Computer modeling of PMT Hamamatsu R11410-20

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ICPPA-2016, 10-14 October 2016, Moscow

Emission two-phase detectors for rare processes

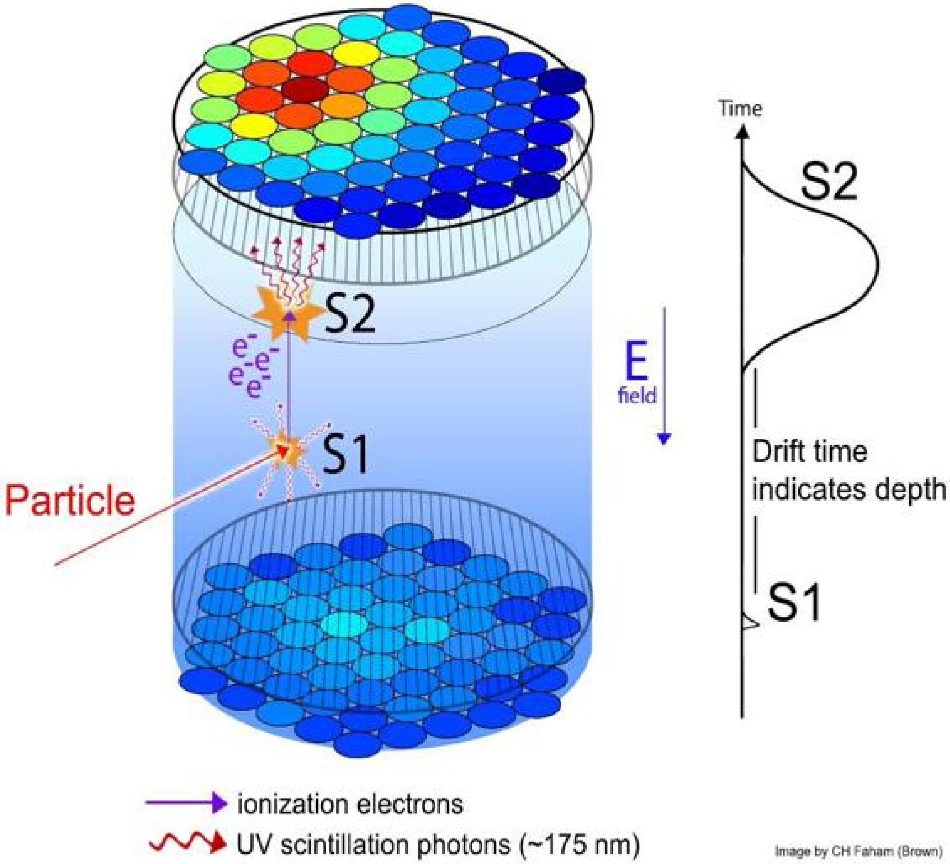

Image by CH Faham (Brown)

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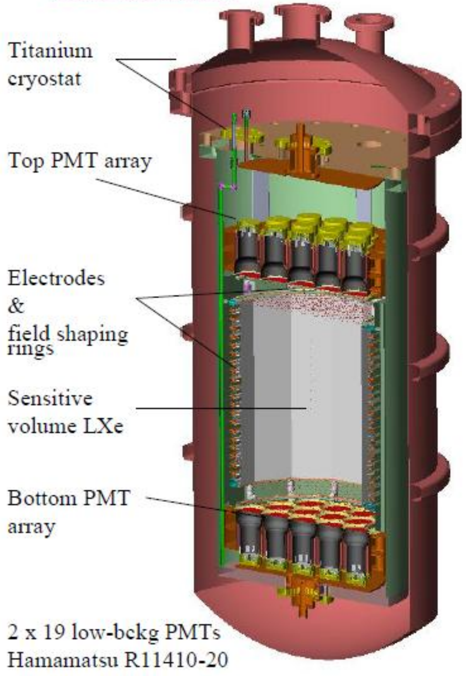
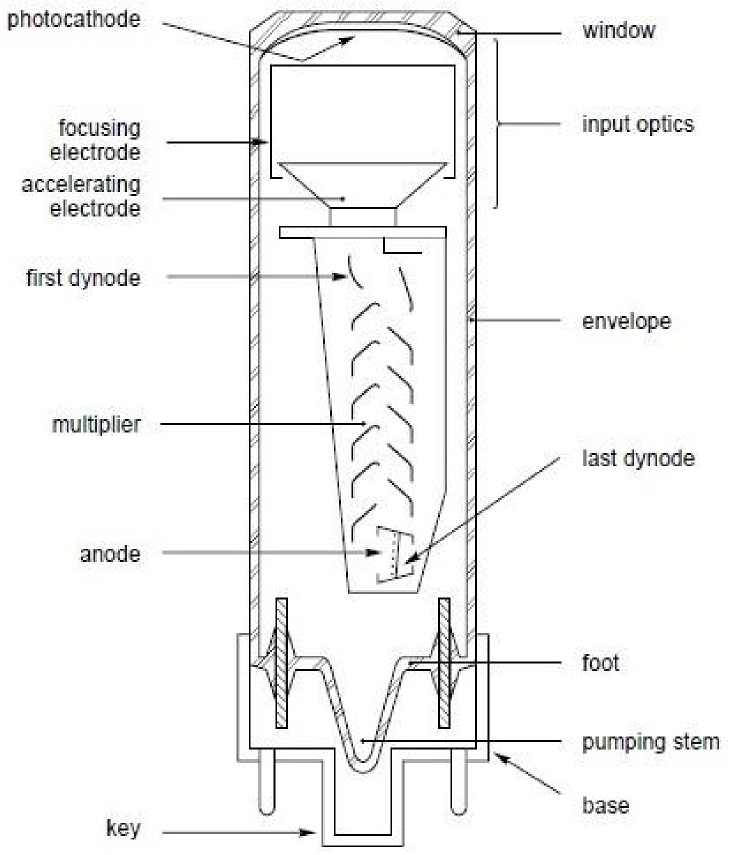
РОССИЙСКИЙ ЭМИССИОННЫЙ ДЕТЕКТОР



