35-45 GHz Image Rejection Star Mixer for Up- and Down Conversion

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Abstract — **For LMDS and MVDS systems, a compact Image Rejection Star Mixer has been developed for use as both up- and down converter. The circuit has been designed in order to ease the integration, to reduce the size and finally to reach the cost requirements for such systems. The MMIC is fabricated on UMS commercially available PH25 GaAs PHEMT processes. At 40-GHz LO-frequency, the up conversion losses are only 7 dB for an LO power of 18 dBm and 1.5-GHz IF. The image rejection is better than –25 dB and the LO/RF isolation is better than 25 dB. With a chip area of only 2 mm^2, compared to previously reported results for image rejection double balanced mixer MMICs operating in the 35-45-GHz frequency range, this represents a chip size reduction by more than 30 %.**

I. Introduction

The development of interactive multimedia services (telephone, high speed internet access, television broadcast, audio and video conferencing, etc.) requires data transmission at higher and higher rates. For these applications, the use of broadband wireless systems at millimeter wave frequencies offers interesting, fast and cost effective solutions for indoor and outdoor professional and consumer applications like Point-to-Point, Point-to-Multi-Point, WLAN [1]. Considering size as the main driving cost of GaAs ICs, in this paper, we present the performance of a compact mixer MMIC addressing LMDS and MVDS applications in the 35-45 GHz frequency band, as well as other applications requiring vector modulations. To address these applications, and in order to perform very good LO suppression, the mixer was designed on the well-known simple star configuration using four diodes [2]. In order to provide an acceptable image rejection, two mixer cells are appropriately combined on a single chip to realize a Single Side Band mixer. As in the star configuration the IF is DC coupled, this topology is very well suited to perform as well vector modulations.

II. Circuit Design

A. Star Mixer Configuration

The basic principle of a star mixer is given in Fig 1; it is based on a four-diode star network, pumped with an high level local oscillator signal in phase opposition. As described by *S.A. Maas* [2], the four diodes have each one electrode connected to a common node, which is used as the IF port, and the other electrode connected to the RF and LO transformers and quarter-wavelength couplers. The main characteristics of the diode star is that the terminals of the RF transformer secondary are virtual ground points for the LO and vice-versa. The center of the diode star is a virtual ground for both LO and RF. When the LO is applied, the diodes D1-D2 and D3-D4 are alternatively switched on and off. During the first half of the LO cycle, when diodes D1-D2 are on, D3 and D4 are off and the upper terminal of the RF secondary is connected to IF input; during the second half of the LO cycle, the polarity is reversed (D3-D4 on, D1-D2 off), and the lower terminal is connected to IF. In other words, the RF is obtained by multiplying the IF by a square-wave switching function of the LO frequency. In order to design a balanced mixer, we use an in-house compact multi-finger *Marchand Balun* very well suited for broadband operation.

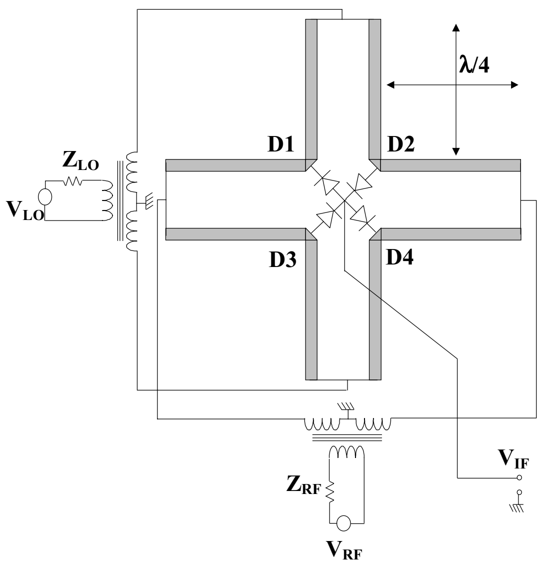

Fig. 1: Topology of a double balanced diode star mixer.

The frequency specification for this single mixer consists of an LO and RF frequencies in the 35-45 GHz band and an IF frequency up to 2 GHz band.

B. Image Rejection Mixer Configuration

The block diagram of the compete Image Rejection Star Mixer (IRM) is shown in Fig. 2.

