Infineon Technologies Bipolar

Triggering Light Triggered Thyristors (LTTs)

Protection Class II,
Reinforced Insulation

Abstract

Triggering light triggered thyristors

Direct light triggered thyristors have been well known since the 1980s. The 8 kV light triggered thyristor disc (beside HVDC applications) is well suited to medium-voltage drives, power supplies, static VAR compensation systems and pulsed power applications [9]. The ceramic disc facilitates an easy way of triggering by using optical fibers to avoid insulation problems between the load and trigger units. This disc increases reliability by reducing high voltage electronic components. They use internal protection functions such as Break over Diode (BoD) and critical rise rate of forward blocking voltage (dv/dt) protection. This ensures safe internal triggering of the thyristor to protect it selves. Due to the outstanding design, it is also possible to use the protection functions for repetitive operation. These features allow continuous operation for redundant series connection even in case of controller failure.
While the control of electrically triggered thyristors is sufficiently well known, light triggered thyristors still require some general explanations.
This application note explains correct trigger signals, optical emitters, fiber optic cable and the trigger behavior of the light triggered thyristor.

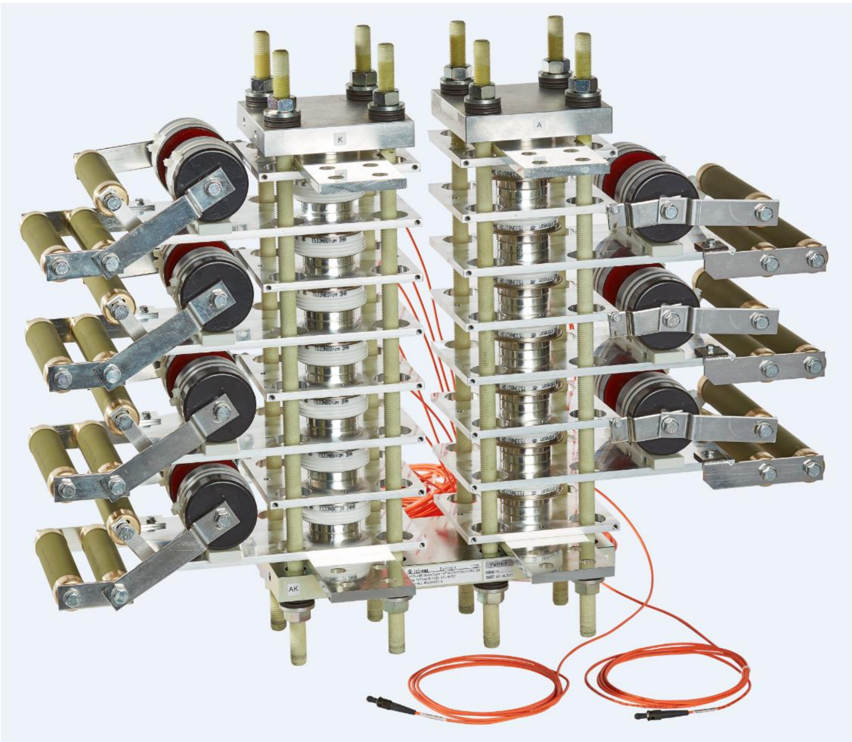

Figure 1. Discharge switch, single phase (W1C)

Document history

Revision	Remark	Name	Date
V0.	Created	JS	20180725
V2.	Language check	TF	20190313
V3-V5	Add on’s	JS	20190215
V6	Four eye check	JS, MS	20190716
V6a	Corrections	JS	20190812
V6b	Corrections	JS	20190917
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Contents

1 Triggering light triggered thyristors (LTTs)

While the control of electrically triggered thyristors (ETT) is sufficiently well known, light triggered thyristors still require some general explanations. Triggering LTTs is quite easy, but the trigger behavior of a LTT is different to the trigger behavior of an ETT. This needs to be taken into account for the whole power stage design [6].
This application note explains correct trigger signals, optical emitters, fiber optic cable and the trigger behavior of the light triggered thyristor.

2 Trigger behavior of light triggered thyristors

For some applications triggering by a 10µs, 40mW light power pulse per sine half wave is a suitable trigger solution. Due to the behavior of the thyristor's optical amplifying gate circuit, the internal electrical gate current will flow for about 100µs (time constant of an e-function). The optical amplifying gate works fine with an anode cathode voltage more than 40V. Therefore, continuous optical triggering is not required because the anode current will rise to the latching current during a 100µs period. Otherwise, the thyristor will not turn on.
To control light triggered thyristors, Laser diodes emitting light in the range of 900 to 1000 nm wavelengths are recommended. Laser (**L**ight **A**mplification by **S**timulated **E**mission of **R**adiation) light provides efficient and safe triggering of the thyristor.
The trigger light power is specified at the output of the optical fiber cable. To provide even turn-on of parallel and series connections, overdriving is recommended in particular for applications with high di/dt requirements.
Infineon recommends the use of the SPL PL90 laser diode (pulsed operation) or devices with similar electrical and optical characteristics (Figure 2) and offers these together with suitable optic fiber cables as ancillary equipment.
In terms of reliability and redundancy, it may be useful to use optical combiners and optical splitters. See chapter 5 for details.

Figure 2. LTT with light guide, optical fiber cable, ST connector and SPL PL90A Laser diode

Currently the LTTs are optimized for infrared light and the maximum sensitivity is achieved between wavelengths of 900 nm and 1000 nm. Usually, an application requires flexibility in regarded to the length of the optical fiber. Fiber lengths of 1 m, 4 m, 15 m and more are required. The attenuation of the optical fiber should be small and calculable. This requirement fits best to the Laser light and Multi-Mode Glass Optical Fiber cables (GOF) [6].

