A Q-Band Uniplanar MMIC Diode Mixer with Lumped-Element Coplanar Waveguide-to-Slotline Transition

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***Abstract* — A uniplanar GaAs MMIC diode mixer is fabricated for Q-band applications using the lumped-element coplanar waveguide-to-slotline transition to implement the required 180° hybrid. By adopting the lumped-element transition, the mixer chip size can be largely reduced with an excellent RF-to-IF isolation. This mixer is designed to operate with RF frequency from 34.5 to 43 GHz, IF frequency from 0.5 to 9 GHz, and LO frequency at 34 GHz. The lower sideband conversion loss is about 7 dB, and the isolations are all better than 20 dB. To our best knowledge, it is the first MMIC with such transition topology in Q-band.**

I. INTRODUCTION

The uniplanar structure has the merits of requiring no via holes and easy connection to the active devices, and it also allows for both shunt and series connections of circuit elements. Furthermore, it has more flexibility in using mixed transmission lines such as coplanar waveguide (CPW), slotline, and coplanar stripline. By taking advantage of these features, a broadband uniplanar 180° hybrid can be realized by suitably combining the slotline and the CPW line.

Several uniplanar mixers have been reported based on such a broadband 180° hybrid [1]-[4]. These mixers contain a CPW-to-slotline transition and a slotline-to-CPW junction both of which may be served as a 180° hybrid to convert the in-phase CPW mode to the out-of-phase coupled-slotline (CSL) mode. The series diode pair is located between the slotline and a quarter-wavelength CPW line. Besides, a diplexer is needed to separate the IF signal from the other signal. Conventionally, the diplexer may be realized by combining both a band-pass filter (BPF) and a low-pass filter (LPF). For such kind of mixers [1]-[3], their operating bandwidth and size are usually limited by the CPW-to-slotline transition.

For the mixer in [1], the hybrid includes CPW-to-slotline transition, tapered slotline, and CPW-to-slotline junction, and the transition uses a slotline-radial-open as a resonant circuit. The hybrids in [2] and [3] are implemented by the double-Y junction transition. All the transitions described above occupy large circuit area and lead to the inefficient use of high-cost substrate and active layers. The twin-spiral CPW-to-slotline transition [5] may be adopted to design a mixer so that 1/4 the size of conventional transitions can be achieved, but a full-wave simulation is needed in part to characterize the transition performance.

In this study, a reduced-size uniplanar diode mixer is developed by adopting the lumped-element CPW-to-slotline transition [6] to implement the 180° hybrid. Therefore, the transition size may largely be reduced, and the transition passband frequency and bandwidth can be predicted and adjusted by the closed-form expressions and simple equivalent-circuit models. Furthermore, to make the mixer more compact, the diplexer and the quarter-wavelength CPW line in the conventional mixer circuit may properly be combined, by making use of the independence nature between the CPW mode and the CSL mode.

II. MIXER CIRCUIT

The proposed uniplanar mixer design is based on the 3" 0.15-μm AlGaAs/InGaAs/GaAs PHEMT MMIC process on 4-mil substrate provided by TRW. This process employs a hybrid lithographic approach using direct-write electron beam lithography for the sub-micron gate definition and optical lithography for the other steps. The diode is realized by connecting the drain and source pads of a HEMT device to form the cathode. In this process, plated air-bridge interconnects are allowed for crossovers, and fabrication of MIM silicon nitride capacitors, via-holes, spiral inductors, and thin film resistors is available.

The configuration of the proposed MMIC uniplanar mixer is shown in Fig. 1. The primary parts of the circuit include the lumped-element CPW-to-slotline transition, the slotline-to-CPW junction, the modified diplexer, and

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two match circuits used to optimize the LO return loss and the conversion loss [7]. Further details are provided below.

