W

Technical Publications and Art Division, 8265, for TIC (2)

SAND79-8203
Unlimited Release

Temperature Evaluation of EMR's 510 PMT and ITT MCP PMT

R. J. Amaral, K. W. Dolan, R. O. Sundahl

Sandia Laboratories

SF 2900 Q(7-73)

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

SAND79-8203
Unlimited Release
Printed February 1979

TEMPERATURE EVALUATION OF EMR's 510 PMT AND ITT MCP PMT

R. J. Amaral
Weapon Subsystems Development Division 8465

K. W. Dolan
Acceptance Technology Division 8444

R. O. Sundahl
Instrumentation Development Division 8466
Sandia Laboratories, Livermore

ABSTRACT

The temperature stability and gain characteristics of EMR 510 photomultiplier tubes and ITT microchannel plate (MCP) photomultiplier tubes were evaluated and compared to the SA 1690 field test tube for potential flight test pulsed neutron diagnostic applications. The temperature variation in gain of the EMR tubes is repeatable between tubes and is less than ± 5% in the range -50°C to +74°C, which are significant improvements over the performance of the SA 1690. The ITT MCP tubes showed anomalous temperature responses with gain changes of as much as a factor of two in the range -50°C to +50°C. Additional data indicate that the temperature instability of the ITT tubes is a photocathode problem.

Introduction

Neutron detectors for flight test applications use either a photomultiplier tube (PMT) or a silicon photodiode as a light detector to monitor the light output of scintillation materials. Silicon diodes lack sensitivity, so PMT's are used in most low flux neutron applications. The SA 1690 is presently the only Sandia qualified PMT. It has a complex temperature response requiring the selection of a temperature compensation circuit during assembly to meet accuracy requirements.

The following study was performed to evaluate the temperature stability of two other light detectors and to compare the results with the performance of the SA 1690.

Test Samples

The two light detector multiplying photo-devices selected for evaluation were:

(a) EMR Schlumberger PMT, Model 510-01-13-03900*

(b) ITT Microchannel Plate PMT, custom design**

The characteristics of these two tubes are compared with those of the SA 1690 in Table 1. The EMR Model 510 PMT is a 13-stage, end-on, glass window tube with a remotely processed, semi-transparent bi-alkali

---

* EMR Schlumberger, Box 44, Princeton, New Jersey

** International Telephone and Telegraph, Electro-Optical Products Division, Fort Wayne, Indiana

TABLE I

Composition of Test Samples

Part	EMR 510	ITT MCP	SA 1690
Window	Glass	GLass	Glass
Photocathode	Bi-alkalai	Bi-alkalai	Cs-Sb
Multiplying Element	Ring Mounted Dynodes	Microchannel Plate	Clamshell Dynodes
Number of Stages	13	1	9
Sensitive Area	79	452	1.5
Voltage	1350	850	1250
Gain	10^6	2×10^3	2×10^6
Length (mm)	94.7	18	34.8
Diameter (mm)	19.1	36	13.5
Quantum Eff. (%)	16	8.6-12	10'
Cathode Luminous Sensitivity (μA/lm)	55	30-45	80
Anode Radiant Sensitivity (A/W)	53	51.3-103	1×10^4
Dark Current	10^{-11}	10^{-12} - 10^{-11}	5×10^{-8}
Rise Time	2	0.2	1.4
Transit Time	25	0.5	6
Volume (cm^3)	27.1	18.3	49.8

photocathode, and a 10 mm diameter sensitive area. The tube is constructed with an outer housing of epoxy fiber glass and potted with epoxy. The dynodes are mounted on separate rings, separated by ceramic insulators for ruggedization.

The maximum overall length without electrical leads is 94.7 mm, and the maximum diameter is 19.05 mm. An interstage resistor string is included with the last three stages containing .001 μfd capacitors.

The EMR PMT has a typical photocathode quantum efficiency of 16% at 410 nm, luminous sensitivity (S_K) of 55 μA/lm, and radiant sensitivity of .953 A/W. Current amplification of 10^6 is available with a -1750 Volt bias. Dark current at a gain of 10^6 is 1.0×10^{-11} Amperes. Anode rise time is 2 nanoseconds and electron transit time is 25 nanoseconds.

Two EMR 510 tubes were evaluated. These tubes were reject tubes that did not meet EMR minimum requirements. EMR 510-01-13-03900, Serial No. 23323, was rejected due to a low electron amplification gain. The EMR 510-01-13-03900, Serial No. 23411, was rejected due to a low photocathode quantum efficiency. This tube also obtained an electron gain of 10^6 with only -1390 Volt bias.

The EMR was instrumented as shown in Figure 1.

The ITT MCP PMT uses a microchannel plate as the electron multiplying element. The plate is basically an array of 25 μm diameter glass capillary tubes fused together in parallel making a single plate of diameter of 24 mm by .05 mm thick (useable aperture 18 mm). The MCP tube has a glass entrance window and a bi-alkali photocathode. The maximum diameter of the

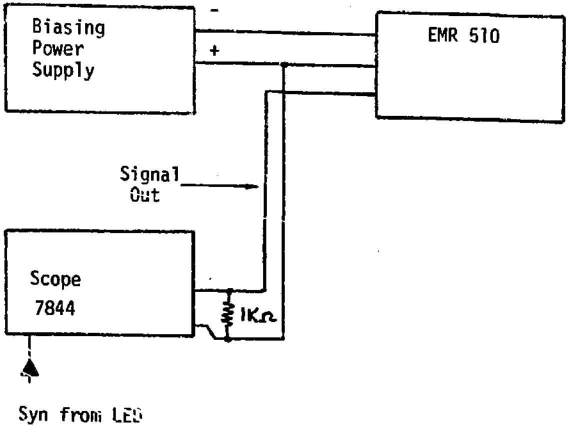


FIGURE 1

EMR 510 Biasing

tube is 36 mm and the length is 18 mm.

Three ITT MCP PMT's were evaluated. These tubes were especially fabricated for Sandia to withstand high-g accelerations. The photocathode efficiency of the three tubes ranged from 8.6 to 12% at 410 nm. The cathode sensitivities ranged from 30 µA/lm to 45 µA/lm. Anode dark currents were 4×10^{-12} to 4.4×10^{-11} Amperes. Anode sensitivities were 51.3 A/W to 103 A/W at 408 nm. Electron gain ranged from 1.8×10^{3} to 3×10^{3} with -850 Volt bias. Specific parameters can be found in the Appendix. For further details on MCP PMT's, see Reference 1.

Figure 2 shows the electrical hookup of the ITT MCP PMT's.

The SA 1690 PMT is a 9-stage, side-on, glass window tube, cesium-antimony photocathode, and a 15 mm^2 active area. The tube has an outer housing of transparent glass with an overall length, excluding semi-flexible leads, of 34.80 mm, and a maximum diameter of 13.46 mm.

The SA 1690 has a typical photocathode efficiency of 10% at 410 nm with a maximum of 10.5% at 350 nm. The luminous sensitivity is 80 µA/lm, current amplification is 2.1×10^{6} with a -1250 Volt bias, dark current is 5×10^{-8} Amperes, anode rise time is 1.4 nanoseconds, and electron transit time is 6 nanoseconds.

The SA 1690 is manufactured by RCA and is comparable to their commercial 8571 PMT. For further details on the SA 1690, see Reference 2.

The SA 1690 was connected electrically as shown in Figure 3.

