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COOLED PREAMPLIFIERS WITH DIODE CURRENT LEAK

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ABSTRACT

A high resolution voltage sensitive cooled preamplifier for semiconductor radiation detectors has been operated with a Schottky barrier diode as the current leak. A resolution of less than 300 eV (fwhm Si) was realised.

NOTE: This paper has been submitted to a journal. Further details can be obtained from the author or the Director of the Research Establishment.

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1. INTRODUCTION

Much development work in the semiconductor detector low noise preamplifier field has been devoted to the input junction field effect transistor (JFET) and the circuit elements connected to its gate.* In particular the high value charge leak resistor can be an important source of noise, while its bulk also increases the stray capacitance to ground. It can be eliminated by the open circuit gate approach (Elad and Nakamura 1967, 1968; Elad 1969) by use of an opto-electronic feedback system (Goulding et al. 1969, 1970) or by pulsed conduction of current from the input (Radeka 1970).

In the open circuit gate approach the gate source potential cannot be varied and the drain current is fixed at its maximum value, which is not necessarily the optimum for low noise operation. The other two approaches increase the complexity of the preamplifier. A simple replacement for the gate resistor is a cooled Si diode, biased so that the current flowing through its depletion or space charge region is equal to that of the detector and JFET gate (which are reverse biased p-i-n or p-n junctions).

2. DIODE AS CHARGE LEAKAGE PATH

Figure 1 shows an input stage using a forward biased diode as the current (I_L) path for the leakage currents from the n-Si JFET gate (I_G) and the semiconductor radiation detector (I_{DET}). With I_S approximately constant, the gate potential increases (to near 0.5 V) until

$$I_L = I_{DET} + I_G \quad . \qquad \ldots(1)$$

When all three devices have similar temperatures their currents are comparable (picoamps near 100°K).

The diode can also be operated with reverse bias, $V_R \approx -30$ V being required to make $I_L \approx 1$ pA (at 100°K). The gate potential can then be controlled by variation of V_R. No difference in the equivalent input noise (e_{in}) was observed between the two connections for $I_L < 2$ pA. When higher values of I_L were required, the forward bias connection gave improved stability.

The ideal diode I-V characteristics can be degraded by minority carrier effects and by surface leakage or field concentrations at the junction edges, under high voltage. The closest approach to the ideal diode characteristics are realised with the majority carrier Si Schottky barrier diodes (Zettler and Cowley

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* Elad and Nakamura (1967, 1968), Elad (1969), Goulding et al. (1969, 1970) Radeka (1969, 1970), Kern and McKenzie (1970).

1969, Saxena 1969, Yu and Mead 1970), which can now be produced at low cost. The HP 5082-2800 is one that has been used in the work reported here. Its small size keeps stray capacitance low and permits it to be mounted close to and at the same temperature as the JFET, and detector, thus reducing the microphonic noise.

With the circuit of Figure 1 the JFET operating conditions can be varied (from outside the cryostat), independently of the gate circuit, by adjusting R_S and R_D. The same circuit can be used with p-Si JFET's (the supply rails being reversed). In this case I_G is reversed and, if larger than I_{DET}, can reverse bias D2. This situation is avoided by keeping V_D lower than the threshold value V_T at which I_G increases rapidly with V_D (Ryan 1969).

Since the standard FET and diode packages add significantly to the input capacitance and noise due to lossy dielectric (Kern and McKenzie 1970), it is evident that improved performance would result from a single low capacitance package for both devices. This could be in either a hybrid form, with separate dice for diode and FET, or a monolithic form on a single substrate, assuming that the diode and FET epitaxial layer diffusion processing could be made compatible. The further step of common packaging of diode, JFET and X-ray detector does not appear to be practical. In addition to the problem of low yield, there is the difference in the optimum temperatures of detector and Si JFET's.

3. PRACTICAL APPLICATION

Two spectra obtained with different cryostats and voltage sensitive pre-amplifiers (Eberhardt 1970) and with forward and reverse biased cooled diode leak paths, are shown in Figure 2. The poorer resolution in spectrum F (forward bias) is due to the detector. The electronic system resolution without a detector (no added capacity) was in both cases below 300 eV (fwhm Si). It is probably limited by JFET and diode case dielectric noise (Kern and McKenzie 1970).