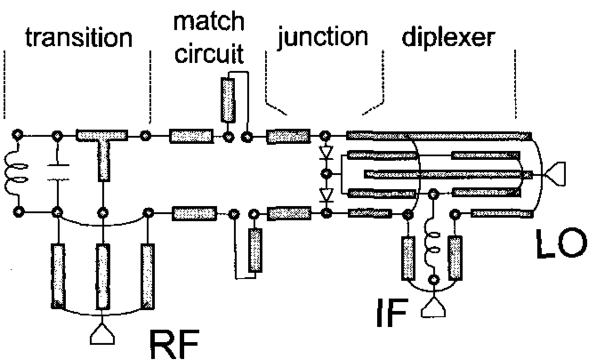

Fig. 1. The configuration of the MMIC uniplanar mixer.

A. Lumped-element CPW-to-slotline transition

To reduce the transition size, a parallel LC resonant circuit composed of an interdigital capacitor and a shorted slotline stub is utilized to replace the conventional $\lambda/4$ transformer structure [6]. It gives an effective open termination at the frequency $f_C = 1/\sqrt{2\pi LC}$ which determines the center frequency of the transition passband. The back-to-back structure is used to measure the performance of the CPW-to-slotline transition. The length of the slotline between two transitions is 300 μm. The transition size is obviously smaller than the conventional $\lambda/4$ slotline-short-stub transition whose length is about 760 μm.

To avoid exciting the parallel-plate mode in measurement and package, the transition is mounted on a 16-mil thick GaAs wafer to increase the impedance of the parallel-plate mode [8]. Thus the effective substrate thickness of the transition is 500 μm. The simulated and measured results for the back-to-back transition structure are shown in Fig. 2. The simulated results are obtained using the full-wave MPIE technique [4]. The insertion loss is 1.5 dB for the back-to-back transition from 25 to 50 GHz frequency range.

To investigate the influence of the parallel-plate mode, the transition structure without and with backside metal are tested. The measured return losses and insertion losses are shown in Fig. 3. It reveals that the influence of the parallel-plate mode can be neglected while a thick substrate is employed.

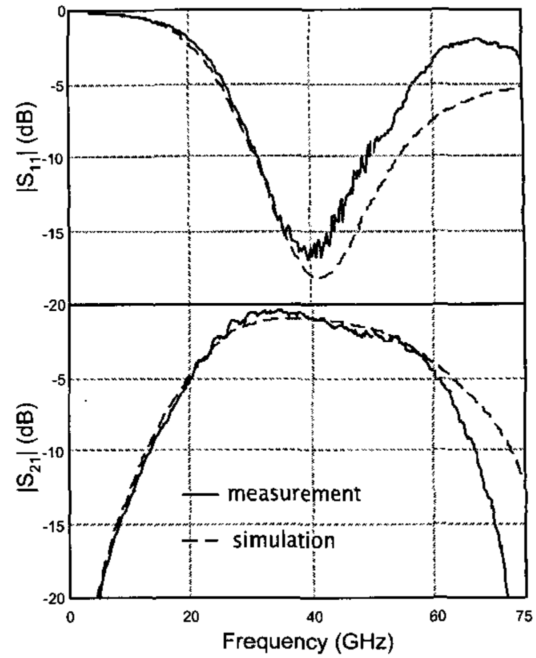

Fig. 2. Measured and simulated results for the back-to-back lumped-element CPW-to-slotline transition.

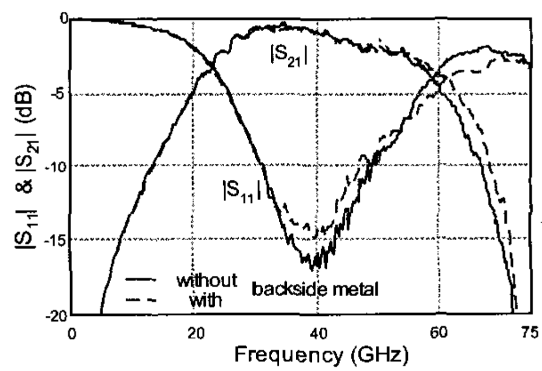

Fig. 3. Measured results for the back-to-back lumped-element CPW-to-slotline transition without and with backside metal.

