Study and implementation of an innovative method of cable diagnosis in the field of transport

Marc Olivas Carrion, Fabrice Auzanneau
CEA, LIST, Laboratoire de Fiabilisation des Systèmes Embarqués
PC 94, Gif-sur-Yvette, F-91191 France
00 33 (0) 1 69 08 48 83
marc.olivas@cea.fr

Charles-Henri Garih
Delphi France SAS, Etablissmeent de Cergy
43 avenue du gros chêne
F-95614 Cergy Pontoise cedex, France
00 33 (0) 1 34 30 34 76
charles.henri.garih@delphi.com

Abstract- **Modern systems in a car must perform real time functions and communicate with each other sometimes in a stringent environment. Increasing complexity, coupled with network connection, leads to important performance, reliability, and security issues. Wired interconnection network is more and more considered a system on its own. Its importance has grown and is now recognized by manufacturers and regulation authorities.**

Wire failures can be the result of many causes and have dramatic consequences. Maintenance now needs to recognize or anticipate them, using wire diagnosis methods and tools. This paper presents an overview of such methods and their application for vehicles developed in the collaborative project SEEDS.

Introduction

Wires are everywhere and wired networks are considered as the backbones of complex systems. They are needed for power supply and still often for signal exchange and intercommunication. The increase of the complexity of modern car has come with the increase of wire lengths. The cumulated length of electrical wires in a modern car is more than 4 km, compared to a few hundred meters 30 years ago.

Whatever their application domain, wires can be subject to aggressive environmental conditions which can cause aging and defects. These defects may have dramatic consequences if the wires are parts of safety critical systems, i.e. systems whose failure may cause death or injury to people, loss or severe damage to equipment or environmental harm. It is therefore important to detect and precisely and quickly locate failures in wired networks as it is usually done for electronic systems. This was officially recognized in the aeronautics domain at the beginning of this century, after some American studies have shown that several hundred wiring faults can be found in wire harnesses of aging aircrafts. The conclusion was that "planes over 20 years old are virtually guaranteed to have wiring problems" [1].

Most systems studied today use reflectometry. Based on the injection of a signal at one end of the network and the analysis of reflected signals, this method provides information for the detection, localization and characterization of electrical faults in the wire network. Time Domain Reflectometry (TDR) sends a pulse signal and analyzes the return signal, composed of all the signals sent by the heterogeneities encountered during propagation. Electromagnetic propagation models have been developed. They give the physical basis of the study of diagnosis. Other methods use different probe signals, more robust to noise or fitted to operational constraints, and specific data processing to provide diagnostic information.

A prototype has been designed to use this diagnosis system in garage for vehicle maintenance. It detects and locates a hard defect with 10 cm accuracy and its type (open circuit, short circuit) through a wireless interface with a PDA.

SEEDS (Smart Embedded Electronic Diagnosis System) project demonstrated the technical, industrial and commercial capacities of a wire diagnostic tool into a garage and laid the first bricks of the onboard sensor.

Wire diagnosis using reflectometry

A. Propagation Model

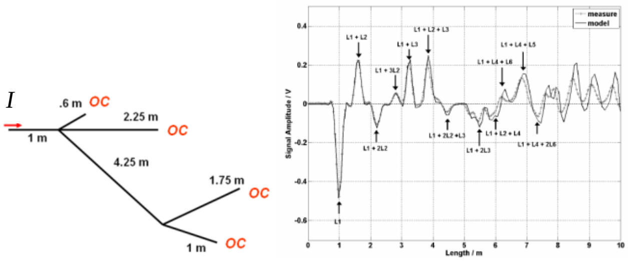
Away from visual inspection and resistance testing, the best diagnosis methods are based on the reflectometry principles. Reflectometry based methods send a high frequency signal down the line, part of its energy reflects back at impedance discontinuities such as connections, branches or defects. Analyzing the reflections returning to the wire's end provides information about the wire's status.

Reflectometry needs only one access port to the cable under test; it can provide useful health information such as detection – localization and characterization of defects [3-4]. It is well suited for hard defects, such as short-circuit or open circuit, although some new advances address soft defects [5]. Reflectometry methods are usually divided in Time domain (TDR) or Frequency domain (FDR) methods, depending on the type of probe signal used. In TDR, a pulse (Gaussian or rectangular) signal is sent down the wire and the reflected signal is roughly a succession of similar pulses delayed in time of the round trip travel time between injection and each impedance discontinuities [6]. If the cable under test does not have a homogeneous characteristic impedance, additional noise is present on the reflectogram, thus increasing the processing difficulty. The same problem happens in case of a complex network topology.

