

A Compact Modified Bow-Tie Antenna for High-Resolution GPR

#A.A. Lestari¹, E. Bharata², A.B. Suksmono², A. Kurniawan², A.G. Yarovoy¹,
L.P. Ligthart¹

¹IRCTR, Delft University of Technology

Mekelweg 4 2628 CD Delft, The Netherlands, a.a.lestari@tudelft.nl

²STEI, Bandung Institute of Technology

Jl. Ganesha 10 Bandung 40132, Indonesia, endonb@ltrgm.ee.itb.ac.id

1. Introduction

For impulse GPR it is generally required that the antenna have sufficiently large bandwidth and a constant phase center. The former is needed to allow transmission of UWB transient pulses with suppressed late-time ringing to avoid masking of targets. Resistive loading has always been the most popular loading scheme in this application as it can easily be applied on the antenna. However, it is well known that substantial decrease of antenna efficiency is the price that has to be paid when using purely resistive loading. In this paper we propose a modified resistively-loaded bow-tie antenna which has been optimized for an impulse GPR application. The proposed antenna has been designed to enable transmission of UWB pulses with higher radiation efficiency and lower level of late-time ringing in comparison with other resistively loaded planar antennas of a comparable or even larger size.

2. Antenna Design

In this work the developed antenna is intended for excitation with a monocycle pulse having 0.8-ns duration shown in Figure 1. This pulse has been found suitable for detection of small objects near the air-ground interface such as anti-personnel landmines. The main objective of this work is to develop a small UWB antenna that is able to transmit this pulse with minimal ringing. In addition, the antenna should exhibit higher radiation efficiency in comparison with conventional resistively loaded bow-tie and dipole antennas generally used in GPR.

The antenna has been developed based on the principle introduced in [1], in which radiation efficiency is enhanced by creating artificial discontinuities along the antenna in such a way that radiations from the feed point and the discontinuities combine constructively in the boreside direction of the antenna. The basic design for the antenna is based on a wire bow-tie antenna with 120° flare angle consisting of 13 wire elements with 10° spacing in each of its arms. It has been found empirically that when the antenna is constructed on FR-4 the chosen flare angle leads to antenna input impedance of around 50 Ω . Artificial discontinuities are created by bending the wires at a certain distance from the feed point in such a way that radiations of the 0.8-ns monocycle pulse from the feed point and the bends combine constructively in the boreside direction of the antenna. Furthermore, the section of the wires from the bends to the antenna ends is directed parallel to the main axis of the antenna for minimizing the antenna size, and resistively loaded for suppressing ringing. The geometry of the proposed antenna is described in Figure 2.

In addition, a shield for the antenna has been developed to suppress antenna coupling, interference and imaging of objects above the ground. The shield has been designed to have minimum dimensions, yet with minimum impact on the antenna characteristics.

3. Experiments

The proposed antenna with its shield has been constructed as depicted in Figure 3. The measurement results of the antenna are reported below.

3.1 Input Impedance and Transmit Waveform

The measured input impedance of the proposed antenna with and without the shield is presented in Figure 4 where the suppressed first resonances in the input impedance curves are

obvious. On the other hand, the resonance due to the shield occurs at around 3.4 GHz as clearly seen in the figure. However, this resonance would not pose a serious problem in the aimed applications since it occurs outside the essential spectrum of the exciting 0.8-ns monocycle pulse.

The measured transmit waveforms of the experimental antenna with and without the shield are plotted in Figure 5. It can be seen that there is good agreement between the measured and computed results as both assume a similar triplet shape with level of late-time ringing of less than -40 dB following the triplet. The small oscillation in the measured waveform observed at 12 ns is a reflection from a reflector nearest to the antenna. As predicted by simulation, the peak-to-peak amplitude of the measured waveform of the shielded antenna is significantly higher than that of the unshielded antenna. However, the shield introduces an additional oscillation following the main triplet.

