Self-Interference Cancellation for Free-Flow Road-Tolling Collection Transceivers at 5.8 GHz

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This paper describes the architecture, the design techniques and technologies suitable at the development of a radio hardware interface for a road-side equipment (RSE), compliant with the requirements of electronic toll collection (ETC) for vehicular applications based on the EN300674-1 standard, [1].

The specific application expects that an array of RSEs operating in frequency carrier diversity and sending the same synchronized down-link message are installed on gates across the road. The information are exchanged with an on-board unit (OBU) installed on cars moving through the gate, cfr. Fig. 1. In the figure is reported the simplified picture of multi-lane free-flow (barrier-free) ETC scenario, where each RSE is supposed to communicate with the same car (i.e. with the same OBU). Being the OBU a semi-passive transponder, [2], the transceiver (cfr. Fig. 2) implements a full-duplex channel radio access and features a digital-IF down-converter scheme at receiver to deal with different profiles, communication modes, carrier frequencies as well as channels.

The communication between RSEs and OBUs imposes several issue for a radio-frequency architecture design point of view, the main of them consists in the self-interference which desensitize the RSE receiver [3]. This issue is even more severe when considering the RSE as a part of an array of RSEs operating in relative close proximity (approximately 3.75 m) and with one out four of the carrier frequency available from the regulatory. Thus the presence of strong signals at the receiver during the reception of the OBU signal, requires that at least the self-interference would be reduced at maximum. This is achieved including a transmitter leakage canceller at the front-end of the RSE transceiver Fig. 3, [4]. It operation mode is effective and in principle quite simple. It sample the transmitter carrier and operates on it a phase rotation and a proper magnitude scale, then re-couples it to cancel the self-interferer at the receiver input. This procedure is proven (cfr. Fig. 4) to improve to about 70 dB the effective isolation between transmitter and receiver, while the signal-to-noise ratio improves up to 38 dB. The effective cancellation of the self-interference makes the requirement on the side RSEs carrier interference less stringent and thus facilitates the installation in complex scenario.

This cooperative RSE down-link operation relies on a complex digital-IF receiver (cfr. Fig. 5). For the multi-lane free-flow ETC applications under consideration, the up-link signal spectrum is schematically depicted in Fig. 6. In the figure we recognize the ASK back-scatted signal in response to two different carriers incident on the same OBU. The frequency planning is such that only the upper and the lower side bands respectively for the higher and the lower carriers results unaffected from the carrier over-imposing, and thus represents the useful band to be detected. This selection is achieved with the complex digital-IF down-converter which is capable to shift the IF spectrum toward either the negative or the positive frequency respectively for the higher of lower carrier. The Fig. 6 (left) reports the schematic spectra during the down conversion at RSE2 (i.e. higher frequency carrier). An example of the measured spectrum after the first analog down-conversion is reported in the Fig. 6 (right), where it is possible to observe the right-side band of the up-link signal about the higher carrier and also the lower one component corrupted by the lower carrier.

The talks provides a detailed discussion of the above highlighted topics giving an inside view of the transceiver design challenges, as well as laboratory experimental result and on-field test carried in the realistic trial field test provided by Autostrade per l’Italia SpA.

References

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[3] N. B. Carvalho, A. Cidronali, R. Gómez-García, editors “White Space Communication Technologies”, Cambridge University Press, Cambridge, (UK), ISBN 9781107055919

[4] S. Maddio, A. Cidronali, G. Manes, “Real-Time Adaptive Transmitter Leakage Cancelling in 5.8-GHz Full-Duplex Transceivers” IEEE Transaction on Microwave Theory and Techniques, Vol.63, Feb. 2015, pp. 509-519

Figures and captions

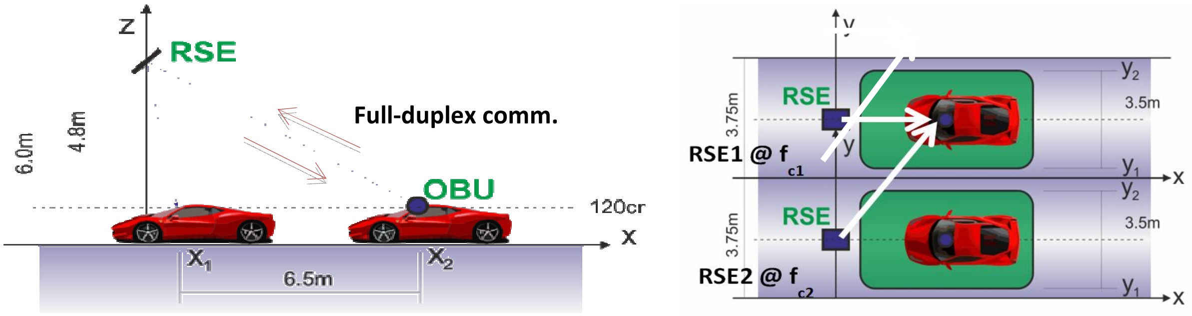

Fig. 1: Layout configuration for of the free-flow ETC system; downlink between two RSEs and same OBU

