FEEDBACK EFFECTS ON THE NOISE PERFORMANCE OF GaAs MESFETS

George D. Vendelin
Varian Associates
611 Hansen Way
Palo Alto, California 94303

Abstract

A technique is presented for evaluating the effect of lossless feedback on the four noise parameters of a transistor. The feedback effects on noise parameters are presented for a FMT940 GaAs MESFET at 4 and 8 GHz.

Introduction

The gain and stability factor of GaAs MESFETs are often varied by feedback effects which are introduced via the package or by the circuit design requirements [1]. Common-lead inductance (L_s) and gate-drain feedback capacitance (C_f) are usually the effects of packaging the device. In addition to the gain and stability factor, the noise parameters of the transistor are also changed. A technique for predicting the resulting changes in the four noise parameters will be presented for the two general cases of lossless feedback, series feedback X_s and parallel feedback X_f (see Fig. 1). From applying this technique to the measured noise parameters of a Fairchild FMT940 GaAs MESFET, the conditions required for varying the noise performance are presented. The result of this analysis will indicate the reasons for the higher noise figure and higher available gain which is measured for the FMT940 (stripline package) compared to the FMT980 (coaxial package) transistor.

Noise Parameters

The noise parameters for any two-port are given by either of the following relations, where the first set of parameters are usually given by the device data sheet.

$$F = F_{min} + \frac{R_n}{G_s} \left| Y_s - Y_{on} \right|^2 \qquad (1)$$

$$F = 1 + \frac{G_n}{G_s} + \frac{R_{no}}{G_s} \left| Y_s + Y_{cor} \right|^2 \qquad (2)$$

The equivalence between these two parameters sets are given by:

$$\left.\begin{aligned} F_{min} &= 1 + 2\, R_{no}(G_{cor} + G_{on}) \\ R_n &= R_{no} \\ G_{on} &= \left[\frac{G_n + R_{no}G_{cor}^2}{R_{no}}\right]^{1/2} \\ B_{on} &= -\, B_{cor} \end{aligned}\right\} \qquad (3)$$

$$\left.\begin{aligned} G_n &= R_n\,(G_{on}^2 - G_{cor}^2) \\ R_{no} &= R_n \\ G_{cor} &= \frac{F_{min} - 1}{2\, R_n} - G_{on} \\ B_{cor} &= -B_{on} \end{aligned}\right\} \qquad (4)$$

Hartmann and Strutt [2] have given the formulas for series and parallel feedback effects in terms of the second noise parameter set. A computer program has been written which uses the input noise parameters of Eq. (3), converts to the second parameter set Eq. (4), adds the lossless feedback transformations given by [2], and converts the result back to the noise parameters of Eq. (3). The results of this analysis are given below for the FMT940 transistor at 4 and 8 GHz. A similar analysis has been presented by Engberg [3] for a UHF bipolar transistor using the second parameter set Eq. (4) and the noise equivalent circuits given by Rothe and Dahlke [4].

Computed Noise Effects for FMT940

The following noise parameters and s-parameters are typical for the FMT940 at 4 and 8 GHz.

Noise Parameters and S-Parameters for FMT 940 at V_{DS} = 5 volts, I_{DS} = 10 mA

f GHz	F_{min} dB	R_n ohm	G_{on} mmho	B_{on} mmho
4	3.3	100	5	-13
8	5.0	35	34	-18

f GHz	S_{11}	S_{21}	S_{12}	S_{22}
4	.86∠-76	.82∠98	.031∠42	.87∠-50
8	.71∠-143	.84∠25	.035∠23	.86∠-101

The effect of adding lossless feedback has been plotted in Figures 2-6. For series feedback, the noise figure will be raised by a small inductance and lowered by capacitance or by reducing the common lead inductance. For parallel feedback, the noise figure can be reduced by increasing the input-output capacitance. Naturally the gain is correspondingly reduced and the minimum noise measure remains invariant to lossless feedback effects, where M_{min} is given by

$$M_{min} = \frac{F_{min} - 1}{1 - 1/g_{av}} \qquad (5)$$

and the resulting noise figure of an infinite chain of amplifiers is given by

$$F_{tot} = M_{min} + 1 \qquad (6)$$

The variations of Z_{on} given in Figures 5 and 6 are particularly significant for low-noise amplifier designs. By proper adjustment of the feedback elements, the condition for simultaneous gain and noise match can be found. This allows the amplifier designer to simultaneously achieve minimum input VSWR and optimum noise performance. Particular attention to stability is required for a useful amplifier design.

