Journal de Ciencia e Ingeniería

Journal de Ciencia e Ingeniería, Vol.5, No.1, Agosto de 2013, pp. 80-87
Investigación - Ingeniería Mecánica y Eléctrica

RFID applied to Vehicular Identification and the Failed Tag Detection

RFID Aplicado a la Identificación Vehicular y el Error de Detección de Etiqueta-Lector

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Recibido:23/3/2013; revisado: 6/5/2013; aceptado: 13/5/2013.

Meneses González, R., Montes Peralta, L.: RFID applied to Vehicular Identification and the Failed Tag Detection. Jou.Cie.Ing. **5** (1): 80-87, 2013. ISSN 2145-2628.

Abstract

Radio Frequency Identification System, a wireless communication system, recently it is applied to vehicular identification, nevertheless this system is not at all perfect for this application, tests in road show detection errors when the vehicle crosses the portal at high speed due to the number of correct readings is not totally successful. 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 very high speed to avoid be detected. In order to propose possible solution, the focus of the work is to analyze the receiver section of the system and find the origin of this situation.

***Keywords*:** RFID, tag, eader quadrature command frame.

Resumen

El Sistema de Identificación por Radio Frecuencia, sistema de comunicación inalámbrico, recientemente es aplicado a la identificación vehicular, sin embargo este sistema no es del todo perfecto para esta aplicación, pruebas en campo muestran errores de detección cuando el vehículo cruza el portal a alta velocidad dado que que el número de lecturas correctas no es del todo exitosa. Este error de detección de etiqueta/lector es una limitación del sistema para esta aplicación, ya que sí el vehículo ha sido robado, probablemente correrá a alta velocidad con objeto de evitar ser detectado. Así que en el sentido de proponer posible solución, el enfoque de este trabajo es analizar la sección de recepción del sistema y encontrar el origen de esta situación.

***Palabras Claves*:** RFID, etiqueta, lector, cuadratura, trama de comando.

1. Introduction

Radio Frequency Identification Technology, RFID applied to the vehicular identification, consists of a wireless communication link between a remote transponder (antenna and integrated circuit), known as the 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,

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etc.

In this radio mobile typical application [7], the base station has a fix position meanwhile the mobile station is moving, that is, 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, an outdoor environment, where vehicles are passively tagged on the windshield and read at high speeds while passing through a portal under a multiple random phenomena, that is, the radio waves reach the tag receiver from different paths, each one with different amplitudes, phases, and time delays; this situation is known as multipath propagation, being the asphalt surface, the vehicles located at adjacent lines of the vehicle under test, and all the objects around the covering area, regular and irregular reflective sources of reflected waves, which change continuously and randomly, experienced by the mobile receiver on the received signal as phase shifts between the different paths, causing constructive or destructive contribution depending upon the relative phases.

During the tests in road the RFID applied to Vehicular identification has showed a positive performance, and actually is applied for it, but the tests have showed too, that successful readings are lower when the vehicle crosses the portal at high speed (140 km/h). This way let us analyze the RFID tag and reader demodulation process in order to establish the weakness of the system performance and improve RFID system applied to vehicular identification.

2. Tag Demodulation Process Analysis

Let us remember that there are two kinds of tags, the active tags which are powered by batteries radiating RF electromagnetic energy permanently and the passive tags which are powered by the reader?s field, the received electromagnetic signal acts as a power source and supply the power to the chip energy answering the reader back. In the case of the RFID applied to vehicular identification the passive tags are appropriate for this application, awaiting a signal from the reader, when they are reached by the reader's field, the tag wakes up and responds to reader. Once the tag has decoded the signal, this one replies to the reader by modulating the reader field, this process is called backscattering modulation. Figure 1 shows the tag architecture, made up of three sections: Antenna, Transmitter/Receiver and Block Memory. About the receiver block, this one is composed of the rectifier, limiter section, and transmitter block is composed of modulator and VCO section.

