Monolithic Ka-band Even-Harmonic Quadrature Resistive Mixer for Direct Conversion Receivers

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Abstract — **This paper describes the design and measured performance of a Ka-band even-harmonic quadrature mixer which employs PHEMT resistive mixer elements. By employing the even-harmonic technique, with a local oscillator at half the RF input frequency, the mixer is better suited for direct conversion receiver application. The chip operates in the 30 to 40 GHz range and has been used to successfully demodulate a 4Mb/s 16-QAM signal at 38GHz.**

I. INTRODUCTION

Direct conversion receivers, that convert the received RF signal directly to baseband, have several advantages over conventional heterodyne systems [1,2]. They have low circuit complexity since the IF circuitry is eliminated. This low circuit complexity is particularly advantageous for monolithic microwave integrated circuit (MMIC) design where chip area must be minimized for low cost. Furthermore, the low complexity leads to lower DC power requirements, which is usually a concern in mobile communications. However, a conventional direct conversion receiver suffers from undesired baseband components produced by second order mixing. This second order distortion is generated from intermodulation (IM2) between RF signals and self-mixing between the LO and the LO noise. This intermodulation limits the instantaneous dynamic range of direct conversion receivers and degrades the communication performance. Fortunately, second order distortion can be eliminated, in principle, by using an even harmonic type of harmonic mixer [3-7]. Theoretically, these mixers have no second-order distortion because they have only odd-symmetric nonlinearity terms.

In this paper we present a monolithic Ka-band even-harmonic quadrature mixer for direct conversion receivers. This is believed to be the first demonstration of the technique at millimeter-wave frequencies. The circuit was designed and fabricated using the EONCOM 0.25μm gate length AlGaAs/InGaAs PHEMT process.

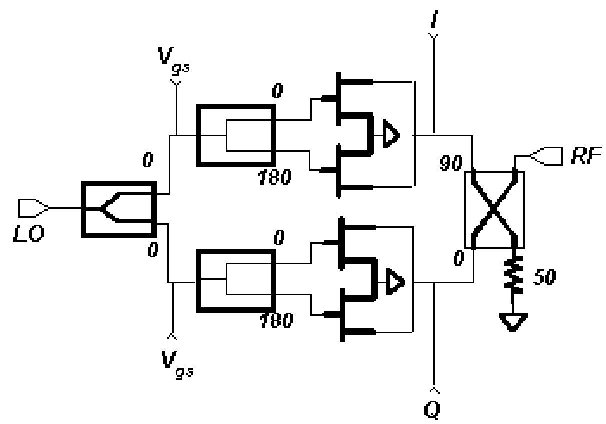

Fig 1. Block diagram of even harmonic quadrature demodulator using resistive mixers

The circuit description is described in Section II. The resistive mixer was selected due to its low DC power consumption and its good linearity. The balun is implemented in a planar form using a Marchand balun topology for wideband operation. There is no external IF filter for the design. The measurement results of LO isolation at RF and IF port, conversion gain and the demodulator performance are presented in Section III. The demodulated waveform from the chip shows the same pattern as the input 16-QAM modulation waveform at 4 Mbit/s data-rate.

II. EVEN HARMONIC QUADRATURE MIXER

A. System Details

Fig. 1 shows the block diagram of the even-harmonic I-Q demodulator which we present in this paper. The LO signal (at half the RF signal frequency) is split in-phase and fed into the I and Q channels. Using LO baluns, each resistive mixer pair is then pumped by the LO in a push-pull manner. The RF signal is applied in quadrature to

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each pair of transistor drains using a Lange coupler. Due to the nonlinearity of the devices, the second-harmonic of the LO is generated and this creates the mixing product of the desired term (2LO+/-RF) at the drain. In addition, due to the push-pull operation, even-order terms of the mixer are cancelled out. The $2xF_{LO}$ signal appearing at the drains is thus mostly cancelled out, reducing the effect of LO leakage to the antenna and preventing DC offset problems which are a critical concern in a direct-conversion receiver. The combination of a resistive mixer and even-harmonic operation results in very low distortion.

B. Circuit description

The subsystem in Fig. 1 has been implemented on a single chip. The LO power divider is realized using a distributed Wilkinson power divider centered at 19 GHz. The LO baluns were realised with a Marchand balun, selected for its wide bandwidth. The balun is designed to function additionally as an input impedance transformer at the gate. Meandered Lange couplers are used for individual coupling sections to form the Marchand balun.