Figure 3 shows the required optical power to trigger the LTT, versus the Laser light wavelength (at a pulse width of 100 µs). While the LTT requires about 6 mW to trigger at 908 nm, the necessary trigger power increases to about 20 mW at 650 nm. The typical datasheet, fiber output, trigger power is P_{LM} =40mW at 900-1000 nm.

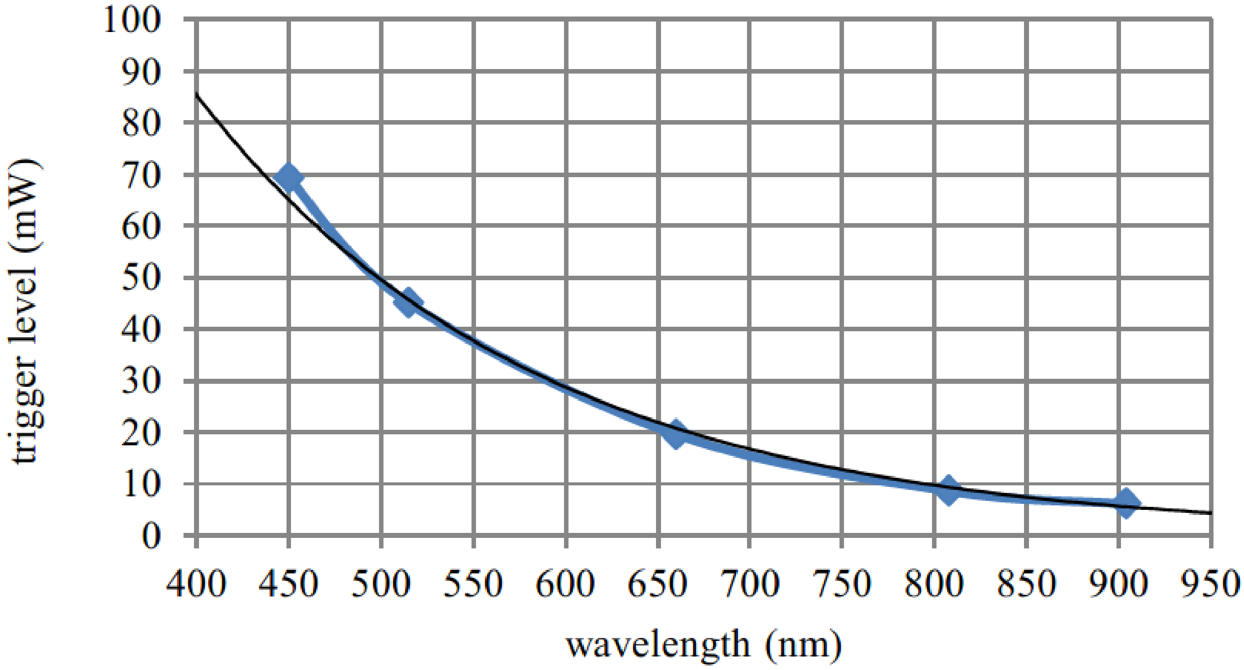


Figure 3. Measured optical power to trigger the LTT in dependence of the wavelength

Working with wavelengths smaller than recommended is allowed. However the required higher trigger power needs to be taken into account. If long or continuous trigger pulses are required for an application a Laser diode for continuous operation may be required. The Laser Diode WSLR-808-180m-M-PD from WAVE spectrum (see Figure 4) may be a candidate [15]. The light wavelength of this diode is 808 nm. From Figure 3, we can determine the required trigger power of about 10mW. It is 1.67 times higher compared to 908nm (6 mW). Therefore the trigger power needs to increase (P_L= 40 mW*1.67 = 66.8 mW).

Figure 4. WAVE spectrum WSLR-808-180m-M-PD (ST connector)

The qualification for the LTT's was done with the Laser Diode SPL-PL90A that has an ST connector (see Figure 5) [18]

Figure 5. SPL-PL90A Laser Diode (SPL-PL90 with housing and ST connector)

2.1 Trigger related characteristic values of LTT's

Table 1 contains recommendation for light triggered thyristors from Infineon. (T533N/NH80, T1503N/NH80, T2563N/NH80, T4003N/NH52, T6900N95 where N is the standard version and NH is the version for high di/dt).

Description	Parameters		Value			
			min	typ	max	
Light wave length		t	900	940	1000	nm
Minimum gate trigger light power	T_{vj} = 25°C, V_D = 40 V (at output of fiber optic cable)	P_{LM}			40	mW
Recommended gate trigger light power	T_{vj} = 25°C, V_D = 40 V	P_{Lrec}		100		mW
Maximum gate trigger light power, continuous signal	T_{vj} = 25°C, V_D = 40 V, continuous	P_{Lmax}			500	mW
Maximum gate trigger light power, pulsed signal	T_{vj} = 25°C, V_D = 40 V, pulsed (10 µs, 6 kHz)	P_{Lmax}			1000	mW
Trigger pulse length	t_{rise} = 0.5 µs	t	10			µs
Trigger energy storage time		τ	100			µs
Trigger pulse frequency	During the planned conduction time of the thyristor	f		6		kHz
Trigger pulse repetition time	During the planned conduction time of the thyristor (= 1/f)	t		166		µs
Holding current	T_{vj} = 25°C	I_H			100	mA
Latching current	T_{vj} = 25°C, V_D = 40 V, P_{LM} = 40 mW, t_{rise} = 0.5 µs	I_L			1	A
Gate controlled delay time	DIN IEC60747-6 T_{vj} = 25°C, V_D = 0.5 V_{DRM}, P_{LM} = 40 mW, t_{rise} = 0.5 µs	t_{gd}			5	µs
Active area of optical gate					0.8	mm

Table 1. Trigger related characteristic values of LTTs

2.2 Visualization for LTT triggering (at Anode-Cathode voltage > 40V)

Figure 6 shows typical waveforms for an LTT when it is triggered on and has an anode cathode voltage > 40V.

