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Design and Implementation of a Single Bias FET Source Mixer

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Abstract

A new type of FET source mixer with a single bias voltage has been presented. It is designed to operate at Vds=0 [V] with only one positive supply voltage, which makes mixer circuits simple. The proposed mixer has shown improved stability and less sensitivity to both bias and LO power compared with conventional active mixers. It also shows lower conversion loss than that of diode mixers. The minimum conversion loss measured at RF frequency of 5.6GHz is 0.6dB for a LO frequency of 5.8GHz.

I. Introduction

Mixers are essential in all system applications that require frequency conversion. In order to perform frequency conversion, typical mixers have been implemented by using the nonlinear voltage-current response of Schottky diodes. Diode-based mixers exhibit conversion loss *ranging from ~3dB for image enhanced mixers to* ~10dB for mixers with high IMD performance.

More recently, MESFETs are being used as a nonlinear element in mixers-primarily for reasons of compatibility with MMIC processing and achieving high conversion gain. Active FET mixers have both advantages and disadvantages, compared with diode mixers. Most significantly, active mixers have conversion gain while diode and other passive mixers always exhibit loss.

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The single-gate active FET mixers are generally categorized into one of three topologies: (1)gate, (2)drain, and (3) source mixers. In the case of the gate mixer, both LO and RF signals are applied to the gate while the IF is extracted from the drain terminal. Since a coupler with a high coupling ratio is used to provide RF and LO signal isolation, a high LO power level is required. The FET is biased near pinch-off so that the applied LO signal can modulate the transconductance of the FET over a highly nonlinear operating regime. For the drain mixer, on the other hand, the LO and RF signals are applied to the drain and the gate, respectively, while the IF signal is extracted from the drain. This mixer operates with the FET drain-source voltage set near the knee between the linear and saturated regions of the I-V curve with a negative gate source bias.

In a source FET mixer, the LO and RF signals are fed into the source and the gate, respectively, while the IF signal is extracted from the drain. This topology allows a reduced level of the LO signal at the IF port and provides a modest degree of LO-to-RF isolation. Since the source FET mixer does not require a coupler or combiner, it is a simple structure compared with other mixer topologies [2]. However, this configuration requires careful bypassing technique in the source for the IF frequency in order to suppress instability. This mixer is also known to show lower conversion gain compared with that of the gate-driven mixer [3].

Conventional FET source mixers are biased at the pinch-off region. And the pinch-off voltage is modulated with the drain-source voltage(V_{ds}), which is known as the ***soft pinch-off*** phenomenon. Thus the active mixers are known to show unstable operation [4]. However, both stability and sensitivity to the bias should be considered in order to make high performance active mixers.

In this paper, we report a new type of FET source mixer biased at V_{ds}=0 [V] with both simple configuration and improved stability. We also comparatively report the stability and the sensitivity of a conventional FET source mixer, which is biased at the active region, to the bias. HP-Avantek ATF 10136 GaAs MESFETs were used in the implementation of mixer circuits and HP-EEsof Libra 6.0 was used in simulation.

II. Operating Principle of Fet Source Mixers

A typical topology for a single-gate FET source mixer is shown in Fig. 1. The LO power injected to the source terminal of the FET modulates both the gate voltage(V_{gs}) and the drain voltage(V_{ds}) simultaneously. Therefore, the operating point of the FET source mixer moves in the I-V characteristic curves as shown in Fig. 2.

Curve a in Fig. 2 explains the operation of the conventional FET source mixer, which is biased at the active region. **Curve b** shows the operation of the proposed FET source mixer whose drain-to-source voltage is fixed at ground(V_{ds}=0 [V]). Compared with **curve a** for the conventional source mixer, **curve b** for the proposed configuration requires higher LO power in order to obtain the same conversion gain. Another case of the source mixer, as shown in curve c, has both V_{gs} and V_{ds} biased at 0 [V]. This configuration doesn't have a conversion gain and thus is of no use.

We implemented two types of source mixers; one for **curve a** and the other for **curve b**. We compared the stability and the sensitivity to the bias and LO power for these two different source mixer configurations.

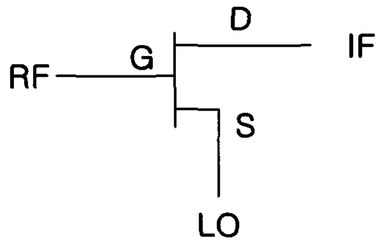


Fig. 1. A Topology of the FET Source Mixer.

