PMT Circuits

ES168 – Fall 2009

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Photomultiplier Tubes

- Optoelectronic device for photon detection
- Consists of:
  - Vacuum Tube – shielded
  - Photocathode
  - Dynodes
  - Anode
  - Accompanying circuitry

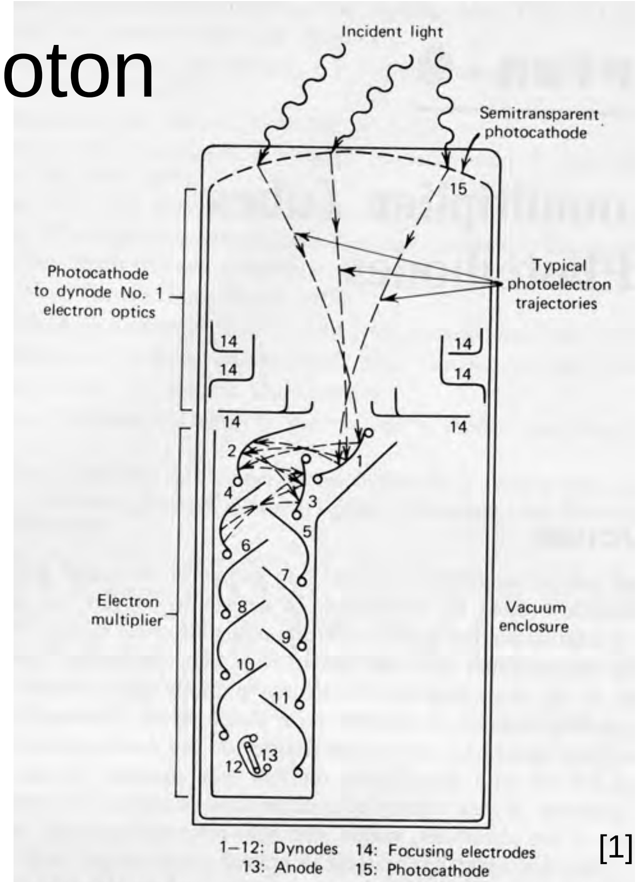


Figure 9-1 Basic elements of a PM tube. (From Ref. 1.)

[1]

