35 GHz LOW NOISE HEMT AMPLIFIER

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Abstract

A low noise HEMT amplifier has been developed for operation at 35 GHz. The three-stage amplifier exhibits a noise figure of 3.1 dB with an associated gain of 17.4 ±0.4 dB across the 34.25 to 35.75 GHz frequency band.

Introduction

In the past several years, a number of laboratories have reported High Electron Mobility Transistor (HEMT) device results at frequencies up to 70 GHz[1,2] and HEMT amplifier results at 20 GHz.[3] However, to date, there have been no reported practical applications of HEMT devices to multistage amplifier applications at millimeter-wave frequencies. This paper presents the first application of GaAs HEMT technology to low noise amplifiers operating at Ka-band frequencies.

HEMT Device Description

The HEMT devices were fabricated using MOCVD material. The MOCVD-grown material has several advantages over MBE-grown material, including the absence of oval and other morphological defects, which impair high yield device fabrication, the potential for high throughput production scale-up, the capability for better run-to-run reproducibility, and a better device reliability.

The material structure consists of a 300 Å N^+-GaAs cap layer, a 500 Å $Al_{.3}Ga_{.7}As$ layer doped to 1.5×10^{17} cm^{-3}, a 10 to 30 Å undoped AlGaAs spacer layer, and a 5000 Å undoped GaAs channel layer grown on a semi-insulating GaAs substrate wafer. The sheet concentration of two-dimensional electron gas is 1.5×10^{12} cm^{-2}, and the electron mobility is 4000 cm^2/v.s. at 300°K and 25,000 cm^2/v.s. at 77°K. The HEMT device geometry consists of two 0.25 x 30 μm gate fingers, for a total gate width of 60 μm. The gates, defined by E-beam lithography, have a mushroom-shaped cross section for low-resistance. Low resistance ohmic contacts are formed using a Au-Ge/Ni/Au metal system and a pulsed thermal alloy technique. The GaAs cap layer is selectively etched off, during the recess, using an $NH_4OH/H_2O_2/H_2O$ solution.

The measured dc transconductance of the HEMT devices is typically in the 300 to 375 mS/mm range. A noise figure of 1.3 dB, with 11 dB associated gain, is consistently measured at 18 GHz. The HEMT performance data are summarized in Table 1. Preliminary reliability tests show no device degradation after 1000 hours of dc-stress at 200°C channel temperature. This demonstrated reliability represents a clear advantage over MBE HEMTs.

TABLE 1
SUMMARY OF HEMT DEVICE PERFORMANCE

F (GHz)	Lg (μm)	TRANSISTOR NF (dB)	TRANSISTOR AG (dB)	AMPLIFIER NF (dB)	AMPLIFIER AG (dB)
12	0.6	1.2	10.0	1.4	9.5
	0.35	1.0	13.0	1.2	12.5
18	0.35	1.5	9.5	1.7	9.0
	0.25*	1.0	11.5	1.3	11.0
35	0.25*	1.8	7.2	2.1	6.6
60	0.25*	4.0	6.0	5.0**	4.0

*Devices fabricated from MOCVD material
**Non-optimized result

Amplifier Configuration

A photograph of the low noise HEMT amplifier is shown in Figure 1. It is similar to configurations previously reported.[4] It consists of three single-ended amplifier stages cascaded directly without isolation. The first stage employs a HEMT device, while the last two stages contain MESFETs. The microstrip matching circuits are fabricated on 10-mil thick fused quartz substrates using MIC techniques. The devices and the circuits are mounted on a single 1.125 x 0.38 inch carrier. The amplifier carrier is mounted in a waveguide channel, below cutoff, which is oriented perpendicular to the waveguide input and output ports. The waveguide-to-microstrip transitions at the input and output are orthogonal E-field probes. This transition approach has demonstrated an insertion loss of less than 0.25 dB per transition at K-band frequencies. External waveguide isolators are employed for minimum loss and VSWR. The top cover (not shown) shields the MIC circuitry and forms the back-short for the waveguide-to-microstrip transitions.

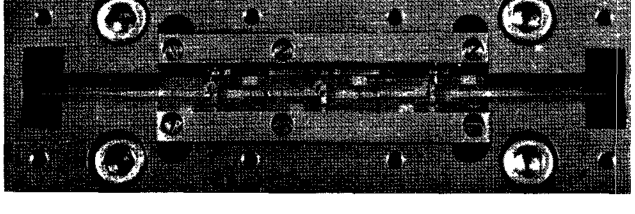

Figure 1 35 GHz amplifier configuration.

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Amplifier Performance

Six HEMT amplifiers have been fabricated and tested at 35 GHz. Typically, the amplifiers produced a noise figure of 3.5 dB, with an associated gain of 17 dB at 35 GHz. The 1-dB gain compression point was typically +7 dBm. The performance of the best LNA is shown in Figure 2. It achieved a noise figure of 3.1 dB with a gain of 17.4 ±0.4 dB across the 34.25 to 35.57 GHz band. The input/output return loss is typically greater than 20 dB. This is waveguide-to-waveguide data, including all sources of input/output losses and mismatches. This data represents the lowest reported noise performance of a multi-stage amplifier operating at 35 GHz.

