# A Q-Band Miniaturized Uniplanar MMIC HEMT Mixer

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***Abstract*** **— A miniaturized uniplanar GaAs MMIC HEMT mixer is proposed based on a compact multifunction transition structure. By the independence nature of the coplanar-wavguide (CPW) mode and the coplanar-stripline (CPS) mode, a novel compact transition which converts the CPW mode into the CPS mode is realized. This transition structure also has the functions of 180° hybrid, RF and LO diplexer, and bandpass filter. Thus the size of the proposed mixer may be drastically reduced, and the LO-to-IF and LO-to-RF isolations and RF conversion gain are excellent. This mixer is designed to operate with RF frequency from 35 to 40 GHz, IF frequency from 0.5 to 6 GHz, and LO frequency at 35 GHz. The lower sideband conversion gain is about 5 dB, the single-sideband (SSB) noise figure is 6.5 dB, the isolations are all better than 30 dB, and the size of the mixer is much compact than those of the conventional mixers.**

***Index Terms — Mixer, uniplanar, transition.***

## I. INTRODUCTION

The uniplanar structure has the merits of 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 (SL), and coplanar stripline (CPS). By taking advantage of these features, a broadband uniplanar 180° hybrid can be realized by suitably combining the CPW line with the slotline or coplanar stripline.

Up to now, several uniplanar mixers have been developed based on such a broadband 180° hybrid [1]-[4]. These mixers contain a CPW-to-SL transition and a SL-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 the quarter-wavelength ($\lambda/4$) 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 bandpass filter (BPF) and a lowpass filter (LPF). For such kind of mixers [1]-[4], their sizes are usually limited by the areas associated with the CPW-to-SL transition, the $\lambda/4$ CPW line, and the diplexer.

Recently, a 1-4.5 GHz uniplanar singly-balanced diode mixer [5] was implemented on the PC board, based on a compact multifunction transition structure. This multifunction structure, which has the function of transition, 180° hybrid, diplexer, and $\lambda/4$ transformer, was realized by making full use of the independence nature between CPW mode and CSL mode. In this study, the similar multifunction transition structure together with the MMIC technology is employed to design a novel miniaturized uniplanar singly-balanced HEMT mixer for Q-band applications. Specifically, the multifunction transition is realized by using the spiral inductors, the MIM capacitors, and the finite-ground CPW line. The CPS-to-CPW transition structure, composed of the spiral inductors and the MIM capacitor, features a lowpass frequency response, and is used to implement the IF lowpass filter.

## II. MIXER CIRCUIT

The proposed uniplanar mixer design is based on the 0.15-μm AlGaAs/InGaAs/GaAs PHEMT MMIC process on 4-mil substrate provided by WIN semiconductors. 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 active device of the gate mixer is chosen to give both the linear $g_m$ curve and high maximum stable gain to create high conversion gain. Here a two-finger 100-μm device is used in this mixer. This device exhibits a typical gate-to-drain breakdown voltage of 10 V, peak dc transconductance of 495 mS/mm, maximum current of 650 mA/mm, unit current gain frequency of 85 GHz and maximum oscillation frequency of greater than 200 GHz at 4-V drain bias. In this process, plated air-bridge interconnects for crossovers are provided, and fabrications of MIM silicon nitride capacitors, via-holes, spiral inductors, and thin film resistors are available.

The pHEMT device is modeled by the EEHEMT Large Signal Model which is scalable with respect to the unit gate width and number of finger. By using this model, one can specify any gate width from 50 μm to 100 μm. Even

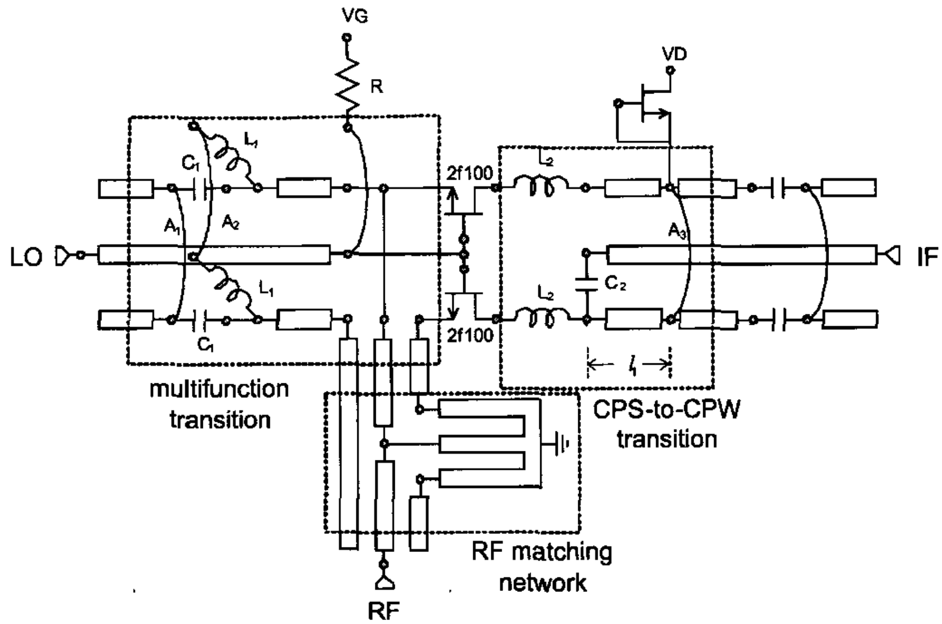


Fig. 1. Schematic of miniaturized uniplanar gate mixer.

