

Noise Simulation Using PSpice for Semiconductor Detectors and Associated Electronics

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The noise in the detector and readout electronics often determines the performance of semiconductor particle detection systems. This article compares the results obtained by simulation, theory, and measurement.

THE APPLICATION

An independent, prompt trigger is frequently useful in semiconductor detectors, for example in the use of silicon pad detectors for X ray imaging, where the position and energy of the incoming photon are accurately determined using well established, very low noise integrated readout [1].

A trigger signal may be obtained from the backplane of the detector. As this is common to many readout channels, power consumption and size are secondary to performance requirements. A capacitance of 5–1,000 pF, and leakage currents of the order of 0.1–1,000 nA are to be expected. The lowest detectable X-ray energy and the accuracy of prompt total energy correlation will depend critically on the lowest trigger noise value obtained.

SIMULATION METHODOLOGY

PSpice simulation of circuit parameters has been well accepted in engineering practice. However, noise simulation has previously been a neglected field, mainly because of the parsimony and inaccuracy of the available models. Some comparisons are presented here of simulation, theory, and measurement.

The charge sensitive pre-amplifier is of conventional design [2]. The choice of input FET is of primordial importance. Optimum signal to noise is obtained when its input capacitance (C_{in}) is about one third of the detector capacitance [3]. Results are presented using the devices SK 300 (SONY, C_{in} = 10pF, g_m > = 25 mS), and the IF 9030 (INTERFET, C_{in} = 80pF, g_m = 90mS). The semi-Gaussian shaping amplifier consists of one differentiation stage and five integration time constants.

Figure 1 shows the simulated transient response for a peaking time of 1 μ s. It confirms how well PSpice corresponds to reality in the time domain. The input was 22,500 electron hole pairs—the signal produced by a minimum-ionizing particle traversing 300 μ m of fully depleted silicon.

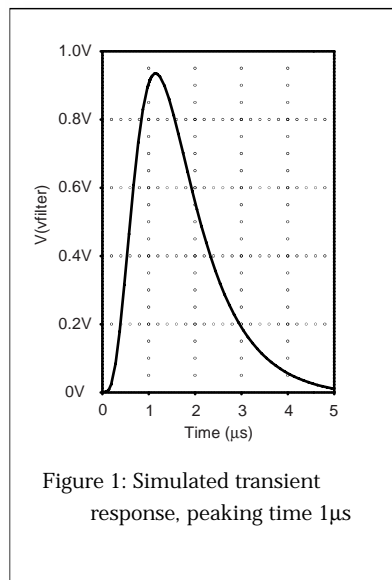


Figure 1: Simulated transient response, peaking time 1 μ s

In order to simulate the system noise, PSpice must calculate the noise bandwidth, which is the area under the power curve, or the integral of the power gain versus frequency, divided by the square of the gain. This may be expressed as

$$\Delta f = \frac{1}{A_{vo}^2} \int_0^{\infty} |A_v(f)|^2 df$$

where A_{vo} is the peak magnitude of the voltage gain, and $|A_v(f)|^2$ is the square of the magnitude of the voltage gain over frequency. This calculation is made in the PROBE post processor by using

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$$V_{nb} = 1/[Avo * Avo] * s[VM[Vout] * VM[Vout]]$$

PSpice is now able to simulate the total system noise. It will calculate the noise in every resistor and semiconductor device and relate this to the independent input current source. The post processor then calculates the Root Mean Square

noise, and thus obtaining the equivalent noise charge (ENC) in terms of RMS electrons, i.e.,

$$ENC = \frac{V_{in(cal)} \times C_{(cal)}}{q} \times \frac{V_{out(noise)}}{V_{out(cal)}}$$

DETECTOR CAPACITANCE AND LEAKAGE CURRENT

The effect of the shunt capacitance of the detector may now be included. Whilst the capacitance is not in itself a noise source, it increases the ENC of the input amplifier.

