Low-Cost, Compatible Dedicated Short Range Communications Chain for Road Transport and Traffic Telematics

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***Abstract* — DSRC (Dedicated Short Range Communications) is a well known widespread technology. One of the main applications of DSRC is RTTT (Road Transport and Traffic Telematics), especially EFC (Electronic Fee Collection) on tolled roads, bridges or tunnels. Other vehicle-related applications had been envisaged, such as car parking or fuel refilling automatic payment. These applications were successfully developed, deployed and are in current use in Portugal. In this paper we present a low-cost, complete DSRC chain developed by the authors that is compatible with the existing DSRC systems already in use.**

I. INTRODUCTION

New European standards were developed by CEN (Comité Européen de Normalisation) regarding the normalization of DSRC systems for RTTT. This standards include EN 12253 (physical layer) [1], EN 12795 (data link layer) [2], EN 12834 (application layer) [3], EN 13372 (communications profiles) [4] and EN ISO/ETSI 14906 (interface for EFC) [5].

EN 12253 [1] specifies the physical parameters for both the OBE (On-Board Equipment, the identifying tag usually placed at the windshield) and the RSE (Road Side Equipment, the fixed station that controls the communications). Communication from the RSE to the OBE is named Downlink, whereas communication from the OBE to the RSE is named Uplink.

In Downlink communication, ASK modulation is used on a carrier around 5.8GHz with a bit rate of 500kbit/s. For uplink communication the carrier is the same with a 1.5MHz or 2.0MHz subcarrier [1][4]. Modulation is BPSK with a 250kbit/s data rate.

The characteristics described above belong to the MDR (Medium Data Rate) system, opposed to the LDR (Low Data Rate) the one currently installed in Portugal. As opposed to the MDR, the LDR is not an open-standard system, but they share some common characteristics.

LDR has a 31.25kbit/s data rate both for Downlink and Uplink, whereas the subcarrier for Uplink is around 1.0MHz. It happens that it is fairly straightforward to re-use the hardware for both LDR and MDR systems.

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II. SIGNALS, SYSTEMS AND MODULATION

A. Downlink

As said, Downlink signal is achieved by simple ASK modulation of the microwave (5.8GHz) carrier. A suitable OBE demodulator receiver has been published in [6]. As said before, bit rate is 31.25kbit/s for LDR and 500kbit/s for MDR. Base-band coding is Manchester for LDR and FM0 (biphasic) for MDR.

A. Uplink

The Uplink signal is a little more complex, and it is shown on Fig. 1 how it is generated. The baseband signal is a NRZI binary sequence (31.25kbit/s for LDR and 250kbit/s for MDR). The subcarrier is 1.0MHz (LDR) or 1.5/2.0MHz (MDR). Note that the main carrier is generated at the RSE even for Uplink, meaning that this carrier must not be turned off after Downlink. The RSE Uplink receiver is described in [7].

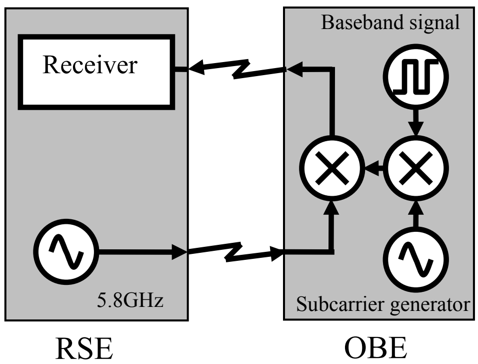

Fig. 1. Uplink signal generation using remote 5.8GHz carrier and locally generated subcarrier and baseband signals.

C. The Road Side Equipment

The Road Side Equipment built may be described by the block diagram depicted on Fig. 2. On that diagram one can observe:

•The microcontroller unit, responsible for Downlink base-band signal generation, Uplink signal decoding and hardware configuration;

•A programmable synthesized microwave generator around 5.8GHz, used for both Downlink and Uplink carrier;

•Downlink up-converter, power amplifier and antenna;
•Uplink antenna, amplifiers, down-converter and demodulator;

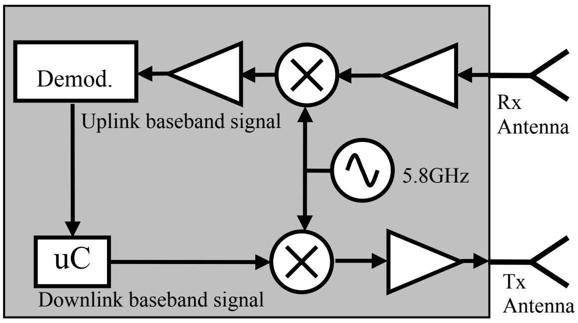

Fig. 2. Road Side Equipment block diagram

D. The On-Board Equipment

The On-Board Equipment (OBE) is a relatively simple device. One can observe, on Fig. 3, a preliminary block diagram.

