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# A Test Bench for Measuring the Sensitivity Threshold of FM Receivers in the Presence of Interference Through Direct Injection of the Radio Signal

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**Abstract**— Evaluating the quality of radio reception is a crucial step in the production process of a vehicle. To evaluate radio reception, several parameters come into play. The radio signal depends on the nature of the electromagnetic propagation channel, the characteristics of the antennas and on the electronic reception chain. The quality of reception is also potentially affected by the interference signals generated at the RF input of the car receiver by the on-board electronics. However, current measurement methods of radio reception quality do not link these interference signals to the radio signal whose reception may be affected or not, according to the nature of interferences. This communication presents an original test bench allowing the evaluation of the quality of radio reception of a vehicle in a semi-anechoic chamber. This test bench constitutes an essential building block of a global methodological process. Its objective is to measure the sensitivity threshold of the radio reception chain (in the AM/FM/DAB bands) of the vehicle and to evaluate the evolution of this threshold as a function of the interference generated by the various components of the vehicle. We have set up two methods to carry out this experiment: injecting the radio signal directly at the input of the radio (conducted mode) and injecting the radio signal using an antenna (radiated mode). This article focuses on the conducted mode and describes the corresponding test bench. Some measurement examples are performed and discussed in the FM band.

**Keywords** — EMC, RF, Radioreception, Vehicle radio, CISPR25, modulation, Interference, noise, audio, Automotive, AM, FM, DAB, anechoic chamber, SIR (signal to interference ratio), degradation sensitivity.

## I. INTRODUCTION

Today, with technological advances in the automotive field, more and more electronic components in the vehicle generate electromagnetic interferences. These interferences constitute parasitic signals for the radio signals (of AM, FM or DAB type) received at the car receiver input [1], [2], [3]. If the radio signal power level is sufficiently higher than the interference level (assuming that this level is itself higher than the receiver sensitivity threshold), the radio signal is correctly demodulated and listening the broadcasted channel is possible [4]. If this is not the case, it then depends on the interference

nature. By using an EMI receiver, it is possible to measure the level of interference generated by the vehicle at the input of the car radio [5], [6]. On the one hand, this indicates the level of interference produced by the vehicle. On the other hand, it does not objectively link the interference measured to the quality of audio output [7], [8]. For instance, some electromagnetic pulses with low repetition rates may not significantly disturb the radio signal. However, to link electromagnetic interferences to the audio output quality, we have thought of exploiting the concept of receiver sensitivity [9], [10], [11]. The voltage sensitivity threshold is defined as the minimum voltage level, measured at the input of the car radio receiver, which allows correct demodulation of the radio signal. The voltage sensitivity of the car radio depends on the intrinsic noise of the radio receiver and on the interference produced by the vehicle. This sensitivity threshold therefore includes more information than the interference measurement at the input of the car radio receiver since it includes all the parameters that influence the radio reception [12]. Thus, the method that we propose consists in measuring the sensitivity threshold while injecting an AM, FM or DAB modulated signal in conducting mode in a semi-anechoic chamber, using a laboratory transmitter to simulate a broadcasting transmitter [13]. The principle of the method consists in automatically controlling the power level of the radio transmitter while measuring the signal to noise and interference ratio in the baseband signal at the audio output of the car receiver radio [14].

The rest of this paper is organized as follows. In section II, we first introduce the test bench dedicated to the sensitivity measurement of the car radio. Then, we present a comparison between the sensitivity measurements for two vehicles. Section III discusses the non-systematic correlation between the interference level and the sensitivity threshold. This discussion is based on the analysis of the voltage sensitivity threshold and the interference measurement at the input of the car radio at different instants. The last section concludes and brings perspectives to this study.

## II. DESCRIPTION OF THE SENSITIVITY THRESHOLD MEASUREMENT BENCH

### II.1. General description of the test bench and measurement principle

In this section, we detail the measuring sensitivity procedure. It consists in determining the minimum voltage of the RF signal modulated in FM (frequency deviation = 75 kHz, audio signal frequency = 1 kHz, audio signal amplitude = 12 dB $\mu$ V) allowing the car radio receiver to correctly produce the audio signal. A schematic view of the complete test set-up is shown in Fig. 1 and 2.

