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Research Article

Directive Stacked Patch Antenna for UWB Applications

Sharif I. Mitu Sheikh, W. Abu-Al-Saud, and A. B. Numan

Electrical Engineering Department, King Fahd University of Petroleum & Minerals, P.O. Box 5038, Dhahran, Saudi Arabia

Correspondence should be addressed to Sharif I. Mitu Sheikh; sheikhsi@kfupm.edu.sa

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Directional ultrawideband (UWB) antennas are popular in wireless signal-tracking and body-area networks. This paper presents a stacked microstrip antenna with an ultrawide impedance bandwidth of 114%, implemented by introducing defects on the radiating patches and the ground plane. The compact (20 × 34 mm) antenna exhibits a directive radiation patterns for all frequencies of the 3–10.6 GHz band. The optimized reflection response and the radiation pattern are experimentally verified. The designed UWB antenna is used to maximize the received power of a software-defined radio (SDR) platform. For an ultrawideband impulse radio system, this class of antennas is essential to improve the performance of the communication channels.

1. Introduction

In impulse communication system, very short electromagnetic pulses are used to transfer information and require UWB antennas to maintain similar radiation characteristics for a wide frequency spectrum [1]. In the literature, majority of the printed UWB antennas are designed to exhibit omnidirectional radiation characteristics [2, 3]. However, wireless body-area network requires directional UWB antennas to minimize the interaction with human body [4]. Steerable and directional UWB arrays are also used in wireless signal tracking and MIMO networks to determine the angle of the received multipath signal for nulling interfering signals [5] and detecting the direction of maximum received power [6].

Although compact and low-profile microstrip antenna and arrays are best suited for the directional impulse communication, their inherently narrow-bandwidth often introduces transmission error. Standard techniques for improving the impedance bandwidth of a microstrip antenna includes electrically thick substrates [7], parasitic patches on the same or the stacked layer [8, 9], which are limited by the dimension and the radiation characteristics of the antenna. Other methods use defected ground structures (DGS), where inherent resonant frequencies can be controlled by changing the shape and the dimension of the defects or slots [10]. These additional resonances, when optimally excited, can considerably increase the impedance bandwidth of a microstrip antenna. In the literature, radiating patches with “U” or “L” shaped slots are popular for improving the bandwidth without increasing dimension of the antenna [11]. Similarly, C-shaped slots on the ground plane can influence the impedance bandwidth by disturbing the shielding currents [12]. However, this technique reduces the antenna directivity through back radiation. The front-to-back ratio of a directional UWB antenna can be improved by using a reflecting plane, which has minimal effect on the input impedance [13].

In this paper, a stacked patch antenna with DGS is designed to realize an impedance bandwidth of 114%. Since UWB antennas are typically multinarrowband antennas, the design process started with the patches (excitation and the parasitic) optimized to resonate at the desired frequencies. Additional resonant structures, like modified C-shaped slots on the ground plane, defects on the parasitic patch, and L-shaped slots on the excitation patch, are then optimally introduced into the antenna to realize the ultrawide impedance bandwidth. Antenna directivity is improved by better managing the back radiation using a reflector plane, implemented through antenna packaging. In an ultrawide band impulse communication system, like software defined radio [14] or impulse radio, very short pulses are used to transmit the data stream and require antennas with uniform radiation and reflection properties throughout the band. Thus, directional

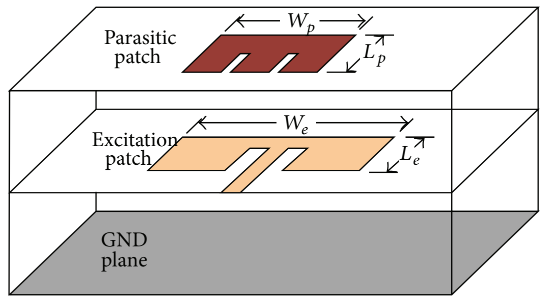


FIGURE 1: Stacked patch antenna having excitation patch (L_e = 8 mm, W_e = 18 mm) with inset (L = 6 mm, W = 1.1 mm) and Parasitic patch (L_p = 7.2 mm, W_p = 10 mm) with inset (L = 3.5 mm, W = 0.5 mm).

