A W-BAND MONOLITHIC LOW NOISE AlGaAs/InGaAs PSEUDOMORPHIC HEMT AMPLIFIER MOUNTED ON A SMALL HERMETICALLY-SEALED PACKAGE WITH WAVEGUIDE INTERFACE

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ABSTRACT

A W-band monolithic low noise AlGaAs/InGaAs/GaAs pseudomorphic HEMT amplifier mounted on a small hermetically-sealed package has been developed for use in Advanced Microwave Scanning Radiometer. A six-stage amplifier cascading three two-stage MMIC amplifier chips is assembled on a small hermetically-sealed package with waveguide interface and has achieved a noise figure of 4.3 dB with a gain of 28.1 dB at 91 GHz. The overall amplifier measures 12 x 32.8 x 5.4 mm^3. This is the first W-band multi-stage monolithic low noise amplifier mounted on a hermetically-sealed package.

INTRODUCTION

Advanced Microwave Scanning Radiometer is under development to be on board the ADEOS-II satellite to observe Earth environments including sea surface temperature, water vapor, sea ice distribution, etc. An extremely low noise and high gain amplifier module is required in order to enhance the resolution of the instrument. W-band multi-stage, low noise, high gain amplifiers consisting of waveguide-to-microstrip transitions and carrier-type amplifier modules have been reported [1],[2]. These amplifiers, however, do not have a hermetically-sealed structure. To address this problem, we developed a W-band multi-stage amplifier module mounted on a small hermetically-sealed package for achieving high reliability. A six-stage amplifier cascading three two-stage MMIC amplifier chips is assembled on a hermetically-sealed package and has achieved a noise figure of 4.3 dB with a gain of 28.1 dB at 91 GHz. The overall amplifier measures 12 x 32.8 x 5.4 mm^3.

AMPLIFIER DESIGN

A photograph of the W-band six-stage low noise amplifier is shown in Fig.1. It consists of three two-stage MMIC amplifier chips, input and output waveguide-to-microstrip transitions, a through line, bypass capacitors, a hermetically-sealed package, and a cover plate having waveguide interface. The overall amplifier measures 12 x 32.8 x 5.4 mm^3. To avoid oscillations related to waveguide modes, the

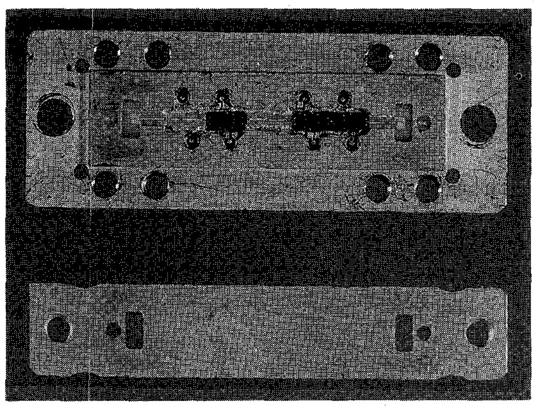


Fig.1 Photograph of the W-band six-stage low noise amplifier

width of inner side of package was designed so that the cutoff frequency becomes higher than 100 GHz. The cover plate has waveguide interface where fused silica substrate is buried for hermetic sealing. The measured insertion loss of the waveguide-to-microstrip transition combined with the cover plate was approximately 0.4 dB at 90 GHz. The gate and drain bias are applied to each MMIC chip through glass beads and bypass capacitors with a capacitance of 40 pF to suppress the lower frequency oscillation.

