EG&G ORTEC describes a better way for...

Optimizing Noise and Energy Resolution of SSB Detectors

Introduction

In many areas of research a need exists for silicon surface barrier (SSB) detectors having very low noise and very good energy resolution. In experiments involving low energy protons and deuterons or medium energy electrons, for example, the detector-amplifier noise needs to be minimized for best energy resolution.

This application note explains the factors affecting SSB detector performance and suggests techniques to optimize the performance.

Noise and Energy Resolution

Much literature has been published on the interaction of light ions with SSB detectors.[1-8] For example, it is well known that the energy resolution of monoenergetic particles obtained with SSB detectors is very different if the detectors are irradiated by beta or alpha particles. There are several factors which contribute to the energy peak broadening. Some of these factors, such as the statistical fluctuation in the ionization process, depend upon the interacting radiation, while others like noise depend solely upon characteristics of the detector and the preamplifier. The FWHM of the energy resolution Δ_{Res} is given by:

$$\Delta^2_{Res} = \Delta^2_D + \Delta^2_N$$

Here Δ_D includes effects due to nuclear collisions in the detector, fluctuations in the number of charge carriers, and absorption in the detector window.

Δ_N is the electrical noise contribution of the detector and preamplifier.

Therefore, the energy resolution depends on which term contributes most. In the case of alpha particles, the major contribution is from window effects and nuclear collision effects, whereas for protons and deuterons these effects are less dominant. Nuclear collision and window effects are of no consequence in beta particle and low-energy gamma-ray interactions; for these the electrical noise is the major factor in determining the energy resolution.[2,3]

Therefore, for the best energy resolution in light particle spectroscopy, the noise contribution must be minimized.

The electrical noise Δ_N is composed of noise Δ_I due to the detector's leakage current and noise Δ_C generated by the preamplifier due to the detector capacitance. Therefore,

$$\Delta_N^2 = \Delta_I^2 + \Delta_C^2$$

These two noise sources will be treated separately in this discussion.

Detector Leakage Current Noise Δ_I

Noise from the detector is caused primarily by its leakage current, which is the sum of several components which influence the noise in different ways. The first of these components has its origin in the bulk volume and is due to the thermal generation of free charge carriers within the depletion region. A second component is the Schottky component due to the thermionic emission of carriers from the metal into the semiconductor over the potential barrier. Both components are temperature dependent; cooling the detector reduces the leakage current and so the noise. A 10° change in the operating temperature of the detector produces approximately a two-fold change in the leakage current. However, noise does not change by the same factor because the leakage current is only one component of the noise.

In addition to the leakage current components mentioned above, the total reverse current also includes the leakage current along the side surfaces of the detector. This surface leakage current originates at the periphery of the junction. Its magnitude depends on the processing techniques and the condition of the surface.[9] EG&G ORTEC's detector processing technique obtains the right surface. This, coupled with proper encapsulation, results in low and stable surface leakage current.

To determine the temperature range for optimum performance, both noise and energy resolution were measured at EG&G ORTEC on SSB detectors. These detectors were mounted with cryogenic epoxies and cooled with a static-well LN_2 reservoir (Figs. 1 and 2). Cooling by flowing LN_2 should be avoided since it tends to induce microphonics and increase the noise.[8]

Noise and energy resolution (FWHM) of 5.48-MeV alpha particles from ^{241}Am are plotted as a function of temperature (Fig. 1). Down to −60° C, noise decreases sharply as the temperature is lowered; however, only slight improvement in alpha resolution is obtained. On the other hand, the energy resolution for electrons improves significantly (Fig. 2). Noise and energy resolution (FWHM) of 974-keV conversion electrons from ^{207}Bi are plotted as a function of temperature. Note that the same degree of cooling improves the energy resolution for electrons about three times as much as for alpha particles.

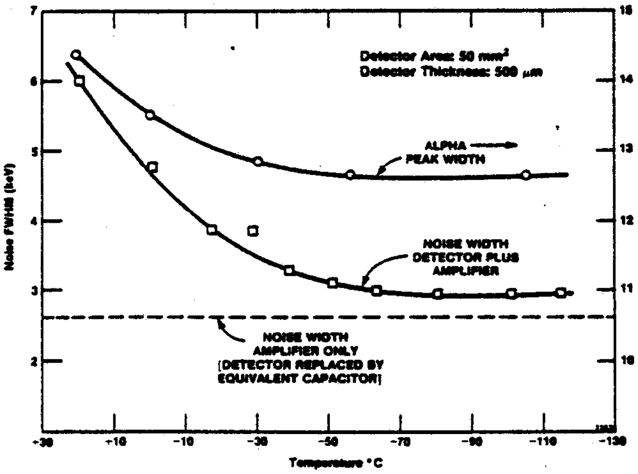

Fig. 1. Detector Noise and Alpha Energy Resolution as a Function of Temperature.

