Hampton University scintillation counters for ID system tests

COSM-06-01. K. Baker, M.C. Long, K. McFarlane, T. Shin, V. Vassilakopoulos.

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Abstract

Three counters have been built to provide a precise timing signal for ID system tests using cosmic rays. The counter scintillators are 1440mm×400mm×25mm in size. Efficiency on through-going cosmic rays is 99%, and their time resolution (rms) on mean time is < 0.28ns. Suggestions for initial setup, and data sheets for components, are included.

1 Description

This note describes these HSC counters. There are three counters, like figure 1.

Each of these counters is intended to:

- Cover the length of the Barrel ID (TRT sensitive region)
- Cover the width of about two type-3 TRT modules
- Give good timing resolution, shorter than the resolution of TRT drift times, when used with appropriate electronics.

Figure 1.1 – Photograph of one HSC.

Three counters have been built, so that several different arrangements are possible. See figure 1.1 for a picture of one counter.

2 Scintillators and light pipes

The scintillators are 1440mm×400mm×25mm in size; the material is Eljen EJ-200 (http://www.eljentechnology.com)

The light pipes are cast acrylic, and are flat triangles.

3 Phototubes and bases

The photomultiplier tubes (PMTs) are Hamamatsu 127mm dia. tubes, R2150 (data sheet attached).

The bases are ORTEC/EG&G type 269 (data sheet attached), modified for the R2150. They use negative high voltage, with DC-coupled anode. The high-impedance dynode output is useful only for monitoring. They draw ~2mA at 3kV.

Connectors are SHV and BNC.

The base potentiometers have been adjusted according to Hamamatsu's recommendation and should not need to be adjusted.

Table 3.1 – List of counters with tube and base serial numbers.

Counter name	End A		End B	
	Tube	Base	Tube	Base
HSC-1	RA2289	1313	RA2283	1314
HSC-2	RA2215	1312	RA2308	1315
HSC-3	RA2286	1316	RA2228	1317

4 Mounting

Each counter is packaged in a frame that is 2852mm long (with handles adding 36mm each end), 406mm wide, and 178mm high. Each scintillator is centered in its frame (see figure 1.1). The frames are made from 80/20 parts, and are sized in inch dimensions.

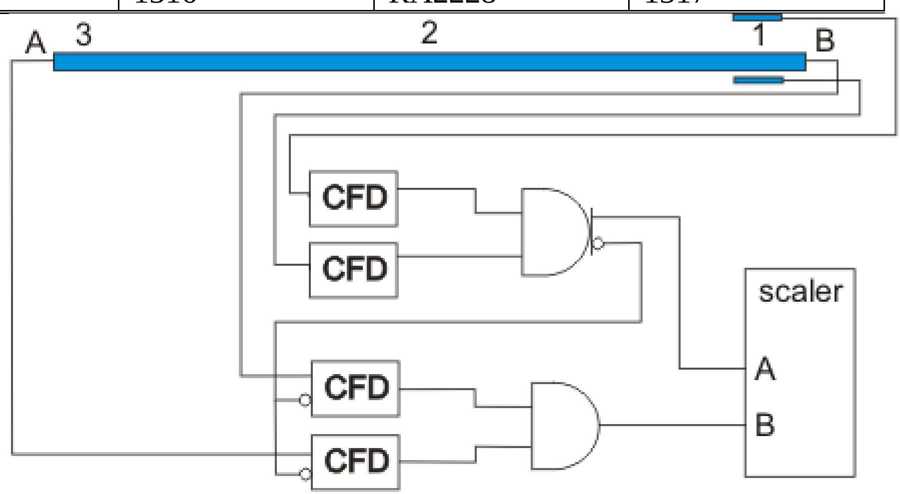


Figure 5.1 – Efficiency setup. The small scintillators make up the cosmic ray telescope (CR) while the large scintillator is the HSC under test. The PMTs are labeled A and B, and test positions 1, 2, and 3.

5 Test Results

5.1 Efficiency measurements

The efficiency measurement setup is shown in figure 5.1. A cosmic ray telescope (CR) of two counters approximately 100m x 150mm separated by ~150mm selected through-going cosmic rays. The electronics consisted of Ortec model 935 constant-fraction discriminators (CFDs), LeCroy coincidence circuits, an Ortec dual scaler, and a LeCroy 3001 qVt. HV was supplied by two Ortec HV supplies, constraining the HV on both tubes (A and B in the above diagram) to be the same. The CR counters were adjusted to trigger below the pulse height from minimum ionizing particles. The CFDs for the HSC A and B PMTs were set at a threshold of 75mV, with an external cable of 4ns for the delay. Pulse lengths of ~30ns were used for the HSC outputs, to allow for the variation of ~20ns in relative timing as the CR telescope was moved from position 1 to 3. The CR coincidence (length ~100ns) gated the constant-fraction discriminators for tube A and B on the HSC.

The results are tabulated in table 5.1. Run lengths differed, hence the differences in the uncertainties. As can be seen, PMT B on HSC-1 likely needs a greater HV than PMT A. However, a HV of 1700V delivers full efficiency on both. In the case of HSC-3, a larger effect was noticed, and it was run at 1800V.

Table 5.1 – Measured counter efficiencies.

