A 20 GHz Peltier-cooled Low Noise HEMT Amplifier

M.Iwakuni, M.Niori, T.Saito, T.Hamabe,
H.Kurihara, K.Jyoshin, M.Mikuni*

Fujitsu Laboratories LTD. Fujitsu LTD.*
1015, Kamiodanaka,
Nakahara-ku, Kawasaki, Japan 211

Abstract

A 20 GHz band 135 K (NF=1.66dB) low-noise HEMT amplifier with 38 dB gain has been developed. This was achieved by extremely low-loss input circuits, accurate device characterization method with a strip line tuner and a compact cooling system. The amplifier is cooled to -55°C by a Peltier-cooling unit which consumes only 60 watts.

Introduction

In recent years, GaAs FETs have found widespread applications in low noise microwave receiving systems, and many papers have reported the excellent performance of the GaAs FET low-noise amplifier (LNA) up to the X band(1).
The GaAs FET LNA is to replace traditional parametric amplifiers because of its high reliability, simple construction and low cost.
To the author's knowledge, this is the first report on a High Electron Mobility Transistor (HEMT) amplifier, for use in the 30/20 GHz band satellite communication systems, which is to replace the parametric amplifier in the K band. For it's excellent noise performance, we have already reported the performance of a low noise HEMT amplifier at room temperature(2). The amplifier is cooled to -55°C by Peltier-cooling which consumes less than 60 watts. This amplifier has a minimum noise temperature of 125 K at 19.5 GHz, and is capable of operating from 17.7 to 19.7 GHz with a noise temperature of less than 135 K and a power gain of more than 38 dB. This paper explains the Peltier-cooled HEMT amplifier design, construction and experimental results.

Device characterization

Table 1. shows the summary of the main device parameters, and the results of the microwave evaluation of the newly developed HEMT chip(3). It should be noted that the noise figure of 1.85 dB at 20 GHz is comparable with those of GaAs FETs with 0.25 μm gate length. For the design of low-noise amplifiers, it is necessary to obtain the S-parameters and the noise performance of the device. The S-parameters above 18 GHz were obtained by making the equivalent circuit analysis using the measured S-parameters below 18 GHz.
Then to fully characterize the noise performance of the HEMT, Gopt,Rn and Fmin were evaluated.
Equation(1) gives the well-known relationship of these parameters expressing the noise figure of a network as a function of source reflection coefficient Γs.

$$F = F_{min} + \frac{4R_n}{Z_o} \times \frac{|\Gamma_{opt} - \Gamma_s|^2}{|1 + \Gamma_{opt}|^2 \times (1 - |\Gamma_s|^2)} \quad (1)$$

where Γopt is the source reflection coefficient that results in the minimum noise figure of the network, Fmin is the minimum noise figure, Zo is the reference impedance for defining Γs and Rn is the equivalent noise resistance. These values can be evaluated by computer optimization using the measured noise figures against some different source reflection coefficients Γs, as they should satisfy equation(1) (4). To realize different Γs values, the external tuner method has been adopted conventionally up to the X-band. However above the X-band, because of the increasing loss of the tuners and the MIC test fixture, it is hard to make accurate measurements. For this reason, we used a strip line tuner. Figure 1 shows the schematic diagram of the tuner. Γs can be adjusted by connecting the stubs(1-5) to the main line by Au ribbons, and changing the stub length also with Au ribbons. Figure 1 also gives the measured noise figure against the different Γs, and the calculated results of Fmin and the constant NF loci at 18.5 GHz. The frequency dependence of the calculated Fmin, Rn and Γopt, which are used to determine the NF loci, is also shown in table 2. The calculated NF loci, in Figure 1, agree well with the measured noise figures. This result provides the proof of the validity of the strip line tuner measurement.

