Title

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Publication Date

1970-06-01

Submitted to Nuclear Instruments and Methods

UCRL-19796
Preprint

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June 1970

AEC Contract No. W-7405-eng-48

UCRL-19796

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PERFORMANCE OF A PULSED-LIGHT FEEDBACK PREAMPLIFIER FOR SEMICONDUCTOR DETECTOR X-RAY SPECTROMETERS

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ABSTRACT

Experimental results are reported for the energy resolution and counting-rate performance of an X-ray spectrometer using pulsed-light feedback to restore the input of a charge-sensitive preamplifier when required.

INTRODUCTION

A conventional high-resolution charge-sensitive preamplifier used for γ- and X-ray spectroscopy employs a dc detector connection to the input FET gate, and a high-valued feedback resistor shunting the integrating feedback capacitor. The resistor provides dc feedback to maintain the stage within its correct operating range, and discharges the feedback capacitor.

Goulding *et al.*1,2) have described a feedback method using a light-emitting diode connected to the output of the stage, with the light directed onto the FET, where the drain-gate junction behaves as a photodiode. This scheme offers the advantages of minimizing the extraneous input capacity on the gate of the FET, and eliminating the feedback resistor--a source of noise and other problems. Using an optoelectronic dc feedback preamplifier of this type, we have demonstrated an electronic energy resolution, with Si detector connected, near 100 eV. The counting-rate behavior of these systems has been poorer than desired for many purposes but the excellent energy resolution has led to them replacing resistor-feedback systems for many applications. We recognize that the major cause of the poor counting-rate behavior of optoelectronic feedback systems is the non-linear characteristics of light-emitting diodes. Since the operating point of the LED changes as a function of counting-rate, the effective time-constant of the feedback circuit fluctuates, and correct pole-zero cancellation for this variable time-constant cannot be achieved. Additional sources of resolution degradation at high-counting rates are noise in the rate-dependent dc feedback current (i.e. in the drain-gate diode of the FET), and base-line fluctuations not completely suppressed by the dc restorer preceeding the pulse-height analyzer.

Kandiah3) described a pulsed-light feedback system where a LED and photodiode were used to discharge the integrating capacitor when the output level of the charge-sensitive stage exceeded a predetermined level. This scheme has the advantage that no voltage droop occurs across the feedback capacitor between radiation-induced pulses--the capacitor discharge is compressed into a short discharge period, during which the amplifier and analysis system can be made inoperative. Radeka4) has reported the use of a pulsed feedback system where the reset waveform feeds through the detector forward biasing the FET gate to source diode, which acts as a diode pump.

We have now combined the advantages of Kandiah's pulsed system and the optoelectronic dc feedback system by using the drain-gate junction as a photodiode with pulsed-light feedback to it5). Figure 1 is a block diagram of the system.

The preamplifier front-end is the same as that of a conventional optoelectronic unit, except that the light coupling between the LED and FET is increased to facilitate rapid discharge of the feedback capacitor, The preamplifier contains a Schmitt trigger circuit used to sense the two limits of the voltage swing at the output of the charge-sensitive stage, and to control the LED accordingly. The design, used for the tests described here, permits a two volt swing across the 0.15 pF feedback capacitor, with a capacitor discharge-time of about 5 μsec. When operating with detector leakage current only flowing in the input circuit, the LED pulsing period is many seconds.

The reverse polarity transient, that occurs due to the rapid discharge of the feedback capacitor, would cause severe overload and recovery problems in a completely conventional amplifier and pulse-processing system. To remove this problem, the firing of the Schmitt trigger in the preamplifier triggers a one-shot producing an inhibit waveform starting just before the capacitor discharge pulse and continuing well past its end. This inhibit waveform controls a clamp across the amplifier differentiator, and also inhibits action of the dc restorer at the input to the analysis system, thereby preventing dc restoration on the spurious transients occuring at this time.

A lithium-drifted silicon detector 0.5 cm in diameter of 3 mm thickness with capacity of 1 pF, exhibiting leakage current between 10^{-14} and 10^{-13}A was used for our tests. The input element was a 2N4416 FET whose temperature was adjusted for optimum performance (~ -130°C).

