Performance Evaluation of SDR Blade RF using Wide-band Monopole Antenna for Spectrum Sensing Applications

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Abstract **─** A spectrum-sensing algorithm is used to detect the available and the occupied frequency bands. The wideband antenna design approach is used for a microstrip fed monopole antenna that can be used for various wireless technologies such as GSM, UMTS, LTE, and WiFi operating at different frequencies from 1.25 to 3 GHz. The antenna is constructed from two copper layers of rectangular radiator and a partial ground plane. These layers are printed on an RO4003 substrate with dimensions 60 x 80 mm^2. The antenna is experimentally fabricated to verify the simulation predictions and good matching between simulated and measured results is achieved. The wide-band antenna is tested by connecting it to the receiver of the Blade-RF Software Defined Radio (SDR) platform. A matlab script is then used to control the SDR board and to perform Spectrum Sensing for Cognitive Radio Applications.

Index Terms **─** Partial ground plane, software defined radio, wide-band monopole antenna, wireless transceivers.

I. INTRODUCTION

The design of wide-band antenna for high speed fixed and mobile wireless communications is regarded as a challenging issue due to the fast development of nowadays technologies [1]. These technologies requires wideband antennas to support various wireless communications due to their advantage in providing higher data rate and lower power consumption as well as smaller system size [2-6]. These wireless communication systems covering different technologies such as GSM, UMTS, LTE and WiFi. The specific frequency bands defined for these standards are as follow: GSM1800 (1710–1880 MHz), GSM1900 (1850–1990 MHz), UMTS (1920–2170 MHz), LTE2300 (2305–2400 MHz), and LTE2500 (2500–2690 MHz). WiFi has different standards like the IEEE 802.11 b/g operating in the ISM-band from 2.4 GHz to 2.48 GHz [7-9]. Many efforts have been directed to widen the bandwidth of the antenna and many techniques have been addressed to meet the requirements of modern wireless technologies. Some of the addressed techniques used to realize wide-band antennas are: loading parasitic structure [10], etching round steps and stepped cuts from the patch [11, 12], hexagonal radiator [13], partial ground plane [14-16], distributed inductive strip [17] and loading stubs based on multi-mode resonance concept [18]. In this paper, we present Spectrum Sensing hardware measurements using a wide-band monopole antenna and a Blade-RF SDR-board [19]. The proposed system is used to detect RF signals in the frequency bands dedicated to GSM, UMTS, LTE and WiFi. The antenna is designed with rectangular microstrip antenna and partial ground plane in order to achieve the required bandwidth for the aforementioned wireless standards. The impedance and radiation characteristics of the monopole antenna are investigated using Computer Simulation Tool (CST) software which is based on the Finite Integration Technique (FIT). The suggested antenna is fabricated on a RO4003 substrate and then measured to validate the simulation outcomes.

II. WIDE-BAND ANTENNA DESIGN

The designed wide-band antenna is fed by a 50 ohm microstrip feed-line and is printed on a RO4003C substrate with dielectric constant of 3.38, loss tangent of 0.0027, and 0.813 mm thickness. The antenna is composed of rectangular microstrip antenna on the top layer of the substrate and partial ground plane on the bottom layer. This antenna is designed to achieve the desired performance to satisfy the requirements of

Submitted On: October 1, 2020
Accepted On: January 18, 2021
https://doi.org/10.47037/2020.ACES.J.360407

different wireless communication standards such as GSM, UMTS, LTE, and WiFi. The suggested antenna with the detailed dimensions is shown in Fig. 1. It can be noticed from the layout that the partial ground length is approximately the same that of the feed-line and the patch is designed with the size of 45 x 38 mm^2 to increase the antenna bandwidth for further operation in the desired band. The initial design of the antenna with full ground plane was resonating at 1.78 GHz with a very narrow bandwidth. Subsequently, a partial ground is utilized to achieve the desired band of operation and this is evident by the simulation results shown in Fig. 2. The simulation results of the proposed antenna are shown in Fig. 2 and it can be demonstrated that the return loss is less than –10 dB for about 1.75 GHz from 1.25 GHz to 3 GHz.

