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Charge Sensitive Amplifier front-end with an nJFET and a forward biased *np* junction

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ABSTRACT - A new configuration of a resistorless charge sensitive preamplifier with an nJFET as an input device was tested. The DC level of the input of the amplifier was kept constant by a slightly forward biased *np* junction from the input of the amplifier to the ground. The noise level of 21.8 r.m.s. electrons was measured at 293 K and 14.3 r.m.s. electrons at 253 K. The dynamic behaviour of the amplifier was investigated with different leakage current conditions. The technological benefits and the suitability of the front-end connection for room temperature detectors, particularly multianode drift chambers, are highlited.

1. INTRODUCTION

Room temperature detectors processed on high purity silicon have been of great interest in recent years. particularly the idea of integrating the first amplifying stage into a close vicinity or on the same chip with the detector has been investigated [1]. The traditional resistive feedback has proven to be inferior in noise performance compared to pulsed reset feedback mechanisms, such as optoelectronic [2], transistor reset [3], drain feedback [4] or pentafet [5] configurations.

Recently Bertuccio *et. al.* have developed the Forward Biased FET Charge Amplifier (FBFA), where the DC-level of the gate of the front-end FET is kept at a constant voltage by forward biasing the gate-source junction of the input FET [6]. As the leakage current and the signal charge from the detector will accumulate on the input capacitance, the system will find an equilibrum, where the total current of the detector caused by both the signal and the leakage current equals the current through the forward biased junction. This configuration has proven to give a very good noise performance when used with silicon diodes close to room temperature. Measurement results and extensive noise calculations have been presented in references [7] and [8]. This type of a continuous reset mechanism of the preamplifier is particularly well suited for multielement detectors where the crosstalk between neighbouring channels due to the reset pulses can be a problem.

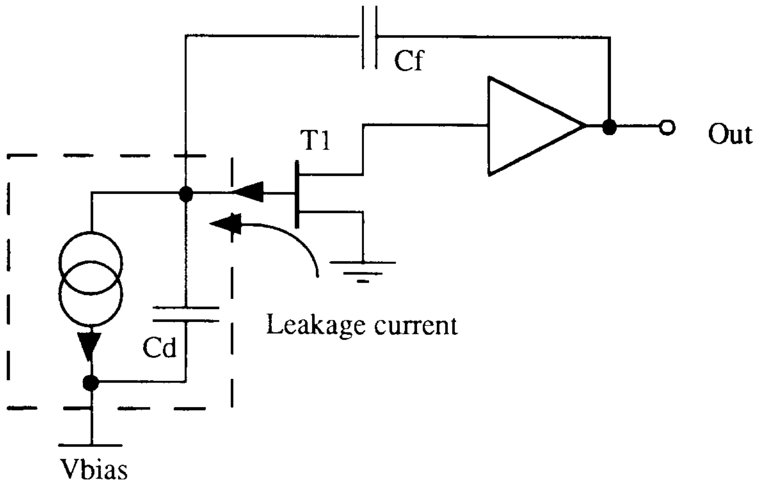
Silicon drift detectors and other large area detectors are usually produced on *n* type silicon In this case in order to make the gate-source junction forward biased, a pJEFT need to be used as the front-end FET. However the realization of an integrated p-channel FET can be technologically difficult. Although there are first reports of success [9], the nJFET technology has been existing already for some time [10]. Another benefit with an nJFET is that the transit time t_e of electrons through the FET channel is three times that of the holes and thus the noise is expected to be lower with a factor 3 compared to a pJFET of same dimensions. In this work we have used the principles of the FBFA amplifier with an nJFET by putting an additional *np* junction from the gate of the transistor to the ground. The price to pay is that the additional junction will increase the total input capacitance, but with an integrated technology this increase can be made very small.

In section II we present the principles of operating the modified FBFA amplifier with an nJFET and an extra *np* diode for continuous resetting. In section III we present experimental results and noise analysis of a device where the transistor and the *np*-diode are integrated on high purity silicon and connected to a small *pn*-diode detector on the same chip. The input current range of the device is also evaluated. In section IV we present conclusions.

