Adaptive GPR Antenna for Multiple Pulse Transmissions

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Abstract

In this paper a concept of adaptive GPR antenna for optimal transmission of multiple pulses is presented. A relatively simple antenna with such an adaptation capability is proposed and experimentally verified for transmitting monocycles of different durations. The proposed antenna is able to adapt to each of those pulses and gives maximal radiation in the broadside direction of the antenna. It would allow GPR operations in various applications to be carried out using one antenna system. Moreover, the antenna would be suitable for quasi-simultaneous transmission of multiple waveforms for improvement of GPR performance.

1. Introduction

This paper presents part of the results achieved in research cooperation on adaptive ground penetrating radar (GPR) antennas between the International Research Centre for Telecommunications and Radar (IRCTR), The Netherlands, and the Indonesian Institute of Sciences (LIPI), Indonesia. This cooperation focuses in particular on the study of adaptive antennas for GPR applications. One of the antennas, as reported in this paper, has been designed to be adaptive against impulse excitations with different pulse durations. In this context adaptive means that the antenna should be able to remain optimum for different exciting pulses to transmit each of those pulses with maximal radiation.

Various GPR applications require different resolutions and penetration depths. For example, road inspection using GPR needs high resolution with only several centimeters of penetration depth, while a hydrological application generally requires low resolution with penetration depth of tens of meters. To achieve high resolution an impulse GPR transmits sufficiently short pulses, while low resolution and large penetration depths are achieved by transmitting sufficiently long pulses. Therefore, to operate the GPR in several applications generally a number of antennas with different dimensions are needed, depending on the required resolutions and penetration depths. Thus, one should have a set of suitable antennas of various dimensions.

In view of the above, in this work we developed a GPR antenna that could be used optimally with a number of excitation pulses of different durations. The proposed antenna is able operate with different resolutions needed for a wide range of GPR applications. Hence, one may say this antenna is adaptive with respect to the excitation impulse. Such an antenna could replace a set of antennas which otherwise would be needed for using a GPR in a wide range of applications.

Theoretical analysis of the antenna by means of the FDTD method has been reported in [1]. In this paper we present only experimental results, which include measured transmitted waveforms due to different exciting pulses and the antenna's input impedance.

2. Antenna Design

A. Exciting Pulses

The abovementioned adaptation concept is demonstrated in this paper for transmission of 4 pulses with different durations. The selected exciting pulses are monocycles with duration of 0.6, 1.2, 2.4, and 4.8 ns as shown in Fig. 1(a). In Fig. 1(b) their spectra are presented where can be seen that the central frequencies assume values of about 1.6 GHz, 900 MHz and 450 MHz and 220 MHz for the 0.6-ns, 1.2-ns, 2.4-ns, and 4.8-ns monocycle, respectively. The 0.6-ns and 1.2-ns monocycles are well suited for high-resolution GPR applications (e.g. road inspection, concrete evaluation), the 2.4-ns monocycle for medium-resolution applications (e.g. archaeology), and the 4.8-ns monocycle for low-resolution applications (e.g. hydrology). To transmit those pulses optimally, 4 separate antennas of different dimensions are normally required. It is the goal of this work is to replace those 4 antennas with a single antenna that can work optimally with the 4 monocycles mentioned above.

B. Radiation Mechanism

A technique to strengthen radiation in the broadside direction of a transient antenna has been introduced in our previous works [2], [3]. By this technique, loading for ringing suppression is applied in the antenna and the part of the loading nearest to the feedpoint becomes a secondary source of radiation due to the discontinuity it introduces in the antenna. The distance between the feedpoint and the loading should be chosen in such a way that in the broadside direction of the antenna the secondary radiation combines constructively with the primary radiation from the feedpoint. As a result, one will observe a significant increase of the amplitude of the waveform transmitted in the broadside direction. This can be achieved when the distance between the feedpoint and the beginning of the loading is chosen to be $\lambda_c/4$, where λ_c is the wavelength corresponding to the central frequency of the pulse [2]. In case of a printed antenna on a dielectric substrate, generally the value of λ_c should be made smaller by a factor of the square root of the effective relative permittivity of the substrate.

The main objective of this work is to implement the abovementioned technique for efficient transmission of different pulses by a single antenna. However, the drawback of this technique is that the antenna is optimized only to a pulse with a certain λ_c. The amplitude of the transmit waveform degrades when the antenna is excited with another pulse with a different λ_c. Hence, the main challenge was to overcome the mentioned drawback so that using the same technique a number of pulses with different durations can be transmitted optimally by the antenna.