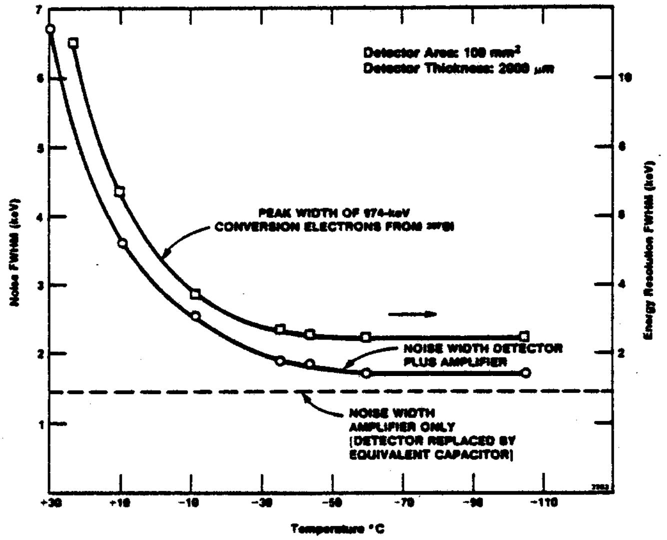

Fig. 2. Detector Noise and Electron Energy Resolution as a Function of Temperature.

Nothing is gained by cooling below −60°C; in fact, the energy resolution deteriorates at extremely low temperatures.[8,10]

Although the reverse leakage current is negligible at low temperature, there still is some noise generated within the detector. This is evident from the fact that the detector plus amplifier noise width does not approach the noise width due to the amplifier with an equivalent capacitor replacing the detector.

Preamplifier Noise Δ_C

Besides the detector, the other source of noise is the preamplifier, due to the capacitive loading of its input. This contribution is determined by the capacitance of the detector and the input cable, if any, as well as the bias resistor through which the operating voltage is applied to the detector. EG&G ORTEC offers two series of extremely low noise charge-sensitive preamplifiers for use up to 1000-V bias and one up to 5000 V. The models 142A and H242A have low noise intercepts and moderate slopes and operate with detectors of capacitances up to 100 pF. The models 142B and H242B have moderate noise intercepts and low slopes and should be used with detectors having capacitances greater than 100 pF. The high voltage preamplifier type 142AH is used with "deep" detectors requiring a bias greater than 1000 V for depletion.

Typical noise data for these preamplifiers (Figs. 3–5) show that low preamplifier noise can only be obtained with small-capacitance detectors.[11] Since the detector capacitance is directly proportional to its area and inversely proportional to its depletion depth, a proper choice for very low noise would be a small area detector with a large depletion depth. Any connecting cables at the input also add to the capacitance.

The effect of bias resistor is also shown in these figures. A high-value resistor gives less noise. A low-value resistor is used only if the detector leakage current is so great as to cause an excessive voltage drop across the resistor. At low temperature, with the detector leakage current negligible, a high-value resistor can be used.

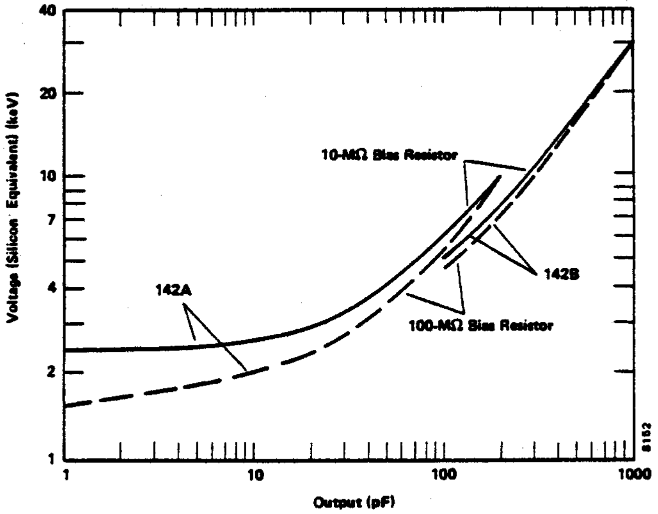

Fig. 3. Typical Noise Data for 142 Preamplifiers.
(Using EG&G ORTEC's 472A Shaping Amplifier
with 0.5-μs shaping time constant.)