II OPERATION PRINCIPLE

The operation principle of the front-end with a diode for continuous resetting compared to the FBFA front-end is presented in the figure 1. The essential difference is that the leakage current from the detector is let to flow through the additional *np* junction D1 at the gate of the JFET. This enables the use of an n-channel JFET as T1 instead of a p-channel device with an electron signal.

a) FBFA Amplifier



b) The amplifier with a diode for the continuous reset

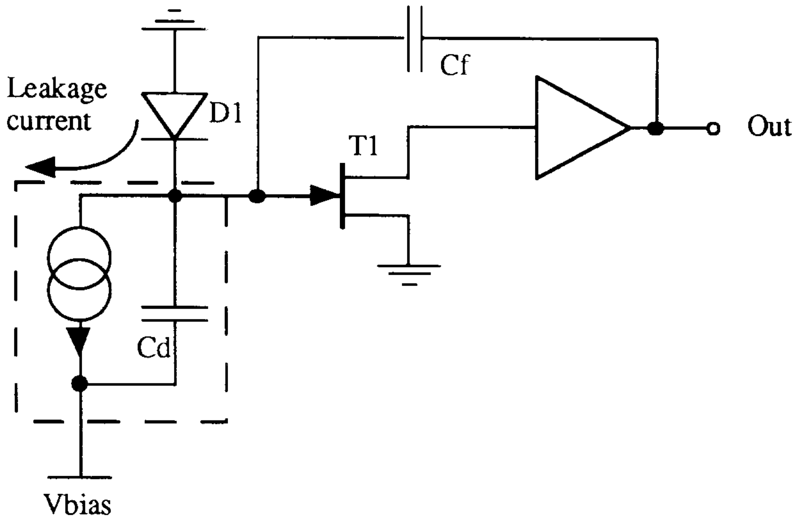


Fig. 1. a) The FBFA Amplifier front-end. The detector is represented by a current source and the capacitance C_d. b) The front-end, realized with a continuous reset diode connection.

The amplifier is realized basically using the FBFA connection of the reference [5] modifying the resistor values of the amplifier to correspond the characteristics of the nJFET transistor. The amplifier circuit is presented in the figure 2.

