A 60 GHz double balanced sub-harmonic mixer MMIC

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ABSTRACT

We present the design and measured results for a 60 GHz double balanced sub-harmonic MMIC mixer fabricated using the TRW 0.15mm gate length GaAs pHEMT foundry process. The sub-harmonic mixer architecture eliminates the need for costly mm-wave sources that are usually required with conventional fundamental frequency mixers. The mixer has been integrated into a coaxial package and a measured conversion loss of less than 10 dB across the 53 GHz to 60 GHz frequency band has been obtained. This conversion loss is believed to be approximately 2 dB better than previously published results.

INTRODUCTION

There is strong interest in the use of telecommunications systems operating at V-band frequencies for both military and civil applications. The high atmospheric absorption of microwave signals at 60 GHz is ideally suited where propagation over significant distances is not desirable, examples include secure communication links and wireless local area networks (WLAN). In addition, very compact equipment and wide bandwidth make V-band attractive for high data rate transmission and for applications where platform space is limited. Realisation of V-band transceiver components using Monolithic Microwave Integrated Circuit (MMIC) technology is also important as this approach is well suited for realising cost effective mm-wave circuit functions.

Conventional fundamental frequency FET based mixers have been demonstrated by numerous authors and have been shown to give good performance at V-band (1), (2), and (3). However, these components require the use of V-band local oscillator (LO) sources which are expensive to realise. The use of a sub-harmonic mixer architecture, as described here, allows transmitters and receivers to operate at mm-wave frequencies without the need for expensive mm-wave LO sources. This type of mixer has received particular attention at Ka-band operating frequencies in recent years, (4), (5), (6) and (7), but limited work has been published at V-band (8).

Previous work performed at QinetiQ has successfully demonstrated a single chip 60GHz integrated receiver (10). This design used a single-ended sub-harmonic mixer to provide the required frequency conversion, however the single-ended mixer topology restricted the conversion loss compression point of the receiver. Since receiver dynamic range is a critical requirement for mm-wave components, a key aim of this work was to develop a sub-harmonic mixer design with improved linearity performance over the previously developed single ended variant, while at the same time achieving low conversion loss.

In this paper we present the results for a double balanced 60GHz sub-harmonic mixer with improved conversion loss and dynamic range performance compared with single-ended equivalents. This circuit was fabricated using a production proven 0.15μm gate length GaAs pHEMT foundry process from TRW.

DESIGN

For our application, the mixer was designed to operate over the 54 to 68GHz frequency range with an IF frequency of 11 GHz. The double balanced sub-harmonic mixer core consists of eight, 2x10μm, diodes connected as 'anti-parallel' pairs. The diodes were realised from pHEMT devices by connecting together the drain and source terminals. Four diode pairs are then arranged in a ring configuration as shown in figure 1. The LO signal is applied in anti-phase across the top and bottom of the ring to provide the switching action for the mixer and to also provide good isolation between the LO and RF/IF ports. The LO "balun" was realised using a Lange coupler and an additional section of $\lambda_{LO}/4$ 50 Ohm transmission line on one arm. To minimise first iteration design risk and simplify circuit layout, the RF signal was applied to the left hand side of the ring in a single ended configuration. Since there is no RF virtual earth, as with a conventional double balanced mixer, a via hole is used to provide an RF ground connection at the right hand side of the diode ring.

Non-linear simulation was used to derive RF and LO matching networks. The LO port matching network was implemented using a radial line stub and a series length of high impedance transmission line. The RF matching network, which connects the RF port to the diode ring, consists of a series connected 50 Ohm transmission line and a short circuit stub. Since this is a high pass matching network it prevents the RF port from loading the IF port. The IF signal was extracted using a $\lambda_{RF}/4$ high impedance transmission line and a radial stub, with IF matching provided using a series capacitor. It should be emphasised that during the design and layout stage, great care was taken to model the effects of electromagnetic coupling between components and verify component models using Sonnet EM.
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A photograph of the fabricated MMIC is given in figure 2. Chip size is 2.35mm x 2mm. No attempt was made to minimise GaAs chip size for this first iteration pass, however this could be reduced considerably in a second design iteration.

