ULTRA-FLAT LOW-POWER PROCESS INSENSITIVE Ku-BAND HEMT FEEDBACK MMIC

D. R. Helms, M. J. Fithian
GE Electronics Laboratory, Syracuse NY 13221

ABSTRACT

A three-stage Ku-band MMIC amplifier, using feedback design and 0.25 µm gate-length single heterojunction HEMT devices, has demonstrated improved process insensitivity with state-of-the-art gain flatness and power dissipation. The amplifier exhibited 0.25 dB flatness from 11.4 - 12.4 GHz using less than 150 mW to deliver 25 dB gain.

INTRODUCTION

Highly flat and highly repeatable MMIC gain/drive blocks are essential for achieving maximum efficiency at the desired linearity in phased-array communication systems. Less than flat drive of linear power amplifiers decreases linearity when the drive peaks and reduces efficiency when the drive drops. Any loss in efficiency raises junction temperatures, reducing power amplifier life. Any loss in linearity increases bit-error-rates. MMIC repeatability, which is crucial in communication systems, cannot be achieved by minimizing process variations alone since reducing process error is essentially finite.

Remote communication systems require very low power dissipation Feedback amplifiers are notorious power users. This characteristic can be explained by the general set of equations:

$$S21 = (-2/\Sigma)[G_m R_{fb} - 1], \quad (1a)$$

$$S11 = S22 = (1/\Sigma)[R_{fb}/Z_0 - G_m Z_0], \quad (1b)$$

$$\Sigma = 2 + G_M Z_0 + R_{FB}/Z_0, \quad (1c)$$

which demonstrates that the amplifiers gain and return loss limits are a function of G_m and R_{fb}.

To achieve good return loss and adequate gain requires a large G_m (>100mS) and low feedback resistance (<350Ω). Table 1 compares typical devices used in feedback amplifiers. MESFETs average 125 ms/mm, while HEMTs average 330 ms/mm; thus, we require a HEMT approximately 37% the size of the MESFET with about the same ratio of current required. The smaller parasitics of the smaller 400 µm HEMT increases gain from 5 to 8 dB per stage Finally, the HEMT, per dB of gain,requires about 12% of the DC power required by the MESFET.

Table 1. Comparison of HEMTs and Typical MESFETs Used in X-Band Feedback Amplifiers.

Parameter	MESFET	HEMT
Gate width	800 µm	400 µm
G_m/mm	125 mS	330 mS
Vds minimum	3	2
Power required	270 mW	50 mW
Gain/stage	5 dB	8 dB
power/dB gain	54 mW	6.25 mW

PROCESS REPEATABILITY

MMIC repeatability requires design techniques that are very process tolerant. One technique often suggested is design centering, which, while useful in improving yield, has finite limits in MMIC reproducibility, that is, maintaining flatness requirements from one process lot to another. Other design techniques are needed to further reduce the effect of process variations on MMIC performance. One such approach uses resistive series and shunt feedback around the device.

Figure 1 demonstrates the process improvement resulting from feedback. Two very similar amplifiers were chosen: each amplifier was designed to operate from 11-13 GHz, using similar device peripheries, with three gain stages and comparable matching networks.

The first amplifier used extensive design centering, with a database of five MESFETs each from ten process cycles. The data was known to statistically represent the device. The second, a HEMT MMIC, replaced design centering with feedback and a statistical device model. Tables 2 and 3 compare the results shown on Figure 1.

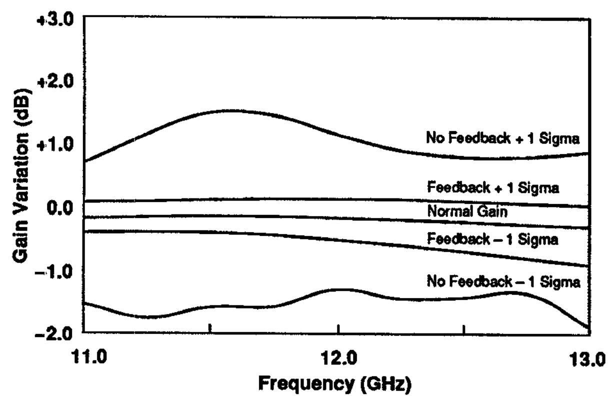

Figure 1. Gain Variations of Feedback vs Design-Centered Amplifiers.