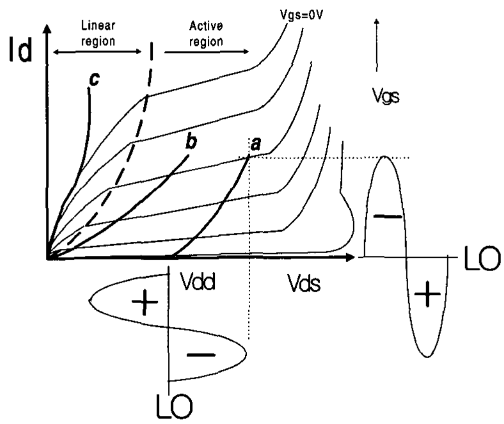


Fig. 2. Bias Curves of FET Source Mixers.
curve a : Active Biased Source Mixer.
curve b : Proposed Source Mixer (V_{ds}=0 [V]).
curve c : Source Mixer with V_{ds}=V_{gs}=0 [V].

III. Implementation of Mixer Circuits

We implemented two types of source mixers. One shows the mixer's operation according to curve **a**, and the other to curve **b** in Fig. 2.

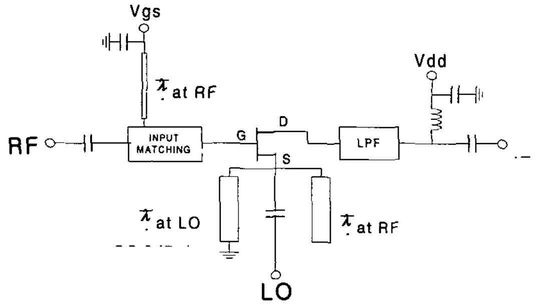
Fig. 3 shows the circuit diagrams of two types of source mixers; Fig. 3(a) is for a conventional type biased at the active region and Fig. 3(b) is for the proposed source mixer with V_{ds}=0 [V].

A significant difference between these circuits can be found in the source and the gate terminals. The gate terminal of the FET is open and the source terminal is short for DC in the conventional source mixer. It also operates in the active region of the FET characteristic curves.

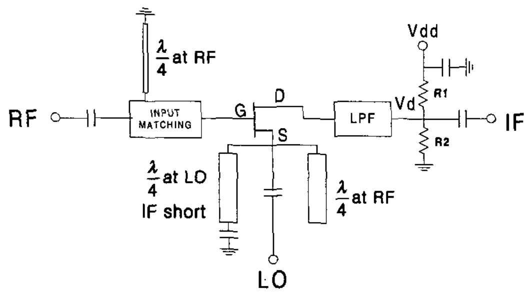
In the case of the proposed source mixer, the gate terminal is short and the source terminal is floated for the DC bias, which set the drain-to-source voltage at zero (V_{ds}=0 [V]). Considering the drain bias feeding through resistors R1 and R2 from V_{dd}, the gate to source bias would be at the pinch-off condition, if the drain-to-ground voltage is equal to the absolute value of the pinch off (V_{ds}= | Vp |). In this manner, the circuit is expected to successfully operate as a source mixer. The proposed source mixer, therefore, requires only one supply voltage which makes the mixer circuit simple. The simulated results of these circuits are shown in Table 1.

Table 1. Simulation Results of Source Mixers.

	Conventional Source Mixer	Proposed Source Mixer (V_{ds}=0[V])
RF	5.6GHz	
LO	5.8GHz(0dBm)	5.8GHz(10dBm)
IF	200MHz	
C.G	>10dB	1dB



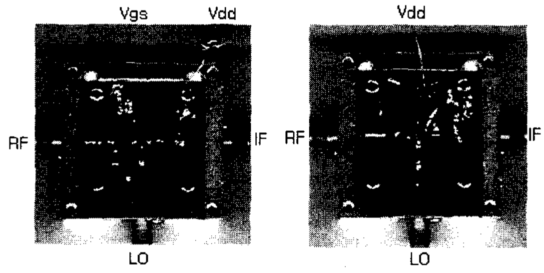
(a)



(b)

Fig. 3. Circuits diagrams of Source Mixers.
(a) Conventional Source Mixer.
(b) Proposed Source Mixer with V_{ds}=0[V].

As shown in Fig. 4, conventional and proposed FET source mixers are fabricated on teflon substrates with ε_r=2.52 and t=0.508mm., where t is the substrate thickness.



(a) (b)

Fig. 4. Fabricated Mixers. (a) Conventional FET Source Mixer. (b) Proposed FET Source Mixer.

Ⅳ. Experimental Results

In this section, we experimentally analyzed the sensitivity and the stability of a conventional type of source mixer to the bias and the LO power. We also comparatively reported the performance of the proposed source mixer(V_{ds}=0 [V]).

The conversion gains of the conventional source mixer are shown in Fig. 5 as a function of the bias and LO power. The dotted circle and arrow in Fig. 5(a) explain that V_{gs} for obtaining the highst conversion gain is a function of V_{ds}. This is due to the ***Soft Pinch off*** phenomenon [4] which forces pinch-off voltage and maximum conversion gain point changes with drain voltage in the active region.