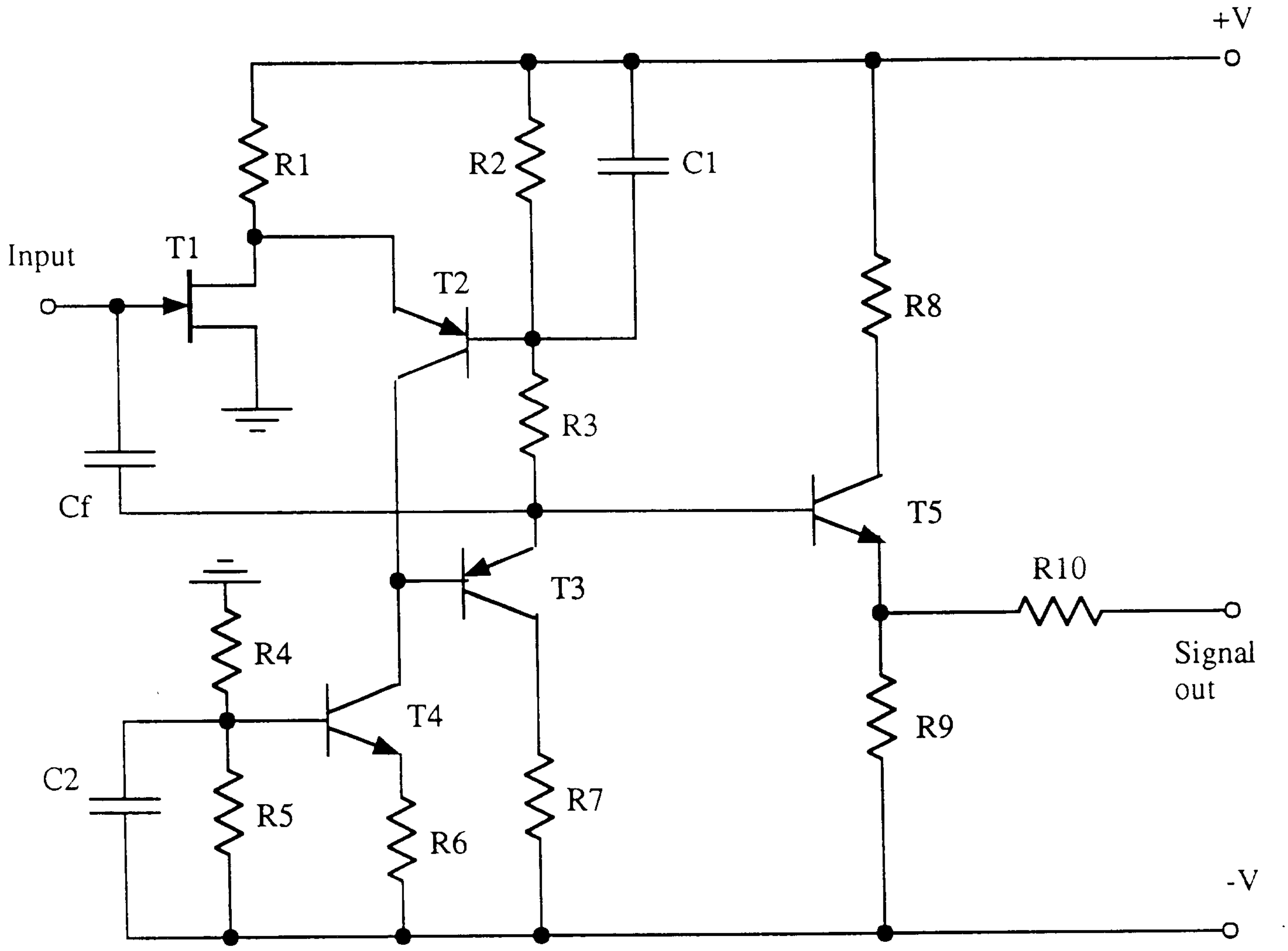


Fig. 2. The amplifier circuit for reading the FBFA amplifier with an *np* diode.

The ENC of the system can be calculated according to [11]

$$\mathrm{ENC} = \sqrt{A_1 \frac{\alpha 2kT}{g_m} C_T^2 \frac{1}{\tau} + A_2 (2\pi a_f C_T^2 + \frac{b_f}{2\pi}) + A_3 2qI_L\tau}\,, \qquad (1),$$

where the constants A_1, A_2 Aand A_3 are the weighting constants of the shaping filter for the noise components. g_m is the transconductance and α the transistor form constant of the JFET. C_T is the open loop total capacitance at the preamplifier input. It is the sum of the capacitances of the detector, JFET input, *np* diode, feedback and stray capacitance. a_f is the JFET 1/f noise coefficient and b_f is the noise coefficient of the dielectric noise. I_L is the value representing the detector leakage current and the current over the reset diode together. τ is the time constant of the shaping filter, T the absolute temperature and q the electron charge.

III MEASUREMENT RESULTS

The transistor characteristics of the integrated nJFET were measured and the value g_m = 0.54 mS. was found at room temperature. The resolution of the system was measured by calibrating the system with the ^{55}Fe radiation source, which gives two peaks at energies 5.89 and 6.45 keV creating charge signals of 1630 and 1780 electrons, and measuring the width of a pulser peak. A wire which was brought to a close vicinity of the small collecting anode was used as a feedback capacitor. The total capacitance value C_T was estimated to be 300 fF. The measured leakage current I over the diode D1 was measured to be 12.4 pA at room temperature, when the detector diode was biased. The Experimental values of the measurement are shown in the figure 3. By fitting a curve according to (1) it was possible to estimate the 1/f noise contribution to the ENC to be 1.18 10^{-11} V^2. The noise level at minimum is ENC_{opt} = 21.8 r.m.s. electrons at τ_{opt} = 0.52.

