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RF Source Characterization Of Tire Pressure Monitoring System

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Abstract- The growing part of electronic embedded systems in automotive applications is motivated by the drastic requirements in transport safety and by the reduction of fuel consumption. Today more and more vehicles are equipped with the Tire Pressure Monitoring System (TPMS) in Europe and USA. The TPMS market is a natural offshoot of the industry's push for higher levels of comfort and security. In the USA this system becomes obligatory: however for safety, ecologic and economic reasons these sensors are largely used [1]. To ensure the good reception of the data transmitted from the sensors via a RF carrier, a good knowledge of our wireless radio-link channel is mandatory. Thus, the transmitter part of the system must be properly described: the RF source characterization for TPMS is discussed in this paper. We propose an original approach to characterize the source, from the transmitter antenna to the whole wheel system: the influence of each element (lumped antenna, rim, tire and ground effects) is quantified by successive embedding around the antenna. Several experimental studies are performed in far and near field conditions for a complete characterization.

I. INTRODUCTION:

A TPM System (Figure1) corresponds to a wireless radiofrequency transmission between a transmitter module (T_X) in each tire of the car and a fixed central receiver (R_X). The transmitter, next called "Wheel Unit", is composed with different electronic sensors (temperature, pressure, acceleration...) for the detection of the tire inflation status [2]. The data are collected by the receiver where the different wheel unit frames from each tire is decoded by the control unit. Then a graphical display informs the driver with the required pressure and temperature variations.

The RF radio-link budget is a keystone of the overall system reliability: the carrier propagation between the wheel unit and the receiver must be effective whatever the ground composition, whatever the angular position or speed of the wheel unit, for each of the four wheel units. Moreover, the

TPMS must be insensitive to RF interferences. The transmission between the wheel units and the receiver is tricky because of the many parameters involved. These environment and operating considerations increase the radio-link budget complexity, and contribute to degrade the global transmission quality of the TPM system.

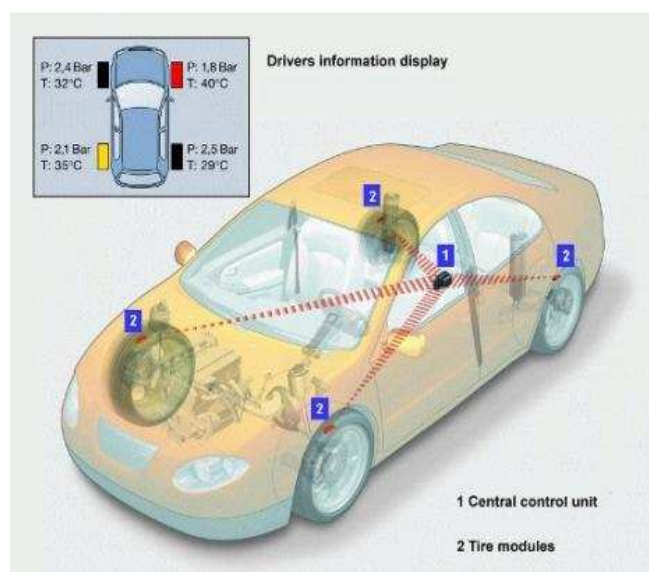


Fig.1: Tire Pressure Monitoring System (TPMS) description

The elements influencing significantly the field distribution of a radiofrequency source are the antenna radiation pattern, the rim design and material, the tire and the ground [3] [4] [5]. These elements deform completely the antenna radiation pattern and change its impedance. This paper focuses on the accurate source characterization, as the starting knowledge for the study of the radio-link budget of the TPMS: next are described the real contribution of each element of the source, by characterizing the power distribution in near and far fields conditions.

II. FAR FIELD CHARACTERIZATION OF THE RF SOURCE:

A. Far field measurement technique:

The far field characterization technique is largely used to define the radiation pattern of antennas. This study analyses the RF source versus the three dimensions (3D), instead of many 2D measurements by cuts: the 3D pattern knowledge is relevant with the natural angular rotation of the wheel unit under driving conditions. For that purpose we make use of a high angular resolution turntable, that allows collect and process the data, and to build an accurate full sphere radiation pattern. The main subsystems of the measurement setup are:

Probe antenna: this is a dual oriented antenna (Horizontal and Vertical polarizations), able to measure the radiated power from the transmitter (wheel unit).

