Switching Characteristics of Single-borehole Monostatic Radar System for Adjacent Tunnel Detection

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Abstract

Switching characteristics of single-borehole monostatic radar system are investigated here for adjacent tunnel detection. The optimum switching time and minimum detectable distance are determined according to the switching time and wave propagation speed.

Keywords : Monostatic Borehole radar Switch

1. Introduction

In the previous work [1], a cross-borehole bistatic radar system was developed to detect underground cavities in the depth of hundreds meters. Since drilling a deep borehole is costly and time consuming, single-borehole bistatic radars have been widely used as a detour. Both TX and RX antennas put into the same borehole and measure the reflected signal from underground target. On the other hand, single-borehole monostatic radar can use only one antenna. The transmitter and receiver are integrated in the same antenna without any optical fiber connection [2],[3]. The separation between the TX and RX signal is generally implemented using circulator or switch for isolation of received signal from direct and ringing signals. A switch is located at the next stage of the circulator in RX path. We exam the switching characteristics of single-borehole monostatic radar to detect tunnel relatively close to the borehole according to the variation of switching time. The absorptive type GaAs transistor switch is used with its switching speed of 25 ns. We change switching time in the range of 80 ns with 10 ns step.

2. Experimental Description

2.1 Monostatic Radar System

A single-borehole monostatic radar transmits pulse signal that is synthesized by field-programmable gate array (FPGA). The pulse signal transmits through TX input port to common port of the circulator. The common port is used for not only TX output port but also RX input port. The TX output signal is radiated by the antenna and reflected back to the same antenna. The reflected signal is put into the common port and passes to the receiver block. The receiver block of the monostatic radar should amplify the weak and noisy received signal up to the level sufficient enough to be sampled by ADC with minimum noise. Figure 1 depicts the block diagram of single-borehole monostatic radar. The block diagram is quite similar in comparison with previous work in [4]. We used the same amplifier as used in [4] except its frontend consisting of active circulator and switch. To achieve the performance for our single-borehole monostatic radar system, the circulator should be accomplished to have frequency bandwidth from 20 MHz to 200 MHz. A ferrite circulator, which is the most popular, is highly dependent on electrical length and operates very shallow frequency bandwidth. To fulfil this frequency bandwidth, we adopt active circulator using operational amplifier [5]. Switch device can suppress the direct and ringing signals which are relatively large amplitude signal in comparison with wanted target signal. The direct signal can occur at the common path which is shared with TX and RX path. The ringing signal, which may occur due to the impedance mismatch between the antenna and background medium, can be suppressed by the switch. The switch devices typically have characteristics that the lower insertion loss involves the higher OIP3/P1dB and the longer switching speed. The specification of switching speed has two considerations as rise/fall time and on/off time. The rise/fall time means the time interval of the RF signal rising from 10% to 90% of its maximum. The on/off time means the delay between applying the digital input with 50% and turning RF output on/off. In our case, we realized that the rise/fall time is participated more in our system. The switch should be selected to consider switching speed and time. In the previous work, the dielectric constant and the conductivity of underground rock samples were measured simultaneously using the open ended probe method [6]. The traveling time of the electromagnetic pulse may be calculated by employing the measured dielectric constant. When an empty tunnel is locate at 5 m apart from the borehole, its turnaround time is about 85 ns under the condition that an average dielectric constant of underground rock is 6.5. We select the switch device which has sufficiently fast switching speed 8 ns of rise/fall time and 20 ns of on/off time. Table 1 represents the specification of switch which is used in this paper [7].

