Q-Band Monolithic GaAs PHEMT Low Noise Amplifiers: Comparative Study of Depletion and Enhancement Mode Transistors

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Two Q-band monolithic low noise amplifiers have been designed and characterized. A study about depletion and enhancement mode HEMTs with the same technology has been performed in order to apply these results to the design of the low noise amplifiers. These circuits have been developed for being used in the Back End module of the radiometers in the European Scientific mission Planck, because there are not commercial circuits available in this frequency band. The main goals for these amplifiers are low noise with a small DC consumption. A minimum noise figure of 2.8 dB with an associated gain of 23.1 dB at 40.4 GHz has been measured for the E-HEMT MMIC LNA and its DC current consumption was 15.4 mA. The D-HEMT MMIC LNA has a minimum noise figure of 3 dB with an associated gain of 23.2 dB at 42 GHz and 30 mA of DC current consumption.

INTRODUCTION

Planck is a mission of the European Space Agency (ESA) Science Program (1), to perform astronomical investigations in the submillimeter and millimeter wave range. The mission will produce calibrated maps of the whole sky with high sensitivity. The Planck Low Frequency Instrument (LFI) receiver is a form of differential radiometer. It must have enough sensitivity to measure Cosmic Microwave Background anisotropies in the frequency range 30 – 100 GHz and it will be split into 4 channels centered at 30 GHz, 44 GHz, 70 GHz and 100 GHz with a 20 per cent bandwidth each one. The 44 GHz radiometer is based on a Front End Module (FEM) with InP HEMT amplifiers cooled at 20K and a Back End Module (BEM) with GaAs HEMT amplifiers at room temperature (300 K). MMIC low noise amplifiers have been developed due to lack of commercial products in this frequency band (39.6 GHz-48.4 GHz). The most critical requirements for these amplifiers are the power dissipation and the noise figure. Both of them should be as low as possible because this circuit will be shipped in a satellite and the instrument will be looking at background noise so its inherent noise must be very low.

D-HEMT AND E-HEMT CHARACTERISTICS

A study about enhancement and depletion transistors has been performed in order to establish the behaviour of both modes. The design and characterization of two low noise amplifiers have been used to verify the conclusions drawn from the study. The technology chosen has been OMMIC ED02AH process, which employs a 0.2 µm Pseudomorphic-High Electron Mobility Transistor (P-HEMT**).**

The enhancement mode is similar in geometry to the depletion mode, but in electrical operation it is normally off and it does not conduct with zero gate voltage. Transistor width has been chosen taking into account the minimum noise factor (Fmin) with a fair drain-source current (Ids). The output noise drain current increases as $\sqrt{W}$ and the signal current increases as W; big transistors improve the signal-to-noise ratio and it means low noise figure. On the other hand big unit gate width means big gate resistance and therefore the noise figure increases.

Figure 1 depicts the variation of the minimum noise figure (Nfmin) versus the total gate width (W) of a transistor with the same unit gate width but different number of fingers, showing that a larger number of fingers implies a decrease in the Nfmin. Transistors with a gate width of 6x15µm have been used for both designs as a low noise and low DC current fulfil.

They have similar minimum noise figures but the enhancement mode has a smaller drain source current, which makes it suitable for on board circuits.

Figure 2 shows a comparison between the minimum noise figure versus drain source current of both transistor modes. Solid line refers to depletion mode and dot line refers to enhancement mode, which has a minimum slightly lower and it occurs with small Ids current.

