Ka-Band Ultra Low Noise MMIC Amplifier Using Pseudomorphic HEMTs

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Abstract

A Ka-band monolithic low noise two stage amplifier has been developed using an AlGaAs/InGaAs/GaAs pseudomorphic HEMT with a gate length of 0.15 μm. For a superior noise figure, the MMIC was optimized by inserting a low loss resonator type stabilizing circuit without sacrificing the gain performance. The amplifier has achieved a 1.0 dB noise figure with an associated gain of 18.0 dB at 32 GHz. These results are the best of AlGaAs/InGaAs/GaAs P-HEMT MMICs ever reported to date.

I. Introduction

Realizing a high performance low noise amplifier is one of the key issues for satellite communication systems. For this application we have developed a Ka-band ultra low noise MMIC amplifier using P-HEMTs. In designing low noise amplifiers, following two factors are usually important. One is improvement of the transistor performance and the other is circuit designing to realize a low noise figure, high gain and stability simultaneously. One of the techniques for the latter factor is employing series inductive feedback circuits that make an amplifier stable with a very low noise figure. However, in the region of Ka-band, sufficiently large inductance for stabilizing an amplifier can lead to degradation of a gain performance.

P-HEMT RF performances were improved for the Ka-band low noise MMIC amplifier by optimizing device structures to achieve a minimum noise figure of 0.9 dB at 35 GHz. In order to obtain a low noise figure with a sufficiently high gain in an MMIC, we used both of a series inductive feedback circuit and a low loss resonator type stabilizing circuit. The inductive feedback circuit is optimized to stabilize the P-HEMT at frequencies over 30 GHz and to minimize gain degradation caused by the source inductance. A low loss resonator type stabilizing circuit is employed and carefully optimized to realize both high stability under 30 GHz and a low noise figure with a sufficiently high gain over 30 GHz. As a result, the amplifier has achieved a noise figure of 1.0 dB at 32 GHz with an associated gain of 18.0 dB. The obtained noise figures are less than 1.4 dB with sufficient stability for the wide frequency range from 26 GHz to 32 GHz. In this paper, we describe device characteristics, circuit designing and measured results of the amplifier.

II. Device Characterization

Figure 1 shows a cross sectional view of the P-HEMT. Epitaxial layers of the P-HEMT are grown by MBE. A Si planar doped layer with a sheet carrier concentration of 5×10^{12} cm^{-2} is inserted into the AlGaAs layer. The gate length of the P-HEMT is 0.15 μm. The 0.15 μm T-shaped gate electrode is defined using electron beam lithography and a selective recess

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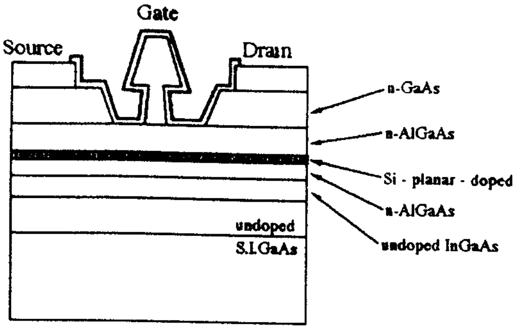


Fig. 1. Cross section of the P-HEMT.

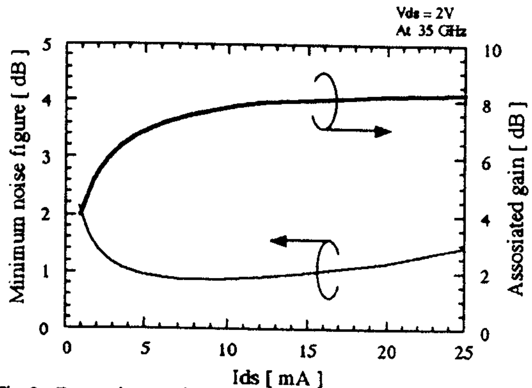
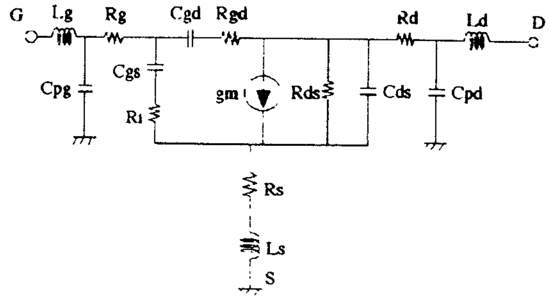


Fig.2 Dependence of minimum noise figure and associated gain on drain current at 35 GHz of the P-HEMT.



(a) Equivalent circuit of the P-HEMT.

