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Equal-Gain Loci and Stability of a Microwave GaAs MESFET Gate Mixer

Masahiko Shimizu and Yoshimasa Daido

Abstract—**The performance of a microwave GaAs MESFET gate mixer is theoretically investigated to clarify the existence of a conditionally stable RF frequency range as well as an unconditionally stable frequency range in which maximum available conversion gain (MACG) can be defined. For the unconditionally stable range, the MACG, and load and source impedances are calculated as functions of RF frequency. For the conditionally stable frequency range, the stability circle and equal gain loci are shown for source RF and load IF impedances. The conditionally stable region of the GaAs MESFET mixer appears around f_T of the MESFET. Higher conversion gain is easily obtained by choosing a MESFET of which the f_T is close to the RF frequency.**

I. Introduction

Since Pucel *et al.* reported the possibility of a GaAs MESFET mixer, many papers have demonstrated the advantages such a mixer confers with regard to conversion gain, better noise performance, and lower intermodulation products [1]–[4]. These papers have established that the mixer performance is determined by circuit conditions at RF, IF, local oscillator (LO), and image frequencies at both drain and gate ports. Better noise performance is obtained by shorting LO output, IF input, image input, and image output circuits [2]. Higher conversion gain is obtained by providing a conjugate matching condition for input RF and output IF circuits [1]–[3].

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TABLE I
PARAMETER VALUES OF THE NONLINEAR ELEMENTS

I_{ds}		I_{fg}	
a	0.26	I_s (pA)	4.72
b	0.75	α	28.4
m	2.96	linear element	
p	0.14	R_g (Ω)	1.4
V_p (V)	1.18	R_d (Ω)	1.6
V_{bi} (V)	0.90	R_s (Ω)	0.7
V_{dss} (V)	0.50	L_g (nH)	0.06
I_{dsp} (mA)	80.6	L_d (nH)	0.05
τ (ps)	4.74	L_s (nH)	0.6
C_{gs}		R_{ds} (Ω)	1093
ϕ (V)	0.11	C_{ds} (pF)	0.06
C_{gs0} (pF)	0.84	$\tau_i = R_i C_{gs}$ (ps)	1.2
F_c	−5.51	C_{gd} (pF)	0.05

However, there are still unknown factors. For example, no paper has yet described an RF frequency range in which instability may occur. This paper describes the calculated performance of a GaAs MESFET gate mixer to determine the conditionally stable RF frequency range. Separation of frequency ranges means that two different approaches are required in the design of the GaAs MESFET mixer. Thus, maximum available conversion gain (MACG), and load and source impedance will be calculated as functions of RF frequency in the unconditionally stable frequency range. In the conditionally stable range, equal gain loci will be calculated for RF source and IF load impedance.

II. Calculation Method of GaAs MESFET Gate Mixer Performance

Since the LO level is much higher than the RF level, the RF signal can be regarded as a perturbation superposed on the LO signal. Thus, large-signal drain and gate currents are calculated for the LO signal. We have calculated derivatives of periodically varying drain and gate currents with respect to gate and drain voltage. The conversion matrix [1] is determined using products of these derivatives and RF signal. In these calculations, the equivalent circuit for the GaAs MESFET is the same as that given in [5]. Three nonlinear elements are assumed: the drain current I_m, the gate–source capacitance C_{gs}, and the forward gate current I_{fg}. These elements are given by [5, eqs. (8)–(10)]. Parameter values of the nonlinear elements are listed in Table I and are determined by the following method. First, I_m, C_{gs}, and I_{fg} are fitted from dc $I-V$, $C_{gs}-V_{gs}$, and diode characteristics, respectively. Next, g_m, $\partial I_{ds}/\partial V_{ds}$, and C_{gs} are calculated at a bias using the nonlinear parameters. Calculated g_m and C_{gs} are compared with those determined from S parameters measured at the same bias. C_{gs} as determined by the former method is multiplied by a constant to set its value equal to that determined by the latter method. A correction to g_m is also made by multiplying another constant by the drain current determined by dc $I-V$. A linear parallel resistance R_{ds} is added to set the derivative of the drain current with respect to V_{ds} equal to that determined by the latter method. Parameters in Table I show corrected values. Remaining circuit elements are also listed in the table.

