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Culvert pipe resonance

Veli Voipio [a]

Abstract:

- *Resonant frequency in the target is revealed using a Gopher antenna designed by the author for the measurements.*
- *Deconvolution is applied after conventional pre-processing.*

Keywords: antenna, deconvolution, GPR, Gopher antenna, target identification.

Introduction

The culvert measurement presented here was part of a series of measurements checking the performance of the Gopher antenna in practical situations. This intriguing result—a clear resonance at the location of the pipe—surfaced after the signal processing was completed using various parameters. The Gopher antenna (Voipio, 2019) is a new type of GPR wideband pulse antenna developed by the author. It is efficient, requiring only low transmitting power. Some challenges remain but, overall, the measurement results have been promising so far.

Data and preprocessing

The roadside gravel-road culvert that was measured has a pipe with a diameter of 30 cm laid so that its top is 40 cm below the surface. The author used a Gopher antenna of his own design (Voipio, 2019). The antenna was filled with neoprene (permittivity $\varepsilon r = 6.7$) to reduce the central frequency to 500 MHz. The pull direction was perpendicular to the pipe direction and the pipe was parallel to the E-plane of the antennas.

Pre-processing included removal of horizontal banding, bandpass filtering, and trace data averaging (for processing methods and practices see Conyers, 2013; Goodman & Piro, 2013; Daniels, 2004; Jol, 2009; Uzi, 2017; Schmelzbach & Huber, 2015). The data was processed in Matlab®, using a file reader (Hansen, 2021) and a code written by the author.

In the final post-processing phase, the deconvolving pulse was a first derivative Gaussian pulse having a central frequency of 140 MHz. Deconvolution is like a band-attenuating (band-stop, notch) filter. In this case, applying deconvolution to the data provides a spectrum where the lower frequencies are attenuated, thus attenuating the system internal reverberation and at the same time producing an inverse Q filtering (wider bandwidth) (Jol, 2009). The resulting averaged spectrum centre is approximately 500 MHz, which is near the estimated centre transmit frequency of the antenna in the ground. Unfortunately, in this case the deconvolution also amplifies the noise in the higher frequencies.

Trace 478 measurement (which is at the 65 cm point in the profile) is shown in Fig. 1. Reflections are visible at 9 ns (pipe top) and at 12 ns (pipe bottom). The reflection around 25 ns is probably a radar ghost (double reflection). The velocity in the dry gravel can be estimated at 0.15 m/ns for this material (from Daniels, 2004, using the mid-value for dry sand). The first peak at 9 ns would correspond to a depth of 67 cm: top of the pipe. The road surface in the track is probably higher than at the roadside, so the measurement sounds realistic.

Velocity inside the pipe (in air) is 30 cm/ns. It would mean an additional 2 ns in the two-way radar trace. The next peak is at 12 ns (3 ns later) from the top of the pipe,

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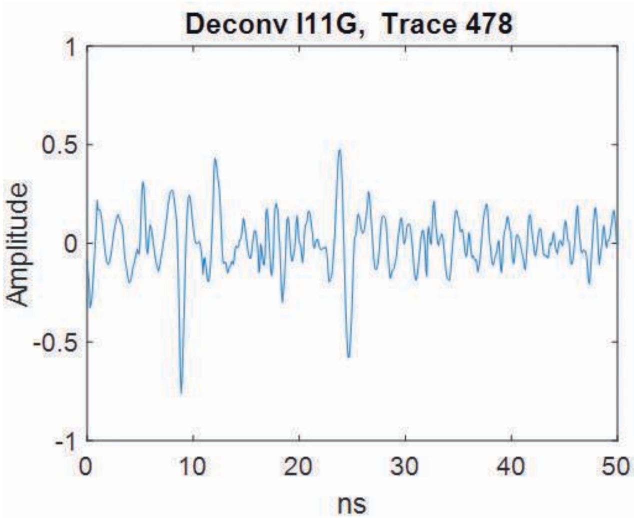

Figure 1: Culvert measurement after deconvolution, trace 478 which is at 0 m distance in Fig. 2. Reflections are at 9 ns and 12 ns. The reflection around 25 ns is probably a radar ghost (double reflection).

which is later than expected, but still sounds realistic. The pipe was dry, but the pipe material (strong plastic) could have affected the velocity.

Pipe resonance in the profile spectrum

A cavity or an object may cause a resonance, and thus a frequency selective reflection. Spacing between objects, like between an antenna and a manhole cover, or along a metallic object, can also cause a resonance. If the relative permittivity is known, the resonance may reveal the size of the target. Here the analysis of resonances is treated as an additional information to the radar profile in Fig. 2. The resonance seems to have potential to locate objects along the profile, although losing the depth information.

The spectrum of each trace is shown along the distance in Fig. 3. A stronger spectrum is visible between 0.5 m and 0.8 m. At some points, a 460 MHz frequency peak is visible, for example in trace 478 at the 0.65 m distance. It shows a strong resonant frequency at 460 MHz. Although there is a generally stronger spectrum in the pipe location between 0.5 m and 0.8 m, this peak stands out in some traces.

