Active Voltage Dividers for Photomultipliers

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Working Principle of Photomultiplier

Different ways to provide voltage gradient with biasing circuit!

- **Photocathode:**
  Photons converted into electrons (photoelectric effect).

- **Multiplier Chain:**
  String of successive electron absorbers with enhanced secondary emission (dynodes).

- **Anode:**
  Collects the resulting charge (= Anode current $I_A$).

- **Biasing circuit:**
  Provides a voltage gradient for the dynodes to accelerate the electrons.
Resistor Voltage Divider

- Capacitors (C) provide charge for fast pulse forming.

**Problem:**
- Potential off all dynodes changes when current is circulating in PMT:

\[ \text{HV=const.} \rightarrow \text{PMT gain rises!} \]

(Depending on Anode current)

From EMI9813B datasheet:

<table>
<thead>
<tr>
<th>( k )</th>
<th>( d_1 )</th>
<th>( d_2 )</th>
<th>( d_{11} )</th>
<th>( d_{12} )</th>
<th>( d_{13} )</th>
<th>( d_{14} )</th>
<th>( a )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>300V</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>B</td>
<td>300V</td>
<td>R</td>
<td>R</td>
<td>1.25R</td>
<td>1.5R</td>
<td>2R</td>
<td>3R</td>
</tr>
</tbody>
</table>

Resistor chain provides potential gradient.

- Equal values across dynodes
- Tapered values reduce non linearity (space-charge effects)

**In general:** \( \frac{I_0'}{I_A} > 100 \) for Linearity!
Figure 5-10: Linearity characteristic using a tapered and a normal voltage-divider circuit

Figure 5-6: Influence of photocurrent on voltage applied to each electrode

From Hamamatsu Photomultiplier Handbook Chapter 5.
Increasing maximum linear Output

Using Zener diodes between last dynodes and the anode
(lower voltage-divider value to increase the divider current)
→ Noise generated by the Zener diode!
Increasing Divider current leads to higher temperatures!
→ increase of dark current and possible fluctuations in the output.

Workaround: Booster voltage for later stages:
Semi Active Voltage Divider (bipolar) by Kerns

Bipolar transistor used to pass an variable current to dynodes while keeping its collector-emitter (CE) voltage constant.

Last transistor current: 
\[ I_a = I'_0 - I_A - \frac{1}{2} I_0 \]

CE-voltage = const. 
def. by resistor chain.

Dynode potential virtual undisturbed for any value \( I_A \) if \( I'_0 > I_A \).

Diodes protect BE junction against reverse voltage.

No need for \( I'_0 > 100I_A \)! Constant gain over large working range!
String of high impedance resistors defining a voltage distribution in parallel a string of P-channel Mosfets (and one resistor to set the standing current) provides current to the dynodes.

→ Voltage divider without limitations on PMT current.
   Current from power supply varies with illumination.
Linearity: Resistor vs. Transistor

Figure 5-16: Output linearity of a voltage-divider circuit (E5815-01) using transistors

From Hamamatsu Photomultiplier Handbook Chapter 5.
2” PMT Voltage dividers at COMPASS

Passive Voltage Divider
Based on resistor network

Active Voltage Divider
Based on NPN transistor
Current draw of different voltage dividers at COMPASS

ET-Enterprise 9813KB with resistor divider (2000 V)
ET-Enterprise 9813KB with active divider (1600 V)
Linearity and Rate Capability

Relative Output (Passive @-2100V DISC@-42mV)

Relative Output (Active @-2100V DISC@-42mV)
Conclusion

- Lower Voltage and current requirements:
  → Less requirements towards HV power supply.
  → Less power dissipation.

- Stable gain over larger HV and current working range:
  → Better rate capability.
  → Better linearity at high rates (stable gain).

- Lower Voltage for same gain/rate requirements:
  → Less ageing for PMTs.

**General better performance with transistors!**

Several designs available at experiments as well as from Manufacturers ...

- e.g. ET-Enterprise C243AON2 for XP2020 \( \approx 200 \text{ Euro} \)

**Make or Buy?**
Thank you for your attention!

Resources:

- Hamamatsu: Photomultiplier Tubes - Basics and Applications - Chapter 5

- ET Enterprise: Understanding Photomultipliers - Chapter 8

- Photonis: Photomultiplier Tube Basics

- Grey Cancer Institute: Getting the best out of photomultiplier tubes.
  http://users.ox.ac.uk/~atdgroup/technicalnotes/Getting%20the%20best%20out%20of%20photomultiplier%20detectors.pdf

- M. Heifets, P. Margulis: Fully active voltage divider for PMT photo-detector

- S. Argiro et. al.: Passive and Active PMT Biasing Networks II