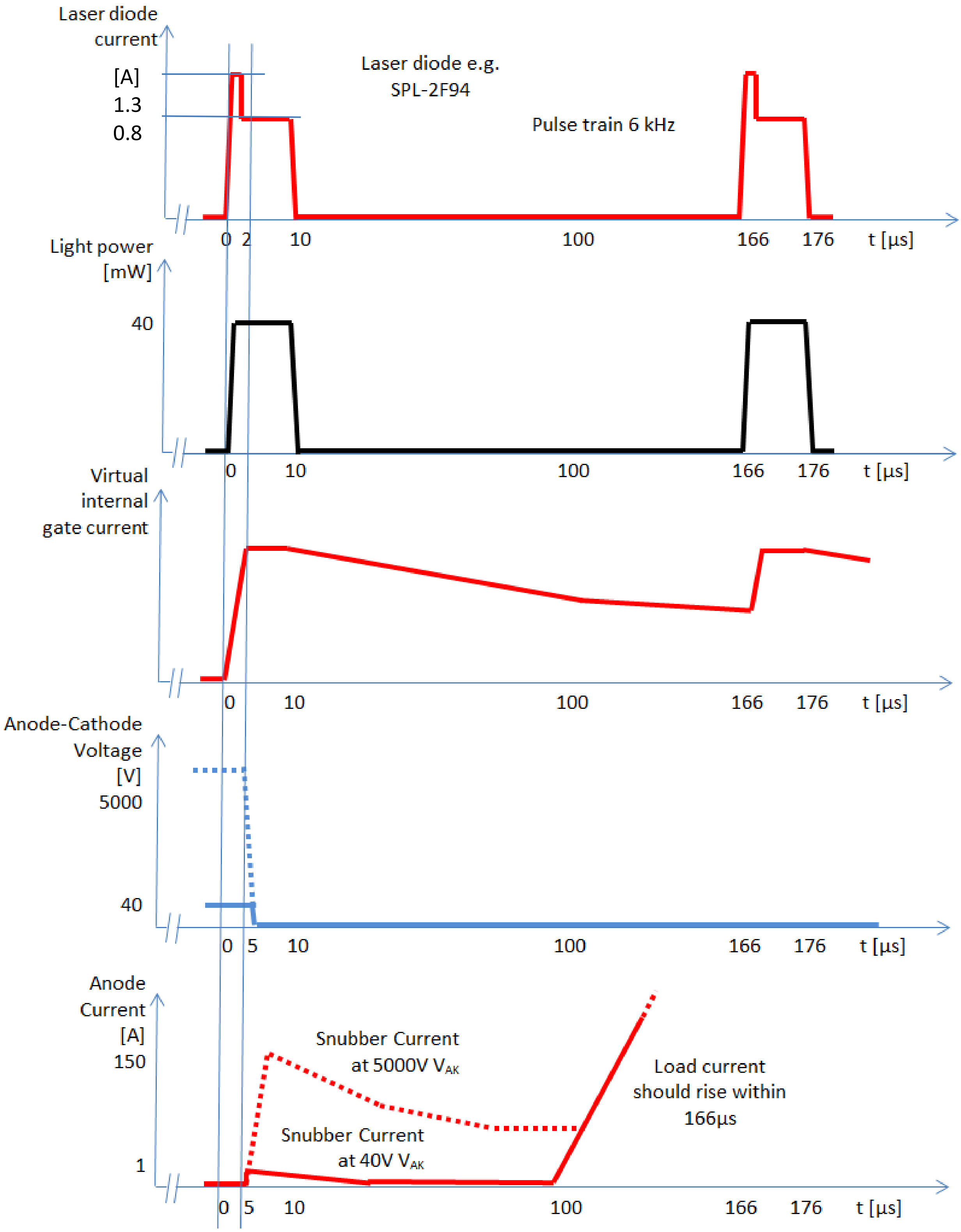


Figure 6. Visualization for LTT triggering (Anode-Cathode voltage >40V)

2.3 Visualization for LTT triggering (at Anode-Cathode voltage < 40V)

Figure 7 shows typical waveforms for an LTT when it is triggered on and has an anode cathode voltage <40V.

