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73 GHz pHEMT Pumped Transconductance RX Mixer with Low Local Oscillator Drive Power

Edward A. Ball[1], and Sumin David Joseph[1]
[1]The University of Sheffield, Sheffield, South Yorkshire, S1 3JD UK

***Abstract*—Future mmWave mobile architectures will benefit from low power RF circuits and systems. In this work we propose two pumped transconductance balanced mixers requiring low LO drive power and DC power. The mixers operate at circa 73 GHz RF and 70 GHz LO. A 90-degree hybrid is used on the input to simplify input matching. Off-chip IF matching is implemented on a test PCB. We observe a conversion gain of -17 dB for an LO power of -10 dBm, with a DC current of 1.3 mA and an IP1dB of -3.3 dBm for one of the prototypes. LO powers down to -20 dBm are also potentially viable, if greater loss can be accepted.**

I. INTRODUCTION

THE RF RX mixer remains an essential component for future 6G mmWave and sub-THz receivers [1] [2]. There is much ongoing research considering future transceiver architectures [3]. Direct digitization at high mmWave carrier frequencies via subsampling is not currently pragmatic. The use of mixers in future mobile devices will require them to be sufficiently high performance for end use-case scenarios, and low power. The local oscillator (LO) power becomes difficult to generate at high mmWave frequencies, implying poor power efficiency. Therefore, the design of RF RX mixers requiring low LO power is an important topic of research.

The field of RF mixer research has explored materials such as GaAs, SiGe [1], [4], and more recently GaN [5]. Architectures tend to favor the Gilbert Cell [6], if IC fabrication provides multiple metal layers for routing. Research into mixer modelling and optimization for best performance also remains important [7], [8], [9]. Future heterogeneous integration will also benefit from using multiple chiplets to construct systems, such as InP for the highest RF frequencies. It therefore remains important to research mixer architectures suitable for use with materials offering only single metal layers (i.e. III-V technologies).

In this work we investigate a pumped transconductance (PT) mixer using balanced input architecture, with LO at 70 GHz and RF at 73 GHz, for future 6G mobile architecture research. The balanced architecture allows the input return loss to the RF port and LO port to be maintained by use of a 90-degree hybrid, simplifying matching requirements. We have implemented two

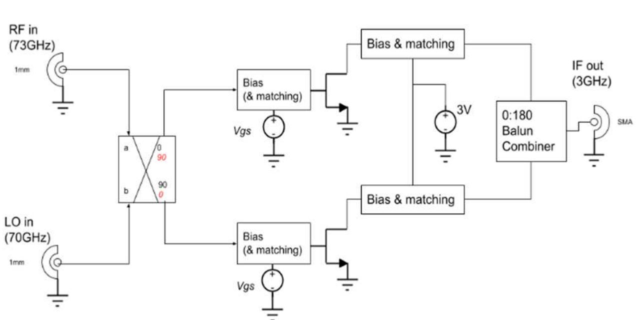

Fig. 1. PT mixer concept.

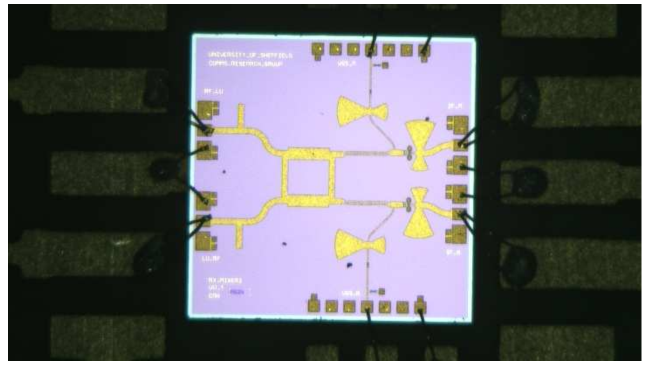

Fig. 2. Mixer 2 bonded to test PCB.

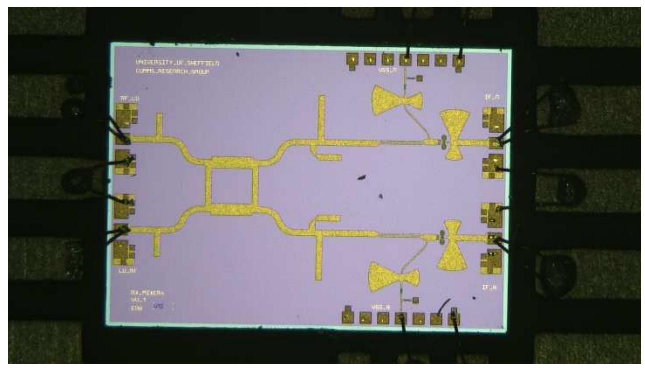

Fig. 3. Mixer 4 bonded to test PCB.

