The Channeltron® Electron Multiplier
Model CEM 4010

(Technical Applications Note 9803)

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INTRODUCTION

Windowless Electron Multipliers

Electron multipliers can amplify electron beams by a factor of 10^8 or greater. Their operation is based on the secondary electron emission phenomenon. Electron multipliers must be operated in a vacuum environment to minimize the interference of gas molecules with the electron beams. A familiar application of electron multipliers is in multiplier phototubes.

There are many applications which require that the electron multiplier be windowless, that is, not enclosed in a vacuum tube. In these applications the quanta to be measured are converted directly to secondary electrons at the low potential end of the dynode structure. Low energy ions and electrons (100 ev to 100 KEV) are detected in this manner. Windowless multipliers are also the most sensitive detectors for photons with equivalent wavelengths between 100 Angstroms (soft X-ray) and 1150 Angstroms (vacuum ultraviolet).

Windowless electron multipliers require a vacuum environment just as those used in vacuum multiplier phototubes. Generally this vacuum is existant in equipment or experiments in which the windowless multipliers are used (mass spectrometers, vacuum UV spectrometers, charged particle energy analyzers, etc.).

As a matter of convenience, windowless multipliers should be exposable to air, either when not in use or when the vacuum chamber is opened to air. Unfortunately, conventional discrete dynode electron multipliers tend to lose a considerable percentage of their gain under conditions of repeated air exposure. Consequently, the multiplier must either be replaced or rejuvenated if possible.

The Bendix Channeltron® Electron Multiplier

The Bendix Channeltron® Electron Multiplier exhibits all of the advantages of windowless electron multipliers. Because of their unique semi-conducting dynode surface, Bendix CEMs maintain their excellent performance characteristics when exposed to air. Special care to keep them under vacuum is not required - they can be handled in the same manner as any component for high vacuum applications.

The Bendix CEM is an electrostatic device with a continuous semi-conducting dynode surface - only two electrical connections are required to establish the necessary voltage distribution for electron multiplication. There is no requirement for a special voltage divider network as is the case with discrete dynode electron multipliers.

The CEM 4010 model was designed specifically for rocket probe investigations of the auroral plasma but has been found to be ideally suited for any application requiring a windowless electron multiplier of small size, light weight, low power consumption, and high electron gain.

Principles of Operation

Basically, a CEM is a hollow glass tube, its inside surface coated with a semi-conducting material. This material serves as the secondary electron emitting dynode surface and also as the voltage divider which establishes the electrostatic field required for acceleration of the secondary electrons.

A particle or photon is detected when it enters the input aperture and impinges on the dynode surface. Electrons are emitted and are accelerated along the axis of the CEM due to the influence of the electrostatic field. Because these electrons have an initial emission velocity they collide with the inner wall of the CEM before they have the opportunity to traverse its entire length. Upon collision with the wall, additional electrons are released and the process is repeated. CEMs are designed to that the number of collisions (stages) and the gain per stage (ratio of the number of secondary electrons per primary electron) result in overall device gain of greater than 10^8.

To summarize, if a single particle or photon enters the CEM input aperture and causes the emission of electrons from the dynode, then a charge pulse containing millions of electrons will emerge from the output aperture.

A more detailed description of the theory of CEM operation is contained in the literature (References 1-7).

PERFORMANCE SPECIFICATIONS
CHANNELTRON® ELECTRON MULTIPLIER CEM 4010

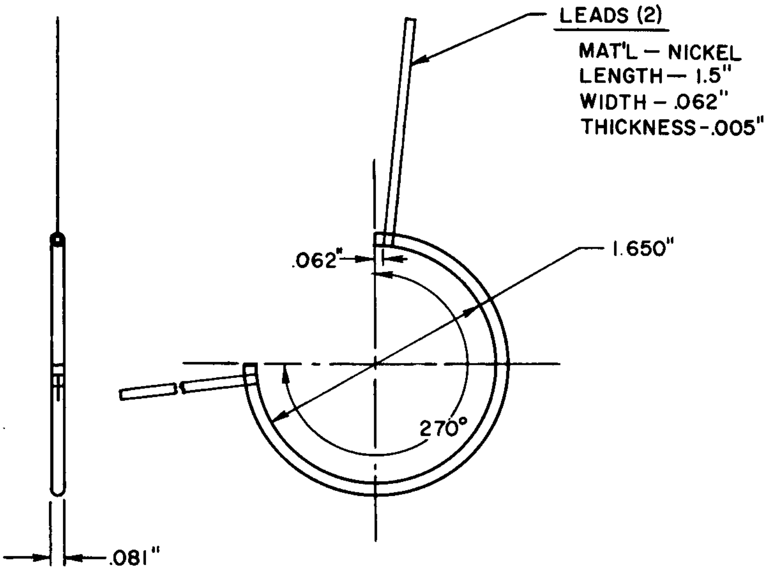


Figure 1 CHANNELTRON® Electron Multiplier

Spectral Response:	1500 Angstroms to below 2 Angstroms (See Figure 2)
Response to Particles:	Absolute detection efficiency data for particles is not extensive, however, CEMs have been used successfully for detection of: electrons (50 eV to 1 MeV) protons (2KeV to 1MeV) positive ions (1 to 238 AMU 2KeV) metastable helium, oxygen, nitrogen Absolute detection efficiency for low energy electrons is shown in Figure 3.
Electron Gain:	See Figure 4
Background Count Rate:	Less than 2 counts/minute
Pulse Height Resolution:	See Figure 5.

