RFID System Investigation for Vehicular Identification Application

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Resumen: *La Identificación Vehicular Automática está siendo extensivamente usada en algunos países. Esta tecnología es una propuesta para identificar todos los vehículos automotores a lo largo de los caminos para tener control sobre toda la flota vehicular. El objetivo de este trabajo es la descripción de las pruebas de comportamiento en laboratorio y campo que se aplicaron a las varias etiquetas RFID comerciales existentes en el mercado,en el sentido de evaluar el cumplimiento de las características y/o especificaciones de cada una de ellas, y que en base al resultado de estas pruebas, se establecieron los criterios para seleccionar la más apropiada para ser usada por la flota vehicular mexicana.*

Palabras clave: RFID; Reader; Tag; Identificación vehicular

Abstract: *Automatic Vehicle Identification (AVI) is being extensively used in some countries. This technology is a proposal to identify all the motor vehicle circulating along the roads and take control on the whole motor vehicle fleet. The objective of this work is the field and laboratory performance tests description applied to several comercial RFID tags to evaluate the compliance of the characteristics and /or specifications of each one, and based on these test results, the selection criterias were established in order to select the appropriate RFID Tag to be used by the mexican vehicle fleet.*

Keywords: RFID; Reader; Tag; Vehicular identification.

I. INTRODUCTION

There are significantly number of ID technologies as bar codes, smart cards, voice recognition, some retinal scan (biometric technology), optical character recognition, etc., but the most appropriately to be applied to vehicular identificaction is the UHF RFID technology, which basically it is a wireless communication [1]. This communication link takes place between a reader and a tag, the reader is an interrogator and the tag is a transponder. Tags can be presented in different ways depends on the objects to identify, and they must be coupled electromagnetically with the material of the object where they are sticked, for the case of the AVI (Automatic Vehicular Identification), the tag is strapped on the vehicle windshield.

The objective of the Radio Frequency Technology applied to vehicular identification is to have all the motor vehicle information inside the memory tag, and generally, it is not necessary a lot of information in the chip memory's, when there is a complete database, with only unique ID number of the tag is possible identify the vehicles, when these tags go through the electric field generated by a reader, they transmit this information back to the reader, which operates as a transmitter and receiver device simultaneously, meanwhile the tag strapped on the car windshield operates as a receiver and storage device, and between them, the Radio Channel, this one influenced on the road by the electric and geometry environment characteristics,a violent outdoor electromagnetic environment,that is, reflections from ground and from various obstacles, for instance, vehicles at side, behind, or in front of the vehicle under test, some of them statics, orrunning at high speed.

The passive UHF RFID systems can carry out the automatic vehicle identification in far field to several meters, depending of tag characteristics (sensitivity-chip and antenna-gain). This technology can be used in heavy rain, snow, cold, or in subzero temperatures, as well as, recognize tags placed on the windshield of moving vehicles, so that drivers do not even need to stop for identification, or to open the vehicle window to enter access codes or push buttons to get a ticket [2].

High electromagnetic pollution environmentsaffects the RF signal propagation in the wireless communication systems, but in the case of UHF RFID systems it should be considered too other propagation problems, such as: if the vehicle identification takes place on a highway, the tags detection probability decreases with increasing vehicle speed; the multipath effect (reflections diffraction and scattering) if the vehicle moves at slow speed (city traffic); the interference reader-reader when they operate at the same time (toll booths) and each one is close to the other, moreover,factors to be considered are reader's antenna position, location and orientation of the tag on the vehicle's windshield, inclination of the vehicle's windshield, and radiation pattern of the reader's antenna and tag's antenna [3].This way, in this work theoretical and experimental researches with different systems have been analyzed under various aspects of the outdoor environment as multipaths, spatial distribution and near and far field performancein order to establishselection criterias to select the appropriate RFID Tag to be used by the Mexican vehicle fleet.

The paper is organized as follows: In section II the RFID tag test are described. In section III radio channel model is derived and finally conclusion in section IV.

