lithic amplifier have been realized using the theory. The results obtained confirm the value of the synthesis approach used. The amplifiers are to be used for optical detection at very high data rates.

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Output Conductance Frequency Dispersion and Low-Frequency Noise in HEMT's and MESFET's

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Abstract —**In this paper it is reported that the large low-frequency noise observed in MESFET's and HEMT's in the saturation regime usually scales with the device output conductance frequency dispersion (in MESFET's) or with the parallel conduction through the GaAlAs (in HEMT's).**

I. Introduction

Both GaAs MESFET's and HEMT's exhibit a large low-frequency noise, which severely limits the possible applications of these devices for wide-band and dc coupled amplifiers, digital analog converters, low-noise oscillators, and mixers [1]–[4].

On the other hand, frequency dispersion of the output conductance of MESFET's [5] is a serious problem for the design of analog circuits such as power amplifiers and certain digital circuits [6].

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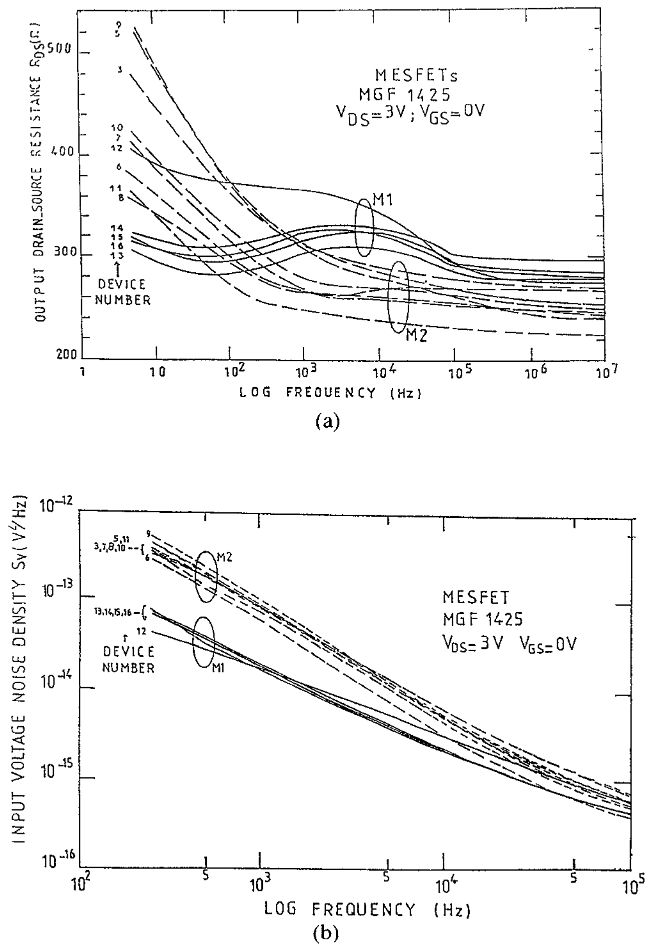

Fig. 1 (a) Frequency dependence of small-signal output drain–source resistance for a set of 13 MESFET's measured in saturation regime at $V_{ds} = 3$ V and $V_{gs} = 0$ V. (b) Spectral noise input voltage for the set of 13 MESFET's measured in saturation regime at $V_{ds} = 3$ V and $V_{gs} = 0$ V.

It has been proposed recently [7] that deep levels of this type can cause low-frequency noise and output conductance frequency dispersion. The present paper first experimentally investigates whether such a correlation between LF noise and conductance dispersion can be observed among some commercially available MESFET's. Second, this paper investigates whether commercially available HEMT's exhibit a similar behavior.

