Rolled-Dipole Array for GPR Application with Variable Antenna Footprint

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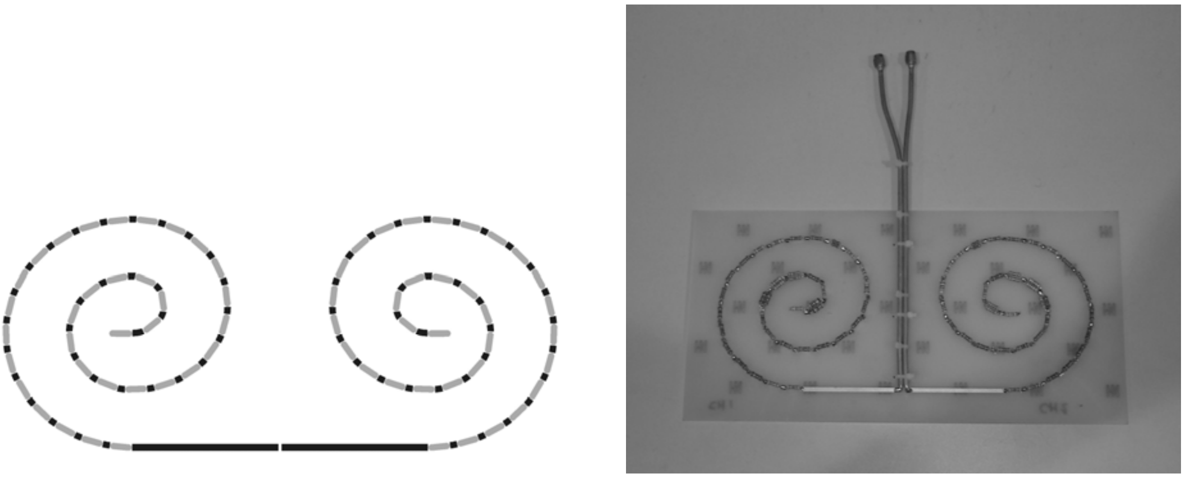
1. Introduction

In ground penetrating radar (GPR) terminology antenna footprint is defined as a collection of peak-to-peak amplitudes of the transmitted pulse measured in a horizontal plane. Antenna footprint indicates the shape and size of the area illuminated by the antenna on the ground surface or subsurface. Its importance lies in the fact that it determines the cross-range resolution of the GPR. If the size of the footprint is larger than the cross section of the target, it may give rise to clutter as the antenna illuminates not only the target but also the surrounding medium. Clutter can be maximally reduced if the size of the footprint is comparable with the cross section of the target. However, this is not always easily achieved as targets usually have different dimensions while the size of the antenna footprint remains fixed. In this work we demonstrate that a specially designed array antenna consisting of a number radiating elements can have a variable footprint by activating certain elements and deactivating the others. In this way the size of the footprint of the antenna can be adjusted to remain comparable with the cross section of targets so that clutter can be minimized for various targets with different dimensions. This paper presents only the results of FDTD simulations of the antenna, while the experimental results will be shown elsewhere.

2. Array Elements

The proposed array antenna consists of a number of rolled-dipole elements introduced in [1]. The geometry of the rolled dipole and its realization as a printed antenna on an FR-4 material are presented in Figure 1. The antenna has been designed mainly for excitation with monocycle pulses of 1.6 ns duration (having a central frequency of 600 MHz) suitable for medium-resolution GPR applications. The total length of the wire is 105 cm and by rolling the wire as shown in the figure the antenna length is reduced by a factor of 4, resulting in antenna length of only 23 cm. The fraction of the wires starting from 6.6 cm from the feed point is resistively loaded according to the Wu-King loading profile, realized by using lumped resistors. In each arm of the dipole we employ 33 resistors. This number of resistors should be sufficient for proper implementation of the Wu-King profile. It should be noted that if the number of resistors is too small, implementation of the Wu-King profile will not be effective since the sharp increase of the loading values at the end section of the Wu-King profile will not be properly approximated by the resistors. The first resistor (the nearest to the feed point) has a value of 200 Ω and is also intended to function as a secondary source of radiation due to the discontinuity it introduces. It has been demonstrated in [2] that when the distance between the feed point and the first resistor is chosen to be $c/(4f_c\sqrt{\varepsilon_{rs}})$, where c is the speed of light, f_c is the central frequency of the exciting pulse and ε_{rs} is the relative permittivity of the substrate, in the broadside direction of the antenna radiation from the secondary source combines constructively with radiation from the feed point, resulting in significant increase in the amplitude of the transmitted pulses. Hence, in this way one can enhance the power transmitted into the subsurface.