II. RFID TAG TESTS

A. RFID Tag Selection

Actually, there is not a global public organization that regulates the frequency bands used by the RFID technology, however, there are a jumble of standars, as EPCglobal UHF Gen 2, ISO/IEC 18000-6, ISO/IEC 18000-7 [4], which are the most important regulations that govern the Air Interface UHF band, and only the standar ISO/IEC 18046-3 RFID technology discusses test procedures [5]. This is a cause of each country is able to select standars and frequency bands, however, there are specific rules, for instance:

USA uses902-928 MHz frequency band with no permission request, but EIRP (Effective Isotropic Radiated Power) must be no more than 4 W, similar case in Europa, which uses 869.40-869.65MHz frequency band, but EIRP must be no more than 2 W, Australia and New Zealand use 918-926MHz frequency band, but EIRP must be between 0.5-4 W range, and China and Japan requires to ask permission for this application.

That´s why the kind of the tag in the course of the selection process meant a source of differences between the manufacturers in the sense of which regulation or particular technical specifications (proprietary) would define the selection criteria, as well as, in the case of active tag manufacturers, they asked to do not bear electromagnetic compatibility aspects in mind. So, in order to establish impartial and strict selection criterias were defined EPC Class 0, Class 1, Class 2, and ISO 18000 as the regulations and technological constraints to satisfy, using the 902-928 MHz frequency band andEIRP must be no more than 4 W.

Let us remember passive and active tagscharacteristics, in the case of active tag it is not necessary line of sight (LOS),however applied to AVI, the active tag detection range normally is around 100 m of distance, in accordance with the standardizedEIRP, but this energy serves to make the electromagnetic environment tense, as a high electromagnetic pollution source. In the case of the passive tag applied to the vehicular identification, the sensitivity of these kind of tags is low, consequently the range detection is short, so, they operate around the reader in accordance with the concept of far field, this way, the communication link requires line of sight (LOS),not far away than 10 m for good performance,and due to normally the tag is strapped to the vehicle windshield to be detected by the reader, it is placed at the front of the vehicle;the price of each passive tag is approximately 0.2 usd and they can be manufactured as holograms, this way, due to characteristics above mentioned relative to the two kind of tags, the Passive UHF RFID Technology was selected for this application with the following characteristics:

StandarISO/IEC 18000-6C;Frequency Range: 902 a 928 MHz; Anticolision Protocol: Random Slotted; Error Detection Technique: CRC-16; Memory bank organization: Bank 00 Reserved, Bank 01 UII, Bank 01 TID and Bank 11 User; Memory Distribution (512 bits):Kill Password (32 bits); Access Password (32 bits); CRC-16 (16 bits); PC (16 bits); UII (96 bits); TID (64 bits); User (256 bits);Minimum sensitivity: -15dBm; Temperature: -20 - +85° C.; UV Protection

B. Static Tests

Nowadays, many kinds of electronic tag identification system based on RIFD are developed by manufacturers and research institutes. This way, different tags were tested in laboratory and field, then, due to the vehicle's windshield angle is not always the same,one of the tests consisted of verify the RFID tag sensitivity degradation, that is, the angle (0°, 15°, 30°, … 90°) at which the tag sensitivity is not enough to be detected. Other test consisted of verify the tag response when this one is strapped on different stationary car windshieldsand requested by a read/write portable reader device (Motorola Mod. MC9090G which meets ISO/IEC180006-C), as shown in Figure 1.A functional RFID tag must be appropriately read at different line of sight positions (-45° , 0° and 45°), not dependent of the inclination of the vehicle's windshield.

On the other hand, once the RFID tag has been sticked to the windshield car, it must approve the non-transferable test, that is, if the tag has been intentionally removed in order to be sticked again on other different vehicle, it should be useless.

C. Portal Installation

The test portal is built at 5.5 m high, where the reader antenna (YagiAndrew mod. ASPJ810) is installed at top and middle of the portal, the antenna inclination angle is 15º related to the vertical, and this one is connected to the reader device through a coaxial cable (LMR400), as shown in Figure 2.

This inclination angle is a common in some scenarios in order to ensure successful readings in the close proximity of the reader, and a minimum tag-reader distance clearance of 4 meters was considered while the mobile traverses the footprint.

The reader device (Impinj Speedway) transmits 4 W (36dBm) EIRP, which radiated power distribution, shown in Figure 3,called "reading area", was measured using a generic RFID tag and connected to a Personal Computer in order to transfer the collected data.

