0.25 μm PHEMT X Band Multifunction LNA MMIC with T/R Switch and Attenuator Achieves 1.85 dB Noise Figure

S.T.Janesch, K.H.G.Duh, P.Ho, S.C.Wang, S.M.J.Liu

General Electric Company
Electronics Laboratory
Syracuse, NY, 13221

Abstract

Performance of a 7-11 GHz LNA MMIC which advances performance and integration standards is presented. A 1.8 dB NF, 19 dB gain LNA is married to a 0.5 dB insertion loss T/R switch and switched attenuator for a MMIC with 1.85 dB NF, 18 dB gain at 10 GHz.

Introduction

The MMIC described in this paper represents an advance in the state of the art in low noise amplifier (LNA) performance and integration for radar applications. The self-biased two stage LNA achieves 1.45 to 1.8 dB noise figure and greater than 19 dB gain from 7 to 11 GHz. Preceding the LNA is a transmit/receive (T/R) switch to protect the LNA when the radar is transmitting. The T/R switch has only 0.5 dB insertion loss and typically 13 dB isolation from 7 to 11 GHz. Following the LNA is a two state 8 dB attenuator which is used to increase dynamic range of the receiver by preventing saturation when strong input signals are present. The switch and attenuator performance results are outstanding in light of the fact that the PHEMTs used are optimized for use in low noise amplifiers.

Device Characterization

The X Band Multifunction LNA MMIC was fabricated on the GE 0.25 μm pseudomorphic HEMT (PHEMT) process. Due to the wide range of gate peripheries expected on this MMIC, a 75 μm unit gate width was chosen for building interdigitated active and switch devices. Active devices with 300 μm periphery in common source and self-biased configurations (with and without inductive source feedback) were processed in a device fabrication lot. Also included in the device lot were switch devices with 150, 300, 450, and 600 μm peripheries, thin film one-Watt resistors, via hole characterization structures and wafer probe calibration standards.

A total of 24 active devices were measured and modeled for noise and/or S-parameters. Average noise and equivalent circuit models were derived, with Fmin of 0.62 dB and Rn of 7.1 Ohms at 10 GHz. Over 100 switch devices from 150 μm to 600 μm periphery were modeled, measured, and averaged, and found to scale well. Cutoff frequency for the switch devices was calculated to be 289 GHz.

MMIC Design

T/R Switch Design -- In order to minimize its impact on the noise figure of the MMIC, the loss of the input transmit/receive switch must be minimized. For this reason, there is no series switch device, as shown in the MMIC schematic in Figure 1. In the receive state, the three devices are pinched off. They are separated by a length of 50 Ohm microstrip, L1, such that their capacitive reactances cancel each other. In the transmit mode, the three PHEMTs are turned on. The output device Q2 gives a low resistance to ground, which appears as a high impedance at the plane of the input devices, thus the RF energy is directed through the input devices Q1 and into R1. Predicted performance is 0.5 dB and 15 dB insertion loss in receive and transmit states, respectively, and better than 15 dB input return loss in both states.

Attenuator Design -- In the low loss state, Q5 is on and Q6 are pinched off. As frequency increases, more energy leaks through Q6, and insertion loss increases. In the attenuated state, Q5 is pinched off and Q6 are on. As frequency increases, more energy leaks through Q5 and

