An 18 to 40GHz Double Balanced Mixer MMIC

Andy Dearn*, Liam Devlin*, Roni Livney†, Sahar Merhav†

* Plextek Ltd, London Road, Great Chesterford, Essex, CB10 1NY, UK; (lmd@plextek.co.uk)
† Elisra Electronic Systems Ltd, 48 Mivtza Kadesh st. Bene beraq Israel, (ronil@elisra.com)

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Abstract

This paper describes the design and evaluation of a broadband, passive mixer IC. The RF frequency range is 18 to 40GHz, the LO 20 to 42GHz and the IF 0.1 to 17 GHz. A double balanced passive topology is used, which functions well as either an upconverter or a downconverter. The RF and LO ports are single-ended and the IC incorporates on-chip baluns to provide the differential interfaces with the double balanced mixer. The IF interface to the MMIC is differential. The IC was fabricated on the PP15-20, 0.15µm gate length PHEMT process of WIN Semiconductor. With an LO drive of +10dBm the mixer has a measured conversion loss of between 7dB and 10dB, depending on frequency. LO to IF rejection is > 30dB.

1. Introduction

The design requirement for the mixer was an RF range of 18 to 40GHz, an IF range of 0.1 to 17GHz and an LO input range of 20 to 42GHz. A passive design was required, as the mixer needed to operate as both an upconverter and a downconverter. A double-balanced design was selected to benefit from the inherent isolation it would offer between the RF, LO and IF ports.

2. Design and Simulation

The first consideration in the design process was the choice of mixer topology. A quad-ring resistive (or switching) mixer was chosen as it offers small size, good linearity [1] and high LO rejection. This topology has a balanced (differential) interface at RF, LO and IF ports, as depicted in Figure 1.

The transistors (PHEMTs) in the mixer are biased at 0V Vds and therefore behave as switches [2]. The LO signal drives the gates of the PHEMTs, switching them between their high and low loss states at the LO frequency. The selected MMIC process needed to have transistors that provided good switching performance to mm-wave frequencies and a short gate length PHEMT process satisfied this criteria.

Initial simulations were undertaken assuming ideal baluns at all ports. This allowed the optimum device size and gate bias voltage to be selected for the mixer transistors (drain-source bias is 0V as stated earlier). An on-chip active bias network was designed to set the gate bias voltage. It operates from a –5V supply and draws < 2mA. The active bias network would also provide a degree of compensation for performance variation with temperature and from unit to unit.

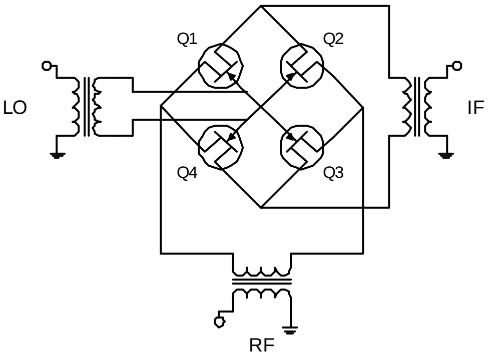

Figure 1: Quad-ring switching mixer

At low frequencies the gate-source/gate-drain capacitance of the PHEMTs in the mixer is small and the reactance is high. A differential resistive load at the LO port can therefore be used to define the terminating load for the LO drive. As frequency increases the capacitive reactance at the gate becomes lower than the terminating resistance. A low impedance at the LO port of the mixer reduces the effective LO voltage swing and degrades the conversion loss and compression performance of the mixer. In order to address this problem an impedance matching network was included at the LO port of the mixer between the LO port balun and the gates. A 200Ω resistor across the gate terminals of the mixer provided a resistive load and a passive LC matching network was designed to maximise LO voltage swing across the gates and provide a reasonable return loss at the LO port.

On-chip baluns were required at the RF and LO ports, and the next stage of the design process was to consider the most appropriate balun structure. One well-proven structure, capable of achieving broadband operation with low insertion loss, is the “Marchand Balun” [3]. This was originally a co-axial balun, but printed versions have since been developed, the simplest of which is depicted in Figure 2.

