A COMPACT X-BAND GaAs MONOLITHIC BALANCED FET MIXER

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ABSTRACT

In this paper, a novel monolithic balanced FET mixer is described, which has a measured conversion gain of 1dB over 5 to 12 GHz. A new circuit technique has been developed which gives both high performance and low complexity. As a result, the mixer is expected to find applications in state-of-the-art monolithic subsystems for communications and radar. The technique employed is to use a passive lumped-element Wilkinson combiner feeding a common-source/common-gate FET pair. The FETs operate as both active balun and mixer elements, giving a very compact balanced mixer. After an exhaustive investigation of MMIC mixers, this new technique is thought to be the optimum blend of active and passive circuitry. As a result, the mixer has the same simplicity and ease-of-use associated with existing double-balanced diode mixers, but in addition has conversion gain and can be directly integrated into MMIC subsystems.

Keywords: Balanced FET Mixers, GaAs MMICs

1. INTRODUCTION

Balanced mixers have proved to be one of the most difficult circuits to realise properly on MMICs, because conventional techniques use non-planar passive baluns or large couplers. A wide variety of possible solutions has been reported, using either FETs or diodes, and with both active and passive baluns. For frequencies up to around 18 GHz, the large size of couplers can be overcome by using lumped-element equivalents [1,2]. More recently, multi-level baluns have been widely reported [3,4] using two overlaid metal layers. FET mixers, and active baluns and combiners have also received considerable attention, particularly for wideband mixers [5,6,7]. Passive diode mixers usually lead to high conversion loss and large chip-size. On the other hand, active techniques can result in compact designs with conversion gain, but they are often over-complex, highly sensitive to the operating conditions, and require many DC bias connections. Hence, there is an optimum combination of active and passive techniques, where the simplicity of passive mixers can be blended with the compactness and potential high performance achievable with active techniques. In this paper, an X-band monolithic mixer design is introduced which aims to achieve this happy medium. The technique employed is to use a lumped-element Wilkinson RF-LO combiner feeding a pair of balanced mixer FETs.

2. CIRCUIT DESCRIPTION

In this circuit, the active balun and mixing functions are neatly integrated into the same devices. A pair of FETs, one in common-source and one in common-gate configuration, achieve both functions. The RF and LO are combined using a lumped-element equivalent of the Wilkinson combiner. The rest of the circuit is simply for DC bias injection and DC blocking. A large spiral inductor at the input serves both to sink the current from the source of the common-gate FET, and to short-circuit the IF at the mixer input. The complete circuit diagram of the mixer (excluding the off-chip IF transformer) is shown in figure 1. The common-gate FET's gate-width is chosen so that the input impedance of the FET pair is close to 50Ω; the common-source FET's gate-width is then chosen so that the LO/RF outputs from each FET are equal (but anti-phase), causing complete cancellation (ideally). Hence, because the common-source configuration has significantly higher gain, the common-source FET's gate-width has to be much smaller. Both FETs are biased near pinch-off and operate in gate-mixer mode. A photograph of the mixer chip is shown in figure 2. This first mixer chip is designed to operate in X-band. The chip was fabricated with the GEC-Marconi (Caswell) standard F20 foundry process, which provides 0.5μm gate-length ion-implanted MESFETs, and through-GaAs via-holes. The chip-size is 1.2x1.5 mm, and there is considerable scope for miniaturisation in a second-design.

3. MEASURED PERFORMANCE

The chip was assembled onto an alumina substrate, and housed in a 1x1" test fixture with SMA connectors. This was necessary because the chip was designed before King's acquired on-wafer test capability. The conversion gain was measured using signal generators and a spectrum analyser. This is found to give very accurate and reliable results. In contrast, considerable care must be taken if gain measurements are made with a noise-figure meter, as the meter does not distinguish between the different output signals sufficiently.

