FIGURES OF MERIT FOR CHARACTERIZING FET OSCILLATORS

by

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ABSTRACT

Simple expressions characterizing FET oscillator performance are presented. A stability criterion has been derived in a fairly general way. New expressions for the loaded quality factor for both fundamental- and harmonic-mode operation are given with expressions for the output PM noise. The results presented in this paper extend the well established analysis of one-port oscillators to two-port oscillators.

INTRODUCTION

Since the last decade, the use of FET in microwave os cillators has greatly been increased. Some theoretical formulations of the FET oscillator noise per- for mance have been introduced [1]-[5]. A lot of experimental work in noise performance and cavity stabilization has been published. In this paper, a simple stability criterion is introduced which is quite general and based on quite acceptable approximations. Under the same approximations, expressions for the noise in FET oscillators are introduced from which a new expression for the loaded quality factor is found. The same concept is also valid for the FET harmonic-mode oscillator. These criteria simplify the study of FET oscillator performance and allow a comparison between different available modes of operation.

THEORETICAL DESCRIPTION

Referring to Fig. 1, the feedback network of the oscillator will be divided into sub-networks each of them operating at one of the frequency harmonics. The oscillation conditions have then to be satisfied between the FET nonlinear network and the linear feedback networks. The terminal currents and voltages will be related by the [Y]-matrices of the feedback networks and the FET's describing functions [6]. In the following work, the FET nonlinear elements, i.e., the gate-source capacitance C_{gs}, the transconductance S and the drain conductance g_d are assumed to be periodic functions of time and are hence represented by Fourier expansions with coefficients C_{gsn}, S_n and g_{dn}, respectively.

The oscillator stability is examined by using the perturbation method. The matrix relating voltage and current perturbations, which will be called the conversion matrix, is of 6^{th} order for fundamental-mode operation and of 10^{th} order for harmonic-mode operation. This makes a numerical solution the only possible one. For a simple mathematical expression that characterizes the stability of the oscillator, the following approximations are taken into account. First, the losses in the biasing network are neglected. Then the bias voltage perturbations are no longer unknowns and the order of the conversion matrix is reduced by two. The second approximation is to neglect the higher coefficients in the Fourier series of the gate-source capacitance C_{gsn} for $n \geq 2$. This approximation is quite reasonable since the values of C_{gsn} for $n \geq 2$ are much

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smaller than those of C_{gso} and C_{gs1}. All frequency dependent functions will be linearized around the resonance frequency because the perturbation frequency ω_p is much smaller than the resonance frequency ω_o. Taking these approximations into account, the determinant of the convergence matrix is simplified to:

$$\det\{[G]\} = j2\omega_p(S_2V + g_{d2})\left(\mathrm{Im}(y'_L) - \frac{2g_{do}}{V}\,\mathrm{Im}(V')\right) \quad (1)$$

where y'_L is the derivative of the load admittance $(-\underline{I}_2/\underline{V}_2)$ with respect to frequency and V is the feedback factor $(\underline{V}_1/\underline{V}_2)$. V' means frequency derivative of V. One should compare this expression for the conversion matrix with that of a one-port oscillator [8]. Both expressions are quite similar except that the quantity $(-2g_{do}\mathrm{Im}(V')/V)$ is added to $\mathrm{Im}(y'_L)$. This extra term arises due to the second port of the oscillator. A stability criterion can now be derived by analogy to that of [8]. It reads

$$\left[\mathrm{Im}(y'_L) - \frac{2g_{do}}{V}\,\mathrm{Im}(V')\right] > 0\ . \quad (2)$$

If the phase between the voltages of the two ports is taken equal to π [7], then V is negative real and the signs of $\mathrm{Im}(y'_L)$ and $\mathrm{Im}(V')$ completely describe the stability of the oscillator. When both are positive, the oscillator is stable. When both are negative, the oscillator is unstable. In case of one sign positive and the other one negative, the oscillator may be stable or not. It should be noted that the stability expression (2) is general and independent of the FET model and the feedback network.

