LOWCAL Ground Receiver: PMT Characterization Procedure and Results

by

John Alexander MacCannell

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John Alexander MacCannell

Manuel Lujan Space Tele-Engineering Program
New Mexico State University
Las Cruces, NM

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Klipsch School of Electrical and Computer Engineering
New Mexico State University
Box 30001, MSC 3-O
Las Cruces, NM 88003-8001

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Symbols and Abbreviations

h .... Planck's Constant

c .... Speed of light (in a vacuum)

η .... Quantum Efficiency

$\Re$ .... Responsivity or Radiant Sensitivity

ϕ .... Optical Power

I .... Current

V .... Voltage

R .... Resistance

λ .... Wavelength

G .... Gain

κ .... Splitting Factor for beam splitter

P .... Optical Power

m - .... milli

n - .... nano

μ - .... micro

W .... watt

A .... ampere

m .... meter

lm .... lumen

NEP .... Noise Equivalent Power

SNR .... Signal to Noise Ratio

PMT .... Photomultiplier Tube

DAQ .... Digital Analog Acquisition Board

LOWCAL ...... Lightweight Optical Wavelength Communications without A Laser in space

1. Introduction

This paper is part of a series of papers for a research project at New Mexico State University. The project is referred to as LOWCAL or Lightweight optical wavelength communications without a laser in space. While some of the material presented is specific to the LOWCAL project, the general procedure for characterization and calibration of a photomultiplier tube is presented.

1.1. Overview

In optical communications, there are many devices that covert optical power into an electric current. The photomultiplier tube (PMT) is one of these devices. A PMT is used for two situations. First, low optical power is being received. Second, an extreme low noise device is needed. In the LOWCAL system both conditions are met making the use of a PMT optimal. The PMT has several factors that need to be characterized before it can be used. These are:

- Responsivity
- Gain
- Dark Current
- Quantum Efficiency
- Sensitivity
- Rise Time
- Transit Time

The manufacturer may give some or all of these however; all are needed to provide a complete system analysis. In the LOWCAL experiment the responsivity and quantum efficiency are needed. An important note is that these two quantities are interrelated. If one is found the other may be directly calculated. The responsivity is the easier value of the two to experimentally determine. However, the quantum efficiency is the fundamental physical quantity. This paper will discuss how to perform this experiment and its results.

1.2. PMT Operation

A PMT is a vacuum electron tube device that is divided into three parts: the photocathode, one or more dynodes, and the anode. By the photoelectric effect when a photon strikes the photocathode, a number of photoelectrons are ejected from its surface. Each electron

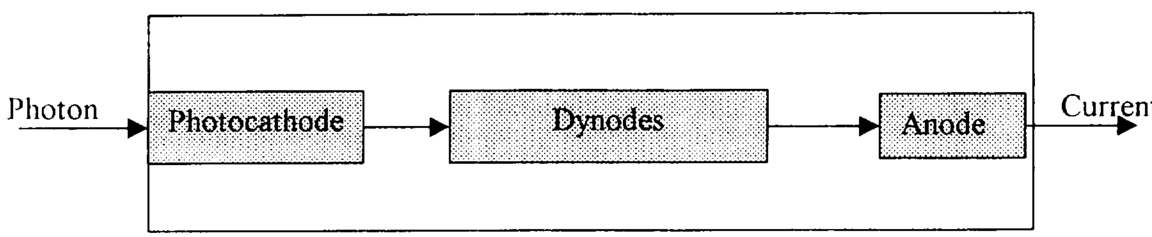

Figure 1.1 PMT Block Diagram

is then accelerated by an electric field and hits the first dynode. This impact releases several more electrons that are further accelerated into the second dynode and so fourth. The overall effect is a gain in the number of electrons that eventually strike the anode. This produces a current. Figure 1.1 shows a block diagram of the PMT. The number of photoelectrons produced is dependent on the wavelength of the light incident on the PMT. Therefore, the current output of a PMT is a function of wavelength as well.

The chance that a photoelectron is produced by a photon is the quantum efficiency. There is a problem because it is not a one-to-one production. Probability makes it hard to determine the exact number of photons. Therefore, the energy of the photons over a time interval is looked at. This gives optical power. Like electrical power this is measured in watts. The optical power is related to the current through the responsivity.

2. Responsivity and Quantum Efficiency Characterization

The total output current of the PMT (I_{out}) is directly proportional to the optical power incident on the tube (ϕ). The proportionality constant is the responsivity ($\Re$) as given by equation 2.1

$$I_{anode} = \Re_G \cdot \phi \qquad 2.1$$

Here the subscript G on the responsivity indicates that it is the generalized responsivity and includes the gain factor of the tube. Equation 2.1 indicates that the units of responsivity are measured in amperes per watt (A/W). A PMT often has its responsivity measured at the anode in A/mW. Factoring the gain factor from the responsivity yields equation 2.2 where the responsivity is the cathode responsivity.

$$I_{anode} = G \cdot \Re \cdot \phi \qquad 2.2$$

$$I_{cathode} = \Re \cdot \phi \qquad 2.3$$

The cathode responsivity is often measured in mA/W. The important factor to note is responsivity is a function of wavelength.

2.1. Relationship Between Responsivity and Quantum Efficiency

The responsivity is a function of wavelength. It also is a proportionality constant between optical power and current. Given a single wavelength the optical power can be converted to photons per second by dividing by the energy per photon.

$$\#Photons/\sec = \frac{\phi}{\frac{h \cdot c}{\lambda}} = \frac{\lambda}{h \cdot c}\phi \qquad 2.4$$

This value may further be converted to the number of electrons per second by finding the number of electrons produced by a photon. Multiplying the number of photons by the quantum efficiency (η) does this. Furthermore a current can be calculated by multiplying the number of electrons by the charge per electron.

$$I = \frac{\eta \cdot q \cdot \lambda}{h \cdot c} \phi \qquad 2.5$$

Comparison of equations 2.3 and 2.5 indicate that the responsivity is given by

$$\Re = \frac{\eta \cdot q \cdot \lambda}{h \cdot c} \qquad 2.6$$

Equation 2.6 shows that the responsivity is directly proportional to both the wavelength and quantum efficiency. Therefore, in order to find the quantum efficiency the wavelength needs to be known.

