A 155-GHz Monolithic InP-Based HEMT Amplifier

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ABSTRACT

This paper presents the development of a three-stage 155-GHz monolithic low noise amplifier (LNA) using 0.1-µm pseudomorphic (PM) InAlAs/InGaAs/InP HEMT technology. This amplifier exhibits a measured small signal gain of 12 dB at 153-155 GHz, and more than 10-dB gain from 151 to 156 GHz. This is the highest frequency amplifier ever reported using three terminal devices.

INTRODUCTION

Millimeter-wave (MMW) LNA are very important components for smart munitions, passive imaging and radiometer applications. The PM HEMT devices using both GaAs and InP materials have demonstrated the high gain and low noise capability at W-band (75-110 GHz) and D-band (110-170 GHz) frequencies for hybrid integrated circuits [1]-[2]. The high gain low noise amplifiers have been successfully developed up to 140 GHz [3]-[6]. For the frequency above 120 GHz, InP-based HEMTs are superior to GaAs-based HEMTs for amplification due to the higher electron peak drift velocity in the InP based HEMT devices. The motivation of this work is to push the state-of-the-art and demonstrate higher frequency performance of a monolithic LNA to 155 GHz using the 0.1-µm passivated InP-based HEMT MMIC technology [11].

This paper presents the design, fabrication and testing of a 155-GHz monolithic three-stage amplifier using the 0.1-µm InAlAs/InGaAs/InP PM HEMT technology. A measured small signal gain of 12 dB is achieved at 153-155 GHz. To our knowledge, this is the highest frequency amplifier ever reported using three terminal devices and demonstrates state-of-the-art high frequency performance of InP HEMT MMIC amplifiers.

DEVICE FABRICATION AND CHARACTERISTICS

The three-stage 155-GHz MMIC LNA chip was fabricated on a 2" Fe-doped semi-insulating InP substrate grown by molecular beam epitaxy and employed 0.1-µm T-gate InP HEMT devices. The InAlAs/InGaAs/InP HEMT ($In_{0.65}Ga_{0.35}As$ channel) structure InP HEMT MMIC process were reported in [2], [11], with wafer passivation and stabilization bake steps introduced to the MMIC process. The device structure and layout are carefully designed to yield minimum parasitic capacitances and resistances. This InP-based PM HEMTs have achieved a dc transconductance of 1200 mS/mm, a unit current gain frequency (f_T) of 200 GHz, and a maximum oscillation frequency (f_{max}) of 400 GHz.

The MMIC LNAs fabricated using the InP HEMT MMIC process have also achieved state-of-the-art high gain

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and low noise figure performance at lower frequencies, which include a Q-band (44.5 GHz) two-stage balanced LNA exhibiting 2.2-dB noise figure with 20-dB associated gain [7], and a W-band four-stage balanced amplifier with small signal gain of 23 dB from 75 to 110 GHz [8]. A two-stage cryogenically cooled W-band LNA also exhibited 0.7-dB NF at 95 GHz with 12-dB associated gain [9].

CIRCUIT DESIGN AND MEASUREMENT RESULTS

The linear small signal model for a 0.1-µm gate length four finger, 30-µm gate width PM InP HEMT, used in this 155-GHz LNA design, is derived from scaling of a four finger, 40-µm gate width device model, which is obtained from curve fitting of the measured small signal S-parameters up to 50 GHz. The resulting parameters are consistent with the estimated values based on device physical dimensions and parameters. The equivalent circuit and parameters of the small signal model can be found in [11].

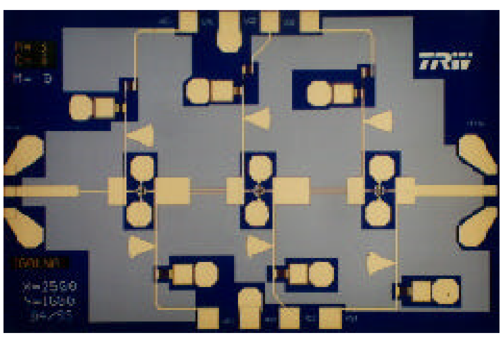

Fig. 1. Chip photograph of the 155-GHz InP-based HEMT MMIC low noise amplifier.