It must be emphasized that rubbish in equals rubbish out, hand calculations must be resorted and used for cross-checking. Not to do so is only inviting disaster [4]. The noise contributions of the various sources may be calculated [5].

Noise due to the input FET:

$$ENC_{ct} = \frac{Cte}{q} \sqrt{\frac{\Gamma(\eta+1)kT}{3Gm Tp}}$$

In the simplest case Γ (excess noise) = 1, and η (transconductance ratio) = 0.

Noise due to the feedback and biasing resistor:

$$ENC_{dr} = \frac{e}{q} \sqrt{\frac{Tp kT}{2Rp}}$$

These are added in quadrature. The results of simulation, theory, and measurement are shown in Figure 2 for the SK300 and Figure 3 for the IF9030. The detector leakage current contributes noise given by:

$$ENC_{dl} = \frac{e}{q} \sqrt{\frac{q Idl Tp}{4}}$$

In the above, $e = 2.718$, $q = 1.6E-19$, $k = 1.38E-23$ and $T = 300$.

This may be simulated in PSpice using the noise model as used in the input circuit. A 1-GF capacitor blocks the DC bias current and enables the AC short

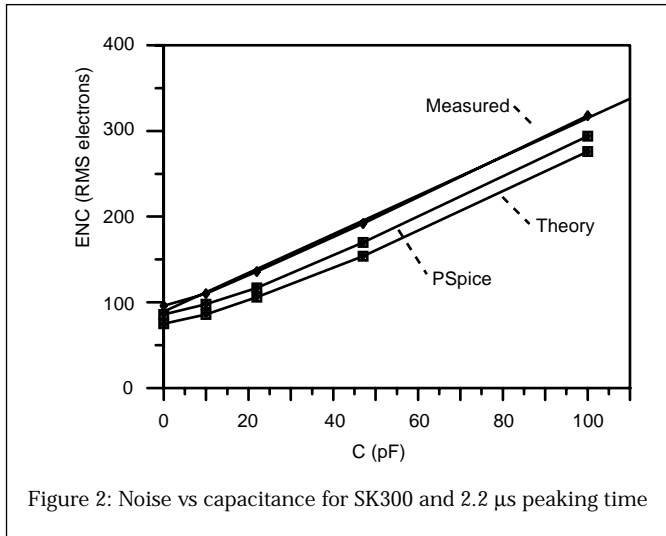


Figure 2: Noise vs capacitance for SK300 and 2.2 μs peaking time

(RMS) of the noise voltage at a specified output node by summing over the curve of noise bandwidth using the expression

$$V_n = \text{sqrt}[s[VM[onoise] * [VM[onoise]]]]$$

The total noise thus obtained may be referred to the input by injecting a known charge, observing the output signal, multiplying by the simulated

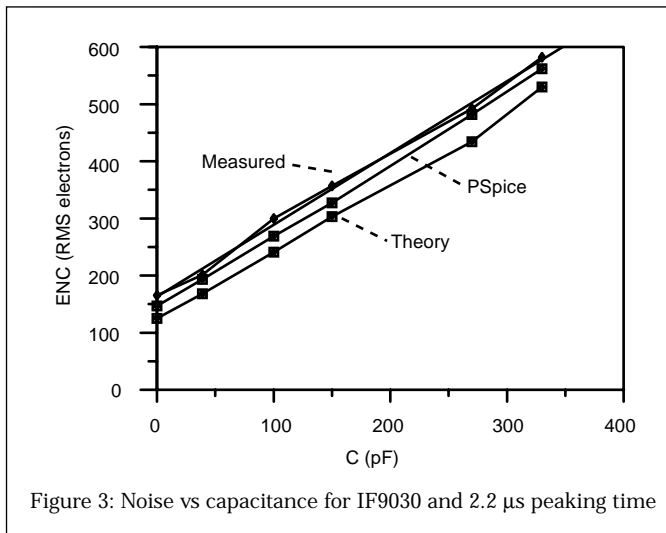


Figure 3: Noise vs capacitance for IF9030 and 2.2 μs peaking time

circuit noise current to be sensed by the current controlled current source. PSpice calculates the noise current in a diode according to:

$$I_d^2 = \frac{KF(I_{dc})^{AF}}{f} + 2qI_{dc}$$

where KF is the flicker noise coefficient in Amperes, and AF is the flicker noise exponent, thus enabling excess 1/f noise to be added to our model.