Electroluminescence signal is very intensive (about two orders higher than scintillation signal) ->coming to edge of linear PMT work

RED-100 inner construction

PMT’s principle of work



It is possible to describe reproduction on the i-th dynode with secondary emission coefficient δ and electron collection efficiency coefficient n:

$$n_{i-1}\delta_i = k_i V^{\alpha}$$

where k and α are coefficients depending dynode’s behavior.

Based on this, it is possible to represent gain for each dynode:

$$g_i = \delta_i n_i$$

Accordingly, total gain is:

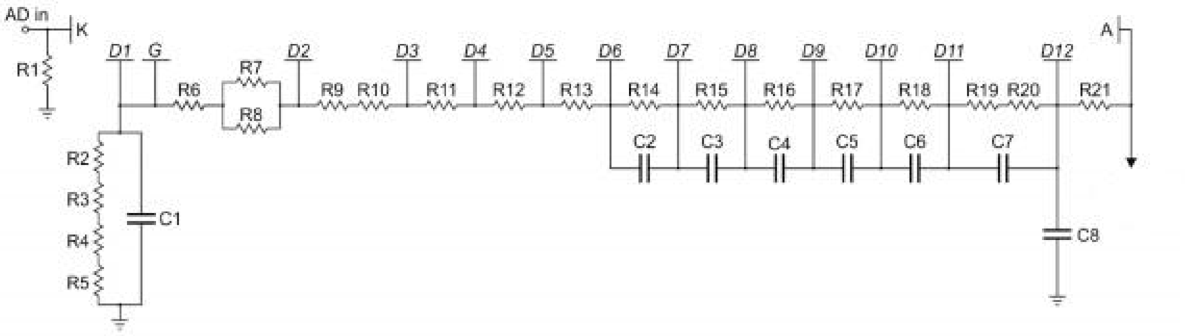
$$G = \prod_{i=1}^{N} g_i$$

Or the overall gain can be expressed in terms of the high-voltage supply:

$$G = \prod_{i=1}^{N} k_i(\epsilon_i V)^{\alpha}$$

where V is supply voltage, ε_i is a fraction of the supply voltage VB owed to the action of the voltage divider circuit.

PMT's principle of work



Voltage divider circuit for R11410-20

For each dynode ε is:

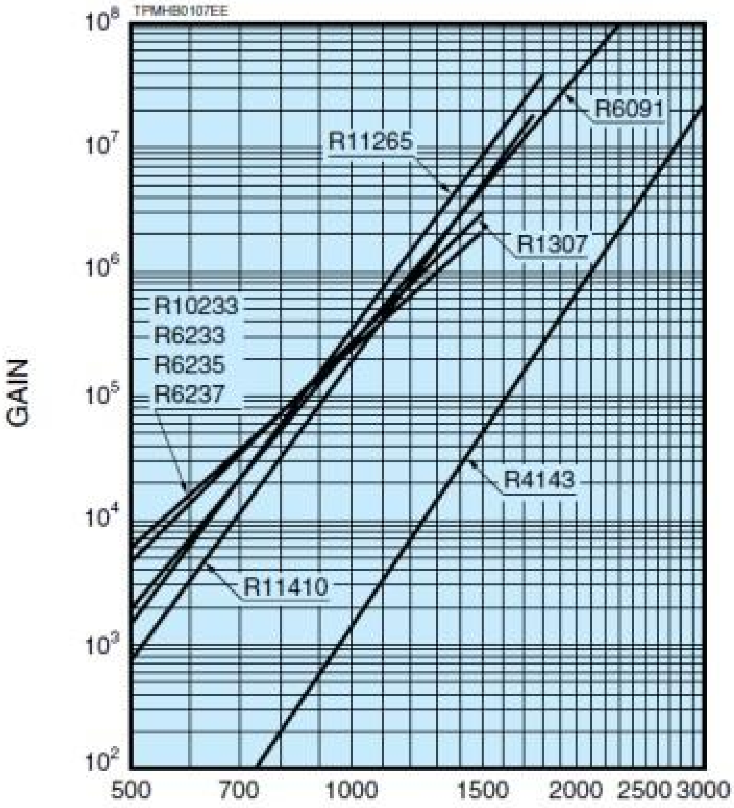
$$\varepsilon_i = \frac{R_i}{R}$$

R_i is resistance of i-th circuit part and R is total resistance.