Various PMT Configurations

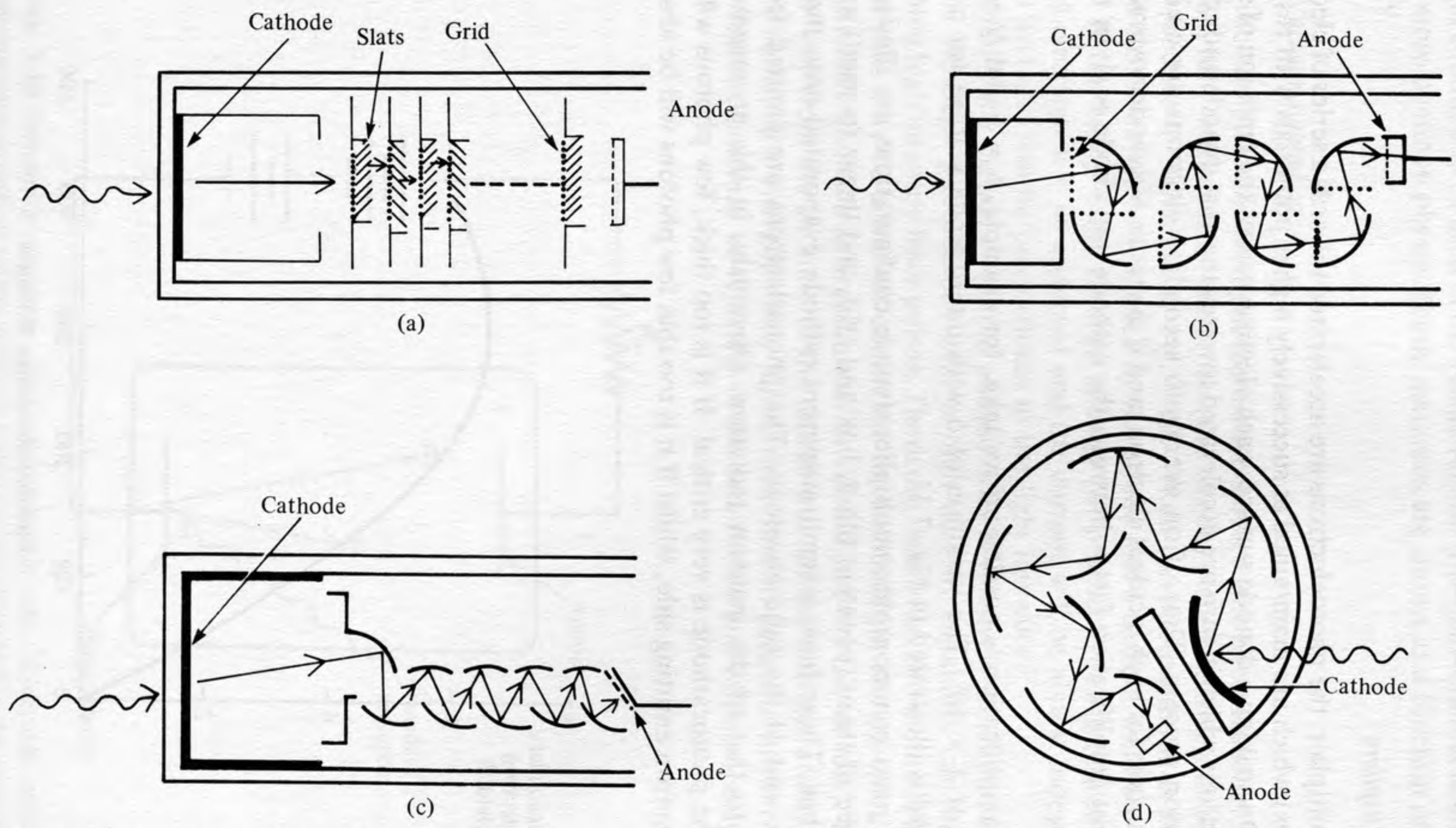


Fig. 7.12 Dynode structures of four common types of photomultiplier: (a) venetian blind, (b) box and grid, (c) linear focused and (d) circular cage focused. Typical trajectories of an electron through the systems are also shown.

[2]

PMT - Continuous Channel

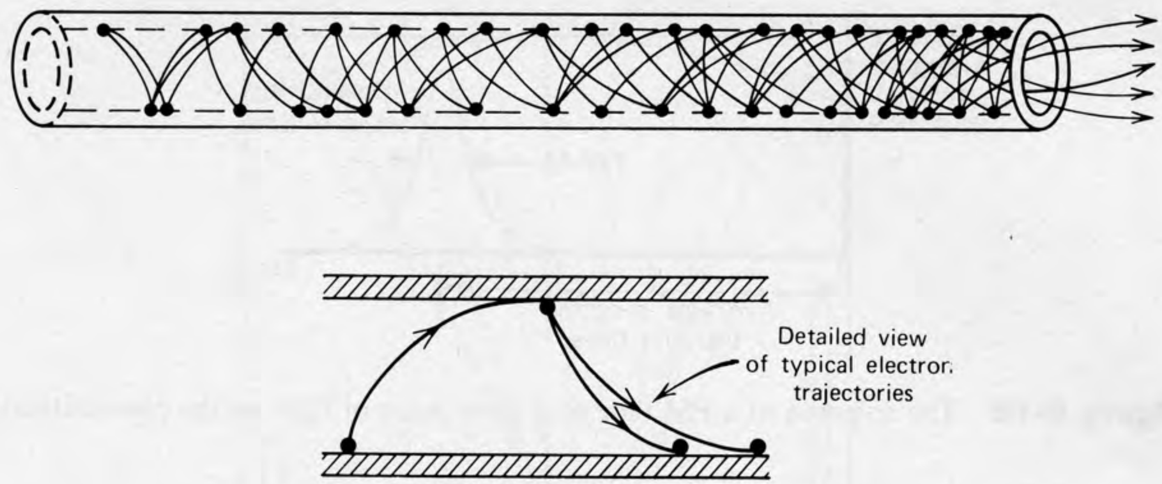


Figure 9-8 Continuous channel electron multiplier.

- Potential difference along length of tube
- Often curved to prevent positive feedback
- Electrical circuits only considered for classical configurations

Dynodes

- Increasingly positive voltage applied to each dynode
  - Accelerates electrons through tube
- Secondary emission results in multiple electrons escaping
- Secondary electron yield is related directly to dynode voltage