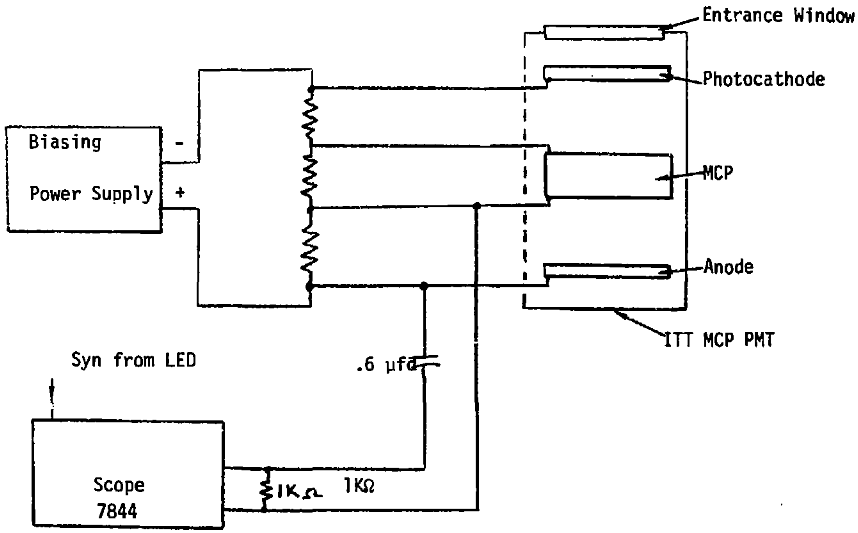


FIGURE 2

MCP Biasing

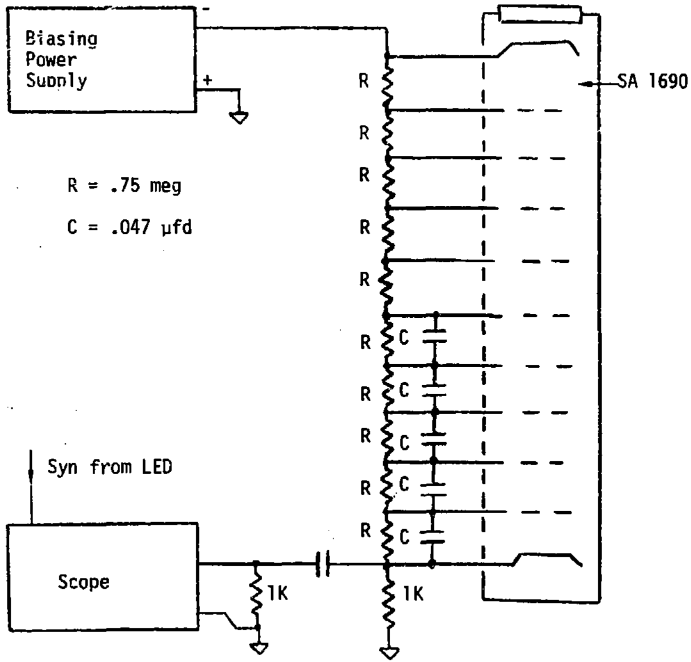


FIGURE 3

SA 1690 Biasing

Test Methods

The gain-vs-temperature evaluation was conducted using the scheme shown in Figure 4. A mechanically-cooled, electrically-heated temperature chamber was used to subject the SA 1690 and EMR 510 tubes to temperatures of -54°C to 74°C. The MCP PMT was kept to a maximum temperature of 49°C to maintain the integrity of an indium seal. To keep condensation from forming on the entrance windows, the devices were placed in an inner chamber, within the temperature chamber, and dry nitrogen was pumped into the inner chamber. This was not done above 15°C. Since the chamber takes approximately 60 minutes to go from ambient to -54°C, no soak time was taken once the chamber reached temperature but from ambient to 49°C and 74°C, a 20-minute soak at temperature was performed.

The light signal to exercise the devices was generated by a light emitting diode (LED) pulser. The light was channeled through a 6.3 mm diameter light guide. Figure 5 shows the LED pulser schematic.

The remaining equipment included a Tektronix scope to monitor device output and a thermocouple temperature sensor.

Discussion

The data taken is plotted in Figure 6. Tube gains in this figure are normalized to unity at ambient temperature, 23°C. The normalized gains of MCP PMT's 18-6, 18-5, and 18-3 were 0.41, 0.61 and 0.89, respectively, at -54°C. At 49°C, the normalized gains were 1.06, 1.097, and 0.95, respectively, These results can be compared to those for the SA 1690 which has a relative gain of 0.85 at -54°C and 0.98

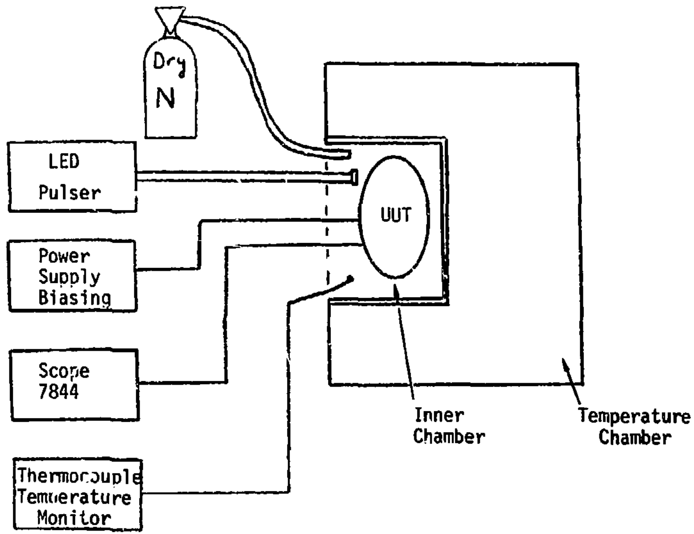
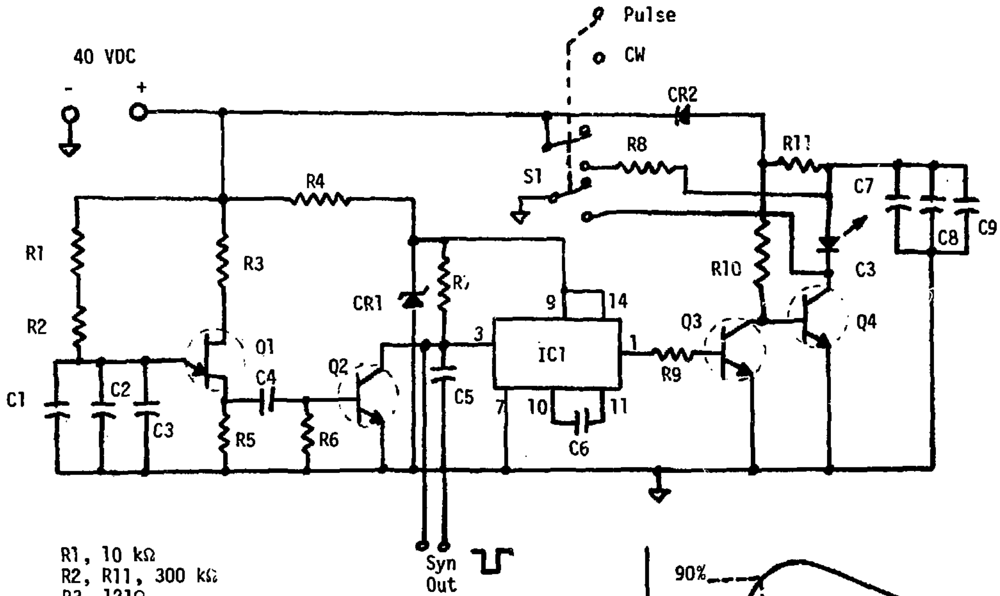


FIGURE 4

Test Scheme



R1, 10 kΩ
R2, R11, 300 kΩ
R3, 121Ω
R4, 800Ω
R5, 249Ω
R6, R8, R9, 3 kΩ
R7, 2.2 Meg Ω
R10, 2.2 kΩ
C1, C2, 4.7 μfd
C3, 6.7 μfd
Q1, 2N490
Q2, Q3, 2N2369

C4, .047 μfd
C5, .47 μfd
C6, 47 pf
C7, 680 pf
C8, C9, 2400 pf
Cr1, 1N751A
CR2, 1N755A
S1, DPDT
IC1, SN74121

