Title:	FastSCAN Laser Hazard Analysis – Version 3		
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Summary

This document outlines hazard analysis for two WorldStar laser line modules, the 3.5mW (ULL5-3.5P-670-45) and 1mW (ULL5-1P-670-45) versions, as used within the FastSCAN laser scanners. Note that we are told that the labelling of the WorldStar 1mW laser module is for marketing purposes and we note the actual output power is in fact higher than stated.

Our tests indicate that both laser modules meet the requirements for class I operation, as outlined in the International Standard IEC 60825-1 Second edition 2007 – 03, when enclosed in the FastSCAN wand housing. The laser modules on their own do not fully comply with the IEC 60825 class I limits. However, within the wand housing the closest point of human access is 96.25mm from the laser module meaning the wand unit as a whole fully complies.

Note the device has not been designed to allow for removal of the laser module even under normal maintenance conditions. If any laser related maintenance work is required it must be returned to the manufacturer for this work to be carried out.

Note that early indications are that both laser modules produce significantly less than the maximum allowable output for class I operations when used in this device. All units measured to date have been well within the calculated required maximum output power level. That said we will continue to individually test 100% of production units until such time as engineering considers that this will not be necessary.

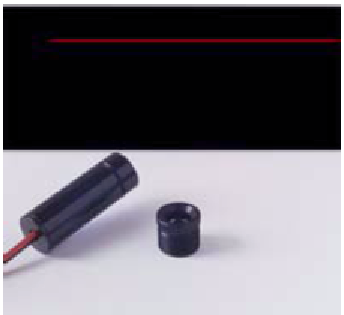
Laser Classification for FastSCAN wand

World Star Tech ULL Series Red Laser Line Module 3.5mw:

ULL Series Red Laser Line Module

WSTech

Part No: ULL5-3.5P-670-45



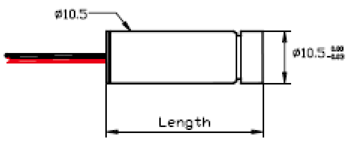
Product Features

- High Stability and low noise
- Collimated or Adjustable focus beam
- Reverse Polarity Protection
- Custom Options Available

Application

- Measurement
- Bioanalytical
- Automation
- Alignment

Mechanical Drawing



Specification

OPTICAL	
Wavelength	670 nm
Optical Output Power	3.5 mW
Stability	<1%
Laser Class	II
Wavelength Drift	0.2nm/°C
Noise (20MHz Bandwidth)	<0.5% RMS
Laser Operation	Continuous
Laser Structure	Single Mode Laser
Line Thickness	Fixed Focus
Minimum Line Thickness	< 2mm up to 1.5 meter
Pointing Stability	<50µrad
ELECTRICAL	
Operating Voltage[1]	3 to 5 VDC
Operating Current	<60 mA
Control Circuit	Auto Power Control
Electrical Connections	+Red, -Black
MECHANICAL	
Dimension (Dia * Length)	10.5mm * 24mm
Cable	380mm
Operating Temperature	-10°C to +50°C
Storage Temperature	-40°C to +80°C
Heat Sink Requirements[2]	Recommended

Notes

1. Higher operating voltage version (9 to12V) is available, the part No. will be: ULL12-3.5P-670-45.
2. Heat Sink: The ULL Series Red Laser Line Module is designed to operate without heat sink. Do not restrict air circulation around the device; an additional heat sink can be used to maximize the performance and life time of the laser.

Caution: The case is internally connected to the circuit; damage to the anodized surface may result in failure of the laser module.

Complies with CDRH 21CFR 1040.10

Operational Hazard-Semiconductor Laser Diode Module: This laser module emits radiation that is visible and harmful to human eye. When in use, do not look directly into the laser emitting aperture. Direct viewing of laser diode emission at close range may cause eye damage.

Limited Warranty: One year. No warranty coverage for disassembly, modifications or damage due to abuse or misapplication.

