Multifunction Interferometric Architectures for Millimeter-Wave and Terahertz Applications

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***Abstract*—This report introduces our recent work in the development of millimeter-wave (mmW) and terahertz (THz) multiport interferometric receivers. Our primary focus is on designing innovative linear interferometric architectures, with particular attention to integrating multichannel, multifunctional, low-power, and polarization-diversified compact front-end systems. Experimental prototypes based on these architectures have been successfully built and validated. In this study, we introduce an all-in-one monoblock interferometric waveguide receiver, designed for multifunctional and dual-polarized wireless systems, including integrated sensing and communication (ISAC). For the first time, we present a unified microwave and THz interferometric front-end that operates concurrently at both 5.8 GHz and 150 GHz. This groundbreaking work, demonstrated both theoretically and experimentally, paves the way for the full-scale integration of data transfer, energy harvesting, and sensing functionalities in future systems.**

***Index Terms*—Direct conversion receiver, multifunction, integrated sensing and communication (ISAC), fifth and sixth generation (5G and 6G), interferometric receiver, multiport receiver, millimeter-wave (mmW), terahertz (THz).**

I. Introduction

MILLIMETER-WAVE (mmW) and terahertz (THz) bands are emerging as the core of future wireless spectrum, complementing established RF/microwave bands for high-mobility applications [1], [2]. In this context, upcoming wireless technologies will greatly benefit from the integration and synergy of mmW and THz multifunctional systems, particularly in areas like integrated sensing and communication (ISAC) and other non-traditional wireless applications. Clearly, multifunction receiver systems are critical to driving the development of these disruptive technologies for future applications.

This report reviews and highlights our progress in developing multiport linear interferometric receivers that support the integration of multifunction, multichannel, and multimode capabilities for emerging multistandard mmW and THz applications. These interferometric architectures are expected to replace traditional mixer-based nonlinear interference systems, offering advantages in terms of low power and cost. The experimental prototypes we have developed demonstrate significant benefits, including compactness, low power consumption, and reduced complexity. Moreover, our newly unified microwave and THz interferometric receiver architecture is poised to have a significant impact on the development of joint RF, mmW, and THz multifunction systems.

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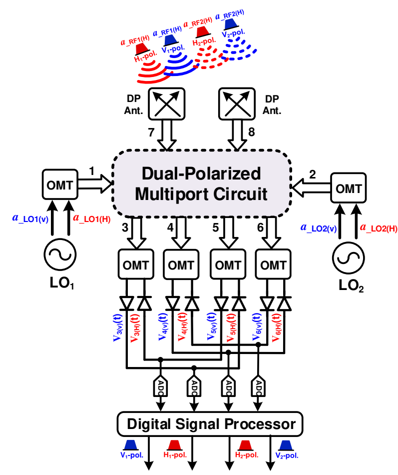


Fig. 1. Proposed dual-polarized metallic interferometric waveguide receiver systems.

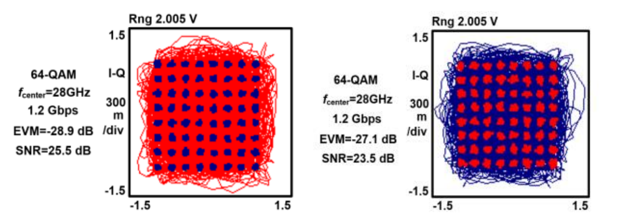


Fig. 2. Measured constellation diagrams of the proposed metallic interferometric waveguide receiver systems. (a) Vertical-polarization 64-QAM at 28 GHz. (b) Horizontal-polarization 64-QAM at 28 GHz.

II. All-in-One Dual-Polarization Waveguide Receiver for Multichannel Wireless Systems

Recently, our introduced all-in-one interferometric receiver architecture features a unique approach for developing compact dual-polarization wireless systems with high communication capacity [3]. Leveraging the intrinsic properties of the square waveguide, both horizontal (H) and vertical (V) polarizations can be simultaneously excited in a monoblock structure, ensuring high isolation transmission. When both polarizations operate at the same carrier frequency, the effective channel capacity is doubled.

