TFDR을 이용한 동축케이블의 다중 결함 측정

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Multiple Fault Detection on a Coaxial Cable via TFDR

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Abstract - In this paper, we considered multiple faults detection on a coaxial cable through Time-Frequency Domain Reflectometry (TFDR). It is well known that TFDR has high resolution accuracy for detecting and estimating the fault detection on a coaxial cable. This approach was based on time-frequency signal analysis and utilized a chirp signal multiplied by a Gaussian time envelope. The Gaussian envelope provided time localization, while the chirp allowed one to excite the system interest. We carried out experiments with 10C-FBT coaxial cable having either one or two faults. The result shows TFDR can be extended to detect multiple faults with high accuracy on a coaxial cable.

1. Introduction

Detecting faults and estimating conditions of wiring have become an import issue in electrical wiring fields. These problems are not limited to aircraft only but also include systems such as the space shuttle, nuclear power plants and very tall buildings [1]. Therefore the detection and localization of faults on a cable is essential to diagnose and maintain of wiring system.

Reflectometry has been commonly used to test the reliability of wires and cables. It is implemented by sending a pulse along the cable and measuring reflections from discontinuities in it. Time domain reflectometry (TDR) is one of the most common instruments used for detecting a fault on cable and transmission lines. TDR sends a step or pulse of voltage down the wire, which reflects at any impedance discontinuity such as a break or short circuit in the wire. The reflected signal from the impedance discontinuity point is detected at the source end. The delay time between the incident and reflected signals implies where the discontinuity point from source is, and the amplitude and polarity of the reflected signal indicates the magnitude and type of fault.

Time-frequency domain reflectometry (TFDR) has been suggested to enhance accuracy in detection and localization of the faults in a coaxial cable and as an extension of TFDR applications, a new load impedance evaluation methodology based on TFDR has been suggested in order to resolve the accuracy limitations of measurement range in classical reflectometry[2]. TFDR transmits a reference signal characterized by a chirp signal with Gaussian envelope which enables one to achieve time localization and to assign energy in the frequency band of interest.

The time-frequency distributions[3] of the reference signal and the reflected signals are calculated. Then these two time-frequency distributions are cross correlated in the time-frequency domain. The peak in the time-frequency cross-correlation function allows one to estimate an accurate round-trip propagation time and, hence, distance, as in classical TDR. The magnitude of reflection coefficient in TFDR is obtained from a normalized time-frequency cross-correlation function considering of frequency dependent attenuation so that the distortion of the reflected signal is to be compensated for an accurate impedance measurement. The phase difference between the reference and the reflected signal is evaluated by the cross time-frequency distribution function which provides time and frequency localized phase difference information of both signals.

In this paper, we introduced an expansion of detecting fault on a cable via TFDR. This experiment was carried out with a coaxial cable having two and three faults on it via TFDR. The results showed the TFDR is able to detect multiple faults on a cable with high accuracy.

2. Time-Frequency Domain Reflectometry

2.1 Design of reference signal

Unlike the traditional reflectometry such as TDR and FDR for detecting and localizing fault on a cable TFDR uses the Gaussian envelop chirp signal as a reference signal. TDR uses a pulse with fixed time duration and compares the reference and reflected signals in the time domain only. Therefore, TDR can not analyze the signal in the frequency domain. On the other hand, FDR uses a set of sinusoidal signals with fixed frequency bandwidth and analyzes the change of the signal in the frequency domain only. Fig. 1 shows reference signals for TDR, FDR and TFDR on a time-frequency plane.

TFDR uses a linearly modulated chirp signal with a Gaussian envelope. The proposed reference signal is written as follows:

$$S(t) = (\frac{\alpha}{\pi})^{\frac{1}{4}} e^{\frac{-\alpha(t-t_0)^2}{2} + \frac{j\beta(t-t_0)^2}{2} + j\omega_0(t-t_0)} \quad (1)$$

where α, β, t_0 and ω_0 determine the time duration, frequency sweep rate, time center, and frequency center, respectively. The Gaussian envelope localizes the reference signal in the time and frequency domain while the instantaneous frequency of the signal increases with time in a linear manner as depicted in Fig. 1.

We have to choose appropriate reference signal by considering physical characteristics of target cables. The main idea of the designing reference signal is that how well we can make the reference signal fitted for the physical characteristics of target cable.

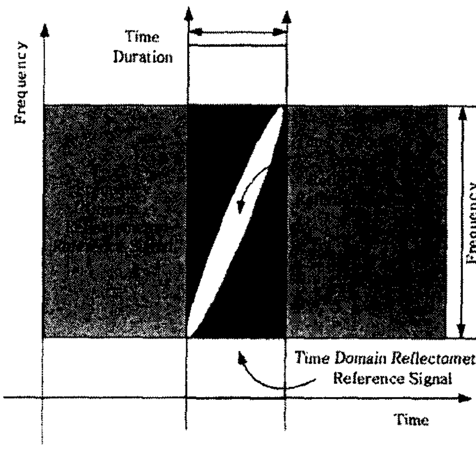
Consider the Wigner time-frequency distribution of the time signal $s(t)$ can be obtained by following transformation:

$$W(t,\omega) = \frac{1}{2\pi} \int s^*(t - \frac{1}{2}\tau) s(t + \frac{1}{2}\tau) e^{-j\tau\omega} d\tau. \quad (2)$$

then the Wigner distribution of the refrence signal $W_s(t,\omega)$ is

$$W_S(t,\omega) = (\frac{1}{\pi}) e^{-\alpha(t-t_0)^2 - \frac{(\omega - \beta(t-t_0) - \omega_0)^2}{\alpha}} \quad (3)$$

The central idea of TFDR is to design a reference signal that "fits" the physical characteristics of the target wire or cable in the time and frequency domain.