World Star Tech.
321 Lesmill Rd. Toronto, Ont. M3B 2V1 Canada
Tel: (416) 363-3332 Fax: (416) 363-3112 www.worldstartech.com

Rev.6 Jun.2005

World Star Tech ULL Series Red Laser Line Module 3.5mw:

Wavelength	670nm
Output Power	3.5mW
Fan Angle	45 degrees
Beam Divergence	1.33mrads (This was calculated assuming a 2mm minimum width at 1.5 metres and the laser originating at a point. In practice, the laser origin is rectangular and therefore 1.33mrads only provides an estimate of the beam divergence).

Consider the laser output geometry illustrated in Figure 1. The laser output power is spread out over a fan angle Θ. The beam width is W. The measurement distance R is the radial distance from the laser vertex. S is the arc length and L is the approximation to S used in these calculations as we are dealing with very small angles. The laser energy passing through an aperture A at a measurement distance R can be determined using basic trigonometry as it is assumed that L ≈ S.

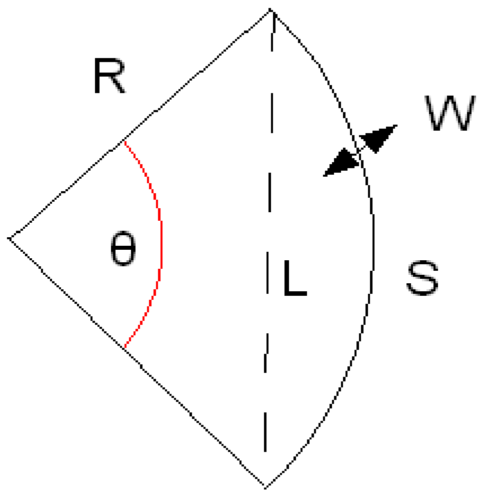


Figure 1 – Schematic of laser output geometry.

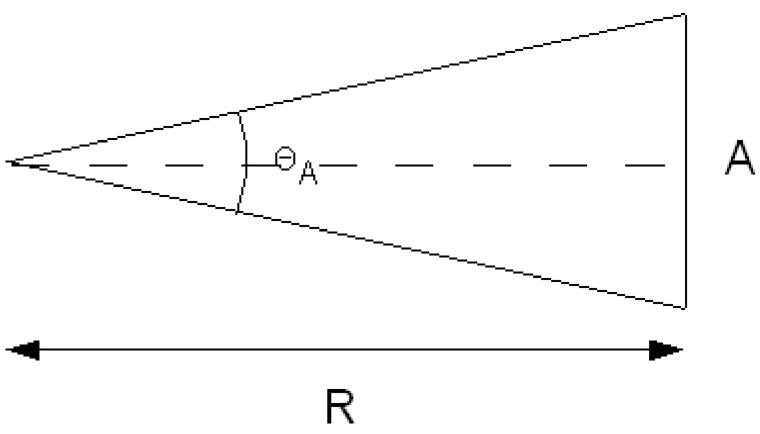


Figure 2 – Percentage of output beam passing through limiting aperture A. Θ_A represents the fraction of the fan angle that passes through the aperture A. This assumes that the beam width is entirely contained within the limiting aperture.

From Figure 2:

$$\tan(\Theta_A / 2) = (A/2)/R$$

$$\Theta_A = 2*\tan^{-1}(A/(2R))$$

$$Pout = (\Theta_A \text{ (degrees)}/ \Theta)*3.5mW$$

Eye Hazard Assessment

Using Table 11 from the IEC 60825 Standard [1] the calculated laser output power for conditions 1, 2 and 3 are presented in Table 1.

	Condition 1		Condition 2		Condition 3	
Wavelength (nm)	A (mm)	R (mm)	A (mm)	R (mm)	A (mm)	R (mm)
400 to 1400	50	2000	7	70	7	100
Pout (mW)	0.1114		0.4453		0.3118	

Table 1 – Calculated Pout for Conditions 1, 2 and 3.