RESULTS

a) Energy Resolution at Low Counting Rates and Low Energies

Figure 2 presents a spectrum obtained at low counting rates with X-rays from magnesium, aluminum and silicon, together with a pulser to indicate the electronic resolution. This experiment employed a Gaussian pulse-shaper, peaking at 45 sec, approximated by a single RC differentiator and four integrators all of 11 μsec time constant. We believe that this spectrum is the first observation ever made of less than 100 eV electronic resolution in a semiconductor detector system. The significant difference in resolution between the pulser and the X-rays is unexplained; detector charge-production statistics can only be partially responsible for it.

b) Counting-Rate Behavior

Figure 3 shows the change in energy resolution, as a function of counting rate, for the 5.9 keV Mn K_α X-rays produced by a ^{55}Fe source. The Gaussian pulse-shape used here is developed by a single RC differentiator and three integrators of equal time constant. The peaking time of the Gaussian-shaped pulse is indicated on the curves, and pulser performance for the same peaking times is also shown.

The high-rate behavior is consistent with the dc restorer failing to clamp the baseline at high-counting rates. At rates where the degraded performance is seen in Fig. 3, the amplifier output exhibits pulse pile-up of almost 100%, and virtually no time is available for the restorer to establish a baseline. This is also illustrated in Fig. 4, where the counting rate in the peak is plotted against the total rate. Large counting-losses occur at rates much lower than those where significant degradation of energy resolution is observed in Fig. 3. It therefore seems that the counting-rate behavior of resolution is as good as is ever likely to be required for low-energy X-rays.

As an indication of the effect of energy on the counting-rate performance, measurements were also carried out using a ^{241}Am source with a suitable absorber to absorb most of the low-energy Np X-rays, leaving nearly all the events in the 60 keV γ-ray peak. The counting rate behavior, when using an 8 μsec peak-time Gaussian shaper, is shown in Fig. 5. This figure also shows the behavior of a low-rate pulser peak counted at the same time as the ^{241}Am source--the indicated rate on the axis is that of the γ-rays alone.

CONCLUSION

The use of a pulsed-light feedback system provides excellent counting-rate behavior. Further improvements in performance depend on obtaining smaller values of series noise in FET's, thereby permitting operation with shorter pulse-shaping times. We note that the results given here were achieved with only minor changes to an existing spectroscopy system.

ACKNOWLEDGEMENTS

We are grateful for the assistance and advice of A. Jue, D. Malone, R. Pehl, W. Searles, and J. Walton in this work. The work was supported by AEC Contract W-7405-eng-48, and was part of the program of the Nuclear Chemistry Division of the Lawrence Radiation Laboratory, University of California

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3) K. Kandiah and A. Sterling, "A direct-coupled pulse amplifying and analyzing system for nuclear-particle spectroscopy" in Semiconductor Nuclear-Particle Detectors and Circuits, National Academy of Sciences, Publication 15943, p. 495 (1969).

4) V. Radeka, "Charge amplification without a charge leak resistor", Brookhaven National Laboratory, BNL 14492. To be published in IEEE Trans. on Nucl. Sci, June 1970.

5) We recently learned that W. Goldsworthy proposed a similar system in an internal LRL note (April 1969).

FIGURE CAPTIONS

Fig. 1. Block and timing diagram of pulsed-light feedback amplifier system.

Fig. 2. Energy spectrum of magnesium, aluminum, and silicon taken at low rate with a pulser included.

Fig. 3. Plot of energy resolution as a function of counting rate in 5.9 keV X-ray peak for different Gaussian shaper peaking times. Pulser resolutions were taken at the same time as X-rays.

Fig. 4. Plot of output counting rate in peak as a function of total input counting rate of the 5.9 keV X-rays for different Gaussian shaper peaking times. Counts lost from peak are due to pile up.

Fig. 5. Plot of energy resolution as a function of counting rate in the 60 keV gamma-rays peak using a Gaussian shaper with 8 μs peaking time. Pulser resolution was taken at the same time as gamma-rays.