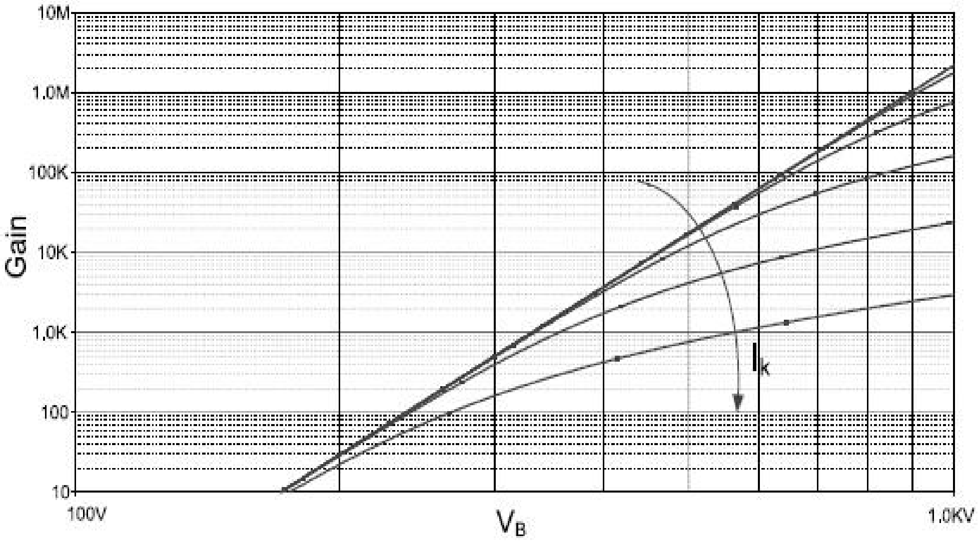
PMT R11410-20

PMT's principle of work.
Gain dependence on supply voltage

Dependence on voltage: $G = k * V_i^{\alpha}$



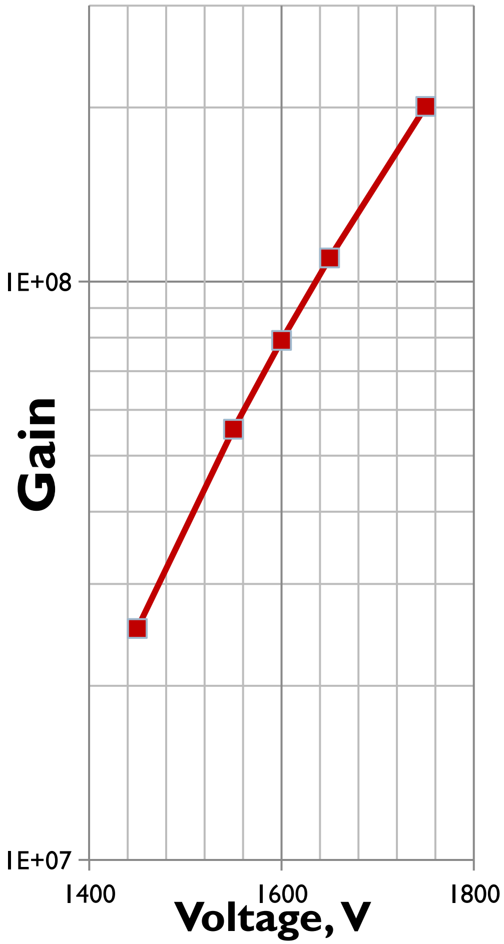
Sample gain dependences on voltage for some Hamamatsu models



Deviation from power law at high anode currents

Coefficients calculation at formula $G = k * V_i^{\alpha}$

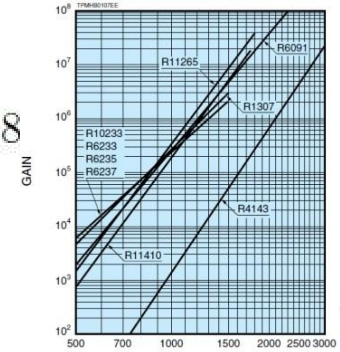
From experimental data for PMT №KB0278:



$$\left\{ \begin{array}{l} k^{12\alpha}\left(\frac{4,4}{20,4}\right)^{\alpha}\left(\frac{1,1}{20,4}\right)^{8\alpha}\left(\frac{2,2}{20,4}\right)^{2\alpha}\left(\frac{1,55}{20,4}\right)^{\alpha}1450^{12\alpha} = 25124843,95 \\ k^{12\alpha}\left(\frac{4,4}{20,4}\right)^{\alpha}\left(\frac{1,1}{20,4}\right)^{8\alpha}\left(\frac{2,2}{20,4}\right)^{2\alpha}\left(\frac{1,55}{20,4}\right)^{\alpha}1550^{12\alpha} = 55555555,56 \\ k^{12\alpha}\left(\frac{4,4}{20,4}\right)^{\alpha}\left(\frac{1,1}{20,4}\right)^{8\alpha}\left(\frac{2,2}{20,4}\right)^{2\alpha}\left(\frac{1,55}{20,4}\right)^{\alpha}1600^{12\alpha} = 79119850,19 \\ k^{12\alpha}\left(\frac{4,4}{20,4}\right)^{\alpha}\left(\frac{1,1}{20,4}\right)^{8\alpha}\left(\frac{2,2}{20,4}\right)^{2\alpha}\left(\frac{1,55}{20,4}\right)^{\alpha}1650^{12\alpha} = 109862671,7 \\ k^{12\alpha}\left(\frac{4,4}{20,4}\right)^{\alpha}\left(\frac{1,1}{20,4}\right)^{8\alpha}\left(\frac{2,2}{20,4}\right)^{2\alpha}\left(\frac{1,55}{20,4}\right)^{\alpha}1750^{12\alpha} = 200842696,6 \end{array} \right.$$

Solution is:

$$k = 0,0587, \alpha = 0,88$$



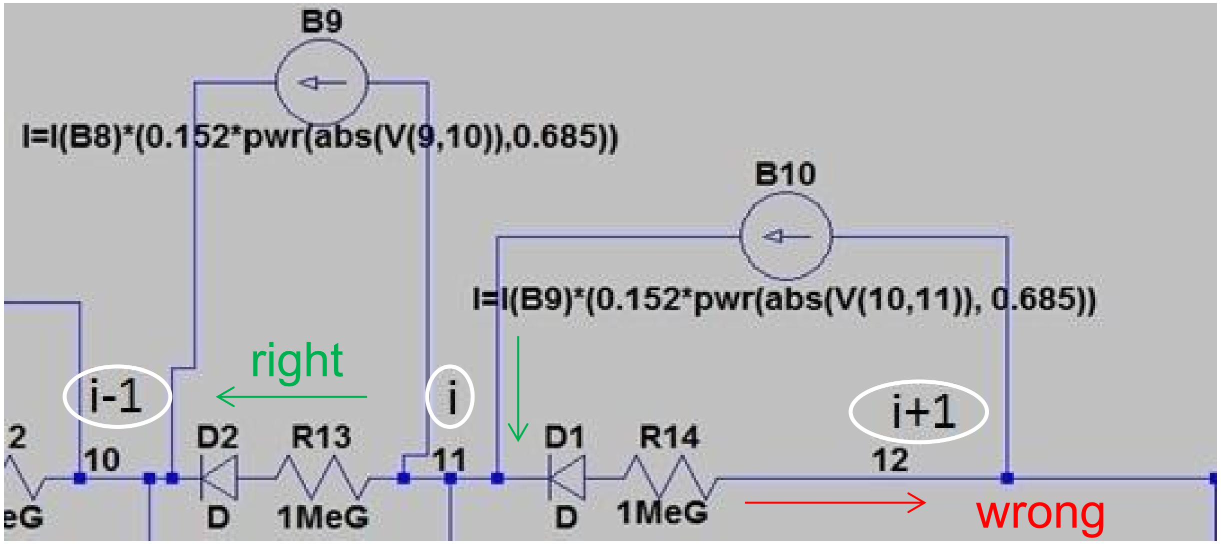
For Hamamatsu typical gain:

$$k = 0,167, \alpha = 0,674$$

First divider models

For current reconstruction between i-th and i+1-th dynodes arbitrary behavioral dependent source was used and current can be set according to formula:

