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MODELLING AND EVALUATION OF DUAL GATE MESFETs AS LOW-NOISE, SELF-OSCILLATING AND IMAGE-REJECTION MIXERS

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Abstract

The three principal modes of non linear operation of DGFET mixers are described and modelled in order to understand the mixing mechanism and optimize critical circuit and device parameters. Theoretical results are compared with experiments on a 12 GHz TV reception mixer with 8 dB conversion gain and 800 MHz bandwidth.

Introduction

Active mixers using GaAs dual gate FETs (DGFET), have been realized for frequencies up to 30 GHz [1] with conversion gain up to 3 dB and noise figure of the order of 10 dB.

The advantages of using DGFETs in a mixer circuit instead of Schottky diodes or single gate FETs (SGFET) are, except for conversion gain and reasonable noise figure, the inherent separation of signal and local oscillator power and the possibility of their direct combination inside the device thus eliminating cumbersome passive couplers as is required for monolithic GaAs circuits, where surface area is to be kept as small as possible. Here DGFET mixers are probably the only adequate solution as has been shown in the case of MMIC receiver applications for X-band direct satellite broadcasting [2].

Even though mixers are one of the most important applications, the mixing mechanism of DGFETs is not yet completely understood. This is due to the floating potential of the intergate channel region (D_1 in fig.1) that is modulated by a local oscillator voltage injected into either of the two gates, consequently changing the bias and saturation conditions of both FET parts of the DGFET causing them to act as a mixer, RF or IF amplifier separately.

In this paper, we will present a computer aided modelling procedure of DGFET mixers and a systematic investigation of the three principal modes of operation.

DGFET mixer modelling

Figure 1 illustrates the principle of DGFET mixer operation : the signal and local oscillator power are injected into either one of the two gates (in this example LO into gate 2, RF into gate 1). The IF is extracted from the drain terminal and, after lossless matching, introduced into a 50Ω load. Since our mixer development is for 12 GHz satellite TV, the chosen frequency bands are : f_{LO} = 10.9 GHz, f_{RF} = 11.7-12.5 GHz, f_{IF} = 0.8-1.6 GHz, but our model is of general validity. The higher frequency bands (f_{LO} , f_{RF}) are nearly short circuited at the drain port by a $\lambda/4$ open μstrip line at f_{LO}. For a given drain bias V_{DS} several device and circuit parameters have to be optimized for best mixer operation :

1. The bias voltages V_{G1} and V_{G2} depending on the desired mode of operation.
2. The three terminal impedances at the main frequency components ω_{RF}, ω_{LO}, ω_{IF} and the image frequency $\omega_{IM} = 2 \cdot \omega_{LO} - \omega_{RF}$.
3. The local oscillator power P_{LO}.

The principal modes of mixer operation : The difficulty of understanding DGFET mixer operation due to the floating D_1 potential (fig. 1) can be overcome by using the bidimensional transfer characteristic [3] shown in fig. 2 : it allows identification of any bias point of the DGFET and specifies the internal biasing of both FET parts, their modulation and expected non-linearities due to excitation by an external oscillator. The characteristic, valid for V_{DS} = const., can also be used for a quasistatic analysis since the output port is short circuited for the L.O. signal.

The three principal bias regions of DGFET mixers are indicated in fig. 2 by the shaded areas : LNM, SOM and IRM : LNM defined by $V_{G2S} < -1.5$ V is the Low-Noise Mixer mode : main non-linearities are the transconductance, the channel resistance and the input capacitance of FET 1 which is the mixing device part. FET 2 acts as an IF post amplifier. Due to the low current, this mode allows low noise operation. SOM, defined by $-0.5\ V < V_{G2S} < 1\ V$; $V_{G1S} > -1$ V is the Self-Oscillating Mixer mode. The mixing properties are as in the LNM mode. Due to high gain, the DGFET can oscillate at 11 GHz and can be used as a self-oscillating mixer [4]. IRM, defined by $2.5\ V < V_{G2S} < 3.5$ V ; $V_{G1S} > -1.5$V is the Image-Rejection Mixer mode : the most important nonlinearities here are the transconductance, channel resistance and the input and feedback capacitances of FET 2, which is now the mixing part of the DGFET. FET 1 acts as an RF preamplifier. Since mixing takes place physically behind the first gate, a modified version of DGFET, the BRFET (Band Rejection FET) [5], can be used as an image rejection mixer : the image-frequency band (9.3-10.1 GHz) is suppressed in front of the mixing FET 2 by an appropriate L-C series resonant circuit placed between the two gates.

