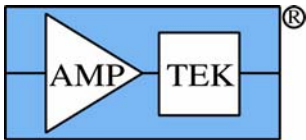

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A250 APPLICATION NOTES

(AN250-2, Revision 3)

TESTING

The A250 can be tested with a pulser by using a small capacitor (usually 1 to 2 pF) to inject a test charge into the input. (see figure 1) The unit will respond to both the negative and positive edge of the test pulse which should have a transition time of less than 20 ns. A square wave or a tail pulse with long fall time (>100 s) may be used. Charge transfer to the input of the A250 is been applied only during the transition time according to $Q = C_t V$, where Q = total charge transferred, C_t = value of test capacitor, and V = amplitude of voltage step. DO NOT connect the test pulser to the input directly or through a test capacitor greater than 100 pF as this can produce a large current pulse at the input FET and cause irreversible damage.

The PC250 Test Board provides a convenient way to test the A250. A 2 pF (±5%) test capacitor is provided as well as INPUT, OUTPUT, and POWER pins set in a ground plane configuration in a 1.75 inch x 1.75 inch PC board.

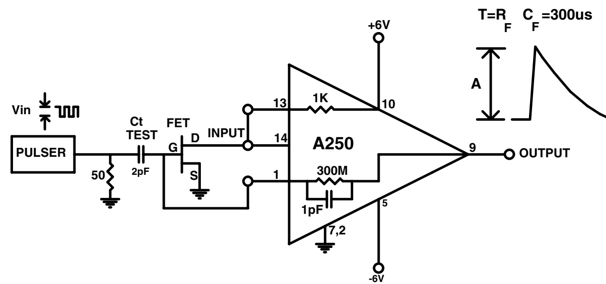

Figure 1: A250 test circuit

Input waveform: Square wave, or Tail pulse ($T_r < 20$ ns, $T_f > 100$ s)

Amplitude: $V = Q/C_t = 500$ mV per picoCoulomb for $C_t = 2$ pF

Example: To simulate 1 MeV in Si detector:
1 MeV (Si) = 0.044 pC
500 mV/pC x 0.044 pC = 22 mV

Hence, a 22 mV step into 2 pF test capacitor simulates the charge generated in a silicon detector by a particle when it loses 1 MeV of its energy.

A250 NOISE MEASUREMENT

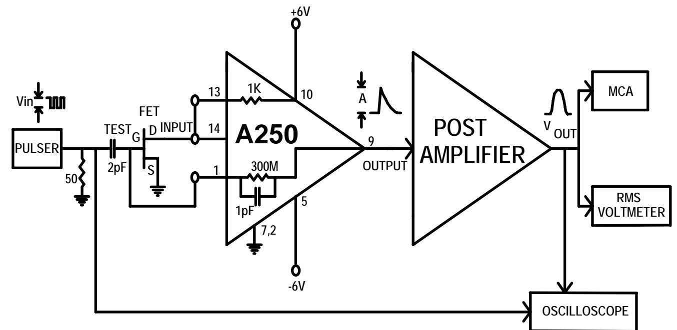

Figure 2: Noise measurement with RMS meter and MCA

The noise of a charge sensitive preamplifier must be tested together with the post amplifier/shaper.

The A250 noise characteristics given in the specifications are associated with specific shaping time constants in the post amplifier. The post amplifier must have very low input noise as in the case of NIM electronics amplifiers or the Amptek A275, so that its contribution to the measurement is minimal. The function of the post amplifier is not only to preserve and amplify the linear information received by the charge amplifier, but also to provide a band pass filter to eliminate frequencies that contribute to noise.

Two methods are normally used to measure noise in the preamplifier: The first one is by using a Multichannel Analyzer (MCA), and the second one is with a wide-bandwidth RMS AC voltmeter.