Note: The laser module is contained within the wand protective housing. The closest point of human access (marked in the FastSCAN wand engineering diagram in Appendix 1) is at 96.25mm from the laser line reference. This means that for the FastSCAN wand, condition 2 can be calculated for an aperture of 7mm at 96.25mm. In practice the laser origin is further back than 96.25mm but this value constitutes a worse case scenario. **Under these conditions the Pout for condition 2 reduces to 0.3240mW.**

To determine the AELs (Accessible Emission Limits) for class I operation it is important to consider the angular subtense (α) of the source. The angular subtense determines the size of the image on the retina and therefore the resulting concentration of laser energy on the retina. Therefore, the angular subtense is directly related to the AEL requirements.

The limiting or most restrictive scenario assumes a point source. At a first glance a laser line module would appear to be an extended source and therefore classified as a function of its angular subtense. Consider the following:

From section 8.3c of [1] – Radiation from extended sources:

The ocular hazard from laser sources in the wavelength range from 400nm to 1400nm is dependent upon the angular subtense of the apparent source α.

NOTE 1 A source is considered an extended source when the angular subtense of the source is greater than α_{min}, where α_{min} = 1,5 mrad. Most laser sources have an angular subtense α less than α_{min}, and appear as an apparent "point source" (small source) when viewed from within the beam (intra-beam viewing). Indeed a circular laser beam cannot be collimated to a divergence less than 1,5 mrad if it is an extended source, thus any laser where a beam divergence in any plane of 1,5mrad or less is specified cannot be treated as an extended source.

NOTE 2 For retinal thermal hazard evaluation (400nm to 1 400nm), the AELs for extended sources vary directly with the angular subtense of the source.

NOTE 3 For the default condition where C_6 = 1, a simplified Table 4 is provided for the AEL of class I and IM.

For sources subtending and angle less than or equal to α_{min}, the AEL and MPE are independent of the angular subtense of the apparent source α.

This would imply that the laser line which has a beam divergence in the plane orthogonal to the plane of fan angle of less than 1.5mrad cannot be treated as an extended source. If an extended source cannot be assumed then the AELs for a point source (using α_{min} = 1.5mrads, C_6 = 1) must be used.

Consider also from “A guide to laser safety”, A. R. Henderson, Pg 141 [2].

The angular size of extended sources having unequal dimensions about two orthogonal axes, such as the rectangular emission area of many laser diodes, should be determined on the basis of the smaller dimension.

As a result of these considerations all calculations were performed assuming the point source (or limiting) angular subtense of α = 1.5mrads. This was used because the angular size of the source was different in different dimensions (i.e. rectangular) and therefore everything was based on the smaller dimension. This was considered to be the limiting or most restrictive scenario. From a practical perspective this also seems to make sense, for example if the laser energy is within AELs assuming the highest concentration of laser energy then it should also be within AELs when the laser energy is in fact less intense or less concentrated. The effect of angular subtense on AELs is illustrated in Appendix 2 and illustrates how the AEL requirements relax as the laser becomes less and less like a point source. Any angular subtense greater than the minimum is only going to relax the AEL requirements.

Therefore, for classification purposes, the point source (or limiting) AEL for Class I classification of 0.3900mW was used (see Table 4 in [1]). Note this is constant for time bases of 10s to 30000s and is therefore appropriate for a time base of 100s as determined from section 8.3e of [1]. Condition 1, Condition 2 (modified) and Condition 3 output powers of 0.1114mW, 0.3240mW and 0.3118mW, are all within this limit and therefore class I operation limitations have been met.

Skin Hazard Assessment

Calculated at point of closest human access. This is 96.25mm as indicated in Appendix 1. An aperture of 3.5mm is used for skin hazard assessment calculations. Assuming a beam width orthogonal to the fan angle of 0.1283mm (calculated using the 1.33 beam divergence) the scenario as illustrated in Figure 3 occurs.