A photograph of the two-stage MMIC amplifier chip with the chip dimensions of 1.2 x 2.6 x 0.1 mm^3 is shown in Fig.2. The amplifier utilizes 0.15 x 60 μm^2 AlGaAs/InGaAs/GaAs pseudomorphic HEMTs with a passivation film [3],[4]. This PHEMT shows a d.c. transconductance of 600 mS/mm, a V_{th} of -0.5 V, an f_T of 133 GHz, and an f_{max} of 186 GHz for V_d = 2 V. The small signal equivalent circuit and noise model parameters [5], which are shown in Fig.3, were obtained on the basis of measured S-parameters up to 50 GHz, and noise parameters at 60 and 90 GHz. The measured minimum noise figure was 2.5 dB and an associated gain was 4.3 dB at 90 GHz. It is quite difficult to make an accurate measurement of the optimum load impedance providing the minimum noise figure at W-band. Therefore the noise parameters at 90 GHz were calculated from the noise model shown in Fig.3, which are $\Gamma_{opt} = 0.42\angle 140^\circ$, $R_n = 10\ \Omega$, T_g = 105 K, and T_d = 1175 K at 90 GHz. The calculated noise circles at 90 GHz are plotted in Fig.4.

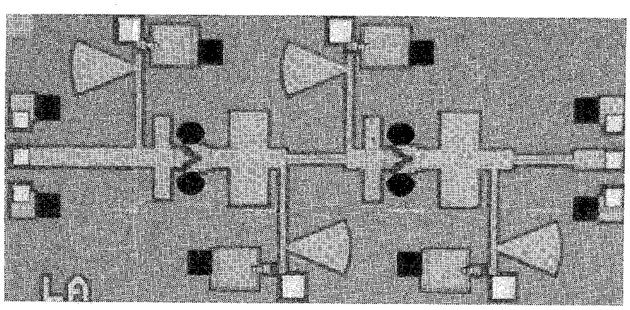
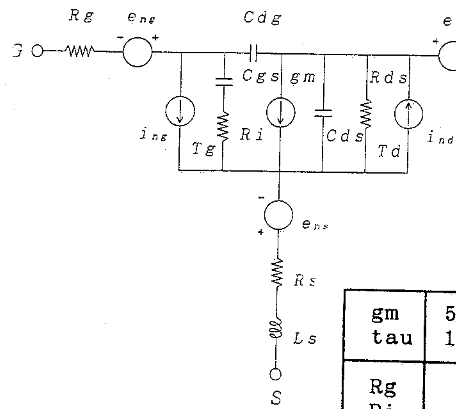
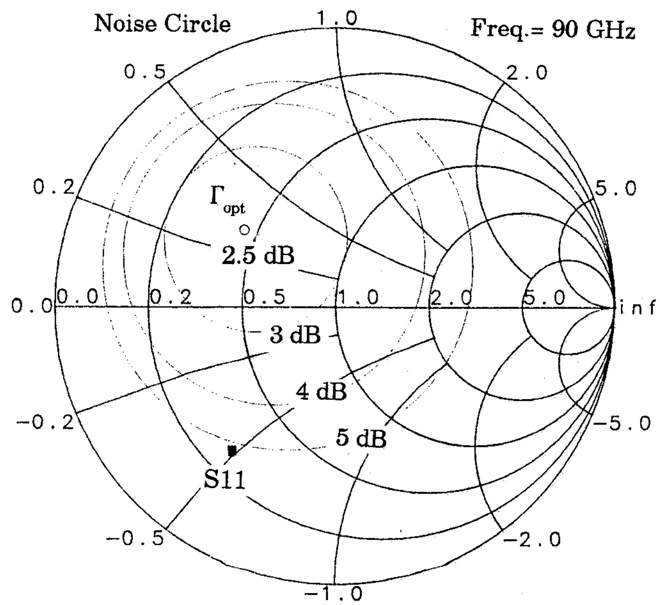


Fig.2 Photograph of the two-stage MMIC amplifier chip



gm	50 mS
tau	1.5 ps
Rg	1 Ω
Ri	12 Ω
Rs	5 Ω
Rd	2 Ω
Rds	150 Ω
Cgs	0.06 pF
Cdg	0.009 pF
Cds	0.04 pF
Ls	0.008 nH