$$i_n = i_{n-1} * k * V_i^{\alpha}$$

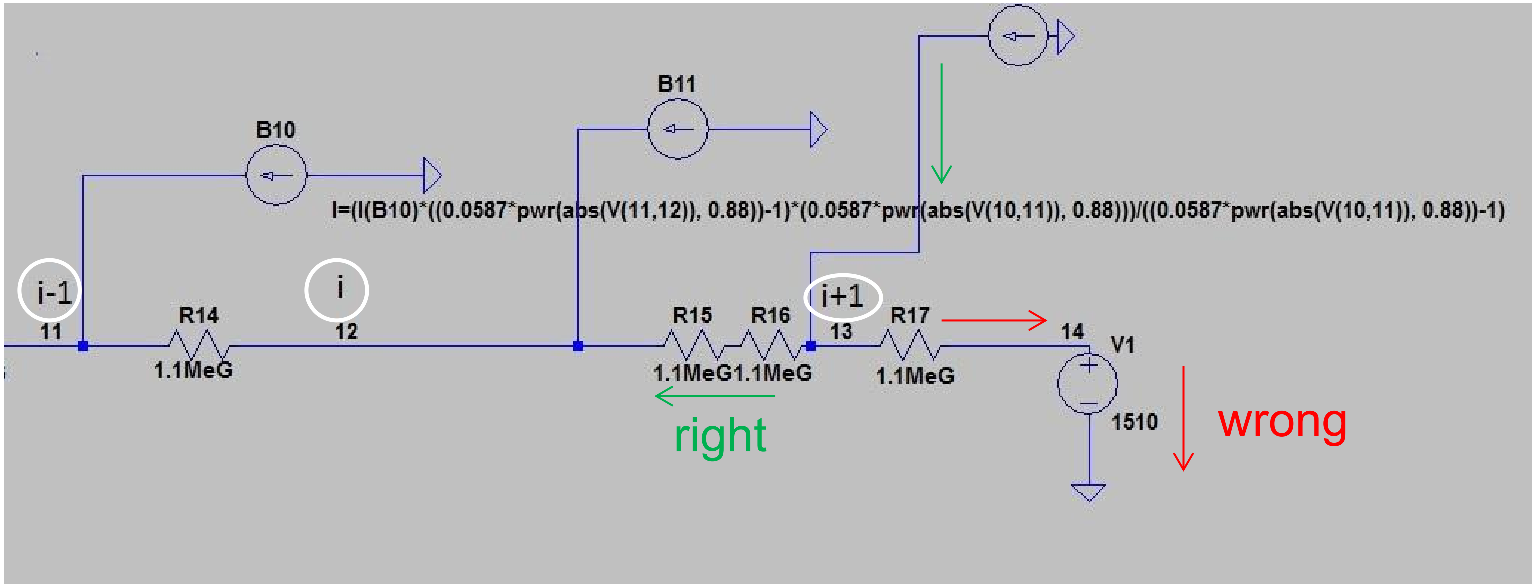


Simplified scheme

First divider models

Dynode current is: $i_n = \frac{i_{n-1} * (k * V_i^{\alpha} - 1) * (k * V_{i-1}^{\alpha})}{k * V_{i-1}^{\alpha} - 1}$

Anode current is: $i_{anode} = \frac{i_{n-1} * (k * V_i^{\alpha}) * (k * V_{i-1}^{\alpha})}{k * V_{i-1}^{\alpha} - 1}$



