HIGH DYNAMIC RANGE MMIC CONVERTERS FOR LMDS APPLICATIONS

Robinder S. Virk*, Thomas A. Bös*, Edmar Camargo* and Yuichi Hasegawa∞

*Fujitsu Compound Semiconductor, Inc.
2355 Zanker Road
San Jose, CA 95131, USA
e-mail: rvirk@fcsi.fujitsu.com

∞Fujitsu Quantum Devices Limited
Kokubo Kogyo Danchi, Showa-chou Nakakoma-gun
Yamanashi-ken, 409-3883, Japan

ABSTRACT

This paper describes the design and performance of high dynamic range MMIC up- and down-converters fabricated in a 0.25-μm PHEMT process. The measured up-converter provides 6 to 8 dB conversion loss in the band from 22 to 34 GHz, where f_{IF} = 1 GHz and P_{LO} = +16 dBm. A two-tone, 3rd-order intermodulation suppression of –50 dBc was measured at P_{out} = -6 dBm per tone for the up-converter and P_{in} = -4 dBm per tone for the down-converter, where each chip consumes a mere 1.5 x 1.8 mm^2. These levels of performance make these chips very attractive for LMDS applications where linearity is critical to system implementation.

INTRODUCTION

In recent years, the subject of MMIC frequency converters for application in the Local Multipoint Distribution Service (LMDS) band has gained interest as an option to improve system performance with lower cost devices. A good example [1], describes a wide band mixer with good conversion loss and matching performance, but the chip size and thickness is not optimal for integration with active elements to improve cost. Another example [2] shows good down-converter performance and impressive small size; however, the mixers described are not yet mature for system applications where other specifications are as important, such as a high intercept point. A design able to cover these objectives requires a mixer that is insensitive to generator impedance, which can be obtained [3] with two independent mixers inserted between a pair of Lange couplers. The drawback of this approach falls on the size of the individual mixers. These must be very small in order to generate a full converter with a reasonable size. Planar spiral transformer (PST) baluns require a very small area and provide good RF performance [4].

There is a trade off between linearity and circuit complexity, size and performance. Resistive FET mixers are known to offer very high linearity, but it is usually obtained at the cost of increased complexity and size. An investigation was performed on the dynamic performance of 0.25 µm gate PHEMT diodes [5], and it was found that a 100 µm gate diode built with this technology would provide a P_{1dB} = +10 dBm while offering the benefit of compact size. Although diode mixers require approximately 6 dB more LO power, compared to resistive FET mixers, it was found that the overall advantages would outweigh this drawback. This paper reports a mixer design which meets LMDS system requirements by providing low intermodulation distortion (IMD), comparable to levels obtained with resistive FET mixers.

CIRCUIT DESIGN

The mixer topology utilized in this work consists of two independent mixers (described below) which are single-balanced through Lange hybrid circuits to enhance the total performance. The total mixer return loss is largely dependent upon the Lange couplers used at each port. These hybrid structures provide a 90° phase shift between each of the independent mixers such that the signals reflected at each independent LO and RF mixer port experience some cancellation at their respective port after passing through the coupler. Another advantage of this approach is the improved LO-to-RF isolation inherent in the configuration.

The diodes used in the mixer are the gate-source junctions of devices built in Fujitsu's 0.25 μm power PHEMT technology previously described in [6]. Since they are fabricated simultaneously with other devices, the main parameter that a designer can control is the diode geometry. In this application, three 33 μm gate fingers are centered between their respective drain/source ohmic contacts to form diodes, where the diode dimensions were chosen to control the device resistance, capacitance and linearity. The diode model used in nonlinear simulations has been described earlier in [5].

Each independent mixer cell utilizes a PST balun structure, similar to a previously described approach [4]. A single coupled-line section was wrapped in a spiral to form a simple compact balun. This planar spiral structure behaves like a bifilar balun, commonly used at low frequencies, where a minimum amount of inductance (wavelengths) is required to obtain the balun action. The structure is comparable in size with other components in the monolithic mixer. The drawbacks of this approach are a reduction in bandwidth and a mismatched balun, due to the proximity of the ground plane, but this mismatch can be compensated. The balanced impedance can even be used as a diode-matching element. The spiral's length and strip dimensions were designed on Sonnet's *em*. The results were then optimized using HP-EEsof's MDS by inserting matching elements. This approach allowed us to build a balun which operates from 22 to 34 GHz in a 0.5 x 0.7 mm^2 area on the 75 μm thick GaAs substrate.

In this unique PST mixer cell configuration, the RF signal is applied through the balun to a pair of diodes connected in series. The LO signal is applied to the junction where the two diodes are connected. A shunt inductance in the LO port matching circuit provides the DC/IF return path. The IF signal is then injected/extracted directly to/from the balun structure in the up-/down-converter configuration. There is a shunt RF/LO bypass capacitor, which provides the necessary ground point for the balun, and the IF signal is injected/extracted at this point. Small capacitors are used in the LO and RF matching circuits to prevent the leakage of IF signal through these ports.