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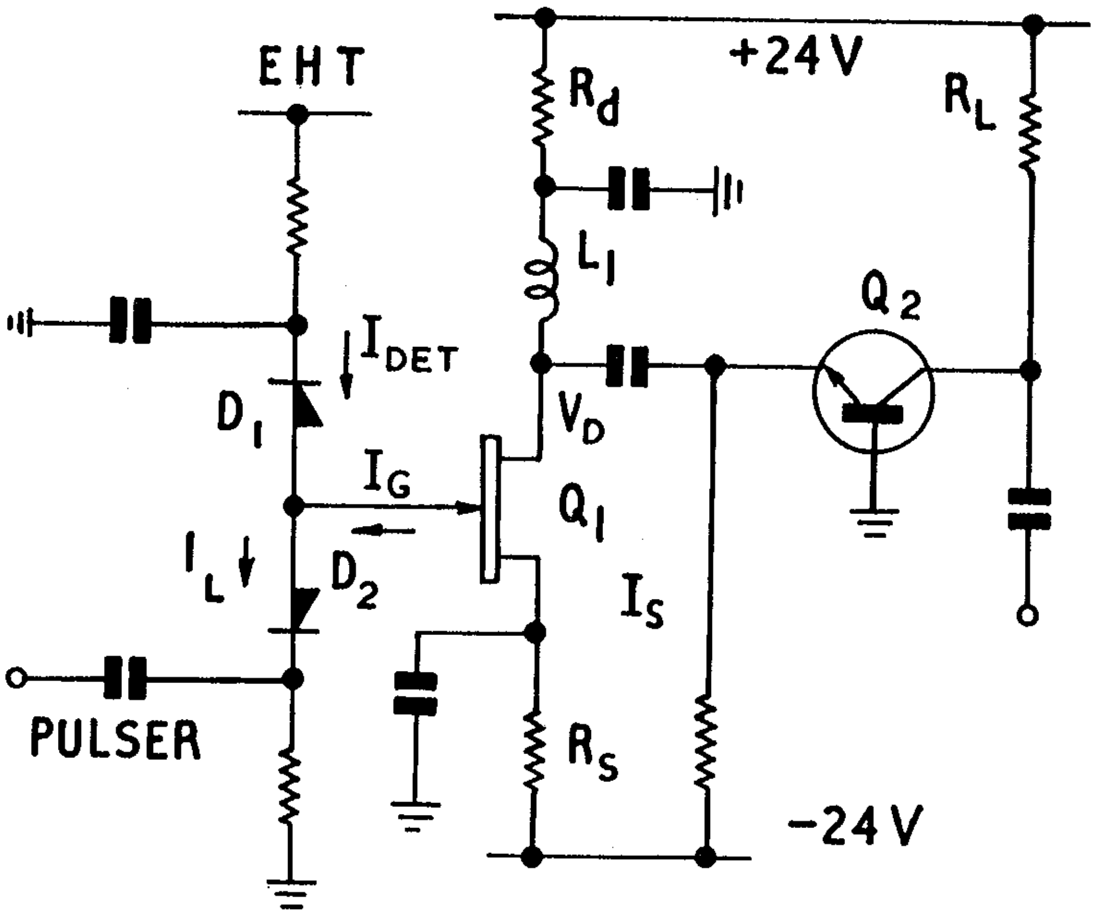

FIGURE 1 CIRCUIT DIAGRAM OF PREAMPLIFIER INPUT STAGE WITH A FORWARD BIASED DIODE (D2) AS CHARGE LEAKAGE PATH. D1 is the detector. The connections of D2 are reversed for the reverse bias mode of operation.

