A Custom Base for using the EMI/Thorn 9816B Photomultiplier Tube with the Products for Research Model TE-182 Thermoelectrically-Cooled PMT Housing for Ultra-Low Light Level Experiments

David Prutchi, Ph.D., May 2021

I've been planning some experiments with single-photon and ultra-low light levels. For these experiments I want the collection area to be large and for the detector to have very broad spectral response, so my preference is to use a photomultiplier tube (PMT) instead of a "silicon photomultiplier" avalanche single-photon detector.

I found a brand new EMI 9816B PMT on eBay® which meets my requirements. The 9816B is a 51 mm (2") diameter end-window photomultiplier, with an S20 infrared-sensitive photocathode (Figure 1), and 14 BeCu dynodes of linear focused design. This tube features a very high gain of 25×10^6 A/lm under nominal conditions (2,200V) with a quantum efficiency of 21% at the peak response wavelength.

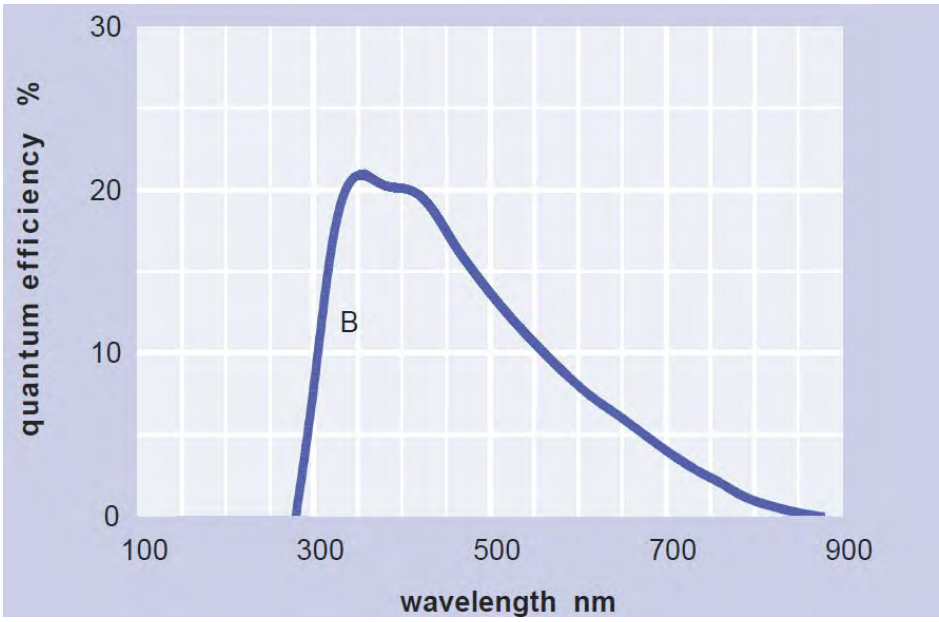
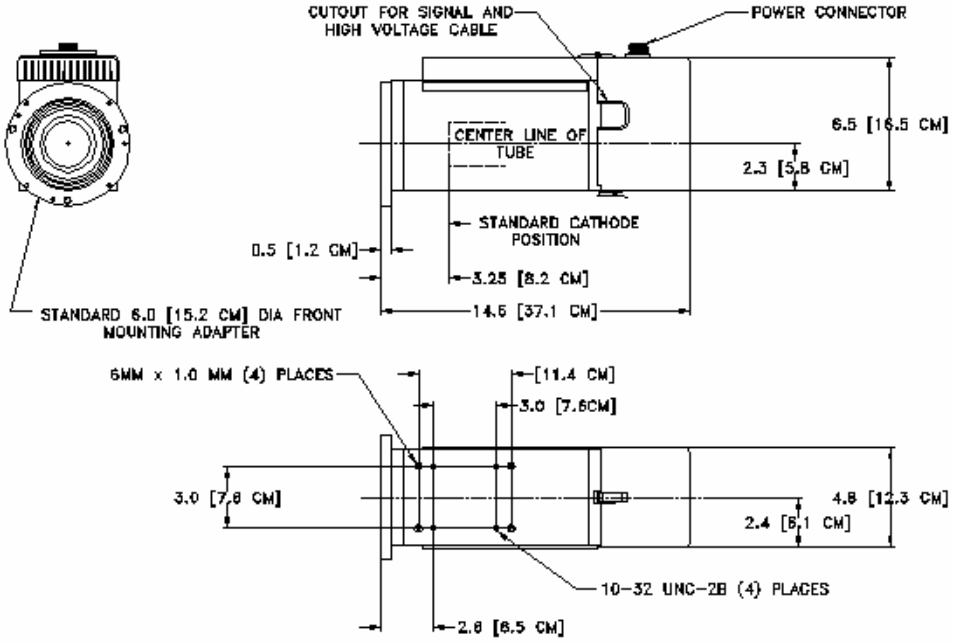


Figure 1 - Typical spectral response of the EMI 9816 PMT

Integration time, and ultimately resolution and sensitivity for detecting single-photons or ultra-weak light levels are dependent on the noise floor (dark counts) which is a function of temperature. Cooling the PMT dramatically reduces its dark current and counts.

I bought a surplus thermoelectrically-cooled housing by Products for Research (Model TE-182) which is made for 2" end-window PMTs. Specifications for this housing are shown in Table 1

Table 1 – Products for Research TE-182 thermoelectrically-cooled PMT housing specifications



Guaranteed ΔT - Ambient air to photocathode	> 40°C with ambient air warmer than 0°C
Cool down time to stability of photocathode	2 hours
Window material	Quartz
Weight	Chamber - 13 lbs. (5.9 kg) Power supply - 13 lbs. (5.9 kg)
Power requirements	85 Watts at either 115 V~, 50/60 Hz or 220 V~, 50/60 Hz

I could not find a surplus base for the EMI 9816B 14-dynode PMT, so I decided to buy a surplus base for a different tube and modify it for the 9816B. Clearing the inside of the base was a very messy affair. This is because the dynode voltage divider chain is partially potted in silicone, and the rest of the base is filled with expanding thermal-isolation foam. Part of the base is made of plastic, so the use of harsh chemical solvents or heat to remove the silicone rubber and expanding foam were not possible. I thus had to use a scalpel and dental picks to remove all this insulation and be able to disassemble the tube socket.