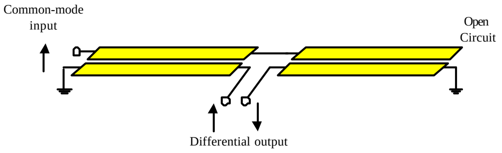

Figure 2: Printed Marchand Balun

The total length of this structure is approximately half a wavelength at the centre frequency. It is more tolerant to low even mode impedance (low coupling ratio) than other printed structures such as the parallel line balun [4] and can have a wider bandwidth.

Increased coupling and so increased bandwidth can be obtained from a planar implementation if multiple coupled lines are used [5], as depicted in Figure 3. Both the RF and LO balun were realised using this type of structure.

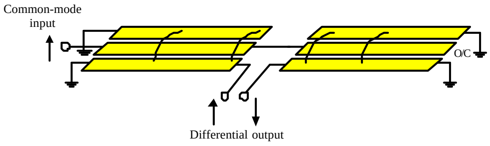

Figure 3: Multiple coupled line Marchand balun

The approach taken with the balun design was to initially use the multiple coupled line models in a conventional RF simulator to predict performance and balun dimensions. A full EM simulation was then undertaken to improve the accuracy of the simulation and allow the final optimisation of the balun dimensions.

Figure 4 shows the amplitude and phase difference predicted by the EM simulation for the RF balun, which had to cover 18 to 40GHz. The amplitude imbalance is < ±0.12dB across the band. The phase imbalance predicted by the EM simulation gradually increases with frequency across the band but is still only 7° away from ideal at 40GHz.

The EM simulated input match and insertion loss through each arm of the RF balun is plotted in Figure 5. The excess loss is less than 0.85dB across the 18 to 40GHz operating band and the input match is better than 14dB.

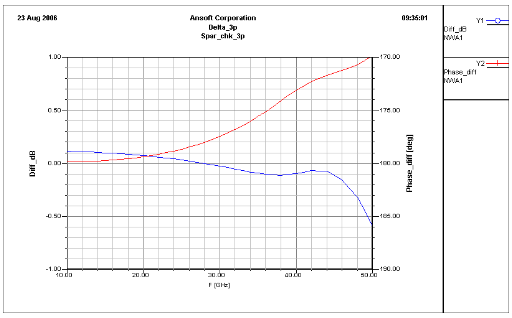

Figure 4: EM simulated, amplitude and phase difference of RF balun

The baluns were also analysed as two port structures, with the outputs differentially combined in an ideal transformer. Figure 6 shows this response for the RF balun. The simulated insertion loss is below 0.8dB across the entire RF band, with a good guard band at the high frequency end.

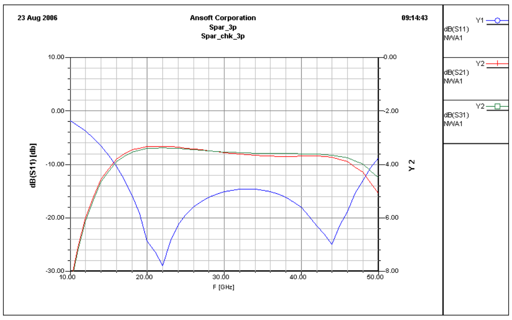

Figure 5: EM simulated, insertion loss and input match of RF balun

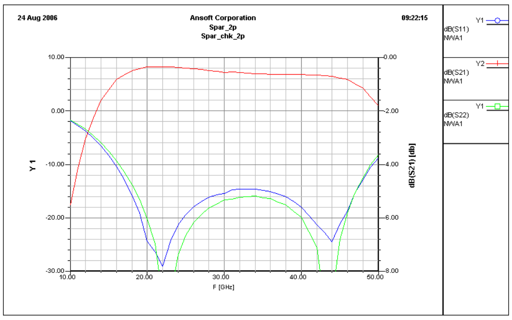

Figure 6: EM simulated, insertion loss and matches of RF balun, as a 2-port

The simulated conversion loss versus LO frequency of the whole mixer MMIC in downconvert mode is plotted in Figure 7. The RF frequency was fixed at 19.6GHz and the LO swept from 20 to 36GHz (resulting in an IF output of between 0.4GHz and 16.4GHz). The red trace represents an LO power of +10dBm and the blue trace an LO power of +13dBm. For an LO drive of +10dBm the simulated conversion loss varies between 8.4dB and 9.7dB across the band.

