Signal Optimization with HV divider of MCP-PMT for JUNO

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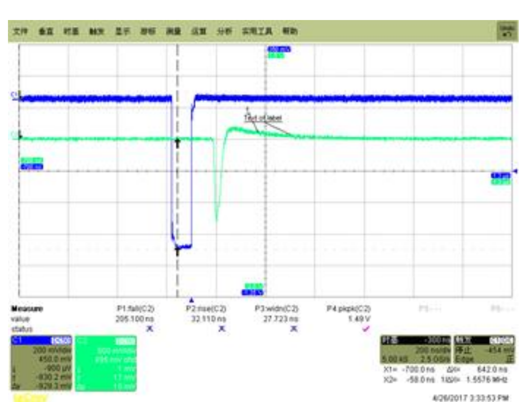
Motivations

The Jiangmen Underground Neutrino Observatory (JUNO) is proposed to determine the neutrino mass hierarchy using a 20 kiloton underground liquid scintillator center detector (CD). One of the key is the energy resolution of the CD to reach <3% at 1 MeV, where totally 15,000 MCP-PMT will be used. The quality of PMT signals is a key for large-size and high-precision neutrino experiments while most of these experiments are affected by the overshoot of PMT signal from the positive HV scheme. The overshoot coupled with positive HV which is troubling trigger, dead time and precise charge measurement, we have studied to control it to less than ~1% of signal amplitude for a better physics measurement. Besides, we will show the study to optimize the MCP-PMT working configuration with JUNO for charge measurement in collection efficiency.

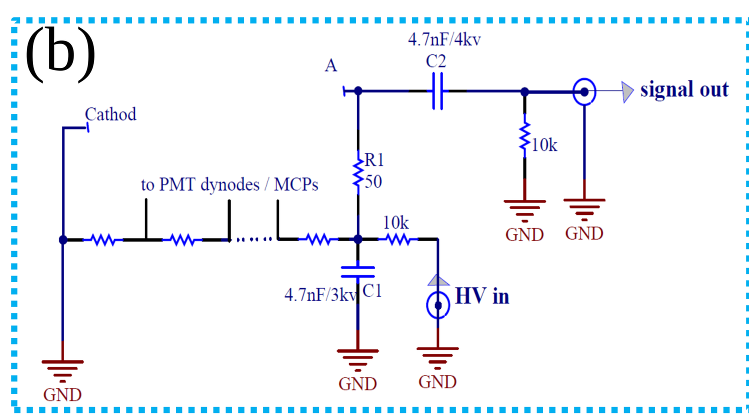
Overshoot with positive HV scheme

❑ Output signal
- Overshoot around 10%;
- Positive HV divider;

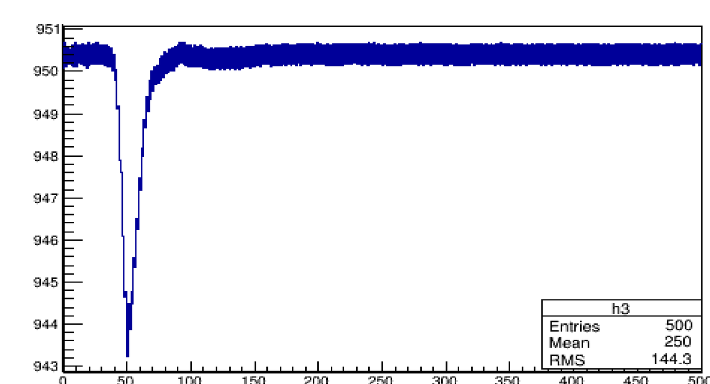
(a)



(b)

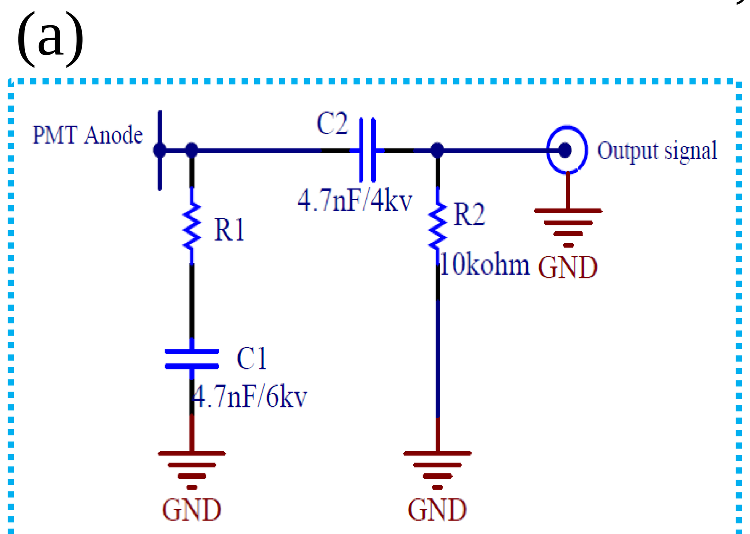


❑ Optimized output signal
- Optimized circuit;
- Overshoot around 1%;