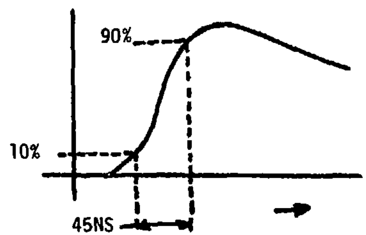
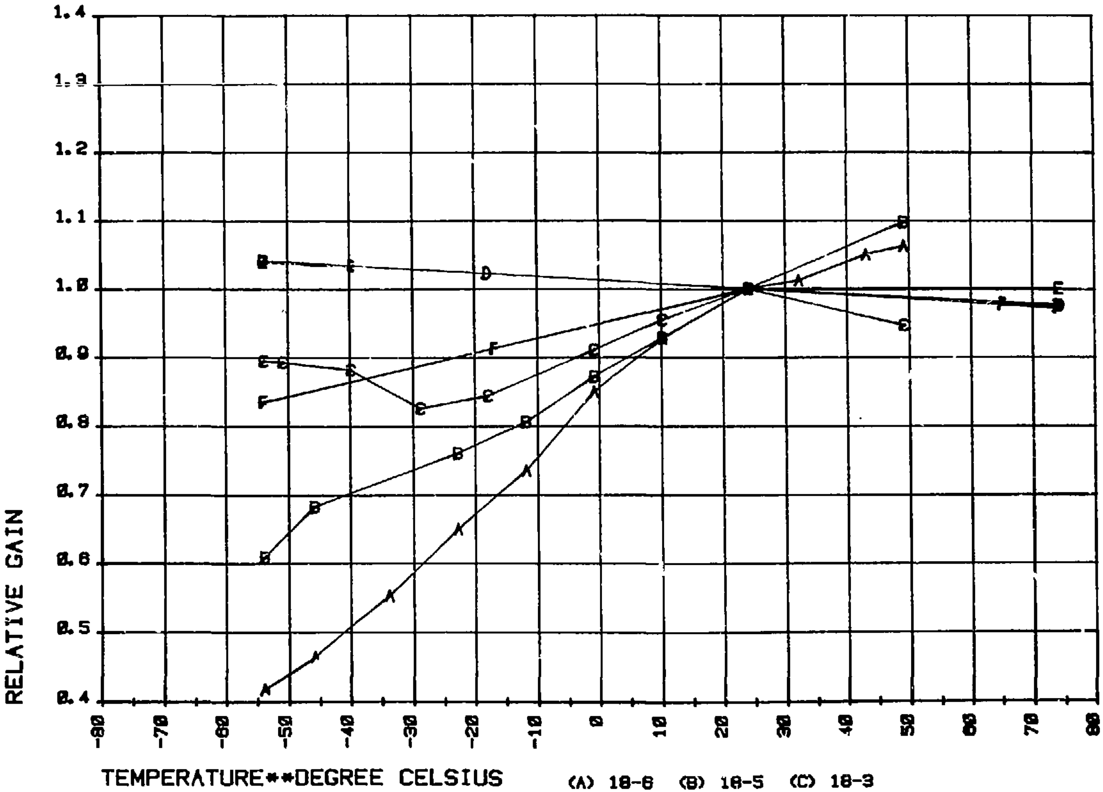


FIGURE 5

LED Pulser



(A) 18-6 (B) 18-5 (C) 18-3
(D) 510/23323 (E) 510/23411
(F) SA1690

FIGURE 6

at 49°C. We see that the temperature response of the MCP PMT's is not an improvement over the response of the SA 1690. In particular, the large gain differences exhibited among the MCP tubes indicate that a temperature compensating circuit would be impractical. The temperature sensitivity results obtained here are different from those obtained in Reference 1 where a smaller and negative temperature gradient was observed. However, a different photocathode is used in the present tubes, and the present MCP's elements were selected for higher gain.

Additional results on possible causes of the temperature instability of the MCP tubes are given in the next section.

Again referring to Figure 6, the two EMR 510 tubes had a change in gain of 1.04 from ambient to -54°C. From ambient to 74°C, tube 510/23323 had a change of 0.975, while 510/23411 had no gain change at all. These small gain changes would allow for a simple temperature compensating circuit design. The tubes closely tracked each other and therefore, if used in a neutron detector, customized calibration would be eliminated.

MCP Phototube Photocathode Temperature Experiment

The overall MCP PMT temperature stability was found to be quite poor. The following experiment was done to determine if the sensitivity to temperature was caused by the photocathode or if it was due to changes in the electron gain of the microchannel plate.

The front surface of the MCP element may be used as an anode to operate the photomultiplier tube strictly as a photodiode. This eliminates the MCP from the circuit and allows testing of the photocathode sensitivity. The manufacturer's specified bias voltage was applied between the photocathode and the front surface of the MCP. Both sides of the MCP element were held at ground potential. A picoammeter and the bias power supply were connected in series with the MCP phototube so that the picoammeter monitored the photoelectron current directly. Figure 7 shows both the physical test setup and the electrical circuit used. Dry nitrogen was introduced slowly into the area of the phototube window to prevent condensation buildup on the window.

Figures 8 and 9 show that the photocathode temperature response of tube Nos. 18-3 and 18-5 track the temperature responses of the complete phototubes, within the accuracy of the measuring equipment.* These data indicate that the temperature instability of the MCP tubes is a photocathode problem, and that the variation between tubes is dependent upon the construction of the photocathode.

---

* Additional data on tube No. 18-6 is not available since this tube was rendered inoperable when exposed to room lights over a period of 24 hours while under bias. Irreparable damage was done to the photocathode and MCP element due to the large currents drawn during this exposure.