Counter	HV (for A and B)	Position 1	Position 2	Position 3
HSC-1	1700V	99.3 ± 0.1%	99.5 ± 0.2%	99.1 ± 0.2%
HSC-1	1600V	99.30 ± 0.04%	99.5 ± 0.2%	99.1 ± 0.2%
HSC-1	1500V	99.15 ± 0.14%	99.0 ± 0.3%	76.7 ± 1.2%
HSC-2	1700V	99.08 ± 0.14%	99.14 ± 0.25%	99.07 ± 0.14%
HSC-3	1800V	99.2 ± 0.2%	99. ± 0.2%	99.4 ± 0.2%

A run was done with the CR gate delayed 40ns after the signals from PMTs A and B, to measure the spurious coincidence counting rate. The rate was 1 count in 9903 CR counts, for an accidental rate of 0.01%.

5.2 Singles rates

Singles rates were measured at various settings, as shown in table 5.2.

Table 5.2 – Singles rates (kHz), with the standard discriminator settings.

Counter		High voltage					
	PMT	1500V	1600V	1700V	1800V	1900V	2000V
HSC-1	A	0.1	0.2	0.4	--	--	--
	B	0.1	0.3	1.9	--	--	--
HSC-2	A	--	--	0.5	--	--	--
	B	--	--	0.3	--	--	--
HSC-3	A	--	--	0.8	1.5	2.4	3.6
	B	--	--	0.1	0.5	0.5	2.3

If singles rates are higher than these rates, suspect light leaks. Based on these results, suggested initial operating high-voltages are given in section 6.4.

5.3 Pulse shapes

Figure 5.2 shows the pulse shapes from different positions on counter HSC-1. The oscilloscope (Tektronix TDS series) was triggered by a CR coincidence. The top graph compares a single pulse with an average of 512 pulses. The rise time of the average is a little greater, because of the time spread (~1ns) of the trigger. (Note that this time spread is due to the physical width of the CR counters.)

Note the time shift of the leading edge, corresponding to a transit time of light along the full length of the scintillator of about 10ns.

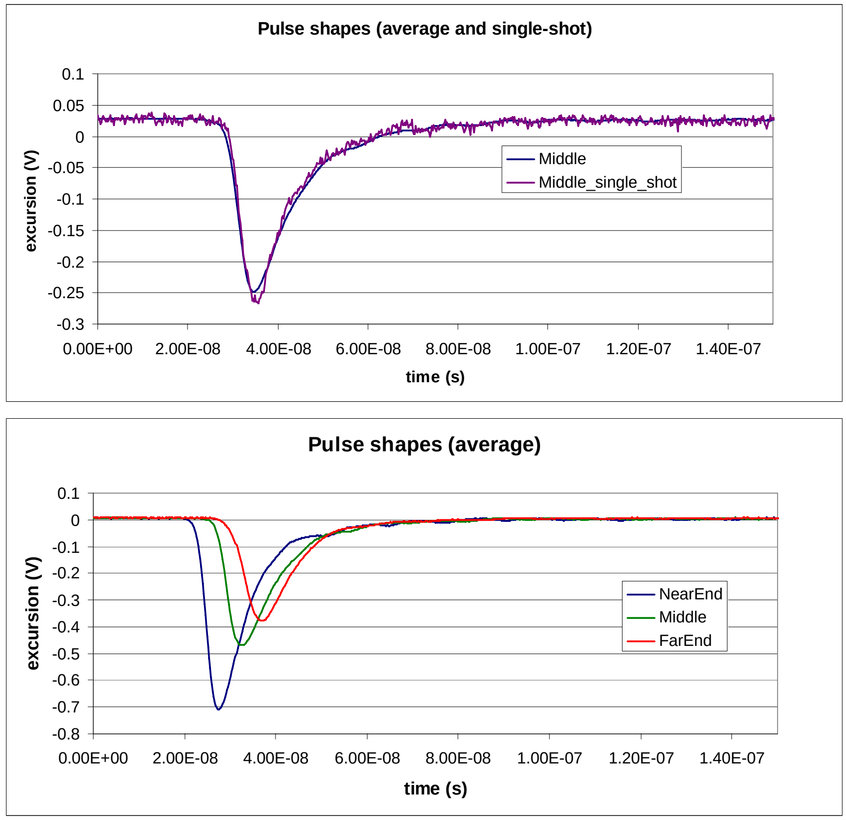


Figure 5.2 – Pulse shapes from an HSC tube A (see figure 5.1). Top, comparison of an average of 512 pulses with a single pulse from HSC-3. Bottom, averages of pulses from HSC-1, tube A, positions 1 (FarEnd), 2 (Middle), and 3 (NearEnd).

5.4 Pulse amplitudes

To measure the pulse amplitude, the arrangement shown in figure 5.3 was set up. Two spectra were taken, as shown in figure 5.4. There is a clear separation in pulse height between through-going cosmic rays and the small number of CR triggers where no pulse is seen, possibly corresponding to the 1% of triggers which give rise to the inefficiency noted in table 5.1.

