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BROADBAND HEMT AMPLIFIER FOR 26.5 - 40.0 GHz

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ABSTRACT

A broadband amplifier operating over 26.5 to 40 GHz has been developed by using 0.25-μm gate HEMTs. The amplifier has been fabricated by cascading five unit amplifiers. Two balanced-type unit amplifiers are used in an input and an output stages to realize good input/output VSWRs. Three single-ended unit amplifiers are installed in the intermediate stages to achieve higher gain. The developed amplifier shows a noise figure of ≤ 7.0 dB, a gain of 18.2 ± 1.6 dB and input/output VSWRs of ≤ 2.0 over 26.5 to 40 GHz.

INTRODUCTION

While the conventional GaAs FET is reaching the performance limitation due to its finest gate geometry, the recent progress on the epitaxial growth and fine gate fabrication technology has made the HEMT (High Electron Mobility Transistor) a very promising microwave low-noise device[1]. We have already demonstrated the broadband amplifier operating over 18 to 26.5 GHz by using 0.4-μm gate HEMT[2] and 18-GHz-band low noise amplifier using 0.25-μm gate HEMT[3]. Through these works, it was found that the HEMT exhibits a superior noise and gain performance to the GaAs FET. In some reports, the HEMTs have been proved to show an excellent performance even in the millimeter-wave region[4],[5].

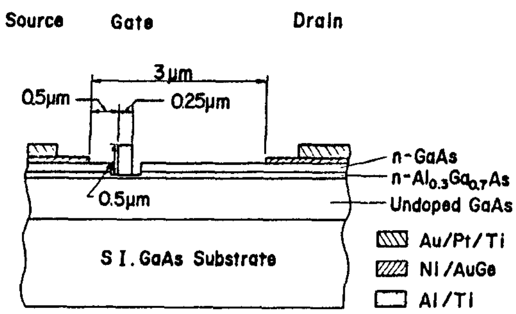

Fig. 1 Schematic cross-sectional view of HEMT.

This paper reports on a broadband amplifier operating over 26.5 to 40 GHz by using 0.25-μm gate HEMTs. The developed HEMT amplifier exhibits a gain of 18 dB, a noise figure of ≤ 7.0 dB and input/output VSWRs of ≤ 2.0.

The following sections describe the HEMT, the unit amplifier design and the RF performance of the amplifier.

DEVICE

Fig. 1 shows the schematic cross section of the HEMT. The HEMT wafer was 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, successively grown by MBE on an undoped GaAs LEC substrate. A recess structure was 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 was delineated by a direct electron-beam lithography.

In designing 26.5 - 40 GHz amplifier, the S-parameters up to 40 GHz have been calculated by an equivalent circuit analysis using measured S-parameters over 2 to 26.5 GHz. Fig. 2 shows the measured and calculated S-parameters for the HEMT chip with a drain voltage of 3 V and a current of 20 mA. Fig. 3 shows the equivalent circuit with element values of the HEMT chip. The maximum stable gain has been calculated to be 9.0 dB at 40 GHz.

UNIT AMPLIFIER DESIGN

In broadband amplifier, several unit amplifiers, which have been designed to give a good gain flatness and input/output VSWRs, are cascaded to achieve a desired power gain. A balanced-type unit amplifier consisting of two single-ended amplifiers with two 3-dB hybrids at input and output ports is commonly used in the broadband amplifier applications below 20 GHz. Since

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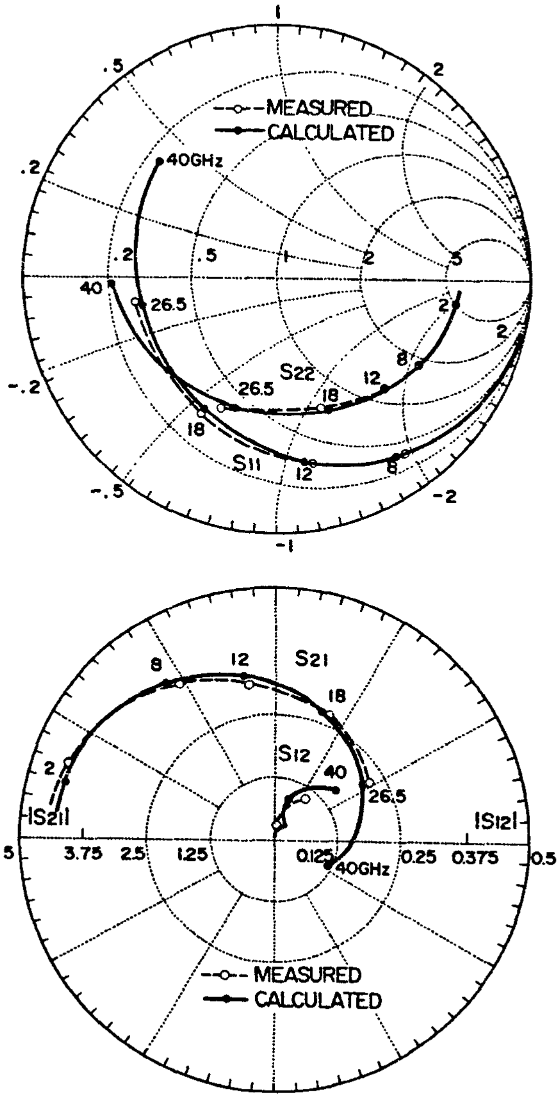