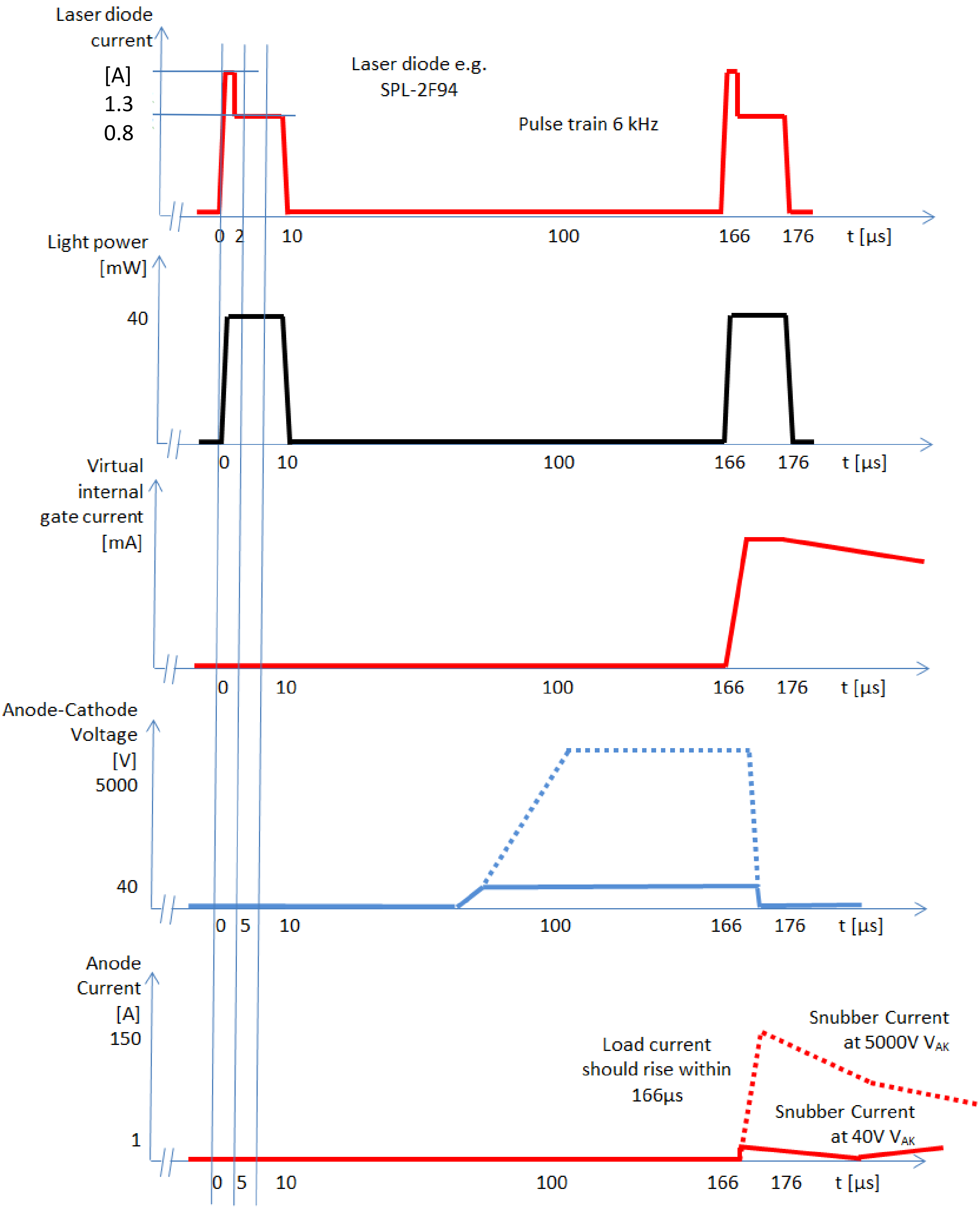


Figure 7. Visualization for LTT triggering (Anode-Cathode voltage < 40V)

2.4 Conclusion about trigger behavior of LTT

Due to the behavior of the optical amplifying gate circuit, the internal electrical gate current will flow for about 100µs (time constant of an e-function). The optical amplifying gate works fine with an anode cathode voltage more than 40V. Continuous optical triggering is therefore not required. The anode current should rise to the latching current in that time. Otherwise the thyristor will not turn on. The repetition frequency for the trigger pulses has to be adjusted according the applications needs!

Since the laser diode SPL-PL90 is designed for pulsed power, the diode losses are limited due to the diode's cooling characteristics (lack of heat sink).
Over the time, several trigger pulse configurations were applied with the laser driver unit LFTD18 [16] (stand-alone driver unit for LTT test purpose and lab use).

Application	peak	roof	Kind of pulse	Laser Diode	Operating mode	Comment
Pulsed power	0 A/0 µs	0.8A/10µs	Single pulse	SPL-PL90A	Continuous	For single thyristors
Pulsed power	1.35A/2µs	0.8A/8µs	Single pulse	SPL-PL90A	Continuous	For series connected thyristors, and high di/dt applications
Drives/Switch	1.35A/2µs	0.8A/8µs	6kHz pulse train	SPL-PL90A	Continuous	Limited by useful life of laser diode
Pulsed power	1.35A/2µs	0.7A/108µs	Single pulse	SPL-PL90A	Intermittent	Limited by laser diode losses and useful life. Laser diode selection required to keep optical trigger power on allowed level (same light power for all diodes in the system, see chapter 5.2)

Table 2. Trigger pulse configurations for some applications

See also chapter 6.2 with information about useful life estimation for the laser diode.

3 LTT in the application

The LTT offers the following internal protection functions.

- Overvoltage protection
- dv/dt protection
- Forward recovery protection

All of these functions can be used repetitive and the LTT will not be damaged. For example if one thyristor of some series connected thyristors is not triggered due to a failure in the control unit,

the thyristor will turn on automatically via internal triggering due to its overvoltage protection. In such a case, the snubber circuit of the thyristor with the missing optical trigger signal will take a higher load. In such a case the snubber capacitor is charged to the BoD voltage of the thyristor. During normal operation, it only will be charged to about 50% of the BoD voltage. This needs to be taken into account for the snubber circuit design. To keep the operation of series connected thyristors under control, voltage monitoring for each individual thyristor is recommended. See chapter 6.3.2 [21].
Common triggering can be done with a common Laser diode for all series connected thyristors and the application of optical splitters. See chapter 0.

4 Applicable optical fiber sets

Definitions:

Optical fiber	the optical fiber with strain relief elements and outer jacket
Light guide	the connector to the optical gate of the thyristor
Connector	the connector on controller or coupler side
Optical fiber set	the complete applicable optical fiber solution

4.1 Comparing the behavior of optical fibers (GOF and POF)

Glass Optical Fibers (GOF) or the Polymer Optical Fibers (POF) can be used to trigger LTTs. GOF is also called PCS-Fiber (Plastic Clad Silica Fiber) and POF is also called PMMA-POF (Polymethylmethacrylat Plastics Optical Fiber). GOF and POF have different properties. The choice of which type of fiber to use depends on application requirements.
The GOF is available as mono mode or multi-mode version. The mono mode GOF lets the Laser light travel straight through the center of the fiber; whereas, multi-mode GOF directs the light by means of reflections on the outer edge of the fiber. Using the multi-mode GOF is recommended.

