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A Sub-harmonic E-band IRM/SSB Realized on a Low Cost PHEMT Process

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Abstract— **E-band spectrum at 71-76GHz and 81-86GHz provides the opportunity for the implementation of very high data-rate wireless links. However, component availability and price has held back the development and adoption of E-band radio links. This paper describes a sub-harmonic E-band Image Reject Mixer (IRM) and Single-SideBand (SSB) upconverter MMIC realized on a low-cost PHEMT process. The LO input to the IRM/SSB is at half the mixing frequency thereby simplifying the development of E-band transceivers. The measured conversion loss is 11dB in upconvert mode and 12dB in downconvert mode with an image rejection (unwanted sideband suppression) of 15dB. The required LO drive level is +14dBm.**

Keywords - E-band; IRM; MMIC; mm-wave; sub-harmonic; SSB

I. Introduction

E-band spectrum at 71-76GHz and 81-86GHz provides worldwide availability of a large amount of spectrum on a "light license" basis [1]. This scheme operates in the US, the UK and many other countries and allows licenses to be obtained quickly and cheaply whilst retaining the benefits of interference protection. Despite the obvious attractions of this spectrum for the wireless transmission of very large amounts of data, limited component availability and high component cost makes E-band radio links difficult to develop and comparatively costly.

This paper describes the development of a sub-harmonic IRM/SSB designed to operate across 71 to 86GHz. The sub-harmonic topology results in a half frequency LO input, which simplifies the radio architecture. The MMIC is realized on a low-cost, optically defined 0.13µm gate length PHEMT process, which means that production die cost is low.

Details of the design, topology and measured performance are presented.

II. Circuit Topology and Design

The IRM topology uses a quadrature splitter at the RF port and an in-phase splitter at the LO port as depicted in Figure 1. The two sub-harmonic mixers are passive diode based sub-circuits, which allows the IRM to also perform well as a Single-SideBand (SSB) upconverter. The use of sub-harmonic mixers in the IRM means that the LO input is at half the mixing frequency (31GHz to 42GHz input range for a mixing frequency range of 62 to 84GHz). This has the advantage of removing the need for LO power generation at E-band. There is a slight conversion loss penalty to pay but this is modest by comparison. The IF outputs of the IRM (IF inputs to the SSB) are in quadrature and must be combined/split using an appropriate off-chip IF quadrature hybrid to benefit from the inherent image rejection/sideband suppression.

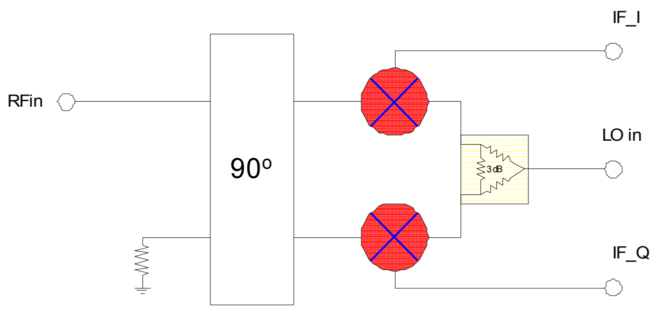

Figure 1: Topology of E-band IRM/SSB

The sub-harmonic mixer topology uses a shunt-mounted anti-podal diode pair as depicted in Figure 2. This structure has no fundamental mixing response at the LO frequency and the resulting mixer has a conversion loss that incurs only a modest increase over a fundamental design [2]. Careful design of the RF, IF and LO filtering structures is required to allow adequate diplexing of the different frequencies.

