30 dB OF AGC FROM AN FET

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SUMMARY

A low-noise single-gate GaAs MESFET has been successfully used to provide a 30-dB AGC range for low-noise amplifiers in down-converters used in microwave communication systems from 4 to 11 GHz. Threshold NF is not affected. With 30 dB of AGC, the FET amplifier NF is 18 dB.

INTRODUCTION

Microwave communication systems continue to stress higher propagation reliability (1). This forces the use of the lowest possible receiver noise figure (NF) and the highest practical received signal level (RSL) to increase the range over which the RSL may change without a system outage.

The requirement arose to operate from a -42 to a -12 dBm RSL when using a 30-dB gain IF amplifier with a maximum IF output level of -5 dBm. The typical RSL would be -25 dBm, so the amplitude response of the 70-MHz IF must remain essentially flat throughout the AGC range. No circuits were to be used that would significantly reduce the system gain at threshold when using a single-stage low-noise RF amplifier (LNA), that would increase the radio NF at threshold, or that would cause the mixer or IF amplifier to be overdriven and increase the third-order distortion. AGC could not be used on the IF amplifier because of high RF power into the mixer; therefore, the AGC circuit should be located within or immediately following the LNA. This paper describes a solution to these requirements.

KNOWN METHODS TO AGC A TRANSISTOR AMPLIFIER

The gain of a transistor amplifier can be changed by a shift in its dc operating point (2). This method is able to provide a 30-dB AGC range but it limited to low frequency transistors with high gain. A dual-gate FET will provide a 30-dB AGC range, but it is more expensive and has a higher NF than a single-gate FET (3). A PIN diode attenuator after the LNA could give 30 dB of AGC, but it has undesirable insertion loss and would be costly, since at least two diodes must be used.

AGC OF FET LNA BY CHANGING GATE VOLTAGE ONLY

It is common knowledge that advancing the gate voltage toward pinch-off will reduce the gain of an FET (3). The curve in Figure 1 shows that the maximum attenuation achievable is slightly over 21 dB. The normal gain of the LNA in Figure 1 is 12.3 dB at 6450 MHz.

The word "attenuation" is used in this paper to define the loss of LNA output signal level when referenced to the maximum gain or normal output power with no AGC control.