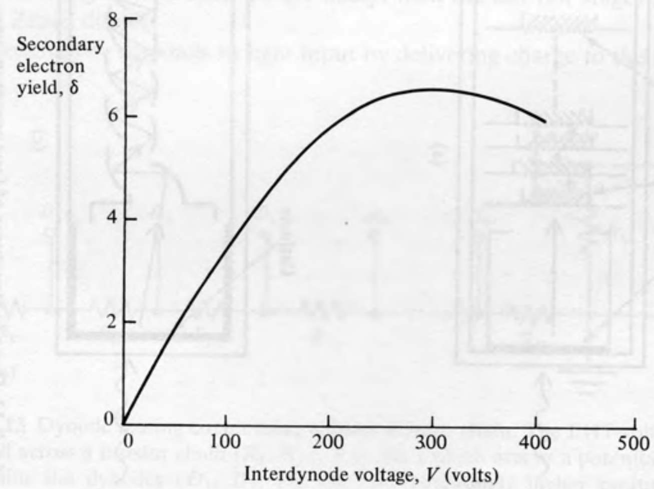


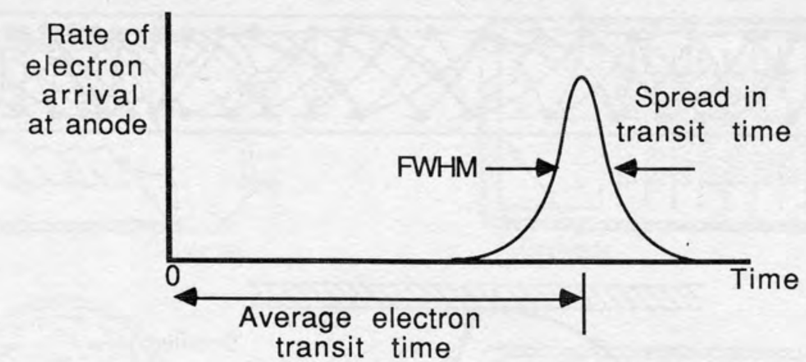
Fig. 7.11 Variation of secondary electron yield δ with interdynode voltage for Be–Cu dynodes.

[2]

$$G \approx \delta^N$$

PMT Transit Time

- Electrons generated from same pulse of light can arrive at anode at different times
- Due to:
  - differing entry trajectories
  - electrons emitted with differing energies
- Results in Gaussian spread in transit time at some average transit time
- Can significantly effect accompanying electronics



[1]

Figure 9-10 The response of a PM tube to a short pulse of light on the photocathode.

PMT Bleeder Circuits

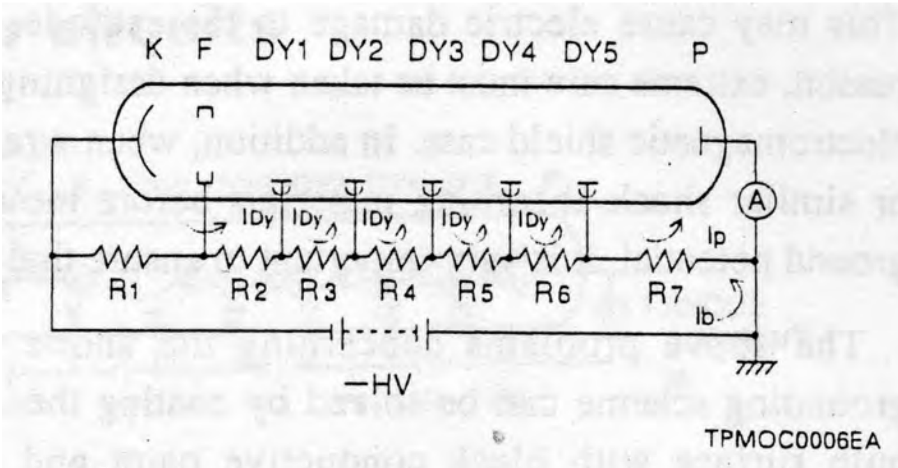


Figure 7-5: Basic operating circuit for a photomultiplier tube

[3]

- High voltage applied across the cathode (K) and the anode (P)
- Dynode voltages regulated by resistors
- Configurations for grounding either cathode or anode
- Diodes may be added to help regulate dynode voltages during operation

Bleeder circuit output characteristic

- Region A: linear region for low output current (low incident light)
- As light intensity increases, dynode voltages begin to vary from ideal (shift to earlier stages)
- Region B: shift results in increased current amplification
- Region C: saturation occurs as voltage between last dynode and anode goes to zero.
- If large linear region is desired – could use individual power supplies for each dynode.

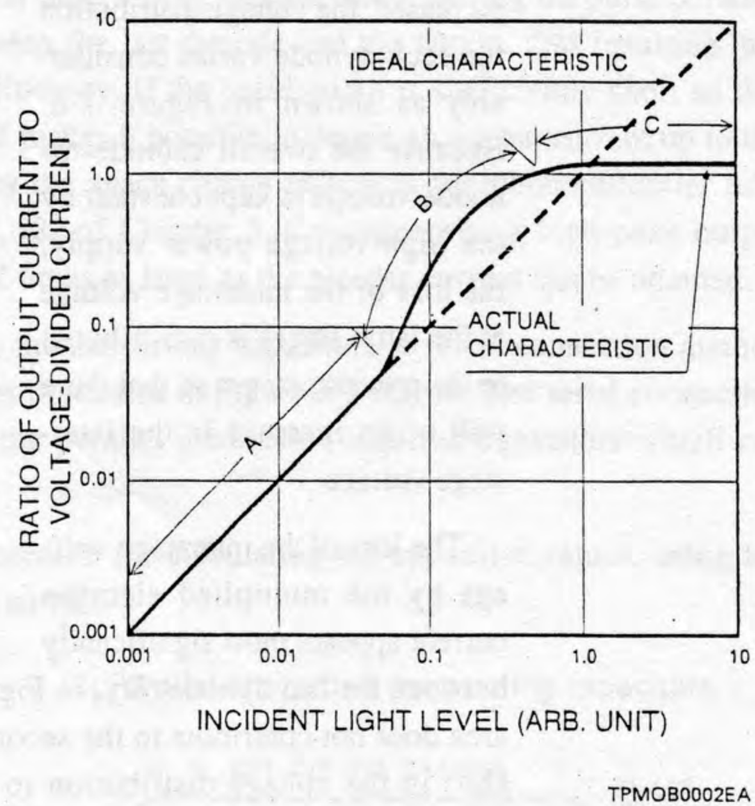


Figure 7-4: Output linearity of a photomultiplier tube

[3]