2.2. Calculation of Responsivity and Quantum Efficiency

The responsivity of the anode can be found by manipulation of equation 2.1 to give

$$\Re_G = \frac{I_{anode}}{\phi} \qquad 2.7$$

Substituting in for $\Re_G$ from equation 2.2 we have

$$\Re = \frac{I_{anode}}{G \cdot \phi} \qquad 2.8$$

Now equation 2.6 gives the relationship between the responsivity and the quantum efficiency therefore equation 2.8 becomes

$$\frac{\eta \cdot q \cdot \lambda}{h \cdot c} = \frac{I_{anode}}{G \cdot \phi} \qquad 2.9$$

The quantum efficiency in equation 2.9 can be solved for giving equation 2.10. Here everything is a known constant or a measurable quantity

$$\eta = \frac{h \cdot c \cdot I_{anode}}{\lambda \cdot G \cdot \phi} \qquad 2.10$$

3. LOWCAL PMT Characterization

The LOWCAL project uses two PMTs. Since the signal to noise calculations are dependent on the responsivity and quantum efficiency, it is important to know these values. Equations 2.8 and 2.10 give a method for calculating them for a given wavelength. However, this is not a problem since the LOWCAL system operates at $\lambda = 852.3$ to 852.5 nm and since the quantum efficiency varies slightly over a small range of 1 to 2 nm. Setting $\lambda = 852 \pm 1$ nm should be sufficient to measure the quantum efficiency and responsivity values. Therefore, all that is needed is a way to measure the anode dark current from, optical power input, and wavelength of light into each PMT being used.

3.1. R2228 PMT Detector Unit

Before discussing the how to make the measurements needed to caculate responsivity and quantum efficiency the detector unit itself should be looked at. The detector units consist of a R2228 PMT made by Hamamatsu Co. (figure 3.1) and a model PC104TSCE housing for the tube made by Products for Research. Inc. (figure 3.2)

