# CAPACITIVELY-TAPERED BOWTIE ANTENNA

**A.A. Lestari, A.G. Yarovoy, L.P. Ligthart**

***International Research Centre for Telecommunications-Transmission and Radar***
***Delft University of Technology - Faculty of Information Technology and Systems***
***Mekelweg 4, 2628 CD, Delft, The Netherlands***
***Phone: +31-15-278-2496, Fax: +31-15-278-4046, E-mail: a.lestari@its.tudelft.nl***

## INTRODUCTION

A number of applications, among which is ground penetrating radar (GPR), generally make use of pulses which are short in duration, especially when targets of interest are electrically small (e.g. anti-personnel landmines). The transmitted pulses should have a simple shape such as a monopulse, a monocycle or their time-derivatives, and their tails should be sufficiently flat to avoid masking of the targets. As high detection rate and low false alarm rate are crucial aspects in GPRs for buried landmine detection, the antenna should be able to radiate efficiently to allow optimal ground penetration. Many GPRs for demining of landmines are designed to be carried by an operator, and hence the antenna system should also be light-weight. Furthermore, demining operations in mine fields can be very expensive because they usually involve vast areas and deployment of many deminers. The GPR should therefore be affordable for such operations and correspondingly low-cost antennas become a necessity. Those mentioned factors are considered as the design criteria for the GPR antenna reported here, i.e., radiating short pulses with a flat tail, possesses good radiation efficiency, light-weight and low-cost.

A common problem in the response of transient antennas is the late-time ringing which is caused by reflections at the antenna open end and the limited antenna bandwidth. A well-known technique to eliminate open-end reflections is the use of a tapered resistive loading [1] with its inherent drawback in the form of low radiation efficiency. An alternative technique – the use of a tapered capacitive loading, which does not possess this drawback – has not been widely reported. Nyquist, *et al*. [2], and Rao, *et al*. [3] are among the firsts who investigated the use of a capacitive loading in non-dissipative wideband antennas. More recently, a form of tapered capacitive loading has been implemented to reduce wideband edge diffraction as reported in [4] and [5]. In this work we propose a different approach: the use of a tapered capacitive loading in combination with microwave absorbers, which proves to be effective in eliminating open-end reflections while keeping the radiation efficiency high. The technique is implemented on the simplest wideband antenna: the bowtie, and utilizes low-cost microwave absorber blocks, resulting in a low-cost, light-weight and efficient ultra-wideband antenna.

## SIMULATION OF TAPERED LOADING

The tapered capacitive loading is realized by constructing a number of slots on the surface of a circular-end bowtie antenna. The width of the slots increases linearly from the feedpoint to the open end and the slots are separated by a constant center-to-center spacing. This arrangement causes partial reflections of different frequency components of the input pulse to take place at each slot. In the resulting time-domain response, the open-end reflection is replaced by a late-time ringing of much lower amplitudes which can be effectively suppressed by placing an absorber block on the slotted surface of the antenna. A low-profile taper consisting of 10 slots with slot widths ranging by a factor of 10 from 1 mm to 10 mm has been designed and analyzed using the finite-difference time-domain (FDTD) method. This rough design is dictated by the difficulty to model a more detailed taper in the FDTD method. However, despite its roughness this approach should give a qualitative indication of how this kind of taper would perform. For this analysis we make use of our in-house FDTD package [6]. The calculated transmitting response of the tapered bowtie and a conventional bowtie (bowtie without taper) is given in Fig. 1, where it can be seen that in the tapered bowtie's response the open-end reflection which occurs at about 0.8 ns disappears and is replaced by a late-time ringing of much lower amplitudes. The main pulse of the tapered bowtie is in fact a superposition of two different pulses originating from the feedpoint and the first slot and hence it has a shape which is proportional to the time-derivative of the input pulse and its maximum amplitude is almost two times higher than that of the conventional bowtie.

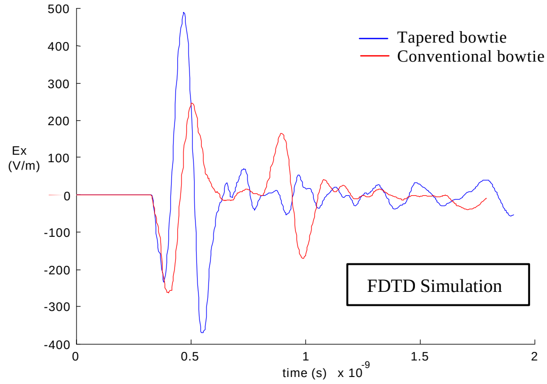



Fig. 1. FDTD-calculated transmitting response of the capacitively-tapered bowtie and a conventional bowtie of the same dimension. The input pulse is a 0.2-ns monocycle.

