenna has an overall volume of 0.3x0.3x16 = 1.44 cm^3. This proposed volume is the total volume of the antenna because it does not require any additional ground planes or matching circuits, and it can be reduced by folding/bending the antenna.

The measured return loss of the antenna is shown in Fig. 3. The return loss is better than -5 dB over all the frequency bands of LTE (700-960 MHz), (1400-2700 MHz), and (3300-3800 MHz) and WiFi (5100-5800 MHz). The measured efficiency of the antenna is shown in Fig. 4 as a function of the frequency. The minimum efficiency is 40%, which only happens at very few frequencies. The efficiency exceeds 90% at some other frequencies. The return loss and the efficiency of the antenna can be further improved by increasing the width and/or the thickness of the antenna. The radiation patterns around the axis of the antenna are presented in Fig. 5 at phi=0 and phi=90 at 1800 MHz as a sample frequency, where the peak gain is 3.3 dBi.

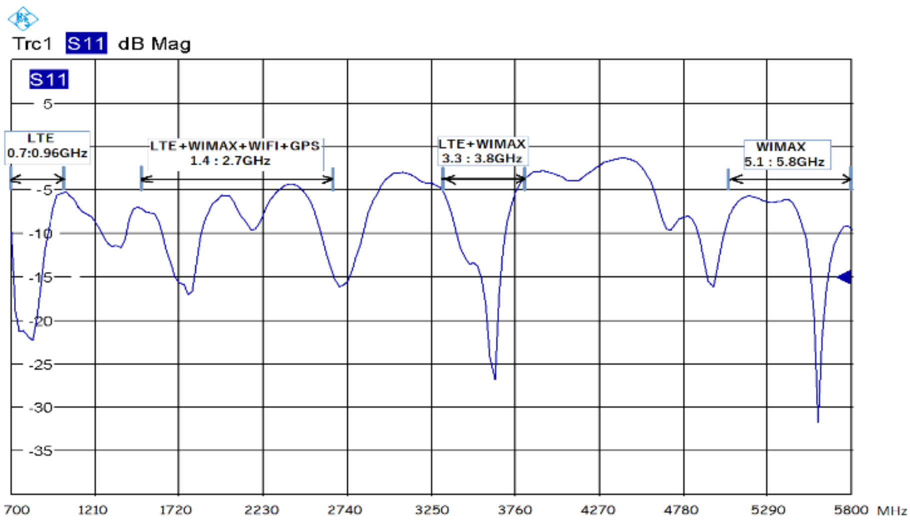

Fig. 3 Measured return loss of the antenna

International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:12, No:1, 2018

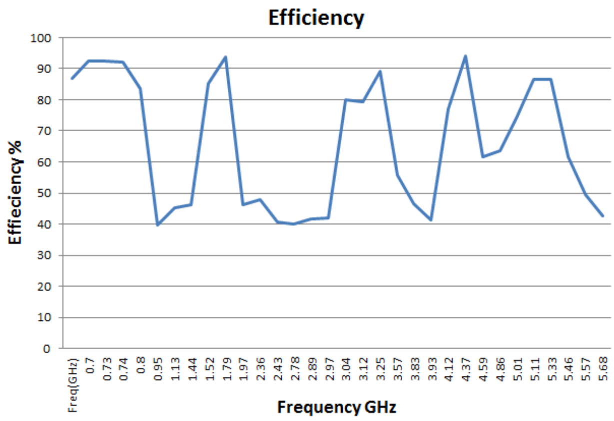

Fig. 4 Measured efficiency of the antenna

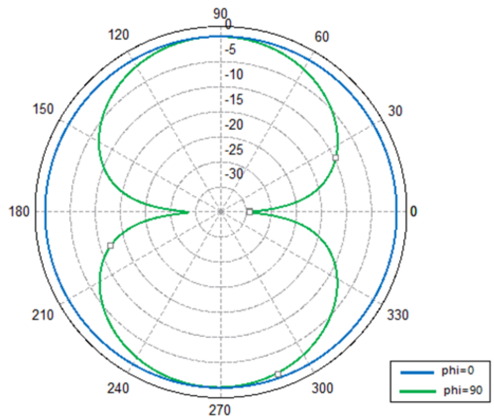

Fig. 5 Radiation pattern around the axis of the antenna at 1800 MHz at phi=0 and phi=90

