BROADBAND HEMT AND GaAs FET AMPLIFIERS FOR 18 - 26.5 GHz

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ABSTRACT

Two types of broadband amplifiers operating over 18 to 26.5 GHz have been developed by using newly developed 0.4-μm gate HEMTs and conventional 0.25-μm gate GaAs FETs. The four-stage HEMT amplifier exhibits a noise figure of ≤ 7.2 dB and a gain of 19.3 ± 1.8 dB and the five-stage GaAs FET amplifier exhibits a noise figure of ≤ 12 dB and a gain of 22.7 ± 2.2 dB over 18 to 26.5 GHz. The minimum noise figures in the measured frequency range are 5.0 dB and 7.5 dB for the HEMT and GaAs FET amplifiers, respectively. No essential difference is found between the amplifiers in input/output VSWR, output power and temperature variation of noise figure and gain.

Introduction

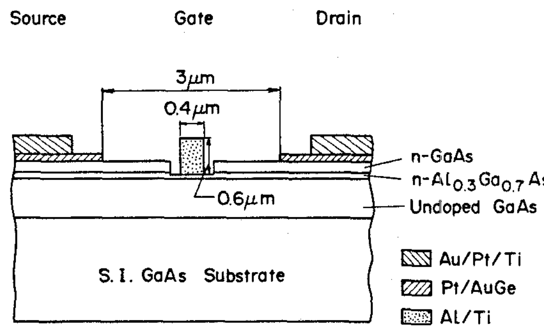
The progress of GaAs FET performance has made it possible to build GaAs FET amplifiers operating up to millimeter-wave region as reported by Rosenberg et al.[1] and Watkins et al.[2]. Considering the fact that the GaAs FET is approaching its theoretically predicted performance with finest geometries feasible at present, almost little can be expected to boost up the amplifier performance using GaAs FETs. Recently, extensive work has been done in many laboratories on HEMT (High Electron Mobility Transistor) that performs much better than the GaAs FET [3],[4].

This paper reports on two types of broadband amplifiers operating from 18 to 26.5 GHz built by using newly developed 0.4-μm gate HEMTs and conventional 0.25-μm gate GaAs FETs. The superiority of HEMT amplifier is shown by this work. The following sections describe the HEMT and GaAs FET employed, the unit amplifier design, and the RF performance of the amplifiers.

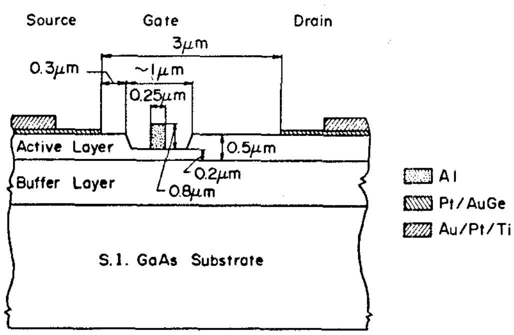
Device

Fig. 1 shows the schematic cross-sectional views of the HEMT (a) and the GaAs FET (b) used in the present work. The HEMTs [5] have been fabricated on expitaxial wafers grown by MBE. The wafer is made of a 1-μm thick undoped GaAs layer, a 300-A thick n-$Al_{0.3}Ga_{0.7}As$ layer and a 500-A thick n-GaAs layer on semi-insulating GaAs substrate. A recess structure is formed to control the drain current by etching the n-GaAs layer and part of n-$Al_{0.3}Ga_{0.7}As$ layer. The gate electrode with a length of 0.4 μm and a width of 200 μm is formed by Al/Ti to a thickness of 0.6 μm. The gate delineation is done by a direct electron-beam lithography.

The GaAs FETs are selected from conventional recessed-gate GaAs FETs (Toshiba JS8830-AS), whose gate electrode is also delineated by a direct electron-beam lithography and has a length of 0.25 μm and a width of 200 μm. Fig. 2 shows the top view of HEMT chip. Two gate bonding



(a) 0.4-μm gate HEMT



(b) 0.25-μm gate GaAs FET

Fig. 1 Schematic cross-sectional view of HEMT (a) and GaAs FET (b).

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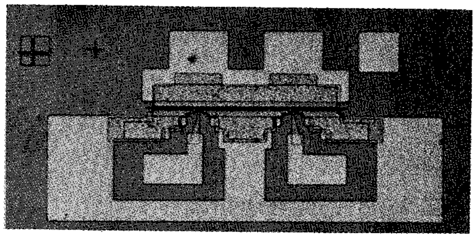


Fig. 2 Top view of HEMT chip.

pads are provided to reduce the gate resistance.