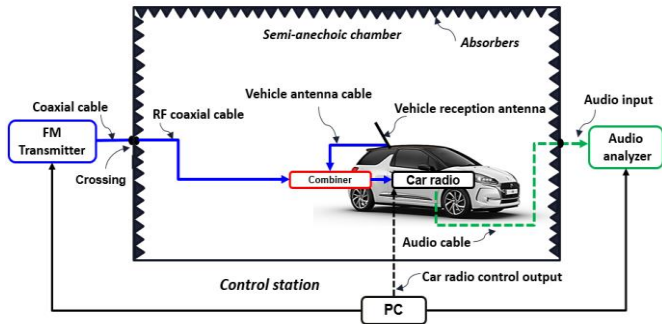


Fig. 1: The sensitivity measurement bench

The principle consists in adding (by means of a combiner marked with a red colored box in Fig. 1 and 2) the RF signal (modulated in FM by a laboratory transmitter) with the interference generated by the vehicle and collected by the vehicle reception antenna. Then, at a given frequency, the level of the radio signal is adjusted while evaluating the quality of the demodulated audio signal at the audio output of the car receiver.

The quality radio signal is evaluated by analyzing the signal (audio) to noise ratio (or noise & interference) (SIR) [15]. This is achieved using an audio analyzer (marked with a green colored box in Fig. 1 and 2). It is then necessary to set a signal distortion threshold (ratio of the noise energy to that carried by the audio signal) which corresponds to an acceptable audio quality [4]. Consequently, the RF voltage for which this distortion equals this prescribed distortion threshold, corresponds to the RF voltage sensitivity threshold of the radio receiver at the considered test frequency. This search is performed automatically over the entire radio frequency band.

Overall, the test bench is composed of three main parts: the vehicle under test, the anechoic chamber, and finally the test bench control room (outside the semi-anechoic chamber). Inside the vehicle is installed the radio chain part which is composed of the FM / DAB radio receiver, the radio control system and finally the audio system (Fig. 2). The radio control system contains a CAN Master control unit (inside vehicle) and a CAN Slave control unit (inside the control room). These control units are needed to be able to change the car radio

receiver frequency via an optical fiber. The PC sends the frequency command change to the Slave control unit that converts this command to the CAN protocol. The Master control unit receives this command and sends it to the car radio receiver.

Moreover, the audio system is composed of audio interfaces. The purpose of these interfaces is to transmit the sound (without alteration) from the audio output of the car radio receiver to the audio analyzer via an optical fiber. Finally, inside the control room of the test bench, we have the laboratory radio transmitter, the audio analyzer, the second CAN control unit (Slave) of the car radio receiver and the PC. A specific program executes the automatic control of the test bench.

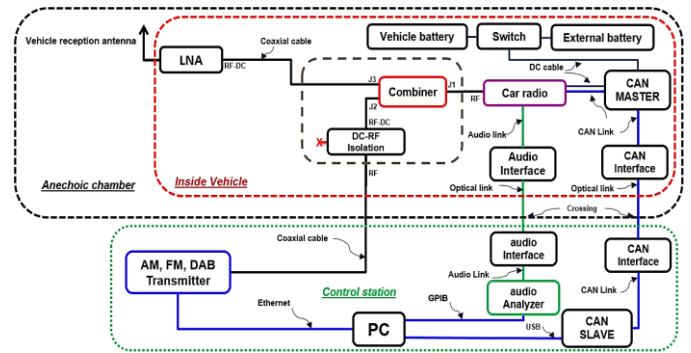


Fig. 2: Diagram of the overall assembly of the sensitivity measurement bench

We have also added a switch that enables to supply the car radio and the Master control unit under two power supply modes: the vehicle battery (mode 1) or an external battery (mode 2). The objective is also to be able to characterize the sensitivity threshold of the car radio alone without taking into account the rest of the vehicle, by performing a measure in the case where the vehicle is switched off (power supply in mode 2). The photo in Fig. 3 shows the assembly on the test vehicle side. It consists of the car radio, the Master CAN control unit, and the two optical interfaces (audio and CAN).

