20 GHz-BAND LOW-NOISE HEMT AMPLIFIER

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Abstract

A 20 GHz-band low-noise amplifier has been developed by using newly developed 0.25-μm gate HEMTs. The amplifier has been fabricated by cascading six single-ended unit amplifiers without any isolators at the interstages.

The HEMT amplifier exhibits a noise temperature of 170 K (NF = 2.0 dB) and a gain of 47 dB over 17.5 to 19.5 GHz in an uncooled operation. Noise temperatures of 130 K (NF = 1.6 dB) and 110 K (NF = 1.4 dB) have been obtained at -20 °C and -50 °C, respectively.

Introduction

A progress of GaAs FET performance has made it possible to build low-noise amplifiers up to millimeter-wave region[1]. However,performance of low-noise GaAs FETs is reaching its limitation because of the finest gate geometry[2], and almost little improvement can be expected for the low-noise GaAs FET amplifiers.

Recently, extensive work on HEMT (High Electron Mobility Transistor) has been done in many laboratories[3], and the noise temperature of 135 K at -55 °C in 20 GHz band has been reported from the Peltier-cooled HEMT amplifier[4]. We have also demonstrated an 18 - 26.5 GHz-band amplifier using 0.4-μm gate HEMT which shows superior performance to the 0.25-μm gate GaAs FET amplifier[5].

This paper reports on a 20 GHz-band low-noise HEMT amplifier for the satellite communication earth station by using newly developed 0.25-um gate HEMT. The developed amplifier exhibits a noise temperature of < 170 K and a gain of > 47 dB over 17.5 to 19.5 GHz in an uncooled condition. The following sections describe the HEMT employed, the unit amplifier design and the RF performance of the low-noise amplifier.

Device

Fig. 1 shows the schematic cross section of the HEMT. The HEMT wafer, grown by MBE, is made of a 1-μm thick undoped GaAs buffer layer, a 20-nm thick n-type $Al_{0.3}Ga_{0.7}As$ layer and a 30-nm thick n-type GaAs cap layer on an undoped GaAs substrate.

The n-type $Al_{0.3}Ga_{0.7}As$ and GaAs layer are heavily doped to 3×10^{18} cm^{-3} with Si. The measured sheet carrier concentration and the electron Hall mobility of the HEMT wafer are 1.5×10^{12} cm^{-2} and 4200 $cm^2V^{-1}s^{-1}$ at room temperature.

A recess structure is formed to control a drain current by etching an n-type GaAs layer and a part of n-type $Al_{0.3}Ga_{0.7}As$ layer. The gate electrode with a length of 0.25 μm and a width of 200 μm is formed by Al/Ti to a thickness of 0.5 μm. The gate electrode delineated by a direct electron-beam lithography is placed with a 0.5 μm spacing from the source contact edge to reduce the source resistance. The source and drain ohmic contacts separated by 3 μm are formed by alloying the evaporated Ni/AuGe.

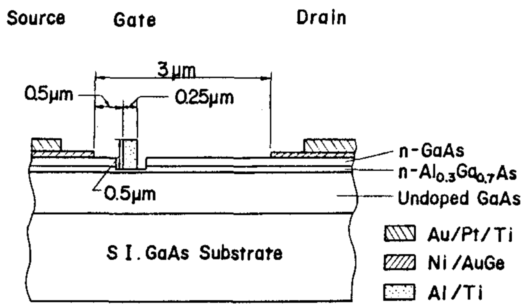

Fig. 1 Schematic cross section of HEMT chip.

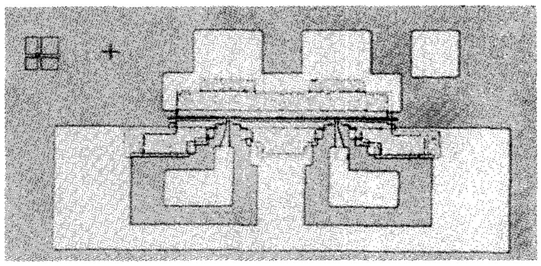

Fig. 2 Microphotograph of HEMT chip.

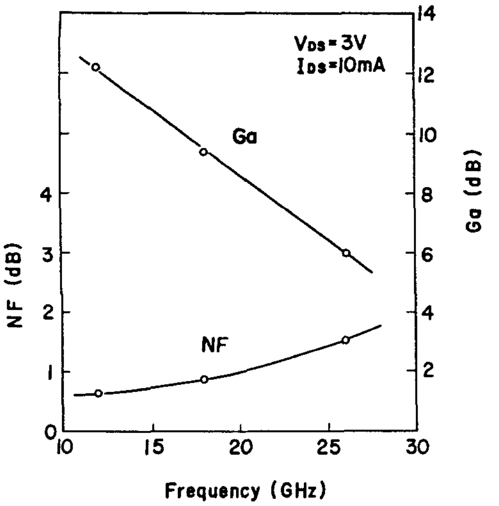

Fig. 3 Minimum noise figure (NF) and associated gain (Ga) vs. frequency of HEMT.

