COMPARATIVE STUDY OF PHASE NOISE IN HEMT AND MESFET MICROWAVE OSCILLATORS

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Summary

Several identical X band cavity stabilized MESFET and HEMT oscillators are presented. Their phase noise and some other noise data are reported. Under exactly the same oscillating conditions, the MESFET oscillators exhibit the best phase noise performance not only because of their lower low frequency noise but also because of a better linearity which provides a smaller LF noise conversion in the microwave frequency range.

Introduction

Solid state oscillators are widely used in most microwave equipment and their spectral purity specifications are among the hardest to satisfy. The reason is that microwave solid state devices, because of their reduced sizes, inherently exhibit a large low frequency (L.F) excess noise which is up-converted by the device non-linearities in the microwave frequency range.

This drawback is particularly noticeable in field effect devices. On the contrary, it is less critical in bipolar devices which exhibit a lower excess noise. Unfortunately silicon bipolar transistors are unable to provide good R.F performances above the X-band and bipolar heterojunction transistors are not commercially available yet.

Therefore only two competitors subsist, i.e., the GaAs MESFET and the GaAs - GaAlAs HEMT. A significant comparison of their phase noise performances has not been made yet since it necessitates very stringent requirements so as to be significant. Indeed, the phase noise performance of an oscillating two-port device depends at least on two main factors :

(i) the low frequency excess noise of the device (LF noise)

(ii) the topology and electrical performance of the circuit in which the device is embedded.

Therefore a significant comparison of the phase noise between two different devices requires firstly that a full characterization of their low frequency noise is completed before they are put into oscillation and secondly that they are embedded in strictly identical oscillating circuits.

This paper reports data obtained on several MESFET and HEMT oscillators complying with the aforementioned requirements. The origins of the observed differencein the oscillator's phase noise are finally discussed in terms of device properties.

Device description

Most of the oscillators were made with MESFET's or HEMT's commercially available at some major manufacturers. They are low noise figure devices featuring a gate length of about 0.5 µm and a gate width of about 300 µm. The HEMTs are usually processed using MBE. For comparison purposes a laboratory device, MOCVD processed by L.E.P. (France), is also included. We also expect the results obtained with some other HEMTs to be available by the time of the conference. Among all such devices a particular attention will be paid to the comparison between the GOULD and THOMSON MESFET and HEMT since these two devices feature an identical layout and similar electrical characteristics.

For the eight different devices available at the time of printing the most significant electrical data are given in table I.

	A MESFET S 8818 THOSHIBA	B MESFET 1405 MITSHUBISHI	C MESFET GOULD OXL0503	D HEMT GOULD MPD H503	E HEMT FUJITSU FRO1FH	F HEMT LEP EP 742	G MESFET THOMSON TC 1403	H TEGFET THOMSON L4313 A
Z (µm)	300 (?)	300(?)	300	300	300(?)	200	300	300
L (µm)	0.5(?)	0.5(?)	0.3	0.5	0.5	0.55	0 55	0.55
V_T (V)	-1	-0,47	-0,8	-0,75	-0,91	-0,65	-1.67	-1.72
I_{DSS} (mA)	29	20	27	23	33	17	55	73
Gass at NF db	10	9	9.5	10.5	10	10.5	9.3	9.6
NF (12 GHz) db	1.5	1.8	1.9	1.2	1.1	1.2	2	1.7

Table I

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All the devices are used into a 70 mil ceramic package.

Oscillator structure and measurements

For comparison purposes it is essential for the oscillating devices to be embedded in exactly the same circuits : the best way to fulfil such a condition is in fact to use only one circuit, whatever the device. Such a circuit, operating at any X-band frequency, is a cavity stabilized feedback structure realized with discrete elements, as shown in Figure 1.

The devices are used in a grounded source configuration. The packaged transistors are inserted into a classical coaxial test fixture. This technique ensures easy substitution of one device for another.