Fig.3 Noise model of 0.15 x 60 μm^2 AlGaAs/InGaAs/GaAs pseudomorphic HEMT



0.15 x 60 μm^2 AlGaAs/InGaAs/GaAs PHEMT

Fig.4 Calculated noise circles at 90 GHz

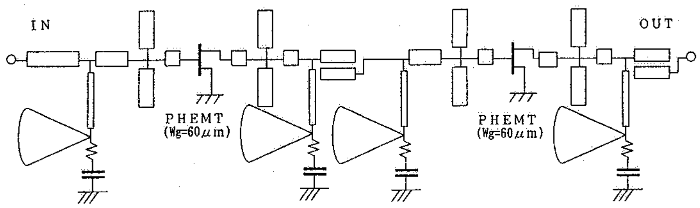


Fig.5 Schematic diagram of the W-band two-stage monolithic amplifier

A schematic diagram of the W-band two-stage monolithic amplifier is shown in Fig.5. To achieve low noise and high gain of the amplifier, a reactive matching method was employed in the design of input noise matching and output gain matching circuits comprised of double open-circuited stubs. In addition to these matching circuits, the amplifier employs edge coupled lines for d.c. block, radial stubs for r.f. bypass, and resistors in the gate and drain bias circuits for high stability at lower frequencies. The circuit parameters shown in Fig.5 were optimized to achieve a noise figure of less than 4 dB with a gain of greater than 8 dB at 90 GHz by using the noise model shown in Fig.3.

AMPLIFIER PERFORMANCE

D.c. and r.f. characteristics of each MMIC amplifier were evaluated by using the wafer prober [6] before assembling to achieve a high yield of the multi-stage amplifier. The calculated and measured noise figure and gain are shown in Fig.6. The measured noise figure of 3.4 dB with a gain of 8.7 dB was obtained at 91 GHz, which are comparable with the best noise figure data reported in References [7],[8]. Bias conditions are $V_d = 2$ V and $I_d = 12$ mA. It is clear in Fig.6 that a good agreement between the measured and calculated results has been achieved for both noise figure and gain. Taking into account the minimum noise figure of 2.5 dB with an associated gain of 4.3 dB at 90 GHz of 0.15 x 60 μm^2 GaAs PHEMTs, a good noise matching has been accomplished. The measured 1 dB compressed power was +9 dBm at 94 GHz for $V_d = 2$ V and $I_d = 24$ mA.

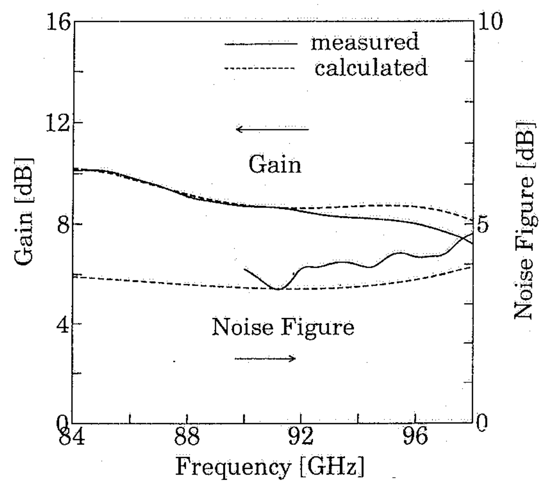


Fig.6 Calculated and measured noise figure and gain of the W-band two-stage monolithic amplifier

The measured noise figure and gain of the W-band six-stage amplifier module are plotted in Fig.7. The amplifier demonstrates a noise figure of 4.3 dB with a gain of 28.1 dB at 91 GHz. The data shown in Fig.7 include an insertion loss of the package. Bias conditions are Vd = 2 V and Id = 6 mA/stage for the 1st and 2nd stage amplifiers to achieve low noise figure and Id = 12 mA/stage for the 3rd to final stage amplifiers to achieve high gain. The amplifier was confirmed that it is stable at all bias conditions without using millimeter-wave absorbers within the package. These results represent the best noise figure performance ever achieved by multi-stage low noise amplifier modules.