II. Measurements

We have investigated simultaneously a set of 13 commercially available MESFET's (MITSUBISHI MGF 1425) and a set of ten commercially available HEMT's (MITSUBISHI MGF 4303). We have successively performed room-temperature measurements on each device concerning a) the low-frequency input voltage noise spectral density between 250 Hz and 100 kHz, b) frequency dispersion of the output drain-source impedance $Z_d(f)$ in the frequency range 5 Hz–10 MHz, and c) static g_m variations versus gate bias. The drain bias was fixed at 3 V (MESFET) and 2 V (HEMT), and the gate bias was taken to be zero for the first and second sets of measurements.

All measurements were controlled and corrected by software. The noise measurement system has been reported elsewhere [4].

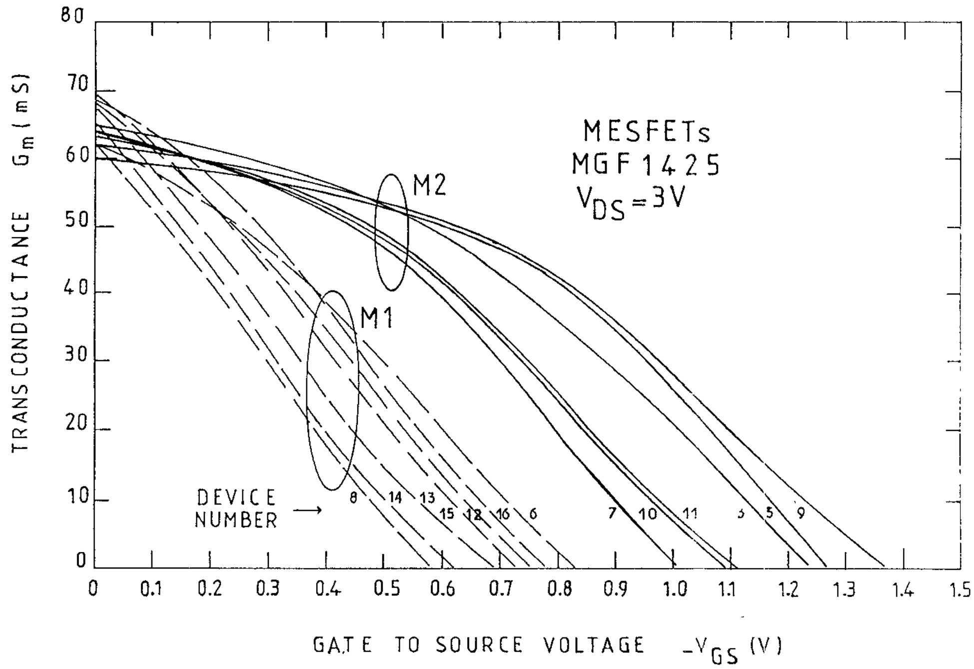

Fig. 2. Transconductance versus gate voltage for a set of 13 MESFET's measured in saturation regime at $V_{ds} = 3$ V.

III. Experimental Results

A. MESFET's

Output impedance frequency dispersion in MESFET's is reported in Fig. 1(a). Results suggest that the investigated set of ten devices can be divided into two subsets:

- Subset M1 (devices referred to as 12, 13, 14, 15, 16) corresponds to devices exhibiting a small dispersion.
- Subset M2 (all others devices) corresponds to devices with a large dispersion between 5 Hz and 1 Hz.

The low-frequency input noise is displayed in Fig. 1(b). Once again experimental data indicate clearly that the two subsets mentioned previously exhibit different noise behaviors. The noise at 1 kHz is approximately 6 dB higher for subset M2, which corresponds to the largest dispersion. Moreover in Fig. 2, which displays the g_m variations versus gate bias, it is apparent that most of the devices from subset M2 exhibit the highest V_t and the highest g_m at gate bias in the range of $V_t/2$. Moreover at a gate bias different from zero, devices from subset M1 have a low g_m decreasing more rapidly with gate bias.