Output Current Pulse at 10^8 Gain:	Rectangular; 25 nsec wide, 0.6 ma
Operating Temperature Range:	-30°C to $+60^\circ$C
Dynode Surface Resistance	10^9 ohms (at room temperature) 1.5×10^9 ohms at -30°C 0.8×10^9 ohms at $+60^\circ$C
Maximum Output Current for Linear Analog Response:	$(0.1 \frac{V}{R})$ where V = operating voltage, R = dynode surface resistance
Electron Gain vs. Count Rate:	See Figure 6
Electron Gain vs. Accumulated Counts:	See Figure 7
Aperture Size:	1 mm diameter
Weight:	less than 1 gram
Collectors:	Capped collector supplied on request. Separate collector supplied by user. (See "Instructions for the use of the CEM 4010).

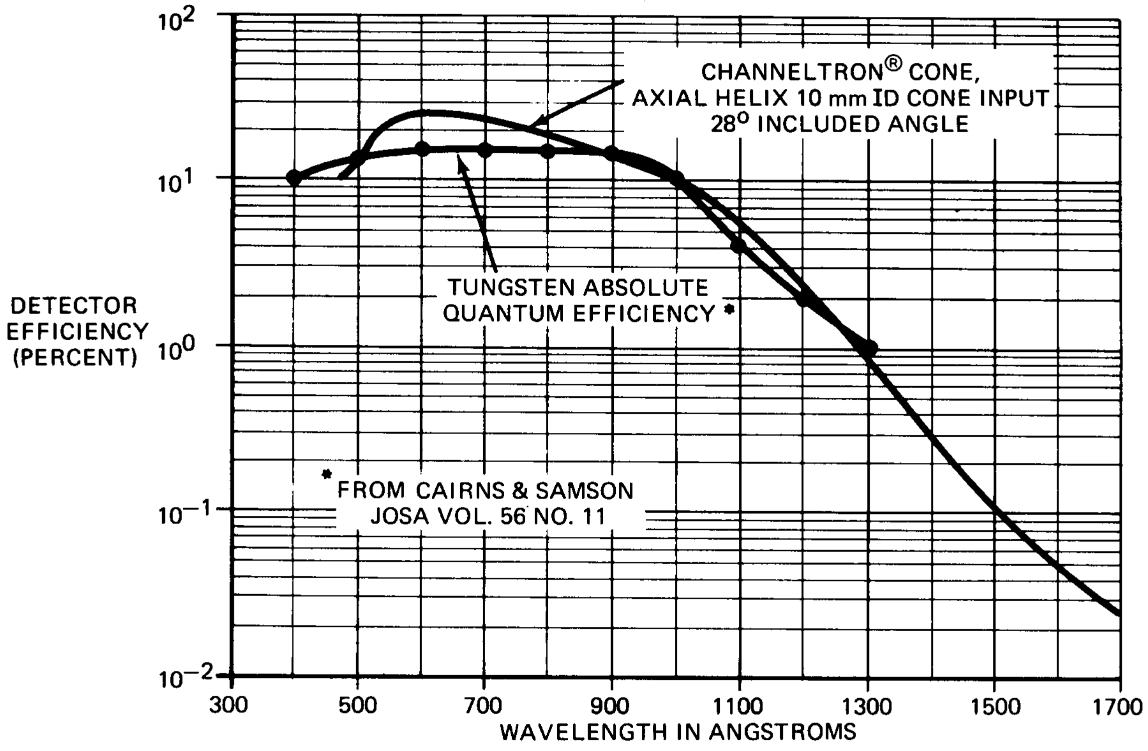


Figure 2 Spectral Response Of Channeltron® Electron Multipliers

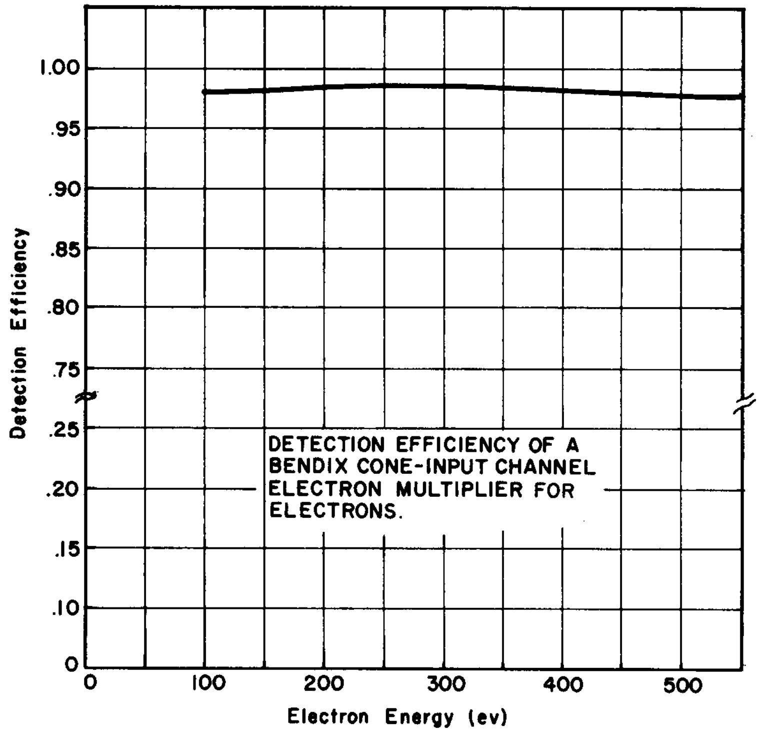


Figure 3 Response of Channeltron® Electron Multipliers for Low Energy Electrons

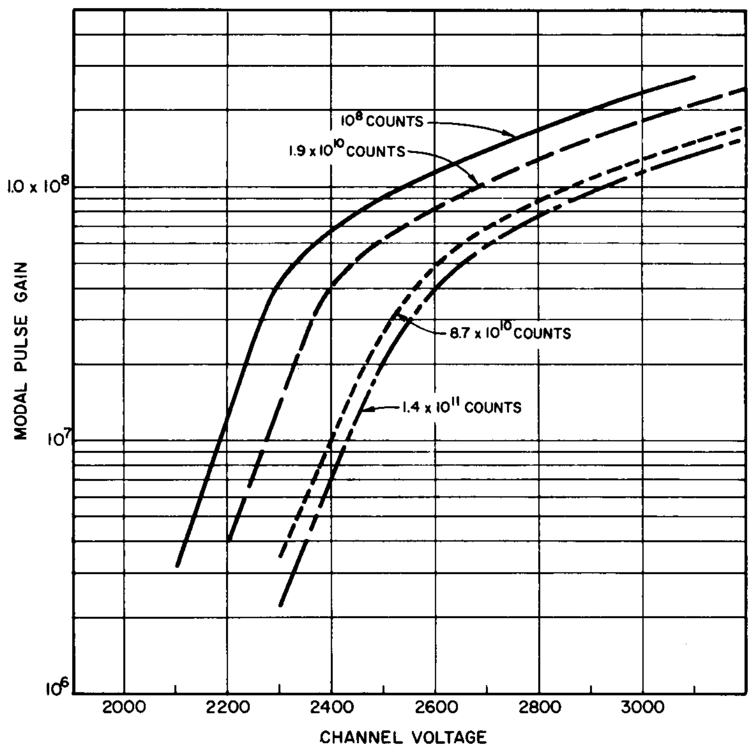


Figure 4 Gain as a Function of Channel Voltage (Accumulated Counts as a Parameter)

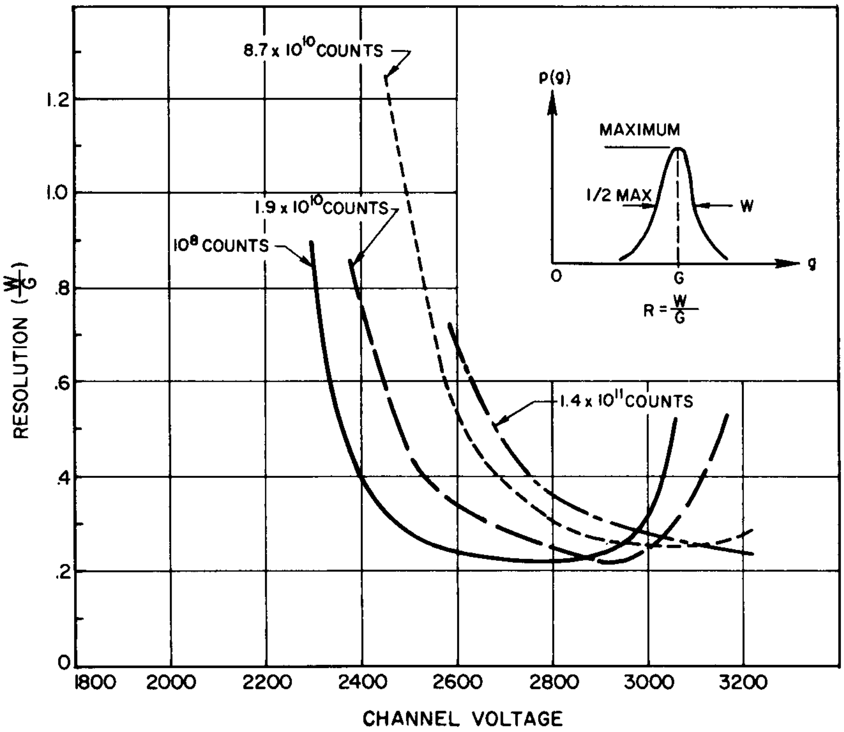


Figure 5 Pulse Height Resolution as a Function of Channel Voltage (Accumulated Counts as a Parameter)

