A Monolithic Variable Gain Ku-Band LNA

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ABSTRACT

A monolithic four-stage low noise amplifier (LNA) has demonstrated over 25 dB gain with gain control exceeding 30 dB and less than 3.5 dB noise figure from 14 GHz to 17 GHz. Single-gate FETs (SGFETs) provide minimum noise figure in the two input stages while dual-gate FETs (DGFETs) in the output stages contribute enhanced gain with gain control. Gain control is achieved without degradation in either input or output VSWR.

INTRODUCTION

Variable gain amplifiers serve useful functions in phased-array applications. With gain control, techniques such as array tapering, temperature compensation, and module-to-module amplitude tracking are possible. DGFETs have been widely used in gain control amplifiers with the amplitude of gain being controlled by the gate-2 bias voltage. The noise figure of a DGFET varies with gate-2 voltage and degrades significantly as the gain decreases. Thus, SGFETs are used in the input two stages and act as a preamplifier for the variable gain-control DGFETs in the output two stages. By using SGFETs in the input two stages, noise figure degradation over gain control is reduced. This paper describes a Ku-band variable gain LNA (see Figure 1) using a SG-, DGFET configuration previously demonstrated at X-band [1].

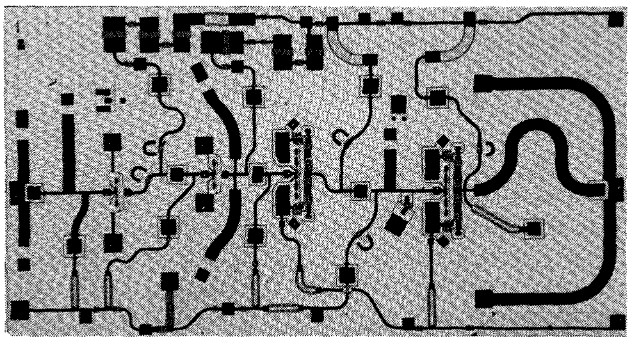

Figure 1. Variable Gain Four-Stage LNA.

CIRCUIT DESIGN

The use of series inductive feedback to achieve simultaneous input VSWR and optimum noise match (Zopt) with a reduction of the equivalent noise resistance has been demonstrated at X-band [2]. This technique has provided similar benefits at Ku-band. To obtain the optimum Zopt and input VSWR matching conditions, device scaling and Smith Chart mapping techniques were utilized. Initially, the SGFET noise and small signal models were scaled to various peripheries. Then mapping techniques were used with varying amounts of inductive feedback to determine the optimum device size and the optimum amount of feedback. The input FET has been scaled to 274 um from a 300 um model to provide the closest noise and input VSWR match with 0.15 nH series inductive feedback over the frequency band of interest (see Figures 2 and 3). Input and first interstage matching networks are designed to provide minimum noise figure and low input VSWR.

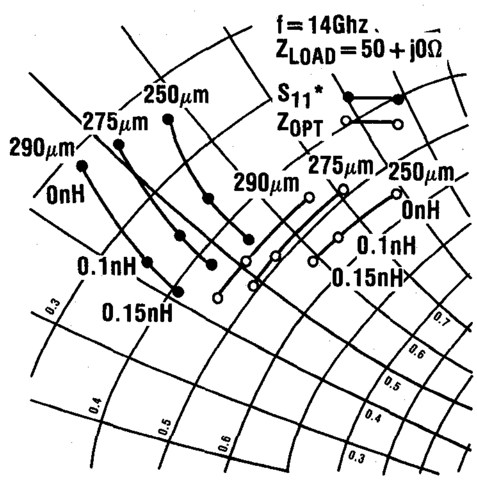

Figure 2. Impedance Mapping of S11* and Zopt Versus Device Size and Feedback at 14 GHz.