FET mixer operation is dependent on the variation of transconductance with gate-to-source voltage.[1] Because the transconductance has the highest variation at the pinch off voltage, mixers are biased at this point(V_P) to obtain maximum conversion gain. The equations which reveal the relation between conversion gain and transconductance are shown below.[1] [4] [7]

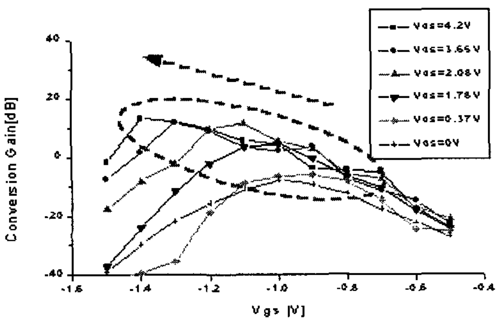
$$G_C = \frac{G_{mMAX}^2 \cdot R_L}{16\omega^2 C_j^2 R_i} \quad (1)$$

$$G_m = \frac{\partial I_d}{\partial V_{gs}} \quad (2)$$

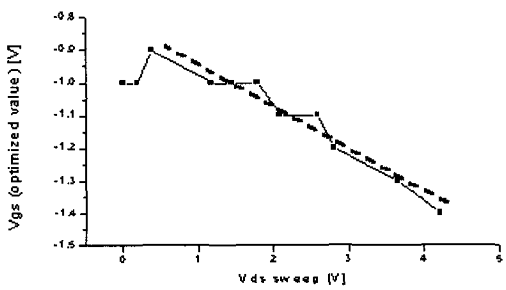
$$I_d = (A_0 + A_1 V_1 + A_2 V_1^2 + A_3 V_1^3)\tanh(\alpha V_d) \quad (3)$$

where

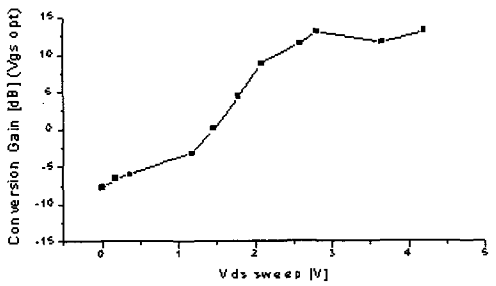
$$V_1 = V_g(1-\tau)(1+\beta(V_{d0}-V_d)) \quad (4)$$



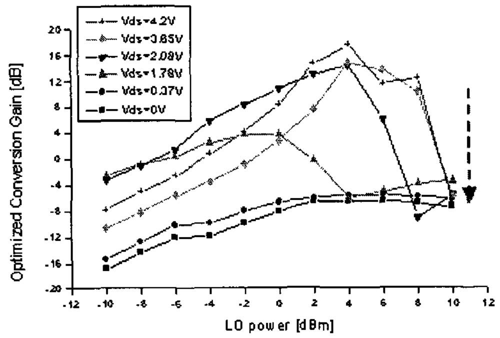
(a)



(b)



(c)



(d)

Fig. 5. Sensitivity and Stability of Conventional Source Mixer. (a) Conversion Gain with Bias varying. (b) Soft Pinch off Phenomenon according to V_{ds}. (c) Maximum Conversion Gain for optimized V_{gs} according to V_{ds}. (d) Conversion Gain for optimized V_{gs} with V_{ds} and LO varying.

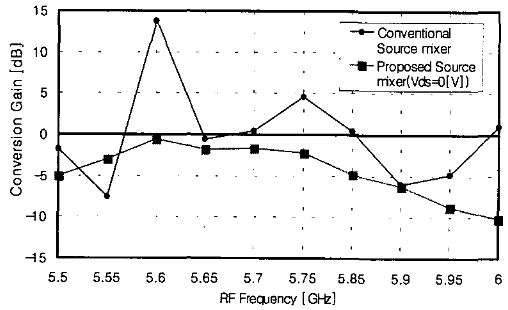
Equations (3) and (4) are about the Curtice-Ettenberg model for MESFET which include the soft pinch off phenomenon. With above equations we can realize that V_{ds} affects the conversion gain as shown in Fig. 5.

We can see that the absolute value of the pinch-off voltage is decreased linearly with increasing V_{ds}. Each point of Fig. 5(c) shows the conversion gain when V_{ds} and V_{gs} were modulated simultaneously to obtain the maximum conversion gain. It also shows that the mixer is very sensitive to the bias supply voltages.

