A Compact Monolithic *C*-Band Direct Conversion Receiver

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***Abstract*—A compact monolithic *C*-band direct conversion receiver has been implemented in a commercial 0.6-μm GaAs MESFET process. Subharmonic mixing is utilized to suppress even-order intermodulations and eliminate dc offsets. Second-order input intercept point (IIP2) of $+17$ dBm, third-order input intercept point (IIP3) of $+8$ dBm, and dc offset of -80 dBm are measured on wafer without the use of additional off-chip components. This receiver occupies a die area of 35$\times$53 mil^2 and operates on 2.7 V with 21 mA of dc current. This is the first demonstration of a *C*-band direct conversion receiver MMIC with excellent linearity, dc offset, and dc power consumption.**

***Index Terms*—Frequency conversion, homodyne detection, microwave mixers, microwave receivers.**

I. Introduction

RECENT growth in wireless consumer electronics has greatly increased the demand for compact and cost effective microwave receivers with fewer off-chip components and monolithic integration of the RF, IF, and baseband circuitry. However, implementation of such products becomes challenging when we consider the level of complexity and the stringent filtering requirements of the popular heterodyne topologies. Alternative topologies such as direct conversion can provide the solution by eliminating the IF and the image-reject filtering, and directly demodulating the RF signal to baseband. However, this topology requires new performance criteria such as second-order intermodulations (IM2), dc-offsets, and in-band LO radiation that are not present in a heterodyne topology. In-band LO radiation is the result of using the same frequency as the input RF carrier for the receiver LO signal. The radiated LO, which is typically larger than the RF, cannot only penetrate and saturate the RF front-end but can also result in generation of a dc-offset voltage by self-mixing in the downconvert mixer. Considering the proximity of the intermodulations and the dc-offset to the demodulated spectrum, the receiver must be designed to suppress the generation of these extraneous signals in order to maintain good signal integrity. By maintaining an IIP3 of 5 dBm, an IIP2 of 13 dBm, and a dc-offset level of -75 dBm, we can ensure the sensitivity and the dynamic range required for most *C*-band wireless applications.

Physical implementations of direct conversion receivers have repeatedly proven to be a compromise between linearity, dc-offset, dc power consumption, and level of on-chip integration [1]–[6]. In this letter we demonstrate the design and the measurement results of the first *C*-band direct conversion receiver that can address all the presented performance criteria in a fully monolithic solution.

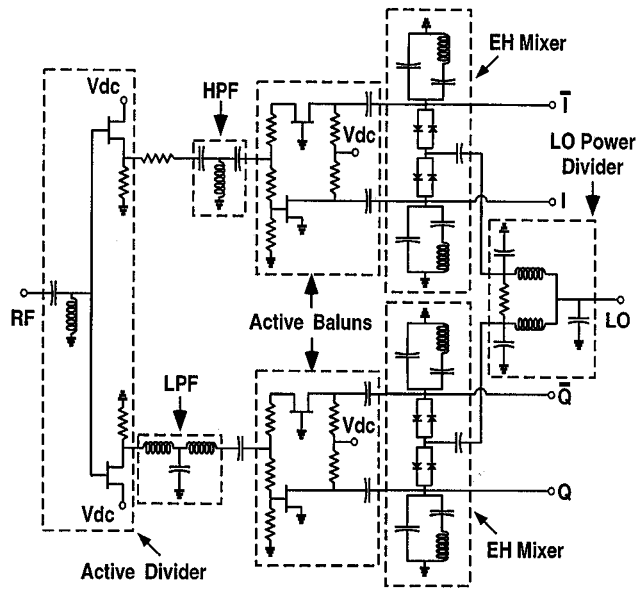

Fig. 1. Circuit schematic of the receiver.

II. Circuit Design

The receiver emulates a simple in-phase (I) and quadrature-phase (Q) demodulator topology with a subharmonic frequency conversion scheme. In this configuration, the RF signal can be directly demodulated using a LO at half the frequency of the RF. This not only alleviates the concern for in-band LO radiation, but also reduces the dc-offsets by suppressing the LO leakage into the RF front-end. Even-order mixing has traditionally proven effective in suppressing second-order intermodulation products; thus it is utilized in this design to reduce IM2 extraneous products in the baseband.

As illustrated in Fig. 1, the receiver consists of different circuit blocks such as dividers, phase shifters, baluns, and mixers. Active implementations are utilized for the RF power divider and baluns to avoid the use of spiral inductors and reduce the die area. However, a passive Wilkinson approach is applied for the LO power divider to withstand high-power LO injection without the need for high current active components. The RF power divider is power matched at the input and provides slight gain that helps to reduce the overall noise figure. Low-pass and high-pass

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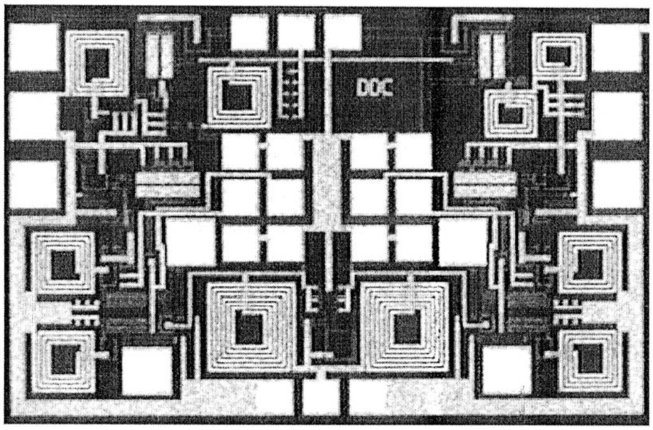

Fig. 2. Photograph of the receiver MMIC.

