FAULT POINT LOCALIZATION OF POWER FEEDING LINES IN OPTICAL SUBMARINE CABLES USING ELECTRIC TIME DOMAIN REFLECTOMETRY AND FREQUENCY DOMAIN REFLECTOMETRY

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Abstract: As techniques for locating faults in the power feeding line of an optical submarine cable, an electric time domain reflector, and an AC impedance measurement are discussed. The authors ascertained the location of faults in the cable using these two methods. The actual fault was directly located by human divers using an AC magnetic field detection method. Comparison of both results confirmed the validity of the electrical fault localization method. The frequency dependency of the phase velocity of the armored cable was obtained based on the measurement results for the frequency response of the cable's input impedance.

1. INTRODUCTION

The majority of submarine cable failures occur due to short-circuiting of the power feeding lines in the seawater. The location of failures can be measured with high accuracy using an optical time domain reflector (OTDR) when an optical fiber is broken. However, when optical fibers are unbroken and the power feeding line fails, the fault can only be located from the landing stations using electric time domain reflectometry (TDR) or DC resistance measurement. In TDR, the round travel time of an electric pulse is measured. However, as frequency dispersion and loss of propagation are considerable, it is not easy to identify accurately the exact location of the fault. An accurate electrical fault point localization method is desirable to facilitate repair work, but such a method has not yet been established.

Recently, the authors had the opportunity to measure the location of an actual submarine cable failure in detail using TDR and AC impedance measurement (FDR: Frequency Domain Reflectometry). In this case, two submarine cables 60 km in length were laid in parallel but one of them was subject to a shunt fault.

A clear reflection from the fault point was measured using TDR. The authors also gathered a large volume of data on a variety of parameters. In the frequency domain measurements, resonances of input impedance were measured. Using the resonance frequency and the actual length of the cable, the frequency dependence of the phase velocity of the single armoured cable was calculated. In this paper, the authors describe more discussion about TDR based on the reference [3].

2. TARGET CABLE SYSTEM

Figure 1 shows the configuration of the submarine cable system. Two submarine cables (East Cable and West Cable) are laid in parallel, and the East Cable has a shunt fault between the landing station and the repeater. The end of the cable is terminated by the end caps, and the power line is electrically isolated from the seawater.

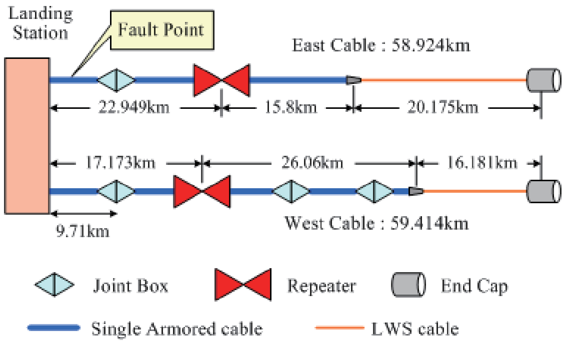

Figure 1: Configuration of the target cable system[3]

3. TIME DOMAIN MEAUREMENT

3.1 Measuring method

Figure 2 shows a block diagram of the TDR measurement. It consists of a function generator, a digital oscilloscope, a hybrid circuit, and a PC. The reflected signal is captured by the digital oscilloscope and waveforms are recorded in the PC. Because reflection signals are small due to the attenuation of the cable, the waveforms are averaged 256 times in order to improve the signal-to-noise ratio. The hybrid circuit separates the drive signal generated by the function generator and the reflected signal from the cable. We use two types of signals: step signals and a single sinusoidal pulse.

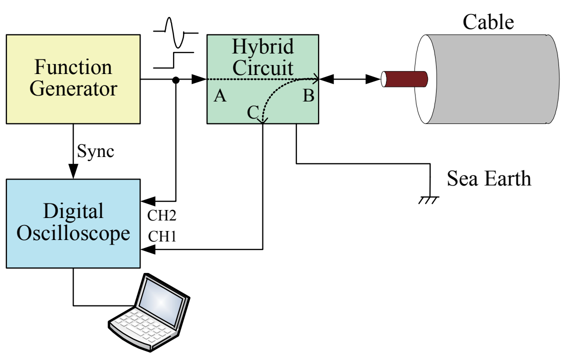

Figure 2: Block diagram of TDR[3]

3.2 Results of TDR using square pulse

Figure 3 and 4 show the measurement results of the pulse echo for the West and East Cables shown in Figure 1. Both are subject to the same measurement conditions. In these figures, the CH1 waveform is the reflection signal and the CH2 waveform is the drive signal from the function generator. We use a square wave for the drive signal when conducting these measurements as shown in the figures.