This way, let us remember that the downlink communication, that is, communication between Reader to Tag, Gen-2, the modulation technique used is ASK Modulation in their different mixed pickles, Double Sideband Amplitude Shift Keying (DSB-ASK), Single?Sideband ASK (SSB-ASK), Phase Reversal ASK (PR-ASK), with data transmission Bit Rate 26.7 to 128 Kbps and Pulse Interval Encoding (PIE) [1,2,3]. The data transmission from the interrogator to the tag is achieved by modulating the carrier amplitude (ASK), the data coding is performed by generating pulses at variable time intervals, and the duration of the interval between two successive pulses carries the data coding information, thus, if the signal emitted by the reader antenna is suitable to be detected by the tag antenna and this one is not disturbed by external sources, is given by:

$$s_r(t) = A(t)\cos\left(\omega_{RF}t + \phi(t)\right), \qquad (1)$$

where $A(t) = (C + m(t))$, C, carrier amplitude and $m(t)$, message.

Therefore if the reader antenna radiation pattern covers appropriately the measurement area, as shown in Figure 2, it is easy for the tag antenna convert the electromagnetic signal to an electric signal that flows to the rectifier section [4], this one works as an envelope detector, taking the signal from the reader as input and providing an output signal which is the envelope of the original signal, that is, $m(t)$.

If the different reflections from the asphalt or objects around the environment are considered [5], these one have impact in the term $(C + m(t))$ with a destructive or constructive action on the amplitude of the carrier and the message signal, and due to the ASK modulation technique is employed, the data could be affected, destroying the symbol data, if the action is destructive. This situation is independent if the speed of the vehicle is low or high.

Let us consider a shift frequency due to high speed of the vehicle (in fact, small change), and the arbitrary (and sometimes variable) distance between the transmitter and receiver, thus, it is possible to express the signal radiated by reader antenna as:

$$s_r(t) = A(t)\cos\left(\left[\omega_{RF}t + \Delta\omega\right]t + \phi(t)\right), \qquad (2)$$

This signal reaches the tag antenna and turned it over to the tag rectifier section, this change in the signal is indifferent moreover if the frequency shift is a small quantity; it only takes the envelope of the original signal, from what, it is possible to establish that the downlink communication is not influenced by the speed of the vehicle and rule out this factor.

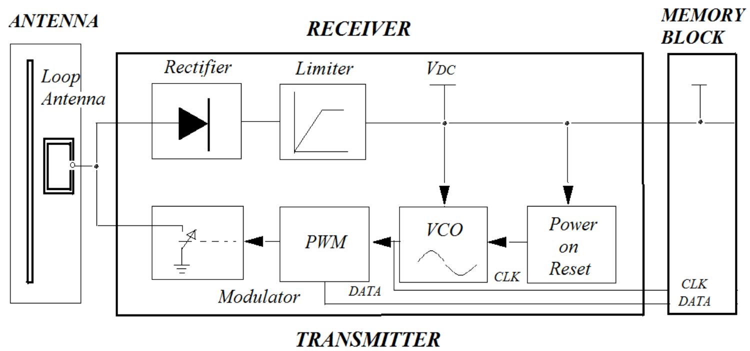

Fig. 1. Tag Architecture.

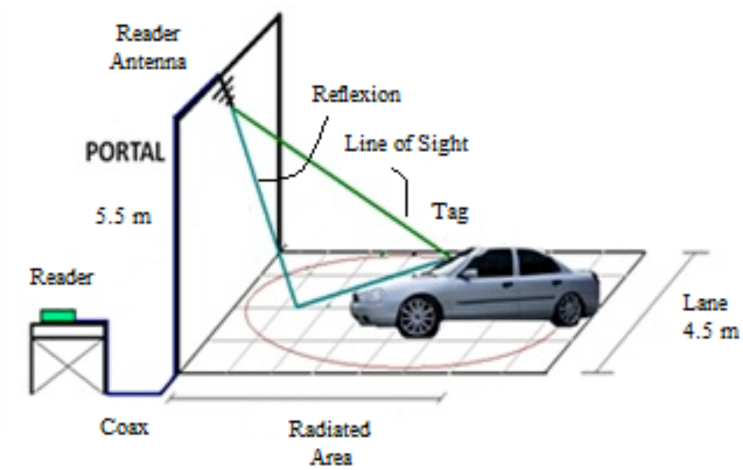

Fig. 2. Vehicle under test.

