NOISE CHARACTERISTICS OF RADIATION–HARD FETS FOR FRONT–END ELECTRONICS

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Abstract

The noise properties of radiation–hard FETs are investigated. The main noise sources in FETs are briefly reviewed, the measurement setup is described, and the input noise voltage density spectra of MESFETs and HEMTs are investigated in a frequency range from 50 Hz to 100 MHz.

[1]This work was supported by the German Bundesministerium für Forschung und Technologie under contract number 056AC11P

1. Introduction

The noise behaviour of the first amplification stage in front–end read out electronics is one of the main limiting factors in high energy particle detection systems. Because of their superior radiation hardness we investigate the DC and noise properties of MESFETs and HEMTs based on large bandgap III–V materials. First investigations on neutron irradiated transistors show good radiation hardness of the investigated FETs and will be reported in another paper. In comparison to silicon, which is less radiation hard, the large bandgap materials show a great amount of low frequency noise: i.e. the background 1/f–noise on which bulges are superimposed resulting from spontaneous generation–recombination with deep levels (g–r noise). At very high frequencies the white thermal noise will be dominant. Both the 1/f–noise and the g–r noise depend on the bias conditions, the size of the transistors, and the materials.

The background 1/f–noise results from energy losses due to scattering of carriers. It can be described as [1]

$$\frac{\overline{v_{1/f}^2}}{\Delta f} = \alpha_H \, q \, \mu_n \, v_s \, I_D U_{DS} \frac{1}{L_g^2 \, g_m^2} \frac{1}{f} \quad ,$$

where α_H is the Hooge parameter, L_g is the effective gate length, v_s is the saturation drift velocity and g_m the transconductance.

The origin of g–r noise in MESFETs are traps in the channel and in the depletion regions, while in the HEMTs such noise is due to traps in the depletion regions both above and below the channel and to interface states between two different layers. The equivalent input noise voltage power density spectrum can be expressed as [2]

$$\frac{\overline{v_{g-r}^2}}{\Delta f} = 4 \, k \, T \sum_{r=1}^{n} \frac{\rho_r \left(\frac{\tau_r}{\tau_0}\right)}{1 \; + \; (2\pi f)^2 \tau_r^2} \quad .$$

τ_0 is a reference level, τ_r is the inverse corner frequency of one particular g–r center and can be used to determine its trap activation energy and capture cross section. ρ_r is an effective resistance which is inversely proportional to the gate area and proportional to the trap concentration.

The channel thermal noise is given by

$$\frac{\overline{v_{th}^2}}{\Delta f} = 4\ k\,T\ \Theta\ \frac{1}{g_m}\ ,$$

where Θ is a factor of approximately 2/3 and depends on the gate length. In the frequency range below 100 MHz the thermal noise was not observed for the transistors under investigation.

Since the noise sources are mutually uncorrelated, the noise voltage power density spectra can be added to obtain the overall series noise of the FETs:

$$\frac{\overline{v_{ss}^2}}{\Delta f} = \frac{\overline{v_{1/f}^2}}{\Delta f} + \frac{\overline{v_{g-r}^2}}{\Delta f} + \frac{\overline{v_{th}^2}}{\Delta f}\ .$$

According to the Wiener–Lee–Theorem [3] the noise voltage power density spectrum at the output of a network (fig.1) satisfies

$$\frac{\overline{v_{gg}^2}}{\Delta f} = \frac{\overline{v_{ss}^2}}{\Delta f}\ |H(f)|^2\ ,$$

where H(f) is the transfer function of the network assumed to be Linear and Time Invariant (LTI).

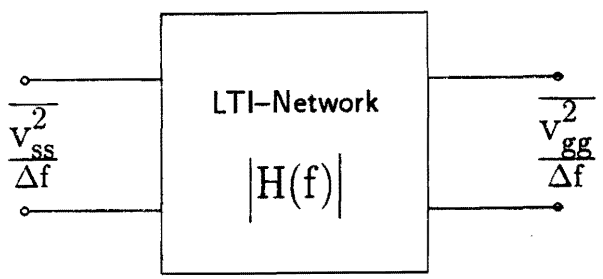

Figure 1: Wiener–Lee Theorem

We have measured the output noise $\overline{v_{gg}^2}/\Delta f$ with the setup shown in fig.2, employing a spectrum analyser HP 3589 after amplification with a self built low noise amplifier [2].