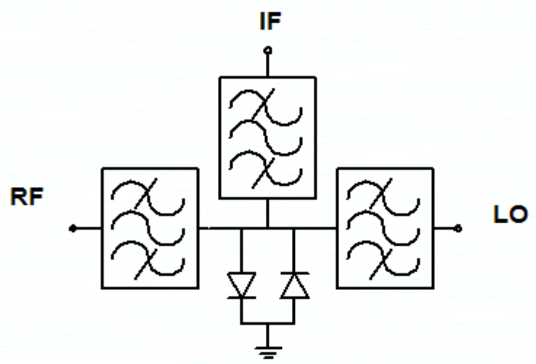

Figure 2: Basic structure of the sub-harmonic diode mixer

The diodes are realized by connecting the source and drain of the PHEMT structures to form the cathode of the diode with the gate forming the anode, as depicted in Figure 3. The RF quadrature power splitter is implemented as a Lange coupler and the in-phase LO power splitter as a simple single-section Wilkinson. The RF, IF and LO path filtering is realized using transmission line inductors and MIM capacitor.

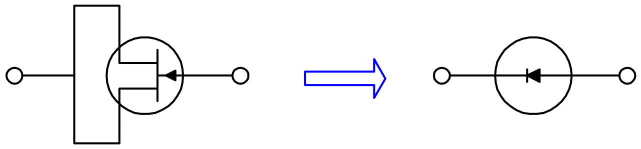

Figure 3: Realising a diode on a PHEMT MMIC process

III. Fabrication

The design was implemented on a 0.13µm gate length PHEMT process. The process makes use of 150mm (≈ 6") diameter wafers and optical gate definition. This means that it is very well suited to low-cost, high-volume production. A photograph of one of the sub-harmonic IRM die is shown in Figure 4.

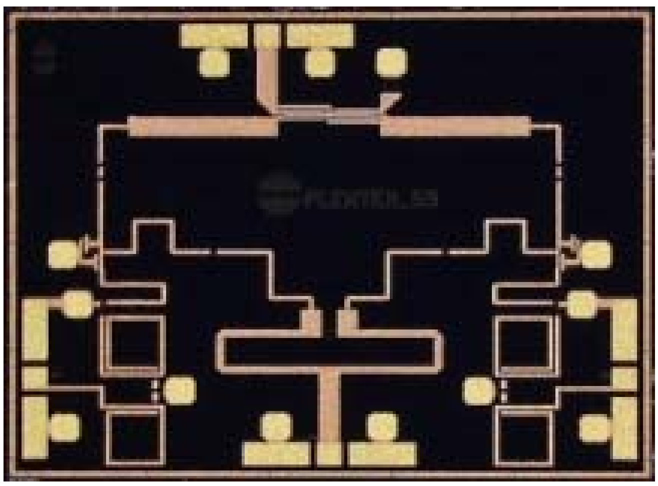

Figure 4: Photograph of the E-band IRM/SSB

IV. Measured Performance

RFOW evaluation of the IC has been performed in both upconvert and downconvert modes. The available LO source used during these initial measurements had an upper frequency limit of 40GHz, which means a maximum mixing frequency of 80GHz could be used during the evaluation. Although the evaluation frequency range was limited the design itself should work well across the full 71 to 86GHz RF frequency range with LO frequencies to 42GHz (mixing frequency of 84GHz).

The measured conversion gain versus RF frequency is plotted in Figure 5. An IF frequency of 2GHz with low side injection was used. The different traces reflect different LO drive levels. When providing an LO drive of +14dBm the measurement source was limited to a maximum frequency of 39GHz (78GHz mixing frequency) and for an LO drive level of +16dBm to 38.5GHz (77GHz mixing frequency).

It can be seen that the LO drive level should be set to 14dBm or higher to avoid increasing the conversion loss. A comparison of the wanted and image conversion gains is shown in Figure 6. The image rejection is typically 15dB.

