Terahertz Schottky diode harmonic mixers

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***Abstract*—This paper summarises the development of the 4.7-THz, ×8-harmonic, single-ended integrated Schottky diode-based harmonic mixer. The harmonic mixer utilises a sub-micron size Schottky diode fabricated with circuit elements on a suspended 2-μm-thick GaAs stripline circuit in an E-plane split-block housing. The harmonic mixer design and simulation results are presented.**

***Index Terms*—Fundamental mixers, Heterodyne receivers, Schottky diodes, Terahertz electronics**

I. INTRODUCTION

Terahertz (THz) heterodyne spectroscopy is a valuable tool for understanding the physics, distribution profile, and concentration of molecular and atomic gas in space [1]. Studying the chemical composition of the Earth and other planetary atmospheres can provide valuable insights into global warming and climate change. In particular, detecting gas species such as atomic oxygen (OI) at 4.7 THz [2] and hydroxyl radical at 3.5 THz in the least explored atmospheric regions can improve the climate and weather prediction models.

However, the lack of THz local oscillator (LO) sources with good frequency stability and low phase noise is one of the main drawbacks in realising THz heterodyne spectrometers [3]. Over the past decade, quantum-cascade lasers (QCLs) have shown steady performance improvement. QCLs can provide a few mW of output power and operate in continuous-wave (CW) mode, making them an ideal candidate for space missions [4]. However, QCLs are prone to frequency instabilities due to variations in bias current and temperature and, thus, require frequency stabilisation. Phase-locking of the QCL to a stable microwave reference oscillator using a Schottky diode-based harmonic mixer can result in a compact solution for realising high-resolution THz receivers for long lifetime space missions [5], [6].

II. DESIGN

First, the embedding impedances of a Schottky diode with a sub-micron anode area were evaluated using a large-signal, harmonic-balance simulation. Using the built-in optimiser in the circuit simulator, the diode-embedding impedances at the RF, IF, and LO frequency were varied to provide a low mixer conversion loss L. Based on this, a full-3D EM simulation model was implemented. Fig. 1 shows the design of 4.7-THz, ×8-harmonic mixer realised on a 2-μm-thick GaAs substrate. The incoming RF signal from the 4.7-THz QCL is coupled to the diode using a diagonal horn integrated into the RF rectangular waveguide WM-48. The mixer is pumped by a Schottky varactor ×64-LO multiplier source. The radial LO probe was optimised to provide wide-band LO matching to the diode around 600 GHz.

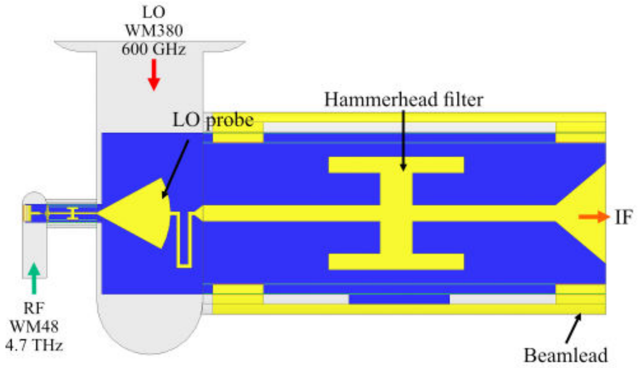

Fig. 1. 4.7-THz harmonic mixer. 3D-EM model of the 4.7-THz, ×8-harmonic mixer. The GaAs circuit is suspended in an E-plane metal split-block by beamleads.

III. FABRICATION PROCESS

The realisation of terahertz integrated circuits demands the alignment of patterns with high accuracy and precision in the order of sub-microns. Hence, we have developed a fabrication process entirely based on electron-beam lithography. The GaAs wafer consists of a 50-nm-thick n-doped epi-layer with a doping concentration of $6 \times 10^{17}\,\mathrm{cm}^{-3}$. Followed by a 500-nm-thick, heavily doped n^{++} buffer layer with a doping concentration of $5 \times 10^{18}\,\mathrm{cm}^{-3}$. The wafer has two (Al,Ga)As etch stop layers.

IV. SIMULATION RESULTS

Conversion loss plotted versus radio frequencies (RF) for LO power of 0 dBm, dc bias of $0.5\,\mathrm{V}$ is shown in Fig. 2. Note: loss in the substrate and low conductive mesa, conductor loss in the RF diagonal horn ($\approx$ 2 mm), and LO access waveguide ($\approx$ 11 mm) are not included in this ideal simulation.

Fig. 3 shows the conversion loss contours for various LO power and dc bias. The occurrence of conversion nulls caused due to the destructive interference of harmonic mixing products is as expected.

V. RF CHARACTERISATION

The fabrication of integrated mixer circuits and machining of mixer blocks is currently underway. Once completed, the RF characterisation of harmonic mixers will be carried out.