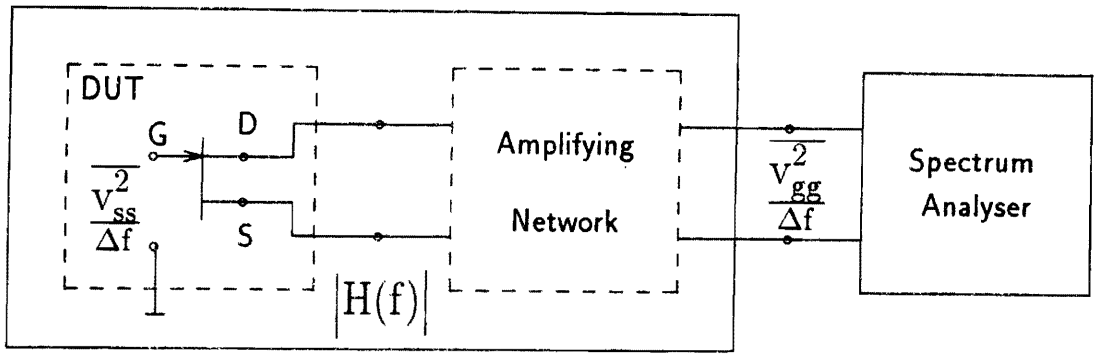

Figure 2: Measurement setup

To eliminate the small noise contribution of the preamplifier a difference measurement is performed with and without the device under test.

2. GaAs transistors under investigation

We investigated the DC parameters and noise properties of available transistors from the manufacturers Thomson, IAF[3] and Honeywell. The different geometrical sizes of the transistors were chosen deliberately to be able to study their influence on the noise behaviour.

Manufacturer	Type	Size $W_G \times L_G$ [$\mu m \times \mu m$]	I_D	g_m/g_{DS}	I_G[nA/mm]
Thomson	MESFET	100×0.5	100	9	90
IAF	HEMT	50×0.3	5	75	36
Honeywell	HEMT	10×1	5	80	550

Table 1: Manufacturer, type, size (W_G : gate – width, L_G : gate – length), drain current densities I_D, voltage amplification g_m/g_{DS} and gate current densities I_G of the transistors under investigation

[2]The device under test operates as a current source with an AC short-circuited gate during the noise measurement and a drain resistance of 1 kΩ.

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Ten samples were measured from each transistor type. The individual DC parameters of a particular transistor type vary within 30%, the noise parameters within 100 %. In the following figures data for typical transistors of each type are shown.

The Thomson MESFETs consist of an n-doped GaAs–channel, the IAF HEMTs of a symmetric AlGaAs–GaAs–AlGaAs channel with δ–doping and the Honeywell HEMTS of an unsymmetric AlGaAs–InGaAs–GaAs channel. The InGaAs layer represents the channel, none of the layers are doped.

3. DC Properties

Figs.3a–c show typical values of the transconductance g_m, the output conductance g_{DS} and the voltage amplification g_m/g_{DS} of the investigated transistors as a function of the drain current density I_D.