<Figure 1> Comparison of reference signals.

2.2 Detection and localization by Time-Frequency Cross Correlation Function

For the detection of the fault, the correlation of the time-frequency distribution of the reference signal and reflected signal is used. Denote the reflected signal as $r(t)$ and its Wigner distribution as $W_r(t,\omega)$ and $W_s(t,\omega)$ as the Wigner distribution of the reference signal $s(t)$. Then we are able to evaluate a time-frequency cross-correlation function $C_{sr}(t)$ as follows:

$$C_{sr}(t) = \frac{2\pi}{E_s E_r} \int \int W_r(t',\omega)\, W_s(t'-t,\omega) d\omega dt' \qquad (4)$$

where

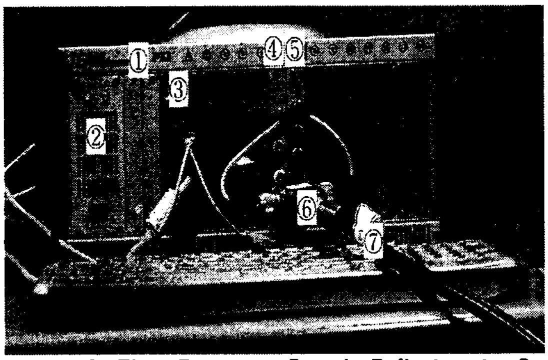
$$E_r = \int \int W_r(t',\omega) d\omega dt' \qquad (5)$$

$$E_s = \int \int W_s(t,\omega) dt d\omega \qquad (6)$$

where the time integrals are carried out over the duration of the reference signal or reflected signal, as appropriate. The denominators and play the role of normalization factors.

2.3 Experimental Setup and Results

We carried out some experiments with TFDR system composed of using some commercial PXI solutions. Fig. 2 shows the TFDR system we used in this experiments. The main components and their specifications of the TFDR system are as follows:



<Figure 2> Time-Frequency Domain Reflectometry System

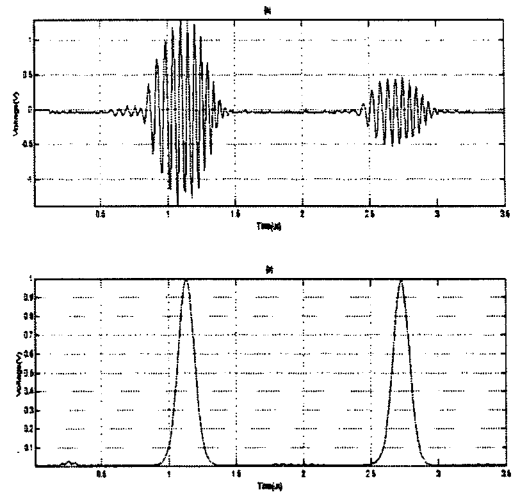
① PXI chassis
② Power supply
③ PXI main controller
④ Distal storage oscilloscope (100MSamples/sec.)
⑤ Arbitrary waveform generator (100MSamples/sec.)
⑥ Ciculator
⑦ Targer cable (10C-FBT)

The faults on target cable were located 100m and 200m from its source. The faults were implemented by general electrical resistors having deferent impedance with the target cable's characteristic impedance, 72±3Ω. As we mentioned before different impedance in the target cable caused reflections. The target cable, 10C-FBT, is typically used to transmit image data between a broadcasting station and subscribers. In the real experiments, the reference signal which has time duration 700[ns] and frequency bandwidth 10-20[MHz] is used.

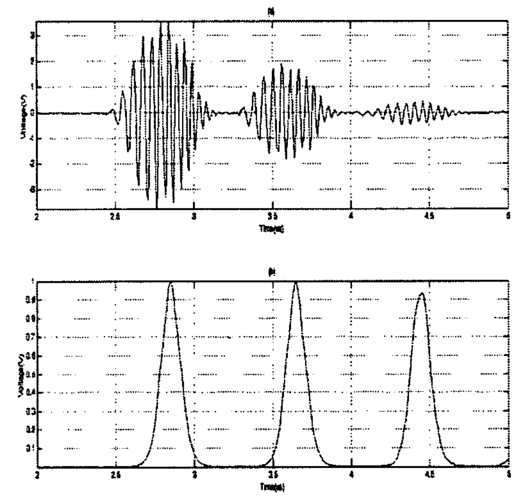
<Table 1> Fault estimation

Fault location [m]	Estimation via TFDR [m]	Error [%]
100	100.0107	0.0107
200	199.9394	0.0303

Table 1 shows the results for estimation of fault location via TFDR. Fig. 3 shows the wave form and its correlation result for detecting fault at 200m in the target cable. When the two faults at 100m and 200m exist in the cable the waveform and its correlation is shown in Fig. 4. In Fig. 3, The first waveform means reference signal and the second waveform from the left side implies reflection. There are two reflections at 100m and 200m in Fig4.



<Figure 3 > Detected waveform and its correlation for a fault at 200m on a coaxial cable



<Figure 4> Detected waveform and its correlation for two faults at 100m and 200m on a coaxial cable

3. Conclusion

In this paper, we carried out experiments for multiple faults detecting on a coaxial cable using TFDR. This experimental results show that the TFDR is able to detect and localize faults on a coaxial cable with high accuracy.

[References]

[1] "Review of federal programs for wire system safety-final report," National Science and Technology Council Committee on Technology, Wire System Safety Interagency Working Group, 2000.

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