Analysis of Location Tracking and Speed Measurements for Moving Objects by using Radio Frequency Identification Systems

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Abstract

A performance evaluation of an ultra-high frequency identification systems with respect to location tracking of moving objects, as well as a novel technique for speed measurement of such objects, are presented. The experiments are performed in out-door and in-door facilities, including the shielded environment provided by the semi-anechoic chamber. Electromagnetic compatibility and human safety issues are first addressed for the systems employed in our analysis and then the performance and the applicability range of the proposed method are discussed. The proposed method performs reasonable well when compared against classical K-band Radar and proves that an additional capability could be added to the current radiofrequency identification systems that mainly focus on transponder localization and information transfer.
Keywords: *radiofrequency identification, radar, electromagnetic compatibility*

1 Introduction

Radio frequency identification (RFID) systems have been under intensive research focus in the last years due to the benefits provided to track physical assets [1, 2], as well as to their applications in various engineering fields, such as near field communication [3], medical treatment and imaging [4], landmine detection [5], or material characterization [6]. The RFID benefits led to their adoption in international supply-chain market and generated the recent mandates and recommendations for using RFID systems from several government agencies and international corporations [1].

In this study we present a performance evaluation of an ultra-high frequency (UHF, 865-945 MHz) RFID system with respect to location tracking of moving objects, as well as a novel technique for speed measurement of such objects. The experiments are performed in out-door and in-door facilities, including the shielded environment provided by the TDK semi-anechoic chamber [7]. A picture of the experimental set-up inside this chamber is presented in Fig. 1. The localization technique used in our approach is a mixed one, based on Time of Arrival and Angle of Arrival methods [8], while the identification tags are active long-range transponders of Claymore type.

Figure 1: Semi-anechoic chamber (left) and experimental set-up for in-door speed measurements (right).

2 Performance evaluation of RFID system

In this section, we present the evaluation of a RFID system operating in the ultra-high frequency band (UHF, 865-945 MHz).

The RFID system considered in our tests is the so-called RFID Radar, made by Trolley Scan [12]. The central control and communication unit is built around a development board from Microchip. The antenna system is formed by three patch panel antennas, one used for signal generation and the other two for signal reception. As opposed to the previous class, this system can be used for long-range applications and multi-transponders localization, being able to determine the positions of up to 50 tags in a range of about 50 meters (if no collisions are involved). The RFID radar measures the path length for the signals traveling from the transponder to the reader in order to determine the distance. By comparing the signals received by the two receiving antennas, the reader determines the angle of arrival of the signals from the transponder. We have used two types of active transponders (Claymore long-range Ecotag and Stick long-range Ecotag) and one type of passive transponder (Ecochiptag 500 μWatts).

The measurements have been done in a 3m TDK semi-anechoic chamber using a Rohde & Schwarz - ESU 26 EMI Test Receiver, calibrated antennas and cables. The turntable and the antenna mast were operated by using an *in-house* made software program. The international standard specifying the emissions level for SRD-RFID equipments is EN 55022 (CISPR 22) - "Information technology equipment - Radio disturbance characteristics - Limits and methods of measurements", while EN 300-220 - "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD)" is used for the operating performances and functional characteristics evaluation.

A standard configuration was used for the tests, as the equipment to be measured (EUT - Equipment Under Test) was positioned on a turn table at 0.8 meters above the ground and at 3 meters distance from the antenna tip. During the measurements, the antenna moved from 1 m to 4 m height and the EUT rotated 360 degrees, to find out the maximum emission level in the 30 to 1000 MHz band (as specified in the standards, in the final scan procedure, the operating frequencies were excluded from the measurement interval). For the first set of tests, we placed the transponders on a zero/emissions rotating device, determining it to pass by the reader every 1.5 - 2 seconds. For the second set, the transponders were placed in front of the RFID Radar antenna system. In accord to the standards mentioned above, the readings were made continuously, one measure per second, using quasi-peak and peak detectors for the pre-scan and the final scan measurements, respectively.

Table 1 shows samples of the radiation emissions levels measured using the experimental setup and procedures previously described. We have also preserved the peaks from the operating frequency range in order to compare them with the peaks outside this band. The limits used for calculations (QP Margin column) were 40 dB for 30 - 230 MHz and 47 dB for 230 - 1000 MHz (according to CISPR 22, 20 dB per decade have to be added for 3 m test distance).