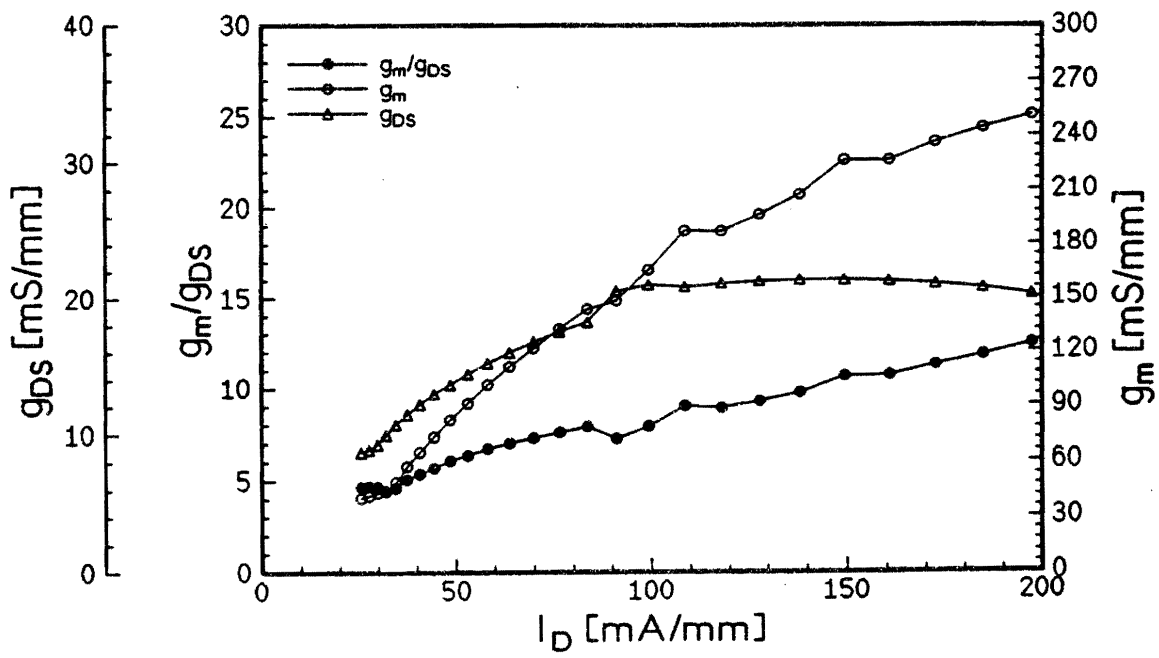

Figure 3a: Transconductance g_m, output conductance g_{DS} and voltage amplification g_m/g_{DS} of Thomson MESFET