Pulse-operation output

- Operating the PMT in pulse mode runs into the same nonlinearity problem
- Decoupling capacitors can increase the linear operating region
  - If pulse width is short, they can decrease the voltage drop between last dynode and anode

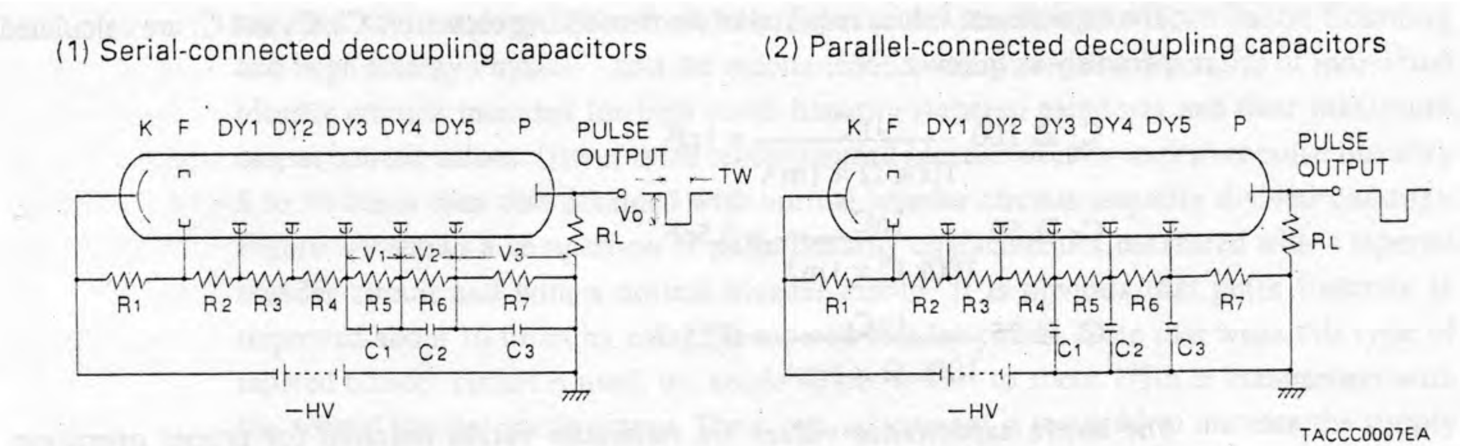


Figure 7-7: Bleeder circuits with decoupling capacitors added

[3]

Voltage distribution

- Saturation will always occur at some input intensity level
- Response can be further improved by using a “tapered bleeder circuit”
  - Alter resistor values so last few stages revive greater voltage gradient
- Voltage distribution levels are often listed for specific PMTs and applications

Cleaning-up Outputs

- Resistances should not be so small as to generate a lot of heat
  - Increased dark current, temp drift, and decreased power supply capacity
- A low pass filter on the high-voltage power supply can reduce noise
- Damping resistors can reduce ringing in output signal