As an example, Figure 1(a) shows a complex network made of coaxial cables of a few meters with an open end

978-1-4244-8218-4/10/$26.00 ©2010 IEEE

and the injection point, tagged *I* in Figure1(a), is matched to 50 Ω.



(a) (b)

Figure 1. TDR comparison between numerical simulation and measurement for a complex ramified network with open circuits at the ends – for simplicity, distances have been divided by two; to better show the line's lengths [6].

A simple model presented in [6] simulates the TDR signal measured from *I* referring to the black line on Figure 1(b). We have compared our model to real measurements, for a complex network made of coaxial cables referring to the dash-line. The impulse response is deduced from the measurement of the S11 parameter with a vector network analyzer (VNA) in the frequency domain from 300 kHz to 500MHz. Figure 1(b) shows a good agreement between measure and simulation, both for positions and amplitudes of the main peaks, the third order peaks being a little bit overestimated by the model, probably due to losses in the connectors.

Sequence Time Domain Reflectometry [7] (STDR) and Spread Spectrum TDR (SSTDR) use pure digital and modulated digital signals, making these methods particularly suited for embarked diagnosis systems and the location of intermittent faults. They have been improved in [8] and [9], aiming at distributed diagnosis to easily handle ramified networks without any ambiguity.

OFF-LINE DIAGNOSIS

To demonstrate the feasibility of this diagnosis tool, the methods developed in the previous section were implemented on a Field Programmable Gate Array (FPGA) platform connected to analog to digital (ADC) and digital to analog (DAC) converters. The output impedance is 50 Ω.
In order to increase accuracy, the FPGA architecture was modified to carry an over-sampling and thus reduce the time between the acquisitions of two samples. The signal generation was adapted to control the DAC's clock signal and thus produce a shifted version of the injected wave [19].
A first system has been developed and thoroughly tested in a garage in England (Delphi location, tested during 1 year) to prove the usability of such tool in garage

EMBEDDED WIRE DIAGNOSIS

Embedded wire diagnosis inside a complex system requires the use of a dedicated diagnosis architecture together with the ad-hoc diagnosis strategy. The latter must be closely related to the application, e.g. in a car one may want wire diagnosis running full time for some specific lines (such as safety critical ones for steer by wire or ABS or airbag systems) and only at engine ignition or periodically for some other wires. The diagnosis strategy must be the result of a compromise between the application needs and the required wire safety degree.

A. Connection diagnosis

In a moving vehicle, where many parts are strongly vibrating, connections may suffer from aging and contact resistance degradation. We have studied, together with Supelec LGEP, the possibility of using a TDR system to remotely detect this aging, thus extending the usual DC measurement to RF frequency. This was fulfilled by designing a vibration bench (Figure 2) able to reproduce the vibration spectrum of a truck and therefore of the embarked network. Sine vibration tests were performed on a contact and the vibration induced degradation of the tin surfaces was recorded. The reported results highlight the feasibility of monitoring the aging of a connector with a reflectometry method at a constant high frequency (Figure 3).

Figure 2. Vibration bench at Supelec LGEP location.

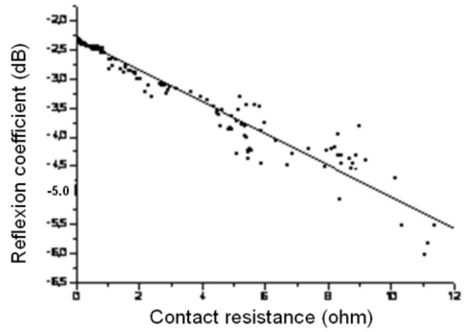


Figure 3. Measured reflection coefficient as a function of contact resistance [10].

B. Intermittent Faults or Micro-cuts

Vibration can also induce micro-cuts in connectors, which can be detected and monitored by an embedded wire TDR diagnosis system. With Supelec LGEP, we have recently proven the feasibility of this kind of system using a very simple experimental setup (Figure 4). This system is based on a TDR system, which continuously sends a probe signal at one extremity of a 1 meter long twisted pair. A computer controlled switch is connected to the other end of the line to simulate an intermittent defect. Figure 5 shows an example of such a record. These curves clearly show the possibility of registering the number and the time of each error occurring in a wire network.