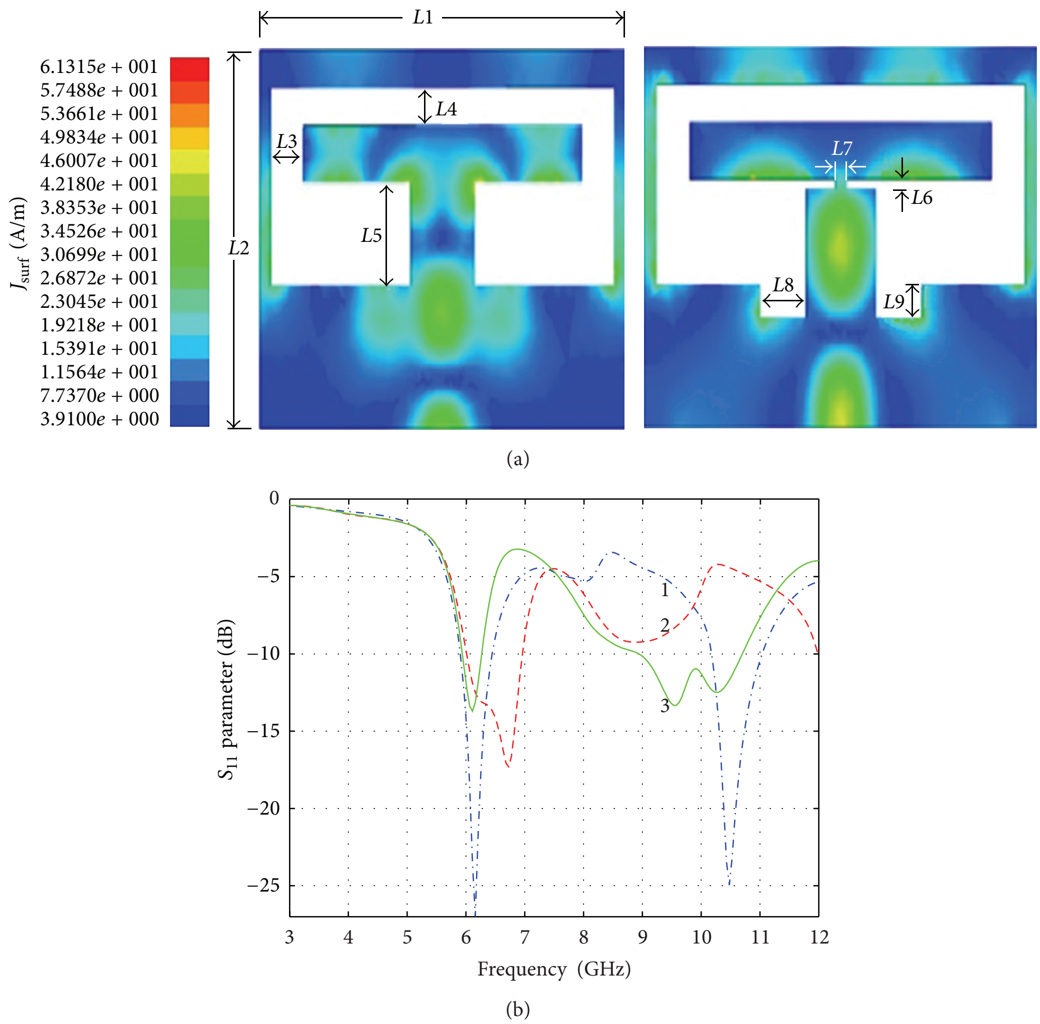


FIGURE 2: (a) Surface current density on the GND plane with/without modified C-shaped slot ($L1$ = 34, $L2$ = 20, $L3$ = 3, $L4$ = 2, $L5$ = 5, $L6$ = 0.5, $L7$ = 1, $L8$ = 1, $L9$ = 1.75 mm's). (b) Reflection responses for different design stages (curves 1, 2, and 3) of the stacked patch antenna.

UWB antennas can be ideal for these devices, which eliminate the need for complex detection mechanism [15] or reconfigurable narrowband patch antennas [16].

2. Antenna Design and Results

The design started by implementing the patch and parasitic radiating element on a stacked FR4 substrate with t = 1.6 mm. The insets of the excitation and parasitic patchs are optimized to produce two resonances within the central location of frequency band of 3–11 GHz. Figure 1 shows the schematic diagram of this antenna with dimensions. The reflection response (S_{11}) of the stacked antenna, shown by curve-1 of Figure 2(b), demonstrates central resonances around 6.1 and 10.4 GHz. To improve the bandwidth of the upper resonance, a C-shaped slot is introduced on the ground