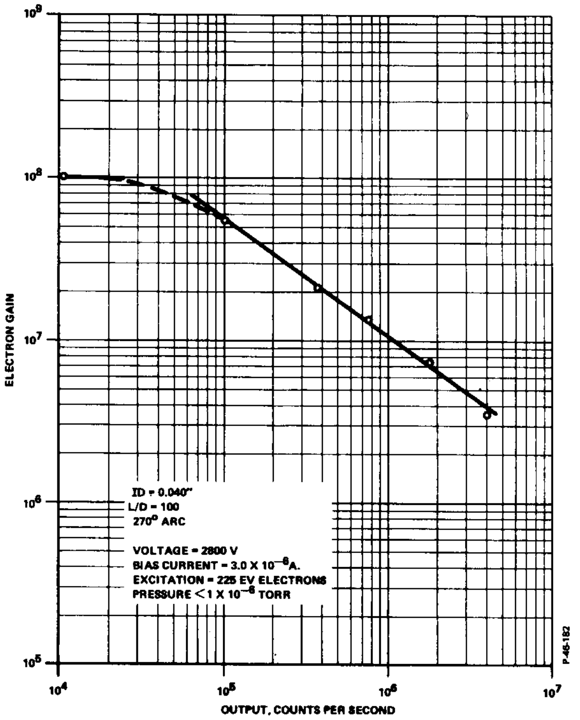


Figure 6 Electron Gain as a Function of Count Rate

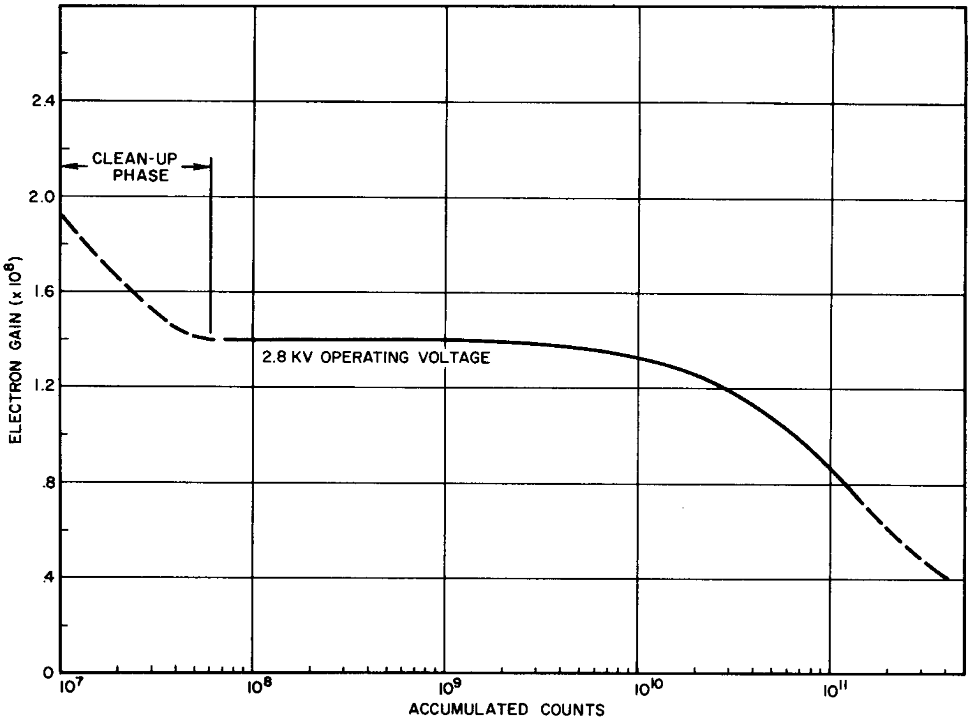


Figure 7 Electron Gain as a Function of Accumulated Counts

APPLICATIONS FOR THE CEM 4010

The CEM is used to its best advantage as a particle/photon counter in applications where a stable detector, exposable to air, with high electron gain and extremely low background noise is required.

The CEM background or "dark" count rate is less than 0.03 counts/second. Consequently, weak particle or photon signals as low as 0.3/second can be detected with a signal/noise ratio of 10 or better.

Because of its stability the CEM has been used with great success as a detector in commercial residual gas analyzers both in the pulse counting and analog modes. The CEM is the most sensitive detector for photons in the spectral region between the cut-off wavelengths of proportional counter windows (100 Angstroms) and lithium fluoride multiplier phototube faceplates (1150 Angstroms). A few examples of the applications in which CEMs have been used are:

measurement of photoionization cross sections
measurement of ionization potentials
measurement of angular distribution of secondary electrons
measurement of ion and electron density in the upper atmosphere and outer space
field ion microscopes
XUV adsorption spectroscopes
mass spectrometers
electron and proton energy spectrometers
scanning electron microscopes

CEM OPERATION

The CEM as a Counter

The high electron gain and narrow pulse height distribution make the CEM particularly well suited for pulse counting. Normally the output current pulses are integrated on the stray capacitance associated with the collector and the preamplifier input. The voltage signal resulting from the detection of a particle or photon (referred to the output of a unity gain preamplifier) is then

$$v_s(t) = \frac{ge}{C} e^{-t/RC} .$$

where g is the number of electrons in the output pulse, e is the electron charge, C is the stray capacitance and R is the value of the parallel combination of the CEM load resistor and the input resistance of the preamplifier. It is obviously advantageous to keep C as small as possible. This is normally done by locating the preamplifier in close proximity to the CEM collector in order to minimize the capacitance associated with electrical leads. The integrating time constant is equal to RC. This time constant should be about 0.1 usec to insure maximum amplitude of the signal pulse. A value for R of 10,000 ohms or greater is usually adequate.

The pulse height distribution obtained from CEMs are typically very narrow. Figure 5 indicates that the FWHM resolution is about 25% at 10^8 electron gain. The amount of charge contained in the output current pulses is approximated by a gaussian probability density distribution. This means that at 10^8 gain 70% of the pulses contain charge between (1.4 and 1.8) x 10^{-11} coulombs.

