Title

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Emanuel Elad and Michiyuki Nakamura

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The excellent energy resolution of semiconductor radiation detectors is experimentally limited by the resolving power of the amplifying system and by statistical fluctuations. The noise contribution of the amplifying system is constant in the energy dynamic range, whereas the contribution of the statistics of electron-hole formation is proportional to the square root of the energy,

$$W = \{W_{amp}^2 + [2.36(FE\epsilon)^{1/2}]^2\}^{1/2},$$

where

W = resolution expressed in FWHM

W_{amp} = amplifier resolution

F = Fano factor

E = energy in eV

ϵ = average energy required to produce one electron-hole pair.

Therefore, at low energies the resolution is limited by the noise of the amplifying system, mainly noise of the detector and the input stage of the preamplifier.

The inherent low noise of the field-effect transistor (FET) made this device superior, when used as the active element of the input stage[1,2] to any low-noise tubes used previously[3]. We describe here an improved version of an FET amplifying stage[4] used as an input stage of a low-noise preamplifier for semiconductor radiation detectors. The elimination of several noise sources has made possible a spectrometer resolution of 0.7 keV, compared with the 1.1 keV resolution achieved with the basic circuit[4]. The schematic of the basic circuit is given in fig. 1.

The noise of a common-source amplifying stage is described by the following formula[5]

$$\bar{i}_{kT}^{2} = 4\,kT \cdot \Delta F[G_S + G_1 + \frac{c}{g_m}(G_S + G_1)^2],$$

where

$R_S = \frac{1}{G_S}$ = source resistance

$R_1 = \frac{1}{G_1}$ = gate resistance

C = a constant

ΔF = bandwidth.

As the noise is a hyperbolic function of the gate resistance, it is advantageous to use high-value resistances for this purpose. However, on analyzing the DC conditions of the stage we find that the bias of the FET is equal to

$$V_{G_S} = (I_g - I_D)R_1,$$

where

I_g = leakage current of the FET

I_D = leakage current of the detector.

Usually $I_D > I_g$, and the bias is negative. The bias increases with R_1 causing a decrease in g_m of the transistor, but also a decrease in its input capacitance. Having these opposing effects, we measured the noise of the stage to establish the optimum R_1. We used a low-leakage detector (I_g = 0.5 nA) and a 2N3823 FET to do this. The results of the measurement (with Hewlett-Packard's rms voltmeter model 3400A) are given in fig. 2. The results obtained from several detector-FET combinations show that very high resistances should be used where low noise is required.

For low-energy radiation measurements we were interested in the lowest noise possible, and therefore we used the circuit shown in fig. 3. The detector was a low-leakage (0.5 nA) low-capacitance (2 pF) lithium-drifted silicon crystal (5-mm diam, 3-mm thick). It was insulated from ground by means of ceramic rods, an arrangement which was described previously[6]. Tne bias voltage used was 250 V. The operating point of the FET stage is defined by the resistance of the detector; for various detector-FET combinations, the FET bias ranged from 0.2 to 0.8 V. The detector and the FET were kept close to liquid nitrogen temperature, ensuring stable operation of the amplifying stage. Although the circuit was voltage sensitive, no long-term (3 months) instabilities were observed. The removal of gate resistor and feedback capacitor eliminated two soldering points on the input lead which create fairly high thermoelectric electromotive forces.

The low-energy spectra measured were the x rays of ^{57}Co and ^{241}Am. Figure 4 shows the x rays of ^{57}Co measured with a resolution of 0.7-keV FWHM. This spectrum shows also the noise limit of the system as being approximately 2 keV. The ^{241}Am spectrum (fig. 5), which exhibits clearly the L_α, L_β, and L_γ x rays, also indicates intergroup separation (L_{β_2} = 16.95 keV - L_{β_1} = 17.76 keV, and L_{γ_1} = 20.80 keV - L_{γ_6} = 21.48 keV) for lines only 0.8 keV apart.

The described system is particularly suited for an integrated circuit arrangement that may improve further the resolution of nuclear spectroscopy.

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Footnote and References

[*] This work was done under the auspices of the U. S. Atomic Energy Commission.

1) T. V. Blalock, IEEE Trans. Nucl. Sci. NS-11 [3], 365 (1964).

2) T. W. Nybakken and V. Vali, Nucl. Instr. and Meth. 32, 121 (1965).

3) J. L. Blankenship, IEEE Trans. Nucl. Sci. NS-11 [3], 373 (1964).

4) Emanuel Elad, Nucl. Instr. and Meth. 37, 327 (1965).

5) D. O. Pederson, Electronic Circuits, (McGraw-Hill, New York, 1965), p. 250.