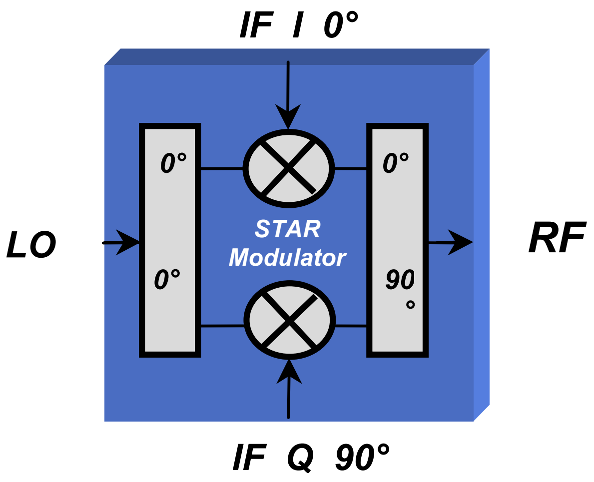

Fig. 2: Block diagram of the Image Rejection Mixer.

The mixer uses a single balanced image rejection configuration that suppresses the lower (or upper) side band. The LO signal is applied in phase via a 40-GHz Wilkinson power divider on both star mixers. The IF (I/Q) signals are applied in quadrature to each single mixers. The RF ports of the mixers are connected to a 90° hybrid coupler easily realized with a Lange coupler. The USB combine at one of the hybrid ports with 180° phase difference while the lower sideband signal at the same port add in phase. In this way, USB rejection is achieved. One of the advantage of this topology is to be usable for both up- and down conversion. The upper/lower side band (USB/LSB) operating cases are selected by choosing the appropriate input on the external 90° IF hybrid while the other port is terminated on 50 Ω.

C. MMIC process technology

The MMIC fabrication is based on the UMS commercially available low noise GaAs PHEMT process (PH25) on 4'' wafers. It uses 0.25-µm Aluminium T-gates. The MMICs are realized in microstrip technology on 100-µm thick substrates, 30-µm diameter via-holes, with two gold metallization levels (1 and 3 µm), 50 Ω/□ NiCr thin film resistors, and 250 pF/mm^2 MIM SiN capacitors. For each mixer cell, four 4×10-µm diodes, with low-junction series resistance, were used for the star configuration. The Lange coupler, the Wilkinson divider and the *Marchand* Baluns are realized in the evaporated gold layer, in order to get smaller metallization width and spacing for lower losses and better isolation properties. All these critical structures were optimised with HP-Momentum© 2.5D electromagnetic simulator in the DC-70 GHz band. A chip photograph of the complete image rejection star mixer is shown in Fig. 3. One main improvement of this new MMIC mixer is the size reduction, with a total die area of the MMIC being 1.76×1.15 mm^2 (2 mm^2,[3]). Finally, it is worth mentioning that this circuit can be transferred easily to a simple Schottky diode process (e.g. UMS BES process).

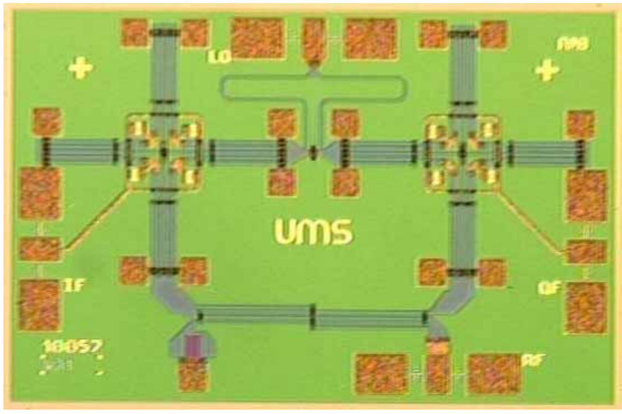

Fig. 3: Microphotograph of the Image Rejection Star Mixer Chip (*CHM-PO10057*, chip size is $1.76 \times 1.15 = 2.0$ mm^2).

III. Measured Performance

A. Mixer Mode

The mixer was measured both on-wafer and in JIG test fixture. The LO signal is generated from a synthesized source and amplified by two medium power amplifiers (CHA3093) to obtain 18-dBm input power level at 40 GHz. The measured performance in the up-converter mode of the MMIC mixer is shown in Fig. 4. In this case, the mixer is tested in supradyne mode with an IF frequency of 1.5 GHz and an LO sweeping from 35- to 44 GHz, therefore the RF_{USB} frequency is between 35.5- and 45.5 GHz. The mixer exhibits typically 7-dB conversion losses (better than 10 dB over the 35-45 GHz band). The image rejection is better than –20 dB, and the LO leakage is typically below –10 dBm for input LO power equal to +18 dBm (let more than 28-dB LO/RF suppression).