NOISE MEASUREMENT USING AN MCA (see ref 1)

1. Use the test circuit shown in Figure 2 to stimulate the input of the A250 with a pulse of known amplitude.
2. Connect the A250 OUTPUT to the post amplifier/shaper with the correct shaping time constant (1-3 s for solid state detectors).
3. Connect the post amplifier output to the MCA input.
4. Calibrate the MCA, in pC/channel or keV/channel, by observing two peaks formed by two different known amplitude test pulses.
5. The Full Width at Half Maximum (FWHM) of a particular energy peak can now be read directly from the analyzer.

NOISE MEASUREMENT USING RMS VOLTMETER

1)Use the circuit shown in Figure 2.
2)The FWHM noise using the RMS voltmeter is given by:
FWHM (keV, Si) = 2.35 (Vrms) (Vin)/Vout

Where: Vrms is the noise in volts from the voltmeter.
V_{in} is the input test pulse in keV equivalent.
V_{out} is the output pulse in volts from the post amplifier.

Example: With a 2 pF test capacitor
Set V_{in} = 22 mV (1 MeV, Si)
Set Post amplifier's gain to obtain 2.35 Volts output pulse
The RMS voltmeter is now calibrated to:

1 mV RMS = 1 keV FWHM (Si)

3) Remove the test pulser and read the RMS voltmeter. Conversion:

1 keV FWHM (Si) = 113 electrons RMS = 1.81×10^{-17} Coulombs RMS

When measuring noise of the system either by the MCA or the RMS voltmeter method the detector must be simultaneously connected with the test circuit to the input of the A250. The noise measurement in this case will include the contribution from the detector due to both its capacitance and its leakage current.

THE A250 CONNECTED TO A SOLID STATE DETECTOR

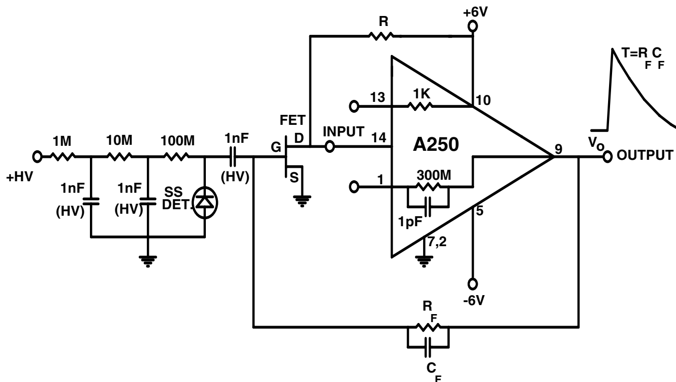

Figure 3: Connection to a solid state detector

1) By connecting Pin 13 to Pin 14 and eliminating the external resistor R, the FET will be biased with 2.75 ma current through the internal 1 k resistor to Pin 10.

2) By connecting Pin 1 to the gate of the FET and eliminating the external feedback components R_fC_f, the 300 M resistor and 1 pF capacitor will be installed in the loop.

The internal components connections will be adequate in most cases. For more critical applications, however, the current through the FET will have to be adjusted through the external resistor R, and the feedback components changed through the external R_fC_f. For low noise applications:

$C_f < 1$ pF typical and $R_f > 1$ G typical

The value of these components will effect the Fall Time of the output pulse ($T = R_fC_f$). The Rise Time of the output pulse will not be effected by the feedback components since it depends mostly on the detector capacitance, the choice of the FET and the internal characteristics of the A250. See A250 specifications.

The Gain defining component in a charge sensitive preamplifier is the feedback capacitor C_f.