B. HEMT's

Output impedance dispersion for the ten different devices are displayed in Fig. 3(a). Once again two different subsets have to be considered:

- Subset H1 (devices referred to as 1, 2, 4, 5, 6, 7), where the dispersion frequency range is similar to that observed in MESFET's.
- Subset H2 (all other devices), where the dispersion occurs in the low-frequency range, beyond 100 Hz.

Noise data shown in Fig. 3(b) indicate:

i) that the average low-frequency noise at 10 kHz is worse by approximately 5 to 20 dB than the LF noise of MESFET's;

ii) that such a high noise level is the consequence of the existence of an LF noise floor so that the LF noise remains essentially constant between 100 Hz and 10 kHz while it decreases as $1/f^{\alpha}$ $(0.5 < \alpha < 1.5)$ in the MESFET's;

iii) that most of the devices from subset H1, which exhibits the smallest dispersion above 100 Hz, experience also the worst LF noise. Moreover the high-frequency output resistance of the H1 devices is approximately 50 percent higher when compared to the H2 devices.

Finally g_m variations versus V_{gs}, shown in Fig. 4, indicate that only devices from subset H2 have a large g_m while devices from subset H1 exhibit either a negative differential g_m at gate biases larger than $|V_t/2|$ (devices 1, 2, 5, 7) or an abnormally low g_m (devices 4 and 6).

IV. Discussion

A. MESFET

Recently published results [10] have established that the frequency dependence of output impedance in the very low frequency range is due to the presence of EL2 centers. Present results confirm that the presence of traps such as EL2 centers at the active layer–substrate or buffer interface simultaneously induce a large LF noise and significant conductance frequency dispersion. Moreover, the presence of traps is also responsible for a shift of the threshold voltage.

B. HEMT

Source–drain conductance in HEMT's has already been found to significantly change under pulsed conditions when compared to the static case [8], while other authors find [9] that the output conductance shows no frequency dispersion.

Our data show that output conductance dispersion can be present in HEMT's but the dispersion frequency range involved (below 1 kHz) is somewhat less than the dispersion frequency range in MESFET's. Moreover the noisiest HEMT's (H1) are those exhibiting smallest dispersion, the highest output resistance, and the smallest g_m. Therefore in contrast to the case in

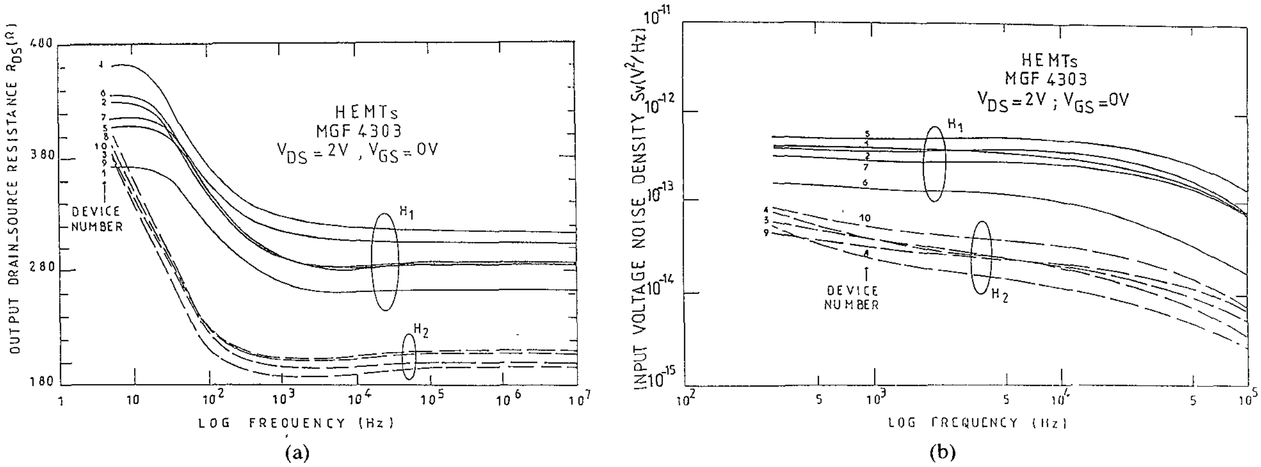

Fig 3 (a) Frequency dependence of small-signal output drain–source resistance for a set of 10 HEMT's measured in saturation regime at $V_{ds} = 2$ V and $V_{gs} = 0$ V (b) Spectral noise input voltage for a set of 10 HEMT's measured in saturation region at $V_{ds} = 2$ V and $V_{gs} = 0$ V