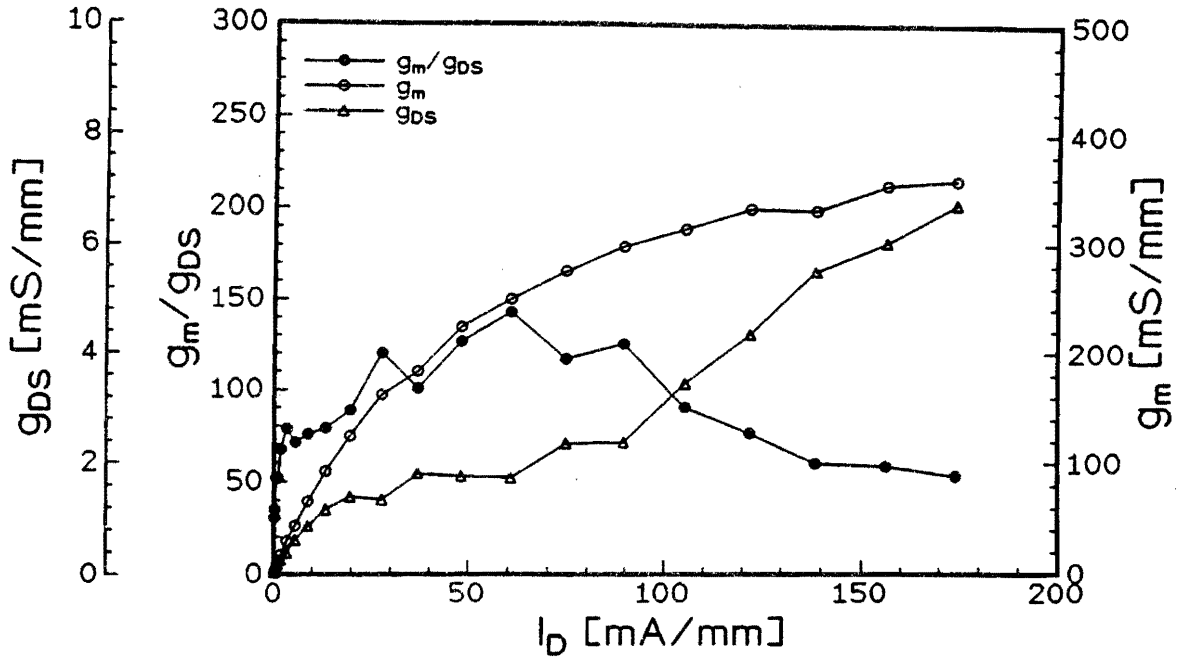

Figure 3b: Transconductance g_m, output conductance g_{DS} and voltage amplification g_m/g_{DS} of IAF HEMT

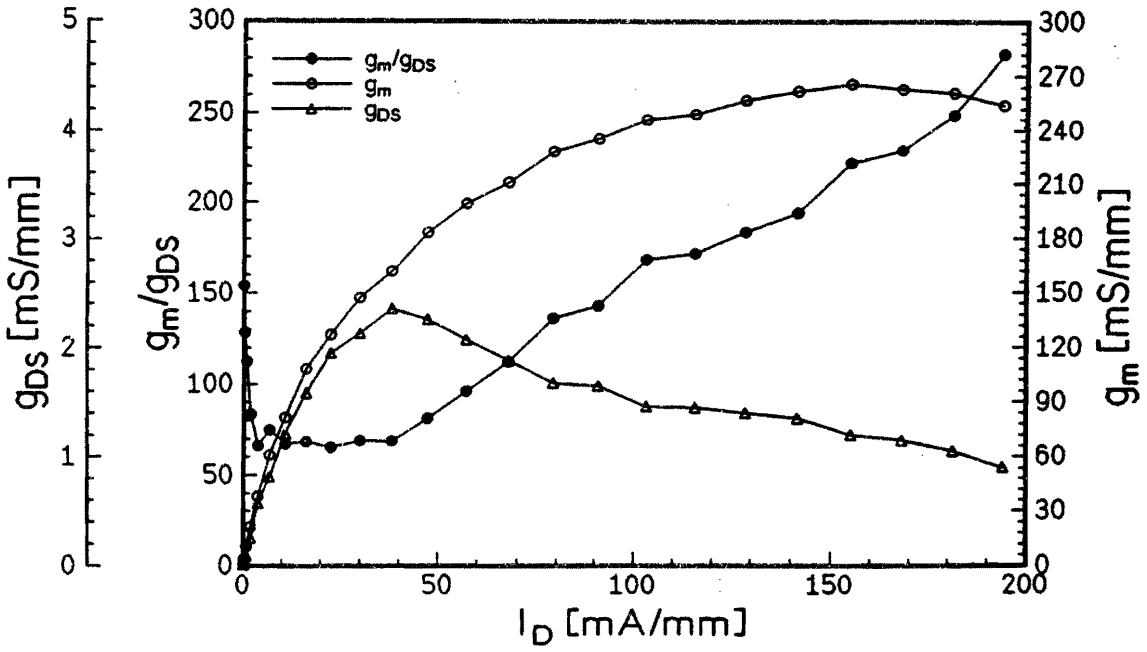

Figure 3c: Transconductance g_m, output conductance g_{DS} and voltage amplification g_m/g_{DS} of Honeywell HEMT

To compare the parameters g_m and g_{DS} independently of the gate–width, the diagrams are normalized to 1mm gate-width.

The HEMTs show approximately a factor of 10 higher voltage amplification g_m/g_{DS} than the MESFETs (table 1). This favours the choice of HEMT based preamplifiers for low power consumption devices.

The voltage amplification of the IAF transistors (fig.3b) shows a maximum at $I_D = 60mA/mm$. At very low drain current densities ($I_D \rightarrow 0$) the Honeywell transistors (fig.3c) show an increase in voltage amplification which is very favourable, since it corresponds to a low power consumption of the input transistor of a preamplifier.

