Channel Characterization Techniques for Wireless Automotive Embedded Systems

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Abstract— The number of wireless systems developed for automotive applications increases for security and comfort considerations. Among these applications, the wireless automotive access systems (Wireless Access Systems: WAS) and the direct intelligent tire information system (Tire Pressure Monitoring System: TPMS) have expanded considerably. The emitted (from the badge or the wheel units) waves change in phase and power according to the Multi-path propagation and produces both destructive and constructive behaviors all along the channel and particularly at the receiver side. These environment and operating considerations increase the radio-link budget complexity, and contribute to degrade the global transmission quality of the systems. It is then necessary to develop non disturbing measurement techniques to avoid interaction between the measurement setup and the measured fields. The purpose of this study is to provide an innovating space characterization technique for TPMS and WAS, to characterize the received power distribution inside and around the vehicle.

1. INTRODUCTION

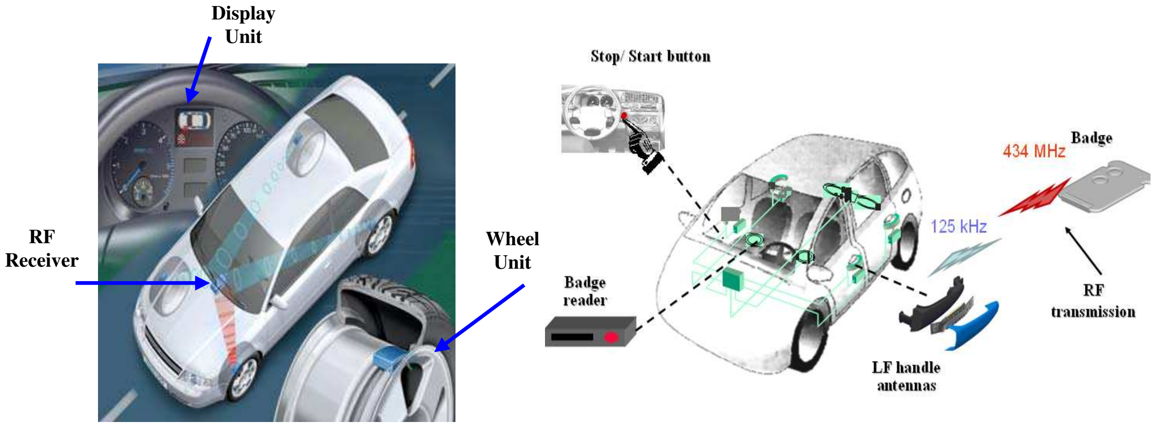
The high potential of accident prevention by using an intelligent tire system can be clearly seen through the different accident analysis. It has been shown that adverse road conditions, tire defects or their combination play an important role in road accidents. Moreover the decrease in the number of fatalities, provided that the entire car fleet is equipped with intelligent tire systems, could be significantly improved by preventing at least 10% of accidents. This would mean that over 4 000 life's could be saved every year in European countries. As shown in Figure 1(a) TPM System corresponds to a wireless communication between a transmitter module (T_X) fixed in each tire of the car, next called "Wheel unit" and a receiver (R_X) [1]. For the detection of the tire inflation problems, the "Wheel Unit" includes different electronic sensors (temperature, pressure, acceleration ...). The data are collected by the receiver where the different wheel unit frames from each tire are decoded by the control unit. Then a graphical display informs the driver with the pressure and temperature variations.

The car access systems operate the bilateral link LF/RF, by sending the different commands at 315 MHz or 434 MHz [2]. The signals are related to an electronic code featuring the key to control the vehicle (lock/unlock of doors and the trunk release, start of the engine, ...). As shown in Figure 1(b), automotive PAssive Start and Entry system (PASE) module generates a low frequency wake-up message (at 125 kHz) from the car towards the badge, and a RF challenge signal communicates back from the badge to the car at triggering event. The free radio license frequency of 434 MHz is chosen for this study [3].