Figure 4 shows theory, simulation, and some measured points for a "large", 33 mm by 33 mm silicon detector, leakage current = 110 nA, C = 335 pF with respect to shaping time. The same has been done for a "small", 7pF, 0.2nA detector (Figure 5). The apparent discrepancy between measurement and theory at longer shaping times is probably due to the difficulty in determining the shot noise component of the DC leakage current.

CONCLUSIONS

PSpice has been shown to simulate charge sensitive amplifiers together with associated semiconductor detectors for various shaping times, input FETs, leakage currents and capacitances. For small area, low leakage current detectors an ENC of less than 100 RMS electrons may be obtained at room temperature. Simulation, theory and measurement have been shown to be in good agreement. This not only increases the confidence of the system designer, but also enables the simulation of detector types and configurations to be performed in cases where measurement would be too expensive or impossible to perform.

REFERENCES

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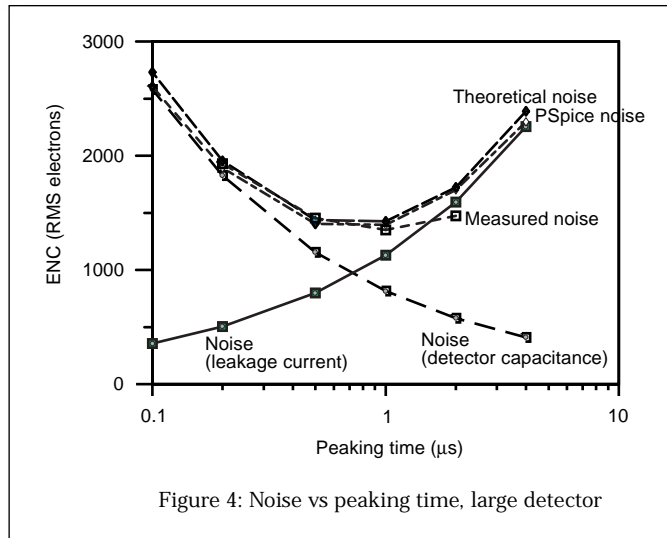


Figure 4: Noise vs peaking time, large detector

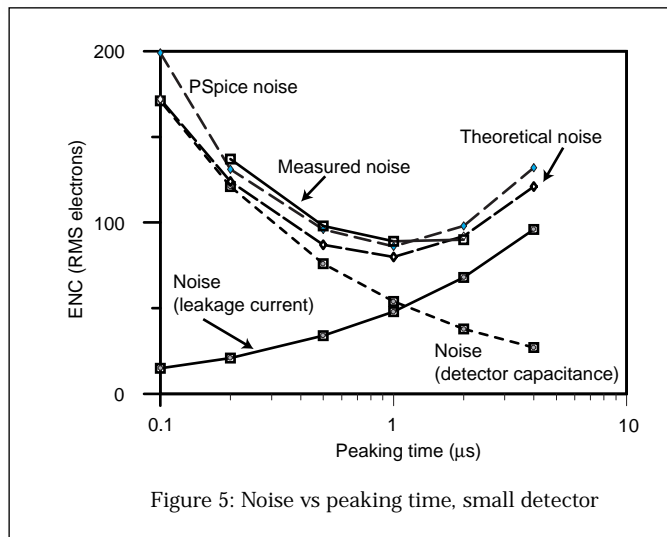


Figure 5: Noise vs peaking time, small detector