# Ultra Low Noise Q-band Monolithic Amplifiers Using InP- and GaAs-Based 0.1μm HEMT Technologies

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## ABSTRACT

Design and development of ultra low noise MMIC Q-band LNAs using both InP and GaAs-based 0.1-μm HEMT technologies with state-of-art noise figures are reported in this paper. For InAlAs/InGaAs/InP HEMT LNAs, we have achieved noise figure performance as low as 1.6 dB with 10-dB associated gain for a one-stage LNA. With a two-stage design, 20 dB gain with 1.8-dB noise figure was obtained. Single- and multistage MMIC LNAs were also designed and fabricated using a production 0.1-μm AlGaAs/InGaAs/GaAs HEMT process. A four-stage LNA also demonstrated 2.5-dB noise figure with 28-dB gain, which is the best MMIC LNA result ever reported for on GaAs-based HEMTs.

## INTRODUCTION

Ultra-low-noise front-end amplifiers are essential for high sensitivity millimeter wave (MMW) communication systems and sensors. The Q-band LNA, is considered one of the critical components necessary in the design of a high performance Q-band receiving systems. Vital to many Q-band communication links, phased array systems, and sensors, the LNA role is key to the system performance. High electron mobility transistors (HEMTS) have successfully demonstrated the low noise capability at MMW frequencies[1]-[4]. The InP HEMTs demonstrated better performance than GaAs-based HEMTs [1]-[3]. However, the GaAs HEMT MMIC process technology is more mature and has demonstrated in production [4]. Both GaAs- and InP-based HEMT Q-band LNAs have been reported [5]-[7]. Recent results [7] have shown an InP HEMT Q-band (44 GHz) three-stage LNA with 22-dB gain and noise figure of 2 dB. Advances with our InP HEMT devices have achieved the lowest noise figure and highest gain among three-terminal devices. We have achieved noise figure performance as low as 1.6 dB with 10-dB associated gain for a one-stage LNA at 44 Ghz. With a two-stage design, 20 dB gain with 1.8-dB noise figure was obtained. A four-stage Q-band LNA based on our 0.1μm GaAs HEMT also demonstrated 2.5-dB noise figure with 28-dB gain, which is the best MMIC LNA result ever reported based on GaAs-based HEMTs. The MMIC LNAs have proven to be reliable with low cost to its hybrid counterparts [8].

## MMIC DESIGN AND DEVICE MODELING

Both designs utilized the same approach with characterization of 80-μm and 60-μm total gate periphery with four finger devices. The HEMT linear small signal equivalent circuit parameters are obtained from careful fit of the measured small signal S-parameters to 50 GHz with noise data taken through 40 GHz. Model parameters are obtained via fitting measured parameters and then extrapolated for frequencies above 40 GHz for designs higher in frequencies well to over 100 Ghz. The matching networks for the InP HEMT MMIC LNAs are fabricated on 70-μm thick semi-insulating InP substrate.

## Q-BAND InP- AND GaAs-BASED HEMT LNAs

The photograph of the one-stage InP Q-band MMIC LNA is shown in Fig. 1, exhibiting 10-dB gain with 1.6-dB noise figure from 43 to 46 GHz as plotted in Fig. 2.

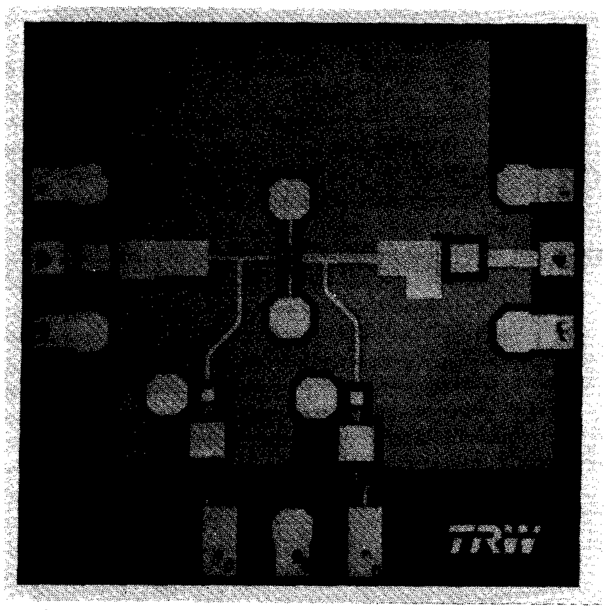


Figure 1. One-stage InP Q-band MMIC LNA MMIC Fabricated Chip.