Operation region (ref.Fig.2)	LNM ($V_{G2S} < -1.5$V)	SOM ($-0.5V < V_{G2S} < +1V$; $-1V < V_{G1S}$)	IRM ($2.5V < V_{G2S} < 3.5V$; $-1.5V < V_{G1S}$)
FET 1 : FET 2 :	Mixer IF-Amplifier	Mixer IF-Amplifier	RF-Amplifier Mixer
Application	Low Noise Mixer	Self-Oscillating Mixer	Image Rejection Mixer

TABLE I : Review of mixer operation of DGFETs

Computer aided modelling procedure : In order to model DGFET mixers, we proceed assuming :

1. Pure sinusoidal LO waveform at G_2.
2. Neglect higher order interactions and spectral components , other than direct conversion to IF.
3. $\omega_{IF} \ll \omega_{LO}$,

as follows :

- Identification of non-linearities in the DGFET, if excited by a local oscillator voltage at one of the gates, using the monogram of fig. 2.

- Estimation of bias point excursion of both FET-parts during L.O. pumping (quasi-static approach).

- Measurement of "S" parameters at 1 GHz of the partial FETs according to the procedure described in [6] at several bias points as defined above (fig. 2).

- Calculation, using a simplified equivalent circuit, of the values g_m, C_{GS}, R_d, (C_{GD}) as a function of V_{G1}, V_{G2}, $V_{D1S}(V_{G1}, V_{G2})$, for FET 1 and FET 2 (fig. 3).

- Introduction of the corresponding bidimensional matrices as data (with interpolation possibility between two successive points) in a HP 9845 desk computer (fig. 3).

- Calculation, using HP 9845 compatible circuit analysis software and complete DGFET small signal models [6] , of admittance parameters Y_{ij} of the non linear device part as a function of L.O. voltage, here V_{G2}.

- Transferal of the sinusoidal L.O. pumping $V_{G2} = V_{G20} + V_0 \cdot \cos \omega_{LO}t$ through the non-linearity voltage characteristic to obtain Y parameter variation with time.

- Fourier harmonic analysis at ω_{LO} of $Y_{21}(\omega_{RF})$, $Y_{11}(\omega_{RF})$ and $Y_{22}(\omega_{IF})$ for different L.O. amplitude (V_0) and bias V_{G20}, (fig. 4).

- Replacement of the mixing FET part by a linear two-port described by $Y^{(0)}{}_{11}(\omega_{RF})$, $Y^{(1)}{}_{21}(\omega_{RF})$ and $Y^{(0)}{}_{22}(\omega_{IF})$,
$Y^{(n)}{}_{ij}(\omega_k)$ being the n-th harmonic of the ij-th complex admittance at frequency ω_k, (fig. 5).

- Optimisation for conversion gain, input (ω_{RF}) and output (ω_{IF}) matching and bandwidth using small signal circuit analysis.

This procedure has been carried out for all three operation modes but the examples of fig. 4, 5, 6 refer to the LNM mode of operation. Results are presented below.

Results and discussion

DGFET mixers have been designed at 12 GHz with a local oscillator of 10.9 GHz and realised in hybrid form on Al_2O_3 substrates for operation in all three non-linear modes. In the IRM mode a BRFET [5] instead of a DGFET has been employed. Its non-linear behaviour is the same as that of a DGFET. Obtained results using DGFETs of LEP with two equal gates of 0.8 µm x 150 µm can be summed up as follows :

- Low Noise Mixer mode : Fig. 5 describes in detail the LNM circuit realised. All matching elements, except Z_2 are easily monolithically integrable. The optimum Z_2 for best conversion gain and IF bandwidth is a pure inductance of 56 nH that could be realised by a spiral inductor containing 16 turns and presenting a parallel resonance at 3 GHz. The conversion gain of that mixer is given in fig. 6 : it is compared with modelling results obtained according to the already described procedure. A close agreement of experimental and modelled values can be stated. SSB noise figure has been measured in the 800 to 1500 MHz IF range using an automatic noise analyser and was of the order of 8 to 9 dB. No predictions on noise figure of DGFET mixers can yet be made, but due to the lower d.c. current in the LNM mode, the best noise figure is expected in this region.