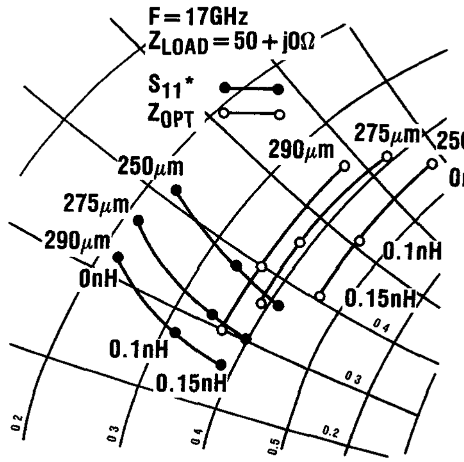

Figure 3. Impedance Mapping of S11* and Zopt Versus Device Size and Feedback at 17 GHz.

500 um DGFETs in the third and fourth stages contribute higher gain than the SGFETs. Parallel resistive feedback between gate-1 and the drain of the DGFETs furnishes broadband device stability. The DGFET gate-2 terminations are RF shorted through a 20 pF capacitor to ground. For design purposes, single-gate FET models were used for the DGFETs. The second and third interstage matching networks are designed to maximize amplifier gain and minimize gain slope across the band. The fourth-stage FET is loaded with a shunt 50 ohm resistor in order to reduce the output VSWR. A 50 ohm quarterwave transformer then rotates the phase of the output reflection coefficient 180 degrees. This phase reversal enables quarterwave shorted stubs, which behave capacitively above resonance and inductively below resonance, to provide a lower output VSWR over more bandwidth than by loading the output FET with only a shunt resistor. A circuit schematic of the LNA is shown in Figure 4. Chip size is 212 mils by 115 mils by 6 mils

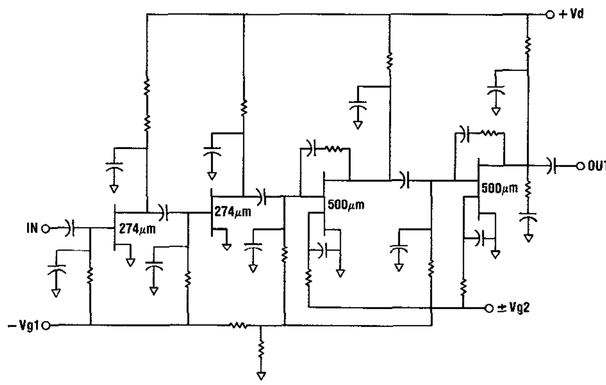

Figure 4. Variable Gain LNA Schematic.

RF PERFORMANCE

The monolithic four-stage variable gain LNA has demonstrated over 25 dB gain with gain control exceeding 30 dB and less than 3.5 dB noise figure from 14 GHz to 17 GHz. The Ku-band gain control response is shown in Figure 5. Input and output return loss is shown in Figure 6. No degradation of input or output VSWR is observed over 30 dB of gain control. Noise figure performance with gate-2 control is displayed in Figure 7. Table 1 lists noise figure, gain, and input third order intercept point at 15.5 GHz as a function of gate-2 bias.

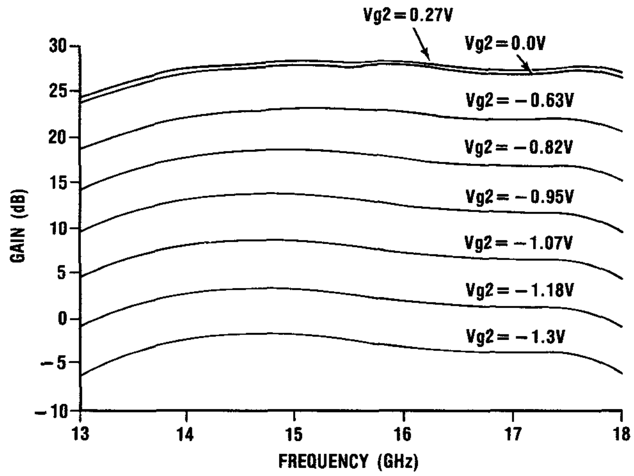

Figure 5. LNA Gain Performance.

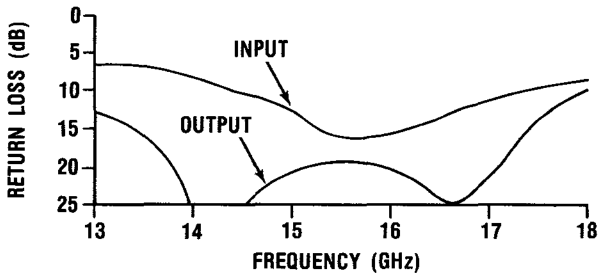

Figure 6. LNA Return Loss Performance.

