# Ka-BAND HEMT-BASED LOW NOISE AMPLIFIER MODULES

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## ABSTRACT

A two-stage low noise amplifier module for the 35.5 - 36.5 GHz band has been designed and developed. The amplifier is based on a conventional high electron mobility transistor (HEMT) with 0.25 um gate length. An equivalent circuit model for this device was derived from measuraments up to 18 GHz. The amplifier module has been implemented in a hybrid form on 0.254 mm $Al_2O_3$ substrate. A noise figure of 2.9 dB with an associated gain of 6.8 dB (coax to microstrip transitions loss included) have been measured at 35.8 GHz. In-band flatness is better than $\pm$ 0.15 dB for noise figure and $\pm$ 0.5 dB for associated gain.

**KEYWORDS**: Low-noise amplifier, HEMT, Ka-Band

## 1. INTRODUCTION

A temperature-compensated six-stage LNA compatible with the specifications of the MIMR front-end subsystem has been designed as part of a technological upgrade programme. The six stages of amplification were grouped into three single-carrier two-stage modules that can be cascaded without any interstage matching. The input module is the most critical in terms of the overall amplifier noise figure, and was consequently given the highest prority in manufacturing and testing. The performance of the subsequent gain stages will not be discussed here.
The limited number of modules needed in the final assembly indicates that a hybrid implementation is the most cost-effective one. As a consequence, a HEMT device in chip form mounted on 0.254 mm alumina substrate was chosen as the basic configuration.
The chosen HEMT device with 0.25 um gate length and a conventional structure (no Indium in the active layer) represents the product of an already mature technology, and is commercially available at relatively low cost. Unfortunately, measured noise parameters were available only up to 26 GHz, while the amplifier frequency specification is 35.5 - 36.5 GHz. The problem has been circumvented through an extrapolation procedure based on an equivalent circuit model.
The performance of the two stage modules has been tested in coaxial K-connector test fixtures. The complete six stage amplifier will adopt a WR28 to microstrip transition at the input, in order to minimise insertion loss and therefore noise figure.
Measurement results for the two-stage amplifier feature a noise figure of 2.9 dB with an associated gain of 6.8 dB (coax to microstrip transition loss included) at 35.8 GHz, with in-band flatness better than $\pm$ 0.15 dB for noise figure and $\pm$ 0.5 dB for associated gain. The expected figures for noise figure and associated gain using a waveguide to microstrip transition in front and eliminating the interstage connectors are 2.7 dB and 7.5 dB respectively. Amplifier unconditional stability has been achieved.

## 2. NOISE AND SMALL-SIGNAL PARAMETERS EXTRACTION

Fig.1 shows the equivalent circuit model used for small signal analysis of the HEMT device. The noise performance has been modeled through a Podell noise model [1]. An iterative optimisation procedure was undertaken to determine the values for the equivalent circuit parameters that give the best fit of the simulated device performance to the measured one. The device model obtained was then used to extrapolate the device performance in the 30 - 40 GHz band. Tab.1 contains the values for the equivalent circuit parameters. Note that a distinction is made between the parameters relevant to the chip itself and those depending upon bond wires. The latter play an extremely important role in determining amplifier performance at these frequencies. The fit of simulated to measured noise figure (up to 26 GHz) and $S_{21}$ is shown in Figs. 2 and 3.

## 3. INPUT TWO-STAGE MODULE DESIGN

The design of transmission line impedance matching elements was based on the use of 0.254 mm $Al_2O_3$ substrate with $\varepsilon_r = 9.9$. The choice of alumina as opposed to fused silica is motivated by the advantages of the latter in terms of ease of handling and repeatability of the etching process. The height to line wavelength ratio, $h/\lambda$, is small enough to ensure that discontinuities in transmission line characteristics are accurately modeled. Great attention was paid in the design to avoid the occurance of transverse resonant modes in low impedance sections. A proprietary 2D e.m. simulator [2] was used to confirm the theoretical results.
The possibility of introducing source series feedback to allineate the optimum noise figure point and the optimum input matching point on the Smith chart was considered, and the optimum length for the source bond wires resulted. The stability of the amplifier both in-band and out-of-band was ensured in the design through an accurate characterization of all of the amplifier sections. Low frequency stability required the introduction of damping sections in the bias networks.
The module dimensions are 5 x 14 mm, and the walls of the amplifier housing are designed to be as close as possible to the alumina substrate in order to increase the cut-off frequency of the loaded cavity modes.

