HIGH PERFORMANCE V-BAND LOW NOISE AMPLIFIERS

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ABSTRACT

Significant advances in high frequency, low noise amplifier (LNA) performance have been achieved. Noise figures under 2.0 dB have been demonstrated with several single stage amplifiers incorporating devices from different wafers. These amplifiers utilized an $Al_{0.48}In_{0.52}As-Ga_{0.47}In_{0.53}As$ lattice matched InP HEMT device with a gate periphery of 50 μm x .2 μm. Typical f_t of these devices are in excess of 120 GHz, with an extrinsic g_m of more than 900 mS/mm. The best results obtained by a single stage LNA was .8 dB, with an associated gain of 8.7 dB at 63.5 GHz [1]. A 3-stage V-band amplifier produced a minimum noise figure of 2.6 dB, with 19.5 dB of gain at 61.0 GHz.

INTRODUCTION

Millimeter wave systems for satellite communications and electronic warfare are advancing rapidly. As a result, tougher performance requirements are placed on components, such as power amplifiers, T/R modules, and receiver front ends. Consequently, these needs are driving the state of the art device technology at a tremendous rate. Competition is fierce among major companies to produce the highest power density, highest efficiency, or lowest noise figure device suitable for harsh environment of space applications.

Recent breakthroughs in low noise device technology have led to phenomenal advances in high frequency, low noise amplifier performance. Figure 1 illustrates the progress we have attained in recent years with V-band low noise amplifiers. These advances are a direct result of an evolving device technology and amplifier/circuit design techniques. The best results obtained by a single stage amplifier was a noise figure of .8 dB with an associated gain of 8.7 dB at 63.56 GHz. This outstanding performance was achieved with an $Al_{0.48}In_{0.52}As-Ga_{0.47}In_{0.53}As$ lattice matched InP HEMT device. Others have reported the significant performance potential of InP based HEMT devices [2].

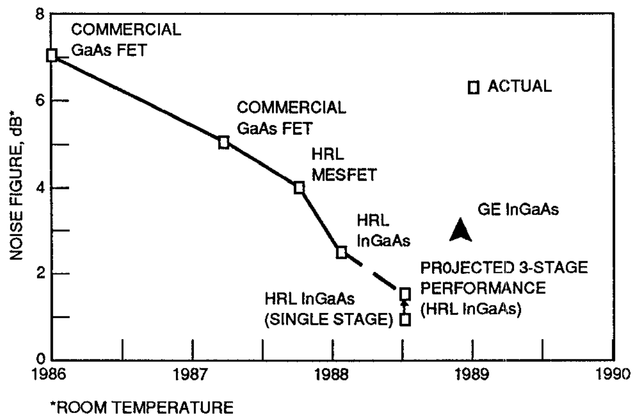

FIGURE 1. ADVANCEMENTS IN V-BAND MULTISTAGE LNA PERFORMANCE

This paper describes the device structure and test results of InP based HEMT devices operating at V-band. Several single stage amplifiers incorporating devices from several different wafers produced noise figures under 2.0 dB, indicating good device processing controls. To date, little reliability data has been published on the new InP based HEMT device technology. This testing is planned for 1989 and will include high temperature DC stress testing and an accelerated life test on an amplifier to characterize RF performance degradation in an effort to provide a meaningful lifetime assessment.

DEVICE DESCRIPTION

In recent years, innovations in device materials and nanometer lithography

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have resulted in substantial high frequency performance improvements. Small geometry GaAs MESFETS, AlGaAs - GaAs HEMT, and AlGaAs pseudomorphic HEMT devices have demonstrated remarkable high frequency performance as a result of this evolving technology [3] [4] [5]. However, the device technology that has shown the most promise is the AlInAs-GaInAs on InP modulation doped structure shown in Figure 2. This structure is grown on Fe doped InP substrate by MBE. A large conduction band gap is formed between the lattice matched $Al_{0.48}In_{0.52}AsGa_{0.47}In_{0.53}$ As layers resulting in a large sheet charge density (N_s=3x10 cm). This, together with a high 300K electron mobility in $Ga_{0.47}In_{0.53}As$ (u=10,000 cm. V S), produces an extremely low resistance per square (200Ω/□) in the two dimensional electron gas. These characteristics give rise to an extrinsic transconductance in excess of 900 mS/mm for a gate geometry of 50 μm x 0.2 μm. Other devices fabricated with gate lengths of .1 μm have demonstrated a maximum extrinsic transconductance of 1100 mS/mm [6].