In order to improve the conversion performance and return loss, each mixer cell was matched to 50 Ω at the LO and RF ports. To calculate the LO input impedance, a simulated, large-signal voltage generator was applied at the LO port, and the resulting current was measured. Similarly, a small-signal voltage source and current monitor were applied to the RF port, while the mixer was under LO drive, to determine the simulated RF port impedance. Based upon the simulated impedances, a simple high-pass matching structure (shunt L, series C) was utilized at the LO port, and a series C (IF block) followed by a low-pass matching structure (shunt C, series L) was utilized at the RF port. The resulting mixer cell has good conversion performance, and the connection of two mixer cells in a quadrature configuration provides a top-level mixer with even better LO and RF port impedances and good LO-to-RF isolation.

Two designs were completed—an up-converter and a down-converter. The structures are almost identical and require 1.5 x 1.8 mm^2 chip area (see Figure 1). Due to the nature of the quadrature configuration, the same circuit cannot be used for both up- and down-conversion when the independent mixer IF ports are connected for a single-ended IF signal. By switching the direction of the diodes in one of the PST mixer cells, an up-converter design can be modified to provide a down-converter mixer.

RESULTS

The conversion characteristic of the mixer in up-converter mode is shown in Figure 2 for f_{IF} = 1 GHz and P_{LO} = +16 dBm. In the frequency range of 22 to 34 GHz, the converter has a USB conversion loss of 6 to 8 dB. The plot also shows a maximum difference between measurement and simulation of 1 dB over the range. The measured third-order IMD characteristic of the mixer is shown in Figure 3. The measurement was done at f_{LO} = 25 GHz, P_{LO} = +16 dBm, and f_{IF} = 1.00 and 1.01 GHz (i.e., using a two-tone frequency spacing of 10 MHz). At –10 dBm output power per tone, the mixer has a suppression of –55 dBc. The suppression becomes less than –50 dBc for output levels higher than –6 dBm. In the output power range of –10 to –4 dBm per tone, the IMD level changes with a slope of 2.5:1 and, up to 0 dBm, with a slope of 3:1.

For the down-converter, the conversion gain characteristic is shown in Figure 4. In the frequency range of 22 to 34 GHz, the mixer has a conversion loss of 10 to 12 dB for f_{IF} = 1 GHz and P_{LO} = +18 dBm. The simulation predicts the conversion characteristic within 1 dB over most of the band. The discrepancy between measurement and simulation becomes larger for +16 dBm LO power. The measured data show a significant roll-off toward the edges of the band. Direct measurement of test cells for the independent mixers and the Lange couplers show that the cause for the deviation is the large loss and over-coupling in the Lange design. This over-coupling also affected the measured LO-to-RF isolation of >32 dB and LO/RF return loss ~12 dB—this is good performance but can be significantly improved by modifying the Lange couplers.

The measured down-converter third-order IMD characteristic is shown in Figure 5 for f_{RF} = 26.00 and 26.01 GHz, f_{LO} = 25 GHz, and P_{LO} = +16 dBm. An intermodulation suppression of –50 dBc is achieved for each single tone input power of –4 dBm. For 0 dBm input power per tone, the IM suppression is reduced to –42 dBc.

CONCLUSION

The design and measured results for two MMIC diode frequency converters were presented. The converters utilize a Lange coupling structure to offer broad band up- and down-conversion performance, and their high dynamic range make them attractive components for use in LMDS applications where linearity is critical. The designs also offer good LO-to-RF isolation and port return losses which are convenient for system implementation.

REFERENCES

[1] S. A. Maas, "An 18 to 40 GHz Monolithic Ring Mixer", *1998 RFIC Symposium*, pp. 29-32, Baltimore, USA, June 1998.

[2] C. J. Trantanella, "Ultra-small MMIC Mixers for K- and Ka-Band Communications", *IEEE International Microwave Symposium Digest*, pp. 647-650, Boston, USA, June 2000.

[3] L. Verweyen *et al*, "LMDS Up- and Down-Converter MMIC", *IEEE International Microwave Symposium Digest*, pp. 1685-1688, Boston, USA, June 2000.

[4] R. S. Virk *et al*, "A Ku-Band Frequency Converter using 0.25 µm PHEMT Technology", *IEEE International Microwave Symposium Digest*, pp. 639-642, Boston, USA, June 2000.

[5] T.A. Bös, E. Camargo, "Design of PHEMT Diodes for MMIC Mixer Applications", *2000 European Gallium Arsenide & Other Semiconductors Application Symposium*, pp. 98 – 101, Paris, France, 2000

[6] C. Poledrelli *et al*, "High Efficiency 1.4 W Power Amplifier for K-Band Satellite Communication System", *1999 European GaAs and Related III-V Compounds, Applications Symposium Digest*, p. 252, Munich, Germany 1999.

[7] S. A. Maas, *Microwave Mixers, 2nd Edition,* Artech House, Norwood, MA, 1993.

