Optical Power Level Limits for Eye Safety: Spreadsheet calculator

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Background

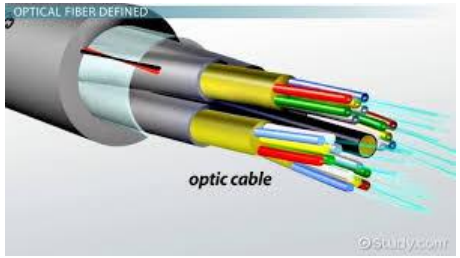
- Richard Johnson affiliated with Finisar and authors affiliated with Panduit collaborated to develop eye safety hazard calculator tools based on latest IEC 60825 documents.
  - The goal was to resolve incongruences or avoid misinterpretations of IEC 60825 standards (see castro_3cm_02a_0518 for more details)
- Richard Johnson implemented a laser hazard model in Python whereas the authors implemented in Excel using VBA.
- Both models agreed in computation results.
- The spreadsheet will be available in 802.3cm.
- In this presentation we describe briefly the main parameters of the calculator for 2 wavelengths.
- Also, we will discuss the impact of NA on the Hazard levels.

Introduction

- There are several IEC 60825 documents related with eye safety for different laser types and applications.
- IEC 60825, part I is used for the laser system qualification.
  - Tests based on this standard used accessible emission levels (AEL) to determine the class of the transceiver, i.e. Class 1 or Class 1M.
- IEC 60825, part II, “Safety of optical fiber communication systems,” is used to evaluate hazards associated to eye or skin damage based on laser class.
  - The maximum permissible exposure (MPE) at any reasonable location of the optical fiber communication system used is evaluated and compared with actual exposure.
- There are many consideration to evaluate the hazard of the optical system such as:
  - Laser wavelength, launch condition, NA of the fibers, number of fibers, fiber spacing, test distance, apertures…
  - All these consideration were included in the spreadsheet calculator

Hazard Level

- The potential hazard at <u>any</u> accessible location within an OFCS. It is based on the level of optical radiation which could become accessible in a reasonably foreseeable event, e.g. a fiber cable break. It is closely related to the laser classification procedure in IEC 60825-1.
  - For hazard 1, the level of radiation is measured with the conditions for Class 1 laser products (IEC 60825-1), but with condition 2 being as defined in clause 4.8.1 of IEC 60825-2
  - For hazard level 1M the level of radiation is measured with the conditions for Class 1M laser products (see IEC 60825-1), but with condition 2 being as defined in clause 4.8.1 of this (IEC 60825-2)



Eye Safety Calculator

Parameter	Wavelength 1			Wavelength 2			Units
λ =	844			900			nm
Power =	3.8			4			dBm
NA =	0.15			0.18			-
N_fiber_vert	1.0						-
N_fibers_horiz	4.0						-
Distance_y	0.25						*mm*
Distance_x	0.25						*mm*
Source size (one)	0.05						*mm*
condition	1	2	3	1	2	3	
d_0 =	50.0	3.5	7.0	50.0	3.5	7.0	*mm*
L =	2000	14	100	2000	14.0	100	*mm*
worst_comb_y	1.00	1.00	1.00	1.0	1.0	1.0	
worst_comb_x	4.00	1.00	2.00	4.0	1.0	2.0	
Source count	4.00	1.00	2.00	4.00	1.00	2.00	
alpha (worst)	1.50	3.57	2.25	1.50	3.57	2.25	*mrad*
T2	10.00	10.50	10.18	10.00	10.50	10.18	*sec*
d_{63} =	356.98	2.50	17.85	430.56	3.01	21.53	*mm*
C_4 =	1.941	1.941	1.941	2.512	2.512	2.512	
C_6 =	1.00	2.38	1.50	1.00	2.38	1.50	
C_7 =	1.0	1.0	1.0	1.0	1.0	1.0	-
η =	0.019	0.859	0.143	0.013	0.740	0.100	-

