A 43 GHz-band Balanced Low-Noise Amplifier

M. Ishizaki *, T. Hamabe *, Y. Oohashi*, S. Asai *,
T. Kasuga ** and K. Miyazawa **

* FUJITSU LABORATORIES LTD. 1015, Kamikodanaka, Nakahara-ku, Kawasaki, Kanagawa 211 Japan
** Nobeyama Radio Observatory, Tokyo Astronomical Observatory, University of Tokyo. Minamimaki-mura, Minamisaku-gun, Nagano 384-13 Japan

ABSTRACT

We have developed a 43 GHz-band balanced low-noise amplifier using HEMTs with a gate length of 0.25 μm.

To reduce the loss, a 3-dB hybrid circuit formed by waveguide branch lines was used for the input/output sections of the amplifier.

The amplifier has a gain of 9 dB, a noise figure of 5 dB or less, and an input/output VSWR of 1.5 or less from 40 to 45.5 GHz. It has a gain of 10 dB and a noise figure of 4.3 dB or less at -30 °C (ambient temperature) .

INTRODUCTION

Recent progress in semiconductor fabrication has allowed amplifiers to be built using FETs, HEMTs especially, having low-noise characteristics, are being studied in various fields as amplifier elements for the microwave and millimeter-wave bands (1)(2)(3). We have already developed a HEMT with a T-shaped 0.25 μm gate structure.

From this, we obtained an optimum noise figure of 1.0 dB and an associated gain of 8.2 dB at 20 GHz, and a noise figure of 1.7 dB and a gain of 6.1 dB at 30 GHz at room temperature (4).

This paper describes the characterization of a HEMT device in the millimeter band and the design and results of trial manufacture of a 43 GHz low-noise amplifier which were done on the basis of the evaluation results.

The case of the amplifier was designed taking into account the super low operating temperature of 20 K, and the requirements for use as a radio astronomical receiver.

DEVICE DESCRIPTION

The devices used were low-noise HEMTs with a gate length of 0.25μm and a gate width of 100μm.

The S-parameters of the device were measured with a wafer prober over 2 to 18 GHz. Figure 1 (a) shows the HEMT equivalent circuit and element values obtained from the S-parameter measurement.

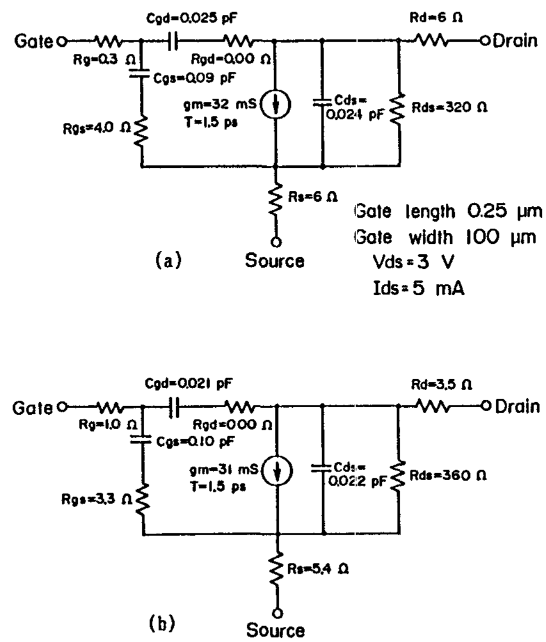

Figure 1 . Equivalent circuit of the HEMT chip
(a) HEMT equivalent circuit and element values obtaind from the S-parameter measurement.
(b) HEMT equivalent circuit and element values were revised from the characteristics of the one-stage amplifier at 50 GHz.

Since it is difficult to use element values directly for the design of a 40 or 50 GHz-band amplifier, we made a prototype of a 50 GHz-band one-stage amplifier and evaluted the gain and noise figure characteristics. Figure 2 shows the gain and noise figure characteristics of the device up to 50 GHz. The noise figure is 5.5 dB for the optimum gain of 5.5 dB, and the gain is 3 dB for the optimum noise figure of 3.6 dB at 50 GHz.

Thus, the device equivalent circuit element values were revised on the basis of the characteristics of the one-stage amplifier at 50 GHz. Figure 1 (b) shows the results.

