Stability analysis of optically controlled MESFET based amplifier using S parameters

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Abstract—**The performance of a microwave GaAs MESFET gate amplifier is theoretically investigated to verify the effect of illumination on the stability circles and gain circles of a conditionally stable device. The theoretical investigation was carried out at different frequencies of interest.**

Index Terms—**Optical illumination, Unconditional stability, Conditional stability, Stability circles, Gain circles**

I. Introduction

Current approaches to amplifier design at RF need special considerations. At RF voltage and current waves impinge upon the active device and this makes it necessary to have appropriate matching to reduce undesirable oscillations.

The stability analysis is usually the first step in the design process and, in conjunction with gain circles, is a basic ingredient needed to develop amplifier circuits.

As not much work has been done to find the stability and performance of the designed MESFET amplifier, in present paper an attempt has been made do theoretical investigation of stability and performance of the designed amplifier. The effect of illumination on the stability circles and gain circles of a conditionally stable device is also investigated.

II. Theory

The most important requirements that an amplifier circuit must meet is a stable performance in the frequency range of interest. This is necessary because RF circuits tend to oscillate depending on operating frequency and termination.

The two port amplifier can be characterized through its S-parameters and external terminations described by reflection coefficient at the load side Γ_L and reflection coefficient at the source side Γ_S. Since the S parameters are fixed for a particular frequency, the only factors that have a parametric effect on the stability are Γ_L and Γ_S.

Stability then implies that the magnitudes of reflection coefficients are less than unity because if reflection coefficients are lesser than unity it causes a diminished return voltage wave (negative feedback) otherwise there will be oscillations for positive feedback.

Depending upon input reflection coefficient (Γ_{in}) and output reflection coefficient (Γ_{out}) we define two types of stability [1]:

1. *Unconditional stability:* The network is unconditionally stable if $|\Gamma_{in}| <1$ and $|\Gamma_{out}| < 1$ for all passive source and load impedances (i.e., $|\Gamma_L| <1$ and $|\Gamma_S| < 1$).
2. *Conditional stability:* The network is conditionally stable if $|\Gamma_{in}| <1$ and $|\Gamma_{out}| < 1$ only for a certain range of passive source and load impedances. This case is also referred to as potentially unstable.

The values of input reflection coefficient (Γ_{in}) and output reflection coefficient (Γ_{out}) can be determined as [1]

$$\left|\Gamma_{in}\right| = \left|\frac{S_{11} - \Gamma_L \Delta}{1 - S_{22}\Gamma_L}\right| < 1. \quad (1)$$

$$\left|\Gamma_{out}\right| = \left|\frac{S_{22} - \Gamma_s \Delta}{1 - S_{11}\Gamma s}\right| < 1. \quad (2)$$

Where

$$\Gamma_L = \frac{Z_L - Z_O}{Z_L + Z_O}. \quad (3)$$

$$\Gamma_S = \frac{Z_S - Z_O}{Z_S + Z_O}. \quad (4)$$

$$\Delta = S_{11}S_{22} - S_{12}S_{21}. \quad (5)$$

The S parameters (S_{11}, S_{12}, S_{21} and S_{22}) can be determined by using Y-S parameter conversions as in [1]. The Y parameters of the MESFET can be derived from the set of equations presented in [2, 3].

The stability condition of a network is frequency dependent, so that it is possible for an amplifier to be stable at its design frequency but unstable at other frequencies.

For conditional finding the stable region can be facilitated by using Smith chart and p1otting the input or output

A. Stability circles.
B. Gain circles

A. Stability Circles

The stability circles are defined as the loci in the Γ_L (or Γ_S) plane for which $|\Gamma_{in}| =1$ (or $|\Gamma_{out}| = 1$). The stability circles are the boundaries between stable and potentially unstable regions of Γ_L and Γ_S. Γ_L and Γ_S must lie on the Smith chart ($|\Gamma_L|<1$ and $|\Gamma_S|< 1$ for passive matching networks).