I built a new divider on a piece of phenolic breadboard according to the schematic of Figure 2. The base is wired for high voltage (-2,300V) applied to the cathode (through a 33kΩ resistor). The dynode_1-to-dynode_14 divider is built with 330kΩ resistors. As suggested by EMI, the cathode-to-focus (and dynode_1) is set at a fixed 300V difference using two 150V Zener diodes in series. Figure 3 shows the modified base.

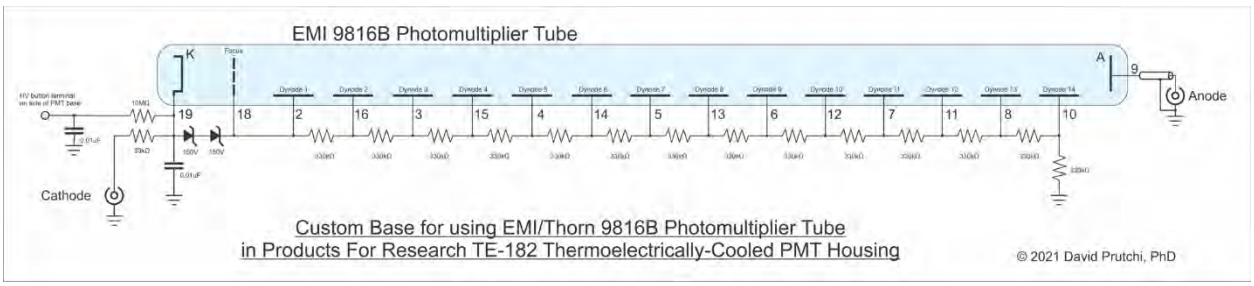


Figure 2 – Schematic diagram of base for the EMI 9816B PMT.

I set up the test system shown in Figure 4 to characterize the dark current / dark counts of the system. I used a Matsusada precision high voltage power supply to power the PMT and measured the anode current by connecting the Anode output directly to a Signal Recovery model 5182 current-mode preamplifier set to a gain of 10-5 A/V. The amplifier's output was measured using a Fluke 187 DVM in mV scale. I measured the pulse rate by connecting the Anode output to a home-made PMT processor at maximum gain (X10 input, X10 secondary) and acquired by a Princeton Applied Research model 1122 Photon Counter/Processor sampling at 0.1 Hz (10s integration time).

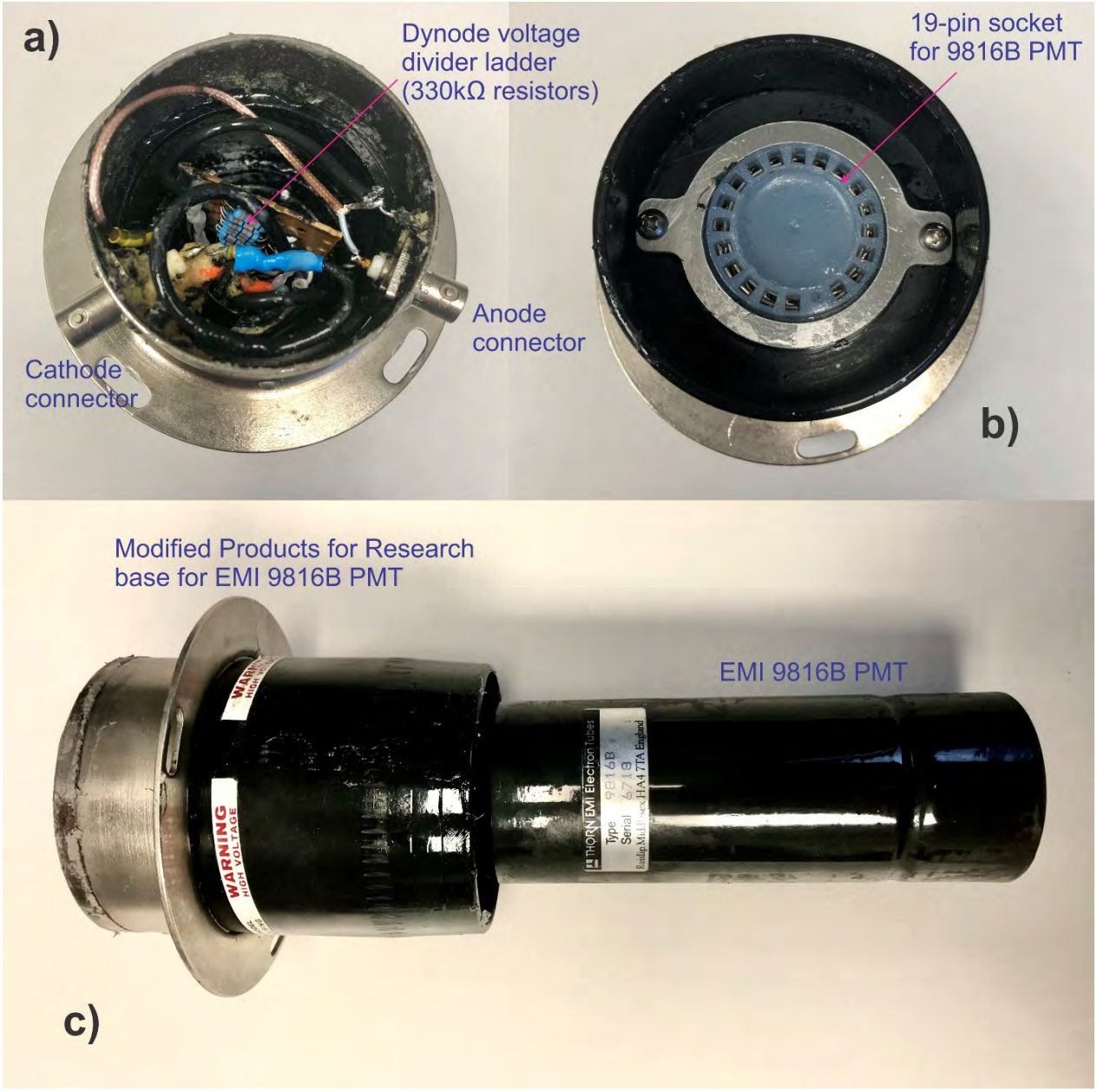


Figure 3 – Products for Research PMT base modified for the EMI 9816B PMT. A) View inside the modified base before filling with thermal insulation foam showing the dynode resistor divider ladder. B) The 19-pin PMT socket is held in place with a custom aluminum bracket. C) The PMT mounted on the base before it is placed in the thermoelectrically-cooled housing.