## 4. MEASURED RESULTS

The low noise two-stage amplifier module is dropped into a test fixture with coaxial K-connectors at both input and output ports. The intrinsic loss of the test fixture was not extracted from the measurements to simulate operative conditions. On the other hand, the final six-stage amplifier housing accomodates a WR28 waveguide to microstrip transition at the input, so that the actual noise figure should improve by a few tens of a dB.
HP8510 and HP8970S systems were employed to perform the small signal and noise measurements, respectively. Two-stage module measured noise figure is reported in Fig.4. Noise figure is better than 3.2 dB all across the measurement band with a minimum of 2.9 dB and a flatness of ± 0.15 dB. Fig.5 shows the gain and input match in dB of the two-stage module. Gain is better than 5.8 dB all across the measurement band with a maximum of 6.8 dB and a flatness of ± 0.5 dB. Input match is better than 8 dB all across the measurement band. The results were achieved without any tuning on the amplifier.

## 5. CONCLUSION

A self-supported technological upgrade programme has been undertaken. One of the objectives of this programme is to design and manufacture high performance millimeter-wave low noise amplifiers. The specifications of the MIMR front-end subsystem were taken as the goal for a six-stage LNA. The building block for this temperature-compensated amplifier was elected to be a two-stage module. The design procedure as well as the measured results for the input module of the amplifier have been presented and the latter are encouraging for the achievement of the final objective. Follow-on research will determine the performance of the modules in the presence of environmental stress and aging.

## ACKNOWLEDGMENTS

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## REFERENCES

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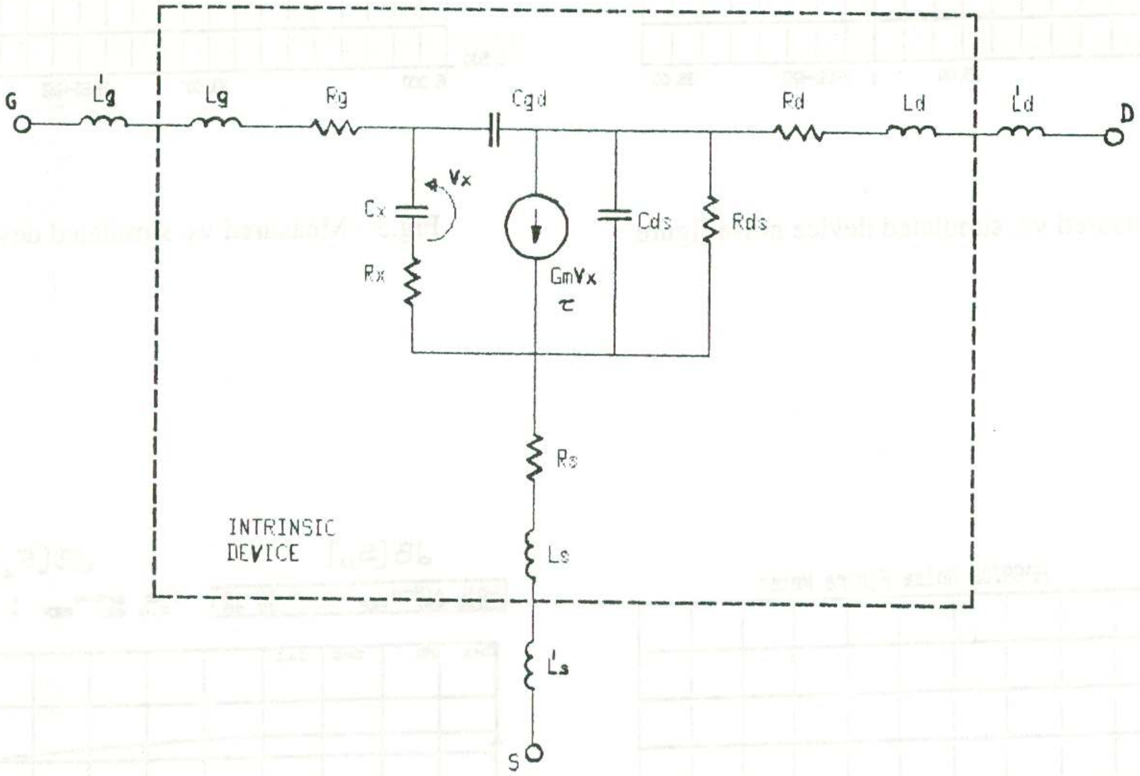


Fig.1 - HEMT device equivalent circuit model

| ELEMENT | UNIT | VALUE |
|---|---|---|
| Cx | pF | 0.15 |
| Cds | pF | 0.09 |
| Cgd | pF | 0.02 |
| Lg | nH | 0.01 |
| Ld | nH | 0.01 |
| Ls | nH | 0.02 |
| Rx | ohm | 3.4 |
| Rg | ohm | 0.6 |
| Rd | ohm | 2.0 |
| Rs | ohm | 1.6 |
| gm | mS | 51.0 |
| τ | pS | 2.0 |
| L'g | nH | 0.13 |
| L'd | nH | 0.15 |
| L's | nH | 0.01 |