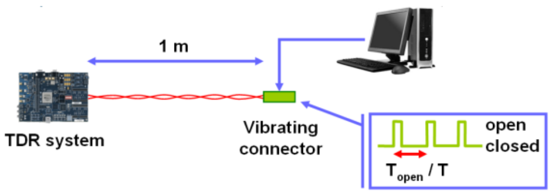


Figure 4. Experimental setup for micro-cuts detection.

Thanks to this system, it is possible to identify a micro-cut longer than 200 µs with a minimum time between each fault of 1 ms. These results were obtained using a prototype TDR system and may be improved in the future.

C. Harmlessness

Harmlessness concerns both the impact of the embarked diagnosis on the system and the impact of the network on the diagnosis. Several methods have been studied in References [7, 8, 9] showing that the diagnosis signals may be chosen so as to minimize their interference with the useful signals running on the network. SSTDR and Modified SSTDR use modulated pseudo noise digital signals in a frequency band well separated from that of the useful signals.

However, it has been shown in Ref. [11] that the diagnosis signals on the wires radiate an electromagnetic field that can induce additional noise on neighboring or remote electronic systems or cables (Figure 5), which is quite high at low frequencies.

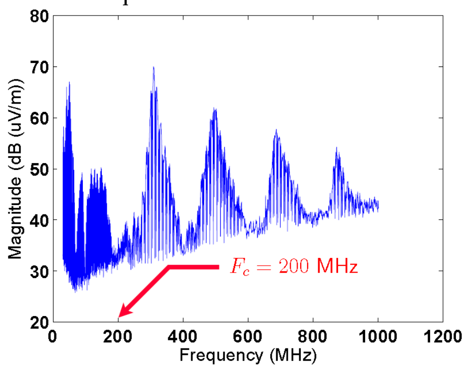


Figure 5. Spectrum of radiated EM field from diagnosis signals for STDR method [11].

We are investigating the use of a new method able to precisely control the power spectrum of diagnosis signals, and therefore to ensure diagnosis harmlessness while preserving is performances. It is a full method able to monitor a complex wired network in a running system. Thanks to this new method it will be possible to identify and to localize an intermittent fault and record the trace of the defect. The Multicarrier Time Domain Reflectometry (MCTDR) [20] has been implemented in a digital platform. A signature is added to the injected signal so that a distributed diagnosis can be performed simultaneously from several points of a complex network, thus allowing solving ambiguities due to multipath wave propagation [21].

CONCLUSION

We have presented the basis of wire diagnosis methods for embarked diagnosis systems, together with some additional concerns about their use in operational context. It is now widely recognized in many application domains that this problem is a real challenge and that testing technologies are needed. It is quite obvious that modern vehicles, which are subject both to harsh environmental aggressions and aging conditions, will require such embarked wire diagnosis systems in the near future.

At CEA LIST, we study generic diagnosis methods and systems, and apply them on specific FPGA based prototypes for various application domains, such as automotive, avionics, oil wells drilling, energy transport, etc. Current systems, using either TDR or STDR methods, provide up to 2 cm localization accuracy which is well suited for embarked needs. Other methods are studied to ensure harmlessness, together with well defined strategy.

A first system has been developed and thoroughly tested in a garage to prove the usability of such a tool. It has shown that the use of this tool can reduce repair time from 2 days to less than 1 hour.

There is a strong link with other industry domains like aeronautics which is essential for the economic aspect and to share the development cost.

ACKNOWLEDGEMENT

This work was made in the course of a research project called SEEDS (Smart Embedded Electronic Diagnosis System) supported by ANR (French National Research Agency). The work at LGEP laboratory was made by Mr. Florent LOETE.

