Characterization of electromagnetic radiation caused by "on line" wire diagnosis

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1 Introduction

Wire diagnosis aims at locating electric faults in cables. Reflectometry is a widely used method for this diagnosis. The principle of this method is to send a wide band test signal down the line, which reflects back at impedance discontinuities such as branches and defects (open or short circuits). This paper is related to "on line" diagnosis which consists in detecting and locating electric faults in wired networks while the target system is running.

Since the target system and the reflectometry are working at the same time, the test signal applied to the network has to satisfy application constraints. These constraints include electromagnetic radiation limitations. Most of time, the test signal is of the same class as those used in UWB (Ultra Wide Band) communications. In some applications, the test signal spectrum covers critical bands (in terms of EMC) such as the FM (76MHz - 108MHz) in vehicular technology or other radio communication bands which are brought under regulation.

Several methods have already been implemented into chips [1] and are ready to be embedded into cars or planes. So it is important to characterize electromagnetic radiations caused by the diagnosis system in order to keep it under control. Series of measurements have been made on typical automotive power supply networks. This work aims at providing EMC criteria for evaluating the appropriateness of reflectometry test-signal for a given application. These criteria will be used as a guideline to develop future reflectometry systems.

2 Reflectometry test-signals

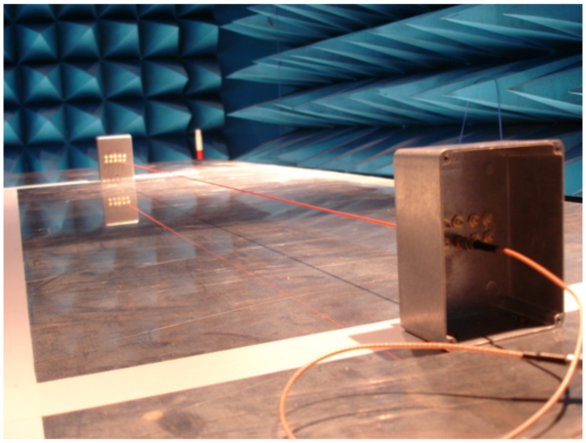
The basic test signal in reflectometry is a rectangular pulse. Usually, the time-energy distribution is improved using *pulse compression* technique [2] so the signal is a digital sequence such as MSequence or equivalent. The power spectral density of such a signal is given by

$$|S_{bb}(f)|^2 = (T_c A_s P)^2 \mathrm{sinc}^2(\pi f T_c) \tag{1}$$

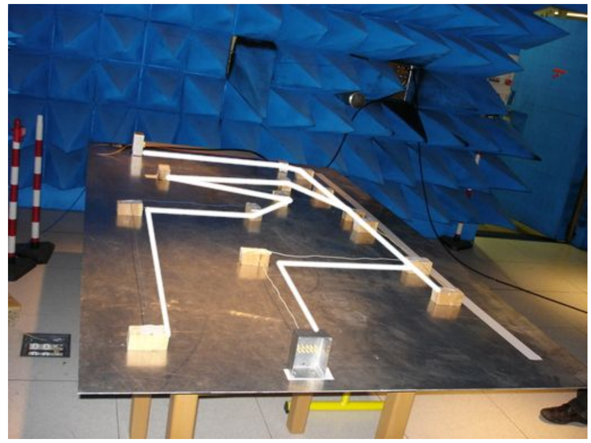
Where T_c, P, A_s are respectively the chip duration, the length of the sequence and its amplitude. T_c can be 10, 5 ns or even smaller, depending on the resolution of the reflectometry system. This signal is used in the STDR method (Sequence Time Domain Reflectometry)[3]. In this method the sequence is sent in baseband so the electromagnetic pollution is very important.

In some applications, it is impossible to inject this signal directly because of its wide spectrum. So a modulated sequence can be used to translate the spectrum. A simple modulation can be made by multiplying the baseband digital signal with a high frequency sinusoidal carrier waveform. The spectrum of such a signal is given by

$$|S_{hf}(f)|^2 = \left[\frac{T_c A_s A_m P}{2}\left(\mathrm{sinc}(\pi(f-F_m)T_c) + \mathrm{sinc}(\pi(f+F_m)T_c)\right)\right]^2 \tag{2}$$



(a) Simple wire



(b) Complex network

Figure 1: Pictures of networks tested in the semi-anechoic chamber

where A_m and F_m are respectively the amplitude and the frequency of the carrier wave. Processing associated to this kind of signal can be made by the SSTDR (Spread Spectrum Time Domain Reflectometry)[3] or the Modified SSTDR [4] methods.

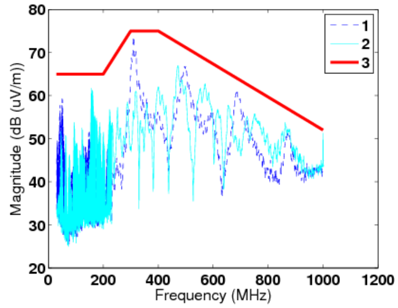
3 Measurement of reflectometry radiation power

The radiation caused by the injection of several reflectometry test signals in wired network was measured in a semi-anechoic chamber. The experiment was made according to regulation recommandations for vehicular technology. The objective of these measurements is the estimation of the radiated electromagnetic field in a far-field region when wire diagnosis is running. For this experiment, two network topologies were considered

- **A 1.5 meters simple line** as shown in figure 1(a). This basic case allows a simple interpretation and can be used as a reference.
- **A complex car network** corresponding to car break lights power-supply. Though the behaviour of such a network is difficult to predict it gives a concrete application result. This network can be seen on figure 1(b).