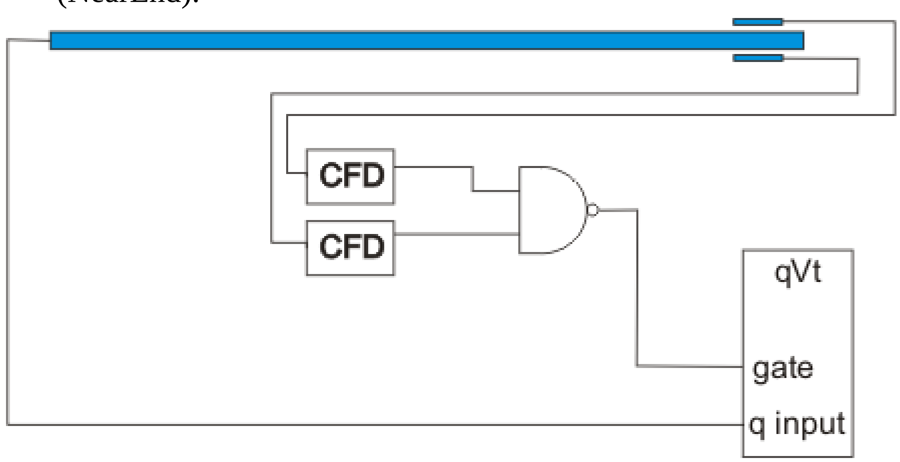


Figure 5.3 – Setup for measuring charge in pulse.

5.5 Timing

Two methods were used to study timing properties. The first was an arrangement like figure 5.1, where the HSC CFDs were gated by the CR telescope, and PMT A was used to start, and PMT B to stop, the qVt in time mode.

In this CR gated mode, time distributions like figure 5.5 were obtained. These show that the time distribution is approximately Gaussian and continue to fall off as the time difference grows. However the width of the distribution is the convolution of the time jitter of the PMT signal and the width of the CR telescope projection on the counter. At ~100mm width, this is larger than the PMT width.

The other mode was to use a collimated Ru-106 source to produce a narrow 'beam' of particles as in figure 5.6. Figure 5.7 shows a typical time distribution obtained in this way. While the peak is narrower and more reflective of the intrinsic time resolution, the wide amplitude variations of the pulses from the source make for longer tails.

The resolutions (FWHM) obtained by this method are listed in table 5.3.

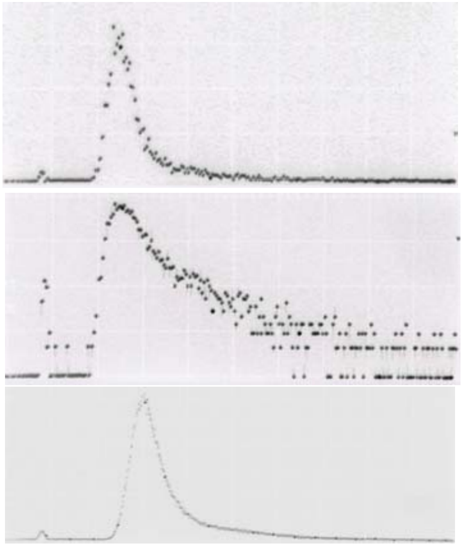


Figure 5.4 – Pulse charge distributions from HSC-3. Top, linear plot from PMT A, as in fig. 5.3. Middle plot, same data on a logarithmic plot. Bottom, plot with CR telescope at center of counter.

Table 5.3 – Resolutions measured with Ru-106 source in TDC units, FWHM

Counter	Position 1	Position 2	Position 3
HSC-1	12 TDU	13 TDU	12.5 TDU
HSC-2	12 TDU	12.5 TDU	--
HSC-3	14 TDU	12.5 TDU	13 TDU

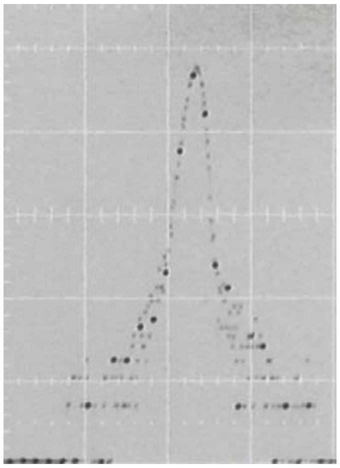


Figure 5.5 – Log plot of time distribution, with CR trigger.

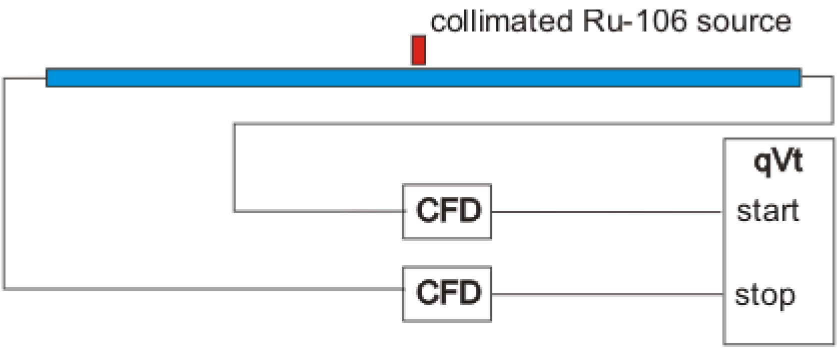


Figure 5.6 – Setup for timing measurements.

Calibration of the qVt gives:

0.098 ± 0.001 ns/TDU.

Using the number, and assuming a gaussian form, we get the RMS resolutions in table 5.4. A gaussian fit to a distribution (figure 5.7) gives an RMS deviation of 0.50 ns.