C. Antenna Geometry

The geometry of the proposed antenna is given in Fig. 2. It can be seen that each arm of the antenna consists of a short and a long element which are arranged to form a bow-tie like structure. The short and long elements are optimized to the 1.2 and 2.4-ns pulses, respectively. Each element can be selected using switching devices which are to be installed across the gaps located near the feedpoint. For the switching devices we are investigating the possibility of using miniature relays as our previous work revealed the difficulty of using PIN diodes for this application [4]. By means of such electronic switching devices it would be possible to remotely activate an element and deactivate the other one for optimizing the antenna to the 1.2-ns or 2.4-ns pulse.

It can be seen in Fig. 2 that each element comprises an unloaded section (between the feedpoint and the bends) and a loaded section (between the bends and the antenna ends). The length of the unloaded section of each element is determined to be $\lambda_c/4$ to obtain maximal radiation in the broadside direction of the antenna, as explained above. As the long element is optimized to the 2.4-ns pulse (central frequency = 450 MHz), assuming the effective relative permittivity of the substrate = 2.5, the optimal length of the unloaded section is found to be around 10 cm. For the short element, which is optimized to the 1.2-ns pulse (central frequency = 900 MHz) the unloaded section is two times shorter. Furthermore, FDTD analysis indicated that angular separation of 70° between the unloaded sections, as illustrated in Fig. 2, provides acceptable isolation between the elements [1]. However, other values of angular separation have not been investigated to determine the optimal isolation.

Although the antenna is originally optimized to the 1.2-ns and 2.4-ns monocycles, two additional pulses, i.e. 0.6-ns and 4.8-ns monocycles, were also used in this work. It will be shown that the adaptation capability of the antenna also works for these extra pulses, which in turn enlarges the applicability of the antenna.

D. Antenna Loading

Resistive loading for ringing suppression is applied along the sections of the antenna between the bends and the ends. In each of the antenna element, part of the loading nearest to a bend and the bend itself introduce a discontinuity that serves as a secondary source of radiation for strengthening pulse transmission in broadside direction. In this work 25 resistors in series were employed as the resistive loading. These resistors were soldered across the gaps along the loaded sections shown in Fig. 2. A similar loading technique has been successfully employed in our previous works for a modified bow-tie antenna [3], [5]. In this paper we applied the loading profile introduced in [5]. However, it should be noted that that loading profile was particularly designed for a bow-tie antenna and therefore may not be optimal for the proposed antenna in which dipole characteristics are still dominant. An improved loading profile using a series of resistors for dipole-like antennas is a subject of our future work. Fig. 3 displays a realization of the loaded antenna proposed in this paper.

3. MEASUREMENT TECHNIQUE

Input impedance measurements in this work were carried out using the technique that has been reported in [6] and thus will not be elaborated here. Only the technique for measurement of transmitted waveforms is described below.

The setup for measurement of transmitted waveforms is illustrated in Fig. 4. The UWB electromagnetic sensor introduced in [7] is employed in this work as the probe and connected to a sampling converter which is fully controlled by a PC. The antenna under test is connected to a pulse generator which excites a monocycle with duration of 30 ps after receiving a trigger from the sampling converter. The spectrum of the 30-ps pulse is much larger than the spectra of the pulses considered in this paper and thus the response of the antenna excited by those pulses can be obtained. Both the antenna and the probe are fed with a twin semi-rigid (TSR) line to avoid need for a balun using the technique introduced in [8]. The used TSR line is sufficiently long to allow adequate observation time window for all of the considered pulses.

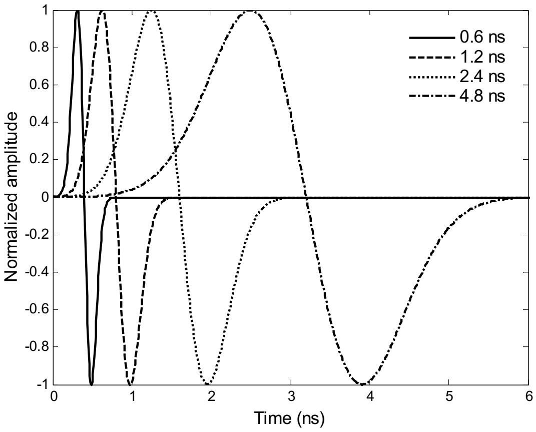
Referring to the setup in Fig. 4 the measured transmitted waveform is given by

$$E_{rad} = F^{-1}\{F[D(V_{probe})]\widetilde{S}_{ex} / \widetilde{S}_{in}\} \qquad (1)$$