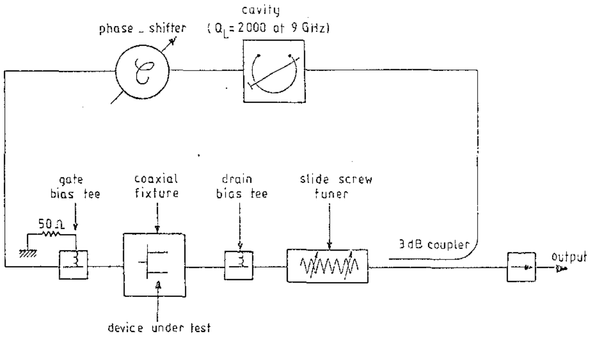

Figure 1 : Block diagram of the cavity stabilized HEMT/MESFET oscillator. The cavity loaded Q is about 2000 at 9 GHz.

For different devices to oscillate at a constant given frequency (9 GHz) when successively embedded in a given circuit, it is requested that they exhibit very similar RF characteristics. This condition was particularly well fulfilled with the GOULD MESFET and its HEMT counterpart where correct oscillating conditions were met without any further tuning of the tuner and/or the phase shifter (see Figure 1) when substituting one device for the other. The other devices necessitated a slight adjustement of the phase shifter to get the oscillation.

The gate bias voltage is fixed at zero volt and the drain bias voltage is adjusted between 3 and 5 V so as to obtain a given power of about 6 mW whatever the device on test.

The S.S.B. phase noise L(f) is firstly measured with an improved frequency discriminator technique at baseband frequencies f between 1 kHz and 100 kHz. The corresponding noise spectra for the eight devices of table I are given in Figure 2.

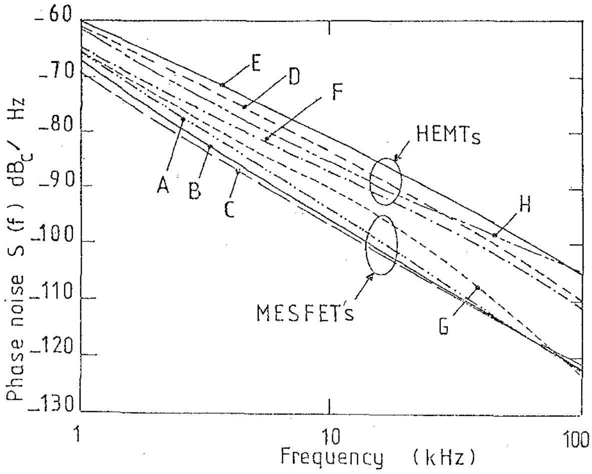

Figure 2 : Phase noise apectra of four different HEMTs compared with four different MESFETs with similar sises and electrical performance (see Table I). (9 GHz)
Vgs=0 V, 3 V < Vds <5 V. A, B, C, G are data from MESFETs of table I and D, E, F, H are data from HEMTs of Table I.

Secondly a white low frequency noise of known spectral density Sv(f) is injected through the gate bias tee (see Figure 1) into the HEMT or the MESFET and the related excess phase noise Le(f) is carefully checked. Next the ratio of the excess frequency fluctuation $f_e(f)_{RMS}$ in $Hz_{RMS}/\sqrt{Hz}$ by the LF noise voltage in $V_{RMS}/\sqrt{Hz}$, called the upconversion coefficient K(f) at the baseband frequency f, is given by :

$$K(f) = \Delta f_e(f) / (\sqrt{Sv(f)}) \qquad (1)$$

where $\Delta fe(f)$ is obtained from :

$$Le(f)_{dBc/Hz} = 20 \log \left[\Delta fe(f) / (\sqrt{2} f) \right] \qquad (2)$$

This coefficient K(f) will be particularly useful for any further discussion on the phase noise since we believe that it is highly significant of the non-linear effects responsible for the noise upconversion in the device.

Low frequency noise

Apart from any microwave measurement, the devices are also inserted between two 50 ohms RF loads to prevent any oscillation and their input low frequency noise voltage spectral density Se(f) is measured between 10 Hz and 100 kHz at the same DC operating points as those previously selected for phase noise investigations.

