NUMERICAL MODELING OF A SPIRAL-ANTENNA GPR SYSTEM

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ABSTRACT

To better study the ground penetrating radar (GPR) problem, an important step is to develop an accurate simulation of the fields induced by the radiating antennas. In this work, a finite-difference time-domain (FDTD) model of a spiral-antenna GPR system was developed and verified against measurements of a prototype system. The paper discusses difficulties in modeling the antenna elements and presents evidence that the model properly predicts the response of the antennas in the presence of the ground.

1. SPIRAL ELEMENT PROTOTYPE DESIGN AND MODELING

The GPR system consists of two two-arm equiangular spiral antennas with a 20.3 cm diameter fabricated on a 1.8 mm thick Rogers RT 5870 dielectric substrate ($\epsilon_r \approx 2.33$). The transmit antenna (T) was chosen to radiate right-hand circular polarization, and the receive antenna (R) was chosen to receive left-hand circular polarization. Each antenna is backed with a metal can that is filled with Eccosorb AN-79 RF absorber to make the pattern of the antennas unidirectional. They are fed with two semi-rigid 0.141 coax lines. Each center conductor is attached to an arm of the spiral and the outer conductors are electrically bound. The lengths and losses of these lines are measured prior to being soldered in place. The geometry of the antenna element is shown in Fig. 1a.

In order to avoid the necessity of modeling a balun, the differential signal is virtually applied during measurement using the principle of superposition. At transmit time, the antennas are run single-ended from a network analyzer. In post-processing, the lengths and losses of the coax lines are calibrated out, and the difference of each calibrated single-ended run is the balanced response of the antenna. The use of single-ended measurements to obtain differential and common-mode scattering parameters is discussed in [1].

The numerical modeling of the antennas is an extension of the work in [2], where the spiral is modeled on the substrate. The first modification to the model is the addition of the absorbing cans. These were initially modeled without the absorbing material present. The cans are 14 cm tall and are the same diameter as the spiral elements. The spiral element was attached to the empty can and driven with a differentiated Gaussian pulse with maximum content at 1.5 GHz. In the top plot in Fig. 1b, the scattered voltage received in the measurement is shown and is compared with the predicted result from the FDTD model. The initial reflection occurs at approximately 1 ns and is caused by the transition from the coax lines to the spiral arms. The second reflection occurs from approximately 4 ns to 15 ns. This is a combination of the reflection from the current that reaches the end of the spiral arms and returns to the feed and the ringing inside of the can that is caused by the lack of an absorber. The primary difference between the measured and modeled response is in the size of the initial reflection, which is caused by minor errors in the geometry of the feed in the model. To dampen this ringing, the absorber was added to the prototype and model.

2. ABSORBER MATERIAL MEASUREMENTS

Prior to including the absorber in the FDTD model, it was necessary to obtain its electrical parameters. Modeling the absorber in FDTD requires the conductivity, dielectric constant, and possibly Debye relaxations. Each of these can be handled with a different update equation as described in [3]. AN-79 absorber consists of six layers of polyurethane foam. Each layer is loaded with a different density of carbon to adjust the loss in the layer. The AN-79 absorber was cut to form a cylinder that was inserted into the can taking up 11 cm of the 14 cm available inside.

To obtain material properties for the absorber layers used in the absorbing can, samples of each layer were cut from different regions of the sheet and measured separately. Initial measurements were based on the assumption that the only parameter of interest was the conductivity, so the DC resistance of each layer was measured using an impedance meter. It was found that only the most densely loaded layers showed a stable DC resistance on the meter. The scattered signal from the FDTD model using these material parameters did not match the measured results very well and further work was necessary.

To obtain a better match, it was decided to measure the complex ϵ_r as a function of frequency. This was done using the coaxial measurement procedure described in [4]. The calculation of ϵ_r was simplified to only require transmission measurements by assuming $\mu_r = 1$. The measured results showed a significant amount of loss for all layers of the absorber, but the loss did not vary as a simple conductance with frequency. To approximate this behavior, a single-pole Debye model with conductivity was fit to the measurements. In the bottom plot in Fig.

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1b, the measured response from the antennas with the absorber in the can, and the predicted result using the FDTD model for the absorber are shown. For comparison, the FDTD result using the purely conductive model of the absorber is also shown. The match using the best-fit Debye model is considerably better than that obtained using the purely conductive material properties.