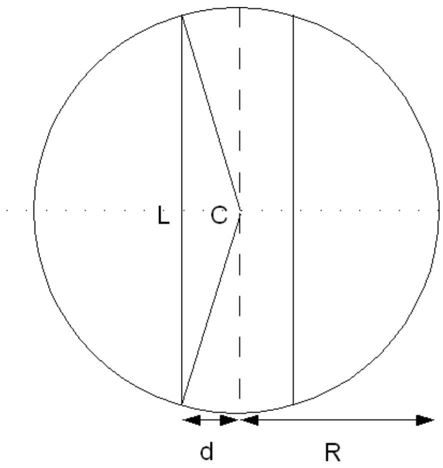


Figure 3 – Laser line area for skin hazard assessment. The limiting aperture diameter is 3.5mm, therefore R is 1.75mm. d is half the width of the beam at the measurement distance. L is the chord distance and C is the angle L makes with the centre of the aperture.

$L = 2\ \mathrm{sqrt}\ (R^2 – d^2)$

$C = 2\ \cos^{-1}(d/R)$

Area of circle "cut off" from rest of circle by chord L =
$CA\ = (R^2 (C- \sin(C)))/2$

Laser line area = $\pi R^2 – 2*CA$

For d = 0.1283/2 = 0.0642mm, Laser line area = 0.4491mm^2 = 4.49e-7m^2

The laser power passing through the 3.5mm aperture at a measurement distance of 96.25mm is 0.1620mW. Dividing by the laser line area gives 360.8174 W/m^2.

However, for comparison with the AELs in [1] the total laser beam power passing through the 3.5mm aperture must be averaged over the area of the limiting aperture. Physically, this is because the heat resulting from the incident laser energy is absorbed by surrounding tissues, moderating the rise in temperature of the irradiated skin. The area of a 3.5mm aperture is 3.85e-5m^2. Dividing the laser power through the 3.5mm aperture of 0.1620mW by this area gives 4.2103 W/m^2. This value is well under the AEL of 2000 W/m^2 given in Table A.3 of [1] for time bases of 10s to 30000s.

Measured Power Output

Compare measured values of laser modules, at eye hazard condition 2 and skin hazard distances, to those calculated above.

Using a Newport Hand-held Optical Meter (Model: 1918-C, Serial Number: 10446) and Photo diode Detector (Model: 918D-SL-0D1, Serial Number: 10194) measurements were taken of five randomly selected ULL5-3.5P-45 laser modules. See Appendix 3 for Certificates of Calibration for the Optical Meter and photo diode detector.

The test setup is configured to represent the closest point of human access to the laser module when housed in a FastSCAN wand, illustrated in Figure 4.

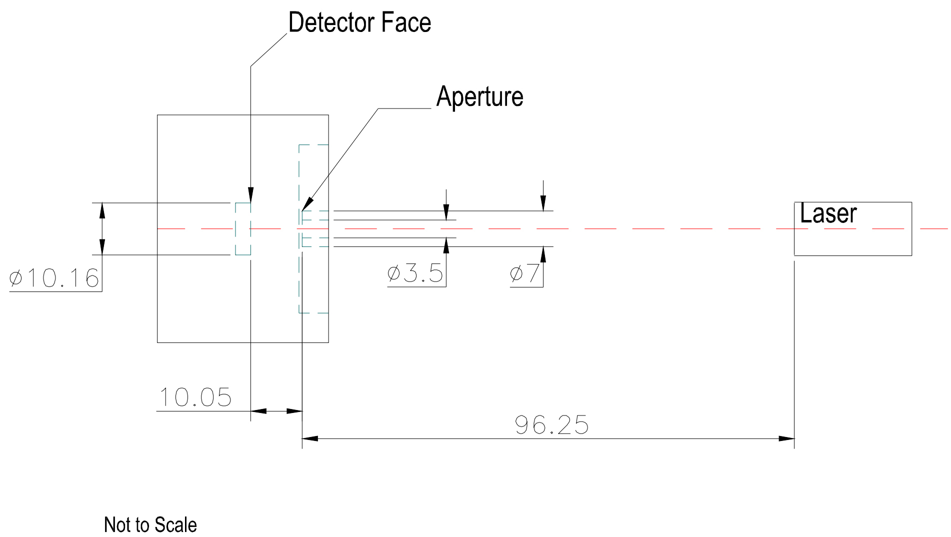


Figure 4 - The 7mm and 3.5mm apertures measure 96.25mm from the front edge of the laser module with the face of the optical detector a further 10.05mm from the aperture.

