

# RFID radio channel performance analysis

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**Abstract:** RFID applied to vehicular identification operates under a complex electromagnetic environment; the radio waves emitted by the reader, propagate, attenuate and join to the reflected waves from the ground and adjacent vehicles, being received by the antenna tag; part of the electromagnetic wave signal is backscattered/reflected back to the reader. In order to obtain a propagation model is carried a deterministic and statistical radio channel analysis out, in such a way that the signal performance could be predictable in an outdoor environment. RFID radio channel multipath environment analysis is the focus of this work.

**Keywords:** Rayleigh, Rician, Radio Channel, Tag, RFID

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## 1. Introduction

Radio wave propagation can be defined as the energy transfer by the electromagnetic radiation in the radiofrequency band. The radio wave propagates in several ways being dependent of the path geometry, the frequency and the electric properties of the propagation medium. In a radio mobile typical application, the base station has a fix position meanwhile the mobile station is moving; this is the case of the Radio Frequency Identification Technology, RFID applied to the vehicular identification, where the wireless communication link is provided between a remote transponder (antenna and integrated circuit), known as tag, containing the information into the memory block, strapped to the vehicle windshield, and an interrogator or reader used to identify with no physical contact or visual supervision; the objective is to have all the motor vehicle information, for example, owner name, driver's license, etc. RFID Technology works in the low, high, ultra high and super high band frequency. ISO 18006-C standard establishes the requirements of the physical and logical levels, where the reader starts the communication in the RFID system, operating in the 860-960 MHz frequency range [1].

Radio waves reach the tag antenna from different paths, each one with different amplitude, phase, and time delay, situation known as multipath propagation, being the asphalt surface, vehicles located at adjacent lines, and all the objects around the covering area, regular and irregular reflec-

tive sources of reflected waves, which change continuously and randomly; a dynamic multipath situation, where a continuous change in the electrical length of each path or ray, and the relative phase shifts between them, as a function of spatial position, complicating the signal envelope, causing a space selective fading as a result of the multipath propagation which is translated into a time selective fading experienced by the mobile receiver on the received signal as phase shifts between the different paths, causing constructive contribution or destructive contribution depending upon the relative phases. In this way a propagation channel analysis has become more important because it is useful for the simulation and analysis of digital transmission and for the quantification of the communication-link degradation within the channel.

This is the focus and motivation of this work, analyze the RFID radio channel, in order to establish a ray trace tractable model to characterize radio propagation RFID channel, in accordance with the observed signal properties in field.

## 2. Radio Channel

Radio Channel has been analyzed extensively in different papers, but no one of them has analyzed the RFID technology applied to vehicular technology. In this application the communication is line of sight, however there are other problems, such as: the multipath generated by asphalt and objects nearby to vehicles, as well as climate change. For line-of-sight channels, computing the electric field and/or

the received power is composed of a direct ray plus numerous rays due to reflections off objects, diffraction around objects, and transmission through objects, as shown in Figure 1, then, in order to predict power spectra, there is a direct path between the transmitter and the receiver, and reflected waves limited to a range of reflection angles. Therefore, RFID system under test is surrounded by the ground (asphalt) and walls (buses, vans, sport cars, etc., located at adjacent lanes), and it can be modeled as deterministic and/or stochastic model.

In this way, a model based on scattering is suitable, assuming that the incident electric field on the tag antenna is composed by a cluster of vertically or horizontally polarized travelling plane waves of random phase, with spatial angles of arrival and phase angles which are random and statistically independent. Then, let us analyze the situation from the deterministic and stochastic point of view.

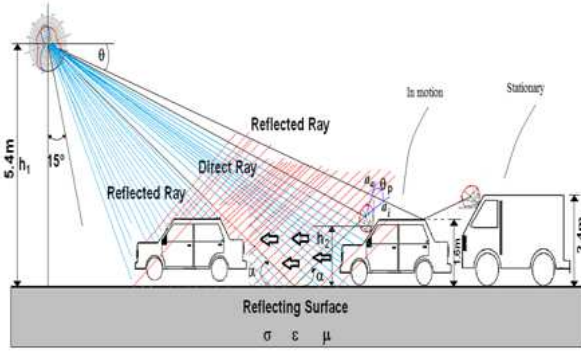


Figure 1. Multipath Environment.