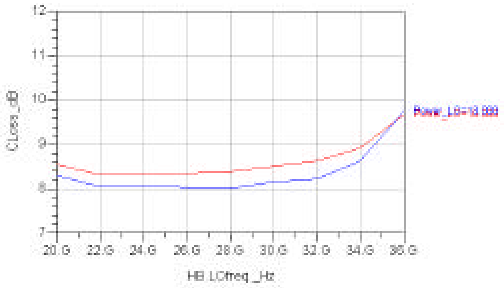

Figure 7: Simulated RF to IF downconversion loss versus LO, RF fixed at 19.6GHz

A simulation of the conversion loss in upconvert mode is plotted in Figure 8. LO frequency is fixed at 23.5GHz with a swept IF. As with the downconvert simulation the red trace represents an LO drive level of +10dBm and the blue trace an LO drive level of +13dBm. For an LO drive of +10dBm the simulated conversion loss varies between 7.6dB and 8.5dB across the band.

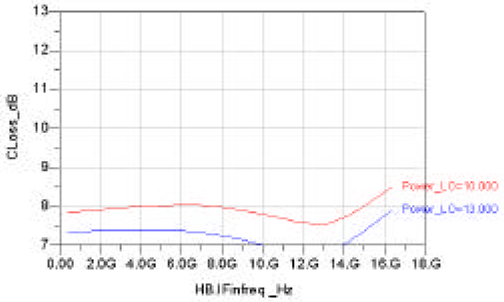

Figure 8: Simulated IF to RF upconversion loss versus IF, LO fixed at 23.5GHz

3. Realisation

The MMIC was fabricated on the PP15-20, 0.15µm gate length PHEMT process of WIN Semiconductor. A photograph of one of the mixer MMICs, whilst under RF On Wafer (RFOW) test, is shown in Figure 9.

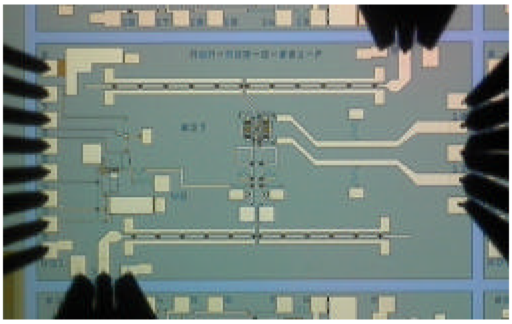

Figure 9: Photograph of the mixer MMIC

The single ended RF port is on the top side of the photograph and the single ended LO port is on the bottom side. These two ports can be seen interfacing to Ground-Signal-Ground (GSG) RFOW probes. The differential IF ports to the right interface to differential G-S-G-S-G RFOW probes for test. The DC probes to the left are for application of the –5V bias and monitoring of various voltages generated by the on-chip active bias network.

4. Measured performance

The possible permutations of measurement that could be presented for a broadband frequency-converting component are extensive. A limited subset of the actual measurements made is necessarily presented here. The data selected attempts to provide adequate representation of most aspects of the mixer’s performance. However, some features that may be of interest to certain readers may have been omitted. In this case interested parties are invited to contact the authors directly.

All of the measurements presented below were made using RFOW probing. An off-chip connectorised balun was used to transform the differential IF signal to single-ended for ease of measurement. The losses of this balun have been accounted for in all of the measurements presented below.

