

Short-Chirp Signal-based Ground Penetrating Radar System for Detecting Shallow-Depth Pipelines

Masaru Tsunasaki¹, Atsuo Senga², and Ichiro Sugimoto³

¹ Osaka Gas Co., Ltd., 5-11-61, Torishima, Konohana-ku, Osaka, 554-0051, Japan

² Nippon Signal Co., Ltd., 1-5-1 Marunouchi, Chiyoda-ku, Tokyo, 100-6513, Japan

³ Laboratory of Energy & Human Life Science Inc., 3-6-2, Asahigaoka, Ikeda-city, Osaka, 63-0022, Japan

Abstract— Since 1988, we have developed four types of impulse ground penetrating radar (GPR) systems for locating buried structures and utility pipes. The main aim of our GPR development has been improving GPR antennas in matching sizes and depths of detected buried objects. In this paper, we propose short-chirp signal processing and implement a short-chirp signal-based GPR system that performs side-lobe suppression against ground-reflected waves. The verification results indicate that the GPR system can scan from 0.2 to 1.8 m depth, which is better than our current impulse GPR system, and resolve a distance of 0.15 m between iron bars within reinforced concrete.

Index Terms— Short chirp signal, Ground penetrating radar, Pipe locating system.

1. Introduction

Since 1988, we have developed four types of impulse ground penetrating radar (GPR) systems for locating buried structures and utility pipes [1]-[4]. Until 2007, the main aim of our GPR development was improving GPR antennas in matching sizes and depths of detected objects [5]. In 2000, an adaptation of a short-chirp signal to a GPR system was proposed for detecting buried objects at over 3.0 m depth [6]. Within a scanning depth of 2.0–5.0 m, short chirp signal-based GPR (short-chirp GPR) systems have technological advantages compared to impulse GPR systems; however, in the scanning depth near the ground surface (e.g., <1.0 m), short-chirp GPR systems have their own technical problems, such as side-lobe interference and SN ratio degradation of the received signal.

In this paper, we propose a method of short-chirp signal processing that performs side-lobe suppression against the waves reflected from the ground surface; we also verify the specifications and performance of a short-chirp GPR system that has been implemented for detecting shallow-depth pipelines.

2. Short-Chirp Signal Processing

A chirp signal is a continuous wave that increases or decreases in frequency with time (FM chirp signal). A short-chirp signal is an intermittent continuous wave that limits the time span of signal length and the frequency span of sweep. A sample of a transmitted short-chirp signal is shown in Fig. 1(a) and that of the received self-correlation signal is shown in Fig. 1(b). The chirp-signal processing is shown in Fig. 2.

In detecting shallow-depth objects, a short-chirp GPR has two technical issues: one is side-lobe interference between the transmitted and received signals, and the other is SN-ratio degradation of the received signal. The chirp signal processing fixes the signal length at almost 15 ns and gradually decreases the amplitude of the envelope; these techniques address the side-lobe suppression against the waves reflected from the ground. The chirp-signal processing shortens the period of the transmitting cycle; this method improves the received signal power and its SN ratio.

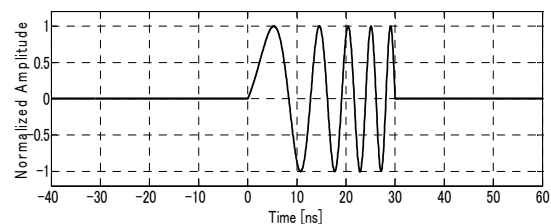


Fig. 1(a). Transmitted short-chirp signal

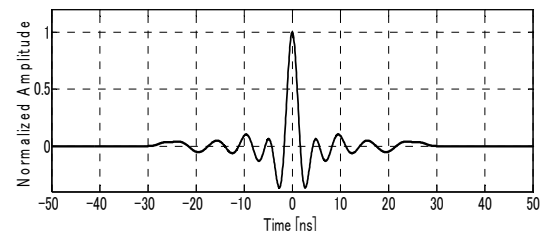


Fig. 1(b). Received self-correlation signal

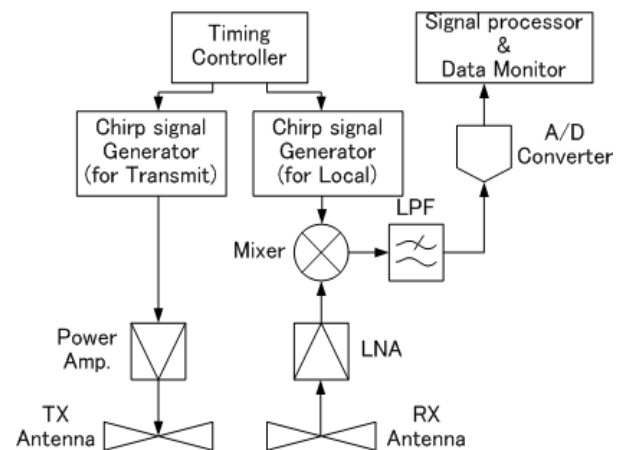


Fig. 2. Diagram of chirp-signal processing

3. Short-Chirp Signal-based GPR System

A prototype of a short-chirp GPR system has been implemented for gas piping work in an urban area whose pipelines are buried relatively shallow. The specifications and performance of the GPR system are detailed below.

