Chemistry 985

Fall, 2o19 | Exam # 2 Practice

Distributed: Wed., 26 Nov. 19 | Due: ?

1. Describe the terms, or distinctions between the terms, used to describe vacuum equipment:
   (a) Effective speed of a pump
   (b) virtual leak
   (c) Pirani vs. Penning Vacuum Gauge
   (d) Hot cathode vs. Cold cathode Vacuum Gauge

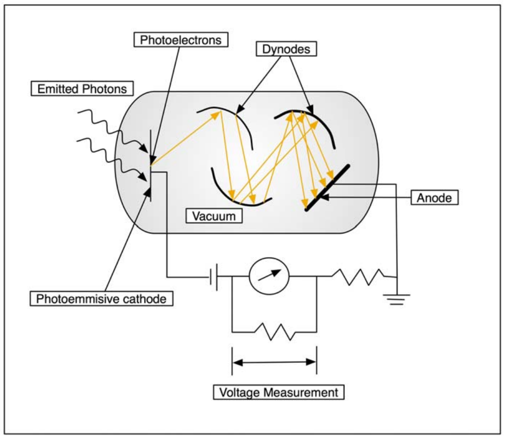
2. A certain Flash ADC model used in nuclear physics experiments uses the ADS4249 chip from Texas Instruments. This is a (two input) 250 MSPS 12-bit ADC for continuous processing of 0 to 2 V signals and the spec sheet gives a DNL = -0.95 / +1.7 LSB while the maximum INL = 4.5 LSB. Consider a 1.500 V signal that should be converted to 3/4 of full scale, what are the maximum and minumum values of the channel number that you could expect the ADC to report based on the manufacturer's specifications?

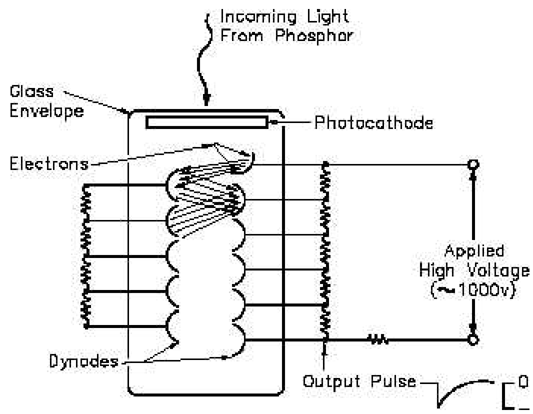
3. What is the ratio of the mean number of photons created in a standard 3"x3" NaI(Tl) detector by the photopeak of the background ^{40}K activity to that created by the average cosmic ray that crosses a diameter of the crystal?

4. The muon detector array for the G-2 experiment relies on detecting the Cherenkov photons from relativistic muons traveling through a PbF_2 "scintillator" read out with a SiPM array. The characteristics of the device were recently reported by Fienberg, et al. in NIM A783(2015)12. They report that the light output, W, is 1.45 photoelectrons/MeV (cf. Fig.10) and that the variance of the observed signal has two terms, the first is a constant for the light collection and the second for the scintillator. They write in Eq. 10:
$$\frac{\sigma_E}{E} = \sqrt{(1.5\%)^2 + \frac{a^2}{E(in\ GeV)}}$$
where a = 3.4%. Make an estimate of the Fano factor for this scintillator from this data.

5. A cylindrical gas proportional counter was used to detect charged particles that deposited 2.00 MeV in gas. The tube had an anode radius of 0.0050 cm, a cathode radius of 5.0 cm, and was filled with P-10 gas at 1.00 atm pressure. If the applied voltage was 3.000 kV, then:
   (a) Calculate the average number of ion pairs in the gas.
   (b) Calculate the multiplication factor for this detector.
   (c) Estimate the amplitude of the voltage pulses into a capacitance of 20 pF.

6. Consider the four figures shown below that were included in descriptions of photomultiplier tubes found on the web (Nov, 2019). Clearly indicate what is wrong with each schematic depiction of a PMT and/or its operation.





