An Ultrawideband to Dual-Band Switchable Antenna Design for Wireless Communication Applications

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***Abstract*—A switchable planar monopole antenna operating in ultrawide band (UWB)and dual-band mode is demonstrated. The switching is triggered with a photoconductive semiconductor switch triggered by light emitting diode. In the switched-off state, the antenna operates in the dual-band/UWB mode, while in the switch-on state the configuration converts to a dual-band antenna due to the extended ground plane. The measured and simulated results show that the dual-band/UWB mode entirely covers the UWB frequency band and the 2.4 GHz wireless local area network WLAN, while the dual-band mode represents a dual-band antenna operating at WiMAX and X-band Satellite communication bands.**

***Index Terms*—Cadmium sulfide (CdS), cadmium sulfide (CdS) photo resistor, multiband antenna, planar monopole antenna, ultrawideband antenna (UWB).**

I. Introduction

PLANAR ultrawideband (UWB) antennas and the multiband antennas serve to overcome the bandwidth limitations of the strip antenna design. Large bandwidth of UWB antennas can be employed to support high data rate indoor applications [1], while multiband antennas serve outdoor and/or indoor wireless applications whose specified spectrums are entirely separated [2]. Designing an antenna with the capability of switching between these two different operational modes leads to more versatile antenna.

An antenna operating in the full UWB spectrum (3.1–10.6 GHz), however, can interfere with some already existing applications, so antennas are designed with band notches to minimize the interference. This is achieved either by designing fixed band notches [3] or by designing controllable notches [4], [5]. UWB antennas have also been designed with additional band or bands (multiband/UWB mode) to support wireless local area network (WLAN) [6], global system for mobile communications (GSM) and global positioning system (GPS) [7], and body area network [8]. Multiband antennas have also been proposed to support two [9], three [10], and sometimes even four applications simultaneously [11].

In this letter, we propose a planar monopole antenna that can switch between dual-band/UWB operation mode and a dual-band mode by controlling the ground plane with a cadmium sulfide (CdS) photoconductive semiconductor switch (PCSS) material which is used to control the bandwidth of a microwave filter without biasing lines [12]. Illuminating CdS leads to enhanced conductivity and extended ground plane, so the antenna operates as a dual-band antenna. By turning off illumination, the CdS conductivity is reduced, and the antenna operates in the UWB mode due to reduction in ground plane size. The measured and simulated results of the dual-band/UWB mode are in very good agreements and show enhanced antenna performance.

Manuscript received January 12, 2015; revised February 09, 2015; accepted March 28, 2015. Date of publication March 31, 2015; date of current version September 02, 2015.

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Digital Object Identifier 10.1109/LAWP.2015.2418679

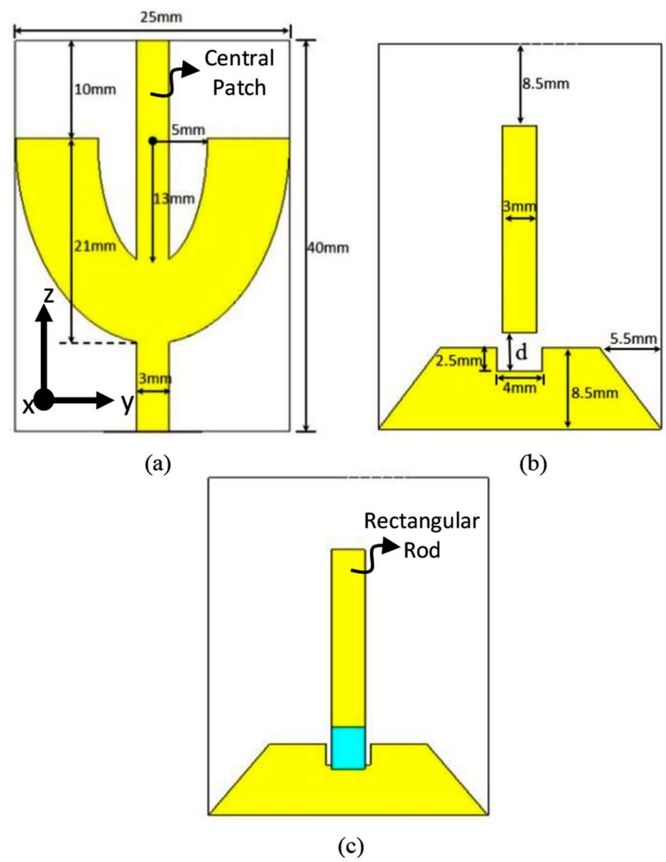

Fig. 1. Geometry of the proposed UWB slot antenna (a) front view, (b) back view, and (c) back view with CdS patch.