REFERENCES

[1] Furse, C., Haupt, R., "Down to the wire: the hidden hazard of aging aircraft wiring", IEEE Spectrum, Volume 38, pp. 34 – 39, Feb. 2001.
[2] "Wiring integrity research (WIRe) pilot study. Design for safety initiative", NASA, A0SP-0001-XB1, Aug. 2000.
[3] Griffiths L.A, Parakh R., Furse,C., Baker, B., "The invisible fray: a critical analysis of the use of reflectometry for fray location", IEEE Sensor Journal, Volume 6, June 2006.
[4] Sharma, C. R., Furse, C., Harrison, R. R., "Low-Power STDR CMOS Sensor for Locating Faults in Aging Aircraft Wiring", IEEE Sensors Journal, Vol. 7, N°1, pp. 43 – 50, Jan. 2007.
[5] Wang J., Crapse P., Shin YJ., Dougal R., "Diagnostics and Prognostics of Electric Cables in Ship Power Systems via Joint Time-Frequency Domain Reflectometry", IEEE International Instrumentation and Measurement Technology Conference, British Columbia, Canada, May 2008.
[6] Auzanneau F., Olivas Carrion M., "A Simple and Accurate Model for Wire Diagnosis Using Reflectometry", PIERS 2007, Prague, Czech Republic, Aug. 2007.
[7] Smith, P., Furse, C., Gunther, J., "Analysis of spread spectrum time domain reflectometry for wire fault location", IEEE Sensors Journal, Volume 5, Issue 6, pp. 1469 – 1478, Dec. 2005.
[8] Olivas Carrion M., Lelong A., Degardin V., Lienard M., "On line Wiring Diagnosis by Modified Spread Spectrum Time Domain Reflectometry", PIERS 2008, Cambridge, USA, July 2008.
[9] Ravot N., Auzanneau A., Olivas Carrion M., Bonhomme Y., Bouillault F., "Distributed Reflectometry-based Diagnosis for Complex Wired Networks", EMC Workshop 2007, Paris, France, June 2007.

[10] Olivas Carrion M., Auzanneau F., Loëte F., Noël S., "Feasibility of the detection of vibration induced faults in connectors by Reflectometry", 24th International Conference on Electrical Contacts – ICEC 2008, Saint Malo, France, June 2008.
[11] Lelong A., Olivas Carrion M., Degardin V., Lienard M., "Characterization of electromagnetic radiation caused by on line wire diagnosis", IEEE AP & URSI 2008 symposium, Chicago, USA, August 2008.
[12] "Demonstration and Validation of the Excited Dielectric Test™ Method to Detect and Locate Defects in Aircraft Wiring Systems", U.S. Department of Transportation, Federal Aviation Administration, DOT/FAA/AR-04/43, Jan. 2005.
[13] N. Ravot, F. Auzanneau, M. Olivas, Y. Bonhomme, F. Bouillault (LGEP), “Distributed Reflectometry-based Diagnosis for Complex Wired Networks”, EMC Workshop 2007, Paris.
[14] B. Essakhi, J. Benel, G. Akoun, L. Pichon, “Interconnect macro-modeling using 3D computational techniques”, ACES 2007, 23th International Review of Progress in Applied Computational Electromagnetics, Vérone, Italie, 19-23 Mars 2007.
[15] B. Essakhi , J. Benel, L. Pichon, “Circuits models from broadband computational techniques”, ISTET 2007, 14th International Symposium on Theoretical Electrical Engineering, Szczecin, Pologne, 20-22 Juin 2007. (Communication invitée).
[16] B. Essakhi, F. Duval, G. Akoun, L. Pichon, B. Mazari, “Interconnect Macromodeling from 3D Field Computation”, COMPUMAG (International conference on the computation of electromagnetic field), Aachen, Allemagne, 25-28 juin 2007.
[17] M. Admane, M. Sorine and Q. Zhang, “Simulation of electric transmission lines with skin effect based on a reduced order differential model”, Reliability in Electromagnetic Systems, Paris, France. May 2007.
[18] F. V. Comandini, M. Mirrahimi and M. Sorine, “On the inverse scattering of star-shape LC-networks”, The 47th IEEE Conference on Decision and Control (CDC), Mexico. December 2008.
[19] J. Guilhemsang, F. Auzanneau, Y. Bonhomme, “Method for Detecting and Locating Defects By Reflectometry in a Wired Electric Network and Corresponding Device”, Patent WO/2009/087045, July 16 2009.
[20] Lelong A., Olivas M, “On Line Wire Diagnosis using Multicarrier Time Domain Reflectometry for Fault Location”, IEEE Sensors Conference, Aug. 2009, Christchurch , New Zealand.
[21] Lelong A, Sommervogel L, Olivas Carrion M, Ravot N, “Distributed Reflectometry Method for Wire Fault Location using Selective Average”, IEEE Sensors Journal, Vol.10, Issue 2, pp 300 – 310, Feb. 2010.