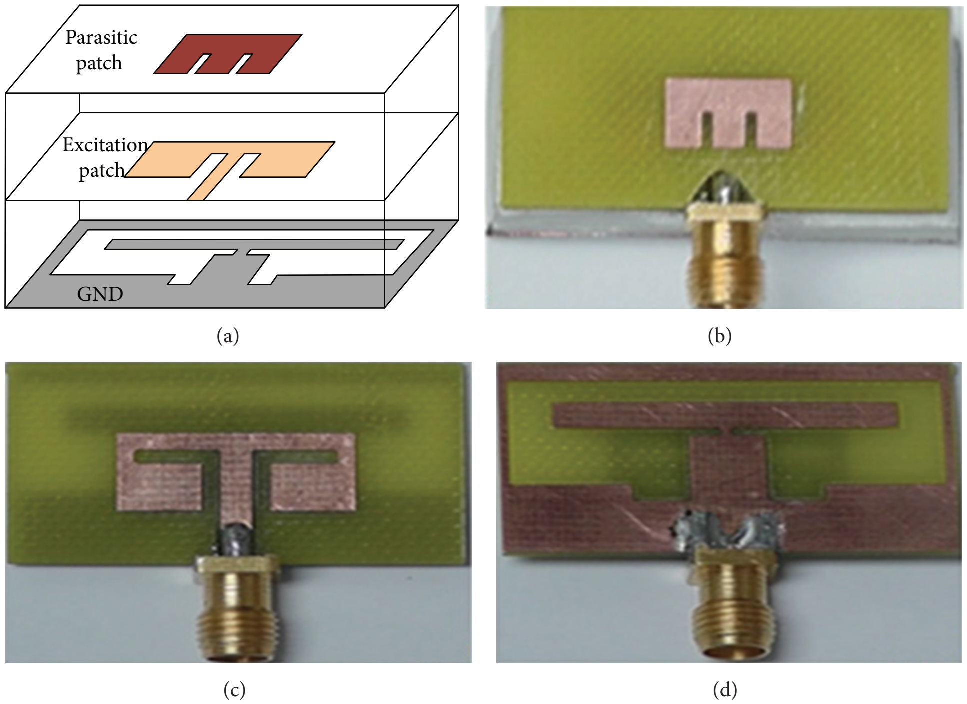


FIGURE 3: (a) Schematic diagram of the UWB antenna. Fabricated antenna elements, (b) parasitic patch, (c) excitation patch, and (d) defected GND.

plane. The resulting S_{11} response is shown by curve-2 of Figure 2(b), which demonstrates the trend of widening upper resonance. C-shaped slot is modified by adding L6, L8, and L9 apertures, shown in Figure 2(a), to introduce additional slot resonances due to currents along the edges of the slots. This further improved the upper resonance bandwidth, as shown by curve-3 of Figure 2(b). The bandwidth of the lower resonance is improved by adding a vertical slot on the patch to realize an L-shaped inset. Using professional software (HFSS), the surface currents and the smith-chart responses of the antenna are analysed to achieve an optimum impedance bandwidth. It is observed that the variation of the patch lengths and the widths affected the lower and the upper resonances of the antenna, respectively.

To improve the front-to-back ratio of the radiation pattern, a reflector is optimally added beneath the ground plane of the antenna. Antenna packaging is exploited to realize the reflector plane.

The schematic diagram of the designed stacked patch antenna with defects on the patches and the ground plane are shown in Figure 3(a) and the fabricated antenna elements are shown in Figures 3(b), 3(c), and 3(d). The simulated and experimental reflection (S_{11}) responses are superimposed in Figure 4, which demonstrates an ultrawide impedance bandwidth throughout the frequency range from 3 GHz to 11 GHz (114%). Minor discrepancies between the simulated and the experimental responses are due to the limitations in computational resources during simulation and experimental resources during fabrication. The radiation patterns of the antenna for several different frequencies of the band are shown in Figure 5. The antenna gain of around 12 dB is