Computed Noise Effects for FMT 980 at 8 GHz

The reduced noise figure of the FMT980 (coaxial package) at 8 GHz is partially a result of the lower common-lead inductance of this package. From measuring short circuited packages, the common lead inductance is estimated at 0.16 nH and 0.08 nH for the stripline and coaxial package respectively. From Figure 2, this would correspond to a change in noise figure of about 0.2 dB, which also results in a change in available gain of about 1 dB. When the calculation for optimum noise performance F_{tot} is performed with the above changes in F_{min} and g_{av}, both transistors have a predicted noise figure of F_{tot} = 6.0 dB. Since the data sheet noise figure is 4.0 dB for the FMT980, the additional discrepancy is due to the package and fixture losses. When these losses are subtracted, the corrected value for F_{tot} is about 5.1 dB for both packages.

Conclusions

A technique has been described for analyzing the feedback effects on the noise performance of low-noise bipolar and field-effect transistor amplifiers. Computer programs which simultaneously predict gain and noise performance will enable low-noise feedback designs to follow. The technique may also be applied to the design of low-noise amplifiers with a minimum input VSWR.

References

(1) Les Besser, "Design Considerations of a 3.1-3.5 GHz GaAs FET Feedback Amplifier", Digest of Technical Papers, 1972 IEEE-GMTT International Microwave Symposium, pp. 230-232.

(2) K. Hartmann and M. J. O. Strutt, "Changes of the Four Noise Parameters Due to General Changes of Linear Two-Port Circuits", IEEE Trans. on Electron Devices, October 1973, pp. 874-877.

(3) Jakob Engberg, "Simultaneous Input Power Match and Noise Optimization Using Feedback", Digest of Technical Papers, European Microwave Conference, September 1974, pp. 385-389.

(4) H. Rothe and W. Dahlke, "Theory of Noisy Fourpoles", Proc. IRE, Vol. 44, June 1956, pp. 811-818.

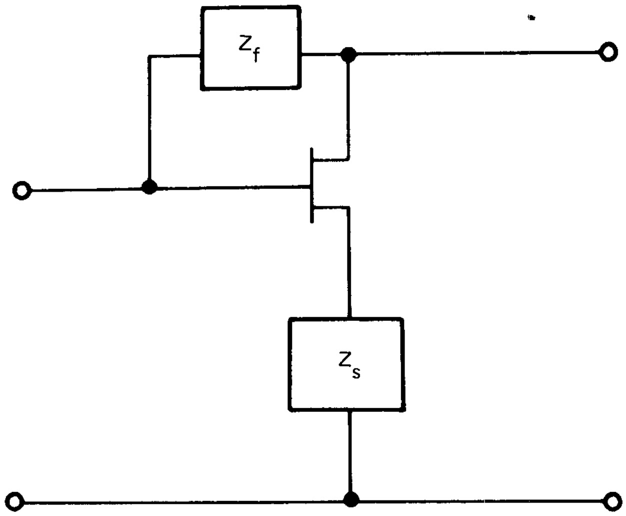


Figure 1. Parallel and series feedback for FET.

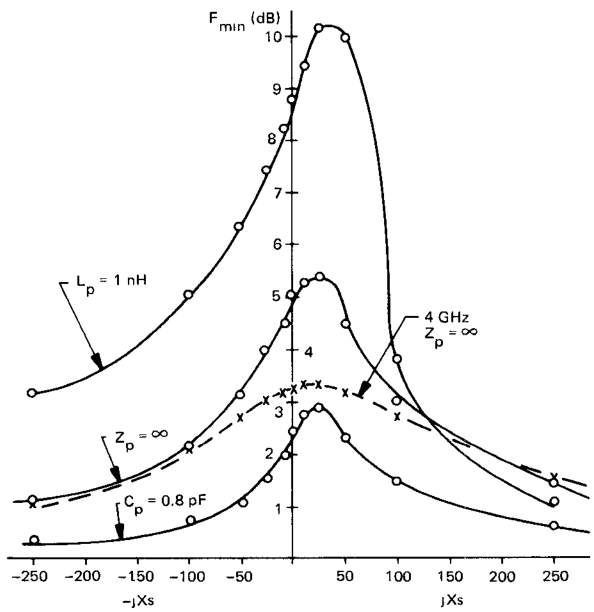


Figure 2. F_{min} vs series feedback for FMT 940 at 4 and 8 GHz.

Figure 3.
F_{min} vs parallel feedback for FMT 940 at 4 and 8 GHz.