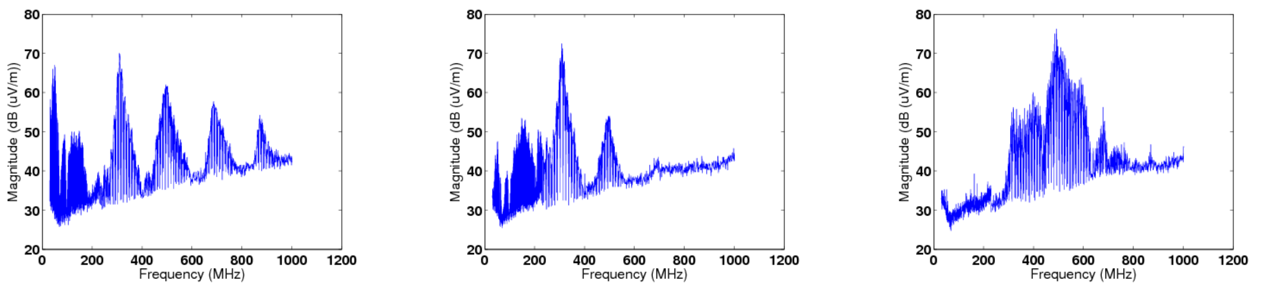
Networks are made of simple non shielded wires, the circuit is fixed 5 cm above a metallic ground plane inside the semi anechoic chamber. The plane is set at 75 cm from the soil. Two antennas were used for these measurements, a biconic one for the 30 to 300 MHz band and a log periodic one for the 300 MHz to 1 GHz band. it was placed 3 meters away from the network. Vertical and horizontal polarisation were measured. Only the vertical component of the electric field which is the highest one will be illustrated here.

In a first step, a wide band characterisation was made using a pseudo random signal with a chip rate $F_c = 1$ GHz. The pseudo random signal is generated by means of a LFSR (Linear feedback shift register), its peak to peak amplitude in the time domain is $V_{pp} = 1V$. Several measurements were made on both topologies. The context of each measurement is characterized by the load ending each branch of the network, by the point on wich the signal is injected and by the position of the ground plane. Two of the obtained results are shown on curve 1 and 2 of figure 2. Curve 3 shows the maximum radiations that can be observed from the considered networks according to these measurements. This window



1	dashed line	Simple line ended by open circuit
2	continuous line	complex network, all branches ended by open circuit
3	bold line	Maximum radiation window

Figure 2: Radiations caused by a 1GHz sampled signal with different topologies



(a) Baseband sequence $F_c = \frac{1}{T_c} = 200MHz$

(b) Modulated sequence (SSTDR) $F_c = 200MHz$, $F_m = 200MHz$

(c) Modulated sequence $F_c = 200MHz$, $F_m = 500MHz$

Figure 3: Radiations caused by typical test signals

is the envelope of all measured radiation spectra. The difference between the maximum window of figure 2 and the test signal spectrum can be considered as the gain of the block representing electrical network and the wave propagation path. This gain can be used as a tool to evaluate the radiated EMI with regulations related to the application when designing test-signals.

4 Reflectometry issues

Radiation limitations depend on the application domain and on the frequency band. When the peak to peak amplitude of the test signal is greater than 100mV, the amplitude of the electric field rise above critical values for some frequency bands. Limiting the amplitude is not always possible, for example, in noisy environments, acceptable signal to noise ratio has to be kept. This can involve the use of high amplitude signals. Even when the amplitude of the test signal is not high, radiations can be increased when several sources are injecting a signal simultaneously, as is the case in *distributed reflectometry*[5].

Since the limitations are not the same for all frequency bands, it is possible to keep a high amplitude by modulating the signal spectrum to fit boundaries defined by regulations so that the power spectral density is reduced in critical bands only. The most common way to achieve this for reflectometry is amplitude modulation as explained previously. The modified SSTDR [4] provides an interesting solution because the carrier frequency can be set as desired (unlike SSTDR).

Measurements of the previous paragraph were made a second time using various reflectometry signals. Results for the simple line are shown on figure 3. The peak to peak amplitude is still 1V (*ie* $A_s = 0.5V$ for the numeric sequence and $A_m = 0.5V$ for the carrier waveform). Spectral modification of radiations appears clearly on this graph. In the first case (fig 3(a)) a non filtered numeric sequence is directly injected, secondary lobes can be reduced by anti-aliasing filtering. On graphs (b) and (c) the sequence is filtered and modulated. The signal energy is the same but the distribution in spectral domain is different. For example the modulation with $F_m = 500MHz$ can be a solution to keep the FM band clean.

Though these methods provide a degree of freedom for the signal spectrum, it is not always enough to complete EMC specifications. One solution for more flexibility is the use of *multicarrier signals* defined by the following relation

$$s(t) = \sum_{n=1}^{N} c_n \cos(\omega_n t + \theta_n) \tag{3}$$

where c_n ω_n θ_n are respectively the amplitude the pulsation and the phase of each carrier. This solution is not available yet because it requires specific signal processing to provide the expected reflectometry results. Only limited methods were developed yet [6]. These processing methods are the object of our current investigation.

5 Conclusion

Until now the main considered constraint for “on line” diagnosis was the interference between the reflectometer and the target system. As shown by the presented results, EMC must also be taken into consideration and it can be a critical problem in some applications. This problematics shows on the one hand the importance of noise immunity (to be able to minimize the injected energy) and on the other hand the motivation of developping new processes such as multicarrier reflectometry.

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