A 25–75 GHz Broadband Gilbert-Cell Mixer Using 90-nm CMOS Technology

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***Abstract*—A compact and broadband 25–75-GHz fully integrated double-balance Gilbert-cell mixer using 90-nm standard mixed-signal/radio frequency (RF) CMOS technology is presented in this letter. A broadband matching network, LC ladder, for Gilbert-cell mixer transconductance stage design is introduced to achieve the flatness of conversion gain and good RF port impedance match over broad bandwidth. This Gilbert-cell mixer exhibits 3 ± 2 dB measured conversion gain (to 50-Ω load) from 25 to 75 GHz with a compact chip size of 0.30 mm^2. The OP$_{1\ \mathrm{dB}}$ of the mixer is 1 dBm and −4 dBm at 40 and 60 GHz, respectively. To the best of our knowledge, this monolithic microwave integrated circuit is the highest frequency CMOS Gilbert-cell mixer to date.**

***Index Terms*—CMOS, Gilbert-cell, millimeter-wave (MMW), mixer, monolithic microwave integrated circuit (MMIC).**

I. Introduction

In recent years, the Federal Communications Commission (FCC) announced that the unlicensed band in millimeter-wave (MMW) frequency bands from 57 to 64 GHz and 71 to 76 GHz were available for wireless application. The allocation provides the possibility of the new products and services, including wireless personal area networks (WPANs) [1], and point-to-point wireless local area networks at gigabit data rates. Up to now, this field was dominated by III-V semiconductors. Due to the possible low cost of silicon and the feasibility of backend integration, modern CMOS technology with downscaling of feature dimensions is an interesting alternative for MMW application. For example, a 60-GHz push–push VCO using 0.25-μm CMOS [2] and 70 GHz a distributed amplifier using 90-nm CMOS were reported [3].

The CMOS passive mixer, with advantages of wide bandwidth and zero dc power, has been reported up to 60 GHz using 90-nm CMOS [4], however this passive mixer has a high conversion-loss of 11.6 dB. The quarter-wave length matching stubs and baluns make the chip size large (2 × 2 mm^2). The CMOS Gilbert-cell based mixers, with the advantages of low conversion-loss, even conversion-gain and compact size, have been demonstrated up to 50 GHz using 0.13-μm CMOS [5]. But the mixer, with larger bandwidths, has poor gain flatness (8.5 ± 3.5 dB from 9 to 50 GHz) and radio frequency (RF) port return loss.

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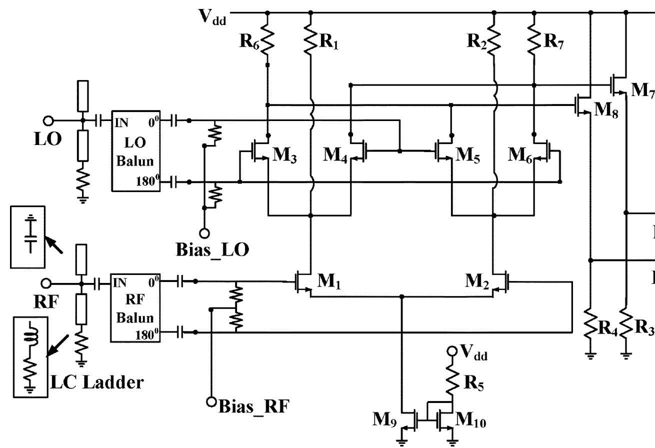

Fig. 1. Schematic of the fully integrated Gilbert-cell mixer.

This letter describes a compact and broadband 25–75 GHz fully integrated double-balance Gilbert-cell mixer using 90-nm standard CMOS technology. A compact 180° balun using Marchand-type transformers [6] is integrated to provide the differential RF and local oscillation (LO) signals. With broadband LC ladder matching networks, the monolithic microwave integrated circuit (MMIC) has a flat measured conversion gain of 3 ± 2 dB and RF port return loss of more than 7.5 dB over broad bandwidth, from 25 to 75 GHz. This MMIC is the highest frequency CMOS Gilbert-cell mixer to date.

II. Circuit Design

The broadband fully integrated Gilbert-cell mixer is fabricated using TSMC commercial standard 90-nm 1P9M CMOS process. This process provides single poly layer for the gates of the MOS and nine metal layers with the top metallization of 3-μm thickness for interconnection. This topology provides a f_t of 160 GHz and $f_{\max}$ of 142 GHz at maximum-transconductance bias. A metal-insulator-metal (MIM) capacitor of 1.5-fF/μm^2 has been developed using oxide inter-metal dielectric. Two types of polysilicon resistors, with several $\Omega/\square$ and k$\Omega/\square$, are provided by choosing the individual dose of ion-implantation separately from the gate electrode doping process.