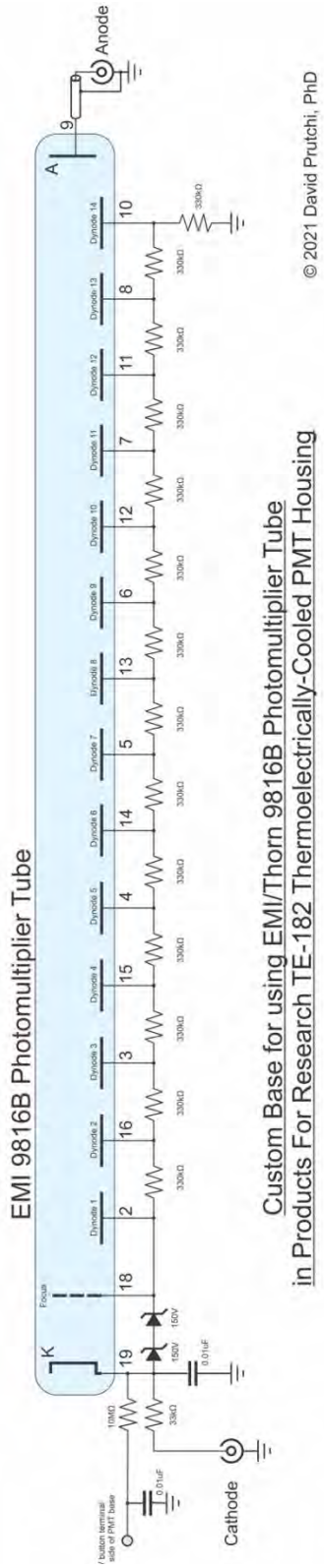
Figure 4 – Dark current / dark counts test setup for the cooled PMT system.

Results from a characterization run are shown in Table 2. The room-temperature dark current agrees with the specified value. A very dramatic drop in dark current and dark count rate can be observed when the PMT is cooled.

Table 2 – Specified and measured performance of the EMI 9812. Measurements were not performed multiple times to account for drift and other errors, so these are presented only to show the dramatic effect of cooling on dark current and counts.

	Spec (@20°C)	**Measured at ~23°C**	**Measured with TE cooler on, stabilized**
Dark current at nominal 2,200V	50 nA typ, 500 nA max	47 nA	>20 nA
Dark current at maximum sensitivity 2,300V [A/lm]	100 nA	67 nA	>20 nA
Dark count rate at nominal 2,200V	15,000 count/s but minimum pulse height not specified	61,000 counts/s	1,800 counts/s
Dark count rate at maximum sensitivity 2,300V	Not specified	83,000 counts/s	790 counts/s

APPENDIX I – High-resolution view of Figure 2



APPENDIX I – EMI 9816B PMT Specifications from EMI 1972 PMT Supplement and from ET Enterprises

50 mm (2 in) diameter fast linear focused tubes with S11, bialkali, or S20 photocathodes

- Semi-transparent curved photocathode surface on end window which is flat externally
- Linear focused dynode structure with caesiated Be O surfaces for high gain and good stability
- Spectral responses S-11, S-13, Bialkali or S-20
- 10, 12 or 14 dynode stages
- Flexibility of envelope configuration, i.e. B19A(uncapped) or B20–102 (overcapped) base; borosilicate (Pyrex) or quartz (Spectrosil) end window material

The 2 in. diameter tubes 9810–9818 are designed for applications requiring very fast response times such as the detection and measurement of short lived nuclear events and pulsed light sources.

This new series has been introduced to replace the 9594 range. Apart from being more comprehensive, it incorporates design modifications to give improved reliability and performance. The external dimensions and pin connections are unchanged to preserve interchangeability.

MECHANICAL CHARACTERISTICS

Maximum envelope diameter	All types 53 mm (2.09 in)
Nominal cathode diameter	All types 46 mm (1.81 in)
Window material (see drawings for shapes)	'B' and 'KB' types borosilicate (Pyrex): 'QB' and 'QKB' types quartz (Spectrosil)
Dynodes	Caesiated Be O surface, linear focused
Base	'B' and 'QB' types B19A (socket supplied) 'KB' and 'QKB' types Jedec B20–102 (socket extra)

PRELIMINARY SELECTION GUIDE

Basic Type*	Spectral Response	Number of Dynodes	Old Type	Remarks
9810B	S-11	14	9594UB	General purpose high gain parent type
9811B	S-11	12	—	Medium gain version of 9810B
9812B	S-11	10	9595UB	Lower gain version of 9810B for higher light levels
9813B	Bialkali	14	—	High gain, low dark current, high "blue" response
9814B	Bialkali	12	—	Medium gain version of 9813B
9815B	Bialkali	10	—	Lower gain version of 9813B for higher light levels
9816B	S-20	14	9597UB	High gain, spectral response extends to IR
9817B	S-20	12	—	Medium gain version of 9816B
9818B	S-20	10	9596UB	Lower gain version of 9816B, for higher light levels

*Versions with quartz end window and/or overcapped are available in which case Q and/or K respectively are added to the type number, e.g. 9813QKB.

Notes

1 a) Each tube is individually calibrated and supplied with a test ticket giving the cathode sensitivity in μA/lm; cathode sensitivity measurements with filters appropriate to type of photocathode; the overall voltages for 50A/lm (10-stage tubes only), 200 A/lm (12-stage tubes only), 5000 A/lm (14-stage tubes only), and the relevant dark current (at 20°C).
A Corning glass filter (CS-5-58 ground to half stock thickness) is used to give a measure of the "blue" sensitivity; a Corning glass filter (CS-2-62), which passes all radiation longer than approximately 600nm, to indicate "red" sensitivity, and a Wratten 87 filter, which passes all radiation longer than approximately 800nm, to indicate sensitivity in the near infra-red region.

b) Test data is obtained with K to d1 held at 300 volts and the non-linear test dynode chain.

c) F (focus) should be connected to d1 for normal operation.

d) Generally, tubes should be operated at or near their rated overall sensitivity. Care should be taken not to exceed the maximum rated sensitivity or voltage.