III. Mounting the Antenna on a Tablet as a Sample Terminal

Since the antenna is self-contained and does not need to use any extended ground plane, as usually happens with internal antennas, it can be mounted anywhere inside or outside any terminal. Furthermore, the antenna is made of a flexible material. Thus, it can be folded/bent around any part of the frame of the terminal. An antenna prototype was used at different positions on various terminals as shown in Fig. 6. The antenna can be mounted on any terminal on the back, the face, or the sides of its chassis. Fig. 7 shows the antenna mounted on the chassis of a tablet at different locations and different orientations. Mounting the antenna on any terminal at any position does not have a significant effect on the return loss of the antenna. Fig. 8 shows the return loss of the antenna mounted on the back of a tablet. As shown in the figure, the antenna return loss is still acceptable over the whole band of LTE and WiFi. On the other hand, as mentioned above, the antenna can be folded/bent in any direction with a negligible effect on its performance. This allows using the antenna in terminals that have a smaller size such as some IoT devices and mobile handsets as shown in Fig. 9. It should be noted that the radiation pattern of the antenna, while it is mounted on any terminal, becomes slightly more directive due to the effect of the body of the terminal. Fig. 10 shows the radiation pattern of the antenna while it is mounted on the back of a tablet at 1800 MHz at phi=0 and phi=90, where the peak gain is 5.8 dBi. The effect of the tablet body on the radiation pattern of the antenna can be observed by comparing Figs. 10 and 5. The effect of the terminal body on the radiation pattern of the antenna depends on the location of the antenna on the terminal. As a result, if multiple antennas are mounted on any terminal at different positions, there will always be a good reception from all sides of the terminal.

Fig. 6 The antenna mounted on different terminals

Fig. 7 The antenna mounted on a tablet at different positions

International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:12, No:1, 2018

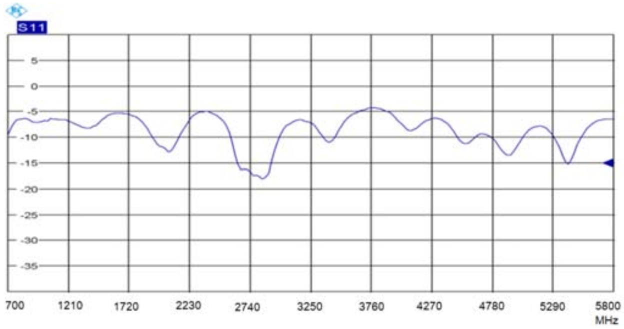

Fig. 8 The return loss of the antenna mounted on a tablet

Fig. 9 Bending the new antenna to mount it on a small size mobile handset

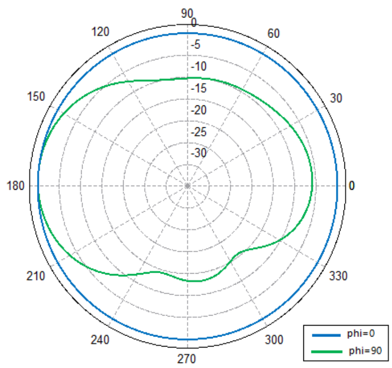

Fig. 10 The radiation pattern of the new antenna mounted on the back of a tablet at 1800 MHz at phi=0 and phi=90

IV. The Antenna in Different MIMO Configurations

As mentioned above, the more the number of MIMO antennas are, the better the performance is. However, if the isolation within the multi-antenna system is insufficient, system performance is reduced due to the coupling between antennas. The antenna can be used in 2x2, 4x4, 8x8, or 12x12 MIMO configurations. Those configurations are very unique as they have very wide bandwidth (700-5800 MHz) with very good isolation between all the antennas. A total of 12 MIMO antennas were mounted on a selected tablet as shown in Fig. 11 and the isolation between each two of them was measured. The highest four isolations are shown in Fig. 12, while the lowest four isolations are shown in Fig. 13. As shown in Figs. 12 and 13, the isolation is always better than -15 dB over the whole LTE and WiFi frequency bands. The highest four isolations are between antennas number 5 and 7, antennas number 3 and 8, antennas number 1 and 2, and antennas number 1 and 6. These isolations are represented in Fig. 12 by S57, S38, S12, and S16 respectively. The lowest four isolations, which are still acceptable, are between antennas number 3 and 7, antennas number 1 and 9, antennas number 1 and 5, and antennas number 3 and 11. These isolations are represented in Fig. 13 by S37, S19, S15, and S311 respectively. The highest isolation is between antenna number 5 and antenna number 7 while the lowest isolation is between antenna number 1 and antenna number 9, which was still better than 15 dB.