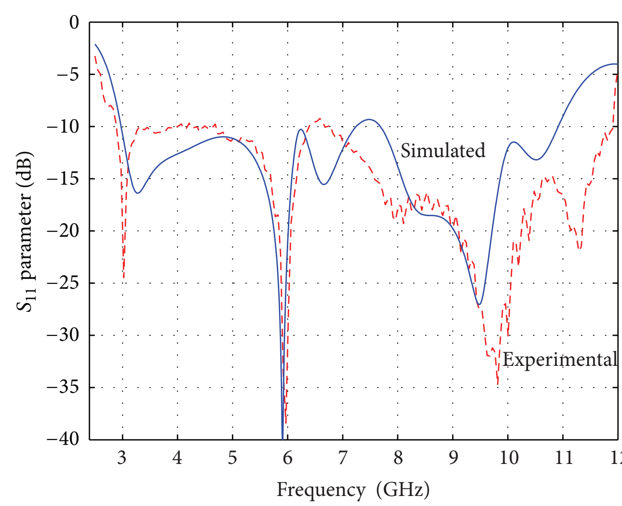
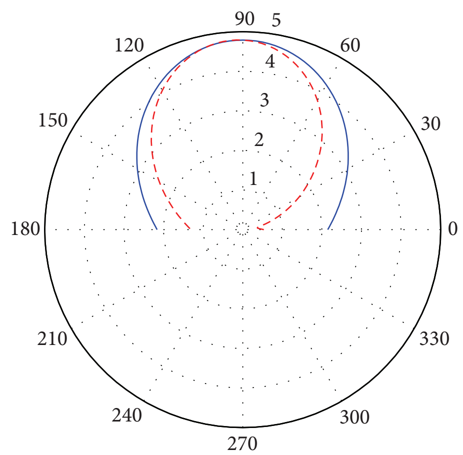


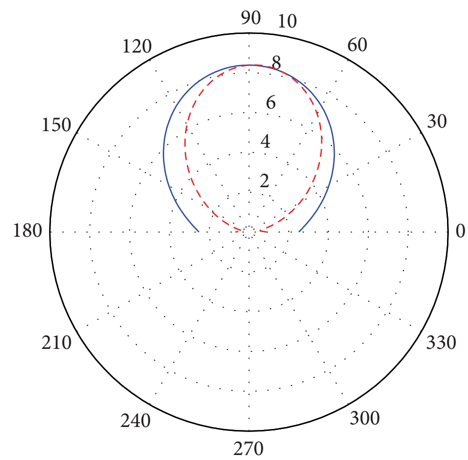
FIGURE 4: Simulated and experimental reflection (S_{11}) responses of the designed UWB antenna.

observed at the centre frequency of 7 GHz. This simulated response is verified with experimental measurements. Note that reduced antenna gain is observed at the lowest operating frequency. The designed UWB antenna is used on a 4 × 4 MIMO software-defined radio (SDR) platform operating at Unlicensed National Information Infrastructure (U-NII) band occupied by channel 23 of 802.11a standard. The transmitter and receiver sides of the SDR platform are each equipped with a Xilinx Vertix 4 FPGA, 8-channel DAC on the transmitter side and 8-channel ADC on the receiver side,



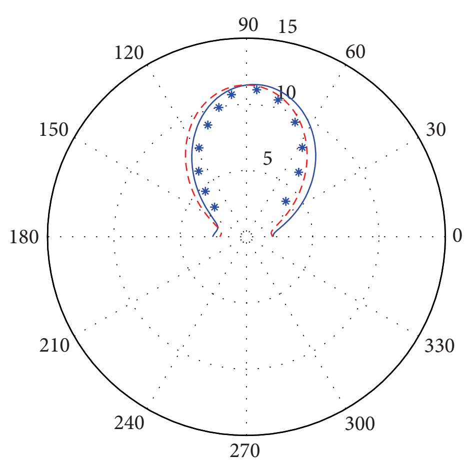
Radiation pattern at 3 GHz

(a)



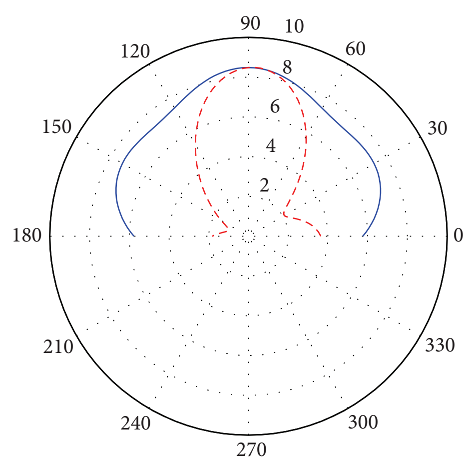
Radiation pattern at 5 GHz

(b)



Radiation pattern at 7 GHz (* measured E-plane)

(c)



Radiation pattern at 10 GHz

(d)

Figure 5: Simulated E and H-plane radiation patterns for 3, 5, 7, and 10 GHz and experimental E-plane radiation pattern for 7 GHz signal ("$*$").