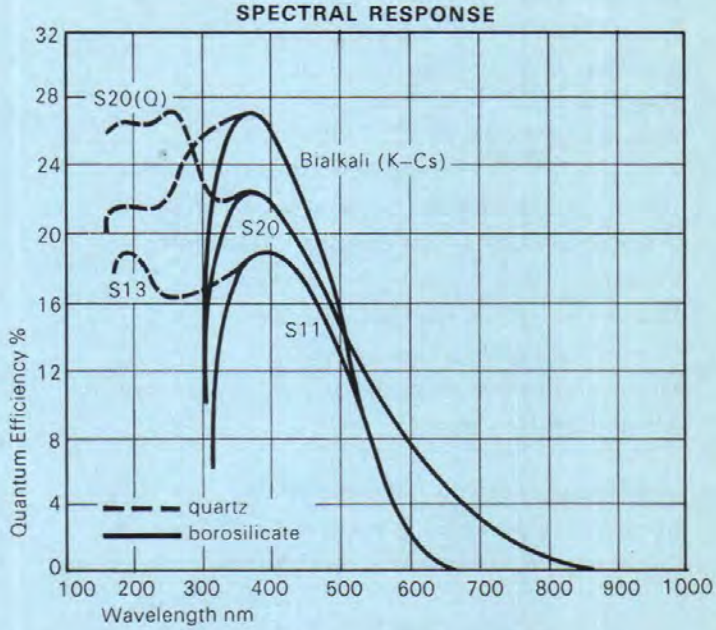
2 For optimum stability under d.c. conditions, the mean anode current should not exceed 10μA.

3 The glass envelope is coated with a screen which is connected to the cathode pin and over-wound with 3M's electrical tape, to ensure optimum dark current performance. Special care should be taken if the tube is operated with the cathode at high negative potential.

4 Overall sensitivity is greatly affected by variations in overall voltage, particularly in the case of tubes with a large number of dynodes.

5 In order to obtain a high value of peak output current, it is necessary to provide high voltages between the last dynode stages. The EMI test dynode chain is recommended for optimum results.

SPECTRAL RESPONSE

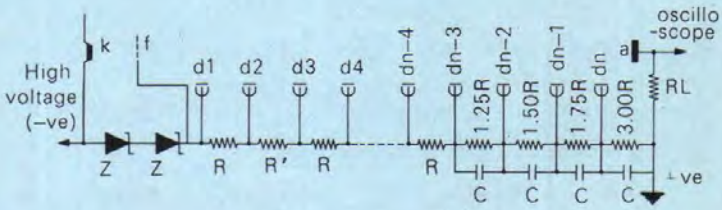


Tube type No.*	Cathode Sensitivity μA/lm		Overall Sensitivity 5000A/lm				Overall Sensitivity 10,000A/lm	
			V Overall		Dark Current nA		V Overall	Dark Current nA
	Min.	Typ.	Typ.	Max.	Typ.	Max.	Typ.	Typ.
9810B†	50	75	2250	2700	100	1000	2380	200
9810B‡			1980	—			2080	
9813B†	§	§	2350	2700	10	100	2480	20
9813B‡			2050	—			2160	
9816B†	100	170	2150	2700	50	1000	2270	100
9816B‡			1900	—			2000	
			Overall Sensitivity 200A/lm				Overall Sensitivity 2000A/lm	
9811B†	50	75	2050	2500	15	100	2600	150
9811B‡			1750	—			2220	
9814B†	§	§	2150	2500	2	8	2750	20
9814B‡			1850	—			2350	
9817B†	100	170	1950	2500	10	100	2470	100
9817B‡			1650	—			2070	
			Overall Sensitivity 50A/lm				Overall Sensitivity 500A/lm	
9812B†	50	75	1850	2300	2	50	2500	20
9812B‡			1560	—			2100	
9815B†	§	§	1950	2300	1	5	2620	10
9815B‡			1640	—			2200	
9818B†	100	170	1750	2300	2	50	2350	20
9818B‡			1470	—			1970	

* Tube characteristics apply equally to overcapped and quartz versions.
† Non-linear dynode chain.
‡ Linear dynode chain.
§ Types 9813, 9814 9815 have a minimum Corning blue cathode sensitivity of 7.0 and typical of 10.0.

DYNODE CHAIN DESIGN

The EMI (Non-linear) test dynode chain is shown below:



R' = 1.4R for normal operation but may be varied between R and 1.4R without significant change in performance

RL = 50 Ω n = number of dynodes

Z = IS4150A (150V) c = 1000pF

The value of R should be chosen to provide a series current, in the divider chain, of at least 10 times the mean expected anode current. To maintain linearity when high current anode pulses are being drawn, the voltages supplying the final dynodes should be increased, and if resistors are being used they should be decoupled by suitably large value capacitors. The photomultiplier output socket will also affect operation under pulsed conditions.

General notes on design aspects are given in the Introduction of the EMI photomultiplier catalogue P001/fP70, available on request.

RATINGS

PARAMETER	TUBE TYPE (All versions)		
	9810	9811	9812
	9813	9814	9815
	9816	9817	9818
Overall sensitivity: Rated	5,000 A/lm	200 A/lm	50 A/lm
Maximum	10,000 A/lm	2,000 A/lm	500 A/lm
Anode pulse rise time: Typical	2.4	2.0	1.6
(n. sec) Maximum	3.0	2.5	2.2
Anode Pulse f.w.h.m.: Typical	3.6	2.8	2.5
(n. sec) Maximum	4.4	4.0	3.5
Electron transit time: Typical (n. sec)	45	39	32
Voltage cathode to d1: Recommended	300	300	300
Maximum	500	500	500
Voltage between dynodes: Maximum	550	550	550
Voltage anode to last dynode: Maximum	550	550	550
Voltage anode to cathode: Maximum	3000	2800	2500
Maximum anode current (mean):	0.2mA	0.2mA	0.1mA
Maximum anode dissipation:	0.1W	0.1W	0.05W
Maximum tolerable cathode current (assuming whole cathode used)	S-11 types	0.3 μA	
	S-20 types	5 μA	
	Bialkali types	0.3 μA	
Maximum operating temperature:	60°C	60°C	60°C
Minimum operating temperature:	—80°C*	—80°C*	—80°C*
Capacitance to all electrodes: Anode	B types 5pf	KB types 7pf	
Last dynode	B types 7pf	KB types 9pf	
Energy resolution using Na I (Tl) crystal measured on type 9813	f.w.h.m. typically 7.5% for ^{137}Cs		
	P/V typically 6.0:1 for ^{60}Co		

* —20°C for 9813, 9814 and 9815

DARK CURRENT SHOT NOISE EQUIVALENT INPUT*

Type	9810	9811	9812	9813	9814	9815	9816	9817	9818
Lumens	2.9×10^{-13}	5.7×10^{-13}	4.1×10^{-13}	9.5×10^{-14}	2.1×10^{-13}	3.0×10^{-13}	1.4×10^{-13}	3.1×10^{-13}	2.7×10^{-13}
Watts	3.6×10^{-16}	6.9×10^{-16}	5.0×10^{-16}	8.1×10^{-17}	1.9×10^{-16}	2.5×10^{-16}	3.4×10^{-16}	7.7×10^{-16}	2.0×10^{-15}

*Calculated from typical performance data using Q.E. at λ peak and assuming Δf of 1Hz and enhancement factor of unity.