- Fig. 6 also gives measured and calculated results of the DGFET in the Self-Oscillating Mixer mode : due to the higher current and the fact that FET 1 is now in the saturated region (fig. 2) the DGFET can oscillate if an appropriate load at gate 2 is presented [4]. However, the presented results of 8 dB conversion gain over 800 MHz bandwidth are obtained using an external local oscillator at gate 2. Noise figure in this case is higher (10 to 12 dB).

- DGFET mixers in the Image Rejection mode employing a BRFET [5] are more difficult to tune at IF port due to the sensitivity of the output impedance to L.O. power (fig. 2). However, as shown in [5] conversion gain of 4 to 6 dB and an associated noise figure of 12-13 dB over 100 MHz bandwidth could be obtained. The corresponding image band rejection was around 30 dB.

Conclusion

A computer aided modelling and design procedure of DGFET mixers has been presented.

The three principal modes of operation, Low Noise Mixer, Self-Oscillating Mixer and Image Rejection Mixer have been identified, modelled and corresponding circuits have been realised.

A DGFET mixer for 12 GHz DBS TV with 5 to 7 dB conversion gain and 8 to 9 dB noise figure over 800 MHz is presented.

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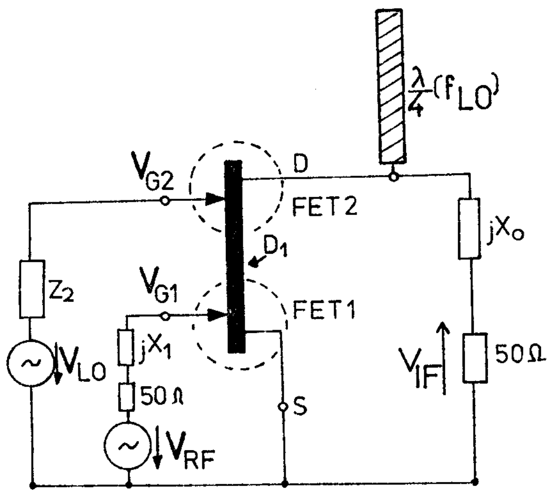

FIG. 1 : Principle of DGFET mixer operation

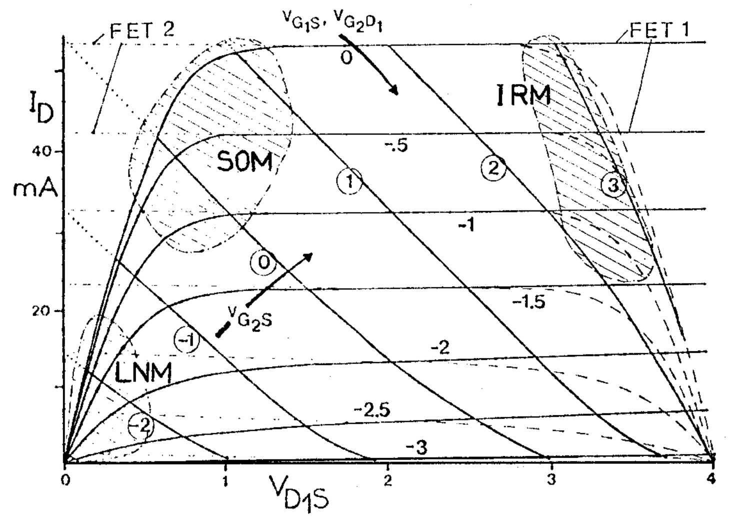

FIG. 2 : Transfer characteristic of DGFET. V_{DS} = 4 V.

