Electrical tagging devices for the removal of fault location ambiguities by reflectometry in complex electrical networks

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***Abstract*—In general, data from a single reflectometer are insufficient to locate defects in wires beyond a branching point. Knowing the distance to the defect, some additional information is required for selecting the faulty wire among possible candidates. This paper presents an innovative method of electrical tagging of wires to get uniqueness of fault location. It presents the tagging devices that may be used instead of additional reflectometers as in the expensive and complex distributed reflectometry techniques. Inexpensive electrical "tags" can be purposely designed with specific frequency signatures using only a few passive components. Preliminary experimental results show how their insertion on the branches of a network can give a proper identity to each one of them without affecting the useful signal frequency band. It is shown how each echo of the time domain impulse response of the line keeps a memory of the branches it has travelled along, thus cancelling its source location ambiguity**

Keywords— Time-domain reflectometry, complex network, distributed system, online wire diagnosis, wire fault detection ambiguity

I. INTRODUCTION

Nowadays, since the electrical networks are getting bigger and more complex, their diagnosis has become a major concern. The most commonly used technique for diagnosing and locating faults is reflectometry. Time domain reflectometry consists in analyzing the impulse response of the electrical line under test from the considered injection point. A high frequency signal is sent down the electrical line, from a single injection point, where it is reflected at each impedance discontinuity. When diagnosing complex electrical networks, i.e. having at least one junction, the injected signal is forked into each branch. The echo pattern rapidly becomes extremely complex and difficult to interpret, especially since nothing can differentiate a signal that has travelled along a branch or another. Consequently, when a fault appears beyond a junction, and using a unique diagnosis system at a single injection point, it is impossible to identify on which branch the defect is placed [1]. Many time or frequency domain reflectometry methods have been developed [2]-[6] but they all suffer from this major ambiguity drawback. Very few works have been reported on methods aiming at solving this major problem. They are all based on the distributed reflectometry approach [7]-[8] which consists in duplicating the diagnosis systems at each but one extremities of the network. Although efficient, they are expensive and require complex signal conditioning and communication between the different modules.

In this work, we present an innovative, yet simple and very inexpensive method to locate, without ambiguity, the fault location in complex electrical harnesses from a single observation point. The method can also be considered in embedded applications since it doesn't perturb the useful signals conducted by the electrical line.

II. ELECTRICAL TAGGING OF ELECTRICAL LINES METHODOLOGY

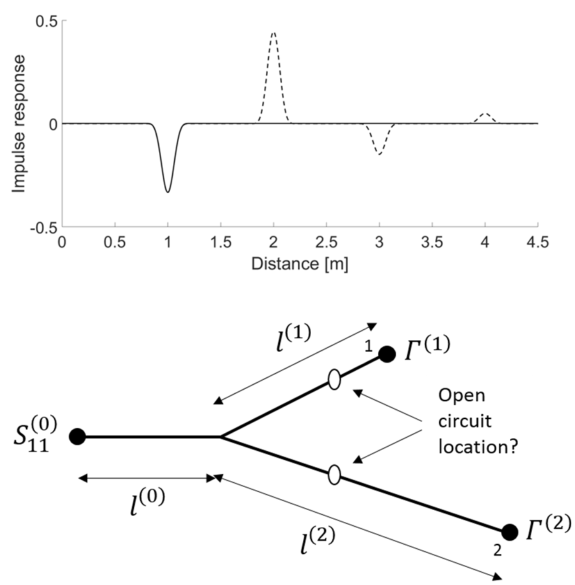

Fig. 1. Location ambiguity of a fault on a complex electrical network topology. Above: Time Domain reflectometer of a Y star-shaped network either adapted at each extremity (—) or affected by an open circuit on a branch (— —). Below: The only knowledge of the distance of the fault to the injection point doesn't allow to state on which branch the fault is located.

For clarity, the principle will be illustrated on a simple Y star shaped network containing 3 lines of different length connected with a single junction (Fig. 1). However one has to note that the following demonstration can be easily adapted to any complex network topology.

The impulse response $h(t)$ of the entire healthy network, with lossless lines and frequency independent termination loads, can be simply expressed for the first reflections at the junction and each extremity, as:

$$h(t) = -\frac{1}{3}\delta(l-l) + \frac{4}{9}.\Gamma^{(1)}.\delta\left(l-\left(l^{(0)}+l^{(1)}\right)\right) + \frac{4}{9}.\Gamma^{(2)}.\delta\left(l-\left(l^{(0)}+l^{(2)}\right)\right)+\ldots \quad (1)$$

Where $l^{(i)}$ and $\Gamma^{(i)}$ are respectively the length and the reflection coefficient on the loads at the end of the branches *i*.