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I=(I(B10)*((0.0587*pwr(abs(V(11,12)), 0.88))-1)*(0.0587*pwr(abs(V(10,11)), 0.88)))/((0.0587*pwr(abs(V(10,11)), 0.88))-1)
```

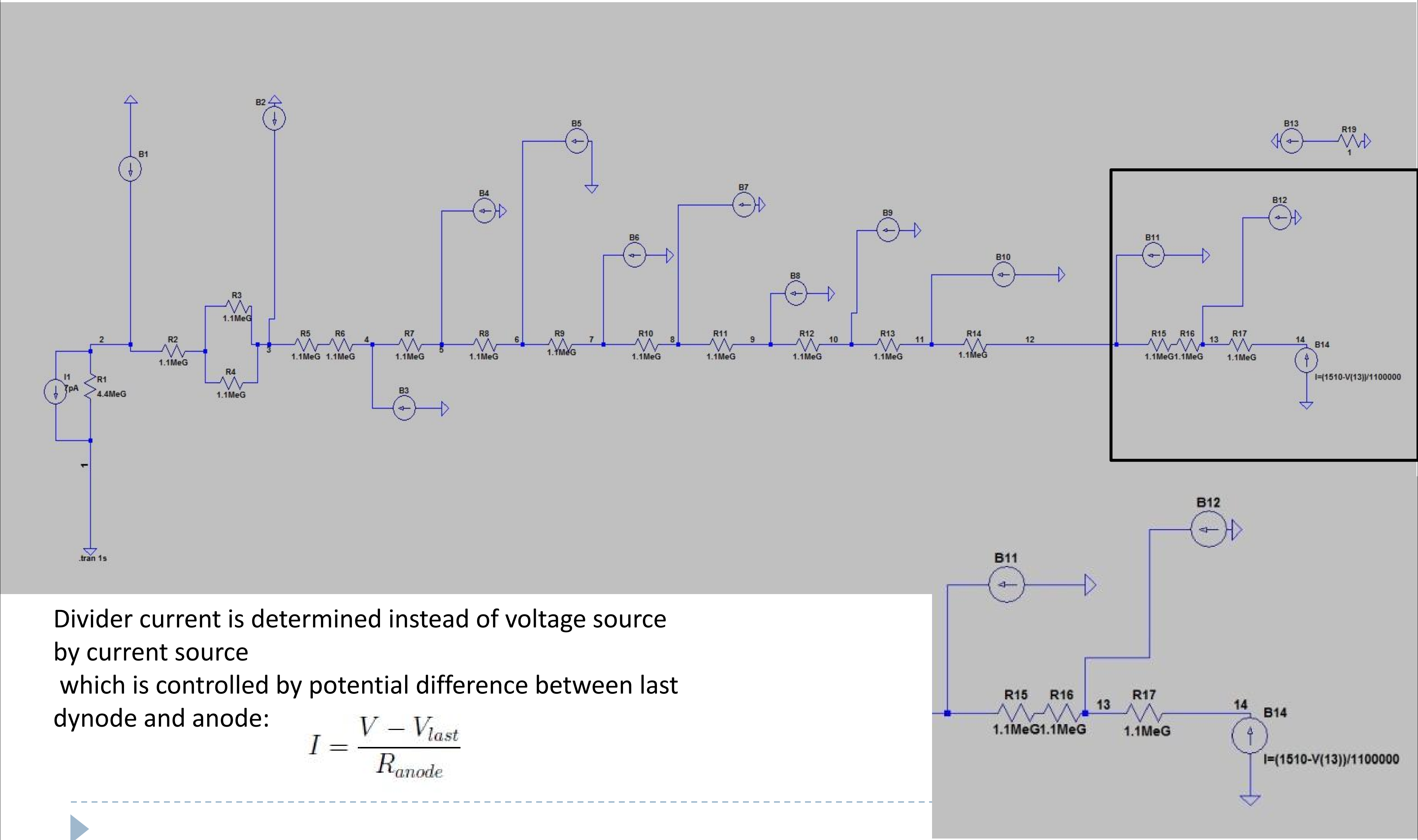
That model is also wrong because potential is changing incorrectly during work.

Problems and solutions

And problem in PMT modeling was found – because of voltage source has zero resistance, current from last dynodes flows through it to earth and don’t come to divider circuit. It leads to incorrect potential between dynodes and accordingly to incorrect total gain.

And there are solution – let’s change voltage source to current voltage-controlled source!
Current source has **infinite resistance!**