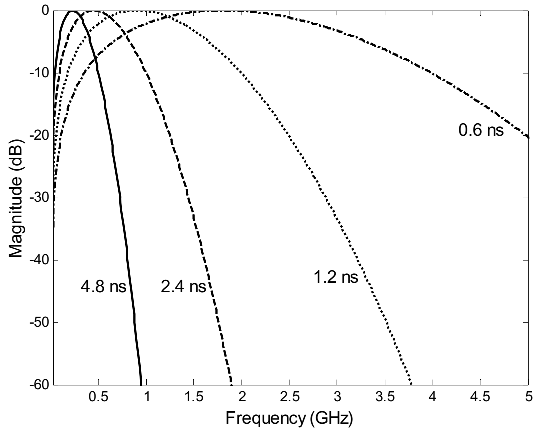
where V_{probe} is the voltage induced on the probe, $\widetilde{S}_{in}$ is the normalized spectrum of the 30-ps monocycle, $\widetilde{S}_{ex}$ is the normalized spectrum of the exciting pulse (the 0.6-ns, 1.2-ns, 2.4-ns or 4.8-ns monocycle), F is the Fourier transformation operator, F^{-1} is the inverse Fourier transformation operator, and D represents the probe's characteristics in the form of a deconvolution operator which removes the probe's influence on the measurement [7].

4. EXPERIMENT

In this paper switching of the short and long elements was done by manually short-circuiting the gaps near the feed point (see Fig. 2). Application of miniature relays as the switching device in the antenna will be reported in a future paper.
For the measurement we considered 3 different element settings, i.e.
1) short element "on", long element "off",
2) long element "on", short element "off",
3) all elements "on".
With "on" we mean the corresponding element is connected to the feed point, and with "off" that element is disconnected. As mentioned previously an element is here connected by short-circuiting the gap near the feed point.

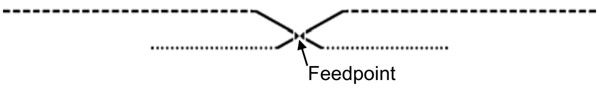


(a)

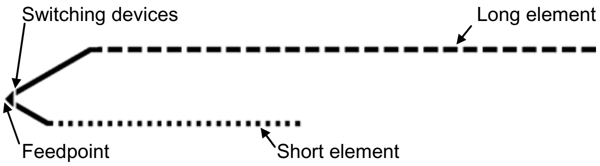


(b)

Fig. 1: Different pulse excitations considered in this paper: monocycles with durations of 0.6, 1.2, 2.4, and 4.8 ns; (a) their waveforms, and (b) their spectra.



(a)



(b)

Figure 2. Geometry of the two-element dipole: (a) whole antenna, and (b) only the right arm shown. Flare angle = 70°. Strip width = 5 mm. Resistors for antenna loading are soldered across the gaps. The long and short elements have the same loading profile. Switching devices are to be installed across the gaps near the feed point. Long element: length = 1.2 m, distance from feed point to the bend = 10 cm. Short Element: length = 60 cm, distance from feed point to the bend = 5 cm. The antenna is realized as a printed antenna on an FR-4 substrate.

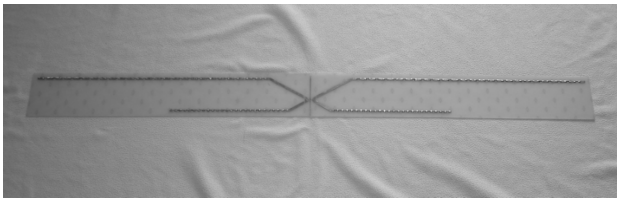


Fig. 3: Realization of the antenna.

