

A UWB Folded-Slot Monopole Antenna for Ground Penetrating Radar

Guanchen Li⁽¹⁾, Zhen-yuan Zhang⁽¹⁾, Nooshin Valizade Shahmirzadi⁽¹⁾, and Natalia K. Nikolova⁽¹⁾

⁽¹⁾ Department of Electrical and Computer Engineering, McMaster University, Hamilton, Canada, lig47@mcmaster.ca

Abstract—A novel ultrawideband (UWB) folded-slot monopole antenna is presented. It contains a circular planar monopole at the back of a printed slot to achieve 1:10 impedance bandwidth and a wide-beam unidirectional pattern, which is desirable for applications in synthetic aperture radar and radar sensing. The antenna is constructed in the shape of a box assembled from five single-layer FR-4 substrates, one for each side of the box, except for the bottom, where a large ground plane ensures unidirectional radiation. It is designed to operate from 0.5 GHz to 5 GHz with a return loss better than 10 dB. The proposed addition of a folded slot above the monopole improves the circular symmetry of the radiation pattern about the boresight direction. The antenna size is $210 \times 250 \times 100 \text{ mm}^3$. With a ground plane size of $500 \times 500 \text{ mm}^2$ the antenna achieves front-to-back ratio (FBR) better than 10 dB across all frequencies. Simulations validate the antenna performance. The proposed compact UWB antenna is to be employed in airborne ground penetrating radar (GPR) and surveillance radar for concealed weapon detection.

I. INTRODUCTION

Ultra-wideband (UWB) technology is expanding toward applications in radar sensing and imaging, where the antennas play a crucial role in the overall system performance [1]. UWB antennas must achieve very wide impedance-match bandwidth as a wide radar bandwidth translates into better range resolution. Various types of UWB antenna designs [2][3] have been proposed, including Vivaldi antennas [4][5], planar monopole antennas [6][7], spiral antennas [8][9], slot antennas [10][11], among others. Among these antenna types, the planar monopole antennas are usually the most compact. However, they have omnidirectional patterns whereas radar applications favor unidirectional patterns. Thus, the planar monopole must be complemented by additional structural components, which ensure unidirectional radiation with good FBR. Here, we propose a novel design, where the printed monopole is coupled with a folded slot structure and is backed by a finite ground plane. The antenna's bandwidth is from 0.5 GHz to 5 GHz, where the return loss is better than 10 dB and the radiation pattern is unidirectional with minimal backward radiation. This frequency bandwidth is chosen to match that of an in-house UWB pulsed radar [12][13][14] for the detection of concealed weapon under clothing.

II. ANTENNA DESIGN

The geometry and dimensions of the proposed antenna are provided in Fig. 1 and Table I. The proposed antenna consists of a simple circular patch (the monopole) fed by a microstrip, which is excited using a 50- Ω bottom-mounted SMA connector as shown in Fig. 1(b). The circular monopole is printed on the bottom layer of the horizontal (x - y plane) FR-4 substrate with

dielectric properties $\epsilon_r = 4.4$, $\tan \delta = 0.02$, and height of 0.8 mm, whereas two pieces of copper form the horizontal part of the slot on the top layer. The copper layers extend along both sides of the antenna box to form the vertical parts of the slot. The folded slot renders the radiation pattern symmetric about the boresight direction without increasing the antenna size. Additionally, two small slots reside at each corner of the top copper layer. They improve the radiation pattern by reducing the effect of higher-order modes [15]. A slot is also inserted in the monopole near the feed point to redirect the surface current, and to enhance the boresight gain, especially at frequencies close to 1.4 GHz. The positions and sizes of all slots are carefully optimized through parametric studies. Four vertical (y - z and x - z plane) FR-4 substrates of height 1.575 mm build the side walls of the antenna box. This ensures that the antenna is mechanically sturdy for mounting on airborne and portable platforms.

The antenna is backed by a ground plane at a distance H from the top of the horizontal PCB. Its size $W_g \times W_g$ must ensure unidirectional radiation patterns from 0.5 GHz to 5 GHz. An absorber (FGM-125 [16]) vertical wall with an embedded copper layer in the middle is built at the edge of the ground plane. Its height H_w and thickness W_{abs} are optimized to provide FBR better than 10 dB across all frequencies.

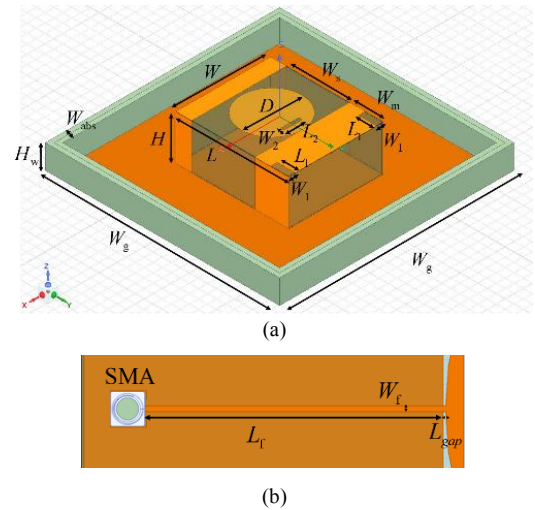


Figure 1. Geometry of the proposed antenna: (a) 3-D view, (b) feedline details.