3. Reader Demodulation Process Analysis

Once the tag has been woken up, it initiates the transmission process, that is, the communication tag to reader, uplink communication, and the tag uses backscatter modulation to respond to a reader. It does this by switching the reflection coefficient of its antenna (using a shunt circuit) from a matched load where the maximum reflected signal is created, to a short at the antenna terminals, that is, reflection coefficient variation of antenna and switching load on antenna in time with bits, which varies input impedance. The reader instructs the tag which method of data encoding to use when sending its data back: Miller Sub-carrier encoding (5 to 320 Kbps) or FM0 Baseband encoding (40 to 640 Kbps) [1,2,3], in this case, FM0 encoding, a transition has to occur at the end of each bit period, but for a zero bit, an addition transition in the middle is required.

On the other hand, due to the reflected signal from a passive tag and from the different objects around the system are at the same frequency as the transmitted signal, the UHF readers are homodyne radios, that is, the received signal is mixed with the transmitted signal and directly converted to baseband with no intermediate-frequency, which is called zero IF receiver or direct conversion, and it is characterized because of the local oscillator frequency is the same as the incoming RF carrier frequency and with it, there is not image problem, but it works only if the desired signal has symmetrical sidebands [6]; the Class 0 receivers use a homodyne image-reject mixer architecture, being good protection to the absolute phase of the received carrier, which leads to interference mitigation and regulatory challenges inclusive, as far as this RFID application is concerned. This way, it is necessary to implement quadrature mixing technique, I & Q signals, in order to separate the upper sideband signal and the lower sideband signal and remove the problem of the phase mismatch between the carrier and the Local Oscillator, as shown in Fig. 3.

Paying attention to the reader demodulation schematic circuit, let us infer that it is not necessary the image rejection between the antenna and the output amplifier, the bandpass filter is responsible of that job, but this configuration present a disadvantage, the DC offset, and in the case of the fixed reflections, they are converted to DC.

With this on mind, firstly let us consider a signal coming from the tag with added reflections from other objects, reaching the reader antenna; once the signal has been processed by the filters in the way, at the quadrature modulator input, the signal is given by:

$$r_i(t) = A_{RF}(t)\cos\left[\omega_{RF}(t) + \phi(t)\right]. \quad (3)$$

I Q signals at the output of each branch are respectively given by:

$$s_I(t) = \frac{1}{2}A_{LO}(t)\,A_{RF}(t)\cos\phi$$
$$s_Q(t) = \frac{1}{2}A_{LO}(t)\,A_{RF}(t)\sin\phi \quad (4)$$

It is necessary recover the term $A_{RF}(t)$. For this, the circuit should be extending, apply the square root operation at the sum of the square of each term of the expression (4), in order to obtain the next result:

$$\frac{1}{2}A_{LO}(t)\,A_{RF}(t). \quad (5)$$

The communication between the reader and the tag [3-4-5], uplink communication, is carried out using PSK Backscatter Modulation and FM0 Baseband Encoding (40 to 640 Kbps); thus, the quadrature stage converts the information to the relative phase between I and Q signals, and in the case of QPSK, hence $\phi(t)$ is $\pi/4(00)$, $3\pi/4(01)$, $5\pi/4(10)$ and $7\pi/4(11)$.

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. Additionally, in the same way, the portal holds at mid-lane a Yagi antenna at 5.5 m height with main beam tilted down 75°, as shown in Fig. 4. This elevation 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. This way let us analyze the reader demodulator response considering reflections from the asphalt, objects around the environment and the possible shift frequency consequence of the high speed of the vehicle.