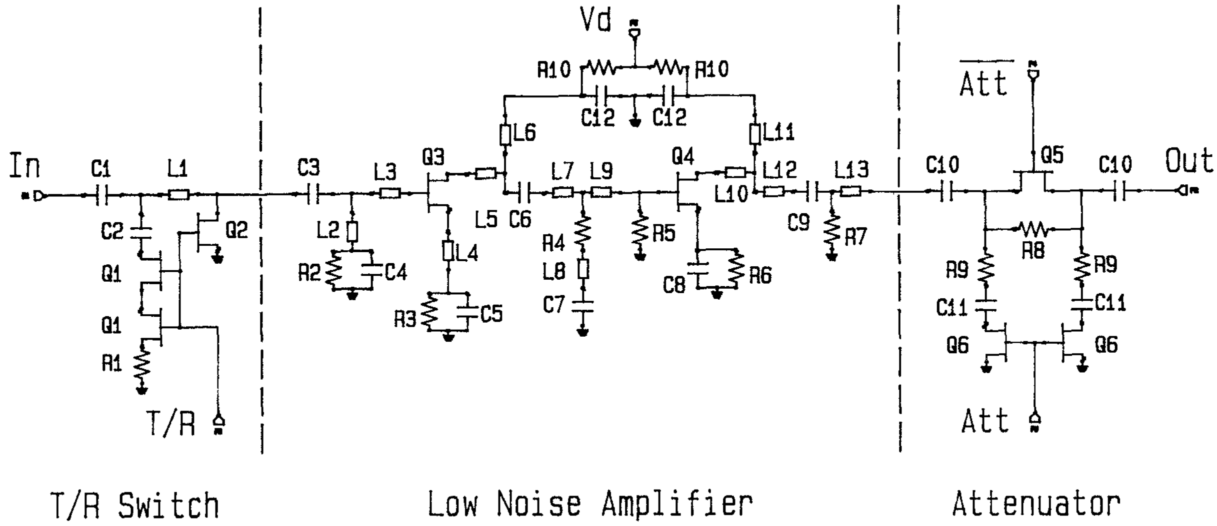

Figure 1. Simplified Multifunction LNA MMIC schematic diagram.

insertion loss decreases. This gives a natural rolloff in differential attenuation which is countered by the presence of the small capacitors C11. Predicted performance in the low loss state shows 1 to 2 dB insertion loss and greater than 10 dB return loss. Predicted differential attenuation is flat at 8 dB with 12 dB return loss in the attenuated state.

LNA Design -- This low noise amplifier is based on previous self-biased LNA topologies. The main difference is the fact that this amplifier is optimized to be placed in between this switch and attenuator. After the switch was designed, it was included as part of the input matching network for the LNA. Similarly, the slope of the insertion loss of the attenuator must not be ignored, so the attenuator was included as part of the output matching network. Figure 2 shows the predicted performance of the LNA by itself. Figure 3 shows the predicted performance of the MMIC in the maximum gain, receive state. Figure 4 shows the predicted performance of the MMIC in the minimum gain, receive state.

MMIC Layout -- A layout diagram of the complete MMIC is given in Figure 5. Airbridge tuning is available on shunt microstrip lines in both the input and interstage matching networks of the LNA. The nominal tuning state is with one of the two segments removed. Also, airbridges are placed in sections of 50 Ohm line in the main RF path between the three different circuits for diagnostics.

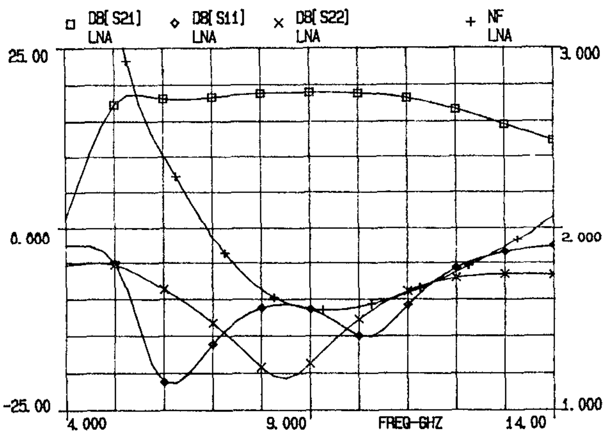

Figure 2. Predicted performance of standalone LNA.

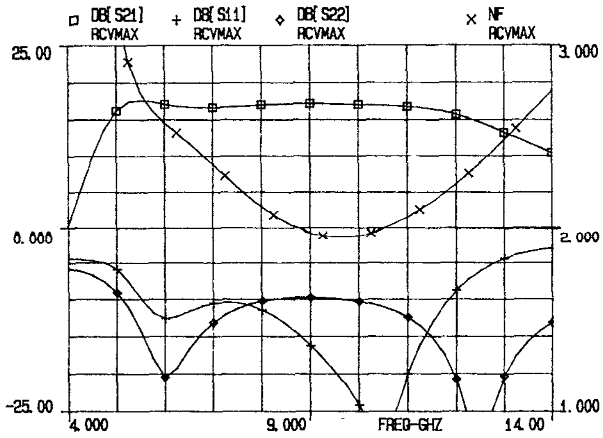

Figure 3. Predicted performance of MMIC in maximum gain state.

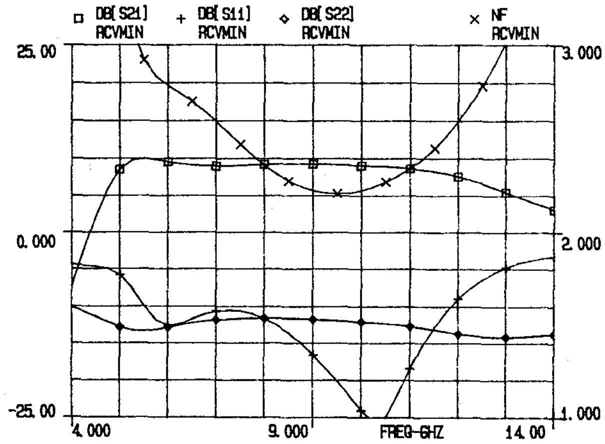

Figure 4. Predicted performance of MMIC in minimum gain state.