The RF functional circuit yield for the double balanced sub-harmonic mixer MMIC component was found to be better than 90% from the four wafers measured to-date.

RF MEASUREMENTS

The performance of the double balanced sub-harmonic mixer MMIC was measured on wafer and also in a co-axial test fixture. Due to equipment limitations it was only possible to perform detailed mixer measurements over the 50 to 60GHz frequency band, however, simulations indicate that the mixer should perform well up to 68GHz. Figure 3 shows the RF on wafer (RFOW) measured conversion loss in both downconvert and upconvert modes of operation. It can be seen that the conversion loss of the mixer is typically 10 dB or better in downconvert, degrading to typically 12dB in upconvert mode. For downconvert, these conversion loss measurements were made with an RF input level of –15.4 dBm, an LO drive level of 9.3 dBm and an IF frequency of 11 GHz. For upconvert, the same LO drive level was used but with an IF input power of -3dBm.

The LO to IF port isolation for the mixer was found to be typically better than 30 dB across the 50 to 60 GHz band, as shown in figure 4. Similarly the fundamental and 2nd harmonic LO to RF port isolation were found to be better than 30dB and 40dB respectively, as illustrated in figure 4 and figure 5. This high level of LO isolation was achieved by using a balanced LO feed structure. The mixer has also been evaluated in a coaxial test fixture using Wiltron V and K type connectors, as shown in figure 8. Similar measured conversion loss performance was obtained with the mixer in its test fixture when compared to RFOW measurements. An RF port return loss measurement for the mixer in its test fixture is shown in figure 6. It can be seen that the RF port return loss is typically 10dB over the 50GHz to 65GHz frequency range, illustrating that this component is well suited for use in a packaged environment.

The sub-harmonic mixer RF input compression performance is plotted in figure 7 for downconvert operation. All compression measurements were performed with an RF frequency of 58 GHz, an IF frequency of 11 GHz and an LO drive level of 9 dBm. It was found that the RF input P1dB compression level of the mixer was +2.5 dBm in down convert mode and +2 dBm in up convert mode. This represents a 6dB improvement over the previous single ended design variant.

CONCLUSION

In this paper a V-band double balanced sub-harmonic mixer MMIC has been presented. A conversion loss of approximately 10 dB or better was measured across the 51 GHz to 60 GHz frequency band with a 6dB improvement in dynamic range compared to a previously designed single ended sub-harmonic mixer topology. To the best of our knowledge, the level of conversion loss achieved with this design is 2 dB better than previously published sub-harmonic mixer results operating in this frequency band. In addition, this performance was achieved using a commercially available, production ready, high yield GaAs process.

A range of V-band MMIC components, designed at QinetiQ, are currently being evaluated for use in military applications, such as covert communications, and also for high data-rate picocellular communications links and WLAN links. This mixer component will form an excellent utility frequency conversion device for such applications

ACKNOWLEDGEMENTS

The authors of this paper gratefully acknowledge the help of G. Ball for RF on wafer measurements, A. Brown and P. Munday for package design and J. Gates for module construction.

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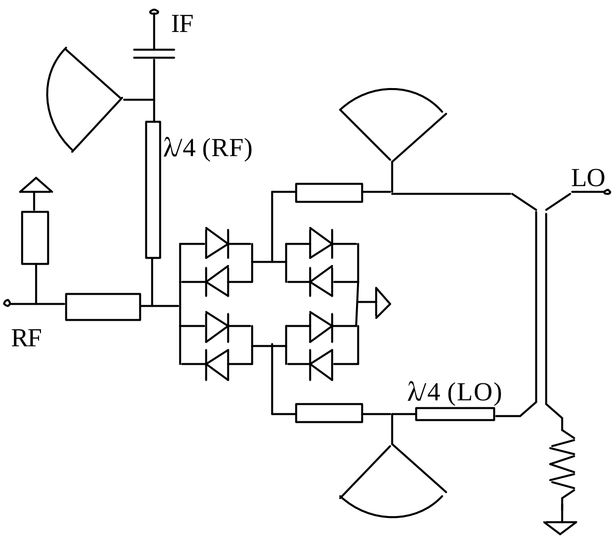