Unit amplifier

From these parameters, a 2-stage HEMT amplifier circuit was designed by computer simulation. Figure 2 shows a block diagram of the newly developed unit amplifier with WG isolator. The unit amplifier consists of a WG-MIC transition circuit, carrier mounted 2-stage amplifier (carrier amplifier) and an output coaxial connector. Figure 2 also shows the characteristics of the amplifier. The dotted line shows the calculated values of the carrier amplifier described above. The dashed line shows the measured result of the carrier amplifier.
It agrees fairly well with the simulated one. This result also demonstrates the accuracy of our device characterization method. The solid line shows the characteristics of the unit amplifier with WG isolator. Figure 3 shows the frequency

0149-645X/85/0000-0551 $01.00 © 1985 IEEE 1985 IEEE MTT-S Digest

characteristics of the WG to MIC transition circuit (electrically coupled type) and WG isolator. This WG isolator was developed for extensive use as a front-end isolator. By reducing the physical dimensions as much as possible, we reduced the insertion losses of the WG to the MIC transition circuit and WG isolator to less than 0.08 dB and 0.07 dB respectively between 17.5 to 20.0 GHz. This transition circuit made it possible to delete the unit amplifier's input dc block so that the input circuit loss could be reduced. Figure 4 is a photograph of the unit amplifier. Thanks to efficient cooling, the size of the amplifier was drastically reduced, to 9 x 16 x 26 mm^3.

Construction of Peltier-cooled HEMT amplifier

Figure 5 is a block diagram of the prototype 4-stage Peltier-cooled HEMT amplifier. The dashed line represents the amplifier housing which has waveguide input/output ports and a thermal-fin. The amplifier consists of two unit amplifiers (A1,A2), an input waveguide isolator, and two invar waveguides. The first cooled amplifier A1 is the one shown in Figure 4. The second, uncooled amplifier A2, is employed to obtain the necessary gain. We recently adopted the use of very thin invar waveguides to reduce the amount of heat inflow to the cooled unit amplifier.
The measured total loss of the input circuit (comprising WG window, WG isolator, and invar WG) was less than 0.15 dB, which operates very excellently on the noise perfomance of the Peltier-cooled HEMT amplifier. The Peltier cooling unit mounted on the thermal-fin was designed to keep the unit amplifier's temperature at -50°c for an ambient temperature of up to 50°c. We achieved cooling with only 60 w power consumption, half the consumption of the conventional Peltier cooling unit, by minimizing the amplifier size and using specialized cooling technique.

Experimental result

The prototype Peltier-cooled HEMT amplifier, using the unit amplifier described above, was tested and measured. The result shows that the minimum noise temperature is 140 k and less than 170 K, from 17.7 to 19.45 GHz, with gain of more than 37dB. Since then, we have achieved a more excellent performance Peltier-cooled HEMT amplifier by utilizing another unit amplifier, with a HEMT chip of minimum noise figure of 1.7 dB at 20 GHz. Figure 6 shows the noise temperature and gain characteristics of this Peltier-cooled HEMT amplifier. The minimum noise temperature achieved at 19.5 GHz was 125 K, and less than 135 K from 17.7 to 19.7 GHz with a 38 dB gain, when the amplifier was cooled to -55°C. This resulted in a great improvement of noise temperature by about 70 K and an improvement of gain by 3 dB, compared with the amplifier performance at room temperature. This performance is comparable to or better than that of the conventional Peltier-cooled parametric amplifier operating in the K band (5). Figure 7 is a photograph of the Peltier-cooled HEMT amplifier. The amplifier dimensions are 250 x 160 x 235 mm^3.

Conclusion

A 20 GHz Peltier-cooled HEMT amplifier was developed for 30/20 GHz satellite communication systems. A practical and simple device characterization method was developed and the validity of the method was verified. A noise temperature of less than 135 K and power gain of more than 38 dB were obtained between 17.7 to 19.7 GHz. The minimum noise temperature was 125 K at 19.5 GHz. This result indicates that the Peltier-cooled HEMT amplifier will be able to replace the conventional Peltier-cooled parametric amplifier even in the K band.

Acknowledgement

The authors would like to thank K. Yamada, Dr. H. Komizo and Y. Tokumitu for supporting and encouraging their work. They are also gratful to Dr. M. Abe, Dr. T. Mimura and Dr. T. Hirachi for providing devices and discussing low noise technology.