The Downlink signal is received by the Rx antenna and is immediately demodulated by a detector stage. Hence, the front-end is simply a matching network and an envelope detector built around a microwave diode [6]. The base-band signal is then amplified, filtered and fed to the microcontroller. Base-band coding is removed by software.

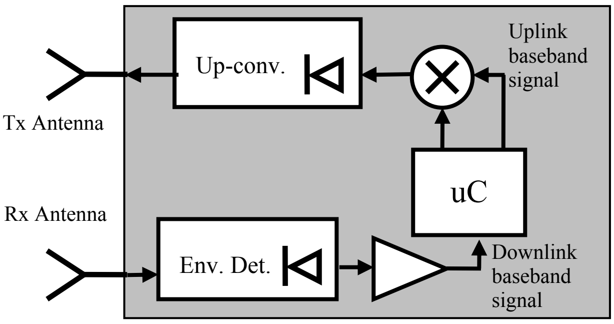

Fig. 3. On-Board Equipment (first block diagram)

For Uplink, we need a baseband signal and a subcarrier. Typically, the base-band signal is generated by the microcontroller, and, in our prototype, the subcarrier is also generated at the microcontroller. The two signals are mixed as described in [6]. The Tx antenna, needed to transmit the Uplink signal, also receives the microwave carrier generated at the RSE, and this carrier is mixed with the subcarrier using a simple microwave diode.

It is easy to realize that the Downlink front-end and the Uplink mixer are very similar: antenna, matching network, microwave diode are common to both. It is possible to use these components both for Uplink and Downlink. This is depicted in Fig. 4. One possible solution is described in [8].

III. LDR AND MDR COMPATIBILITY

Compatibility is always an issue whenever a technology migration takes place. Retro-compatibility is mandatory if there are already many users equipped with the "old" technology. For instance, Portugal is a country with roughly 5.6 million vehicles on its roads (late 2006 figure), and is estimated there are 2 million OBEs in use (2007 figure, about 36% market penetration). Any new technology for EFC purposes should retain compatibility with these existing OBEs.

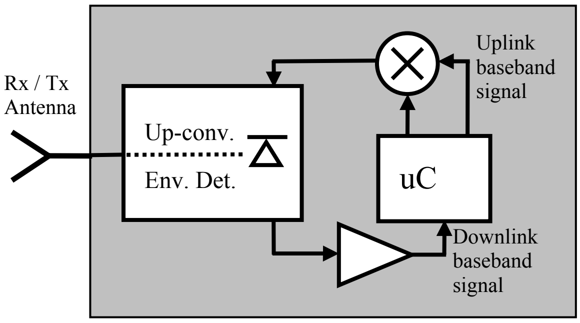

Fig. 4. On-Board Equipment (improved block diagram)

It is unimportant for the new OBEs to retain compatibility with older OBEs. After all, a DSRC OBE never communicate with another OBE, communication always takes place between an RSE and an OBE. Of course, it is essential that every new RSE to comply with the old and the new technology in order to benefit of existing OBEs as well supporting newer OBEs.

In this paper we mostly consider differences in the physical layer, since differences in other layers can be ordinarily accomplished by software most of the times.

Table I
Some LDR and MDR differences

DSRC type	Downlink		Uplink	
	Bit rate (kbps)	Base-band coding	Bit rate (kbps)	Subcarrier freq. (MHz)
LDR	31.25	Manchester	31.25	1.0
MDR	500	FM0	250	1.5
MDR	500	FM0	250	2.0

In Table I we summarize some physical layer differences between LDR and MDR. MDR appears twice in the table since it has two different communication profiles [4] which demand two different subcarrier frequencies: 1.5MHz and 2.0MHz.

A. Road Side Equipment description

Regarding the RSE for Downlink, one can see on Fig. 2, the base-band signal on our prototype is directly generated by the microcontroller unit, and this includes base-band coding. The employed microcontroller is a simple 8-bit, 16 MHz clock unit. With the aid of a single embedded timer, it is fairly easy to generate the Downlink signal for both LDR and MDR. The built prototype has no hardware differences for both LDR and MDR.

