W-band Metamorphic Low Noise and Power Amplifiers

C. S. Whelan, K. Herrick, R. E. Leoni III, P. F. Marsh, Y. Zhang, S. Lardizabal
W. E. Hoke, S. Lichwala, J. Kotce, P. Balas, T. E. Kazior and D. Laighton

Raytheon RF Components
362 Lowell St. Andover, MA 01810, cwhelan@raytheon.com

Abstract - **Low noise metamorphic amplifiers fabricated on our 4" manufacturing line demonstrate 3.5 dB noise figure at 92 GHz. By tailoring the device's material, geometry and processing, our device designers have achieved 320 mW/mm, 10 dB of small signal gain at 100 GHz, and 28% PAE at 95 GHz from a single stage, matched FET.**

I. INTRODUCTION

GaAs based metamorphic HEMT (MHEMT) technology has emerged as an attractive, low cost alternative to InP HEMTs. The strain-induced imperfections caused by high indium content layers on GaAs is eliminated in metamorphic devices by providing a properly grown lattice-grading buffer between the substrate and active device layers. With this limitation overcome, it is now possible to provide the superior performance of InP-based devices with the cost advantages of highly manufacturable 4-inch GaAs wafers that can easily be integrated on existing GaAs fabrication lines [1]-[21].

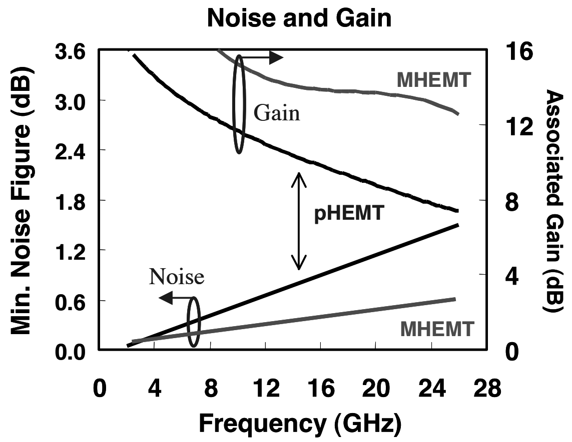

Figure 1. The 0.18 micron 60% indium MHEMT shows ½ the minimum noise figure and 4 dB more associated gain from 2-26 GHz.

Figure 1 shows the superior noise and associated gain performance of our production MHEMT device as compared to our pHEMT device, demonstrating ½ the minimum noise figure and 4 dB more associated gain. Perhaps the largest advantage of metamorphic technology is the ability to tailor the indium content of the active layer(s) ($In_xGa_{1-x}As$) to the specific application. We have exploited this freedom in our production 60% indium low noise technology as well as in our new 43%/53% split channel indium devices created for W-band power applications.

II. LOW NOISE AND POWER PROCESSES

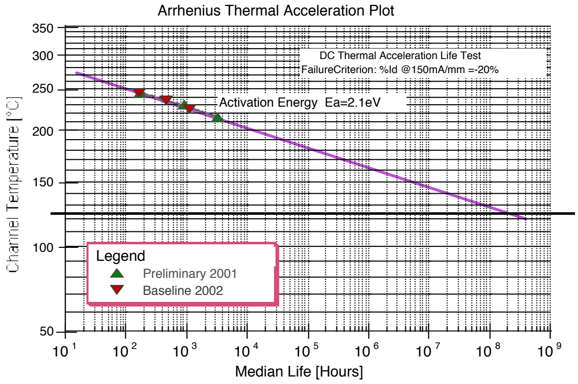

Figure 2. The production 60% In MHEMT shows a MTTF of $>1x10^8$ hours MTTF at 125C for a 20% change in I_{ds}.