Fig. 2 shows a microphotograph of the monolithic Ka-band even-harmonic quadrature mixer chip. The LO input is at the top, the RF input is at the bottom and the I, Q and DC bias pads are on the left- and right-hand sides. The circuit was fabricated using the EONCOM process, which employs 0.25 μm gate length AlGaAs/InGaAs pHEMT on 100 μm GaAs substrate. The process incorporates silicon nitride MIM capacitors, nichrome resistors, air-bridge interconnects and via holes. The simulations were carried out using Libra™ with Foundry model data, and the layout completed using Wavemaker™. The chip size is approximately $2.1x2.9\ mm^2$.

For the mixer, the gate bias of the transistors is applied at the grounded ends of these Lange couplers via a quarter-wavelength transmission line and a decoupling capacitor. The transistor gate is connected at the balun outputs via the isolation ports of the couplers. The 90-degree hybrid coupler at RF is also implemented using a Lange coupler (at twice the LO frequency).

The I-Q outputs are each obtained via a simple low-pass filter consisting of a high impedance microstrip line and MIM decoupling capacitor. The resistive mixer was designed at zero-drain bias and –1.2 V gate-source bias with 4x60 μm PHEMT devices. This optimum bias was selected to obtain the best mixer conversion loss. The resistive mixer was selected for its excellent linearity and low DC power consumption requirement.

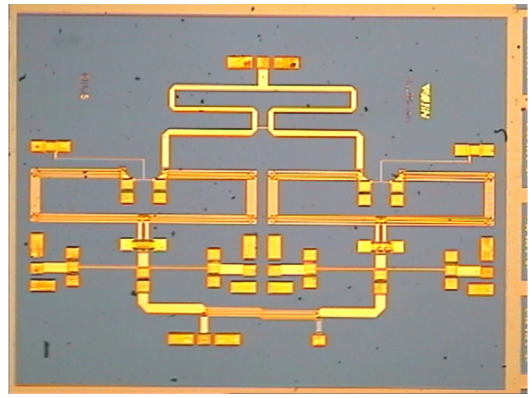

Fig 2. Microphotograph of the even-harmonic quadrature mixer chip

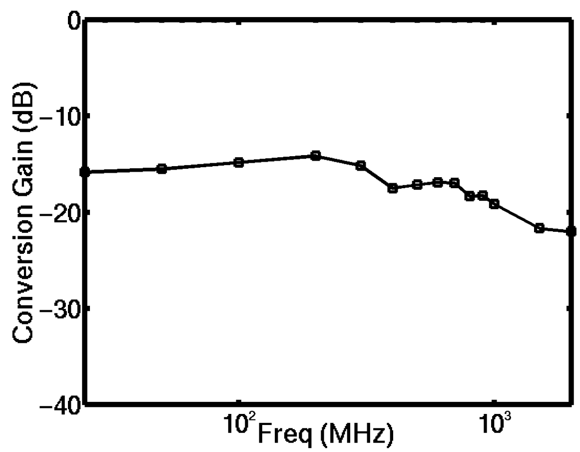

Fig. 3 Conversion loss vs. IF frequency

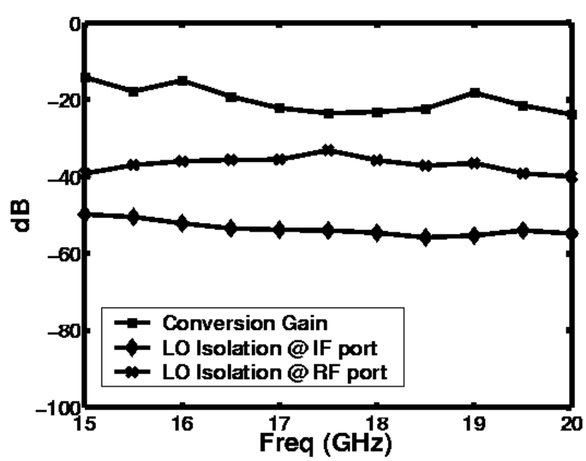

Fig. 4 Conversion loss and LO leakage vs. LO frequency (fixed IF)