Table 5.4 – RMS resolutions (ns)

Counter	Position 1	Position 2	Position 3
HSC-1	0.50	0.54	0.52
HSC-2	0.50	0.52	--
HSC-3	0.59	0.52	0.54

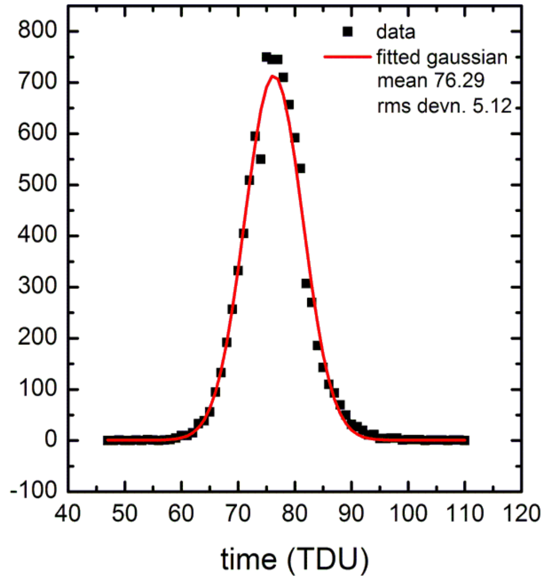


Figure 5.7 – Time difference distribution from HSC,using Ru-106 source, in TDU.

Since the time difference spread is twice the time average spread (with proper equipment), the time average spread is expected to be:

σ ~< 0.28 ns.

This will make a negligible contribution to timing of TRT signals, which have a bin width of 3.125ns, corresponding to an RMS deviation of 0.9ns.

Thus the goal of the HSC counters is achieved.

6 Appendices

6.1 Ortec 269 (modified).

6.2 Hamamatsu R2150.

6.3 Eljen scintillator.

6.4 Operating suggestions.

Magnetic shields

Added note: The magnetic shields used in these counters are model 23P101X57, by Magnetic Shields Corp. They should be satisfactory up to ~40 Oersted transverse field. A longitudinal field will be more of a problem. If the counter is mounted with its long axis horizontal, the Earth's field will be well attenuated.

6.1 Ortec 269 Modifications

This tube base, as received from the factory, is set up for the 56AVP and similar 52mm head-on fast PMTs. The ones used in the HSC counters have been modified for the Hamamatsu R1250 as follows:

1. The resistors labeled R-18A (2 x 150k, each 1W) were added between the photocathode (pin 20) and first dynode (pin 2).

2. R17 was adjusted so that the potential difference between pin 20 and pin 19 was 25% of the photocathode to first dynode PD: $(V_{20} - V_{19}) = 0.25*(V_{20} - V_2)$. This was done with 1,000V applied to the base, and using a >10MΩ input impedance DMM, so the actual setting is between 25 and 27% of the pin 20 to pin 2 difference.

3. R15 was adjusted so $(V_1 - V_2)$ is zero (or resistance from pin 1 to pin 2 is zero).

4. R26 was adjusted so that the resistance from pin 11 to ground is 150kΩ (no applied HV!).

Table 6.1 gives the pin-out of the base and tubes, while table 6.2 gives nominal resistance values, and potential differences. The base schematic follows.

Table 6.1 – Hamamatsu R1250 and Ortec 269 Base pin and socket labels

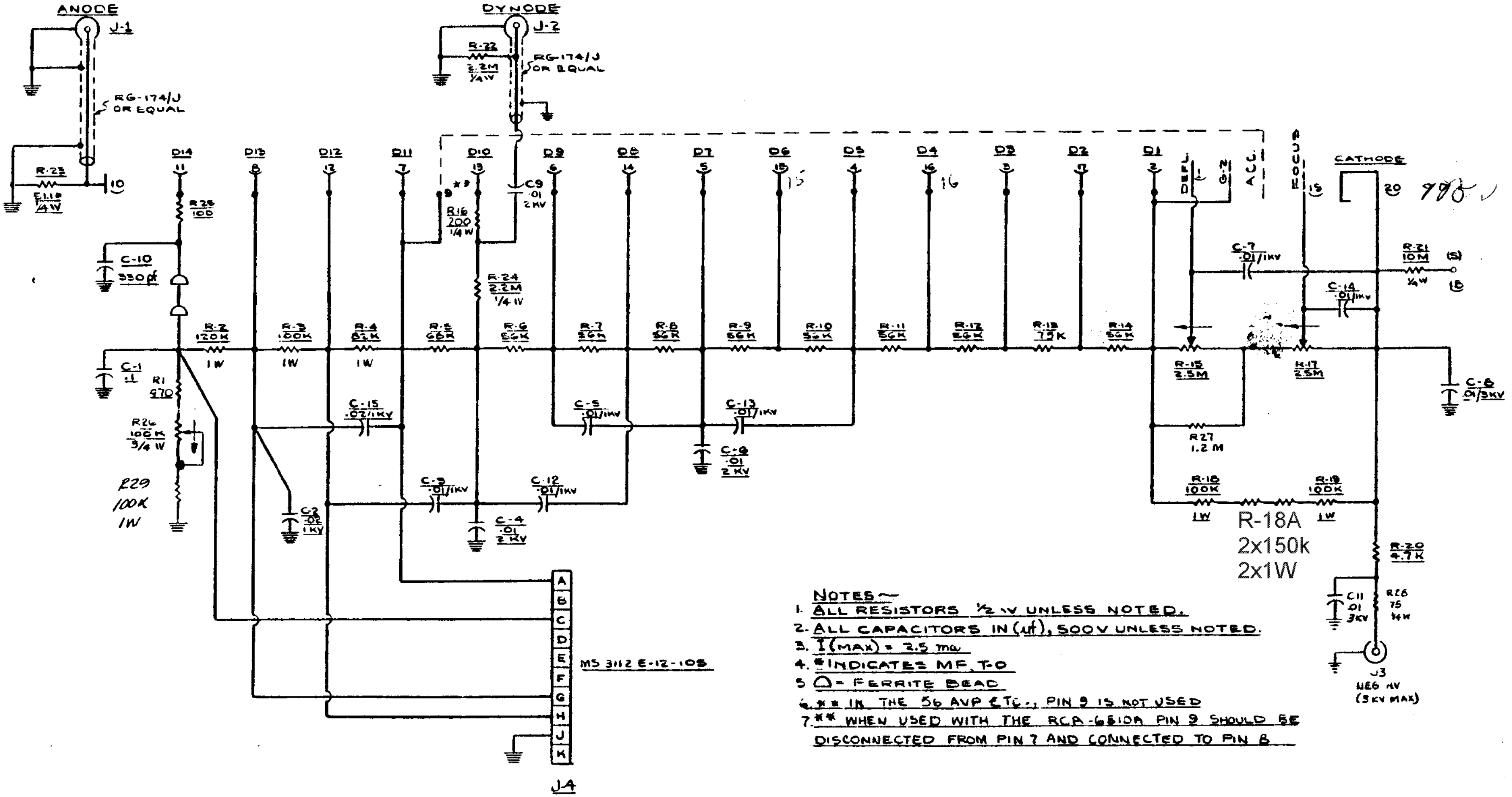
Pin/socket number	Hamamatsu R1250 pin label	Ortec 269 base socket label
1	i.c.	defl
2	d1,g2	d1,g2
3	d3	d3
4	d5	d5
5	d7	d7
6	d9	d9
7	d11	d11
8	d13	d13
9	i.c.	acc/i.c.
10	plate	a
11	d14	d14
12	d12	d12
13	d10	d10
14	d8	d8
15	d6	d6
16	d4	d4
17	d2	d2
18	ic	outer
19	g1	g1
20	k	k