(1) Specifications and Configuration

The primary specifications of the short-chirp GPR system are shown in Table I, and the configuration of the GPR system is displayed in Fig. 3. The dimensions are almost the same as and the weight is less than our current impulse GPR system, “Radar-mini,” which was developed in 2007 [2].

TABLE I
Specifications of the short-chirp GPR system

Item		Specification
Dimensions		470 mm × 610 mm × 870 mm
Weight		25 kg (approximately)
Operation time		2 h (on battery power)
Search time (Range)		0.2 ns × 256 points (0–51 ns)
Short-Chirp Signal	Chirp Sweep Frequency	70–850 MHz
	Signal Length	15 ns (approximately)
Antenna	Type	Bow-tie antenna with loading resistance, the same as Radar-mini
	Element width	190 mm



Fig. 3. Configuration of the short-chirp GPR system

(2) Verification Results

The performance tests of the GPR system were conducted on various test fields and compared to the performance of the Radar-mini. The verification results are as follows:

- Scanning depth: 0.2–1.8 m of buried pipeline, which is better than the Radar-mini (0.2–1.2 m).
- Resolution: 0.15 m horizontal distance between iron bars inside reinforced concrete.
- Subsurface cavity detection: 0.15 m thick cavity at 0.6 m depth detectable.

One of the depth-scanning results is shown in Fig. 4; this is the scanning output image (B-scope) of the GPR system with the cross-section of a test field made of sand and asphalt pavement.

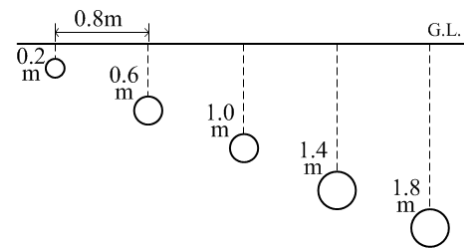
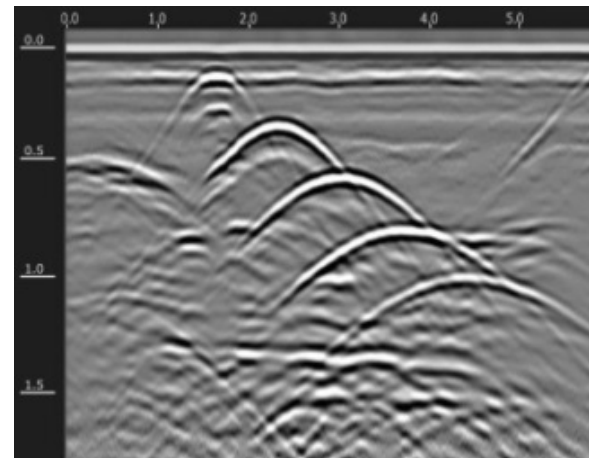


Fig. 4. B-scope output image (upper) and cross section of test field (lower)

4. Conclusion

For scanning shallow-depth objects in an urban area, the short-chirp signal processing introduces novel techniques that suppress the side lobes and improve the SN ratio of the received signals. A short-chirp signal-based GPR system that is of the same size and lighter than a previous device has been implemented. The performance tests of the GPR system have been executed in various test fields and compared to our current, impulse GPR system. The verification results indicate that at the scanning depth of near-ground-level areas, the scanning resolution and the subsurface cavity detection are the same as or better than those of our current, impulse GPR system.

References

- [1] I. Sugimoto, T. Kikuta, and M. Tsunasaki, “Compact Underground Radar System,” *Proceeding of IAPR Workshop on Computer Vision*, pp.361–364, Oct. 12–14, Tokyo, 1988.
- [2] Osaka Gas Engineering Co., Ltd, New Release “Radar-mini,” (in Japanese). URL:http://www.oge.co.jp/gas_supply_technology/miniradar/point/#abNav, (Access on February 12, 2016)
- [3] T. Nakauchi, “Pipe detection GPR developed by Osaka Gas,” *Abstract of Japan Geoscience Union Meeting*, Q227–003, Makuhari, 2007.
- [4] T. Nakauchi, M. Tsunasaki, et al, “Development of a Small GPR for Narrow Space,” *Proceeding of RAEG 2004*, Kyoto, 2004.
- [5] M. Tsunasaki, “The ability which can investigate the present GPR is measured,” *Proceeding of SEGJ Conference*, Kochi, Japan, Oct. 2013, (in Japanese).
- [6] Y. Tomizawa, M. Hirose, I. Arai, and K. Tanabe, “A Novel Subsurface Radar using a Short Chirp Signal to expand the detection range,” *IEICE Transaction, Communication*, Vol. E83-B, No.10 October 2000