Fig. 3 shows the frequency dependence of microwave noise figure (NF) and associated gain (Ga) for the HEMT and GaAs FET chips measured with a microstrip test fixture. The HEMTs and GaAs FETs have shown typical values of NF = 1.4 dB with Ga = 9.7 dB and NF = 1.8 dB with Ga = 9.0 dB, respectively, at 18 GHz. At higher frequencies, the HEMT has exhibited an NF of 2 dB at 26 GHz, and the FET has an NF of 3.3 dB at 30 GHz. It has been found that the HEMT has 0.5-dB better noise figure and 1-dB higher gain than the GaAs FET at 8, 12 and 18 GHz.

Unit Amplifier Design

In broadband amplifier applications below 20 GHz, a balanced-type unit amplifier consisting of two single-ended amplifiers with two 3-dB hybrids at input and output ports is commonly used. Since the maximum available gain of FET decreases and the 3-dB hybrid loss increases with higher frequency, we have designed and evaluated a single-ended unit amplifier as well as a balanced one for our application. Fig. 4 shows the equivalent circuits of the single-ended unit amplifier (a) and the half of the balanced-type unit amplifier excluding 3-dB hybrids (b).

The single-ended unit amplifier has been designed to give good input and output VSWRs and gain flatness. Since a pure

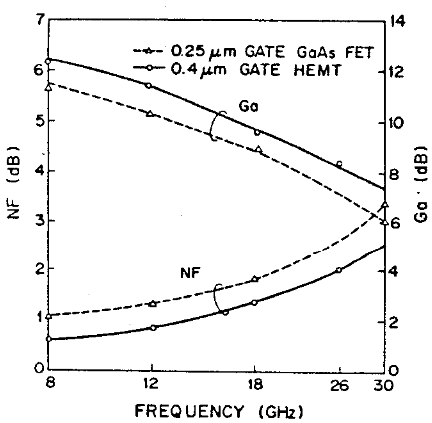
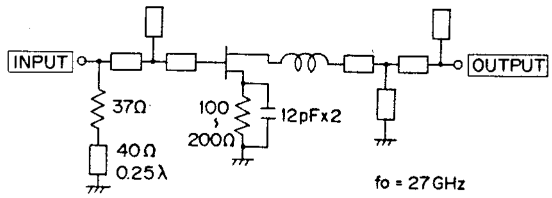
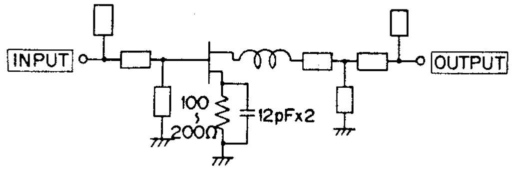


Fig. 3 Measured minimum noise figure (NFmin) and associated gain (Ga) for HEMT and GaAs FET.



(a) Single-ended



(b) Half of balanced-type

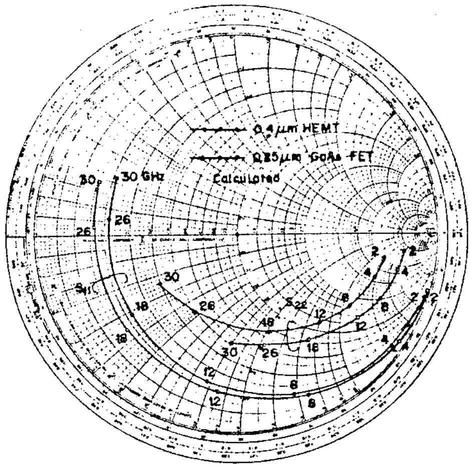
Fig. 4 Equivalent circuit of unit amplifiers.

reactive matching network cannot realize the desired results, a resistor with a quarter-wavelength shorted stub is shunted at the input port to achieve a good input VSWR and gain flatness. The balanced-type unit amplifier has been designed only from a gain flatness point of view. In both unit amplifiers, source resistors and RF-bypass capacitors are incorporated for single power supply operation. Circuit parameters of two types of amplifiers have been optimized by a computer simulation to give a gain flatness of less than 1 dB and VSWRs of less than 2.0. In this optimization, the S-parameters of the HEMT and FET shown in Fig. 5 have been used. The S-parameters have been calculated up to 30 GHz using the equivalent circuit element values determined from 2 to 18 GHz S-parameter measurements.

