RESISTIVE FET MIXER CONVERSION LOSS AND IMD OPTIMIZATION BY SELECTIVE DRAIN BIAS


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ABSTRACT

This paper describes a dedicated nonlinear MESFET model extraction technique, which was used to accurately characterize the device’s channel resistance nonlinearity. Plotting $I_{ds}(V_{gs},V_{ds})$ Taylor series expansion coefficients across $V_{GS}$ and $V_{DS}$ revealed not only the presence of important minimum conversion loss bias, but also of in-band IMD sweet spots that were then used to optimize a FET resistive mixer performance.

INTRODUCTION

Nowadays, there are many telecommunications systems demanding very high dynamic range components, such as amplifiers, mixers or switches. In the design process, this not only means good noise performance, but also high linearity or low in-band intermodulation distortion (IMD) levels. Recently, it has become clear that the empirical nonlinear models usually adopted to represent FET devices, could not be used to produce accurate IMD calculations since they were not conceived to fit the device’s current/voltage (I/V) and charge/voltage (Q/V) derivatives [1]. Thus, specific techniques for IMD characterization of MESFETs and HEMTs have appeared, which are getting increased acceptance by microwave circuit designers.

The direct experimental extraction either of the predominant coefficients or the complete set for the $I_{ds}(V_{gs},V_{ds})$ expansion in (1) is perhaps the most significant example, since these coefficients are mainly responsible for the device’s small signal (linear or weakly nonlinear) behavior.

$$I_{ds}(V_{gs},V_{ds}) = I_{ds}(V_{ds},V_{gs}) + G_{m1}v_{gs} + G_{d2}v_{ds} + G_{m2}v_{gs}^2 +$$
$$+ G_{md}v_{gs}v_{ds} + G_{d3}v_{ds}^3 + G_{m3}v_{gs}^3 + G_{m2}v_{gs}v_{ds}^2 +$$
$$+ G_{md}v_{gs}v_{ds}^2 + G_{d3}v_{ds}^4$$

Besides the obvious help these methods have brought in nonlinear microwave circuits CAD, they also revealed unexpected MESFET IMD sweet spots in the saturation zone that have already been used in the design of very high dynamic range amplifiers [2-3]. The aim of the present paper is to extend these results to the device’s linear zone, by relating the presence of both optimum conversion loss gate bias and drain bias induced IMD sweet spots (of practical interest for the design of MESFET resistive mixers or switches) to the $I_{ds}(V_{gs},V_{ds})$ derivatives’ behavior. The simplified output conductance description, properly employed in [4], will be overcome through the inclusion of the currently available nine Taylor coefficients in the appropriate method of nonlinear circuit analysis.
NONLINEAR CHARACTERIZATION RESULTS
By using the two-sided harmonic measurement set-up already presented and discussed in [5], the authors have completely characterized the nonlinear channel resistance of a general purpose MESFET of 6x50 µm gate periphery, which exhibits a pinch-off voltage of nearly -1.35V and an Idss of 50mA.

In Fig. 1 we show Gds, Gmd and Gm2d across VGS for a constant VDS in the linear zone (VDS=0V). Gmd and Gm2d describe the variation of the nonlinear channel resistance (in fact the output conductance Gds) as a function of the input control voltage, the role played by the local oscillator (LO) drive in a FET resistive mixer [6]. In this way, they could be easily employed to approximately predict the optimum VGS bias point for minimum conversion loss. For the present device this point is expected to be located around VGS= -1.30V, the point where the coefficient Gmd \(\equiv \partial Gds/\partial Vgs\) has a maximum. This point can also be consider as the effective pinch-off voltage, VT.

Fig. 2 displays Gds, Gd2 and Gd3 evolution across VDS for a constant VGS of –0.9V. Gd2 and Gd3 represent the residual nonlinearity of the FET’s channel resistance, the Gds dependence on Vds mainly responsible for the device’s IMD behavior in a resistive mixer application (the RF signal is applied between the drain and source terminals). A careful observation of these curves reveals a Gd3 null near VDS=0.25V, which is a clear indication that the device can present its best in-band linearity performance not exactly under cold bias but for a slightly positive VDS.

A FET resistive mixer has been properly considered as a sort of ‘linear mixer’ [7], but the device nonlinearity near pinch-off (mainly responsible for its third order IMD behavior) seems to be even weaker for a small VDS.

A conclusion that may be anticipated from the existence of these Gd3 nulls is that, in a similar way as bias is used to improve conversion loss in a diode mixer, a small amount of VDS bias could also be applied to optimize IMD performance of a MESFET switch or resistive mixer.

RESISTIVE MIXER CONVERSION LOSS AND IMD OPTIMIZATION
To study the practical usefulness of the above conclusions, an illustrative resistive FET mixer was designed and simulated using a mix of strong nonlinear time domain techniques (for finding LO induced quiescent point excursion) and time-varying Volterra series (for mixer