Firstly, if the carrier is affected by a frequency shift , due to high speed of the vehicle, the signal coming from the tag is processed by the low pass filter and turned it over to the quadrature I & Q mixing demodulator input, expressed as:

$$r_i(t) = A_{RF}(t)\cos\left[(\omega_{RF} + \Delta\omega)\,t + \phi(t)\right]. \quad (6)$$

Once the low pass filters eliminate the upper side band, the signals I and Q at the output of each branch are given, respectively by:

$$s_I(t) = \frac{1}{2}A_{LO}(t)\,A_{RF}(t)\cos\left[\Delta\omega(t) + \phi(t)\right]$$
$$s_Q(t) = \frac{1}{2}A_{LO}(t)\,A_{RF}(t)\sin\left[\Delta\omega(t) + \phi(t)\right] \quad (7)$$

Once again square root operation is applied to the sum of $s_I^2(t)$ and $s_Q^2(t)$ output signals, resulting:

$$\frac{1}{2}A_{LO}(t)\,A_{RF}(t). \quad (8)$$

This way, the reader receiver is enabled to detect the tag signal even a small shift frequency.

Now if the reflections from the asphalt and other objects cause constructive and/or destructive actions in the received signal, they have an impact on the amplitude, that is, in the term $A_{RF}(t)$ of the expression (6), but not enough to produce a malfunction of the system, unless a strong destructive reflection minimize or cancel the amplitude of the received signal, in the same way as the downlink communication [6]. Thus, in view of the demodulation stage is not the responsible of low successful readings; let us take a look at the digital transmission.

4. Frame Format

The communication protocol between reader and tag is defined by exchange instructions and data between the reader and the transponder in both directions, "reader talks firs" which means that any tag shall not start transmitting unless it has received and properly decoded an instruction sent by the reader. Each command consists of a request from the reader to the tag and a response from the tag to the reader. Requests and responses are contained within a frame with the delimiters SOF and EOF and composed of different fields as: Flags, command codes, parameters and data fields and CRC, as shown in the Fig. 5. The reader encoding known as pulse-interval modulation, PIE modulation [1,2,3], as shown in Fig. 6, employs varying-length signal, low pulses at the beginning of each symbol to denote binary "0", binary "1", and "null" (state transitions in the tags), and the tag encoding employs FM0 technique, also known as

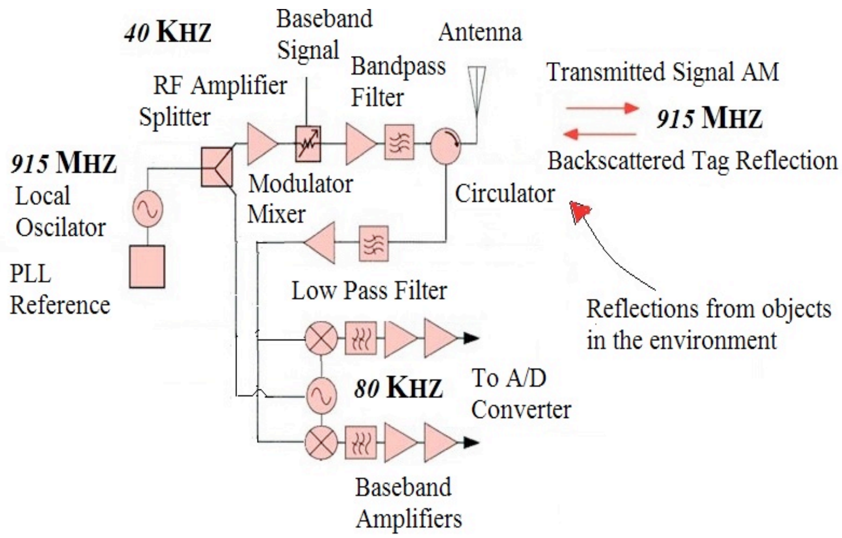

Fig. 3. Reader Demodulation Architecture.

Fig. 4. Tests in road.

Bi-Phase Space encoding (40 to 640 Kbps), in this case the Return link bit time is 25 μs to 1.5 μs and transition has to occur at the end of each bit period, but for a zero bit, an addition transition in the middle is required.

The symbols are referenced to the interval Tari and have a duration of 1 Tari, 2 Tari, and 4 Tari being integer multiples of Tari. Let us remember that the time Tari specifies the reference interval between the falling edges of two successive pulses representing the symbol “0” as transmitted by the interrogator, and its value is 20 μs.

