A Monolithic, 2 to 18GHz Upconverter

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Abstract **This paper describes the design and evaluation of an upconverter IC for Electronic Surveillance Measures (ESM) applications. The purpose of the IC is to enable a signal anywhere in the 2-18GHz frequency band to be converted to 21-23GHz for subsequent downconversion to an IF suitable for digitisation. The required LO range is 23-41GHz. The RF, LO and IF ports of the IC are all single ended but the internal mixer is balanced at all ports and single-ended to differential conversion is realised on-chip, using novel broadband active and passive balun structures. The IC has been fabricated on the Triquint Semiconductor Texas' 0.25µm PHEMT process and has a measured conversion loss of 7dB to 14GHz, rising to 10dB by 18GHz. Input return loss is better than 12dB from 2 to 18GHz and LO rejection is over 30dB.**

I. Introduction

The upconverter was required to operate with an IF input range of 2-18GHz and an LO input range of 23-41GHz. These very wide operating bandwidths represented one of the key design challenges of the development.

It was decided that the IC should be based around a double-balanced mixer topology. Monolithic mixer implementations are well suited to a balanced configuration and the benefits it offers are significant:

- All mixer ports are inherently isolated
- All even order products of the LO and/or the RF are suppressed
- Local oscillator AM noise is suppressed
- Improved linearity compared to single-balanced and single-ended designs

From this starting point it was then possible to make decisions about the most appropriate circuit topologies and to start the detailed design process, as described below.

II. Design

The first consideration in the design process was the choice of mixer topology. Both active (transconductance) and passive (conductance) mixers can be realised on a PHEMT process. It is also possible to realise diodes by connecting the source and drain of PHEMTs together to form the cathode. After careful consideration and analysis, a quad-ring resistive mixer was chosen. This topology offers small size, good linearity [1] and high LO rejection.

The quad-ring resistive mixer topology is balanced at all ports. Initial simulations assumed the availability of ideal baluns at each port and a plot of the simulated conversion loss, versus LO drive level, is shown in Fig. 2. The different traces represent RF frequencies of 2GHz, 10GHz and 18GHz. Conversion loss increases with RF frequency due to the drain-source capacitance of the PHEMT devices presenting an increasing reactance in parallel with the channel resistance. For an LO drive of +7dBm, conversion loss varies from 7dB at 2GHz to 11.5dB at 18GHz.

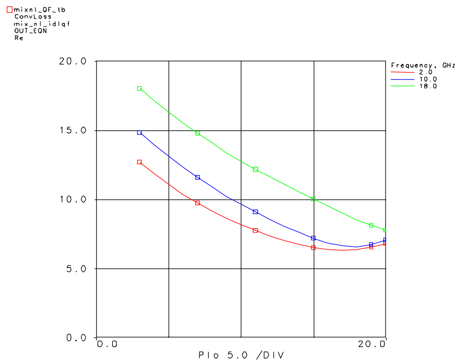

Fig. 2. Simulated mixer performance

The next stage of the design was to consider the most appropriate balun topologies. Details of the balun design process are included below. It resulted in the RF (21-23GHz) and LO (23-41GHz) baluns being realised as uniplanar Marchand baluns and the IF (2-18GHz) balun as an active long-tail pair differential amplifier. Thus the architecture of the entire unpconverter IC is that shown in Fig. 3.

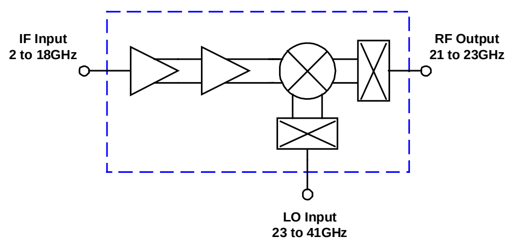

Fig. 3. MMIC architecture

In terms of realising printed MMIC baluns, one well-proven structure, capable of achieving broadband operation with low insertion loss, is the “Marchand Balun”. This is derived from the co-axial balun, described by Nathan Marchand in 1944 [2]. The printed version of the Marchand balun is shown in its simplest form in Fig. 4. 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 [3] and can have a wider bandwidth.