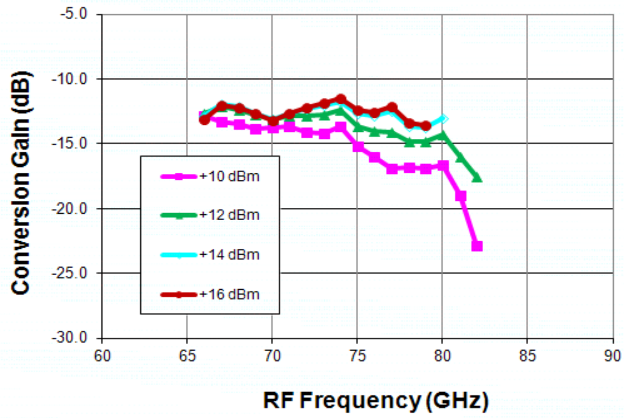

Figure 5: Measured conversion gain in downconvert mode for various LO power levels (IF=2GHz, USB)

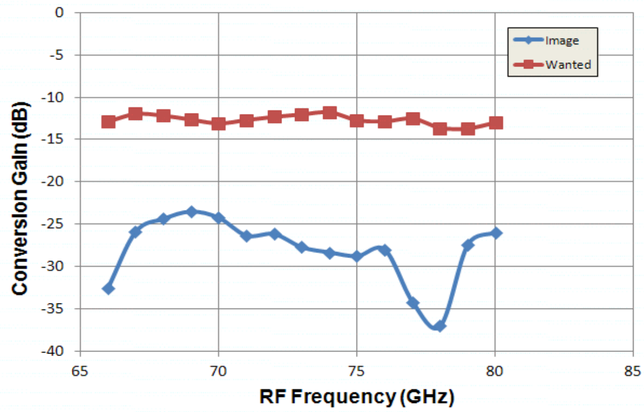

Figure 6: Comparison of measured conversion gain and image rejection

The IRM is designed to operate with IF frequencies of up to 11GHz. Measurement has been performed with swept IF up to 7GHz. The resulting conversion gain versus IF frequency in receive mode is plotted in Figure 7.

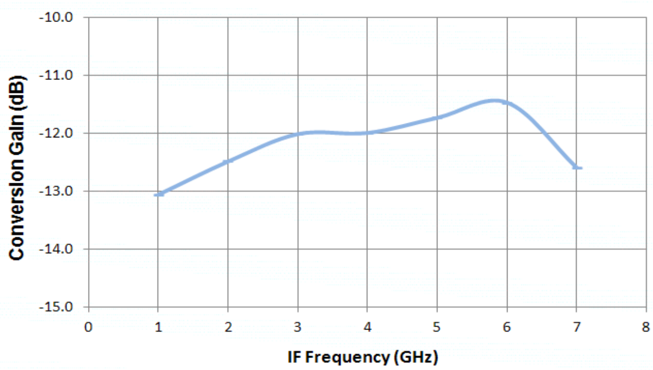

Figure 7: Measured receive mode conversion gain versus IF frequency, USB, LO=34GHz (2.LO=68GHz)

Evaluation was also performed with the MMIC operating as an SSB upconverter. The measured conversion gain versus RF frequency is plotted in Figure 8. As before the IF frequency is 2GHz with low side injection and the different traces reflect different LO drive levels. The conversion loss is slightly lower than in downcovert mode at around 11dB for an LO drive of 14dBm.

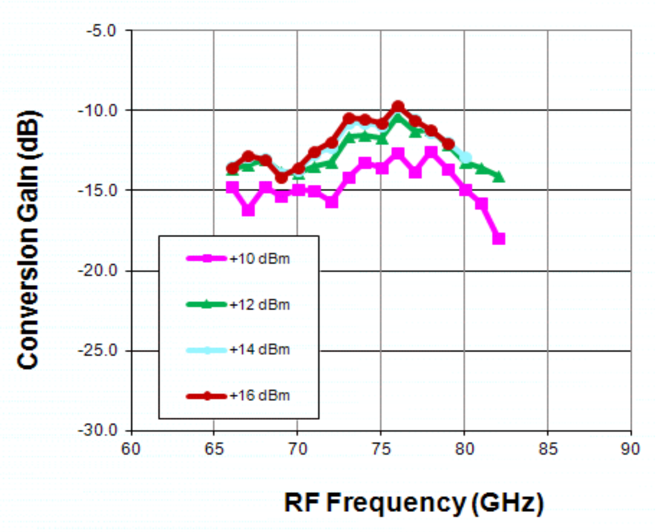

Figure 8: Measured conversion gain versus RF frequency in upconvert mode (IF=2GHz, USB)

A comparison of the measured conversion gain of the wanted and unwanted sidebands is plotted in Figure 9. The unwanted sideband is rejected by over 17dB across the band.