GaInAs	n^+ CONTACT LAYER (5 nm)
AlInAs	UNDOPED BARRIER LAYER (20 nm)
AlInAs	n^+ DONOR LAYER (12.5 nm)
AlInAs	UNDOPED SPACER LAYER (2 nm)
GaInAs	UNDOPED CHANNEL (40 nm)
AlInAs/GaInAs	UNDOPED SUPERLATTICE
AlInAs	UNDOPED BUFFER LAYER
InP	SEMI-INSULATING SUBSTRATE

FIGURE 2. TYPICAL MODULATION-DOPED $Al_{0.48}In_{0.52}As$-$Ga_{0.47}In_{0.53}As$ ON InP STRUCTURE GROWN BY MBE

AMPLIFIER DESIGN

CAD device modeling was used as a starting point for amplifier circuit design. Using on-wafer S-parameters taken with a cascade RF probe station from .045 to 26.5 GHz, a lumped equivalent model was derived. Using this model, high frequency performance was extrapolated through V-band. An in-house analysis program generated the required source and load impedances for a minimum noise figure. From this data, matching circuitry was synthesized and optimized using standard CAD techniques. Stability analysis performed on the amplifier circuit indicated the usual low frequency oscillation problems associated with extremely high gain devices. To overcome this, out of band resistive loading was incorporated into the bias network.

TEST FIXTURE/AMPLIFIER DESCRIPTION

A single stage test fixture used for device evaluation is shown in Figure 3. The waveguide to MIC transition is accomplished with .010 inch thick alumina probes. The geometry of the probes was optimized to prevent moding in the waveguide at the higher frequencies. Special attention was given to the probe to carrier interface and grounding to minimize loss and mismatch. As shown in Figure 4, the thru loss for the entire fixture and .20 inch of 50 Ω line is approximately .5 dB. This fixture has proven to be repeatable and durable through many device characterizations.

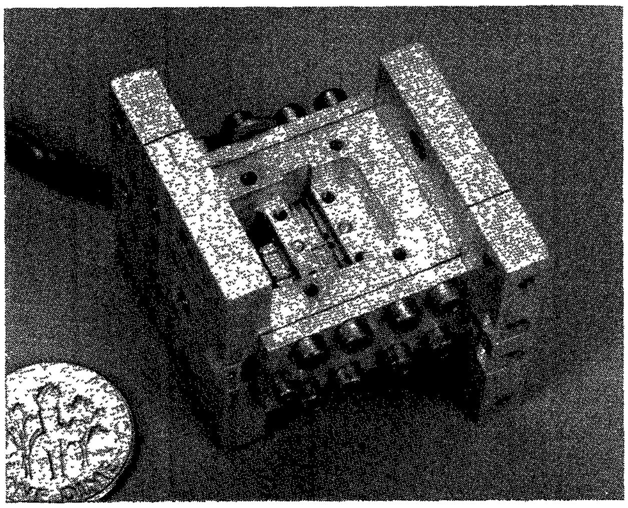

FIGURE 3. V-BAND SINGLE STAGE TEST FIXTURE

The HEMT device is embedded on a Kovar carrier between .010 inch thick alumina matching circuits. Alumina was chosen over quartz because of its durable mechanical properties. In addition, because of the small physical size of the matching circuits, quartz did not offer significantly lower loss. Only the most critical matching elements were printed on the substrates to allow greater tuning flexibility. Generally, the addition of one or two tuning ribbons achieved optimal performance.

Chip and wire construction is used throughout the amplifier. Every effort was made to reduce parasitics and extra bond inductance to achieve maximum gain and bandwidth.

Eutectic solders are utilized for substrate, FET, and component attachment, resulting in a rugged assembly that can withstand the requirements of a space environment.

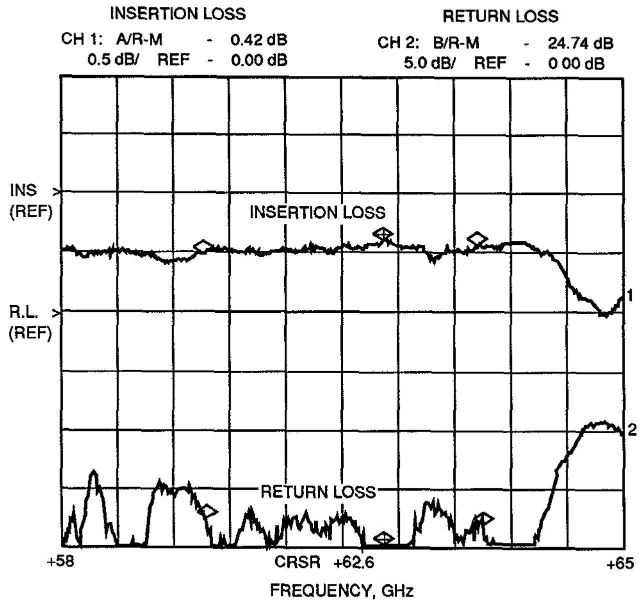

FIGURE 4. TEST HOUSING INSERTION/ RETURN LOSS

TEST RESULTS

Test results of a single stage amplifier are presented in Figure 5 without loss correction. As shown in Figure 6, similar results have been attained from other wafers. Measurements were taken with a noise source calibrated at our calibration labs and verified to within ±.25 dB by a recognized independent contractor using two different measurement techniques (hot/cold load and radiometer).