Fig. 2 shows a microphotograph of the HEMT chip. The chip size is 250 x 500 μm. Two gate bonding pads are provided to reduce the gate resistance.

Static characteristic of the HEMT has been measured and the transconductance g_m is 250 mS/mm for a drain current of 10 mA.

Microwave minimum noise figure (NF) and associated gain (Ga) have been measured on the HEMT chip mounted on a microstrip test fixture. Fig. 3 shows a frequency dependence of NF and Ga measured at room temperature at a drain current of 10 mA. The HEMT has shown typical noise figures (NF) and gains (Ga) of NF = 0.7 dB / Ga = 11.8 dB, NF = 0.9dB / Ga = 9.4 dB and NF = 1.5 dB / Ga = 6.0 dB at 12 , 18 and 26 GHz ,respectively.

The noise parameters and S-parameters of the HEMT have been measured for the sake of amplifier design. The noise

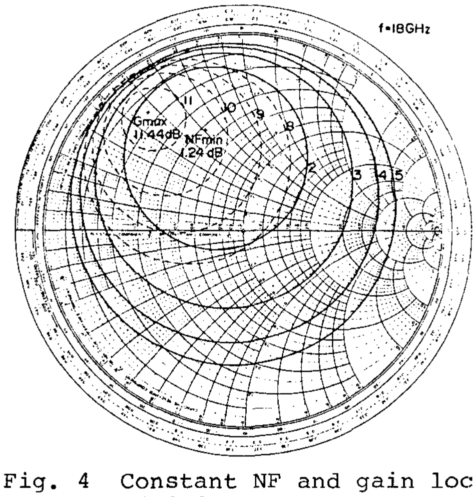

Fig. 4 Constant NF and gain loci of 0.25-μm gate HEMT.

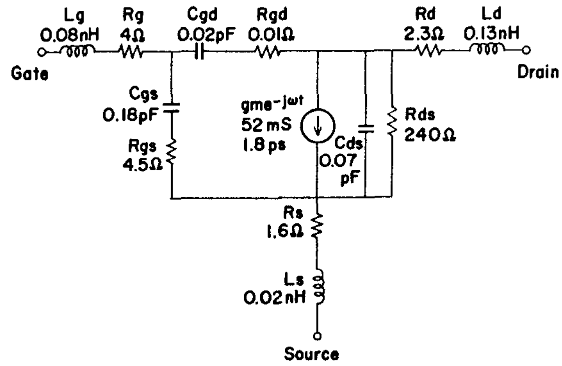

Fig. 5 Equivalent circuit with element values of 0.25-μm gate HEMT.

parameters were obtained by Adamian and Uhlir's method, in which the output noise power was measured by connecting a 50 ohm load and off-set shorts at the input port[6]. Fig. 4 shows the constant noise figure and gain loci of the HEMT at 18 GHz. The minimum noise figure (NF_{min}) of 1.24 dB, the equivalent noise resistance (Rn) of 7.63 ohm and the optimum source reflection coefficient (Γopt) of 0.543 $\angle$ 126° have been obtained at 18 GHz. The S-parameters up to 24 GHz have been calculated by the equivalent circuit analysis using measured S-parameters over 2 to 18 GHz. Fig. 5 shows the equivalent circuit with element values for the drain current of 10mA. The cut-off frequency f_T is calculated to be 46 GHz.

Unit Amplifier Design

For the optimum design of six-stage low-noise amplifier, we have designed noise figure optimized (NFopt) and gain optimized (Gopt) unit amplifiers. The NFopt unit amplifiers are used for the first and the second stages and the Gopt unit amplifiers are used from the third to the sixth stages. Fig. 6 shows the equivalent circuit of the unit amplifier. The single-ended unit amplifier has been designed to give a good stability for the cascade connection. The gate bias circuit, which consists of the lumped elements with bonding wires, chip capacitors and a resistor, makes the amplifier stable in lower frequency range. A quarter-

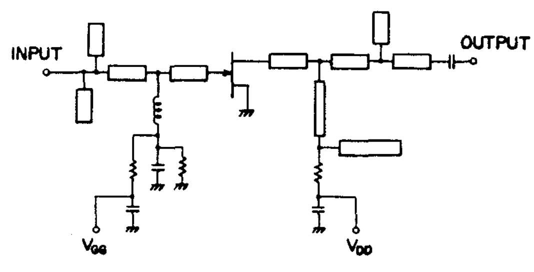

Fig. 6 Equivalent circuit of unit amplifier.