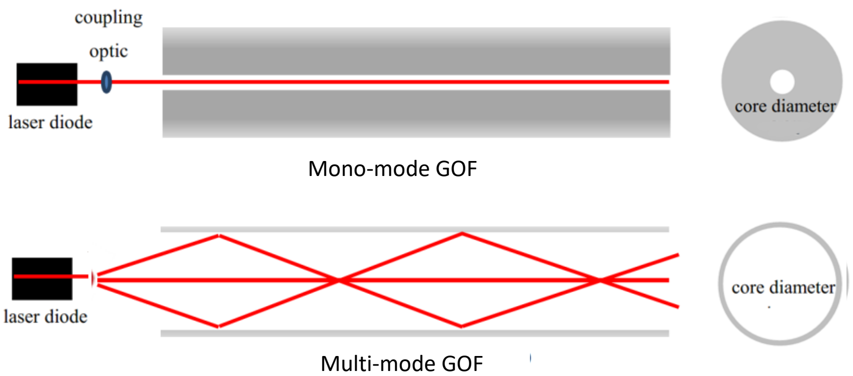


Figure 8. Comparison between mono-mode and multi-mode GOF

The power at the output of the Laser fed GOF experiences attenuation proportional to the GOF length.
For POF certain wavelengths experience high attenuation depending on the POF length. The POF is a cheap solution but limited by attenuation and reflexing effects.
LED emitting wavelength, POF length, further damping effects and required LTT trigger power must be coordinated.

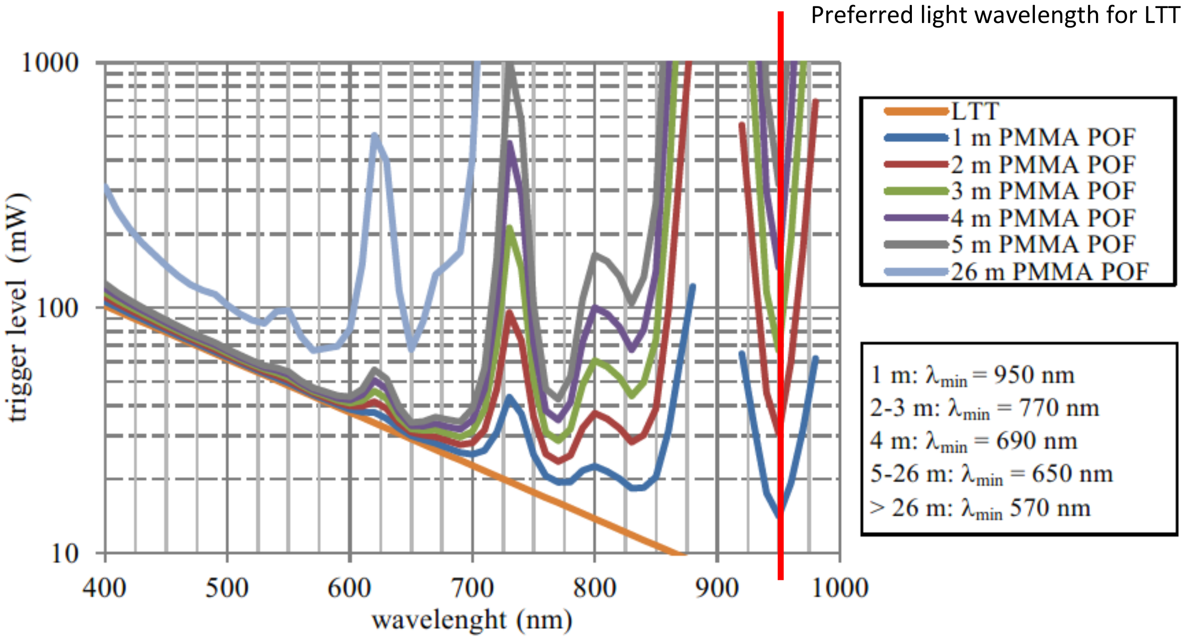


Figure 9. Wavelength dependent trigger levels for 1 m to 26 m PMMA POF

Using the data from Figure 10 it is now possible to determine the optimum wave length depending on the POF fiber length (Figure 9) assuming the same coupling efficiency of a Ø 200 µm PCS fiber.
The yellow straight line above shows the necessary trigger level of the LTT without fiber losses. The blue line above shows the wavelength dependent trigger level for 1 m POF: whereas, the red line is for 2 m POF etc. In the right box, the optimum wavelength for the lowest trigger level is listed for different distances.

A wavelength of 950 nm should thus be used for a fiber length < 1 m PMMA POF. For fiber lengths between 2 m to 3 m a wavelength of 770nm would be optimal and for fiber lengths between 5 m and 26 m, a 650 nm light source should be used. 570 nm is only useful for distances greater than 26 m. However, for a 26 m fiber length, a fiber output power of 67 mW is necessary (higher coupling losses of 1 mm POF compared to PCS-fiber is not included).

Depending on the fiber diameter, additional coupling losses must be taken into account. The active optical area of the LTT is 0.8mm diameter.