The gate current densities I_G are also shown in table 1, measured at drain current densities of $I_D = 5mA/mm$ for the HEMTs and $I_D = 100mA/mm$ for the MESFETs, since the latter do not work properly at lower current densities. The gate currents of the Honeywell HEMTs are considerably high. This behaviour leads to a larger parallel noise, in particular for large gate area transistors. However the values of the gate currents can be optimized since they depend strongly on the bias conditions.

4. Noise Properties

With the previously described measurement setup we evaluated the equivalent input noise voltage density $\sqrt{\overline{v_{ss}^2}/\Delta f}$ of the transistors. Fig.4 shows a typical spectrum of an IAF–HEMT at a drain current density of $I_D = 100mA/mm$ and $U_{DS} = 2V$. The whole spectrum exhibits mainly a 1/f – noise behaviour in the whole frequency range from 50 Hz to 100 MHz.

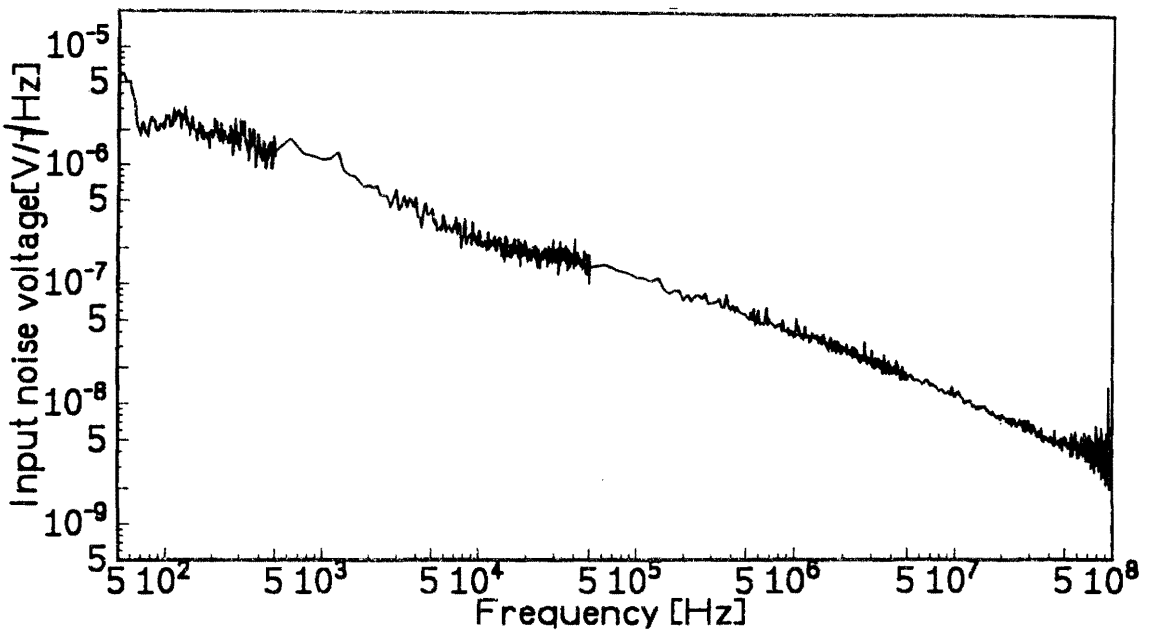

Figure 4: Input noise voltage spectrum of IAF–HEMT

Fig.5 shows a typical input noise voltage spectrum of a Honeywell HEMT measured at the same bias conditions (I_D = 100mA/mm, U_{DS} = 2V) . It also exhibits mainly a 1/f behaviour.