Figure 1. Schematic diagram of the double balanced sub-harmonic mixer MMIC

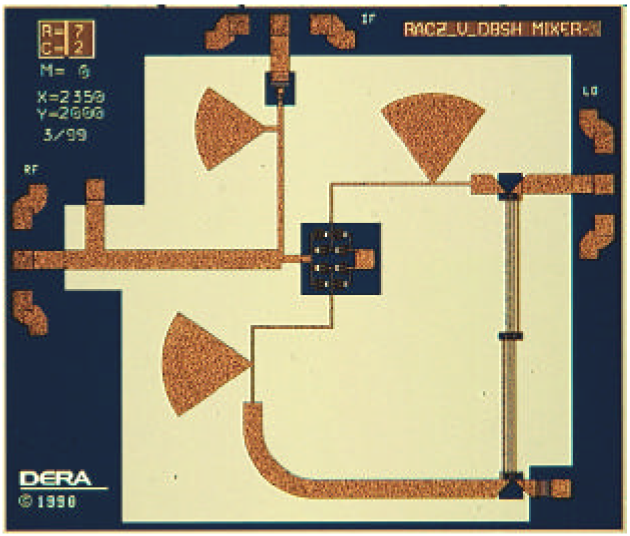

Figure 2. Photograph of double balanced sub-harmonic mixer MMIC

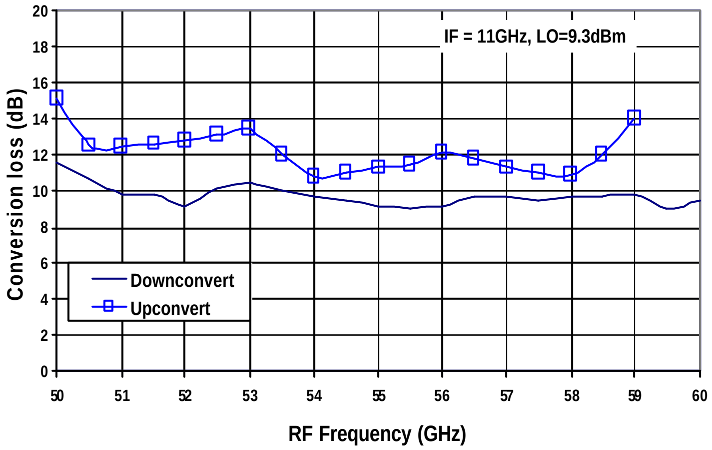

Figure 3. Measured conversion loss

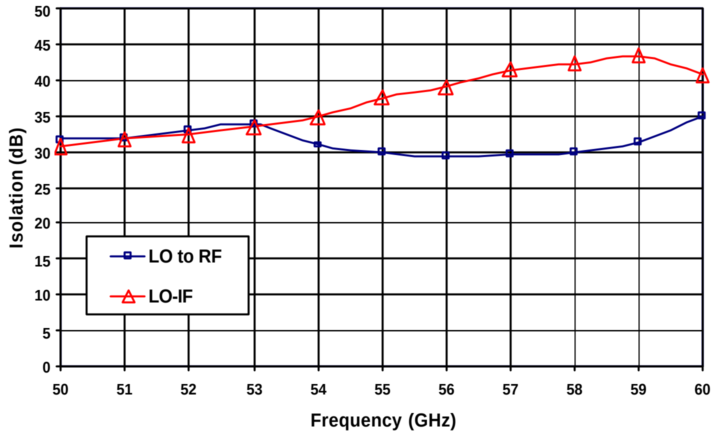

Figure 4. Measured LO to RF and LO to IF isolation