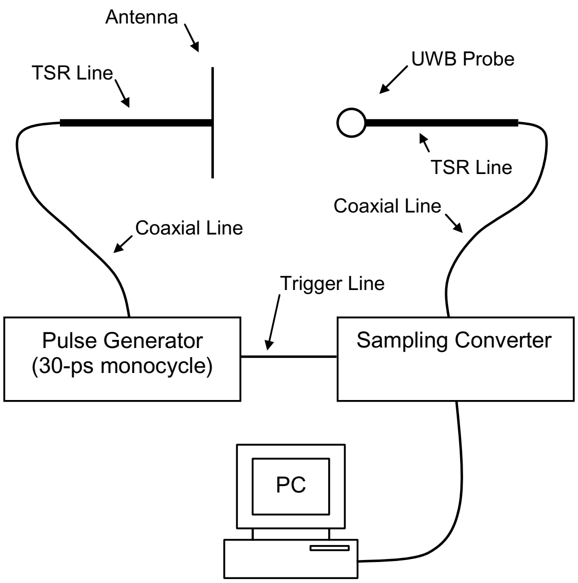
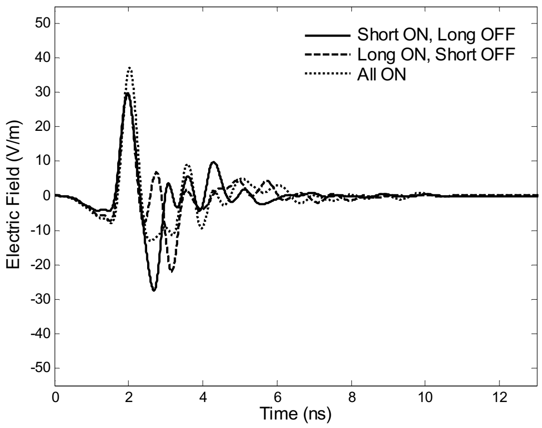
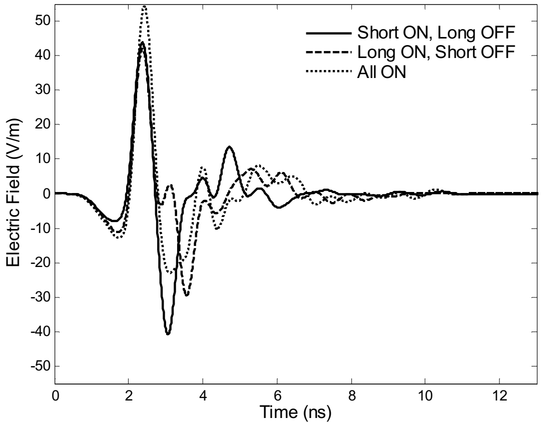


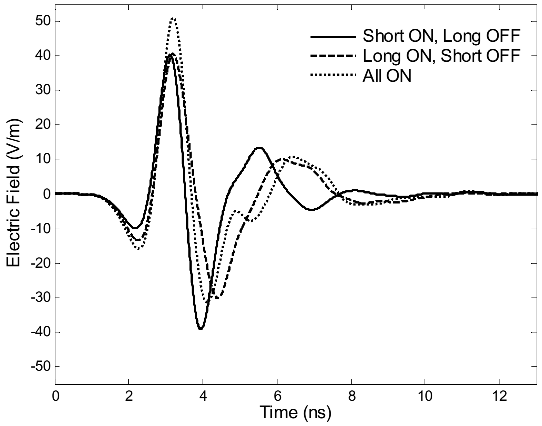
Fig. 4: Setup for measurements of transmitted waveforms.



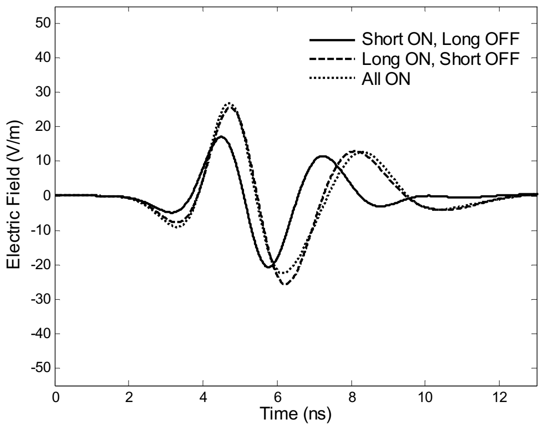
(a)



(b)



(c)



(d)

Fig. 5: Measured transmitted waveforms of the antenna for different element settings. The antenna excitations are the (a) 0.6-ns, (b) 1.2-ns, (c) 2.4-ns, and (d) 4.8-ns monocycle.

TABLE 1: RELATIVE AMPLITUDE FOR DIFFERENT ELEMENT SETTINGS

Monocycle Duration	Relative Peak-to-Peak Amplitude		
	Short ON Long OFF	Long ON Short OFF	All Elements ON
0.6 ns	1	0.65	0.88
1.2 ns	1	0.84	0.91
2.4 ns	0.96	0.85	1
4.8 ns	0.73	1	0.96

For each element setting the antenna is excited with each of the considered pulses (0.6, 1.2, 2.4, and 4.8 ns monocycles). The main subject of observation in these measurements is the peak-to-peak amplitude of the transmitted waveforms. As indicated by simulations [1], one should be able to obtain maximum peak-to-peak amplitude of each of the considered pulses by selecting one of the aforementioned 3 element settings. In particular, setting 1 should lead to maximum peak-to-peak amplitude for shorter pulses and setting 2 for longer pulses. Furthermore, we may expect setting 3 to be optimal for intermediate pulses. If this could be achieved we may say that the antenna is adaptive with respect to the exciting pulses as it possesses a capability of maintaining maximum radiation for all of those pulses.