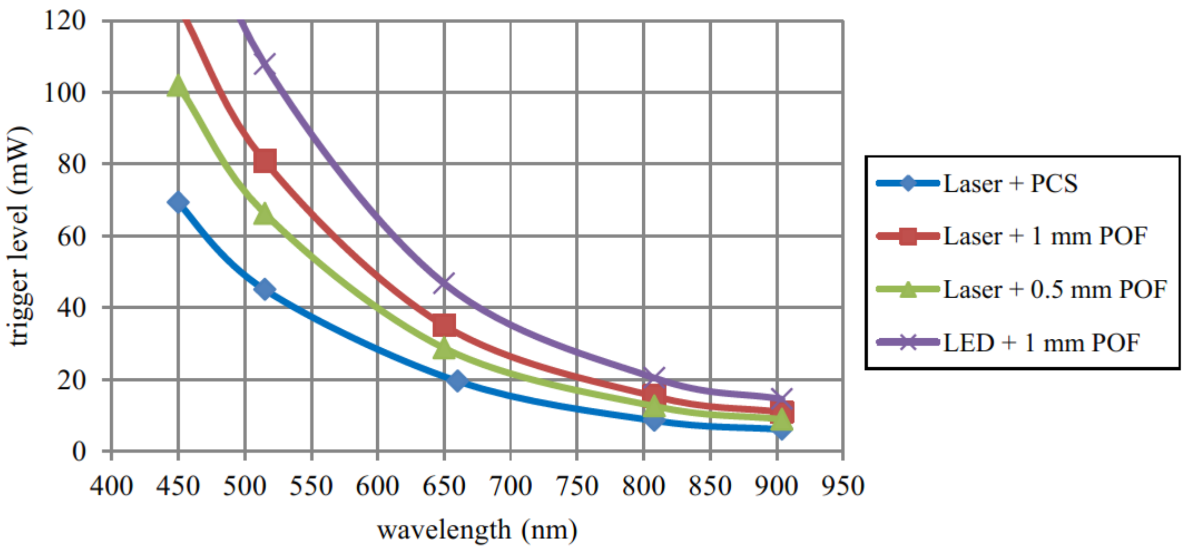


Figure 10. Wavelength dependent trigger level for PCS (GOF) and POF

The solution with GOF and Laser diode is expensive and fine for long distance connections; the solution with POF and LED is cheap. An individual qualification is required.
[6]

4.2 Optical fibers are differentiated as follows:

Designation	Short	Remark	Application area
Silica-Silica-Fiber (no plastics)	GOF	Glass optical fiber (GOF) (preferred)	Variable distance. Under oil
Plastic Cladded Silica Fiber	PCS, HCF	Plastic Cladded Fiber (PCF)	Variable distance. Under air
All Plastic Fiber	APF	Plastic optical fiber(POF)	Fixed distance

Table 3. Differentiation for optical fiber

4.3 Typical application areas for optical fibers

Fiber type	Core/jacket [µm]	Area	Expansion [km]	Data rate
GOF	9/125	Tele communication	>10	MBit/s to GBit/s
GOF	50/125 (62.5/125)	LAN	Up to 4	< 155 MBit/s
PCF, HCS	200/230	LAN in buildings	Up to 2	< 100 MBit/s
POF	980/1000	LAN in buildings, industry and automotive	Up to 0.1	< 40 MBit/s

Table 4. Typical application areas for optical fiber

[8]

It seems that POF is the right material for triggering power thyristors; but, due to the hard to calculate fiber attenuation, behavior the proper design takes more effort.

4.4 Important requirements for high voltage applications

For power electronics we need an insulation capability according IEC 60664-1 and a PD (partial discharge) free connection between Thyristor and ground. The standard IEC 60071-2 is also dedicated to the insulation topics.
The optical fibers are in general nonconductive due to the basic materials silica and plastics. They contain at least 2 different materials.

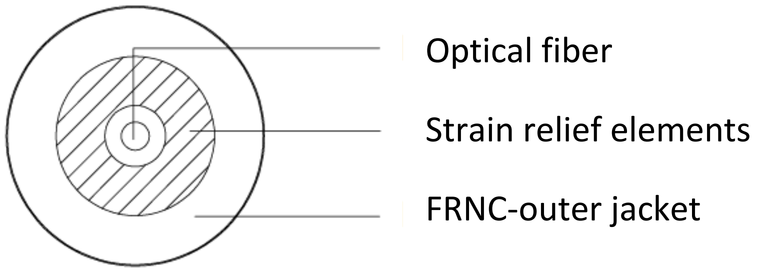


Figure 11. Profile of PCF I-V(ZN)H 1K200/230 (e.g.)

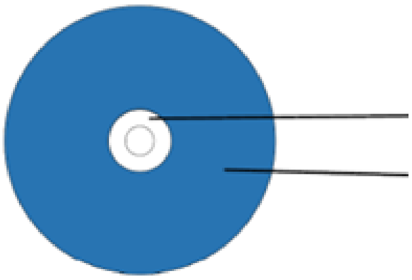


Figure 12. Profile of PCF V-4Y 1K200/230 2.15mm (e.g.)

4.4.1 Clearance

Clearance needs to be designed for reinforced insulation.
The fiber length between the thyristor and the first contact to a cable channel, the laser driver or the optical coupler is important for the clearance.
E.g. for 12.5 kV RMS to ground applications, a clearance of at least 55 mm according to table F.4 and multipliers from IEC 60664-1 needs to be realized (pollution degree 2). [11]

4.4.2 Creepage

Creepage needs to be designed for reinforced insulation.
The outer jacket of the optical fiber is important for the creepage design.
E.g. the material FRNC (made from PE) has a CTI of 600; therefore, it belongs to the material group I according to IEC60664-1.
E.g. for 12.5 kV RMS to ground applications, a creepage of at least 100.8 mm according to table F.4 and multipliers from IEC 60664-1 needs to be realized (pollution degree 2). [11]
A good applicable design rule is to have 20mm of creepage distance per 1kV RMS operating voltage (some safety margin included).