3.2 Comparison with Other Antennas

To verify the antenna's improved radiation efficiency, we perform a comparison between the proposed antenna and other commonly-used GPR antennas, i.e. a conventional solid bow tie, a planar dipole and a wire dipole. Scaled geometries of these antennas are shown in Figure 6 where can be seen that the size of the proposed antenna is significantly smaller relative to the others. The measured transmit waveforms of these antennas are presented in Figure 7 and a comparison of their peak-to-peak amplitudes is given in Table 1. It is obvious that despite its relatively small size the proposed antenna exhibits the highest peak-to-peak amplitude. The waveform amplitude of the proposed antenna is slightly higher than that of the conventional bow tie (which has considerably larger dimensions), 18% higher than that of the planar dipole (which is 1.7 times longer and has a much wider surface), and 45% higher than that of the wire dipole (which is 2 times longer). We note that among the 4 antennas mentioned above, the proposed antenna is the only one which is resistively loaded. The others are intentionally not loaded as they are used here for a comparison purpose only. In fact, for most GPR applications they should have proper resistive loading in order to achieve adequate late-time ringing suppression required by those applications. As a result, the applied resistive loading will cause a significant reduction in the amplitude of their transmitted waveforms. Therefore, in practice their waveform amplitudes would be significantly smaller than those listed in Table 1, which makes the proposed antenna even more favorable. Thus, the above results indicate the improved radiation efficiency demonstrated by the proposed antenna.

3.3 GPR Field Test

The proposed antenna has been integrated in a hand-held commercially-available GPR system as depicted in Figure 8. As can be seen, two shielded antennas have been manufactured and served as the transmit and receive antennas for the GPR. Both antennas have been arranged in a side-by-side configuration and improved results have been obtained from real GPR surveys. As an example of the results, in Figure 9 we present a B-scan image obtained from a GPR measurement over a concrete floor. The shown image is displayed directly from the measured raw data and no post-processing for image enhancement has been applied. Nevertheless, in the figure one can clearly observe a detailed image of the subsurface which reflects the improved performance of the antennas for pulse radiation.

4. Conclusions

A compact modified bow-tie antenna for high-resolution GPR application has been proposed. It has been demonstrated that the proposed antenna exhibits stronger pulse radiation with suppressed late-time ringing in comparison with commonly-used GPR antennas of significantly larger dimensions. Using the developed antennas, improved results have been obtained from real GPR surveys. An example of B-scan obtained from a GPR measurement over a concrete floor shows a clear and detailed image of the subsurface, which reflects the antennas' improved characteristics for pulse radiation.

References

- [1] A. A. Lestari, A. G. Yarovoy and L. P. Ligthart, "RC-loaded bow-tie antenna for improved pulse radiation," *IEEE Trans. Antennas Propagat.*, vol. 52, no. 10, pp. 2555-2563, Oct. 2004.

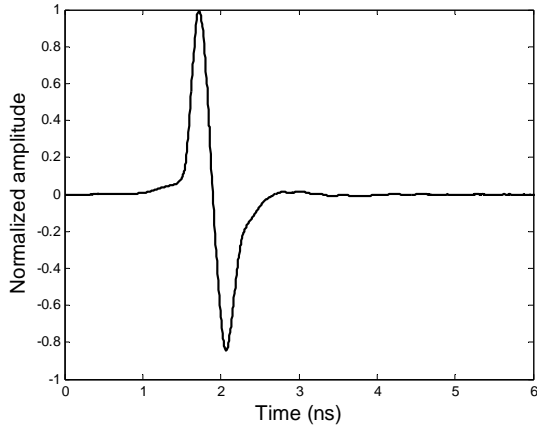


Figure 1: Monocycle with 0.8-ns duration for antenna excitation.

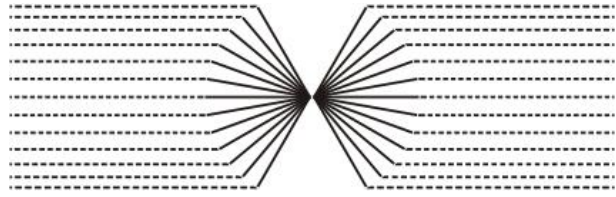


Figure 2: Antenna geometry: the flare angle is 120° ; distance between the feed point and the bends is 4 cm; total length and width of the antenna is 23 cm and 7 cm, respectively. The gaps are the locations of resistive loading realized using 25 lumped resistors along each of the wires. This geometry is optimized for realization as a printed antenna on FR-4 with strip width of 1 mm and excitation with a 0.8-ns monocycle pulse.