II. Antenna Structure

Fig. 1 shows the front and the back views of the proposed antenna, and the dimensions of each of its components. Fig. 1(a) shows that the antenna front view is approximately similar to a design proposed earlier [6], but with half elliptical ring instead of circular base and two stubs. The antenna is fed

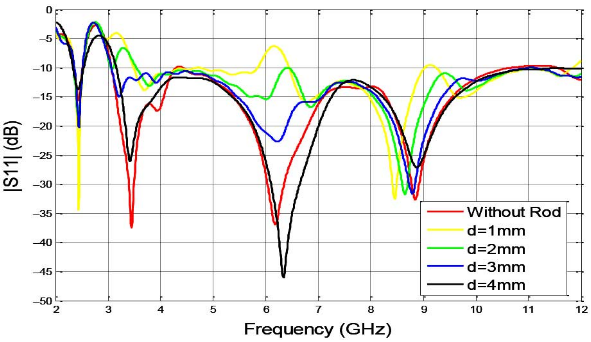

Fig. 2. Antenna simulated reflection coefficient for different separation distances between the rectangular rod and the ground plane when the light is off.

by 50-Ω microstrip line and etched on FR4 dielectric substrate with dielectric constant $\varepsilon_r = 4.3$, loss tangent of 0.025, and height $h = 1.6$ mm. The back view [Fig. 1(b)] shows a modified ground plane and a rectangular rod separated from the ground plane by distance (d). The rectangular rod can be connected and disconnected from the ground plane by illuminating and darkening the CdS patch shown in Fig. 1(c). Connecting and disconnecting the rectangular rod of Fig. 1(b) switch the operating mode to dual-band mode and dual-band/UWB mode, respectively. For dual-band/UWB mode, the rectangular rod is kept away from the ground plane so that there is no electromagnetic (EM) coupling between them.

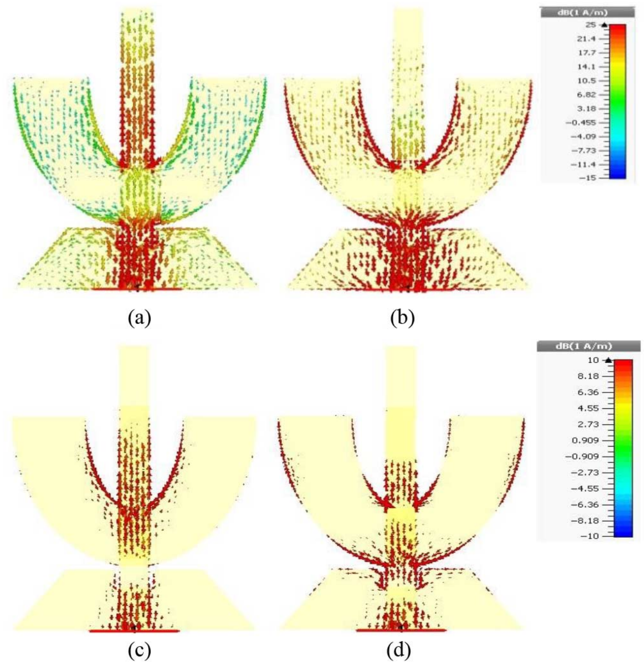

Fig. 3. Current distribution of the proposed antenna when (a) the light is off at 2.4 GHz, (b) the light is off at 3.4 GHz, (c) the light is on at 3.5 GHz, and (d) the light is on at 7.5 GHz.