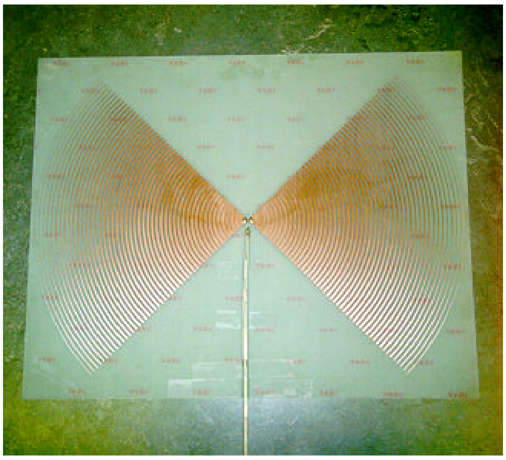


Fig. 2. The experimental capacitively-tapered bowtie antenna.

## EXPERIMENTS

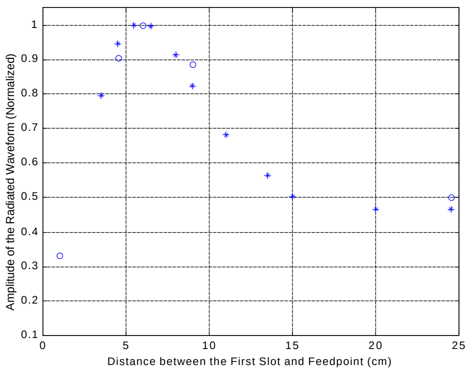
For the purpose of experimental verifications a circular-end bowtie antenna with a high-profile taper has been built as shown in Fig. 2. The tapered bowtie has a half-length of 24.4 cm and a flare angle of 90°, constructed by means of a photo-etching method on a 0.8 mm thick epoxy substrate. The taper consists of 47 slots having linearly increasing widths towards the open end, with the narrowest being 0.2 mm and the widest 4.8 mm wide. The slots are separated by a constant center-to-center spacing of 5 mm. For comparison purposes a conventional bowtie of the same dimension is used. The antennas are fed by a 50-ohm transmission line and during this experiment neither balun nor matching network is employed. The input pulses used are a 0.8-ns monocycle and a 0.35-ns monopulse. The pulse generators have been produced by a Russian company, SATIS, and the sampling oscilloscope by a Lithuanian company, GeoZondas. A detailed description of the hardware can be found in [7].

It is found that the maximum amplitude of the radiated pulse is a function of the distance between the feedpoint and the first slot (the slot directly adjacent to the feedpoint). Fig. 3 gives the measurement results and FDTD calculation of the maximum amplitude of the radiated pulse as a function of the feedpoint-first slot distance for both the 0.8-ns monocycle and 0.35-ns monopulse. The different feedpoint-first slot distances are realized here by short-circuiting the slots. As it can be seen, when the 0.8-ns monocycle is used, the highest maximum amplitude occurs when the feedpoint-first slot distance is 5.5 cm. In this case the center frequency in the frequency spectrum of the radiated pulse is about 1.4 GHz. This results in a 'length to center-wavelength' ratio of 0.5. Correspondingly, when the 0.35-ns monopulse is used, the highest maximum amplitude occurs when the feedpoint-first slot distance is 11 cm, and in this case the center frequency of the radiated pulse is about 0.7 GHz. This also gives a 'length to center-wavelength' ratio of 0.5. Thus, we can formulate the above results as

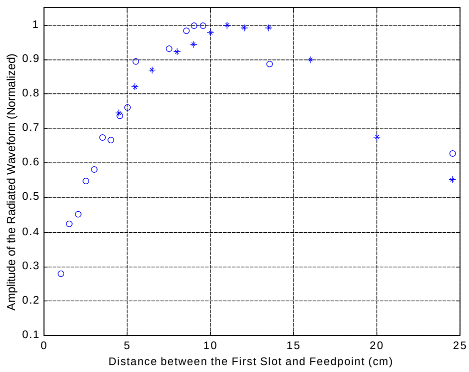
$$l_m = 0.5\lambda_c \qquad (1)$$

where $l_m$ is 2 × the feedpoint-first slot distance at which maximal radiation occurs and $\lambda_c$ is the center wavelength of the radiated pulse. Equation (1) indicates that in analogy to the time-harmonics, a resonance phenomenon also takes place in transient antennas. We have verified that this 'resonance' corresponds only to the length and not to the flare angle of the bowtie. Equation (1) finds its importance if the tapered bowtie will be optimized to radiate maximal power.