Peak measurements were taken for the five laser modules with the results shown in Table 2. In each case the measured output power is well below the computed upper limits of 0.3240mW for the 7mm aperture and 0.1620mW for the 3.5mm aperture.

Aperture size (mm)	Measured Laser Output Power (mW)				
	1	2	3	4	5
7mm (condition 2)	0.2643	0.2774	0.2694	0.2787	0.2705
3.5mm (Skin hazard Assessment)	0.1311	0.1391	0.1360	0.1398	0.1354

Table 2 – Measured results of five ULL5-3.5P-45 laser modules

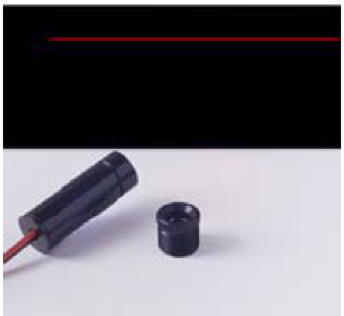
The measurements were repeated for:

World Star Tech ULL Series Red Laser Line Module 1mW:

ULL Series Red Laser Line Module

WSTech

Part No: ULL5-1P-670-45



Specification

OPTICAL	
Wavelength	670 nm
Optical Output Power	1 mW
Stability	<1%
Laser Class	Class II
Wavelength Drift	0.2nm/°C
Noise (20MHz Bandwidth)	<0.5% RMS
Laser Operation	Continuous
Laser Structure	Single Mode Laser
Line Thickness	Fixed Focus
Minimum Line Thickness	< 2mm up to 1.5 meter
Pointing Stability	<50μrad
ELECTRICAL	
Operating Voltage[1]	3 to 5 VDC
Operating Current	<60 mA
Control Circuit	Auto Power Control
Electrical Connections	+Red, -Black
MECHANICAL	
Dimension (Dia * Length)	10.5mm * 24mm
Cable	380mm
Operating Temperature	-10°C to +50°C
Storage Temperature	-40°C to +80°C
Heat Sink Requirements[2]	Recommended

Notes

1. Higher operating voltage version (9 to12V) is available, the part No. will be: ULL12-1P-670-45.

2. Heat Sink: The ULL Series Red Laser Line Module is designed to operate without heat sink. Do not restrict air circulation around the device; an additional heat sink can be used to maximize the performance and life time of the laser.

Caution: The case is internally connected to the circuit; damage to the anodized surface may result in failure of the laser module.

Complies with CDRH 21CFR 1040.10

Product Features

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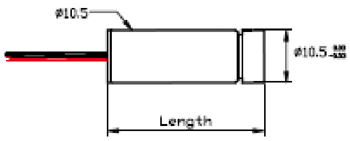

Operational Hazard-Semiconductor Laser Diode Module: This laser module emits radiation that is visible and harmful to human eye. When in use, do not look directly into the laser emitting aperture. Direct viewing of laser diode emission at close range may cause eye damage.

Limited Warranty: One year. No warranty coverage for disassembly, modifications or damage due to abuse or misapplication.

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321 Lesmill Rd. Toronto, Ont. M3B 2V1 Canada
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Rev.6 Jun.2005

The peak power was measured for three ULL5-1P-45 laser modules from World Star Tech with the results shown in Table 3.

