A Low-Power and Low-Cost Monostatic Beamforming Radar Array Based on a Novel 2-Port Transceiver Chain Using Mutually Injection-Locked Oscillators

Daniel Rodriguez, Graduate Student Member, *IEEE*, and Changzhi Li, Senior *Member, IEEE*

***Abstract*— This report gives a brief overview of the outcomes of the project "A Low-Power and Low-Cost Monostatic Beamforming Radar Array Based on a Novel 2-Port Transceiver Chain Using Mutually Injection-Locked Oscillators". This project seeks to develop a novel, low-power and low-cost 2-port monostatic beamforming radar that features compact size and only one active device in the RF front-end. Prototypes of the 2-port single channel monostatic radars working at 5.8-GHz and 24-GHz have been developed. Additionally, a quadrature version (e.g., *I*/*Q* channels) working at 5.8-GHz was developed and tested. The performance of the three prototypes has been experimentally verified to assess the proposed architecture. In addition, the *I*/*Q* channels distortion present in the proposed quadrature architecture was analyzed.**

***Index Terms*— Doppler radar, Interferometric radar, Internet of things, Schottky diode.**

I. Introduction

THE upcoming IoT era has increased the interest on low-power and self-powered smart sensors with small form factors suitable for massive fabrication [1]. Therefore, it is imperative to pursue the design of ultra-low-cost on-board electronics to make feasible the deployment of the large number of sensors demanded in the IoT era [1]. For many portable radar sensors, the quadrature direct down-conversion architecture has been widely used due to its low complexity and easy on-chip integration. However, this architecture uses several active components that increase its power consumption, form factor, as well as cost. Additionally, the quadrature direct-conversion receiver presents *I*/*Q* channels phase and amplitude imbalance due to circuit non-idealities that destroys the orthogonality of the received signal [2].

Another problem lies in detecting multiple targets located at the same distance from the radar simultaneously. To overcome this problem, electrical beam-scanning techniques such as frequency-scanning arrays and planar phased arrays have been proposed. Frequency-scanning arrays use different frequencies to steer the antenna beam, which introduce a poor spectrum efficiency. For planar phased arrays, RF and digital beamforming are the two main approaches for its implementation. For RF beamforming, a dedicated phase shifter is needed for each antenna element, which dramatically increases the hardware complexity and cost. On the other hand, digital beamforming offers higher amplitude and phase control accuracy by controlling the phase an amplitude of each antenna in the digital domain. Dedicated high-speed digitizers or digital-to-analog converters are required for each antenna element, which might increase the cost of the system. However, this technique can be applied to the down-converted baseband signal instead of the RF, highly relaxing the digitizer constrains. To achieve a decent angular resolution within 5°, a planar phased array may require hundreds of antenna elements that usually use dedicated LNAs, which makes the system complex and expensive. To reduce the cost and power consumption of portable beamforming radar sensors and meet the requirements of the IoT era, new radar front-end architectures must be developed using fewer active components per antenna element.

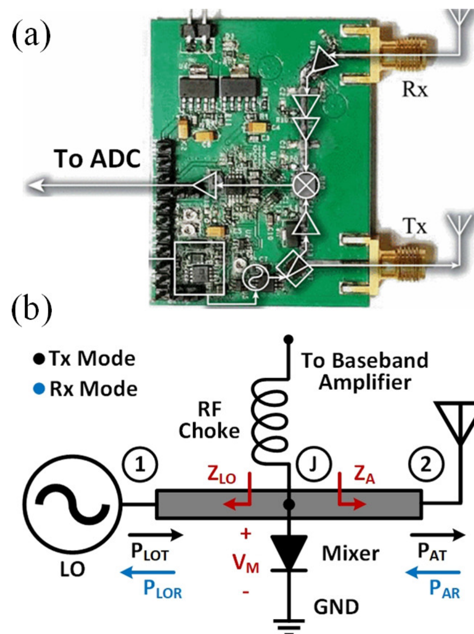

Fig. 1. Radar architectures: (a) Conventional direct conversion radar [3], (b) Proposed 2-Port monostatic radar.

II. Project Outcomes

A. 5.8-GHz & 24-GHz Single Channel 2-Port Monostatic Radar

Two novel, low-power, and low-cost 2-port monostatic

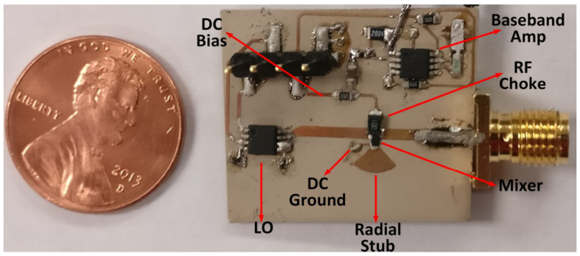

Fig. 2. Photo of the 5.8-GHz radar prototype.