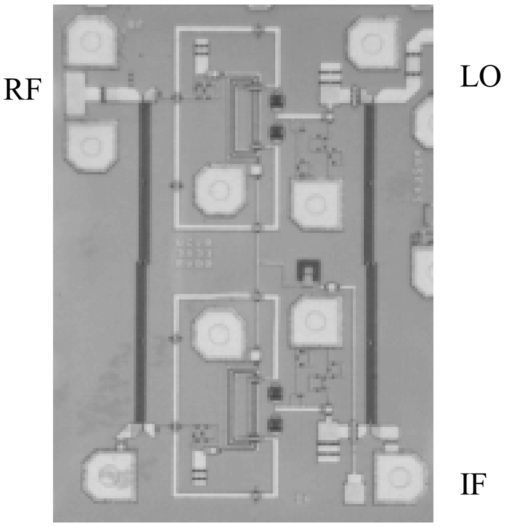

Figure 1. Photograph of Lange-coupled PST up-converter circuit.

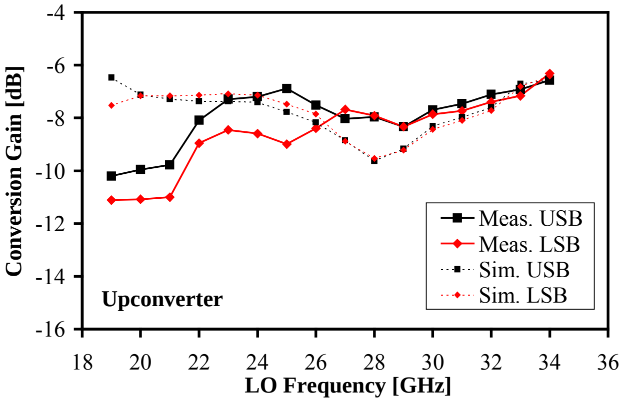

Figure 2. Measured and simulated USB and LSB conversion gain in the up-converter circuit for f_{IF} = 1 GHz and P_{LO} = +16 dBm.

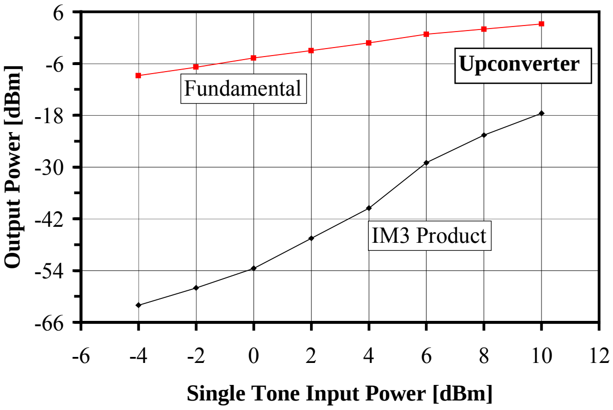

Figure 3. Measured USB up-converted output power (per tone) and third-order intermodulation characteristic for f_{LO} = 25 GHz, P_{LO} = +16 dBm and f_{IF} = 1.00 and 1.01 GHz.

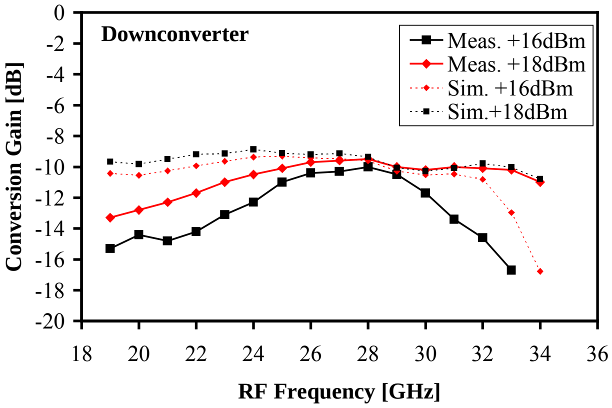

Figure 4. Measured and simulated conversion gain for the down-converter circuit for f_{IF} = 1 GHz and P_{LO} = +16 and + 18 dBm.

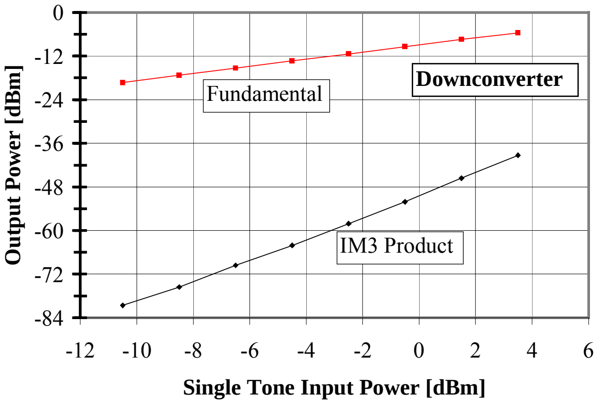

Figure 5. Measured down-converted output power (per tone) and third-order intermodulation characteristic for f_{LO} = 25 GHz, P_{LO} = +16 dBm and f_{RF} = 26.00 and 26.01 GHz.