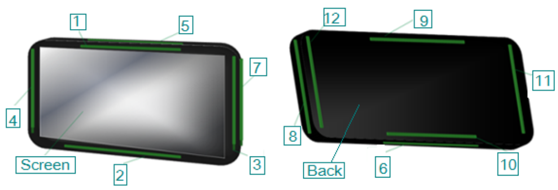

Fig. 11 12 MIMO antennas mounted on a small size tablet

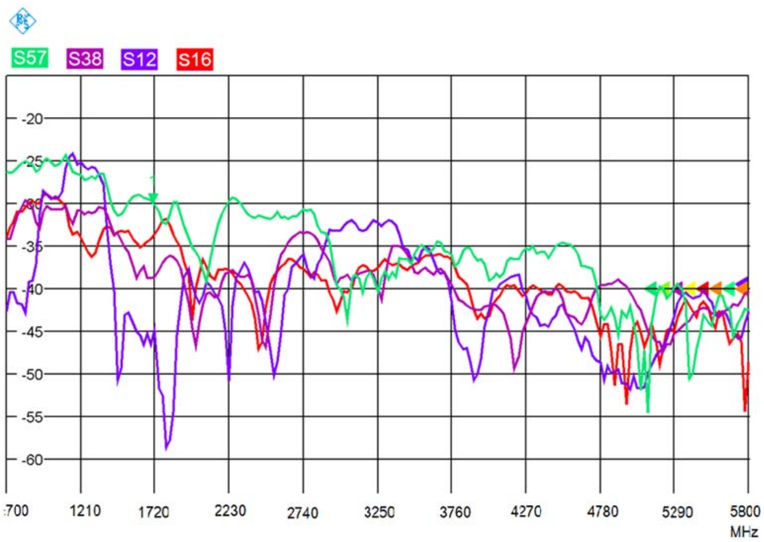

Fig. 12 The highest isolation between the 12 MIMO antennas mounted on small size mobile handset

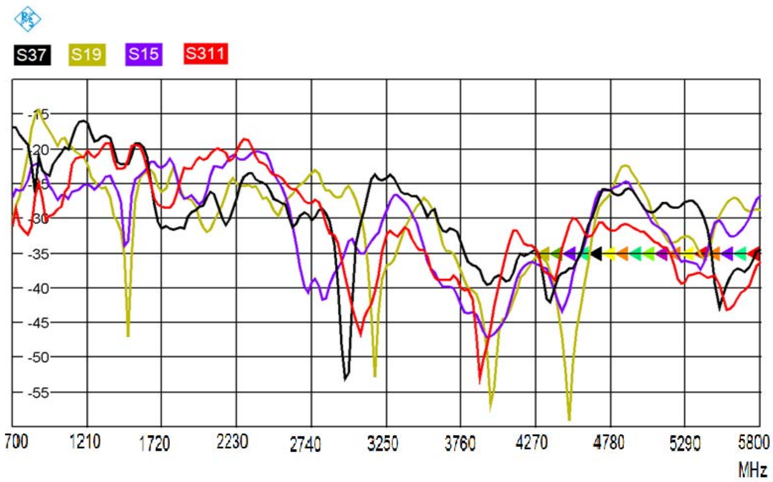

Fig. 13 The lowest isolation between the 12 MIMO antennas mounted on small size mobile handset

V. Other Configurations of the MIMO Antenna

The MIMO antennas do not have to be mounted at the corners of the terminal as was done in the above configurations. They can also be mounted in other positions on the face or the back of the terminal, as shown in Fig. 14, with an acceptable isolation between them. Thus, it is possible to use more than 12 MIMO antennas on the same terminal, where each of them covers the whole LTE and WiFi spectrum (700-5800 MHz). Fig. 15 shows the isolation between two antennas mounted on the back of a tablet close to its center and parallel to each other with 5 cm separation between them. As shown in the figure, the isolation is still better than 15 dB.

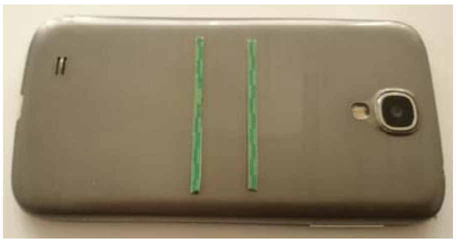

Fig. 14 2x2 MIMO antennas on the back, close to the center

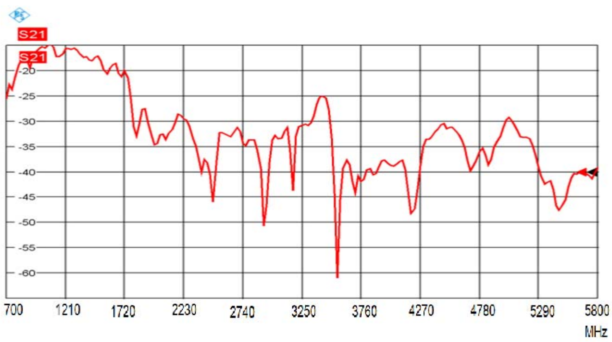

Fig. 15 The isolation between 2x2 MIMO antennas mounted on a tablet and separated by 5 cm