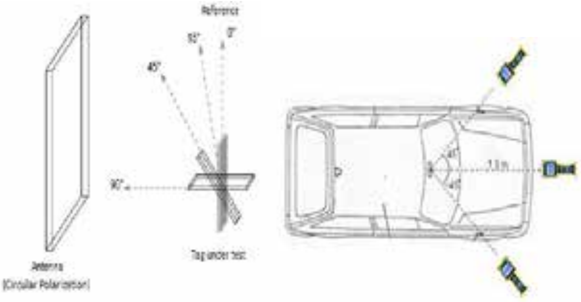

Figure 1. Tag tested at different angles.

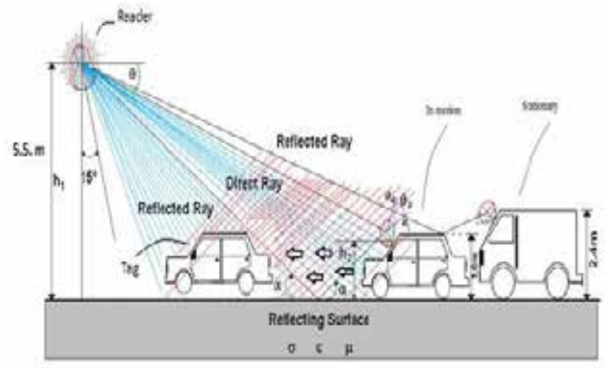

Figure 2. Measuring scenary.

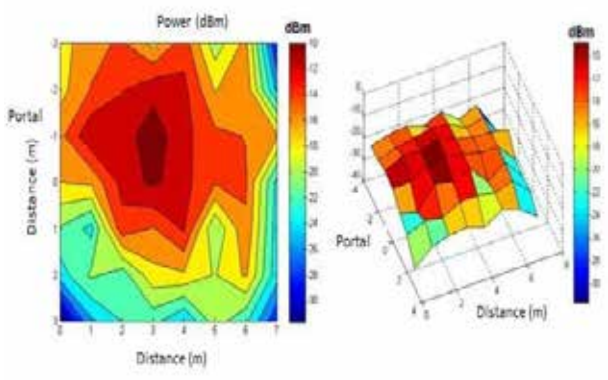

Figure 3. Radiated power distribution.

D. Dynamic Tests

Dynamic performance tests on the road consisted ofdetect the tag strapped on the windshield vehicle, when this one is running through the portalat different speeds (30km/h, 50km/h and 80km/h). The test is repeated three times for each vehicle, and different vehicles were used for it. Figure 4 shows the case when a bus, under test, runs through the portal.

Tests in road show detection errors when the vehicle crosses the portal at high speed (> 120 km/h) due to the number of correct readings is considerably not successful.

This situation is due to the communication between the reader and the tag must be established during a short interval time, let us call it, cross time period, which is the time during the vehicle crosses the portal, now, let us assume that the speed of the vehicle is faster than 120 km/h, and it runs at a this speed across the detection area (4 m), then, this small distance is covered during an interval time less than 100 ms, and if the data rate is 40 kbps, considering extreme case, that is, only 0´s, which it is equal to 20 ktaris, 400 ms time length, or only 1´s, which it is equal to 10 ktaris, 100 ms time length, then, based in the length of the frames, part of them will be received no complete by the tag or reader, resulting a failed tag detection.

Figure 4. Bus running through the portal.

Therefore, in order to establish the feasibility of RFID to Vehicular Identification, the obtained results have been very positive to this application, even though successful data transfer is lower when the vehicle crosses the portal at high speed (>120 km/h). This tag/reader detection error is a limitation of the system applied to vehicular identification, since if the vehicle has been stolen, probably it will be running at high speed to avoid be detected, being a disadvantage of the RFID Technology applied to vehiculat identification.

III. Radio Channel Model

A radio channel model proposal is the objective of this section, based in multipath environment and variables found in the experimental work, a set of tests were implemented in laboratory and in the field, results and performance curves will be presented along this section, this way, the reader can evaluate the convenience of the model for use in a particular analysis, in order to know the RFID signal performance applied to vehicular identification.