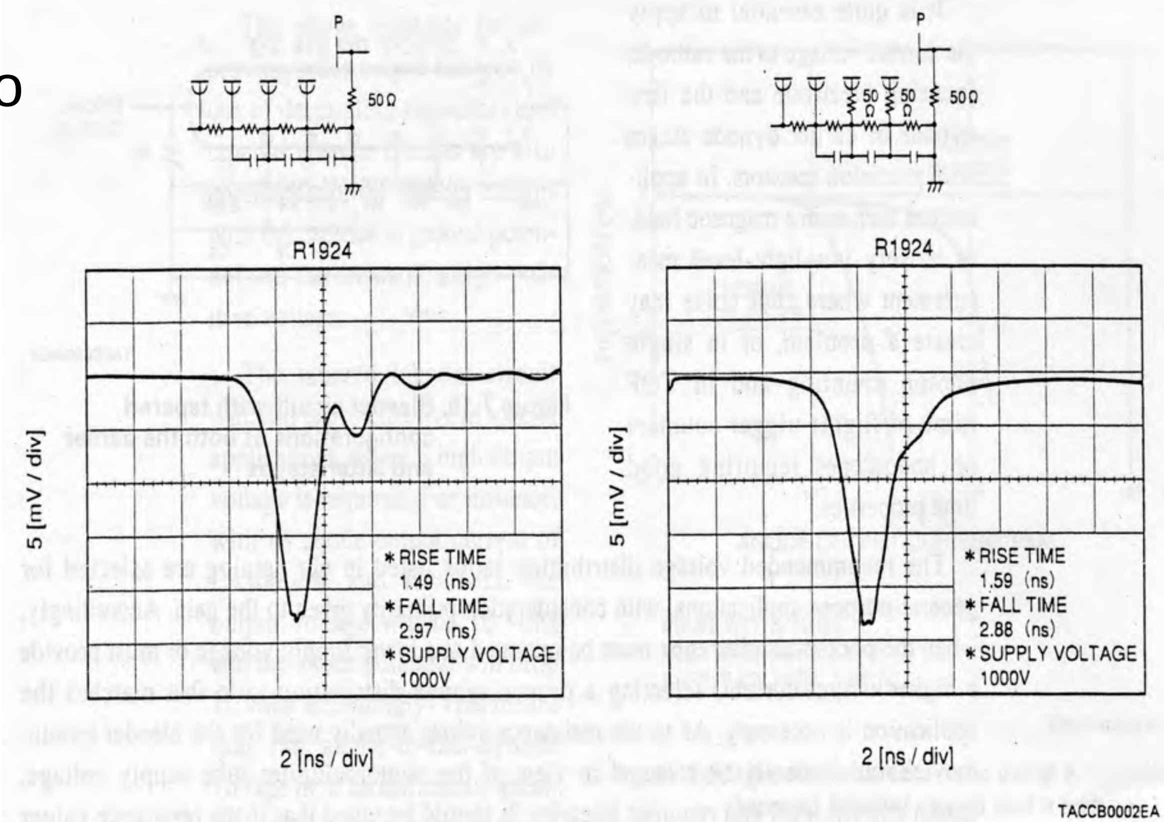


Figure 7-12: Effect of damping resistors on ringing

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Output Control Circuit

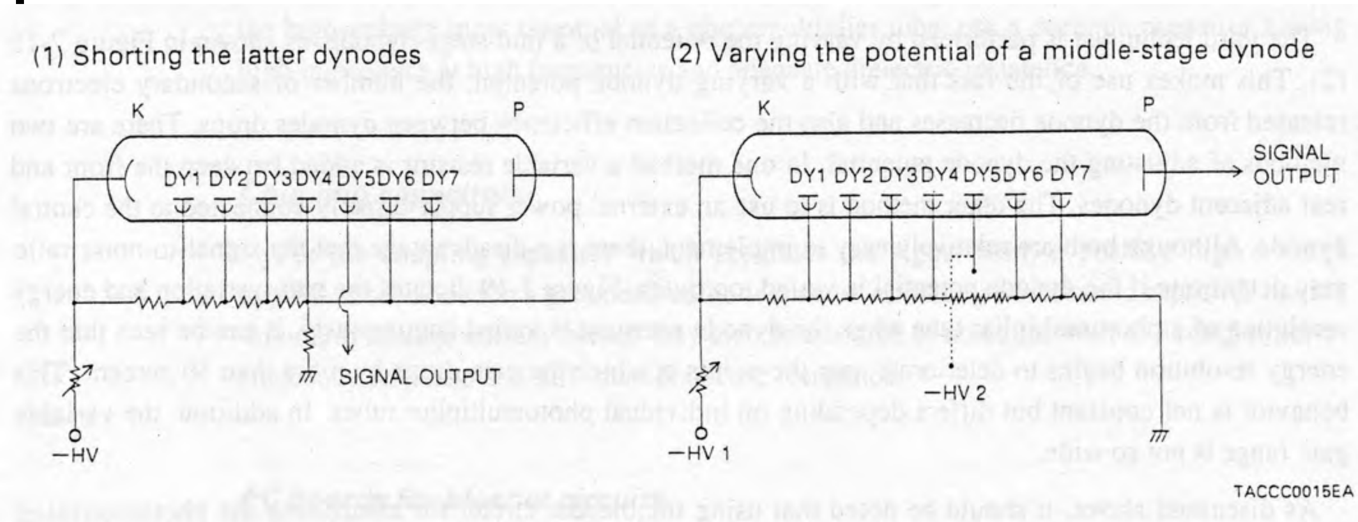

Figure 7-18: Output control circuits

[3]

- Variable resistor on power supply – affects PMT gain
- Shorting some stages increases inter-stage voltages by remove stages – effective if gain too high otherwise
- Driving mid stage dynode with 2nd source or variable resistor