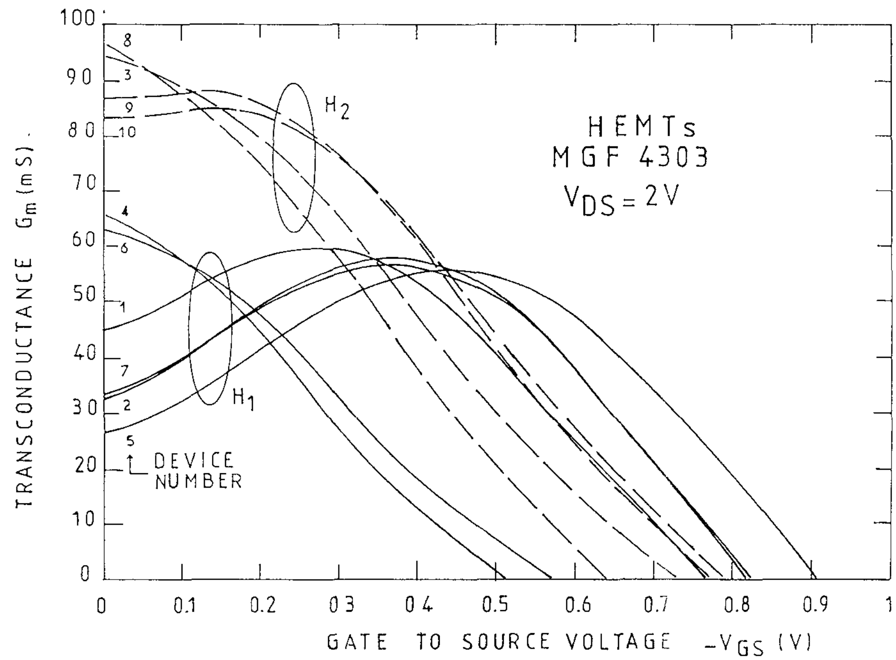

Fig 4. Transconductance versus gate to source voltage for a set of 10 HEMT's measured in saturation regime at $V_{ds} = 2$ V

MESFET's we cannot expect dispersion and LF noise to have the same origins in HEMT's as in MESFET's.

Present results indicate also that LF noise is enhanced in those devices which experience both a low g_m and a negative differential g_m, a behavior commonly observed in HEMT's if some parallel conduction occurs through the GaAlAs. Therefore parallel conduction in the GaAlAs layer is not only responsible for low values of g_m, and (or) negative differential g_m; it also contributes to the low-frequency generation–recombination noise. However, output impedance is not degraded but enhanced as a consequence of some degradation of mobility caused by electron scattering with impurities in the GaAlAs layer.

V. Conclusion

Low-frequency noise and output resistance frequency dispersion are closely related in MESFET's operated under saturation conditions. Low-frequency noise and parallel conduction appear to be closely related in HEMT devices and do not seem to be directly related to output resistance frequency dispersion. However, the fundamental reason for the origin of output resistance dispersion in HEMT's is still unknown. Thermal feedback effects, low-frequency variations of series resistances, and trap-related effects are among possible origins that require investigation.