The LNA operates from a 3 volt drain supply for both SGFETs and DGFETs. To increase the 1 dB output power compression point, a 5 volt drain supply could be used for the DGFETs with the on-chip resistive dividers supplying 3 volts to the SGFETs. The 3 volt drain voltage reduces the power dissipation in the

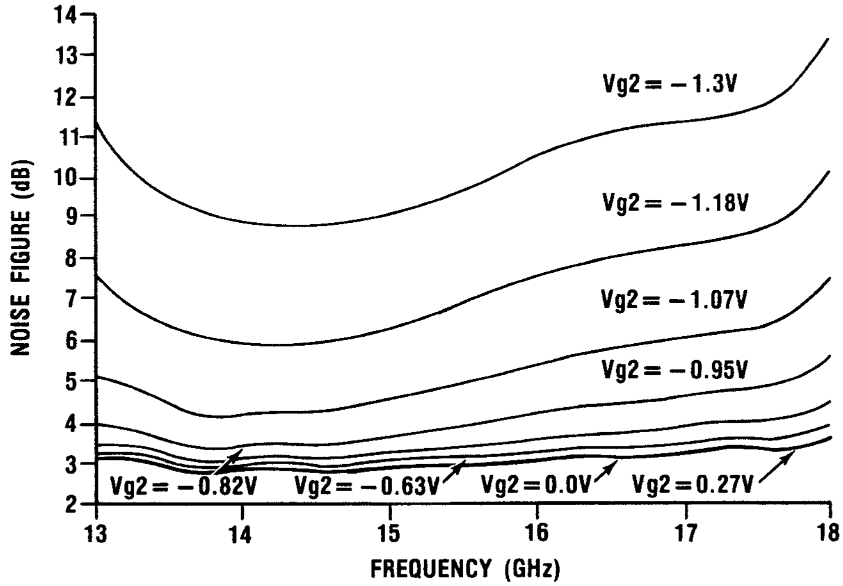

Figure 7. LNA Noise Figure Performance.

TABLE 1. 15.5-GHz PERFORMANCE OF VARIABLE GAIN LNA

GATE 2 (VOLTS)	DRAIN CURRENT (mA)	GAIN (dB)	NOISE FIGURE (dB)	THIRD-ORDER INTERCEPT (dBm)
0.27	72	28.17	2.98	-10 5
0.00	69	27 78	2.99	-10.4
-0.63	61	23.07	3.14	-12.5
-0.82	57	18 35	3.43	-9.3
-0.95	54	13 29	3.98	-5 1
-1.07	50	8.13	5 01	0 5
-1.18	46	2.77	6 91	-1 5
-1.30	42	-2.48	10 04	-1 1

dual gate FETs compared to the 5 volt operation, thus improving device reliability and reducing module overall mean time between failure (MTBF). Nominal bias conditions for maximum gain are Vds = 3 V, Ids = 80 mA, Vg1 = -0.9 V, Vg2 = 0.3 V. The LNA was tested over 0° C to 85° C temperature range with Vg2 = 0 V. The LNA was stable over this temperature range. VSWR characteristics did not significantly change over temperature, and the temperature coefficient for gain is 0.062 dB/C°.

CONCLUSIONS

A variable gain LNA has been demonstrated at Ku-band which employs single- and dual-gate FETs in a single chip to accomplish a minimum degradation of noise figure over gain control. The use of series inductive feedback to provide a simultaneous input VSWR and noise match at Ku-band has been demonstrated.

REFERENCES

[1] D. D. Heston and R. E. Lehmann, "X-band monolithic variable gain series feedback LNA," IEEE MTT-S International Microwave Symposium Digest, pp. 79-81, 1988.

[2] R. E. Lehmann and D. D. Heston, "X-band monolithic series feedback LNA," IEEE MTT, Vol. MTT-33, No. 1, pp. 1560-1566, Dec. 1985.

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