Figure 3 shows the measured conversion gain frequency response (with a swept LO and a fixed IF of 500 MHz) for 10 dBm of LO power. The mixer has 1dB gain, which is exceptionally flat over the 5 to 12 GHz range, and the mixer inputs are well matched to 50Ω as shown in figure 4. The port-to-port isolations are also very good: As shown in figure 5, 20 dB of LO/RF-to-IF isolation is achieved. This is a considerable improvement compared with single-ended FET mixers, which often amplify the LO signal. The measured LO to RF isolation, which is governed by the lumped-element Wilkinson combiner, is shown in figure 6. Over 15dB isolation is achieved over most of the band, but the centre-frequency of the combiner appears to be too high, and a second pass design could easily achieve higher isolation. Alternatively, an active combiner could be used, which would give more gain and high LO-RF isolation. As well as providing port-to-port isolations, balanced mixers are important for the rejection of unwanted signals. The IF output spectrum, from DC to 2 GHz, is shown in figure 7, and unwanted harmonics of the IF are clearly suppressed, being well over 50dB down on the IF. The noise figure of the mixer was measured in a DSB measurement system, using an HP8970 noise figure meter. The measurements are then corrected approximately for SSB noise figure by adding 3dB. This corrected SSB noise figure is plotted in figure 8 for an RF input between 2 and 14 GHz.

The measured two-tone third-order intermodulation characteristics are shown in figure 9, for a 10dBm LO at 8.5 GHz and two RF inputs at 8 GHz, but separated by approximately 4 MHz. The third-order intercept point is found to be at an IF output level of 10dBm. The IF output spectrum, when the mixer is at saturation for the two-tone test, is shown in figure 10. In a single-tone test the 1dB conversion gain compression occurs at an IF output power of 5dBm, and the IF output saturates at well over 5dBm (the RF signal generator ran out of power). These results compare favourably with those achieved with conventional double-balanced diode mixers with the same LO power. In addition, this MMIC mixer could handle more LO power if it were available, and this would improve these results further.

4. CONCLUSIONS

This balanced FET mixer has demonstrated that an optimum combination of active and passive techniques can be used to realise compact and simple balanced MMIC mixers. Unlike many other FET mixers, this mixer is found to be very tolerant to changes in DC bias, LO power, and terminating impedances. This first prototype has achieved 1dB conversion gain with low VSWRs and good port-to-port isolations. Hence it can be used as a reliable function-block in a wide range of applications. The noise figure is quite disappointing: However, a better understanding of the noise mechanisms, and the noise figure analysis of non-linear circuits, are actively being pursued by many researchers, and so improvements in this performance are expected.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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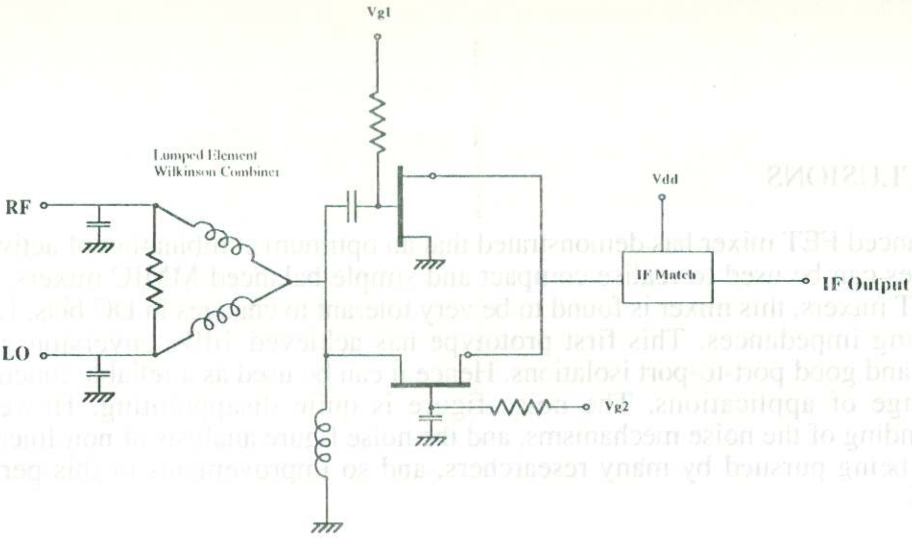