Observing PMT Output

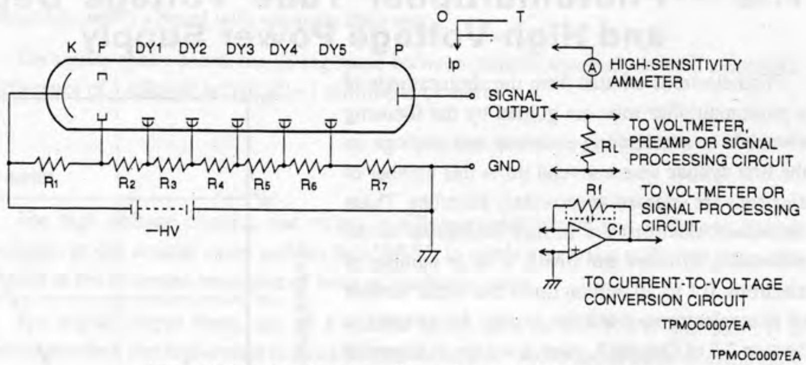

Figure 7-21: Anode grounding scheme in DC operation

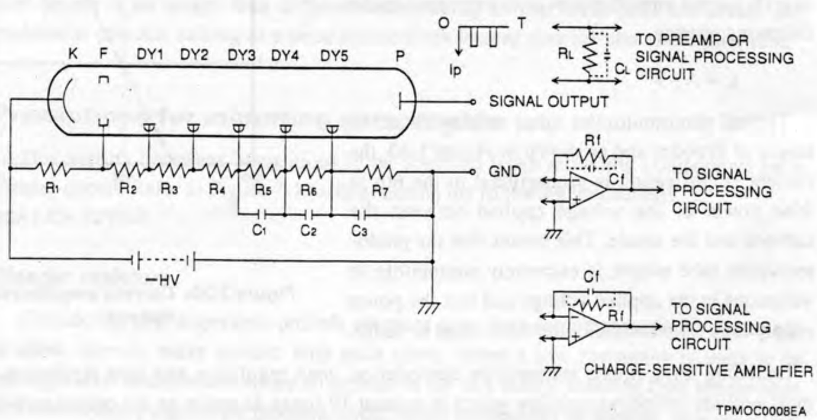

Figure 7-22: Anode grounding scheme in pulse operation

[3]

- Cathode and anode grounding circuits
- Coupling capacitor can be used to remove DC components from signal
  - Pulse width < time constant
  - Base-line shift if pulse period increases

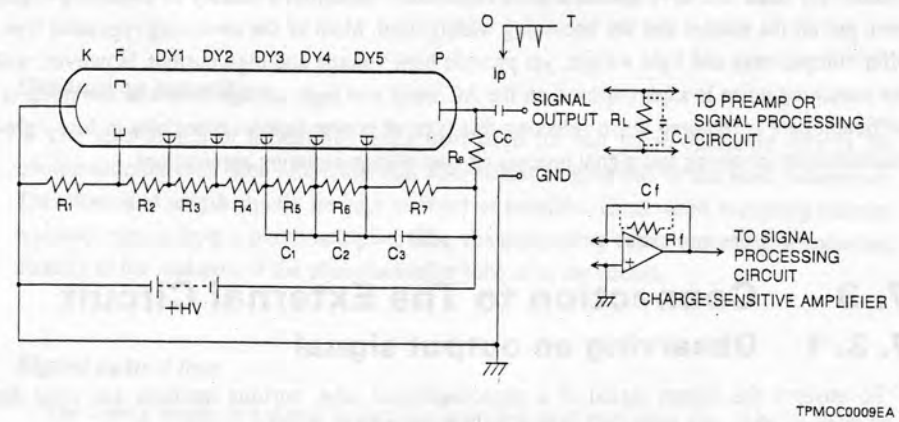

Figure 7-23: Cathode grounding scheme in pulse operation

[3]

Output Current to Voltage

- PMT output is a current
  - Often desire voltage output for use in signal processing circuit
- Can use load resistor or op-amps to convert current to voltage
  - Load resistance limited by desired frequency response and output linearity
    - $F_c = 1/(2\pi C_s R_L)$

Output Current to Voltage

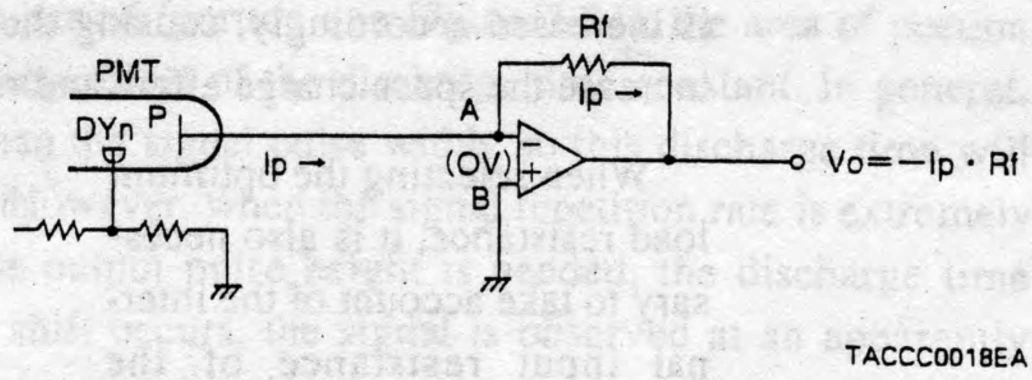

Figure 7-27: Current-to-voltage conversion circuit using an operational amplifier