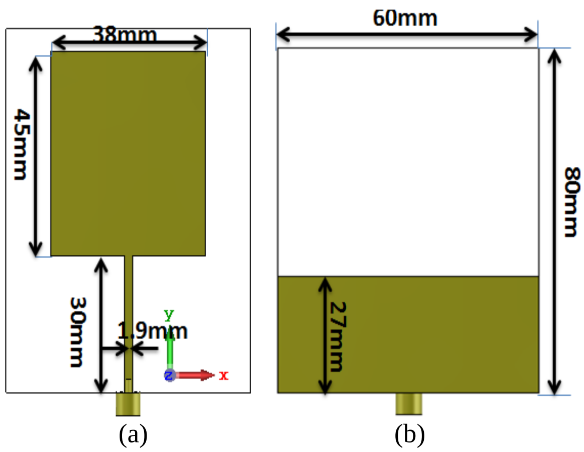

Fig. 1. The geometry of the proposed wide-band monopole antenna: (a) top view and (b) back view.

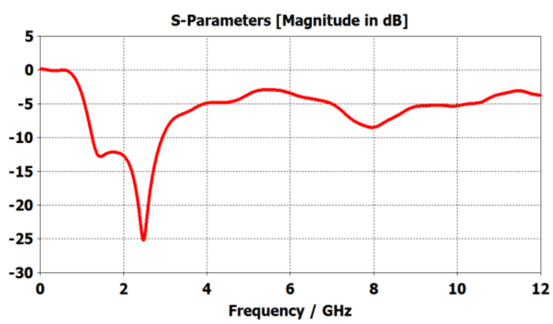

Fig. 2. The simulated S_{11} of the wide-band antenna.

III. RESULTS AND DISCUSSIONS

A. Wide band antenna results

A photograph of the fabricated wide-band antenna is depicted in Fig. 3. The antenna was tested for its impedance characteristics using Agilent N9918A vector network analyzer (VNA). The radiation pattern and gain were measured in an anechoic chamber. Figure 4 shows a comparison between the simulated and measured S_{11} results of the proposed wide-band monopole antenna, where the experimental results resemble the simulation results over the achieved bandwidth. It is seen from Fig. 4 that both the simulated and the measured S_{11} are both below –10 dB in the desired band. Nevertheless, the two curves are not identical since the simulation results show a minimum reflection of –25 dB at 2.5 GHz while the measurement results show a minimum reflection of –50dB at 2.2 GHz. This discrepancy is due the connector loss and the fabrication tolerance. In all cases, the proposed antenna can be considered as an adequate antenna for the various targeted wireless communications standards due to its good impedance matching performance.

Fig. 3. Photograph of the fabricated wide-band monopole antenna.

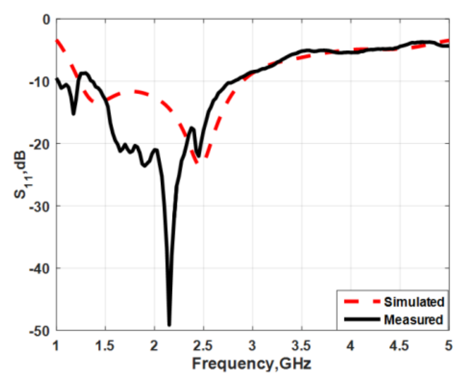

Fig. 4. Simulated and measured S_{11} of the proposed antenna against frequency.

The normalized simulated and measured radiation patterns in E- and H-planes of the proposed antenna are shown in Fig. 5(a) at f = 1.8 GHz and in Fig. 5 (b) at f = 2.4 GHz. It is obvious from Fig. 5 that the wide-band monopole antenna has a dipole-like radaiation pattern since it has a bi-directional pattern in the E-plane and omnidirectional pattern in H-plane for both frequencies. From the previous results, it is clear that the proposed antenna is convenient for different wireless communication standards in the 1.25-3.0GHz frequency range. A comparison between simulation and measurement results realized gain of the proposed wide-band monopole is shown in Fig. 6. The simulated gain varries from 1.9 dB to 3.05 dB while the measured one varies from 1.6 dB to 3.1 dB. The average gain in simulation is 2.43 dB and the average gain in measurements is 2.38 dB. It is hence possible to conclude that simulation and measurement results are very similar.