Measured Performance

Figure 6 gives on-wafer gain and noise figure for the MMIC under two different bias conditions. The first condition shows gain staying in the 16 to 18 dB window and noise figure below 2.25 dB for 7 to 11 GHz. With bias optimized for noise figure, gain increases by almost 3 dB and noise figure improves by roughly 0.1 dB for a minimum of 1.85 dB at 10 GHz. Figure 7 gives wideband S-parameters for the first bias condition. Note the excellent match to the predicted performance of Figure 3. In the minimum gain state, gain drops by 7 to 8 dB across the band and noise figure typically increases by 0.2 dB.

Figure 8 gives wideband S-parameters for the LNA, again with very good correlation to predicted performance. Figure 9 gives on-wafer gain and noise figure for an LNA salvaged from a MMIC with a failed T/R switch. Gain is between 19 dB and 23 dB, with noise figures from 1.8 dB at 7 GHz to below 1.5 dB from 8 to 10 GHz.

Figure 10 gives measured S-parameters of the T/R switch in both transmit and receive states. Receive state insertion loss is 0.6 dB with return loss between 15 and 21 dB from 7 to 11 GHz. Transmit state insertion loss is 15 to 16 dB and input return loss is greater than 18 dB across the band. Figure 11 shows measured insertion loss and return loss in both states. In the low loss state, insertion loss ranges from 1.5 to 2.25 dB with return loss near 10 dB from 7 to 11 GHz. In the attenuated state, insertion loss ranges from 9.25 to 9.5 dB for a step of 7.5 +/- 0.25 dB across the 7 to 11 GHz band.

Conclusions

The integration of three receiver functions on one 0.25 μm PHEMT MMIC has been achieved with outstanding results on the first process iteration. Noise figure for the MMIC is below 2.2 dB (minimum 1.85 dB), gain is above 20dB and input return loss is better than 13 dB from 7 GHz to 11 GHz. The T/R switch and 8 dB attenuator function as designed. This excellent performance can be attributed to careful measurement, accurate modelling of a large number of devices, thorough design, and careful, repeatable fabrication.

Acknowledgement

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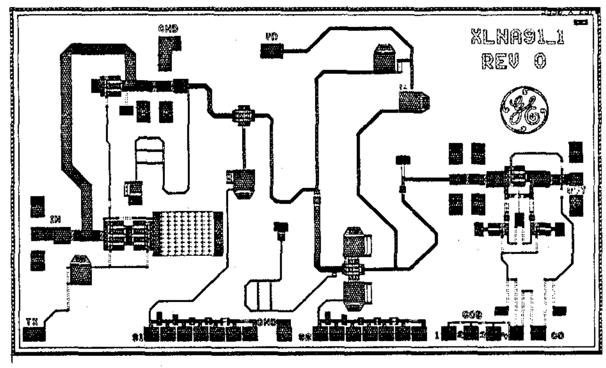

Figure 5. Layout of X Band Multifunction LNA MMIC.

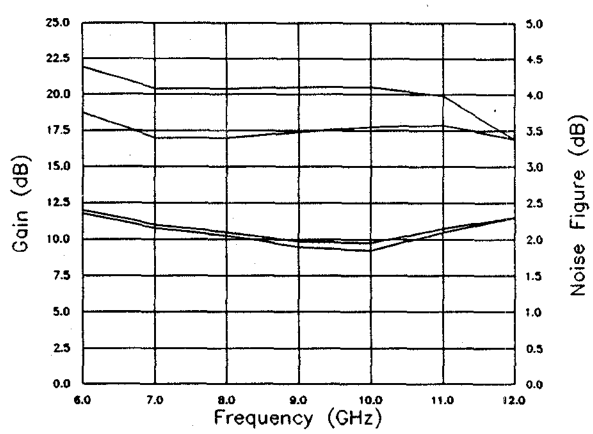

Figure 6. Measured gain and noise figure of MMIC in maximum gain state with bias optimized for (1) 18dB gain and (2) minimum noise figure.