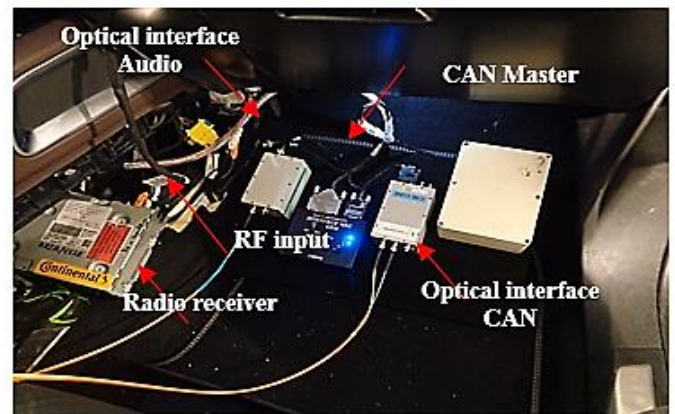


Fig. 3: View of test bench equipment installed on the passenger compartment side.

Since we have introduced extra equipment (CAN Master, optical modules) into vehicles, we checked that these have a sufficiently low radiated emission level. It was verified from measurements where only these interfaces and the car radio were supplied.

## II.2. Comparison between sensitivity threshold measurement at the input of the vehicle A and vehicle B radio receivers

This section presents a comparison between sensitivity thresholds measured at the input of the car radio for two different vehicles named A and B. The aim of this comparison is to show the effectiveness and aptitude of the method to classify vehicles according to the quality of their radio reception chain and according to the level of interference generated respectively.

It should be noted that the term interference in our case means, the interference of the vehicle components (I) plus the noise (N) of the car radio receiver which is part of the vehicle and which cannot be turned off. The acceptable audio interference criterion (C) is not based on the RF signal measured at the car receiver input but on the interference and noise level contained in the audio signal (after demodulation).

The criterion is arbitrary set to 0.8 % and 1 %, which corresponds to the noise and interference level contained in the audio signal. This means that the percentage of noise + interference must not exceed 1 %, otherwise the audio output is considered poor. Furthermore, the power level of the radio transmitter at which C is reached corresponds to the sensitivity threshold of the receiver.

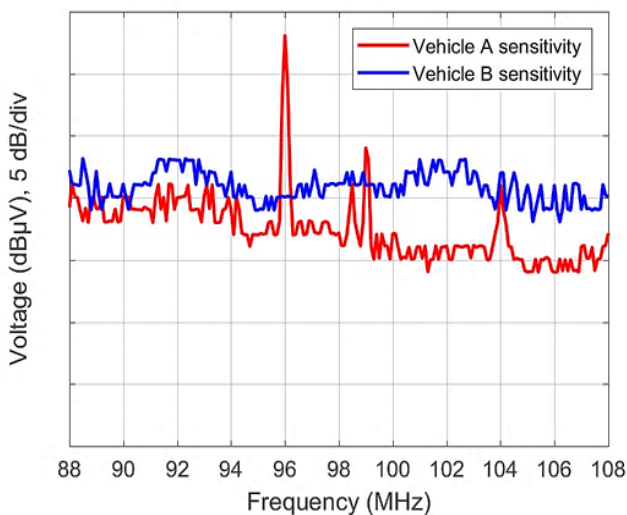


Fig. 4: Comparison between sensitivity measurement at the input of the vehicle A and B radio receivers (case where the engines are running)

The Fig. 4 presents the comparison between the sensitivity measurements at the car radio input of the two vehicles (in FM band) with a frequency step of 100 kHz in relative way (5

dB/div). However, the blue curve represents the sensitivity threshold measured on vehicle B and the red curve is the sensitivity threshold measured on vehicle A. On average, the sensitivity threshold of vehicle A is significantly lower than that of vehicle B with notable exceptions at the particular frequencies (96 MHz and 99 MHz). The sensitivity threshold is respectively of 13 dB and 4 dB higher than the voltage threshold levels of the vehicle B at the same frequencies. In this case, the narrowband degradation of the sensitivity threshold may be related to the narrowband emissions of vehicle components, such as the automotive electronic control units. It is evidenced in the next section where we compare the sensitivity threshold level and the interference levels measured at the car radio receiver input of each vehicle.

