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A Method for Provisioning a Twisted Pair Cable's Integrity Based on a Reflected Waveform Analysis of an Emitted Pulse

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Abstract - **Twisted pair copper cables nowadays are widely used as a media for transferring and delivering services to end customers. Typically, they find applications in xDSL where a triple play service can be delivered. Cable's integrity provisioning however is sometimes a tough issue to cope with. A typical method for sorting out failures such as cable discontinuities is by using TDRs (Time domain reflectometers). By emitting a single pulse into the line and exercising a mathematical analysis on the reflected waveform it is possible for the exact place of failure to be figured out. This paper proposes a method for cable provisioning based on the TDR.**

Keywords – **TDR, reflected wave, cable provisioning**

I. INTRODUCTION

The Internet is a global network that carries information over many different types of media. One typical example is the copper twisted pair. It is a type of wiring in which two circuits are twisted together for the purpose of cancelling out electromagnetic interference from external sources and preventing crosstalk between neighbouring pairs.

Usually twisted pair cables are placed into the ground starting from the service provider and finishing at the end customer hence services are delivered. Each service demands provisioning and in case of failures tools for diagnostics are required to have the issues sorted out. Typical breakdowns include cables discontinuities, thefts from network shafts, outages due to construction works, etc.

An appropriate device for evaluating such failures of twisted pair lines is the time domain reflectometer. It analyzes the line by emitting a single pulse into it and evaluates the length of the cable by the reflected waveform.

This study presents a method for cable's integrity evaluation based on the TDR.

In section II a background is exposed that is necessary for the study. Section III describes the used hardware and the logical block diagram. In section IV it is explained the physical, electrical and mathematical basis of proposed method. Section V reveals the experimental setups as well as the numerical results and their corresponding constraints in calculation. Finally, an overview about future works is mentioned.

II. BACKGROUND

Each twisted pair line has a characteristic impedance. It is shown in Figure 1. Z_0, is the ratio of E to I at every point along the line. For maximum transfer of electrical power, the characteristic impedance and load impedance must be matched.

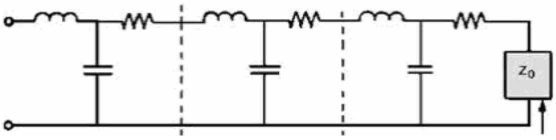

Fig. 1. Characteristic impedance of a twisted pair line

The V_{factor} at which a wave travels over a given length of the transmission line is different depending on the material. For copper it is approximately 0.65.

When a pulse is emitted into a short-circuited line, the voltage is reflected back with opposite polarity. If the line is an open-ended one, the returned pulse is always with the same polarity as the emitted pulse. It is shown in Figure 2 and Figure 3 [2].

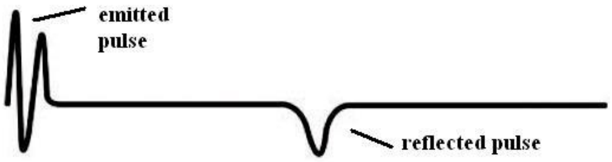

Fig. 2. Short-circuited line reflection

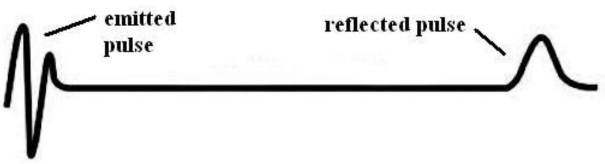

Fig. 3. Open-circuited line reflection

III. FUNCTIONAL BLOCK DIAGRAM

Based on the exposed background a functional block diagram is created. It includes both the transmitting and the receiving path for the signal as well as a specific transformer responsible for insulating the electronic circuits from the line side. The functional block diagram of the line interface is shown in Figure 4.

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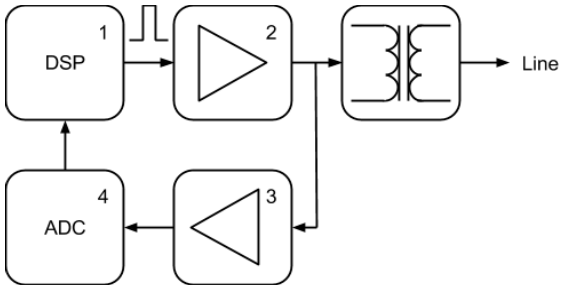

Fig. 4. Functional block diagram

Upon a software trigger the DSP (Digital Signal Processor) 1 generates a short pulse. The pulse's width depends on the length of the twisted pair that has to be provisioned. Longer pulses correspond to more energy that has to be injected into the cable.