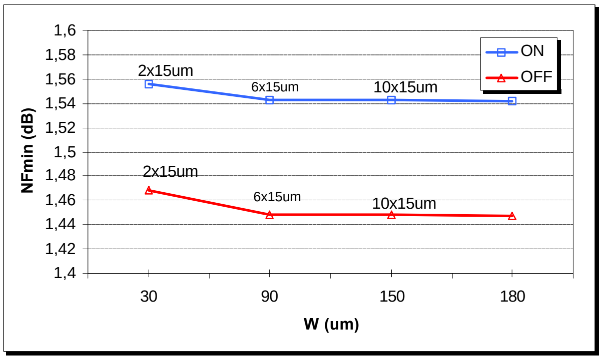

Figure 1. NFmin versus gate width (W) of a D-HEMT and E-HEMT @ 44 GHz

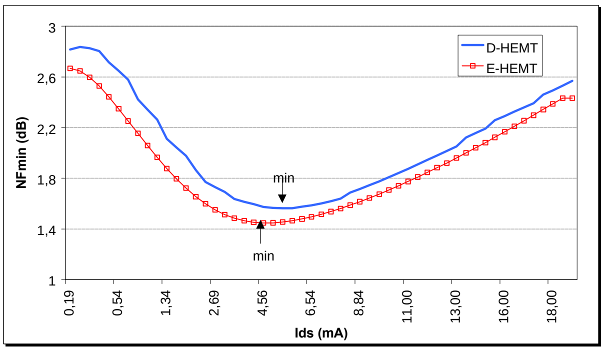

Figure 2. NFmin versus Ids of D-HEMT and E-HEMT 6x15mm @ 44 GHz

At low drain currents in order to provide low noise figures it is required high values of transconductance, since the increase in Nfmin at low drain currents is mainly determined by the Gm-Vgs relation. At very low drain-source currents gm and cut-off frequency both approach zero, yielding a sharp increase in Nfmin near the threshold, Soares (2). But this point of minimum noise figure does not correspond with the point of maximum transconductance but a slightly smaller, which means that minimum noise figure is achieved with a trade off between low drain-source current and gm-vgs relation.

Transconductance (gm) and the minimum noise figure (Nfmin) versus Vgs for the transistors under study are depicted in Figure 3 and Figure 4. For a similar NFmin the transconductance is a bit higher for the enhancement mode transistor; the same gain will be achievable with lower drain-current. Intermodulation performance for the E-prototype is expected to be worse than for the D-prototype, however the low noise amplifiers of the radiometer must be sensitive to work with weak signals.

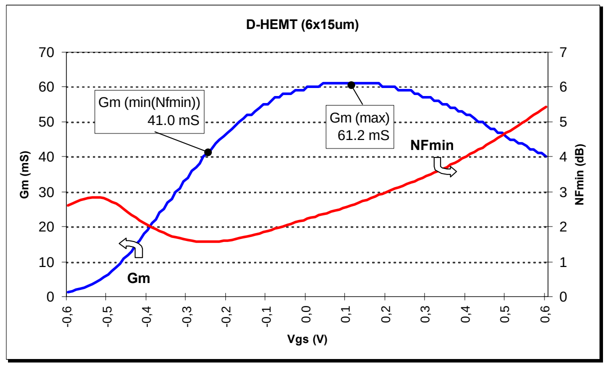

Figure 3. Gm and Nfmin versus Vgs of D-HEMT 6x15mm @ 44 GHz

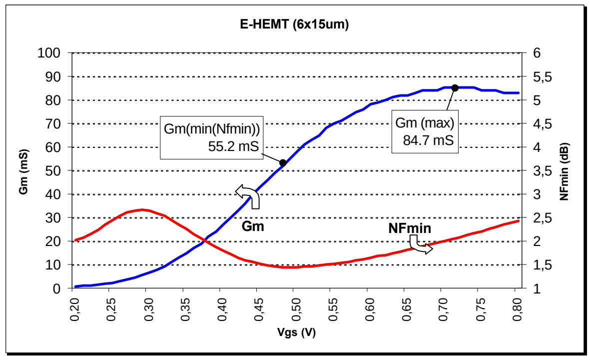

Figure 4. Gm and Nfmin versus Vgs of E-HEMT 6x15mm @ 44 GHz

LOW NOISE AMPLIFIERS DESIGN

The two amplifiers have been designed using the same design method; one of them with depletion mode transistors and the other with enhancement mode transistors. A schematic of the Q-band four-stage MMIC low noise amplifiers is shown in Figure 5. The two first stages use inductive source feedback to achieve a low noise performance, Engberg (3), with reasonable gain and return loss.