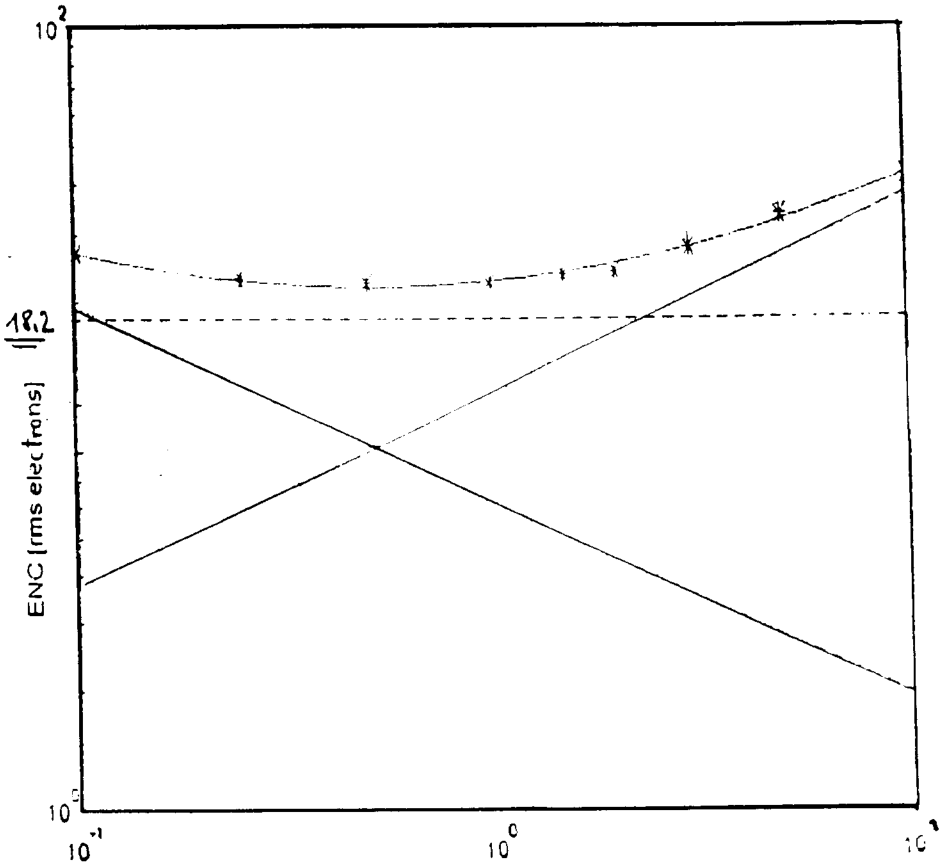


Fig. 3. The measured noise values as a function of shaping time at room temperature with the fitted curve and the noise components disentangled.

The noise measurement at -20 °C is presented in figure 4. The value of I_L is negligible and in the curve fitting it is assumed to be zero. The minimum noise is acquired at the maximum shaping time and it's value is converging to 14.3 r.m.s. electrons.

The fig. 4 shows that with long shaping times the noise is limited by 1/f noise, which remains constant as a function of τ. With short shaping times the series noise caused by the JFET becomes dominant. The ^{55}Fe spectrum at room temperature is shown in figure 5. and at - 20 °C in figure 6.

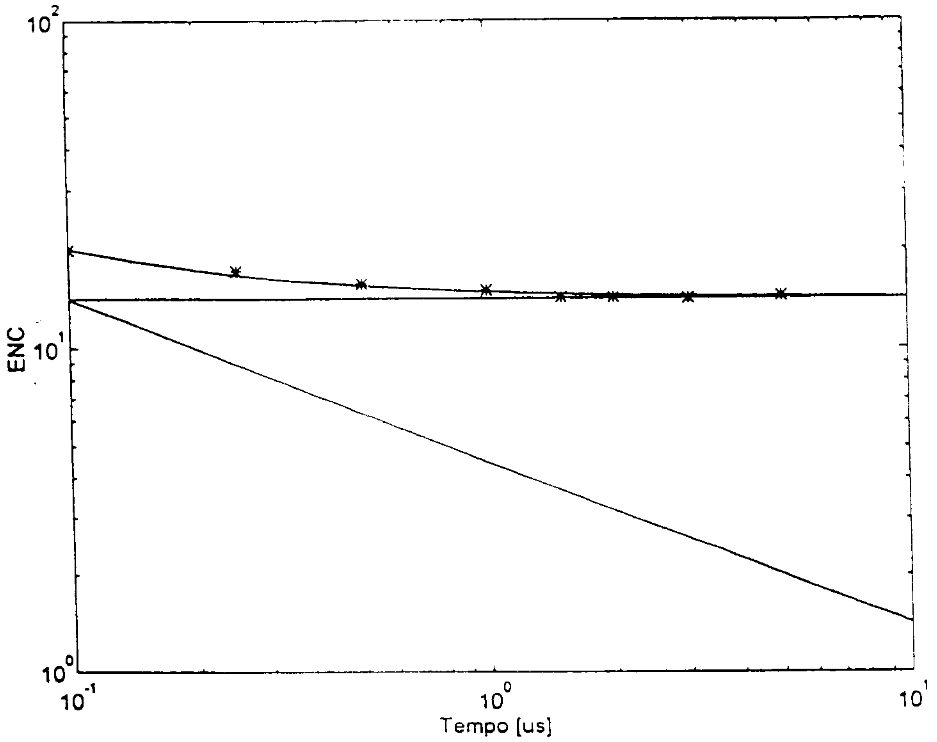


Fig. 4. The noise vs. shaping time measurement at -20 °C .