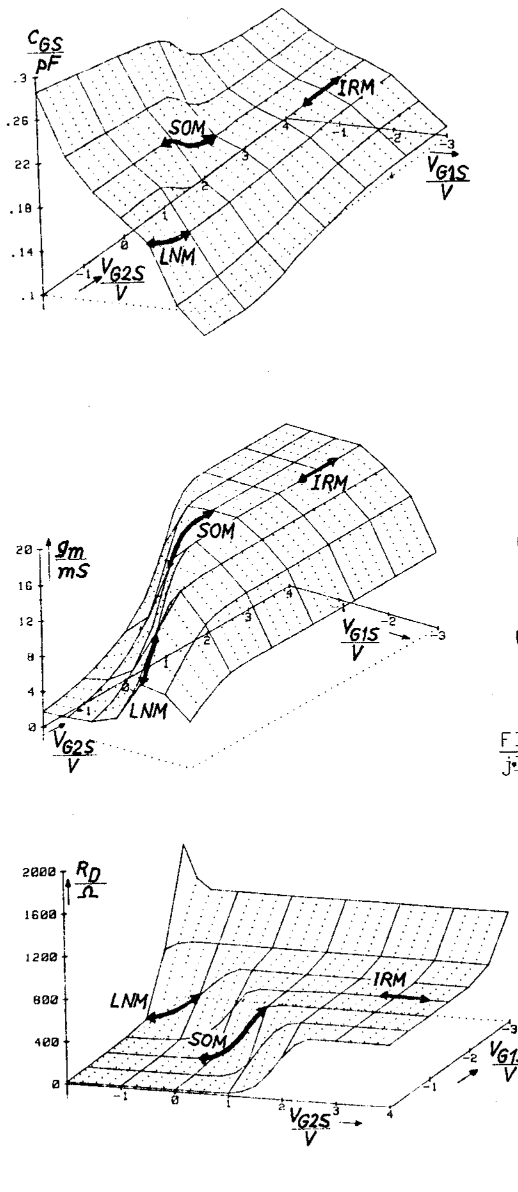

FIG. 3 : Dependence of small signal elements of FET 1 on local oscillator excursion.

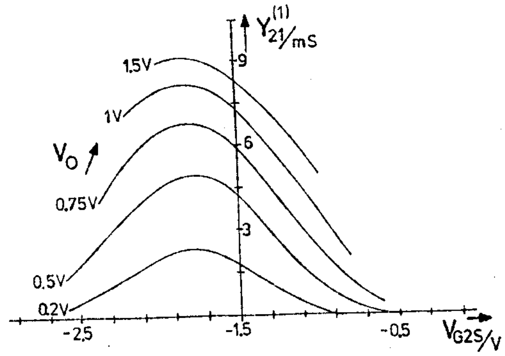

FIG. 4 : Conversion transconductance $Y_{21}^{(1)}(\omega_{RF})$ as a function of bias and L.O. excitation voltage in LNM region. V_{G1S} = - 2 V.

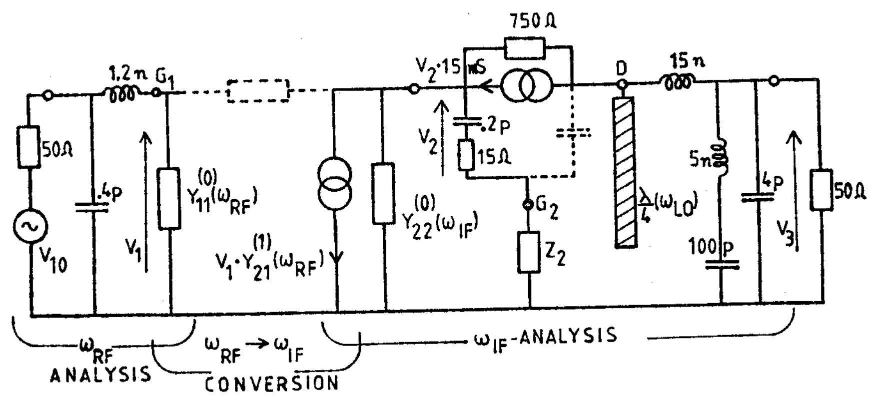

FIG. 5 : Equivalent circuit for DGFET LNM and SOM modelling. Y_{11} = (7 + j16)mS, Y_{21} = (9 - j1)mS, Y_{22} = 10 mS, Z_2 (ω_{IF}) = (40 + j450)Ω .

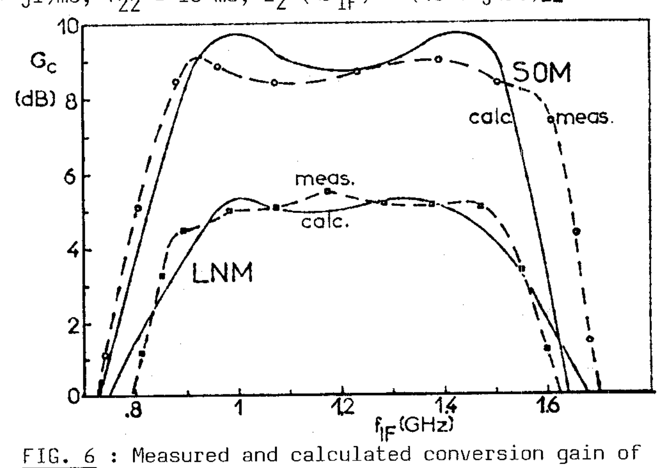

FIG. 6 : Measured and calculated conversion gain of DGFET mixers in the LNM and SOM regions.