Table 6.2 – Ortec 269 base and Hamamatsu PMT R1250

R1250 pin label	Pin no.	Ortec 269 socket label	Hamamatsu recommended potential difference ratios		Hama-matsu base resis-tances (kΩ)	Hama-matsu potential diff-erences at 1.5kV (V)	Modified base (v2) nominal resist-ance values * (kΩ)	Modified base (v2) nominal potential differ-ences to ground at 1.5kV** (V)
HV					10	6	4.7	5
k	20	k	2.5	k-g1	240	1494	117	1495
g1	19	g1, focus	7.5	g1-d1,g2	750	1372	318	1377
i.c.	1	defl	--	--	--	990	0	1055
d1,g2	2	d1,g2	1.2	d1-d2	120	990	56	1055
d2	17	d2	1.8	d2-d3	180	929	75	999
d3	3	d3	1	d3-d4	100	837	56	923
d4	16	d4	1	d4-d5	100	786	56	866
d5	4	d5	1	d5-d6	100	735	56	809
d6	15	d6	1	d6-d7	100	684	56	753
d7	5	d7	1	d7-d8	100	633	56	696
d8	14	d8	1	d8-d9	100	582	56	639
d9	6	d9	1	d9-d10	100	531	56	583
d10	13	d10	1	d10-d11	100	480	68	526
d11	7	d11	1.5	d11-d12	150	429	82	457
d12	12	d12	1.5	d12-d13	150	352	100	374
d13	8	d13	3	d13-d14	300	276	120	273
d14	11	d14	2.5	d14-gnd	240	122	150	152
gnd	--	--	--	--	--	0	--	0
plate	10	anode		gnd	50 Ω	0	50 Ω	0
i.c.	1	defl		--	n.c.	--	--	--
i.c.	9	acc/i.c.		--	n.c.	--	--	--
i.c.	18	(s)/outer		--	n.c.	--	--	--

* The potentiometers R-15 and R-17 and the resistor R27 are in parallel with R-18, 18A, and 19, so that measured resistances between sockets are much higher and do not directly predict potentials.

** Note that most DMMs are rated only to 1,000V.



NOTES~

1. ALL RESISTORS 1/2 W UNLESS NOTED.
2. ALL CAPACITORS IN (μf), 500V UNLESS NOTED.
3. I(MAX) = 2.5 ma
4. *INDICATES MF T-0
5. ◯ = FERRITE BEAD
6. ** IN THE 56 AVP ETC., PIN 9 IS NOT USED
7. ** WHEN USED WITH THE RCA-6810A PIN 9 SHOULD BE DISCONNECTED FROM PIN 7 AND CONNECTED TO PIN 8

REV	ECN NO	DATE	BY	APPD.
A	269-3	12-66	UDW	
B	269-5	1-67	UDW	
C	269-10	5-67	UDW	
D	269-11	5-67	UDW	
E	269-14	8-67	KUDW	
F	269-19		CS	
G	269-28	3-1-72	KC	WH

REVISIONS

UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES
TOLERANCES
FRACTION ±
DECIMALS ±
ANGLES ±
SURFACE FINISH √RMS
APPLIED PRACTICES