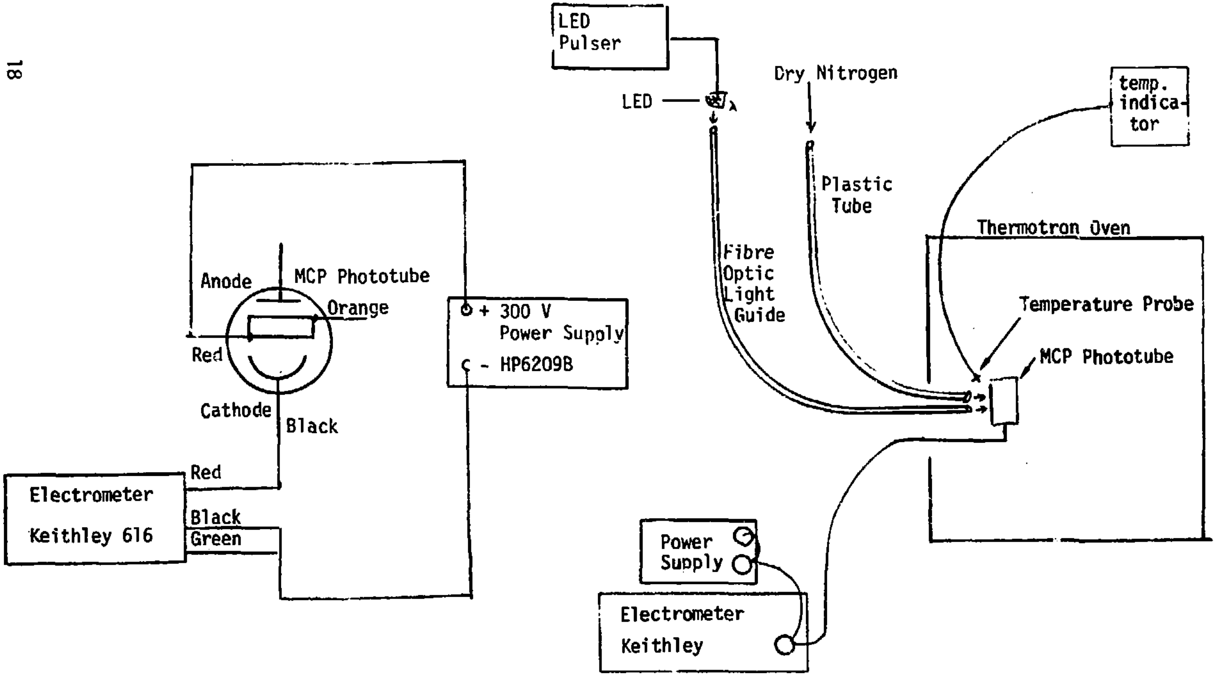


FIGURE 7

Photocathode Temperature Response

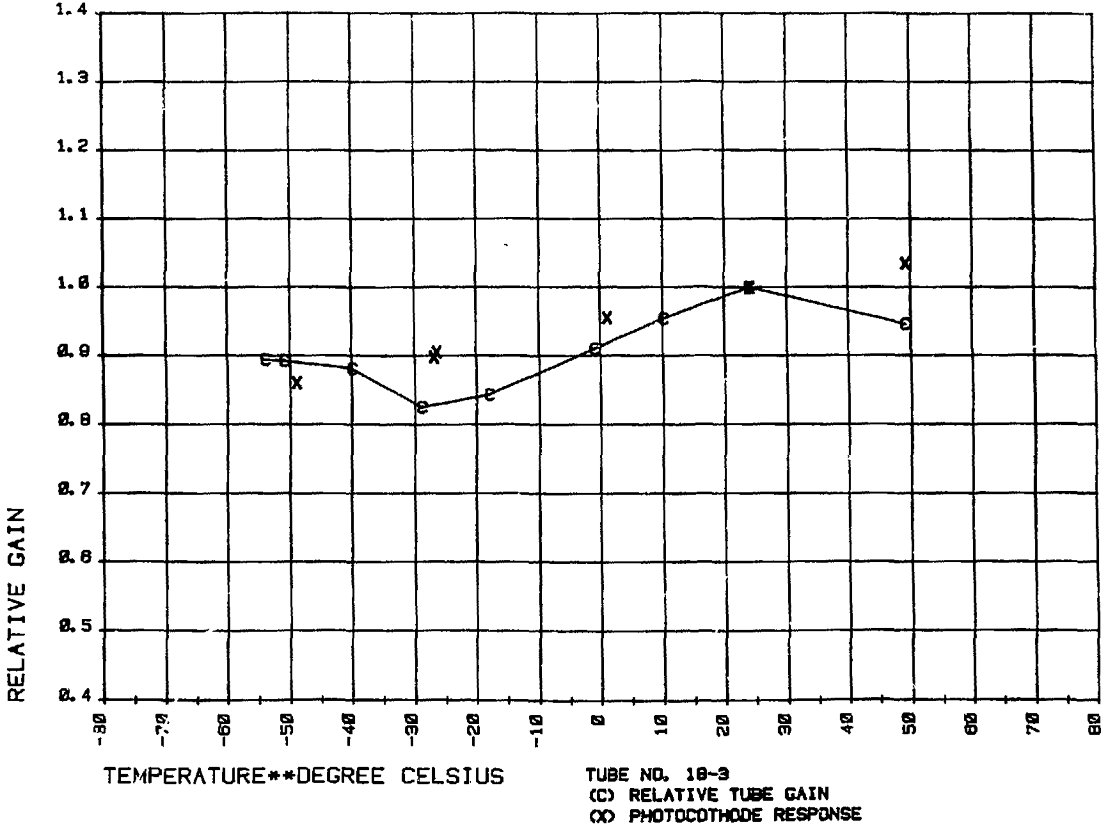
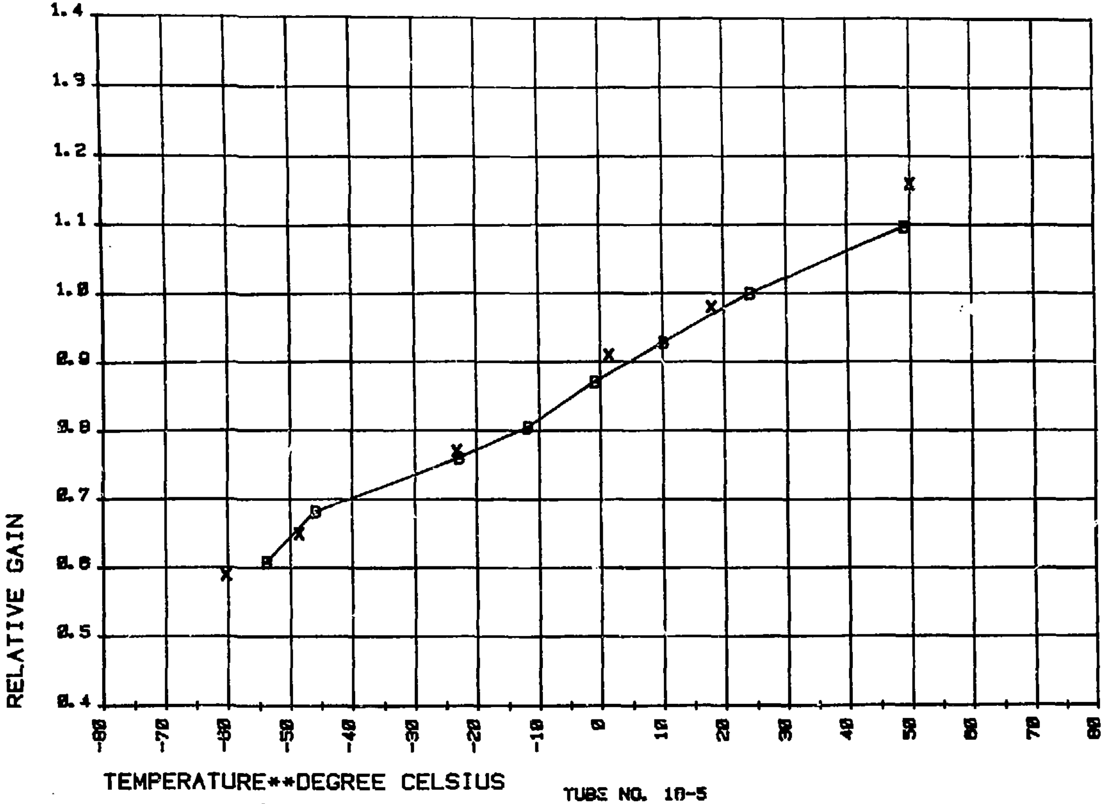

1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
RELATIVE GAIN
-80
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
40
50
60
70
80
TEMPERATURE**DEGREE CELSIUS
TUBE NO. 18-3
(C) RELATIVE TUBE GAIN
(X) PHOTOCOTHODE RESPONSE

FIGURE 8



TUBE NO. 10-5
(B) RELATIVE TUBE GAIN
(X) PHOTOCATHODE RESPONSE
FIGURE 9

Conclusion

The data collected in these tests indicate that the EMR 510 PMT temperature stability is superior to both the SA 1690 and the present design of the MCP PMT. In addition, the temperature instability of the MCP PMT appears to be a photocathode problem. A proposed fix for this problem could warrant re-evaluation of this tube at a later date.

APPENDIX

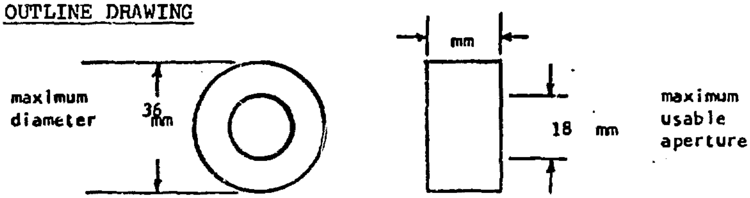
ITT

ELECTRO-OPTICAL PRODUCTS DIVISION
TUBE and SENSOR LABORATORIES
3700 East Pontiac Street
Fort Wayne, Indiana 46803
Telephone 219-423-4341 TWX 810-332-1413

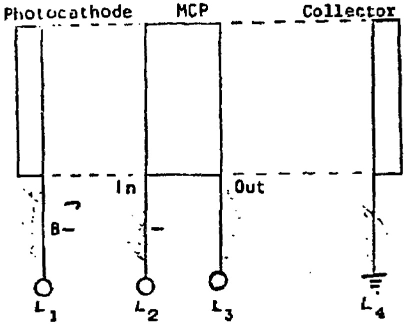
MCP Photomultiplier Tube

TYPE High G SERIAL NO. 18-5 DATE 6-30-78

1.0 OUTLINE DRAWING



2.0 ELECTRICAL SCEMATIC



3.0 LEAD CONNECTIONS

LEAD	COLOR	ELEMENT
1	Black	Photocathode (neg.)
2	Red	MCP Input (neg.)
3	Orange	MCP Output (neg.)
4	Weld Ring	Collector Anode (gnd.)

