A 40 –45 GHz MONOLITHIC GILBERT CELL MIXER

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Introduction

Millimetre-wave mixers are commonly realised using hybrid fabrication techniques, with diodes as the non-linear mixing elements. The main reasons for this are that the modelling issues for the passive hybrids/baluns and the relatively simple diode structures are well characterised and understood. The cost of such mixers can also be very low (Ref. 1). The major disadvantage of diode mixers is the relatively high conversion loss. At microwave frequencies active mixers utilising FET devices are now commonplace, and offer greatly reduced conversion loss, or even gain (Ref. 2). For mm-wave frequencies the Pseudomorphic HEMT Transistor allows similar active circuits to be fabricated, particularly in GaAs Monolithic Microwave Integrated Circuit (MMIC) form. The major advantage of the mm-wave MMIC mixer is that of reproducibility. This is critical at high frequencies where parasitic elements can very easily destroy circuit performance.

The application for the mixer described in this paper is as the downconvert mixer in a mm-wave Broadband Wireless Access Receiver. The design goals were conversion loss less than 6 dB when driven by a reasonable LO power of +10 dBm, and for minimal GaAs chip area, and hence cost.

Design Method

The chosen design configuration was a balanced pHEMT structure as shown in Figure 1. Biasing and RF and LO port matching circuits are not illustrated for simplicity. This type of mixer generally uses a balun on the LO port, and utilises the upper transistors as a switch at the LO frequency (Ref. 3). The lower device operates as an amplifier for the RF signal. In this application the LO balun was eliminated by directly RF grounding the gate of one of the upper transistors. In this configuration the upper devices essentially form a differential amplifier, and the lower device a constant current source. This circuit is now analogous to one half of the well-known Gilbert Cell Multiplier (Ref.. 4).

The Gilbert cell was originally developed for use at low frequencies with bipolar IC processes. It is now the topology used for mixers on the vast majority of RF bipolar ICs. The technique has since been utilised with MOSFETs for example (Ref. 5), and at microwave frequencies using MESFETs. With the advent of the GaAs Heterojunction Bipolar Transistor, the original concept has now been extended to around 20 GHz. To the author's knowledge this is the first time such a technique has been demonstrated using pHEMTs at greater than 40 GHz.

It should be noted that a full mm-wave double-balanced Gilbert cell mixer utilising two differential pairs and baluns at all three ports was seen to be too costly (in terms of GaAs chip area) for commercial applications.

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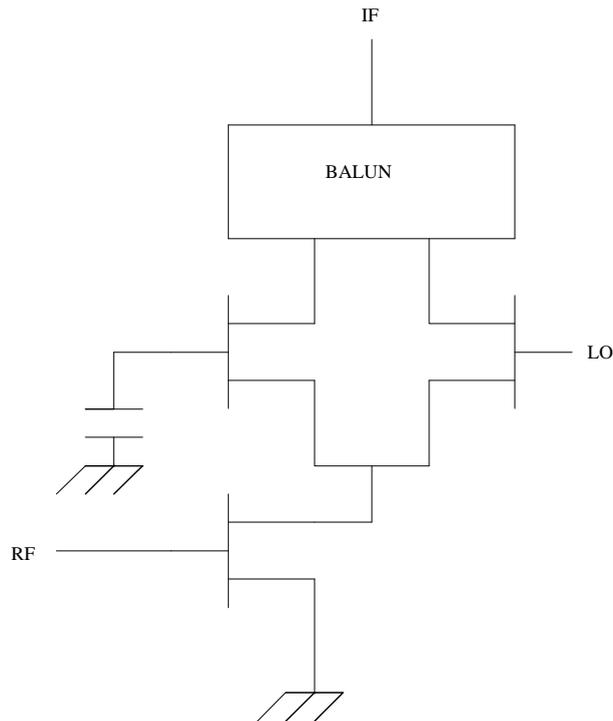
Figure 1: Simplified Mixer Schematic

The mixer was designed on the Marconi Materials Technology (MMT) H40 HEMT foundry process. Simulation was carried out on the HP-EEsof Series IV harmonic balance simulator, using SMART library models supplied by MMT. The circuit was designed as a downconverter for nominally 44 GHz RF and 5.2 GHz fixed IF. The available LO power was nominally set to +10 dBm at 38.8 GHz.

The three transistors in the circuit were chosen to be of equal gate width. A +5 V supply was used, resulting in a Vds of +2.5 V for each stage. The current source was biased to approximately 25% Idss by a negative voltage. This resulted in approximately 12.5% Idss flowing in each one of the mixer pair. This is a suitable bias point (near pinch-off) for non-linear operation. The IF balun was designed as a lumped-element Wilkinson Combiner, preceded by a low-pass/high-pass filter pair. This configuration can be optimised for good amplitude balance and the desired 180° phase difference. The RF and LO signals are correctly terminated (short-circuited) at the IF output by the use of quarter-wavelength radial stubs.