Figure 3 shows a comparison between the values calculated using the equivalent-circuit element

0149-645X/88/0000-0461$01.00 © 1988 IEEE

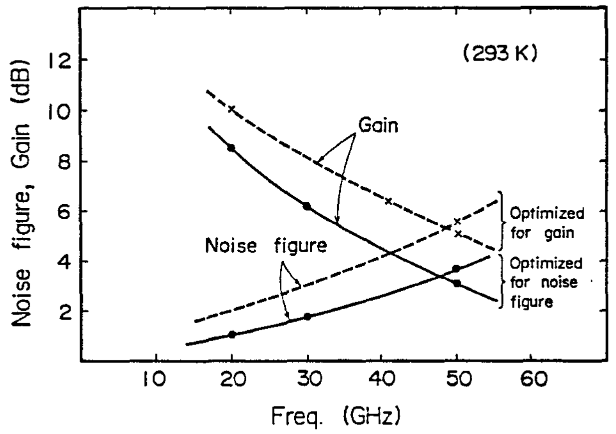

Figure 2 . Characteristics of a 0.25μm gate lengh HEMT.

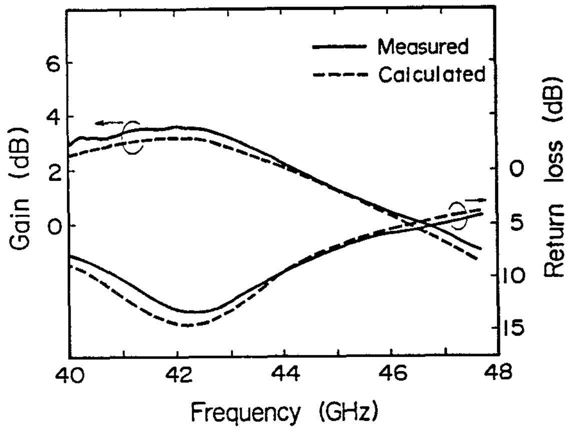

Figure 3 . Comparison of computer-predicted and measured gain and return loss of the 43 GHz-band amplifier.

values shown in Figure 1 (b) and the measured characteristics at 43 GHz. The calculated gain and input return loss characteristics approximate the measured ones.

AMPLIFIER CONFIGURATION AND DESIGN

A circulator is usually connected to the input/output sections of a low-noise amplifier so that the amplifier impedance matches that of other circuits. However, the circulator characteristics at superlow temperatures are unknown. Therefore, we adopted a balanced amplifier configuration in which a waveguide-type hybrid was used as the input/output section of the amplifier. Figure 4 is a schematic of the configuration.

The amplifier consisted of hybrid circuits, waveguide to microwave IC (MIC) transition circuits, and carrier mounted amplifiers.

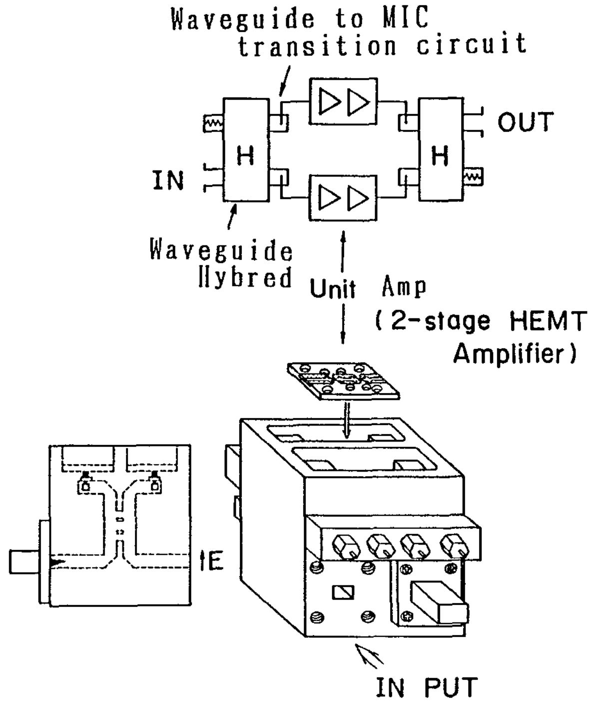

Figure 4 . Configuration of the amplifier.