This way, the tag shall be able to decode a PIE encoded transmission having symbols of duration as specified in Fig. 5. The bits transmitted by the interrogator to the tag are embedded in a frame, but before sending the frame, the interrogator shall ensure that it has established an unmodulated carrier for a duration of at least Taq (Quiet time) of 300 μs [1,2,3].

The frame consists of a Start of Frame (SOF), immediately followed by the data bits and terminated by an End of Frame (EOF). After having sent the EOF the interrogator shall maintain a steady carrier for the time specified by the protocol so that the tags are powered for transmitting their response. During this time, the interrogator shall not modulate the carrier and it should provide steady power to the tag, that is, any tag must not transmit unless it has received and properly instruction sent by the interrogator, an exchange of a command

Symbol	Number of Tari
'0'	1
'1'	2
SOF	4
EOF	4

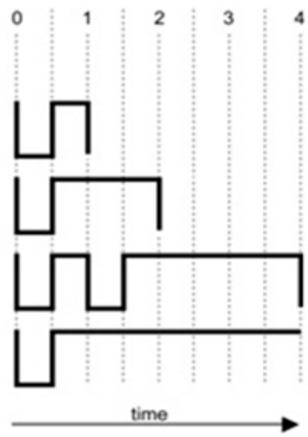

Fig. 5. PIE Symbols [1,2].

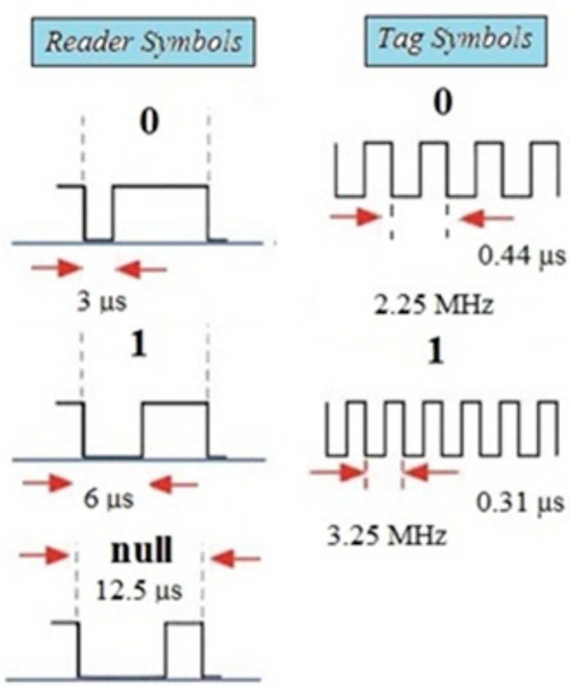

Fig. 6. PIE Reader/Tag Symbol Length Time.

from the interrogator to the tag and a response from the tag(s) to the interrogator as shown in Fig. 7.

Each command and each response are contained in the frame as shown in Fig. 7. A long command consists of the following fields: SOF, RFU, Command Code, Parameters, CRC-5, Optional Parameters depending of the command, Application Data Fields, CRC-16, EOF as shown in Fig. 8 and the response consists of SOF, Flags, Mandatory and Optional Parameters depending of the command, Application Data Fields, CRC-16 and EOF.

With this on mind, the communication between the reader and the tag must be established during a short interval time, let us call it, cross time, which is the time during the vehicle crosses, the portal. Assuming that the high speed of the vehicle is faster than 120 km/h, and runs constant across the detection area (4 meters), this small distance is covered during an interval time less than 100 ms, this way if the data rate is 40 Kbps, considering extreme cases, that is, only 0´s, equal to 20 Ktaris, 400 ms, only 1´ s, 10Ktaris equal to 100 ms, and based in the length of the frames, part of them (Taq and some fields else of the command of the response frame) will be received no complete by the tag or reader, resulting a failed tag detection, similar situation even if the data rate is increased to 640 Kbps.

Although it is not enough, in order to prevent failed tag detection the data rate in both links should be increased, in the case of high speed detection.

Table 1 and graphic in Fig. 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 simply with the aim to make the tests with different equipment, there is not a correlation between the tag number and reader and due to there is not a readings units needed standard for establish successful detection of a vehicle, around this fact only it is possible to establish that the number of successful readings is lower when the vehicle crosses the portal at high speed, being a defect of the system at this application.