4.4.3 Partial discharge

The connection between hot parts and ground should be free of partial discharge.
All materials of an optical fiber are relevant for the partial discharge (PD). The plastics are more critical with regard to partial discharge effects than the silica core.
In air, partial discharges can occur at peak voltages in excess of 300 V (the Paschen Minimum). Failure is by gradual erosion or treeing leading to puncture or surface flashover. Furthermore partial discharge occurs in the air in inhomogeneous fields that have a peak voltage more than 12kV and a distance less than 320mm.
Insulation systems have different properties: Some can tolerate discharges throughout their anticipated life (e.g. ceramic insulators), while others have to be discharge-free (e.g. capacitors). Voltage, repetition rate of discharges and discharge magnitude are important parameters.
The PD behavior is influenced by the frequency of the applied voltage. It is established from accelerated life tests at increased frequency that the time to failure is approximately inversely proportional to the frequency of the applied voltage. However, practical experience only covers frequencies up to 5 kHz since, at higher frequencies, other failure mechanisms may also be present, for example dielectric heating. [12]
Ceramic insulators can easily be implemented in the connector of the optical fiber. E.g. the ST connector is available with ceramics inlet. This may help lowering the partial discharge. It depends on overall PD design (including cable positioning).

4.4.4 Conclusions for the insulation topics

The fiber length between the thyristor and the first contact to other potential (e.g. cable channel, the laser driver or the optical coupler), is important. That length needs to be defined according the

voltage to ground. To reduce PD effects in the optical fiber the distance between active parts and grounded parts should be as long as possible. E.g. for 12.5 kV RMS to ground applications 0.5 to 1m is needed. This is the longest distance compared to the clearance and creepage distances (see Figure 13).
Since the optical fibers are mainly used for telecommunications, there is little information on insulation characteristics. The following characteristics are recommended for testing the electrical suitability of an optical waveguide.

Recommended electrical data for wave guide tests:

Specific resistance:	> 10E10 Ohm/m (at 23°C, 50% rel. Humidity)
No flash over at:	4 kV/cm
Partial discharge:	< 5 pC at AC test voltage of 1.2 kV/cm (> 1 min) (regarded to the length of the waveguide)

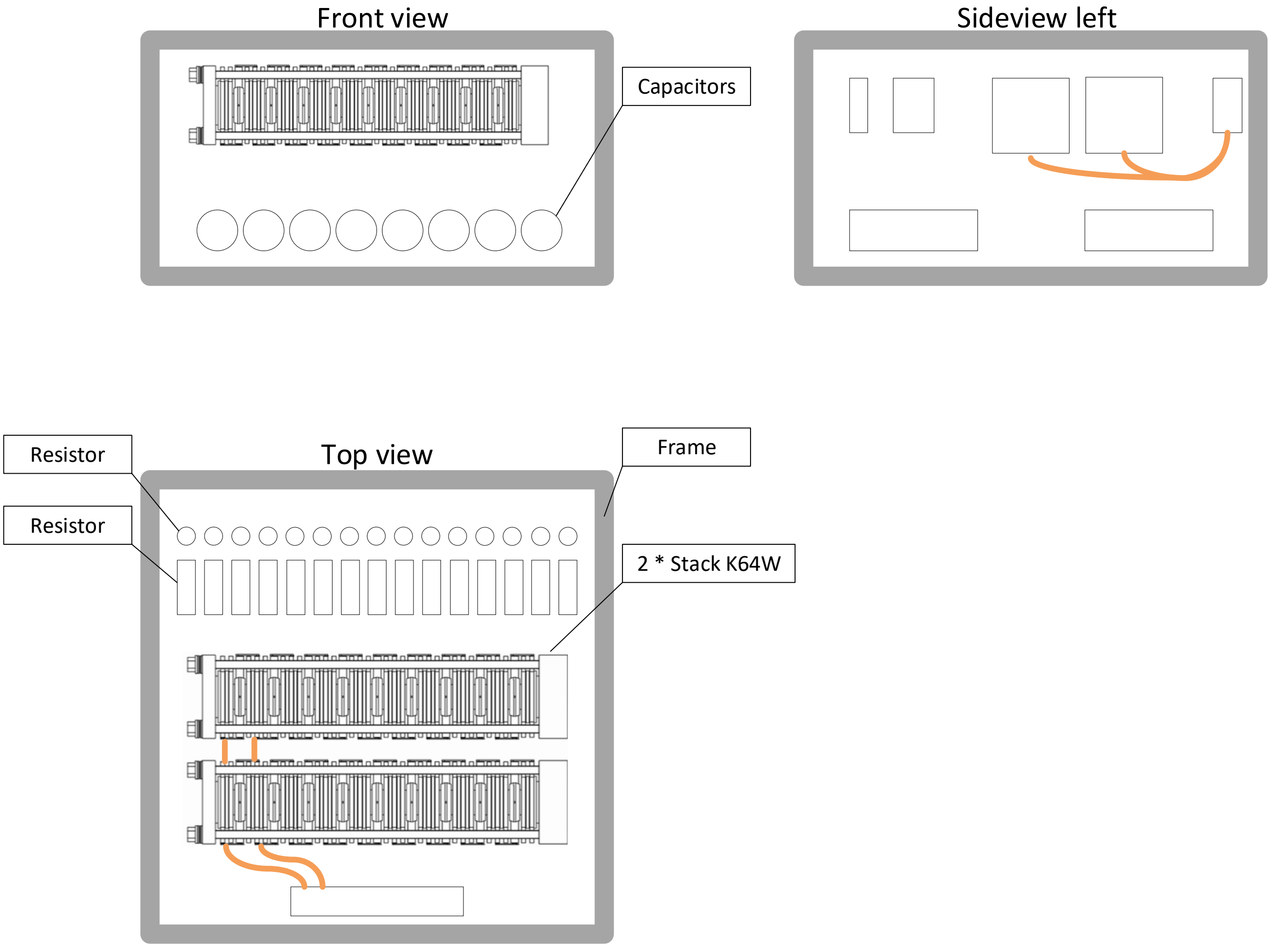


Figure 13. Example for optical fiber cabling (orange = optical fiber)

4.5 Other requirements

Following is an overview of the capabilities for common plastics optical fibers [17].