Our low noise, 60% indium InGaAs, 4" MHEMT process has been in production for over a year. It achieves < 0.6 dB F_{min} and 12 dB associated gain at 26 GHz measured on a 2x50 micron device. F_t is in excess of 150 GHz, with an F_{max} of > 200 GHz, both of which were achieved at one volt drain bias. The device utilizes a single wide, self-aligned, selectively-etched, gate recess and SiN for passivation. The gate consists of a hybrid e-beam defined stem and an optically patterned T-top, resulting in gate lengths of

0.18-0.20 microns and T-tops of nearly one micron. The wafers are then thinned to 4 mils and employ end-source vias for grounding, with airbridges completing the connection to the remaining sources. These devices have repeatedly demonstrated reliability in excess of 1×10^8 hours MTTF at 125C for a 20% change in I_{ds}. Figure 2 shows an accumulation of over 100 devices tested at five different temperatures, demonstrating an activation energy of 2.1 eV. Low noise X-band amplifiers have also been RF stressed at 85C in 2 dB of compression for over 6,500 hours with no change in output power, noise figure, or gain.

Recently, we have begun work on a new type of metamorphic HEMT aimed at high frequency power applications. To increase the breakdown voltage, we have reduced the indium to content to either a single 53% indium channel or a split channel with an average indium content of 48%. We have designed a variety of devices utilizing self-aligned single and double recesses with etch stops, and reduced the SiN thickness to lower parasitic capacitances. The gate length has been reduced from 0.18-0.20 micron to 0.15 micron to improve high frequency performance without sacrificing manufacturability. These devices are thinned to 2 mils and use individual source vias for better thermal dissipation and lower source inductance.

III. W-BAND LOW NOISE AMPLIFIERS

Using our low noise 4-inch production MHEMT process, our designers have created a number of W-band LNAs with state-of-the-art results. The s-parameters from 5-stage LNAs are shown in Figure 3. The five LNAs plotted show 20 dB of gain from 80-100 GHz, a S_{11} of –5 to –10 dB and a S_{22} of better than –10 dB. State-of-the-art noise figure was measured to be less than 3.5 dB from 91-92 GHz. Our test equipment prohibited a wider measurement bandwidth.

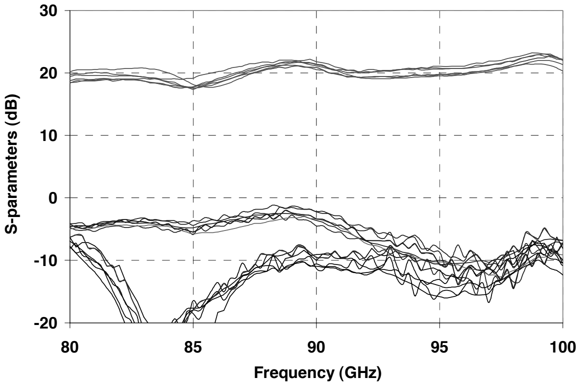

Figure 3. S-parameters of 5-stage LNAs using our production MHEMT process. (No averaging used during measurements).

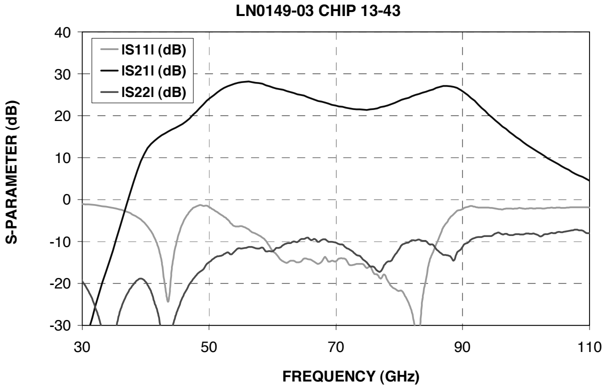

Figure 4. S-parameters of second 5-stage LNA using our production MHEMT process.

Figure 4 shows a second production MHEMT 5-stage W-band LNA with 25 dB of gain from 60-90 GHz.

IV. W-BAND POWER AMPLIFIERS

Using our new power MHEMT material and device processing, we achieved state-of-the-art W-band power results. Single stage W-band pre-matched FETs with 150 microns of periphery were used to characterize the process and as building blocks for future amplifier design. Pulsed IV data is overlaid upon static IV curves in Figure 5, and shows no current collapse, a necessity for achieving good power and efficiency. The device also demonstrates an I_{max} of 700 mA/mm and an on-state breakdown of over 4V at 200 mA/mm.