The hybrid circuit was formed by waveguide branch lines using WRI-400 (WR-22) waveguides (5)(6). It was designed with a center frequency of 43 GHz, and the case was made of Invar, which has a small coefficient of linear expansion. Figure 5 shows the performance of the hybrid circuit. The coupling loss was 3.1 ±0.1 dB and the return loss and isolation were 18 dB or more from 40 to 45 GHz.

The waveguide to MIC circuit transition used coaxial terminals with electric field coupling. This structure maintains an atmosphere separation between the waveguide and the MIC. Figure 6 shows the structure and characteristics of the

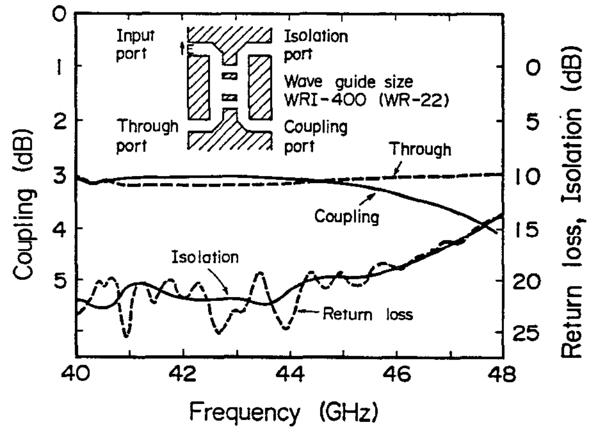

Figure 5 . Performance of 43 GHz-band waveguide hybrid.

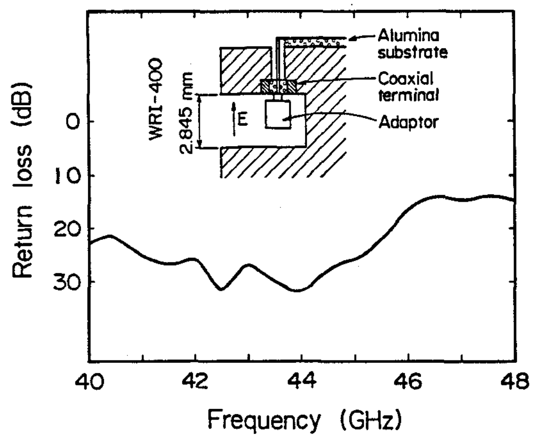

Figure 6 . Configuration and performance of the waveguide to MIC transition circuit.

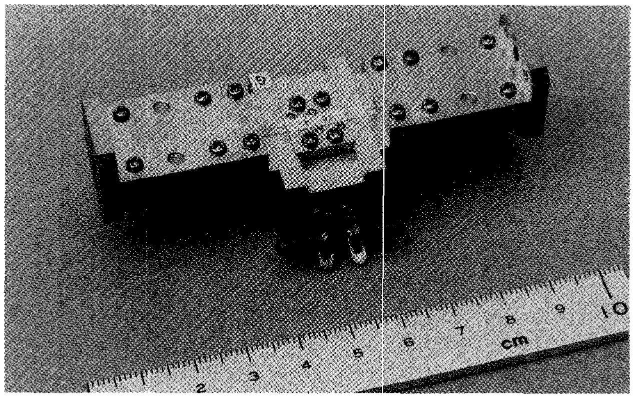

Figure 7 . A 43 GHz-band ridge waveguide to MIC transition circuit.

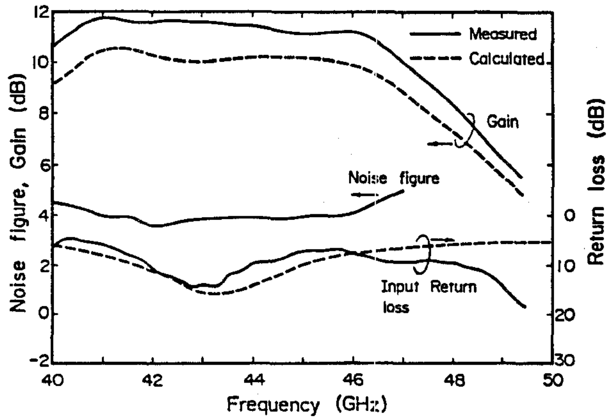

Figure 8 . Measured noise figure and gain of unit amplifier (2-stage HEMTs amplifier).

waveguide to MIC transition circuit. An insertion loss of 0.3 dB and a return loss of 22 dB or more were obtained from 40.5 to 45.5 GHz.