INPUT PARAMETERS

Measurement Conditions

Worst case combinations

Working Parameters

Operational wavelengths

Average power per wavelength

Numerical Aperture

Number of Tx fibers in each axis

Fiber separation

Source size: Fiber MFD for SMF or fiber Core diameter for MMF

Aperture diameter and distance for each measurement condition

Angular subtense

Max emission duration

Correction factors

Collecting efficiency

Eye Safety Calculator

Class 1, 1M Emission Limits for range

700 nm to 1400 nm

INPUT PARAMETER

Bi-directional = 0	1
Co-directional = 1	

Informative

Condition		
	1	= Telescope
	2	= Microscope
	3	= Naked eye

FINAL RESULTS (HAZARDs)

Class 1 Hazard	1.947	EXCEEDED
Class 1M Hazard	0.941	PASS

INPUT PARAMETERS

WORKING PARAMETERS

Parameter	Wavelength 1			Wavelength 2			Units
λ =	844			900			nm
Power =	3.0			4			dBm
NA =	0.15			0.18			-
N_fiber_vert	2						-
N_fibers_horiz	4.0						-
Distance_y	0.25						*mm*
Distance_x	0.25						*mm*
Source size (one)	0.05						*mm*
condition	**1**	**2**	**3**	**1**	**2**	**3**	
d_0 =	50.0	3.5	7.0	50.0	3.5	7.0	*mm*
L =	2000	14	100	2000	14.0	100	*mm*
worst_comb_y	1.00	1.00	1.00	1.0	1.0	1.0	
worst_comb_x	4.00	1.00	2.00	4.0	1.0	2.0	
Source count	4.00	1.00	2.00	4.00	1.00	2.00	
alpha (worst)	1.50	3.57	2.25	1.50	3.57	2.25	*mrad*
T2	10.00	10.50	10.18	10.00	10.50	10.18	*sec*
d_{63} =	356.98	2.50	17.85	430.56	2.01	21.53	*mm*
C_4 =	1.941	1.941	1.941	2.512	2.512	2.512	
C_6 =	1.00	2.38	1.50	1.00	2.38	1.50	
C_7 =	1.0	1.0	1.0	1.0	1.0	1.0	-
η =	0.019	0.859	0.143	0.013	0.740	0.100	-

MAX. PERMISIBLE POWER vs ACTUAL POWER

AEL per Class/condition

Class 1	**AEL**	0.757	1.797	1.141	0.980	2.326	1.477	*mW*
Max permissible power for hazard 1:		38.964	2.091	8.004	73.134	3.141	14.718	*mW*
Total Power per wavelength per condition:		**9.595**	**2.399**	**4.798**	**10.048**	**2.512**	**5.024**	*mW*

Computation

- Compute the correction factors based on the input parameters
  - C4 : wavelength correction factor
  - C6 : spatial correction factor
- Determine the accessible emission levels for each tested condition (1- Telescope, 2- Microscope, 3-Naked eye).
- Compare the AEL with the transmitted optical power for each testing condition (after discounting the losses due collector efficiency)

Examples

400G BASE-SR8

- Maximum average power of 7.54 dBm per lane, NA=0.18.
- Around 5.8 dBm OMA (assuming extinction ratio=2)
- Condition 2 trigger the hazard
- NA=0.16 reduces the average power to 6.5 dBm. Still well beyond the limit (4 dBm).
- No reduction in the power per lane when increasing from 4 to 8 fibers

Class 1, 1M Emission Limits for range

700 nm to 1400 nm

Condition		
	1	= Telescope
	2	= Microscope
	3	= Naked eye or Low power Magnifiers

Class 1 Hazard	2.338	EXCEEDED
Class 1M Hazard	0.998	PASS

Parameter	Wavelength 1		
λ =	844		
Power =	7.54		
NA =	0.18		
N_fiber_vert	1.0		
N_fibers_horiz	8.0		
Distance_y	0.25		
Distance_x	0.25		
Source size (one)	0.05		
condition	1	2	3
d_0 =	50.0	3.5	7.0
L =	2000	14	100
worst_comb_y	1.00	1.00	1.00
worst_comb_x	8.00	1.00	2.00
Source count	8.00	1.00	2.00
alpha (worst)	1.50	3.57	2.25
T2	10.00	10.50	10.18
d_{63} =	430.56	3.01	21.53
C_4 =	1.941	1.941	1.941
C_6 =	1.00	2.38	1.50
C_7 =	1.0	1.0	1.0
η =	0.013	0.740	0.100