(a) (b)

Figure 1: (a) Geometry of the rolled dipole. Resistors for antenna loading are indicated in grey. The total length of the wire is 105 cm while the length of the rolled dipole is 23 cm, giving a reduction factor of larger than 4. The height of the antenna is 11 cm and the length of the unloaded section (from the feed point to the first resistor) is 6.6 cm. (b) Realization as a printed antenna on FR-4.

3. Array Configuration

The proposed array configuration consists of 9 rolled-dipole elements with feedpoint-to-feedpoint distance between adjacent elements of 25 cm, as illustrated in Figure 2. This distance is half of the wavelength which corresponds to the central frequency of the transmitted pulse. It has been found from simulations that this is the optimal separation between the elements which will give maximal variation of the footprint. This optimal distance agrees with [2]. Note that in the figure the direction of radiation is downwards as the array is situated above the ground.

The array should be fed by a specially designed feed system consisting of RF switching devices to allow selection of active elements. The design and implementation of such a feed system will be discussed elsewhere.

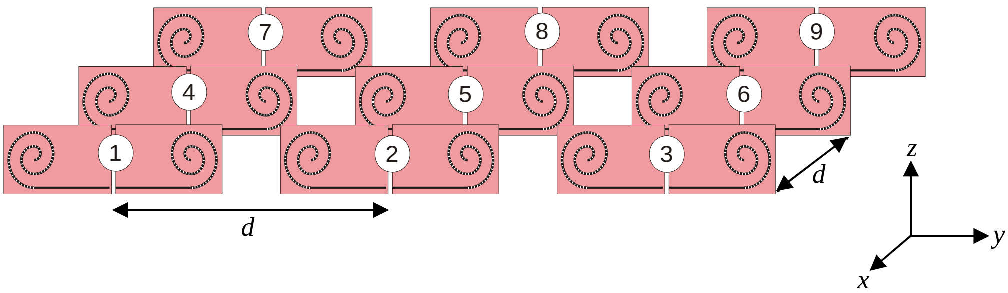


Figure 2: Configuration of the proposed array antenna. The array consists of 9 rolled-dipole elements shown in Figure 1. The feedpoint-to-feedpoint distance *d* between adjacent elements is 25 cm (half of the wavelength corresponding to the central frequency of the transmitted pulse). Each element is numbered as shown above.

4. Simulation Results

The proposed array has been analyzed theoretically using a standard FDTD package [3]. The employed FDTD model is shown in Figure 3. The array is situated on the surface of a real ground, chosen to be dry sand with relative permittivity of 4 and very small conductivity. As an electric wall is defined on the y = 0 plane, only half of the problem is considered as can be seen in the figure.