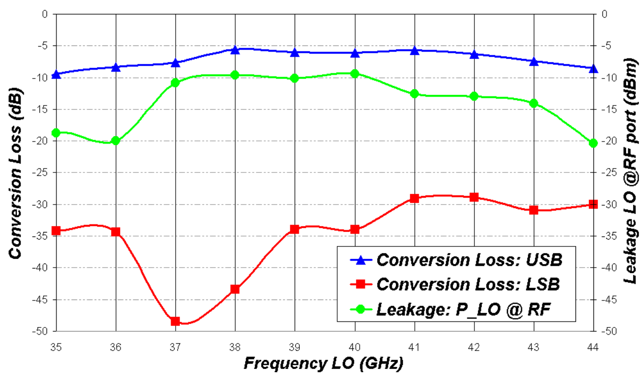

Fig. 4: Measured conversion loss, image rejection and leakages versus LO frequency of the IRM as up-converter in supradyne mode. P_{LO}=18 dBm and f_{IF}=1.5 GHz.

In infradyne mode, f_{IF} is 1.5 GHz, and $f_{LO} \in$ [35-44 GHz], let $f_{RF,USB}$=[33.5-41.5GHz]. The measured performance in the up-converter mode of the MMIC mixer is shown in Fig. 5. The performance is comparable to the supradyne mode, with typical conversion losses better than 10 dB, an image rejection better than –20dB, and an LO leakage of -10 dBm. Due to the high LO pump level, the mixer exhibits input compression point better than +7 dBm at f_{RF} =45.5GHz and 10 dBm at 36.5GHz. For different LO frequency and P_{LO}=19dBm we have tested the input compression point of the mixer. Results are shown in Fig. 6.

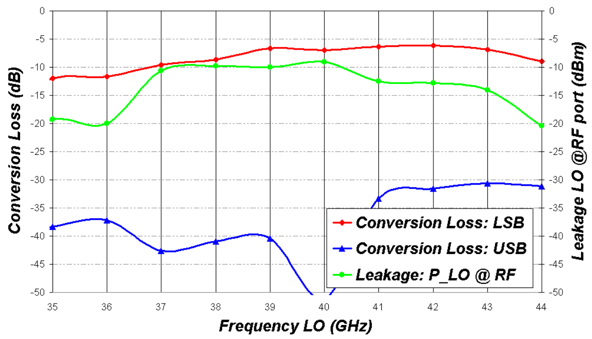

Fig. 5: Measured conversion loss, image rejection and leakages versus LO frequency of IRM as up-converter in infradyne mode. P_{LO}=18 dBm and f_{IF}=1.5 GHz.

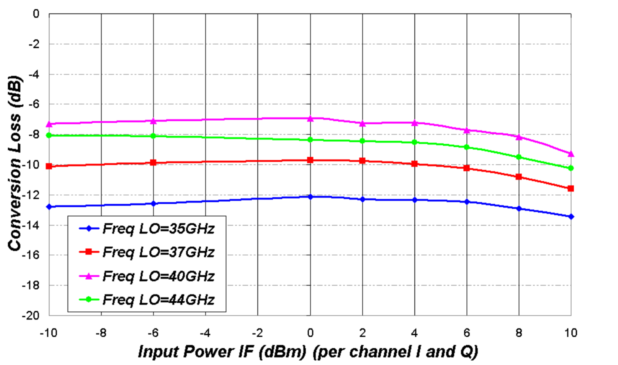

Fig. 6: On-wafer measured conversion loss (mode supradyne) versus IF power (P_{-1dB}) of image rejection star mixer as up-converter. P_{LO}=19 dBm, f_{IF}=1.5 GHz.

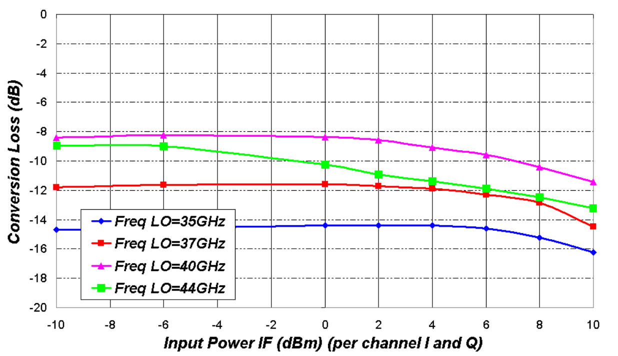

Fig. 7: On-wafer measured conversion loss (mode supradyne) versus IF power (P_{-1dB}) of image rejection star mixer as up-converter. P_{LO}=16 dBm, f_{IF}=1.5 GHz.