TUBE REPLACEMENT GUIDE

RCA	EMI*	PHILIPS	EMI†
4459	9817KB	56AVP	9810KB
6810	9810KB	56TUVP	9816QKB
6810A	9810KB	56DVP	9813KB
7264	9810KB	56DUVP	9813QKB
7265	9816KB	**PHILIPS**	**EMI***
7326	9818KB	XP1000	9812KB
7746	9812KB	XP1001	9812KB
7850	9811KB	XP1002	9818KB
8575	9814QB	XP1003	9818QKB

*nearest equivalent given – see data for differences
†direct plug-in replacement (focus voltage will need adjustment)

NOTES ON TIME CHARACTERISTICS

The anode pulse rise time is the time taken for the output pulse to rise from 10% to 90% of the peak when the photocathode of the tube is illuminated by a flash of light of very short duration.

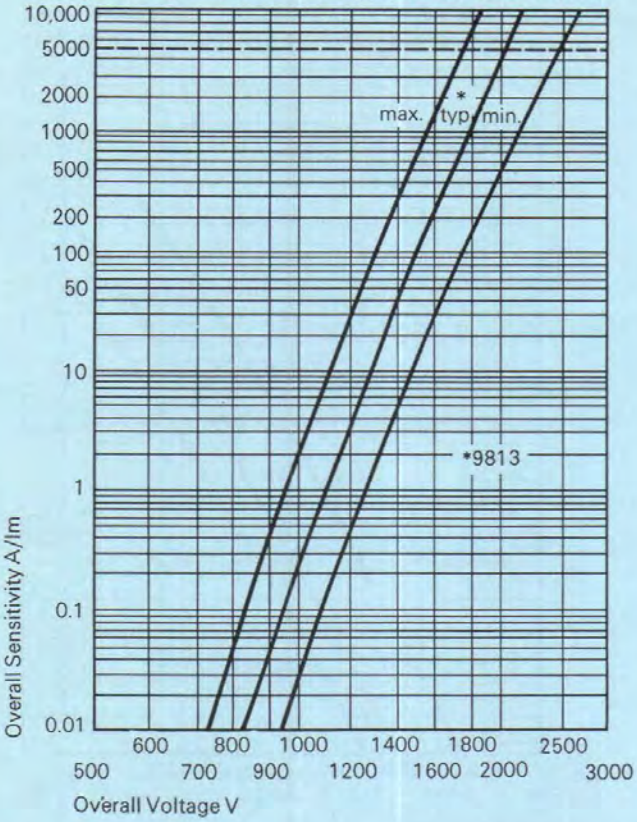
The anode pulse f.w.h.m. is the full width of the output pulse measured at half maximum amplitude.

The electron transit time is the time difference between the arrival of a flash of light at the photocathode and the instant when the output pulse is a maximum.

In each case the whole photocathode is illuminated by a point source situated about 50 mm above its centre. Measurements referred to in the "electrical ratings" were made at the maximum rated voltage for 10 and 12 stage tubes and the standard rated voltage for 14 stage tubes.

