HEMT LOW-NOISE AMPLIFIER FOR Ka-BAND

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ABSTRACT

Using 0.25 micron gate-length High Electron Mobility Transistors (HEMTs), a two-stage amplifier has been developed that demonstrates the potential for high-gain, low-noise pre-amplification at K_a-band. The amplifier exhibits a noise figure of 4.0 dB with 16.5 dB gain at 37.5 GHz and under slightly different bias conditions shows flat gain of around 11.0 dB from 30.5-37.5 GHz.

INTRODUCTION

As the required component technology matures, the lower millimeter-wave frequencies are being used more and more for radar, electronic warfare, and communications systems. A millimeter-wave seeker system, for instance, operating around 35 GHz could benefit greatly from increased receiver sensitivity with low noise amplifiers (LNAs) either in the (phased array) antenna or in the receiver channel of the radar. With a lower system noise figure, the required transmitter power and antenna aperture can be reduced for detection of a given target.

This paper describes the development of a K_a-band LNA using low-noise AlGaAs/GaAs HEMTs that has resulted in a two-stage amplifier with flat gain of around 11.0 dB across a 20% bandwidth from 30.5-37.5 GHz. When biased at a higher drain voltage, the amplifier has over 18.5 dB small signal gain at 35 GHz, but in this case gain flatness across the band is sacrificed. Measured noise figure indicates a minimum value of 3.8 dB at 37 5 GHz and is less than 6 dB from 32-39 GHz. The best overall noise measure was obtained when the amplifier was biased for a more narrow band response at 37.5 GHz: 4.0 dB noise figure and 16.5 dB gain. All figures include the assembly losses of two co-axial launches, measured to be around 0.5 dB per launch at 30-40 GHz.

Further development work will reduce the noise figure of the amplifier (the devices themselves have a minimum noise figure of 1.8 dB at 40 GHz), however, this work has already shown the potential for high-gain, low-noise pre-amplification over a 20% bandwidth at K_a-band--all in a very small assembly less than 1 in. x 1 in.

DEVICE

The HEMT has recently demonstrated its low noise capabilities well into the lower millimeter-wave frequencies with amplifiers operating at 40, 60 and 70GHz (1) and as high as 94 GHz (2). The 0.25 micron gate-length HEMTs developed in our laboratory display some of the lowest reported noise figures of any microwave transistor. These low-noise devices have been evaluated at frequencies ranging from 8-62 GHz in terms of minimum noise figure and associated gain. The measured value for minimum noise figure corresponds very well to those predicted by Fukui's expression relating minimum noise figure to equivalent circuit elements (3) :

$$F_{min} = 1 + kfC_{gs}\sqrt{(R_g + R_s)/g_m}\,.$$

Table I summarizes the measured and predicted noise figures and the measured associated gains of our devices at frequencies between 8 and 62 GHz (4).

TABLE I. ROOM TEMPERATURE PERFORMANCE OF 0.25 MICRON HEMT

Frequency (GHz)	Measured F_{min} (dB)	Calculated F_{min} (dB)	Associated Gain (dB)
8	0.4	0.45	15.2
18	0.8	0.96	12.5
30	1.5	1.48	10.0
40	1.8	1.86	7.5
62	2.6	2.60	4.4

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The devices were fabricated on selectively doped AlGaAs/GaAs heterostructures grown by molecular beam epitaxy (MBE) and incorporate a graded aluminum composition contact to reduce contact resistance and increase sheet electron concentration. The HEMTs employ large cross-section T-shaped gates to reduce series gate resistance to less than 80 Ω/mm; the devices used in this development have a single gate stripe 50 microns wide, fed at the center, an example of which is shown in Figure 1, so that the device gate resistance is only 0.3 Ω.

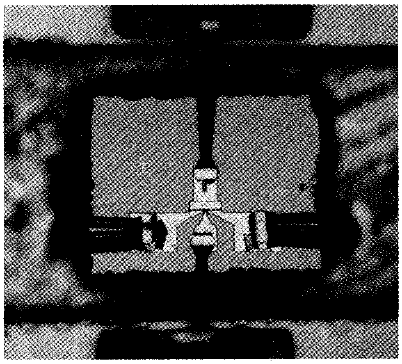

Figure 1. 50 micron gate-width HEMT used in K_a-Band Amplifier.