### 2.1. Deterministic Model: Ray Tracing

As a result from the applied tests, the RFID feasibility to vehicular identification, depends of several variables, for example, the mismatch polarization between the tag antenna and the reader antenna due to frequent scenario's geometry changes, it should be remembered that the vehicle's windshield angle is not always the same, the speed of the mobile due to the vehicles don't move with uniform speed at the reader's antenna coverage area and incident reflected waves to the tag antenna coming from the reflecting surface and other objects. These parameters must be considered in an effort to meet a radio channel model.

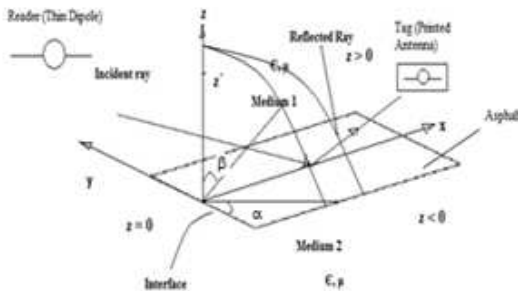


Figure 2. RFID Radio Channel Geometry.

In this way, let us consider an incident plane wave transmitted by the reader from region 0 (free space), where the plane of incidence is parallel to the plane  $xz$ , as shown in Figure 2. Expression (1) considers a multi ray situation [2] in accordance with the statement of the problem, involving the antenna polarization and the reflection coefficient in uplink and downlink communication.

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

where:

$P_r$  , received power  $G_t$  , transmitting antenna gain  
 $k = 2\pi/\lambda$  , wave number  $P_t$  , transmitted power  
 $\lambda$  , wavelength of radio frequency signal  
 PLF, polarization loss factor

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

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

$\alpha = \sin^{-1}(h_1 + (h_2/r_2))$  , incidence angle on the reflecting surface

$h_1$  and  $h_2$  are the height of the reader antenna and height of the tag antenna respectively

$d$  , separation between antennas

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

The reflected wave is the incident wave in itself affected by the Fresnel Reflection Coefficient, which alters the amplitude, phase and delay; the electric field polarization is defined relative to the plane of incidence, which contains the normal to the reflecting surface and the incident propagation vector, that is, parallel polarized electric fields lie in the plane of incidence and perpendicular polarized fields are orthogonal, given respectively by:

Vertical Polarization [3, 4]:

$$\Gamma_{\parallel}(\alpha) = \frac{k_e \cos \alpha - \sqrt{k_e - \sin^2 \alpha}}{k_e \cos \alpha + \sqrt{k_e - \sin^2 \alpha}}$$

Horizontal Polarization [3, 4]:

$$\Gamma_{\perp}(\alpha) = \frac{\cos \alpha - \sqrt{k_e - \sin^2 \alpha}}{\cos \alpha + \sqrt{k_e - \sin^2 \alpha}}$$

And the complex permittivity is given by:

$k_e = \epsilon_r - j60\sigma\lambda$  where  $\epsilon_r$  is the relative dielectric constant of the reflecting surface,  $\sigma$  (Siemens/m) is the conductivity of the reflecting surface and  $\lambda$  is the wavelength of the incident radio frequency signal.

Graphic of Figure 3 shows the radio channel performance, the rays are constructively or destructively combined in different points of covering area. It is convenient

to be mentioned that the ground surface is dry asphalt [5],  $\epsilon_r = 5$ .