Figure 1. Mixer Circuit Diagram

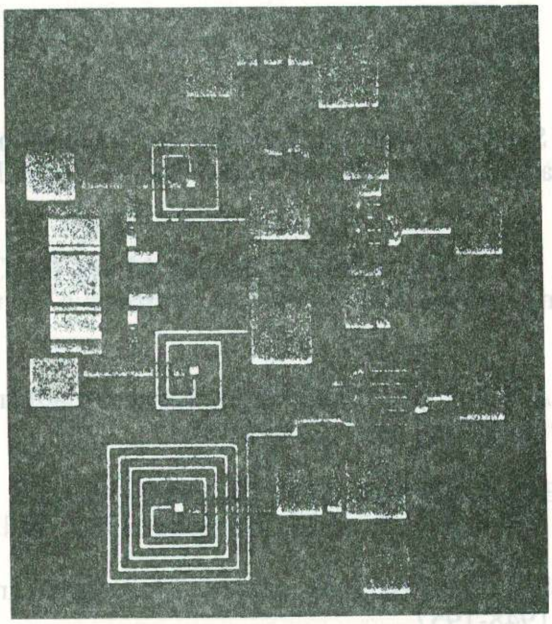

Figure 2. Photograph of the Mixer Chip

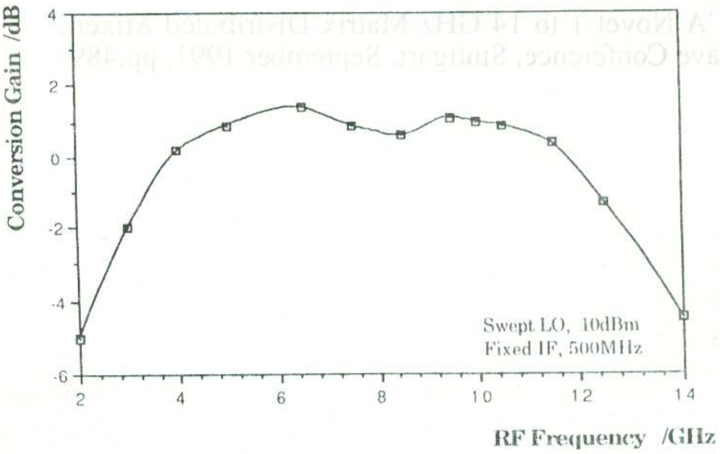

Figure 3. Measured Conversion Gain

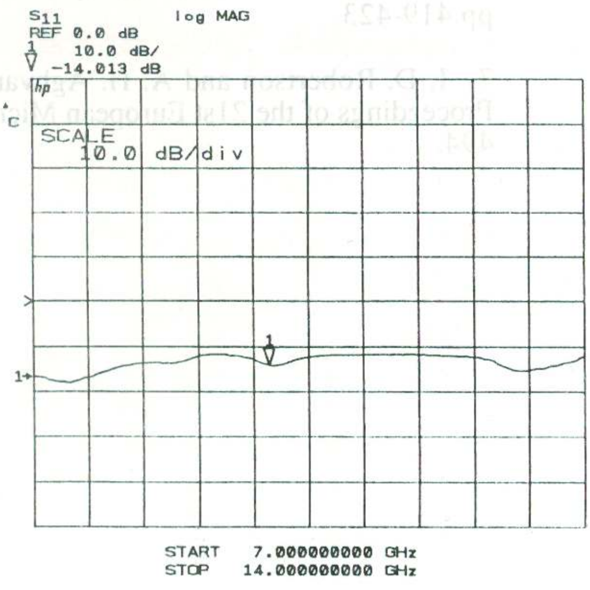

Figure 4. RF Input Match