The schematic of the broadband mixer is shown in Fig. 1. The Gilbert-cell configuration is selected for its double-balance implementation which offers high spur suppression in a very compact die size. The NMOS M_1 and M_2 (16 μm/0.1 μm, and

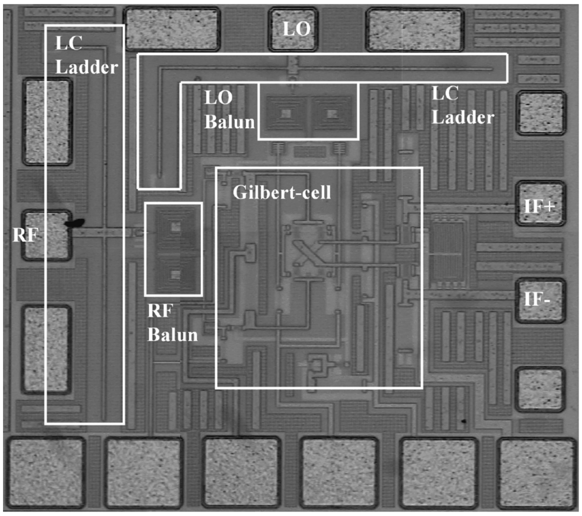

Fig. 2. Chip photo of the fully integrated Gilbert-cell mixer with chip size of 0.55 mm × 0.55 mm.

four-finger each with 4-μm unit finger length) are biased at saturation region, which converts RF input signal to output current. The LO switching quad consists of two parallel connected NMOS pairs, $M_3 - M_6$ (16 μm/0.1 μm) are biased at near pinch-off region. The performance of the CMOS Gilbert-cell mixer can be improved by using a charge-injection method. Two resistors, R_1 (500 Ω) and R_2 (500 Ω), are used as a charge-injection circuit incorporated to bleed the drain current flowing into M_1 and M_2. With this charge-injection circuit, the drain current of the switching quad transistors and the voltage drop in load resistors can be reduced. Therefore the value of these load resistors can be increased, thus raising the voltage conversion gain. Two source-follower transistors are added, which are composed of M_7 (128 μm/0.1 μm), M_8 (128 μm/0.1 μm), R_3 (300 Ω), and R_4 (300 Ω) for output impedance matching. The total bias current of the Gilbert-cell core is determined by a current mirror source, which is composed of M_9 (16 μm/0.1 μm), M_{10} (16 μm/0.1 μm), and R_5 (300 Ω). The monolithic Marchand-type transformer [6] is used to provide the differential RF and LO signals. The Marchand-type transformers can be wound into a very compact coil and the coil of the transformer is implemented using thin-film microstrip (TFMS) structures. The TFMS lines consist of the metal 1 (bottom layer) in the 1P9M CMOS process as ground plane and the metal 8 as the microstrip signal line with the thick SiO_2 layer as substrate. The line width (w) and gap (g) are both 1 μm and the RF/LO transformers have a compact area of 90 × 40 μm^2.

The parasitic capacitances of CMOS technology limit the operation frequency. In order to improve the bandwidth, the LC ladder matching networks [7] are introduced in this mixer design. As shown in Fig. 2, the open/short TFMS lines form the LC ladder matching networks are adopted in front of the transconductance stage of the mixer to achieve wideband matching. The passive components including the discontinuities of the TFMS lines, transformers, and capacitors were simulated by a full-wave EM simulator (Sonnet software). The completed circuit of the Gilbert-cell mixer was simulated using Agilent ADS. Fig. 2 illustrates the chip photograph of the fabricated broadband CMOS active mixer. The chip size is only 0.55×0.55 mm^2 including all testing pads and dummy metal.

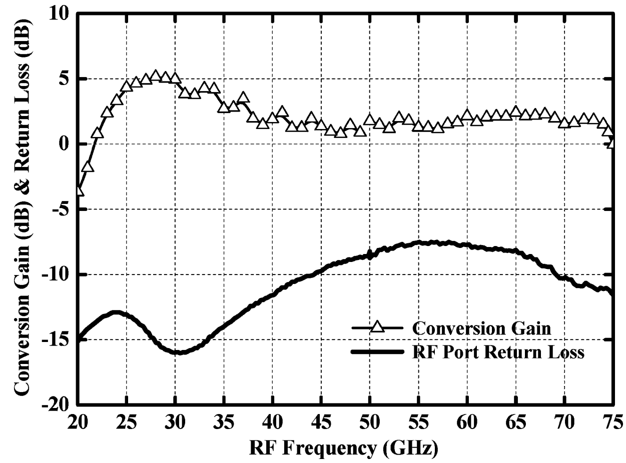

Fig. 3. Measured conversion gain and RF port return loss of the fully integrated Gilbert-cell mixer from 20 to 75 GHz.