VI. Increased Size Version of the Antenna

As mentioned before, the return loss and the efficiency of the antenna can be improved by increasing the width and/or the thickness of the antenna. This can be suitable for some terminals that do not have a very small size. The increased size version of the new antenna has a total volume of 0.4x0.75x16 = 4.8 cm^3. Fig. 16 shows the return loss of the increased size version, which is better than -10 dB over all the frequency bands of LTE (700-960 MHz), (1400-2700 MHz), (3300-3800 MHz) and the WiFi band (5100-5800 MHz). The measured efficiency of the increased size antenna is shown in Fig. 17 as a function of the frequency. The minimum efficiency is 60%, which only happens at very few frequencies. The efficiency exceeds 95% at some other frequencies.

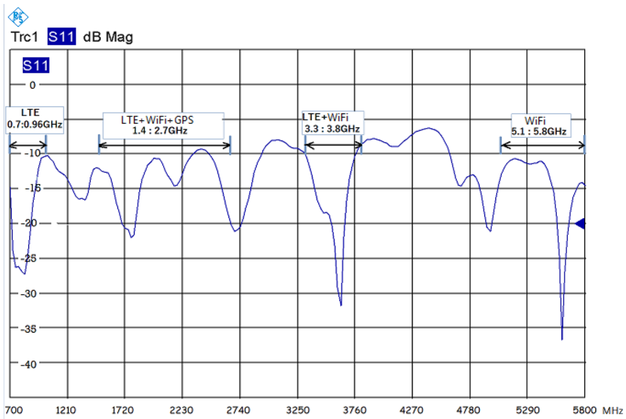

Fig. 16 Return loss of the increased size version of the new antenna

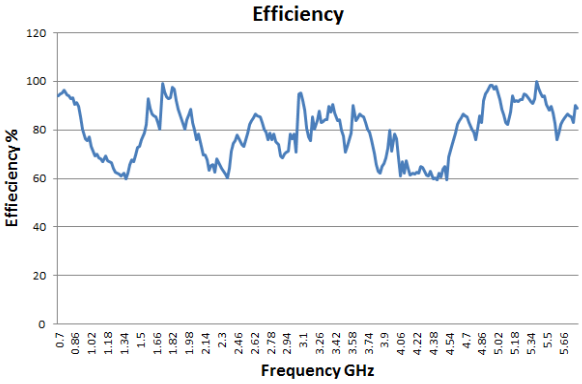

Fig. 17 Measured efficiency of the increased size version of the new antenna

VII. Conclusion

A broadband terminal antenna has been developed. A single resonant antenna could cover the whole LTE spectrum plus the WiFi band besides the existing 2G and 3G bands (700-5800 MHz) without using any matching/tuning circuits. The antenna was self-contained and did not need to use any extended ground planes as usually happens with internal antennas. Hence, it could be mounted anywhere inside or outside any terminal. Furthermore, the antenna was made of a flexible material. Thus, it could be folded and/or bent around any part of the frame of the terminal. It could be mounted on the terminal in different locations on the back, the face, or the sides of the chassis. Mounting the antenna on any terminal at any position did not have a significant effect on the return loss of the antenna. On the other hand, the antenna was manufactured from a flexible material that was easy to bend and/or fold in any direction. This allowed using the antenna in terminals that have a smaller size such as some mobile handset and IOT devices. The radiation pattern of the antenna, while it was mounted on any terminal, became slightly more directive due to the effect of the body of the terminal. The effect of the terminal body on the radiation pattern of the antenna depended on the location of the antenna on the terminal. As a result, if multiple antennas were mounted on any terminal at different positions, there would always be a good reception from all sides of the terminal.

The antenna could be used in 2x2, 4x4, 8x8, or 12x12 MIMO configurations. Those configurations were very unique as they had very wide bandwidth (700-5800 MHz) with very good isolation between all the antennas. A total of 12 MIMO antennas were tried and the isolation between each two of them was measured. The isolation between all of them was always better than 15 dB. The MIMO antennas did not have to be mounted at the corners of the terminal. They could be mounted in other positions on the face or the back of the terminal while the isolation between them was still acceptable. Thus, there might be more than 12 MIMO antennas on the same terminal, where each of them covered the whole LTE and WiFi spectrum (700-5800 MHz).