In terms of the amplifier's output port for $|\Gamma_{in}| =1$, the output stability circle radius is given by [1]

$$r_{out} = \frac{|S_{12}S_{21}|}{\left||S_{22}|^2 - |\Delta|^2\right|} \quad . \tag{6}$$

The center of this circle is located at

$$C_{out} = \frac{(S_{22} - S_{11}^*\Delta)^*}{|S_{22}|^2 - |\Delta|^2} . \tag{7}$$

* Complex conjugate

Or

In terms of the amplifier's input port for $|\Gamma_{out}| =1$, the input stability circle radius is given by [1]

$$r_{in} = \frac{|S_{12}S_{21}|}{\left||S_{11}|^2 - |\Delta|^2\right|} \quad . \tag{8}$$

The center of this circle is located at

$$C_{in} = \frac{(S_{11} - S_{22}^*\Delta)^*}{|S_{11}|^2 - |\Delta|^2} . \tag{9}$$

For a given S parameters of the device at a particular frequency the input and output stability circles can be plotted on the smith chart. The region on the smith chart for which $|\Gamma_{in}| <1$ and $|\Gamma_{out}| < 1$ represent the stable region.For $|S_{11}| <1$, the origin is part of the stable region. However, for $|S_{11}| > 1$ the origin is part of the unstable region.

The two stability domains for the input stability circle. The rule-of-thumb is the inspection if $|S_{22}| < 1$, which leads to the conclusion that the center must be stable, otherwise the center becomes unstable for $|S_{22}|>1$.

B. Gain Circles

In addition to stability the device should give the desired gain is another important consideration in the amplifier design task. To understand the effect of illumination on the gain of the device we also plot gain loci for different illuminations. The centre and radius of the gain loci at input side is given by [1]

$$d_{gs} = \frac{g_s S_{11}^*}{1 - |S_{11}|^2 (1 - g_s)} . \tag{10}$$

$$r_{gs} = \frac{\sqrt{1 - g_s}\,(1 - |S_{11}|^2)}{1 - |S_{11}|^2 (1 - g_s)} . \tag{11}$$

Where

$$g_s = \frac{G_s}{G_{s\max}} . \tag{12a}$$

$$g_L = \frac{G_L}{G_{L\max}} . \tag{12b}$$

$$G_S = \frac{1 - |\Gamma_S|^2}{|1 - S_{11}\Gamma_S|^2} . \tag{12c}$$

$$G_L = \frac{1 - |\Gamma_L|^2}{|1 - S_{22}\Gamma_L|^2} . \tag{12d}$$

$$G_{S\max} = \frac{1}{1 - |S_{11}|^2} . \tag{12e}$$

$$G_{L\max} = \frac{1}{1 - |S_{22}|^2} . \tag{12f}$$

Similarly we can find the centre and radius of the gain loci at load side by replacing $S_{11}$by S_{22} and g_s by g_L.

III. Effect Of Illumination

When the device is illuminated at the gate terminal new charges are generated in the channel which change the intrinsic parameters of the device. The change in the charge concentration with illumination is because of the photo voltage developed across Schottky junction at the gate and can be calculated as in [4, 5].

Due to photovoltage developed across the device the gate bias changes by V_{op} that is net gate bias changes from V_{gs} to $(V_{gs}+V_{op})$.

IV. Results And Discussion

The MESFET under consideration is assumed to have a channel with Gaussian profile. The structure has a channel length of 0.25µm and active region thickness of 0.15µm with an opaque gate.

The Vds is set at Vp as the device is very sensitive at the pinchoff and Vgs=-0.5V. The opaque metallic gate is made of gold. This metal gate and the type channel region forms a Schottky barrier.

The Schottky barrier depletion region under the gate extends into the active region. It controls the cross section of the conduction channel under the gate and it modulates the channel conductivity. Hence it can modulate the drain to source current [4, 5]. The schematic of amplifier under consideration is shown in fig.1.The illumination falls on the gate of the device.

Fig. 2 shows the stability curves under dark for different frequencies (F_1=1.6GHz, F_2=6.4 GHz, F_3=12.8 GHz and F_4=25.6GHz).From the curve we can find the stable region as for the designed MESFET ($|S_{11}|<1$) and ($|S_{22}|<1$) so centre is the part of stable region. From the curves we can see the stable region changes with change in frequency.

Fig. 3 shows the gain curves under dark for different frequencies (F_1=1.6GHz, F_2=6.4 GHz, F_3=12.8 GHz and F_4=25.6GHz).From the curves we can see the change in the gain curves at different frequencies.

