On Board Equipment for DSRC Systems

Ricardo Prata, Nuno Fernandes, António Serrador, Fernando Fortes

Instituto Superior de Engenharia de Lisboa, Rua Conselheiro E. Navarro,
1949-014 Lisboa, Portugal Phone: +351-218317000, Fax: +351-218317114,
e-mail: *{rprata, nfernandes, aserrador, ffortes}@deetc.isel.ipl.pt*

ABSTRACT

The Electronic Tolling is used in the majority of countries, in special the Dedicated Short Range Communication (DSRC) but with no compatibility between systems/countries. With the newer sub-standard created by European Committee for Standardization (CEN), the Medium Data Rate (MDR) enables the enhancement of communications between systems/countries. This paper proposes an On Board Equipment (OBE) capable of communicate with DSRC-MDR system using low-level software to simplify hardware. Moreover this proposed OBE offers the possibility to transfer non-standard data through an external port available. Therefore, this OBE can be used has a DSRC data terminal controlled by a host.

I. INTRODUCTION

The DSRC is a microwave system for short-range communication that was designed for Electronic Tolling Fee Collection. Nowadays, the system has been extended for other applications, like parking and gas station payments. Several countries have Electronic Tolling Systems with DSRC but without compatibility between systems/countries. Each country uses different sub-standard according to the applications needs.

The system architecture is based on two main equipments: OBE and Road Side Equipment (RSE). The communication between RSE and OBE is half-duplex. When the RSE sends frames to OBE it is considered as downlink and the opposite direction as uplink. The communication is initiated by the RSE, by sending beacons to wake up

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the OBE and by establishing a bidirectional communication. The OBE stays in sleep mode until it is awaken by these beacon frames.

In Europe, all DSRC sub-standards are using the 5.8 GHz band. At the moment, the Low Data Rate (LDR) sub-standard is used in Portugal with the following features: Left Hand Circular Polarization (LHCP); Amplitude Modulation (AM) in downlink; sub-carrier of 1 MHz; Differential Phase Shift Keying (DPSK) for sub-carrier modulation and bit rate of 31.5 kbps in both directions [1].

There are some differences between the LDR and the MDR sub-standards, like the sub-carrier frequency (1.5 MHz or 2 MHz), and a bit rate of 500 kbps in downlink and 250 kbps in uplink. The Italian System also has differences as can be observed in Table I. These intrinsic differences, clearly lead to incompatibilities among systems.

Table I – DSRC system data rates (adapted from [1]).

System	Data rates [kbps]	
	Downlink	Uplink
MDR	500	250
Portugal (LDR)	31.5	31.5
Italy (low speed)	921	144
Italy (high speed)	921	921

The main goal of this work [2] is to create a newer OBE/Tag using the DSRC system with an external port available to transfer non-standard data that does not exist on commercial DSRC tags (as far as the author's knowledge). The idea behind joining DSRC with this external port is to allow the non-standard data transfer from toll payments.

This paper is structured as follows: in Section II description of OBE for MDR sub-standard; in section III the electronic of buildings blocks and the main features; in Section IV final results are presented and analysed; finally, conclusions are drawn in Section V.

II. OBE FOR MDR SUB-STANDARD

The MDR sub-standard was created by CEN. This standard will allow the mobility between countries using this system. The sub-standard by itself is not enough, therefore in different European projects, mobility between the different countries was addressed. In this work, the Pilot on Interoperable Systems for Tolling Applications (PISTA) Project [3] was followed, since the RSE used to evaluate the project supports it. This project shows all messages at data link layer level, in order to make a toll payment transaction. The unformatted transmission data was not considered on

PISTA so the CEN specifications were used on the application layer [4] that provides a bit stream for sending non formatted data. This method is used to send data from an external port available.

Table II – Downlink parameters from MDR sub-standard [5].

Data coding	Bi-phase space (FM0)
Bit rate	500 kbps
Minimal length frame to wake-up	12 bytes
Maximum start time	≤ 5 ms
Length of preamble	16 ± 1 bit
Waveform of preamble	All bits at level "1"

Table III – Uplink parameters from MDR sub-standard [5].

Sub-carrier frequency	1.5 and 2 MHz
Sub-carrier modulation	Binary Phase-Shift Keying (BPSK)
Modulation of carrier	Multiplication by sub-carrier
Data coding	Non Return to Zero Inverted (NRZI)
Bit rate	250 kbps

The parameters presented in Tables II and III are especially important for the software development link in sampling time definition and generation of a modulated sub-carrier. At the beginning of communication the beacon sends a 12 bytes wake-up frame. When OBE receives these data, has less than 5 ms to wake-up and be able to establish communication with RSE.

Figures I and II show the downlink and uplink blocks diagrams, respectively. The downlink block receives the RF signal through a patch antenna and an envelope detector recovers the base-band signal. The base-band signal is then amplified and processed by the microcontroller.