Table 2. Gain Variation of Design-Centering Technique vs Feedback

Parameter	No Feedback	Feedback
Nominal	0.2dB	0.2dB
- sigma	0.7dB	0.1dB
+ sigma	0.5dB	0.4dB

92CH3162-5/92/0000-0017$01.00 © 1992 IEEE

As shown in Table 2, the feedback amplifier has approximately 45% of the ripple of the non-feedback amplifier. Table 3 demonstrates that the feedback amplifier has roughly 25% of the gain variation of the non-feedback amplifier.

Table 3. Gain Variation from Nominal with Normal Process Variation.

Parameter	No Feedback	Feedback
- sigma	1.3dB	0.3dB
+ sigma	1.5dB	0.4dB

Feedback amplifiers have been used extensively up to lower X-band. Inadequate device gain, however, has prevented using feedback at Ku-band and above. Feedback amplifiers require $G_{ds} << G_m$ and $G_{ds}Z_0 << 1$. In other words[2], feedback reduces process variations when 3 to 6 dB of device gain can be sacrificed, but MESFETs have little gain to spare at X-band and above. Feedback on MESFETs at this frequency requires increasing the number of gain stages, which, in turn, increases power consumption while only slightly improving gain flatness. In essence, flatness does not improve when minimal (1-2 dB) feedback is used or when the number of stages is doubled to compensate for the feedback. Thus, feedback only minimally improves X-band MESFET amplifier flatness.[3]

HEMTs, on the other hand, have excess gain and in mass production tend to experience similar processing variations as MESFETs. HEMTs tend to be less linear than MESFETs because of their non-flat G_m versus I_{ds} characteristic. Using feedback techniques on HEMT devices takes advantage of their higher gain while tending to buffer linearity by limiting signal swing. Series feedback from source to ground tends to increase the input impedance from a low impedance to one closer to 50 ohms, thus greatly reducing the effect of the C_{gs} on input matching variation. Shunt feedback from drain to gate acts in parallel with the output conductance and transconductance minimizing G_m, R_{ds}, and C_{ds} variations on amplifier performance, thereby effectively improving process tolerance.

AMPLIFIER DESIGN

Litton 0.25 µm x 400 µm devices were chosen for their high G_m and process repeatability. Device variations, from three lots, were studied to generate statistical representative models for design centering. The statistical HEMT model used three device models that represent the majority of possible Litton HEMT devices: a mean device model, and device models one sigma above and below the mean model in G_m and equivalent model capacitances.

Using the statistical HEMT model, a series of tradeoffs were made to determine the amount of series/shunt feedback needed to achieve the desired gain flatness with the expected process variation. Tradeoffs analysis of drain and feedback inductances were adjusted between C_{ds} absorption through L_d, which peaks gain, and L_{fb}, which gives frequency selectivity to the feedback. The amplifier, shown in Figure 2, achieved stability through series feedback with a series resistance at the device gate. Shunt feedback improved stability at microwave frequencies. A series network consisting of a 50 ohm resistor and 0.05 pf capacitor connected from gate to ground stabilized the amplifier at millimeter-wave frequencies. After the feedback and stability structures were established, matching was achieved with wideband bandpass matching networks.

PERFORMANCE

Figure 3 illustrates the typical gain response and Figure 4 the typical matching response. Flatness was 0.25 dB from 11.4 to 12.4 GHz. Narrow-band flatness was less than 0.05 dB for any 50 MHz frequency band. Median input return loss was 20 dB and median output return loss was 16 dB. Lot mean flatness was 0.18 dB peak to peak with a standard deviation of 0.12 dB. The RF yield criteria required the MMIC to have greater than 24 dB of gain. Mean gain was 26 dB; RF yield was 20%.