Lg(nH)	Ls(nH)	Ld(nH)	Rg(Ω)	Rs(Ω)	Rd(Ω)
0.057	0.008	0.039	2.64	2.79	3.29
Rgd(Ω)	Rds(Ω)	Ri(Ω)	Cpg(pF)	Cpd(pF)	Cgs(pF)
2.69	163.45	1.59	0.028	0.052	0.11
Cds(pF)	gm(mS)	τ (ps)			
0.005	84	0.23			

(b) Parameters of the P-HEMT.

Fig.3 Equivalent Circuit and parameters of the P-HEMT.

etching process[1]. In addition, a narrow source to drain space of 1.5 μm is employed to reduce parasitic resistance. The recess width was especially optimized to obtain a superior noise figure.

Figure 2 shows minimum noise figures and associated gains versus drain currents at 35 GHz. The gate width of the P-HEMT is 120 μm. The minimum noise figure of 0.9 dB is obtained at a drain current of 12 mA. Figure 3 shows an equivalent circuit of the P-HEMT. Small signal parameters are extracted from S-parameters measured from 1 to 40 GHz using the hot and cold model measurements. Noise parameters in the designed frequency are extracted by calculation using the equivalent circuit and a minimum noise figure at 35 GHz by a method described in the literature[2].

III. Circuit Design

In designing an LNA, it is required to obtain low noise, high gain, and low VSWR performances with sufficient circuit stability. Series inductive feedback is usually used to obtain good stability and a good noise performance as well. In our design, source inductors are formed by inserting two transmission lines between source electrodes and via hole grounds of the P-HEMT. Figure 4 shows calculated MAG/MSG performances for different transmission line lengths. As the transmission line length increases, the K factors of the P-HEMT become high. It seems to require a transmission line length of 250 μm to obtain good stability from the 20 to 30 GHz range. However the gain is seriously deteriorated in this case. We employed an inductor length of 50 μm in order to

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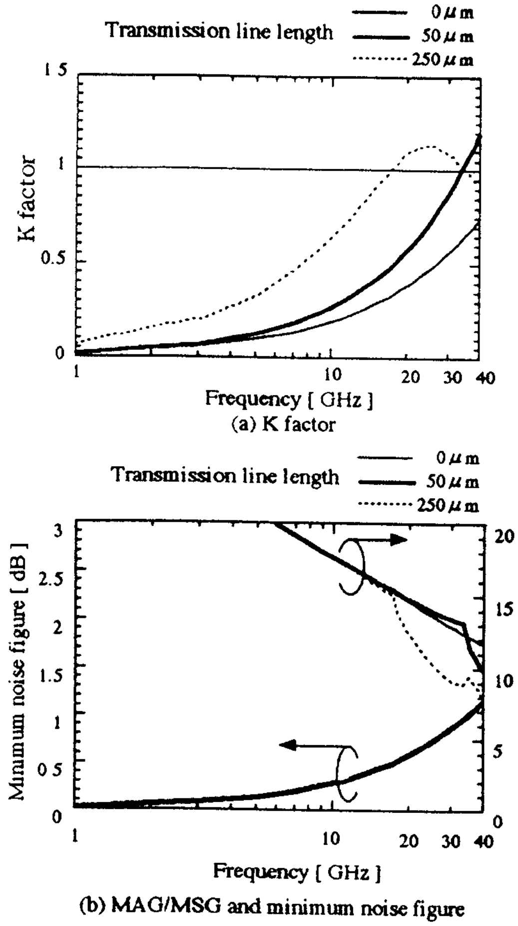

Fig. 4 Calculated performance of the P-HEMT

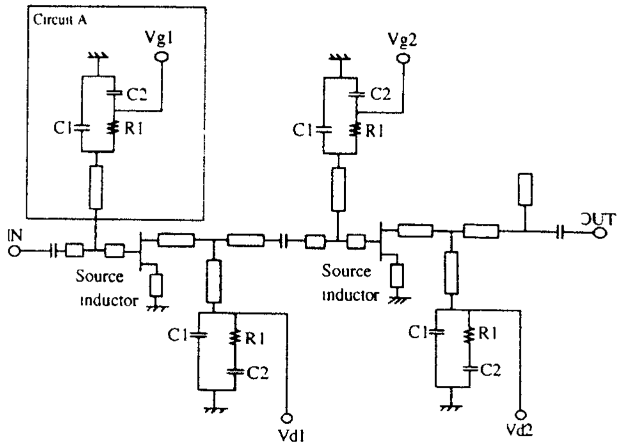

Fig.5 Circuit diagram of the MMIC

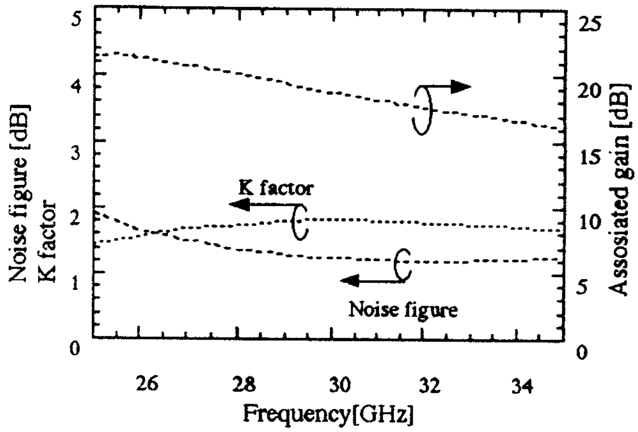

Fig.6 Simulated results.

stabilize the amplifier as well as to obtain good gains above 30 GHz.