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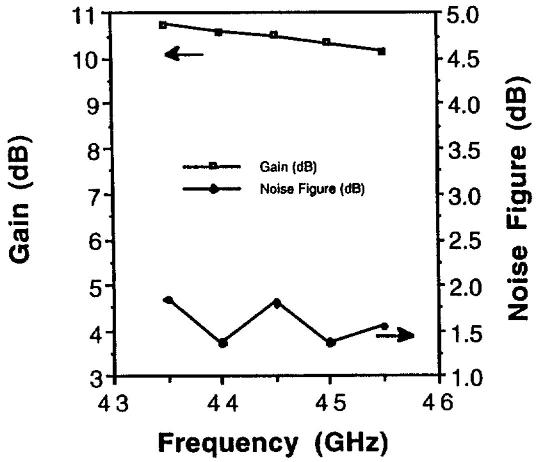
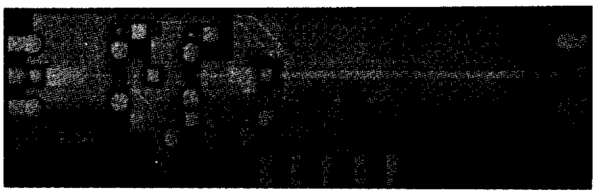


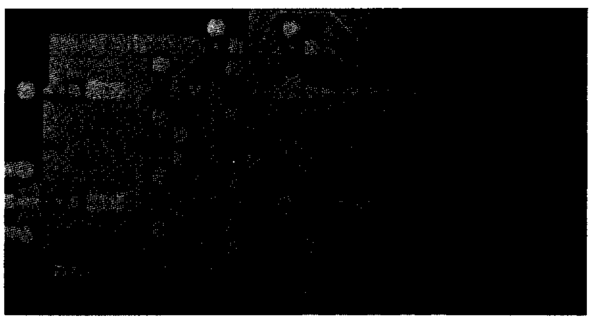

Figure 2. Noise figure and gain for the one-stage InP Q-band MMIC LNA.

To date this represents the lowest noise achieved compared with the published MMIC LNA at Q-band [4] in the area of 2-dB noise figure.

In addition, single-ended and balanced two-stage InP Q-band MMIC LNA's have also been developed as shown in Fig.3.



(a)



(b)

Figure 3. Two-stage InP Q-band MMIC LNA (a) Single-Ended (b) Balanced Fabricated MMIC Chip

It demonstrates 20-dB gain with 1.8-dB noise figure as shown in Fig. 4. A balanced design based on the two-stage single-ended LNA with Lange couplers for good input/output VSWR performance achieved 20-dB gain and 2.2-dB noise figure as shown in Figure. 5.

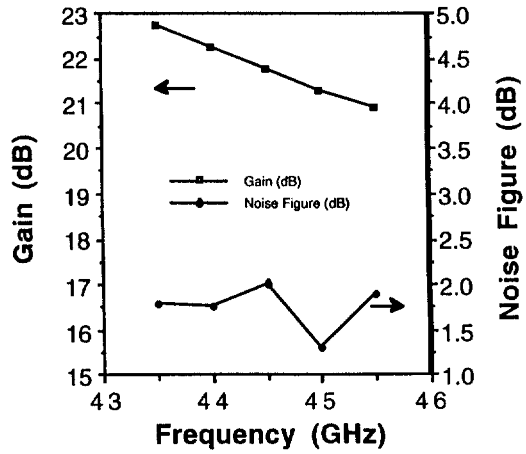



Figure 4. Noise figure and gain for the two-stage single-ended InP Q-band MMIC LNA.