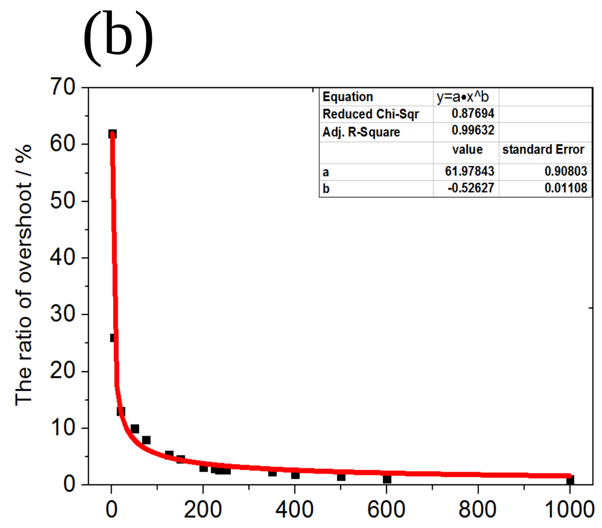
❑ Analysis
- Simplified circuit (a);
- Discharge of C1 and C2;
- $R1 \times C1$ and $R2 \times C2$;

(a)

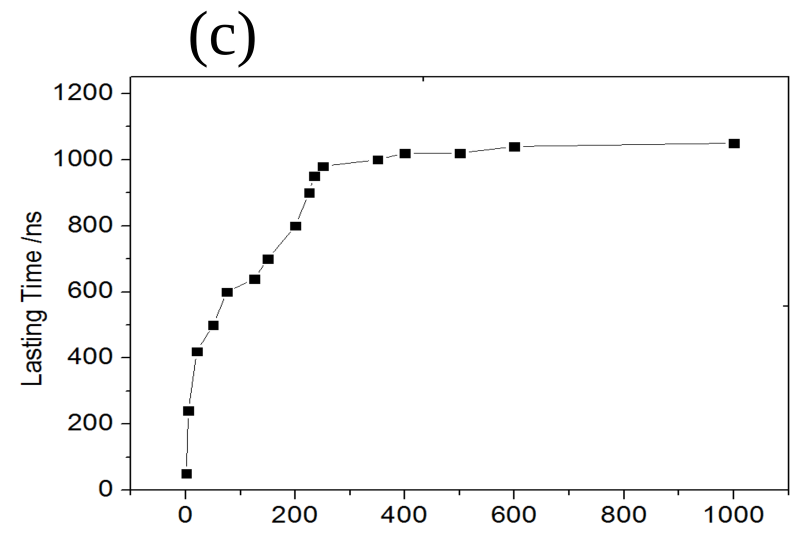


❑ Experiments
- C2=22nF,R2=50ohm, C1=4.7nF, varying R1(b)(c);
- Cross check with C2,R2 and C1;

(b)

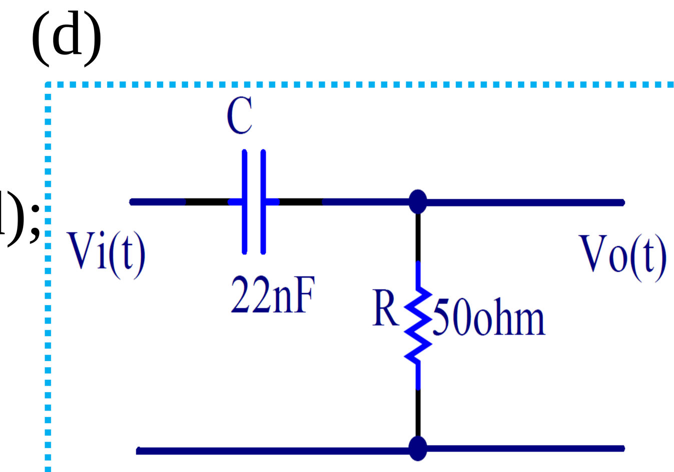


(c)



❑ Overshoot model
- C2 = 22nF, R2=50ohm;
- Further simplified circuit(d);
- Fourier transformation analysis.