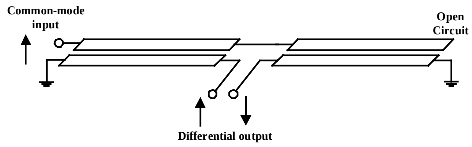

Fig. 4. Printed Marchand Balun

Increased coupling and so increased bandwidth can be obtained from a planar implementation if multiple coupled lines are used, as depicted in Fig. 5.

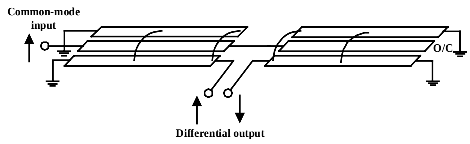

Fig. 5. Multiple coupled line Marchand balun

This structure was selected for the RF and LO baluns. The RF balun (21-24GHz) combines the differential RF outputs of the mixer and the LO balun (23-41GHz) produces a differential LO drive from the single-ended LO input. The layout of the LO balun is shown in Fig. 6. The layout was meandered to reduce the chip size.

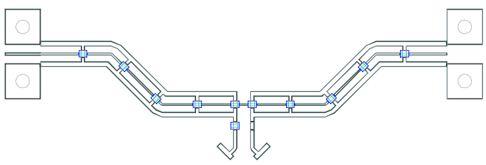

Fig. 6. Layout of LO balun

Electromagnetic simulation of the Marchand baluns was carried out to properly account for the discontinuity and coupling effects of the layout. Fig. 7. shows the simulated amplitude and phase difference between the two branches, which is within 0.9dB and 9° of ideal from 14 to 44GHz. This simulation considers the balun as a three port network. Two port simulations were also performed with the balun’s outputs differentially combined in an ideal transformer. Fig. 8. shows the results of the electromagnetic simulation in this instance. Good return losses and low insertion loss (less than 0.5dB) are observed from 23 to 41GHz.

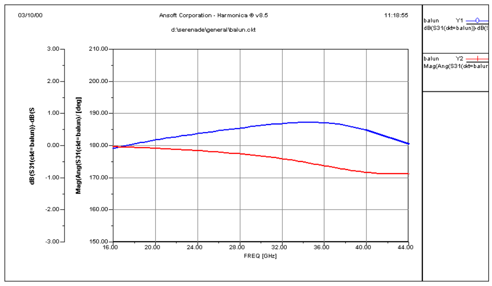

Fig. 7. Electromagnetic simulation of amplitude and phase difference of the LO balun

A small “glitch” can be seen in the simulated return loss of Fig. 8. at around 27GHz. This is a real effect, which is only observed when the balun is analysed with its outputs differentially combined [4]. It is a result of the even mode impedance of the coupler (Zoe) being too low. In some instances it can become severe but in this case it was relatively minor and could be ignored. The subsequent measurement of the complete upconverter showed no unusual behaviour at LO frequencies in the region of 27GHz.

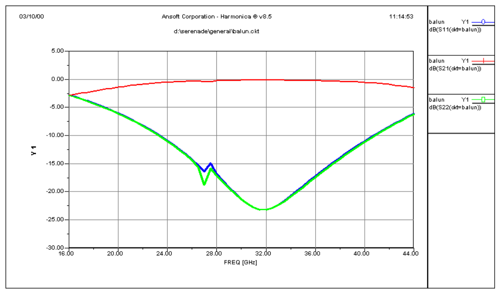

Fig. 8. Electromagnetic 2-port simulation of the LO balun

The IF port balun needs to work from 2 to 18GHz so a Marchand balun was not appropriate, both in terms of the area it would occupy and the difficulty of realising tight enough coupling to achieve the required operating bandwidth.

The solution adopted for the IF balun was to use a two stage differential amplifier. A simplified circuit diagram of the first stage is shown in Fig. 9. The input is a long-tail pair biased with a current source (Q5). One transistor in the differential pair (Q4) has its gate held at ground and the gate of the other transistor (Q3) is the LO input port which is matched to 50Ω with a broadband lossy input matching network. The drain terminals are biased using active loads (Q1 and Q2) with their gate and source terminals capacitively coupled to hold them at the same RF potential.

The output of this amplifier stage is a differential signal, the balance of which is improved by the use of a second differential amplifier stage.

