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Wen-Cheih Liu [a] & Mao-Hong Lu [a]
[a] Institute of Electro-Optical Engineering National Chiao Tung University 1001 Ta-Hsueh Road Hsinchu 30050 Taiwan
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Locating faults on cables by applying the principle of the transmission line oscillator

WEN-CHIEH LIU† and MAO-HONG LU*†

A new method for locating the break point of a cable has been developed. It operates by application of the principle of the transmission line oscillator. Coaxial cables of four different lengths (1.5 m, 5 m, 10 m, 20 m) were measured in accordance with this method. The results show high precision (deviation <0.5 cm) and accuracy (error ≤ 3 cm).

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1. Introduction

In the past, there were two methods for locating a cable's break point. One was the pulse-echo technique based on the time-domain reflectometry principle (Leo *et al.* 1990); the other was the frequency scanning method (Leung and Lam 1993). The former applies a narrow pulse to a faulty cable and measures the time delay of the pulse received from the break point on the cable. The time delay is used to estimate the location of the break point. Highly accurate measurements are possible only when using a high-resolution circuit for the time interval measurement, one therefore needs a complicated circuit. The latter method employs signals of different frequencies to scan a faulty cable so that the break point can be located. Using this method, one must equip one's system with sophisticated instruments such as a frequency synthesizer, sweep generator and oscilloscope or frequency analyser.

Use in the field requires accuracy, ease of use and portability of a cable-test system. Its electronic circuit(s) must be simple. The two methods mentioned above are complicated and unsuitable. In this paper, we will present a new method: the pulse-reflection-oscillation (PRO) method, which operates by application of the principle of the transmission line oscillator. We will demonstrate the design, the prototype, and the experimental results.

2. System and principle

Figure 1 shows a time-delay oscillator. One can employ a common transmission line as the delay line of this oscillator. This method was used for measuring the propagation delay of optical fibres (Johnson and Ulrich 1978, Michael 1987) and proved very accurate. In figure 1, 'Start' is the triggering pulse, 'Loop 1' is the closed-loop oscillation loop. The length of the transmission line can be calculated from the oscillation period. If one adds an amplifier and a passing circuit to detect the pulse reflected from the break point, one can construct a pulse-reflection

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*Corresponding author. e-mail: mhlu@cc.nctu.edu.tw
†Institute of Electro-Optical Engineering, National Chiao Tung University, 1001 Ta-Hsueh Road, Hsinchu 30050, Taiwan.

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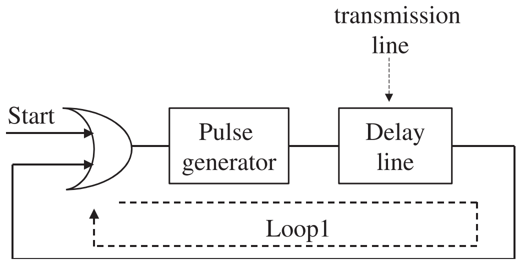

Figure 1. Time delay oscillator.

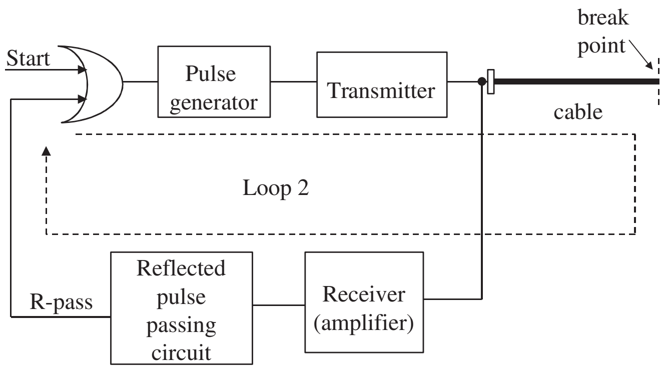

Figure 2. Pulse reflection oscillator.

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oscillator (figure 2). 'Loop 2' is the oscillation loop. The break point is located by measuring the oscillation period.