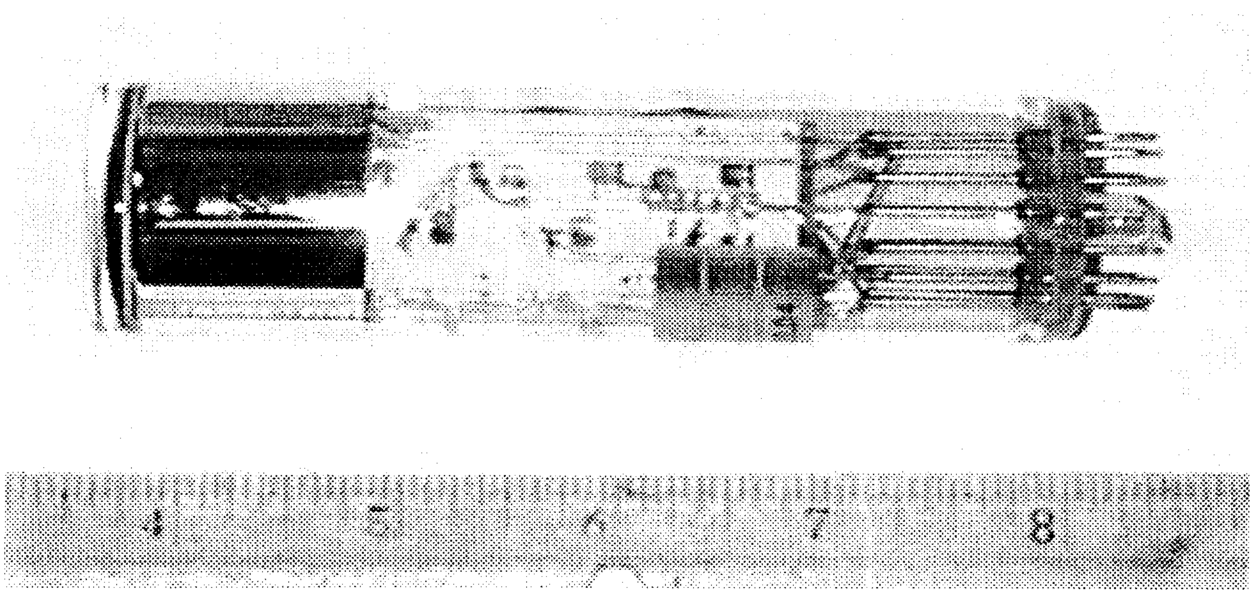

Figure 3.1 Hamamatsu R2228 Photomultiplier Tube

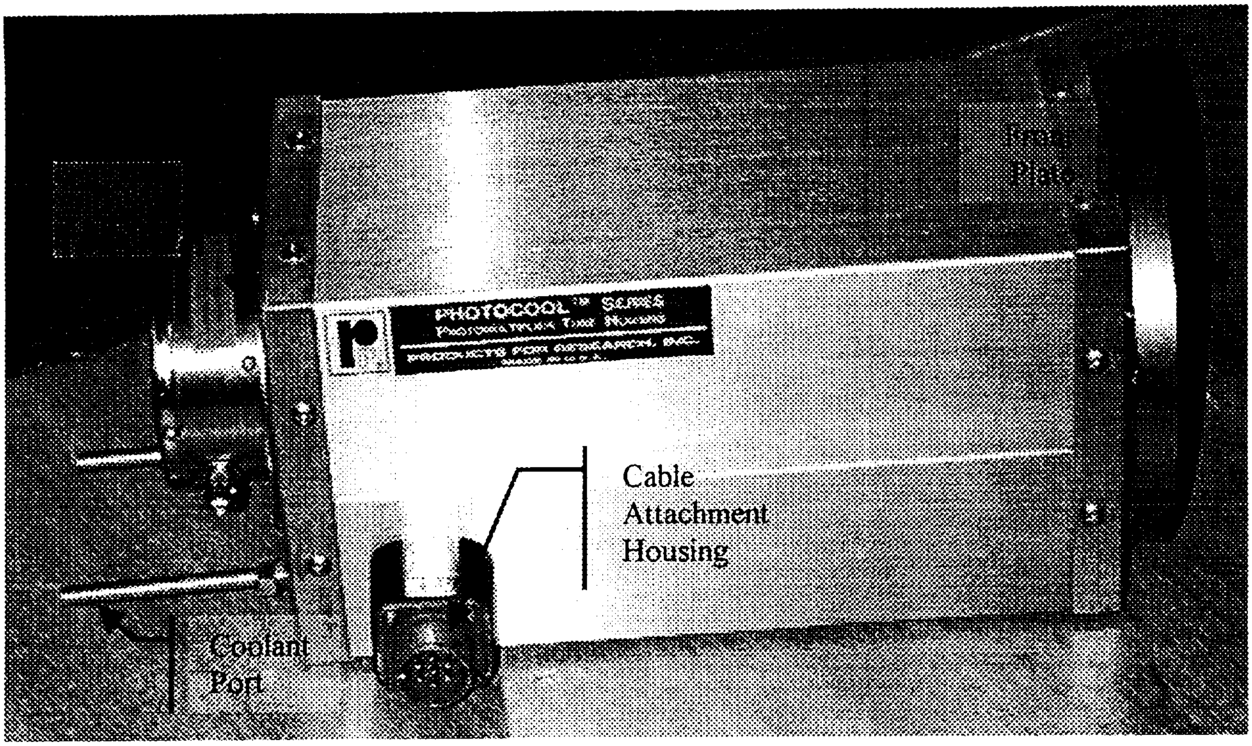

Figure 3.2 PC104TSCE housing

This particular housing allows for the cooling of the PMT to -40°C if desired. They also provided a way to form a light-tight seal, which will be needed for the characterization tests.

The R2228 PMT made by Hamamatsu is a head-on design having 11 stages. The tube contains an extended red Multialkali photocathode 25 mm in diameter. The tube is made from a Borosilicate glass and its dynodes are set in a box-grid structure. Its intrinsic capacitance is approximately 3 pF and is nominally operated with a 1 kV supply voltage with the maximum being 1.5 kV. The PMT takes 30 minutes to stabilize after power up yielding an average dark current of 8 nA, 30 nA maximum. Table 3.1 gives the specified characteristics for the two PMTs used. Hamamatsu provides a test result sheet with the cathode sensitivity, anode sensitivity, and anode dark current. The gain is directly calculated by dividing the anode sensitivity by the cathode sensitivity. The rise time and transit time are taken from the manufactures provided specification sheet and are nominal values.

<table>
<tr><th rowspan="2">PMT Tube</th><th colspan="2">Sensitivity</th><th rowspan="2">Gain x10^5</th><th rowspan="2">Anode Dark Current nA</th><th rowspan="2">Rise Time ns</th><th rowspan="2">Transit time ns</th></tr>
<tr><th>Cathode µA/lm</th><th>Anode A/lm</th></tr>
<tr><td>TA4735</td><td>258.00</td><td>135.00</td><td>5.2</td><td>1.60</td><td rowspan="2">15</td><td rowspan="2">60</td></tr>
<tr><td>TA4749</td><td>222.00</td><td>105.00</td><td>4.7</td><td>1.10</td></tr>
</table>

Table 3.1 Hamamatsu R2228 PMT Specified Characteristics

The two PMTs used for LOWCAL are slightly different. The reason for this is shown in figure 3.3. It shows several responsivity curves for different types of PMTs made by Hamamatsu, the curve of interest is the 501K curve. The tubes have a response from 300 to 1000 nm. The wavelength of operation is 852 nm. This is in the steep cut-off region of the PMT producing high variance in sensitivity. There are also differences caused by manufacturing of the tubes.

Another important factor about the R2228 PMT is that it has a wide range of input power. The maximum input power is 100 nW with a 1 µW damage point. For general health and welfare of the tube the input power should not go above approximately 10 nW. This is reasonable since the NEP is 5 pW nominally meaning an input on the order of 1 nW will be three orders of magnitude greater in power than needed for a SNR of 1.

3.2. R2228 Quantum Efficiency Measurement Overview

The steepness of the responsivity curve made it necessary to determine the exact quantum efficiency for the PMT. In order to do this, the tubes had to have their output current and input power measured. The measurement was obtained by first calibrating a beam-splitting unit so that the optical power measured on one leg was a known factor of the power output of the second leg. This ensured that the power incident on the PMT surface was known. After the calibration, the beam splitting unit was attached to the PMT housing unit in a light-tight manner, which insured that no stray light was incident on the PMT. The output current of the PMT and the optical power of the split beam were measured. From this set of data the quantum efficiency of the PMT could be calculated. Measuring the PMT quantum efficiency this way allowed for another set of tests measuring the effect of quantum efficiency as a function of temperature. The results of this test gave a unexpected result. The quantum efficiency increased as the

