A High Performance W-Band Monolithic Pseudomorphic InGaAs HEMT LNA

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ABSTRACT

A high performance W-band monolithic two-stage LNA based on pseudomorphic InGaAs/GaAs HEMT devices has been developed. This amplifier has a measured small signal gain of 13.3 dB at 94 GHz and 17 dB at 89 GHz. The noise figure is 5.5 dB from 91 to 95 GHz. This is the best reported performance of a W-band monolithic LNA. The measured results of this MMIC LNA even rival some of the recently reported hybrid LNAs. A rigorous analysis procedure was incorporated in the design, including accurate active device modeling and full-wave EM analysis of passive structures. The first pass success of this LNA chip design indicates the importance of a rigorous analysis/design methodology in the millimeter wave monolithic IC development.

INTRODUCTION

Monolithic HEMT-based W-band low noise amplifiers have the advantages of miniature, high volume and low cost over the conventional diode or HEMT based hybrid integrated circuit components in millimeter wave radar, electronic warfare, smart weapon, and surveillance system applications. The motivation of this work is to explore the possibility of a high performance W-band monolithic LNA to achieve the system requirements.

A W-band monolithic two stage LNA has been designed, fabricated and tested. The LNA chip has demonstrated a superior performance: 13.3 dB gain at 94 GHz, 17 dB gain at 89 GHz and 5.5 dB noise figure from 91 to 95 GHz. These results not only are the best MMIC LNA performance at W-band frequency reported to date [1]-[5], but also rival some recently reported hybrid LNA results [6]. Moreover, the first monolithic W-band downconverter has also been successfully developed using the similar LNA design [9]. Good modeling techniques were essential to the success of this MMIC design, which included active device and full-wave EM analysis of passive matching structures.

DEVICE CHARACTERISTICS

The devices reported in this paper have been optimized for high gain operation at W-band. The 22% PM InGaAs HEMT uses planar doping to achieve high channel aspect ratio as well as higher electron transfer efficiency. The MMIC fabrication process used for this work has been previously reported [8]. A cross-section of the HEMT is shown in Fig. 1(a). The 0.1 μm T-gate PM InGaAs HEMTs fabricated using this process typically have a DC transconductance of 670 mS/mm with f_t as high as 130 GHz. In this design, the 40 μm gate periphery HEMT has been chosen for both stages. The linear equivalent circuit model of this device used for

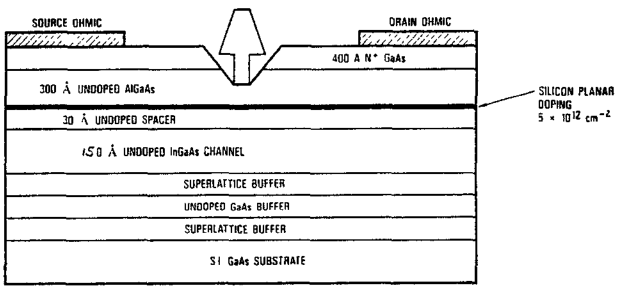

Fig. 1(a). The InGaAs HEMT profile.

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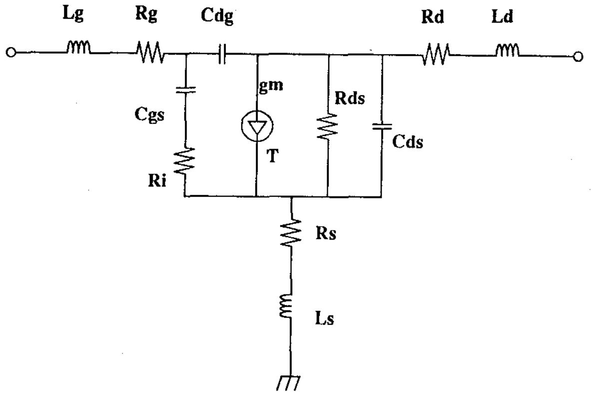
simulation is obtained from careful fit of the measured small signal S-parameters up to 40 GHz as well as estimation based on device physical parameters. The circuit parameters are shown in Fig. 1(b).



Cdg (fF)	Cgs (fF)	Cds (fF)	gm (mS)	Rds (ohm)	Ri (ohm)	Rg (ohm)	Rs (ohm)	Rd (ohm)	Lg (pH)	Ls (pH)	Ld (pH)
9.52	24.1	12.5	26.5	450	6.76	1.34	6.02	12.7	2.43	1.2	1

Fig. 1(b). The linear small signal equivalent circuit model of 40 μm InGaAs HEMT.

CIRCUIT ANALYSIS AND DESIGN

Fig. 2 shows a photograph of the complete monolithic two-stage LNA. The circuit is designed based on conventional reactive matching technique. All the matching networks are realized by microstrip lines on 100 μm thick GaAs substrate. Edge coupled lines are used for DC block and radial stubs are employed for RF by pass. N^+ bulk resistors are used to ensure bias network stability, and reactive ion etching (RIE) technique is applied to fabricate back side via holes.