number of finger is acceptable. The detail parameters of the EEHEMT model are described in [6]

The configuration of the proposed MMIC HEMT uniplanar mixer is shown in Fig. 1, which includes the multifunction transition, the lumped-element CPS-to-CPW transition, bias networks, and matching network to optimize the RF return loss, noise figure, and the conversion gain [7]. The primary parts of the multifunction transition structure include the lumped-element CPW-to-CPS transition, the BPF for LO port, and the CPS-to-CPW junction. Further details are provided below.

*A. Multifunction transition structure*

The resonant circuit of the multifunction transition consists of $C_1$, $L_1$, and airbridges $A_1$, $A_2$. To reduce the transition size, the lumped-element LC resonant circuit composed of the MIM capacitors and the spiral inductors is utilized to replace the conventional $\lambda/4$ transformer structure [8], [9]. This LC circuit gives an effective open termination at the frequency $f_C = 1/\sqrt{2\pi LC}$ which determines the center frequency of the transition passband. Unlike the diode mixer, the LO port and RF port in the gate mixer need to be located at the same side. Thus the resonant circuit should behave like a shunt LC circuit when it is operated at CPS mode and should have a bandpass behavior when it is operated at CPW mode. For the RF signal the corresponding equivalent circuit is shown in Fig. 2(a), and the multifunction transition is employed to transfer the CPW mode of the RF signal to the CPS mode. The resonant circuit is operated at CPS mode and is realized by shunting two series MIM capacitors $C_1$ and two series spiral inductors $L_1$. The airbridges $A_1$, $A_2$ are equivalent to two series inductances in this mode. For the LO signal (CPW mode) the corresponding equivalent circuit is shown in Fig. 2(b), and the bandpass filter is established by two shunt MIM capacitors $C_1$ and two uniform CPW lines, which are

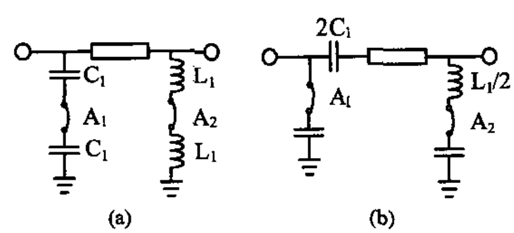


Fig. 2. Equivalent circuits of the resonant circuit operated at (a) CPS mode and (b) CPW mode.

treated as the inductive elements and connected to the capacitor $C_1$ in series. By the independence nature of the CPW mode and CPS mode, two spiral inductors $L_1$ have very little influence on the transition performance.

The transition size is obviously smaller than the conventional $\lambda/4$ slotline-shorted-stub transition whose length is about 760 μm.

### *B. Lumped-element CPS-to-CPW transition*

Since the IF output is an out-of-phase signal, another transition which converts CPS mode into CPW mode is needed. This transition is composed of the MIM capacitor $C_2$, spiral inductors $L_2$, uniform finite-ground CPW line, and the airbridge $A_3$. In addition to producing mode conversion, it also has the lowpass behavior to separate the LO signal (CPW mode) and the RF signal (CPS mode) from the IF signal.

### *C. Uniplanar gate mixer*

Two-finger 100 μm HEMTs are selected for the mixer design. The 180° hybrid is realized by using the multifunction transition described above. By this transition, the RF signal (CPW mode) can convert into the CPS mode. At the same time, the bandpass behavior of the resonant circuit to the CPW mode can separate the LO signal from the IF signal. For bandwidth consideration, the passband of the transition between CPW mode and CPS mode is designed around 38 GHz, and the passband of the LO bandpass filter is around 35GHz. In practice, the CPW line with the airbridge $A_1$ is still not enough to suppress the CPS mode signal completely. It still has a little leakage that can propagate through the airbridge and is suppressed by the GSG RF probe. This leakage affects the transition bandwidth for the RF signal and the isolation between the RF and LO ports. And it is not easy to predict the leakage phenomenon at higher frequency. The matching network at the RF port is realized by a shunt shorted-stub, which can improve the RF return loss and noise performance. The bandpass filter is also designed to have a good return loss at LO port to decrease the LO input power.

The photograph of this HEMT mixer is shown in Fig. 3. The total chip size is 1mm x 1mm. The active load is used as a drain bias network to avoid the IF signal leaking to the power supply. The gate bias is supplied by a series resistor. The bias conditions for the mixer are $V_d$=3 V, and $I_d$=11 mA. For this circuit, it is not enough to model the transition by the conventional equivalent transmission-line circuit model which does not include the discontinuity effect across the transition. The CPW mode-to-CPS mode transition is simulated by Sonnet. And the harmonic balanced method is then used to analyze the nonlinear behavior. The full-wave analysis tool is also used in the simulation of the RF matching network, the IF lowpass transition, and the bias networks. Their parasitic discontinuity effects cannot be neglected due to the non-uniform structure. Thus the simple equivalent transmission-line circuit models are not adequate in dealing with the filter circuits.