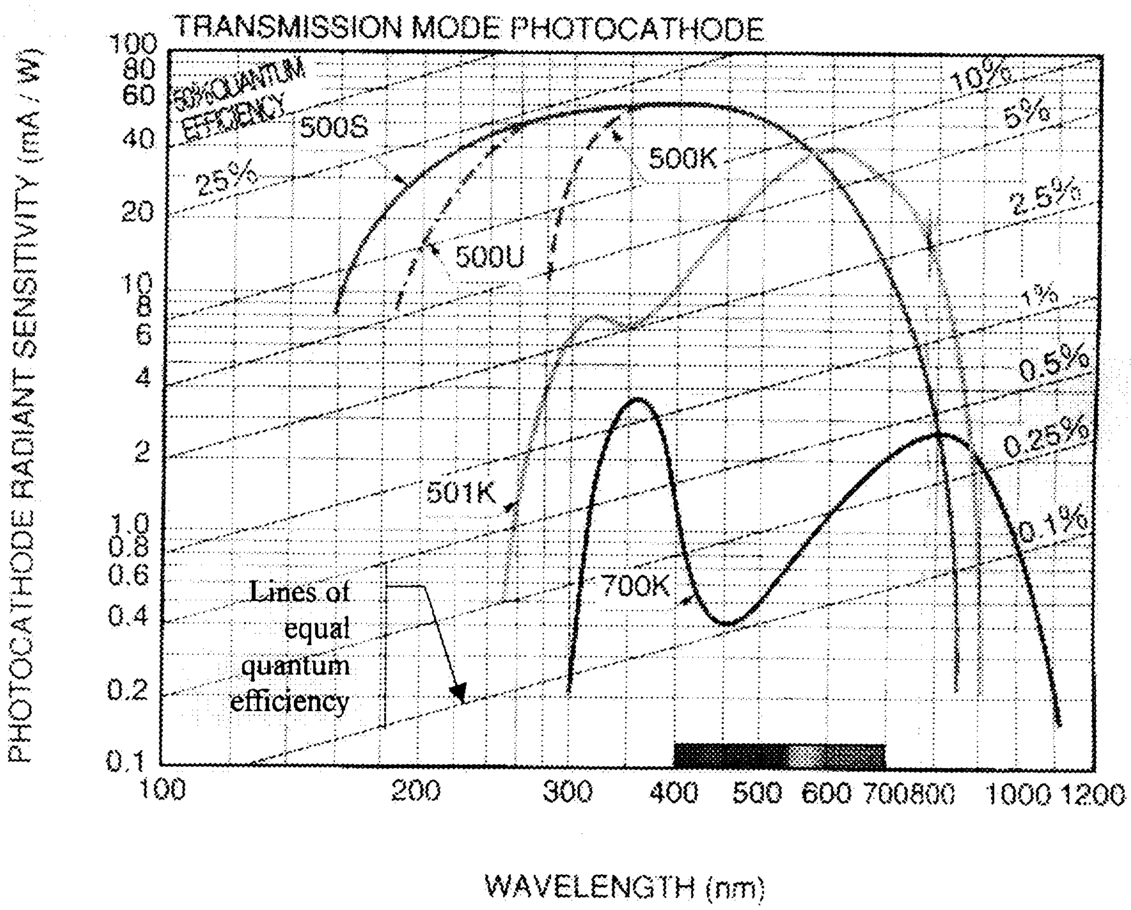

Figure 3.3 Cathode Responsivity curve 501K

temperature was decreased. Normally, as the temperature of a PMT is decreased the quantum efficiency will decrease. This is because usually the curves shown in figure 3.3 usually shift down as the temperature is lowered. A possible solution is that the decrease in temperature causes the work function of the photocathode to change making it easier for electrons to be ejected.

4. R2228 Characterization

The characterization of the R2228 PMT was performed by use of equations 2.8 and 2.10. However, a modification was needed. The anode current and the optical input power could not be measured directly. The anode current went through a transimpedance filter giving a voltage. The voltage is easily measured and can be converted into the anode current by dividing by the transimpedance (resistance).

$$I_{anode} = \frac{V_{trans}}{R_{trans}} \qquad 4.1$$

The power input to the PMT was harder to measure. This quantity had to be measured from a secondary measurement. The input beam to the PMT had to be split and the split had to be calibrated so the amount of power that went into each branch is known. Therefore, the power on the PMT is equal to the power on the branch times a splitting factor.

$$P_{PMT} = \kappa \cdot P_{branch} \qquad 4.2$$

With equations 4.1 and 4.2 added to equations 2.8 and 2.10 the characterization of the PMT can be done.

4.1. Beam Split Calibration

The first step in finding the responsivity and quantum efficiency of the PMT is to calibrate the beam splitter. The device shown in figure 4.1 is the beam splitter housing. This housing is used to form a light tight seal between the beam splitter and the PC104TSCE PMT housing. The procedure for calibration of the beam splitter (see appendix A) is simple. Input a laser beam of a known wavelength into the unit and see how much power comes out of each path. Here λ = 852.1 nm was used. Then it is a simple mater of dividing the output power of the PMT path by the output power of the power meter path to find the power split coefficient κ.