Gain (Sensitivity): $A = 1/C_f$ Volts/picoCoulomb (C_f in pF)

In the case of silicon detector:

$A = 44/C_f$ in mV/MeV (C_f in pF)

Hence, for a 1 pF feedback capacitor the output of the A250 will produce a 44 mV pulse when a 1 MeV particle loses all of its energy in the detector.
It is important to note that in the charge sensitive preamplifier mode of operation the feedback resistor R_f does not effect the gain of the amplifier, it simply returns the output of the integrating loop to the baseline.
The charge sensitive preamplifier mode of operation will give the best overall signal to noise ratio. It is primarily used in applications where the signal from the detector is small as in the case of solid state detectors and proportional counters.
In applications where the counting rate of the incoming pulses approaches the R_fC_f time constant, the output of a charge sensitive preamplifier is shown in Figure 4.

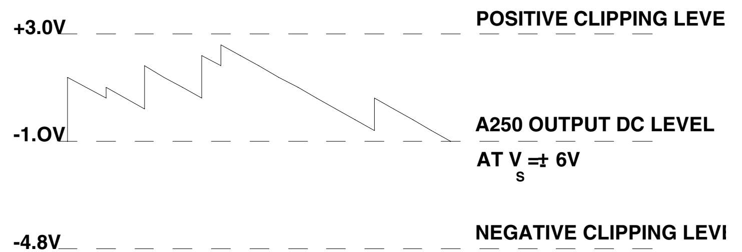

Figure 4: A250 output at high counting rates

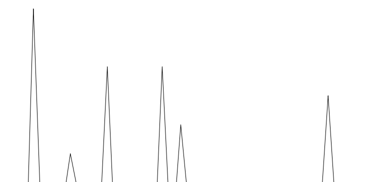

Figure 5: Post amplifier input waveform at high counting rates

Care should be taken not to exceed the positive or negative clipping level of the A250. The RfCf feedback components should be chosen to accommodate the expected count rates of the particular application.
Since the charge sensitive preamplifier is AC coupled to the post amplifier/shaper with a pole zero differentiator the resulting waveform will be as shown in Figure 5.

FOR CURRENT (TRANSIMPEDANCE) PREAMPLIFIER APPLICATIONS

In applications where the signal generated by the detector is large and preserving the rise time information is of importance the current preamplifier mode of operation is preferred. These applications include high counting rates in electron multipliers or photodiodes in optical and laser communications. Referring to Figure 3, the size of the feedback components are typically:

$$C_f = 2 \text{ pF and } R_f = 50 \text{ K}$$

If (I) is the input current, then: Gain: $Vo = (I)R_f$

In this case, the Gain defining component is the R_f. The feedback capacitor C_f simply stabilizes the loop. The fall time constant will now be $T = R_f C_f$ (approximately 100 ns).

LOW NOISE CONSIDERATIONS USING A SOLID STATE DETECTOR

In order to achieve low noise performance using the A250 Charge Sensitive Preamplifier with a solid state detector the following factors should be considered:

1) The detector + stray capacitance, and leakage current
2) The type of input FET used
3) The operating temperature of detector + FET
4) The preamplifier feedback resistor
5) The post amplifier and its shaping time constant

A short discussion of each of these subjects follows:

NOISE DUE TO DETECTOR + STRAY CAPACITANCE, AND LEAKAGE CURRENT

$$(N_t)^2 = (N_i)^2 + (N_c)^2$$

Where: N_t is the total electrical noise generated by the detector. N_i is the noise due the detector leakage current. N_c is the noise generated due to the detector capacitance, the cable capacitance, the stray capacitance, and the bias resistor to the detector. N_i can be minimized by selecting a detector with low leakage current and by lowering the operating temperature of the detector. Care should be taken in selecting a detector due to the different manufacturing processes (see ref 2,3). The topic of cooling the detector is discussed below. N_c can be minimized by using a short cable between detector and preamplifier and by minimizing any stray capacitance due to PC board layout and coaxial connectors. Typical capacitance for RG58, 50 coaxial cable is 100 pF/m. The high voltage bias resistor should be chosen to have low noise, typically less than 0.5 db above thermal noise with a value greater than 1 G for detectors with low leakage current. The voltage applied to the detector is :

$$V_d = V_b - (I)R$$

Where: V_d is the actual voltage on the detector. V_b is the power supply voltage. (I) is the detector leakage current. R is the bias resistor

If the leakage current in the detector is high, care should be taken to calculate the voltage drop across the bias resistor. Typically the leakage current in the detector doubles for every 8 C increase in temperature. The power supply voltage minus the voltage drop across the bias resistor should be equal to the manufacturer's recommended operating voltage for the detector at a given temperature. Also, the voltage drop across the bias resistor should not be more than 10% of the supply voltage.

