DESIGN OF GaAs MESFET OSCILLATOR USING LARGE SIGNAL S-PARAMETERS

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Abstract

A design method of GaAs MESFET oscillator using large signal S-parameters has been discussed. Together with the measurement results of the dependence of large signal S-parameters on power level and bias condition, computer analysis of the equivalent circuit for MESFET's has qualitatively clarified the large signal properties of MESFET's. On the basis of these S-parameters has been designed the MESFET oscillator over the frequency range of 6-10 GHz, which has resulted in power output of 45 mW at 10 GHz with 19% efficiency and 350 mW at 6.5 GHz with 26% efficiency respectively. Good agreements between predicted and obtained performance of MIC positive feedback oscillator have been ascertained, verifying the validity of the design method using large signal S-parameters.

Introduction

Excellent performances of GaAs MESFET's in frequency[1] and power[2] have provoked the attention of microwave system engineers to the design of GaAs MESFET oscillators[3,4] as a microwave power source or a local oscillator. Since microwave oscillators using GaAs MESFET's operate under large signal condition, circuit designers have been forced to utilize cut and try methods to achieve the optimum design, modifying the design with small signal S-parameters. This paper describes a successful design method of low noise GaAs MESFET oscillator using measured large signal S-parameters[5].

Large Signal S-Parameters

Each transistor used in this experiment has a 1 μm long and 300 μm wide gate, a channel doping of $7\text{-}9 \times 10^{16}$ cm^{-3} and pinch off voltage of 4.0 V nominally, which is mounted in a microdisk package.

Large signal S-parameters measured can be used to calculated gate and drain rf current amplitudes $|\tilde{i}_{gs}|$ and $|\tilde{i}_{ds}|$ as a function of the available power of signal generator P_I;

$$P_I = |a_i|^2 \quad (i = 1,2) \tag{1}$$

$$S_{11} = \left(\frac{b_1}{a_1}\right)_{a_2=0} = \frac{Z_{L1} - Z_O}{Z_{L1} + Z_O} \tag{2}$$

$$P_I(1 - |S_{11}|^2) = \frac{1}{2}\mathrm{Re}(Z_{L1})\,|\tilde{i}_{gs}|^2 \tag{3}$$

$$S_{22} = \left(\frac{b_2}{a_2}\right)_{a_1=0} = \frac{Z_{L2} - Z_O}{Z_{L2} + Z_O} \tag{4}$$

$$P_I(1 - |S_{22}|^2) = \frac{1}{2}\mathrm{Re}(Z_{L2})\,|\tilde{i}_{ds}|^2 \tag{5}$$

where Z_{L1}, Z_{L2} are the input and output impedance of FET and $Z_O = 50\,\Omega$.

Large signal S-parameters of this device have been measured by a standing wave method for S_{11}, S_{22}, by a direct observation of transmission power for $|S_{21}|$, $|S_{12}|$, and by a magic T method for $\angle S_{21}$, $\angle S_{12}$ at power levels ranging from -10 dBm to 20 dBm, over the frequency range of 6.0 - 10.0 GHz.

The typical results of the dependence of the amplitudes $|S_{ij}|$ on the incident power levels at 10.0 GHz are shown in Fig. 1. No significant variations of phase angles of S-parameters have been detected. When gate was biased in the range of $V_p/2 \pm 1.0$ V in this power range, the changes of input parameters $|S_{11}|$, $|S_{21}|$ have not so strongly been dependent on the signal levels as those of output ones $|S_{22}|$, $|S_{12}|$.

Computer analysis of the well known lumped element equivalent circuit for MESFET's has clarified that the remarkable changes of $|S_{22}|$ and $|S_{12}|$ with the increase of power level, as indicated in Fig. 1, are mainly due to the increase of drain conductance and feedback capacitance.

Oscillator Design

Using these large signal S-parameters, the parallel feedback FET oscillator under common source has been designed which is, as indicated in Fig. 2, composed of an input matching circuit (characteristic impedance Z_A, electric length θ_A), a short transmission line between source and earth (Z_B, θ_B), a feedback network from drain to gate (Z_C, θ_C) and an output matching circuit (Z_D, θ_D). This oscillator contains a series feedback element, corresponding to the part B in Fig. 1.

Design procedure is as follows. Output, impedance at drain terminal ($Z_{out} = -R_O + jX_O$) is calculated as the function of Z_A, Z_B, Z_C, θ_A, θ_B, θ_C and the large signal S-parameters. Fig. 3 illustrates the calculated result in the case of f = 10.0 GHz, Z_A, $Z_C = 50\,\Omega$, $Z_B = 30\,\Omega$, $B = \pi/12$, where the shaded area represents the negative resistance region. As the power level in the S-parameter measurement increases, the negative resistance region shrinks toward points P, Q and R. In this circuit configuration, an area, where the maximum negative resistance is obtained at the small signal level, does not necessarily mean the condition of stable oscillation. We have adopted the circuit condition of either P, Q or R, as the optimum design point of FET oscillator.

