Microwave Passive Sensing Topologies for Indoor Applications

Davi V. Q. Rodrigues, *Graduate Student Member*, *IEEE*, and Changzhi Li, *Senior Member*, *IEEE*

***Abstract*—This project aims to develop microwave passive sensing architectures for indoor applications. Three different prototypes working at 2.4-GHz have been implemented. The sensors can provide accurate Doppler information by taking advantage of the direct-path signals emitted by a transmitter and the RF signals backscattered by a moving target. Experiments with the proposed architectures have been performed to reveal their capabilities for small amplitude motion detection, vital sign recognition, and hand gesture identification.**

***Index Terms*—injection-locking, injection-pulling, passive sensing, spectrum sharing, wireless sensing.**

I. Introduction

PASSIVE sensing approaches have the potential to enable a wide range of new applications and services in various fields, including healthcare, smart homes, and smart cities [1]-[2]. These techniques are intended to exploit the electromagnetic waves transmitted by other wireless devices to detect, locate, or to characterize targets or the environment. The microwave passive sensor and the transmitter of opportunity can be arranged in a bistatic or multi-static geometry. Thanks to the widespread presence of Wi-Fi access points and other sources of radio-frequency signals in indoor scenarios, it is beneficial to design systems that can leverage third-party transmitters as illuminators for various indoor applications. Such systems will contribute to efficient spectrum usage, radio interference mitigation, and to joint sensing-communication capabilities. Existing works have proposed approaches that achieve the goal of leveraging pervasive Wi-Fi signals for passive sensing purposes. However, these solutions either require customized RF transceivers or complex algorithms to extract reasonable information from the baseband signals. The aim of this project, as well as part of my PhD research, is to design high-sensitivity microwave passive topologies that will be able to leverage signal transmitted by current and next-generation wireless networks. This report outlines the progress made towards building three different microwave architectures, which were tested by evaluating their sensitivity to small amplitude motion and their use in smart living and healthcare applications.

II. Project Outcomes

A. Injection-Locking and Injection-Pulling -Based Topology

An injection-locking and injection-pulling (ILIP) -based prototype was developed as shown in Fig. 1. The technique

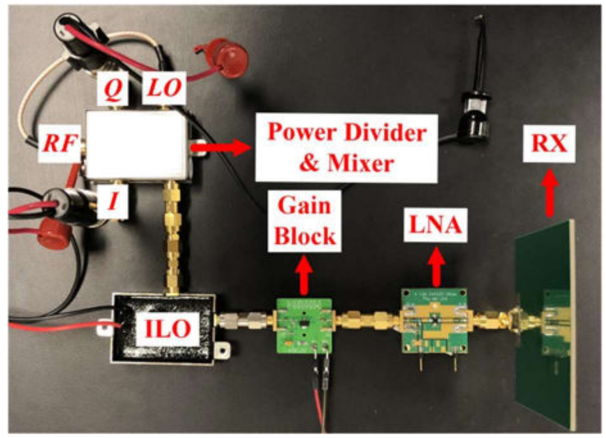

Fig. 1. Photograph of the ILIP-based passive sensing device. From [3].

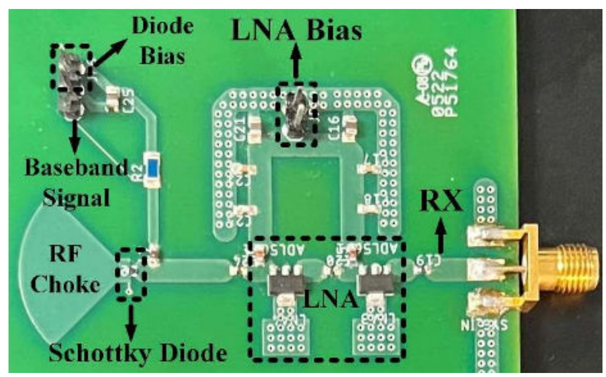

Fig. 2. Photograph of the diode-mixer-based microwave passive sensing topology. From [4].

leverages the ability of the injection-locking oscillator (ILO) to synchronize to the direct-path signals (injection-locking) and a commonly undesirable behavior known as injection-pulling caused by the phase-modulated signals backscattered by a moving target. The Doppler frequencies associated with the target's movement can then be retrieved after mixing the products generated by the injection-locking and injection-pulling phenomena. By concurrently feeding the direct-path ambient signals and the phase-modulated signals backscattered from the target of interest into the input of an injection-locked oscillator, the injection-locking and the injection-pulling mechanisms successfully allowed the detection of small amplitude motion and the identification of the vital signs of a person seated in front the ILIP-based passive sensing device. Details of the system implementation and the experimental evaluation can be found in [3].

B. Diode-Mixer-Based Topology

A single-channel diode-mixer-based topology with no on-board oscillator was also proposed. Fig. 2 exhibits the

D.V.Q Rodrigues and C. Li are with Department of Electrical & Computer Engineering, Texas Tech University, TX, 79409, USA. (e-mail: davi.rodrigues@ttu.edu).