III. Switching and Antenna Operation Concepts

Fig. 2 shows the reflection coefficient of the antenna without the rectangular rod and for different separation distances d to minimize electromagnetic coupling between the rectangular rod and the ground plane. The optimum value is found to be 4 mm at which the reflection coefficient is almost similar to that when the rectangular rod is removed since the rectangular rod is electromagnetically disconnected from the ground plane. Photoconductive materials, which act both as conductors and insulators at the same time were used as switch. Conventional switches reflect EM wave, causing EM coupling between the rectangular rod and the ground plane via their metallic parts even if they are turned off.

Illumination of the CdS)wafer l connects the ground plane with the rectangular rod because the illumination leads to enhance the CdS conductivity significantly [13]. This connection extends the antenna ground plane, and the antenna operates in multi narrow band modes instead of UWB mode. This connection extends the antenna ground plane, and the antenna operates in multi narrow band modes instead of UWB mode. Turning off the LED disconnect the ground plane from the rectangular rod, and this modification makes the antenna operates in the UWB mode. Improving contact between the conductor and semiconductor requires high doping between the two but it was not necessary in this case, and would add large cost to the overall design [13]. Therefore, CdS photo resistor has been used as a compromise between CdS wafer and PIN diodes, which require biasing circuits to switch them on and off.

It is worthwhile to highlight the antenna operation mechanism of the proposed antenna. When the light is switched off, the rectangular rod has negligible effect on the antenna, as shown in Fig. 2. Therefore, the antenna operates as an UWB antenna. The central patch shown in Fig. 1(a) operates as a narrow band quarter wavelength monopole antenna radiating at 2.4 GHz. The half elliptical ring resonates at three resonant frequencies centered at 3.4, 6.3, and 8.9 GHz, and the resulted antenna bandwidth covers the UWB frequency band entirely. Fig. 3(a) and (b) shows the current distribution of the antenna at 2.4 GHz and 3.4 GHz, respectively. It is clear that the current is concentrated at the central patch at 2.4 GHz, while it is concentrated at the half ring at 3.4 GHz. On the other hand, turning the light on leads to eliminate the effect of the central patch since it is almost covered by the ground plane. The sides of the elliptical ring that are not covered by the rectangular rod operate as an antenna resonating at 3.5 GHz and 7.5 GHz, respectively, as shown in Fig. 3(c) and (d), respectively. Since the resonant frequencies are far from each other and unoverlapped, the antenna operates as a multiband antenna.

IV. Fabrication and Measurements

Fig. 4 shows the fabricated antenna attached with a CdS photo resistor. Prior to fabrication and testing, the antenna design was simulated using the CST Microwave Studio commercial simulation suite, where CdS material was added to the library with a conductivity of 82℧/m while operating in the dark and a 10^4℧/m illumination value. Measurements were done using a Hewlett Packard 8719A Vector Network Analyzer. The photo resistor is controlled by a 3 V battery connected to a switch and a 20 mA LED, so the power consumption is 60 mW.

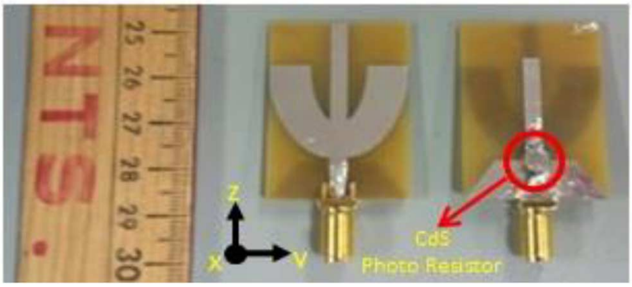

Fig. 4. Prototype of the proposed antenna.

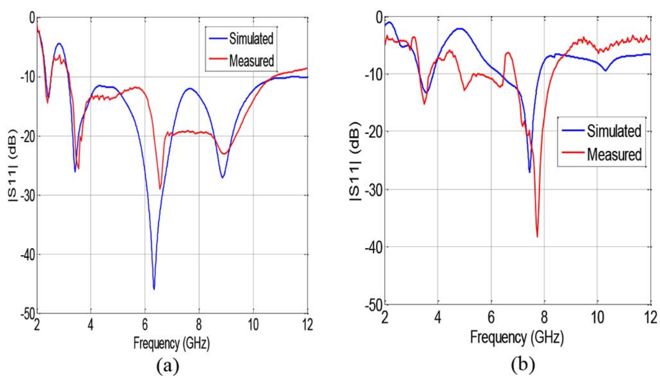

Fig. 5. Measured and simulated reflection coefficient of the proposed antenna when (a) the light is off and (b) the light is on.