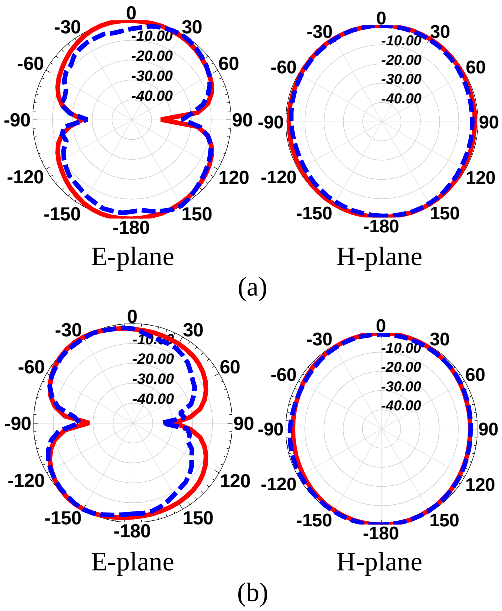

Fig. 5. The simulated (solid) and measured (dashed) normalized radiation patterns: (a) f = 1.8 GHz and (b) f = 2.4 GHz.

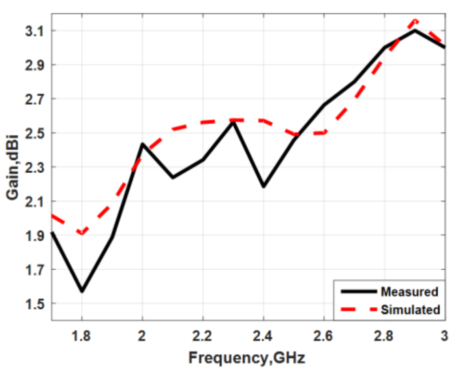

Fig. 6. The simulated and measured realized gain of the wide-band antenna.

B. Software defined radio with antenna

For the Spectrum Sensing operation, we use the SDR transceiver of the Blade RF board [19]. As shown in Fig. 7, the transceiver has one port for RF transmission and anotherport for RF reception. The Blade RF SDR can operate in a frequency band from 0.3 GHz to 3.8 GHz. The transmitter gain control range is 56 dB and the receiver gain control range is 61dB. The signal bandwidth can be selected from 1.5 MHz up to 28 MHz. The Analog Front End (AFE) of the Blade-RF board uses the LM6002 transceiver with several imperfections like DC offset and IQ imbalance. The effects of these imperfections are digitally compensated using the on-board FPGA in order to avoid any degradation in the overall system performance.

Spectrum sensing can be performed either in the time-domain or in the frequency domain. In this work, we used frequency domain Spectrum Sensing because of its higher resolution [20]. The spectrum is divided into many sub-bands. Spectrum sensing is carried out by dividing the total band of interest, B, into R_{sb} sub-bands each having a bandwidth of B/R_{sb}. After down-conversion, these sub-bands are converted to the digital domain. Finally, an N-points FFT is performed for each sub-band to calculate the Power Spectral Density (PSD):

$$PSD(f) = |F(x(nT))|^2, \qquad (1)$$

where F(x(nT)) represents the Fourier Transform of the sampled signal in the time domain, x[nT], where T is the sampling period.

The $PSD_{sbi}(f)$ is the PSD of sub-band number (i), which has a range from 0 to R_{sb}-1. In order to achieve higher resolution, the number of FFT points, N, should be increased. However, larger N increases the time required for sensing. The parameters that are used in the spectrum sensing detection are as follows: the frequency range used for Spectrum Sensing is B = 2.7 GHz (0.3 - 3 GHz). This range is divided into R_{sb} = 135 sub-bands, each sub-band with a bandwidth of B/R_{sb} = 20 MHz. The number of FFT points N = 1024 and the sampling frequency is 40 MHz. The total sensing time in this case is 3.47 ms.