ORTEC
OAK RIDGE TECHNICAL ENTERPRISES CORPORATION
OAK RIDGE TENNESSEE

TITLE: MODEL 269 56AVP / 58AVP P.M. BASE

DRAFTSMAN: HW DATE: 6/12/66
ENG APPROVAL: 5/31/66
REV ENG: C. WILLIAMS
CHECKED: 6/15/66
DRAWING NO.: 269-0101-S1

PRINTS TO FILE

HAMAMATSU

PHOTOMULTIPLIER TUBE
R1250

For High Energy Physics, Fast Time Response, High Pulse Linearity
127mm (5 Inch) Diameter, Bialkali Photocathode, 14-Stage, Head-on Type

GENERAL

Parameter		Description/Value	Unit
Spectral Response		300 to 650	nm
Wavelength of Maximum Response		420	nm
Photocathode	Material	Bialkali	—
	Minimum Useful Diameter	120	mm dia.
Window	Material	Borosilicate glass	—
Dynode	Structure	Linear focused	—
	Number of Stages	14	—
Base		20-pin base	—
Suitable Socket		E678-20A (supplied)	—

MAXIMUM RATINGS (Absolute Maximum Values)

Parameter		Value	Unit
Supply Voltage	Between Anode and Cathode	3000	Vdc
	Between Anode and Last Dynode	500	Vdc
Average Anode Current		0.2	mA
Ambient Temperature		-30 to +50	°C

CHARACTERISTICS (at 25°C)

Parameter		Min.	Typ.	Max.	Unit
Cathode Sensitivity	Luminous (2856K)	55	70	—	μA/lm
	Blue (with CS 5-58 filter)	7.0	9.0	—	μA/lm-b
	Quantum Efficiency at 390nm	—	22	—	%
Anode Sensitivity	Luminous (2856K)	300	1000	—	A/lm
	Blue (with CS 5-58 filter)	—	130	—	A/lm-b
Gain		—	1.4×10^7	—	—
Anode Dark Current (after 30min. storage in darkness)		—	50	300	nA
Time Response	Anode Pulse Rise Time	—	2.5	—	ns
	Electron Transit Time	—	54	—	ns
	Transit Time Spread	—	1.2	—	ns
Pulse Height Resolution with ^{137}Cs		—	8.3	—	%
Gain Deviation	Long Term	—	1.0	—	%
	Short Term	—	1.0	—	%
Pulse Linearity *	2% Deviation	—	160	—	%
	5% Deviation	—	250	—	%

* Measured with special voltage distribution ratios shown in the Table 2.

Table 1: VOLTAGE DISTRIBUTION RATIO AND SUPPLY VOLTAGE

Electrode	K	G1	G2	Dy1	Dy2	Dy3	Dy4	Dy5	Dy6	Dy7	Dy8	Dy9	Dy10	Dy11	Dy12	Dy13	Dy14	P
Ratio	2.5	7.5	0	1.2	1.8	1	1	1	1	1	1	1	1	1.5	1.5	3	2.5	

Supply Voltage: 2000Vdc, K: Cathode, Dy: Dynode, P: Anode, G: Grid

Table 2: SPECIAL VOLTAGE DISTRIBUTION RATIO AND SUPPLY VOLTAGE FOR PULSE LINEARITY MEASUREMENT

Electrode	K	G1	G2	Dy1	Dy2	Dy3	Dy4	Dy5	Dy6	Dy7	Dy8	Dy9	Dy10	Dy11	Dy12	Dy13	Dy14	P
Ratio	2.5	7.5	0	1.2	1.8	1	1	1	1	1.2	1.5	2	2.8	4	5.7	8	5	
Capacitors in μF											0.01	0.01	0.02	0.02	0.02	0.04	0.06	