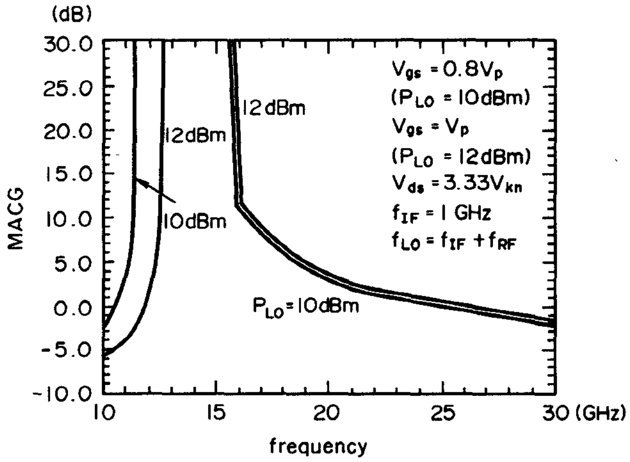

Fig. 1. Maximum available conversion gain (MACG) versus RF frequency. Pinch-off voltage is $V_p = -1.8$ V, and knee voltage is $V_{kn} = 0.6$ V.

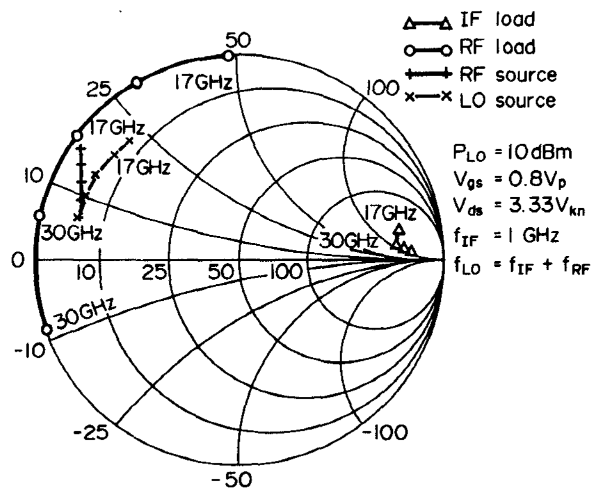

Fig. 2. Matching impedances versus RF frequency in unconditionally stable region.

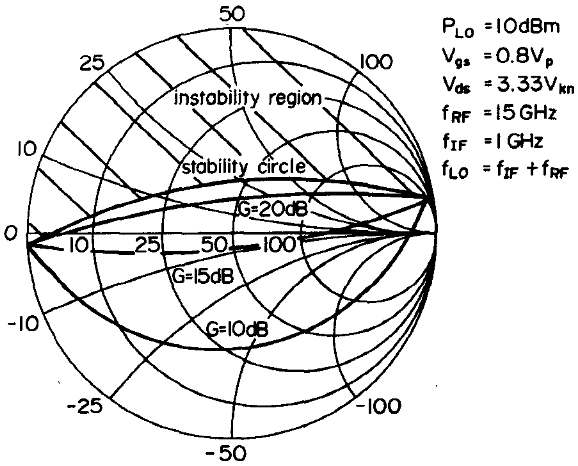

Fig. 3. Stability circle and equal gain loci (IF load impedance) at RF frequency of 15 GHz in conditionally stable region. RF source impedance is matched to the input impedance of the FET.