A. Multi-Ray Outdoor Environment

Recently, traffic control, vehicle monitoring and toll road applications have been developed, while indoor RFID applications can be conducted in fairly controlled conditions, vehicular environments are subject to multiple random phenomena. Therefore, in order to ensure a good readability, redundant readers are often used and some channel models validated through field observations in different automotive scenarios.

Several factors must be considered, for instance the reader's antenna position, the location and orientation of the tag on the vehicle's windshield, the inclination of the vehicle's windscreen, the radiation pattern of the reader's antenna and the tag's antenna. Other factors are the electrical and physical characteristics of the asphalt, the speed of the mobile and the nearby traffic conditions. All scenarios are analyzed considering the RF signal emitted by the reader, the effect of antenna coupling polarization (reader-tag), the RF signal multi-rays and the dispersion of the generated signals for different vehicle heights. Generally, some works have analyzed the radio frequency environment and the geometric RF signal channel propagation scenarios in different forms, but not relative to the propagation analysis applied for the vehicular environments [6].

A simplified model is proposed which fits with experimental data obtained in field, from a geometric perspective and equipment characteristics, it must comply with local regulations and technological constraints. Most regions restrict a device's EIRP, which is essentially the radio's transmit power plus the transmit antenna gain. To comply with EIRP limits, each device must either reduce its radio's output power, or antenna gain, or both. For instance, in relation to the downlink, the interrogator transmitted power is standardized, in the region 2, North America, the EIRP at the reader's antenna is limited to 4 W or 36dBm.[ERM, EMC Standard for Radio Equipment and Services Part 1: Common Technical Requirement, ETSI EN 301 489-1]. Additionally, the sensitivity of the tag's integrated circuit imposes a physical limitation with nominal sensitivity values, typically in the range from -10dBm to -18dBm depending on the manufacturer. On the other hand, in relation to the uplink direction, limitation factors relates the tag's efficiency of the backscattering signal which is associated with the antenna-chip coupling impedances and with the reader's sensitivity, whose typical levels are in the -80dBm to -95dBm range. Figure 2 illustrates a multi-ray scenario where the reader is above ground and the tag experiences a direct ray and reflected ray that depending on the current location and local conditions may be coming from the asphalt, from the vehicle's hood or from another vehicle's roof, as well as, it is exposed to multipath fading and variable delays, which, it is moving as the mobile moves, that is, the tag is involved in a violent electromagnetic environment.

B. Deterministic Multi-Ray Model for RFID Applied to Vehicular Identification

The vehicle identification's performance is highly dependent on the scenario's geometry and the RFID performance is highly dependent on the environment characteristics. While, in well controlled conditions, a deterministic analysis provides a good phenomenon understanding, and a probabilistic approach allows an adequate modeling in scenarios where tight control of the parameters is not feasible. The ray tracing technique has been used to model specific environment, but in this case, applied to vehicular technology, it is necessary consider the transmitter modeled as a source of many rays in all directions around it, each ray should be traced as it bounces and penetrates different objects in the environment, including, the ground (asphalt) and walls (buses, vans, sport cars, etc., located at adjacent lanes).

Then, multi-ray model [7, 8, 9] is widely known and can be applied and adjusted to the RFID vehicle identification process. Based on the Two Ray Model [9],shown in Figure 5, and the Friss equation, we propose the expression (1) in accordance with the statement of the problem, which geometry is shown in Figure 6, for both uplink and downlink signals, considering a multi ray environment,antenna polarization, andreflection coefficient, this way, the received power is given by:

$$P_r = P_t G_t G_r \, PLF \left(\frac{\lambda}{4\pi}\right)^2 \left| \frac{1}{r_1}\exp(-jkr_1) + \sum_{i=1}^{N} \Gamma_T(\alpha_i) \frac{1}{r_i}\exp(-jkr_i) \right|^2 \quad (1)$$

where:

P_r, received power G_t, transmitting antenna gain

$k = 2\pi/\lambda$, wave number P_t, transmitted power

λ, wavelength of radio frequency signal

$\Gamma_T(\alpha_i)$, total reflection coefficient

PLF, polarization loss factor

$r_1 = \sqrt{d^2 + (h_1 - h_2)^2}$, direct ray length

$r_2 = \sqrt{d^2 + (h_1 + h_2)^2}$, reflected ray length

$\alpha = \sin^{-1}\left((h_1 + h_2)/r_2\right)$, incidence angle

N, ray number

Note that the Fresnel reflection coefficient depends on the incident angle, α_i, reflecting surface electrical characteristic (conductivity σ, relative permittivity ε_r and relative permeability μ_r), and the polarization of the incident wave on the surface. Then, for a polarized TEM plane wave with the electric field parallel on the incidence surface (vertical polarization) the Fresnel reflection coefficient [10, 11] is given by:

$$\Gamma_{\|}(\alpha) = \frac{k_z \cos\alpha - \sqrt{k_z - \sin^2\alpha}}{k_z \cos\alpha + \sqrt{k_z - \sin^2\alpha}} \quad (2)$$

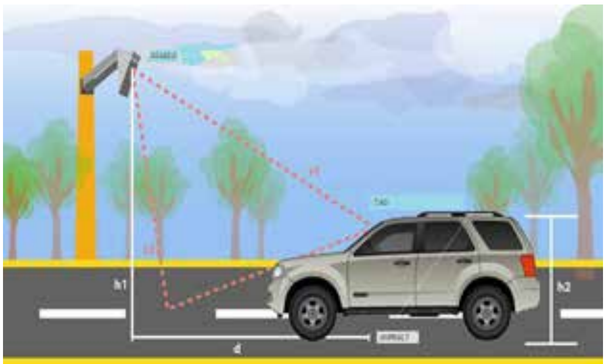

Figure 5. Two-Ray Model.

For a polarized TEM plane wave with the electric field perpendicular to the incidence surface (horizontal polarization), the Fresnel refection coefficient [10,11] is given by:

$$\Gamma_{\perp}(\alpha) = \frac{\cos\alpha - \sqrt{k_\varepsilon - \sin^2\alpha}}{\cos\alpha + \sqrt{k_\varepsilon - \sin^2\alpha}} \quad (3)$$

The parameter $k_\varepsilon = \varepsilon_r - j60\sigma\lambda$ is the complex permittivity where ε_r is reflecting surface relative dielectric constant, σ *Siemens/m* reflecting surface conductivity and λ incident signalwavelength.

An important impairment in RFID technology is the mismatch polarization between tag and reader antennas. For vehicular identification this problem is critical as the geometry changes frequently,in such a setting, that polarization coupling cannot be guaranteed. For example, the vehicle's windshield angle is not the same for all the kind of motor cars, then, the polarization mismatch renders an extra loss. Mutual polarization efficiency[12] is expressed in (4):

$$PLF = \frac{1+|\hat{\rho}_1|^2|\hat{\rho}_2|^2+2|\hat{\rho}_1||\hat{\rho}_2|\cos(\theta_1-\theta_2)}{(1+|\hat{\rho}_1|^2)(1+|\hat{\rho}_2|^2)} \quad (4)$$

where:

θ_1,θ_2, polarization phase ratios of reader and tag antenna respectively, and $\hat{\rho}_1$, $\hat{\rho}_2$ complex polarization ratio ofreader and tag antenna respectively.

Antenna polarization in a given direction is defined as the radiated wave polarization relative to the position antenna, and if the incoming wave electric field can be expressed as $\vec{E}_i = \hat{a}_w E_i$ then, polarization of the electric field at the receiving antenna can be written as $\vec{E}_a = \hat{a}E_a$, where $\hat{a}$ is unitary vector, and the polarization loss effects are quantified by the polarization loss factor (PLF), which is defined according to antenna polarization and the transmission mode, given by [13]:

$$PLF = |\hat{a}_w \bullet \hat{a}_a|^2 = |\cos\theta_p| \quad (5)$$

where:

θ_p is the angle between the two unit vectors, given by:

$$\theta_p = \tan^{-1}\left[\frac{h_1-h_2}{d}\right] \quad (6)$$

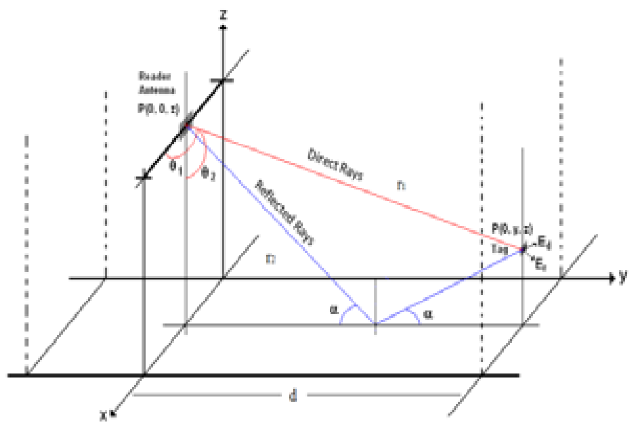

Figure 6. Model Geometry.