As shown in Figure 3, no marked reflection is seen because there are no problems affecting the West Cable. One division of the time scale of this figure corresponds to 7 km when the electric pulse velocity is assumed to be $1.4x10^8$m/s[1]. Therefore, this figure may cover a range of about 63 km. The reflection from the cable end is not observed in this figure though the total length of the cable is 50 km. This is because the speed of the LWS cable is slower than that of the SAM cable or the pulse speed is less than $1.4x10^8$m/s.

On the other hand, in the East Cable, a shunt-fault waveform can be seen in Figure 4. The time-scale of this figure is 10 μS/div. The position of the shunt-fault was found to be located 68 microseconds away from the landing station as shown in this figure. It is necessary to know the actual propagation velocity to convert this propagation time into actual distance.

In a transmission line subject to loss, such as the power feeding line of the optical submarine cables, the propagation speed varies as a function of frequency [1]. For example, the group velocity of the LW cable is about $7x10^7$m/s for a frequency of 10 kHz. Therefore, in the case of a step waveform, it is difficult to determine the most appropriate pulse velocity.

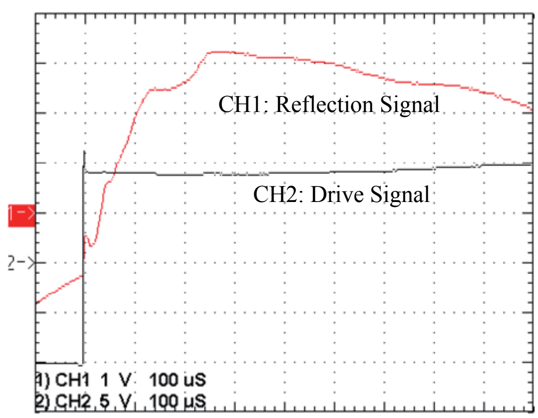

Figure 3: Result of TDR of the West Cable using a square wave

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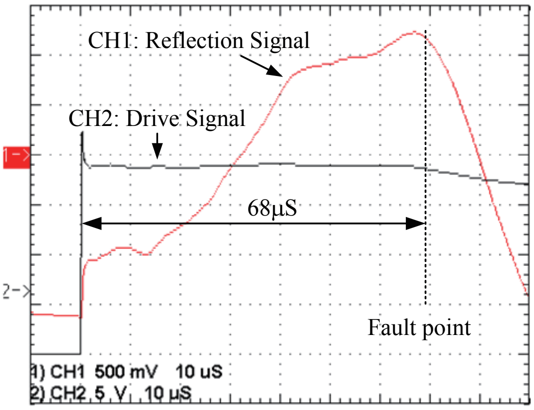

Figure 4: Result of TDR of the East Cable using a square wave

3,3 Results of TDR using sinusoidal pulse

Figures 5 to 8 show some results of the electric time-domain reflectometry using a one-cycle sinusoidal pulse as the input signal.

Figure 5 shows the measurement result for the West Cable. In this measurement, the pulse width of the input signal is 500 µS (2 kHz). In this figure, a small reflection can be seen at the position of about 1.17 milliseconds. This seems to be a reflection from the cable end judging from the polarity of the signal and the round-trip time for the cable length of 59.414 km.

Figure 6 to 8 are the measurement results of the East Cable showing what occurs when the pulse width of the drive signal is changed. A clear reflection from the shunt fault position can be seen in these figures, because the polarity of the reflection signal is reversed with the input signal. The measured time delay varies as a function of the input pulse width because the pulse propagation velocity is a function of the frequency[1]. Therefore, we assume that the velocity for the measurement in Figure 7 is 1.4×10^8m/s because the same pulse width as shown in the reference [1] was used. In this case, the distance of the fault point is

$1.4 \times 10^8 \times 79 \times 10^{-6} \times 0.5$ = 5500 meters.

As the water depth was about 38 meters in this area, the actual fault position was subsequently confirmed by a human diver. The result was 5430meters, so the correspondence between the estimated and actual measured distance was close. This means that the pulse velocity is accurate.