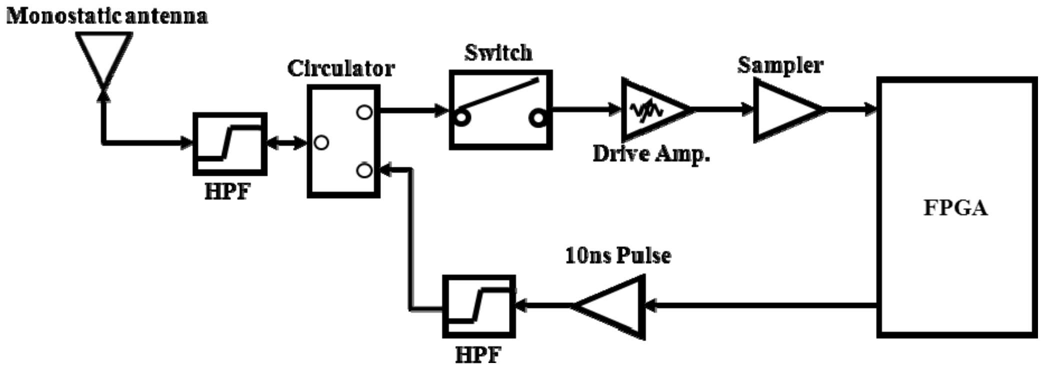


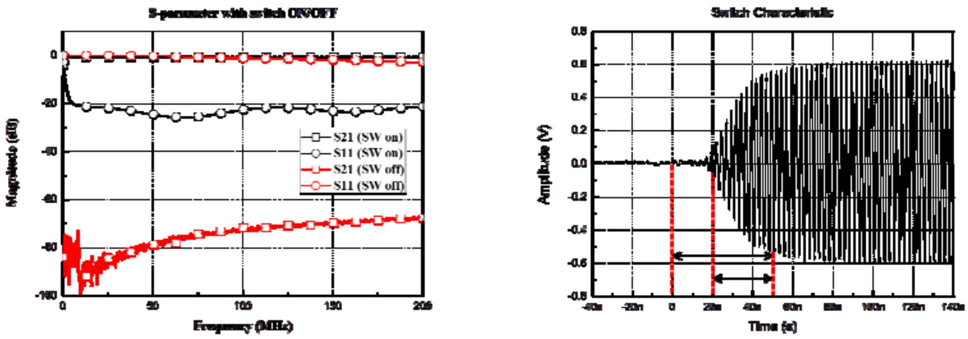
Figure 1: Briefly Block Diagram of Single-Borehole Monostatic Radar

Table 1: The Specification of the Switch Device [7]

Parameter		Minimum	Typical	Maximum
Insertion Loss			1.2 dB	1.6 dB
OIP3		37 dBm	42 dBm	
P1dB		20 dBm	25 dBm	
Switching Speed	rise/fall time		8 ns	
	on/off time		20 ns	

2.2 Switch Characteristics

In practice, we need to measure the characteristics of the switch devices because the specification is guaranteed by design, not subject to production test. Furthermore, measurement situation cannot agree with the setup of datasheet. Figure 2 (a) shows the frequency response in S-parameter in cases of the switch on/off states, respectively. We use VNA (vector network analyser) to measure. The horizontal and vertical axes represent frequency in MHz and magnitude in dB scale, respectively. When the switch is on state, the insertion loss (S21) and return loss (S11) of the switch device are under 1 dB and under 20 dB, respectively. Therefore the switch device is well matched at 50 Ohm system. The isolation level of the device is under -65 dB in whole frequency range, when the switch is off state. Figure 2 (b) depicts switching time of the switch device when its states is changed. We use oscilloscope and signal generator for measurement. The horizontal and vertical axes represent time in seconds and amplitude in volts, respectively. The zero time means 50% amplitude of the control signal when it changes the state from low to high. We configure on time and rise time approximately in this measurement results. Because of input and output time constants of the switch, the measurement results are slightly different from the specification of datasheet provided by the manufacturer. The switch has about 50 ns on time and 30 ns rise time in this case.