3. MEASUREMENTS OVER GROUND

With a match to the model obtained for the spiral element, the two antennas were placed over a bed of dry sand in the configuration shown on the lower part of Fig. 1a. The T antenna transmitted a differentiated Gaussian pulse and the response measured on the R antenna was recorded. The measurements were compared to the FDTD model computed using a half-space of dielectric $\epsilon_r = 2.2$. Slight variations in the distance to the surface caused the measurements at a particular point to sometimes fail to match the FDTD model. To account for these variations, the response was measured over the full length of the sandbox and averaged. The average values are shown in Fig. 1c compared with the FDTD modeled response for distances to the ground ranging from 2 cm to 10 cm. The modeled responses match the averaged measurements fairly well.

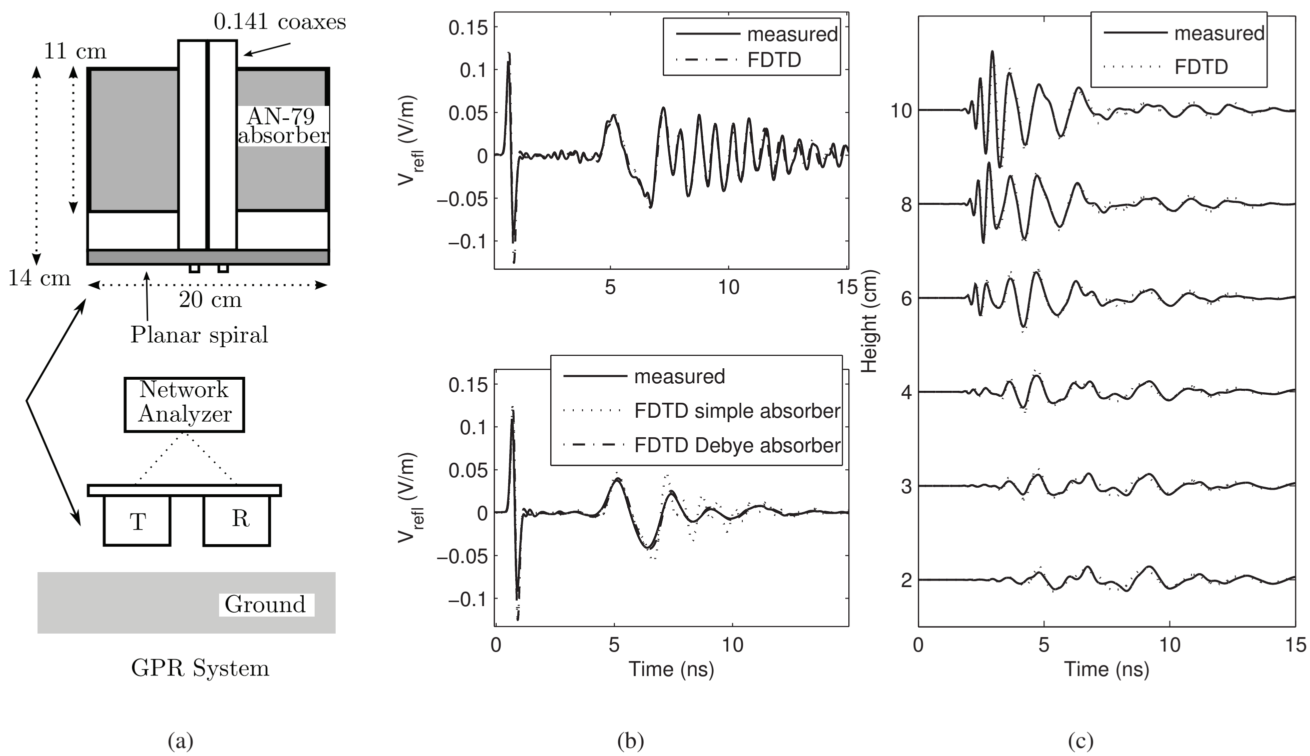

Fig. 1. (a) Geometry of the spiral element and the bistatic GPR system. The sizes of the 0.141 semi-rigid coax lines are exaggerated for clarity. (b) V_{refl} measured and modeled for the spiral antenna element with an empty can (top) and with the absorber (bottom). The FDTD simple absorber curve is the predicted response using a purely conductive material model. (c) Reflection from the ground on the receive antenna for various heights from the ground, modeled and measured.

4. REFERENCES

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