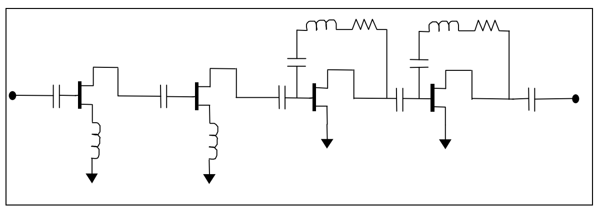

Figure 5. Schematic diagram of the Q-band four-stage low noise MMIC amplifier

Parallel feedback, Niclas (4) Niclas et al (5), has been used in the last two stages to obtain flat gain over the operating bandwidth. In the first stage the load impedance to achieve low noise figure and minimum reflection coefficient is the same by using source inductor, but this improvement is at the cost of a loss of gain. So at the second stage a source inductor has been included to obtain a bit higher gain with low noise. Source inductors with different values have been employed for each stage in order to get a low noise figure with low input return loss and a reasonable gain, since in this way the last stages have a little impact on the total noise figure as a multistage amplifier. Parallel feedback has the advantage of increasing the stability factor, improving input and output return losses and flattering gains over widebands.

Figure 6 and Figure 7 show a photograph of the low noise amplifiers. The chip size is 3 mm2 each one.

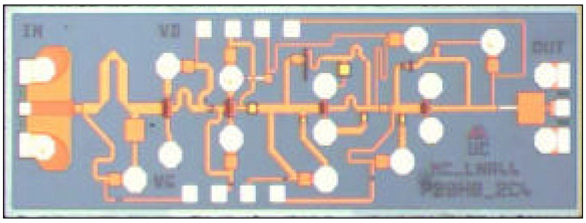

Figure 6. Photograph of the MMIC LNA with D-HEMT

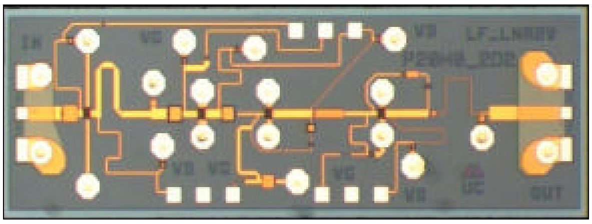

Figure 7. Photograph of the MMIC LNA with E-HEMT

LOW NOISE AMPLIFIERS PERFORMANCE

The chips have been measured on wafer and the noise figure and associated gain are depicted in Figure 8 and Figure 9 .

The minimum noise figure is 2.8 dB with an associated gain of 23.1 dB at 40.4 GHz for the E-HEMT MMIC LNA. In the case of the D-HEMT MMIC LNA the minimum noise figure is 3 dB with associated gain of 23.2 dB at 42 GHz. The total DC consumption for the D-protoype is 30 mA and 15.4 mA for the E-prototype, which agrees with the expected results.