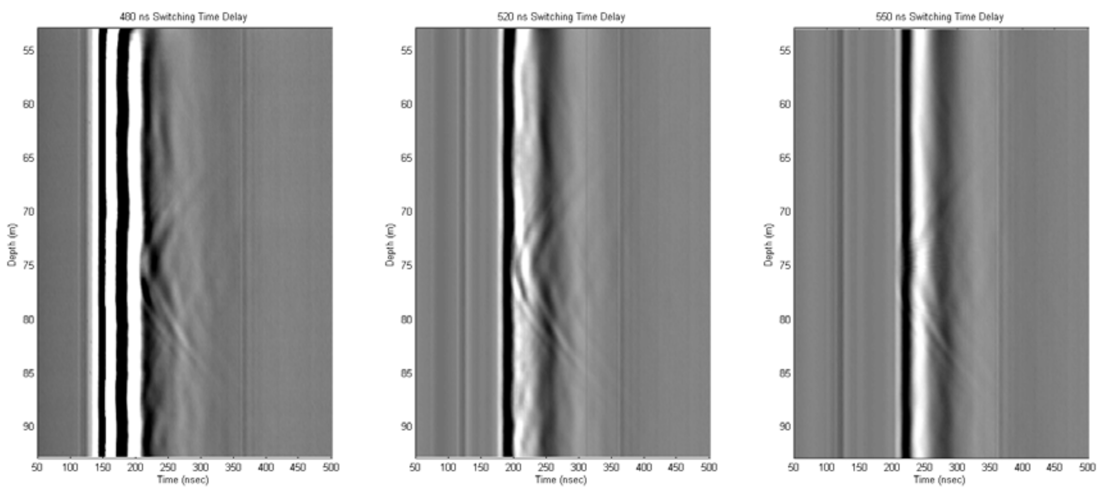


(a) S-parameter with Switch ON/OFF State (b) Switching Speed

Figure 2: Frequency and Time Response of the Switch Device

2.3 Experiments

The above switch is included in our single-borehole monostatic radar, and then field experiments are performed at a well-suited tunnel test site in South Korea. The empty dormant tunnel is about 2 m in diameter and in 73 m depth. And the distance between the tunnel and the empty borehole is about 4 m distance. Figure 4 (a), (b) and (c) represent the experimental results in raw data with various switching time of 480 ns, 520 ns, 550 ns, respectively. Control signal of the switching time can be adjusted with 10 ns step. The horizontal axis is the time in nano-second scale and the vertical axis is depth in meter. The parabolic pattern as one of clear symptoms of an empty tunnel appears in the region about 65 m to 85 m. In front of the parabolic pattern of Figure 4(a), relatively strong pattern, which is direct and ringing signal in the region of switch on, shows all range of depth. This strong signal makes low noise amplifier of the receiver block saturation and distortion. In Figure 4 (b) and (c), similar strong signal pattern is shown and delayed by switching control signal since the direct and ringing signal is not shown like Figure 4 (a) anymore. This strong common signal is the switching noise which is one of the fundamental noises in switching mechanism. In Figure 4 (c), one may find that the frontend of the parabolic pattern disappears due to the switching noise. In contrast, Figure 4 (b) illustrates the parabolic pattern clearly. It implies that the switching noise and parabolic signal can be divided in time.



(a) 480 ns switching time (b) 520 ns switching time (c) 550 ns switching time

Figure 4: Experimental Results

Figure 5 shows the waveform at 75 m in case of 520 ns switching time. The time gap between the switching noise and the target signal is about 30 ns which is well agree with the previous measurement of rise time. Then we can calculate minimum traveling distance of 3.53 m in same manner. The result renders it possible to detect an empty tunnel apart from the borehole at least 1.8 m.

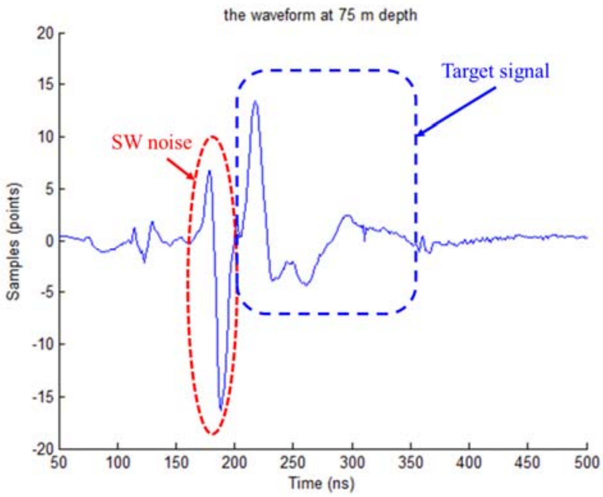


Figure 5: The Waveform at 75 m Depth for 520 ns Switching Time

3. Conclusions

A single-borehole monostatic radar system was constructed and experimented in a well suited tunnel test site. The characteristics of the switch device were measured by authorized equipment. According to the variation switching time, the tunnel signature can appear or disappear due to the overlap of the direct and ringing signal. This result may lead us to conclude that for optimal design of a single-borehole monostatic radar system, the rise time and switching delay of an employed switch should be adjust properly.

References

[1] S.W. Kim, S.Y. Hyun, J.H. Lee, S.Y. Lee, J.H. Cho, K.T. Oh, S.Y. Kim, “The development of a pulse borehole radar system for underground cavity detection”, Technical report of IEICE SANE, Vol. 107, No. 277, pp. 93-97, 2007.

[2] I. M. Mason, J. H. Cloete, W. van Brakel, and J. E. Hargreaves, “Electromagnetic reverberation at VHF on wires in uncased water-filled boreholes,” Electron. Lett., vol. 42, no. 5, pp. 306–307, Mar. 2006.

[3] I.M.Mason, A. J. Bray, T.G. Sindle, C. M. Simmat, and J.H. Cloete, “The effects of conduction on VHF radar images shot in water-filled boreholes,” IEEE Geosci. Remote Sens. Lett., vol. 5, no. 2, pp. 304–307, Apr. 2008.

[4] J.H. Cho, S.Y. Hyun, S.Y. Kim, J.G. Yook, “Fabrication and distortion analysis of variable gain amplifier for borehole radar receiver”, 2007 Autumn Microwave & Radio Wave Conference, Korea, 2007.

[5] C. Wenzel, “Low frequency circulator/isolator uses no ferrite or magnet,” RF Design, pp. 39-41, Jul. 1991.

[6] J.H. Jung and S.Y. Kim, “Measured dielectric properties of borehole cores using an open-ended coaxial probe,” Technical report of IEICE SANE, vol.107, no. 277, pp. 99-102, Oct. 2007.

[7] Available: https://www.hittite.com/content/documents/data_sheet/hmc349ms8g.pdf.

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