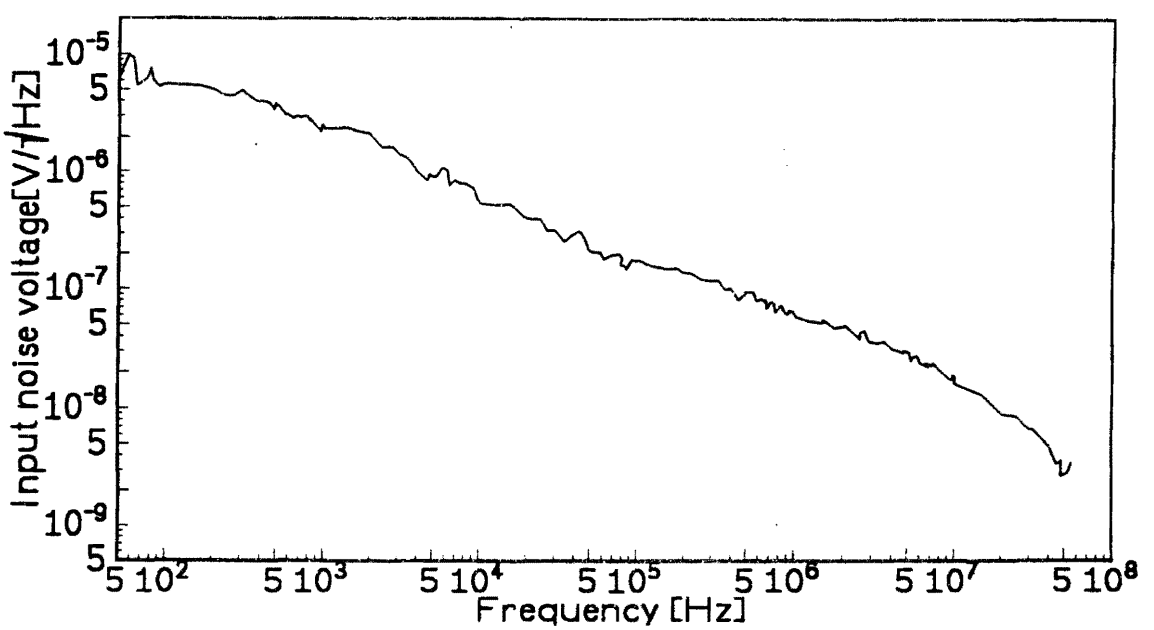

Figure 5: Input noise voltage spectrum of Honeywell–HEMT

The larger input noise voltage compared to the IAF HEMT can be explained by the smaller gate area (see fig.7).

A typical Thomson MESFET spectrum is shown in fig.6 (I_D = 100mA/mm, U_{DS} = 2V).