Figure 3 is the schematic of the cable-break-point locating system we designed, based on the PRO method. When the start pulse is triggered, the pulse generator generates a narrow pulse of 10 ns. The transmitter (made by MC10116) sends the pulse to the reference cable. Both the emitted pulse and the reflected pulse from the break point pass through the receiver (also made by MC10116), which amplifies the reflected pulse to an ECL level. The passing circuit permits only the reflected pulse to pass and generates an R-pass pulse signal of 20 ns to trigger the pulse generator. The ECL/TTL converter converts the ECL signals into TTL signals to allow the frequency counter to function. The computer, through its I/O interface, reads the data from the frequency counter and calculates the location of the break point. Figure 4 is the passing circuit for the reflected pulse. It comprises a 2-bit shift register (made with two D-type flip-flops) and a delay circuit of 20 ns. It blocks the T-pulse and transmits the next R-pulse. The pulse width of the R-pulse is converted to 20 ns.

At the end of the transmitter output ('Connector 1') we attached a short reference cable made of the same material as the faulty cable (figure 3). Doing so allows the system to maintain oscillation even when it is not applied to a faulty cable. The oscillation period T is decided by

$$\begin{aligned} T &= T_{\mathrm{ref}} + T_{\mathrm{cab}} \\ &= T_{\mathrm{ref}} + 2L/V_{\mathrm{p}} \end{aligned} \quad (1)$$

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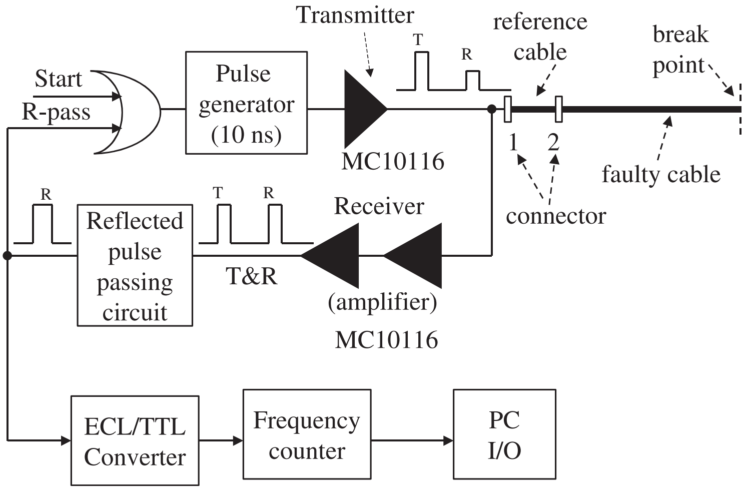

Figure 3. Schematic of the cable break locating system.

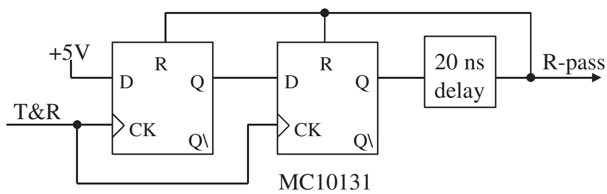

Figure 4. Reflected pulse passing circuit.

where T_{ref} is the oscillation period when the system is not applied to any faulty cable. Its value is the sum of the propagation delay due to the circuit components and the propagation delay due to the reference cable. L is the length of the faulty cable; V_p is the pulse propagation velocity in the cable. The propagation delay of the faulty cable, T_{cab}, can be obtained from $T - T_{ref}$.

3. Experiment and results

We took CATV 75 coaxial cable (RG-6/U type) of four nominal lengths (1.5 m, 5 m, 10 m, 20 m) to serve as the faulty cables. At room temperature of 25°C, the system was warmed up for 30 minutes and then subjected to measurement. We first attached one end of the 5 m reference cable to the transmitter output. The other end was left open. It is worth remarking here that with an attached reference cable of length less than 2 m the system would be unable to oscillate. We measured the reference oscillation period, T_{ref}, taking 50 samplings with a frequency-counting duration of one second and a sampling-to-sampling interval of 30 seconds. We then attached one end of each of the four 'faulty' cables to 'Connector 2' (figure 3). The other end was left open. The oscillation period T was measured in the same way as with the reference cable. The data was stored in a computer. After measuring each faulty cable one by one, the computer calculates the averaged value and the standard deviation so that the statistical properties of the system—such as precision and accuracy—can be understood. For each faulty cable, the averaged propagation

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delay, $T - T_{ref}$, can be used to estimate the real length of the cable. Considering the 1.5 m length of faulty cable, we first calculate the pulse propagation velocity in the cable

$$V_p = 2 \times \frac{1.5}{T - T_{ref}}$$

Then, from the equation

$$L = (T - T_{ref}) \times \frac{V_p}{2},$$

we can obtain the calculated length of any of the other three faulty cables. The error of measurement for each faulty cable can be obtained by comparing the calculated value with the true value obtained by another professional length-measurement laboratory.