One can notice in (1) that since the termination loads are frequency independent, the shape of the impulses responses associated to the reflections on the impedance mismatches contained on each branches are all Dirac pulses.

Consequently, as illustrated in Fig. 1, a defect created at the same distance after the junction on either one of the two branches would results on the same modification of the impulse response of the Y shaped harness. One can therefore not differentiate a pulse coming from branch 1 or 2 and state on the location of the defect with certainty.

The principle of the proposed method [9] is presented in Fig. 2. It consists in functionalizing each branch with an electrical "Tag". These electrical devices can be inserted either at the junction, in the middle or at the end of a branch. In the frequency band used by the interconnected devices, each "Tag" is designed to have the same characteristic impedance as the line it is placed in, thus not affecting the useful conducted signals. Outside of this useful band, a specific frequency behavior of the impedance of the tag is purposely designed.

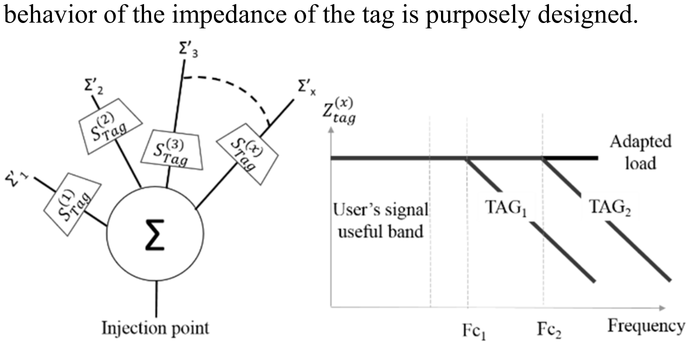

Fig. 2. Each extremity branch of a complex electrical network Σ is equipped with an electrical "tag" designed with a specific frequency pattern. As an example, the specific frequency signatures of the two TAGs were designed as low pass filters with two different cutoff frequencies outside the useful band.

Consequently each tag has a specific impulse response that will affect the echoes coming back from each branch. Each echo is tagged with the identity of the branch it is coming from thus removing the location ambiguity of the defect.

III. Experimental Tagging of a Star Shaped Network

A. Electrical tags characteristics

In the example presented in this work, two tags were used in order to give a unique signature to each extremity of the Y star shape network of Fig. 1. The network was made of 50 Ω RG58 coaxial cables. The lengths $l^{(0)}$, $l^{(1)}$, and $l^{(2)}$ were respectively 0.6 m, 1.6 m and 5 m. The two frequency dependent tags were designed with simple Pi Butterworth low pass filters of order 3 made of only two capacitances and one inductance (Fig. 3).

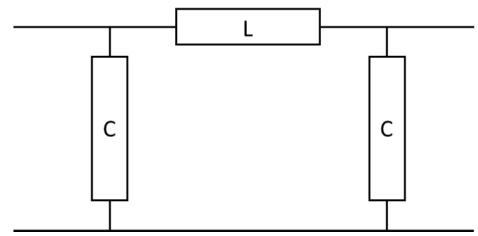

Fig. 3. Equivalent circuit of the electrical Tags inserted at extremities of the Y shaped network. The two tags are Pi Butterworth low pass filters with respective cutoff frequenies of 40 MHz and 65MHz.