The simulated mixer performance at 44 GHz RF was 3 dB conversion loss, including 0.3 nH bond-wire inductances at each port, which is typical at this frequency. This is illustrated in Figure 2. With bond-wires removed (that is, a prediction of the expected RF-On-Wafer performance), the simulated conversion loss deteriorated to 5.3 dB, as shown in Figure 3. This is because the bond-wires were purposely used to form an integral part of the matching circuit design. The predicted performance against various bond-wire inductances (at 44 GHz RF) is illustrated in Figure 4. It can be seen that conversion loss increases rapidly as the bond-wire inductance gets much above 0.3 nH.
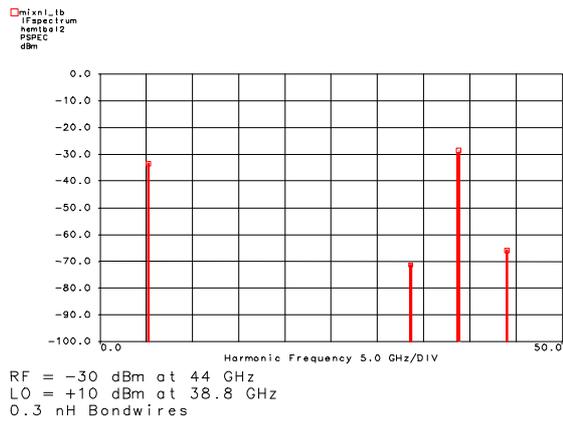
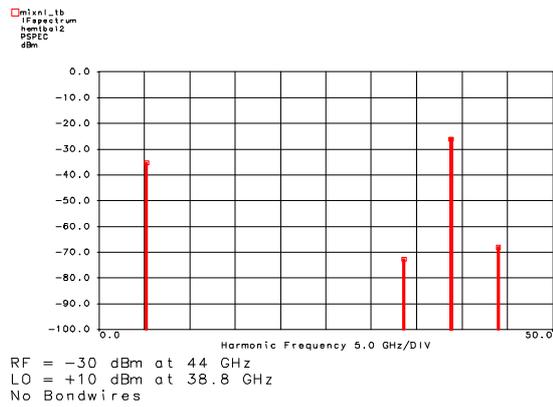**Figure 2: Non-Linear Simulation (0.3 nH Bondwire Inductance)**

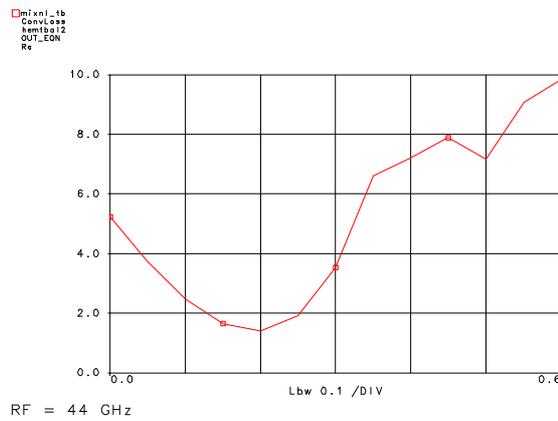**Figure 3: Non-Linear Simulation (No Bondwire Inductance)**

Figure 4: Simulated Conversion Loss (dB) vs. Bondwire Inductance (nH) at 44 GHz

Layout of the mixer was performed to minimise GaAs area. The final active area of the resulting design was 1.65 mm^2. In actual fact the mixer was incorporated on a multi-function/multi-project mask-set, and this size was incompatibly small with other circuits. Transmission line lengths were therefore adjusted to fit a larger cell area, as shown in the photograph of Figure 5.
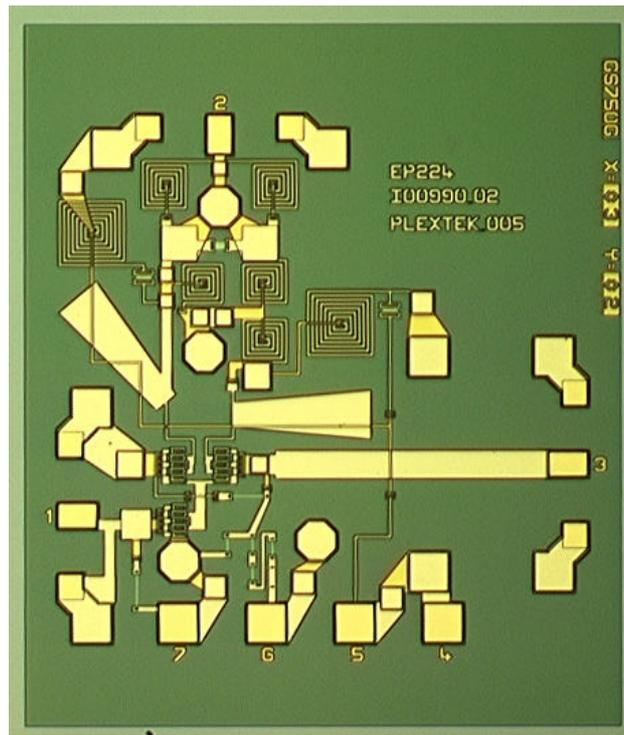