PT mixer concepts, based on the topology of Fig. 1. The RF and LO signals feed into an on-chip 90 degree hybrid. The outputs from the hybrid are then fed into two pHEMTs. Due to the hybrid, one transistor is driven by the RF & (LO+90 degrees) and the other transistor is driven by LO & (RF+90 degrees). This results in two IF output signals that are in antiphase. The drains are biased and matched off-chip and then combined using a balun. The mixer ICs were developed using Keysight ADS and UMS Ltd PH10 PDK. The only difference between the designs is Mixer 2 has no gate side match and Mixer 4 has a gate side pre-match to 50 ohms, to improve LO-RF isolation

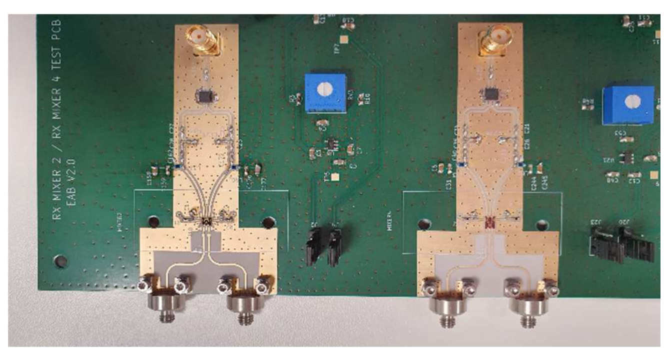

Fig. 4. Mixer 2 (left) & Mixer 4 (right) test PCB. RF and LO 1mm connector ports visible at bottom. IF output SMA ports visible at top.

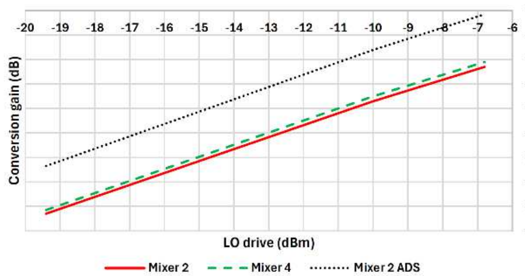

Fig. 5. Mixer 2 and Mixer 4 conversion gain vs LO drive.

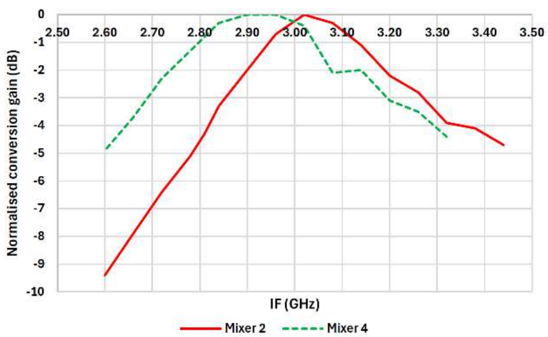

Fig. 6. Mixer 2 and Mixer 4 normalized conversion gain vs IF frequency (RF swept and LO held).

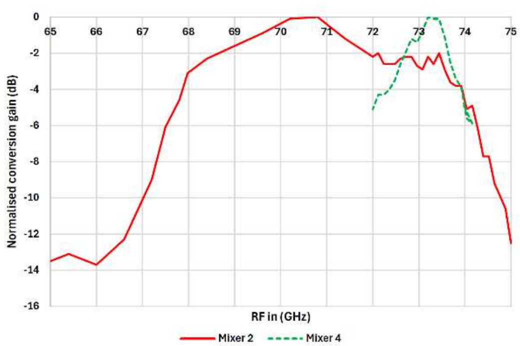

Fig. 7. Mixer 2 and Mixer 4 normalized conversion gain vs RF input frequency (LO adjusted to maintain a 3GHz IF).

from the hybrid. The Mixer 2 die is shown in Fig. 2 and Mixer 4 in Fig. 3. The chips mounted to the PCB are shown in Fig 4.

II. Results

We fully co-simulated and then measured the manufactured mixer dies. Measurements were performed at [10]. Fig. 5 presents the conversion gain, showing an expected relationship with LO drive power. The measured conversion gain is circa 4 dB below ADS predictions, possibly due to additional losses in the PCB and IF matching components. Both mixers provide a conversion gain close to -17 dB for an LO power of -10 dBm.

Fig. 6 shows that the IF outputs are closely centered to 3 GHz, as necessary for the chosen LO and RF. The IF match is defined by PCB lumped components.

We also investigated the requirements of the IF match as a function of LO drive, and DC bias *Vgs* for both pHEMTs. This identified that a fixed IF match was acceptable, since the IF impedance providing maximum IF power transfer was not a function of LO power. This was evaluated using ADS load pull simulations on the drain at the IF, whilst DC bias and LO power was varied.

Fig. 7 shows an interesting result that suggests Mixer 2 enables broader band RF & LO operation, whereas Mixer 4 has a narrow band of operation, possibly due to the gate input matching used. Mixer 4 could be useful for narrow band applications where additional rejection of unwanted signals is beneficial. Mixer 2 could be more applicable to broadband operations, providing a 3 dB bandwidth of 68 – 73.5 GHz.

Both mixers work with a tested LO power of down to -20 dBm, with attendant degradation in conversion gain. This feature may be useful for reconfigurable radio systems that do not always need the best conversion gain for an operational use case. This could then further save LO drive power.

The mixers' IP1dB has been measured. For Mixer 2, with an LO drive of -10 dBm, the IP1dB was -3.3 dBm. For Mixer 4, with an LO drive of -10 dBm, the IP1dB was -6.3 dBm.

The total DC current draw from the 3 V supply was 1.3 mA for Mixer 2 and 1.9 mA for Mixer 4.

We propose that these mixers (and the PT approach more broadly), can be relevant for future LO power constrained applications in high mmWave bands.

III. Summary

In this work we present the results of initial tests on two PT mixers operating at circa 73GHz, for use in future mmWave mobile research platforms. A key aim was to provide viable mixer operation with low LO power and low DC power requirements, to enable power efficiency. The use of an unmatched pair of pHEMTs fed by a hybrid gave the broadest RF bandwidth. Conversion gain of -17 dB was measured for a -10 dBm LO at 70 GHz.

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