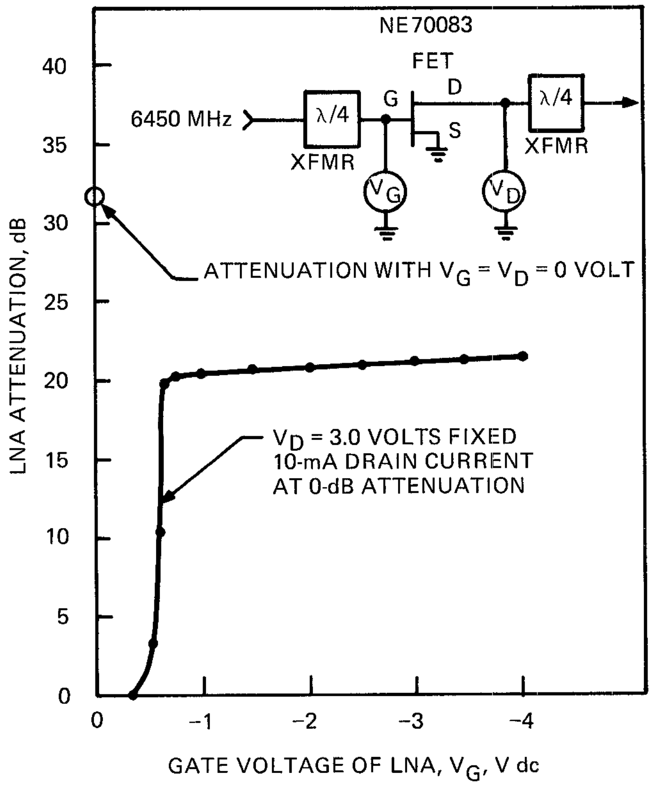

Figure 1. Using gate voltage of LNA to control attenuation

AGC OF FET LNA BY CHANGING BOTH GATE AND DRAIN VOLTAGES

Investigations into the change of both gate and drain voltages of the FET resulted in the group of curves given in Figure 2 for fixed values of attenuation. Note that for low values of attenuation there is usually more than one value for the gate voltage for a given drain voltage. This is shown near the dashed portion of the attenuation curves. On the right side of the dashed portion of the curves, we see one combination of gate and drain voltages when the gate voltage is moved in the direction of pinch-off. The other set of voltages takes place when the gate voltage is moved toward saturation, or zero gate voltage.

EFFECTS OF LNA AGC ON NOISE FIGURE AND GAIN

The data in Figure 3 was taken to understand the change of the LNA gain and its NF over the AGC range at 6450 MHz. The gain

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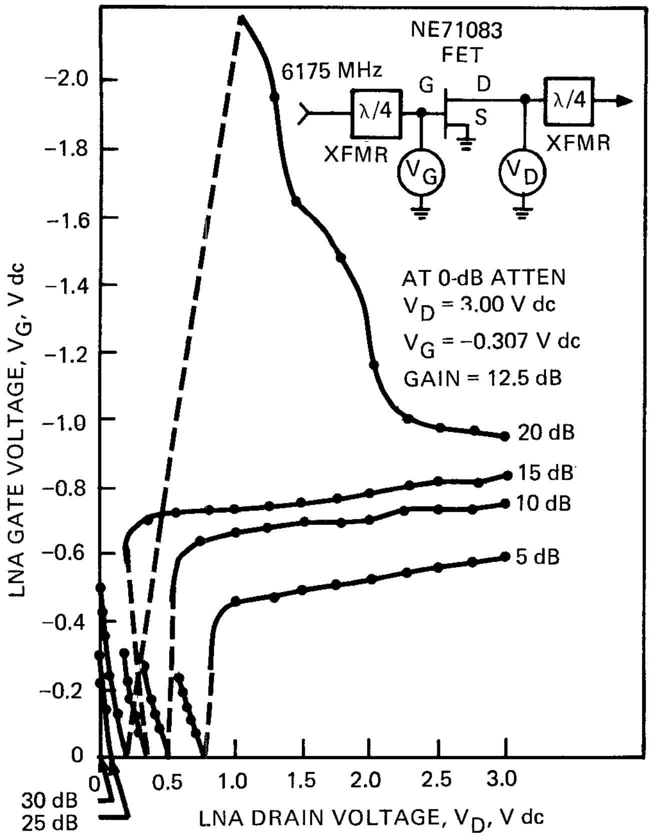