BLOCK & TIMING DIAGRAMS OF THE SYSTEM

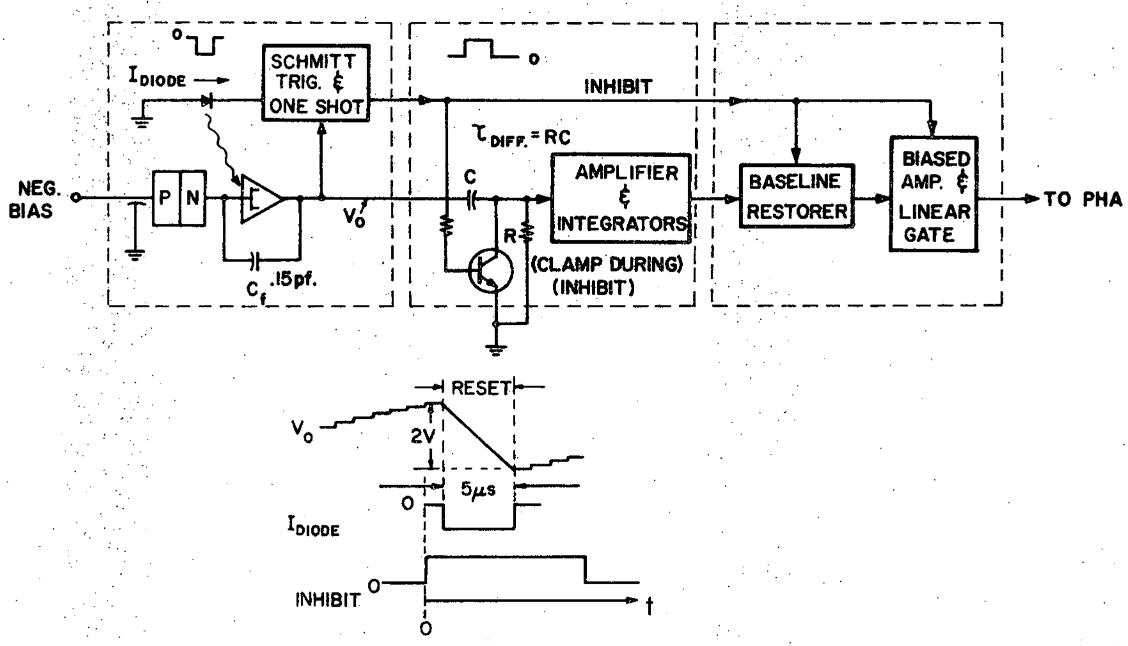
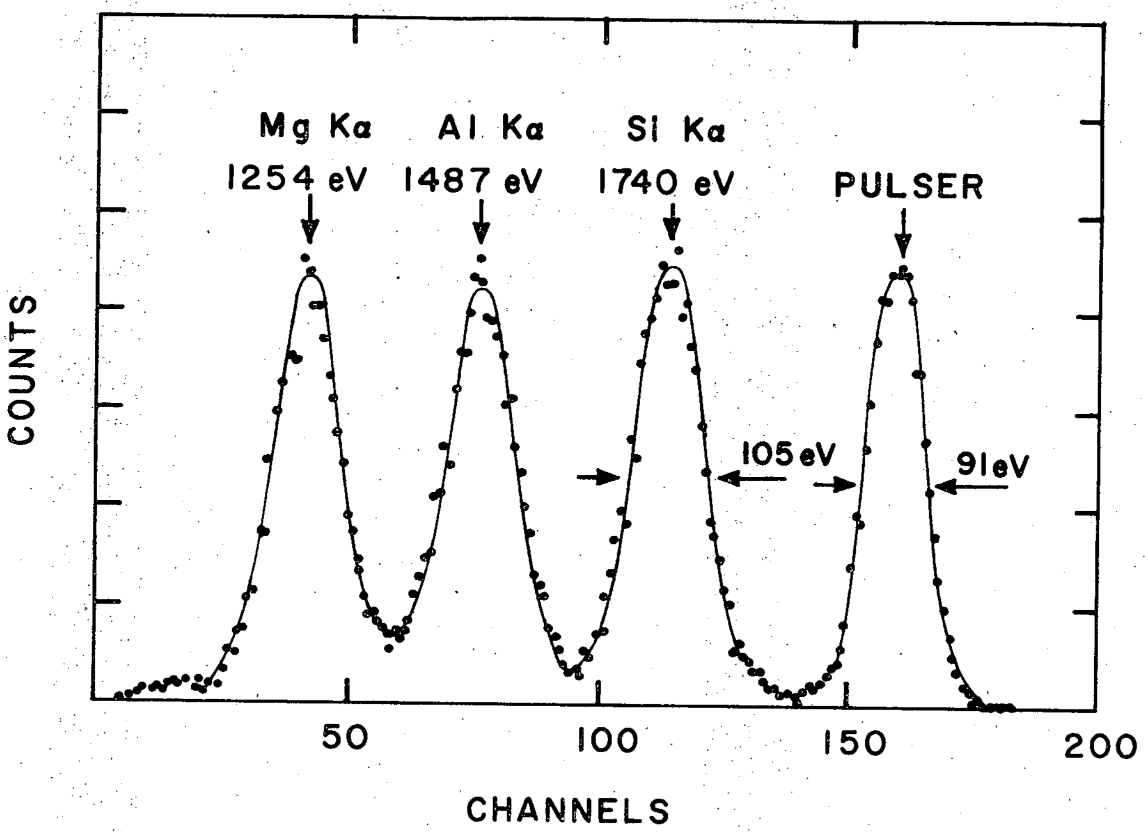