In what it comes for the Uplink, the receiver at the RSE was built according the architecture described on [7], which general block diagram is shown on Fig. 5. The microwave section (around 5.8 GHz) is the same for LDR and MDR. However, the back-end of the receiver is a bit more complex, since several blocks have to be adjusted. The all-pass filter responsible for a 90º delay needs to be tuned for the three possible subcarriers: 1.0, 1.5 and 2.0 MHz. The same happens with the amplifier just before the demodulator. In this case, for good performance, it is also important to change the bandwidth between 62.5kHz (LDR) and 500 kHz (MDR). The demodulator also needs to support these three subcarriers and the two different bit rates.

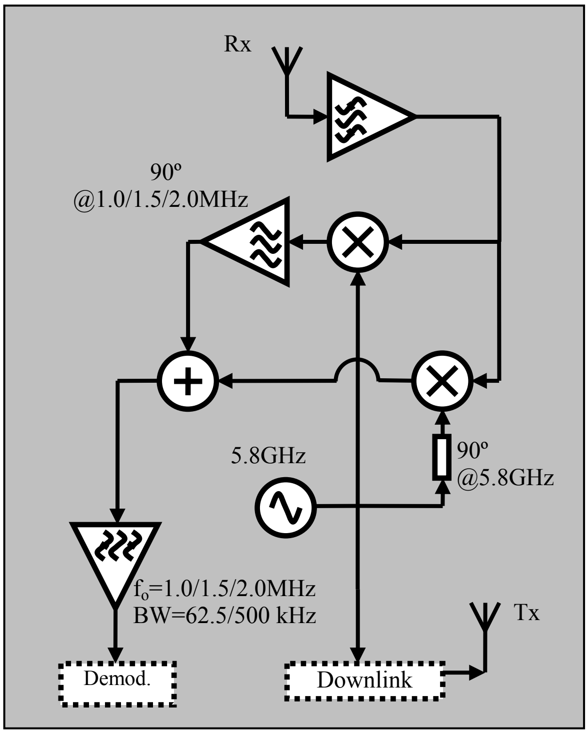

Fig. 5. RSE Uplink receiver

B. On-Board Equipment description

As said before, there is no need for the OBEs to be compatible with both DSRC technologies. One can have OBEs just for LDR (the legacy ones) and introduce independent MDR OBEs. Anyway, their layout is fairly the same [7].

In both LDR and MDR either reception or transmission is done at 5.8 GHz, so one can use the same antenna and matching network.

Detector stage and filters throughout the OBE have different specifications for LDR and MDR regarding the needed subcarrier(s) and signal bandwidth. But, unlike the RSE, there is no need to dynamically change the characteristics of these filters since an OBE is either LDR or MDR, not both.

IV. THE PROTOTYPES

Two prototypes (one RSE and one OBE) have been developed at the site of Aveiro of Instituto de Telecomunicações, Portugal. In this section we make a brief description of both.

First, at Fig. 6, one can observe a general view of the RSE hardware. Fig. 7 helps us to identify the several different parts. The microcontroller (μC) is mounted at the center. The 5.8GHz synthesized programmable generator (Generator) is at the bottom left corner, the Downlink modulator and power amplifier (Modulator and PA) at the bottom left corner with the mixing stage (Mixer) just above. At top right corner we find the Uplink low noise amplifier (LNA), followed at its left by the low-frequency amplification (Amplif.) and demodulator (Dem.).

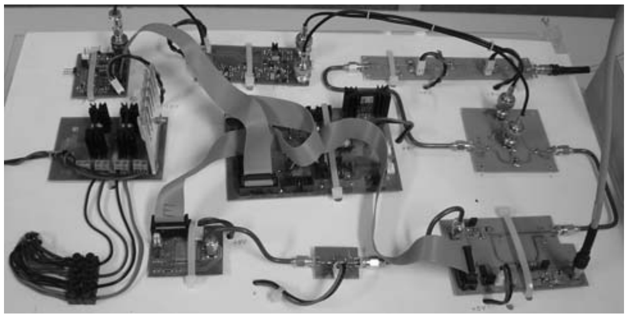

Fig. 6. RSE prototype, general hardware view

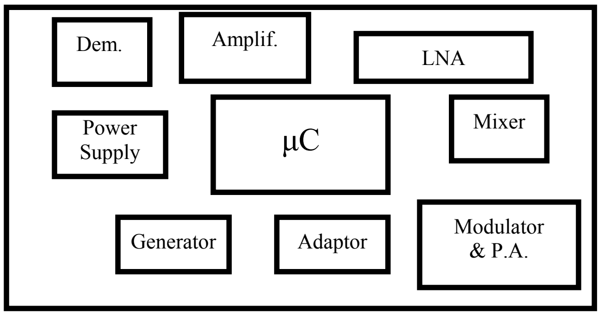

Fig. 7. RSE prototype blocks.