Tab.1 - Equivalent circuit parameter values

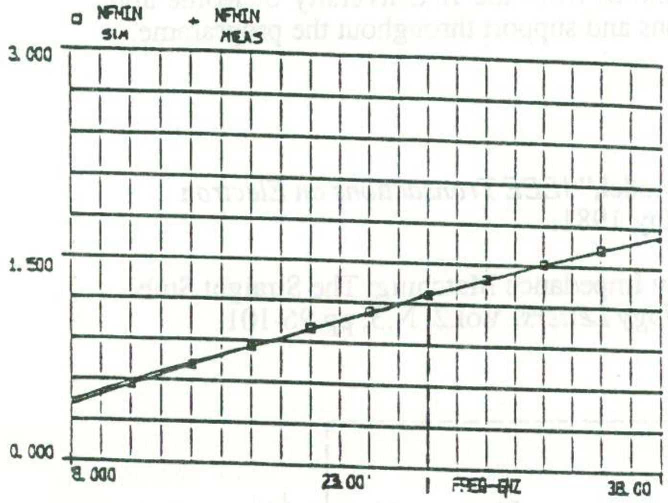


Fig.2 - Measured vs. simulated device noise figure

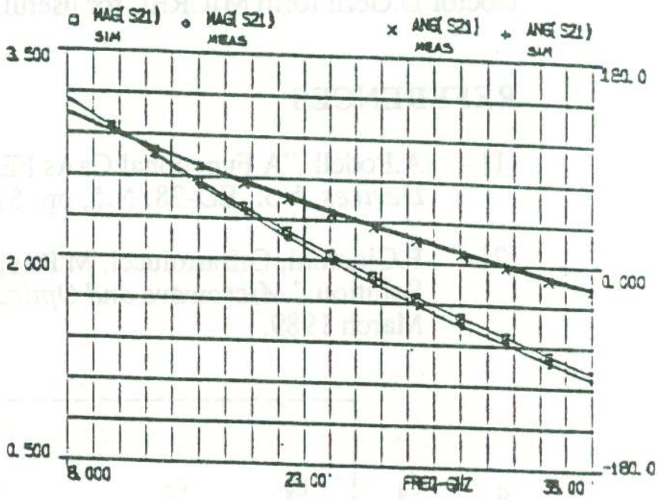


Fig.3 - Measured vs. simulated device $S_{21}$

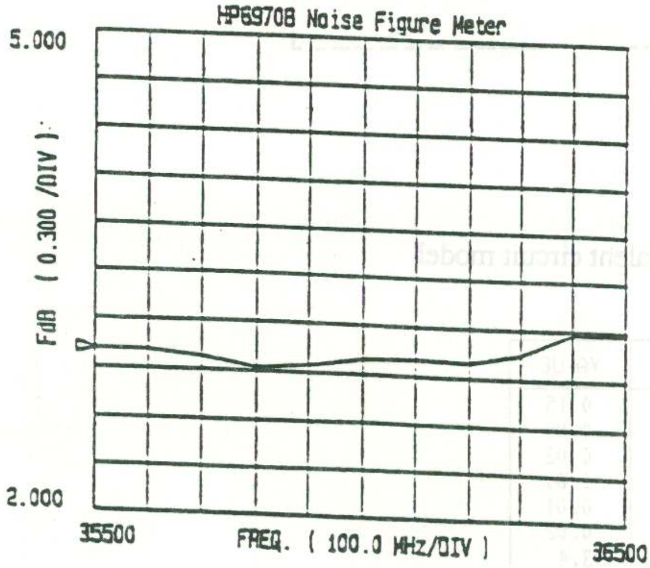


Fig.4 - Measured amplifier noise figure

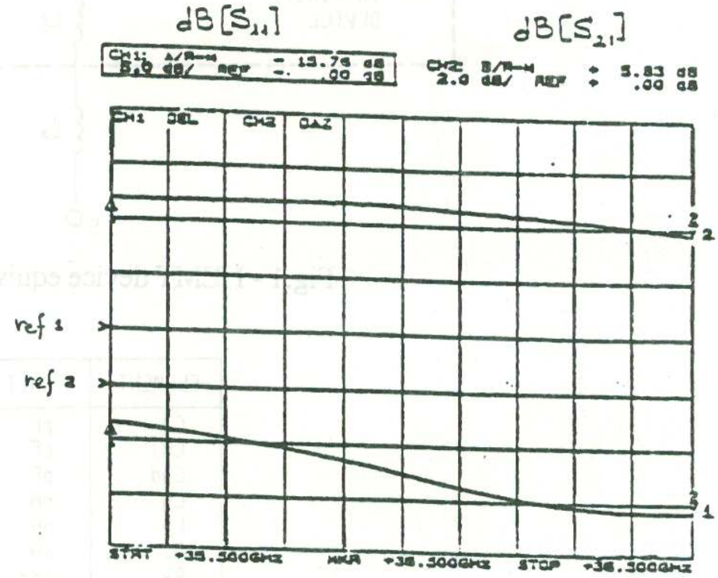


Fig.5 - Measured amplifier gain and input match