References

(1) T. Watanabe et al, "11 GHz-band 150 K Thermo-electrically-cooled GaAs FET Amplifier ," 1987 National Conv. Rec. IECE Japan,No157.
(2) M. Niori et al, "A 20 GHz High Electron Mobility Transistor Amplifier for Satellite Communications," 1983 IEEE ISSCC pp. 198-199.
(3) K. Joshin et al, "Low Noise HEMT with Self-Aligned Gate Structure," Proc. of the 16th Conference on Solid State Devices and Materials pp. 347-350, 1984.
(4) R. Q. Lane, "The Determination of Device Noise Parameters," Proc. IEEE, vol. 57, pp. 1416-1462, August 1969.
(5) T. Inoue et al, "30/20 GHz Band Small Earth for ISSDN Experiment," IEEE Trans. AES-17, pp. 757-765, November 1981.

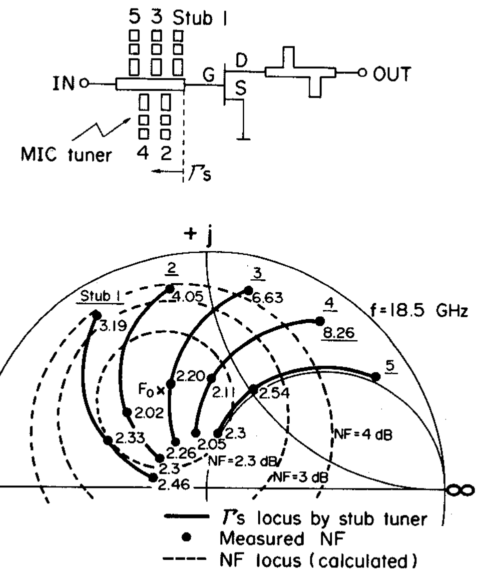

Fig. 1 Configuration of stub tuner, measured NF against the different Γs, and calculated constant NF loci.

Table 1 Summary of device parameters.

Gate length.	Lg(μm)	0.5
Gate width.	Wg(μm)	200
Saturation current.	Idss(mA)	40 - 50
Pinch-off voltage.	Voff(V)	1 - 1.5
Minimum noise figure.	Fmin(dB)	1.85 at 20GHz
Associated gain.	Ga(dB)	9.0

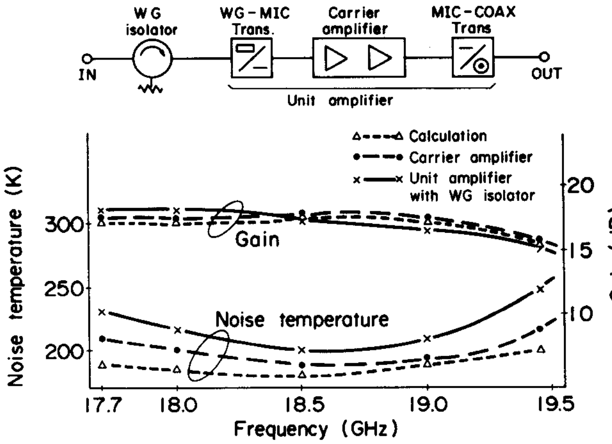

Fig. 2 Performance of the two stage amplifier.

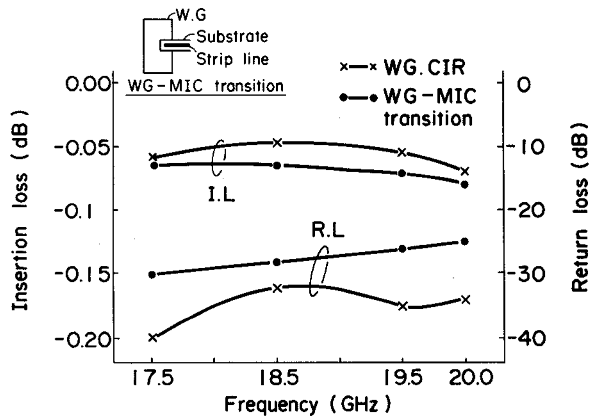

Fig. 3 Performance of W.G. CIR and W.G./MIC transition.