To maximize conversion gain, bias conditions and the load and source impedances at the RF, image, and IF frequencies should be optimized. The optimized gate and drain bias is equal to 0.8 times the pinch-off ($V_p = -1.8$V) and 3.33 times the knee voltage of 0.6 V. The optimized LO level is 10 dBm. The load and source impedances should be optimized at the RF, image, and IF frequencies. Fortunately, Maas [2] has shown that the source impedance at the IF and image frequencies and the load impedance at the image frequency should be shorted to improve the noise figure. Camacho-Penalosa *et al.* [4] have pointed out the existence of an optimum RF load impedance, which maximizes conversion gain. This paper also adopts the three impedances specified by Maas and the RF optimum load impedance. Thus, conversion gain can be calculated as a function of the RF source impedance, Z_{in}, and IF load impedance, Z_L.

III. Performance of GaAs MESFET Mixer

Fig. 1 shows the MACG as a function of RF frequency. This figure clearly shows that there is a frequency range in which the conversion gain is infinite. This infinite conversion gain corresponds to the existence of instability, which has been suggested by Maas [2] and confirmed by Camacho-Penalosa *et al.* [4]. At frequencies higher than 15 GHz, the tendency of the MACG is similar to that of $G_{a\max}$ of an amplifier. However, this figure shows that there is another region of unconditional stability at lower frequencies. The existence of two unconditionally stable regions is peculiar to the mixer. From a practical point of view, the conditionally stable region can be recommended for use if a high conversion gain is desired. Biased at 0.5 times the pinch-off voltage, f_T of the MESFET is about 15 GHz. It can be said that the conditionally stable region appears around f_T at this gate bias.

Fig. 2 shows the impedance loci to realize the MACG. As pointed out in [4], there is an optimum RF load impedance. This is shown in Fig. 2 as the locus marked with open circles. The imaginary part of the optimum RF load impedance is considered to cancel the drain–source capacitance and to shift the point of the short circuit from the drain terminal to just at the current source, I_m.

In the conditionally stable RF frequency region, circuit stability should be clarified. Here the RF frequency is fixed at 15 GHz by way of example. To discuss stability, we should point out that stability is determined by the combination of RF source impedance and IF load impedance. Thus, the stability circle for an RF or IF impedance differs, depending on whether the other is fixed or arbitrary. Here, the stability of the IF load impedance is estimated without defining the RF source impedance. The results are shown in Fig. 3 together with the equal-gain loci. In this figure, the unstable region is hatched. The unstable region does not mean that the mixer is always unstable regardless of the value of RF impedance but rather that there is at least one RF impedance which makes the mixer unstable. This figure shows that the major part of the unstable region corresponds to an inductive IF load impedance, as expected (cancellation of C_{ds} by inductive IF impedance increases conversion gain).

Next, the IF load impedance is fixed at a value in the unstable region ($100 + j100$ Ω), and a stability circle of RF source impedance is calculated (Fig. 4). In this case, the stability circle almost coincides with the edge of the Smith chart, and the area outside of the Smith chart is unstable. As can be seen from the figure, instability can easily be avoided by increasing the real part of the RF source impedance slightly. However, the equal gain loci shown in this figure suggest that a highly accurate input RF matching circuit must be designed to obtain a conversion gain higher than 10 dB.

The impedance that corresponds to an infinite conversion gain is $0.36 + j18.91$ Ω. Fig. 5 shows the stability circle and equal

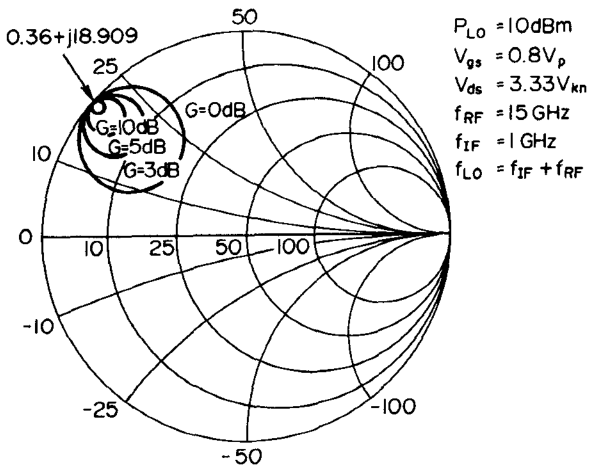

Fig. 4. Equal gain loci (RF source impedance) at RF frequency of 15 GHz. IF load impedance is fixed at $100+j100\ \Omega$.