B. Modified diplexer

Fig. 4 shows the geometry of the modified diplexer. The band-pass filter for the LO signal (CPW mode) is realized by the quarter-wavelength CPW coupled line structure. It should be noted that part of the CPW coupled line section between the series diode pair and the airbridge A_1 can also be served as the impedance transformer for the RF signal (CSL mode). This impedance transformer can be used to optimize the return loss of the RF port, and it can also achieve better transfer of power from the RF port to the series diode pair. The lengths of the CPW coupled line and the transformer are different. Specifically, the length l_1 of the CPW coupled line is around the quarter-wavelength of the LO signal (CPW mode), and the length l_2 of the transformer is decided by the propagation constant of the RF signal (CSL mode) and the parasitic effect of the airbridge A_1.

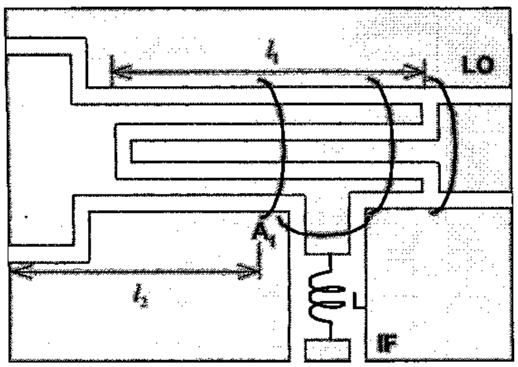

Fig. 4. The geometry of the modified diplexer.

C. Uniplanar mixer

Two-finger 16 μm diodes are selected for the mixer design. A match network instead of a taper slotline is included between the transition and the slotline-to-CPW junction to improve the conversion loss of the mixer. The impedance transformer here is implemented by the stepped impedance line, which gives more compact size than the uniform line, and then combined with the diplexer. The low-pass filter is designed just using an inductor and the LO match network is also included in the mixer. The microphotograph of the MMIC uniplanar mixer is shown in Fig. 5.

III. RESULTS

Shown in Figs. 6(a)-(d) are the simulated and measured results for the diode mixer shown in Fig. 5. The mixer is measured by mounting it on a 16-mil thick GaAs wafer. This mixer exhibits a conversion loss of 6.5-8.0 dB for an LO signal of 10 dBm when the RF is swept from 34.5 to 43 GHz, and the best is at 40 GHz. The conversion loss begins to saturate around 8 dBm LO input power and changes very little above 10 dBm. The simulated results are predicted by the full-wave MPIE technique [4]. Fig. 6(d) shows the LO-to-IF and RF-to-IF isolations versus RF frequency. All of them are better than 20dB. The measured IP3 calculated from the inter-modulation curve shown in Fig. 7 is about 15 dBm at f_{RF}=38 GHz.

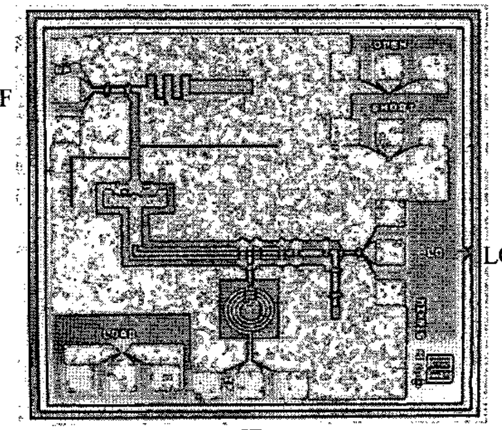

Fig. 5. The microphotograph of the MMIC uniplanar mixer with a chip size of 1.5 x 1.5 mm^2.

IV. CONCLUSION

A Q-band uniplarar singly balanced diode mixer has been implemented. By using the lumped-element CPW-to-slotline transition and suitably modifying the diplexer, the mixer size may be drastically reduced. The conversion loss of this mixer is around 7 dB for the RF frequency from 34.5 to 43 GHz while LO frequency is 34 GHz. The isolations are all better than 20 dB. Furthermore, the isolation between RF and IF is very good due to the use of the broadband uniplanar 180° hybrid.