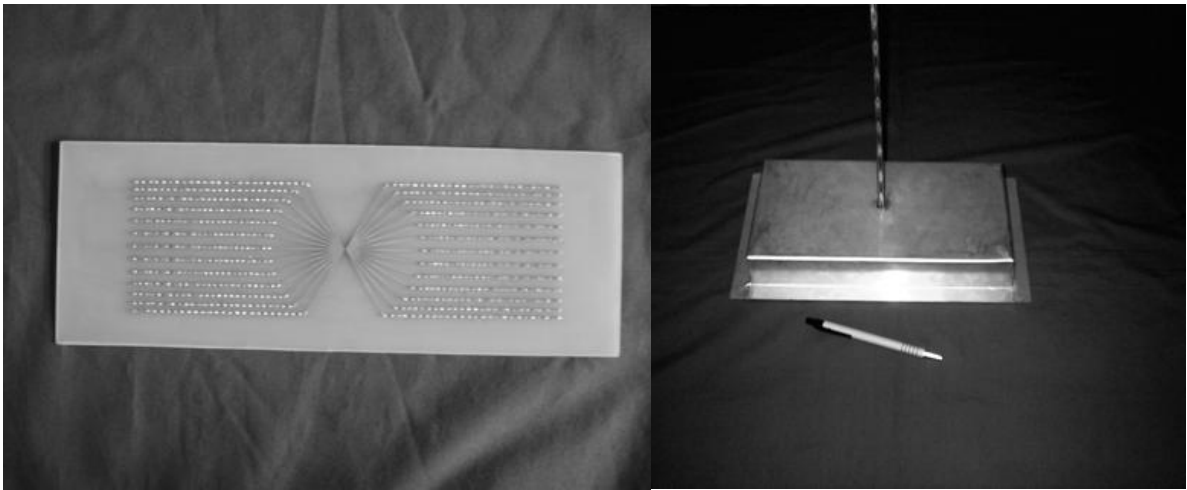


Figure 3: The proposed antenna constructed on FR-4 (left) and with its shield (right).

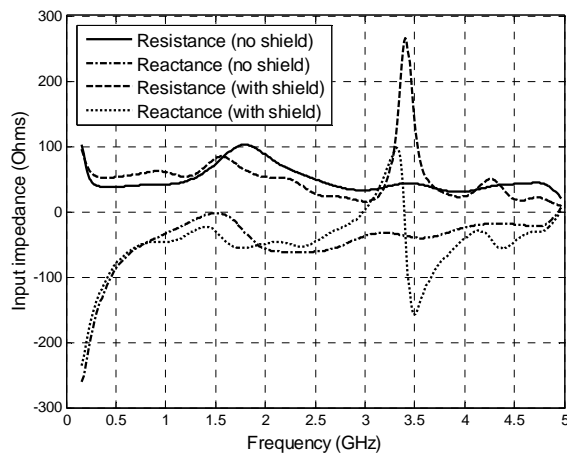


Figure 4: Measured input impedance of the proposed antenna with and without shield.

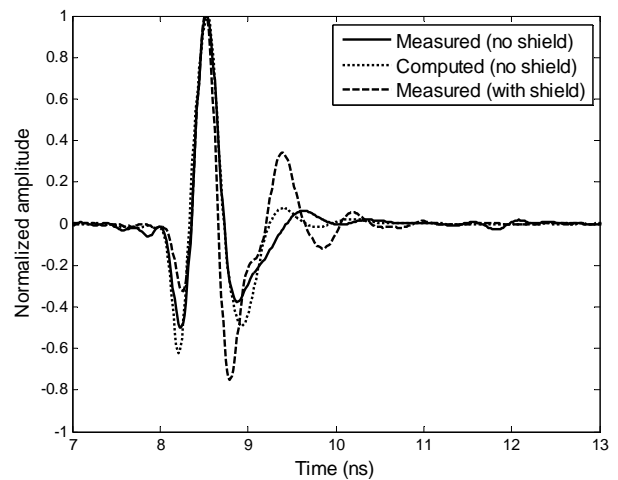


Figure 5: Transmit waveform of the proposed antenna with and without shield.

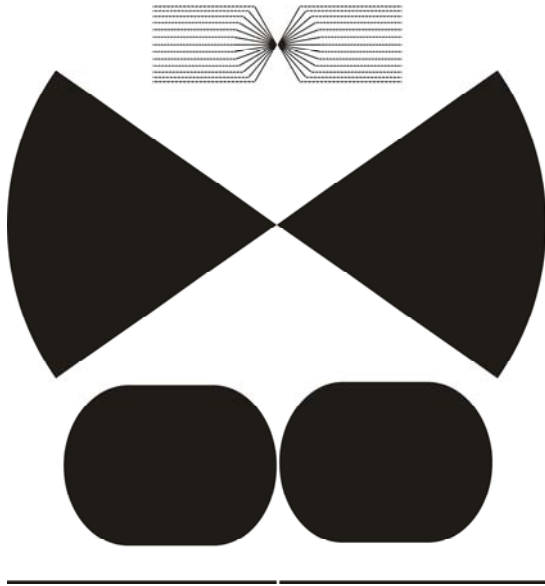


Figure 6: Scaled geometries of different GPR antennas for comparison purposes. From top: the proposed antenna (length = 23 cm, resistively loaded), a conventional solid bow-tie antenna (length = 50 cm, flare angle = 70° , not loaded), a planar dipole (length = 40 cm, width = 15 cm, not loaded), a wire dipole (length = 50 cm, not loaded).