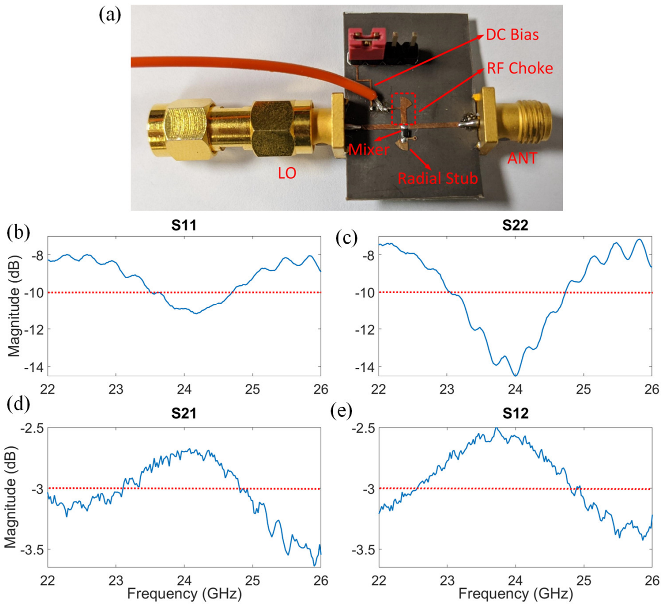

Fig. 3. (a) Photo of the 24-GHz prototype. (b) Measured S_{11}. (c) Measured S_{22}. (d) Measured S_{21}. (e) Measured S_{12}.

radars suitable for massive fabrication and array implementation have been developed for this project. Unlike conventional radar systems, these prototypes do not use separate signal chains for Tx/Rx, just exhibit a single antenna, and does not use a hybrid or circulator in the RF front-end. Besides the local oscillator (LO), there is no other active device consuming any DC power. A comparison between the conventional direct conversion radar architecture and the proposed 2-port monostatic radar is depicted in Figure 1(a)-(b).

The photo of the 5.8-GHz prototype is depicted in Figure 2, its design details can be found in [1]. Experiments with the 5.8-GHz radar revealed its high sensitivity and suitability for short range applications.

Figure 3 depicts the photo of the 24-GHz prototype along with its measured scattering parameters. As illustrated in Figure 3(b)-(c), the antenna and the LO ports of the radar are matched at 24-GHz, what is desirable for high sensitivity. Additionally, the antenna's and LO's power was almost equally divided among the system's RF paths, as depicted in Figure 3(d)-(e). In other words, almost half of the LO's power is transmitted by the antenna and the remaining power is used to drive the Schottky diode. On the other hand, almost half of the antenna's Rx power is mixed by the diode with the LO's signal, while the remaining Rx power goes to the LO port.

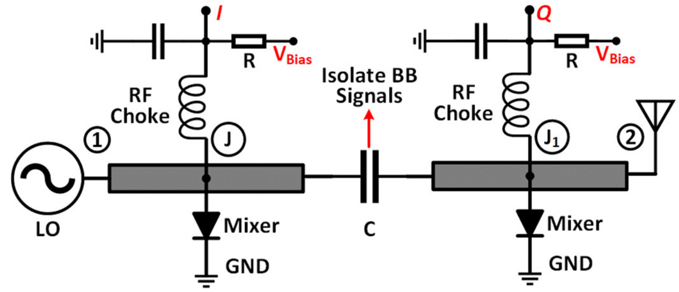

Fig. 4. Quadrature 2-port monostatic radar schematic.

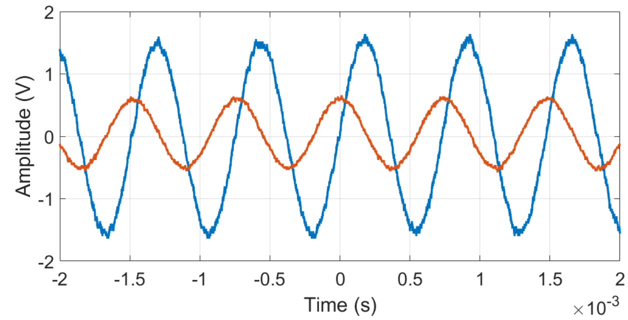

Fig. 5. Measured quadrature baseband signals.

B. *5.8-GHz Quadrature Version*

To expand the possible applications of the proposed radar, a quadrature 2-port monostatic radar was designed, fabricated, and tested. Figure 4 illustrates the schematic of the proposed architecture, a capacitor was used to isolate the quadrature baseband signals and the desired phase shift was introduced using transmission line propagation. The system performance was measured by feeding a 5.8-GHz signal into port 1 and a signal with 1.5-KHz offset into port 2. The quadrature down-converted 1.5-KHz baseband signals are shown in Fig. 5. As depicted, the phase difference between the quadrature channels is almost 90°. However, they present an *I*/*Q* amplitude imbalance of 7.9 dBV. This imbalance can be easily corrected in digital domain after proper system characterization [2].

III. Career Plan and Fellowship Impact

I would like to sincerely thank MTT-S for awarding me this fellowship. It has encouraged and enabled me to conduct this research. This award provided me financial stability during this difficult time and the recognition of my work. For me, it is an honor to be one of the recipients of this prestigious award, it encouraged me to continue studying the amazing field of microwave engineering from either academia or industry.

References

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