Acknowledgment

The authors would like to thank Ibrahim Abdelgaied and Aya Osama for their great effort in preparing this paper. A part of this R&D project was financed by Vodafone.

References

[1] Deshun Sun and Chongyu Wei, “Analysis and Design of 4 × 4 MIMO-Antenna Systems in Mobile”, Journal of Computer and Communications, 2016, 4, 26-33

[2] Sun, X.Y. and Xu, P.F. (2015) Analysis of Channel Capacity of Wireless MIMO Systems. Computer and Telecom, 7, 35-38.

[3] Lee, W.-W. and Rhee, B.-H. (2013) Characterization of Performance of a Mobile MIMO Antenna in Free Space. IEEE, Antennas and Wireless Propagation Letters, 12, 1153-1156.

[4] M. Sanad and N. Hassan, “Dual antenna configuration for multi-standard multifunction handsets and portable computers,” in Proceedings of the 3rd European Wireless Technology Conference (EuWiT ’10), pp. 173–176, September 2010.

[5] M. Sanad and N. Hassan, "Low-Interference Dual Resonant Antenna Configurations for Multistandard Multifunction Handsets and Portable Computers", International Journal of Antennas and Propagation, March 2012.

[6] M. Sanad and N. Hassan, “Novel Wideband MIMO Antennas That Can Cover the Whole LTE Spectrum in Handsets and Portable Computers”, IEEE Radio Science Conference (NRSC), 2013 30th National, November 2013.

[7] M. Sanad and N. Hassan, “A Novel Dual Resonant Antenna Configuration for Mobile Laptop, Notebook and Palmtop Computers”, IEEE Antennas and Propagation Society International Symposium (APSURSI), September 2010.

[8] M. Sanad and N.Hassan, "Compact Internal Multiband Microstrip Antennas for Portable GPS, PCS, Cellular and Satellite Phones", Microwave Journal,1999

[9] http://www.atmsindia.org/images/SATIMO_ANTENNAMEAS_SLAB_final.pdf. Accessed on 15/9/2017.

Mohamed Sanad is a professor at the Faculty of Engineering, Cairo University. He was also an adjunct professor at the Department of Electrical Engineering, University of Nevada, Reno, USA. He has founded "Amant Antennas" (www.amantantennas.com) in Reno, Nevada, USA and then he moved it to Egypt. Dr. Sanad got his Ph.D. degrees from the Department of Electrical Engineering, University of Manitoba, Canada. He filed more than 30 patents in the USA and worldwide and published more than 80 antenna papers.

Dr. Sanad directed and achieved several research projects for some of the largest telecommunication companies in the USA and the world such as Nokia Mobile Phones, Texas Instruments, Amplica Inc, Metricom Inc, Snap Track Inc, Antennas America Inc, HiPoint Technology Inc, Aetherwire Inc and others. He established antenna research centers for some of these companies from scratch and He directed their technical strategic planning. Dr. Sanad is the one who invented the first internal (embedded) integrated microstrip antenna for cellular phones when he was leading the antenna development team at Nokia Mobile Phones in San Diego, California.

Recently, Dr. Sanad has invented another novel technology, which is a handset antenna that covers the whole LTE (4G) spectrum plus the WiMAX, 2G and 3G bands. A single passive antenna could cover all the important wireless applications without using any matching or tuning circuits. This makes it feasible to use the same handset everywhere in the world (global roaming) with all generations of wireless applications included (G2, G3, G4, ------ etc.). On the other hand, Dr. Sanad has invented a new multiple beam cellular base station antenna that can simultaneously cover an unlimited number of wireless applications, regardless of their frequency bands. This will significantly enhance the efforts to develop new wireless technologies and add new applications.

In March, 2012, Mohamed Sanad won the 2012 Innovation Prize for Africa, "IPA", (US$100,000) (http://www.innovationprizeforafrica.org/media.asp). "IPA" was awarded by the United Nation Economic Commission for Africa "UNECA" and the African Innovation Foundation "AIF" in recognition of one of his base station antenna innovations.

Noha Hassan is an associate professor at the Department of Biomedical Engineering, Cairo University. Her research interests are focused on the interaction between electromagnetic waves and the human body as well as therapeutic applications of EMFs. She has published several papers in International journals and conferences about the interaction between antennas and the human body, antenna shielding techniques and antenna applications in biomedical instruments. Dr. Hassan was graduated from the Department of Biomedical Engineering, Cairo University. She got her Ph.D. degree from the Department of Biomedical Engineering, University of Nevada, Reno, USA. Her Ph.D. thesis was on the interaction of electromagnetic fields with biological cells as well as modeling the interaction with cell aggregates.