Frequency (MHz)	**Polarization.**	**Table Angle (deg)**	**QP (dBuV)**	**Frequency peak (MHz)**	**QP Margin (dB)**	**QP Trace (dB)**
188.7	H	65.5	33.20	184.01	-6.80	18.21
202.5	V	44.2	33.98	194.61	-6.02	18.11
865.2	H	18.2	89.00	869.91	42.00	65.36

865.2	V	153.2	72.54	869.91	25.54	48.90
867.0	H	17.7	88.70	869.92	41.70	65.06
867.0	V	150.5	42.38	869.92	-4.62	18.74
868.3	H	18.5	80.43	869.97	33.43	56.79
869.3	H	17.4	72.57	870.00	25.57	48.93
869.3	V	150.9	55.89	870.00	9.11	32.25
869.9	H	18.8	89.46	869.90	42.46	65.82
869.9	V	152.0	72.85	869.90	25.85	49.21
945.6	H	12.6	133.10	945.75	86.10	109.17
945.8	V	62.0	117.61	945.80	70.61	93.68

Table 1: The emission levels measured in the semi-anechoic chamber at 3 m distance for RFID RADAR ultra-high frequency band system

As it is also apparent from the tables, our measurements proved that the RFID system has relatively high emission levels for the main operating frequency band. This level of emissions is above the maximum allowed by the standards, may not only lead to electromagnetic interferences for electrical equipments operating nearby, but it also raises human safety issues. In ETSI EN 300 220-1 V2.2.1 (2008-04) - Electromagnetic compatibility and Radio spectrum Matters (ERM), the power limit for devices operating between 30 MHz and 1000 MHz is 500 mW for all the bands reserved for short range devices. There are other regulations in the EU [11] where power levels up to 2 Watts are permitted for RFID systems with non/modulated carrier. As a result, long time exposure to the EM field produced by the antenna RFID Radar system could be dangerous for humans.

3 Speed measurements methods

While the evolution of the RFID system performances with respect to transponder localization and information transfer has been impressive over the last years, very few progresses were made in the area of speed measurements for a moving transponder. The addition of speed measurement capabilities to the RFID systems could be extremely useful in various applications, such as production chains or vehicle identification and localization. Instead of using two separate systems, one for object identification and another one for speed measurement, we proved that a single system can performed relatively well both functions. That would not only increase the process efficiency and the overall speed in data processing, but it would also reduce the operation costs.

The method for measuring the transponder speed developed by our group is based on the Time of Arrival and Angle of Arrival information provided by the RFID radar analyzed in the previous section. Let us define reference point O as the middle of the antenna system and reference axis x. Since this RFID radar has two receiving antennas, the time difference between the two signals received from the transponder located in the area covered by the emitting antenna, along with the range data, can be used to compute the distance between the object and the reference point, as well as the angle between the reference axis and the line connecting the reference point O to the transponder. Let us assumed a planar motion for the transponder and that the distance between the object and the antennas are much greater than the distance d12 between the two consecutive measurement points P1 and P2. Let us denote by (d1, α1, t1) and (d2, α2, t2) the (distance, angle, time) information provided by the radar for two consecutive readings P1 and P2 of a transponder in range. By making use of the generalized Pitagora theorem in OP1P2, (see Fig. 2) one can easily arrive to the following expression for the transponder speed:

$$v \approx \frac{d_{12}}{t_{12}} = \frac{\sqrt{d_1^2 + d_2^2 - 2d_1 d_2 \cos(\alpha_2 - \alpha_1)}}{t_2 - t_1} \quad (1)$$

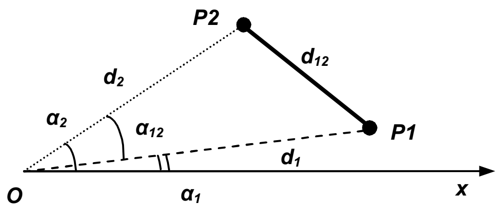

Figure 2: Diagram used for calculation of transponder speed from two consecutive measurements data.