2. RF SOURCE CHARACTERIZATION FOR TPMS IN NEAR FIELD

The radiofrequency source contains different elements which affect significantly the overall performance of the RF radio-link budget [4, 5]. Therefore, it is compulsorily to take in account the electromagnetic influence of each component influencing the field distribution of a radiofrequency source for TPMS (the antenna pattern, the rim, the tire and the ground). The main elements of the near field probing system are shown in Figure 2.

The full wheel with the ground influence is estimated in near field and reported in Figure 3. The near field measurements are performed for two different positions of the sensor at 90° (middle height of the wheel) and 180° (bottom of the wheel). The field distribution using a metallic plate as a ground put forward a distributed radiating source, whatever the position of the sensor. The presence of metallic walls close to the emitting module alters its radiating pattern. Other studies at higher RF frequencies show a larger number of distributed sources around the wheel unit, according to a distance close to the half-wavelength of the carrier $\lambda/2$.



(a) (b)

Figure 1: (a) Tire pressure monitoring systems. (b) Wireless car access systems.

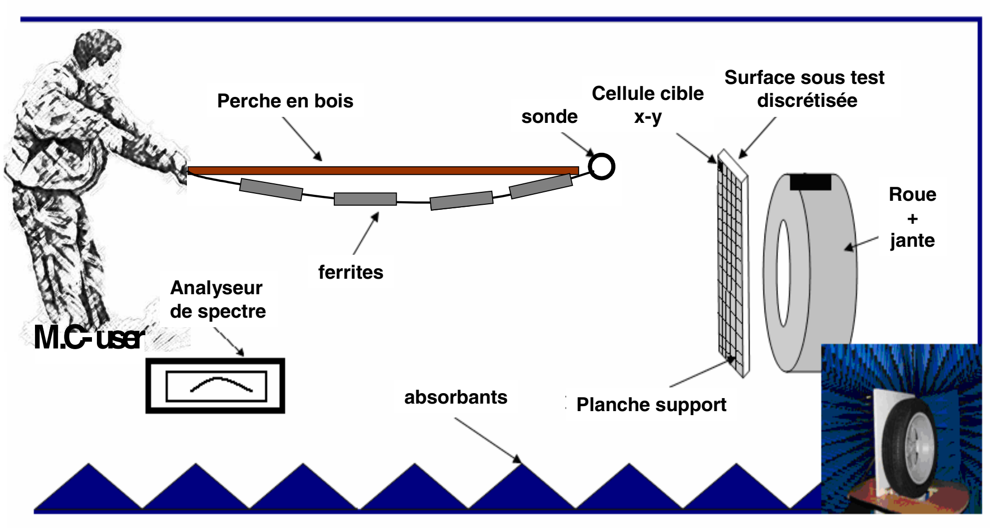


Figure 2: Near field measurement setup.

The measured power in near field varies between −67 dBm and −46 dBm (power dynamic range of 21 dB). Furthermore, the lumped source is divided into four main zones due to the reflections generated by the ground.

3. RADIO COVERAGE CHARACTERIZATION FOR TIRE PRESSURE MONITORING SYSTEMS

An efficient probing system for TPMS must provide a complete and reliable analysis of the radiofrequency channel. Thus, it is necessary to implement non disturbing measurement techniques to avoid harmful effects and to ensure an efficient field probing.

The principal elements constituting the characterization system for TPMS are:

- RF Transceiver system: is activated by LF commands, the wheel unit generates a pure carrier at 433.92 MHz during four minutes to ascertain a stable signal level for one wheel rotation.
- Reception system: is moved in eight different positions inside the sounded zone. For each receiver location we collect the angular power variation over three wheel turns. The receiver computes the RSSI values (Received Signal Strength Indicator).
- Transmission link: the harnesses have harmful effects on the electromagnetic measurements. Hence, a fiber optic link is used to connect the probed zone to the acquisition system without perturbations.

- Encoder angle: attached on a wheel and allows measuring precisely the angular variation of the probed wheel.
- Winch: pulls the probed vehicle with a constant speed (0.017 m/s) to ensure a complete wheel rotation with a high angular resolution (10 RSSI per degree).
- Acquisition system: developed software acquires the measured field from the receiver versus the rotation.
- Post processing: interpolate various measurement data with MATLAB and establish a spatial mapping of the internal coverage versus the angular sensor position and versus the space variation.

