Multifunctional Receiver Architectures for Sustainable Wireless Systems and Applications

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***Abstract*—This report aims to summarize the latest progress of the awardee's Ph.D. project in part supported by the 2021 IEEE MTT-S Graduate Fellowship Program. This work shows how to propose and exploit several innovative aspects of multifunctional multiport wireless receivers for energy-efficient and reconfigurable radio terminals. The principles of the proposed techniques are not limited to the printed-circuit-board (PCB) or miniaturized-hybrid-microwave-integrated-circuit (MHMIC) and can be extended for integrated circuits (ICs) implementation such as MMICs and RFICs.**

***Index Terms*—Multiport, interferometry, 5G and beyond, receiver, power detection, energy efficiency, multifunction.**

I. Introduction

THE emerging trends towards the multi-level integration and addition of more functions, standards, and bands set the stage for exploring and developing an efficient and flexible transceiver architecture for sustainable future wireless systems. The fifth-generation (5G) of mobile networks intends to not only address the limitations present in the previous cellular standards but also becomes a potential key enabler for future internet-of-things (IoT) applications. The IoT network is envisioned as a paradigm shift within wireless systems wherein massive-IoT connections are characterized by a huge volume of low-cost and low-power consumption devices with relatively low throughput requirements. On the contrary, critical-IoT devices require low latency, ultra-reliability, and high data throughput connections. The number of connected things related to an IoT network, which demands a disruptive evolution of the current state-of-the-art transceivers and microwave components. Energy efficiency is surely one of the most important aspects of IoT as most of the IoT devices are battery-powered, and often they require a long time-period operation without human intervention. Energy management techniques such as lightweight protocols and scheduling optimization as well as energy harvesting are playing an important role in energy-constrained wireless networks. In addition, the integration of multiple wireless functionalities into a single unified system has emerged for design simplicity, smaller form factor, lower cost, better efficiency, and lower power consumption.

This doctoral thesis research aims to investigate and propose novel approaches to exploiting multi-functional receiver architectures for future wireless systems. In the framework of this thesis, several innovative and crucial contexts of multi-functional multiport interferometric systems have been considered [1-3]. In addition, response efficiency is studied to expose the latency contribution of RF front-end transceivers to next-generation mobile networks [4].

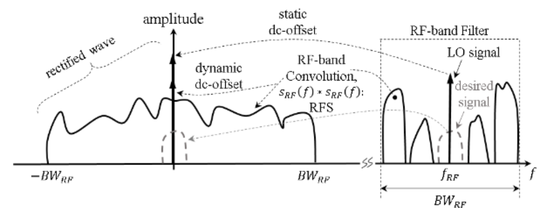

Fig. 1. Characterization of the rectified wave (square-law nonlinearity).

II. Multiport Interferometric Receivers

Multiport interferometric receivers present a competitive solution for low-power and low-cost multifunction wireless applications. Its principle of operation is based on additive mixing for frequency translation, which is accomplished by linearly combining input signals that pass through a nonlinear processing element, thus resulting in a desired interference. These receivers offer various attractive benefits over conventional mixer-based topologies, such as low-power requirement for detection operation, easily achievable broadband capability, and robustness for power level variations. In this connection, they have recently gained a lot of research interest in terms of system modelling and calibration, together with multifunction architecture developments.

Although homodyne interferometry has been a principal choice in conventional multiport receivers, the systematically generated rectified wave components can cause the receiver to saturate (see Fig. 1). These undesired baseband signal generations are highly related to temporal- and power-changes, and to the number of sub-channels in a frequency band of interest. We present a heterodyne detection in an RF/microwave interferometric receiver, the first of its kind, which separates the desired frequency signals from the rectified wave components with two output ports through a frequency offset [3]. This architecture also makes use of the field-effect transistor (FET)-based power detectors to combine the received and reference signals, which reduces a theoretical multiport junction loss of 6 dB to 3 dB (Fig. 2). Fig. 3 shows the measurement results when a received frequency band has several in-band interferers. The multi-channel signals are generated by a Keysight M8190A

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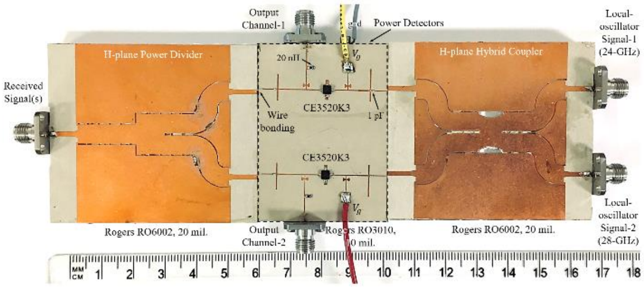

Fig. 2. Heterodyne interferometric receiver hardware demonstration for dual-band reception.