RF source and turntable: the RF source is placed over a turntable, and we control its rotation over 360° , with an angular resolution of 0.3° . The RF azimuth can be tuned from 0° to 180° with 10° angular resolution.

PC control and post processing: the probe polarization and turntable rotation are controlled via a personal computer. The data are collected and processed with MATLAB to plot a three dimensional sphere pattern.

B. Rim influence:

The 3D metallic frame of the rim interacts with the transmitter, because of the coupling between the antenna and the hole in the rim. The radiation pattern deformation is analysed versus the rim size and manufacture, using a monopole antenna emitting at 433.92 MHz.

The far field of this 'RF source' is characterized for different polarizations. The size of the rim under test is 16".

The wheel unit radiation pattern (without rim, tire, ground) characteristics are given in table 1 for horizontal polarization (H) and for vertical polarization (V).

Table.1: wheel unit alone

Radiated power	Horizontal polarization	Vertical polarization
Maximum	57 dB μ V/m	57 dB μ V/m
Average	53 dB μ V/m	50 dB μ V/m
Minimum	29 dB μ V/m	15 dB μ V/m

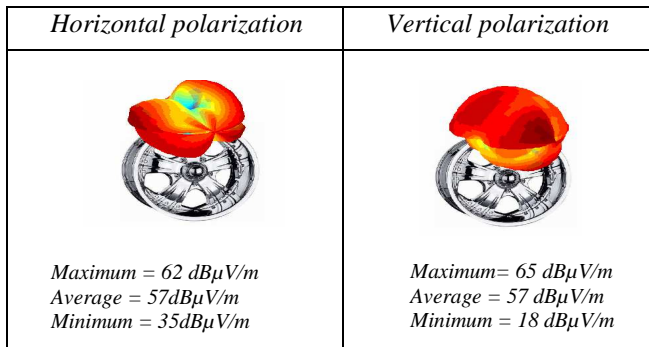


Fig.2: Rim influence in far field.

As shown in figure. 2, the maximum measured power becomes larger than the wheel unit alone, and the rim increases the maximal power by 5 to 8 dB. The average power level is 7dB higher for H polarization and 4dB higher for V polarization with the presence of the rim: the metallic rim affects the lower part of the sphere, and the hot zone is located in the upper right. The mean power values benefit from the metal shape reflector of the rim. However, even if far field measurements brings useful information about the isotropy and about the overall gain of the emitting module, the rim is close to the body of the car and these two frames interact as for a near field situation.

C. Tire influence:

The same far field measurement procedure is applied to the source once the tire is embedded to the structure: the influence of the tire is characterized with a rim size of 17" (cf. figure.3):

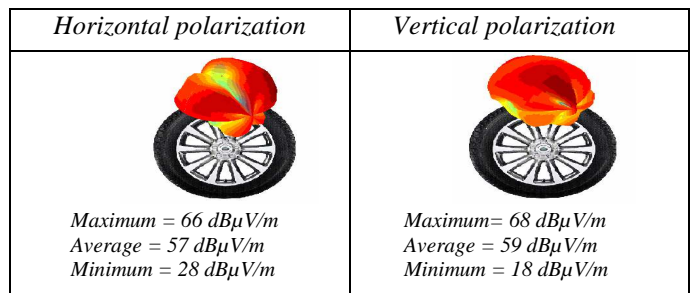


Fig.3: Tire influence in far field.

The presence of the tire on the rim increases the directivity by increasing the maximal that is focused in the upper right corner of the sphere where the antenna is located. The average power and minimum power do not change for V polarization, whereas the minimum power decreases for H polarization (the average value remains stable).

D. Ground influence:

Next, once the rim and the tire are embedded with the sensor module, the ground influence is estimated at first order (as the composition of the ground and the distance between ground and wheel vary): the ground effect is evaluated using a metallic plate (figure 4).

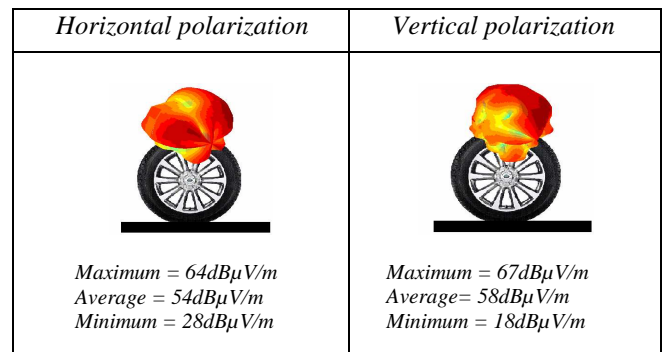


Fig. 4: Ground effect in far field.