## III. RESULTS

The mixer is measured, using the on-wafer probing technique. To avoid exciting the parallel-plate mode in measurement and package, the chip is mounted on a 10-mm thick Styrofoam broad, whose dielectric constant is about unity, to increase the impedance of the parallel-plate mode [10].

The measured conversion gain is shown in Fig. 4(a). It exhibits a conversion gain of 4-5 dB for an LO signal of 3dBm when the RF signal is swept from 35 to 40 GHz. Shown in Figs. 4(b) and 4(c) are the measured isolations and RF return losses of the mixer. The RF return loss is better than 10 dB when the RF signal is swept from 36 to 40 GHz. The high LO-to-IF and LO-to-RF isolations shown in Fig. 4(b) are due to the independence nature between CPW mode and CSL mode. All of the isolations are better than 30 dB. The measured SSB noise shown in Fig. 4(d) is about 6.5 dB at $f_{RF}$=38 GHz.

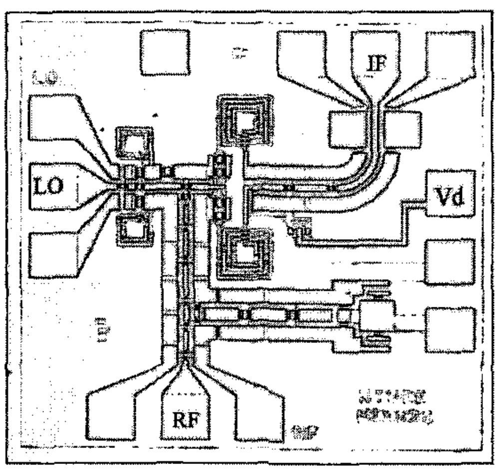


Fig. 3. Microphotograph of the uniplanar MMIC HEMT mixer with a chip size of 1.0 x 1.0 $mm^2$.

## IV. Conclusion

In this study, a novel miniaturized uniplanar singly-balanced MMIC HEMT mixer has been implemented. The proposed mixer has a simple architecture and is easy to fabricate. By suitably designing the novel compact multifunction transition structure to possess the functions of transition, hybrid, $\lambda/4$ transformer, and diplexer for RF and IF ports, the proposed uniplanar mixer can achieve a more compact size comparing with the previously developed uniplanar singly-balanced mixer [4].

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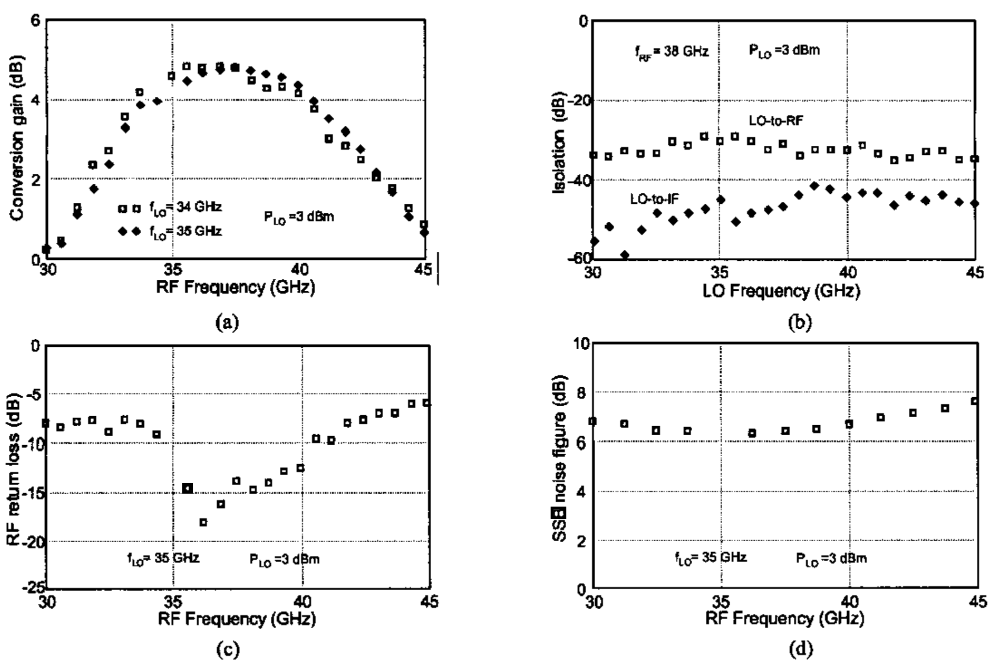


Fig. 4. Measured results for the proposed mixer (Fig. 3): (a) conversion gain, (b) LO-to-IF and LO-to-RF isolations, (c) RF return loss, and (d) SSB noise figure.