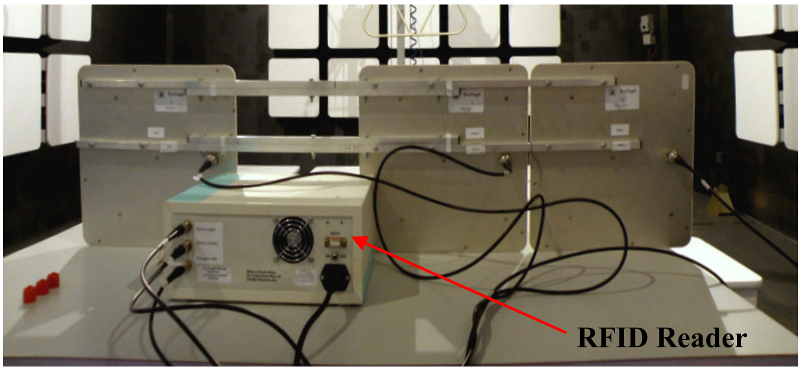

Figure 3: Experimental setup used for localization and speed measurements

The software developed for calculating the speed begins with a system initialization procedure, followed by a calibration routine. After these operations, we wait for a transponder to come in the active range of the antennas. When the transponder enters the range, we get the current information, such as the unique ID, the location and time information. We do not need, and consequently, do not process any information stored in the transponder internal memory. After a delay of about 100 ms, the program enters a routine expecting the next reading. When receiving the same ID, the program gets the new values for location and time information, and then, it computes and displays the distance traveled by the transponder, and its speed. When the current transponder ID is out of range, the program will acquire a new unique ID to calculate the new speed. If another transponder comes into the active range of the reader while the software is acquiring the speed for one transponder, the newcomer object will not be read.

The program was developed on a platform running Windows XP as an operating system. We used Power Basic for writing and compiling the program, with very good results regarding the processing speed. Data was exchanged with the RFID system by using the RS232C serial interface. Results were delivered in a text box and were written in a text file on the local disk.

4 Experimental implementation and discussion

The diagrams shown below are obtained from the signal transmitted between the receiving antennas preprocessor and the digital processing board located inside the reader. A LeCroy 104Xi scope and 1/10 passive probes were used for measurements. A typical signal received by the processing board, when only one active transponder is in the active area of the reader, is represented in Fig. 4.

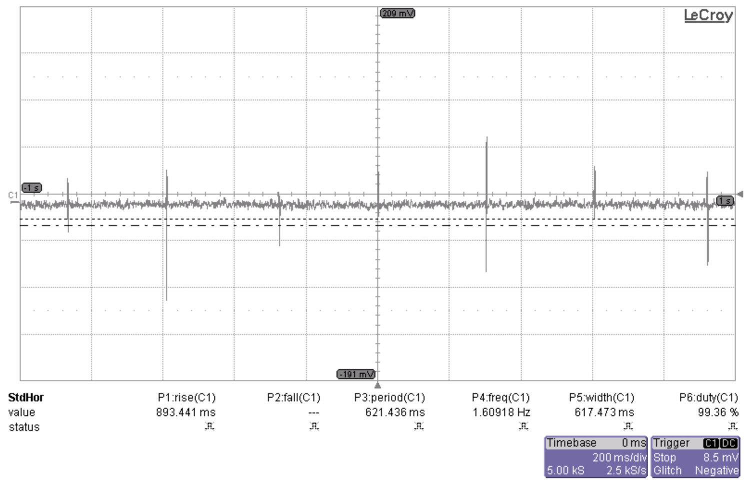

Figure 4: The signal received by the RFID Radar when only one transponder unit is in the active area

When multiple transponders are located in the Radar range, the received signal contains multiple data streams, as one can see in Fig. 5, where the signal received in the presence of four transponders is presented. The information transmitted by the reader system to the processing board inside the reader is plotted in Fig. 6. The data transmission for one transponder takes approximately 2.66 milliseconds for 1024 bits, and it contains the identification bits, as well as the information regarding the angle and time relative to the receiving antennas.