Table 1. Different vehicles under test

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

Conclusions

In order to establish the feasibility of RFID to Vehicular Identification, this technology was tested in laboratory and road, and the obtained results have been very positive to this application, nevertheless successful data transfer is lower when the vehicle crosses the portal at high speed. This way the tag and reader demodulation stage were analyzed with the aim of find the cause of the bad tag detection. Based in this analysis we have found that the cause of this bad detection 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 frame are not appropriately received. Increase the data rate in both directions gives a chance to prevent it.

Even though the RFID technology applied to Vehicular Identification, the obtained results have been very positive, this system requires the vehicles to drive in some specific ways, for example, at fixed position and limited speed.

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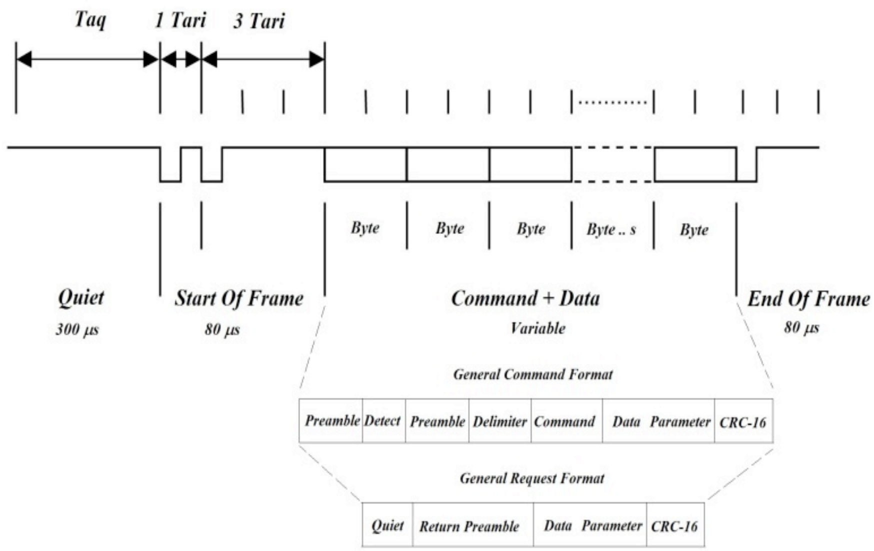

Fig. 7. Downlink and Uplink Frame Format.

SOF	RFU	Command Code	Parameters of Flags	CRC-5	SUID (Optional)	Data	Data (Optional)	CRC-16	EOF
	1 bit	6 bits	4 bits	5 bits	40 bits	8 bits	8 a n	16 bits	

Fig. 8. Long Command Format.

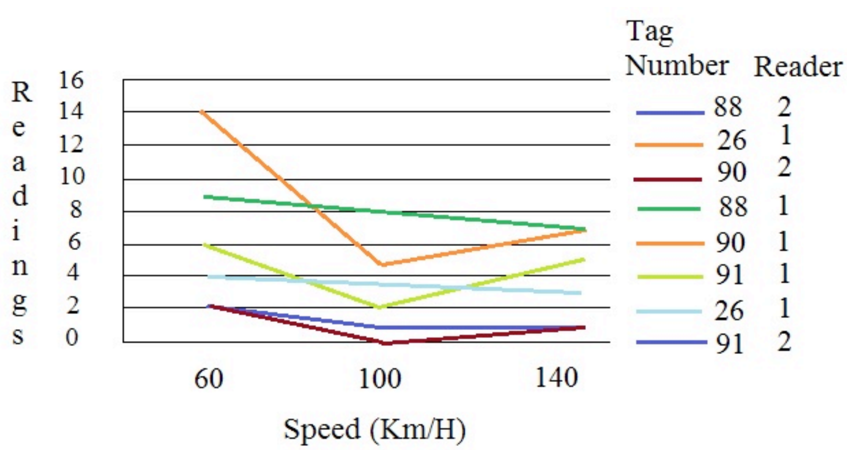

Fig. 9. Speed Test Results.