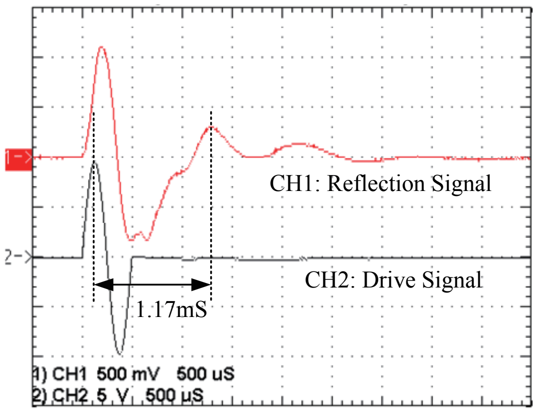

Figure 5: Result of TDR of the West Cable using a sinusoidal pulse (PW=500µS)

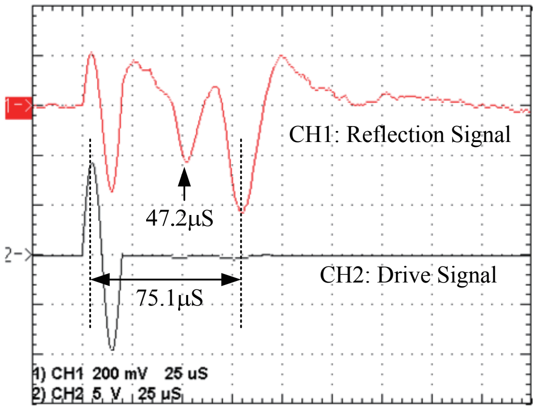

Figure 6: Result of TDR for the East Cable using a sinusoidal pulse (PW=20µS)

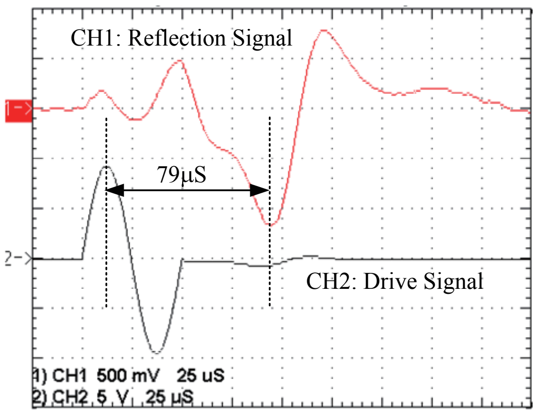

Figure 7: Response of the East Cable using a sinusoidal pulse (PW=50µS)

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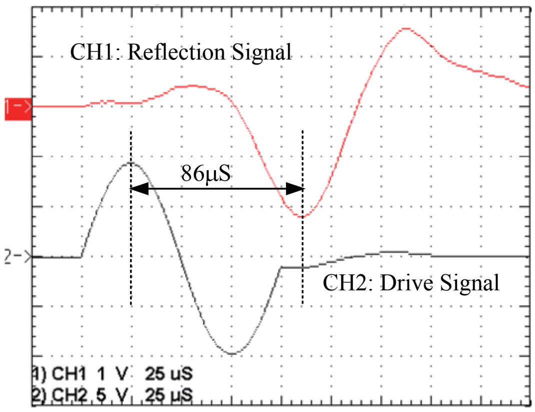

Figure 8: Response of the East Cable using a sinusoidal pulse (PW=100µS)

4. FDR[3]

4.1 Measuring method

Figure 9 shows a block diagram of the measurement of the input impedance of the cable. The frequency characteristics of the electric current and the voltage are measured by a two-phase lock-in amplifier. The input impedance is calculated by the following expression:

$$Z_{IN} = \frac{V_i}{I_i} = \frac{A_{IN} R}{A_{IN} - B_{IN}} \qquad (1)$$

Where, A_{IN} and B_{IN} are measured by the lock-in amplifier as vector voltages. In order to reduce noise, the time constant of the lock-in amplifier is set to one second.

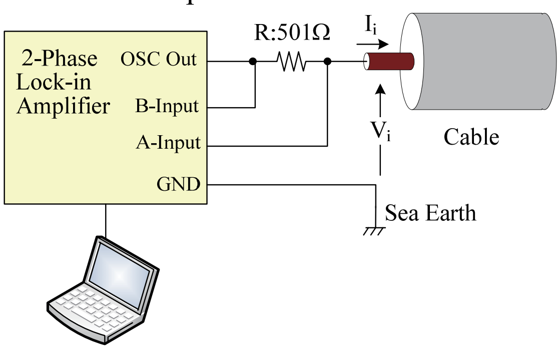

Figure 9: Block diagram of the impedance measurement[3]