## III. ANALYSIS OF THE CORRELATION BETWEEN THE INTERFERENCE LEVEL AND THE SENSITIVITY THRESHOLD

In this paragraph, we present two measurements (according to the CISPR 25 standard) of the interference level at the RF input of the car radio in FM band with an EMI receiver (RBW = 9 kHz, SPAN = 250 kHz, time sweep = 10 ms / pts, VBW = auto). The two measurements are carried out on the same vehicle and in the same experimental conditions. The time between both measurements is one minute. The interference measurement at the input of the car radio (Fig. 5) is a different test from the sensitivity measurement at the input of the car radio. The principle consists in connecting an EMI receiver (through a RF amplifier) to the car radio and measuring the interference picked up by the vehicle antenna in an anechoic chamber. First, the active antenna of the vehicle must be supplied with a 12 V battery and then connected to the RF input of the EMI receiver using a coaxial cable. A PC controls automatically the test bench with a dedicated program. It provides the EMI level after compensation of cable losses and RF amplifier gain.

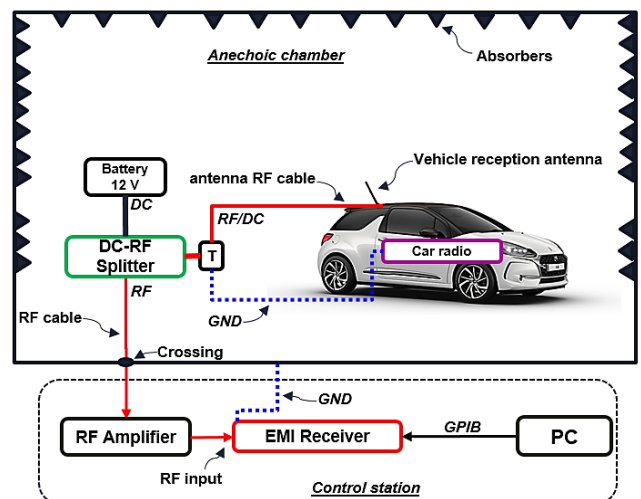


Fig. 5: View of interference measurement bench

a) *Interference measured at the car radio receiver input of vehicle A*

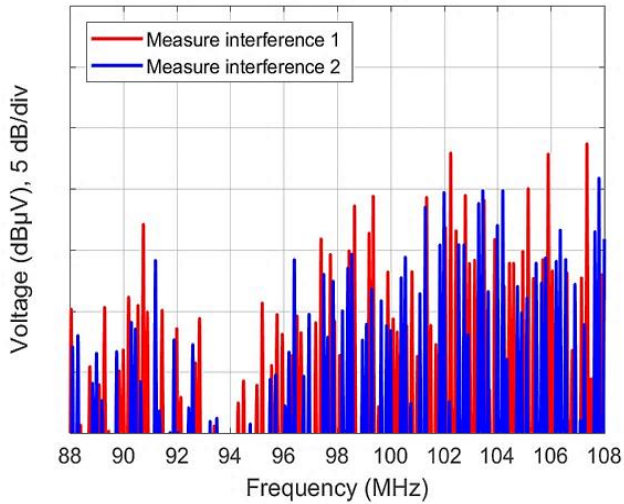


Fig. 6: Comparison between two interference measurements at the RF input of the car radio in FM band on the same vehicle A (case where the engines are running)

The Fig. 6 shows, in red and in blue, the superposition of two levels of interference measured at the input of the car radio in relative way (5 dB/div). For both measurements the interferences level variations are around 25 dB in peak measurement. However, we observe that, at some frequencies, the two measurements do not coincide with each other. It is also appears that between the two measurements the electromagnetic emission of the vehicle components changes in amplitude at the same frequencies. Radiated emissions may even appear or disappear at same frequencies. This highlights that certain electromagnetic emissions in vehicles are temporary. From this result, we conclude that it is not possible to confirm from an instantaneous measured interference that it is likely to degrade the radio reception.

b) *Interference measured at the car radio receiver input of vehicle B*

In this paragraph, we present two measurements of the interference level at the RF input of the vehicle B radio in the FM band. The two measurements are carried out under the same experimental conditions.