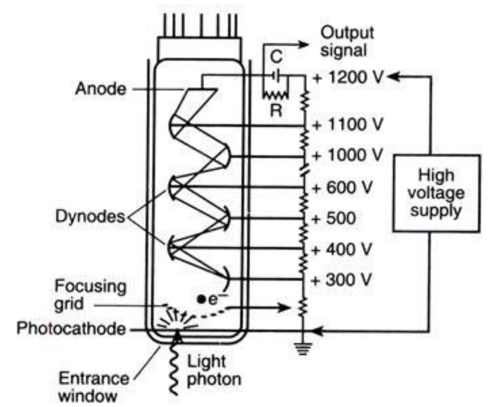
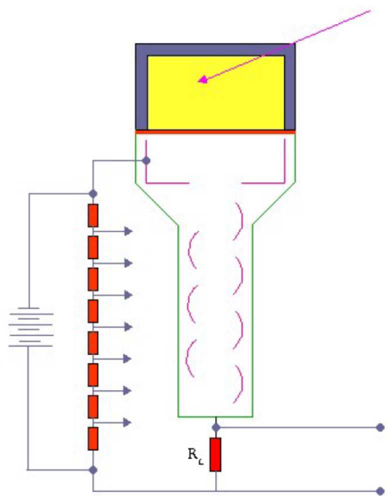
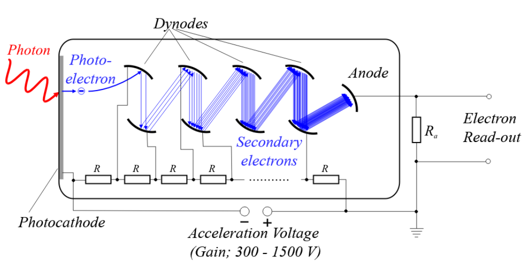
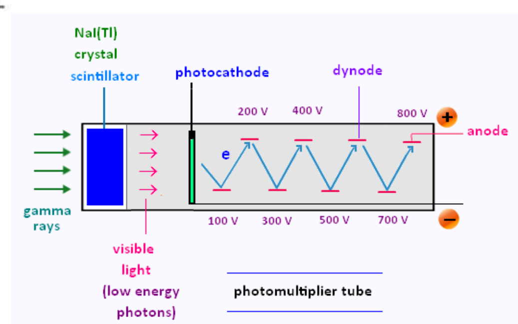


Fig. 13.14: Details and mode of action of photomultiplier tube



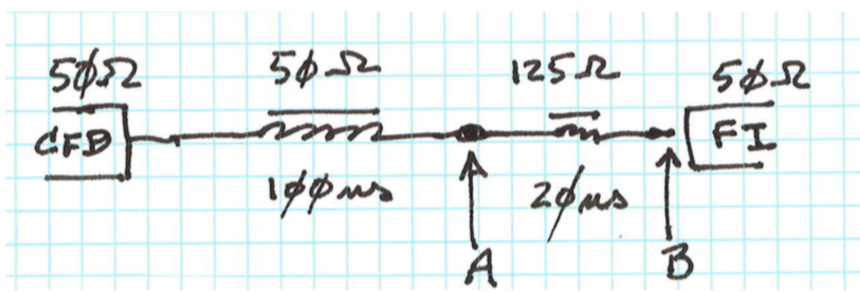




7. Based on the information in the attached spec-sheet from CREMAT corporation for their CR-110 preamp, (a) what is the gain in V/MeV in silicon, (b) what is the ENC (RMS or FWHM) of this device (alone) in keV when it is used with a PPAC detector filled with P-10 gas, and (c) what is their predicted rise time for the pulse out of the preamp when the preamp is connected to a (1-dimensional) NSCL 10x10 cm^2 PPAC that has a 3 mm anode-cathode gap [a formula for a parallel plate capacitance was given in lecture]?

8. The logic signal output from a constant fraction discriminator (CFD, Z=50Ω) was sent down a high quality RG-213/U delay line (50Ω, 100 ns long) and then connected with a 20 ns cable to a Fan-In (logical OR, Z=50Ω). A new student randomly picks a Z=125Ω cable to make the connection between the output of the delay line and the Fan-In. Make a sketch of the time dependence of the voltage signal that will appear at the input of the Fan-In if a NIM-standard pulse that is 10 ns wide is output by the CFD. You can assume that the output of the CFD can absorb incoming pulses.

$$\frac{V_{\text{refl}}}{V_{\text{inc}}} = \frac{Z_L - Z_0}{Z_L + Z_0} \qquad\qquad \frac{V_L}{V_{\text{inc}}} = \frac{2Z_L}{Z_L + Z_0}$$



CR-110 charge sensitive preamplifier: application guide

Rev. 2 (Dec. 2012)

General Description

Cremat's CR-110 is a single channel charge sensitive preamplifier module intended for use with various types of radiation detectors including semiconductor detectors (e.g. CdTe and CZT), p-i-n photodiodes, avalanche photodiodes (APDs), and various gas-based detectors. The CR-110 is one of a series of four charge sensitive preamplifiers offered by Cremat, which differ from each other most notably by their gain. A guide to selecting the best charge sensitive preamplifier for your application can be found at our web site: http://cremat.com. As with all Cremat's preamplifier modules, the CR-110 is small (less than one square inch in area), allowing for compact multichannel detection systems to be constructed using a modular design.

