ULTRA LOW NOISE HIGH GAIN W-BAND InP-BASED HEMT DOWNCONVERTER*

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Abstract

State-of-the-art performance have been achieved at W-band on a two-stage LNA and on a single-ended active mixer fabricated using 0.15 micron T-gate InP HEMT devices. The LNA showed 3 dB noise figure and 16.5 dB associated gain at the waveguide interface at 93 GHz. The active HEMT mixer has 2.4 dB conversion gain and 7.3 dB noise figure at 94 GHz RF and 85 GHz LO. At the same RF and LO frequencies, the complete downconverter showed 3.6 dB noise figure and 17.8 dB conversion gain at the waveguide input and output.

Introduction

InP-based InGaAs High Electron Mobility Transistor (InP HEMT) has demonstrated the lowest noise figure and highest gain among all three terminal devices at millimeter wave frequency [1]. Low noise hybrid [2] and monolithic [3-4] millimeter wave amplifiers have been demonstrated using the InP HEMT devices. This paper reports on an InP HEMT-based W-band downconverter which consists of a two-stage LNA and a single-ended active mixer fabricated using 0.15 micron T-gate InP HEMTs. The complete downconverter showed 3.6 dB noise figure and 17.8 dB conversion gain at 94 GHz. The two-stage LNA showed 3 dB noise figure and 16.5 dB associated gain at 93 GHz. This is the best reported performance achieved from a two-stage LNA at this frequency. These LNA and downconverter data contains a waveguide-to-microstrip transition loss of 1.2 dB. The active HEMT mixer has 2.4 dB conversion gain and 7.3 dB noise figure at 94 GHz. With a noise figure comparable to the Schottky diode mixer, this is the first reported mixer with conversion gain at 94 GHz. These results demonstrate that an ultra low noise and high conversion gain MMIC downconverter can be constructed using the InP HEMT technology for W-band passive imaging camera and missile seeker applications which require very sensitive receiver front ends.

InP HEMT Device

Figure 1 shows a cross section of the 40x0.15 micron T-gate planar-doped $Al_{0.48}In_{0.52}As$/ $In_{0.53}Ga_{0.47}As$/InP HEMT devices used in this work. The device heterojunction structure was grown lattice matched to the InP substrate using the MBE technique. It has shown 1.7 dB noise figure and 7.7 dB associated gain at 93 GHz when biased and matched for minimum noise figure (Figure 2). When biased and tuned for maximum gain, we have routinely obtained 11 to 12 dB gain from the same devices .

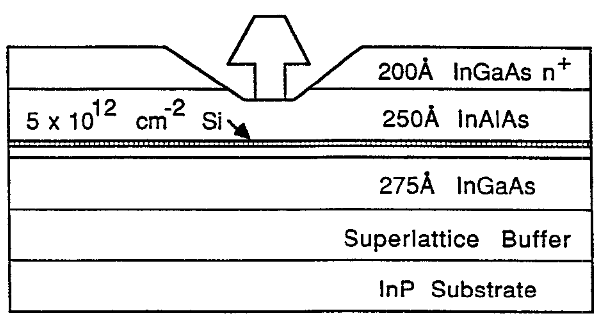

Figure 1. Cross section of InP-based InGaAs HEMT device structure.

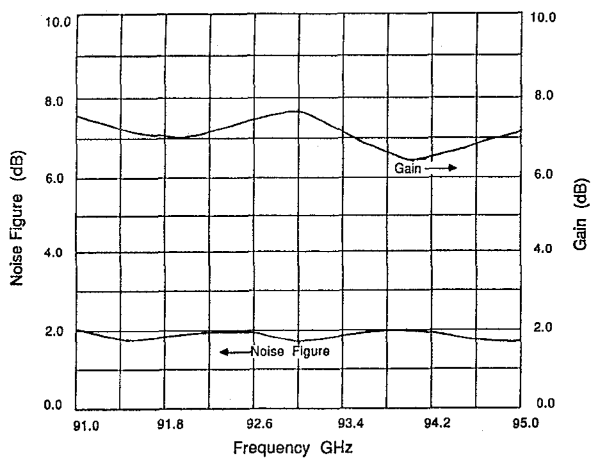

Figure 2. Measure noise figure and associated gain of TRW 0.15 micron T-gate HEMT device from 91 to 95 GHz.

Two-Stage InP HEMT LNA

Figure 3 shows a photo of the W-band two-stage hybrid LNA. The LNA circuits as well as the input and output waveguide-to-microstrip finline transition are fabricated on 5 mil quartz substrates. Coupled lines are used as the DC blocks between the two single-ended stages. Figure 4 shows the noise figure and associated gain of the two-stage InP HEMT LNA from 91 to 95 GHz measured at the waveguide interfaces. This data contains 1.2 dB loss associated with the two input and output waveguide-to-microstrip transitions. Corrected with the test fixture loss, the two-stage amplifier showed 2.5 dB noise figure and 17.7 dB associated gain at 93 GHz at the microstrip interfaces. Compared to previously reported two-stage InP HEMT LNA results [2], our two-stage LNA has shown lower noise figure and significantly higher gain due to the higher device gain and lower transition loss.