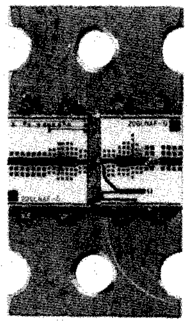

Fig. 7 Top view of unit amplifier.

wavelength open stub terminated via a resistor and a capacitor in the drain bias circuit are used to stabilize the amplifier near operating frequency. The circuit parameters for both unit amplifiers have been optimized by a computer simulation using measured noise parameters and S-parameters. The predicted noise figure (NF) and the gain (Ga) over 17.5 to 19.5 GHz are NF < 1.4 dB and Ga > 8.7 dB for the NFopt unit amplifier, and NF < 2.1 dB and Ga > 10 dB for the Gopt unit amplifier.

Fig. 7 shows the top view of the unit amplifier. The input and output matching circuits have been fabricated on 0.38-mm thick alumina substrates with Ti/Pt/Au microstrip lines and Ta_3N_4 thin film resistors. Each substrate for input and output circuits has a size of 4 x 3.6 mm and is soldered to a 0.7-mm thick Kovar carrier.

Fig. 8 shows the measured noise figure and gain performance for the NFopt and Gopt unit amplifiers under the drain voltage of 3 V and the current of 10 mA. The typical NFopt unit amplifier shows NF < 1.5 dB and Ga > 8dB over 17.5 to 19.5 GHz, and the minimum noise figure of 1.35 dB are obtained at 18GHz. The Gopt unit amplifier shows NF < 2.5 dB and Ga > 9 dB in the same frequencies. These measured values show a good agreement to the predicted performance. Since the gain of the NFopt unit amplifier decreases in higher frequency, the Gopt unit amplifier has been designed to increase the gain at higher frequency of our interest.

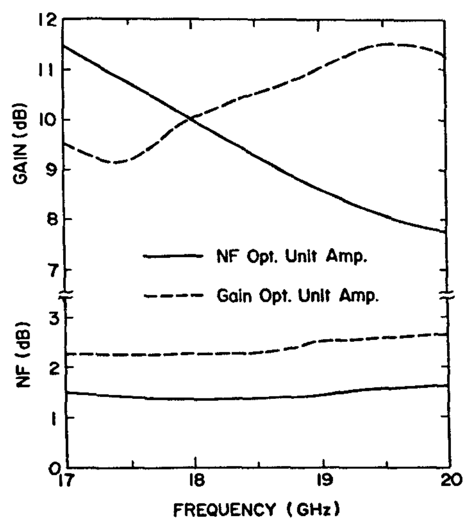

Fig. 8 Measured noise figure and gain of NFopt and Gopt unit amplifiers.

Low-noise Amplifier

In order to obtain the system required gain of > 45 dB over 17.5 to 19.5 GHz, the amplifier has been built by cascading six unit amplifiers. Fig. 9 shows the configuration of the amplifier. In cascading six single-ended unit amplifiers, one or two isolators are commonly installed at the interstages in order to avoid an unexpected oscillation and an excess inband gain ripple. But the use of isolators increases the size and the cost of the amplifier, so we have designed the amplifier without any isolators at the interstages.

Fig. 10 shows the inside view of the HEMT amplifier measuring 33 x 33 x 110 mm. Six unit amplifiers are installed into the hermetically sealed housing. Waveguide to microstrip transitions with 50 ohm coaxial feedthroughs are prepared at the input and output ports. One end of the coaxial feedthrough is connected to the microstrip line of the unit amplifier by a gold ribbon, and the other end is inserted into

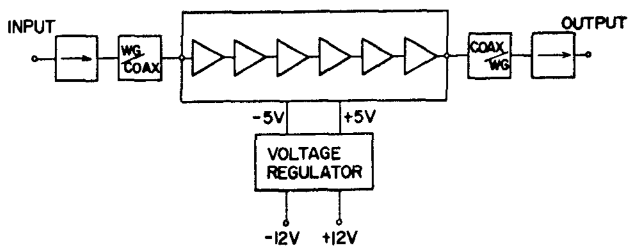

Fig. 9 Configuration of low-noise amplifier.