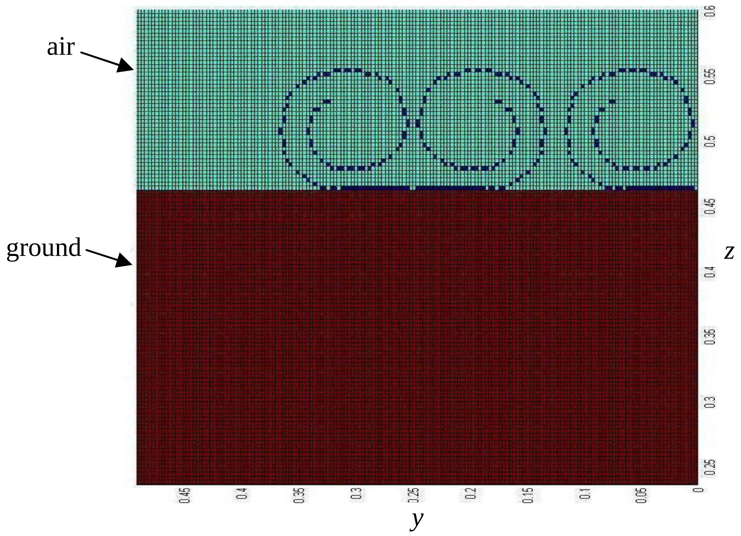


Figure 3: FDTD model of the proposed array antenna. The array is situated on a real ground (dry sand with ε_r = 4 and very small σ). An electric wall is defined on the y = 0 plane.

Table 1: Footprint size in x-direction (parallel with H-plane) for different dB levels and activated elements.

dB Level	**Setting1, Element ON: 5**	**Setting2, Element ON: 2, 5, 8**	**Setting3, Element ON: 4, 5, 6**	**Setting4, Element ON: 1, 2, 3, 4, 5, 6, 7, 8, 9**
-3 dB	45 cm (70%)	65 cm (100%)	60 cm (92%)	40 cm (61%)
-6 dB	65 cm (65%)	95 cm (95%)	75 cm (75%)	100 cm (100%)
-10 dB	85 cm (65%)	115 cm (88%)	100 cm (77%)	130 cm (100%)

Table 2: Footprint size in y-direction (parallel with E-plane) for different dB levels and activated elements.

dB Level	**Setting1, Element ON: 5**	**Setting2, Element ON: 2, 5, 8**	**Setting3, Element ON: 4, 5, 6**	**Setting4, Element ON: 1, 2, 3, 4, 5, 6, 7, 8, 9**
-3 dB	10 cm (15%)	15 cm (23%)	65 cm (100%)	65 cm (100%)
-6 dB	20 cm (26%)	30 cm (40%)	75 cm (100%)	75 cm (100%)
-10 dB	35 cm (37%)	45 cm (47%)	85 cm (89%)	95 cm (100%)

The footprints at a depth of 15 cm from the air-ground interface were computed for different dB levels and array settings, i.e., Setting 1: only element 5 is active, Setting 2: only elements 2, 5, and 8 are active, Setting 3: only elements 4, 5, and 6 are active, and Setting 4: all elements are active. The results are presented in Figure 4 where can be seen that the size of the footprints varies significantly for different settings in both x- and y-direction. The variation of the footprint can be observed quantitatively in Tables 1 and 2 for variation in the x- and y-direction, respectively. It is demonstrated that in general the dimension of the footprint increases from Setting 1 to 4. For example, at the -3 dB level in the y-direction the footprint dimension due to Setting 1 is as small as 15% of that due to Setting 4. For optimal utilization of this feature the array setting should be selected according to the size of the considered targets and the direction of the GPR survey. Correct selection of the array setting and the direction of the GPR survey would result in an optimal footprint dimension for the targets under consideration and thus minimize clutter.