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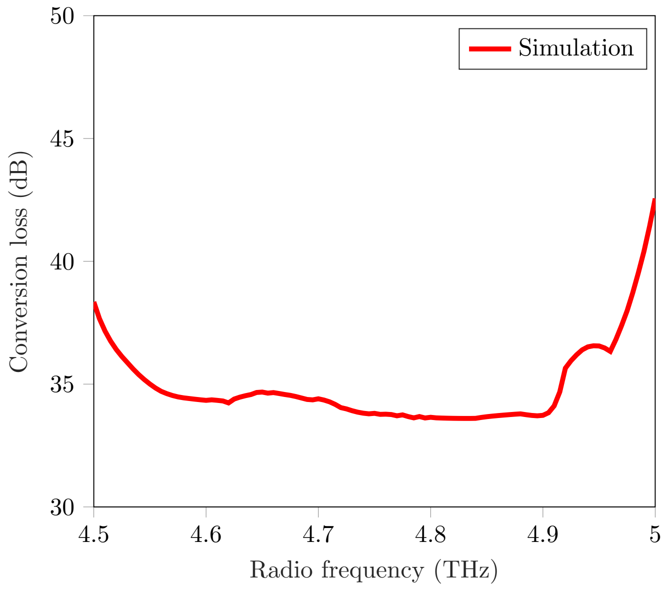

Fig. 2. Simulated 4.7-THz, ×8-harmonic mixer performance versus RF.

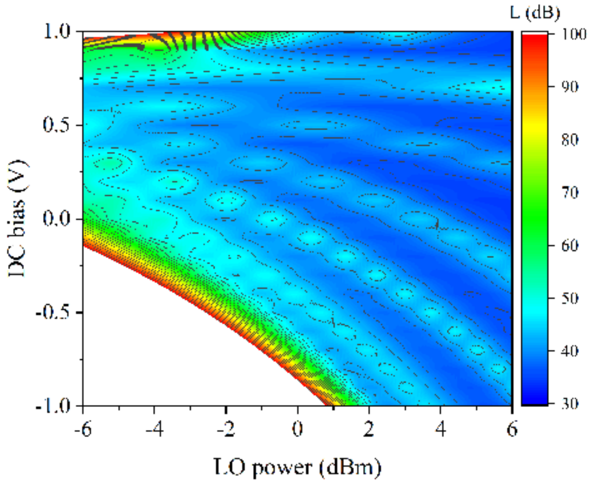

Fig. 3. Simulated 4.7-THz, ×8-harmonic mixer conversion loss contour as a function of LO power and bias.

The schematic 4 shows the characterisation setup of the 4.7-THz harmonic mixer. The 4.7-THz QCL is placed in the AIM cryocooler, and the THz signal is focused on the mixer using a TPX lens. The mixer is pumped using a 600-GHz, ×64 varactor-based Schottky multiplier chain.

VI. CAREER PLAN

I want to thank IEEE MTT-S for awarding the graduate fellowship. I am honoured to receive this prestigious award. It profoundly impacted my research career and helped me broaden my horizon. Upon graduation, I intend to pursue a career in academia and focus on developing supra-THz electronics for space instrumentation.

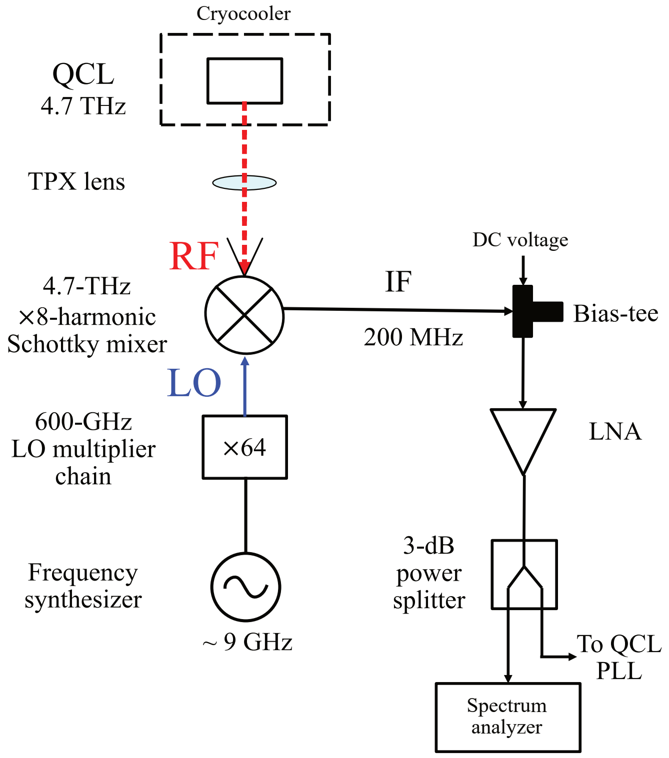

Fig. 4. RF characterisation setup of the harmonic mixer.

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