4.0 TYPICAL OPERATING VOLTAGES *

Cathode to MCP input 300 volts
MCP input to MCP output 850 volts
MCP output to Collector 50 volts
*voltages for 2.6x10³ gain

4.1 MAXIMUM OPERATING VOLTAGES

Cathode to MCP input 600 volts
MCP input to MCP output 850 volts
MCP output to Collector 50 volts (High Leakage on Body)
3×10^{-11} A at 50 V_{coll}

5.0 CATHODE SENSITVITY

30 ua/lumen

6.0 Anode Dark Current

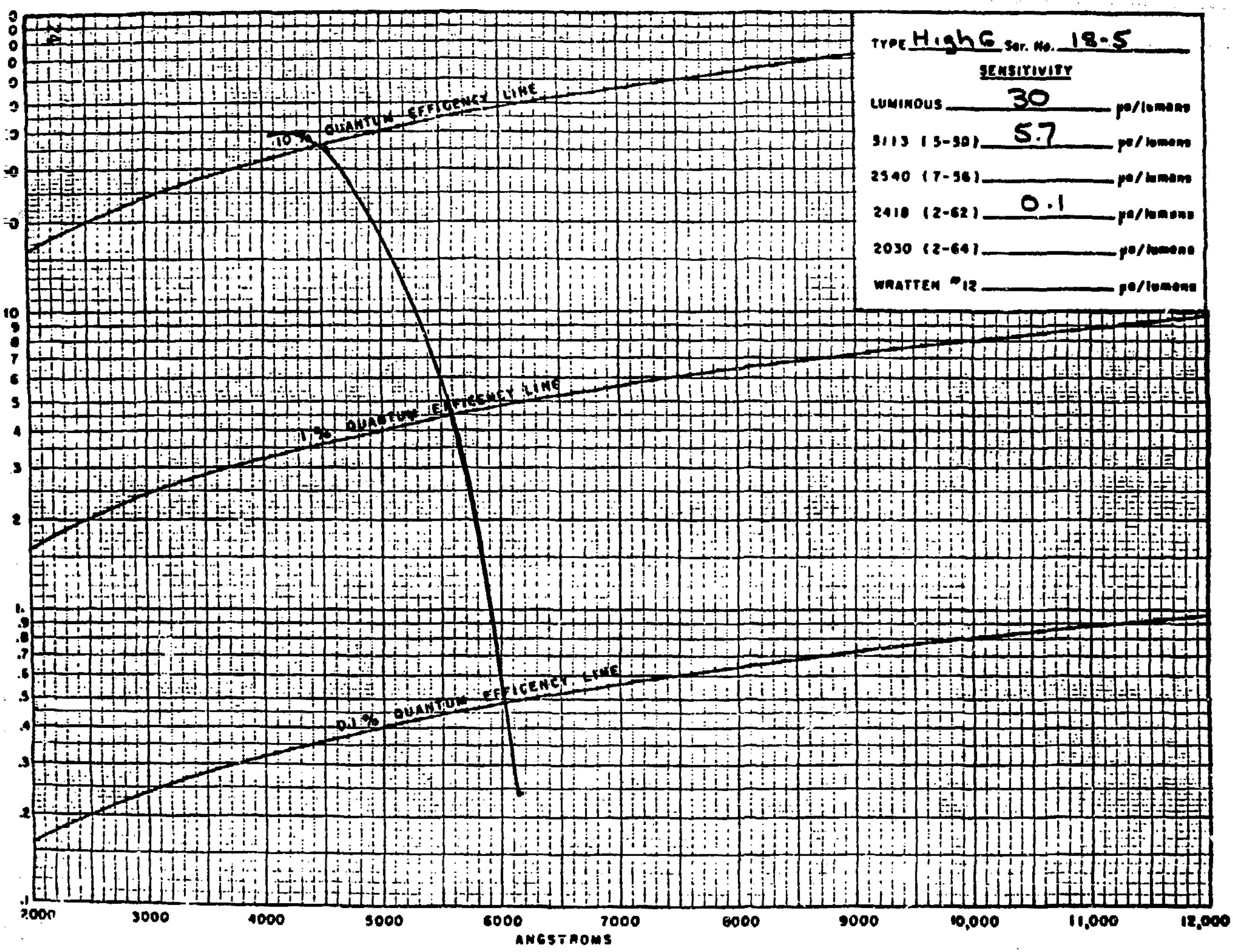
3×10^{-11} A at All Volts

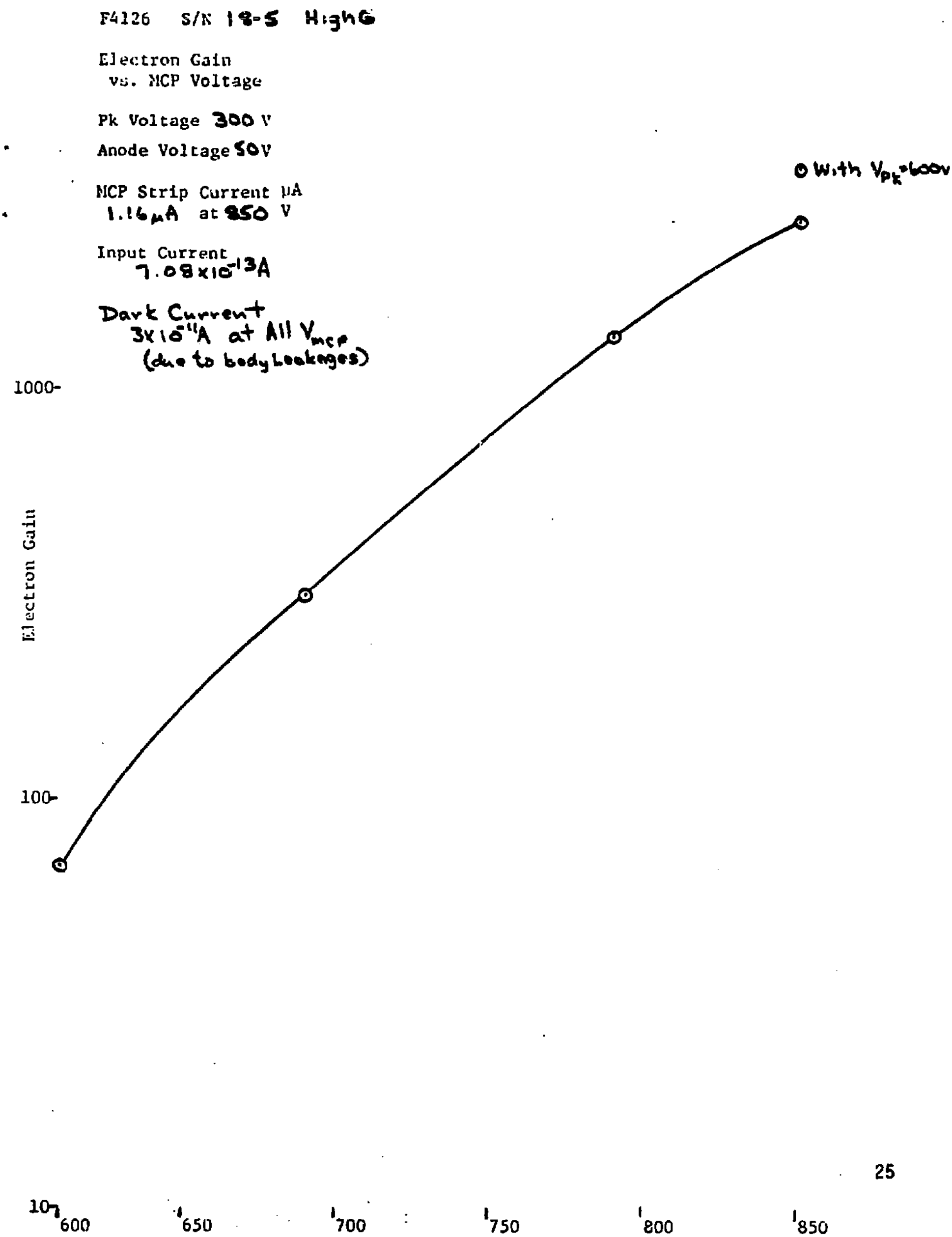
7.0 Anode Sensitivity

103 A/W at 408 nm

8.0 MCP Strip Current

1.16 μA at 850 V_{mcp}.