For the frequencies under 30 GHz, the P-HEMT device is still not stable. The low loss resonator type stabilizing circuit (circuit A) is adopted to stabilize the lower frequency range. This stabilization circuit, shown in Fig.5, does not degrade noise and gain performances over 30 GHz. The circuit consists of a transmission line, two capacitors (C1 and C2) and a resistor (R1). It has weak resonance in the vicinity of 20 GHz. The resistor R1 acts as a dumping resistor at around 20 GHz to reduce the amplifier gain in this frequency band. The values of the capacitors are optimized to obtain an appropriate resonance frequency. The capacitance values are set as 0.4 pF and 0.5 pF for C1 and C2, respectively. The same circuit topology is adopted for 1st and 2nd stage of the amplifier. Figure 6 shows the simulated results. Noise figures under 1.6 dB with gains over 16 dB are obtained in the frequency range from 26 to 32 GHz. In the same frequency range, K factors are kept over 1.

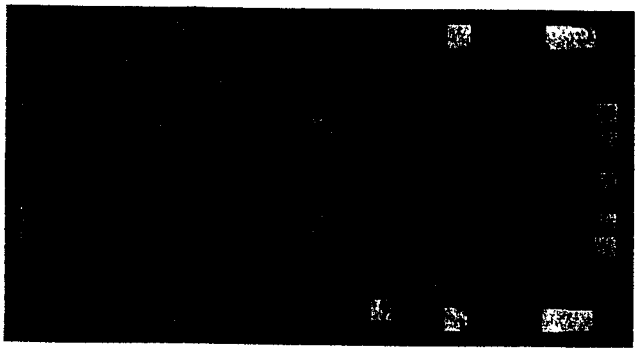

Fig.7 Photograph of the

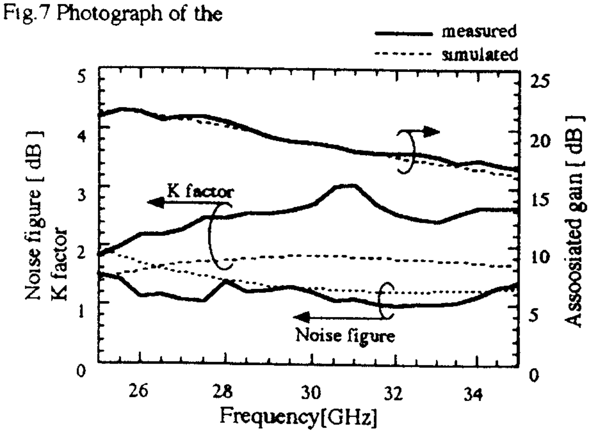

Fig.8 The measured results of the amplifier compared with the designed data.

IV. Measured Result

Figure 7 shows a photograph of the amplifier. The chip size is 2.3 mm x 1.3 mm. Figure 8 shows the measured results of the amplifier compared with the designed data. The noise figure is less than 1.4 dB from 26 GHz to 35 GHz. In the same frequency range, K factors are kept over 1. These results show good agreement with the simulated data. Figure 9 shows noise performances of the LNA in the frequency range from 25 GHz to 40 GHz. These measured results are the best of AlGaAs/InGaAs/GaAs P-HEMT MMICs ever reported to date.

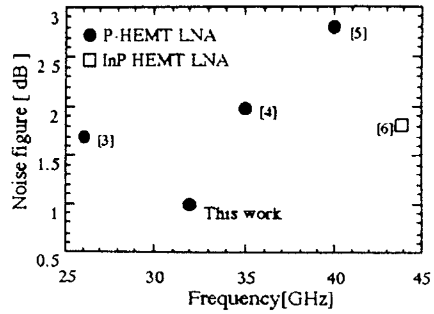

Fig.9 Noise performances of HEMT LNA MMICs in the frequency range from 25 GHz to 45 GHz

V. Conclusion

A Ka-band monolithic low noise two stage amplifier has been developed and it has achieved a 1.0 dB noise figure with an 18.0 dB associated gain at 32 GHz. Noise figures less than 1.4 dB were obtained from 26 GHz to 32 GHz. K factors over 1 are obtained and the amplifier is stable at any frequency. The success of this LNA development came from low noise performance of the used P-HEMT and the MMIC designing method to increase stability without sacrificing noise or gain performances.

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