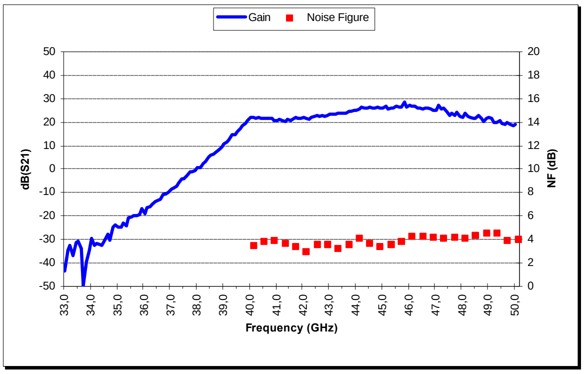

Figure 8. Gain and Noise Figure of the D-HEMT MMIC LNA

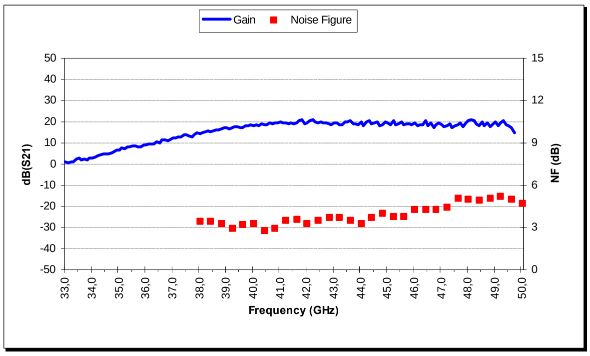

Figure 9. Gain and Noise Figure of the E-HEMT MMIC LNA

Figure 10 and Figure 11 show that measured and simulated noise figure of the low noise MMIC amplifiers agree quite well, which means that the noise model used is reasonably good. The solid line is the simulation and the dot line corresponds to the measurement.

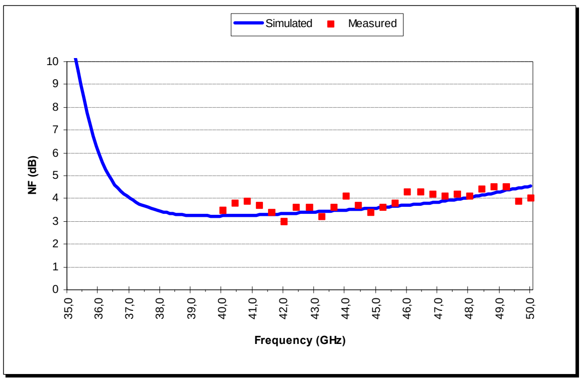

Figure 10. Comparison measurement and simulation of the Noise Figure D-HEMT MMIC LNA

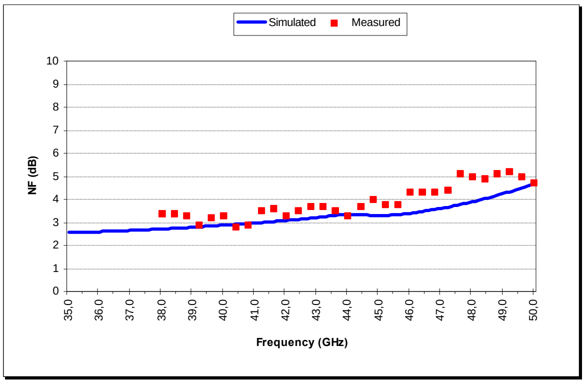

Figure 11. Comparison measurement and simulation of the Noise Figure E-HEMT MMIC LNA

CONCLUSIONS

A study about depletion and enhancement mode HEMT has been performed, whose results has been used in the design of two Q-band low noise MMIC amplifiers. Both of them have shown similar minimum noise figures and gains, but the E-HEMT with lower drain-source current. A small variation of the gate-source voltage is more critical for the noise figure of the enhancement mode transistors. The low noise amplifier with D-HEMT has a noise figure of 3 dB and a gain of 23.2 dB at 42 GHz. For the LNA with E-HEMT a noise figure of 2.8 dB with a gain of 23.2 dB at 40.4 GHz has been measured. Similar noise figures have been measured with a power saving close to the fifty per cent for the enhancement prototype.

ACKNOWLEDGEMENT

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REFERENCES

(1) ESA Astrophysics Home page of Science team of Planck: http://astro.estec.esa.nl/Planck/

(2) R. Soares, GaAs MESFET Circuit Design, Artech House 1988

(3) J. Engberg, Simultaneous input power match and noise optimization using feedback, in Proc. 4th European Microwave Conf. 1974, pp.385-389.

(4) K.B. Niclas, GaAs MESFET feedback amplifiers: design considerations and characteristics, Microwave Journal, pp. 39-48 & 85, Mar. 1980.

(5) K.B. Niclas, W. T. Wilser, R. B. Gold & W. R. Hitchens, The matched feedback amplifier: Ultrawide-band microwave amplification with GaAs MESFETs, IEEE Trans. Microwave Theory Tech, vol. MTT-28, pp.285-294, Apr. 1980.