A. Dual-Band/UWB Mode (Light is OFF)

The simulated and measured reflection coefficients are illustrated in Fig. 5(a). The central rectangular patch, shown in Fig. 1(a), operates as a quarter wavelength narrow band monopole antenna radiating at 2.4 GHz. The half elliptical ring covers the frequency band specified for UWB applications. In fact, the antenna in this mode covers the entire indoor applications. The discrepancy between the measured and simulated results is caused by fabrication tolerations or imperfect SMA connector soldering, which may cause a close loop path between the connector and the feed line. Fig. 6 shows the simulated and measured power patterns in the E-plane and H-plane of the proposed antenna at the four resonant frequencies (2.4, 3.4, 6.3, and 8.9 GHz). The radiation pattern is almost stable along the operating band with bidirectional E-plane and omnidirectional H-plane patterns.

The simulated and measured gain of the proposed antenna as a function of frequency is shown in Fig. 7(a). It has an almost stable value over the UWB coverage as well as accepted value at the 2.4 GHz WLAN. Between these two bands and outside them the gain has reduced value. This is expected since the antenna shows high losses for the undesired frequencies.

Fig. 8 shows the normalized source (fourth order Rayleigh pulse) and the measured received pulses. As discussed in [14], the pulse fidelity of face-to-face, face-to-side, and side-to-side alignments are 0.61, 0.54, and 0.57, respectively. The values of the pulse fidelity are larger than 0.5 and this is acceptable in most of the UWB applications [14].

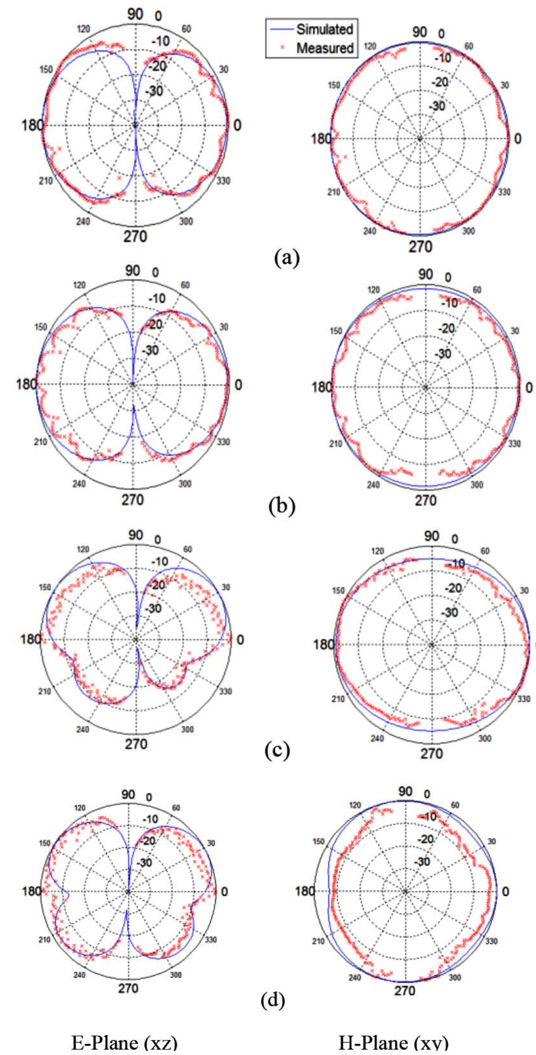

Fig. 6. Measured and simulated power patterns of the proposed antenna when the light is off at (a) $f = 2.4$ GHz, (b) $f = 3.4$ GHz, (c) $f = 6.3$ GHz, and (d) $f = 8.9$ GHz.

