Design Pulse Source for TDR System with Large Deformation Distributed Measurement

DaWei Guo\textsuperscript{1, \ast}, RenYuan Tong\textsuperscript{2, b} and Qing Li\textsuperscript{2}

\textsuperscript{1}China Jiliang University, Hangzhou, China
\textsuperscript{2}China Jiliang University, Hangzhou, China

\ast Corresponding author e-mail: lq13306532957@163.com, \textsuperscript{a}271963372@qq.com, \textsuperscript{b}tongrenyuan@126.com

Abstract. Distributed measurement of rock-soil deformation is one of the important technologies for geological disaster monitoring. TDR combined with helical sensing cable enables large deformation distributed measurement. A TDR system for distributed measurement of large deformation combines narrow pulse generator circuit, helical sensing cable, reflected wave processing and sampling circuit. The current work mainly includes the design of narrow pulse generation circuit based on avalanche transistor and step recovery diode. The suitable parameters of the components are given, and the nanosecond pulse with larger amplitude, faster falling edge and rising edge is obtained.

1. Introduction

In recent years, with the rapid development of China's economy and the coverage of high-speed transportation networks, a large number of engineering slopes will be produced. In addition to the naturally occurring slopes, slopes caused by human engineering operations can also pose potential hazards for landslides.

Geological disaster are accompanied by different degrees of rock-soil deformation. Monitoring rock-soil deformation is an important way to understand and study geological disasters. The use of large-stretch and bendable helical sensing cables as sensors to achieve large deformation distributed measurement. During the landslide monitoring, the monitoring system transmits a pulse signal to the helical sensing cable embedded in the monitoring hole. When the soil or rock squeezing helical sensing cable [1], the pulse signal will be reflected at the deformation point. By sampling and analyzing reflected signals, positioning deformation points and slip amount [2].

The pulse generation circuit [3-6] of the time domain reflection system is one of the key points. The pulse performance is reflected in the pulse width, rise time, amplitude. Reasonable pulse width, rise time, amplitude, which is conducive to improve the resolution of the reflected wave.

2. Principle Of TDR

The principle of time domain reflection is quantitatively described by the reflection coefficient, the characteristic impedance is obtained by the reflected voltage, and the stretch deformation is obtained by the characteristic impedance. The position at which the impedance changes can be located by the transmission time and the transmission speed of signal.
\[ Z = Z_0 \frac{1 + \rho}{1 - \rho} = Z_0 \frac{V_{\text{incident}} + V_{\text{reflected}}}{V_{\text{incident}} - V_{\text{reflected}}} = Z_0 \frac{V_{\text{measured}}}{2V_{\text{incident}} - V_{\text{measured}}} = f(V) \]  

(1)

\[ Z = \frac{(R + j\omega L)}{(G + j\omega C)} \approx \frac{L}{C} = f(s) \]  

(2)

\[ L = \frac{v \cdot T}{2} \]  

(3)

\( Z \) is the characteristic impedance, \( \rho \) is the reflection coefficient; \( Z_0 \) is 50\( \Omega \); \( V_{\text{measured}} \) is the measured voltage value; \( V_{\text{incident}} \) is the voltage value of the incident signal; \( V_{\text{reflected}} \) is the voltage value of the reflected signal.

3. Helical Sensing Cable

The structure of helical sensing cable is shown in Figure 1, which is mainly composed of a central silica gel strip, a parallel copper wire of a silica gel outer skin, and an outermost silica gel protective cover. Since the silica gel material itself has an elasticity, and then the copper wire is spirally wrapped around the center silica gel strip, the helical sensing cable has a large stretchable property.

4. Narrow Pulse Generation Circuit

The length of helical sensing cable used in the experiment is 6.6m. Since the pulse emission and reflection are on the same cable, for making the reflected wave easy to observe, the pulse width of the transmitted pulse should be as small as possible, but the peak-to-peak value of the pulse should not be too small. Therefore, the avalanche transistor and the step recovery diode are used to achieve the narrow pulse generating circuit. Using the FPGA to generate a square wave trigger signal to the narrow pulse generation circuit. The front stage uses the avalanche transistor to generate a large amplitude negative pulse, and the latter step recovery diode accelerates to further narrow the negative pulse.