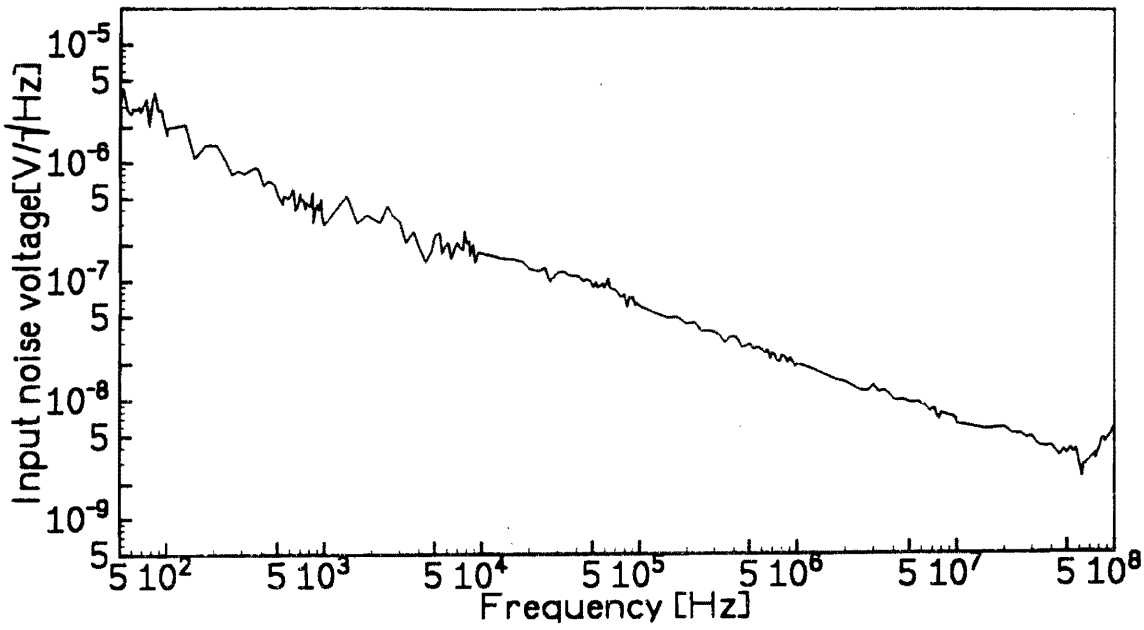

Figure 6: Input noise voltage spectrum of Thomson MESFET

As can be seen from figs.5 and 6 there is a slightly different behaviour between the Honeywell HEMTs and the Thomson MESFETs in the frequency range between 100 Hz and 10 kHz arising from the DX–complex in AlGaAs layers. Since our HEMTs are undoped we assume that material impurities within the AlGaAs–layer are responsible for the excess below 10 kHz.

Fig.7 shows the spectra of the three transistors (figs.4–6) normalized to the same gate area of 100 μm^2 [4]. There is no significant difference in the normalized input noise voltage density spectra between the transistors of the different manufacturers

[4]by multiplying the individual spectra with $\sqrt{F/100\mu m^2}$ where F is the gate area of the transistors

in the frequency range between 100 kHz and 10 MHz, which is the frequency range of our interest. The remaining difference in shape of the spectra is assumed to be due to different g–r noise bulges. The DX–excess of the Honewywell HEMT below 10 kHz compared to the other transistors can be seen clearly.

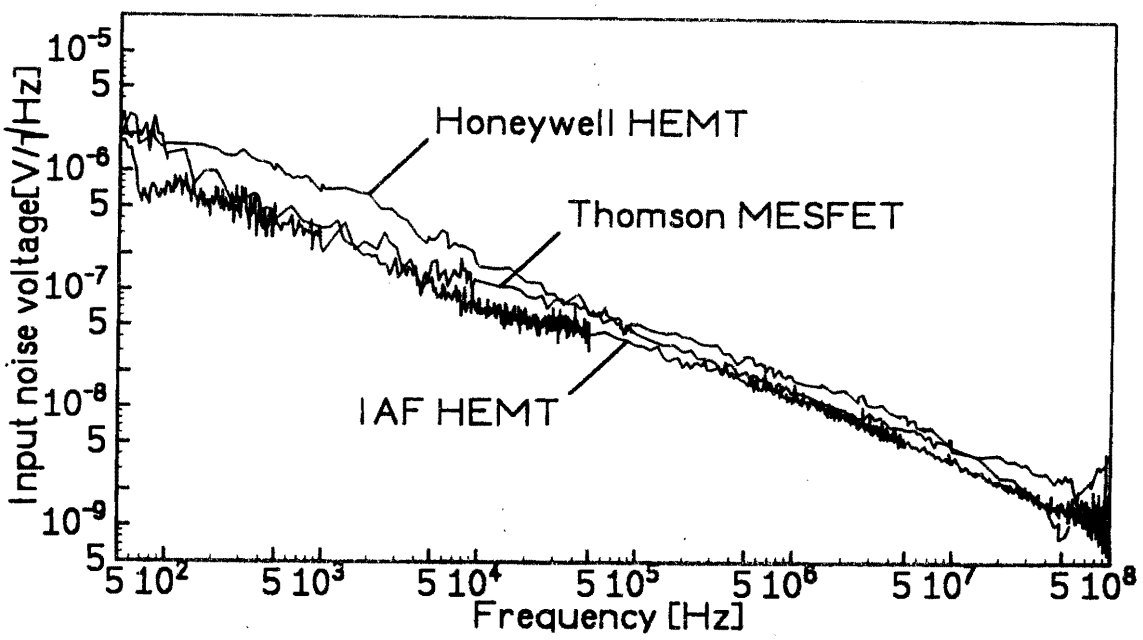

Figure 7: Input noise voltage spectra (normalized) of fig.5–7

In High Energy Physics applications, the energy deposited by a high energetic particle is converted to electric charge. Therefore the noise behaviour of the detector and the readout electronics is commonly expressed as Equivalent input Noise Charge, ENC.