Fig.7 shows, in red and in blue, the superposition of the two interference levels measured at the RF input of the car radio in relative way (5 dB/div). For both measurements the interference level variations are around 10 dB at peak measurement. Contrary to the case of Vehicle A, we observe that the two measurements have a similar spectrum over the entire FM frequency band. It is also observed that between the two measurements the amplitudes of the electromagnetic spectrum does not change significantly as a function of frequency, except at 101 MHz, 104 MHz and 106 MHz with slight changes of about 2 dB between both instants of measurements.

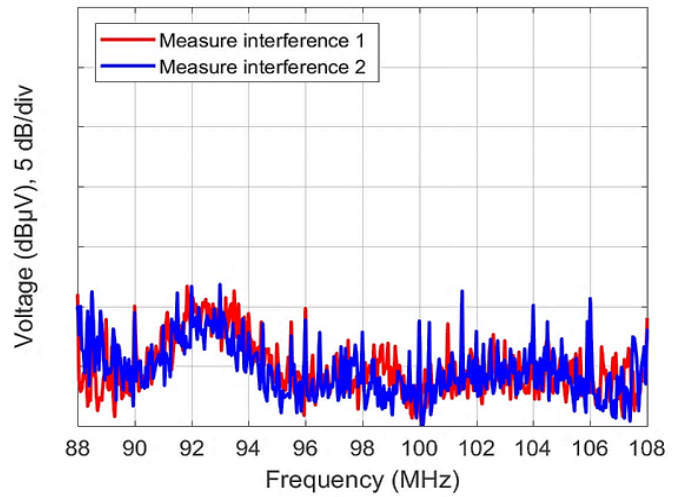


Fig. 7: Comparison between two interference measurements at the RF input of the car radio in FM band on the same vehicle B (case where the engines are running)

In addition, we notice that there are no spectrum components, which disappear, while others appear. The measurements show that for vehicle B almost the majority of the electromagnetic spectrum is rather permanent than temporary compared to vehicle A (Fig. 6).

In the following section, we discuss the measured interference levels and the sensitivity measurement results at the input of the car radio of the two vehicles.

c) *Comparison between interference and voltage sensitivity measured at the car radio input for both vehicles*

Performing this comparison between interference measurements and sensitivity threshold at the input of the car radio (of vehicle A and B) provides a way to validate both the methodology and the measurement process presented in this paper.

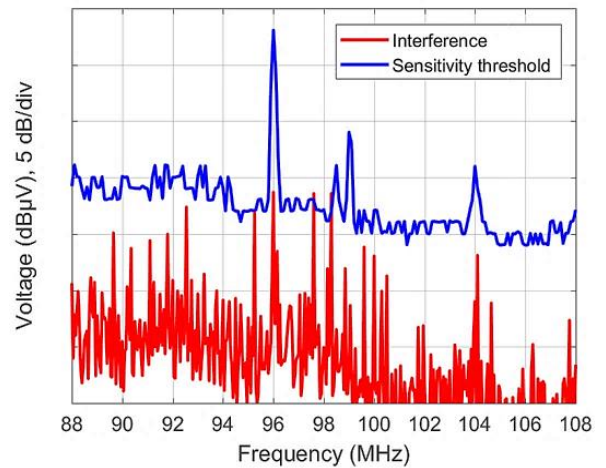


Fig. 8: Comparison between interference measurement and sensitivity threshold at the input of the car radio for vehicle A (case where the engines are running)