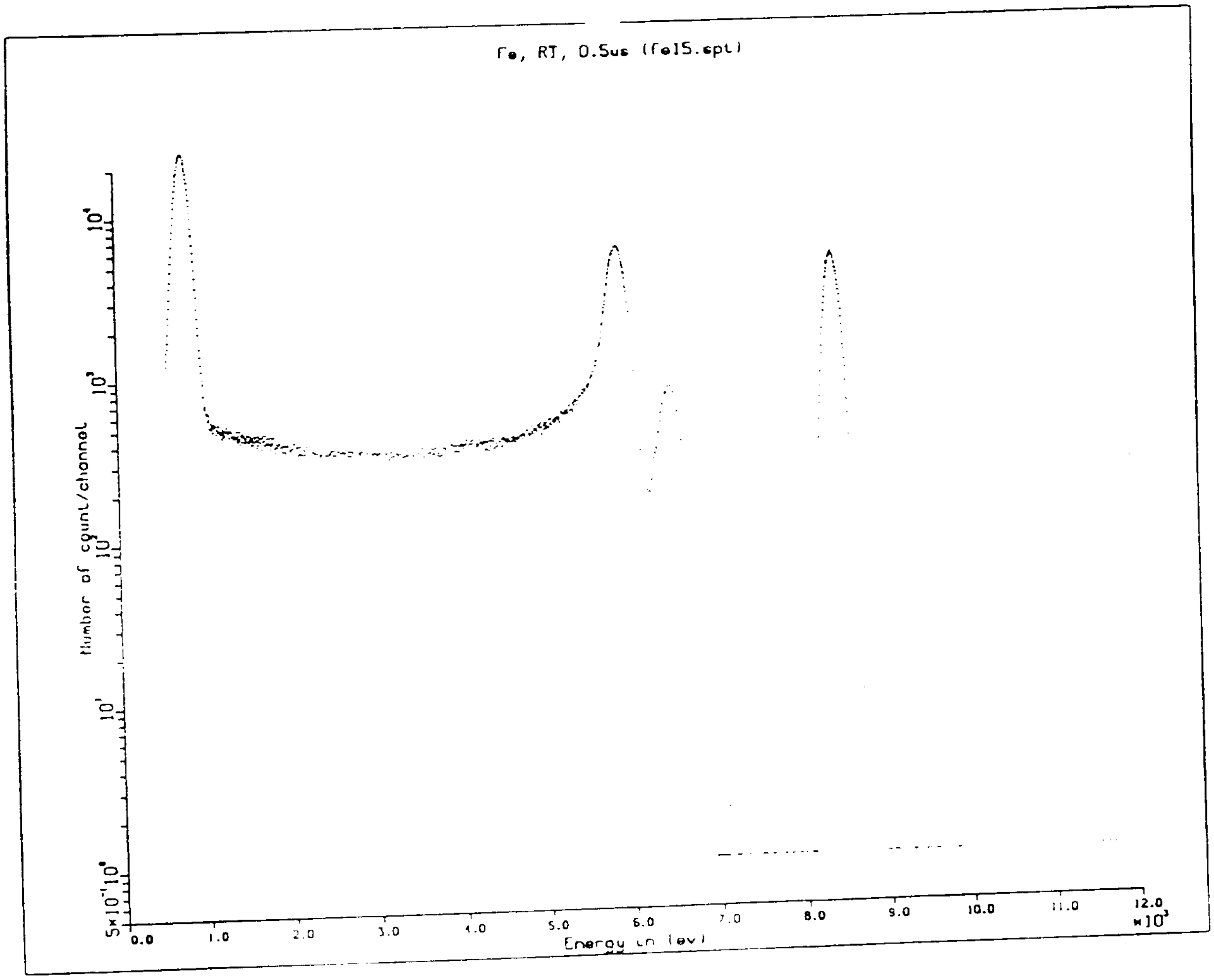


Fig. 5. ^{55}Fe spectrum at room temperature.