The practical consequences of the narrow pulse height distribution and high electron gain of the CEM are:

(1) Amplifiers do not have to be designed to handle signal pulses which vary in amplitude by as much as a factor of 1000 as is typically the case with conventional discrete dynode multipliers.

(2) Setting the discrimination level at about 10% of the average signal amplitude (as referred to the output of a unity gain preamplifier) insures that all signal pulses are counted. Furthermore, because most pulses have amplitudes ten times greater than the discrimination level, the signal count rate is unaffected by relatively large changes in either the discrimination level, the multiplier gain or the high voltage power supply.

Example

Assume:

(1) Electron multiplier average gain of 1×10^8, 25% FWHM resolution.

(2) Stray collector and preamplifier capacitance of 65 pfarads (this value is typical. Much lower values are realizable if the preamplifier is mounted within a few inches of the CEM collector).

(3) Preamplifier has unity voltage gain.

Calculate:

Average Pulse Amplitude: $$\bar{v} = \frac{(1.6 \times 10^{-19}) \times 10^8}{65 \times 10^{-12}}$$

$$\simeq 0.25 \text{ volt}$$

Pulse Spread: 70% of pulse between 0.22 volt and 0.28 volt

Discrimination Level: Set at 0.025 volt

Typical connection of the CEM for pulse counting applications is shown in Figure 8. A block diagram of digital readout instrumentation is seen in Figure 9. An emitter follower circuit which is easily made from stock item electronic components is shown in Figure 10. This circuit has been used successfully as a preamplifier at Bendix, and has been found to work exceptionally well with CEMs.

CEM Lifetime

Of major concern to the users of electron multipliers is its useful lifetime. Evaluations of this important characteristic have been carried out at Bendix Research Laboratories. The results of these evaluations are shown in Figure 7.

The useful lifetime of the CEM is primarily dependent on the sensitivity of the digital readout instrumentation. The example of the previous section will be used to illustrate the relationship between sensitivity and lifetime.

In the previous example, the discrimination level was at 0.025 volt. To insure that all pulses are counted, assume that the average signal amplitude should be at least four times greater than the discrimination level (about 0.1 volt). If the collector circuit is loaded with 65 picofarads stray capacity, the 0.1 volt signal level is equivalent to an electron gain of 4×10^7. The data of Figure 7 indicates that the gain will drop to this level after 4×10^{11} counts are accumulated. This accumulation is equivalent to one year's operation at 12,700 counts per second.

It should be remembered that the useful lifetime of the CEM can be extended by increasing the high voltage applied to it. Under normal operating conditions, lifetime should not be a critical factor when the CEM is used in the pulse-counting mode.

Dynamic Range - Pulse Counting Mode

Dynamic range is usually defined as the $\log_{10}$ of the ratio of highest to lowest signal rates detectable by the electron multiplier and its readout equipment.

The lowest signal rate that can be detected by the CEM is determined by its background count rate. The maximum signal rate obtainable is dependent on both the CEM gain characteristics and the sensitivity and pulse pair resolution of the digital readout instrumentation.

The background rate of the CEM 4010 is 0.03 counts per second or lower. If a digital signal to noise ratio of 10:1 is desired, then signals as low as 0.3 counts per second can be measured.

The upper count rate limitation is related to the output current capabilities of the CEM 4010. Its gain gradually decreases as the output current approaches 10% of the dynode bias current. In normal operation this decrease will begin at about 3×10^{-7} amps output current. The count rate at this current level is equivalent to