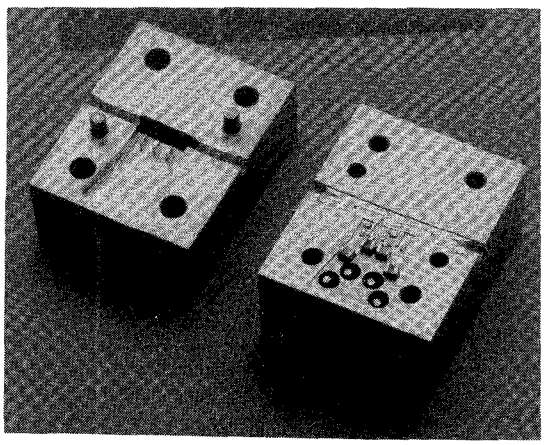

Figure 3. W-band hybrid two-Stage InP HEMT low noise amplifier.

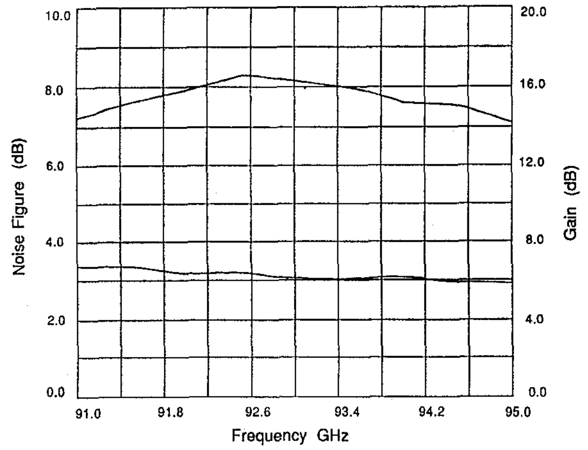

Figure 4. Measured noise figure and associated gain of the W-band two-stage InP HEMT LNA. The data includes 1.2 dB loss associated with the input and output waveguide-to-microstrip transitions.

InP HEMT Active Mixer

The W-band mixer is a single-ended active mixer design using one 40x0.15 micron InP HEMT device. It was fabricated on 5-mil quartz substrates. The detailed mixer design and its photo have been reported previously [5]. The LO and RF signal are fed at the gate using an external waveguide coupler and the 9 to 10 GHz IF signal was extracted from the drain. Figure 5 shows the measured noise figure and associated conversion gain of the mixer from 92 to 95 GHz. This data is taken with a fixed LO at 85 GHz and 3 dBm power. The mixer shows 2.4 dB conversion gain and 7.3 dB single-sideband noise figure at 94 GHz. To the best of our knowledge, this is the first reported conversion gain for a mixer at W-band. Our InP HEMT mixer result is much better than the monolithic InP HEMT mixer reported recently [6] probably due to better device characteristics and better circuit matching conditions. The compression characteristics of the InP HEMT mixer is shown in Figure 6. The input RF power at the 1-dB gain compression point is -8 dBm.

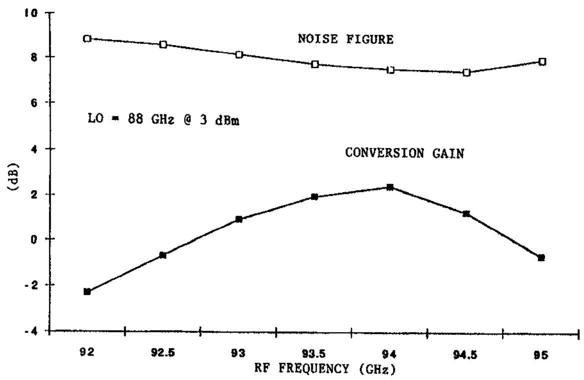

Figure 5 Measures noise figure and associated conversion gain of the W-band InP HEMT active mixer. The LO is fixed at 85 GHz and 3 dBm power.

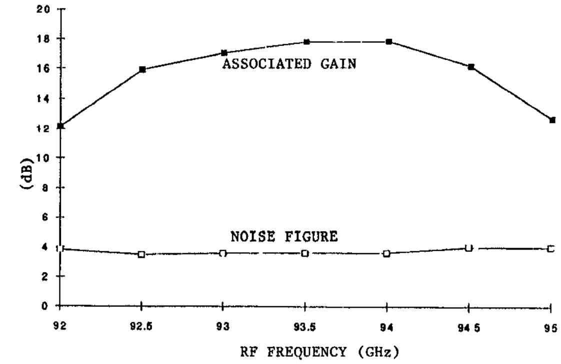

Figure 7. Measured W-band InP HEMT downconverter noise figure and gain. The LO is at 85 GHz and 3 dBm.