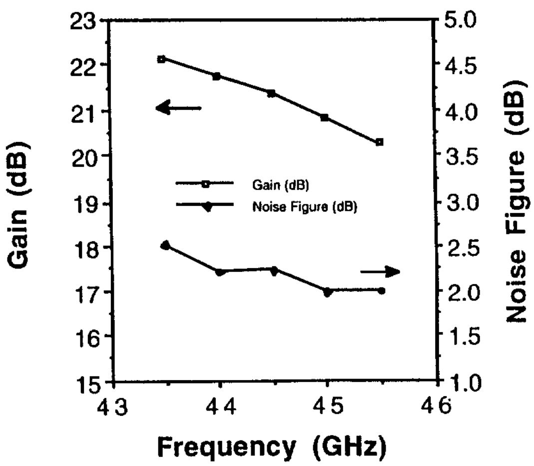



Figure 5. Noise figure and gain for the two-stage balanced InP Q-band MMIC LNA.

These reports represent the lowest noise figures and highest gain per stage for a Q-band InP LNA reported to date. These InP MMIC LNAs utilize 80-

μm four finger devices. The HEMT device structure cross section is shown in Fig. 6. This InP HEMT operates at 0.9-V drain voltage with 10-mA current for an 80-μm device. Thus the dc power is about three times lower than that of the GaAs counterparts.

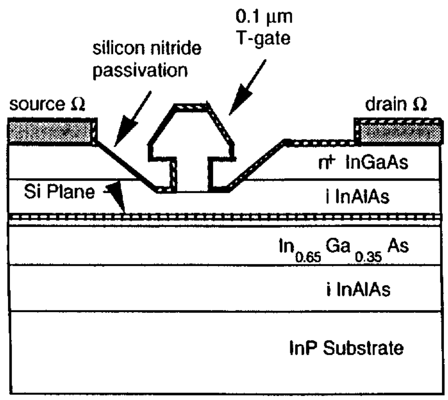



Figure 6. A cross section of the InP HEMT structure

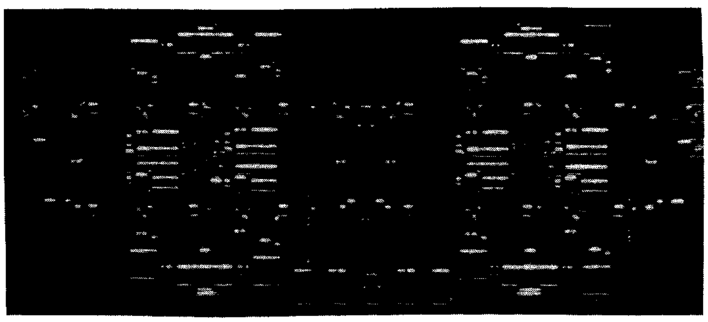


Figure 7. Four-stage GaAs Q-band MMIC LNA Photograph

Since the GaAs-based 0.1-μm HEMT process has been transformed to production line and demonstrated highly repeatability [4], we also developed Q-band MMIC LNA using this process. A four-stage balanced design as shown in Fig. 7 based on 60-μm four finger devices produces 28-dB gain with 2.5-dB noise figure as illustrated in Fig. 8. Another single-stage LNA exhibits 8-dB gain with a noise figure around 2-dB as shown in Fig. 9 These are the best MMIC LNA results ever reported using GaAs-based HEMTs.