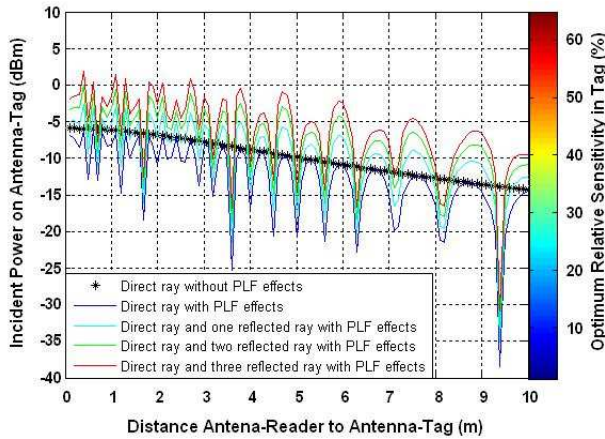


Figure 3. Vertical polarization,  $\epsilon_r = 5$  (dry asphalt).

### 2.2. Statistical Model

Reader sends a continuous wave carrier; tag receives the carrier for power supply, given by (2) and backscatters by changing the reflection coefficients of antenna. In such a way, data is sent to reader from tag.

$$E_n(t) = C_n \cos[\omega_0 t - \frac{2\pi}{\lambda} (x_0 \cos \alpha_n \cos \beta_n +$$

$$y_0 \sin \alpha_n \cos \beta_n + z_0 \sin \beta_n) + \phi_n]$$

where:

$$E(t) = \sum_{n=1}^N E_n(t), \text{ resultant field at the receiving point } (x_0, y_0, z_0)$$

$C_n$ ,  $n$ th incoming wave amplitude

$\alpha_n$ , spatial angle of arrival,  $x$ - $y$  plane, as shown in Fig. 2.

$\beta_n$ , spatial angle of arrival,  $x$ - $z$  plane, as shown in Fig. 2.

2.

$\phi_n$ ,  $n$ th incoming wave phase

Meanwhile the tag (the mobile) moves in the plane  $x$ - $y$  with a velocity  $v$  in a direction making a certain angle respect to the  $x$ -axis in accordance with the car movement, the tag antenna is under far field, as it comes closer to the reader, it is under the near field influence. Far electric field is due to when the distance between source and observation is large, and the near field when the source and observation point is short.

As we know in the passive RFID System, the reader supplies tag with electromagnetic energy, in this way, the interrogation signal is detected by the tag demodulator, which can be expressed in terms of in-phase and quadrature components [7], given by:

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

$$Q(t) = \sum_{n=1}^N C_n \sin(\omega_n t + \theta_n)$$

On the other hand, a small Doppler Shift of the  $n$ th wave component is given by:

$$\omega_n = \frac{2\pi v}{\lambda} \cos(\varphi - \alpha_n) \cos \beta_n$$

$$\theta_n = \frac{2\pi z_0}{\lambda} \sin \beta_n + \phi_n$$

Quadrature components are Gaussian components characterized by zero-mean, from that,  $\langle E(t) \rangle = 0$  in consequence the variance  $\sigma^2$  of  $I(t)$  and  $Q(t)$  is the same and equal to mean square value, that is, the mean power, in this way the probabilistic distribution function, pdf, is given by:

$$p_x(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{x^2}{2\sigma^2}\right)$$

where:

$$x(t) = I(t) \text{ Or } x(t) = Q(t)$$

$$\sigma^2 = \langle C_n^2 \rangle = \frac{C_0}{N}, \text{ } C_0 \text{ constant}$$

And the complex signal envelope  $E(t)$  is expressed by:

$$r(t) = \sqrt{I^2(t) + Q^2(t)} \quad \theta(t) = \tan^{-1} \left[ \frac{Q(t)}{I(t)} \right] \tag{4}$$

Figure 4 shows the tag demodulator in terms of In-phase and Quadrature components.

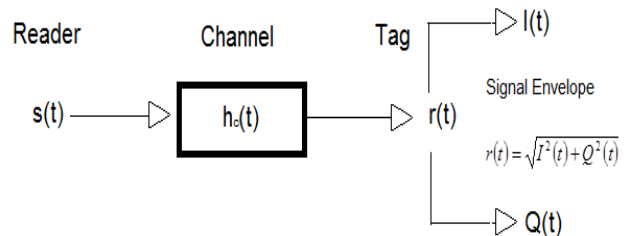


Figure 4. In-phase and quadrature components.