(d)



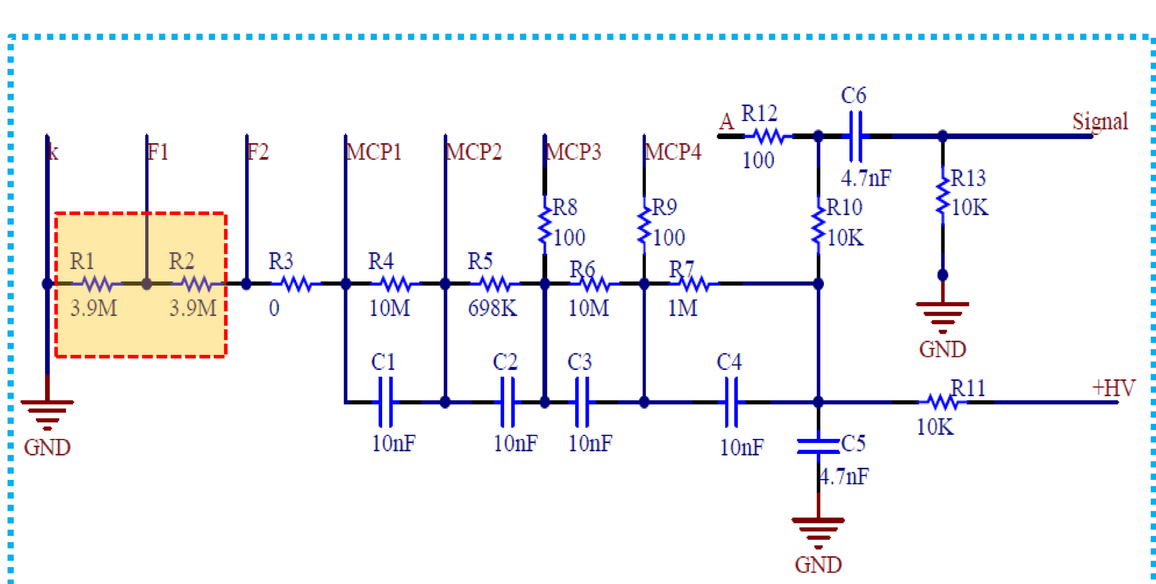
$$\begin{cases} V_o(\omega) = V_i(\omega) \times H(\omega) \\ H(\omega) = j\,\omega/(j\omega + 1/\tau) \\ V_i(t) = -Q/C_i \times \exp(-t/\tau_i) \\ V_i(w) = -Q/C_i \times 1/(j\omega + 1/\tau_i) \end{cases} \rightarrow V_O(\omega)$$

$$V_o(t) = Q/C_i \times (1/(\tau_i - \tau)) \times (\tau_i \exp(-t/\tau) - \tau \exp(-t/\tau_i))$$

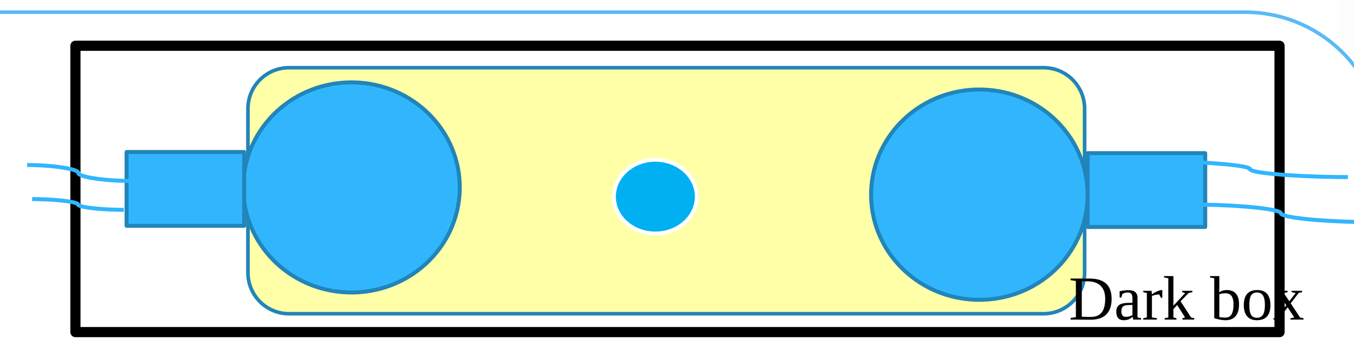
Overshoot ratio: $\frac{V\_}{V_M} = \frac{\tau_i}{\tau}$ (consistent with experiment results)

