A SIMPLIFIED METHOD TO PREDICT THE CONVERSION LOSS OF FET RESISTIVE MIXERS

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ABSTRACT

In FET resistive mixers, FET behaves like a switch when LO signal excites the gate terminal. By modeling the on-state conductance of the FET as a linear function of the gate voltage, we are able to analytically evaluate the conversion loss of the mixers by a simple Fourier transform. We have applied this method to calculate the conversion loss of an NE71000 MESFET and an NE32400 HFET resistive mixers at X-band, and compared with measured data. Excellent agreement was obtained in each case. The advantage of this method is apparent: good predictions of the conversion loss of FET resistive mixers can be quickly obtained without using sophisticated nonlinear device model and Harmonic-Balance circuit simulator.

INTRODUCTION

FET resistive mixers [1] have been gaining favor over their diode mixer counterparts due to their very low distortion, low noise figure, and comparable conversion loss. They are also often preferable over the conventional type of FET gate mixers because of their much better intermodulation (IM) performance and no dc bias required for the drain [2]-[5]. The low distortion performance of the FET resistive mixers has recently been studied theoretically [6],[7], which involved sophisticated nonlinear device modeling and circuit simulation. At the present time, even just to obtain the conversion loss of FET resistive mixers, intensive nonlinear device modeling and Harmonic-Balance circuit simulator are normally required. The process is thus quite cumbersome and time consuming. Therefore, an analytical approach to help circuit designer quickly evaluate the conversion performance of FET resistive mixers is in great demand.

This paper describes a simple analytical method to accurately predict the conversion performance of FET resistive mixers.

MODELING THE CHANNEL CONDUCTANCE

In order to achieve optimal conversion efficiency in FET resistive mixers, the gate terminal of FET is biased near the pinch-off voltage with no bias required at the drain terminal. Under this dc biasing condition the device behaves like a switch when the gate terminal of the device is excited by the LO signal. The device is turned on during one half of the LO cycle, and off during the other half. In order to achieve minimal IM distortion and maximal conversion performance, the switching from off-state to on-state has to be as quickly as possible and the resistance of the on-state has to be as small as possible [8],[9]. However, the switching from off-state to on-state of practical FET's is not steep and, moreover, most of FET's have gradually varying conductance with the on-state voltage.

A typical FET nonlinear equivalent circuit with no drain bias is shown in Figure 1. The most nonlinear element in this equivalent circuit is the channel conductance (G_d). Frequency mixing occurs due to its functional dependence on the gate voltage. Its functional dependence on the gate voltage can be obtained by fitting the equivalent circuit to measured S-param-

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eter data at various gate bias voltages. Figures 2 and 3 show the channel conductance of an NE71000 MESFET and an NE32400 HFET versus the gate voltage, respectively. When the device is turned on, i.e. the gate voltage greater than -1.9V for the NE71000 MESFET and -0.45V for the NE32400 HFET, the channel conductance in both devices varies almost linearly with the gate voltage. The functional dependence of the channel conductance on the gate voltage, hence, can be modeled by a straight line as follows.

$$G_d = K(V_g - V_p) \quad \text{for} \quad V_g > V_p$$
$$= 0 \quad \text{for} \quad V_g \le V_p \tag{1}$$

where V_g is the internal gate-source voltage, V_p is the pinch-off voltage, and K is the slope of the channel conductance in the on-state. From Figures 2 and 3 we can get K=0.102 for the NE71000 MESFET and K=0.211 for the NE32400 HFET, respectively.

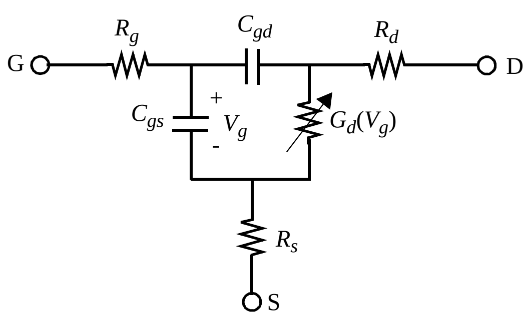

Figure 1. A typical FET nonlinear equivalent circuit with no drain bias.

CONVERSION LOSS ANALYSIS

Modeling the channel conductance of FET's as equation (1) allows us to analytically evaluate the conversion loss of the mixers. LO equivalent circuit of the resistive mixers is shown in Figure 4a and can be simplified as in Figure 4b [1]. We then can easily determine the internal gate-source voltage ($V_{g,LO}$) from the supplied LO power using Figure 4b. The approximate small-signal equivalent circuit is shown in Figure 5a and can be simplified as in Figure 5b [1]. From Figure 5b, we can obtain the small-signal current (i_d):

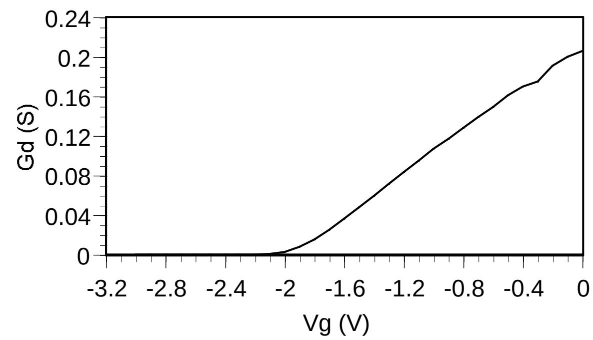

Figure 2. Measured G_d of a NE71000 MESFET.