The specialized amplifier 2 is triggered by the generated pulse and it outputs a pulse with a specific shape. The shape corresponds best to the frequency characteristics of the cable. In this setup maximum portion of energy is able to travel along the cable without significant attenuation. The impedance between the amplifier 2 and the transformer as well as the impedance Z_0 of the line are strictly matched for minimum reflections [3].

In the opposite direction the cable response is applied on a highly sensitive input operational amplifier 3. It has a high input impedance and practically has no impact on the impedance matching of the line. The input amplifier receives the line response and attenuates it in order to match to the input of the ADC (Analog-to-Digital Converter) 4.

The ADC that is used in this method is chosen to be 12 bit/10 MSPS to carry out enough resolution to the DSP. The ADC is clocked by the DSP and it transfers digital words over a specific parallel bus independent of the main processing unit of the DSP. The collected digital information corresponds to the unique cable response wave and it is further stored into memory for analysis [1].

IV. METHOD FUNDAMENTALS

The proposed algorithm is split into three stages - calibration, provisioning and fault evaluation. It is shown in Figure 5.

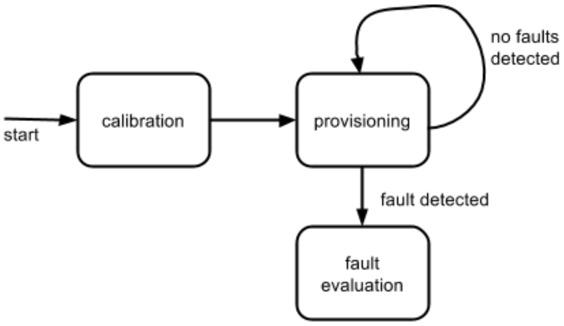

Fig. 5. Algorithm diagram

Firstly, it is necessary that the approximate distance of the cable is known prior to calibration and the twisted pair is short-circuited at the end.

The calibration stage starts by emitting a single pulse into the twisted pair under provisioning. During the emission the line is sampled to a predefined number of times. The sampling frequency F_s is 10MHz. A digital bandpass FIR (Finite impulse response) filter [4] with bandwidth from 10kHz to 200kHz is applied on the signal obtained from the ADC. It is necessary that the reflected waveform is released from undesired high frequency noise. The next step is to find all of the local minimums and local maximums. After counting the number of samples $N_{samples}$ between the peak of the emitted pulse and each extremum certain distances can be figured out. The following equation is used:

$$D = N_{samples} \frac{cV_{factor}}{2F_s}, \qquad (1)$$

where $c = 3\times10^8$ is the speed of light. If one of the calculated distances matches the exact distance within 3% error and the local extremum is a minimum (short circuit expected) it is claimed that the integrity of the line is intact. The samples are finally stored and are called the calibrated 'signature' of the line. The algorithm transitions to the next stage.

The provisioning stage does exactly the same calculations as in the calibration stage. The only addition is that each newly calculated signature are correlated with the stored one. If the correlation is less than a predefined value the cable is considered faulty. On such a decision the algorithm moves to the fault evaluation stage.

In the fault evaluation stage the algorithm compares the latest signature of the line with the stored one. The extremum that has the greatest disparity from the stored signature is considered the place where the cable is discontinued.

V. EXPERIMENTAL RESULTS AND METHOD CONSTRAINTS

Experiments have been conducted on a UTP cable with a length of 305m and a section of 0.5mm^2. Each pair is consecutively connected to a neighbouring pair so that the accomplished resulting pair length is 1220m. The last pair is short-circuited at the end due to the demand of the evaluation method. By having such a setup it is easy to experimentally cut the cable at a pace of 305m. Measurements have confirmed that an error of 3% is achieved.

A typical constraint the experiments have revealed is failures at shorter than 100m distances. In such a measurement the reflected pulse overlaps with the emitted one and the algorithm needs enhancements so that this effect is correctly handled.

VI. FUTURE WORKS

In order to improve the proposed method a few facts must be taken into consideration. Firstly, the issue that has to be handled is the 'blind' zone at short distances where the reflected pulse goes on top of the emitted one.

Secondly, there is such a tendency that the reflected pulse becomes less distinctive with increasing the length of the cable. This makes the method more error prone.

If the reflected pulse is amplified before being passed to the ADC it may provide the echo with a more distinctive amplitude.

VII. CONCLUSION

It has been proposed an algorithm for provisioning a copper twisted pair cable’s integrity based on the TDR. The method and the approach as a whole take place in a real product and are used for theft prevention of cables in an existing network.

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