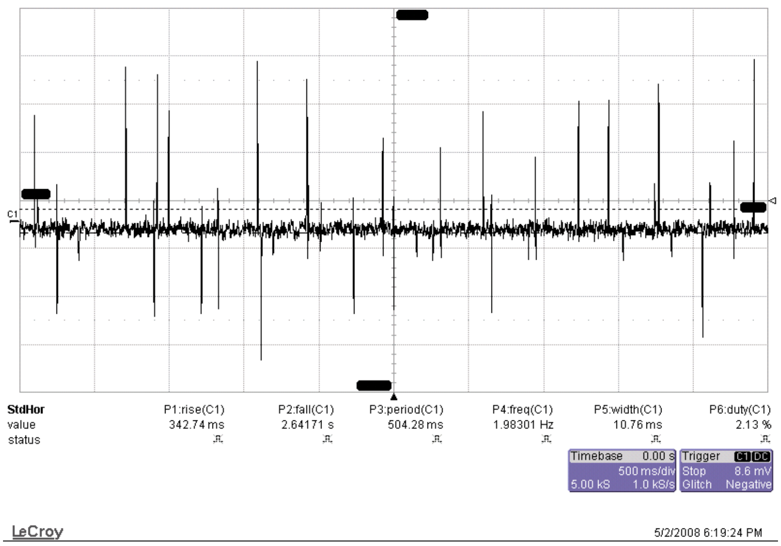

Figure 5: The signal received by the RFID Radar when four transponder units are in the active area

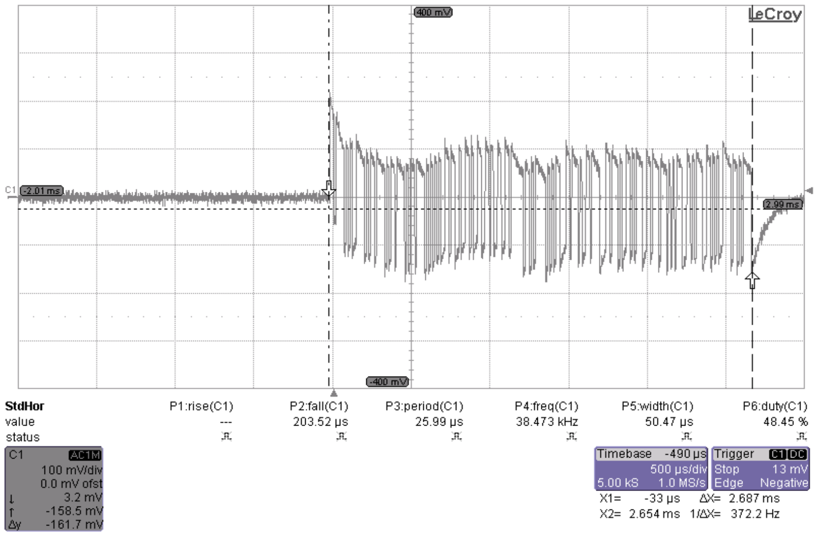

Figure 6: The content for one transponder memory content takes 2.66 milliseconds (the demodulated signal received by the processing unit)

Since the system is able to solve angles between -30 and +30 degrees and the time spacing between two transponder transmissions is about 333 milliseconds, as seen in Fig. 4, one can estimate the maximum theoretical speed that can be measured by our method given the current experimental set-up.

These estimations are in good agreement with the experimental results presented in Table 2, except for distances larger than 40 meters between the antenna system and the transponder when multiple reflections in real working conditions were negatively influencing the measurements.

The previous analysis has presented the main theoretical and practical limitations which were identified for the proposed speed measurement method. However, we have to stress that the method has been successful in determining the object speed inside its applicability region. The tests performed for this evaluation have included objects moving with a known speed, as well as comparisons with the well-established speed measurement method based on K-Band Radar. The repeatability of the measurements was tested by performing 50 measurements of the transponder moving with 10 km/h for each of the following distances: 20m, 30m and 40m. The results obtained by using the RFID radar and the K-Band radar are presented Table 3.

Distance to the antenna system (m)	10	20	30	40	50
Speed (km/h)	6	24	32	36	n/a

Table 2: Maximum measured speed as a function of the distance between the transponder and the antenna system

Distance to the antenna system (m)	20	30	40
Number of speed measurements within 10% error for the RFID Radar (%)	84	72	64
Number of speed measurements within 10% error for the K-Band Radar (%)	96	84	78

Table 3: Repeatability of the measurements

In conclusion, the RFID Radar method performed reasonable well when compared against classical K-band Radar, and proved that an additional capability could be added to the current RFID system that mainly focus on transponder localization and information transfer.

Acknowledgements

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