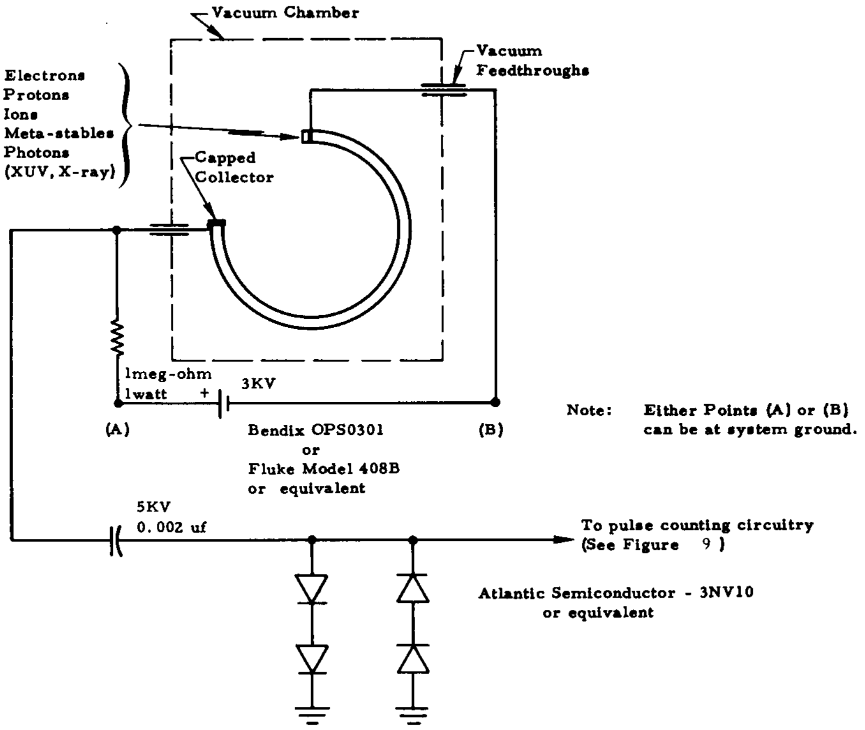
$$n = \frac{I_o}{eG}$$

or

$$n = \frac{(3 \times 10^{-7})}{(1.6 \times 10^{-19})(1 \times 10^{8})}$$

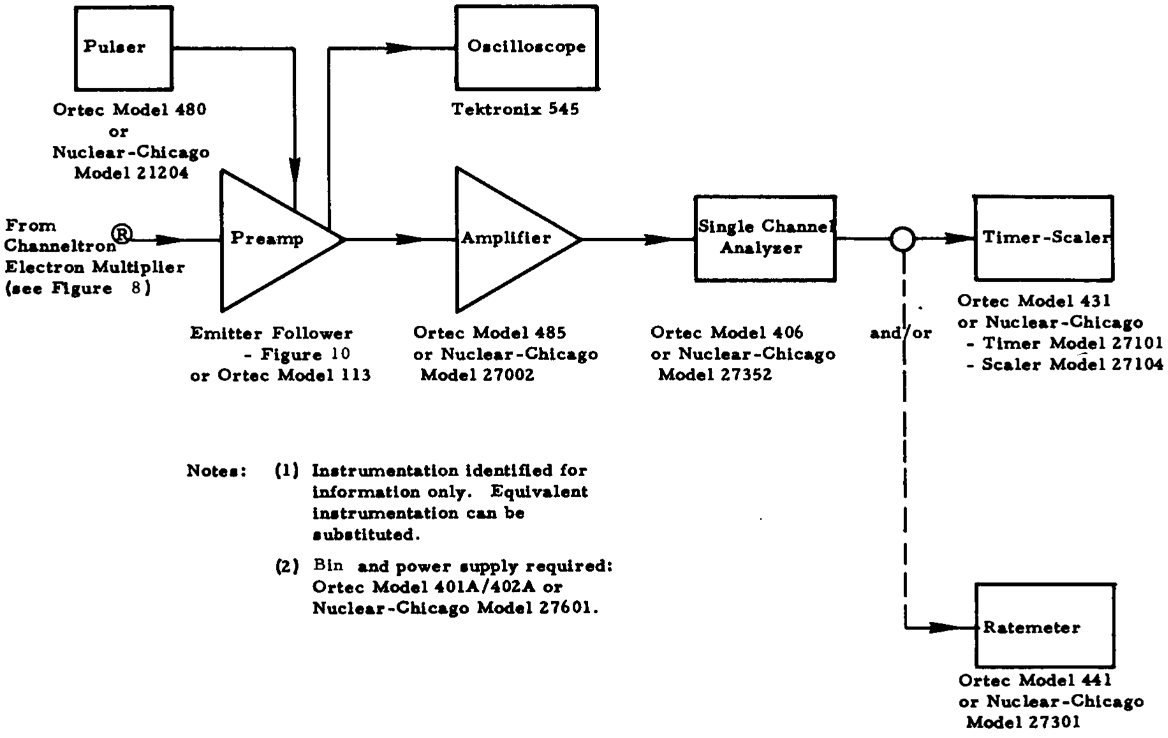
or about 2×10^4 counts per second, when the electron gain at low signal rates is 1×10^8. The gain vs. count rate characteristic is shown in Figure 6.

The gain of the CEM 4010 is 1×10^7 at 10^6 counts per second, according to Figure 6. If it is desired to measure this signal rate with a CEM, the digital instrumentation should be sensitive to charge pulses of 10^6 electrons and also should be capable of counting pulses spaced as close as 0.1 usecond.



Note: Either Points (A) or (B) can be at system ground.

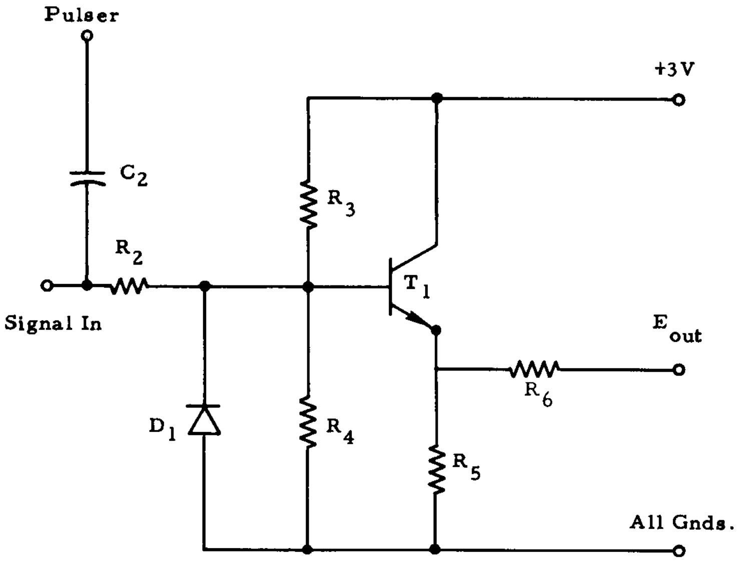
Figure 8 Typical Electrical Connections for Pulse Counting



Notes: (1) Instrumentation identified for information only. Equivalent instrumentation can be substituted.

(2) Bin and power supply required: Ortec Model 401A/402A or Nuclear-Chicago Model 27601.