Fig. 1

XBL 706-1070



XBL 706-1069

Fig. 2

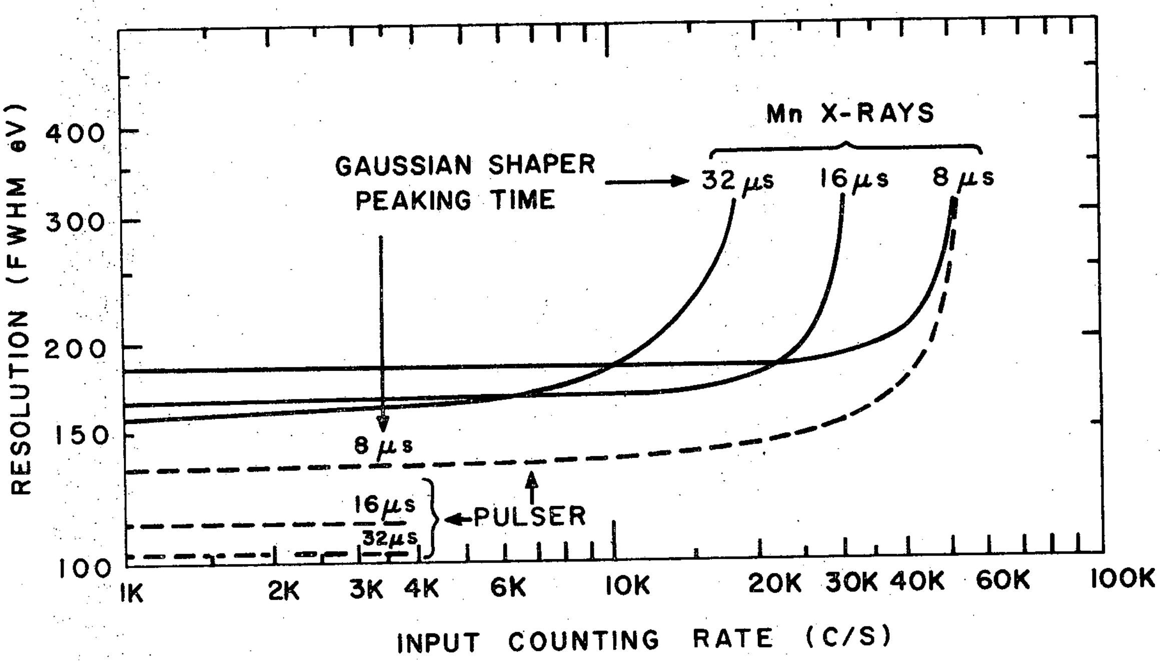


Fig. 3

XBL 706-1072

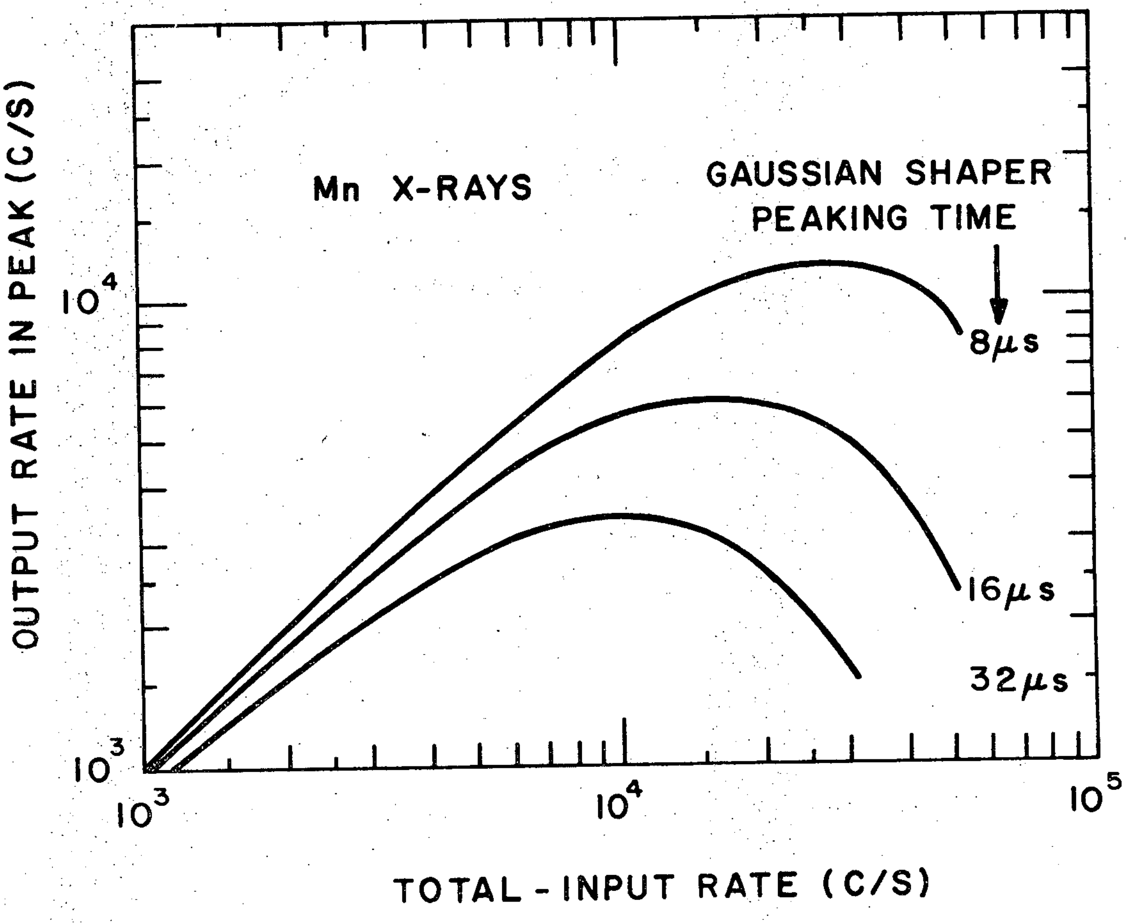


Fig. 4

XBL 706-1071

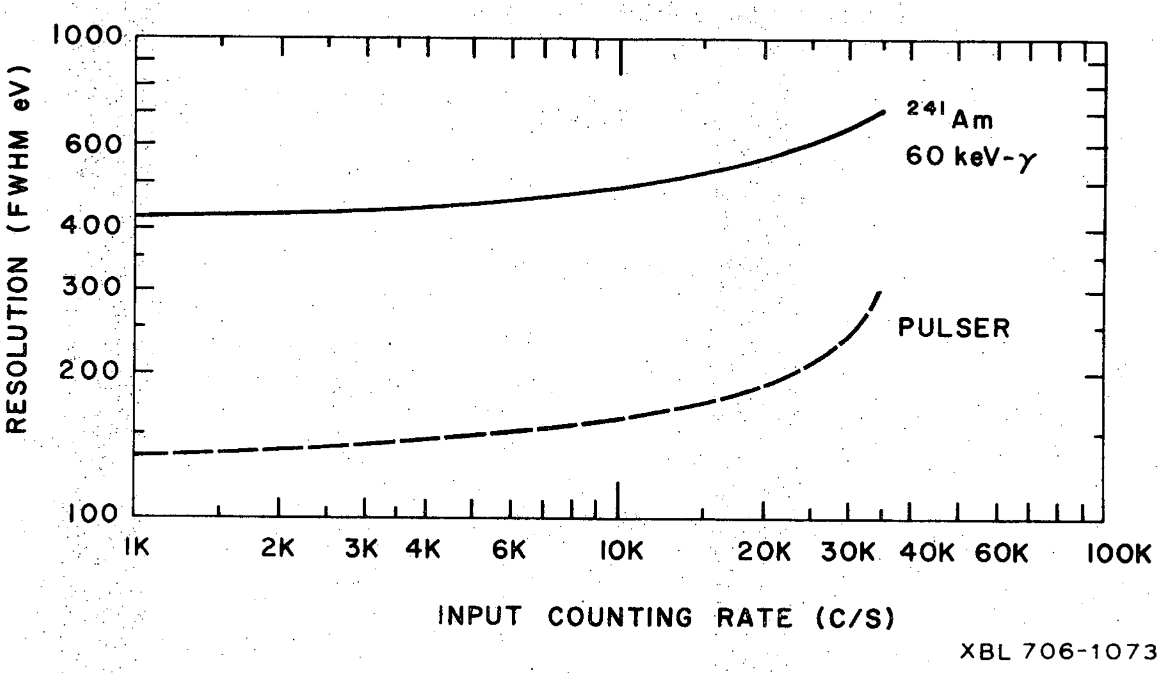

1000
600
400
300
200
100
RESOLUTION (FWHM eV)
1K
2K
3K
4K
6K
10K
20K
30K
40K
60K
100K
INPUT COUNTING RATE (C/S)
^{241}Am
60 keV-γ
PULSER
XBL 706-1073

Fig. 5

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