Before starting in detection, the blade RF should be calibrated to balance the transmitting and receiving output powers. The signal with constant power and operated at frequency band from 0.3 GHz to 3 GHz is used to configure the transmitting end. While the signal from RF generator with constant power and operated from 0.3 GHz to 3 GHz is used at the receiving port.

The wide-band antenna is attached at the receiving port as shown in Fig. 7 after finishing the calibration process. The wide-band antenna is used to detect the surrounding energy spectrum to be sensed. Then matlab digital signal processing (DSP) algorithm is utilized to analyze the detected energy as shown in Fig. 8. It is clear that the antenna detected (commercial signals from the air) GSM signal at 1.8 GHz, UMTS signal at 2.1 GHz and WiFi signal at 2.4 GHz as shown from the Power Spectral Density shown in Fig. 8.

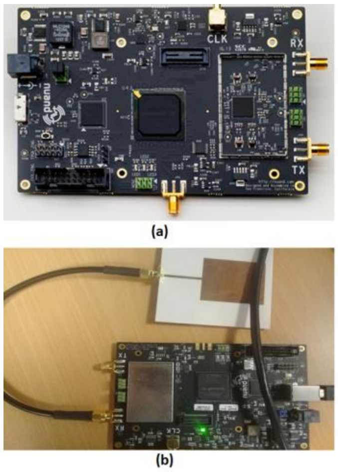

Fig. 7. (a) SDR blade RF [19], and (b) blade RF connected with wide band antenna.

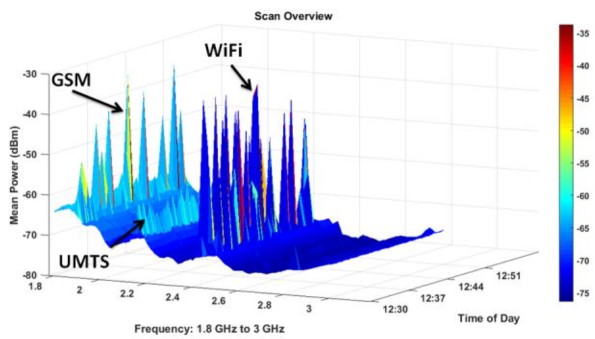

Fig. 8. The mean power density spectrums of blade RF at frequency range from 1.8 GHz up to 3 GHz.

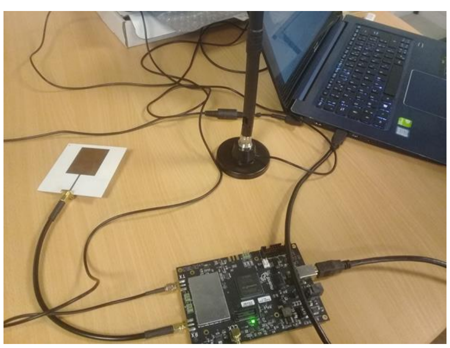

Fig. 9. The transmitting (using monopole) and receiving (using wide band antenna) setup of SDR blade RF.

In order to obtain a complete evaluation of the SDR Blade RF, The transmitting port is connected with conventional monopole as shown in Fig. 9. The monopole antenna is operated from 0.3 GHz up to 2.9 GHz. The DSP algorithm is used to produce power at the transmitting port; two frequency bands (2.44 GHz and 2.7 GHz) are used for transmission. The setup of this experiment is carried out inside isolated room to prevent the interference with other wireless signals. The receiving antenna is put at the far field. The receiving antenna is detected the energy of the two bands as shown in Fig. 10 and Fig. 11. It is seen that the spectral power densities are high at the two transmitting frequency bands 2.44 GHz and 2.7 GHz. Finally we can conclude that, the wide band antenna, spectrum sensing algorithm and SDR blade RF are used in spectrum sensing applications which enables our system can be used in cognitive radio applications.