With the same approximations, expressions for the output PM noise have been derived. These expressions are based on the relationships between the describing functions and the nonlinear elements of the FET. The output noise is a function of the intrinsic noise current and voltage sources. For the fundamental noise current sources at the drain port, the resulting output noise is given by

$$P_{PM} = \frac{\langle|\underline{i}_{2u}|^2\rangle + \langle|\underline{i}_{2\ell}|^2\rangle}{\omega_p^2|\underline{V}_2^2|\left[\mathrm{Im}(y'_L) - 2g_{do}\dfrac{\mathrm{Im}(V')}{V}\right]^2} \quad (3)$$

where u and ℓ stand for the upper and lower sidebands $(\omega_o + \omega_p)$ and $(\omega_o - \omega_p)$, respectively. When this expression is compared with that of the one-port oscillator [9], one obtains the following expression for the loaded quality factor:

$$Q_L = \frac{\omega_o}{2y_L}\left[\mathrm{Im}(y'_L) - \frac{2g_{do}}{V}\,\mathrm{Im}(V')\right]\ . \quad (4)$$

The quality factor of the harmonic-mode circuit has the same form if ω_o is replaced by $m\omega_o$ and the quantities y_L and V by those of the harmonic circuit.

One of the most important noise sources is the bias circuit noise source $\underline{u}_1$. This noise is upconverted to both the fundamental and the harmonic frequencies. The values of the output PM noise for the fundamental and harmonic frequencies, respectively, are given by

$$P_{PM} = \frac{\omega_o^4\, C_{gs1}^2\langle|\underline{u}_1|^2\rangle}{\omega_p^2\,|\underline{I}_2|^2\,Q_L^2}\,\mathrm{Re}^2\left\{\frac{y_{21}+S_o}{\bar{y}_{11}} - \frac{S_2}{\bar{y}^*_{11}}\right\}\ , \quad (5)$$

$$P_{PM} = \frac{m^2\omega_o^4\, C_{gsm}^2\langle|\underline{u}_1|^2\rangle}{\omega_p^2\,|\underline{I}_2|^2\,Q_L^2}\,\mathrm{Re}^2\left\{\frac{y_{21}+S_o}{\bar{y}_{11}} - \frac{S_{2m}}{\bar{y}^*_{11}}\right\}\ , \quad (6)$$

where $\bar{y}_{11}$ stands for $y_{11} + jm\omega C_{gso}$. y_{11} and y_{12} are elements of the [Y] matrix. The quantities ($\underline{I}_2$, $\bar{y}_{11}$, y_{22}, and Q_L) in equation (5) belong to the fundamental circuit, while in equation (6) they belong to the harmonic circuit.

RESULTS

To illustrate the validity of the presented work, the suggested figure of merit is examined for some cases. Fig. 2 shows the relation between the loaded quality factor Q_L and the output power P_L. Two cases have been regarded, the simple model when the FET is represented only by its nonlinear elements, and the complete model which takes the FET parasitic elements into account. The Q_L values for both cases give the expected figures. Q_L is well suited as a figure of merit to compare between different modes of operation, e.g. different types of cavities used for stabilization, different feedback networks, different locations of the load, and for many other applications.

The PM noise expressions obtained are simple and related to the quality factor in a similar way as for the one-port oscillator. Fig. 3 compares between the PM noise which is calculated from eqs. (5) and (6) and the numerical results obtained without any approximations for different values of V_{10}. Fig. 4 shows the same comparison for different values of $|\underline{V}_{11}|$. It can be concluded that the approximate expressions are quite good for different values of the operating point. Fig. 5 gives the frequency spectra for both the fundamental and the harmonic output PM noise. For $\omega_p << \omega_0$, the approximate expressions give excellent values for the noise, because the linearization around ω_0 is still valid.

REFERENCES

[1] B.T. Debney and J.S. Joshi: IEEE Trans. ED, vol. ED-30, pp. 769-776, 1983.

[2] C. Rauscher and H.A. Willing: IEEE Trans. MTT, vol. MTT-27, pp. 834-840, 1979.

[3] C. Rauscher and H.A. Willing: IEEE Trans. MTT, vol. MTT-28, pp. 1054-1059, 1980.

[4] R.A. Pucel and J. Curtis: IEEE MTT-S, pp. 282-284, 1983.

[5] H.J. Siweris and B. Schiek: IEEE Trans. MTT, vol. MTT-30, pp. 233-242, 1985.

[6] L. Gustafsson, G.H.B. Hanson, and K.I. Lundström: IEEE Trans. MTT, vol. MTT-20, pp. 402-409, 1972.

[7] C. Rauscher: IEEE Trans. MTT, vol. MTT-29, pp. 293-304, 1981.

[8] R. Knöchel, K. Schünemann, and J.D. Büchs: IEE J. Microwaves, Optics and Acoustics, vol. 1, pp. 143-155, 1977.

[9] K. Schünemann and K. Behm: IEEE Trans. MTT, vol. MTT-27, pp. 452-1458, 1979.