AEL per Class/condition

Class 1	AEL	0.757	1.797	1.141
Max permissible power for hazard 1:		56.509	2.427	11.373
Total Power per wavelength per condition:		45.404	5.675	11.351
Hazard per wavelength per conditions Class 1 =		0.8035	2.3381	0.9981
Maximum Level per wavelength	Class 1	2.338		
	Class 1M	0.998		

400G BASE-SR4.2

- The max. average power per lane identical to the 400G BASE-SR8 case due to the Bi-directional transmission
- Co-directional transmission would have reduced the max. power in about 2.5 dB

Class 1, 1M Emission Limits for range

700 nm to 1400 nm

Bi-directional = 0	0
Co-directional = 1	

Condition	1	= Telescope
	2	= Microscope
	3	= Naked eye or Low power Magnifiers

Class 1 Hazard	2.338	EXCEEDED
Class 1M Hazard	0.998	PASS

Parameter	Wavelength 1			Wavelength 2			Units
λ =	844			900			nm
Power =	7.54			7.54			dBm
NA =	0.18			0.18			-
N_fiber_vert	1.0						-
N_fibers_horiz	4.0						-
Distance_y	0.25						*mm*
Distance_x	0.25						*mm*
Source size (one)	0.05						*mm*
condition	1	2	3	1	2	3	
d_0 =	50.0	3.5	7.0	50.0	3.5	7.0	*mm*
L =	2000	14	100	2000	14.0	100	*mm*
worst_comb_y	1.00	1.00	1.00	1.0	1.0	1.0	
worst_comb_x	4.00	1.00	2.00	4.0	1.0	2.0	
Source count	4.00	1.00	2.00	4.00	1.00	2.00	
alpha (worst)	1.50	3.57	2.25	1.50	3.57	2.25	*mrad*
T2	10.00	10.50	10.18	10.00	10.50	10.18	*sec*
d_{63} =	430.56	3.01	21.53	430.56	3.01	21.53	*mm*
C_4 =	1.941	1.941	1.941	2.512	2.512	2.512	
C_6 =	1.00	2.38	1.50	1.00	2.38	1.50	
C_7 =	1.0	1.0	1.0	1.0	1.0	1.0	-
η =	0.013	0.740	0.100	0.013	0.740	0.100	-