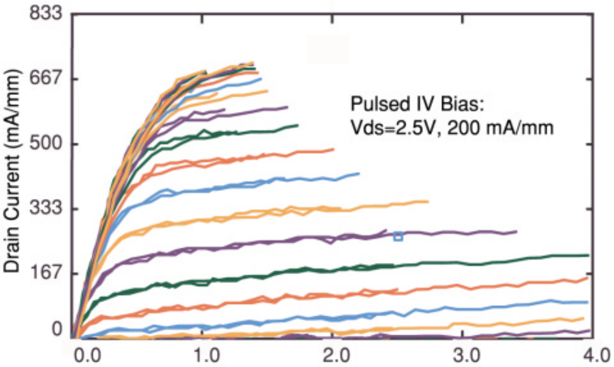

Figure 5. Pulsed IV overlaid upon static IV curves.

S-parameters of these single stage pre-matched devices were taken on our 110 GHz ANA at 2.5V and 200 mA/mm and are shown in Figure 6. This 0.15 micron gate length power device shows 12 dB of measured gain at 104 GHz from a single stage. Extrapolating Gmax at –6 dB/octave from 110 GHz gives an F_{max} of greater than 400 GHz.

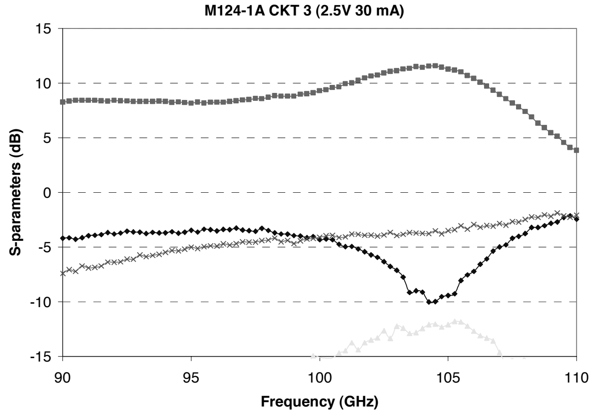

Figure 6. S-parameters of a single stage pre-matched device.

These same power matched devices were then measured for power at 95 GHz, as shown in Figure 7. The 150 micron device shows a P_{sat} of 16.8 dBm with 28% power added efficiency and 4.5 dB of compressed gain (1.5 dB of compression). This equates to 319 mW/mm. These numbers compare favorably to state-of-the-art InP results.

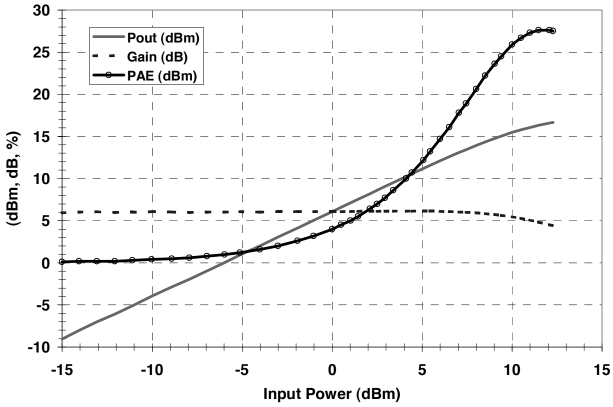

Figure 7. Power, gain and efficiency of a 150 micron device measured at 95 GHz.

V. CONCLUSION

Raytheon's low noise production process has been used to designed state-of-the-art W-band LNAs with 20 dB of gain and 3.5 dB of noise figure. A new power process shows more than 10 dB of gain per stage at 100 GHz, 320 mW/mm power density and 28% power added efficiency at 95 GHz.

VI. ACKNOWLEDGMENTS

The authors would like to acknowledge the invaluable help of F. Fay, T. Kennedy, and P. Lyman. We would also like to thank Sander Weinreb (JPL) and Matt Morgan (Caltech) for sharing the data shown in Figure 4.

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