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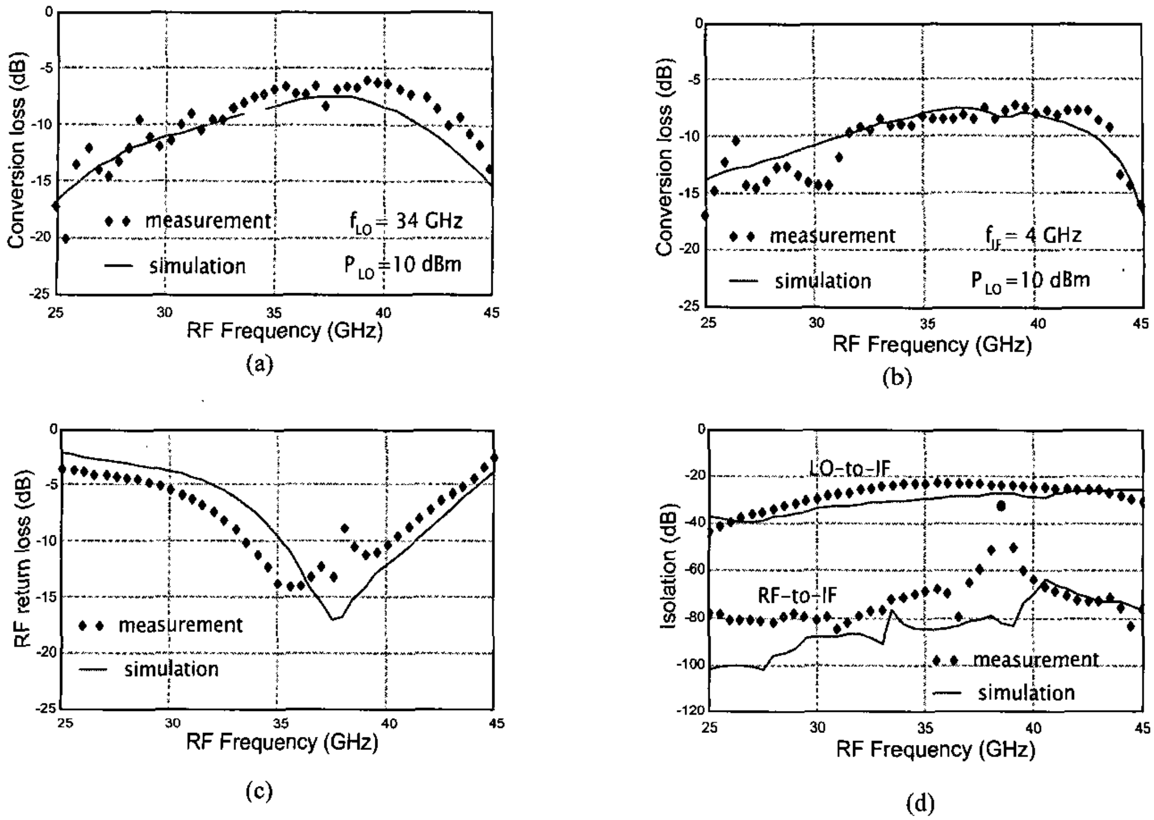

Fig. 6. Simulated and measured results for the mixer (Fig. 5): (a), (b) conversion loss, (c) return loss, and (d) RF-to-IF and LO-to-IF isolations.

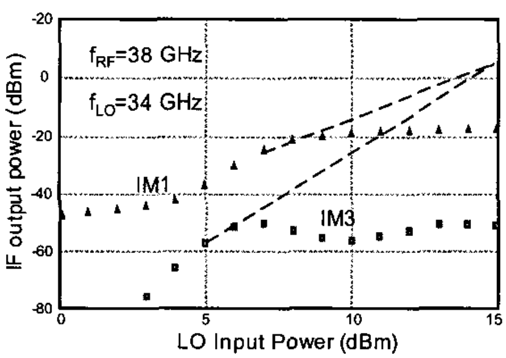

Fig. 7. Measured inter-modulation curve.