The ground effect redistributes the radiation pattern for the vertical polarization (comparison between figure 4 and figure 3). However the maximum, minimum and average values do not change significantly (less than 2dB). Measurements in far field conditions only provide qualitative behaviour of the source distribution. The influence is more pronounced for H polarization, and only the minimum value remains stable at a higher level than for V polarization (28dB μ V/m versus 18dB μ V/m). This last characteristic can be one of the levers to overcome the black spots occurring in the radio-link budget of the TPM system.

E. Rim size and Tire manufacturer influence:

Each parameter constituting the ‘wheel unit’ potentially affects the radiating pattern in near field and in far field conditions: the influence of the rim size is thus a relevant parameter to study [6]. Comparisons are performed over three different rim sizes (16”, 17” and 19”), their radiation patterns are investigated only in one cut, and a cumulative distribution function (CDF) is used to compare statistically the rim size effect at 10% of the CDF :

Table 2: Rim size effect

Rim size	16"	17"	19"
Measured power at 10% of CDF	-39dBm	-36dBm	-34dBm

From the measurements in table 2, a cumulative distribution function (CDF) of 10% is given 5 dB higher for the 16” rim size compared to the 19” rim, and 3 dB higher compared to the 17” rim. To complete this study, an experimental evaluation of the tire construction’s influence is given in table 3: four different kinds of tires featuring the same size are compared, originating from different manufacturers (M1 to M4 in table 3):

Table 3: Tire manufacturer influence

Tire manufacturer	Measured power at 10% of CDF
M1	-36 dBm
M2	-35 dBm
M3	-31 dBm
M4	-30 dBm

As presented in table 3, the tire construction plays an important role in the RF source radiation. The tires coming from different manufacturers do not feature the same power repartition, or the same power levels. The difference on the radiated power is 6 dB higher for the tire manufacturer M4 compared to manufacturer M1. From this experiment, it is clear that the rim size and tire manufacture impacts greatly the radiation pattern and gain of the emitting source; these parameters highly impact the global budget link.

Next are presented the experimental data from the near field characterization: as the body of the car is close to the complete wheel unit, and considering the wavelength of the radio frequency carrier (about 69 cm), this study brings

complementary information about the radiation profile of the source, and about its interaction within the car structure.

III. NEAR FIELD CHARACTERIZATION OF THE RF SOURCE:

A. Near field measurement technique:

The radiofrequency SCAN function is used to characterize the power variation in near field conditions, close to the source position around the wheel unit. The measurement system is made of a spectrum analyser used to check the signal level via a probe positioning antenna (small sniffer-loop) and of a polystyrene board (100cm x 100cm). The results are given in a 2D array representation, where the power levels are indicated with coloured areas: red areas indicate high emission levels whereas blue areas stand for lower power cells (cf. figure 5 to figure 7). The system is placed into an anechoic room to prevent from external disturbances. This technique gives a representation of the spatial electromagnetic distribution of the wheel unit. Moreover, the contribution of each element to the overall wheel unit radiation can be characterized by embedding successively the rim, the tire and the ground to the transmitter. Some of the reasons why the RF link fails can be analysed with such a model of the RF source field distribution.

B. Rim influence:

By using the scanning positioning technique from figure, the near field map of the RF source mounted in the rim is fully characterized. The source distribution at near field is shown in Figure 5, when the wheel unit is placed at 0°.

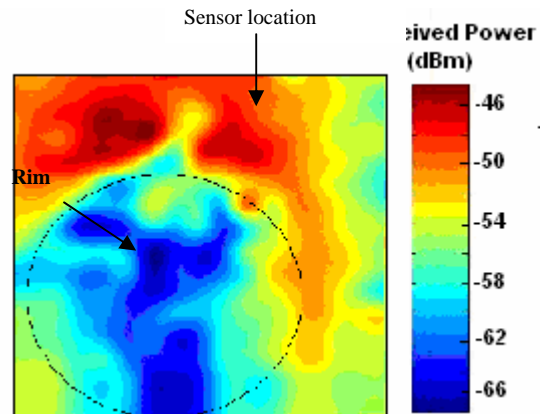


Figure 5: measurement of the influence of the rim over the source distribution in near field conditions.