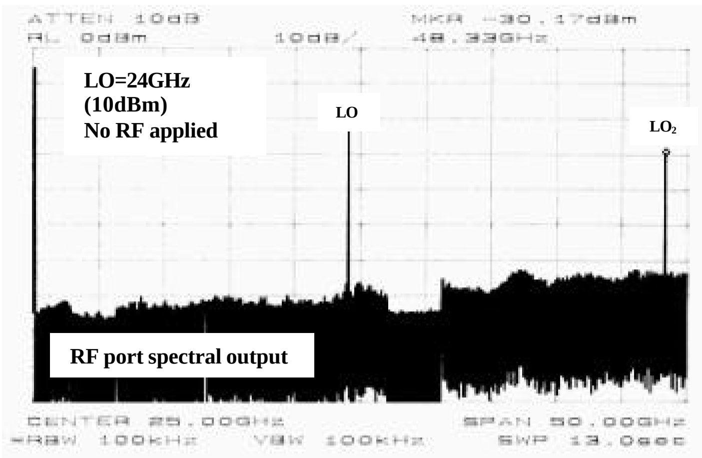

Figure 5. Fundamental and 2nd harmonic LO leakage from RF port.

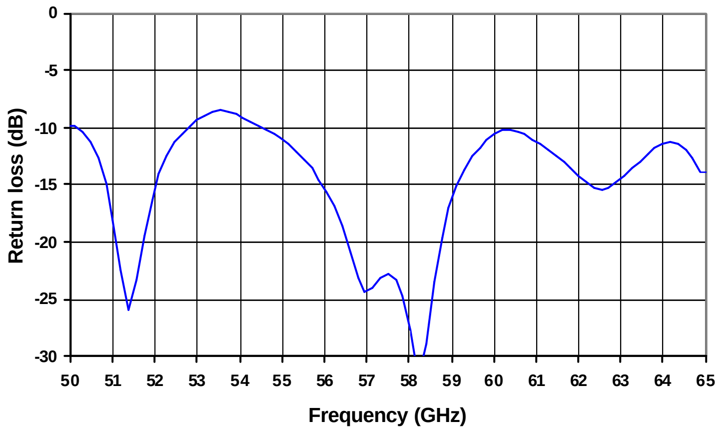

Figure 6. Measured RF port return loss

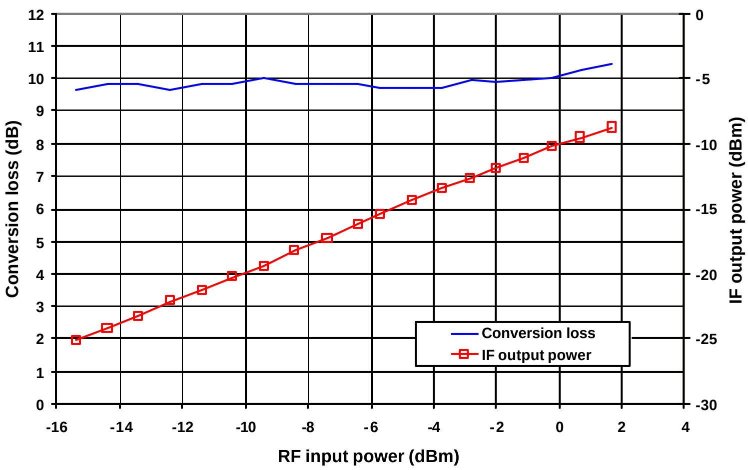

Figure 7. Compression performance in down convert mode

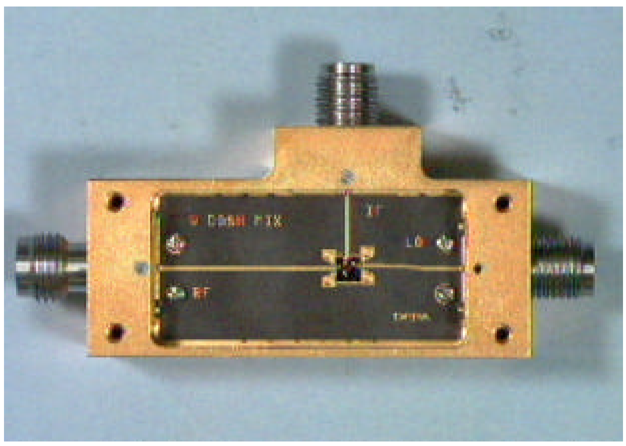

Figure 8. Photograph of mixer in coaxial test fixture