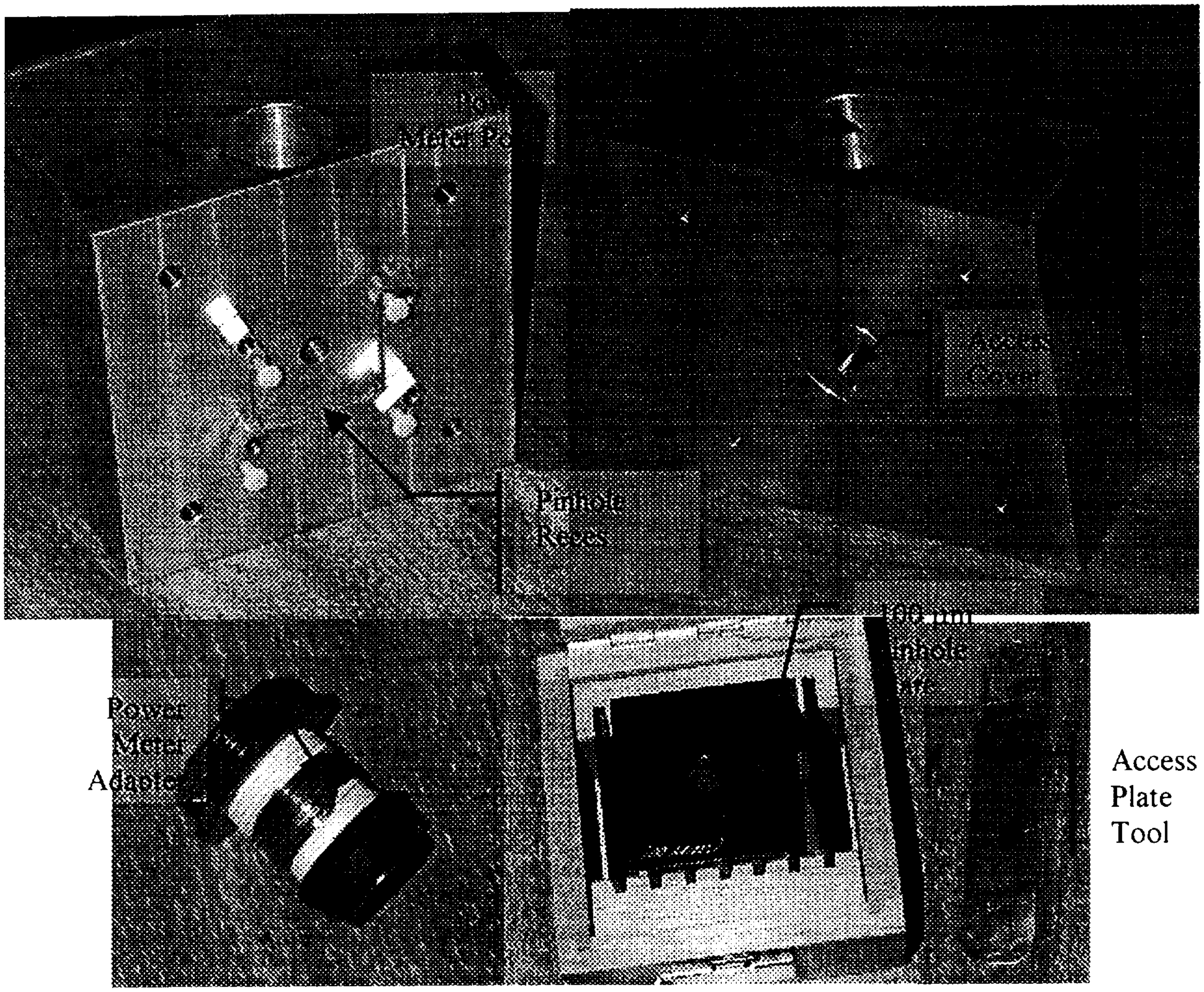

Figure 4.1 Power Measurement Beam Splitter

The data was collected from the power meters by a generic LabView® VI program that samples the voltage on two ports. The computer used has a AT-MIO E series DAQ in it. This card has a 16-bit analog to digital converter. Three data sets of ten points each were taken under the conditions specified in appendix A.

Now the output of the power meters is a voltage and it is 1.3 V full-scale (except for smallest scale then it is 1.6 V). The power was needed to make the correct calculations. In order to convert to power a conversion factor of -23.08 nW/V was found via manufactures instructions. This then allowed for the conversion of the data into usable values. Figure 4.2 shows the results. Next the powers were divided to calculate the splitting coefficient.

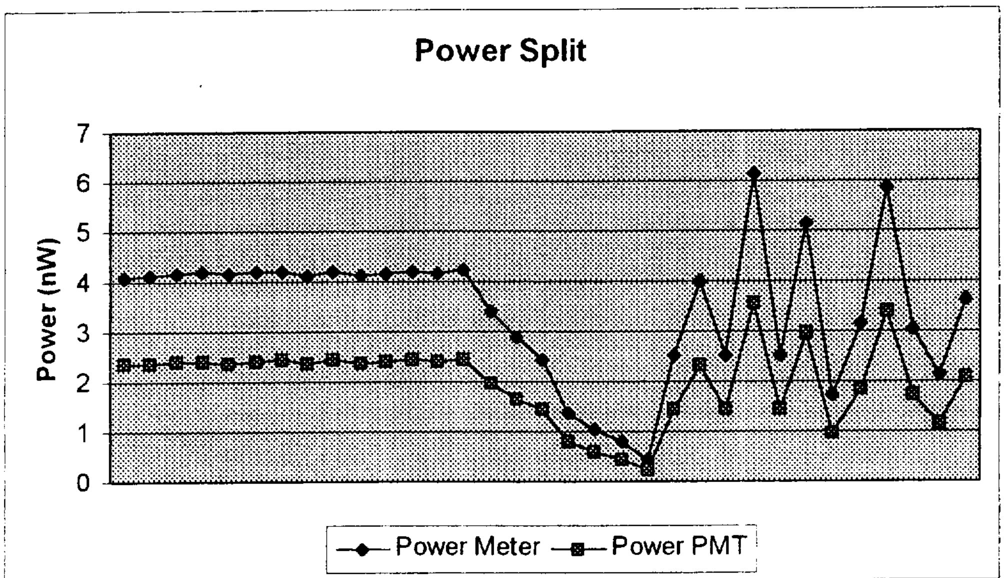

Figure 4.2 Beam Splitter Calibration Data

The splitting is 0.5747 with a standard deviation of 0.007514. Therefore how much light goes to the PMT from the beam splitter is known by how much power is in the other path.

4.2. PMT Responsivity and Quantum Efficiency Data Collection

Now that the beam splitter has been calibrated the PMT calibration can begin. However, one small thing stands in the way that is the transmission of the PC104TSCE window, which is, located in front plate (figure 4.3). To calculate this the front plate was removed and a high intensity laser beam on the order of 10 mW was transmitted through it. This is a high enough power that the room lights are in the noise of the meter. The power of the beam was measured before and after the window and it was found to have an 84% transmission. After this we have everything set in place to run the characterization experiment and calculate the responsivity and quantum efficiency of the PMT tubes used in the LOWCAL experiment.