Aperture size (mm)	Measured Laser Output Power (mW)		
	1	2	3
7mm (condition 2)	0.2591	0.2496	0.2556
3.5mm (Skin hazard Assessment)	0.1308	0.1256	0.1290

Table 3 – Measured results of three ULL5-1P-45 laser modules

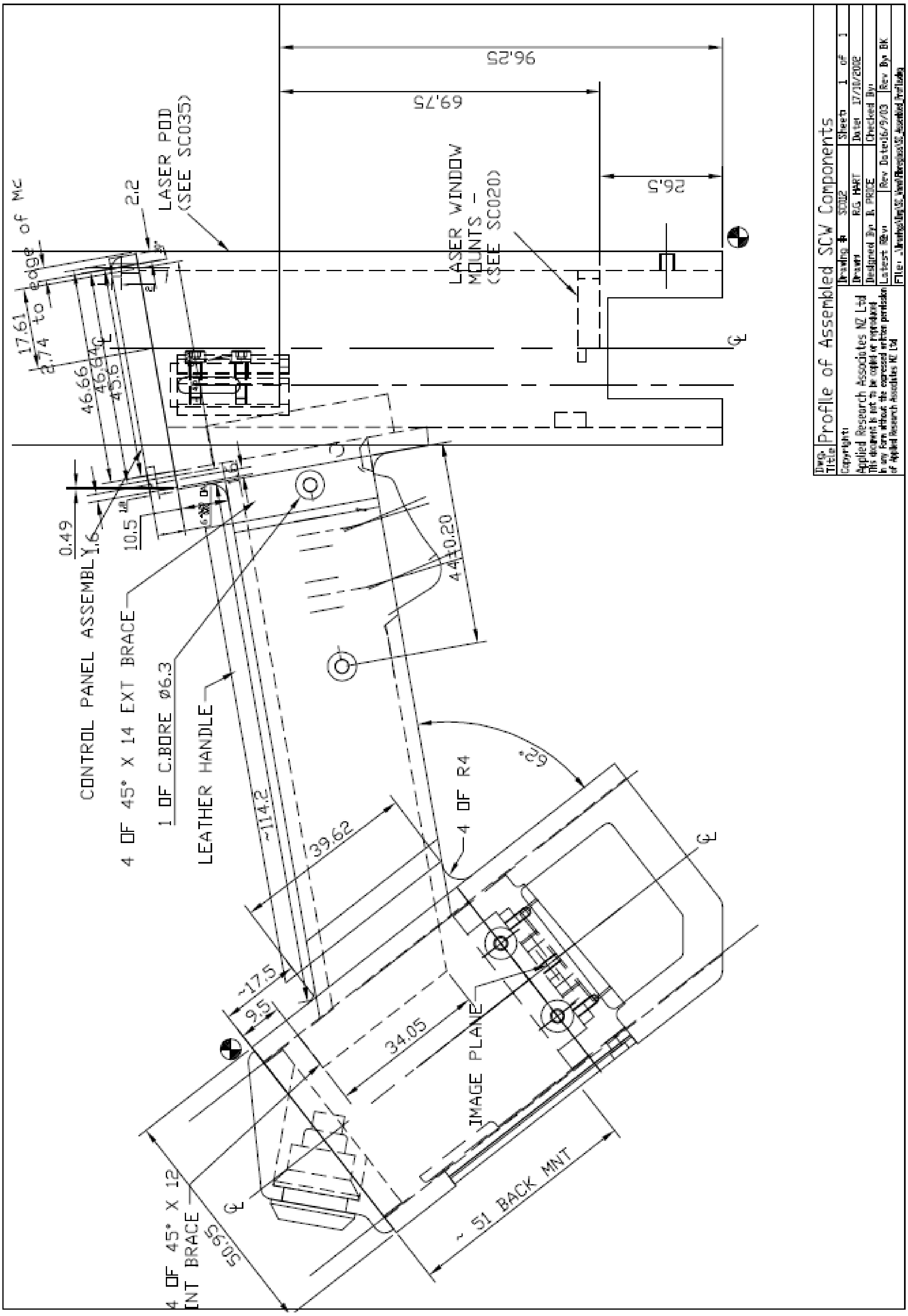
These results indicate that the measured output power for the 1mW module is only slightly reduced over the output power of the 3.5mw laser module. The 1mw label is clearly a misnomer. However, these output powers (as for the 3.5mw module) are sufficiently low to meet the requirements for Class I classification.