In addition to the 35 GHz amplifiers, several other Ka-band HEMT amplifiers have been fabricated and tested. These amplifiers are similar in construction to the 35 GHz amplifiers, except that they contain four stages: two HEMTs followed by two MESFETs. The frequency performance of the low Ka-band unit is shown in Figure 3, and the high Ka-band unit is shown in Figure 4. Over the 26.5 to 33.5 GHz frequency band, the low Ka-band unit achieved an average noise figure of 2.85 dB, with a worst case of 3.2 dB at 30 GHz. The gain is 23.3 dB ±1.4 dB across the band.

The high Ka-band unit demonstrated an average noise figure of 3.1 dB and a worst case of 3.5 dB across the 35.5 to 40 GHz frequency band. The gain is 21.4 dB ±0.5 dB across this band. This unit achieved its best performance, 2.7 dB noise figure, at 38 GHz. When it was tuned specifically at this frequency for minimum noise, it produced a noise figure below 2.5 dB. This corresponds to a device noise measurement of better than 1.9 dB and a device noise figure of approximately 1.5 dB at 38 GHz. This represents the best device results yet reported at this frequency.

Conclusions

The above results represent new levels of performance for LNAs operating at Ka-band frequencies. These results clearly demonstrate the viability of GaAs HEMT technology at millimeter-wave frequencies, particularly for low noise receiver applications. With the continued development of GaAs HEMT technology, amplifiers with sub-3 dB noise figures at 35 GHz will soon be available commercially.

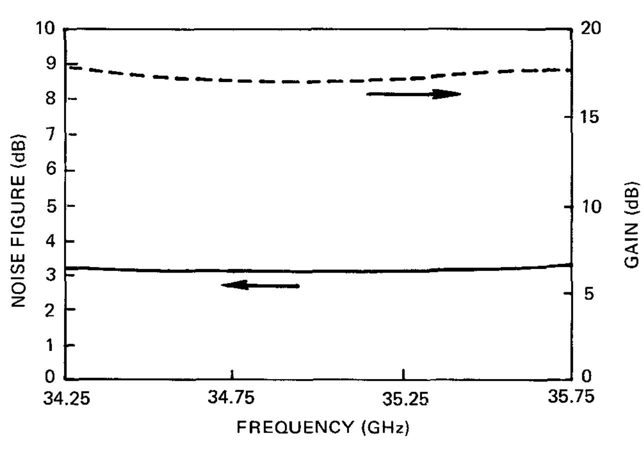

Figure 2 Performance of 35 GHz HEMT LNA.

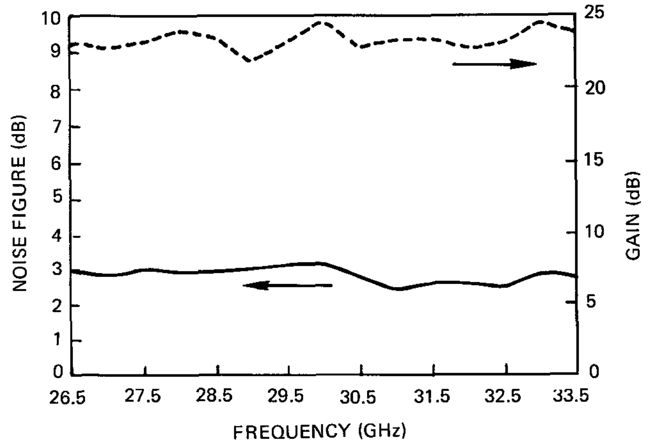

Figure 3 Frequency response of low band HEMT LNA.

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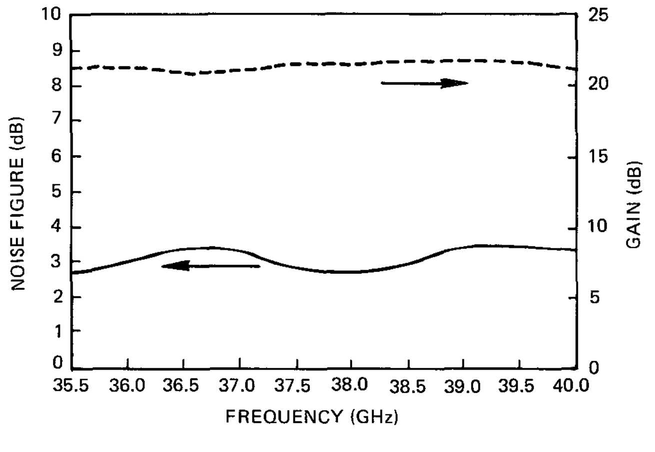

Figure 4 Frequency response of high band HEMT LNA.