6) E. Elad and M. Nakamura, High-Resolution X-Ray and Electron Spectrometer, Nucl. Instr. and Meth. (to be published) (Lawrence Radiation Laboratory Report UCRL-16515, Dec. 1965).

Figure Captions

Fig. 1. Basic circuit of the FET input stage.

Fig. 2. Preamplifier noise versus gate resistance of the FET.

Fig. 3. Improved circuit of the FET input stage.

Fig. 4. X-ray spectrum of ^{57}Co.

Fig. 5. X-ray spectrum of ^{241}Am.

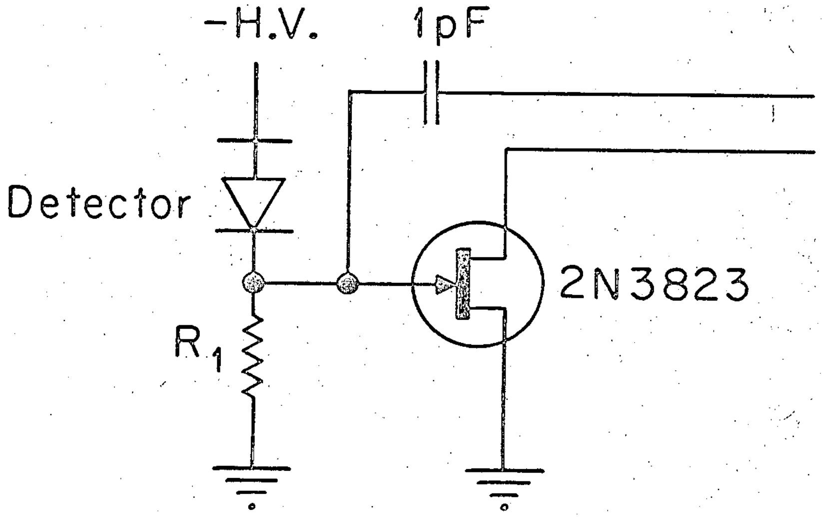