References:

[1] International Standard IEC 60825-1 Second edition 2007 – 03
Safety of laser products -
Part 1: Equipment classification and requirements.

[2] A. R. Henderson, “A guide to laser safety”, Chapman & Hall, 1997.

Appendix 1: FastSCAN Wand Engineering Diagram



Appendix 2: Effect of Angular Subtense on Accessible Emission Limits

The AELs (Accessible Emission Limits) for Class 1 classification for angular subtenses α from 0.1 to 10mrads are plotted in Figure 4.

α (mrads)	t (s)	T_2 (s)	C_6	AEL (mW)
1	100	10.0	1.0	0.39
20	100	15.4	13.3	4.70
50	100	31.1	33.3	9.90
100	100	100.0	66.7	14.8

Table 4 – AELs for angular subtenses of 1, 20m 50 and 100mrads.

AELs for extended sources were investigated. An extended object is defined as having α > 1.5mrads. With α > 100mrads being set to 100mrads. AELs for α = 1mrads (i.e. Point source), 20mrads, 50mrads and 100mrads are detailed in Table 2 below. From section 8.3e a time base of t = 100s was used as appropriate for class 1 classification. Calculations were also repeated for t = 30000s assuming intentional misuse of the system – these did not differ from the results for t = 100s. These calculations were performed using formulae from Table 5 in [1].

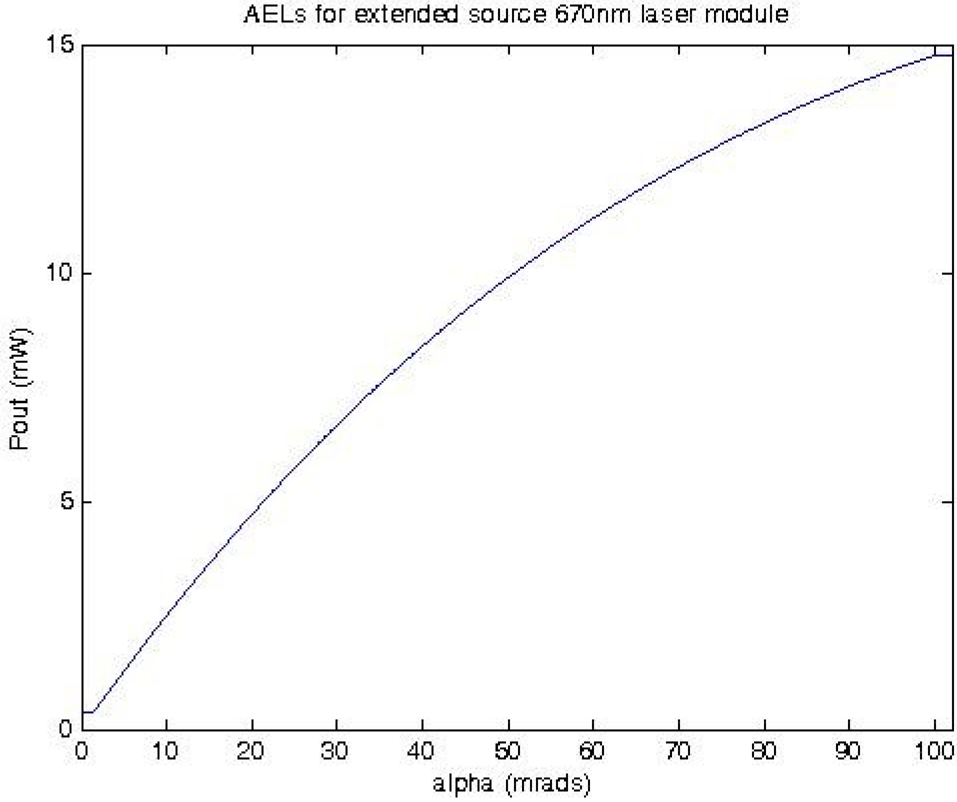


Figure 5 : AELs for 670nm laser for varying α.