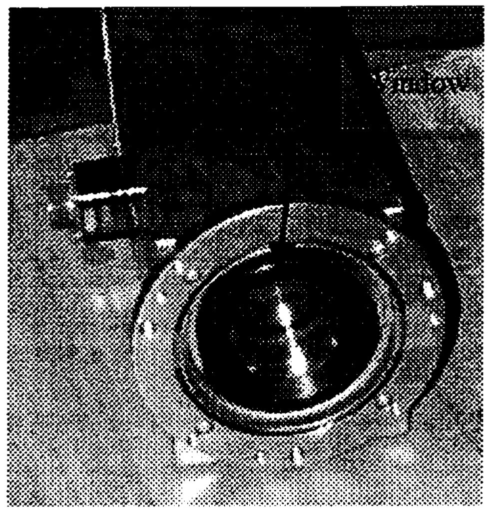

Figure 4.3 PC104TSCE Housing Front View

The general setup of the test is shown in figure 4.3. Here a laser is shown through a beam splitter and the optical power of the secondary path is recorded by the computer along with

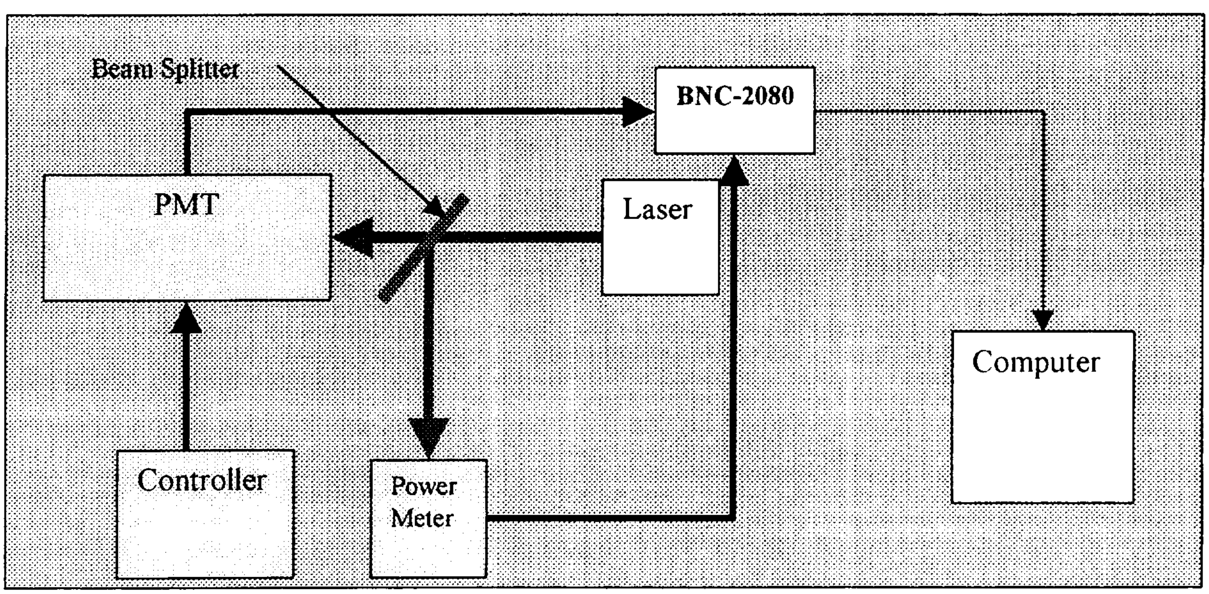

Figure 4.4 Block Diagram of Calibration Experiment

the voltage of the transimpedance filter. Data was collected for each tube over a range of temperatures as specified in appendix D. Each tube was tested three times, one run on each day. Only one tube could be tested each day because of how long a run usually takes. Each run would generate 8 data files corresponding to the 8 temperature settings. From these files the responsivity and quantum efficiency were calculated.

The tests were easy to accomplish. Appendix D gives the procedure. The hardest part of the test was to make sure the pinhole and laser were aligned properly. Once this was done it was a mater of sitting back and waiting. Periodically, the wave meter had to be checked to see if the laser diode wavelength had drifted. It stayed at $\lambda = 852.12 \pm 0.01$ nm. After the test runs, the responsivity and quantum efficiency were calculated by use of the following equations:

$$\phi_{meter} = V_{meter}(-23.08\ \tfrac{\mathrm{nW}}{\mathrm{V}}) \qquad 4.3$$

$$\phi_{PMT} = .86 \cdot \kappa \cdot \phi_{meter} \qquad 4.4$$

$$I_{anode} = \frac{V_{trans}}{R_{trans}} \qquad 4.5$$

$$I_{cathode} = \frac{I_{anode}}{G} \qquad 4.6$$

$$\Re = \frac{I_{cathode}}{\phi_{PMT}} \qquad 4.7$$

$$\eta = \frac{h \cdot c \cdot \Re}{q \cdot \lambda} \qquad 4.8$$

Equations 4.3 through 4.8 give a nice analytical method for finding the responsivity and the quantum efficiencies of the photomultiplier tubes. The overall method is simple. What made it hard in this case was that a specialized beam splitter needed to be made which added the step of calibrating it. Table 4.1 shows the final results for the data taken. It gives only the results in terms of the quantum efficiency because it is the physical value and it is required in the signal to noise calculations.

Table 4.1 R2228 Quantum Efficiency Results

Temperature °C	Quantum Efficiency					
	Run A		Run B		Run C	
	Tube A	Tube B	Tube A	Tube B	Tube A	Tube B
15	0.305%	1.149%	0.293%	1.189%	0.291%	1.318%
10	0.327%	1.214%	0.310%	1.264%	0.314%	1.426%
5	0.340%	1.293%	0.336%	1.360%	0.340%	1.529%
0	0.381%	1.391%	0.359%	1.444%	0.361%	1.642%
-5	0.405%	1.481%	0.387%	1.546%	0.388%	1.800%
-10	0.436%	1.543%	0.415%	1.727%	0.413%	1.932%
-15	0.460%	1.686%	0.438%	1.737%	0.444%	1.972%
-20	0.485%	1.773%	0.464%	1.800%	NA	2.121%
Tube A = TA4749				Tube B = TA4735		

5. Conclusions

The results for the quantum efficiency show a wide variation between the two tubes. As mentioned this is because of the location of the wavelength on the responsivity curve shown in figure 3.3. The differences in manufacturing plus the quality of the base materials can cause the quantum efficiency to vary anywhere between 0.25% and 2.5%. Even though these two PMTs have a wide range in their quantum efficiencies they show the same tendency that the quantum efficiency increases as the temperature drops.