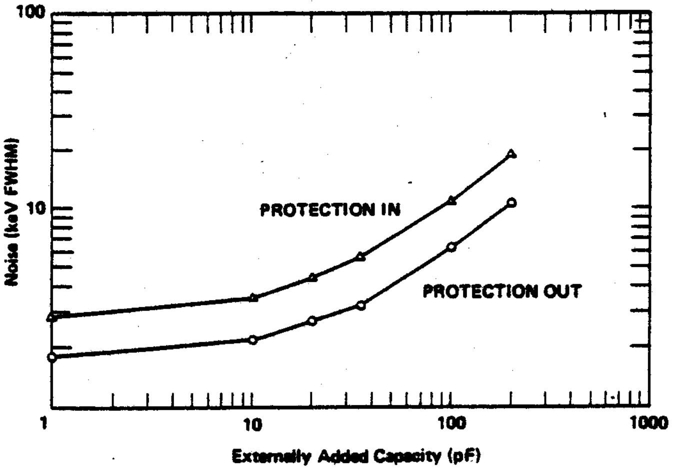

Fig. 4. 142AH Typical Noise (0.5 μs).

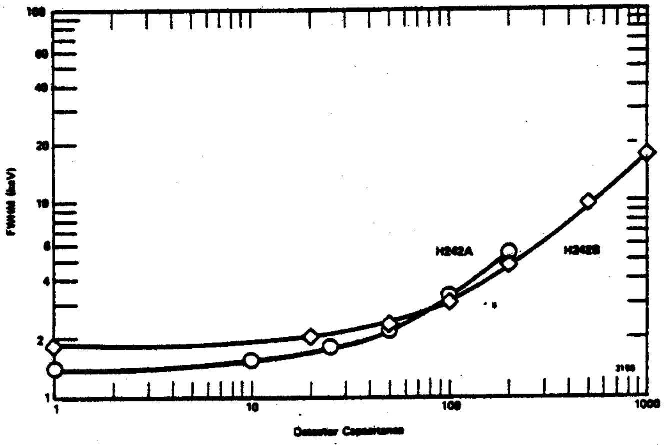

Fig. 5. Typical Noise Data for H242A and H242B Preamplifiers. (Using EG&G ORTEC's 572 Amplifier with 2.0-μs shaping time constant.)

Amplifier Shaping Time Constants

For optimum signal-to-noise ratio, choice of pulse shaping time constant τ is important. At room temperature, SSB detectors have their best energy resolution at 0.5-μs shaping time. However, at low temperatures, noise is reduced and better energy resolution achieved by using longer amplifier shaping times. The explanation is that the detector leakage current component of noise and the preamplifier component of noise have different frequency dependence. The former is predominantly low frequency noise while the latter is mostly high frequency. At room temperature, with the main contribution to noise arising from the detector leakage current, a shorter shaping time constant is more suitable. At low temperature, with the leakage current contribution negligible and the preamplifier contribution dominant, a longer shaping time constant is better.

Figures 6 and 7 show noise and energy resolution (FWHM) of 974-keV conversion electrons from ^{207}Bi as a function of shaping time constant τ at different temperatures. For decreasing temperatures, the noise minima lie at progressively longer time constants.

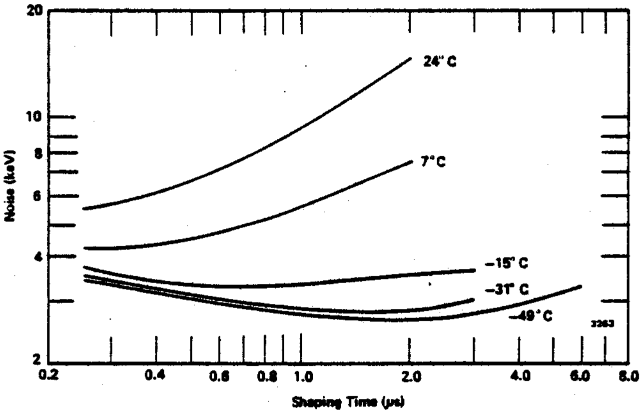

Fig. 6. Detector Noise as a Function of Amplifier Shaping Time.

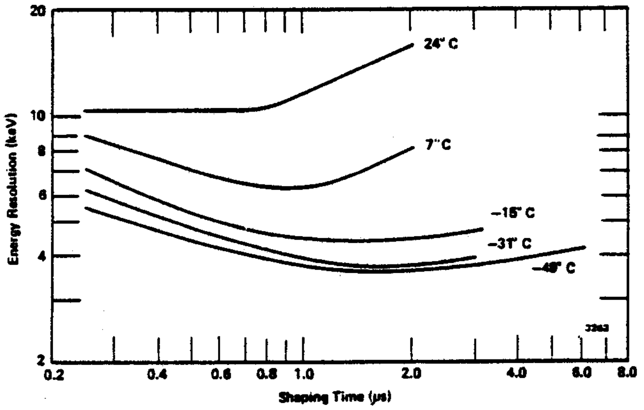

Fig. 7. Electron Energy Resolution as a Function of Amplifier Shaping Time.

Summary

Signal-to-noise ratio can be improved by 1) cooling the detector to reduce its leakage current, 2) making the preamplifier input capacitance as small as possible to minimize the preamplifier noise, 3) using a high-value bias resistor to reduce the bias-resistor noise, and 4) optimizing the amplifier shaping time constant.

References

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