Figure 2. Ranges of LNA gate and drain voltages for fixed attenuation values

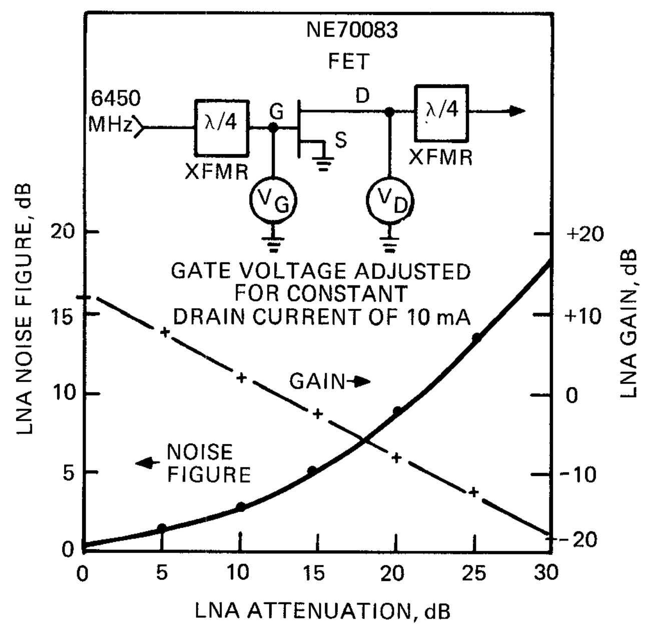

Figure 3. LNA gain and noise figure in AGC

changed from a normal value of 12.3 dB to -17.7 dB at 30-dB attenuation. The NF increased from a normal value of 1.2 dB at 0-dB attenuation to a little over 3 dB when the gain reached 0 dB. At 30-dB attenuation, the NF only reached 18 dB, which is almost equal to the negative gain, or loss, in the LNA.

PERFORMANCE OF A TYPICAL LNA IN AGC

Since an infinite number of gate-drain voltage combinations exist for any given value of LNA attenuation, a choice must be made that optimizes the RF signal transmission performance and that must also be realizable with a practical AGC control circuit. We chose to control the drain voltage with the AGC loop and to have the gate voltage follow the drain voltage to maximize the third-order distortion product ratio (ratio of desired signal level to third-order produce level). The relation of gate and drain voltages, drain current, and third-order distortion ratio to the attenuation value for a typical 6-GHz LNA is shown in Figure 4. The FET is different from the one used for previous data, but there is a remarkable similarity of AGC behavior between different types as well as different vendors of GaAs MESFET's. A relationship that has been found to apply from 4 to 11 GHz is that the maximum value of attenuation is equal to the normal gain plus about 20 dB of loss when the gate and drain voltages are reduced to zero.

The 4-GHz LNA required the gate voltage to be driven positive to maximize the third-order distortion ratio as the 30-dB attenuation limit was reached. The LNA parameters as a function of attenuation for positive gate voltages are plotted in Figure 5. The improvement in third-order distortion with a positive gate voltage is linked to the increase of the AGC range. Since the Schottky barrier contact potential causes a finite depletion layer thickness when the gate voltage is zero, the conducting channel thickness, and consequently the AGC range, may be progressively increased