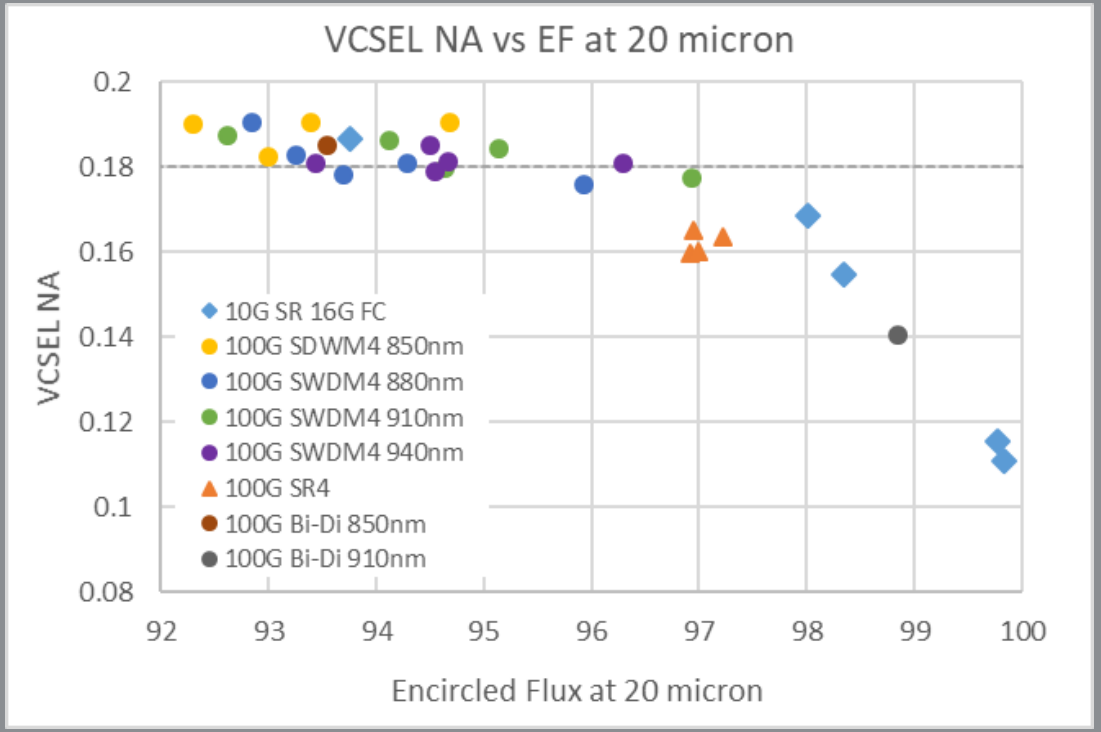
AEL per Class/condition

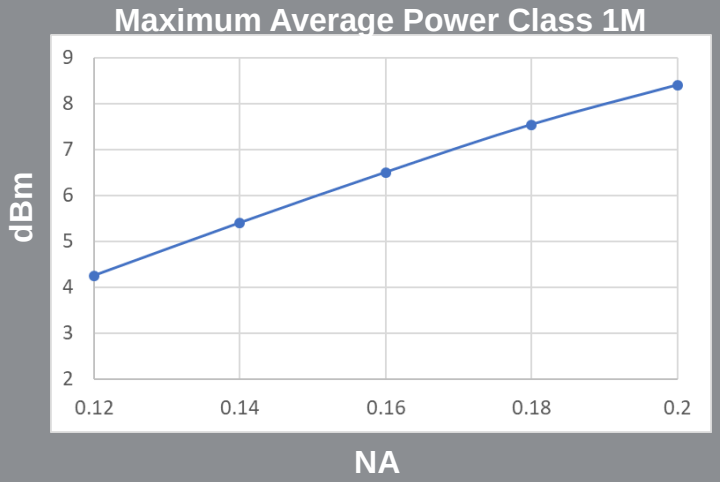
Class 1	AEL	0.757	1.797	1.141	0.980	2.326	1.477	*mW*
Max permissible power for hazard 1:		56.509	2.427	11.373	73.134	3.141	14.718	*mW*
Total Power per wavelength per condition:		**22.702**	**5.675**	**11.351**	**22.702**	**5.675**	**11.351**	*mW*
Hazard per wavelength per conditions Class 1 =		**0.4017**	**2.3381**	**0.9981**	**0.3104**	**1.8066**	**0.7712**	-
Maximum Level per wavelength	Class 1	2.338			1.807			Worst case
	Class 1M	0.998			0.771			

Effect of NA

- For NA=0.18, the max. average power per lane (7.54 dBm) is far from the 4 dBm in the 802.3 cm draft.
- However, VCSELs do not overfill the NA of the fiber.
- There were interest in the people participating in this study to know if actual NA values can produce eye safety hazards.
- We use the eye safety calculator for NA values 0.18, 0.16 and 0.14.
- The maximum average power reduced from 7.45 dBm (NA=0.18) to 5.4 dBm for NA=0.14.
- Actual NA values from different VCSEL/TOSA generation were measured in next slide

Experimental





Summary and Conclusions

- Collaborative study from contributors from two companies to clarify uncertainties in max power levels for next generation multimode fiber variants.
  - Result could be useful in IEEE 802.3cm or future Fibre Channel physical interfaces.
- Bi-directional transmission advantageous to avoid eye safety concerns. Increase margins by 2.5 dB
- The impact of NA is significant in eye safety estimations. However, estimated max. average powers for class 1M is still far from specified in current 802.3 draft.
  - It gets close to eye safety limit for NA=0.12

Appendix

400G using 2 wavelength Co-directional Tx

Class 1, 1M Emission Limits for range

700 nm to 1400 nm

Bi-directional = 0	1
Co-directional = 1	

Condition		
	1	= Telescope
	2	= Microscope
	3	= Naked eye or Low power Magnifiers