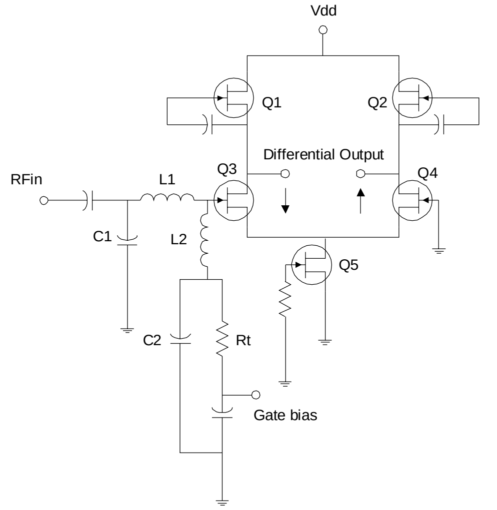

Fig. 9. Input stage of IF active balun

The simulated performance of the complete active balun showed a phase difference of within 180° ± 2° and an amplitude difference of less than 0.2dB from 1 to 20GHz.

Fig. 10. shows simulated performance of the active balun as a 2-port with the outputs differentially combined. The gain increases from 1.2dB at 2GHz to around 3dB at 18GHz. This positive gain slope versus frequency helps counter the negative gain slope versus frequency of the mixer (Fig. 2.).

The simulated input return loss is over 13dB from 2 to 18GHz and the output return loss is around 8dB. The output is resistively matched and so any increase in return loss would be at the expense of gain, hence this compromise was decided upon. The effects of this mismatch are included in the simulations of the complete upconverter performance shown below.

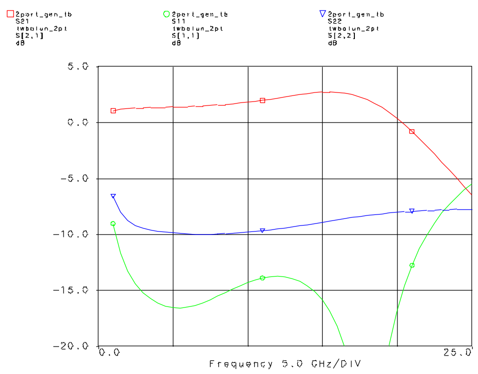

Fig. 10. Two-port simulation of the active balun

The simulated performance of the complete upconverter, including quad-ring mixer, active IF balun and passive RF and LO baluns is shown in Fig. 11. Input return loss and conversion loss is shown for LO drive levels of +8, +10 and +12dBm. The input return loss is better than 12dB from 2 to 18GHz and does not change noticeably with varying LO input power. This is a result of the isolation provided by the active balun. Across 2-18GHz the simulated conversion loss is less than 12dB for an LO drive of +10dBm.

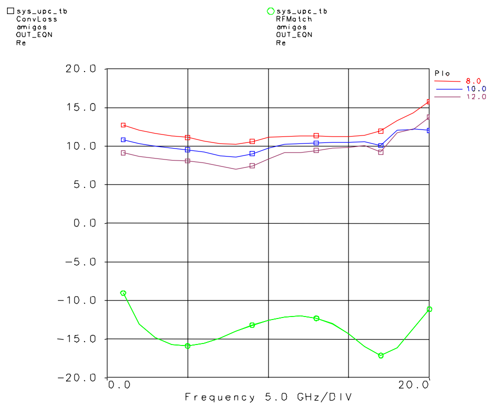

Fig. 11. Final simulated performance of the upconverter

III. Realisation And Measured Performance

A photograph of the upconverter IC is shown in Fig. 12., the die size is 3.04mm x 3.28mm.

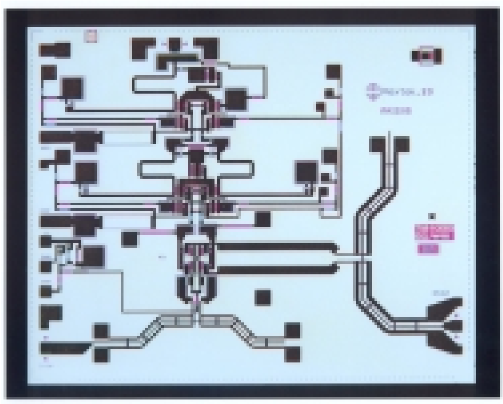

Fig. 12. Photograph of the IC

Evaluation of the upconverter was carried out on ICs assembled onto an MIC carrier tile, as shown in Fig. 13. This was fabricated from 0.01” thick RT/Duroid 5880 with a brass backing to give rigidity.