Figure 5 illustrates that the AELs increase as a function of α from 0.39mW to 14.8mW. The limiting case for α < 1.5mrads (i.e. a point source) is 0.39mW.

Appendix 3: Certificates of Calibration

Newport Corporation
1791 Deere Avenue
Irvine, CA 92606
Phone: (949) 863-3144
Fax: (949) 253-1800

PA16449TW
Certificate Number

CERTIFICATE OF CALIBRATION

Model No: 1918-C
Serial No: 10446
Description: Single-Channel Optical Meter
Customer Name: Initial Purchaser
Address:
Calibrated Per Procedure No: PTP-44950-01

Environment Conditions

Temperature: 23.4 °C
Relative Humidity: 56 %

Standards Used

Model	Serial or ID No.	Description	Cal Due Date	Calibration Traceability Number
Keithley 263	0680096	Current Source	20-JUN-2009	108170105340
Agilent 34970A	US37002199	Acquisition/Switch	02-MAR-2010	1085898589
Agilent 33120A	US36046789	Function Gen.	02-MAR-2010	1085898586

Newport certifies that the calibration that was performed using Standards that are traceable to the National Institute of Standards and Technology (NIST), other recognized national standards laboratories, using natural physical constants, or ratio calibration techniques. The calibration complies with ANSI/NCSL Z540-1-1994 and ISO-9001. This certificate shall not be reproduced except in full, without the written approval of Newport. Specific information concerning parameters and measurements is in attachment(s). Calibration ratio is at least 4:1 unless otherwise stated.

Calibration Date: 24-Apr-09 (DD-MMM-YY)
Calibration By: S.Y.L S.Y.L (Print/Sign)
Reviewed By: S.Y.L
Title: Technician

Newport
SN 10446
CALIBRATED BY S.Y.L
DATE 24 Apr 09
DUE 24 Jul 10
DD MMM YY

Please remove and apply Calibration sticker to the Instrument as required.

Page 1 of 1

P/N 21650-01 Rev. K

NEWPORT CORPORATION
1791 DEERE AVENUE
IRVINE, CA 92606
PHONE: (949) 863-3144
FAX: (949) 253-1800

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PA002352CN
CERTIFICATE NUMBER

CERTIFICATE OF CALIBRATION

Model No: 918D-SL-OD1
Serial No: 10194
Description: Low Power Detector
Customer Name: Initial Purchaser
Address:
Calibrated Per Procedure No: PTP44571-1

Environment Conditions

Temperature: 23.5 °C
Relative Humidity: 52.49 %

Standard Used Model	Serial or ID Number	Description	Calibration Due Date	Calibration Traceability Number
Hamamatsu	D214	NIST Standard	04/10/2010	844/276336-08

Newport certifies that the calibration that was performed using Standards that are traceable to the National Institute of Standards and Technology (NIST), other recognized national standards laboratories, using natural physical constants, or ratio calibration techniques. The calibration complies with ANSI/NCSL Z540-1-1994 and ISO-9001. This certificate shall not be reproduced except in full, without the written approval of Newport. Specific information concerning parameters and measurements is in attachment(s). Calibration ratio is at least 4:1 unless otherwise stated.

Calibration Date: 28-Jul-2009
DD-MMM-YY
Calibration By: Moon Yan Moon
Print/Sign
Reviewed By: Moon Yan
Title: Technician

Newport
SN 10194
CALIBRATED BY Moon
DATE
DUE
DD–MMM–YY

Newport recommends recalibration 12 months after customer receives product. Fill in the date and due date on calibration sticker. Remove and apply it to the Instrument as required.

Page 1 of 1

P/N 21650-01 Rev. L