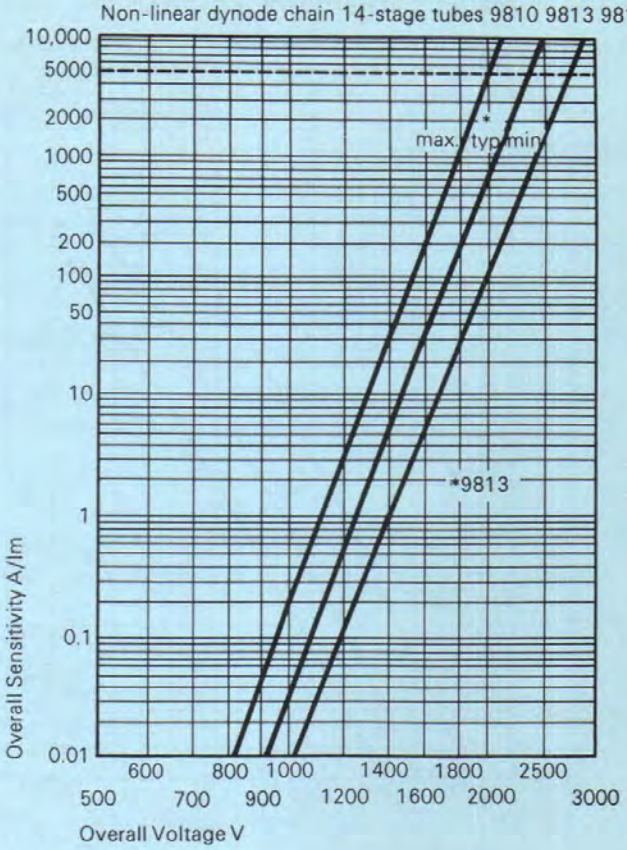
OVERALL SENSITIVITY vs OVERALL VOLTAGE

Linear dynode chain 14 stage tubes 9810 9813 9816



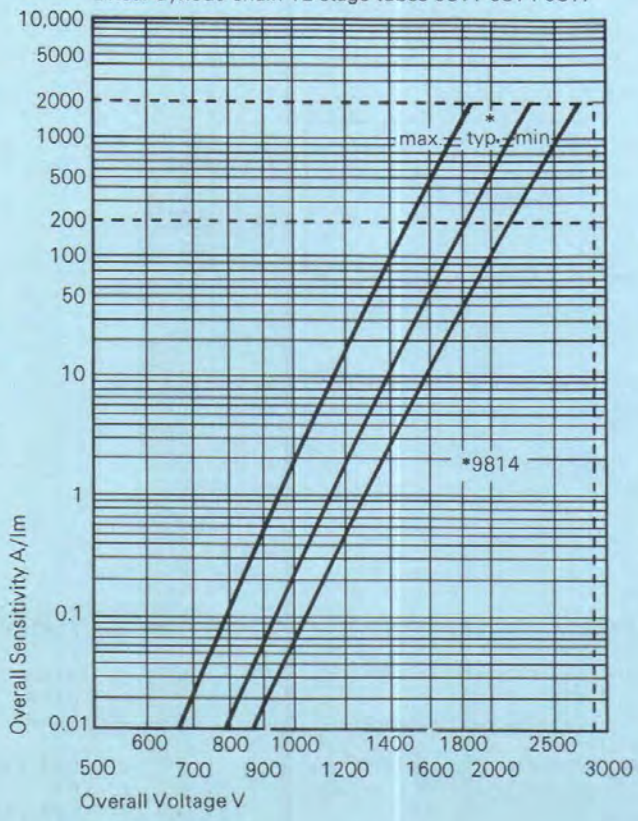
OVERALL SENSITIVITY vs OVERALL VOLTAGE

Non-linear dynode chain 14-stage tubes 9810 9813 9816



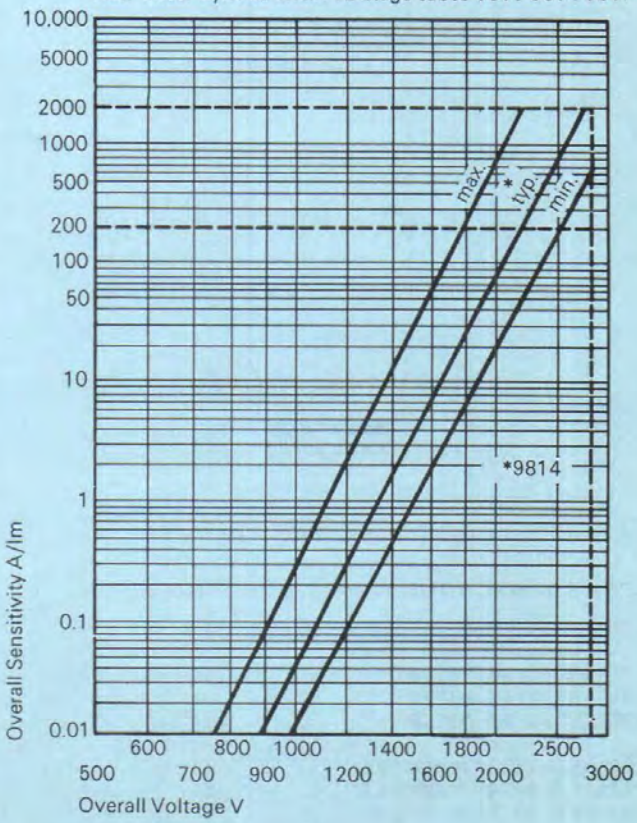
OVERALL SENSITIVITY vs OVERALL VOLTAGE

Linear dynode chain 12 stage tubes 9811 9814 9817



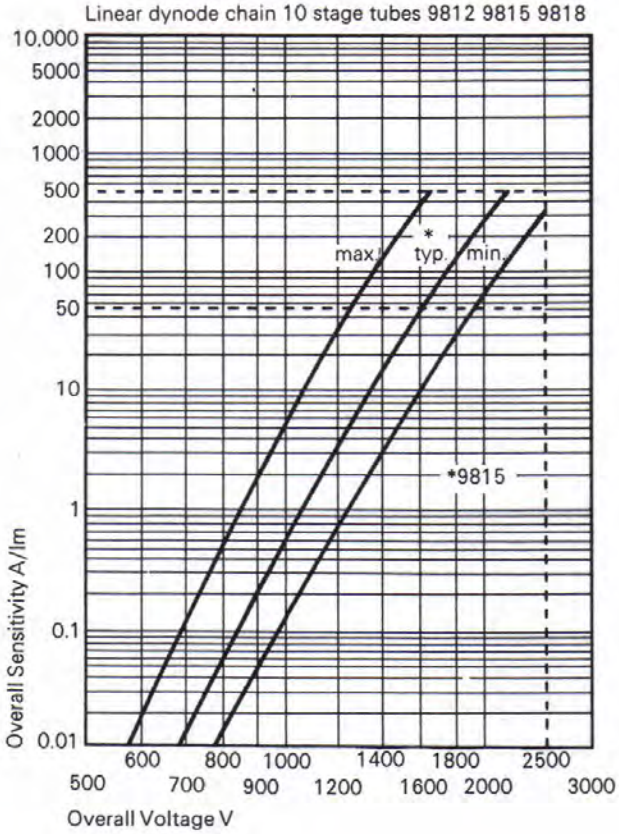
OVERALL SENSITIVITY vs OVERALL VOLTAGE

Non-linear dynode chain 12 stage tubes 9811 9814 9817



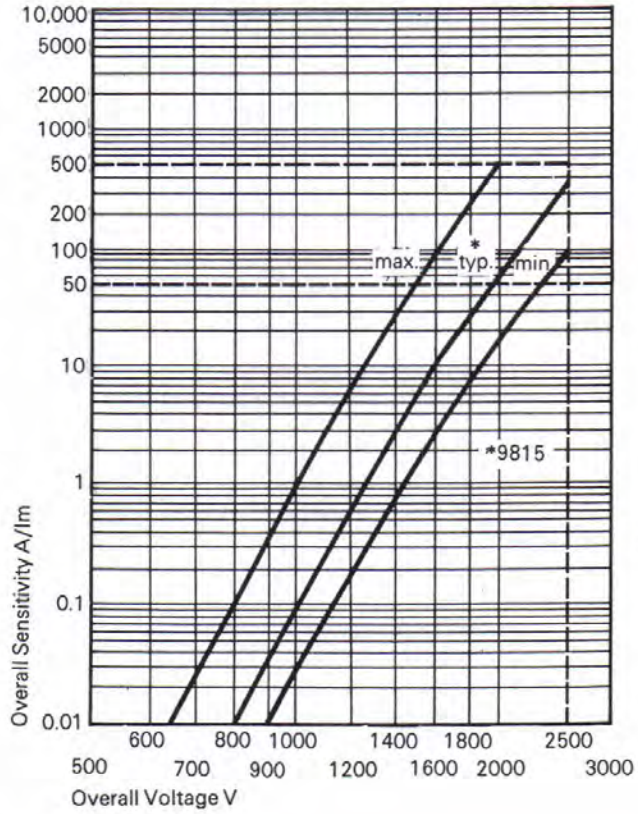
OVERALL SENSITIVITY vs OVERALL VOLTAGE

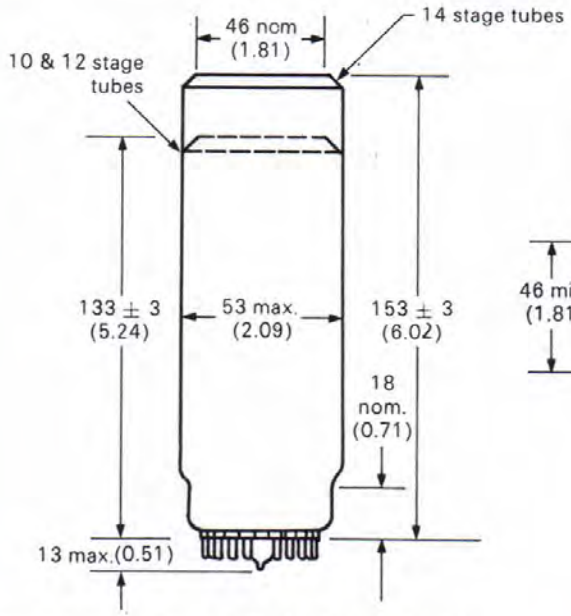
Linear dynode chain 10 stage tubes 9812 9815 9818

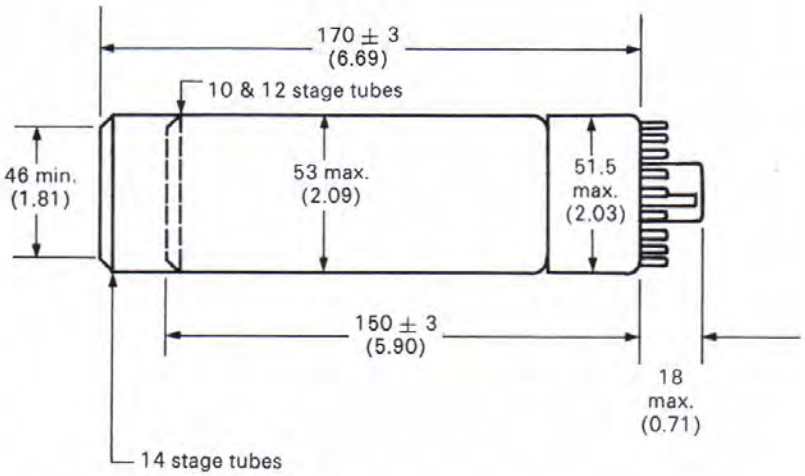


OVERALL SENSITIVITY vs OVERALL VOLTAGE

Non-linear dynode chain 10 stage tubes 9812 9815 9818







All dimensions in millimetres (inches in parenthesis).

PIN CONNECTIONS (viewed from below starting left of short pin or key)

Type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	SOCKET