In this way, let us analyze two possible scenarios, the case of a scattered environment, with not well defined direct ray, and the case where there is a line of sight propagation path.

### 2.2.1. Rayleigh Distribution

It is possible to presume the presence of a direct propagation path. However, line of sight shadowing may occur when a tag to be read is in the nominal reader foot print and the tag is behind a tall vehicle that obstructs the direct path. In a practical scenario the tag to front vehicle distance is determined by the car hoot and the safety guard distance that tends to increase with vehicles' speed reducing the likelihood of a mobile being in a shadowing region, as shown in Figure 5. In traffic jam conditions the vehicles separation will be less and the speed will also be reduced increasing the number of readings as the mobile stays longer in the interrogator footprint.

In this case, the subject is a scenery scattered environment and each ray is independent and randomly phased, thus, the envelope of the signal will be Rayleigh Distribution, and the received signal envelope is described as Rayleigh Density Function [8] expressed as:

$$p_r(r) = \frac{r}{\sigma^2} \exp\left(-\frac{r^2}{2\sigma^2}\right)$$

where:

$\sigma^2$ , mean power

$r^2/2$ , signal power

And the statistical parameters of the envelope are:

Mean Value:  $\langle r \rangle = 1.2533\sigma$

Mean Square Value:  $\langle r^2 \rangle = 2\sigma^2$

Variance:  $\sigma_r^2 = 0.429\sigma^2$

It should be considered an additional effect, the phase fluctuations, however pdf follows a uniform distribution in the received signal as a result of the multipath propagation and due to RFID application works in the UHF Frequency Band, the wavelength is short and not disturbed in the phase by small changes in path length. Then, it is possible assume that the phase angles have a uniform density function:

$$\langle \theta \rangle = \pi; \quad \langle \sigma^2 \rangle = 4\pi^2/3; \quad \sigma_\theta^2 = \pi^2/3$$

### 2.2.2. Rician Distribution

In this case there is a line of sight propagation path, as shown in Figure 6, the buses at side of the vehicle under test are the scattered environment part causing that the signal reaches at the receiver by several different paths, but at least one of them is line of sight as shown in Figure 3.

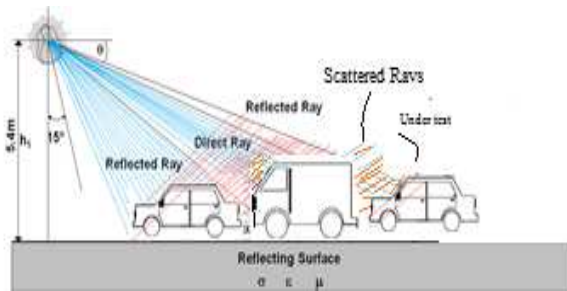


Figure 5. Rayleigh Environment.

First part in the expression (1) represents the power in the line-of-sight,  $C_0^2/2$ , and the second part represents the reflected and scattered components, that is, a dominant component signal and Rician Fading signal, which can be represented in terms of in-phase and quadrature components, as shown in Figure 7.



Figure 6. Rician Environment.

The mean value of the In-Phase and Quadrature components in Rician fading is non-zero due to a deterministic strong wave [9], the line of sight ray, being the Rician factor  $K$  defined as the ratio of dominant component power over the (local-mean) scattered power, that is, faded envelope power produced by the mean value of  $I(t)$  and  $Q(t)$ , given by,  $K = C_0/2\sigma^2$ .

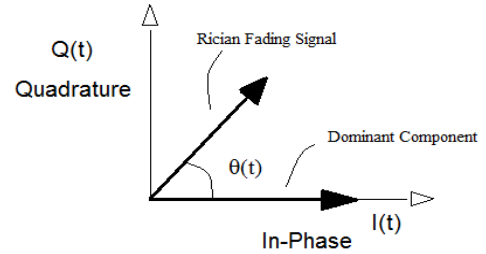


Figure 7. Dominant component and Rician Fading signal.