[3]

$$V_o = -I_p * R_f$$

Charge Sensitive Amplifier

Integrator →

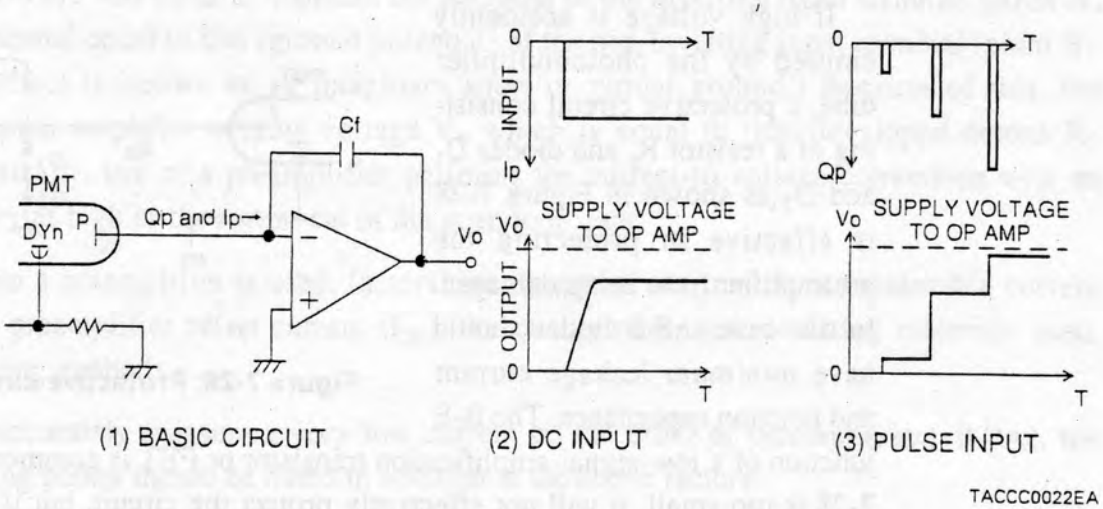

Figure 7-31: Charge-sensitive amplifier circuit and its operation [3]

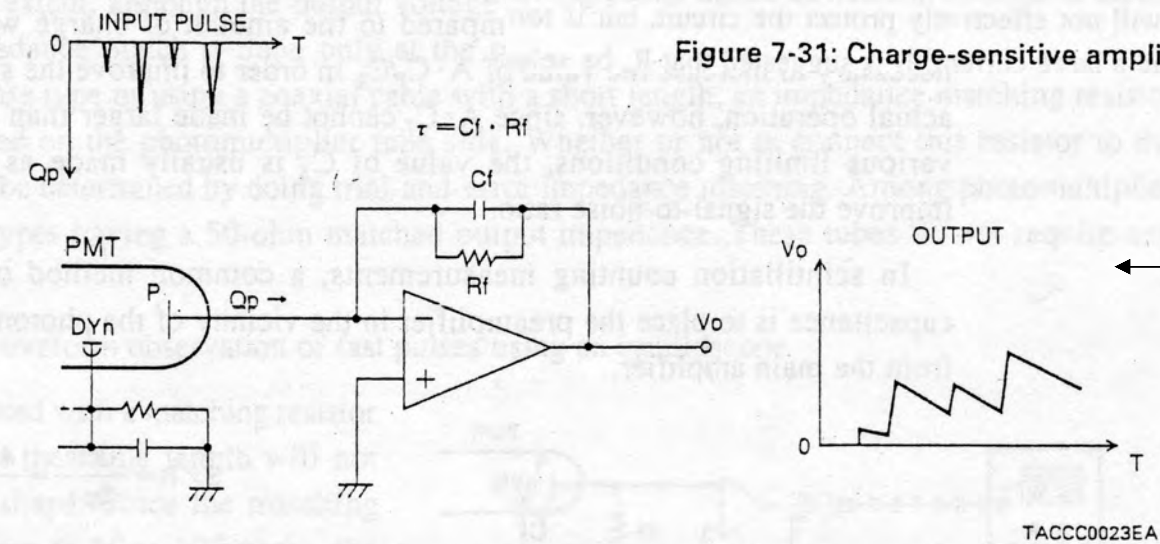

Figure 7-32: Pulse input type charge-sensitive amplifier [3]

← Introduce RC time constant for discharge

Shielding

- PMTs very sensitive to magnetic fields
  - Especially "head-on" types
  - Effects travel path of electrons
- Light shielding and electrostatic shield also important