III. Measurement Results

The demodulator was measured on–wafer. The LO signal was obtained from a synthesized source (HP83650) and the RF signal was obtained from a network analyzer in CW mode. The IF output signal was first measured using a spectrum analyzer (HP8563E). All LO and RF power levels from the sources were calibrated before the measurements. The conversion loss was found to be around 14 dB at a 200 MHz IF, which is in agreement with expectations for a harmonic mixer. The 3-dB IF bandwidth of the demodulator is around 0.4 GHz, as shown in Fig. 3. Fig 4 shows the performance of the mixer with the LO swept from 15 GHz to 20 GHz. Without external IF filters, the LO leakage power at the IF and RF port is less than –33 dBm and –50 dBm, respectively. All measurements were performed with V_{gs} = -1V and V_{ds} = 0V for the demodulator biasing.

Single-tone distortion measurements of the mixer were performed at 13 dBm LO power (at 19GHz) with a 38GHz RF signal. The RF signal power was swept from –26.5 dBm to –16.5 dBm. The input second-order (IIP2) and third-order intercept point (IIP3) of the mixer are +21 and +23 dBm, respectively, as shown in Fig. 5.

The demodulation performance of the chip was tested on a 16-QAM signal at 4 Mbits/s. The 38GHz 16-QAM signal was generated using baseband signals from an arbitrary function generator feeding a vector modulator chip, previously designed at 38 GHz. This vector modulator chip was designed based on the analog reflection-type topology [8] operated in a balanced mode to obtain a full 360-degree phase coverage. Consequently, the modulator chip requires 4 baseband signals to generate a modulation waveform, which are I, Q and their complementary signals [9]. The vector modulator chip was wire bonded onto an alumina substrate and connected to with RFOW probes. The carrier signal was obtained from the network analyser.

Fig. 6 shows a comparison of the modulating and demodulated signal (I-channel shown) in the time-domain from the oscilloscope display. The output signal has the same pattern as the input, illustrating the application in millimeter-wave communication applications.

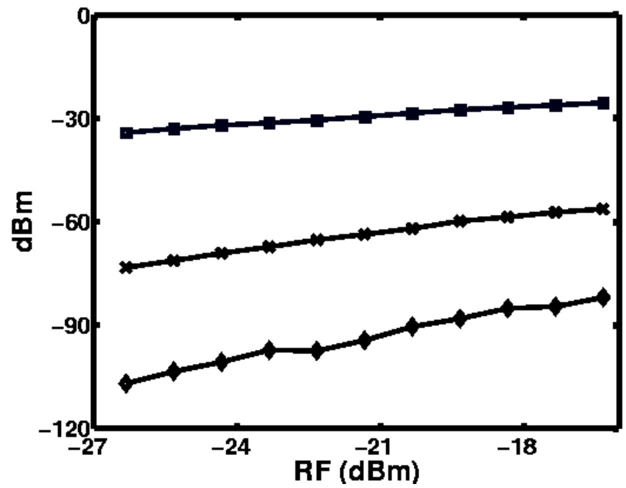

Fig. 5 Intercept diagram

IV. Conclusion

This paper has described the design and performance of a Ka-band even-harmonic quadrature mixer using PHEMTs as resistive mixers. The chip has successfully been used to directly demodulate a 4Mb/s 16-QAM signal at 38GHz. This successfully extends the even-harmonic direct conversion concept into the millimeter-wave range, where point-to-point and point-to-multipoint communications systems are of increasing commercial interest.

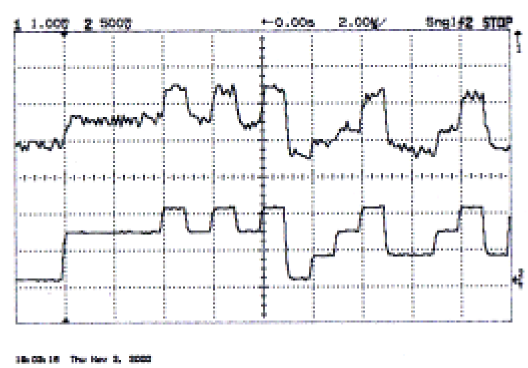

Fig. 6 4Mb/s 16-QAM modulated and demodulated signal from the demodulator chip at 38 GHz RF (I-channel shown)

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