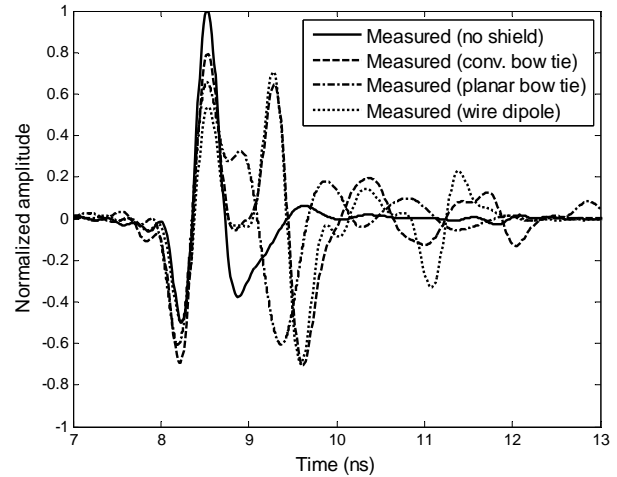


Figure 7: Comparison of measured transmit waveforms (in boreside direction) among the GPR antennas shown in Figure 6. The proposed antenna (not shielded) is indicated with solid line. Comparison of the peak-to-peak amplitude of the waveforms is given in Table 1.

Table 1: Comparison of the measured peak-to-peak amplitudes of the pulse transmitted in boreside direction for the GPR antennas indicated in Figure 6.

Antenna	Peak-to-Peak Amplitude (Normalized)
This work (length = 23 cm, resistively loaded)	1
Conventional bow tie (length = 50 cm, not loaded)	0.99
Planar bow tie (length = 23 cm, not loaded)	0.85
Wire dipole (length = 50 cm, not loaded)	0.69

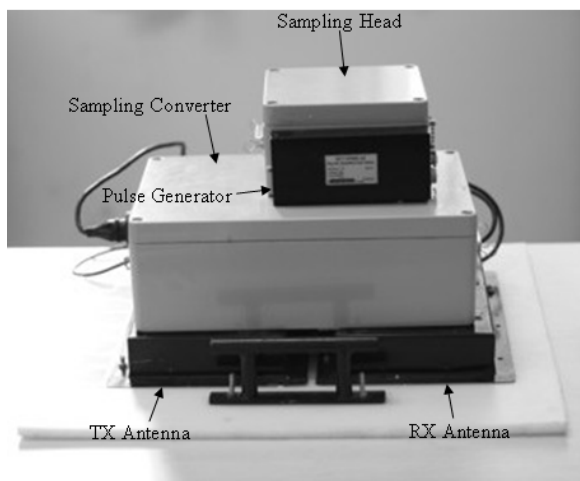


Figure 8: Integration of the proposed antenna in a hand-held GPR system.

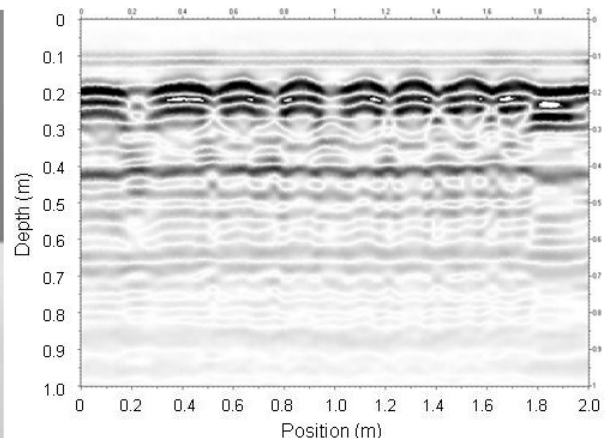


Figure 9: B-scan obtained from a GPR measurement over a concrete floor using the GPR system in Figure 8. The hyperbolas at the 0.2-m depth and the layer at the 0.4-m depth indicate the metallic reinforcing bars and the bottom of the concrete floor, respectively.