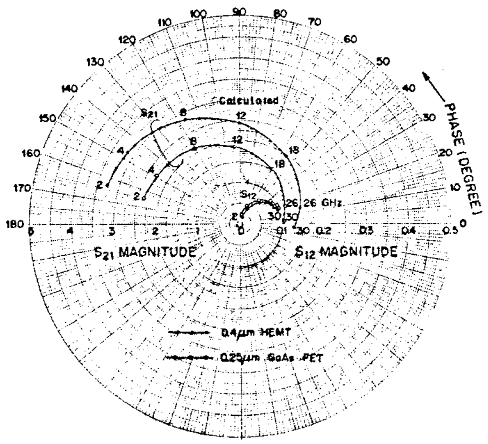
The predicted gains of single-ended unit amplifier are 7.0 dB and 6.3 dB for the HEMT and FET amplifiers, respectively, with an inband ripple of less than 1 dB over 18 to 26.5 GHz. The predicted gains of balanced-type unit amplifier are 7.5 dB and 6.3 dB for the HEMT and the FET amplifiers, respectively, with an inband ripple of 0.6 dB excluding the loss due to 3-dB hybrids.

The 3-dB hybrid designed for the balanced-type unit amplifier is an interdigitated coupler with four strips [6]. Alumina substrate with 0.38mm thickness has been used considering the radiation loss of microstrip and the etching accuracy of the narrow gaps of the hybrid. The fabricated 3-dB hybrid has shown an insertion loss of 0.4 dB and VSWR of $\leq$ 2.0 over 18 to 26.5 GHz.

Fig. 6 shows the top view of the single-ended (a) and balanced-type (b) unit amplifiers. The unit amplifiers have been fabricated on a 0.38-mm thick alumina substrate with Ti/Pt/Au microstrip lines and Ta_3N_4 thin film resistors. The substrate has a size of 2.5 x 6 mm and is



(a) S_{11} and S_{22}



(b) S_{21} and S_{12}

Fig. 5 Calculated S-parameters up to 30 GHz for HEMT and GaAs FET.

soldered to a 0.5-mm thick Kovar carrier. Table 1 summarizes the measured performance of the single-ended and balanced-type amplifiers. The single-ended unit amplifiers using the HEMT and GaAs FET have given gains of 6.2 ± 0.6 dB and 5.5 ± 0.7 dB under a DC supply of 13 mA x 3 V and 22 mA x 3 V, respectively, over 18 to 26.5 GHz. The balanced-type unit amplifiers employing the HEMT and GaAs FET have shown gains of 5.7 ± 0.6 dB and 5.6 ± 0.6 dB under a DC supply of 26 mA x 3 V and 46 mA x 3 V, respectively, over the same frequency range. Since the used HEMT has lower drain current than that used in the simulation, the measured gains of the HEMT unit amplifiers are 1 dB less than the predicted values.

Multi-Stage Amplifiers

Two types of multi-stage amplifiers have been built by cascading four HEMT unit amplifiers and five GaAs FET unit amplifiers in order to realize a total amplifier gain of 20 dB. Fig. 7 shows the configuration of the amplifiers. In both

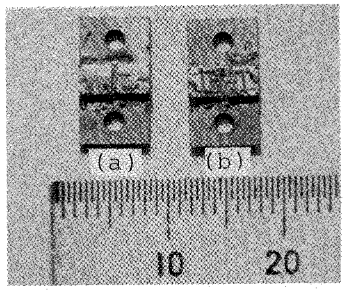


Fig. 6 Top view of single-ended (a) and balanced-type (b) unit amplifiers.

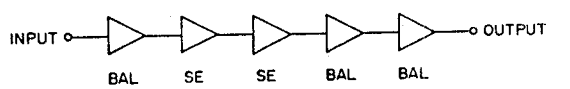
Table 1 Performance of single-ended and balanced-type unit amplifier measured over 18 - 26.5 GHz. I_{DS} : drain current.

	0.4μm HEMT		0.25μm FET	
	I_{DS}(mA)	GAIN (dB)	I_{DS}(mA)	GAIN (dB)
SINGLE-ENDED	13	6.2 ± 0.6	22	5.5 ± 0.7
BALANCED-TYPE	26	5.7 ± 0.6	46	5.6 ± 0.6

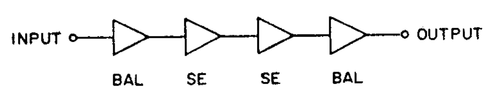
amplifiers, the balanced-type unit amplifiers are used for input and output stages to obtain good VSWR. In each amplifier, two single-ended amplifiers are used for interstage to achieve higher gain.