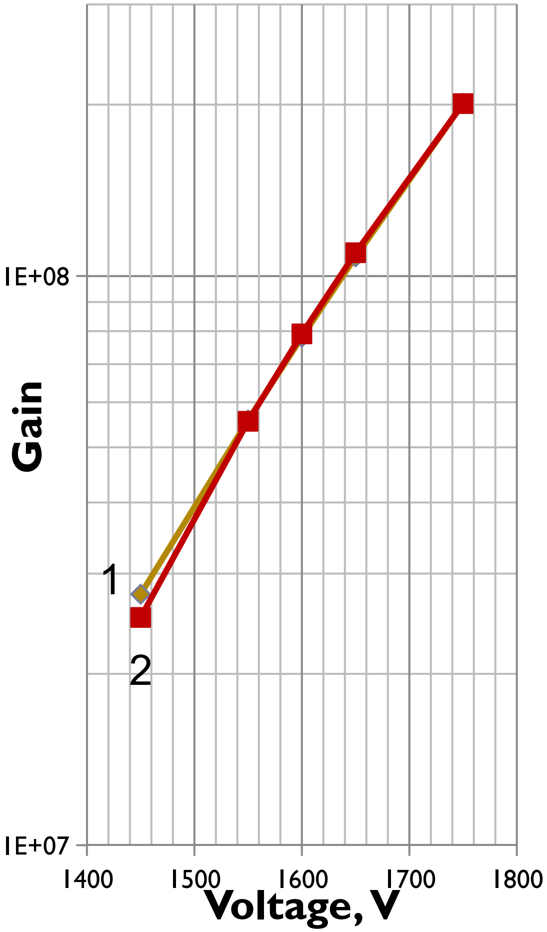
Final model



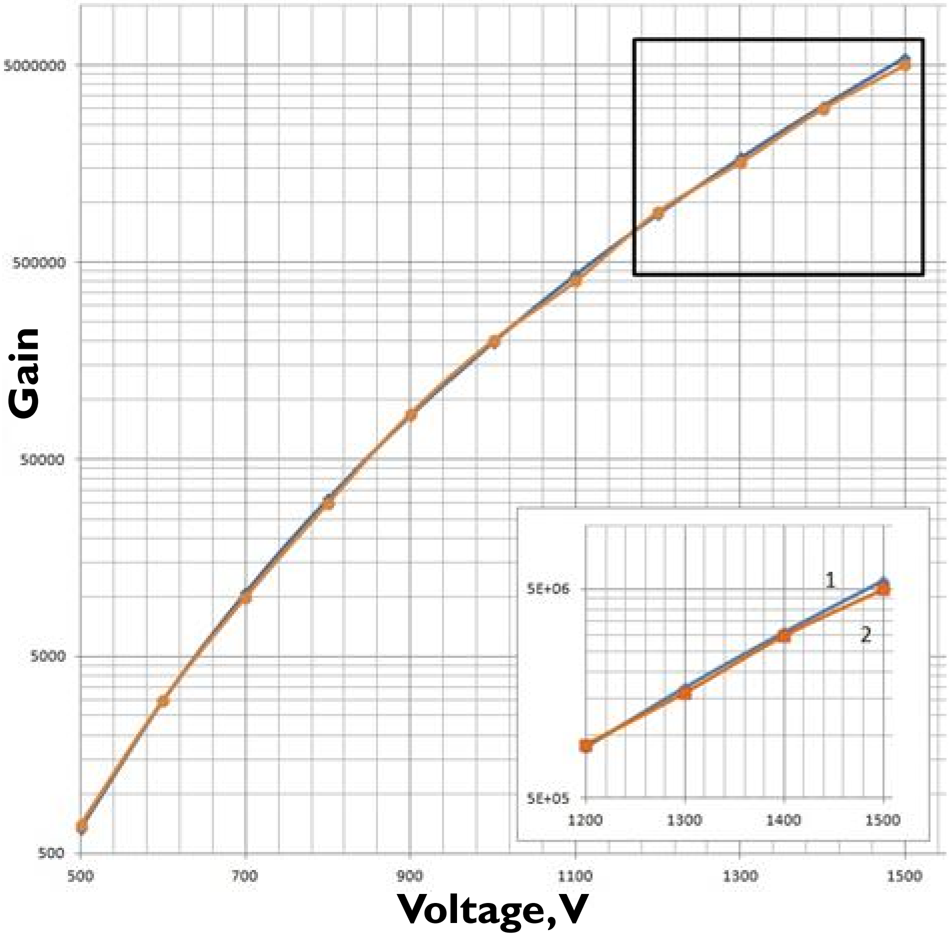
Divider current is determined instead of voltage source by current source
 which is controlled by potential difference between last dynode and anode:

$$I = \frac{V - V_{last}}{R_{anode}}$$

Modeling results, G=f(V)

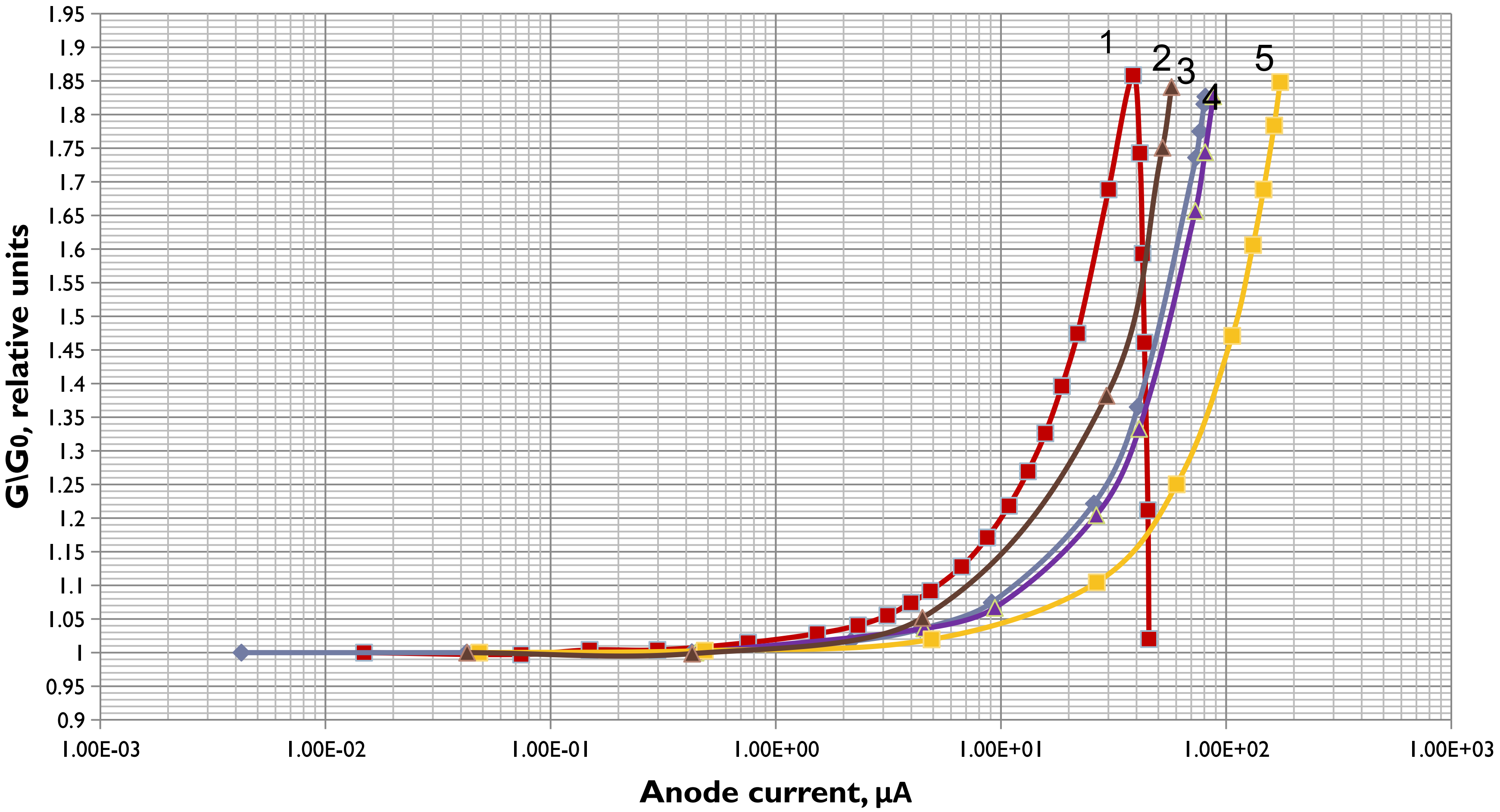


Gain dependence on supply voltage. Model(1) and experimental (2) characteristics for PMTNº KB0278



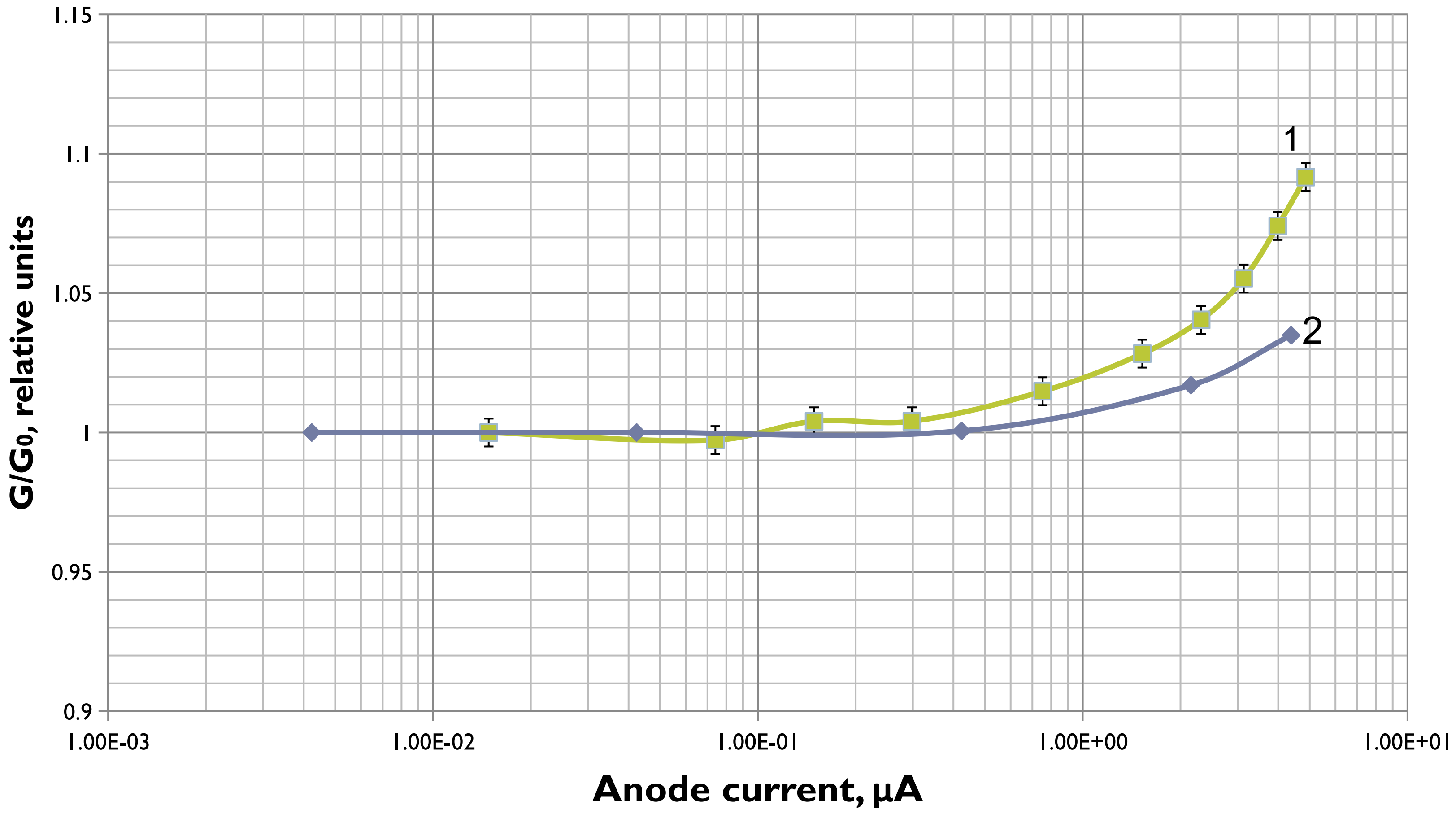
Gain dependence on supply voltage. Model(1) and typical gain(2) characteristics for Hamamatsu R11410-20

Modeling results, $G/G_0=f(Ia)$



Gain dependence on anode current for PMT № KB0278: 1 - experimental, 2, 3, 4, 5 – modeling for Ri = 1,5, 1,1, 1 u 0,5 MOhm

Modeling results, $G/G_0=f(Ia)$



Experimental (1) and model (2) gain dependences (for R = 1.1 MOhm) on anode current for PMT № KB0278 enlarged

Conclusion

A SPICE model for the simulation of the divider behavior of a PMT has been constructed.
Model parameters were extracted from experimental and typical Hamamatsu gain.

Problem with incorrect potential behavior was found and solved (as we know, first time in the world).

The results of simulation are in a reasonable agreement with the experimentally measured characteristics of the PMT with serial # KB0278.

The model can be used for simulation of any type of PMT.

Thank you for attention!