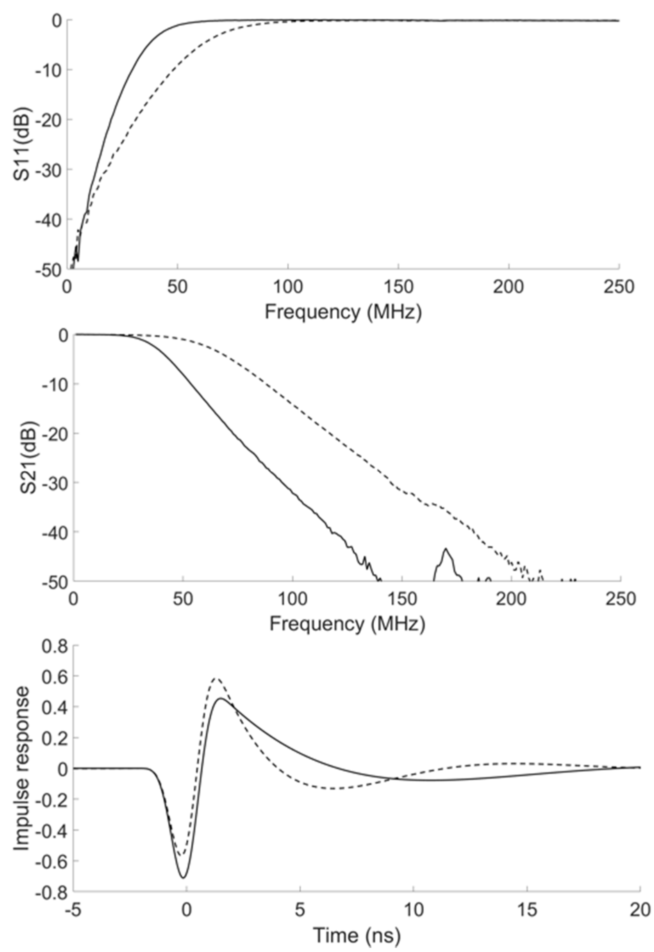

Fig. 4. Impulse response, reflection and transmission scattering parameters of the Butterworth pi filters $Tag1$ (—) and $Tag2$ (— —).

The cutoff frequencies of the tags placed on the branches 1 and 2 were respectively 40MHz and 65MHz. Even if the Fig. 1 presented in section II clearly shows that the tags can be placed anywhere on the branches, since the tag are low pass filters and a limited frequency band can go through the filter, one could not expect to detect a defect with a good accuracy after the tag. Consequently the tags were placed at the extremities of the branches.

The experimentally measured scattering parameter of Tag1 and Tag2 are shown in Fig. 4. One can see that with such cutoff frequencies, a tag would not affect the transmission, or cause unwanted reflection in the network, on a signal composed of harmonics below the lowest cutoff frequency. As an example, the CAN protocol, which is widely used in automotive or aeronautical application, works at 500 kHz with buses made of 120 Ω twisted pairs. With minor modifications on the component values of the filters, the tags could be adapted still ensuring the CAN messages integrity.

B. Experimental results and identification of each branch of the network

The impulses responses $h_{Tag1}(t)$ and $h_{Tag2}(t)$ of the two tags presented in Fig. 4 are clearly different and can be distinguished without ambiguity. Once inserted on the Y star shaped network they dramatically affect the impulse response of the whole network and as expected each echo has a specific shape contrary to an untagged network as shown in Fig. 5.

Consequently the echoes coming back to the injection point have a unique shape that is the memory of their multiple travels through the branches. It follows that the location ambiguity of the defect can be removed easily. This can be conducted by analyzing the tag signatures present or absent in the impulse response of the line.

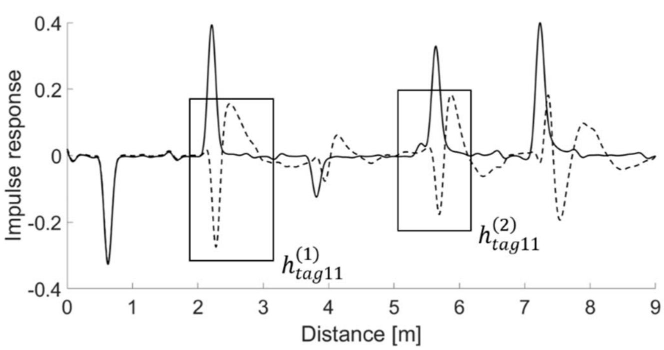

Fig. 5. Comparison of the time domain response of an untagged network (─) and a tagged one (──). Each echo has a shape which is the memory of its travel along the branches.

If this healthy tagged network is affected by a defect such as an open circuit on a branch, as shown in Fig. 6, the signature of the tag associated to the defective branch disappears. By simply identifying the tags still present in the response, one can easily state on which branch the defect is located.

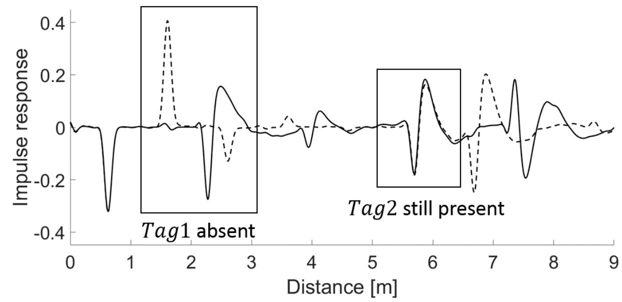

Fig. 6. Tagged Y star shaped network. Impulse response of the healthy tagged network (─) or the defective one affected by an open circuit on branch 1 at 1m after the junction. The impulse response of Tag1 has disappeared from the impulse response of the line.

IV. CONCLUSION

In this paper we have proposed a new method allowing to efficiently solve the extremely important ambiguity location problem of the defects in complex electrical harness by reflectometry. The proposed electrical tagging method is powerful but yet very inexpensive and may give for embedded automotive or aeronautical systems a viable alternative to the costly existing methods. The analysis of the simple low pass filter tags present in the line allow to rapidly state without ambiguity on the location of a defect on a complex electrical network.

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