Figure 10 shows the measured conversion loss of the mixer in downconvert mode with LO fixed at 28GHz and the RF swept between 18GHz and 27GHz (giving an IF output of between 10GHz and 1GHz). The results for three representative devices (the solid traces) are plotted showing good device to device repeatability with the conversion loss varying between 7.9dB and 9.9dB across the band. This compares favourably with the simulated performance, the dotted trace in Figure 10, which predicted an almost flat conversion loss of around 8.4dB.

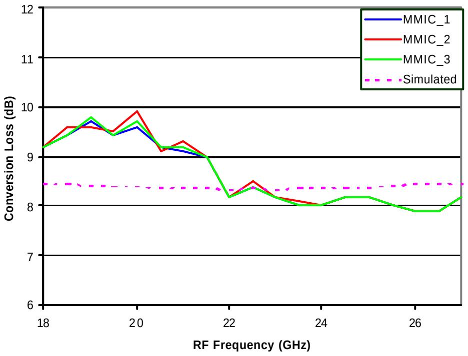

Figure 10: RF to IF downconversion loss versus RF, LO fixed at 28GHz

Figure 11 shows the conversion loss of the mixer in upconvert mode with the LO fixed at 36GHz and the IF swept between 0.5GHz and 17GHz. The resulting RF output is between

35.5GHz and 19GHz. Measured results for the same three representative devices are plotted (the solid traces) along with the original simulated performance (the dotted trace). The measured conversion loss varies between 6.9dB and 10.4dB across the band. This compares favourably with the simulated performance, which has a flatter response with conversion loss varying between 8.6dB and 9.3dB across the band.

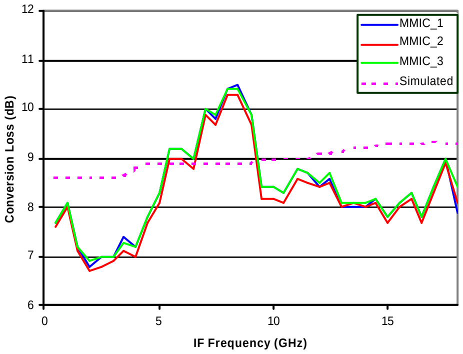

Figure 11: IF to RF upconversion loss versus IF frequency, LO fixed at 36GHz

The measured input return loss at the LO port (strictly speaking the s11) is plotted for the same three representative devices in Figure 12. This return loss is around 10dB across the band. Whilst not a perfect 50Ω, it is in good agreement with the simulated performance. During the design process this level of return loss was selected as representing a good-trade-off between input match and high LO voltage swing across the gates of the mixer.

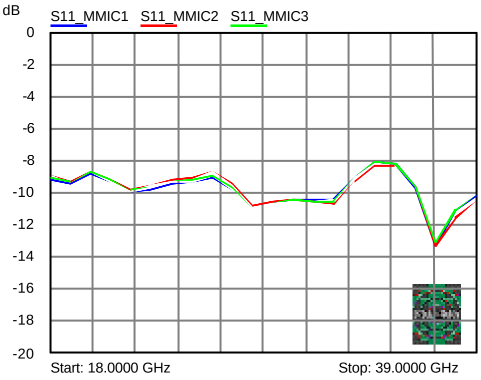

Figure 12: LO port return loss (strictly s11) for the 3 MMICs

The conversion loss performance versus LO drive level is plotted in Figure 13 for an LO of 28GHz and an RF input of 22GHz. Conversion loss is still reasonable even with an LO drive as low as +5dBm. As LO drive increases the conversion loss reduces gently. By the time the LO drive is +10dBm the conversion loss variation is levelling off. The simulated performance (dotted trace) is in good agreement with the measured.