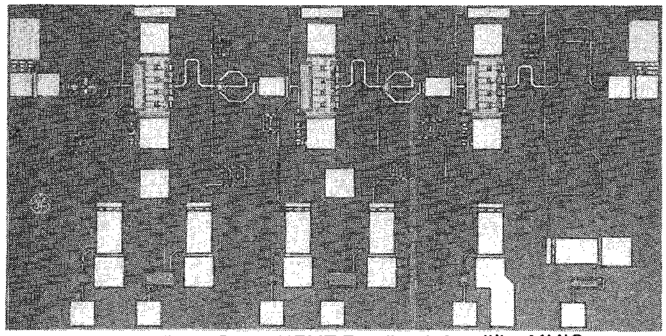

Figure 2. Three-Stage HEMT Feedback Amplifier MMIC.

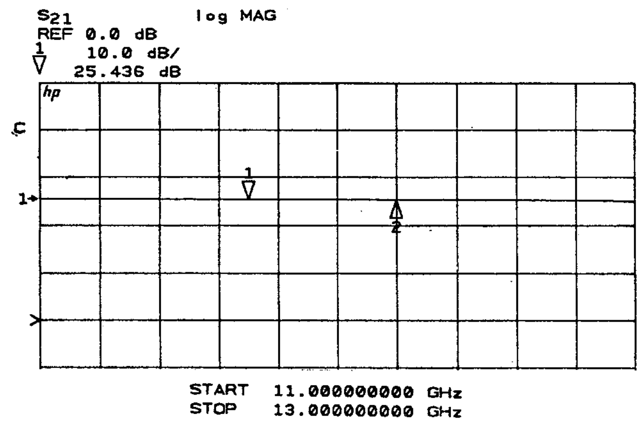

Figure 3. Gain Response of Three-Stage HEMT Feedback MMIC Amplifier.

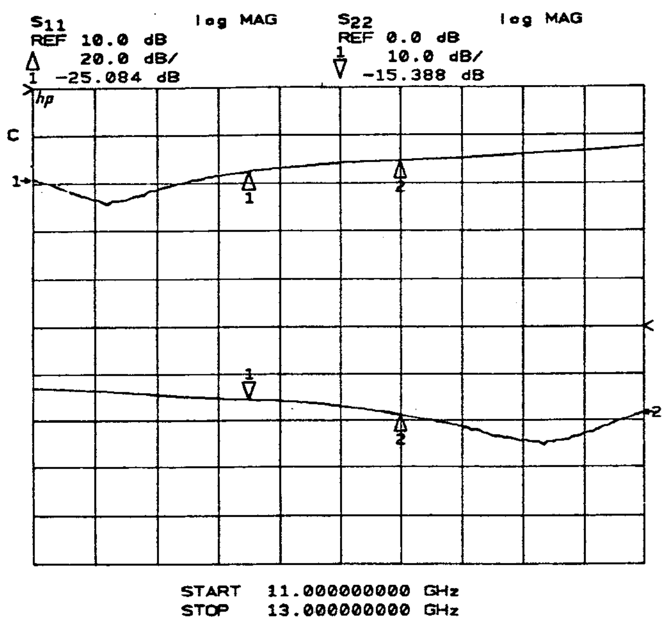

Figure 4. Return Loss of Three-Stage HEMT Feedback MMIC Amplifier.

CONCLUSION

A HEMT feedback amplifier MMIC operating at Ku-band demonstrated excellent process repeatability and flatness while using minimal DC power.

ACKNOWLEDGEMENTS

Special thanks to Cindy Yuen for processing and David Hogue for his measurement devotion.

REFERENCES

1. Karl B. Niclas et al. "The Matched Feedback Amplifier: Ultrawide-Band Microwave Amplification with GaAs MESFETs," IEEE Trans. Microwave Theory and Techniques (April 1980), pp 285-94.

2. Niclas

3. A. M. Pavio "A Network Modeling and Design Method for a 2-18 GHz Feedback Amplifier," IEEE MTT-S Digest (1982), pp 162-65.