Fig. 2 Measured and calculated S-parameters of HEMT chip.

the maximum available gain of HEMT decreases and 3-dB hybrid loss increases in higher frequency, we have designed and evaluated single-ended unit amplifiers as well as balanced-type ones for our application.

Fig. 4 shows the equivalent circuit of the single-ended unit amplifier. The single-ended unit amplifier was designed to give a good gain flatness and higer gain at a little sacrifice of input/output VSWRs. Since a pure reactive matching network cannot realize the desired performances, a resistor with a quarter-wavelength shorted stub is shunted in the input and output matching networks. The balanced-type unit amplifier has been designed mainly from a gain flatness point of view. The 3-dB hybrid designed for the balanced-type unit amplifier is an interdigitated coupler with four

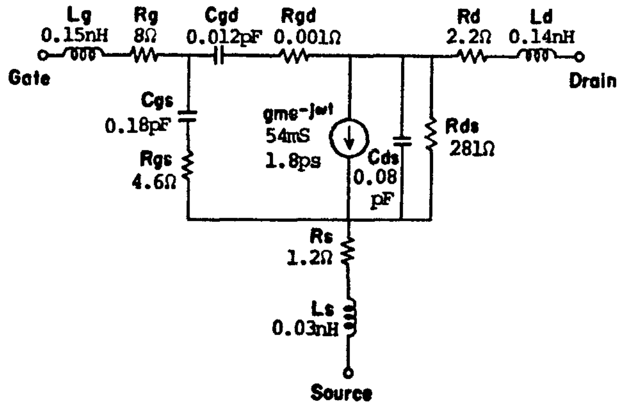


Fig. 3 Equivalent circuit of HEMT chip.

strips[6].

Circuit parameters of unit amplifiers have been optimized by a computer simulation to give a gain flatness of less than 1 dB over 26.5 to 40 GHz. The predicted performance of the single-ended unit amplifier showed the gain of 5.3 dB and the VSWRs of ≤ 2.5. The balanced-type unit amplifier was predicted to give the gain of 3.9 dB and the VSWR of ≤ 1.5.

Unit amplifiers were fabricated on alumina substrates with Ti/W/Au microstrip lines and Ta_3N_4 thin film resistors. The thickness of the alumina substrate has to be thinner in higher frequency of 40 GHz in order to reduce the parasitics due to the discontinuity at the interconnected unit amplifiers and to minimize a radiation effect from microstrip lines. The single-ended unit amplifiers were made by 0.25-mm thick alumina substrates, however, 0.38-mm thick alumina substrates were used in the balanced-type unit amplifiers because of the fabrication difficulties of the interdigitated 3-dB hybrids. Fig. 5 shows the top view of two types of unit amplifiers which measure 5 x 11 mm. The alumina substrates and HEMT chips were soldered to a 0.5-mm thick Kovar carrier plate.

Fig. 6 and Fig. 7 show the measured performance of the single-ended and

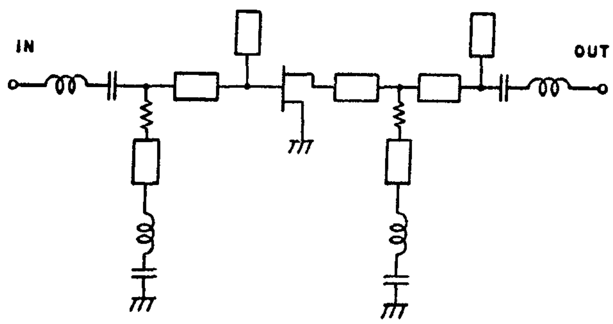
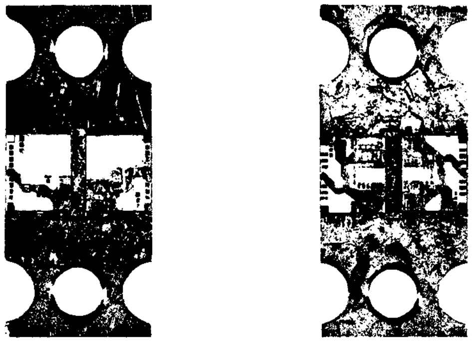


Fig. 4 Equivalent circuit of single-ended unit amplifier.