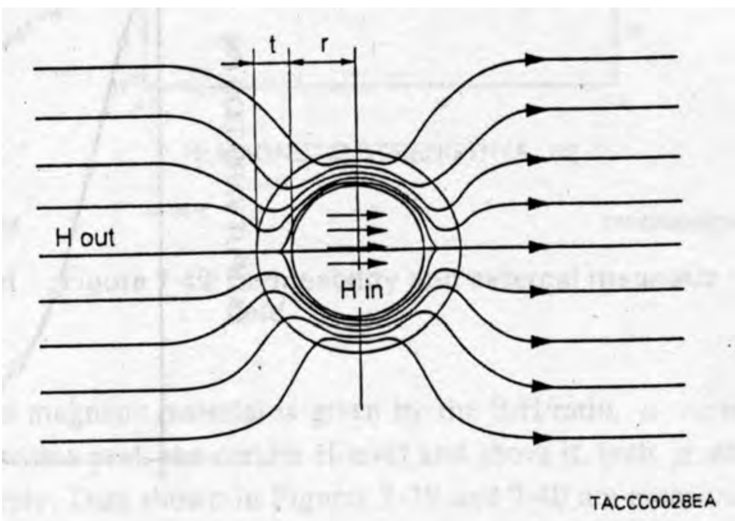

Figure 7-37: Shielding effect of a magnetic shield case

[3]

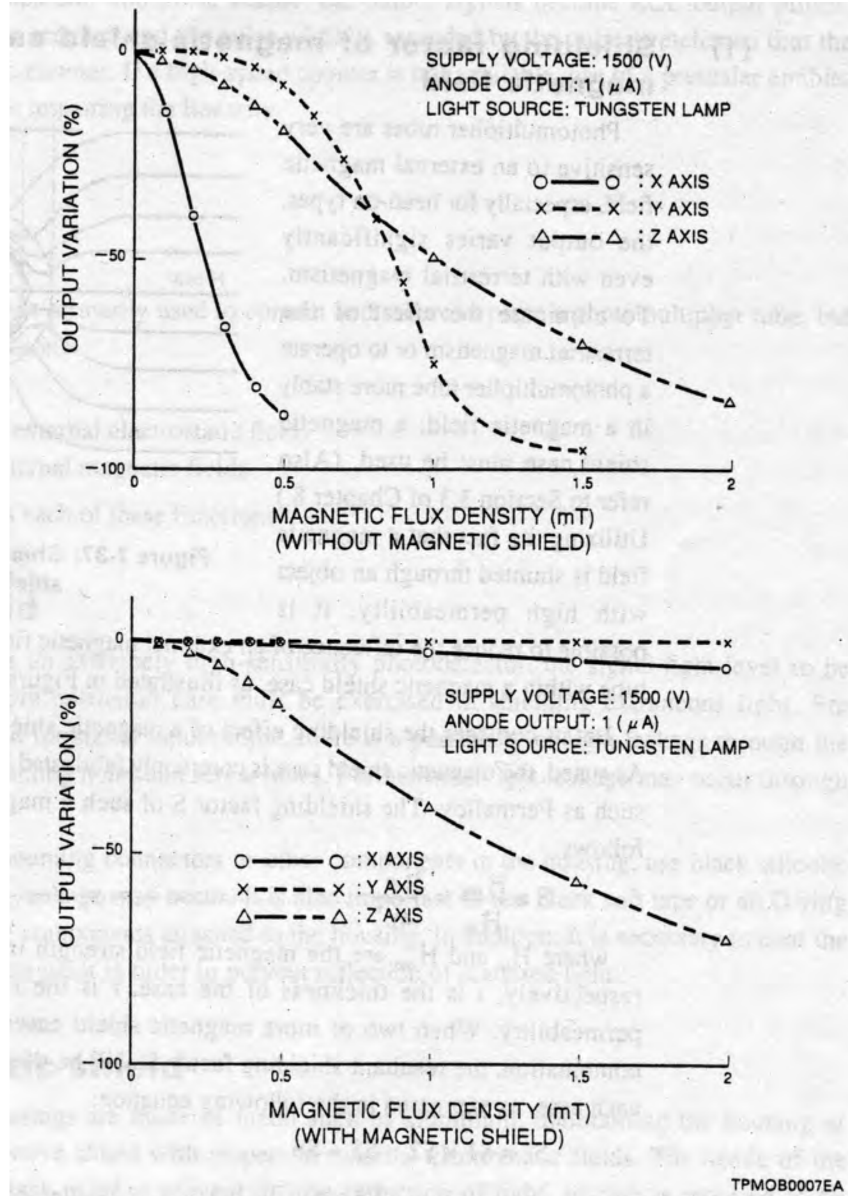

Figure 7-38: Magnetic characteristics of a photomultiplier tube

[3]

References

1. Knoll, G. **Radiation Detection and Measurement**. 2nd Ed. Wiley & Sons (New York: 1989). Chapter 9, p 251-286.
2. Wilson, J., Hawkes, J.F.B. **Optoelectronics, An Introduction**. 2nd Ed. Prentice Hall (New York: 1989) p265-270.
3. Hamamatsu Photonics. "Chapter 7: How to use Photomultiplier Tubes and Associated Circuits." **Photomultiplier Tube, principle to application**. March 1994.