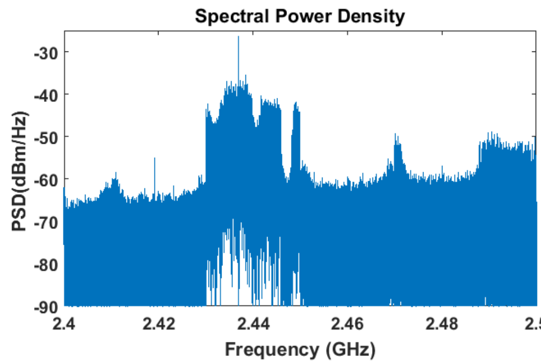

Fig. 10. The scanned spectral power density of SDR blade RF with wide band antenna at receiving end and conventional monopole at transmitting end.

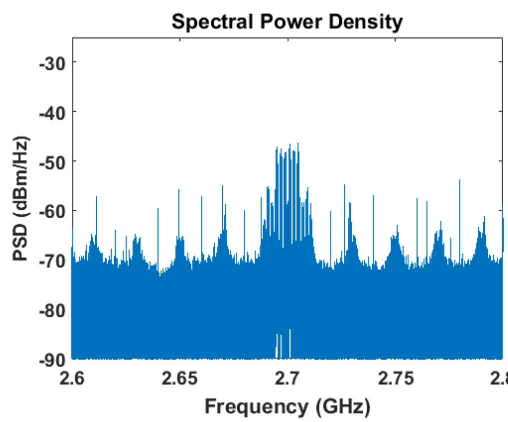

Fig. 11. The scanned spectral power density of SDR blade RF with wide band antenna at receiving end and conventional monopole at transmitting end.

IV. CONCLUSION

Hardware measurements using SDR blade RF platform has been used to detect the surrounding energy by using spectrum sensing algorithm. The wide-band monopole antenna has been designed, fabricated, measured and utilized at the receiving end of the blade RF to detect GSM/UMTS/LTE/WLAN applications. The antenna is operated at frequency band form 1.25

GHz up to 3 GHz. The blade RF first has been calibrated to balance the frequency gains between the transmissions and reception modes. The proposed wide band antenna has been utlized at receiving end to sense the spectrum energy from 1.25 GHz up to 3 GHz. Also the antenna has been received power from conventional monopole antenna added at the transmitting end of the balde RF. The blade RF sensing setup has been introduced with sensing time of 41.4 $=uS$ for 20 MHz band and 3.47 mS for the whole 2.7 GHz band.

ACKNOWLEDGMENTS

This work was supported by the French and Egyptian governments through a co-financed fellowship granted by the French Embassy in Egypt (Institute Français d'Egypt), the Scientific and Technology Development Fund (STDF) (Project ID 30642) and the French Research Agency: TOLTECA project ANR-16-CE04-001301. We would also like to thank Tamer Badran, Alan Rodrigo Diaz Rizo and Alexandre Mendy from Sorbonne University for their help with the Blade-RF SDR board.

REFERENCES

[1] A. Kurniawan and S. Mukhlishin, "Wideband antenna design and fabrication for modern wireless communications systems," *Procedia Technology, 11 of International Conference on Electrical Engineering and Informatics*, Kualalumpur, Malaysia, pp. 335-340, June 2013.

[2] H. Liu, C. Yin, W. Gao, and Y. Sun, "Optimization and design of wideband antenna based on factor," *International Journal of Antennas and Propagation*, 2015.

[3] A. A. Ibrahim, J. Machac, and R. M. Shubair, "UWB MIMO antenna for high speed wireless applications," *Applied Computational Electromagnetics Society Journal*, vol. 34, no. 9, pp. 1294-1299, 2019.

[4] W. Hu, Z. Tang, L. Zhou, and Y. Yin, "Design of planar differential-fed antenna with dual band-notched characteristics for UWB applications," *Applied Computational Electromagnetics Society Journal*, vol. 32, no. 3, pp. 209-214, 2017.