The field variation of the channel is measured versus space and wheel rotation angle for TPMS. The high resolution sounding system allows to track the channel variations and to locate fading effects. Optical components are used to get an accurate non disturbing field measurement technique. The RSSI (Received Signal Strength Indicator) collected at each reception cell is emitted through an optical fiber system which constituted with an optical transmitter, a receiver and a fiber link. The sounded zones are then presented versus a two dimensions diagram inside the vehicle close to the expected reception zone. The absence of any metallic cable (as usually used in dedicated setups) prevents from any interaction of the probing technique with the EM distribution close to the receiver or in the channel of propagation. Figure 5 shows a three dimensional representation of the collected radiofrequency power for a given TPMS emitter (wheel unit). The power variations

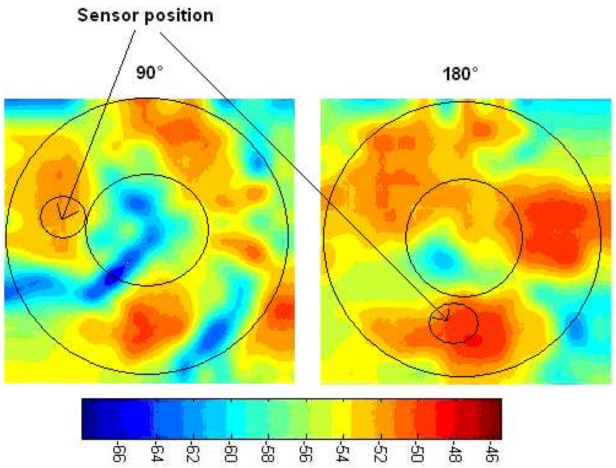


Figure 3: Near ground influence in near field measurement conditions (the sensor location is given by the black circle).

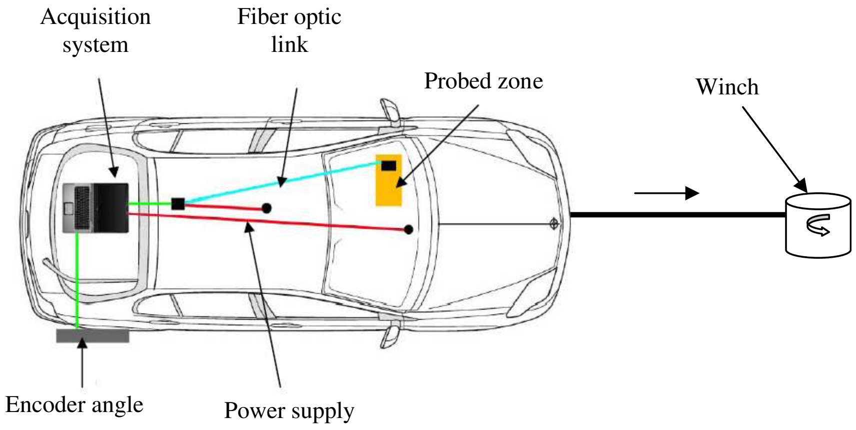


Figure 4: TPMS measurement setup for the inside coverage.