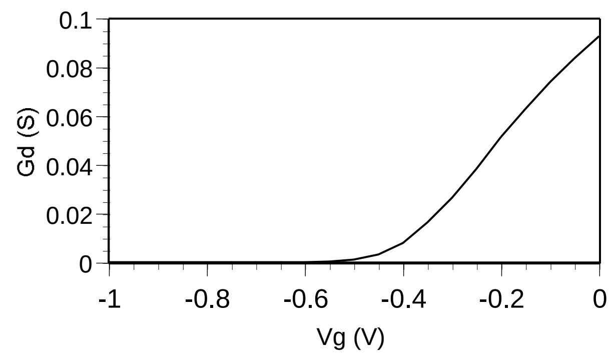

Figure 3. Measured G_d of a NE32400 HFET.

$$i_d = \frac{G_d(V_{g,LO})v_{RF}\cos(\omega_{RF}t)}{1 + G_d(V_{g,LO})(R_d + R_s + Z_{DRF})}$$
$$= f(\omega_{LO}t)v_{RF}\cos(\omega_{RF}t) \tag{2}$$

Since the device is biased near the pinch-off voltage, $G_d(V_{g,LO})$ can be written as:

$$G_d(V_{g,LO}) = KV_{g,LO}\cos(\omega_{LO}t + \theta) \quad \text{for} \quad -\frac{\pi}{2} \le \omega_{LO}t + \theta \le \frac{\pi}{2}$$
$$= 0 \quad \text{for} \quad \frac{\pi}{2} \le \omega_{LO}t + \theta \le \frac{3\pi}{2} \tag{3}$$

Substituting equation (3) into equation (2) the fundamental LO frequency component of $f(\omega_{LO}t)$ can be obtained using Fourier transform. It has the following form:

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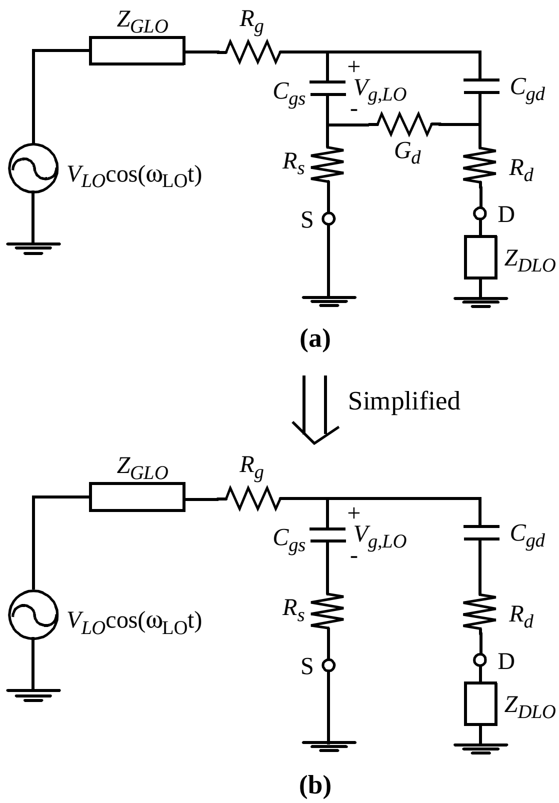

Figure 4. LO equivalent circuit

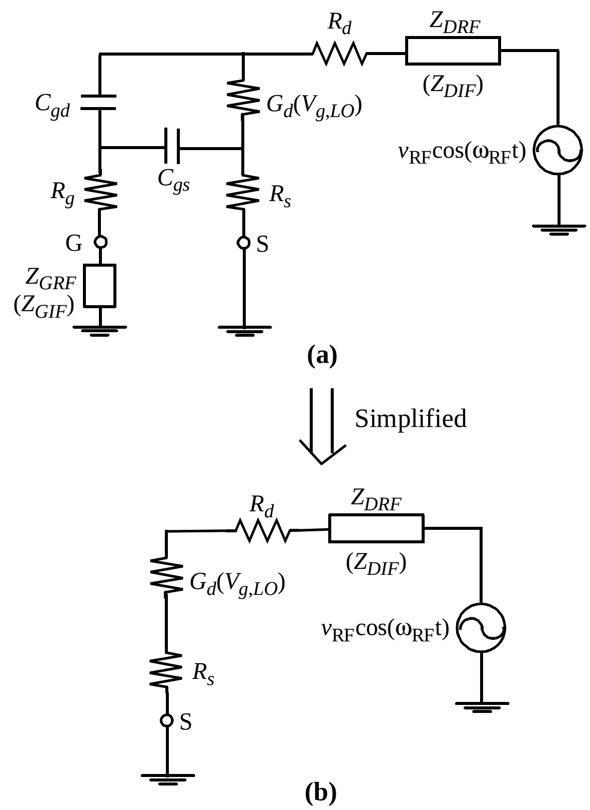

Figure 5. Approximate small-signal equivalent circuit.