[5] W. A. E. Ali and A. A. Ibrahim, "Tunable band-notched UWB antenna from WLAN to WiMAX with open loop resonators using lumped capacitors," *Applied Computational Electromagnetics Society Journal*, vol. 33, no. 6, pp. 603-609, 2018.

[6] A. Boutejdar, A. A. Ibrahim, and E. P. Burte, "Novel microstrip antenna aims at UWB applications," *Microwaves & RF Magazine*, vol. 7, no. 7, pp. 8-14, 2015.

[7] X. Wang, Y. Wu, W. Wang, and A. A. Kishk, "A simple multi-broadband planar antenna for LTE/GSM/UMTS and WLAN/WiMAX mobile handset applications," *IEEE Access*, vol. 6, pp. 74453-74461, 2018.

[8] Y. Hong, J. Tak, J. Baek, B. Myeong, and J. Choi, "Design of a multiband antenna for LTE/GSM/UMTS band operation," *International Journal of Antennas and Propagation*, vol. 7, pp. 1187-1190, 2014.

[9] A. A. R. Saad, A. A. Ibrahim, O. M. Haraz, and A. Elboushi, "Tri-band compact ACS-fed meander-line antenna for wireless communications," *International Journal of Microwave and Wireless Technologies*, vol. 9, no. 9, pp. 1895-1903, 2017.

[10] M. Ojaroudi, S. Yazdanifard, N. Ojaroudi, and M. Naser-Moghaddasi, "Small square monopole antenna with enhanced bandwidth by using inverted T-shaped slot and conductor-backed plane," *IEEE Transactions on Antennas and Propagation*, vol. 59, no. 2, pp. 670-674, 2011.

[11] N. M. Awad and M. K. Abdelazeez, "Multislot microstrip antenna for ultra-wide band applications," *Journal of King Saud University-Engineering Sciences*, vol. 30, no. 1, pp. 38-45, 2018.

[12] A. Boutejdar and W. A. Ellatif, "A novel compact UWB monopole antenna with enhanced bandwidth using triangular defected microstrip structure and stepped cut technique," *Microwave and Optical Technology Letters*, vol. 58, no. 6, pp. 1514-1519, 2016.

[13] A. Joshi and R. Singhal, "Probe-fed hexagonal ultra wideband antenna using flangeless SMA connector," *Wireless Personal Communications*, vol. 110, no. 2, pp. 973-982, 2020.

[14] A. Bekasiewicz and S. Koziel, "Compact UWB monopole antenna for internet of things applications," *Electronics Letters*, vol. 52, no. 7, pp. 492-494, 2016.

[15] W. Ali, A. A. Ibrahim, and J. Machac, "Compact size UWB monopole antenna with triple band-notches," *Radioengineering*, vol. 26, no. 1, pp. 57-63, 2017.

[16] W. A. Ali, A. M. Mansour, and D. A. Mohamed, "Compact UWB wearable planar antenna mounted on different phantoms and human body," *Microwave and Optical Technology Letters*, vol. 58, no. 10, pp. 2531-2536, 2016.

[17] G.-H. Kim and T.-Y. Yun, "Small wideband monopole antenna with a distributed inductive strip for LTE/GSM/UMTS," *IEEE Antennas and Wireless Propagation Letters*, vol. 14, pp. 1677-1680, 2015.

[18] W.-J. Lu, L. Zhu, K. W. Tam, and H.-B. Zhu, "Wideband dipole antenna using multi-mode resonance concept," *International Journal of Microwave and Wireless Technologies*, vol. 9, no. 2, pp. 365-371, 2017.

[19] Nuand, "Blade-RF software defined radio." https://www.nuand.com/product/bladerf-x40/

[20] T. Badran, "Spectrum Sensing Using RF Software

Defined Radio Receivers," *Ph.D. Thesis*, Sorbonne University, Paris, France, June 2020.

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