INPUT FET TRANSISTOR

Almost all the noise produced by the input FET + A250 combination is due to the FET. The A250 circuit design has been optimized so that its noise contribution is negligible compared to the total noise of the system.

The choice of the input FET is left to the user so that it can be matched to the detector and optimized to the specific application. The A250 can be used with a number of FETs whose noise performance as a function of detector capacitance and shaping time constants in the post amplifier is given in the specifications. Usually, an FET is chosen with large transconductance (gm), while matching the FET's input capacitance (Ciss), to the detector capacitance (C_d).

COOLING OF THE DETECTOR AND FET

When cooling the detector, cooling the input FET is also recommended. The A250 does not need to be cooled. If, however, it is more convenient to cool the detector + FET + A250, then the lowest temperature the A250 can be operated at is -55 C. When cooling the detector + FET, the preamplifier feedback resistor and capacitor must be near the FET, with shielded wires connecting to the A250. In this configuration, do not use the internal feedback components in the A250. Use external resistor and capacitor.

As the temperature decreases, the detector leakage current and noise decreases. Also, the gm of the FET increases. This results in a larger signal to noise ratio. In most FETs the gm stops increasing at approximately -140 C (133 K), because of freeze-out of the dopant of the semiconductor material. Hence, for most FETs the transconductance will be maximum at approximately 133 K and then it will drop by about 10% as the temperature reaches 77 K (Liquid Nitrogen, LN2). In many experiments requiring cooling, the detector is placed at the LN2 temperature, and the FET is placed further away or heated, so that its temperature is near 133 K. Example of FETs used in experiments requiring cooling are: 2N4416, 2N6451, 2SK152, 2N6550, and 2N3823.

In cryogenic experiments where both the detector and the FET must be at Liquid Helium temperature (4 K), different FETs must be used. The manufacturing process of these FETs allows them to be cooled down to 4 K. An example is the SONY GaAs MESFET SGM2006M (previously known as 3SK164). Use of this FET, however, at higher temperatures (near 133 K) is not

recommended because its noise performance will be inferior to the FETs previously mentioned.
Most low noise FETs exhibit a noise of about 100 - 120 electrons RMS at room temperature. This noise decreases to approximately 15 - 25 electrons RMS as the temperature reaches 133 K.

THE PREAMPLIFIER FEEDBACK RESISTOR (R_f)

Since the feedback capacitor must be discharged, a resistor is usually placed in parallel with that capacitor. This resistor is a source of noise for the input and should be as large as possible. With low leakage detectors, the value of the feedback resistor may be several G . The A250 has an internal feedback resistor of 300 M available at Pin 1. This was the largest value resistor that could be accommodated inside the hybrid package at the time of the original design. Although this internal resistor is adequate for many applications, it should not be used in high resolution experiments. Instead, an external feedback resistor should be used of as large a value as detector leakage current allows. For systems with AC coupled detectors, the maximum feedback resistance is determined by the gate leakage current of the FET. Typically, the gate voltage will be about –1 V.
The A250 output voltage will be :

$$DCV_{out} = -1\ V - R_f \times (\text{gate leakage current})$$

For an FET with gate leakage current < 50 pA. DCV_{out} must not be allowed to reach the clipping level. If DCV_{out} is to be about –2 V, then R_f must be <20 G .