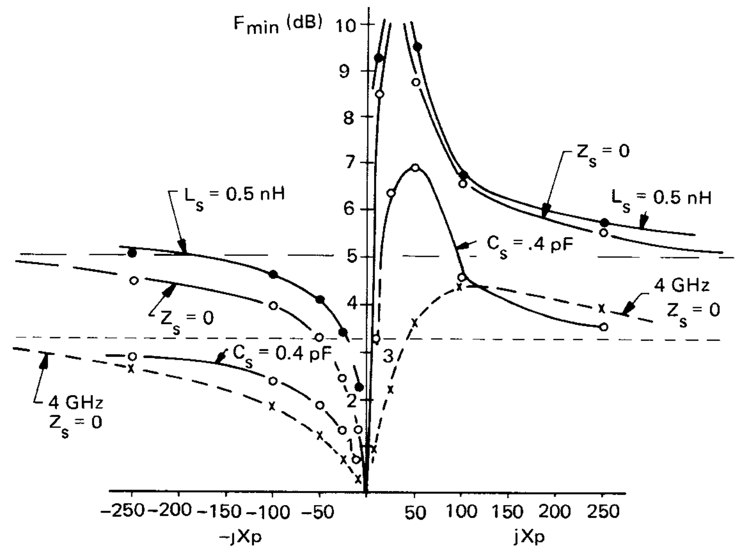
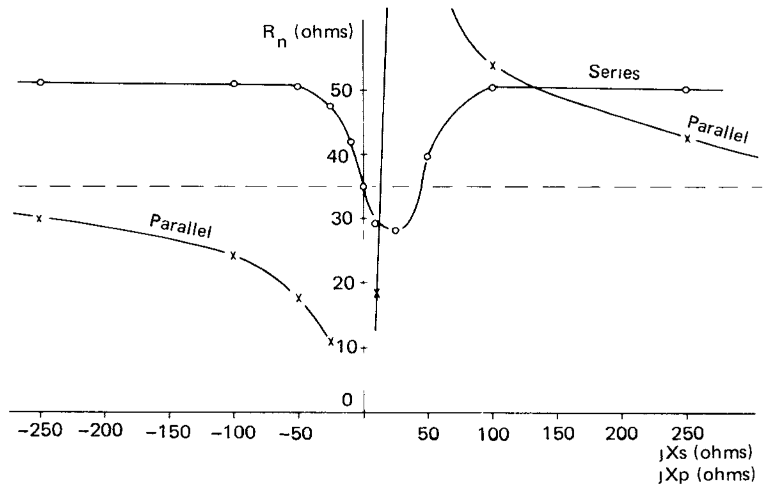


Figure 4.
R_n vs series and parallel feedback for FMT 940 at 8 GHz.



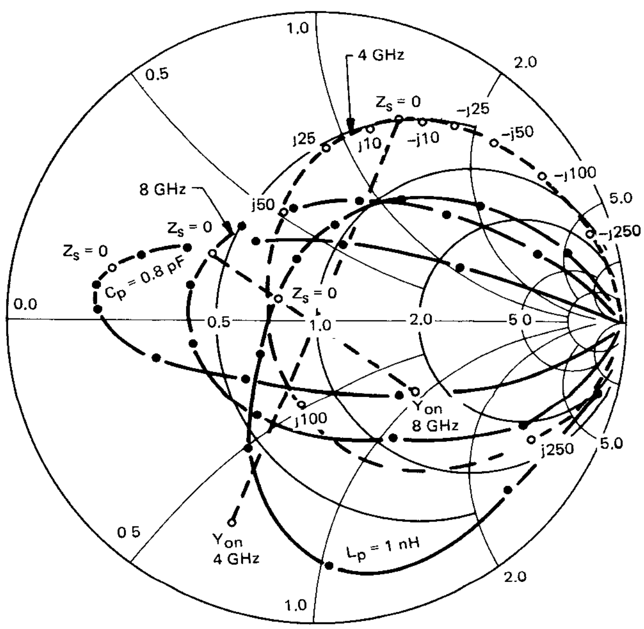


Figure 5. Optimum source impedance vs series feedback for FMT 940 at 4 and 8 GHz.

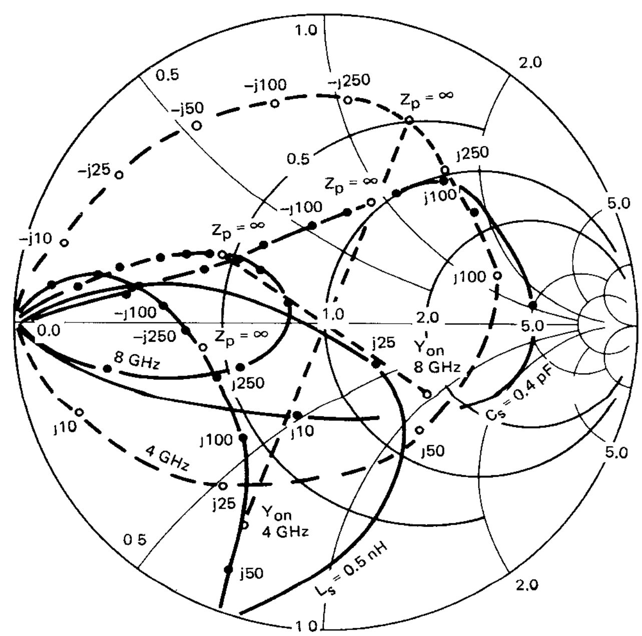


Figure 6. Optimum source impedance vs parallel feedback for FMT 940 at 4 and 8 GHz.