$$g_1 = \frac{1}{\pi}\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \frac{KV_{g,LO}(\cos(x))^2}{1+|R_d+R_s+Z_{DRF}|KV_{g,LO}\cos(x)}dx \quad (4)$$

Equation (4) can be easily evaluated numerically.

The IF drain current is

$$i_{d,IF} = \frac{g_1 v_{RF}}{2}\cos((\omega_{LO}-\omega_{RF})t) \quad (5)$$

and then the IF output power level is

$$P_{IF} = \frac{(g_1 v_{RF})^2}{8}Re(Z_{DIF}) \quad (6)$$

The conversion loss can then be determined.

RESULTS

We have applied this method to calculate the conversion loss of the NE71000 MESFET and NE32400 HFET resistive mixers at X-band. The main purpose of this work is to verify this simplified method. We thus just used a simple 50Ω input and output circuit network at all frequencies for the mixers (Z_{GLO}=Z_{DLO}=Z_{DRF}=Z_{DIF}=50Ω). The LO frequency was chosen to be 10.8 GHz and the RF 11.1 GHz. The IF frequency is 300 MHz. The values of the device elements used in the calculation are shown in Table 1.

Device	Cgs (pF)	Cgd (pF)	Rg (Ω)	Rd (Ω)	Rs (Ω)
NE71000	0.145	0.106	0.5	0.4	1.9
NE32400	0.11	0.055	1.8	2.2	2.3

TABLE 1. Device element values.

We have also performed measurement for comparison. The results of measured and calculated conversion loss data at various LO power level are shown in Figures 6 and 7 for the NE71000 MESFET and NE32400 HFET resistive mixers, respectively. Excel-

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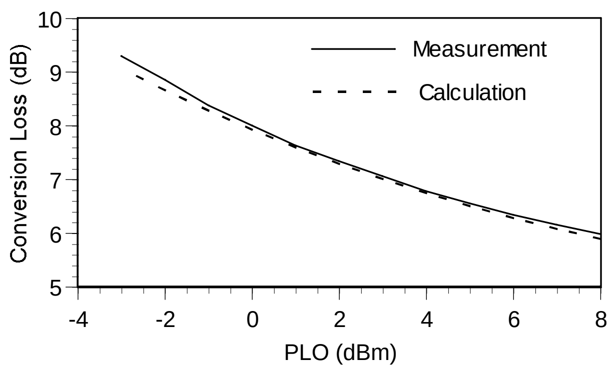

Figure 6. Comparison of calculated and measured conversion loss of a NE71000 MESFET resistive mixer at X-band. Gate bias is at -1.9V.

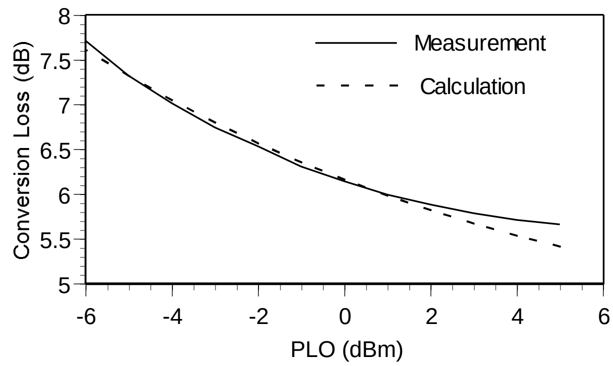

Figure 7. Comparison of calculated and measured conversion loss of a NE32400 HFET resistive mixer at X-band. Gate bias is at -0.45V.

lent agreement between the calculated and measured data is evident.

CONCLUSIONS

We have introduced a simplified method to quickly evaluate the conversion loss of FET resistive mixers. The channel conductance of FET is modeled as a linear function of the gate voltage when the device is on. By doing this, we are able to analytically derive the conversion loss of the mixers. The method has been applied to two FET resistive mixers: one uses an NE71000 MESFET and the other uses an NE32400 HFET. Both mixers have shown good agreement between the prediction and measurement. The advantage of the this method is that good predictions of the conversion loss of FET resistive mixers can be quickly obtained without using sophisticated nonlinear device model and Harmonic-Balance circuit simulator.

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