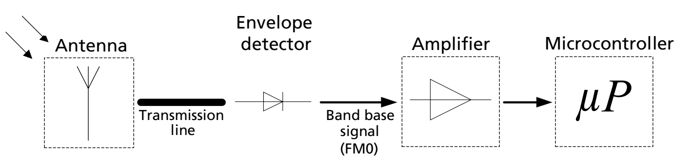

Figure I – Downlink block diagram.

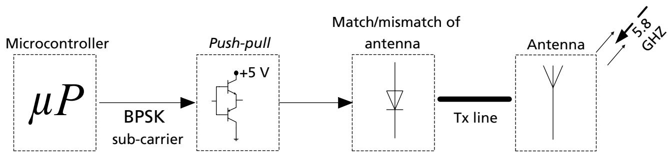

Figure II – Uplink block diagram.

The uplink block receives a carrier sent by the RSE and by matching/mismatching the antenna is able to modulate the carrier and reflect it back to the RSE. The matching/mismatching is done by changing the diode bias with the voltage levels generated in the microcontroller according to the data bits.

III. BUILDING BLOCKS

The advantage presented by DSRC is the possibility of using a small and low cost OBE that doesn't generate any carrier directly, only generates a sub-carrier that has a smaller frequency (≤2 MHz) than the carrier.

A patch antenna is used since it has the adequate physical characteristics to implement on small box. A LHCP patch antenna has many possible designs, as well as the antenna feeds such as transmission line, gap or coaxial cable. Transmission line was chosen because of its good reproducibility and simple construction. For the antenna design the book [6] was followed and the design chosen is shown on Figure III(a). The simulation software used was "Ansoft Designer SV2" [7] that automatically generates the antenna dimensions, in function of frequency (f=5.8 GHz) and dielectric constant (ε_r=4.4).

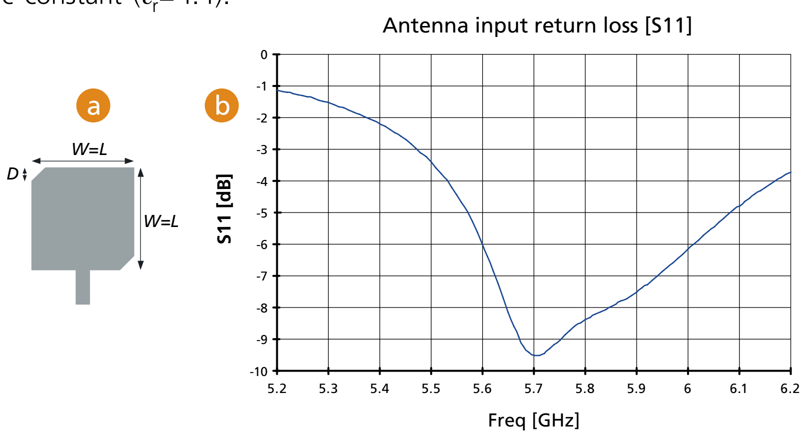

Figure III – Antenna design and input return loss factor.

The antenna dimensions are W=11.86 mm and D=1.538 mm. Figure III(b) presents the simulated input return losses (S_{11} parameter) and the central frequency, 5.7 GHz. The transmission line length was calculated using the "Serenade SV 8.5" software [7]. Using a line width of 1.4 mm, the software returned 7 mm and 21 mm as the bests line lengths. For these lengths the S_{11} parameter is showed in Figure IV. Its magnitude with 7 mm and 21 mm is similar at 5.8 GHz because the length difference is close to $\lambda/2$.

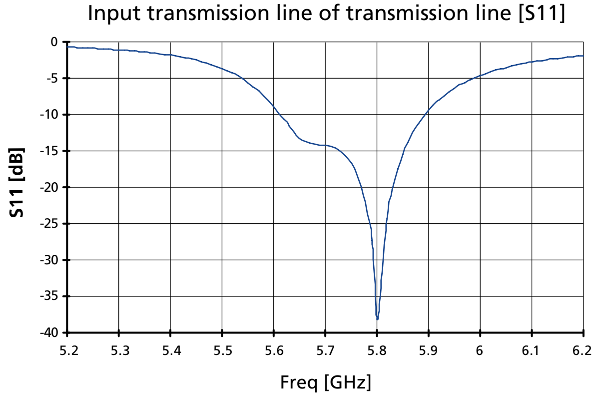

Figure IV – Input return loss factor.

Because 7 mm is short when comparing with the antenna (11.86 mm) and 21 mm is quite long the chosen line length became 13.3 mm. With this value good results were obtained for the antenna performance.