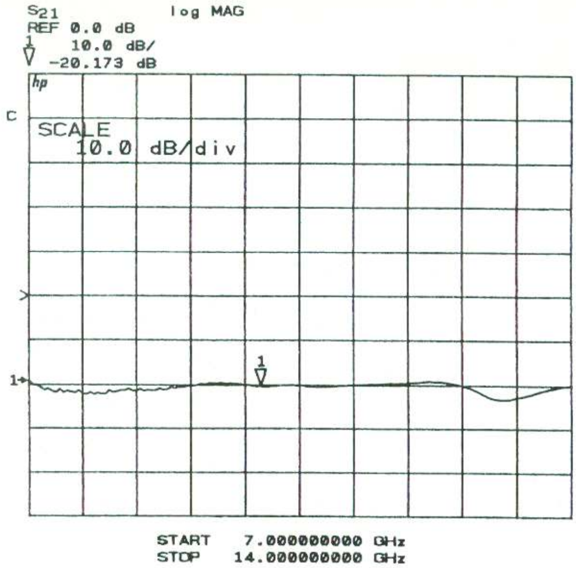

Figure 5. LO to IF Port Isolation

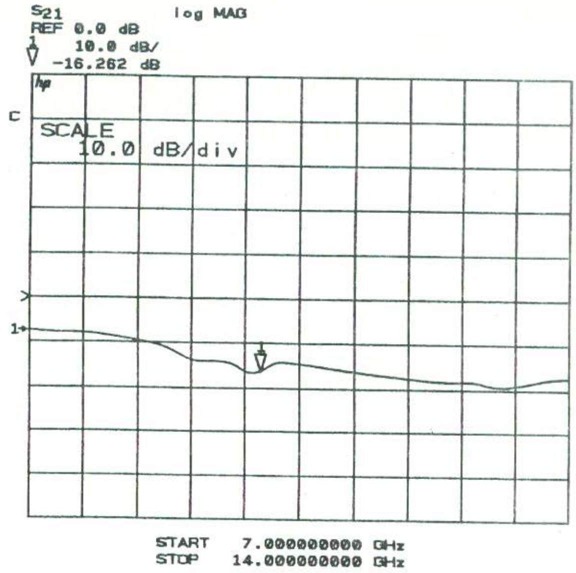

Figure 6. LO to RF Port Isolation

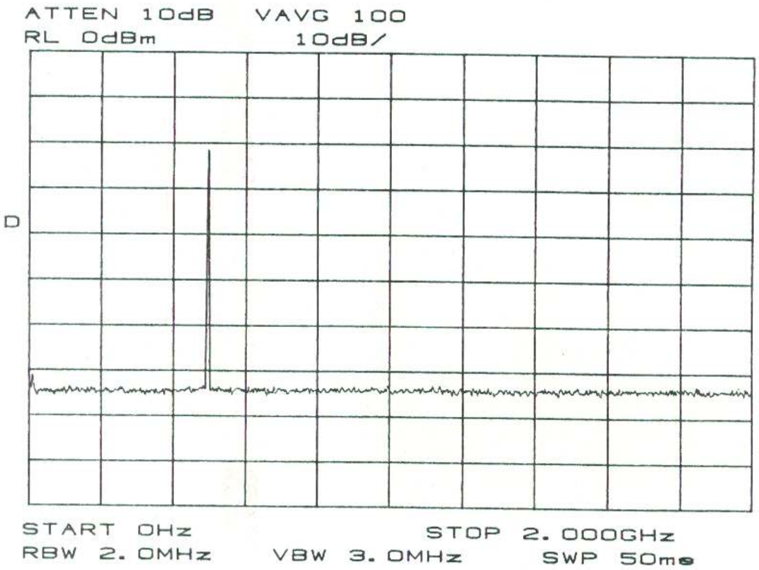

Figure 7. IF Output Spectrum

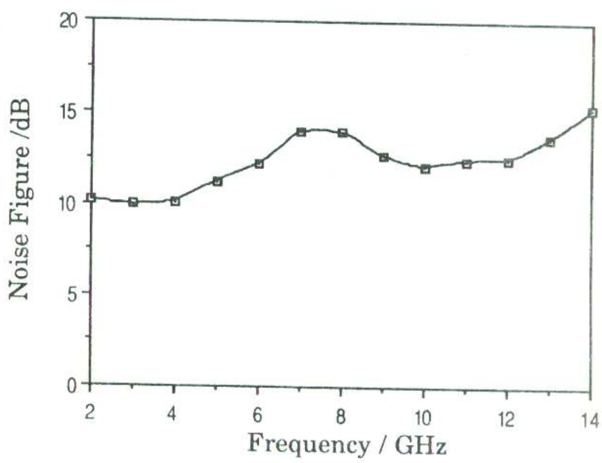