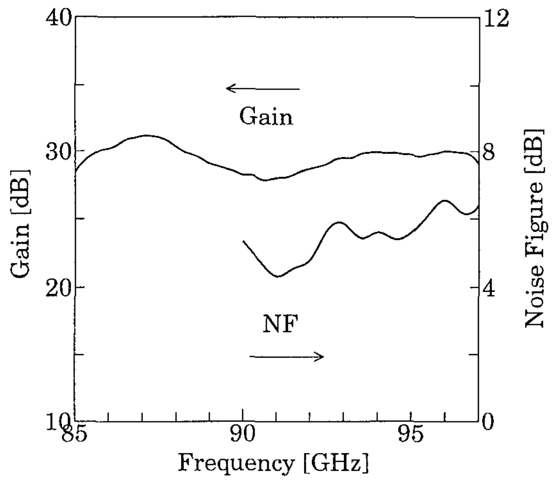


Fig.7 Measured noise figure and gain of the W-band six-stage amplifier module

CONCLUSION

A W-band monolithic low noise amplifier module mounted on a small hermetically-sealed package has been developed by using 0.15 x 60 μm^2 AlGaAs/InGaAs/GaAs pseudomorphic HEMTs. A six-stage amplifier cascading three two-stage MMIC amplifier chips has been assembled on a small hermetically-sealed package with waveguide interface and has achieved a noise figure of 4.3 dB with a gain of 28.1 dB at 91 GHz. The overall amplifier measured 12 x 32.8 x 5.4 mm^3. This result demonstrates that this amplifier design would be a good candidate for achieving highly stable, high gain, low noise, monolithic amplifier modules having a hermetically-sealed structure at millimeter-wave frequencies. In addition, it can be expected that this result significantly improves the radiometric performance of the Advanced Microwave Scanning Radiometer to be on board the ADEOS-II satellite.

REFERENCES

[1] T.N.Ton, B.Allen, H.Wang, G.S.Dow, E. Barnachea, and J.Berenz,"A W-Band, High Gain, Low-Noise Amplifier Using PHEMT MMIC,"IEEE Microwave and Guided Wave Letters, vol.2, No.2, pp.63-64, Feb. 1992.

[2] H.Yoshinaga, K.Masuda, S.Takagi, B.Abe, K.Shibata, H.Kawasaki, H.Tokuda, and I. Tokaji,"A 94 GHz-Band Low Noise Down-converter,"1993 IEEE MTT-S International Microwave Symposium Digest, pp.779-782.

[3] T.Katoh, N.Yoshida, H.Minami, T.Kashiwa, and S.Orisaka,"A 60GHz-Band Ultra Low Noise Planar-Doped HEMT,"1993 IEEE MTT-S International Microwave Symposium Digest, pp.337-340.

[4] T.Kashiwa, N.Tanino, H.Minami, T.Katoh, N. Yoshida, Y.Itoh, Y.Mitsui, T.Imatani, and S. Mitsui,"Design of W-Band Monolithic Low Noise Amplifiers Using Accurate HEMT Modeling,"1994 IEEE MTT-S International Microwave Symposium Digest, pp.289-292.

[5] M.W.Pospieszalski,"Modeling of Noise Parameters of MESFET's and MODFET's and Their Frequency and Temperature Dependence," IEEE Trans.on MTT, vol.37, No.9, pp.1340-1350, Sep. 1989.

[6] S.M.J.Liu and G.G.Boll,"A New Probe for W-Band On-Wafer Measurements,"1993 IEEE MTT-S International Microwave Symposium Digest, pp.1335-1338.

[7] H.Wang, K.L.Tan, T.N.Ton, G.S.Dow, P.H.Liu, D.C.Streit, J.Berenz, M.W.Pospieszalski, and S.K.Pan,"A High Gain Low Noise 110 GHz Monolithic Two-Stage Amplifier,"1993 IEEE MTT-S International Microwave Symposium Digest, pp.783-785.

[8] H.Wang, T.N.Ton, K.L.Tan, G.S.Dow, T.H.Chen, K.W.Chang, J.Berenz, B.Allen, P.Liu, D.Streit, G.Hayashibara, and L.C T.Liu,"An Ultra Low Noise W-Band Monolithic Three-Stage Amplifier Using 0.1 μm Pseudomorphic InGaAs/GaAs HEMT Technology,"1992 IEEE MTT-S International Microwave Symposium Digest, pp. 803-806.