DC COUPLED PIN-PHOTODIODE TO THE A250

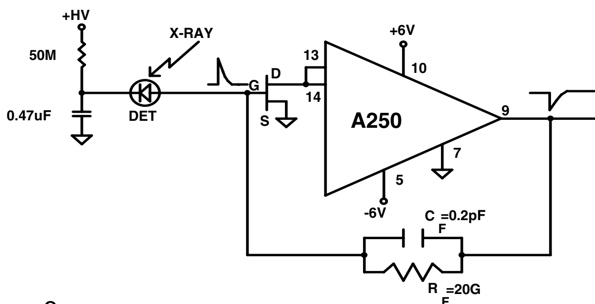

Figure 6

For DC coupled detector systems, the detector leakage current must be added to the gate leakage current in the DCV_{out} formula above. Usually, detector leakage dominates FET leakage. For example, with a 1 nA detector leakage current and DCV_{out}= -2V, R_f must be less than 1 G .
In very high resolution systems measuring X-Rays or Gamma Rays other methods are used in order to discharge the feedback capacitor. These methods are optical pulsed feedback, and transistor reset circuits.
(see ref.5,6)

THE POST AMPLIFIER AND ITS SHAPING TIME CONSTANT (see ref. 4)

The purpose of the post amplifier is to provide amplification and to filter out low and high frequency noise. This amplifier should be of low noise, typically less than 4 nV/ Hz. Most operational amplifiers are too noisy or have insufficient gain-bandwidth or slew rate to be suitable for shaping amplifiers.
The shaping time constant in the post amplifier should be selected for each application. For room temperature experiments the shaping time constant is usually between 0.5 s and 3 s. For cooled experiments greater than 3 s is used.
There are many types of shaping methods used to filter out low and high frequency noise (RC-RC, Gaussian, Cusp, Triangular, Trapezoidal and others). The most commonly used is the Gaussian shaper. An example of a 3 pole Gaussian shaper is given at the back of the A250 specifications and of a 5 pole Gaussian shaper at the back of the A275 specifications. Increasing the number of poles normally improves the symmetry of the output pulse, which improves the noise and count rate performance of the system.

Example: For a cooled system to reach a total noise of about 20 electrons RMS (180 eV FWHM, Si):

a) The detector must have a low capacitance.
b) The detector leakage must decrease at low temperatures.
c) The FET must withstand the low temperatures and $C_{iss} = C_d$.
d) The preamplifier must incorporate optical feedback or transistor reset.
e) The post amplifier must have low noise (like the A275) and correct shaping time constant (longer than 3 s).

The A250 did not enter into the considerations because its noise contribution is negligible compared to that of the input FET and detector.

References:

1) ANSI/IEEE Std 301-1988, IEEE Standard Test Procedures for Amplifiers and Preamplifiers used with Detectors of Ionizing Radiation.
2) ANSI/IEEE Std 300-1988, IEEE Standard Test Procedures for Semiconductor Charged Particle Detectors.
3) ANSI/IEEE Std 325-1986, IEEE Standard Test Procedures for Germanium Gamma-Ray Detectors.
4) "Signal Processing for Semiconductor Detectors" F.S. Goulding and D.A. Landis, IEEE Transaction of Nuclear Science, Vol. NS-29, No 3, June 1982.
5) "Transistor Reset Preamplifier for High Rate High Resolution Spectroscopy" D.A. Landis, C.P. Cork, N.W. Madden, and F.S. Goulding, IEEE Transactions of Nuclear Science, Vol. NS-29, No.1, February 1982.
6) "An Improved operating Mode for a Si(Li) X-Ray Spectrometer" N.W. Madden, F.S. Goulding, J.M. Jaklevic, D.A. Landis and C.S. Rossington, IEEE Transactions of Nuclear Science, Vol. 37, No 2, April 1990.
7) “Nuclear Electronics” P.W. Nicholson, UMI, Books on Demand, 300 North Zeeb Rd., Ann Arbor, MI 48106-1346.

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