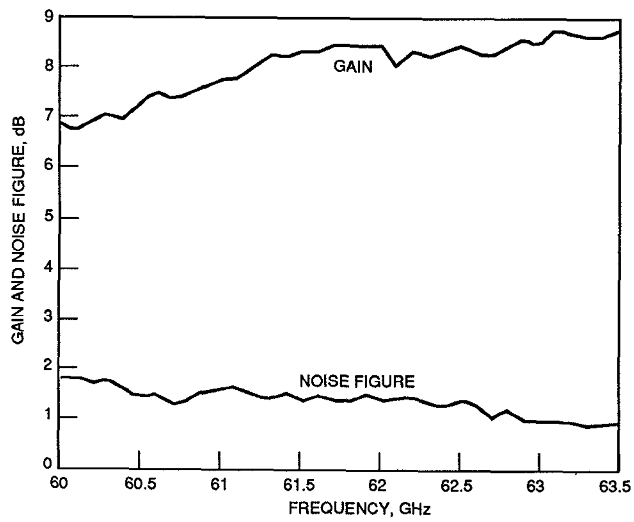

FIGURE 5. V-BAND SINGLE STAGE AMPLIFIER

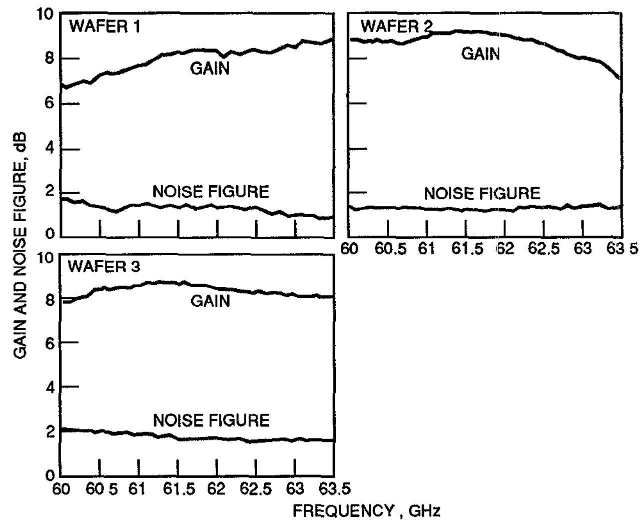

FIGURE 6. SINGLE STAGE AMPLIFIER RESULTS FROM DIFFERENT WAFERS

To investigate the effects of an ambient environment, a single stage LNA with a noise figure of 2.0 dB and 7.5 dB gain has been in continuous operation for 8 months with no change in RF or DC characteristics. Additionally, a VCO and several DC test circuits have shown similar results.

A 3-stage LNA incorporating unselected devices produced a minimum noise figure of 2.6 dB, with a gain of 19.5 dB across 3.5 GHz (see Figure 7). On this particular amplifier, gain flatness was emphasized, which resulted in a slightly higher noise figure.

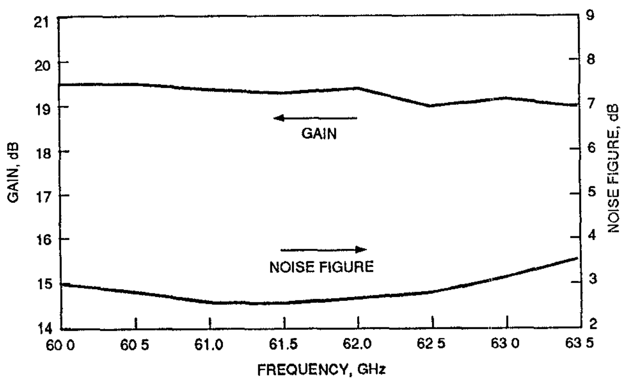

FIGURE 7. V-BAND 3-STAGE LNA PERFORMANCE

CONCLUSIONS

The performance potential of the AlInAs-GaInAs HEMT device has been demonstrated. Evaluation of several single stage amplifiers incorporating devices from different wafers have produced noise figures under 2.0 dB at V-band. The best single stage LNA produced a record noise figure of .8 dB, with an associated gain of 8.7 dB at 63.5 GHz. Devices exposed to ambient lab environments for over 8 months have shown no changes in RF or DC performance.

Because these devices exhibit extremely high f_t (~135 GHz), their usefulness in low noise applications will extend through W-band (94 GHz).

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