The pipe diameter is 30 cm, and the 460 MHz spectral peak corresponds to a diameter size of 33 cm of the air-filled culvert. There is also a weaker resonance at 560 MHz at around 0.75 m distance, which corresponds to a 27 cm-diameter in the air. Could it be that the pipe has become elliptical under the pressure of road gravel?

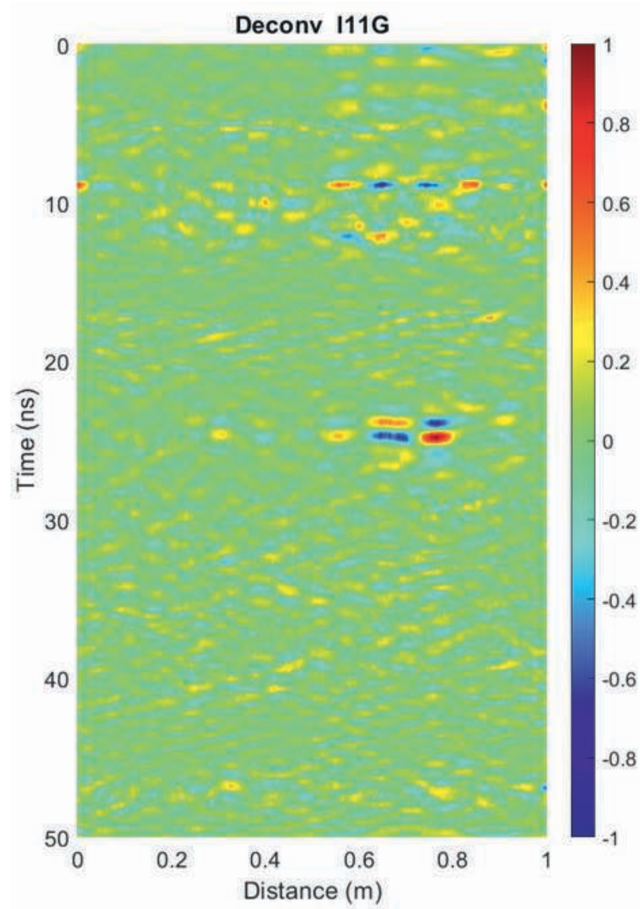

Figure 2: Measured profile over the pipe after deconvolution. The pipe is located between 0.5–0.8 m distance, between 9 and 12 ns. The reflections around 25 ns are interpreted as a secondary reflection (radar ghost). Trace 478 is at 0.65 m distance

Conclusion

The spectra of the traces along the profile reveal resonant frequencies in the area of the culvert pipe, after filtering the data so that strong basic frequencies are attenuated e.g. with deconvolution. As I see it, this spectral analysis can augment a traditional analysis of radargrams by implying the size and horizontal location of the objects.

This study also supports the claim that the Gopher antenna is usable in GPR: it has a wide spectrum, and relatively clean pulses are received from the target. Future research could include tests using various targets, antenna polarities and post-processing filters. Some simulations should be run. It is also expected that some objects would reveal spectral signatures further improving the analysis.

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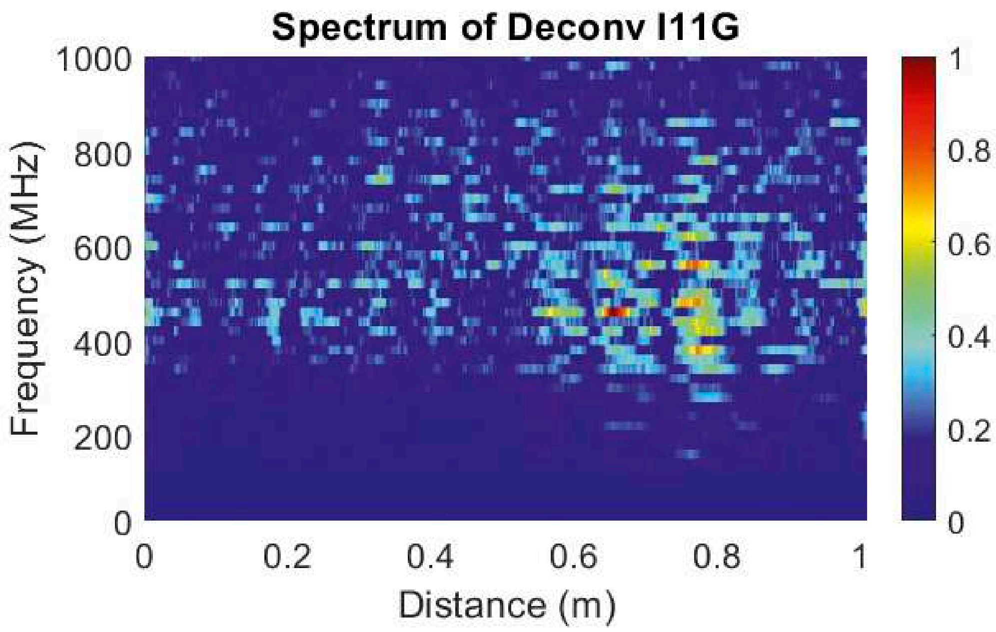

Figure 3: Spectrum of traces along a 1 m profile. The pipe is located between 0.5-0.8 m distance. Trace 478 is at 0.65 m distance.

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