The measured transmitted waveforms are plotted in Fig. 5 for all element settings and considered pulses. The peak-to-peak amplitudes of the measured waveforms are listed in Table 1. It is shown that, as expected, setting 1 gives maximum radiation for shorter pulses (0.6 and 1.2 ns), setting 2 for a longer pulse (4.8 ns) and setting 3 for an intermediate pulse (2.4 ns). These results demonstrate the adaptation capability of the antenna for optimal transmission of multiple pulses.

It should be noted that in the above results mismatch loss is taken into account. The measured input impedances of the antenna for all settings are plotted in Fig. 6, and in view of

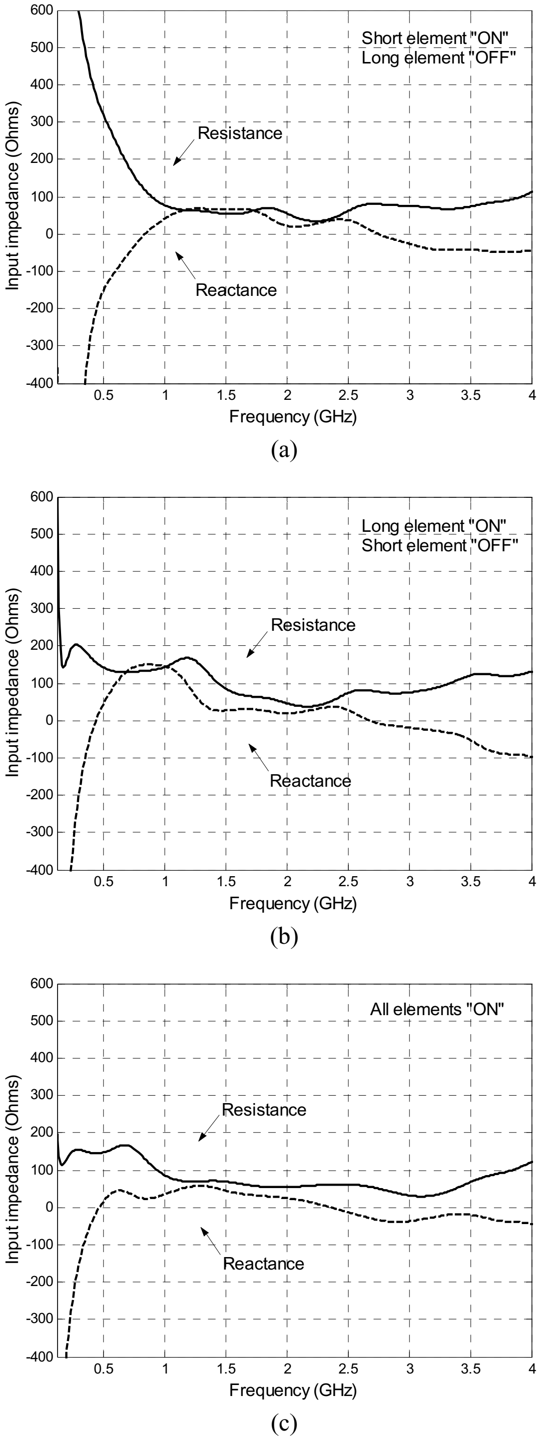


Fig. 6: Measured input impedance of the antenna, (a) only short element is "on", (b) only long element is "on", and (c) both elements are "on".

this result the most straightforward implementation of the antenna would be to integrate the RF front end with the antenna since in this way neither balun nor matching device are required.

In addition, when one employs fast switching devices (e.g. miniature relays) in the antenna, optimal quasi-simultaneous transmission of multiple waveforms would be possible. It has been demonstrated that this technique is useful for enlarging the bandwidth of GPR's probing signals and responses, which in turn enhances the overall performance of the GPR [9].

5. CONCLUSION

A demonstrator of an adaptive GPR antenna for optimum transmission of multiple pulses has been introduced and experimentally verified. The proposed antenna was applied for transmitting 4 monocycles with different durations, i.e. 0.6, 1.2, 2.4, and 4.8 ns. It has been shown that this antenna can adapt to those pulses and transmits each of those pulses with maximum peak-to-peak amplitude in the broadside direction. This antenna would allow GPR operations in different applications to be carried out using a single antenna system. In addition, it would be possible to perform optimal quasi-simultaneous transmission of multiple waveforms for improvement of the GPR's performance.

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