Figure 8. Mixer Noise Figure: Corrected for SSB, 500 MHz IF

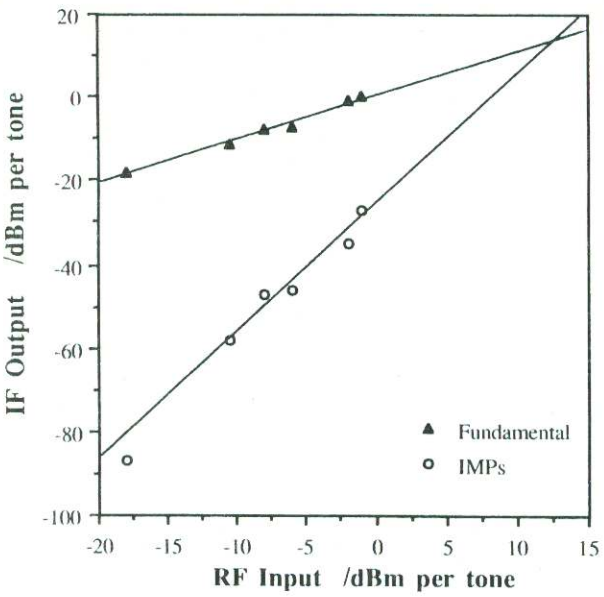

Figure 9. Two-Tone Intermodulation Characteristic

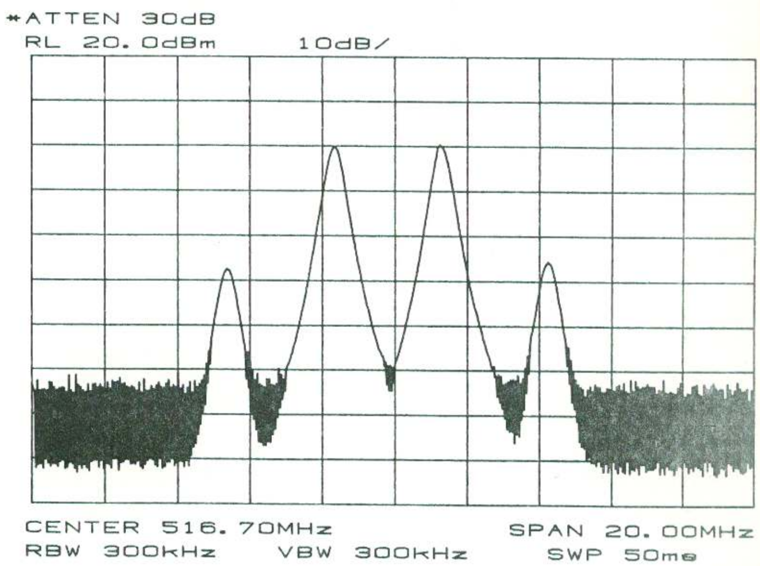

Figure 10. IF Output Spectrum at Saturation for two-tone test