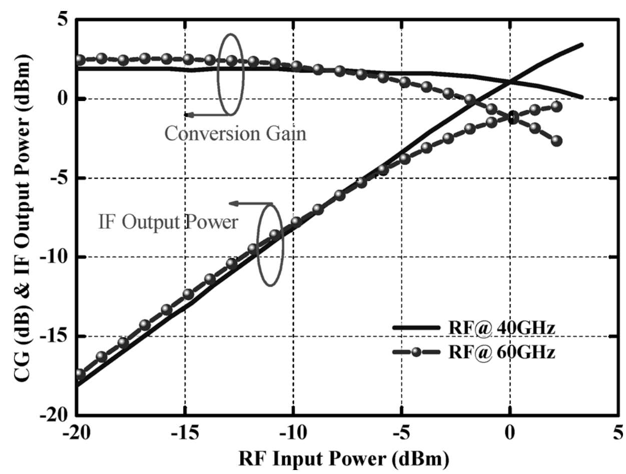

Fig. 4. Measured RF input power versus conversion gain and IF output power of the fully integrated Gilbert-cell mixer at 40 and 60 GHz.

III. Measured Results

The broadband CMOS Gilbert-cell mixer chip was measured using on-wafer probing on RF and LO input ports. It was measured using wire bonding of output pads as the IF output port. The output was then connected to a spectrum analyzer (50-Ω load) through dc-blocking capacitors. The measured conversion loss swept with LO pumped power is saturated at +6 dBm at RF frequency of 40 GHz and IF frequency of 10 MHz. Fig. 3 plots the 25 to 75 GHz measured conversion gain and RF port return loss. With broadband LC ladder matching networks, the flatness of conversion loss and good RF port return loss over broad bandwidth, from 25 to 75 GHz, can be achieved. The conversion gain is 3 ± 2 dB and the RF port return loss is better than 7.5 dB from 25 to 75 GHz. The measured IF output power versus swept RF input shows in Fig. 4. The input 1-dB compression point of the mixer is 2.1 and -4.5 dBm at RF of 40 and 60 GHz, respectively. The measured RF to LO and LO to RF isolation are better

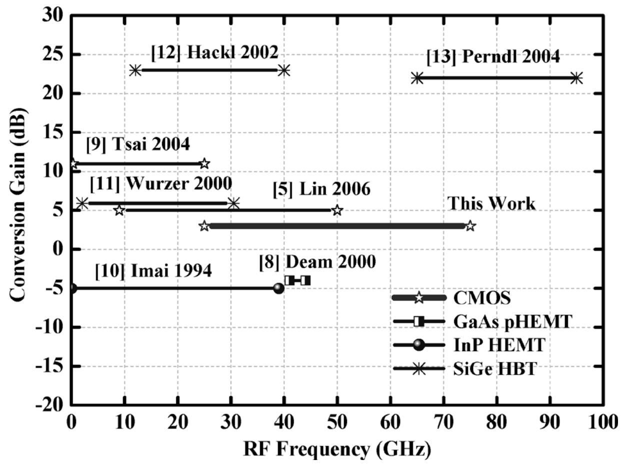

Fig. 5. Comparison of monolithic integrated wideband mixers in various MMIC technologies.

than 30 dB. To investigate the intermodulation properties of the mixer, a two-tone intermodulation measurement system is used with the frequency offset of ±500 kHz. The measured IIP3 is 11 dBm for RF two-tone of 40.0005 GHz and 39.9995 GHz. The mixer employs a 3-V dc power supply and total dc power consumption of the mixer is 93 mW.

Fig. 5 summarizes the conversion gain and bandwidth performance of previously published wide-band Gilbert-cell mixer integrated-circuit. Although the fundamental Gilbert-based mixers have been demonstrated with various MMIC technologies, the MMIC in this letter is believed to be the highest frequency CMOS Gilbert-cell mixer to date. It also achieves a good conversion gain performance with a compact chip size [8]–[13].

IV. Conclusion

A compact and broadband 25 to 75-GHz fully integrated double-balance Gilbert-cell mixer has been designed and fabricated using TSMC commercial standard 90-nm 1P9M CMOS process. The mixer consists of broadband and compact Marchand-type transformers to provide the differential RF and LO signals. A broadband matching technique, LC ladder matching network, is applied to achieve the flatness of conversion gain over broad bandwidth. This CMOS Gilbert-cell mixer exhibits 3 ± 2 dB measured conversion gain (to 50-Ω load) from 25 to 75 GHz with a miniature chip size of 0.3025 mm^2. The measurement results of the CMOS Gilbert-cell mixer indicate the standard CMOS technology is suitable for MMW receiver applications.

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