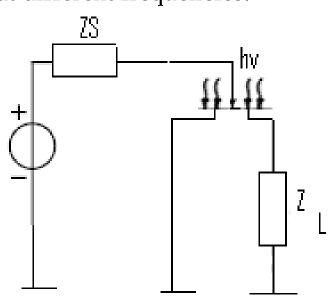

Figure 1. Schematic of amplifier

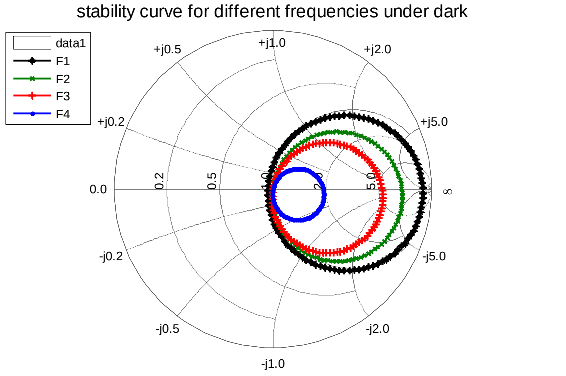

Figure 2. Effect of Frequency on input Stability curve under dark

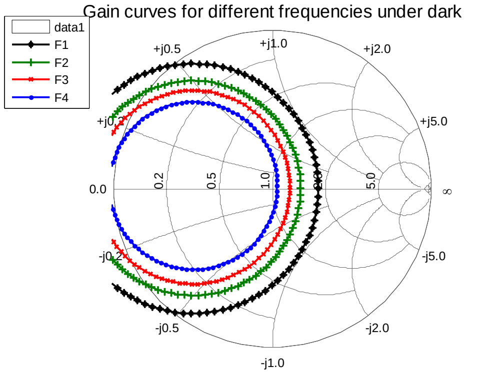

Figure 3. Effect of frequency on gain loci at the input side under dark

Fig. 4 shows the effect of illumination on the stability curves at 6.4GHz .It shows the stability curves for different illuminations ($phi_1=10^{10}$ Wb/m^3, $phi_2=10^{15}$ Wb/m^3 and under dark condition).From the curves we can find the stable region and can conclude that the stable region changes with change in illumination.

Fig. 5 shows the gain curve at a fixed frequency of 6.4GHz for different illuminations ($phi_1=10^{10}$ Wb/m^3, $phi_2=10^{15}$ Wb/m^3 and under dark condition).From the curves we can see that the radius of the gain curve is reducing as the illumination increases that is the gain is increasing. This is because as illumination increases the device transconductance increases hence the gain increases with the increase in illumination.

Efforts should be taken to set the operating point in the stable region may be at a gain less than desired.

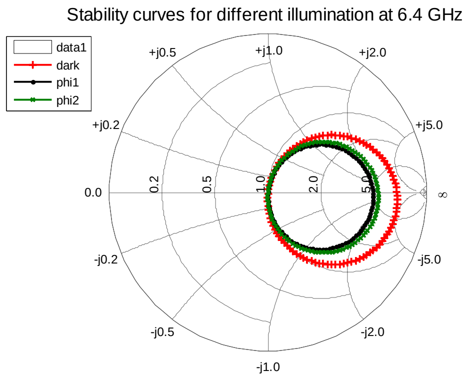

Figure 4. Effect of illumination on input Stability curve at 6.4 GHz

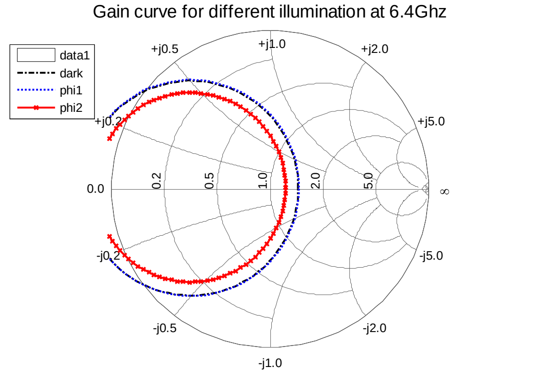

Figure 5. Effect of illumination on Gain at the input side Curve at 6.4 GHz

V. Conclusions

For the conditionally stable RF frequency region stability circles and gain loci have been shown. The results suggest that the stability and gain circles are not only affected by frequency, but also by the illumination conditions as the illumination changes the intrinsic parameters (like transconductance, Capacitances, Y-parameters, S-parameters).It was observed from the plots that gain of the device increase with increase in illumination.

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