TYPE High G Ser. No. 18-5
SENSITIVITY
LUMINOUS 30 μa/lumens
3113 (5-30) 5.7 μa/lumens
2540 (7-56) μa/lumens
2418 (2-62) 0.1 μa/lumens
2030 (2-64) μa/lumens
WRATTEN #12 μa/lumens
10 % QUANTUM EFFICENCY LINE
1 % QUANTUM EFFICENCY LINE
0.1 % QUANTUM EFFICENCY LINE
10
9
8
7
6
5
4
3
2
1.
.9
.8
.7
.6
.5
.4
.3
.2
.1
2000
3000
4000
5000
6000
7000
8000
9000
10,000
11,000
12,000
ANGSTROMS


F4126 S/N 18-5 HighG
Electron Gain
vs. MCP Voltage
Pk Voltage 300 V
Anode Voltage 50V
MCP Strip Current µA
1.16µA at 850 V
Input Current
7.08x10-13A
Dark Current
3x10-11A at All Vmcp
(due to body Leakages)
With Vpk=600v
1000
100
10
600
650
700
750
800
850
Electron Gain

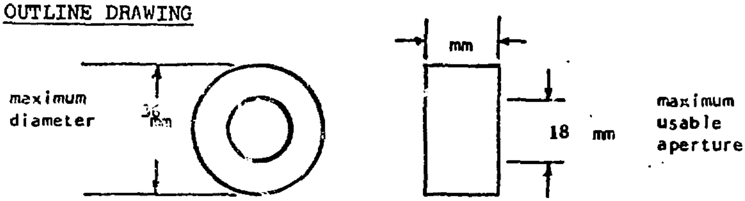
ITT

ELECTRO-OPTICAL PRODUCTS DIVISION
TUBE and SENSOR LABORATORIES
3700 East Pontiac Street
Fort Wayne, Indiana 46803
Telephone 219-423-4341 TWX 810-332-1413

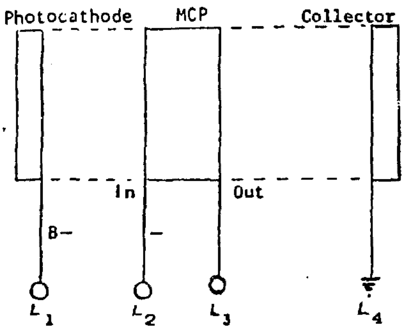
MCP Photomultiplier Tube

TYPE High G SERIAL NO. 18-3 DATE 6-30-78

1.0 OUTLINE DRAWING



2.0 ELECTRICAL SCEMATIC



3.0 LEAD CONNECTIONS

LEAD	COLOR	ELEMENT
1	Black	Photocathode (neg.)
2	Red	MCP Input (neg.)
3	Orange	MCP Output (neg.)
4	Weld Ring	Collector Anode (gnd.)

4.0 TYPICAL OPERATING VOLTAGES *

Cathode to MCP input 150 (175) volts
MCP input to MCP output 850 (?) volts
MCP output to Collector 100 (?) volts
*voltages for 1.8×10^3 gain

4.1 MAXIMUM OPERATING VOLTAGES

Cathode to MCP input 300 volts (Maximum Tried - Should take up to 600v)
MCP input to MCP output 850 volts
MCP output to Collector 100 volts (Saturates Lower-if needed because of high Leakage currents)