The eight different LF noise spectra are given in Figure 3. They indicate that in the frequency range of interest (1 kHz-100 kHz) :

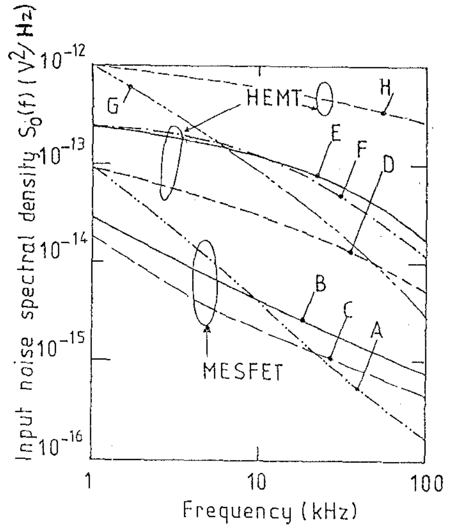

Figure 3 : Input voltage low frequency noise spectral density of the eight different devices involved in Table I and Figure 2. Bias conditions are identical to those used for phase noise measurements (Vgs=0 V, Vds 3 V).

(i) HEMTs exhibit 4 to 20 dB more noise at 10 kHz than the MESFETs

(ii) the noise spectral density varies as $1/f^{\alpha}$ with $0.5 \leq \alpha \leq 1.5$ for MESFET's and $0 < \alpha \leq 1$ for HEMT's. The existence of a noise bulge in the 1-10 kHz frequency range for most of the HEMTs results from some generation-recombination noise on DX centers at the GaAs/GaAlAs interface [1, 2].

Discussion and conclusion

The phase noise spectra displayed in Figure 4 makes it possible to state, first, that the phase noise of most of the MESFET's is about -95 dBc at 10 kHz off the carrier, which is very near from the state of the art performance obtained on low noise figure devices[3] although a further noise reduction should be possible when using power or medium power devices [4, 5] or larger Q resonators[3].

The most stringent result obtained from Figure 2 is that the phase noise in HEMT's is in average 10 dB larger than in MESFET's at 10 kHz off the carrier. The evolution of this difference when optimizing the gate bias of each device for a minimum phase noise is currently under investigation. Moreover this difference dramatically increases at larger baseband frequencies since an average -30 dBc/decade slope is observed for MESFETs and must be compared with about -20 dBc/decade slope only for HEMTs. This is the consequence of the larger α ($\alpha \simeq 1$) of MESFETs. The Lorentzian LF noise spectrum of DX centers in HEMTs results in more phase noise at larger baseband frequencies (10 kHz - 100 kHz). To get better insight, into the way in which this LF noise is upconverted, the average upconversion coefficient (which is almost a constant between 1 kHz and 100 kHz) is given in table 2.

Device	A	B	C	D	E	F	G	H
K(MHz/V)	1.25	0.82	0.9	1.5	1.3	1	0.55	0.65

Table 2

Table 2 shows that in average the upconversion is 3 dB larger in HEMTs than in MESFETs. For example, the GOULD devices exhibit 3dB difference in upconversion and a 10dB difference in LF noise which correctly accounts for the 12dB difference observed in the phase noise at 10 kHz off the carrier. Also worth mentioning is the fact that HEMTs from LEP and THOMSON**(F,H)** exhibits the smallest K which accounts for the smallest phase noise of these devices in comparison with other HEMTs.

It is therefore possible to conclude that HEMTs are not suitable yet for low noise oscillator applications because :

(i) they exhibit a larger low frequency noise partly due to DX centers in the GaAlAs layer, responsible for GR noise in the 10 kHz frequency range and therefore for the extra phase noise at the corresponding baseband frequencies

(ii) they feature a larger upconversion of this noise in the microwave range which probably denotes a non-linearity stronger than in MESFETs.

However future HEMTs will probably overcome these drawbacks provided that :

(i) a more matured technology results in less LF noise

(ii) a precise analysis of the nonlinear behavior results in a better design of the device and of the embedding circuits which may differ from those known to ensure a minimum phase noise in MESFET's oscillators.

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