Table 1 shows the results of measurement. From the table, it is seen that our PRO method offers a maximum standard deviation of 16.5 ps (associated with the measurement of the 10 m length of faulty cable). Our system is precise. The table also shows that our method offers a maximum error of 3 cm (associated with the measurement of the 20 m length of faulty cable). Our system is accurate. Figure 5 shows the deviation variation for the measurement of the oscillation period of the four faulty cables. The abscissa is the sequential order of measurement; the ordinate is the deviation. The maximum deviation is 0.5 cm (associated with the measurement of the 10 m length of faulty cable). All data indicates that ours is a highly precise system.

Coaxial cable length (m)	True length (cm)	Average oscillation period (ns)	Standard deviation (ps)	Average propagation delay (ns)	Calculated cable length (cm)	Measured error (cm)
0	0	79.477	7.2	0	0	0
1.5	149.5	91.721	2.2	12.444	149.5	0
5	497.5	120.359	12.7	40.882	499.2	1.7
10	1016.0	162.568	16.5	83.091	1014.5	−1.5
20	1996.5	243.240	6.1	163.763	1999.5	3

Table 1. Measurement results for different cable lengths.

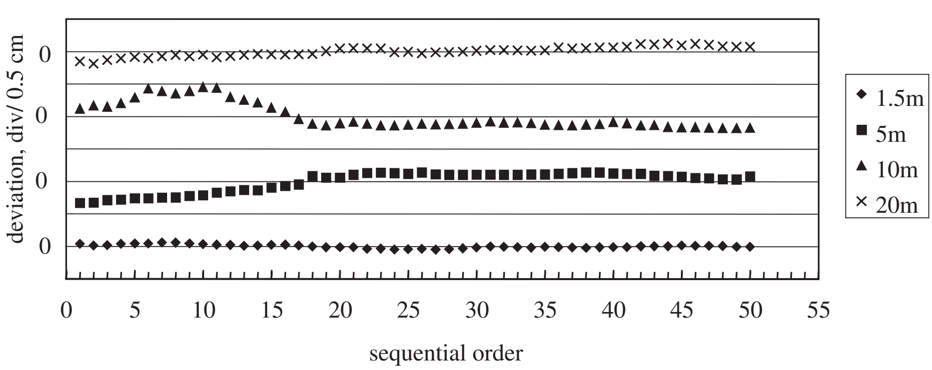

Figure 5. Deviation variation of the four faulty cables.

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4. Discussion

In this paper, we focus on our PRO method. To verify the feasibility of the method, a prototype system was designed, constructed and tested. The prototype has proven to be highly accurate as well as highly precise. Some related details have not been taken into account. We would like to point out these potential problems here so that the system can be improved in the future.

In detecting the reflected pulse, we did not adjust the threshold level. Rather, we used a triple differential line receiver (MC10116) to amplify the reflected pulse to an ECL level. Because faulty cables of different lengths provide reflected pulses of different amplitudes, the propagation delay of an amplifier in measuring a long cable is different from that in measuring a short one. This could cause error.

In the design of the oscillation circuit, we use the ECL 10K logic family. This results in the limitation of the pulse width by the bandwidth of the ECL gates and the limitation of the amplitude of the emitting pulse by the voltage of the ECL level. In this situation, the resolution and the maximum measurable length of our system are limited.

The reference cable, the faulty cable and the cable connectors are purchased from wherever they are available. In connecting the cables, the impedance between any two of these cables and connectors might not be matched. Therefore, unexpected bi-directional reflections might occur at some connection points. This could reduce the signal-to-noise ratio of the system.

The deviation of the drift due to faulty cables of different lengths (figure 5) requires further investigation in the future.

5. Conclusion

In our experiment, the circuit was constructed on a universal printed circuit board. The noise suppression and circuit layout were not taken into account. Even so, the system performs at a high level. The maximum deviation of measurement of only 0.5 cm demonstrates that our system is highly precise; the maximum error of measurement of only 3 cm demonstrates that our system is highly accurate. We have developed a precise, accurate cable break point locating system. Its simple circuit promises practical in-field application.

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