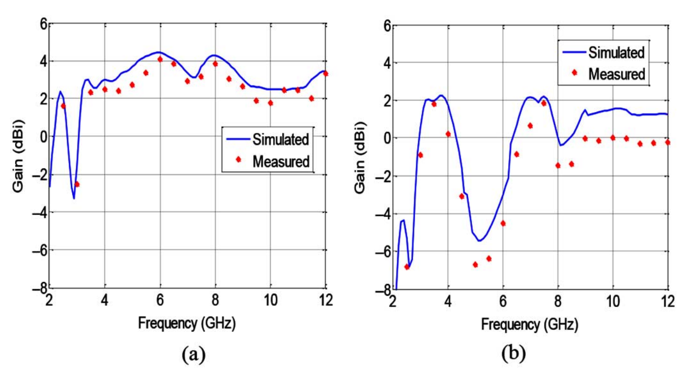

Fig. 7. Measured and simulated peak gain in dBi of the proposed antenna when (a) the light is off and (b) the light is on.

B. Dual-Band Mode (Light is ON)

When applying light on the CdS photo resistor, the antenna ground plane is extended and the antenna is not UWB

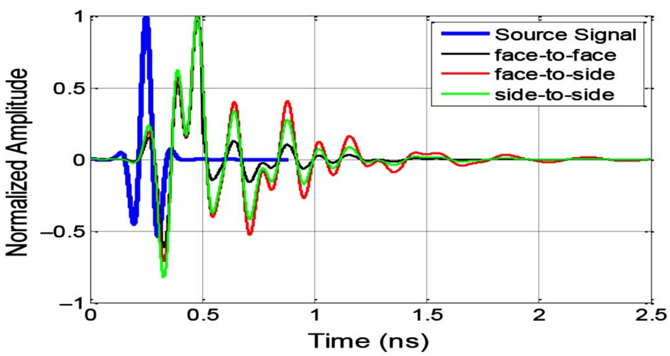

Fig. 8. Normalized source and received pulses when aligning two identical antennas.

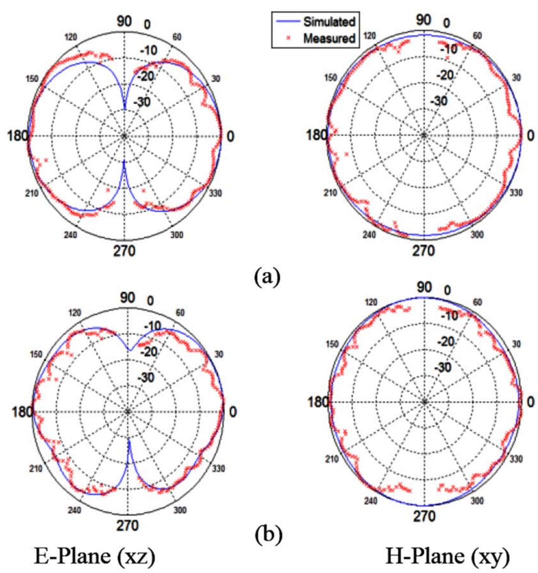

Fig. 9. Measured and simulated power patterns of the proposed antenna when the light is on at (a) f = 3.5 GHz and (b) f = 7.5 GHz.

monopole antenna, but operates as a dual-band antenna radiating at 3.5 GHz for WiMAX (3.3–3.7 GHz) applications and at 7.5 GHz, in a network that wirelessly connects the main reflector antenna of X-band satellite communications (7.25–7.745 GHz) with receivers. Fig. 5(b) illustrates the measured and simulated $|S_{11}|$ of the proposed antenna at this mode. There is a good agreement between the measured and simulated $|S_{11}|$ except at the 4.8–6.4 GHz frequency range at which there is some undesired impedance matching. This undesired matching is caused by the extra power dissipation due to the usage of photo resistance instead of CdS wafer. The minimum resistance value is $\sim 90\,\Omega$ at turn-on, so the contact between the rectangular rod and the ground plane is not perfect. However, attaching the CdS photo resistor reduces antenna cost effectively. In addition, it does not need biasing circuit to control its operation.

The simulated and measured power patterns are shown in Fig. 9. The antenna has bidirectional E-plane pattern and omnidirectional H-plane pattern for both frequencies. The peak gain as a function of frequency when the light is on is illustrated in Fig. 7(b). The measured gain has noticeably reduced value compared to the simulated one due to the finite conductivity of the photo resistor which accumulates additional loss to the antenna. Different resistors affect the antenna gain differently depending on the conductivity of the resistor after illumination.