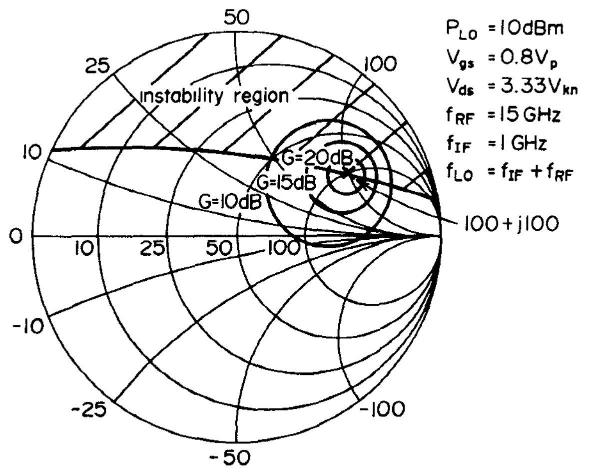

Fig. 5. Equal gain loci (IF load impedance) at RF frequency of 15 GHz. RF source impedance is fixed at $0.36+j18.91\ \Omega$.

gain loci of the IF load impedance under a fixed RF impedance of $0.36+j18.91\ \Omega$. At an IF output impedance of $100+j100\ \Omega$, the conversion gain is infinite, as expected. Fig. 5 shows that the tolerance of the IF load impedance is much wider than that of the RF source impedance. This means that the design accuracy of the RF input matching circuit mainly determines the maximum conversion gain.

IV. Conclusion

The MACG of a GaAs MESFET mixer has been estimated as a function of RF frequency under a fixed IF frequency of 1 GHz. The estimated conversion gain suggests that there are two unconditionally stable RF frequency regions. For the unconditionally stable RF frequency region, the optimum IF load impedance and the RF source impedance have been shown.

For the conditionally stable RF frequency region, stability circles and equal gain loci have been shown. The results suggest that instability can be avoided by increasing the RF source impedance slightly. The tolerance of the IF load impedance to obtain high gain is much wider than that of the RF source impedance. Thus, the maximum conversion gain of the actual mixer is mainly determined by the design accuracy of the RF source impedance.

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Projected Frequency Limits of GaAs MESFET's

J. Michael Golio and Janet R. J. Golio

Abstract —**Limits to the ultimate frequency performance which can be realized with GaAs MESFET's have been projected. These predictions are based on the reported performance of 137 devices fabricated between 1966 and 1988 and on first-order modeling. The predictions indicate that ultimate maximum frequency of oscillation values may approach 700 GHz while gain-bandwidth product values as high as 200 GHz may be realized.**

I. Introduction

The frequency limits of GaAs MESFET's have been extended each year since the device was first introduced in 1966 [1]. Most of the improvements have been realized by reducing the device dimensions (scaling). A study of scaling rules and limitations for GaAs MESFET's indicates that the physical properties of the device will require gate length dimensions to be greater than approximately 0.1 μm [2]. Although further reductions in gate length are technologically realizable, such devices will not exhibit improved frequency characteristics and will be useful only for a very limited number of applications.

Like the previous work, the present investigation confronts the scaling problem using an empirical–statistical approach in combination with some simple theoretical relationships. Gallium arsenide device manuscripts listed in the indexes of the IEEE Transactions on Microwave Theory and Techniques, the IEEE Transactions on Electron Devices, and the IEEE Electron Device Letters between 1966 and 1988 were considered for the investigation. During the early years of GaAs FET development, when few reports in the literature were available, other technical literature sources were also utilized. If the published report was not specifically stated to be for power or specialized applications, and information on at least two of the design details regarding gate length, epi-thickness, or doping density of the active channel was included, the device was used

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