Fig. 8 shows the inside view of the HEMT amplifier measuring 22 x 22 x 48 mm. Two rows of metal blocks on the inner side of the lid are for suppressing a waveguide mode within the housing. The spacing between the rows is 3 mm and the metal blocks make contact with Kovar carrier of the unit amplifier through conducting rubber. A DC voltage regulator is installed in the backside of the housing, and the amplifier can operate for an external supply voltage of 9 - 20 V.

Fig. 9 shows the measured noise figure and gain of the four-stage HEMT amplifier at a supply voltage and current of 15 V and 96 mA. A noise figure of ≤ 7.2 dB and a gain of 19.3 ± 1.8 dB are obtained over the



(a) 5-stage GaAs FET amplifier



(b) 4-stage HEMT amplifier

Fig. 7 Multi-stage amplifier configuration using GaAs FETs (a) and HEMTs (b).

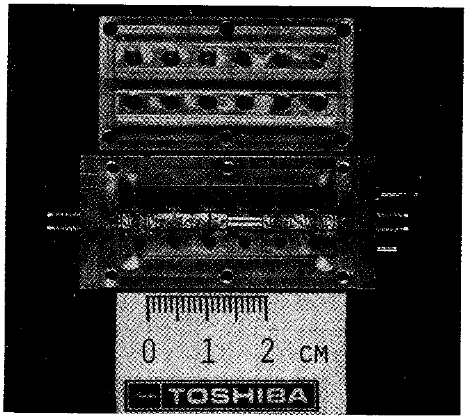


Fig. 8 Inside view of HEMT amplifier (lower) and inner of lid (upper).

frequency range of 18 to 26.5 GHz. Fig. 10 shows the measured noise figure and gain of the five-stage GaAs FET amplifier at a supply voltage and current of 15 V and 165 mA. A noise figure of ≤ 12 dB and a gain of 22.7 ± 2.2 dB are obtained over the same frequency range. In the measured frequency band, the minimum noise figure is 5.0 dB for the HEMT amplifier and 7.5 dB for the FET amplifier. It has been found that HEMTs are superior to GaAs FETs in terms of the noise figure and gain. Input and output VSWRs are ≤ 2.0 for both types of amplifiers over 18 to 26.5 GHz.

The temperature dependence of noise figure and gain has been measured for both amplifiers. It has been found that the noise figure changes against temperature at a rate of ≃ 0.013 dB/°C for both amplifiers and the gain changes at a rate of -0.02 dB/°C and -0.03 dB/°C for the HEMT and GaAs FET amplifiers, respectively. The output power at 1-dB gain compression is 12 dBm and 13 dBm for the HEMT and GaAs FET amplifiers, respectively.

Conclusion

Broadband amplifiers operating over 18 to 26.5 GHz have been developed by using 0.4-μm gate HEMTs and 0.25-μm gate GaAs FETs. Through this work, it has been

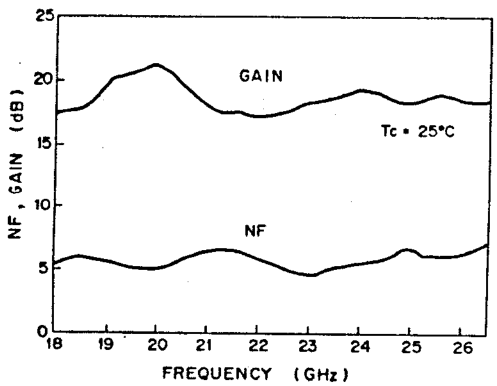


Fig. 9 Measured noise figure (NF) and gain of 4-stage HEMT amplifier.

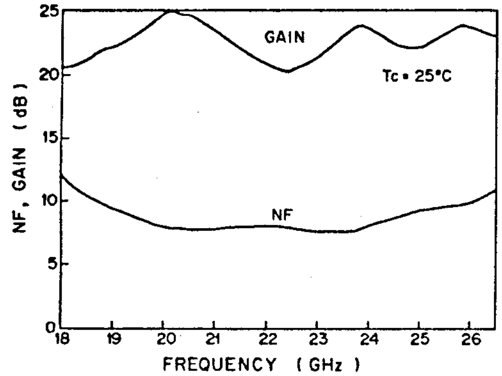


Fig. 10 Measured noise figure (NF) and gain of 5-stage GaAs FET amplifier.

demonstrated that the amplifier using the HEMT shows better performance than the GaAs FET amplifier in terms of noise figure and gain. Both types of amplifiers have shown nearly the same characteristics with respect to VSWR, output power and temperature variation. Because of its inherent advantage, the HEMT will be widely used above Ku band in the broadband applications as well as the low-noise applications.

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