Supply Voltage: 2500Vdc, K: Cathode, Dy: Dynode, P: Anode, G: Grid

PHOTOMULTIPLIER TUBE R1250

Figure 1: Typical Spectral Response

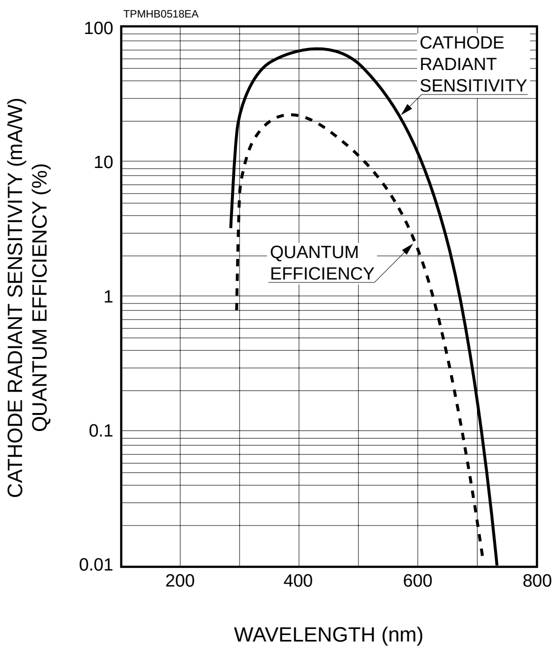


Figure 2: Typical Gain Characteristics

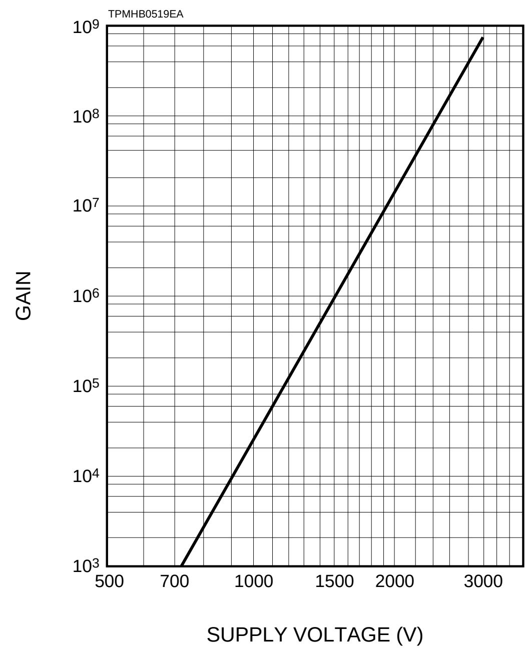
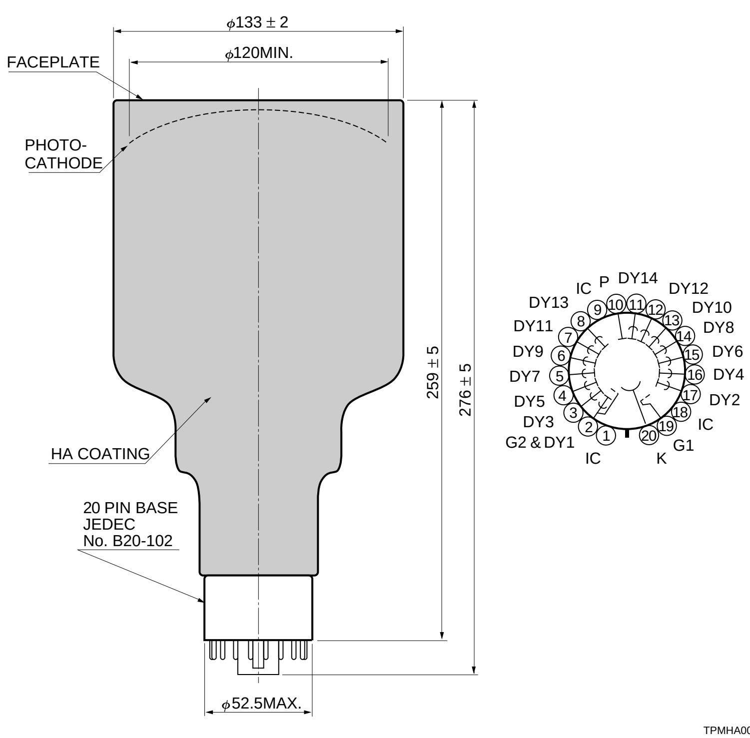
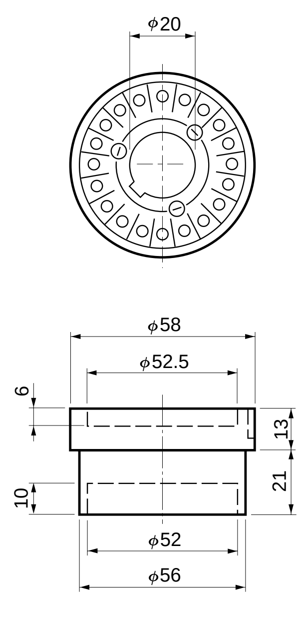


Figure 3: Dimensional Outline and Basing Diagram (Unit: mm)



Socket (E678-20A)



HAMAMATSU

HOMEPAGE URL http://www.hamamatsu.com

HAMAMATSU PHOTONICS K.K., Electron Tube Center

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TPMH1213E02
DEC. 1999

6.3 Ejlen EJ-200 Scintillator

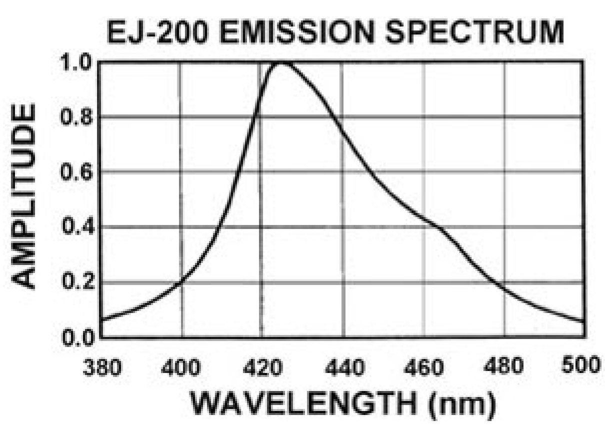
EJ-200 Plastic Scintillator

This plastic scintillator combines the two important properties of long attenuation length and fast timing and is therefore particularly useful for time-of-flight systems using scintillators greater than one meter long. Typical measurements of 4 meter optical attenuation length are achieved in strips of cast sheet in which a representative size is 2cm x 20cm x 300cm.

The combination of long attenuation length, high light output, and emission spectrum well matched to the common photomultipliers recommends EJ-200 as the detector of choice for many industrial applications such as gauging and environmental protection where high sensitivity of signal uniformity are critical operating requirements.