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Fig. 1

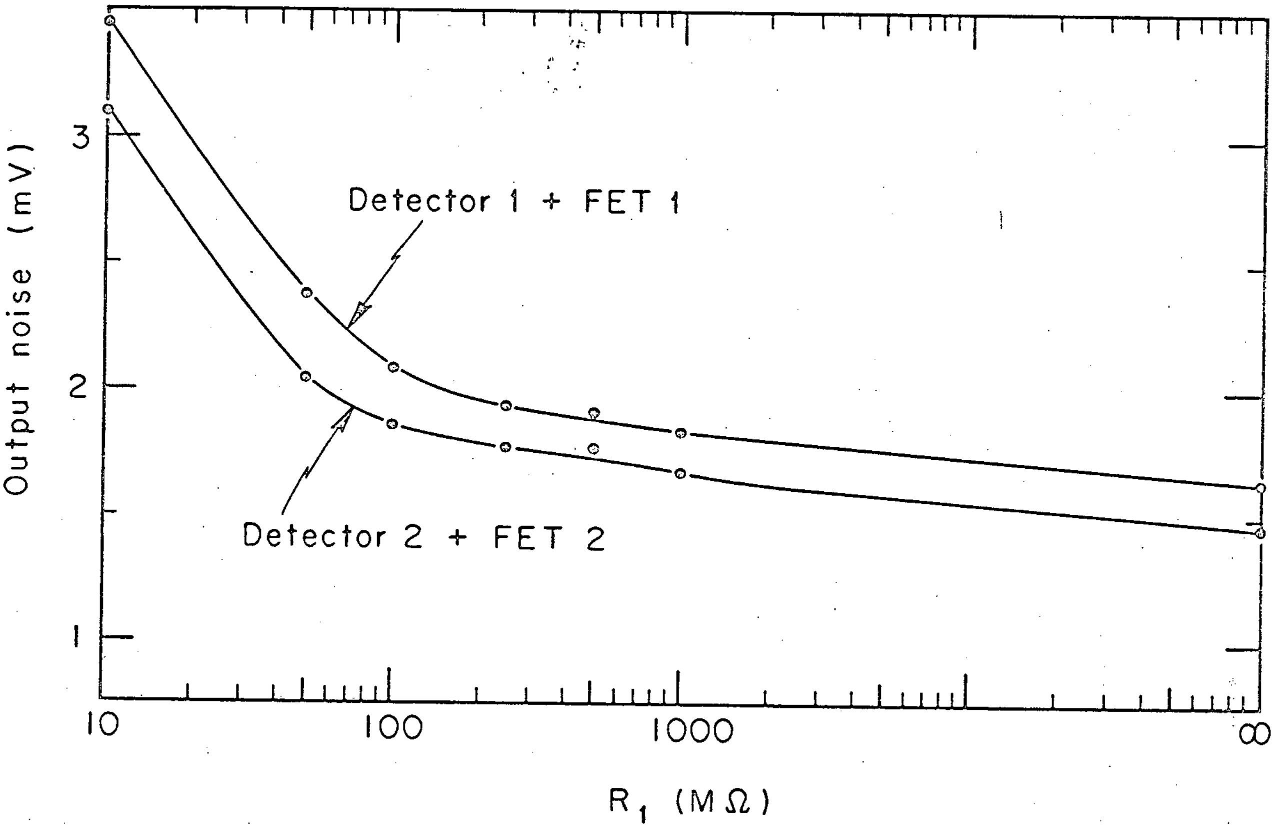

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Fig. 2

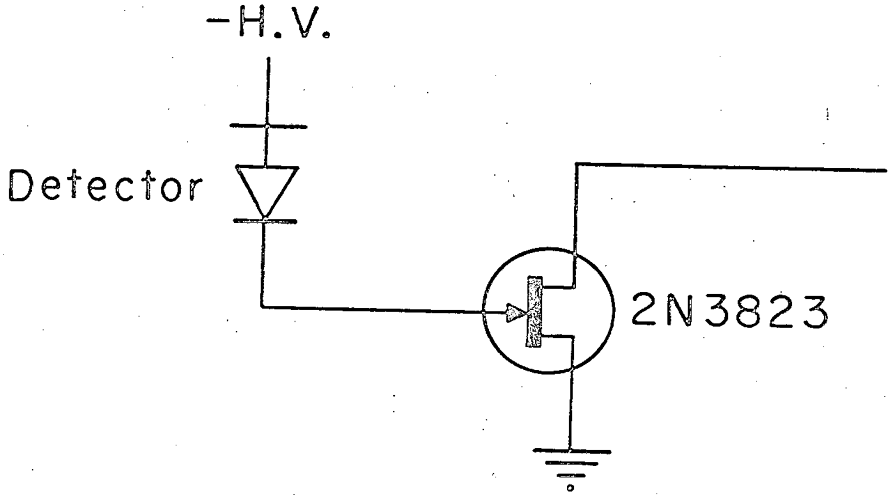

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Fig. 3

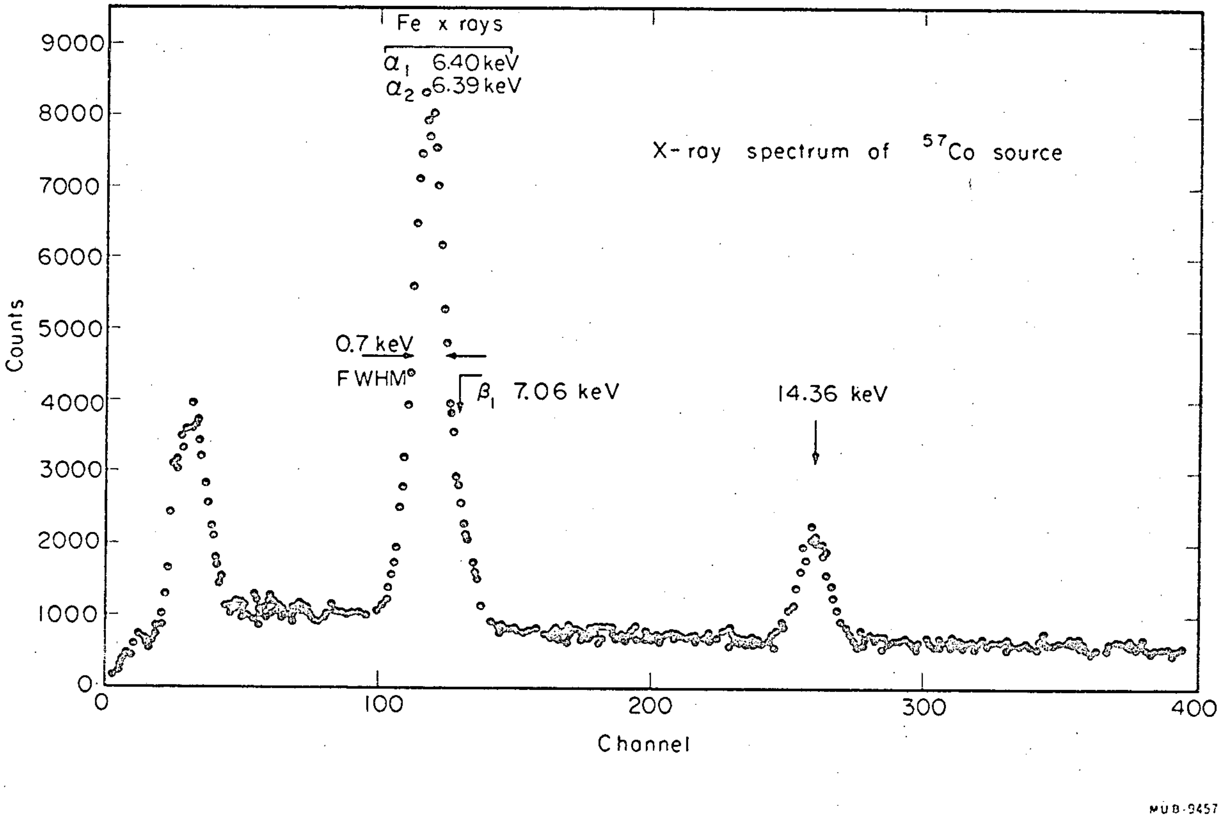
Fe x rays
α_1 6.40 keV
α_2 6.39 keV
X-ray spectrum of ^{57}Co source
0.7 keV
FWHM
β_1 7.06 keV
14.36 keV
Counts
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Channel
0
100
200
300
400
MUB-9457