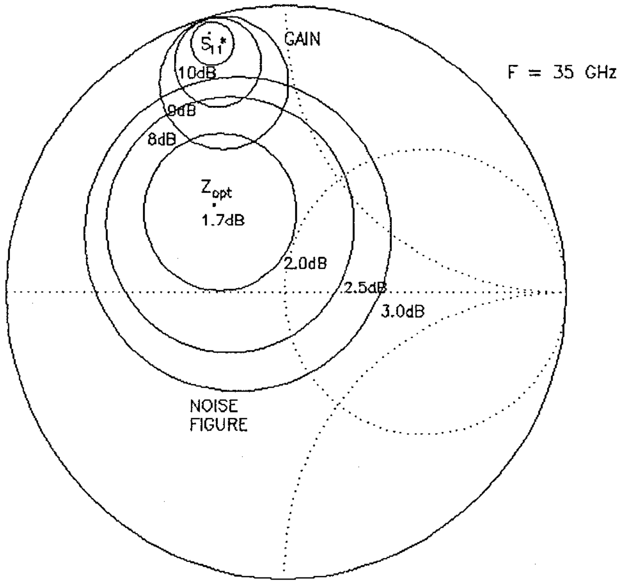

Figure 2. Constant Noise Figure and Gain Circles for 0.25 x 50 micron HEMT at 35 GHz.

These devices have a high extrinsic transconductance of greater than 400 mS/mm, at low noise bias, which is considered to be a major factor in their superior millimeter-wave performance.

CIRCUIT DESIGN AND ASSEMBLY

The two-stage amplifier was designed using a device model obtained from lower frequency S-parameter measurements. Both the small-signal model and the noise model were modified slightly by taking maximum gain and minimum noise figure measurements at frequencies within K_a-band.

The noise figure and gain circles of a typical device, shown at 35 GHz in Figure 2, aid the design of the LNA and help to better understand the device performance tradeoffs. At 35 GHz this device has a minimum noise figure of 1.7 dB and a conjugate match gain of 10.6 dB. If the source impedance required for conjugate match were presented to the device, a noise figure of 5.5 dB would result, whereas if the source impedance were adjusted to the optimum noise match, Z_{opt}, a 3.5 dB mismatch loss, or 7:1 VSWR, at the input would occur. This presents the designer with the usual compromise problem for a simple single-ended amplifier where both gain and noise figure are degraded to a point where the most suitable performance is achieved.

These NF and gain circles for the HEMT demonstrate some notable traits of the devices. First, the spatial separation between the noise figure circles is larger than is typically seen with GaAs MESFETs, meaning that the circuit noise figure will be relatively tolerant to change in source impedance. The spatial distance between two circles is related to the equivalent source resistance R_n; the lower the value of R_n, the larger the circle separation. Secondly, the conjugate match gain of the device at this low-noise bias point is very good, almost 11 dB, which allows one to contemplate using different amplifier configurations such as series feedback to aid simultaneous noise and power matching that results in only a slight degradation of gain. Series feedback is often discarded as a candidate for millimeter-wave amplifiers because usually the gain per stage would be too low resulting in an unacceptably high cascaded noise figure. The hybrid amplifier described here does not use series feedback, but this technique is suited to a monolithic millimeter-wave LNA where the source feedback can be achieved in a repeatable manner. R_n also has a close relationship with power gain; the smaller the R_n value corresponds to a higher gain for a given gate structure, so in the design of low-noise devices it is just as important to reduce the value of R_n as it is to achieve a low value for F_{min}. This can be achieved by obtaining a very high transconductance for the device at low noise bias.

The two-stage amplifier uses microstrip transmission lines on 0.010 in. thick polished alumina and was designed and tuned as a complete amplifier rather than a cascade of separate tuned stages. A photograph of the complete assembly containing the circuit and bias networks is shown in Figure 3.

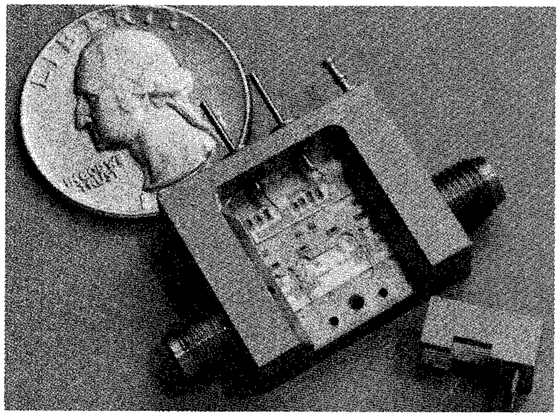

Figure 3. *Two-Stage K_a-Band amplifier assembly, using Wiltron K-connectors, is only 1 in. x 1 in.*

Using the Wiltron K-connector for the microstrip transition makes the assembly very compact, compared with a waveguide assembly; the housing is only 0.80 in. x 0.95 in. The microstrip substrates are placed in a channel less than a half wavelength wide at the highest frequency to prevent any spurious mode propagation. Only one drain and gate supply is needed for the two devices--a voltage divider network is used to adjust the bias to the first HEMT for optimum gain and noise performance. DC power consumption of the amplifier is only 21.5 mW when operating at its flat gain bias.