Optimization the collection efficiency with HV divider

❑ Optimization of the divider ratio
- HV divider;
- Divider ratio: K-F1:F1-F2;
- Optimal work configuration of PMT;



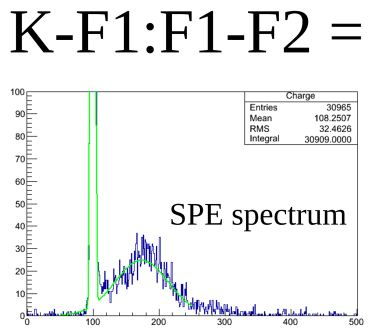
❑ Method of experiment
- Gain@1*10^7 with EMF shielding;
- Reference PMT: Hamamatsu PMT;
- Keeping the PMT position the same;
- MCP-PMT with HV divider of different divider ratio;
- Detection efficiency: relative output charge;

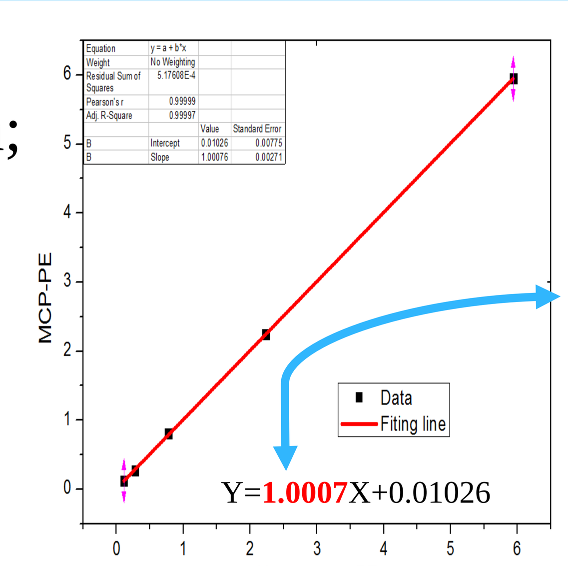


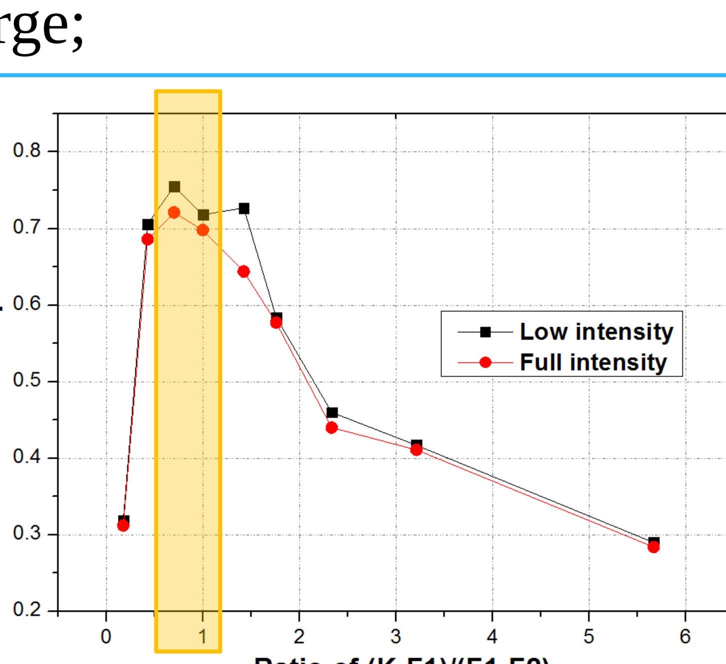
Hamamatsu-PMT:EA0073

MCP-PMT

❑ Results
- Charge spectrum;
- Mean charge;
- K-F1:F1-F2 = 1;







- K-F1:F1-F2=1.2:6.8
- K-F1:F1-F2=2.4:5.6
- K-F1:F1-F2=3.3:4.7
- K-F1:F1-F2=3.9:3.9
- K-F1:F1-F2=4.7:3.3
- K-F1:F1-F2=5.1:2.9
- K-F1:F1-F2=5.6:2.4
- K-F1:F1-F2=6.1:1.9
- K-F1:F1-F2=6.8:1.2

Conclusions

- Confirm a large overshoot of the PMT output the level of 10% as observed by the Daya Bay experiment;
- Make clear the cause of overshoot and established a model to explain overshoot, optimize the ratio of overshoot from 10% to 1%;
- Optimize the HV ratio to achieve the optimal efficiency of MCP-PMT;

References

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