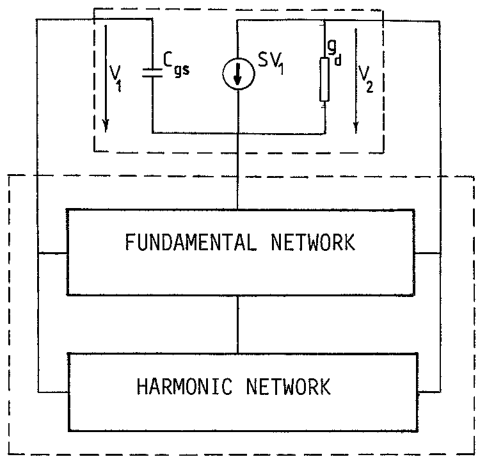

Fig. 1: FET oscillator model.

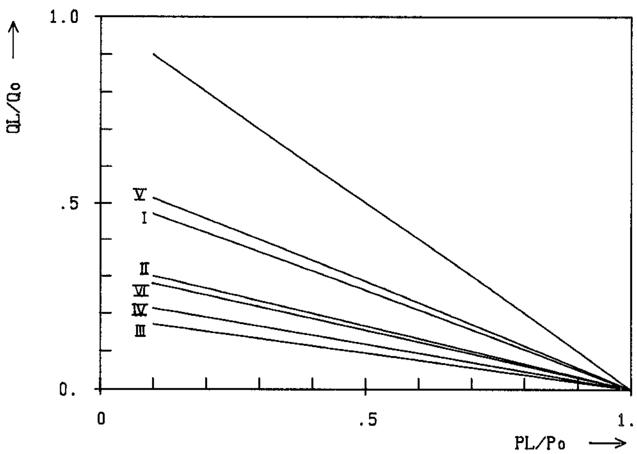

Fig. 2(a): Loaded quality factor against output power for different feedback circuits at 10 GHz.

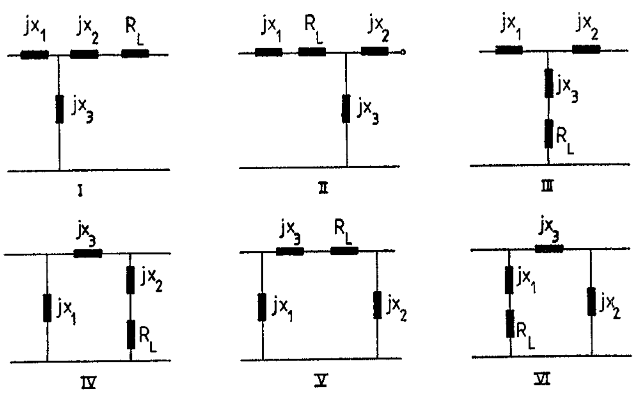

Fig. 2(b): Different feedback circuits of Fig. 2(a).

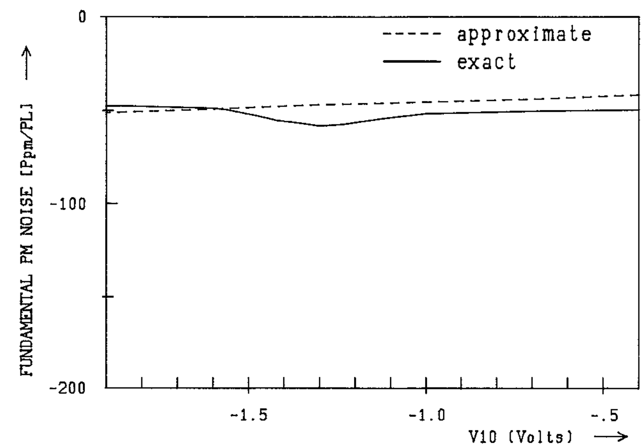

Fig. 3(a): Dependence of fundamental PM noise on V_{10}.

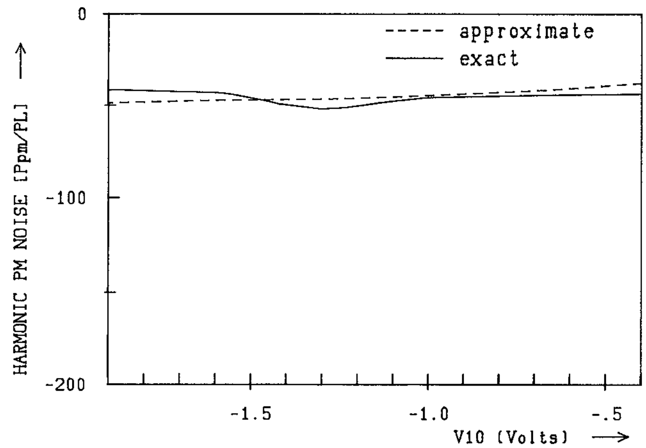

Fig. 3(b): Dependence of harmonic PM noise on V_{10}.