Figure 5: Microphotograph of GaAs Mixer

Practical Results

The mixer was measured RF-On-Wafer at the GaAs foundry. Two high frequency synthesised swept sources were used, and the resulting fixed IF observed on a spectrum analyser. Figure 6 shows the measured conversion loss over the desired RF frequency range of 41 to 44 GHz, for various LO power levels. The conversion loss of 6 dB at 44 GHz and +10 dBm LO power, for example, is in excellent agreement with the aforementioned 5.3 dB simulation. As expected, the performance falls off with lower LO powers. Interestingly, at 41 GHz less than 9 dB loss is achieved with just 0 dBm LO power. A typical diode mixer would require at least +10 dBm to achieve this performance.
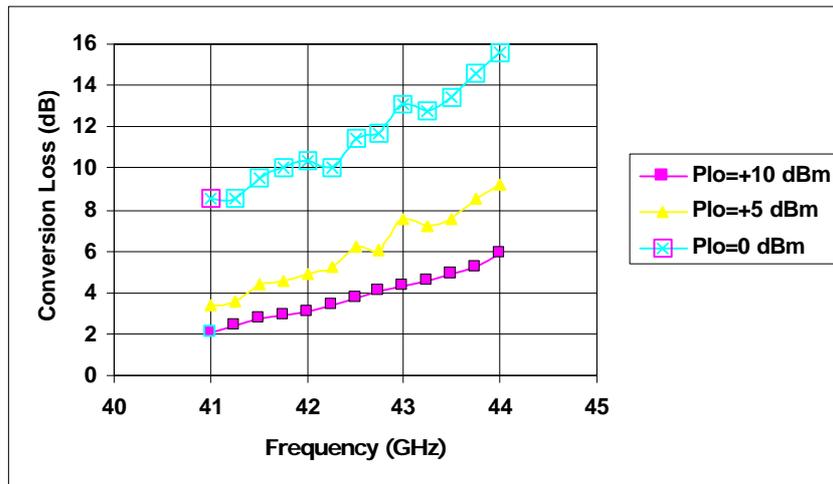
Figure 6: RF-On-Wafer Measured Mixer Result

Figure 7 compares the measured results at the high end of the RF band (44 GHz) with non-linear simulations. The difference varies with LO power, but is typically 2 dB at +3 dBm, and 0.7 dB at +10 dBm.
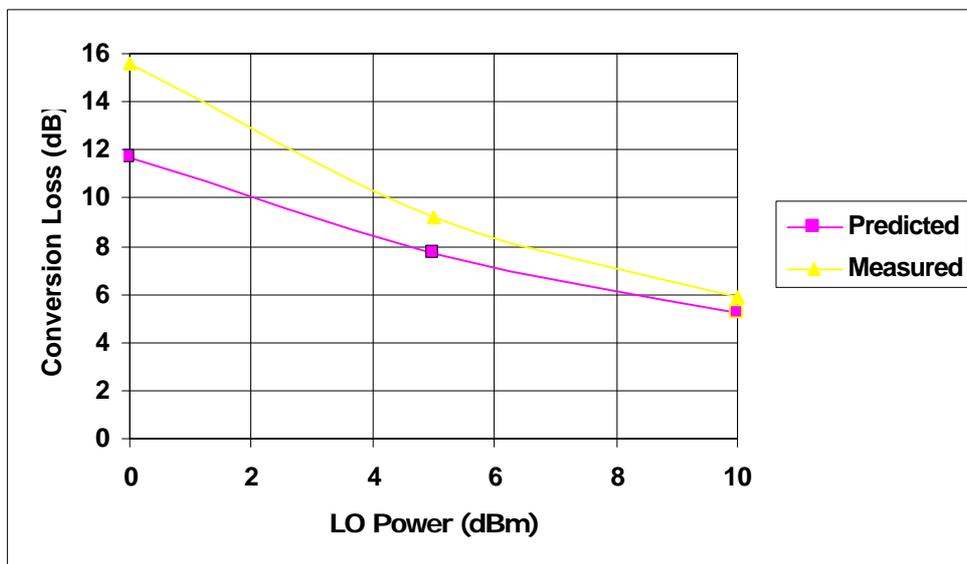

Figure 7: RF-On-Wafer Measured vs. Simulated Mixer Result, at 44 GHz

Conclusions

This work has shown that the Gilbert cell multiplier configuration is readily applicable to mm-wave applications utilising pHEMTs in a monolithic environment. Relatively low conversion losses of approximately 3 dB can be achieved with commonly used LO powers of around +10 dBm. The half-Gilbert cell technique with LO balun eliminated results in very small chip area (1.65 mm^2). This relates directly to very low cost for high volume applications. The simulation of the chip in the bonded environment shows just how crucial the bond-wire inductance is at mm-wave frequencies.

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