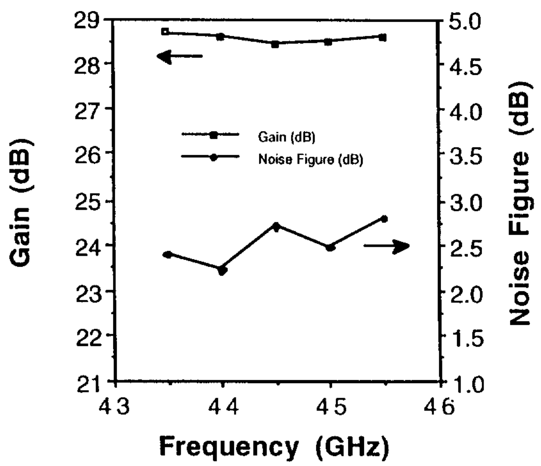



Figure 8. Noise figure and gain for the four-stage GaAs Q-band MMIC LNA

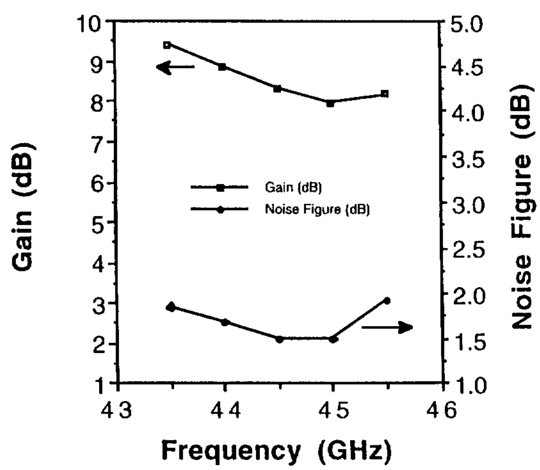
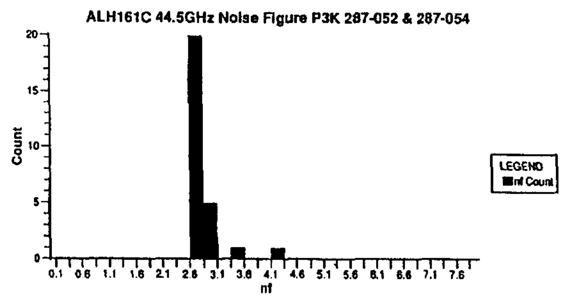



Figure 9. Noise figure and gain for the one-stage GaAs Q-band MMIC LNA.

Figure 10 shows the histograms for gain and noise figure distribution of the four stage balanced GaAs HEMT LNAs from two wafers. This 0.1μm GaAs HEMT process has successfully demonstrated hundreds of wafers of W-band MMIC LNAs and produced with excellent yield and uniformity [4].



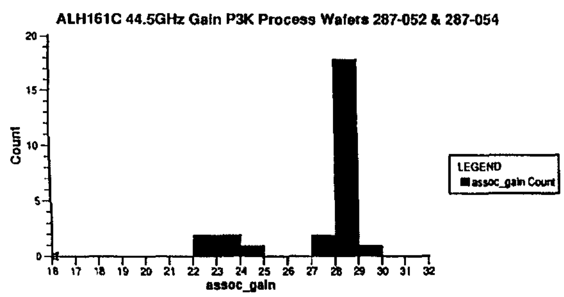




Figure 10. Histogram of noise figure and gain at 44.5GHzfor the four-stage 0.1µm GaAs MMIC LNA.

## CONCLUSION

We have demonstrated high performance monolithic Q-band LNAs in both InP and GaAs-based HEMTs with state-of-the-art results. For InP HEMT LNA, a noise figures as low as 1.6-dB is achieved for a one-stage amplifier with 10-dB gain. A two-stage amplifier exhibiting gain of 20 dB with 1.8-dB noise figure. On the other hand, we have also demonstrated a 44-GHz four-stage LNA based on 0.1-µm GaAs HEMTs which is a manufacturable MMIC production process with only 2.5-dB noise figure. The repeatability for MMIC LNA is extremely important, for example, in phased array systems where LNAs require close amplitude and phase matching to insure successful phased arrays. The GaAs HEMT MMIC Q-band LNAs are proven to be viable and can provide high performance at low cost compared to the hybrid-MIC approaches.

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