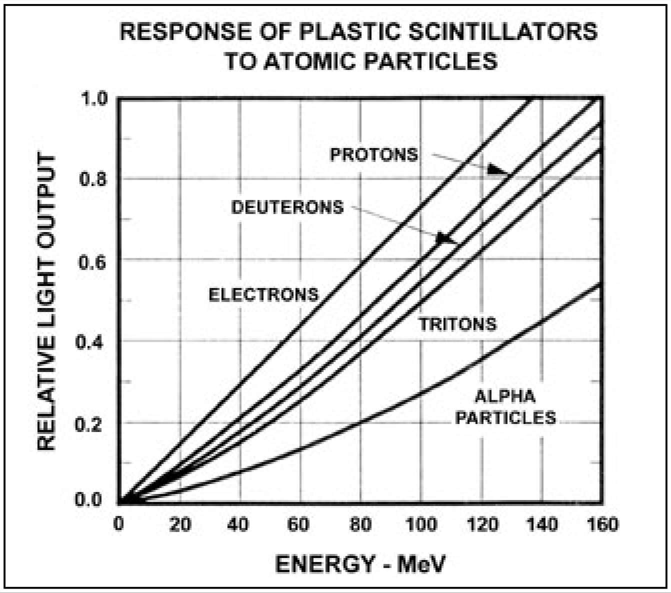
Physical and Scintillation Constants:

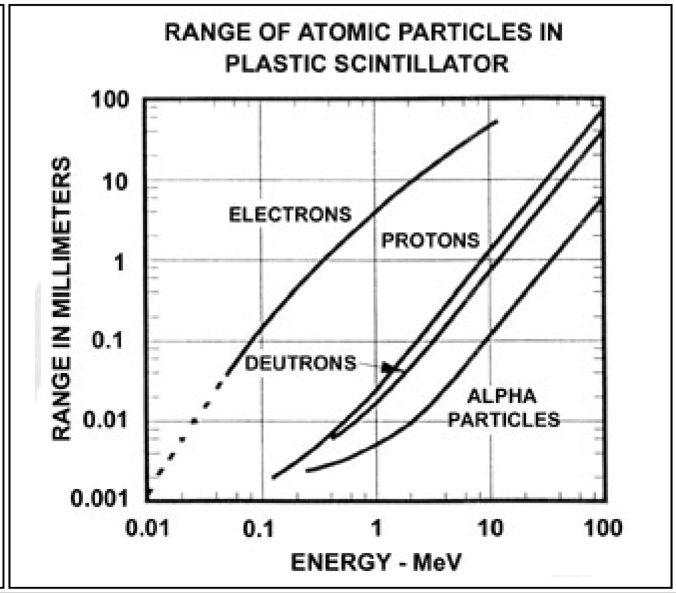
Light Output, % Anthracene..........................	64
Scintillation Efficiency, photons/1 MeV e........	10,000
Wavelength of Max. Emission, nm.................	425
Rise Time, ns...	0.9
Decay Time, ns...	2.1
Pulse Width, FWHM, ns..............................	~2.5
No. of H Atoms per cm^3, x 10^{22}....................	5.23
No. of C Atoms per cm^3, x10^{22}.....................	4.74
No. of Electrons per cm^3, x 10^{23}..................	3.37
Density, g/cc:...	1.032



Polymer Base:	Polyvinyltoluene
Refractive Index:	1.58
Vapor Pressure:	Is vacuum-compatible
Coefficient of Linear Expansion:	7.8 x 10E-5 below +67° C
Light Output vs. Temperature:	At +60° C, L.O.=95% of that at +20° C No change from +20° C to -60° C
Chemical Compatability:	Is attacked by aromatic solvents, chlorinated solvents, ketones, solvent bonding cements, etc. It is stable in water, dilute acids and alkalis, lower alcohols and silicone greases. It is safe to use most epoxies and "super

glues" with EJ-200.





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6.4 Unpacking/moving/setting up

The counters use negative high voltage, with DC-coupled anode. The high-impedance dynode output is useful only for monitoring. The bases draw ~0.6 mA per kV, with a maximum of -3kV, though operating voltages of ~1700V are typical. The bases are ORTEC/EG&G type 269 (data sheet attached), modified for the Hamamatsu R2150.

Connectors are SHV and BNC.

The base potentiometers have been adjusted according to Hamamatsu's recommendation and should not need to be adjusted.

6.4.1 Check for broken glue joint

Carefully remove the bases (electronics packages) by loosening only the top screws.

Gently exert a little sideways pressure on the base of the tube (connector with pins) to see if it is loose.

If any looseness is felt, a repair is needed. Consult an expert.

If there is no looseness, re-install the base, and tighten the top screws finger-tight. Add some low-strength thread-locking fluid (Loctite).

6.4.2 Check for light leaks

It is important to check regularly for light leaks:

1. Turn the (negative) HV on gradually (100V steps) while looking at the anode output, scope input on DC in, trigger threshold ~-100mV (negative-going edge), scope sensitivity ~200mV/div.

- A baseline shift below 1000V indicates a serious leak.
- 'Grass' developing below 1500V indicates a less-serious leak, but one that needs to be fixed.
- At a high-voltage of -1500V, the measured singles rate should be less than ~10kHz. If more, suspect a light leak.

2. Raise the HV to -1700V (or operating voltage). Check the singles rate again; it should be <<30kHz. See table 5.2.

6.4.3 Standard setup

Table 6.3 has suggested initial high voltages. It is unlikely that an operating voltage greater than 1800V will be needed. If the signal is poor at 1800V, suspect a malfunction in base, cables, or electronics. Do not operate above 1800V without a proper investigation.

The counters drive 50ohm cables (a good cable is important). The dynode output should be terminated in 50Ω, as shipped.

Table 5.3 – Suggested operating high voltages

Counter	PMT	
	A	B
HSC-1	1700V	1700V
HSC-2	1700V	1700V
HSC-3	1700V	1800V