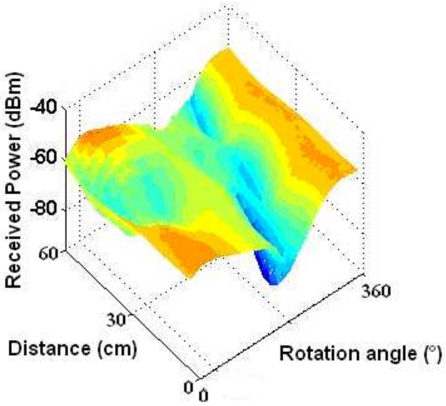
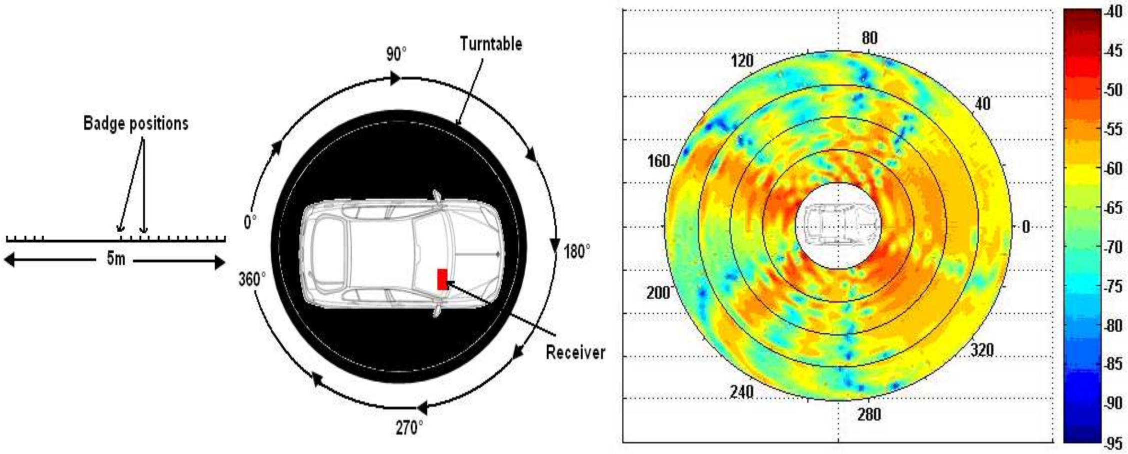


Figure 5: Radiofrequency channel variation in function of the distance and the wheel rotation.



(a) (b)

Figure 6: (a) WAS measurement setup for the outside coverage. (b) Measured power around the car for the horizontal polarization. $R_{\min} = 2\,\mathrm{m}$ and $R_{\max} = 6\,\mathrm{m}$.

are measured versus the rotation angle (wheel unit's emitter) and the antenna position (receiver location). The channel profile is unique for each wheel position and vehicle type.

It can be seen in Figure 5 that the multi-paths phenomena generates a stronger field variation. Further, some signal fading (zone with power is lower than the sensitivity threshold: $-90\,\mathrm{dBm}$) can be observed in the measured channel profile.

4. RADIO COVERAGE CHARACTERIZATION FOR WIRELESS ACCESS SYSTEMS

Various environmental parameters affect considerably the signal reception for WAS (Wireless Access Systems):

- Ground: the overall performance of an antenna system is extensively modified by the presence of the ground beneath it (power fall is observed for the horizontal polarization at 1.7 m in our systems).
- Path Loss: the measured path loss value is approximately 30 dB at 16 m from the transmitter.
- Vehicle structure: affects significantly the radiation patterns for both polarizations.
- Human body: decreases the antenna efficiency and deforms its pattern.

An effective measurement setup for the Wireless Access System is used to characterize the RF coverage around the vehicle and to track all space-angular fading. The measurement setup consists of five aim elements (shown in Figure 6(a)).

- Round table: turns the tested vehicle with a constant angular speed.

- Transceiver system: the badge is moved in 28 different positions form 2 to 6 m (the shift of the badge is about $\lambda/4$). For each badge location, we collect the angular power variation (0° to 360°).
- Receiver and post processing: collect the RSSI values and establish a 2D polar mapping of the external coverage.

A no-disturbed RF coverage in a defined zone outside vehicle (2 to 6 m) is shown in Figure 6(b). We notice that the received power varies importantly as function of the badge position around the vehicle.

5. CONCLUSIONS

Full innovating probing techniques were applied to characterize the field distribution in and around the vehicle. The presented procedures are used to model effectively the RF channel behavior inside the vehicle (versus the space location and the angle rotation) for TPMS and outside the vehicle for WAS (versus the badge position). An optical link is used to connect the probed zone to the acquisition system without creating any perturbation, and enabling to get an accurate field value. Based on the high measurement resolution, this technique allows to locate all signal fading effects. The probed zones are then mapped versus two dimensions polar diagram to define the suitable receiver position in order to improve the RF coverage. On the basis of the different experiments versus several car configurations (presence of many passengers, tire manufacturer, rim sizes ...), we have proposed matched strategies for improving the reliability of PASE and TPMS systems [6]: time diversity, space diversity or polarization diversity techniques have provided improvements up to 12 dB.

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