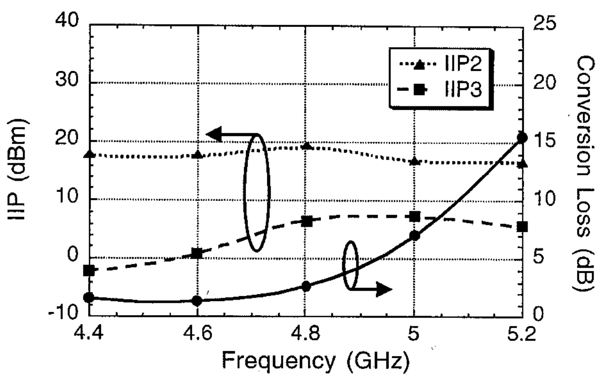

Fig. 3. Linearity and conversion characteristics of the receiver.

filters are utilized as ±45° phase shifters on the RF path for quadrature phase differentiation. Active baluns are used to convert the single-ended RF signal into differential before the balanced mixers [7].

Balanced evenharmonic (EH) mixers are implemented using N^+ overlap Schottky barrier diodes in an anti-parallel diode pair configuration. This EH mixer topology provides excellent suppression of even-order intermodulations [5], [6]. Each mixer consists of two diode pairs that are pumped at the common node by a LO signal from the Wilkinson power divider. The diode pairs are terminated by two resonant tanks that are designed as short circuits at the LO and open circuits at the RF frequencies. This configuration is utilized to improve the LO to RF isolation, and to reduce the conversion loss by maximizing the LO voltage drop across the diode pairs. The mixers are designed for high output load impedance to maximize voltage conversion characteristics.

III. Measurements

The receiver chip, shown in Fig. 2, was mounted on a test board and the baseband output pads were wirebonded to output connectors. The LO and RF pads were probed on wafer using air coplanar probes, and the dc voltages were supplied using dc

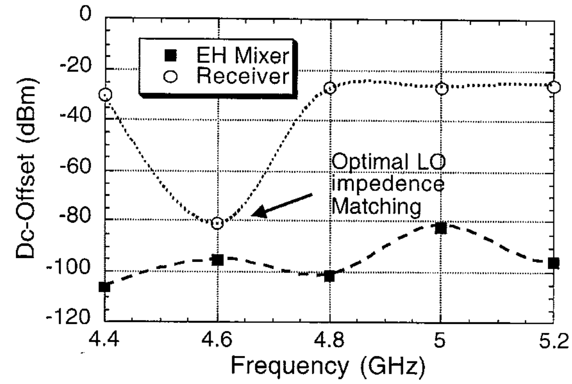

Fig. 4. Output dc-offset of the receiver and the EH mixer.

probes. The receiver was powered by four 2.7-V sources supplying a total dc current of 21 mA. The receiver and the EH mixer were fully characterized for noise figure, conversion loss, linearity and dc-offset performance from 4.4 to 5.2 GHz. Noise figure measurements of the receiver using HP3561A dynamic signal analyzer show an average noise figure of 15 dB with an increase to 26 dB at 1 kHz due to 1/f noise. Two-tone measurements were performed over the input RF frequency range of 4.6–5.2 GHz with the corresponding LO frequency range of 2.3–2.6 GHz using a LO power of +16 dBm. The baseband spectrum was monitored for intermodulations and dc-offset using the HP3561A. Fig. 3 summarizes the results of the two-tone measurements in a plot of the conversion loss, IIP2 and IIP3 as a function of the input RF frequency. Broad-band dc-offset performance of the EH mixer and the receiver is plotted in Fig. 4. The mixer demonstrates excellent dc-offset suppression over a broad band of frequencies while the receiver confirms these results for a narrow band of operation. The receiver dc-offset level decreases significantly at the LO frequency of 2.3 GHz where an optimal matching condition eliminates the LO signal reflections between the LO power divider and the LO input port of the mixer. This narrow band impedance matching is an inherent characteristic of the Wilkinson LO power divider. A more robust divider interface between the mixers and the LO input port of the receiver will result in a broadband dc-offset performance similar to that of the individual EH mixers.

IV. Conclusion

A fully monolithic direct conversion receiver has been demonstrated in a commercial GaAs MESFET process. Even harmonic mixing is utilized to obtain excellent linearity and dc-offset suppression while alleviating the concern for in-band LO radiation. Comparison between the mixer and receiver measurements concludes that the matching condition of the mixer LO port can significantly impact dc-offset performance of the receiver. This is the first demonstration of a *C*-band direct conversion receiver MMIC with excellent linearity, dc-offset, and dc power consumption.

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