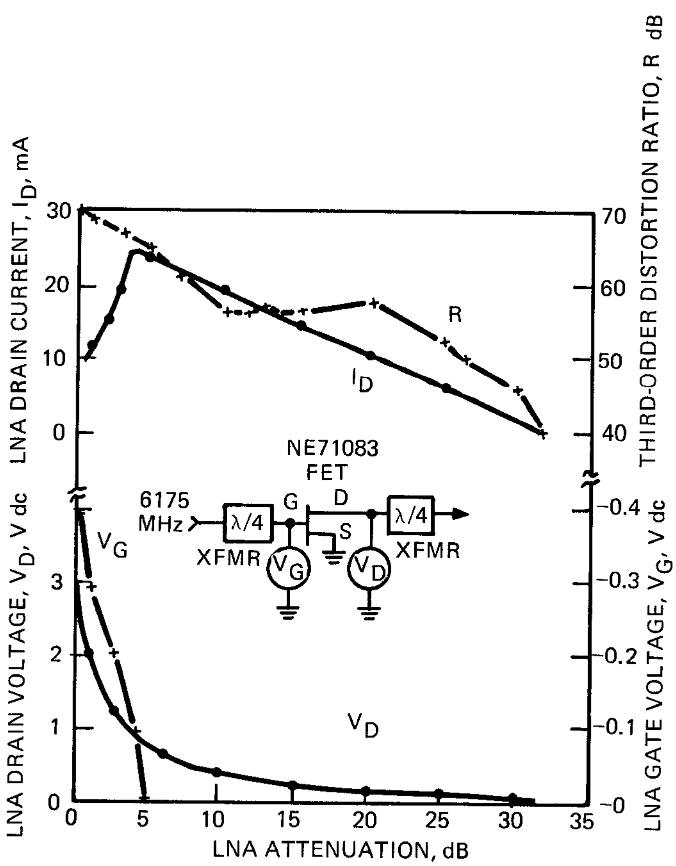

Figure 4. Characteristics of LNA in AGC

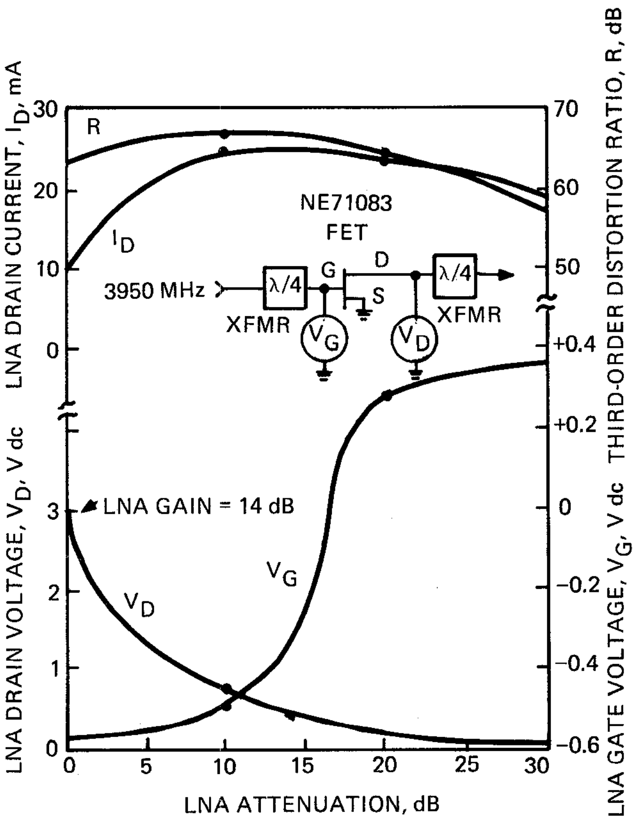

Figure 5. Typical LNA parameters in AGC with positive gate voltage

for increasing positive gate voltages up to this contact potential. Tests at 6 GHz resulted in a 40-dB AGC range for a gate voltage of +0.625 volt and a gate current of 2.9 milliamperes, at which point the third-order products vanished from sight. Precautions are obviously required to prevent damage to the fragile gate structure by excessive current.

IMPEDANCE OF FET LNA IN AGC

The return loss looking into the drain terminal of the FET LNA was investigated when amplitude slope changes appeared in the IF output response during AGC control when operating the LNA directly into the mixer. The Smith chart plot of the return loss referenced to the drain terminal of the FET appears in Figure 6 for the tuned LNA and in Figure 7 for the FET only with no tuning transformers. Quarter-wave transformers were used to tune the LNA at 6170 MHz. The decrease in the drain impedance as the attenuation is increased may be understood by an inspection of the FET equivalent circuit (4, 5, 6, 7). Reducing the gate and drain voltages reduces the depletion layer thickness which increases the conducting channel thickness, thereby decreasing the drain to source resistance. The behavior of the FET impedance in AGC was seen to be a normal behavior that could not be altered to correct the IF amplitude slope change.

Further testing showed the IF amplitude slope to be caused in part by the single-sideband (SSB) mixer and its IF 90-degree hybrid power output being changed over the 50- to 90-MHz IF frequency range by the changing source impedance from the LNA. The IF output impedance of the mixer 90-degree IF hybrid also changed over the IF frequency range. This caused the IF amplifier that followed to see primarily a magnitude change in its source impedance over the IF frequency range and this contributed further to the IF amplitude slope. Changing the space between the LNA and the mixer would change the IF amplitude slope with a cyclic periodicity to give a positive, negative, or a flat amplitude slope. Changing from a bridge to a ring diode quad in the SSB mixer also lowered the IF impedance to the IF amplifier and greatly reduced the IF amplitude slope (8). The most expedient solution was to place a circulator between the LNA and the mixer.