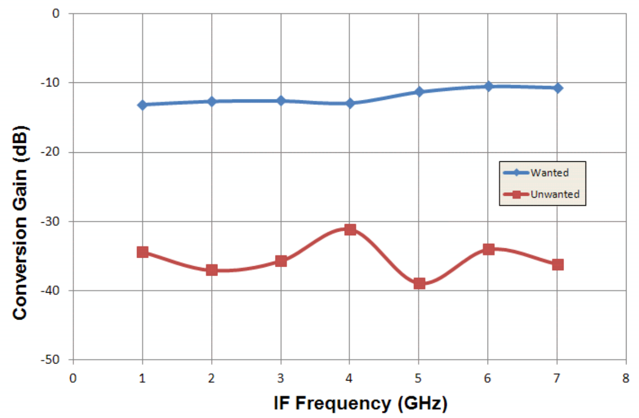

Figure 9: Measured conversion gain of wanted and unwanted sidebands versus IF frequency, USB, LO=34GHz (2.LO=68GHz)

The measured and the simulated conversion gains versus IF frequency are shown in Figure 10. It can be seen that the measured conversion loss is actually a little lower than the simulated. This reflects limitations in the large signal PHEMT transistor model when used as an un-biased diode and it was known during the design process that the simulated conversion loss was pessimistic. Although measurement to date has been limited to IF frequencies of 7GHz, it can be seen that good performance to IF frequencies of 11GHz is expected.

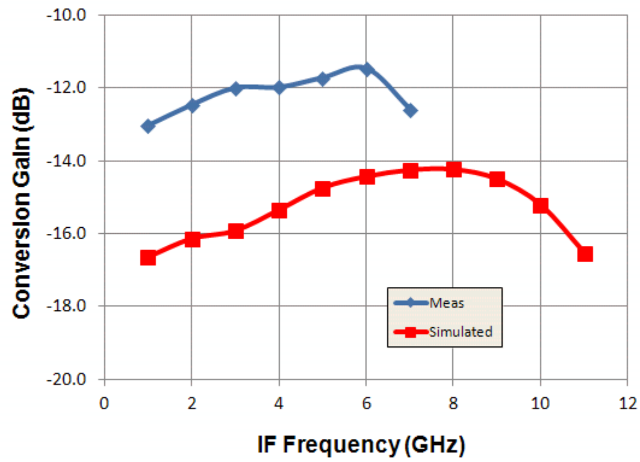

Figure 10: Comparison of measured and simulated conversion gain versus IF frequency, downconvert mode

V. CONCLUSIONS

This paper has presented the design, realization and measured performance of a sub-harmonic IRM MMIC covering the E-band spectrum at 71 – 86GHz. The IRM uses diode based sub-harmonic mixers and also functions well as a SSB upconveter. With an LO drive level of +14dBm the conversion loss is 11dB in upconvert mode and 12dB in downconvert mode. A typical image rejection of 15dB and an unwanted sideband suppression of 17dB have been measured.

The sub-harmonic implementation means that the MMIC accepts a half frequency LO input, which simplifies the architecture of E-band radios. It was realized on a low cost, optically defined PHEMT process and is suitable for low cost, high volume production.

REFERENCES

[1] J.A. Wells, "Multi-Gigabit Microwave and Millimeter-Wave Wireless Communications," Boston, Artech House, 2010

[2] S.A. Maas, "Microwave Mixers", Artech House, ISBN 0-89006-605-1.