On Fig. 8 we find the RSE prototype where one can observe two arrays of printed-circuit board patch antennas specially designed for this project connected to a personal computer for log view. Fig. 9 shows us part of a log with a transaction just made with an existing LDR OBE. Note the matching identification number and control digit.

Finally, on Fig. 10, is shown the OBE prototype, much simpler than the RSE as one could expect. On the right side is a generic microcontroller board (just like the one found at the RSE prototype) and on the left side there is some additional hardware, comprising the Downlink envelope detector and signal conditioning, and the Uplink modulator and mixer. The microwave elements (patch antenna, matching network and diode) are common to Downlink and Uplink as found in [8].

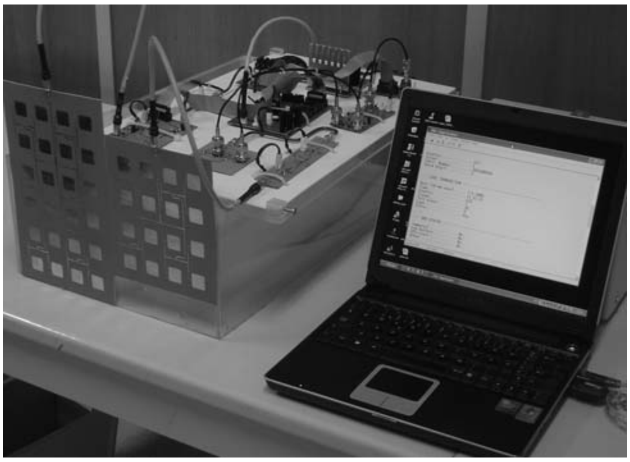

Fig. 8. RSE with a pair of antenna arrays and a log view

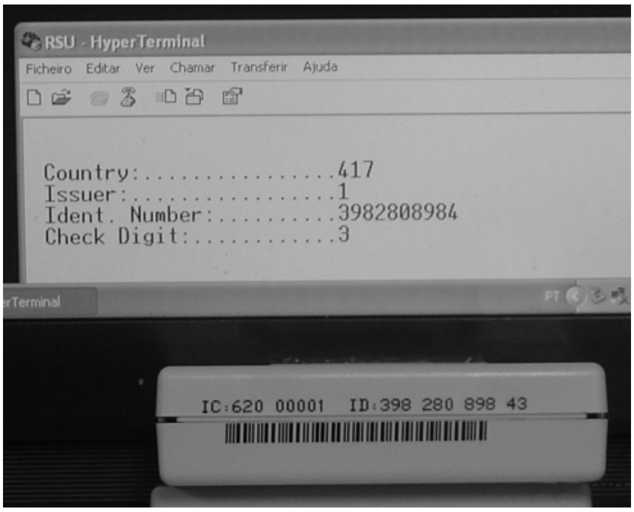

Fig. 9. An existing OBE and part of a transaction log

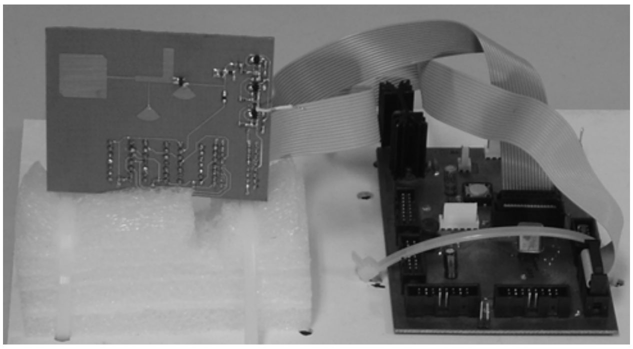

Fig. 10. The OBE prototype

V. CONCLUSION

In this paper we explored the differences between two different technologies for DSRC/RTTT, which are known as Low Data Rate (LDR) and Medium Data Rate (MDR). Although LDR is not a standard technology, it is widely in use in some European countries. On the other hand, MDR is described by several standards from CEN (Comité Européen de Normalisation).

The basic differences between these two technologies at physical level were shown, and the hardware differences to support them both were pointed out.

A prototype was built and tested by the authors with satisfactory results, with a communication distance about 10 meters between RSE and OBE.

ACKNOWLEDGEMENT

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