The test had two sources of error. First, there are questions on the calibration of the optical power meters. This introduces error in the conversion factor between the power meter voltage and the optical power read. Second, the angle of the beam splitter could have shifted during the process of attaching the two housings. This would result in an invalid κ and thus would cause error in the calculation of the power reaching the PMT. There are other sources of error that could not be controlled. An example would be digitization noise of the DAQ. The largest source of error as mentioned earlier is the alignment of the pinhole and laser beam. This is a controllable by isolating the table from vibrations. Overall these sources of error should not affect the test result enough to invalidate the test.

The test procedure presented shows a simple way to calculate the responsivity and quantum efficiency of a PMT. These values are needed to calculate the SNR of a system. The LOWCAL project uses two Hamamatsu R2228 tubes. The project operates in the cutoff region of the tubes and therefore it is extra important to know the quantum efficiencies. Further testing shows that the R2228 PMT has an increase in quantum efficiency as the temperature drops. As an aside it is important to note that the testing procedure presented can be used with any PMT tube provided its gain is known and the appropriate scaling on optical and electrical power is used.

Appendix A Beam Splitter Calibration Procedure

Equipment:

- 2 Newport Optical Power Meters
- 2 male banana jack to BNC connectors
- 2 BNC Cables
- National Instruments AT-MIO E series DAQ
- National Instruments BNC-2080
- Intel Pentium Class PC equivalent or better
- National Instruments LabView 5.1 Software
- Power Meter Head adapter
- Beam Splitter Housing
- Melles Griot 100 μm pinhole plate
- Neutral Density Filter ND 0.5 from New Focus ND filter kit 5249
- Newport Lens KBC043 (–50 mm biconcave)
- Laser Diode Head
- Laser Diode Driver
- SDL-5401-G1 Laser Diode or Equivalent
- Beam Splitter
- Optical wave meter
- Neutral Density Optical Attenuator
- Black Electrical Tape

Procedure:

Part A: Laser Beam Preparation

1. Insert laser diode into laser diode head ensuring proper grounding of operator

NOTE: Laser Diodes are extremely static sensitive. Operator must take proper grounding precautions at all times.

2. Turn on laser diode driver
3. Turn current up until diode "lases"
4. Place Beam Splitter in laser beam
5. Direct one branch of the laser beam into wave meter
6. Adjust temperature and current of laser diode until a wavelength of 852.x is read on the meter

NOTE: Use proper safety when working with laser. DO NOT place eyes in beam

Part B: Beam Splitter Housing Preparation

1. Remove access cover
2. Remove core holder
3. Place KBC043 Lens at front of core holder
4. Place the ND 0.5 filter in core holder
5. Insert core holder into beam splitter housing
6. Attach power meter adapter to rear of housing
7. Place one power meter head in housing power meter port
8. Seal power meter port with black electrical tape
9. Place second power meter head on power meter adapter

10. Place 100 μm pinhole plate in pinhole recess

Part C: Power Meter Setup

1. Insert banana jacks into rear ports on power meters
2. Attach BNC cables to jacks
3. Attach BNC cables to BNC-2080 board.
4. Turn on power meter
5. Set the mid band of the detectors to 850 nm
6. Turn off auto scale feature
7. Set the scale to the 20 nW scale

Part D: Data Acquisition

1. Align pinhole to beam
2. Adjust Input power to housing using neutral density optical attenuator until power meters read in range.
3. Use LabView generic Record data points VI to record 10 data points with same input power
4. Record 10 data points with input power decreasing
5. Record 10 data points with the input power increasing and decreasing

Appendix B PMT Power Up and Power Down Sequences

1. Disconnect high voltage power supply from PMT Cathode connection on PC104TSE PMT Housing
2. Turn on high voltage power supply
3. Make sure high voltage power supply is set to 0-V
4. Turn off high voltage power supply
5. Connect high voltage power supply to PMT Cathode connection on PC104TSE PMT Housing
6. If capable, set the output polarity of the high voltage power supply to negative
7. Connect PMT Anode connection on PC104TSE PMT Housing to low pass transimpedance filter
8. Connect the low pass transimpedance filter to equipment to be used
9. Make sure room lights are off or light shroud is on PMT housing
10. Turn on high voltage power supply
11. Slowly turn voltage to -1 kV

Power Down

1. Slowly turn voltage to 0 V
2. Make sure voltage reads 0 V
3. Turn off high voltage power supply

Appendix C PC104TSCE Controller Startup Sequence

1. Make sure PC104TSCE PMT housing and control unit are attached via the PPC104TSCE control cable
2. Turn on coolant flow to PC104TSCE PMT Housing
3. Turn on control unit

NOTE: Coolant flow must be turned on before controller may be turned on

4. Press *SET\ENT* key
5. Set the desired temperature using arrow keys
6. Press *SET\ENT* key again

NOTE: It takes from 5 minutes to 2 hours to reach the set point and stabilize.

Appendix D PMT Responsivity and Quantum Efficiency Data Collection Procedure

Equipment:

- 2 Newport Optical Power Meters
- Male banana jack to BNC connectors
- 2 BNC Cables
- National Instruments AT-MIO E series DAQ
- National Instruments BNC-2080
- Intel Pentium Class PC equivalent or better
- National Instruments LabView 5.1 Software
- Power Meter Head adapter
- Beam Splitter Housing
- Melles Griot 100 μm pinhole plate
- Neutral Density Filter ND 0.5 from New Focus ND filter kit 5249
- Newport Lens KBC043 (–50 mm biconcave)
- Laser Diode Head
- Laser Diode Driver
- SDL-5401-G1 Laser Diode or Equivalent
- Beam Splitter
- Optical wave meter
- Neutral Density Optical Attenuator
- Black Electrical Tape

- PC104TSCE PMT Housing
- PC104TSCE Controller Unit
- PC104TSCE Controller Cable
- R2228 PMT Tube
- High Voltage Power Supply
- High Voltage BNC Cable
- Desk Lamp

Procedure:

Part A: Laser Beam Preparation

1. Insert laser diode into laser diode head ensuring proper grounding of operator

NOTE: Laser Diodes are extremely static sensitive. Operator must take proper grounding precautions at all times.