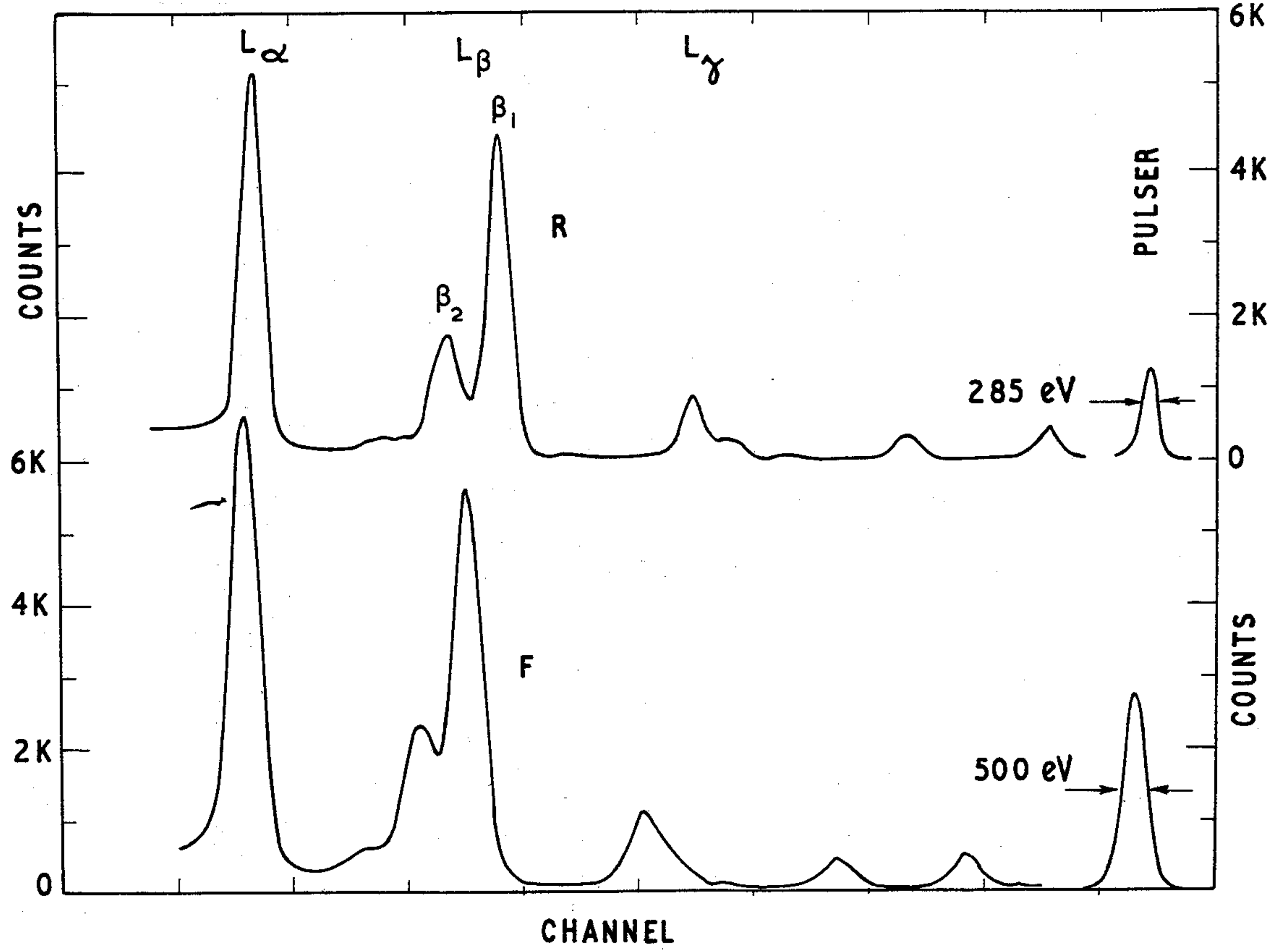

FIGURE 2 TWO ^{241}Am SOURCE X-RAY SPECTRA OBTAINED WITH SCHOTTKY BARRIER DIODES AS CHARGE LEAKAGE PATHS, 2N4416 INPUT JFET's AND Si SURFACE BARRIER DETECTORS. Spectrum F, preamplifier as in Figure 1, diode forward biased. Spectrum R, diode reverse biased (V_R = 32 V) obtained by J.E. Eberhardt of this laboratory (1970).