A unit amplifier consisting of a MIC two-stage amplifier was constructed on 0.254 mm thick alumina substrate, which was mounted on a 12 mm× 14 mm carrier made of Kovar.

A two-stage amplifier having a 5 GHz bandwidth at 43 GHz was designed with the CAE program on the basis of the equivalent circuit shown in Figure 1(b). A wide-band waveguide to MIC transition circuit using a ridge waveguide was employed to evaluate the characteristics of the devices and the unit amplifier (7). Figure 7 shows the wide-band waveguide to MIC transition circuit.

CHARACTERISTICS OF THE LOW-NOISE AMPLIFIER

Figure 8 shows the gain, noise figure, and input return loss characteristics of the unit amplifier.

The amplifier had a gain of 11 dB and a noise figure of 4.2 dB or less over 40 to 46 GHz when biased with a drain voltage of 3 V, and a drain current of 8 mA for the front stage and 10 mA for the rear stage. The dotted lines in Figure 8 represent the gain and input return loss characteristics obtained by computer simulation, which approximate the actual ones. This shows that the equivalent circuit element values shown Figure 1(b) can be used in this frequency band.

Two unit amplifiers with the same characteristics were built in this way and housed in the case shown in Figure 4. Figure 9 shows the characteristics of the amplifier consisting of these amplifiers. A gain of 9 dB or more, a noise figure of 5 dB or less, and input/output return losses of 15 dB or more were obtained over 40 to 50 GHz. The satisfactory VSWRs of the amplifier

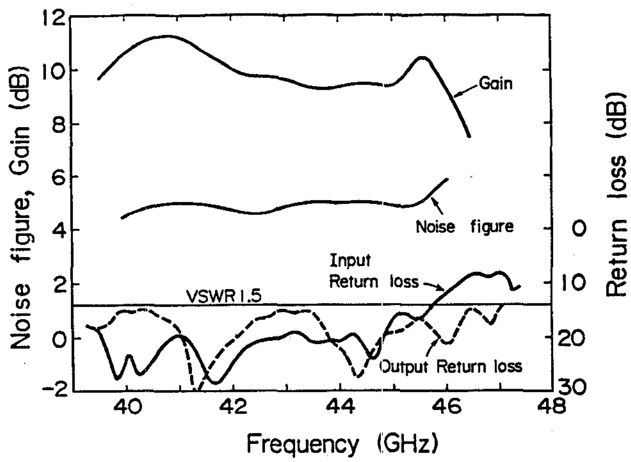

Figure 9 . Gain, noise figure and return loss performance of the 43 GHz-band amplifier.

enable direct multistage connection of amplifiers. Figure 10 shows the characteristics of the amplifier obtained by connecting two amplifiers directly.

Figure 11 shows the temperature characteristics of the amplifier. A gain of 10 dB or more and a noise figure of 4.3 dB were obtained at -30 ° C (ambient temperature).

Figure 12 shows the amplifier. Its size is 43× 41.8 × 40 mm .

CONCLUSION

We evaluated the characteristics of a HEMT with a gate length 0.25μm and gate width 100μm in the millimeter-wave band and obtained the equivalent circuit that can be used for frequencies up to 55 GHz. A 43 GHz-band balanced low-noise amplifier was developed using these results. To reduce the loss, a 3 dB hybrid circuit formed by waveguide branch lines was adopted for the input/output sections of the amplifier. The amplifier has a gain 9 dB or more, a noise figure of 5 dB or less, and input/output VSWRs of 1.5 or less from 40 to 45.5 GHz. It has gain of 10 dB or more and a noise figure of 4.3 dB or less at -30° C (ambient temperature).

ACKNOWLEDGEMENT

The authors wish to thank Dr. N. Kaifu of the Nobeyama Radio Astronomical Observatory, and Messrs. M. Abe, H. Nakamura, H. Kurihara, Y. Hirachi and S. Takenaka of Fujitsu Laboratories Ltd for encouraging and supporting this work.