Detector coupling

The CR-110 can be used either in a direct coupled (DC) mode, or an AC coupled mode. If the detector current exceeds 10 nA, it is recommended that an AC coupled mode be used to prevent the resulting DC offset of the preamplifier output from saturating. Low frequency detector current (e.g. 'dark' current, or leakage current) produces an offset in the preamplifier output voltage at a rate of 0.2 V per nA. The use of AC coupling also is useful in improving the counting rate capability of the preamplifier. A schematic diagram of an AC-coupled charge sensitive preamplifier detection circuit can be found at **http://cremat.com/CSP_app_notes.htm**

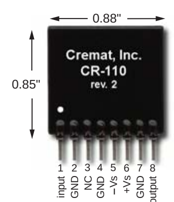


Figure 1

Package Specifications

The CR-110 circuit is contacted via an 8-pin SIP connection (0.100" spacing). Leads are 0.020 inches wide. Pin 1 is marked with a white dot for identification.

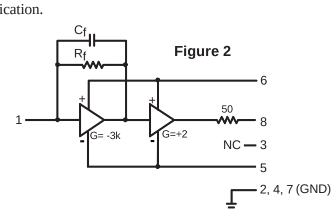


Figure 2

Equivalent circuit diagram

Figure 2 above shows a simplified equivalent circuit diagram of the CR-110, which is a two stage amplifier. The first stage is high gain, and the second stage is low gain with an emphasis on supplying sufficient output current to drive a terminated coaxial cable. Pin numbers corresponding with the CR-110 preamplifier are shown. R_f (100 MΩ) and C_f (1.4 pF) are the feedback resistor and capacitor respectively.

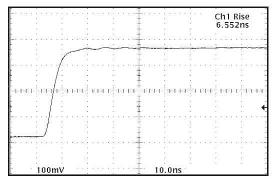
Output waveform

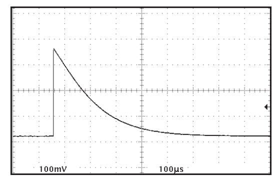
Charge sensitive preamplifiers are used when radiation is detected as a series of pulses, resulting in brief bursts of current flowing into or out of the preamplifier input. Depending on the type of detector, this burst of current may be very brief (<1 ns) or as long as a few µs. For an idealized detection current pulse taking the form of a delta function, the detected charge (time integral of the input current) will ideally take the form of a step function.

The output waveform of an actual charge sensitive preamplifier will of course have a non-zero rise time: for the CR-110 this figure is approximately 7 ns. Furthermore, capacitance at the preamplifier input (i.e. detector capacitance) will further slow the rise time at a rate of 0.4 ns / pF.

Keep in mind the output rise time will also be limited by the speed of the detector. For example, the detection current pulse from a CsI(Tl)/photodiode scintillation detector has a duration of approximately a couple µs, so the expected rise time of the charge sensitive preamplifier output will be at least that long.

The output waveform of the CR-110 using a capacitively-coupled fast square wave pulser at the input is shown below to the left. At long time domains, the output decays due to the discharge of the feedback capacitor through the feedback resistor, with an RC time constant of 140 µs. This decay of the output waveform is also shown below, to the right.





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Specifications

Assume temp =20 °C, V_s = ±6.1V, unloaded output

	CR-110	**units**
Preamplification channels	1	
Equivalent noise charge (ENC)*		
ENC RMS	200	electrons
	0.03	femtoCoul.
Equivalent noise in silicon	1.7	keV (FWHM)
Equivalent noise in CdZnTe	2.4	keV (FWHM)
ENC slope	4	elect. RMS /pF
Gain	1.4	volts /pC
Rise time **	7	ns
Decay time constant	140	µs
Unsaturated output swing	-3 to +3	volts
Maximum charge detectable per event	1.3×10^7	electrons
	2.1	pC
Power supply voltage (V_s)		
maximum	V_s = ±13	volts
minimum	V_s = ±6	volts
Power supply current (pos)	7.5	mA
(neg)	3.5	mA
Power dissipation	70	mW
Operating temperature	-40 to +85	°C
Output offset	+0.2 to -0.2	volts
Output impedance	50	ohms

* Measured with input unconnected, using Gaussian shaping amplifier with time constant =1 µs. With a detector attached to the input, noise from the detector capacitance, leakage current, and dielectric losses will add to this figure.

** Pulse rise time (defined as the time to attain 90% of maximum value) has a linear relationship with input capacitance. Value cited in the table assumes zero added input capacitance. To calculate pulse rise time for practical situations, use the equation: $t_r = 0.4\, C_d + 7$ ns, where t_r is the pulse rise time in ns, and C_d is the added capacitance (e.g. detector capacitance) in pF. Keep in mind that others factors within the detection system may further limit this value.