The avalanche transistor [3-4] working area includes saturated zone, linear zone, cut-off zone, and avalanche zone. When the base current \( IB > 0 \) of NPN transistor, the base junction is biased, which is...
saturated or linear zone. When the base current IB < 0, the base junction reverse bias, as the cut-off zone. Increasing the collector voltage UCE, when the collector current IC changes sharply with UCE and IB, it enters the avalanche zone. In the avalanche zone, the collector voltage is high, and the carriers of collector are accelerated by strong electric field, which results in new electron-hole pairs colliding with the nearby lattice, and the new electrons and holes are accelerated by strong electric field, respectively, and the above process is repeated. The junction current then grows rapidly like "avalanche" type. Therefore, avalanche effect can be used to generate high voltage and narrow pulse. The pulse width is from ns to μs.

The step recovery diode [5-6] stores a large amount of electric charge during forward conduction. And when the diode is reverse biased, the stored charge returns to form a reverse current until the charge is depleted, the reverse current rapidly decreases, and immediately returns to the reverse cut-off state, forming the "step" characteristic of current jump.

5. Experimental Results
The avalanche transistors Q1 and Q2 selected in the experiment are 2N2222A, Vceo=40V, Vcbo=75V, ft=300 MHz. The step recovery diode D1 is mp4023, reverse voltage = 20V, reverse recovery time = 50ps. C1=10nf, C2=10uf/100v, C3=470pf, C4=C5=C6=100pf, R1=R2=R3=51kΩ, R4=2kΩ, R5=100Ω, R6=10kΩ, R7=47Ω, Vcc1=40V, Vcc2=5V, the trigger signal is 3.3V, 10Khz, 50% duty cycle square wave.

The trigger signal passes through the avalanche transistor at first. The avalanche transistor circuit output pulse Vpp=13.8V, negative pulse width=46ns, as shown in Figure 3. The step recovery diode circuit output pulse Vpp=7.76V, negative pulse width=10ns, as shown in Figure 4. And then the pulse output at this time is connected to the helical sensing cable, as shown in Figure 5, the pulse will have a certain attenuation through the helical sensing cable, and the effective waveform range of the transmitted wave and the reflected wave is 400ns.
Figure 3. Avalanche transistor circuit.

Figure 4. Step recovery diode circuit

Figure 5. Waveform after a narrow pulse. Passes through the helical sensing cable

Tensile positioning data obtained through the laboratory’s existing stretching device and oscilloscope is following.

Table 1. Tensile positioning data.

| Stretching position/cm | Positioning result/cm | Positioning relative error/% |
|------------------------|-----------------------|-----------------------------|
| 34                     | 35.29                 | 3.79                        |
| 77.8                   | 79.40                 | 2.06                        |
| 121.4                  | 123.51                | 1.74                        |
| 164.9                  | 167.63                | 1.66                        |
| 211.3                  | 211.73                | 0.20                        |
| 253.8                  | 255.85                | 0.81                        |
| 303.3                  | 299.96                | -1.10                       |
| 349.8                  | 344.07                | -1.64                       |
| 394.2                  | 388.18                | -1.53                       |
| 439.2                  | 432.30                | -1.57                       |
| 485.7                  | 485.23                | -0.10                       |
| 532.3                  | 529.34                | -0.56                       |
| 579.5                  | 573.45                | -1.04                       |
| 626.5                  | 625.39                | -0.17                       |
6. Conclusion
The design of the pulse source is realized. The waveform which is presented after the pulse is connected to the helical sensing cable can clearly distinguish the transmitted wave and the reflected wave. Next, we will continue to perform echo processing on the waveform on the helical sensing cable, including limiting circuit, amplifying circuit, to achieve equivalent sampling, and to analyze and process the sampled data to obtain the relationship between voltage and tensile amount.

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