94 GHz CMOS Down-Conversion Micromixer

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***Abstract*—A W-band (75~110 GHz) down-conversion mixer for 94 GHz image radar sensors in 90 nm CMOS is reported. Micromixer-based gain-enhanced technique, i.e. inductive series-peaking gain-enhanced single-in differential-out (SIDO) class-AB RF GM stage, is used to increase the output impedance and suppress the feedback capacitance C_{gd} of RF GM stage. Hence, conversion gain (CG), noise figure (NF) and LO-RF isolation of the mixer can be enhanced. The mixer consumes 7.2 mW and achieves excellent RF-port input reflection coefficient of −10~−14.4 dB for frequencies of 81.4~110 GHz. The corresponding −10 dB input matching bandwidth is greater than 28.6 GHz. In addition, for frequencies of 90~96 GHz, the mixer achieves CG of 10.5~12 dB (the corresponding 3-dB CG bandwidth is 22 GHz) and LO-RF isolation of 40.2~46.2 dB, one of the best CG and LO-RF isolation results ever reported for a down-conversion mixer with operation frequency around 94 GHz. Furthermore, the mixer achieves an input third-order intercept point (IIP3) of 1 dBm at 94 GHz. These results demonstrate the proposed down-conversion mixer architecture is very promising for 94 GHz image radar sensors.**

Keywords—CMOS; 94 GHz; down-conversion micromixer

I. INTRODUCTION

Thanks to the rapid development of CMOS processes, it has become possible to use them to implement W-band RFICs [1]-[3]. In transceiver design, down-conversion mixer is a critical block that receives signals from LNA over the band of interest, and then amplifies and down-converts the signals with a good SNDR property. In addition to low power, the basic requirements for a down-conversion mixer include good input and output impedance matching, high port-to-port isolation, low NF, and high CG over the band of interest. Nowadays, researchers have introduced several splendid W-band CMOS and GaAs mixers for down-conversion [1]-[3]. For instance, in [1], a 77 GHz double-balanced mixer for down-conversion in 65 nm bulk CMOS technology (with f_T higher than 150 GHz) is reported. The mixer has two transformer-based baluns that convert RF and LO inputs to differential outputs. Excellent power performance of 6 mW is obtained. However, CG of −8 dB and LO-RF isolation of 21 dB are unsatisfactory. In [2], a 94 GHz down-conversion mixer using branch line couplers in 0.1 μm GaAs process (with f_T of 189 GHz) is demonstrated. Similarly, its performances such as CG of −14.7 dB, LO-RF isolation of 35.2 dB and chip area of 3.38 mm^2 are not good enough. In this work, we report a 94 GHz down-conversion micromixer in 90 nm CMOS (with f_T of 130 GHz).

II. CIRCUIT DESIGN

The 94 GHz down-conversion micromixer was designed and implemented in 90 nm CMOS. Fig. 1(a) illustrates the circuit diagram of the double-balanced mixer for direct down-conversion. The mixer is made up of a double-balanced Gilbert cell with an inductive series-peaking gain-enhanced single-in differential-out (SIDO) class-AB RF GM stage, one miniature planar Marchand balun that converts LO input to

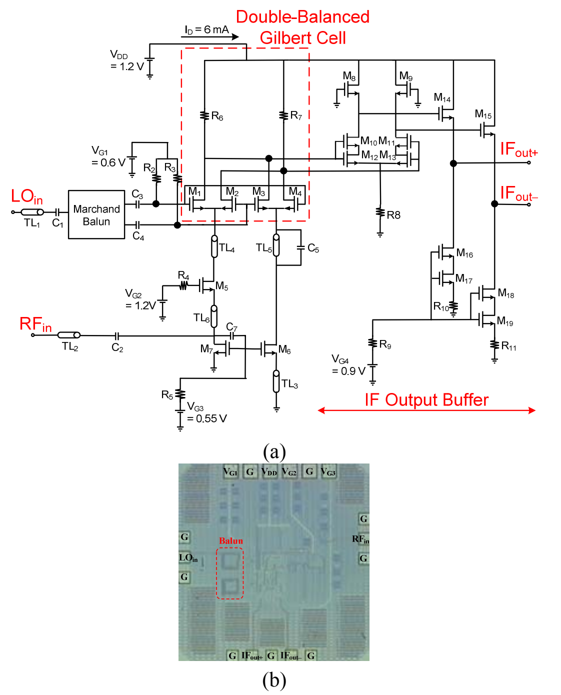


Fig. 1 (a) Schematic diagram, and (b) chip microphotograph of the 94 GHz CMOS down-conversion micromixer.