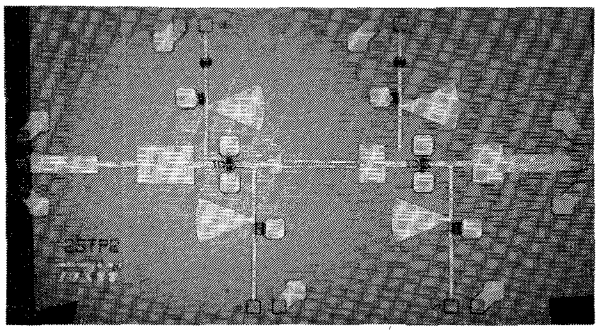


Fig. 2. Photograph of the W-band two stage MMIC LNA.

The importance of passive elements modeling at W-band frequencies has been stressed. To improve the matching and bias structure design accuracy, a full EM analysis was used. The edged coupled line and radial stub are chosen as critical components and characterized by the method of moment solution of full-wave integral equation based on the assumption of stratified medium in a conducting box [7]. Significant discrepancies exist between the conventional quasi-static and full wave analyses as shown in Fig. 3. The S-parameters calculated from the full wave EM analysis of these critical components are used to perform the circuit simulation. After design is finished, the complete matching structures are analyzed by EM theory again to ensure no severe coupling effects between elements.

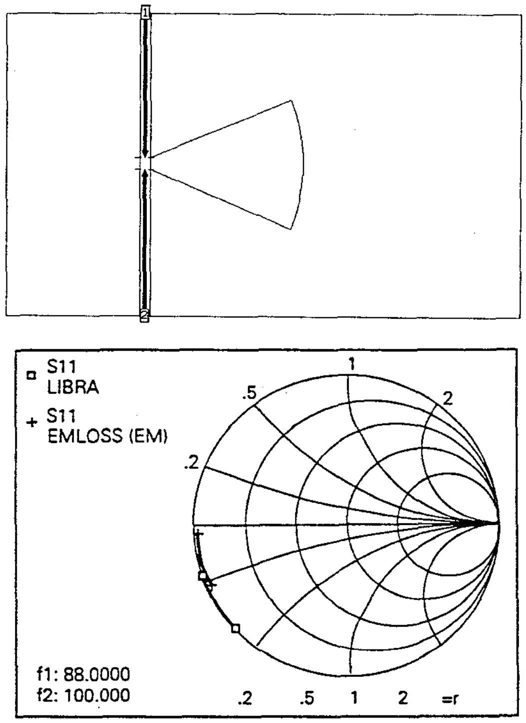
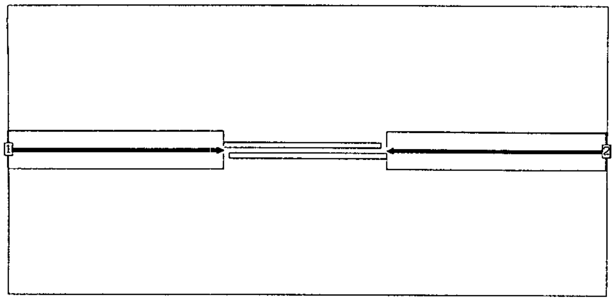


Fig. 3(a). Comparison of S-parameters for the radial stub analyzed via full-wave EM theory (EM) and quasi-static assumption (LIBRA).

MEASUREMENT RESULTS

The circuit is measured in a specially designed test fixture. Finline transitions on 3 *mil* fused silicon are used to couple the signal from



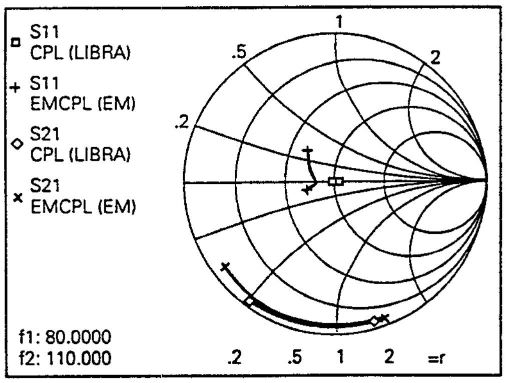


Fig. 3(b). Comparison of S-parameters for the edge coupled lines analyzed via full-wave EM theory (EM) and quasi-static assumption (LIBRA).

waveguide to microstrip. The insertion loss of this transition fixture with a back to back transition connection is 1.7 to 2 dB from 88 to 96 GHz (Fig. 4(a)). All the measurement results are corrected by this factor.

The measurement data are presented in Fig. 4(b)-(e). The noise figure and associated small signal gain performances from 91 to 95 GHz are shown in Fig. 4(b). Fig. 4(c) illustrates the input return loss and uncorrected gain from 80 to 100 GHz. The input return loss are better than 10 dB from 91 to 97 GHz and at 89 GHz, the measured gain including fixture loss is 15.3 dB which is 17 dB after correction. Fig. 4(d) presents output return loss better than 5 dB across the 80 to 100 GHz band. The input power vs. output power plot is shown in Fig. 4(e). The output 1 dB compression point of this LNA is 4 dBm and the output IP3 is 13 dBm. The results presented above are all under $3V$ drain bias condition with 0.1 V gate voltage (near g_m peak) for both stages, the gain is 1 dB lower when biased at $2V$ drain voltage.