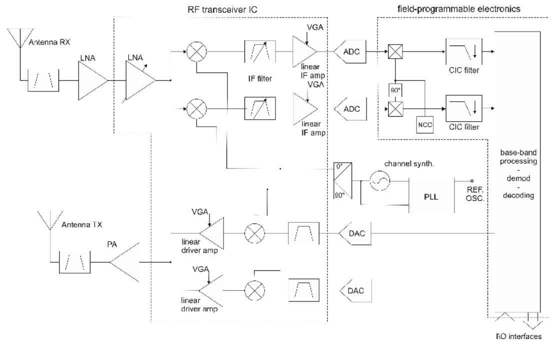

Fig. 2: Architecture of the 5.8 GHz full-duplex transceiver

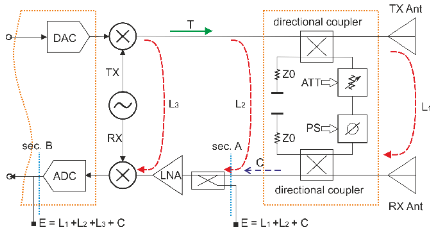

Fig. 3: Analog active canceller architecture

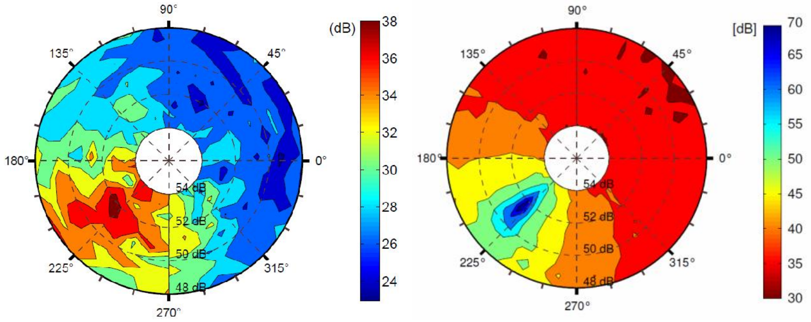

Fig. 4: Experimental validation of the canceller performance (left) and the related SNR improvement (right)

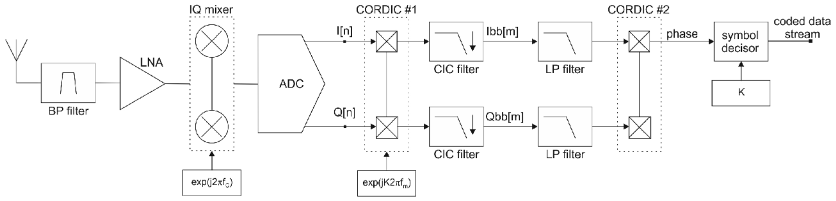

Fig. 5:schematic representation of the receiver chain with the digital-IF section

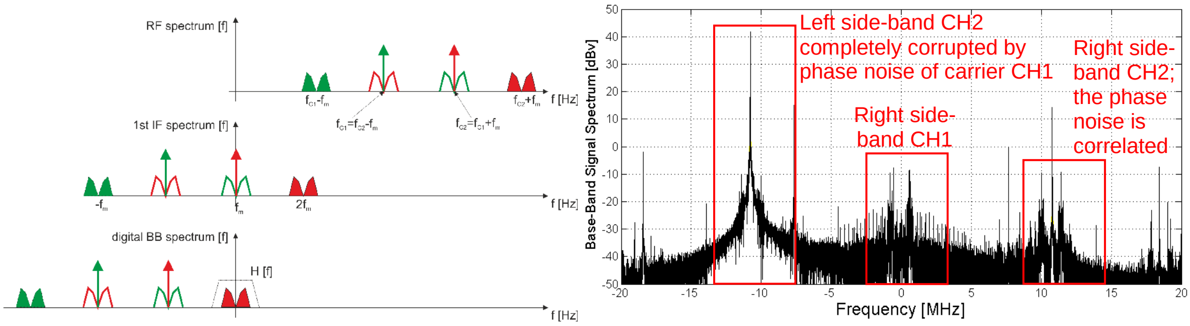

Fig. 6: Schematic representation of the up-link spectrum at different section of the receiver for multi-line multi-carrier mode (left); measured spectrum at firs down-conversion for carrier #2 (right)