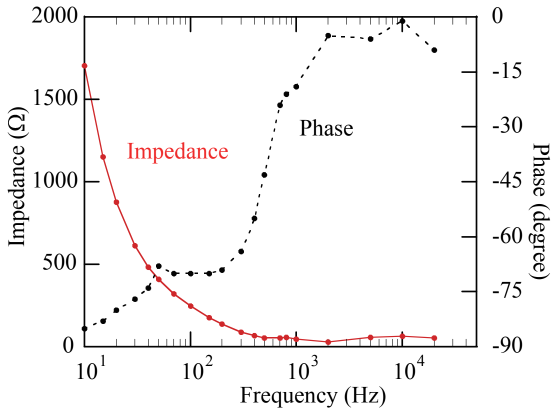

Figure 10: Frequency characteristic[s] of the input impedance of the West Cable[3]

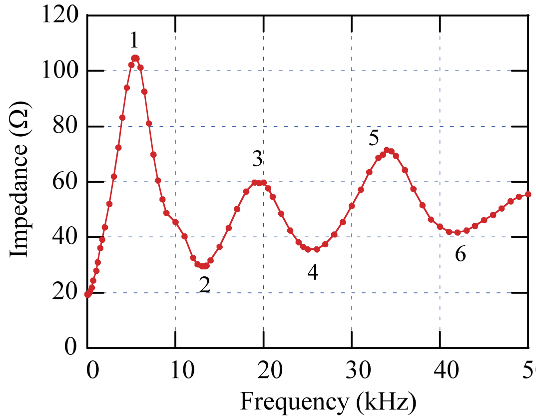

Figure 11. Frequency characteristic[s] of the input impedance of the East Cable[3]

4.2 Results of FDR

Figure 10 shows the measurement result of the input impedance of the West Cable. As the termination of this cable is open-ended, the result of the impedance at a low frequency is almost capacitive. For example, the input impedance at a frequency of 10 Hz is 1700 Ω and 85 degrees, and the corresponding capacity becomes 9.4 µF. The capacity of the unit length is 9.4 µF/59.414 km=0.16 µF/km. This result is corresponding to the theoretical value 0.17 µF/km.

Figure 11 shows the frequency response of the input impedance of the East Cable. Considerable resonances are seen in this figure. The phase velocity can be calculated from the resonance frequency if the length of the transmission line is already known. In general, the resonance frequency of the transmission line in the

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short-end condition is given by the following expression:

$$L = \frac{n\lambda}{4} = \frac{nV_n}{4f_n}, \text{ n=1,2,3,...} \qquad (2)$$

Where L is the length of the cable, λ is the wavelength, and V_n is the phase velocity. As the actual length of the cable is 5.430 km, V_n, can be calculated as the following equation:

$$V_n = \frac{4f_nL}{n} = \frac{21720f_n}{n}, \text{ n=1,2,3,...} \qquad (3)$$

The index number 'n' is shown in figure 11. The calculation results of the velocity are shown in Figure 12. Because another small peak is seen around the frequency of 10 kHz, the second resonance frequency shifts to slightly higher frequency. Therefore, the result of the speed at 12 kHz differs from other data.

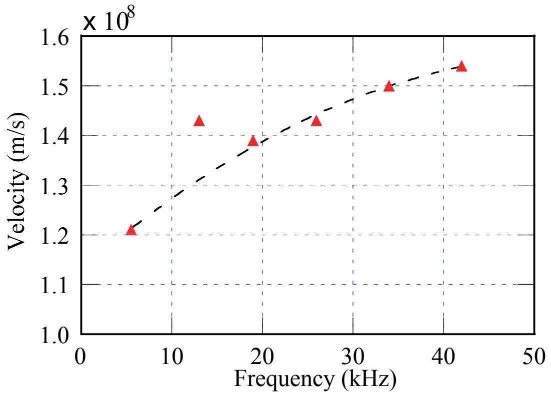

Figure 12: Phase velocity of the single armored cable[3]

5. CONCLUSION

As techniques for locating a fault on a power feeding line of an optical submarine cable, electric time-domain reflectometry, and AC impedance measurement were discussed. We measured the fault point of an actual submarine cable by TDR and confirmed the actual fault point using a human diver. The results of estimation and actual measurements corresponded closely. In the electric measurements, it is important to know the pulse propagation velocity in order to locate the fault position accurately. We measured the frequency dependency of the phase velocity in an armored cable using the result of the frequency response of the AC impedance measurement.

6. REFERENCES

[1] K. Asakawa and J. Kojima, "Localization of fault point of optical underwater telecommunication cable with electric method," proc. of SUBOPTIC'93, pp. 513-517, 1993.

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[3] J. Kojima, S. Matsumoto and K. Asakawa, 'Fault point localization of power feeding lines in optical submarine cables', Proc. OCEANS'08 MTS/IEEE Quebec, S0pt. 2008.