We have experimentally verified that the responses of the antenna using the 0.8-ns monocycle input pulse are generally better than when the 0.35-ns monopulse is used. This is due to the fact that the 0.35-ns monopulse contains considerable low frequency components down to dc which cannot be radiated properly by a bowtie of such dimension and thus consequently are reflected back to the feedpoint, giving rise to the level of late-time ringing.




(a)




(b)

Fig. 3. Normalized maximum amplitude of the radiated pulse as a function of distance between the feedpoint and the first slot obtained from measurement (circle) and FDTD calculation (star), when the input pulse is: (a) the 0.8-ns monocycle (b) the 0.35-ns monopulse.

For GPR applications, the tapered bowtie is here optimized for the lowest level of late-time ringing and therefore the 0.8-ns monocycle input pulse is preferred. It is experimentally found that using this monocycle as input pulse the lowest level of late-time ringing is obtained when the first 16 slots are short-circuited giving the feedpoint-first slot distance of 9 cm and the first slot width of 1.8 mm. The response of the tapered bowtie with this feedpoint-first slot distance fed by the 0.8-ns monocycle is shown in Fig. 4a. It is obvious that the main pulse is in the form of the time derivative of the input pulse and following the main pulse a significant late-time ringing occurs as a result of partial reflections at each slot. The portion of the energy that would have been radiated at the open end of the bowtie is now distributed at the slots, resulting in minor radiation from each slot which can be effectively suppressed by covering the slots with merely low-cost absorbers. This gives a late-time ringing level of lower than –40 dB after less than 2 ns from the beginning of the pulse. Note that using absorbers drops the maximum amplitude only slightly. It is furthermore observed that the absorbers should be placed only on the upper side of the bowtie as placing them on the lower side causes shadowing of radiation into the ground.

Table 1. Comparison of the maximum amplitude of the tapered bowtie without absorbers, the tapered bowtie with absorbers and the conventional bowtie.

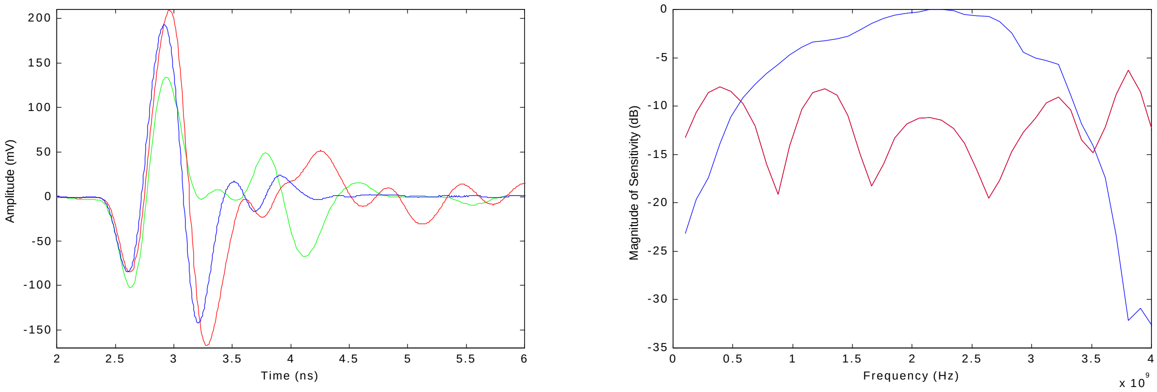
| Bowtie Type | Max. Amplitude (mV) | Max. Amplitude (compared to A) |
|---|---|---|
| A. Tapered Bowtie (no absorbers) | 208.7 | — |
| B. Tapered Bowtie (with absorbers) | 192.3 | –0.7dB (92%) |
| C. Conventional Bowtie | 131.1 | –4 dB (63%) |

The comparison of the maximum amplitude of the radiated pulses from the conventional bowtie and the tapered bowtie with and without absorbers is given in Table 1. Since the shape of the waveform radiated from the conventional and tapered bowtie is not equal, in making the comparison the global maximum of the response is considered. It can be seen that using the absorbers reduces the maximum amplitude by only –0.7 dB and that the maximum amplitude is still 47% higher than that of the conventional bowtie.