Fig. 1 shows the chip photograph of this monolithic amplifier. The size of this chip is 2.5 mm x 1.6 mm. The 155-GHz amplifier is a three-stage single-ended design and each stage uses a 30-µm PM InP HEMT. The input, output and interstage matching networks are all constructed by cascading high-low impedance microstrip lines on a 75-µm thick InP substrate. Edge coupled lines are used for dc blocking and radial stubs are employed for RF bypass. Shunt RC networks are included in the bias networks for amplifier stability. A wet chemical etching process is used to fabricate back side via holes for grounding. The design and analysis procedures of this the monolithic chip design, which include accurate active device modeling and full-wave electromagnetic (EM) analysis of passive structures, is documented in [10].

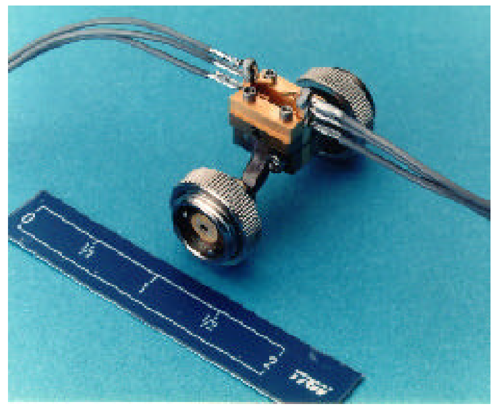

Fig. 2. Photograph of the 155-GHz MMIC LNA mounted in the test-fixture.

The chip was tested in a G-band (140-220 GHz) waveguide fixture. Microstrip-line to waveguide E-plan probe transitions fabricated on 3-mil quartz substrates were used to couple the MMIC chip to the waveguide measurement system. The measured insertion loss for a pair of back-to-back transitions was 2.5 dB with a return loss about 15 dB from 152 to 168 GHz. The complete fixture with the MMIC chip mounted is shown in the photograph as Fig. 2. Fig. 3 plots the gain and input/output return losses performance from 144 to 170 GHz. A peak gain of 12 dB occurs at 153-155 GHz and the amplifier demonstrates more than 10 dB gain from 151 to 156 GHz with an input return loss better than 5 dB and an output return loss better than 10 dB. The gain results are corrected by the 2.5-dB E-plan probe transition loss factor. The noise figure will be measured and reported later. The total dc power consumption of this chip is only 35 mW (V_d = 1.4 V, I_{total}

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= 25 mA). To our knowledge, this is the first report of an amplifier operating in this frequency range using three terminal devices.

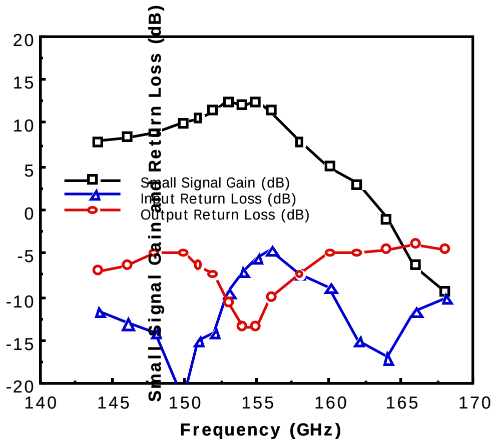

Fig. 3. The plot for the measured small signal gain and return losses of the 155-GHz MMIC LNA from 144 to 170 GHz.

CONCLUSION

We have presented the development of 155-GHz monolithic low noise amplifiers using 0.1-µm pseudomorphic AlInAs/InGaAs/InP HEMT technology. The three-stage single-ended 155-GHz monolithic LNA exhibits a small signal gain of 12 dB at 155 GHz, and more than 10-dB gain from 151 to 156 GHz. To the best of our knowledge, this is the highest frequency amplifier ever reported using three terminal devices.

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