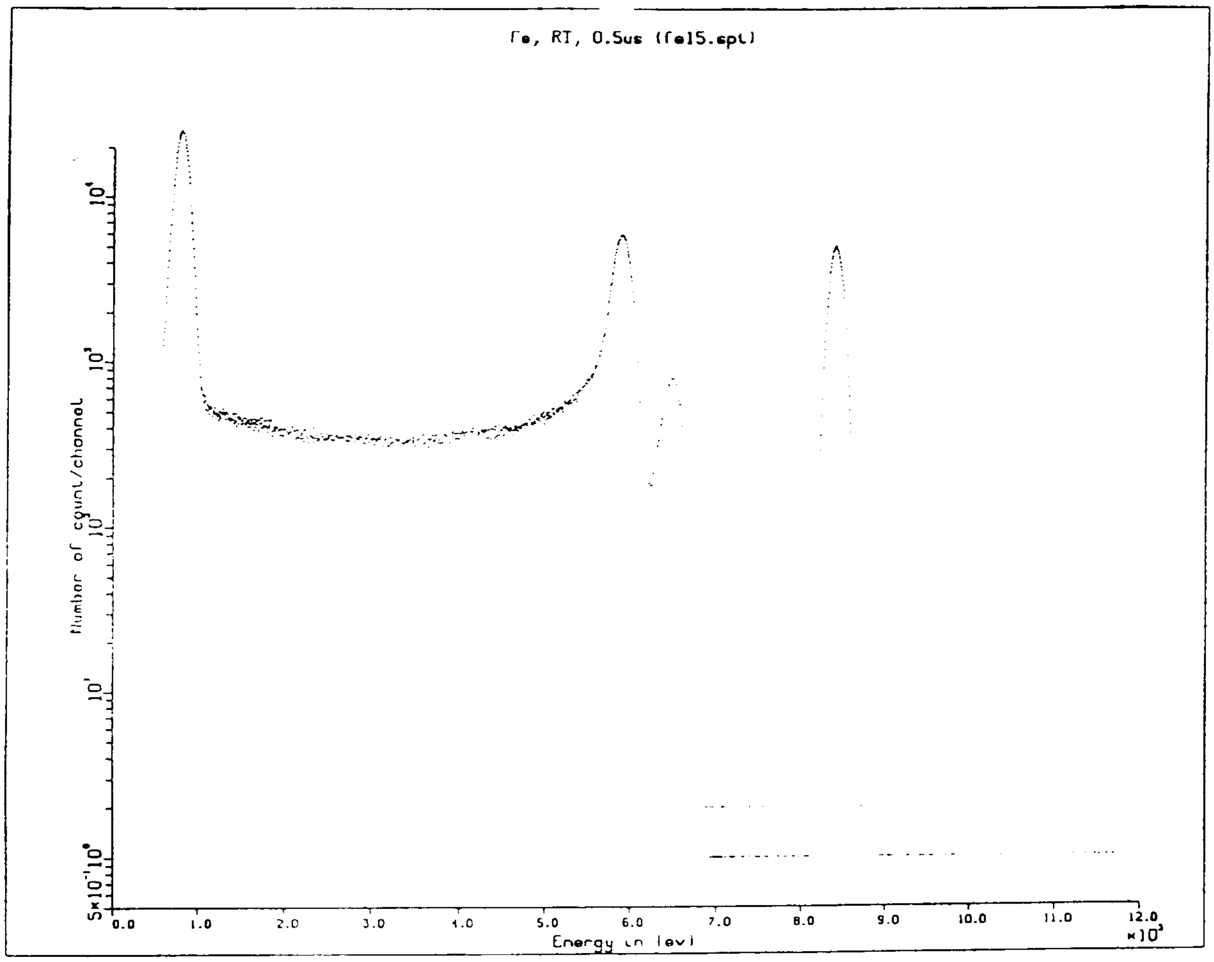


fig. 6. ^{55}Fe spectrum at -20 °C.

The system was tested also by illuminating the chip with light and that way increasing the leakage current. When the chip was shown light it could be seen that the width of the peak increased considerably. The leakage current with illumination was of the order of nA and the widening of the peak matches the corresponding increase of the parallel noise. However the position of the peak's centroid remained at the same place. This indicates that the amplifier is still stable and it can operate over very wide range of leakage current values.

IV CONCLUSIONS

The previously introduced Forward biased FET charge amplifier was modified to operate with an nJFET as the input device for a detector with electron signals. This was achieved by having an additional *np* diode from the amplifier input to the ground to have the continuous resetting. When using an integrated connection, where the detector, the diode and the FET are processed on the same chip, the capacitance of the diode does not increase the total capacitance significantly and the noise level as good as 14 r.m.s. electrons at 253 K was achieved.

The amplifier has been found to be stable and linear over a large dynamic range of different leakage current conditions. This implies that the amplifier can tolerate very high count rates and that it's amplification does not change as result of leakage current changes, which can be caused for example by temperature variations

The amplifier is particularly useful with large area multianode detectors, like silicon drift chambers or CCDs, because it enables the use of an nJFET as the front end transistor when reading the electron signal. A similar type of a front-end connection has also been implemented recently with a cylindrical drift chamber [12].

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