In order to analyze the frequency characteristics of the tapered bowtie (with absorbers) we define the receiving sensitivity of the antenna as:

$$S^r = \frac{h_e}{Z_{in} + Z_L} \tag{2}$$

where $h_e$, $Z_{in}$, and $Z_L$ are the antenna effective length, the antenna input impedance and the load impedance, respectively. Fig. 4b shows the plot of the receiving sensitivity of the tapered bowtie (with absorbers) and the conventional bowtie as a function of frequency. It can be seen that the tapered bowtie does not exhibit any high-Q resonance and the curve is confined within the –5 dB level in the 1 - 3 GHz frequency band.




(a) (b)

Fig. 4. (a) Time-domain response of the tapered bowtie antenna without absorbers (red line), with absorbers (blue line), and the conventional bowtie (green line). (b) Receiving sensitivity of the tapered bowtie with absorbers (blue line) and the conventional bowtie (red line). The input pulse used is the 0.8-ns monocycle.

## CONCLUSIONS

A novel technique to construct an efficient, light-weight and low-cost ultra-wideband antenna for ground penetrating radar is presented. This technique makes use of a tapered capacitive loading implemented on a circular-end bowtie antenna and realized by constructing a number of slots with linearly increasing widths towards the open end. Low-cost microwave absorbers are successfully employed to suppress the resulting late-time ringing. A general rule of thumb to obtain maximal radiation from the tapered bowtie is formulated. The technique proves to be effective in eliminating reflections at the open end of the bowtie while keeping the radiation efficiency high. Using a 0.8-ns monocycle as input pulse, the radiated waveform is in the form of the time derivative of the input pulse and its maximum amplitude is about 47% higher than that of a conventional bowtie of the same dimension. A late-time ringing level of below –40 dB after less than 2 ns from the beginning of the pulse is obtained.

## ACKNOWLEDGEMENT

This work was supported by the Dutch Technology Foundation STW under the project "Improved Ground Penetrating Radar Technology". The authors wish to thank Dr. G. Mur for his invaluable assistance during the FDTD simulations.

## REFERENCES

[1] T.T. Wu, R.W.P. King, "The Cylindrical Antenna with Nonreflecting Resistive Loading", *IEEE Trans. on AP*, vol. AP-13, p. 369-373, May 1965.
[2] D.P. Nyquist, K. Chen, "The Traveling-Wave Linear Antenna with Nondisipative Loading", *IEEE Trans. on AP*, vol. AP-16, no.1, p.21-31, Jan. 1968.
[3] B.L.J. Rao, J.E. Ferris, W.E. Zimmerman, "Broadband Characteristics of Cylindrical Antennas with Exponentially Tapered Capacitive Loading", *IEEE Trans. on AP*, vol. AP-17, no.2, p. 145-151, Mar. 1969.
[4] R.A. Burleson, A.J. Terzuoli, E.K. English, "Two-Dimensional Tapered Periodic Edge Treatments for Broadband Diffraction Reduction", *Ultra-wideband, Short-Pulse Electromagnetics 2*, p.215-226, Plenum Press, New York, 1995.
[5] E.K. English, "Tapered Periodic Surfaces: A Basic Building Block for Broadband Antenna Design", *Ultra-wideband, Short-Pulse Electromagnetics 2*, p.227-235, Plenum Press, New York, 1995.
[6] G. Mur, "User's Guide for FDTD3D – The Time-Domain Finite-Difference Code in C++", IRCTR and Laboratory of Electromagnetic Research, Delft University of Technology, Jan. 1999.
[7] A.G. Yarovoy, B. Sai, G. Hermans, P. van Genderen, L.P. Ligthart, A.D. Schukin, I.V. Kaploun, "Ground Penetrating Impulse Radar for Detection of Small and Shallow-Buried Objects", *Proc. of IGARSS '99*, Vol. 5, pp. 2468-2470, June/July, 1999.