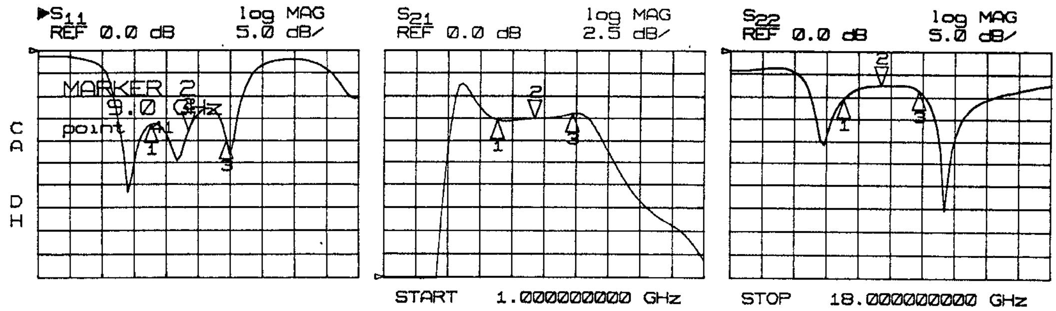

Figure 7. Measured wideband S-parameters of MMIC in maximum gain state.

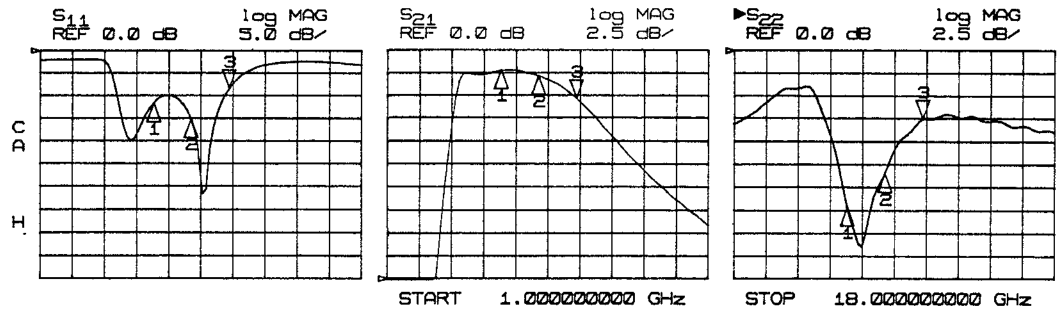

Figure 8. Measured wideband S-parameters of LNA only.

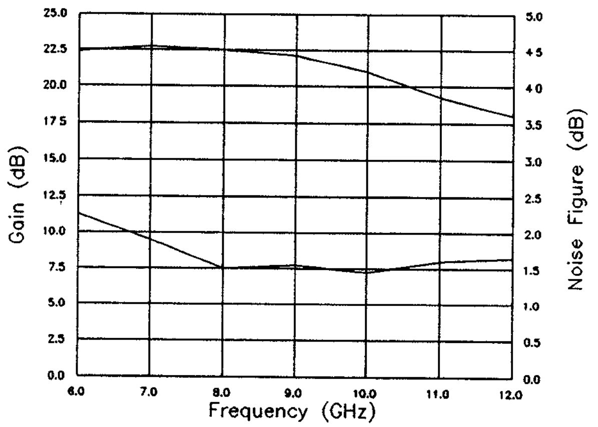

Figure 9. Measured gain and noise figure of LNA only.

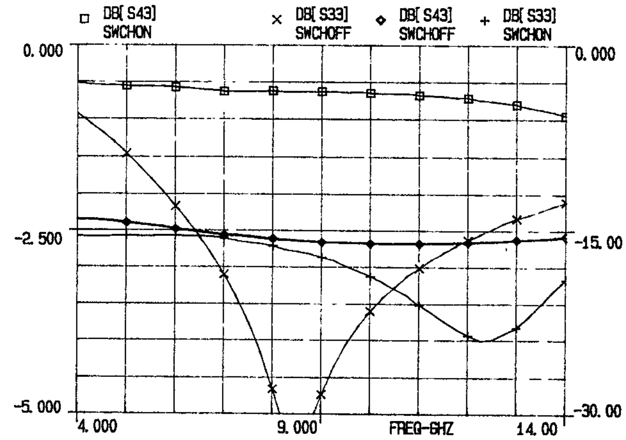

Figure 10. Measured performance of T/R switch.

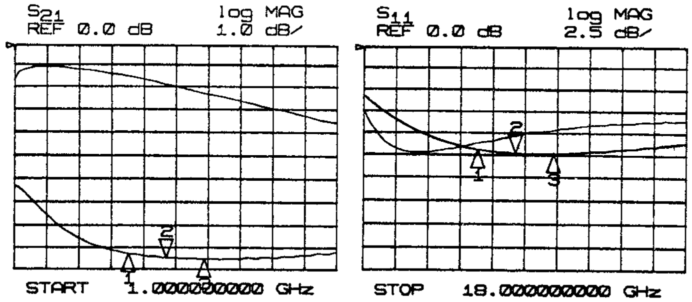

Figure 11. Measured wideband performance of attenuator.