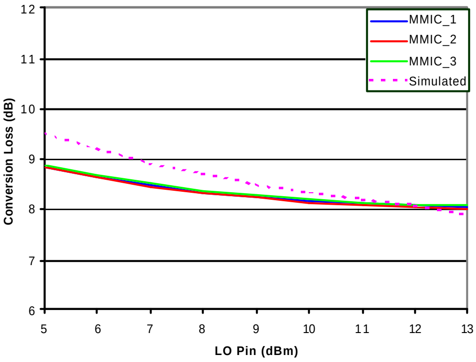

Figure 13: Downconvert conversion loss versus LO power level, LO=28GHz, RF=22GHz

Power transfer characteristics of the mixer were measured in both up and downconversion modes. Figure 14 shows the input power versus output power for the three representative devices at an RF of 40GHz and an LO of 42GHz (the top of both bands respectively). The input referred 1dB gain compression point (P-1dB) is around +3dBm. The measured P-1dB at lower LO frequencies increases to around +7dBm.

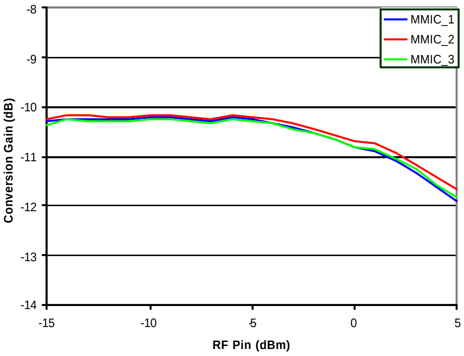

Figure 14: Downconversion compression characteristics, RF=40GHz, LO=42GHz

Similar power transfer characteristics in upconvert mode are plotted in Figure 15. The IF input is 9GHz and the LO is 36GHz, resulting in an RF output of 27GHz. The input referred P-1dB in this case is around +7dBm.

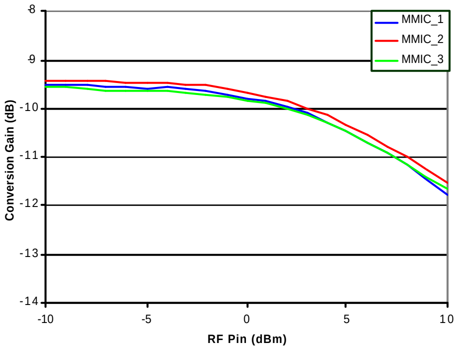

Figure 15: Upconversion compression characteristics, IF=9GHz, LO=36GHz

The measured LO to RF rejection is plotted against LO frequency in Figure 16 (strictly speaking the plot shows the LO to RF transmission rather than rejection). The level of rejection is determined by the performance of the on-chip baluns, the symmetry of the IC layout and the matching between devices on the IC. Leakage between the measurement probes can also affect the measurement and care must be taken to ensure that isolation between the probes is adequate. At low LO frequencies the LO to RF rejection is around 40dB. As may be expected this degrades gradually with frequency to around 27dB at the top of the LO band (42GHz). The LO to IF rejection was also measured and found to be greater than 30dB across the band.

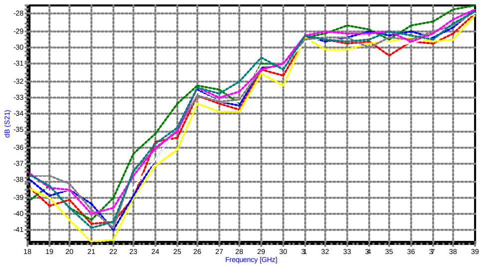

Figure 16: LO to RF transmission versus LO frequency

5. Summary and Conclusions

This paper has presented the design and measured performance of a broadband, passive (bi-directional) mixer MMIC realised on a commercially available PHEMT process. A summary of the measured performance is presented in Table 1.

Except where indicated, all measurements were made on-wafer with an LO drive level of +10dBm.

Parameter	Performance	Units
IF range	0.1 – 17	GHz
RF range	18 – 40	GHz
LO range	20 – 42	GHz
Conv. loss	7 to 10	dB
P-1dB (input)	3 to 7	dBm
LO to RF rej.	> 27	dB
LO to IF rej.	> 30	dB
LO port return loss	> 8	dB

Table 1: Measured performance summary

It should be noted that this MMIC design in the property of Elisra Electronic Systems Ltd.

6. References

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