5.0 CATHODE SENSITVITY

35 ua/lumen

6.0 Anode Dark Current

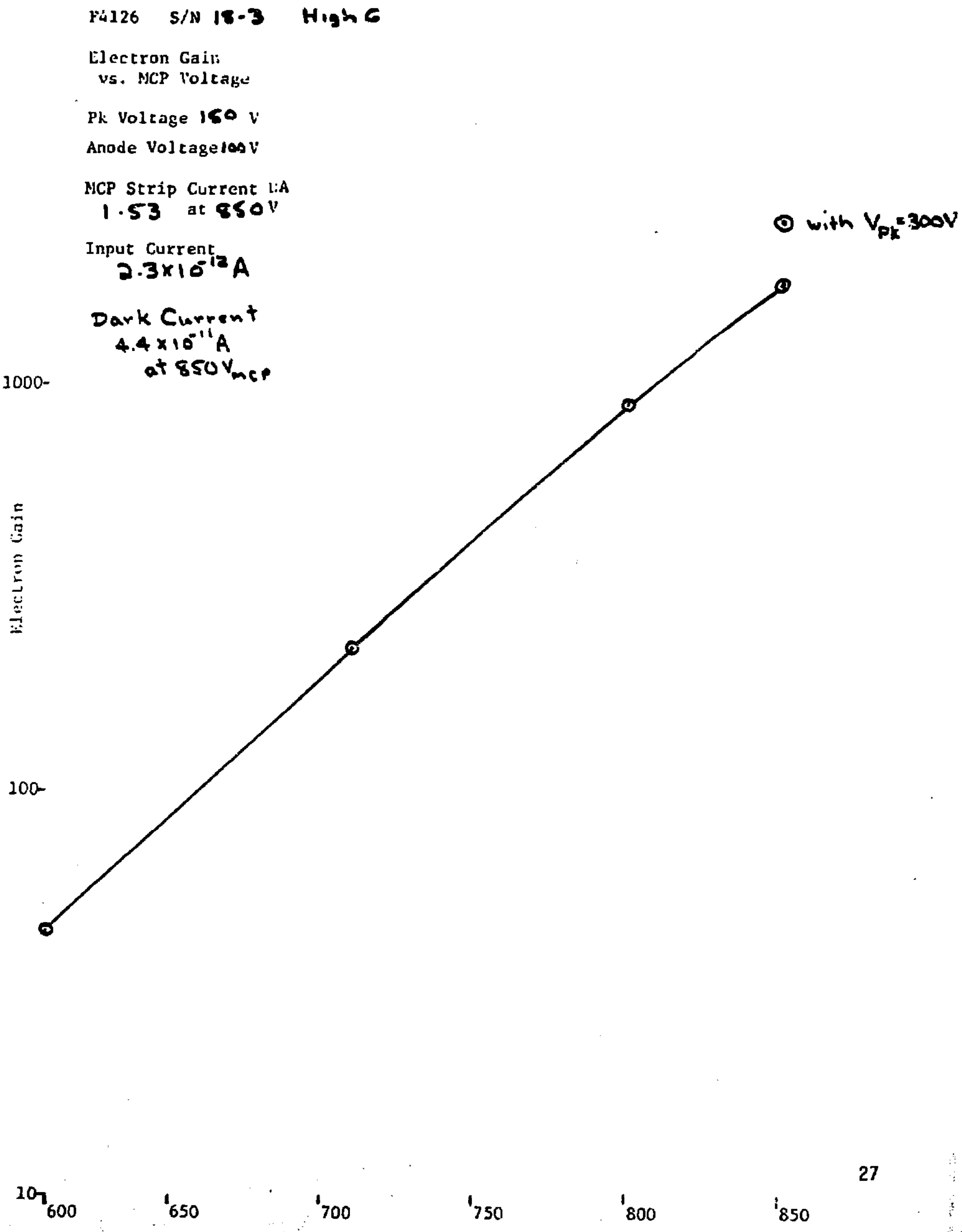
4.4×10^{-11} A at 850 $Volts_{MCP}$

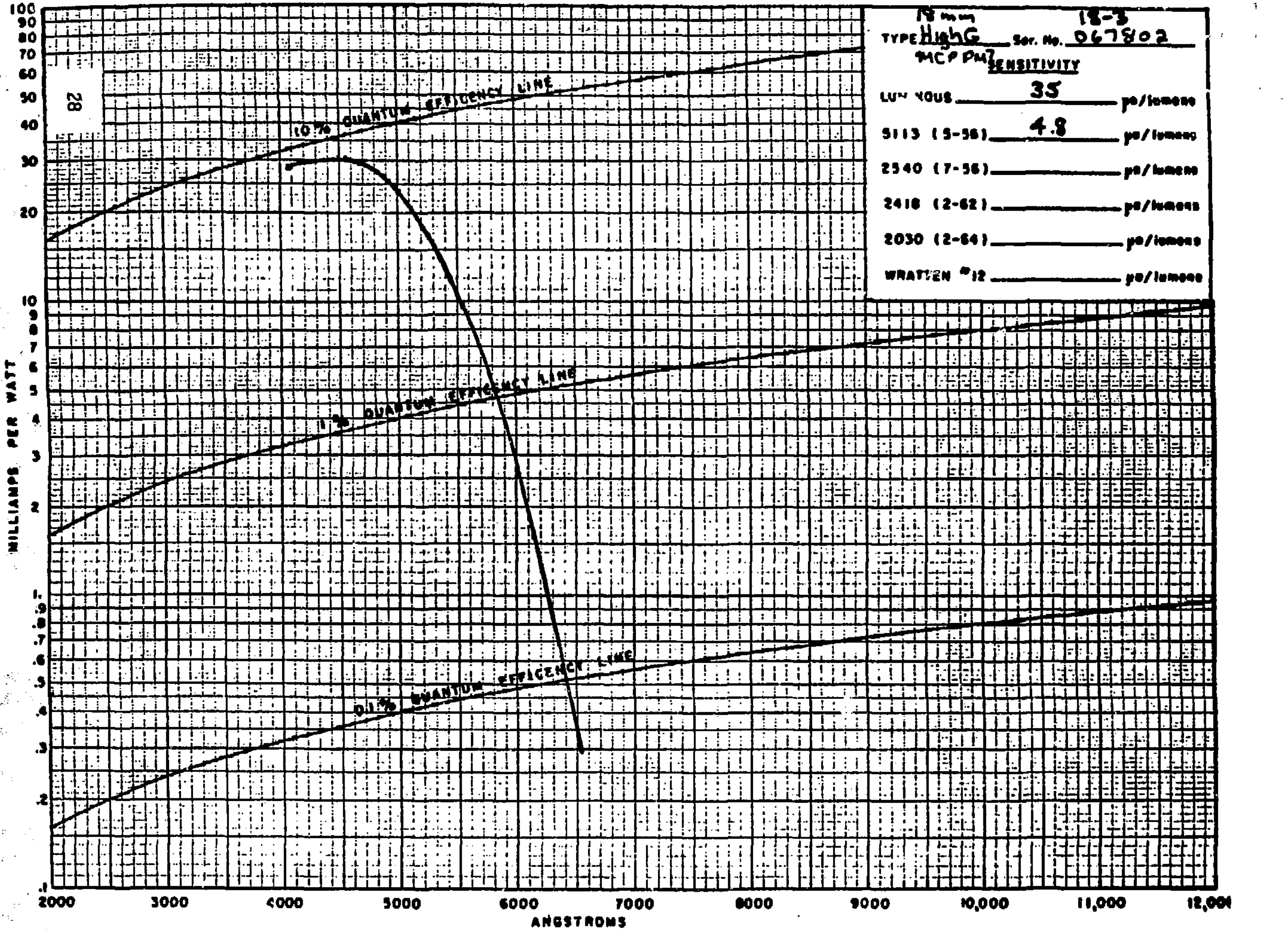
7.0 Anode Sensitivity

51.3 A/W at 408 nm.

8.0 MCP Strip Current

1.53 μA at 850 V_{mcp}


F4126 S/N 18-3 High G
Electron Gain
vs. MCP Voltage
Pk Voltage 150 V
Anode Voltage 100 V
MCP Strip Current µA
1.53 at 850 V
Input Current
2.3x10^-12 A
Dark Current
4.4x10^-11 A
at 850 V_MCP
⊙ with V_pk=300V
Electron Gain
1000
100
10
600
650
700
750
800
850

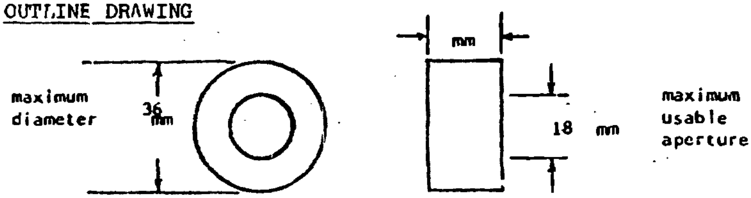

TYPE HighG Ser. No. 067802
18-3
SENSITIVITY
LUMINOUS 35 µa/lumens
5113 (5-56) 4.8 µa/lumens
2540 (7-56) µa/lumens
2418 (2-62) µa/lumens
2030 (2-64) µa/lumens
WRATTEN #12 µa/lumens
82
10% QUANTUM EFFICIENCY LINE
1% QUANTUM EFFICIENCY LINE
0.1% QUANTUM EFFICIENCY LINE
MILLIAMPS PER WATT
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1.
.9
.8
.7
.6
.5
.4
.3
.2
.1
2000
3000
4000
5000
6000
7000
8000
9000
10,000
11,000
ANGSTROMS

ITT
ELECTRO-OPTICAL PRODUCTS DIVISION
TUBE and SENSOR LABORATORIES
3700 East Pontiac Street
Fort Wayne, Indiana 46803
Telephone 219 423-4341 TWX 810-332-1413

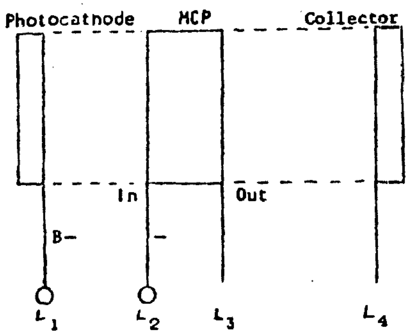
MCP Photomultiplier Tube

TYPE High G SERIAL NO. 18-6 DATE 8/16/78

1.0 OUTLINE DRAWING



2.0 ELECTRICAL SCEMATIC



3.0 LEAD CONNECTIONS

LEAD	COLOR	ELEMENT
1	Black	Photocathode (neg.)
2	Red	MCP Input (neg.)
3	Orange	MCP Output (neg.)
4		Collector Anode (gnd.)

4.0 TYPICAL OPERATING VOLTAGES *

Cathode to MCP input 300 volts
MCP input to MCP output 850 volts
MCP output to Collector 50 volts
*voltages for 3×10^3 gain

4.1 MAXIMUM OPERATING VOLTAGES

Cathode to MCP input 600 volts
MCP input to MCP output 850 volts
MCP output to Collector 50 volts