Figure 9 Typical Digital Readout Instrumentation for Pulse Counting



R_2	Ohmite	1000 ohms
R_3		100 K-ohms
R_4		220 K-ohms
R_5		820 ohms
R_6		100 ohms
C_2	Mucon Corp.	1 pf 25V or equiv.
T_1		2N930
D_1		IN916

Figure 10 Schematic of Emitter Follower

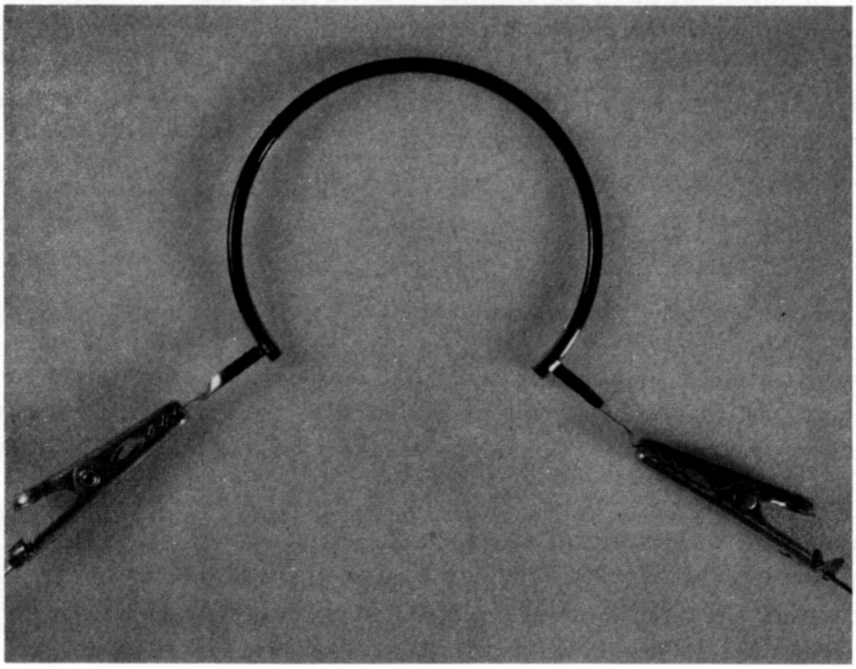


Figure 11 CEM 4010, Supported with Alligator Clip Leads

INSTRUCTIONS FOR THE USE OF THE CEM 4010

Storage

1. CEMs should not be contaminated with dust, lint, or other particulate matter.

2. The electron gain of Bendix CEMs is not reduced by exposure to normal laboratory environment. It is suggested, however, that prolonged exposure (two months or more) to high humidity be avoided by storing the multiplier in a dry box.

Handling

CEMs are used in vacuum equipment. They should be handled with the care normally given high-vacuum components.

1. The multipliers should not be handled with bare hands. Tweezers, talc-free finger cots or lint-free gloves are recommended.

2. Although it is unnecessary to handle CEMs in a dust-free clean room, it should be recognized that gross contamination with particulate matter can increase the normally low background noise level of these devices. It is recommended that they be handled in work areas where good housekeeping practices are maintained.

Operation

1. Mounting

   a. For applications where mechanical shock and vibration are not a factor, the leads supplied with the multiplier are usually adequate for its support. This method of support is shown in Figure 11.

   b. If more permanent support is desired, the multiplier can also be mounted on a block made of an insulating material which has a machined groove to serve as a recepticle for the CEM. Alumina, boron nitride, "Kel-F", "Supramica" have all been found to be satisfactory materials for this purpose.

2. Vacuum Requirements

   a. CEMs are typically operated at pressures of 1×10^{-5} torr or lower. Operation at relatively high pressure (1×10^{-5} or higher) increases the probability of spurious signals in the form of afterpulses.

b. CEMs should not have high voltage applied at pressures where arcing can occur (usually 1 x 10^{-3} torr or higher).

c. A liquid nitrogen cold trap will help to minimize backstreaming from oil diffusion pumps, thereby minimizing contamination of the CEM dynode surface.

3. Power Supply Requirements

a. The CEM requires as much as 3000 volts at 3 microamps for operation.

b. Figures 8 and 12 show typical connections of the high voltage circuit.

c. WARNING: Commercial high voltage supplies can be lethal. Care must be exercised in their use.

d. Ripple voltages should not trigger the counting circuitry when the CEM is operated in the pulse counting mode. A ripple specification of 50 mv peak to peak is normally adequate. The Bendix OPS-0301 power supply, Fluke Model 208B or the Ortec Model 446 high voltage supplies are typical of commercial equipment with excellent ripple specifications.

4. Digital Readout (Pulse-Counting Mode)

a. A capped collector is normally attached to the CEM when it is used for pulse counting. The capped collector is supplied by Bendix Electro-Optics Division on request. The gain of a CEM 4010 with capped collector is about 60% that of an uncapped unit.

b. Typical electrical connections for pulse counting is shown in Figure 8. Digital readout equipment which has been successfully used in pulse counting applications is shown in Figure 9.

c. The capacitance associated with the collector and preamplifier should be as low as possible to maximize the signal to noise ratio. Capacitance is minimized by connecting the preamplifier to the CEM output circuit with the shortest length of shielded cable that is convenient.

d. Circuits should be shielded so that the peak noise signal is about 10% of the average output pulse height referred to the output of a unity gain preamplifier. Because of the CEM's high electron gain, shielding requirements are usually easily fulfilled.