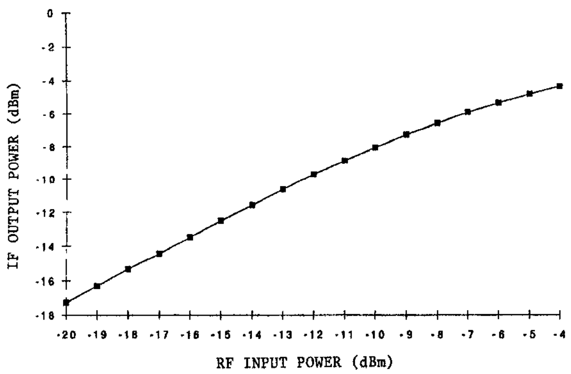

Figure 6. Measured compression characteristics of the W-band InP HEMT mixer at 94 GHz RF. The LO is at 85 GHz and 3 dBm power.

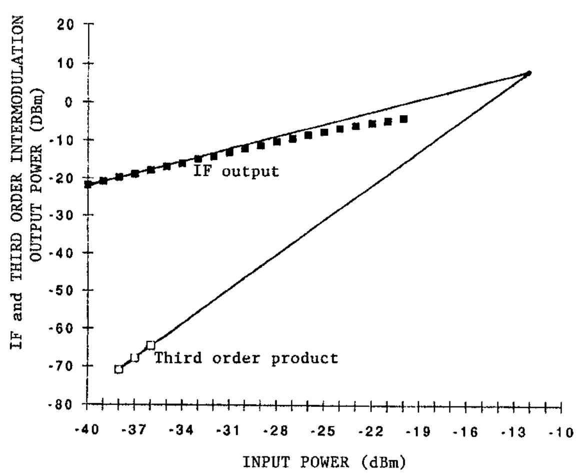

Figure 8. Measured compression and third order intermodulation characteristics of the W-band InP HEMT downconverter at 94 GHz RF and 3 dBm LO power at 85 GHz.

Downconverter Performance

The two-stage LNA and the active HEMT mixer were integrated together to form a downconverter. An in-house made waveguide isolator with about 0.5 dB insertion loss was used between the LNA and the mixer to avoid any need to retune the circuit. All the data reported below on the downconverter are referenced at the waveguide interface. Figure 7 shows the measured downconverter noise figure and associated gain from 92 to 95 GHz with LO at 85 GHz and 3 dBm. It has demonstrated 3.6 dB noise figure and 17.8 dB associated gain at 94 GHz. The noise figure is below 4 dB and the gain is greater than 12 dB over a 3 GHz bandwidth. Figure 8 shows the compression and the third-order intermodulation characteristics of the downconverter. The input powers at the 1-dB gain compression and at the third-order intercept point are -23 dBm and -12 dBm, respectively. It meets the requirement of most passive imaging camera or seeker systems. The downconverter conversion gain as a function of LO power is plotted in Figure 9. This data indicates that the active InP HEMT mixer and the InP HEMT based downconverter can be operated with extremely low LO power while maintaining low conversion loss for the mixer and good conversion gain for the downconverter.

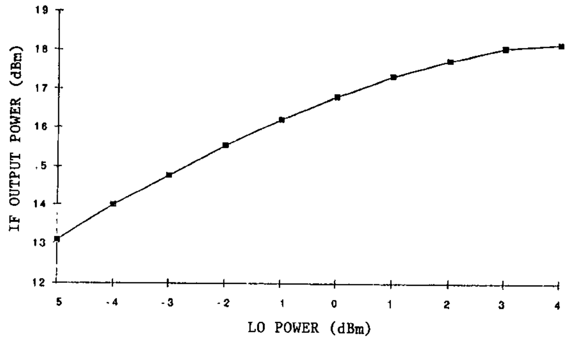

Figure 9. Measured conversion gain as a function of the LO power of the W-band InP HEMT downconverter at 94 GHz RF and 85 GHz LO.

Conclusion

We have reported a two-stage InP HEMT LNA which shows 3 dB noise figure and 16.5 dB associated gain at the waveguide interface at 93 GHz. The InP HEMT active mixer showed 2.4 dB conversion gain and 7.3 dB noise figure. The mixer conversion gain will reduce the noise contribution from the IF stages. These state-of-the-art LNA and mixer performance demonstrated that the InP HEMT is not only the preferred device for LNA applications but also very attractive for use in low conversion loss mixers. Our results indicate that a complete MMIC W-band downconverter with extremely low noise figure and high conversion gain can be fabricated on the same wafer using the InP HEMT technology. This higher level of chip integration eliminates bondwires at W-band, thereby improving the downconverter performance and and reliability. It also reduces the testing and assembly costs for the downconverter.

Reference

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