To express the ENC in terms of the input noise voltage density spectra, a chain consisting of a preamplifier. including the input transistor under investigation, followed by a bipolar shaper was simulated with PSpice[5]. The measured noise voltage density spectra are then fed into the amplifier–shaper chain and the output noise

[5]PSpice circuit analysis, version 4.05, January 1991, MicroSim Corporation, California

voltage was obtained by integrating the resulting output spectrum. Dividing by the amplification β obtained by simulation as the response to a test charge, we obtain the ENC of the input transistor.

In fig.8 the simulated ENC values for ten different shaping times are compared with the measured values from a hardware chain [4] identical to the one used in the simulation for an IAF HEMT. A good agreement of the ENC values obtained by the two completely independent methods is found.

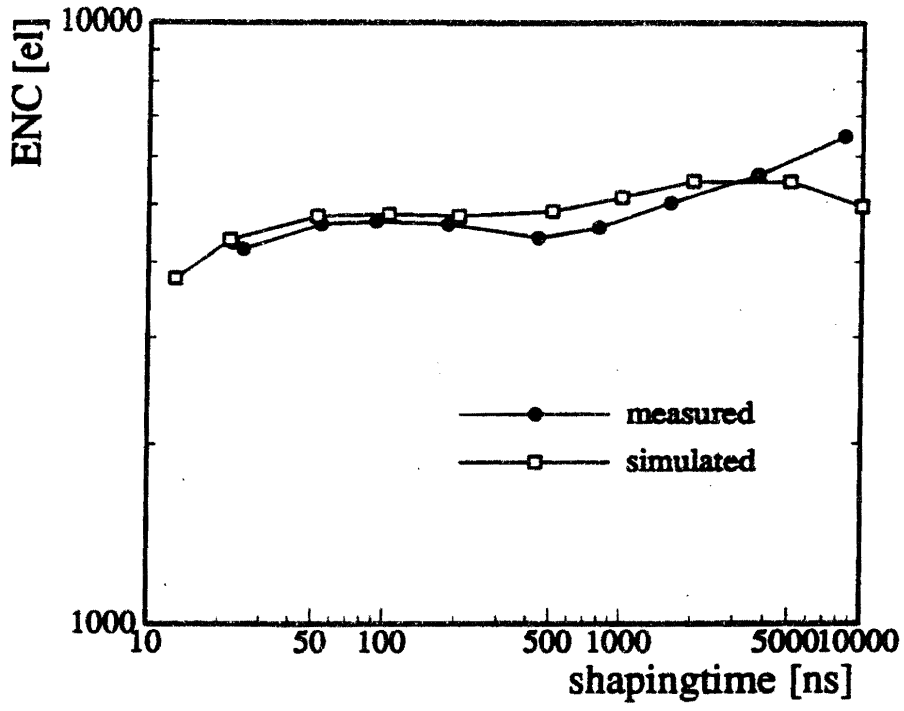

Figure 8: Comparison of simulation with ENC-measurement [4] for the IAF HEMT (I_D = 30mA/mm, not normalized, C_D = 10pF)

5. Conclusion

We investigated HEMTs and MESFETs from three different manufacturers. Noise- and DC parameters were measured. We did not find any significant differences in the noise parameters after normalization to the gate-area. The HEMTs show superior transconductance and voltage amplification. For this reason HEMTs are favoured in our opinion for building a high gain and low power consumption amplifier. First investigations on neutron irradiated transistors indicate good radiation hardness (publication in preparation).

6. Acknowledgements

We wish to thank Tilo Ehlen from the Institut für Technische Elektronik der RWTH Aachen for very useful discussions and for using their spectrum analyser in our first measurements. We also want to thank Antonio Mesquida Küsters and Volker Sommer from the Institut für Halbleitertechnik, Lehrstuhl I, der RWTH Aachen for supporting us with useful information and very helpful discussions. The DC measurements were performed with the help of their semiconductor parameter analyser HP4145A. Last but not least we want to thank Dr. D. Pandoulas for carefully reading the manuscript.

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