Fig. 4 shows the dependence of $-R_O$ and X_O on the rf output current amplitude $|\tilde{i}_O|$ calculated at the point Q in Fig. 3. It is found that $|-R_O|$ does not decrease linearly with the increase of $|\tilde{i}_O|$ and the change of X_O is relatively small, because of the slight variation of $\angle S_{ij}$. From Fig. 4, the optimum load conditions (Z_D, θ_D) are determined and the oscillation power and efficiency are estimated.

Experimental Results

On the basis of the above mentioned procedure, oscillator circuits have been fabricated on alumina ceramic substrates. A photograph of one of the fabricated oscillators is shown in Fig. 5.

When the circuit elements have been adjusted to points S, P, Q by turns in Fig. 3, maximum oscillation powers have been obtained near the point P ($f = 9.95$ GHz, $P_{out} = 45$ mW, $\eta = 19.1\%$) and the point Q ($f = 10.05$ GHz, $P_{out} = 38$ mW, $\eta = 16.2\%$). These results almost agree with the predicted powers and frequencies from Fig. 4. Fig 6 shows the output power, efficiency, oscillation frequency and drain currents as the function of drain voltage for the oscillator corresponding to the point Q.

As for the frequency sensitivity of the oscillator to drain and gate bias, $\Delta f / \Delta V_{ds} \simeq 10$-$30$ MHz/V and $\Delta f / \Delta V_{gs} \simeq 70$ MHz are obtained respectively.

Noise performances of these oscillators have also been measured. The FM and AM noise are -74 dB/Hz ($Q_{ex} \simeq 40$) and -156 dB/Hz respectively for the offcarrier frequency of 10 KHz at the point Q, which are comparable to those of a Gunn oscillator.

Several oscillators with center frequencies from 6 to 10 GHz have also been designed and an output power of 350 mW with 26% efficiency at 6.5 GHz have been obtained using five chips in parallel combination, in this case the effective gate width is 1500 μm.

Frequency dependence of maximum oscillation powers obtained with several kinds of FET samples indicates that the extrapolation leads to the maximum frequency of oscillation of the device 50 GHz.

Conclusion

FET for an oscillator design should be characterized by large signal S-parameters, which is to be expressed as a function of drain current amplitude $|\tilde{i}_{ds}|$ and gate current amplitude $|\tilde{i}_{gs}|$.

A design method of MESFET oscillator has been developed by taking these current amplitudes into consideration.

Predicted powers and frequencies have been obtained from fabricated MIC oscillators over the frequency range of 6 to 10 GHz, verifying the validity of the design method using large signal S-parameters.

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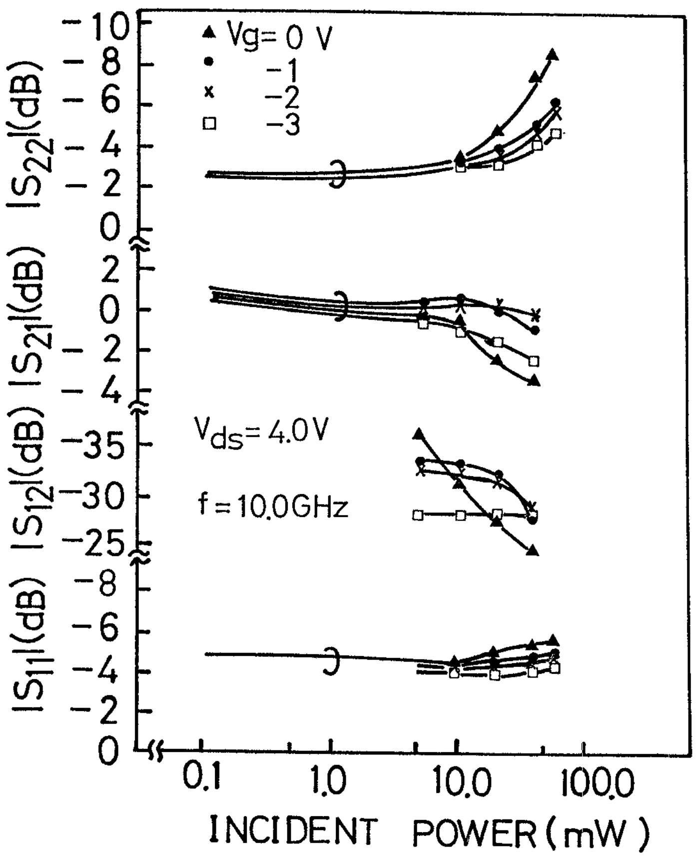

Fig.1 Dependence of the amplitude of the S-parameters on the incident power level.