Fig. 8 represents the superposition of the interference (red curve) and the sensitivity (blue curve) measured at the input of the vehicle (A) radio receiver in the FM band (in relative way (5 dB/div)). On average, the interference level (red) is well below the sensitivity threshold (blue). Indeed, the acceptable audio interference criterion (C) was set to only 1% which corresponds to a weak distortion of the baseband audio signal. The difference between the two levels is approximately 14 dB in average over the entire band. In addition, the sensitivity measurement at the input of the car radio exhibits particularly high levels of sensitivity at some frequencies (96 MHz, 98 MHz and 104 MHz) where high electromagnetic interference levels were also recorded. Although the sensitivity threshold is higher at those frequencies this increase seems to be strictly related to the increase of the measured interference at 96 MHz but not at 104 MHz. We also observe that the sensitivity threshold is not influenced at some other frequencies where peaks of interference are recorded. The explanation given to this phenomenon is that the peak levels detected by the sensitivity measurement (in blue) are due to permanent or frequent electromagnetic interferences that have an impact on radio reception. The other spectrum components that are not detected by the sensitivity measurement are probably transient ones. As already mentioned, interference measurements of vehicle A at different times provide some changes of the EMI spectrum.

In the following paragraph, we show the same results for vehicle B. We perform a comparison between the measurement of sensitivity and the measurement of interference at the input of the car radio of this vehicle.

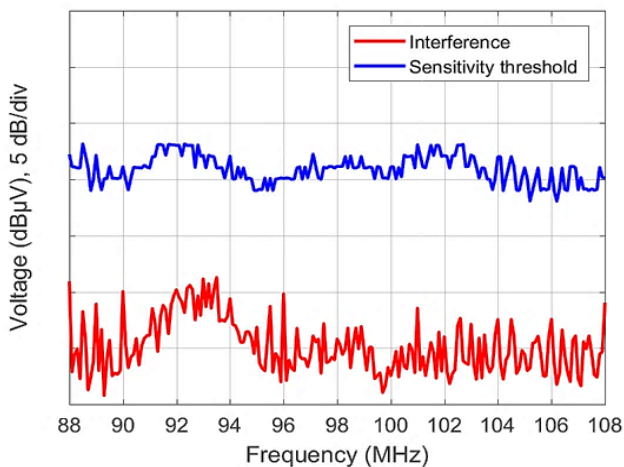


Fig. 9: Comparison between interference measurement and sensitivity threshold at the input of the car radio for vehicle B (case where the engines are running)

Fig. 9 represents the superposition of the interference (in red) and the sensitivity (in blue) measured at the input of the vehicle (B) radio receiver in the FM band (in relative way (5 dB/div)). In this scenario, we observe a better correlation between the two measurements as opposed to vehicle A. In this case, we reproduce the spectrum of the parasitic signal

globally with our sensitivity threshold measurement method. If we refer to Fig. 7, we indeed noticed that the spectrum of interference is approximately stable between the two measurements. The interferences measured in Fig. 7 are likely to be permanent, so the sensitivity threshold fluctuations according to frequency follow quite well the interference curve.

#### IV. CONCLUSION

This communication described a test bench for qualifying vehicle radio reception. The test bench with an automatic program is able to measure the sensitivity of the vehicle receiver input over the entire frequency band. This study showed that it is not possible to trust the interference measurements at the input of the car radio receiver to qualify the radio reception. Indeed, according to the measurements, we have shown that in the spectrum of electromagnetic interference, there are certain temporary components that do not affect the radio reception. The originality of our method is to be able to detect the electromagnetic spectrum components, which affects the radio reception. Furthermore, our method has some advantages compared to other methods presented in the literature. This method does not require a listener (subjective measurement) and is not limited to a few frequency tests (manual test), using an artificial signal interferer [16], [17] simulation methods [18], or implementation of a numerical filter in the receiver to reduce the disturbances [19], [20]. This test method can also be applied for digital communication (DAB).

One of the perspectives of the study is to show that with the test bench for sensitivity measurement in radiated mode, it is possible to find the same sensitivity results in conducted mode.

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