The DC block between the stages uses a parallel coupled line design, with line and gap spacings on the order of 0.001 in. and has a dissipation loss of only 0.2 dB at 30-40 GHz. The bias network design provides for out-of-band stability of the amplifier while introducing very little loss in the band.

PERFORMANCE

The small-signal gain of the amplifier, including fixture losses, is 11.0 ± 1.0 dB from 30.5-37.5 GHz, as shown in the lower curve of Figure 4. Gain can be improved with a higher drain voltage, indicated in the upper curve of Figure 4, where a gain of over 18.5 dB is observed at 35 GHz. At the higher bias point the gain flatness across the band is compromised, but over narrow bandwidths the improvement in gain is significant.

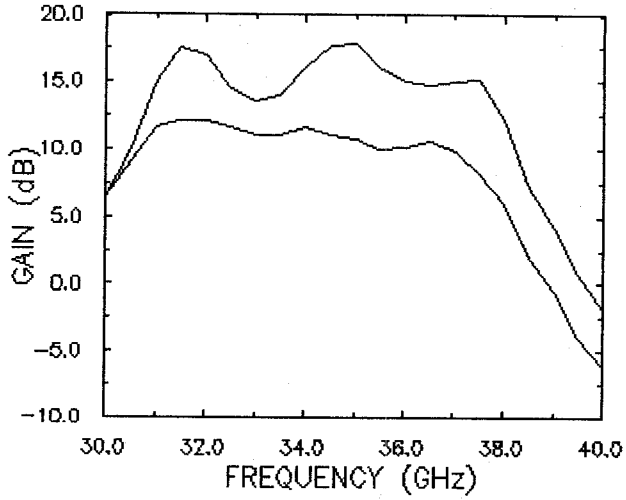

Figure 4. *Small Signal Gain of Two-Stage Amplifier. The lower curve is for a drain voltage optimized for flat gain, the upper curve is the response with a higher drain voltage, showing a significant increase in gain but compromising the gain flatness across the band.*

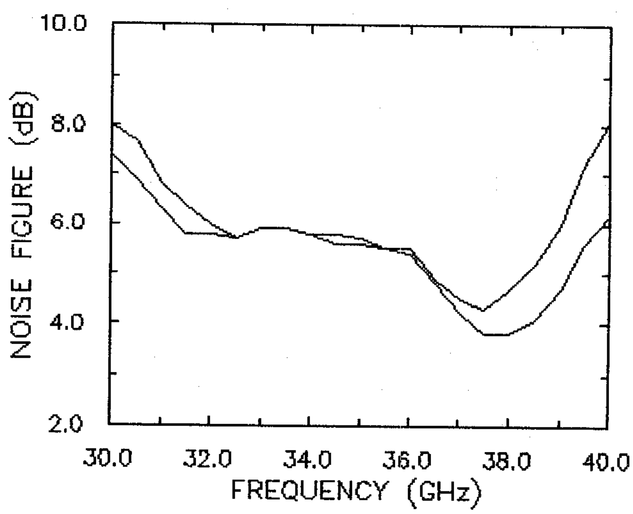

Figure 5. *Noise Figure of Two-Stage Amplifier for different drain voltages showing only minor changes with bias.*

The noise figure of the amplifier assembly changes very little with the two different bias points. Again, noise figure of less than 6 dB from 32-39 GHz was measured and is optimum around 37-38 GHz where a noise figure of only 3.8 dB was observed. Figure 5 shows how the noise figure varies across the 30-40 GHz frequency range for both bias conditions. At 37.5 GHz the optimum response obtained was 4.0 dB noise figure with 16.5 dB gain.

CONCLUSION

The work described here demonstrates the potential for high-gain, low-noise pre-amplification at K_a-band. The HEMT devices used in the circuit have shown excellent millimeter-wave performance, demonstrating gain and noise performance better than any other microwave transistors. Using these devices we have demonstrated a flat gain, 20% bandwidth low-noise amplifier with excellent noise performance over part of the band. Furthermore if gain flatness can be compromised, exceptionally high gain (for a two-stage LNA) can be achieved without significant change in noise figure. Further development work is continuing on K_a-band amplifiers with the goal of reducing the noise figure of the amplifier to less than 3.0 dB at 35 GHz, a goal that seems likely in the near future.

ACKNOWLEDGEMENTS

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