V. Conclusion

A switchable antenna has been fabricated and analyzed to demonstrate a planar monopole antenna operating in two different modes. The switching between the two modes is achieved by illuminating a CdS photoconductive semiconductor switch (PCSS) attached to the antenna ground plane. Illuminating the PCSS switches the antenna from dual-band/UWB mode to dual-band mode. Measured results show that at dual-band/UWB mode the antenna covers the 2.4 GHz WLAN and the UWB applications, while at the dual-band mode it covers the WiMAX and the X-band satellite communications. For multiband mode and low cost operation, the toleration in the measured reflection coefficient due to the use of CdS photo resistor rather than CdS wafer is deemed acceptable.

References

[1] X. Begaud, *Ultra Wide Band Antennas*. Hoboken, NJ, USA: Wiley, 2011.

[2] K. L. Wong, *Compact and Broadband Microstrip Antennas*. Hoboken, NJ, USA: Wiley, 2002.

[3] H. Schantz, G. Wolence, and E. Myszka, "Frequency notched UWB antennas," in *Proc. IEEE Ultra Wideband Syst. Technol. Conf.*, 2003, pp. 214–218.

[4] E. Antonino-Daviu, M. Cabedo-Fabres, M. Ferrando-Bataller, and A. Vila-Jimenez, "Active UWB antenna with tunable band-notched behavior," *Electron. Lett.*, vol. 43, no. 18, pp. 959–960, 2007.

[5] Q. Chu, C. Mao, and H. Zhu, "A compact notched band UWB slot antenna with sharp selectivity and controllable bandwidth," *IEEE Trans. Antennas Propag.*, vol. 61, no. 8, pp. 3961–3966, Aug. 2013.

[6] S. Mishra, R. Gupta, A. Vaidya, and J. Mukherjee, "A compact dual-band fork-shaped monopole antenna for Bluetooth and UWB applications," *IEEE Antennas Wireless Propag. Lett.*, vol. 10, pp. 627–630, 2011.

[7] A. Foudazi, H. Hassani, and S. Nezhad, "Small UWB planar monopole antenna with added GPS/GSM/WLAN bands," *IEEE Trans. Antennas Propag.*, vol. 60, no. 6, pp. 2987–2992, Jun. 2012.

[8] M. Alam and S. Moury, "Conversion of an ultra-wide-band (UWB) antenna to dual-band antenna for wireless body area network (WBAN) applications," in *Proc. IEEE 3rd Int. Inf., Electron., Vision*, 2014, pp. 1–4.

[9] K. Lee, K. Luk, K. Mak, and S. Yang, "On the use of U-slots in the design of dual- and triple-band patch antennas," *IEEE Antennas Propag. Mag.*, vol. 53, no. 3, pp. 60–74, Jun. 2011.

[10] Z. Wang, L. Lee, D. Psychoudakis, and J. Volakis, "Embroidered multiband body-worn antenna for GSM/PCS/WLAN communications," *IEEE Trans. Antennas Propag.*, vol. 62, no. 6, pp. 3321–3329, Jun. 2014.

[11] F. Alnahwi, M. Zidan, and N. Islam, "Design and analysis of planar, single feed, four-band microstrip antenna operating in the same polarization plane," *J. Telecommun.*, vol. 26, no. 2, pp. 1–5, Aug. 2014.

[12] J. Wu and I. Shih, "A novel switchable microwave filter constructed with inter-coupled split-ring resonators and photosensitive cadmium sulfide," in *Proc. Int. Symp. Signals, Syst. Electron.*, 2007, pp. 435–438.

[13] D. Neamen, *Semiconductor Physics and Devices Basic Principles*, 3rd ed. New York, NY, USA: McGraw-Hill, 2003.

[14] L. Guo, "Study and miniaturisation of antennas for ultra wideband communication systems," Ph.D. dissertation, School of Electronic Engineering and Computer Science, Queen Mary, University of London, London, U.K., Sep. 2009.