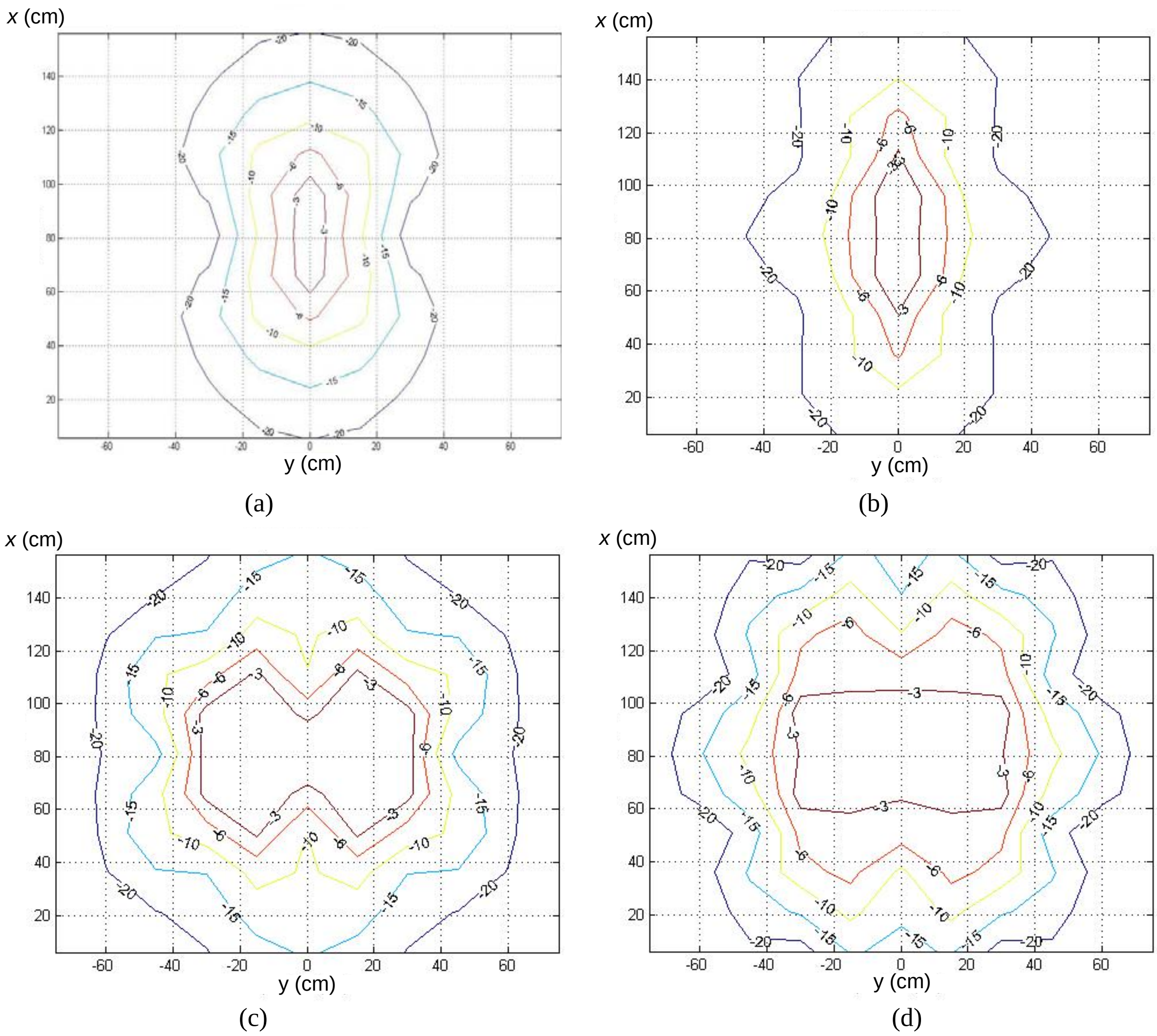


Figure 4: Computed footprints of the proposed array antenna at a 15-cm depth from the air-ground interface when one only activates element number (a) 5, (b) 2, 5, 8, (c) 4, 5, 6, (d) 1, 2, 3, 4, 5, 6, 7, 8, 9, while other elements are inactivated.

5. Conclusions

A concept of array antenna for GPR application with adjustable footprint has been introduced. It has been shown theoretically that the size of the antenna footprint can be varied by activating a number of selected array elements and inactivating the others. This result demonstrates the capability of the array to adapt the size of its footprint to be comparable with the size of the target for reducing clutter and thus improving the GPR data.

References

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