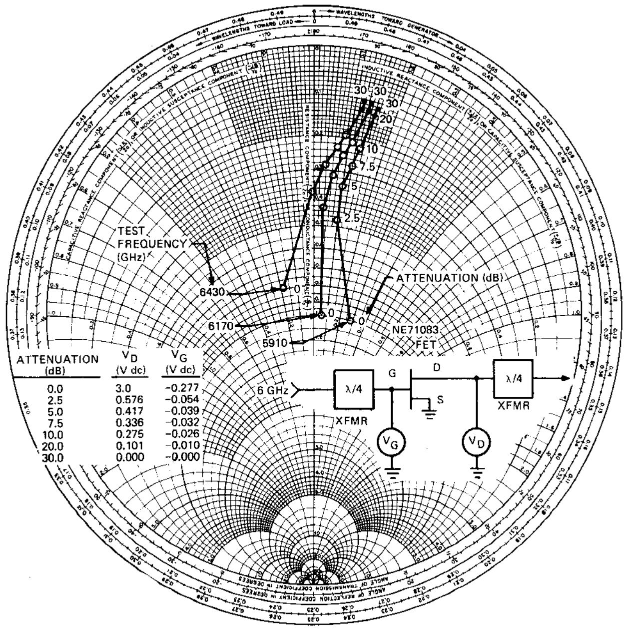

Figure 6. Output return loss of tuned FET in AGC referenced to drain terminal

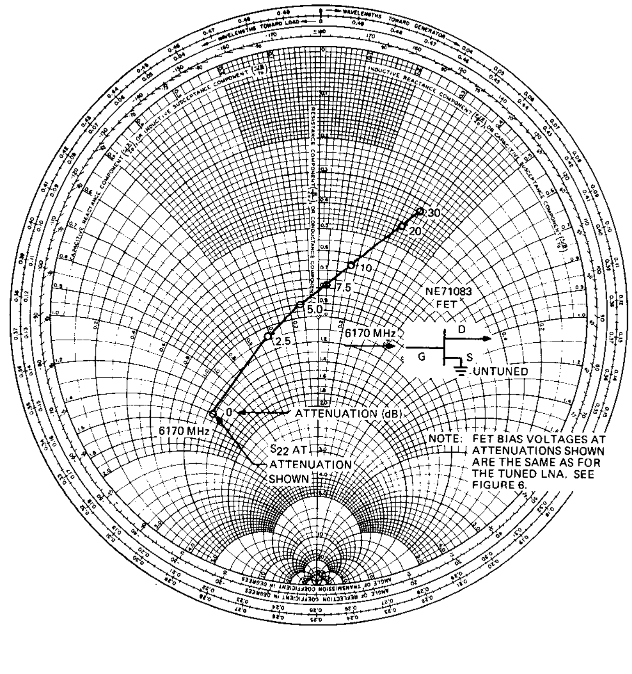

Figure 7. Output return loss of untuned FET in AGC referenced to drain terminal

CONCLUSIONS

Over 30 dB of AGC in a single-gate GaAs MESFET LNA has been successfully demonstrated, through lab and production testing, to be a vital part in the reliable performance of microwave communication systems in the 4- to 11-GHz frequency range. A few advantages are summarized below to conclude the description:

1. Prevents mixer and IF amplifier from being overdriven since attenuation is present at the receiver front end.

2. Protects receiver front end from RF input power levels up to and exceeding 0 dBm by reflecting input power by a return loss that decreases as the LNA attenuation increases up to about 32 dB.

3. No loss of gain or NF in FET below AGC and reasonably low NF in AGC.

4. Uses an existing component, making it economical and causing a reduction in parts count.

5. Exceptionally good RF signal transmission fidelity in AGC.

ACKNOWLEDGMENT

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