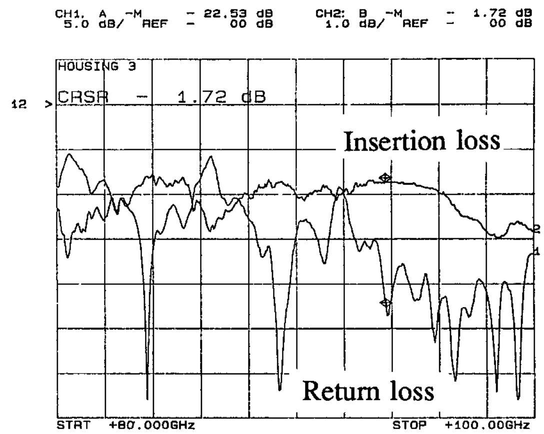


Fig. 4(a). Measured insertion loss and return loss of the finline transition.

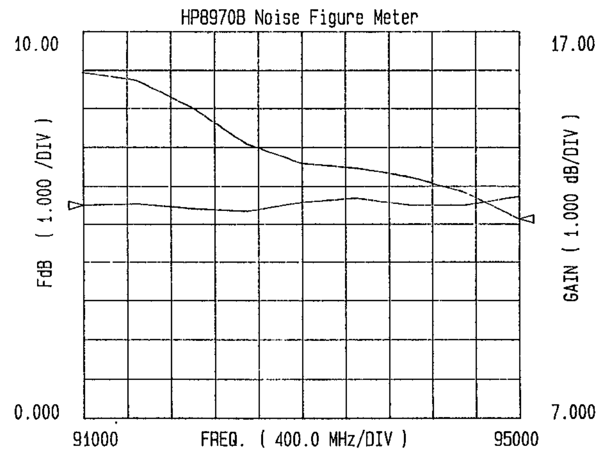


Fig. 4(b). Measured noise figure and associated small signal gain.

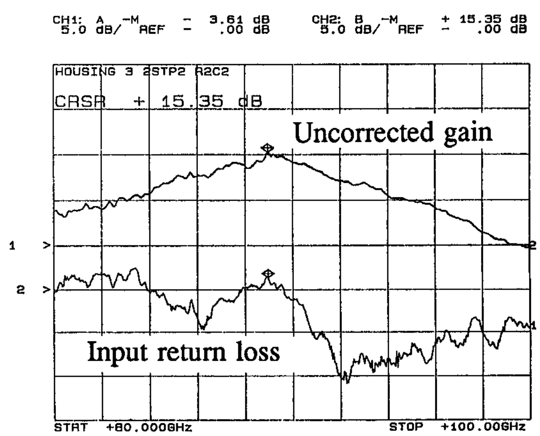


Fig. 4(c) Measured input return loss and uncorrected gain.

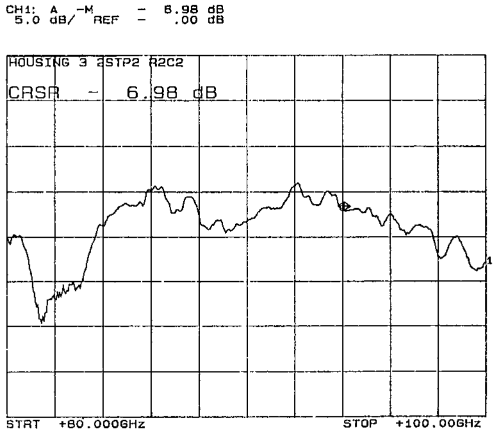


Fig. 4(d) Measured output return loss.

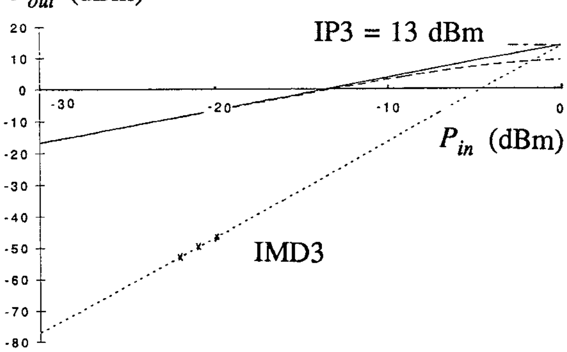


Fig. 4(e) P_{in} vs. P_{out} and third harmonic intermodulation.

CONCLUSIONS

We have demonstrated a W-band MMIC two stage LNA. At 94 GHz, a gain of 13.3 dB and a noise figure of 5.5 dB have been achieved. These encouraging results shows the potential of InGaAs HEMTs for W-band high performance receiver applications. The excellent device characteristics and rigorous analysis/design methodology are the foundations of this successful MMIC design.

ACKNOWLEDGEMENT

The authors would like to thank Drs. T. H. Chen, K. W. Chang, Y. S. Hwang, L. C. T. Liu for their helpful discussions and suggestions, D. Shiroma, W. Bartolome, J. Coakley for their layout support and D. Garske for her testing effort.

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