TABLE I. DIMENSIONS OF THE PROPOSED ANTENNA (IN MM)

L	W	W_s	L_1	W_1	W_g	D	W_{abs}
250	210	140	41	15	500	67	19.2
L_2	W_2	L_f	W_f	W_m	L_{gap}	H	H_w
41	8	61	1.2	75	0.6	100	50

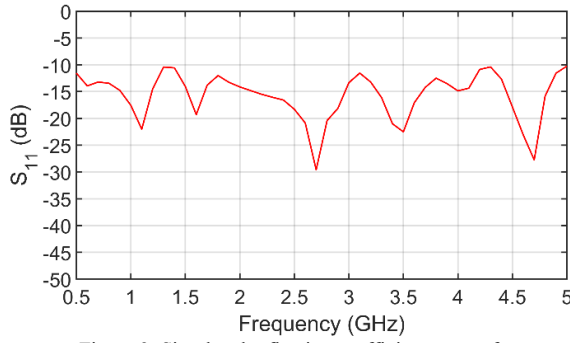


Figure 2. Simulated reflection coefficient *versus* frequency.

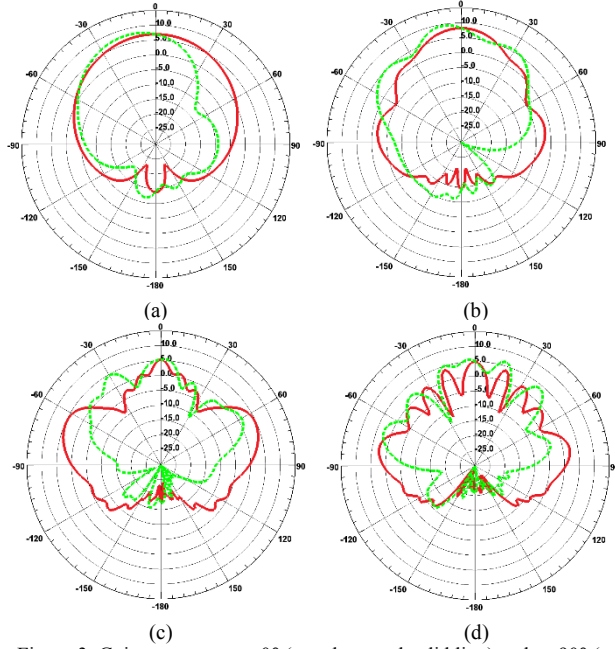


Figure 3. Gain patterns at $\phi=0^\circ$ (x - z plane, red solid line) and $\phi=90^\circ$ (y - z plane, green dash line) at: (a) 0.8 GHz, (b) 1.8 GHz, (c) 3.5 GHz, (d) 5 GHz.

III. SIMULATION RESULTS AND DISCUSSION

The proposed antenna is validated through simulations with HFSS. Fig. 2 shows the reflection coefficient *versus* frequency. The impedance-match bandwidth at the -10 dB level covers well the desired range from 0.5 GHz to 5 GHz.

Fig. 3 shows representative 2D gain patterns at 0.8 GHz, 1.8 GHz, 3.5 GHz, and 5 GHz. As the frequency increases, pattern distortions appear, likely due to diffraction effects. The patterns are wide-beam and unidirectional, which is desirable in imaging radars. With a ground-plane size of $W_g = 500$ mm, the FBR is better than 10 dB across the band; see Fig. 4 for plots of the gain at boresight ($\theta = 0^\circ$) and at $\theta = 180^\circ$. The radiation efficiency decreases monotonically from 95% at 0.5 GHz to 54% at 5 GHz.

IV. CONCLUSION

A compact broadband folded-slot monopole antenna is designed to operate from 0.5 GHz to 5 GHz with a return loss better than 10 dB. Unidirectional patterns across the band are achieved by incorporating a finite ground plane (smaller than the longest wavelength) terminated with an absorbing vertical wall. The addition of the folded slot is important in improving the rotational symmetry of the patterns about the boresight direction.

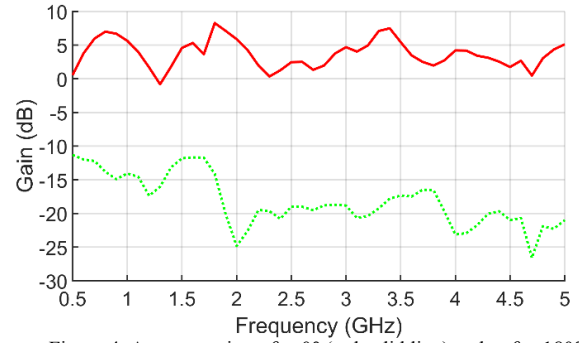


Figure 4. Antenna gain at $\theta = 0^\circ$ (red solid line) and at $\theta = 180^\circ$ (green dotted line) *versus* frequency.

Further work must address the FBR improvement while reducing the overall size and improving the antenna efficiency.

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