9810B 9813B 9816B	ic	d1	d3	d5	d7	d9	d11	d13	A	d14	d12	d10	d8	d6	d4	d2	ic	F	K	—	**B19A**
9811B 9814B 9817B	ic	d1	d1	d3	d5	d7	d9	d11	A	d12	d10	d8	d6	d4	d2	ic	ic	F	K	—	**B19A**
9812B 9815B 9818B	ic	d1	d1	d1	d3	d5	d7	d9	A	d10	d8	d6	d4	d2	ic	ic	ic	F	K	—	**B19A**
9810KB 9813KB 9816KB	ic	d1	d3	d5	d7	d9	d11	d13	ic	A	d14	d12	d10	d8	d6	d4	d2	ic	F	K	**B20-102**
9811KB 9814KB 9817KB	ic	d1	d1	d3	d5	d7	d9	d11	ic	A	d12	d10	d8	d6	d4	d2	ic	ic	F	K	**B20-102**
9812KB 9815KB 9818KB	ic	d1	d1	d1	d3	d5	d7	d9	ic	A	d10	d8	d6	d4	d2	ic	ic	ic	F	K	**B20-102**

51 mm (2") photomultiplier
9816B series data sheet

ET Enterprises electron tubes

1 description

The 9816B is a 51mm (2″) diameter end window photomultiplier, with S20 infra-red sensitive photocathode, and 14 BeCu dynodes of linear focused design.

2 applications

- high energy physics studies
- low light level detection

3 features

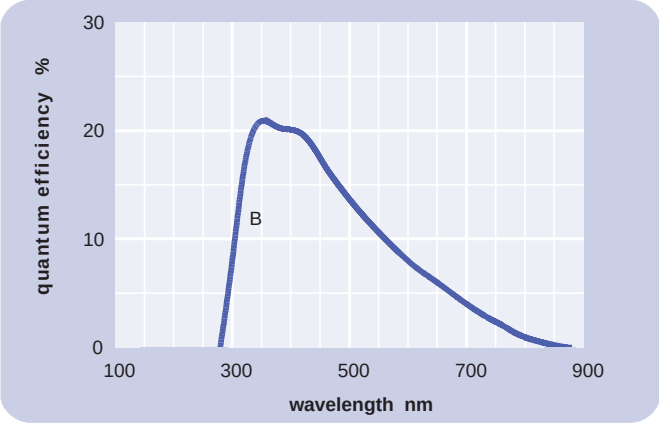
- high gain
- high pulsed linearity

4 window characteristics

	9816B borosilicate
spectral range *(nm)	290 - 870
refractive index (n_d)	1.49
K (ppm)	300
Th (ppb)	250
U (ppb)	100