(a) (b)

Fig. 5 Top view of single-ended (a) and balanced-type (b) unit amplifiers.

balanced-type unit amplifiers, respectively. The single-ended unit amplifier has given a gain of 4.7 ± 1.2 dB and input/output VSWRs of ≤ 3.0 over 26.5 to 40 GHz with a DC power supply of 3 V x 20 mA. The balanced-type unit amplifier has shown a gain of 3.5 ± 1 dB and the VSWRs of ≤ 2.0 with a DC power supply of 3 V x 40 mA. Since the measured performance have shown higher in-band gain ripple, it might be caused by the discrepancy between the actual and calculated S-parameters of HEMT.

MULTISTAGE AMPLIFIER

Multistage amplifier was developed by cascading five unit amplifiers as shown in Fig. 8 in order to realize a total gain of 20 dB. The balanced-type unit amplifiers were used for input and output stages to obtain good VSWRs, and the single-ended unit amplifiers were used for intermediate stages for achieving higher gain. Fig. 9 shows the inside view of the amplifier measuring 20 x 22 x 43 mm. Five unit amplifiers were installed into the hermetically sealed housing. Two rows of metal blocks on the inner side of the lid

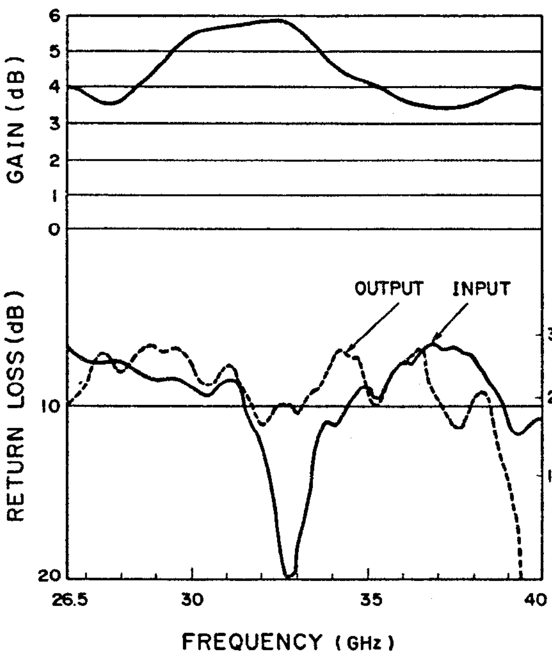


Fig. 6 Measured gain and return losses of single-ended unit amplifier.

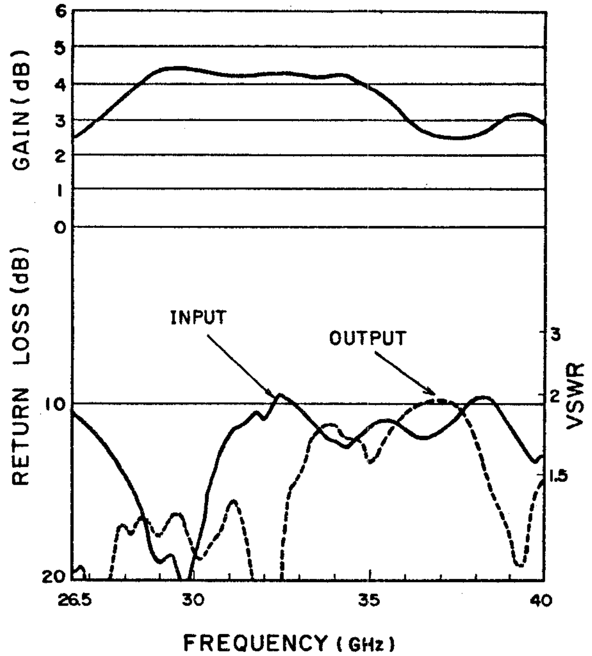


Fig. 7 Measured gain and return losses of balanced-type unit amplifier.

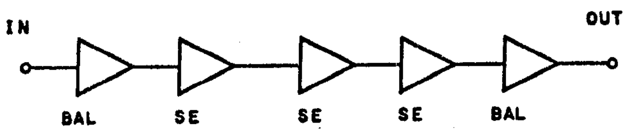


Fig. 8 Configuration of multi-stage amplifier.