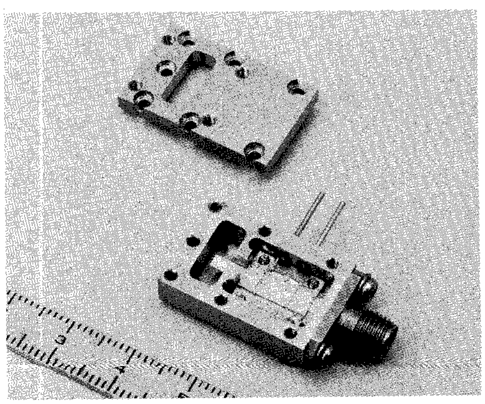

Fig. 4 A unit amplifier.

Table 2 Calculated values of Fmin,Rn and Γopt

F (GHz)	Fmin (dB)	Rn/Zo	Go/Zo	Bo/Zo
18.0	1.90	0.29	0.88	-0.83
18.5	1.95	0.23	0.95	-1.02
19.0	2.0	0.22	0.83	-1.18
19.5	2.09	0.29	0.83	-1.15

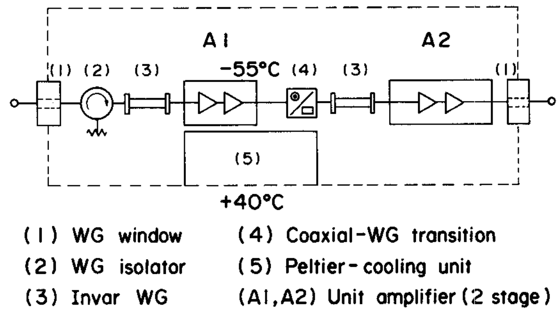

Fig. 5 Block diagram of Peltier-cooled HEMT amplifier.

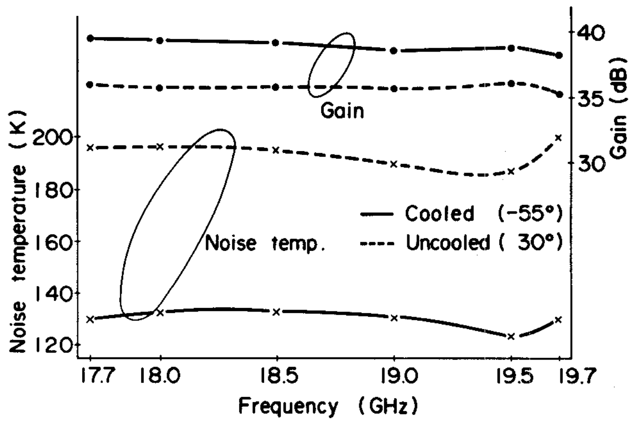

Fig. 6 Performance of Peltier-cooled HEMT amplifier.

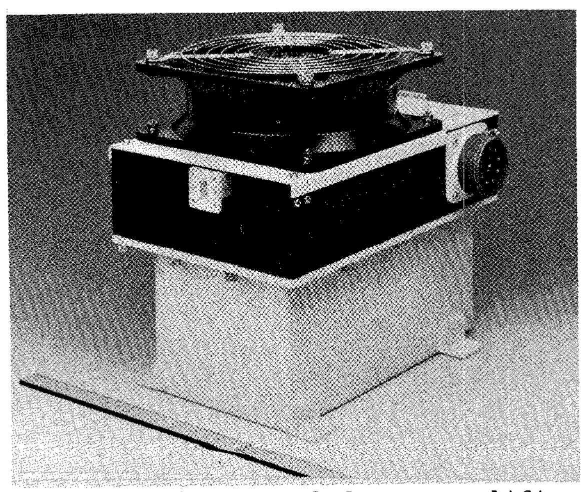

Fig. 7 Peltier-cooled HEMT amplifier.