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Optimal Computer-Aided Design of Monolithic Microwave Integrated Oscillators

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Abstract —**A technique for the optimal computer-aided design of MMIC oscillators is described. A novel dual-source technique is used in conjunction with the device computer simulation in order to obtain the terminating impedances required by the FET, which ensures the optimal circuit conditions to obtain the required frequency and power output from the oscillator. A number of GaAs MESFET MMIC oscillators have been designed and fabricated. Experimental results agree very closely with the predicted data for the complete set of working circuits.**

I. Introduction

GaAs MESFET's are widely used to build microwave oscillators [1]–[4]. Various design techniques have been developed which are commonly based on device large-signal measurements. Improved results can be achieved by using these techniques, compared with those obtained chiefly from methods based on small-signal S parameters of the devices, because the effect of the nonlinear behavior associated with the MESFET's has been included in the design of the microwave oscillators. However, the techniques become questionable when the signal level, harmonic content, and terminating impedances of the FET's deviate from those present during the original device characterization.

In view of the shortcomings of these existing large-signal techniques, a new microwave oscillator design technique has recently been developed and used successfully in the design of both MIC and MMIC oscillators. The new technique enables optimum performance to be obtained from the device, as well as ensuring that the circuit operates to required specifications. By using a dual-source technique, there is no limitation imposed by the terminations on the FET's response, and the terminating impedances are automatically and exclusively determined by the characteristics of the FET itself rather than being chosen and/or adjusted empirically by the designer. The passive embedding circuit used to form the oscillator is designed in such a way that it presents terminating impedances to the device equivalent to those obtained during the device simulation. In this way, optimum performance of the device and accurate prediction on both output power and frequency are achieved.

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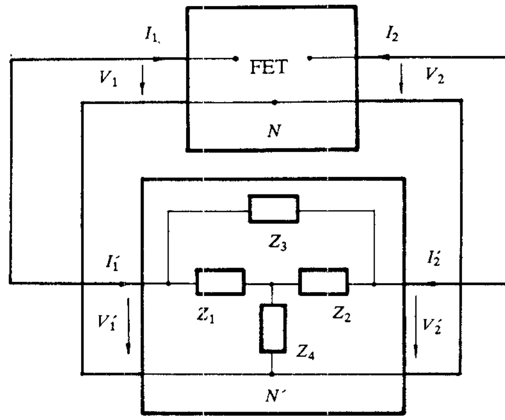

Fig. 1 Interconnection of the device N and the passive embedding network N′.

II. Microwave Oscillator Design Technique

Details of the theoretical aspects of this technique and design equations concerning fundamental frequency components and parallel feedback circuits have been given in [4]. In this section, the design equations which have been extended to account for harmonic components and combined parallel and series feedback configurations are presented. The basic procedures of the technique are also outlined in the steps (a) and (b) below.

(a) Taking the active device without embedding elements as a two-port N (Fig. 1), apply two voltage sources $V_1(t)$ and $V_2(t)$ to port I and port II respectively and obtain the current responses in each port, (namely $i_1(t)$ and $i_2(t)$). The time-domain variables are transformed into the frequency domain so that $V_{1,h}$, $V_{2,h}$, $I_{1,h}$, and $I_{2,h}$ are obtained, where $h = 0,1,2,\cdots,H$ represents the variables at the hth harmonic and H is the number of harmonics of significance. Optimization, for maximum output power or harmonic content as required, should be performed in this stage.

(b) Using the optimized $V_{1,h}$, $V_{2,h}$, $I_{1,h}$, and $I_{2,h}$ as the port variables, the passive embedding 2-port network, N′, is synthesized (Fig. 1).

Step (a) can be carried out by using equivalent circuit models or physical modeling techniques. The circuit model of GaAs MESFET's using SPICE II as a tool of simulation can be found in [5]. The details of the physical modeling technique developed by one of the authors, which has been used in the oscillator design, were described previously [3].

The use of two sources in step (a) to simulate the isolated FET is emphasized, because it results in several special features and advantages of the technique.

(i) Since the current flowing through a voltage source (with given voltage value) is determined *exclusively* by the