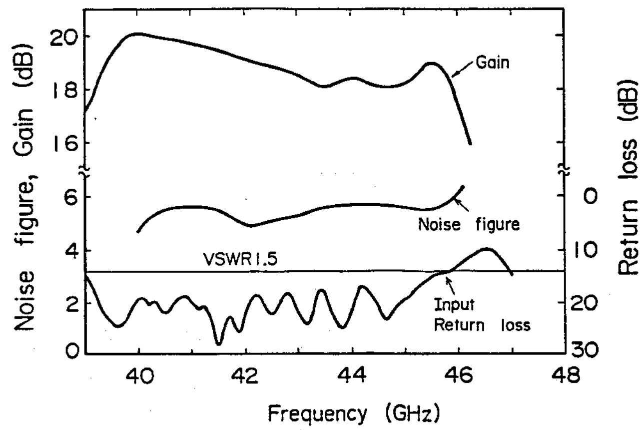

Figure 10. Performance of two cascaded amplifiers.

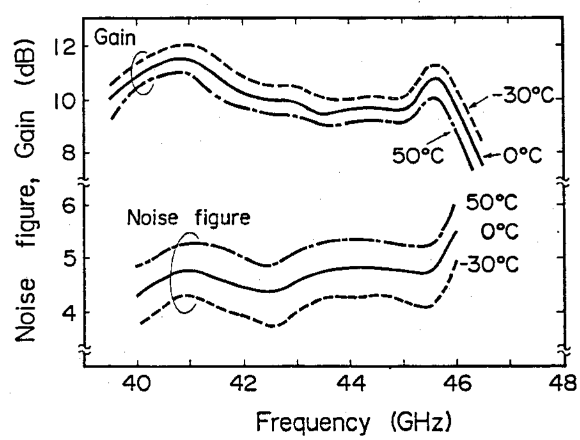

Figure 11 . Temperature dependence of noise figure and gain of the amplifier.

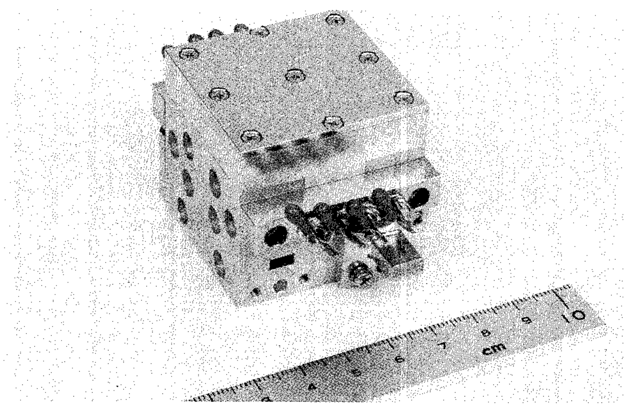

Figure 12 . The 43 GHz-band balanced HEMT low noise amplifier.

REFERENCES

(1) E.T. Watkins, J.M. Schellenberg, L.H. Hackett, H. Yamasaki, and M. Freng, " A 60 GHz GaAs FET Amplifier,"1983 IEEE MTT-S Digest, pp.145-147, June 1983.

(2) M. Sholley, A. Nichols, " 60 and 70 GHz (HEMT) Amplifiers,"1986 IEEE MTT-S Digest, pp.463-465, June 1986.

(3) K. Shibata, B. Abe, S. Hori and K. Kamei, " Broadband HEMT Amplifier for 26.5-40.0 GHz," 1987 IEEE MTT-S Digest, pp.1011 - 1014, June 1987.

(4) S. Asai, K. Joshin, Y. Hirachi and M. Abe, " Super Low Noise HEMTs with a T-shaped Gate Structure," 1987 IEEE MTT-S Digest , pp.1019-1022, June 1987.

(5) K.G. Patterson," A Method for Accurate Design of a Broad-Band Multibranch Waveguide Coupler," IRE Trans. on Microwave Theory and Techniques, vol.MTT-7, pp.466-473, October 1959.

(6) N. Marcuvitz,"Waveguide Handbook," McGraw-Hill Book Co., Inc., New York, N.Y., pp336-350, 1948.

(7) Y. Tokumitsu, M. Ishizaki, M. Iwakuni and T. Saito, " 50-GHz IC Components Using Alumina Substrates, " IEEE Transactions on Microwave Theory and Techniques, vol.MTT-31, No.2, February 1983.