and quad RF modules that operate at 5.8-GHz band. The SDR platform hosted a 4 × 4 MIMO single-carrier QPSK burst modem communication system used in a 1 × 1 SISO configuration with transmission bandwidth of nearly 15 MHz. Each transmitted burst consists of a start bit followed by channel estimation pulses followed by the QPSK data pulses. For comparison purposes, a 5.8 GHz patch antenna is designed and used to transfer the data stream based on narrow band modulation. The resulted QPSK constellations are plotted in Figure 6(a) for 5.8 GHz dipole (inner constellation) and patch (outer constellation) antennas. Note that microstrip patch antennas demonstrate enhanced power reception due to the directive transmission. The constellation diagram related to the designed UWB antenna is shown in Figure 6(b). It is evident from these figures that the directional UWB antenna response is similar to that of the patch antenna in terms of power reception.

Note that the main advantage of this UWB antenna is its ability to improve the channel properties for an impulse communication system, where successful transfer of a wide band of frequency components is essential [15].

3. Conclusion

A directive ultrawideband (UWB) antenna is designed to support the frequency range of 3–11 GHz. Impedance bandwidth is improved by introducing a parasitic stacked patch and optimized defects on the radiators and the ground plane. Simulated and measured S_{11} results agreed well and exhibited an impedance bandwidth of 114%. The directive radiation pattern for the 7 GHz response is experimentally varied. A proof of principle experiment using the designed antenna attached to a software defined radio (SDR) platform exhibited improvement in received power. Further improvement in

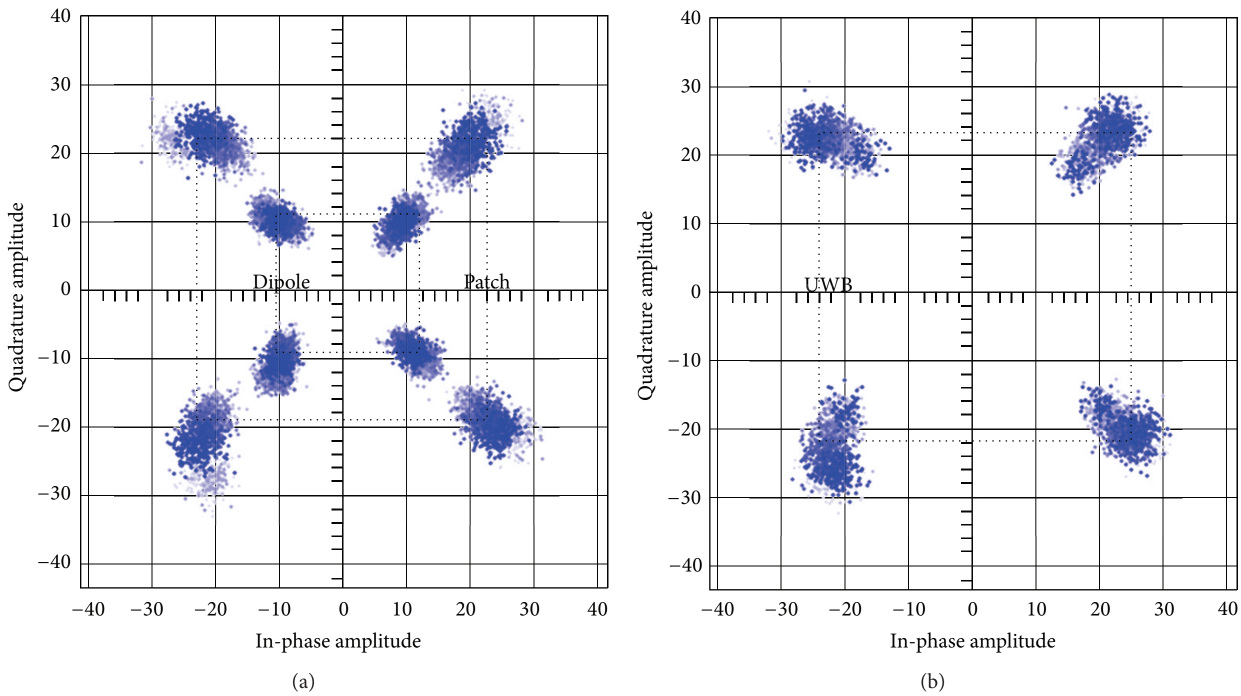


FIGURE 6: QPSK constellation diagrams related to a SDR platform operating at 5.8 GHz band and using (a) the Dipole (inner) or the Patch (outer) antenna and (b) the designed UWB antenna.

the channel properties can be observed if the SDR platform is used for impulse communication.

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