Fig. 1 illustrates the receiver configuration, which consists mainly of a core dual-polarization multiport circuit with four cruciform couplers and a phase shifter. Four pairs of balanced power detectors are connected to output ports 3 to 6, while ports 7 and 8 are used to connect the dual-polarization antennas. The modulated V/H-polarization signals are combined with the

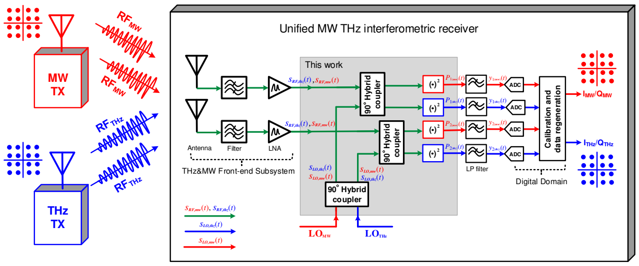
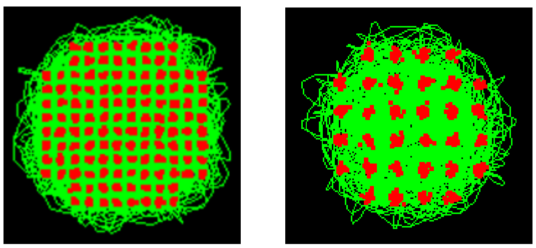


Fig. 3. Proposed unified microwave and terahertz interferometric receiver.



(a) (b)

Fig. 4. Measured constellation diagrams of the proposed unified microwave and terahertz interferometric receiver. (a) 128-QAM at 5.8 GHz. (b) 32-QAM at 150 GHz.

local oscillator (LO) signals and fed to the power detectors at ports 3 to 6. Due to the nonlinear properties of the power detectors, the RF signal is downconverted to intermediate frequency (IF) or baseband signals, allowing the recovery of I and Q components from the modulated V/H-polarized signals.

To validate this receiver architecture, we developed a prototype using metallic waveguide technology. The dual-polarization performance of the receiver was demonstrated with V/H-polarized RF signals modulated at millimeter-wave (mmW) frequencies. The demodulated constellation diagrams shown in Fig. 2 confirms the excellent performance of the proposed all-in-one receiver, providing a promising solution for multistandard dual-polarization wireless systems.

III. Unified Microwave and Terahertz Interferometric Receiver

Emerging wireless technologies stand to gain from the integration of microwave (MW) and terahertz (THz) technologies, which could provide a solution for future multifunctional, multistandard, and coexisting smart wireless platforms that support a wide range of joint sensing and communication services. However, integrating both MW and THz bands into a single receiver hardware is challenging due to the large frequency disparity. In [4], a unified MW and THz receiver architecture was proposed for the first time.

As depicted in Fig. 3, modulated MW and THz signals are directed into the wave-correlator network, consisting of three 90-degree hybrid couplers. The MW and THz local oscillator (LO) signals are then combined with their corresponding MW and THz RF signals, with relative phase shifts, and sent to output power detectors for linear interference. To enable simultaneous demodulation of the RF signals, separate MW and THz power detectors are employed. Both power detectors operate in their square-law linear region, simultaneously demodulating the individual channels to intermediate frequency (IF) bands.

A proof-of-concept experimental prototype was developed and fabricated using an MHMIC manufacturing process at our Poly-Grames Research Center. Measurements were conducted with various M-QAM signals at 5.8 GHz and 150 GHz for the MW and THz bands, respectively. Fig. 4 shows the measured results of the prototype. The measured average error vector magnitude (EVM) does not exceed -30 dB and -24 dB for the MW and THz bands, respectively, validating the proposed MW and THz channel unification concept. It is also notable that the proposed receiver could facilitate energy harvesting in the MW band and data communication in the THz band, potentially enabling the system to be energy-autonomous and fully or partially self-powered.

IV. Conclusion

The techniques we have presented showcase the potential of utilizing multiport linear interferometric receiver architectures for various mmW and THz applications. With their inherent low power consumption, simple structure, and broad bandwidth performance, these interferometric receivers are well-suited to support the large-scale deployment of 5G, 6G, and future wireless systems. We anticipate that these significant advancements in linear interferometric technology will play a pivotal role in shaping the future of emerging mmW and THz multifunction wireless sensing and communication systems, having a profound impact on their development.

V. Career Plan and Fellowship Impact

Receiving the IEEE MTT-S Graduate Fellowship has been a great source of encouragement and has significantly boosted my confidence in continuing my academic journey. I am also deeply grateful to the MTT-S Educational Committee for offering such flexible financial support. I truly believe that this opportunity will be an invaluable experience, and I am eagerly looking forward to it.

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