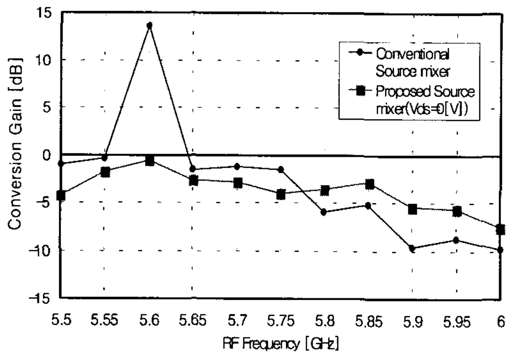
The dependence on the LO power of the mixer is shown in Fig. 5(d) and the conversion gain gets softened with V_{ds} being reduced. We can expect that the sensitivity would be weakest and more unstable at V_{ds}=0 [V].

Fig. 6 shows comparative experimental results between the conventional type source mixer and the proposed source mixer with V_{ds}=0 [V].

Variance of the conversion gain is shown as a function of the IF frequency in Fig. 6(a). Fig. 6(b) also shows the dependence of the conversion gain on the frequency of the RF signal. In Fig.s 6(c) and 6(d), variations of the conversion gain are plotted as a function of the LO power and bias voltages(V_{gs}), respectively.



(a)



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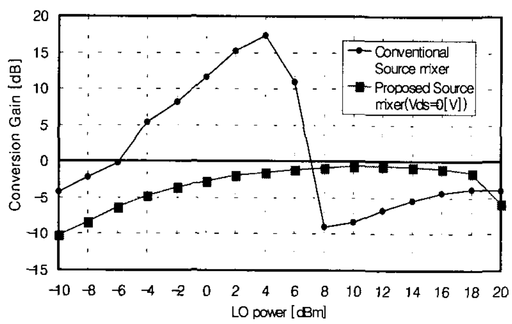
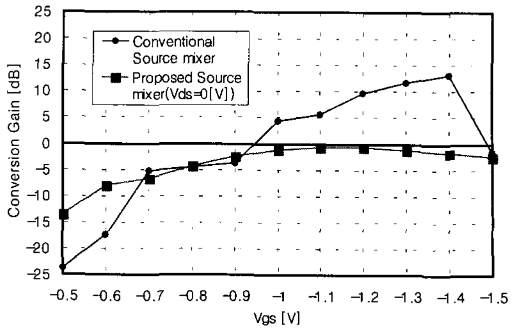


(c)



(d)

Fig. 6. Comparison of the Conventional Source Mixer (V_{gs}=-1.4[V], V_{ds}=2[V], and PLO=0[dBm]) vs. the Proposed Source Mixer (V_{ds}=0[V], PLO=10[dBm]). (a) Conversion Gain with IF Frequency Varying (fLO=5.8GHz, fRF varying). (b) Conversion Gain with RF Frequency Varying (fIF=200MHz). (c) Conversion Gain with LO power Varying. (d) Conversion Gain with Bias Varying.

Table 2. Summary of Experimental Comparison between Conventional Source Mixer and Proposed Source Mixer (V_{ds}=0 [V]).

	Conventional Source Mixer	Proposed Source Mixer
Bias Condition	V_{gs}= -1.4V V_{ds}= 2.0V	V_{ds}=0V
LO power	0dBm	10dBm
Conversion Gain	13.2dB	-0.6dB
Sensitivity to Bias	Very Sensitive	Less Sensitive
Bias Circuit Structure	Complicated (V_{ds}, V_{gs})	Simple (V_{dd})
Stability	Very Unstable (LO, Bias)	Stable

All of these measurement results show that the characteristics of the proposed source mixer with a single supply voltage (V_{ds}=0 [V]) has uppressed sensitivity to variation of the bias compared with the conventional source mixer. We also obtained improved bandwidth for consistent performance over a wide frequency range from the proposed source mixer. The experimental results are summarized in Table 2.

V. Conclusions

In this paper, an FET source mixer with V_{ds}=0 [V] is introduced to obtain simple structure and stable operation for the LO power and the supply voltage. The conversion gain of the proposed single bias source mixer was lower than that of the conventional FET source mixer. However, the proposed FET source mixer with V_{ds}=0 [V] was found to be more stable and less sensitive to the supply voltage compared with the conventional FET source mixer biased at the active region. The proposed source mixer would be advantagous in MMIC application for stable operation and smaller chip size.

It does not require quadrature hybrid to improve the isolation. And it uses resistors instead of inductor for IF choke. These can give us the size-reduction effects. And the softened sensitivity can improve the yield for MMIC.

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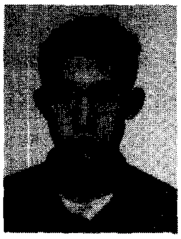

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