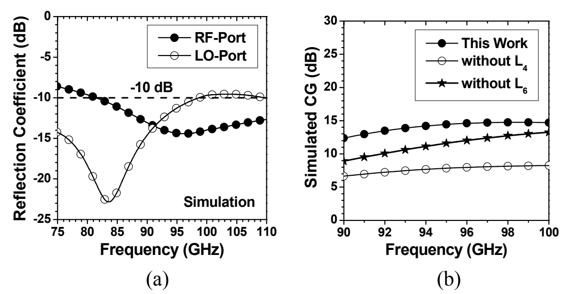
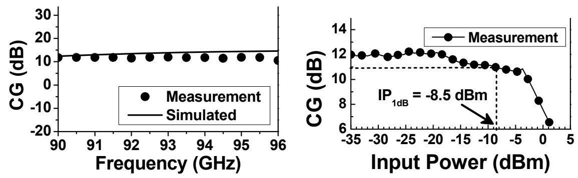


Fig. 2 Simulated (a) RF-port and LO-port reflection coefficients, and (b) CG versus frequency characteristics of the micromixer

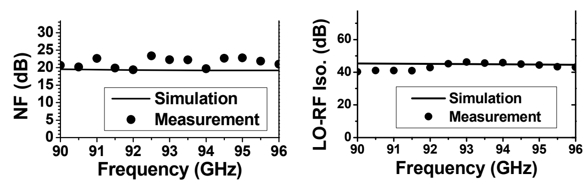
Table I Summary of the implemented DC micromixer, and recently reported state-of-the-art W-band DC mixers.

Reference	Process	Topology	RF Frequency (GHz)	LO Power (dBm)	CG (dB)	LO-RF Isolation (dB)	NF (dB)	Power (mW)	FOM (no unit)
This Work	90-nm CMOS	Micromixer-based Gain-Enhanced RF GM Stage	94	0	11.7	45.8	19.7	7.2	4.37×10^{-4}
[1] (2009 MWCL)	65-nm CMOS	Gilbert-Cell with On-Chip Baluns	76~77	4	−8	21	17.8	6	1.01×10^{-4}
[2] (2012 GSMM)	100-nm GaAs	Single-Balanced Using Branch Line Couplers	94	10	−14.7	35.2	NA	NA	NA
[3] (2008 MWCL)	90-nm CMOS	Sub-harmonic Gilbert-Cell	30~100	10	−1.5	47	NA	58	NA



(a) (b)

Fig. 3 (a) Measured and simulated CG versus frequency, and (b) measured CG versus RF power characteristics of the micromixer.



(a) (b)

Fig. 4 Measured and simulated (a) NF, and (b) LO-RF isolation versus frequency characteristics of the micromixer.

differential output, and an IF output buffer. Fig. 1(b) shows the chip micrograph of the down-conversion micromixer. The chip area is 0.88×0.74 mm^2 (i.e. 0.651 mm^2).

Fig. 2(a) shows the simulated input reflection coefficients at RF-port (S_{11}) versus frequency characteristics of the down-conversion micromixer. The micromixer achieves S_{11} of −14.2 dB at 94 GHz, minimal S_{11} of −14.4 dB at 96.2 GHz, and S_{11} smaller than −10 dB for RF frequencies of 81.4~110 GHz. What is also shown in Fig. 2(a) is the simulated input reflection coefficients at LO-port (S_{22}) versus frequency characteristics of the down-conversion mixer. The mixer achieves S_{22} of −11.7 dB at 94 GHz, minimal S_{22} of −22.8 dB at 83.6 GHz, and S_{22} smaller than −10 dB for LO frequencies of 61.3~98.7 GHz.

Fig. 2(b) shows the simulated CG versus frequency characteristics of the micromixer in various conditions. RF input power is −35 dBm and LO input power is 0 dBm. For the case with both the series-peaking inductors L_4 and L_6 (i.e. this work), the micromixer achieves CG of 12.4~14.8 dB for frequencies of 90~100 GHz, better than that (CG of 6.7~8.2 dB for frequencies of 90~100 GHz) for the case without L_4, and that (CG of −8.9~13.3 dB for frequencies of 90~100 GHz) for the case without L_6.

III. Results and Discussions

Fig. 3(a) shows the measured and simulated CG versus frequency characteristics of the micromixer. RF input power is −35 dBm and LO input power is 0 dBm. For frequencies of 90~96 GHz, the mixer achieves CG of 10.5~12 dB, close to that (12.4~14.6 dB) of the simulated one. In addition, the 3dB CG bandwidth of the mixer is 22 GHz (not shown here). Fig. 3(b) shows the measured CG versus RF input power characteristics of the mixer. The mixer achieves an excellent input P_{1dB} of −8.5 dBm, and an IIP3 of 1 dBm (not shown here).

Fig. 4(a) shows the measured and simulated NF versus frequency characteristics of the mixer. The measured result conforms with the simulated one well. The mixer achieves minimal NF of 19.4 dB at 92 GHz, and NF of 19.4~22.7 dB for frequencies of 90~96 GHz. Fig. 4(b) shows the measured and simulated LO-RF isolation versus frequency characteristics. The measured result conforms with the simulated one well. The mixer achieves maximal LO-RF isolation of 46.2 dB at 93 GHz, and LO-RF isolation of 40.2~46.2 dB for frequencies of 90~96 GHz. The excellent LO-RF isolation is mainly attributed to the LO-RF leakage through capacitance C_{gd6} of the RF GM stage transistor M_6 is suppressed by TL_5/C_5. To the authors' knowledge, this is one of the best LO-RF isolation results ever reported for a W-band down-conversion mixer (see Table I).

IV. Conclusion

We demonstrate a 94 GHz CMOS down-conversion mixer. The mixer is made up of a double-balanced Gilbert-cell with an inductive series-peaking gain-enhanced SIDO class-AB RF GM stage, one LO-port balun, and an IF output buffer. The mixer dissipates 7.2 mW and obtains remarkable CG and LO-to-RF isolation performances. This result indicates that the mixer is promising in W-band systems.

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