Other feature that contributes to the simplicity and small size of the OBE is the type of modulation, since the AM signal on the downlink is demodulated using a simple envelope detector circuit. This circuit is composed by a schottky diode, a resistor and a capacitor. After testing, this circuit didn't provide good results due to the capaci

tor and, therefore, a stub was used to replace it (Figure V) resulting in a better performance. The stub is open-ended with $\lambda/4$ length (at 5.8 GHz) to present a short-circuit at the diode.

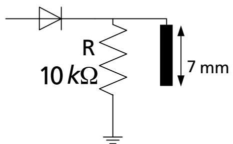

Figure V Detector circuit.

After the RF signal demodulation it's necessary to amplify the base-band signal so that the microcontroller can decode the data sent by RSE. The chosen Operational Amplifier (OpAmp) was the AD8031 which has a bandwidth-gain product of 80

MHz and a maximum gain of amplifier for the FM0 signal (base band signal) is 160 (80 MHz/500 kHz).

In order to decode the signal it is necessary to use a sampling time of 2 μs considering the data coding is FM0. Afterwards an exclusive-OR operation (XOR) between the last and current sample is made to recover the current bit.

The used microcontroller was a PIC18F2550 that supports a maximum clock of 48 MHz but, for each machine cycle, it needs 4 clock-cycles, resulting in 12 Million Instructions Per Second (MIPS). It includes two comparators but only one was used. The maximum Input Common Mode Voltage (ICMV) is 3.5 V when using 5 V power supply. The demodulation circuit produces a DC offset of 44 mV. Thus, the maximum gain for amplifier is 3.5 V/44 mV≈80. The chosen gain was 57 so that the micro-controller comparator does not work at its limit. The amplifier circuit is presented in Figure VI. Since the comparator is located after the amplifier, a low pass filter with a cutoff frequency of 157.9 Hz was made to capture the DC component.

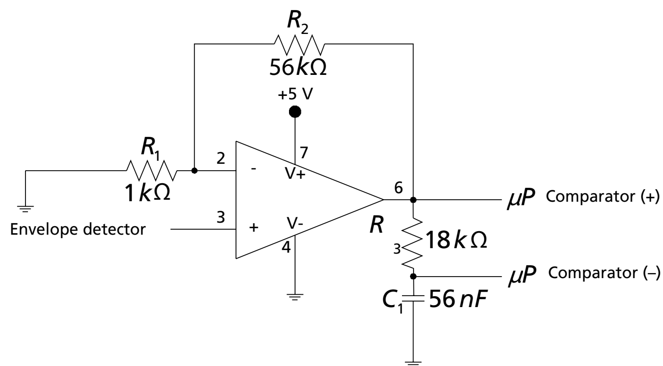

Figure VI – Amplifier circuit.

After the two signals enter the comparator, the software developed to the microcontroler decodes the message sent by the RSE, which is a novelty when compared with other commercial implementations that rely on hardware based solutions.

To make the uplink, the software of the microcontroller generates the sub-carrier modulated in BPSK. This sub-carrier is applied at the push-pull block that drives the same diode used in downlink. Thus, the square zone of the diode curve multiplies the carrier received from the RSE with the sub-carrier generated by the microcontroller. In order to finish the uplink, by matching and mismatching the antenna, the signal is reflected back to the RSE. The modulation circuit is presented in Figure VII. The antenna, diode, resistor and stub are the same as in the envelope detector, as already described.

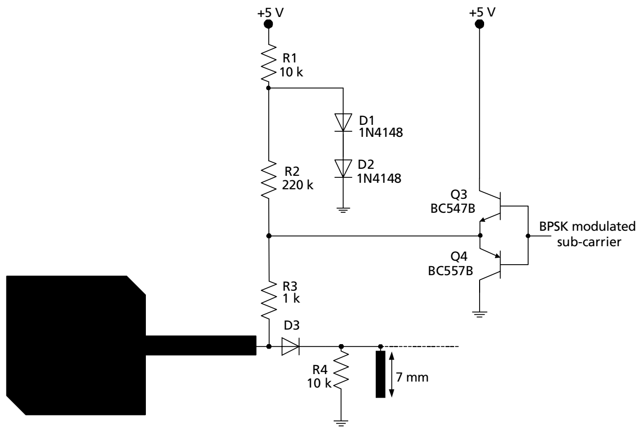

Figure VII – Uplink circuit.

IV. RESULTS

An HP8753D Vector Network Analyser was used to measure the actual input return losses of the antenna combined with the transmission line. The results are presented in Figure VIII.

It is possible to verify that the combination of antenna and transmission line is perfectly tuned at 5.8 GHz as intended for DSRC system. The matching was not as good as expected comparing with the input return loss factor present in Figure IV, but the performance was good enough for the proposed application.