Fig. 4

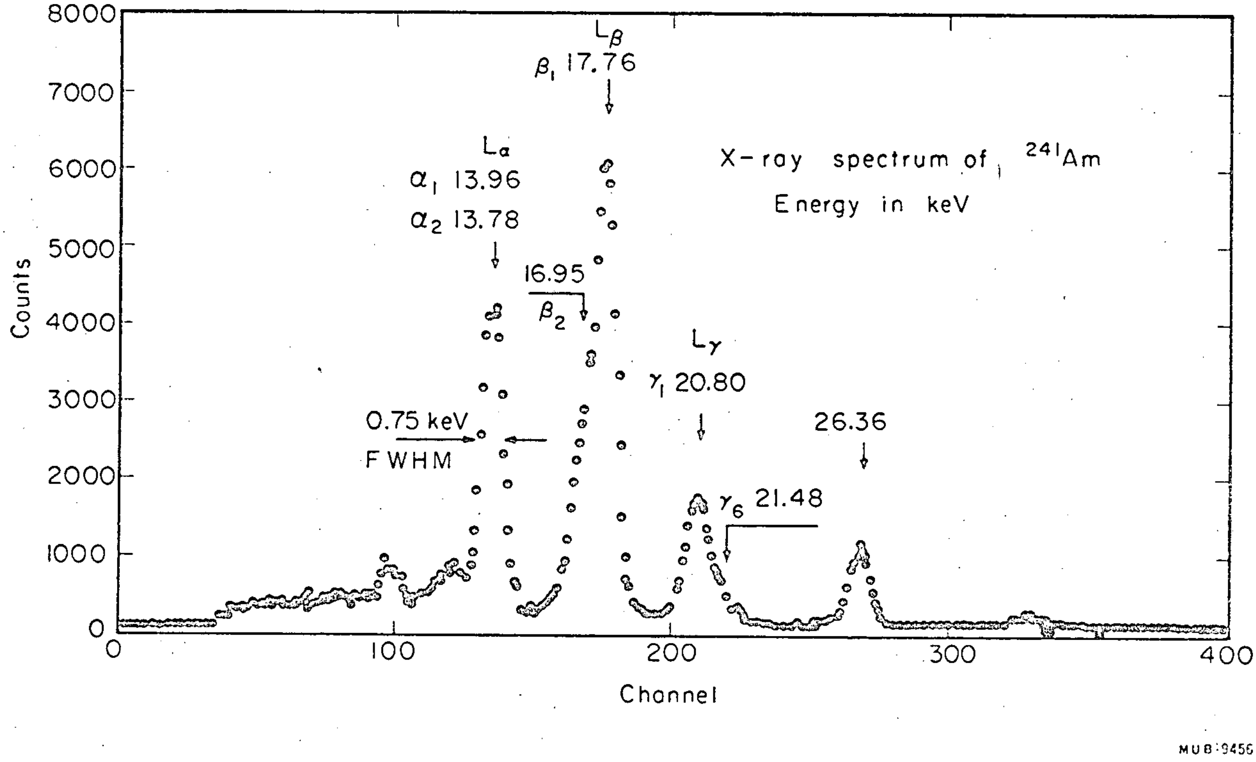
8000
7000
6000
5000
4000
3000
2000
1000
0
Counts
0
100
200
300
400
Channel
L_β
β_1 17.76
L_α
α_1 13.96
α_2 13.78
16.95
β_2
X-ray spectrum of ^{241}Am
Energy in keV
L_γ
γ_1 20.80
26.36
0.75 keV
FWHM
γ_6 21.48
MUB-9456

Fig. 5