2. Turn on laser diode driver
3. Turn current up until diode "lases"
4. Place Beam Splitter in laser beam
5. Direct one branch of the laser beam into wave meter
6. Adjust temperature and current of laser diode until a wavelength of 852.x is read on the meter

NOTE: Use proper safety when working with laser. DO NOT place eyes in beam

Part B: Beam Splitter Housing Setup

NOTE: If Beam Splitter Housing is all ready attached to PC104TSCE PMT Housing skip to part c

1. Remove access cover
2. Remove core holder
3. Place KBC043 Lens at front of core holder
4. Place the ND 0.5 filter in core holder
5. Insert core holder into beam splitter housing
6. Attach access cover to housing
7. Place one power meter head in housing power meter port
8. Seal power meter port with black electrical tape
9. Place 100 μm pinhole plate in pinhole recess
10. Attach beam splitter housing to PC104TSCE PMT housing front plate so that power meter port is facing up.

Part C: PC104TSCE PMT Housing Setup

1. Unscrew rear plate from PC104TSCE housing (3 Philips pan head screws)
2. Remove rear plate from PC104TSCE Housing
3. Turn on desk lamp
4. Tilt desk lamp so that major portion of light is away from work area
5. Turn **OFF** overhead and/or all other room lights.

NOTE: PMT is sensitive to light even when no power is applied

6. Remove PMT from box (both PMT tubes and boxes have serial number)
7. Record serial number from tube
8. Insert PMT into rear plate (PMT pins and plate are keyed)
9. Remove PMT photocathode cover and set aside for later **DO NOT LOOSE**

10. Insert PMT-Rear Plate assemblely into housing

11. Attach rear plate with screws

NOTE: At this point the room lights may be turned on

12. Attach photocathode connector to high voltage power supply using the high voltage BMC cable

13. Attach lowpass transimpedance filter to anode connector

14. Attach transimpedance filter to BNC-2080 board

Part D: Power Meter Setup

8. Insert banana jacks into rear ports on power meters

9. Attach BNC cables to jacks

10. Attach BNC cables to BNC-2080 board.

11. Turn on power meter

12. Set the mid band of the detectors to 850 nm

13. Turn off auto scale feature

14. Set the scale to the 20 nW scale

Part E: Data Acquisition Setup

1. Start LabView®

2. Select *Solution Wizards* button

3. Fallow Steps when asked select *Solutions Gallery*

4. Select *Data logging* and Simple *Data Logger*

5. Set device and channels according to set up.

   a. Default device 1

   b. Channel 0 and 1 used

6. Set sample rate to every 5 seconds

7. Set current sets to default values

8. Save file for future use

Part F: Data Collection Procedure

1. Align laser beam with pinhole

2. Turn on optical power meter

3. Use neutral density optical attenuator to adjust the input power until power meter reads in range

4. Start LabView and load data logging VI from part E

5. Place light shroud over housings extending in front of them to minimize stray light

6. Turn on desk lamp

7. Turn off room lights

8. Turn on power to PMT as specified in appendix B

9. Let PMT warm up for 15 minutes to ½ hour

10. Turn on PC104TSCE Controller as specified in appendix C

11. Set the temperature to 15° C and let settle

12. Start data log program

NOTE: Program will ask for a file name. Indicate in name tube and temperature

13. Log for ½ hour to 45 minutes

14. Stop Data log

15. Repeat Steps 11 through 14 for 10, 5, 0, -5, -10, -15, and -20° C

16. Turn of Power to PMT as specified in appendix B

17. Set temperature on controller to 20° C

18. Let PMT warm up to temperature

Part G PMT Removal Procedure

1. Turn on desk lamp

2. Tilt desk lamp so that major portion of light is away from work area

3. Turn **OFF** overhead and/or all other room lights.

NOTE: PMT is sensitive to light even when no power is applied

4. Remove high voltage BNC cable from photocathode connector

5. Remove transimpedance filter from anode connector

6. Unscrew rear plate from PC104TSCE housing (3 Philips pan head screws)

7. Remove rear plate from PC104TSCE Housing

8. Place PMT photocathode cover on PMT

9. Remove PMT from rear plate

10. Place PMT in box making sure that serial numbers match

NOTE: At this point the room lights may be turned on

11. Attach rear plate to housing with screws

Part H: Calculation of PMT Responsivity and Quantum Efficiency

1. Open data file from data logger program in spread sheet program (Excel was used)

2. There will be four columns Date, Time. Channel 0, Channel 1. It will be assumed here that channel 0 is the transimpedance voltage and channel 1 is the power meter voltage.
3. Form a fifth column containing the power in nW read by the power meter by multiplying the channel 1 value by the calibration value of the power meter.
4. Next multiply this by the beam splitter coefficient κ to get the power to the PMT.
5. Now multiply the power in the PMT channel by the transmission of the housing window to get the actual power on the PMT.
6. Now find the Anode current by dividing the transimpedance voltage by the transimpedance filter resistance.
7. The cathode current is found by dividing the anode current by the tube gain
8. Responsivity is calculated by dividing the cathode current by the power on the PMT
9. Quantum efficiency is found multiplying by hc and dividing by $q\lambda$

References

"Photomultiplier Tube Catalog", Hamamatsu Co. Dec 1997.

R2228 PMT Specifications Sheet, Hamamatsu Co. Jan, 2000, http://www.hamamatsu.com

Dereniak, E. J., Boreman G. D. Infrared Detectors and Systems. John Wiley and Sons Inc. New York 1996.

RCA Electro-Optics Handbook (PA 17604) RCA Corporation C 1974