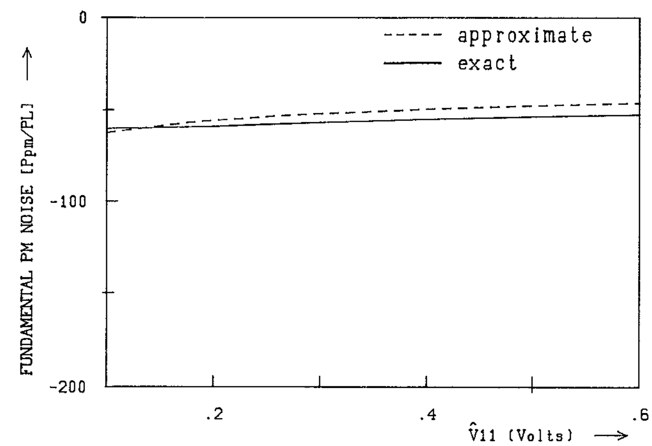

Fig. 4(a): Dependence of fundamental PM noise on $|\underline{V}_{11}|$.

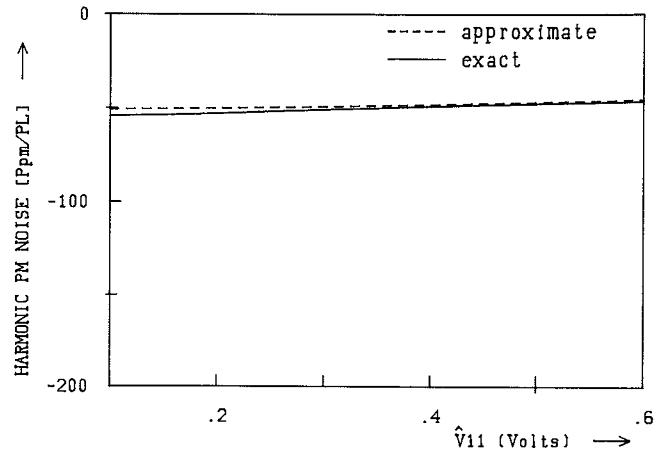

Fig. 4(b): Dependence of harmonic PM noise on $|\underline{V}_{11}|$.

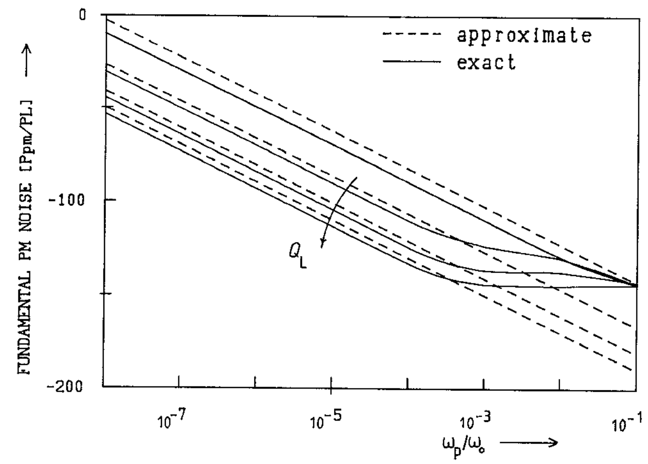

Fig. 5(a): Fundamental PM noise spectrum for different values of Q_L.

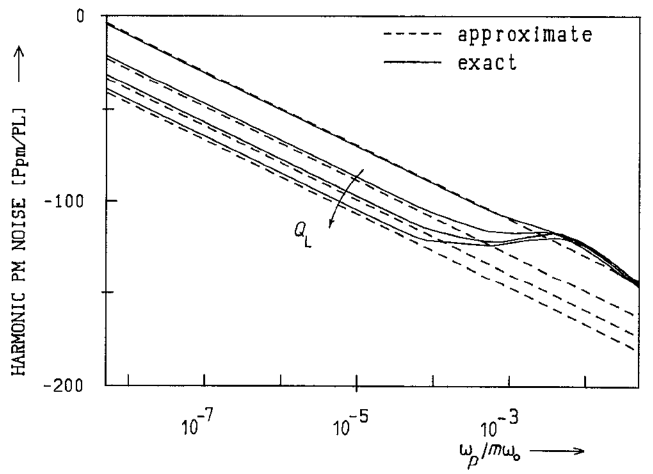

Fig. 5(b): Harmonic PM noise spectrum for different values of Q_L.