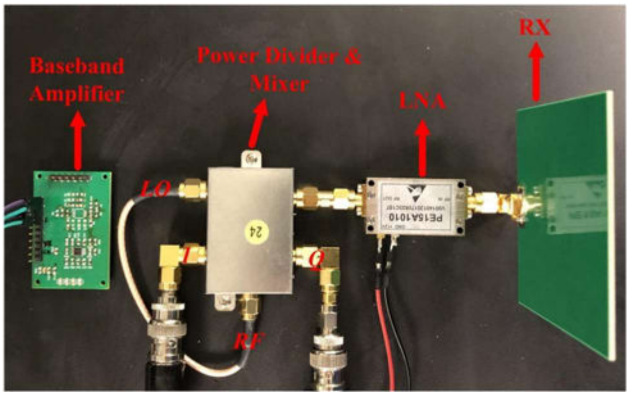

Fig. 3. Photograph of the quadrature-mixer-based microwave passive sensing topology. From [5].

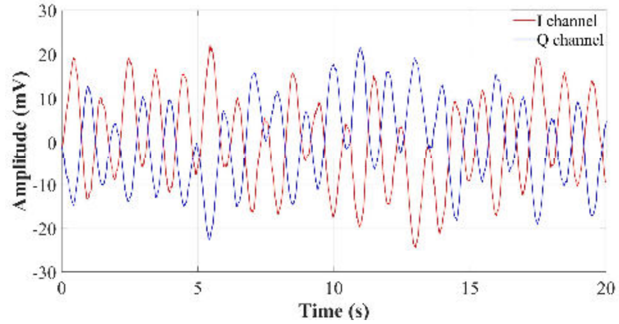

Fig. 4. Experimental results. Recovered *I*/*Q* baseband signals. From [5].

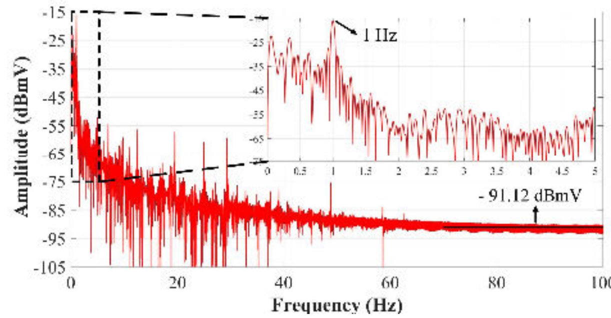

Fig. 5. Experimental results. Spectra of the recovered *I*/*Q* baseband signals. From [5].

customized diode-based topology, which was designed in a low-cost printed-circuit board to maximize the system's down-conversion gain. The sensitivity of the proposed sensor was evaluated by doing vital-sign measurements and hand gesture identification. Design details of diode-based passive radar can be found in [4].

C. Quadrature-Mixer-Based Topology

Fig. 3 reveals the developed quadrature-mixer-based architecture. Since the proposed sensor can only be used to extract Doppler information from the received signals, the active microwave source was a signal generator operating at 2.4-GHz. In the proposed design, the receiving antenna captures two signals. One is the direct-path signal that is emitted by the transmitter. On the other hand, part of the transmitted microwave energy travels towards a moving target, and a portion of the Doppler-modulated signals are backscattered towards the receiving antenna. As shown in Fig. 3, the receiving antenna is followed by a 41-dB low-noise amplifier with noise figure and input referred P1dB of -25 dBm and 0.9 dB at 2.4-GHz, respectively. These two signals are, then, fed into the input port of a power splitter, which is followed by a passive mixer. The internal asymmetric of the local-oscillator (LO)/RF ports of a nonlinear detector allows the mixing of the two tones, and the Doppler frequencies associated with the moving target can be estimated by Fourier analysis. To evaluate the sensitivity of the proposed architecture to small amplitude motion, experiments were conducted using a rectangular metal place with dimensions of 10 cm × 10 cm attached to a programmable mechanical actuator. Fig. 4 and Fig. 5 exhibit the recovered baseband signals in the time-domain and in the frequency-domain for a 1 mm/1 Hz motion, respectively. A moving-average technique was applied along each channel. Further design details of the proposed architecture can be found in [5].

III. Conclusion

Three different microwave topologies that leverage ambient RF radiations from a source of electromagnetic signals for passive sensing were proposed and experimentally validated. After being optimized and fully integrated, the proposed topologies can be utilized in several industrial and consumer electronics applications, including microwave/millimeter-wave passive vital sign tracking, passive presence detection, and passive gesture control.

IV. Professional Career Plan, Fellowship Impact and Acknowledgement

Following my PhD studies, I intend to pursue a career as a radar researcher either in the academia or the industry. It was a great honor for me to receive the 2022 IEEE MTT-S Tom Brazil Graduate Fellowship Award. This prestigious recognition has motivated me to continue pushing the boundaries of the RF/microwave engineering field. I would like to express my most sincere appreciation to the IEEE Microwave Theory and Technology Society for the support and for sponsoring my attendance to the 2022 IMS in Denver, CO, USA. Also, I am grateful to my advisor, Dr. Changhzi Li, for providing consistent guidance and encouragement for my research endeavors.

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