5. Analog Readout

a. Analog readout of the CEM output current requires a separate collector. A metal disc, two millimeters in diameter spaced approximately one millimeter from the end of the CEM serves as an excellent electron collector.

b. Typical electrical connections for analog readout are shown in Figure 12.

c. As shown in Figure 7, there will be a loss of gain immediately after the CEM is put into operation. The multiplier should either be allowed to stabilize for a few hours at an output current of about 0.3 microamps or provisions for calibrating multiplier gain should be provided.

d. The CEM will operate as a linear analog detector for output currents up to approximately 10% of the bias current. The dynode surface has a nominal resistance of 10^9 ohms. Therefore, the multiplier will be linear to

$$\left(\frac{V}{10^9} \times 0.1\right) \text{ amps}$$

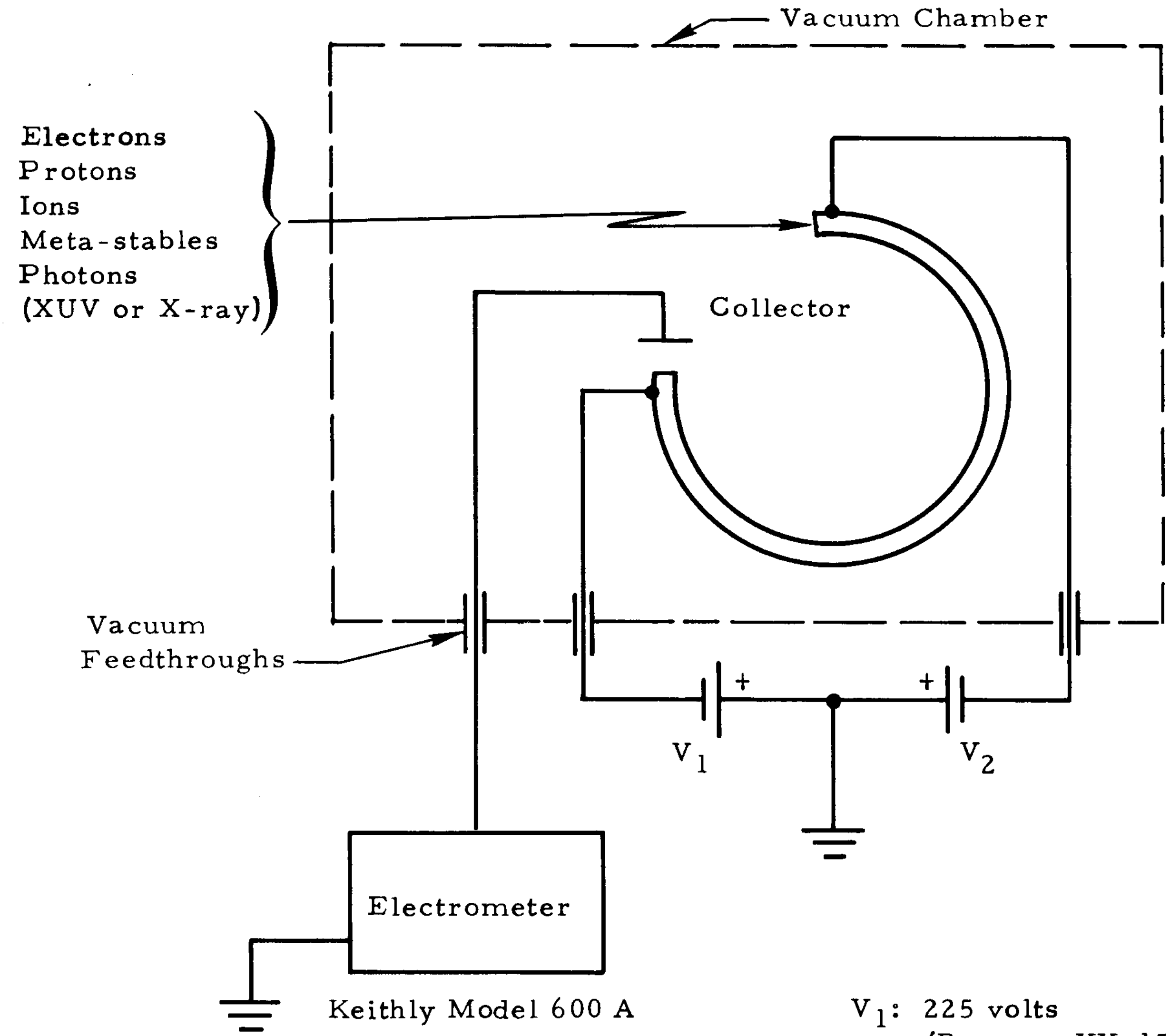
where V is the voltage applied to the CEM.

. Vacuum Bake Out

a. The uncapped CEM 4010 has been baked to 300°C under vacuum conditions.

b. Bake out decreases the initial gain of the CEM as compared to an unbaked CEM. For example, a baked CEM will require about 3000 volts for 10^8 electron gain, compared to about 2400 volts for the unbaked device.

c. CAUTION - The conductive epoxy used to attach the capped collector to the CEM 4010 is not bakeable above approximately 100°C.



V_1: 225 volts
(Burgess XX-150)

V_2: Bendix OPS0301
or Fluke Model 408B

Figure 12 Typical Electrical Connection for Analog Current Readout

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