Clearly, as shown in figure 5 the metallic rim structure prevents the penetration of electromagnetic waves in accordance with theory: thus, the lowest field levels are concentrated in the middle of the rim, whereas the highest fields are radiated on the upper part outside the rim (where the wheel unit is located), and decreases from part of the external shape of the rim. The difference between the maximum and minimum values is about 20 dB.

C. Tire influence:

The analysis in near field reported in figure 6 confirms the previous observations in far field: at first sight the field distribution in near field changes greatly. A large concentration of energy is located in the upper position around the transmitter (zone*), while a secondary emitting zone (zone**) featuring less energy (about 10 dB below the level from zone*) is observed in the lower part of the wheel.

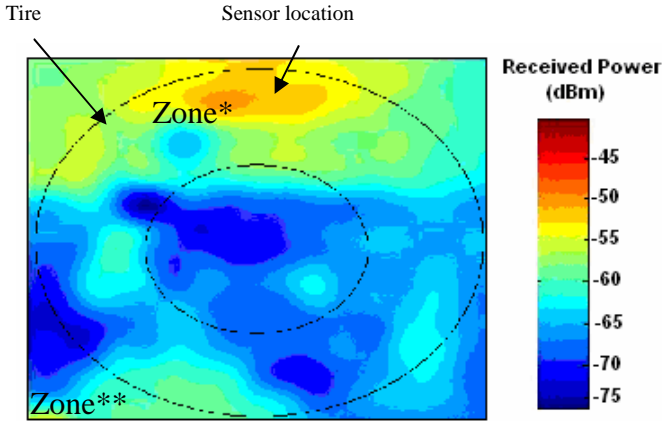


Fig. 6: tire influence on the emitting source in near field measurement conditions.

The maximum and minimum measured values are -42 dBm and -75 dBm respectively: the effect of the tire increases by 4 dB the maximal power (-46 dBm for the rim alone, figure 5), while the minimum power drops at -75 dBm (-66 dBm in figure 5). The range of power variation increases on account of the presence of the tire ($\Delta P=33$ dB with tire, $\Delta P=19$ dB rim alone). Results obtained in near field confirm the expected bad influence of the tire for the RF transmission budget.

D. Near field measurements technique:

In figure 7, the near field measurements are performed for one particular position of the sensor at 90° (0° , 180° have also been investigated). The new power distribution using a metallic plate (ground) put forward a distributed radiating source, whatever the position of the sensor.

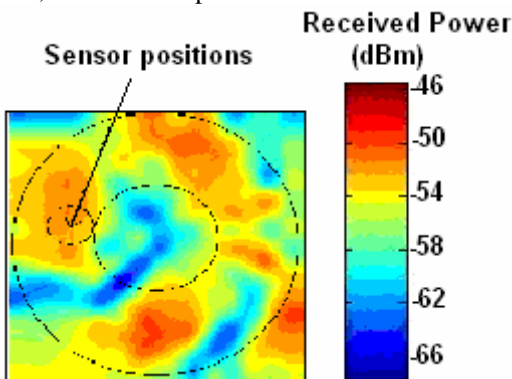


Fig. 7: Near ground influence in near field measurement conditions.

The presence of metallic walls close to the emitting module alters its radiating pattern. Other studies at higher RF frequencies (2.45 GHz for example) evidence a larger number

of distributed sources around the wheel unit, according to a distance close to the half-wavelength of the carrier $\lambda/2$. This last result has been confirmed by electromagnetic simulations using Empire software.

IV. CONCLUSIONS:

The design of a wireless system in a car module goes through the knowledge of the source, the propagation medium and the receiver module. An accurate modelling of the source is mandatory to build an efficient TPM System. This paper proposes a full characterization method to analyse the real radiofrequency source in Tire Pressure Monitoring Systems (TPMS), involving the rim, tire and ground reflector. From these numerous studies (near field, far field conditions), it is clear that the emitting source is largely influenced by the embedding of each different element: the power magnitude and distribution used as the source definition in a radio-link budget is thus not trite. Moreover, the source cannot be assigned as a lumped element, but as a distributed source. The metallic walls alter the shape of the source, close to the source: the body of the car is also an interferer for the TPMS module. The proposed model of the source can be assigned in electromagnetic software to compute the radio-link propagation (near field propagation) of the signal issued from the wheel unit, and thus find the better location for the receiver.

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