The measured conversion loss of the upconverter versus IF input frequency is shown in Fig. 14. for a fixed RF of 22GHz. With an LO drive of +10dBm the conversion loss is around 7dB to 14GHz, rising to 10dB by 18GHz, which is slightly better than simulated. If the LO drive is reduced to

+7dBm, the conversion loss increases by around 1dB. The LO rejection is shown on the same plot and is over 30dB across the entire band. This was measured with an LO input level of +10dBm.

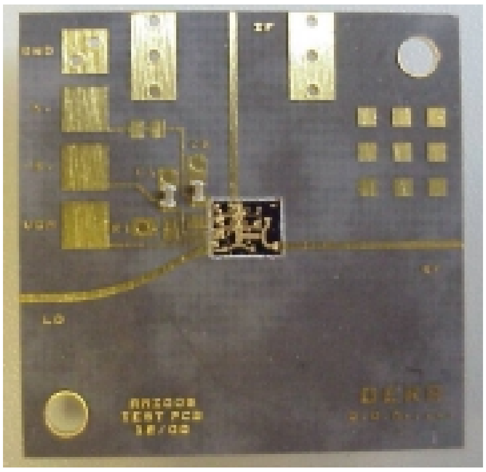

Fig. 13. Photograph of an IC assembled onto a carrier

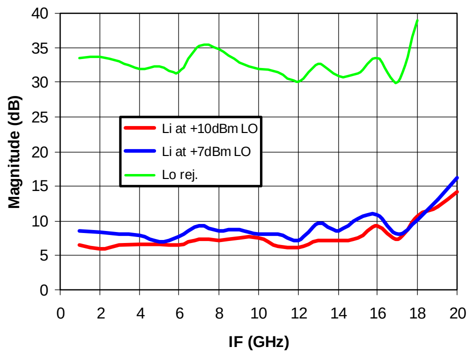

Fig. 14. Measured conversion loss and LO rejection of the upconverter IC

Measurements of conversion loss versus RF frequency were also made for a range of fixed IFs with a fixed LO drive level of +10dBm. The results are plotted in Fig. 15. and show a slight increase in conversion loss with increasing RF frequency. The increased conversion loss at the top end of the IF input band (18GHz) is also evident.

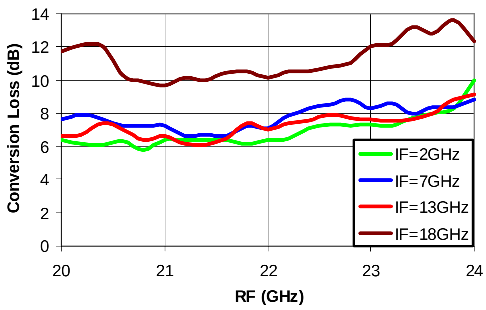

Fig. 15. Measured conversion loss across RF band

The measured IF port return loss is plotted against IF frequency in Fig. 16. The return loss is better than 12dB from 2 to 18GHz and is in good agreement with the simulated performance of Fig. 11.

Fig. 16. Measured IF port match

IV. Summary

A 2-18GHz upconverter MMIC has been designed, fabricated and evaluated. The RF output is from 21 to 23GHz and the LO input range is from 23 to 41GHz. The design includes novel broadband active and passive baluns and the die size is 3.04mm x 3.28mm. Evaluation was carried out on die assembled onto an MIC carrier.

The measured conversion loss for an LO drive level of +10dBm, is around 7dB below 14GHz, rising to 10dB by 18GHz. If the LO drive is reduced to +7dBm, the conversion loss increases by around 1dB. Input return loss is better than 12dB from 2 to 18GHz and an LO rejection of greater than 30dB is achieved.

V. References

[1] Maas, S.A., “A GaAs MESFET Balanced Mixer with Very Low Intermodulation”, 1987 IEEE MTT Symposium Digest, p895

[2] Marchand, N. “Transmission-Line Conversion”, Electronics December 1944, pp 142-145

[3] Cho, C and Gupta, K.C., “A New Design Procedure for Single-Layer and Two-Layer Three-Line Baluns”, IEEE Transactions on Microwave Theory and Techniques, Vol. 46, No. 12, December 1998, pp 2514-2519

[4] Maas, S.A. “Microwave Mixers”, Artech House, ISBN 0-89006-605-1