5.0 CATHODE SENSITVITY

45 ua/lumen
K_2CsSb Bi-Alkali

6.0 Anode Dark Current

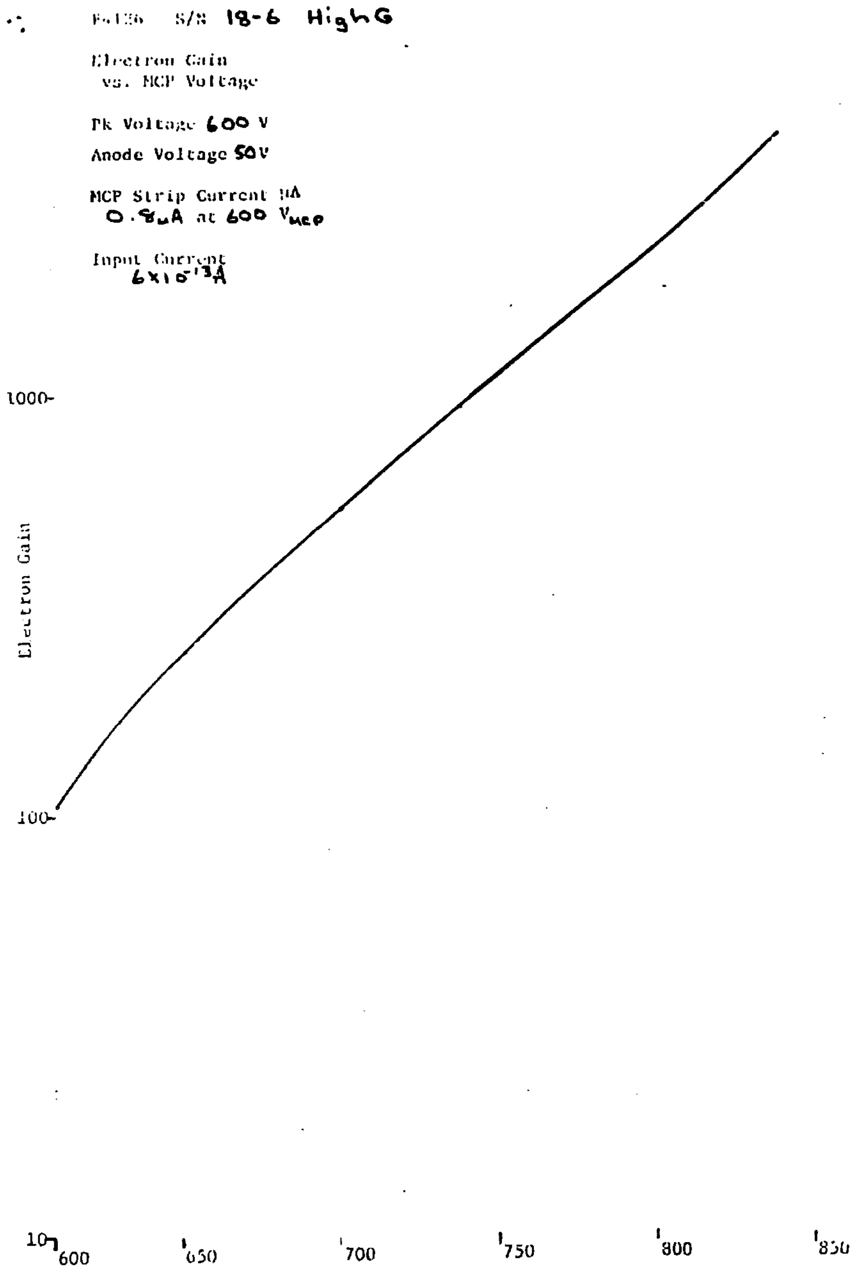
10^{-12} A at 850 $Volts_{MCP}$

7.0 Anode Sensitivity

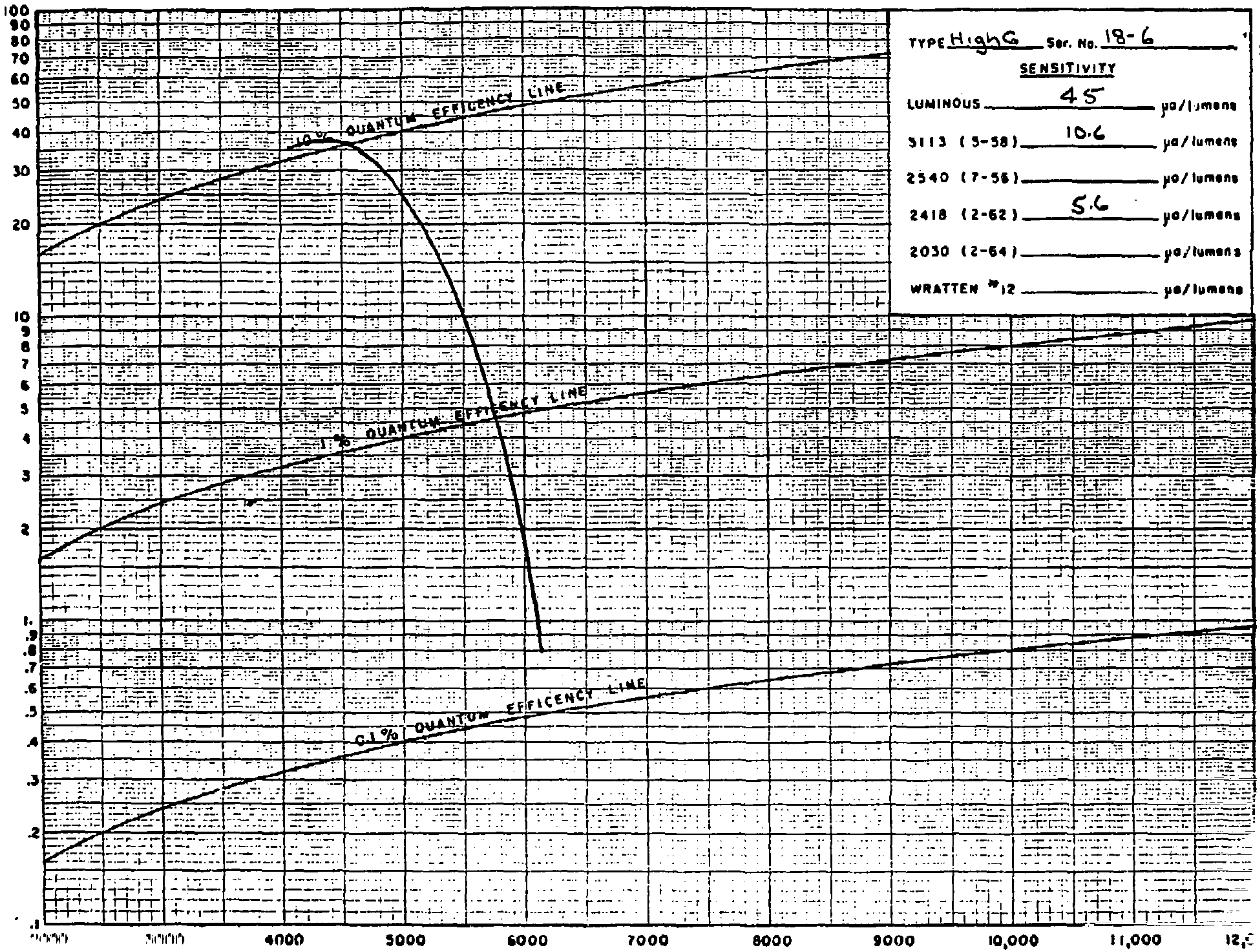
A/W at 408 nm

8.0 MCP Strip Current

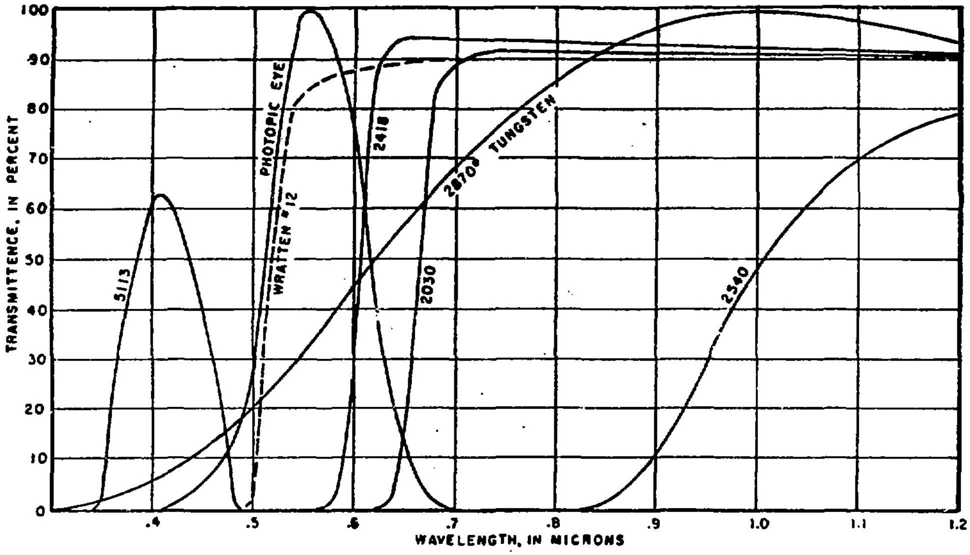
0.8 μA at 600 V_{MCP}.



S/N 18-6 HighG
Electron Gain
vs. MCP Voltage
Pk Voltage 600 V
Anode Voltage 50V
MCP Strip Current μA
0.8μA at 600 V_MCP
Input Current
6x10^-13A
1000
100
10
600
650
700
750
800
850
MCP Voltage
Electron Gain



TYPE High G Ser. No. 18-6
SENSITIVITY
LUMINOUS 45 μa/lumens
5113 (5-58) 10.6 μa/lumens
2540 (7-56) μa/lumens
2418 (2-62) 5.6 μa/lumens
2030 (2-64) μa/lumens
WRATTEN #12 μa/lumens
10% QUANTUM EFFICENCY LINE
1% QUANTUM EFFICENCY LINE
0.1% QUANTUM EFFICENCY LINE
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1.
.9
.8
.7
.6
.5
.4
.3
.2
.1
4000
5000
6000
7000
8000
9000
10,000
11,000



The standard luminous sensitivity is the response of the photocathode (in microamperes per lumen) to a tungsten lamp operating at 2870°K. The various numbered sensitivities are the response of the photocathode when Corning filters (filter numbers are four digits; dashed, three digit numbers in parentheses are a color specification number) of half stock thickness are interposed between the 2870°K lamp and the photocathode. Plotted above are the transmittance, in percent, of the filters, and the spectral distribution, in relative units, of 2870°K tungsten. Also shown are the photopic eye response and the transmission of a Wratten #12 filter.

References

1. K. W. Dolan, "Microchannel Plate Photomultiplier Tube Feasibility Study for Pulse Neutron Diagnostics", Sandia Laboratories Report No. RS8144/140, September 1977.

2. Sandia Laboratories Product Specification Drawing No. PS359229-002, Sandia Laboratories, Livermore.