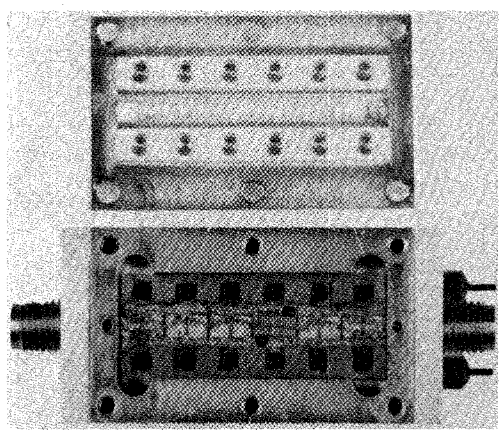


Fig. 9 Inside view of HEMT amplifier (lower) and inner of lid (upper).

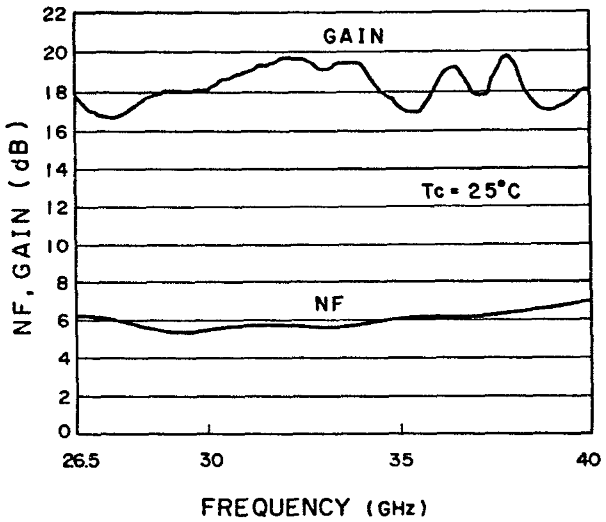


Fig. 10 Measured noise figure (NF) and gain of 5-stage (HEMT) amplifer.

are prepared for suppressing a waveguide mode within the housing. The spacing between the rows is 3 mm and the metal blocks make contact with Kovar carriers of the unit amplifier. The hermetic K-connectors were used for the input and output ports of the amplifier. DC voltage regulators are installed in the back-side of the housing, and the amplifier can operate for an external supply voltage of +15 V with a current of 135 mA and -15 V with a current of 20 mA.

Fig. 10 shows the measured gain and noise figure of the HEMT amplifier. A noise figure of ≤ 7.0 dB and a gain of 18.2 ± 1.6 dB were obtained over 26.5 to 40 GHz, the maximum gain of 19.6 dB with a noise figure of 5.7 dB was obtained at 32 GHz.

Fig. 11 shows the input and output VSWRs of the amplifier, and the maximum VSWR was found to be 2.0. The use of balanced-type unit amplifiers at input and output ports was proved very effective to

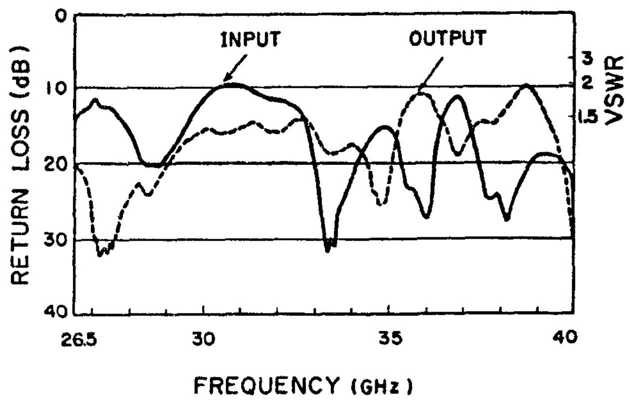


Fig. 11 Measured input / output VSWRs of 5-stage amplifier.

achieve good VSWRs even in the millimeter-wave region.

The temperature dependence of the noise figure (NF) and gain (Ga) were measured. NF / Ga of 4.2 dB / 20.6 dB, 7.1 dB / 18.2 dB at 32 GHz were obtained at the temperature of -40 °C and 70 °C, respectively. The power characteristic of the amplifier was measured, and the output power at 1-dB gain compression point was ≥ 7.6 dBm.

CONCLUSION

Broadband amplifier operating over 26.5 to 40 GHz have been developed by using 0.25-μm gate HEMTs. A gain of 18.2 ± 1.6 dB, the noise figure of ≤ 7.0 dB and the input/output VSWRs of ≤ 2.0 have been obtained.

The use of balanced-type unit amplifiers for the input and output ports and the single-ended unit amplifiers for the intermediate stages has been proved to be very effective in realizing good input/output VSWRs and higher gain simultaneously. The inherent characteristic of the HEMT with its further improvement suggests that the HEMT will be widely used in the millimeter-wave region for the broadband applications as well as low-noise applications.

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