On the other hand, reflecting surface parameters, conductivity and relative permittivity have influence in the Fresnel reflection coefficient. For the case of asphalt, the typical values reported in the literature [14, 15] are: conductivity approximately equal to 0.001 to 0.005 range for dry asphalt and 0.1 for wet asphalt. In the case of the relative dielectric permittivity equal to 5 - 6 range for dry asphalt and 12 - 18 range for wet asphalt.This way, considering dry asphalt reflecting surface, $\varepsilon_r = 5$, $\sigma = 0.005$, wet asphaltreflecting surface, $\varepsilon_r = 15$, $\sigma = 0.1$ and operation frequency equal to 915 MHz, downlink analysis results are shown in Figure 7 and 8 for vertical polarization.

The best conditions occur for vertical polarization and a wet environment.

IV. CONCLUSION

Mexico proposes to use this technology to identify all the motor vehicle circulating along the whole national territory, which, it has motivated this investigation work, supported under several tests in road to different systems, analyzing the possible and different propagation environments where the system operate, with the purpose to establish the feasibility of this technology.

The principal aspects analyzed are the propagation paths, the cover distribution, the radio and electronic devices involved in the radio channel. Based in this analysis the appropriate tag antenna polarization,minimum detection distance between reader and tag, and position and inclination of the tag reader antenna are definedin order to establish the covering area and the spatial distribution of the electric field.From this analysis, the tag selection decision was founded on the stated criteria parameters and the best tag performance.

Finally, multipath propagation, polarization mismatch antennas, speed of the mobile, speed of surrounding objects, ground reflections and the transmission bandwidth of the signal are the most important physical factors in the radio propagation channel influence. The better conditions for the analyzed propagation channel are those with vertical polarization of the reflection coefficient and wet environment.

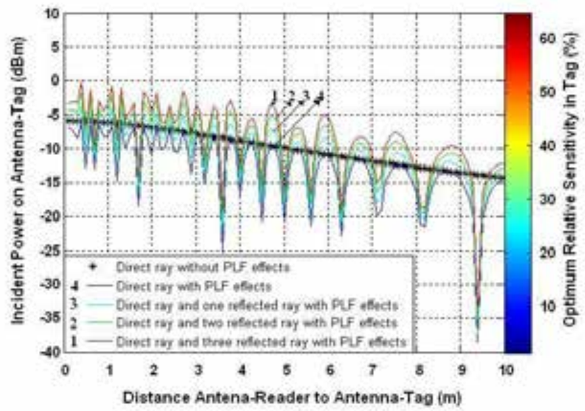

Figure 7. Vertical Polarization ($\varepsilon_r = 5$).

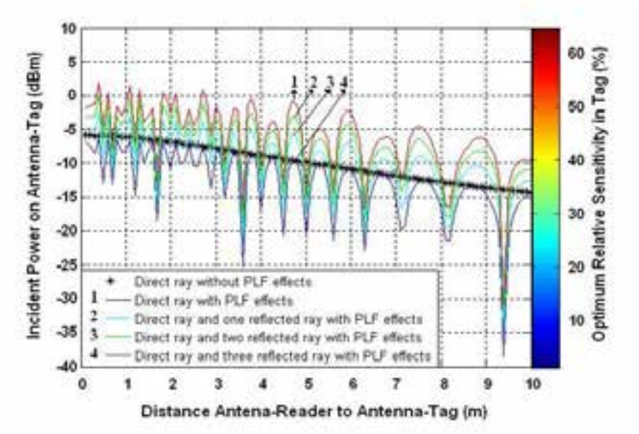

Figure 8. Vertical polarization ($\varepsilon_r = 15$).

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