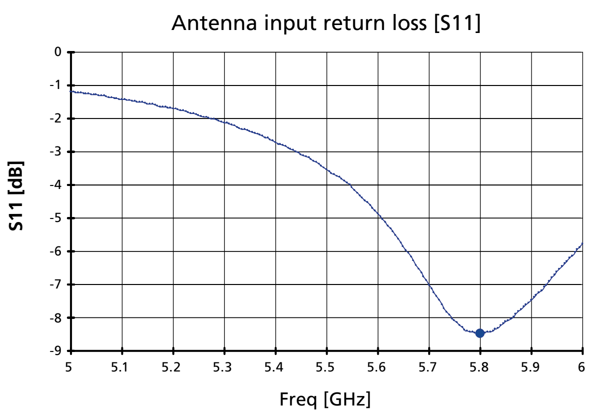

Figure VIII – Input return loss of antenna with transmission line.

Figures IX and X present the horizontal and vertical radiation patterns of the antenna, respectively. The red line represents the -3dB antenna gain relative to maximum gain. The results are only valid between -120º and +120º, since there was a mechanical problem in the anechoic chamber where these measurements were made.

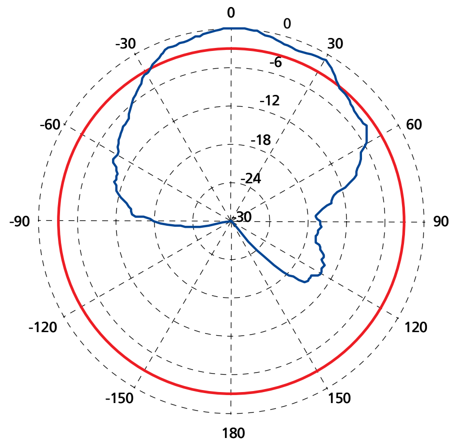

Figure IX – Horizontal radiation Pattern.

As expected, the diagrams show similar results in terms of -3dB beamwidth, because the antenna has the same construction in the E and H plane (Figure VII). The diagram in Figure IX shows that the gain peak occurs at 0º but the antenna beamwidth is not symmetric around this value, which is caused by the transmission line feeding the antenna.

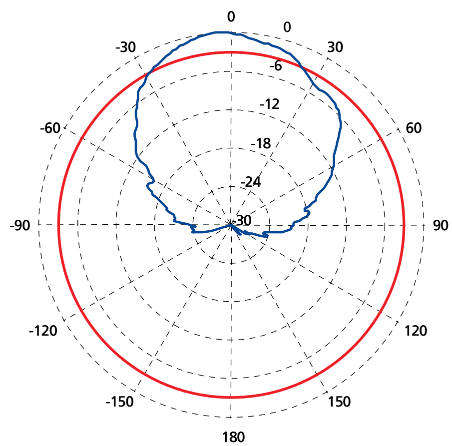

Figure X – Vertical radiation Pattern.

The validation of the radiation patterns in the field test operation site Figure XI, should be considered.

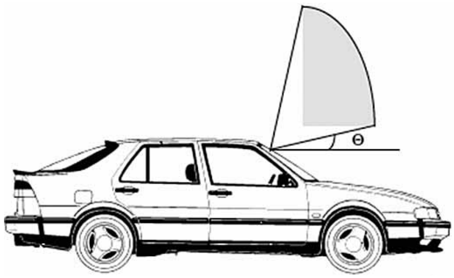

Figure XI – Vertical beam of OBE (extracted from [8]).

According to [8], the angle Θ range is between 35° and 80°, and the horizontal beamwidth must be ±25º. From Figure IX it's possible to verify that the horizontal radiation pattern of the antenna accomplish this characteristics. The vertical beam-width is close to 50º, which can accomplish the main characteristics, depending on the vehicle windshield angle.

The antenna was made on a 1.52 mm FR4 substrate. Its gain is 1.7 dBi which can be improved by using a lower loss substrate material.

The European Telecommunications Standards Institute (ETSI) specifies an OBE sensitivity [9] of -43 dBm at ±35º for the vertical orientation. The results from the presented OBE do not accomplish these specifications, but still enables communications between DSRC entities validated up to 5 m. The results are presented in the Table III.

Table III – OBE sensitivity for some key angles.

Vertical orientation of OBE [º]	Sensitivity [dBm]
+30	-32
0	-36
-30	-32

To improve the communication distance and the angle specifications, it's necessary to optimise the antenna and the baseband hardware.

CONCLUSIONS

This paper proposes a new OBE architecture using low level software to implement the physical layer of the DSRC system. The software approach allows changes on radio interface and the transfer of non-standard data using an external port. In this mode the DSRC system can be used as complementary system for specific short range communications, with high moving terminals or other applications and scenarios.

Experimental results showed that the OBE was able to communicate up to 5 meters although its specifications do not accomplish ETSI standard. The antenna and baseband hardware are currently being optimised to improve sensitivity.

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