Class 1 Hazard	2.336	EXCEEDED
Class 1M Hazard	0.997	PASS

Parameter	Wavelength 1			Wavelength 2			Units
λ =	844			900			nm
Power =	5.05			5.05			dBm
NA =	0.18			0.18			-
N_fiber_vert	1.0						-
N_fibers_horiz	4.0						-
Distance_y	0.25						*mm*
Distance_x	0.25						*mm*
Source size (one)	0.05						*mm*
condition	1	2	3	1	2	3	
d_0 =	50.0	3.5	7.0	50.0	3.5	7.0	*mm*
L =	2000	14	100	2000	14.0	100	*mm*
worst_comb_y	1.00	1.00	1.00	1.0	1.0	1.0	
worst_comb_x	4.00	1.00	2.00	4.0	1.0	2.0	
Source count	4.00	1.00	2.00	4.00	1.00	2.00	
alpha (worst)	1.50	3.57	2.25	1.50	3.57	2.25	*mrad*
T2	10.00	10.50	10.18	10.00	10.50	10.18	*sec*
d_{63} =	430.56	3.01	21.53	430.56	3.01	21.53	*mm*
C_4 =	1.941	1.941	1.941	2.512	2.512	2.512	
C_6 =	1.00	2.38	1.50	1.00	2.38	1.50	
C_7 =	1.0	1.0	1.0	1.0	1.0	1.0	-
η =	0.013	0.740	0.100	0.013	0.740	0.100	-

AEL per Class/condition

Class 1 AEL	0.757	1.797	1.141	0.980	2.326	1.477	*mW*
Max permissible power for hazard 1:	56.509	2.427	11.373	73.134	3.141	14.718	*mW*
Total Power per wavelength per condition:	**12.796**	**3.199**	**6.398**	**12.796**	**3.199**	**6.398**	*mW*
Hazard per wavelength per conditions Class 1 =	**0.2264**	**1.3179**	**0.5626**	**0.1750**	**1.0183**	**0.4347**	-

Maximum Level per wavelength	**Class 1**	1.318	1.018	**Worst case for each wavelength**
	Class 1M	0.563	0.435	

Annex: Eye Safety Models comparison

Both implementation shown identical results.

Excel Spreadsheet version (Panduit)

Class 1, 1M Emission Limits for range

700 nm to 1400 nm

Bi-directional = 0	1
Co-directional = 1	

Condition	1	= Telescope
	2	= Microscope
	3	= Naked eye or Low power Magnifiers

Class 1 Hazard	1.788	EXCEEDED
Class 1M Hazard	0.763	PASS

Parameter	Wavelength 1			Wavelength 2			Units
λ =	844			900			nm
Power =	3.8			4			dBm
NA =	0.18			0.18			-
N_fiber_vert	1.0						-
N_fibers_horiz	4.0						-
Distance_y	0.25						*mm*
Distance_x	0.25						*mm*
Source size (one)	0.05						*mm*
condition	1	2	3	1	2	3	
d_0 =	50.0	3.5	7.0	50.0	3.5	7.0	*mm*
L =	2000	14	100	2000	14.0	100	*mm*
worst_comb_y	1.00	1.00	1.00	1.0	1.0	1.0	
worst_comb_x	4.00	1.00	2.00	4.0	1.0	2.0	
Source count	4.00	1.00	2.00	4.00	1.00	2.00	
alpha (worst)	1.50	3.57	2.25	1.50	3.57	2.25	*mrad*
T2	10.00	10.50	10.18	10.00	10.50	10.18	*sec*
d_{63} =	430.56	3.01	21.53	430.56	3.01	21.53	*mm*
C_4 =	1.941	1.941	1.941	2.512	2.512	2.512	
C_6 =	1.00	2.38	1.50	1.00	2.38	1.50	
C_7 =	1.0	1.0	1.0	1.0	1.0	1.0	-
η =	0.013	0.740	0.100	0.013	0.740	0.100	-

AEL per Class/condition

Class 1 AEL	0.757	1.797	1.141	0.980	2.326	1.477	*mW*
Max permissible power for hazard 1:	56.509	2.427	11.373	73.134	3.141	14.718	*mW*
Total Power per wavelength per condition:	9.595	2.399	4.798	10.048	2.512	5.024	*mW*
Hazard per wavelength per conditions Class 1 =	0.1698	0.9883	0.4219	0.1374	0.7996	0.3413	-

Maximum Level per wavelength	Class 1	0.988	0.800	Worst case for each wavelength
	Class 1M	0.422	0.341	

Python version (Richard Johnson)