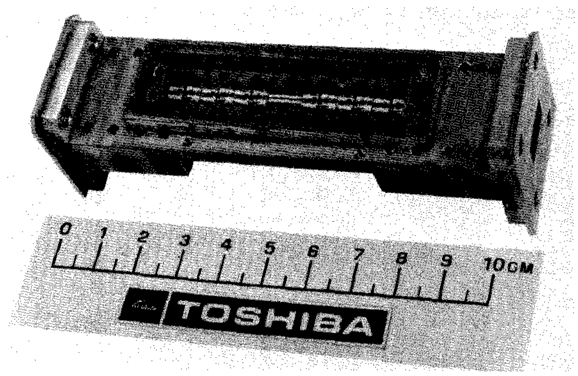

Fig. 10 Inside view of low-noise HEMT amplifier.

the waveguide. The waveguide isolators are used at the input and output ports of the amplifier to achive good VSWRs. The measured insertion loss of the input isolator is 0.2 dB. A DC voltage regulator is installed in the backside of the housing, and the amplifier can operate for an external supply voltage of 12 V with a current of 50 mA and -12 V with a current of 8 mA.

Fig. 11 shows the measured noise figure and gain of the low-noise amplifier. A noise figure of < 2.0 dB (noise temperature T_N < 170 K) and a gain of > 47 dB are obtained over the frequency range of 17.5 to 19.5 GHz. In the measured frequency band, the minimum noise figure is 1.85 dB (T_N = 154 K) at 18.5 GHz. The input and output VSWRs of the amplifier are < 1.2 over 17.5 to 19.5 GHz.

Fig. 12 shows the temperature dependence of the noise figure and the gain at 18.5 GHz. At the temperature of 50 °C, the amplifier shows NF = 2.2 dB (T_N = 190 K) and the gain of 47 dB. Furthermore, it shows the NF = 1.6 dB (T_N = 130 K) and NF = 1.4 dB (T_N = 110 K) at the temperature of -20 °C and -50 °C, respectively. It has been found that the noise figure change against temperature at a rate of 0.008 dB/ °C. Since the gain of the amplifier changes at a rate of -0.012 dB/ °C, the gain change of the unit amplifier is calculated to be -0.002 dB/ °C.

The output power of the amplifier at 1-dB gain compression is 8.6 dBm. The obtained output power is sufficient for the low-noise amplifier for the satellite communication receivers.

Conclusion

A 20 GHz-band low-noise amplifier has been developed by using newly developed 0.25-µm gate HEMT. A noise temperature of 170 K (NF = 2.0 dB) and a gain of 47 dB

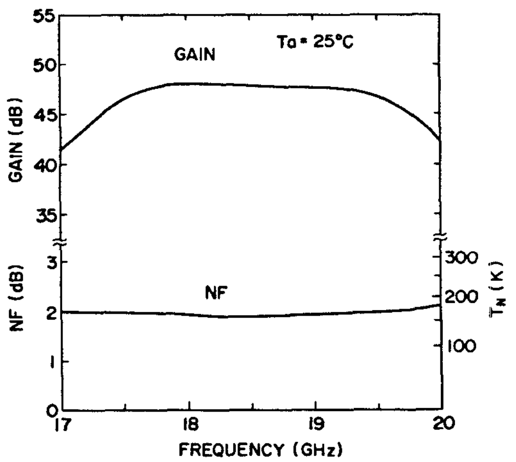

Fig. 11 Measured noise figure and gain of low-noise amplifier.

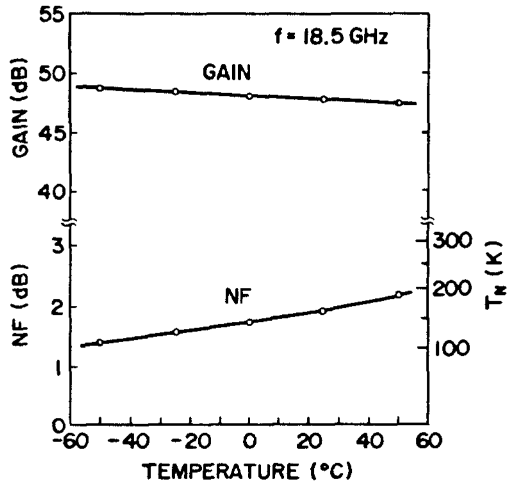

Fig. 12 Temperature dependence of noise figure and gain of low-noise amplifier.

have been obtained over 17.5 to 19.5 GHz at a room temperature.

Through this work, it has been found that the low-noise receiver with the system required noise temperature of < 200 K can be realized without a Peltier-cooling system. The uncooled HEMT amplifier will replace the Peltier-cooled amplifier, since it will be very effective to reduce the size, cost and power consumption of the satellite communication receivers.

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