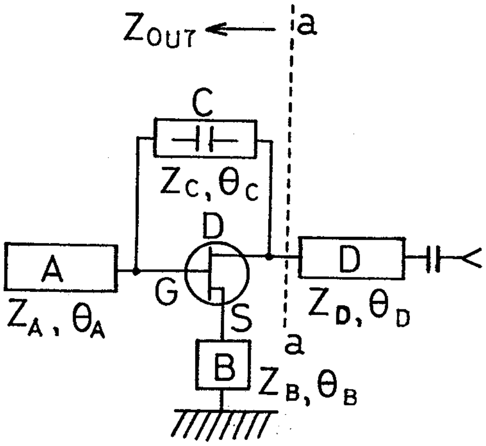

Fig.2 FET feedback oscillator configuration.

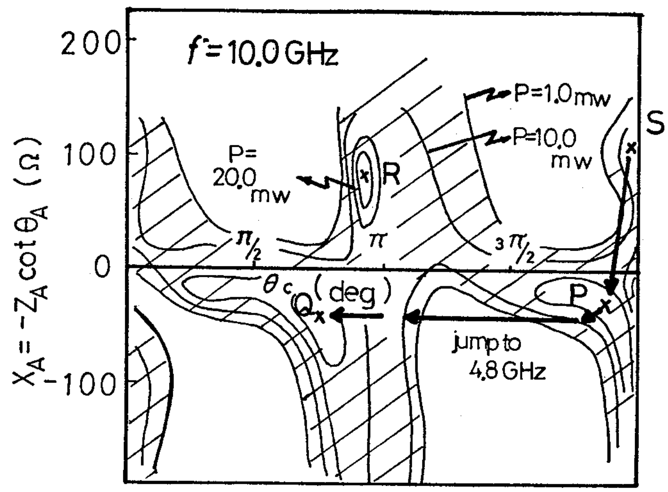

Fig.3 Calculated negative registance area as a function of θ_A, θ_C and the large signal S-parameters.

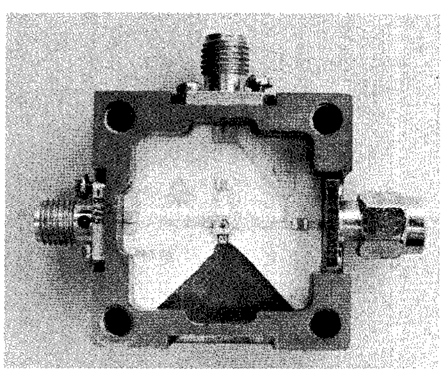

Fig.5 Photograph of an integrated X band FET oscillator

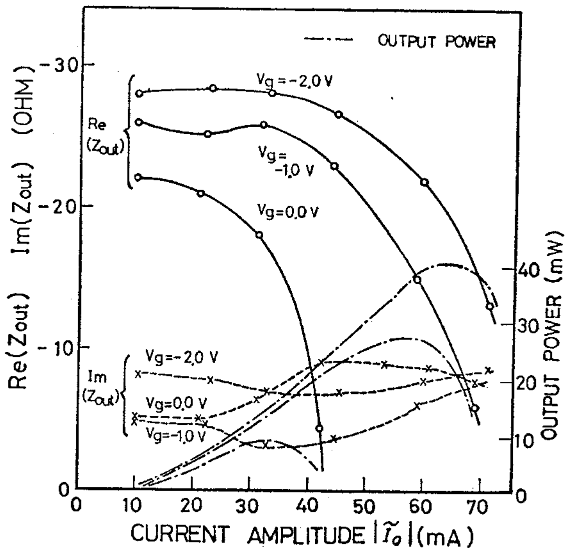

Fig.4 Dependence of Z_{out} on the RF current amplitude and the calculated power.

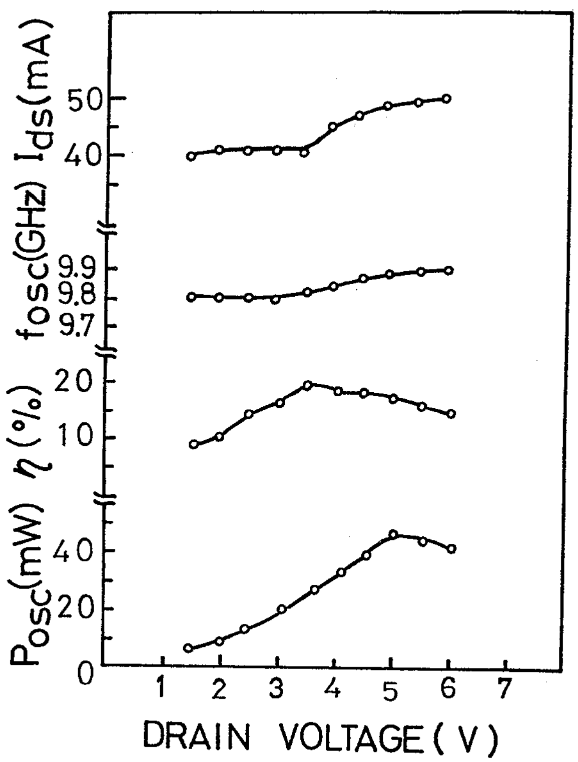

Fig.6 Microwave performance of X band GaAs m.e.s.f.e.t.