When reducing input LO power (P_{LO}=16 dBm), mixer exhibits lower input compression point At f_{LO}=44 GHz, P_{1dB} showed in Fig. 7 is only 0 dBm. But for lower frequencies (35 GHz and 37 GHz) input compression point is better than 8 dBm [4].

B. Measurements in modulator mode.

The image rejection star mixer can be used as well as a vector modulator. Ideally, the modulator output signal should be proportional to (Eq. 1):

$$RF(t)=I(t)\cdot\sin(\omega_{LO}t)+Q(t)\cdot\cos(\omega_{LO}t), \qquad (1)$$

where I(t) and Q(t) are the base band modulation signals and ω_{LO} is the carrier coming from the LO port. By applying different I and Q base band signals, it is possible to characterize the modulator in accuracy, intermodulation distortion, error-vector magnitude, output compression. For a simple test setup characterization, the base band modulation signals applied to I and Q ports of the modulator are two sinusoids in quadrature. Applying these signals to the I/Q modulator, the trajectory diagram at RF port ideally follows a circle with constant rate of phase change. The deviation from this ideal response is due to distortion in the modulator, LO leakages and LO/RF imbalances. Modulation error can be expressed in term of phase error. To estimate this RMS phase error, SSB suppression can be used with the following formula [5]:

$$Suppression_{SSB}=10\cdot\log[(1+\cos\varphi)/(1-\cos\varphi)], \qquad (2)$$

where φ is the average phase error in degrees. The mixer in modulator mode was measured with a vector network analyzer to perform S_{21} measurements. On Fig. 8, one can see the response of several chips when the sine base band signals are applied. The dotted circle is the input modulating signal. Although in this measurement the input power level for the base band signal is too high (compressing and modifying the trajectory diagram at the RF port), the MMIC demonstrates potential use as a vector modulator. On Fig. 9, the mixer mounted in JIG test fixture is measured with same vector modulation method. The mixer has been tested at frequency of 35 GHz with a 19 dBm input signal and a sine base band signal amplitude equal to 0.5 V. The average measured phase error is 4.68°, so calculated value of SSB suppression is 27dBc This value, very close to the measured value of image rejection (25 dBc @ 35GHz) in mixer mode demonstrates the accuracy of the method.

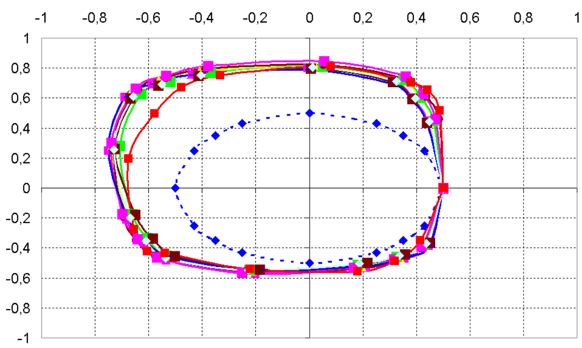

Fig. 8: On Wafer Measurements. I/Q modulator magnitude and phase error results. f_{LO}=40 GHz, P_{LO}=18 dBm, $V_{baseband}$=0.5 V.

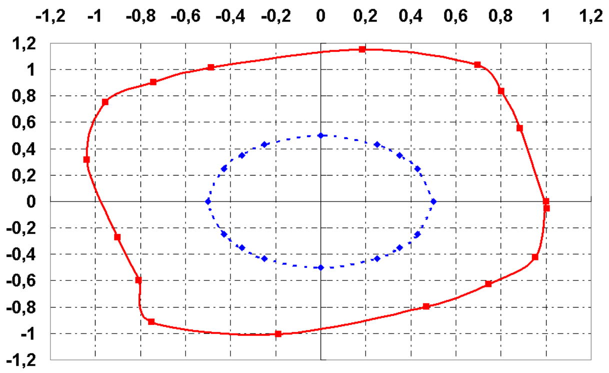

Fig. 9: JIG test fixture measurements of the I/Q modulator. Magnitude and phase error results at f_{LO}=35 GHz, P_{LO}=19 dBm, $V_{baseband}$=0.5 V.

IV. Conclusion

For use in millimetre wave communication systems, a very compact (2 mm^2) 35-45GHz image rejection star mixer MMIC can be operated as up-converter in the transmitter and as down-converter in the receiver with an excellent performance. The typical up-conversion loss is 7 dB in supradyne and 8 dB infradyne mode. The LO/RF isolation is better than 28 dB. Measurements in modulator mode have been performed as well, demonstrating potentially good performance for vector modulation scheme.

Acknowledgement

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