The number of the component waves vary as the tag moves, the envelope follows a non-Stationary Rician Process, that would mean, a root mean square value  $\sigma$  not constant, that is,  $\sigma(t)$ , and the received signal tag antenna will be a Rician Distribution fluctuating quantity with a baseband spectrum approximately equal to  $2\nu/\lambda$ , being,  $\nu$ , the mobile speed. Hence if the tag detection is successful when the speed of the vehicle is up to approximately 120 Km/H, thus the Rician Distribution baseband spectrum fluctuates up to 203 Hz.

### 2.3. Speed Factor

Let us remember that the Passive RFID tags answer to a reader query by transponding a modulated signal according



to the information already stored in the memory of the tag, operating on the road, where vehicles are passively tagged on the windshield and read at high speeds while passing through a portal is subject to multiple random phenomena. Additionally, in the same way, a portal holding at mid-lane Yagi at 5.4 m height with main beam tilted down  $75^\circ$ . This elevation angle is a common in some scenarios in order to ensure successful readings in the close proximity of the reader. A minimum tag-reader distance clearance of 4 meters is considered and the reader enquiries several attempts while the mobile traverses the footprint, as shown in Figure 8.



Figure 8. Vehicle under test crosses through the portal.

In this way, the communication between the reader and the tag must be established during the short interval time when the vehicle crosses (40 km/H to 140 km/H) through the portal where the reader is installed. Table 1 and graphic in Figure 9 show the results of the performance tag detection at different speeds 80 Km/H, 120 Km/H, and 140 Km/H. Four different vehicles and different tags were used for the speed test.

Table 1. Different vehicles under test.

Vehicle	TagNumber
Jeep Liberty	Tag No. 91
GM Van	Tag No. 90
Stratus Chrysler	Tag No. 26
Mustang Ford	Tag No. 88

The communication establishment must be able to adjust to the interval time during the vehicle crosses through the portal, the speed of the vehicle is going from 40 Km/H to 120 Km/H, and keeps uniform, the vehicle takes the area detection (4 meters), from 0.36 seg. to 0.12 seg., respectively, resulting clear that these time intervals are enough long to host several reader tag communication trials. However the obtained results have been very positive to this application, the test results in road casts doubts on the tag detection performance, due of the number of successful readings is lower when the vehicle crosses the portal at high speed, as shown in Figure 9, this failed tag detection

performance at high speed represents a weaknesses of the system applied to vehicular identification, due to if the vehicle has been stolen, probably it will be running at very high speed to avoid be detected. Based in this analysis it is possible to say that the origin of this fail situation is due to time interval during the vehicle crosses at high speed is not enough long to enable the communication between reader-tag and tag-reader, causing that commands or responses contained in the data frame are not appropriately received. Increase the data rate in both directions gives a chance to prevent it.

### 3. Conclusion

In this work the RFID radio channel applied to the vehicular identification has been analyzed from a deterministic and stochastic point of view, which conducts oneself as Rayleigh and/or Rician probabilistic density function. It has been found that the antenna polarizations, ray incidence angles, reflections off objects, car speed are the factors that have influence on the radio channel. The expressions in this work model the RFID radio channel applied to vehicular identification which constitute a contribution resulted of the work in field and laboratory.

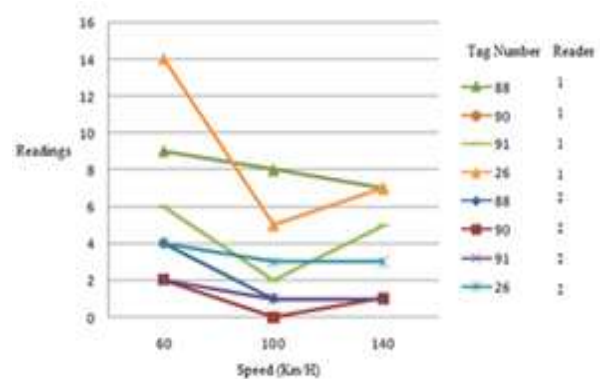


Figure 9. Speed Test Results.

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