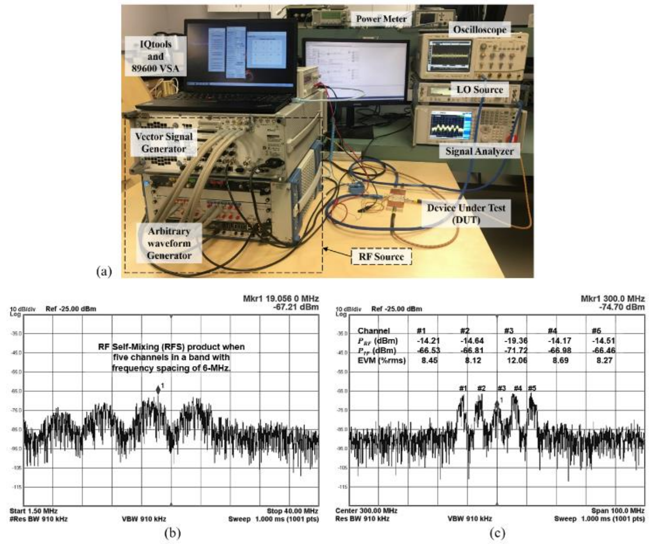

Fig. 3. Measurement of multi-channel signals in a received frequency band. (a) Digital photograph of the experimental test bench. The measurement equipment is synchronized with a 10 MHz reference signal. (b) Undesired baseband signal generation when a power detector operated in its square-law region. (c) The desired heterodyne detected frequency signals, when five channels, each with QAM-16 modulation type and 2MSps symbol rate, with relative magnitude (dB) of {0, 0, -5, 0, 0}, frequency spacing of 6-MHz and V_g = -0.40 V.

arbitrary waveform generator (AWG) using IQtools, which is then up-converted in a frequency band of interest through an Agilent E8267D source. The detected interferometric signals at the output of the receiver module are probed using an Agilent N9030A PXA signal analyzer and analyzed in an 89600 VSA software. The measurement results are demonstrated when the 24-GHz band has five channels, each with QAM-16 modulation type and 2MSps symbol rate, at -30 dBm of LO signal. It is worthwhile mentioning that the desired frequency signal is separated from the rectified wave components through a heterodyne detection. The similar results are observed in the 28-GHz band. The proposed heterodyne microwave interferometry technique is particularly attractive for narrow-channel standards.

On the other hand, a balanced detection technique in direct-conversion interferometric receivers [5] is proposed to suppress the rectified wave composition for the second-order nonlinearity and to enhance the signal quality for reconfigurable wireless terminals. This proposed receiver relies on the differential acquisition of the detected interferometric signals. The balanced detection scheme also reduces baseband-processing paths as compared to a conventional six-port interferometric receiver, which results in footprint and power savings in connection with the required number of filters and data converters.

Also in this work, a cooperative radar-communication (RadCom) system employing an interferometer receiver [6] is also introduced and demonstrated. The proposed system operates in both radar sensing and radio communication modes, which are arranged in different time slots within a single hardware platform. The interferometric receiver for a unified multifunction operation benefits from the cooperative approach as it does not require a receiver front-end with a high dynamic range.

III. Career Plan and Fellowship Impact

I am now on track to finishing my Ph.D. by the end of winter term 2022. I would like to continue my research interest in multifunction wireless systems and keep working closely with the MTT-S community. This award was a true honor, it has given me the confidence, motivation, and visibility that I needed to keep pursuing revolutionary research and connecting with others in and outside my field. Even though I did not have the chance to attend IMS 2021 in person due to the pandemic, the support of the fellowship allowed me to develop my research and networking skills through extensive meetings with teams from different areas. I look forward to participating in future events hosted by the IEEE MTT-S society.

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