* wavelength range over which quantum efficiency exceeds 1 % of peak

5 typical spectral response curves

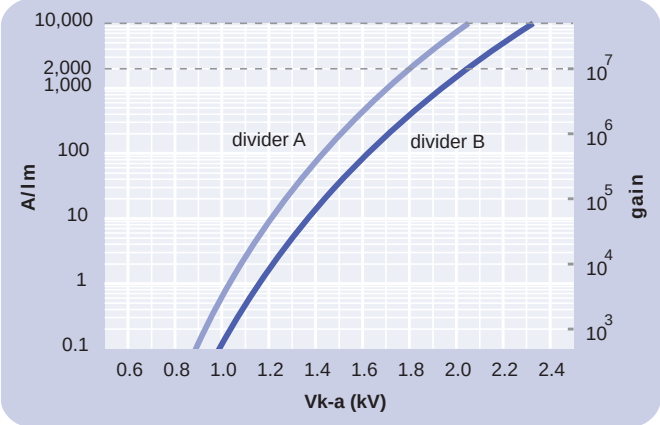


6 characteristics

	unit	min	typ	max
photocathode: S20				
active diameter	mm		46	
quantum efficiency at peak	%		21	
luminous sensitivity	µA/lm	120	200	
with CB filter			9	
with CR filter			90	
with IR filter			12	
dynodes: 14LFBeCu				
anode sensitivity in divider B:				
nominal anode sensitivity	A/lm		5000	
max. rated anode sensitivity	A/lm		10000	
overall V for nominal A/lm	V		2200	2500
overall V for max. rated A/lm	V		2300	
gain at nominal A/lm	x 10^6		25	
dark current at 20 ºC:				
dc at nominal A/lm	nA		50	500
dc at max. rated A/lm	nA		100	
dark count rate	s^{-1}		15000	
pulsed linearity (-5% deviation):				
divider A	mA		50	
divider B	mA		150	
rate effect (I_a for $\Delta g/g$=1%):	µA		1	
magnetic field sensitivity:				
the field for which the output decreases by 50 %				
most sensitive direction	T x 10^{-4}		1	
temperature coefficient:	% $ºC^{-1}$		± 0.5	
timing:				
single electron rise time	ns		2	
single electron fwhm	ns		3	
single electron jitter (fwhm)	ns		2.2	
transit time	ns		46	
weight:	g		180	
maximum ratings:				
anode current	µA			100
cathode current	nA			1000
gain	x 10^6			50
sensitivity	A/lm			10000
temperature	°C	-80		60
V (k-a)[1]	V			3000
V (k-d1)	V			500
V (d-d)[2]	V			450
ambient pressure (absolute)	kPa			202

[1] subject to not exceeding max. rated sensitivity [2] subject to not exceeding max rated V(k-a)

7 typical voltage gain characteristics



8 voltage divider distribution

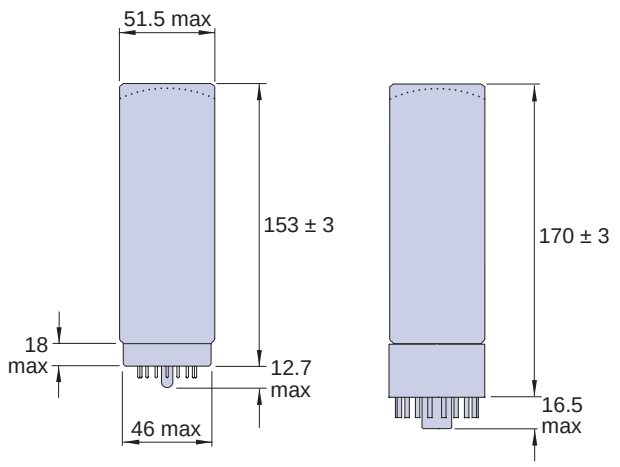
	k	d_1	d_2	.....	d_{11}	d_{12}	d_{13}	d_{14}	a	
A	300V	R		.....	R	R	R	R	R	Standard
B	300V	R		.....	R	1.25R	1.5R	2R	3R	High Pulsed linearity

note: focus connected to d_1

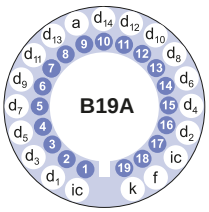
Characteristics contained in this data sheet refer to divider B unless stated otherwise.

9 external dimensions mm

The drawings below show the 9816B in hardpin format and the 9816KB with the B20 cap fitted.

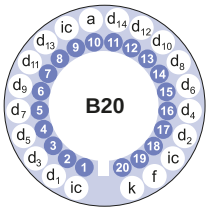


10 base configuration (viewed from below)



B19A hardpin base
(for 9816B)
'ic' indicates an internal connection

note: connect f to d_1



B20 cap
(for 9816KB)
'ic' indicates an internal connection

note: connect f to d_1

Our range of B19A sockets is available to suit the hardpin base. Our range of B20 sockets is available to suit the B20 cap. Both socket ranges include versions with or without a mounting flange, and versions with contacts for mounting directly onto printed circuit boards.

11 ordering information

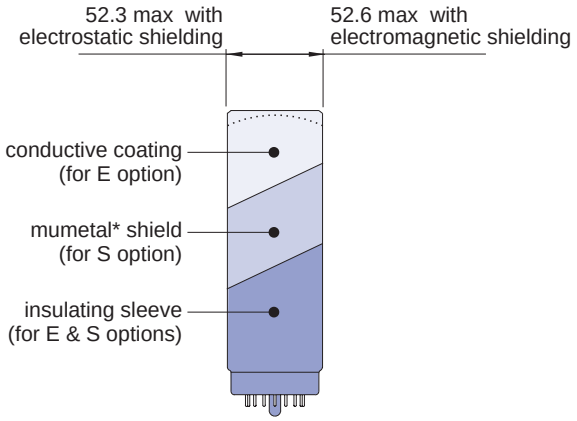
The 9816B meets the specification given in this data sheet. You may order **variants** by adding a suffix to the type number. You may also order **options** by adding a suffix to the type number. You may order product with **specification options** by discussing your requirements with us. If your selection option is for one-off order, then the product will be referred to as 9816A. For a repeat order, ET Enterprises will give the product a two digit suffix after the letter B, for example B21. This identifies your specific requirement.

9816 ☐ ☐ ☐

base options
K capped

options
E electrostatic shielding see drawing below
S electromagnetic shielding see drawing below
M supplied with spectral response calibration

specification options
B as given in data sheet
A single order to selected specification
Bnn repeat order to selected specification



12 voltage dividers

The standard voltage dividers available for these pmts are tabulated below:

9816B	9816KB	k	d_1	d_2	.....	d_{10}	d_{11}	d_{12}	d_{13}	d_{14}	a
C638A	C643A	3R	R		.....	R	R	R	R	R	
C638B	C643B	3R	R		.....	R	1.25R	1.5R	2R	3R	
C638C	C643C	300 V	R		.....	R	R	R	R	R	
C638D	C643D	300 V	R		.....	R	1.25R	1.5R	2R	3R	

R = 330 kΩ note: focus connected to d_1

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choose accessories for this pmt on our website

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