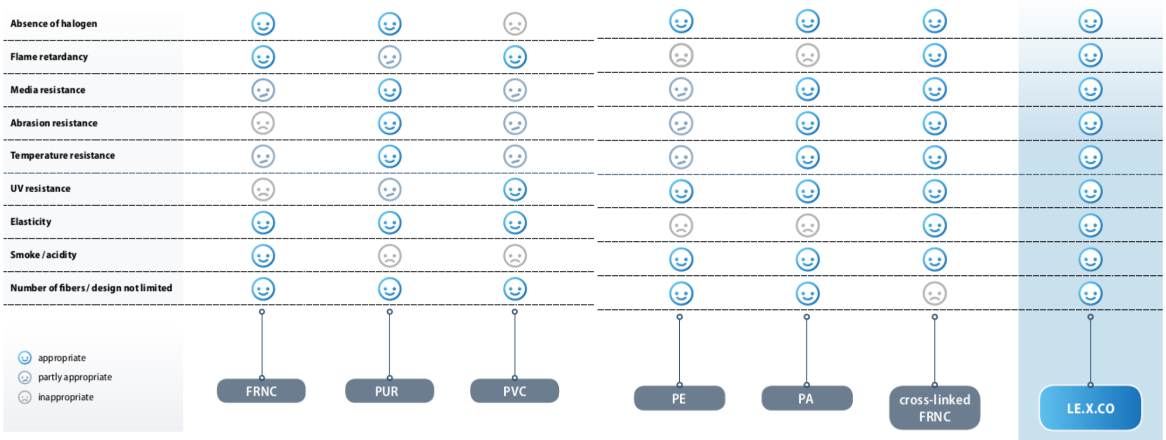


Figure 14. Requirements for optical fiber

Following are some other general technical data for common wave guide jackets materials. The final characteristics depend on the material mixtures.

Material	Designation	Density [g/cm³]	Tensile strength [N/mm²]	Contact resistance [Ohm*cm]	Dielectric strength [kV/mm]	Moisture absorption [%]	Temperature [°C]
Polyamid	PA	1.14	50	10^12	80	3	-40 to +100
Polyethylene	PE	0.95	24	10^18	80	0	-100 to +80
FRNC	Similar to PE						-100 to +80
LSZH	TPE						-20 to +105
Polyvinylchlorid	PVC-U	1.4	50-75	10^13	unknown	small	-50 to+60

Table 5. Some other technical data for wave guide jackets

4.6 Applicable optical fiber (raw materials)

Following are type designations from Infineon documents

Type designation	Type	Fiber	Outer jacket			Manufacturer, (Supplier)	Part No.
			Diameter [mm]	Material	Color		
HCP-M0200T-A01ZS (LWL 2,2 200AH)	HCS	200/230	2.5	LSZH	Orange	AOS (OFS)	#C21050
HCP-M0200T-A01ZS For V-Pin connector	HCS	200/230	2.5	LSZH	Orange	AOS (OFS)	#C21058
I-V(ZN)H 1K200/230	PCF	200/230		FRNC	Orange	Leoni Fiber Optics	84P00100T
V-4Y 1K200/230 2,15 mm	PCF	200/230	2.15	Polyamid (PA)	Blue	Leoni Fiber Optics	84P02100T

Table 6. Applicable optical fiber

4.7 Optical fiber properties (raw materials)

The optical fiber to be used depends on application. See the following list for general optical fiber properties.

Fiber designation	Properties	Comment
HCP-M0200T-A01ZS (LWL 2.2 200 AH) (Orange)	Outer jacket LSZH (TPE-O), indoor, halogen-free, flame retardant, -20 to105°C, bending radius min 38mm (25mm unloaded), Zero moisture absorption, pull force max 489/245N, damping @850 nm <6dB/km, no resistance against oil, petrol, acid and leach, UV-resistant, ETFE Buffer CTI 600	Indoor use, pull force high, wide temperature range, no resistance against oil etc. Small damping Pd strength needs to be checked. Compatible with ST connector.
HCP-M0200T-A01ZS For V-Pin connector (Diameter: 2.2mm) (Orange)	Outer jacket LSZH (TPE-O), indoor, halogen-free, flame retardant, -20 to105°C, bending radius min 33mm (22mm unloaded), Zero moisture absorption, pull force max 111/22N, damping @850 nm <8dB/km, no resistance against oil, petrol, acid and leach, UV-resistant ETFE-Buffer CTI 600	Indoor use, pull force medium, wide temperature range, no resistance against oil etc. Pd strength needs to be checked. Compatible with V-Pin connector.
I-V(ZN)H 1K200/230 (Yellow)	Outer jacket FRNC (TPE-O), indoor, halogen-free (except buffer), flame retardant, -20 to70 °C, bending radius min 60mm (30mm unloaded), Zero moisture absorption, pull force max 300/100N, damping @850nm < 8dB/km, no resistance against oil, petrol, acid and leach, UV-resistant ETFE Buffer CTI 600	Indoor use, pull force high, small temperature range, no resistance against oil etc. Pd strength needs to be checked. Compatible with ST connector.
V-4Y 1K200/230 2.15 mm (Blue)	Outer jacket PA, halogen-free, flame retardant acc. UL94HB, -20 to70°C, bending radius min 50mm (30mm unloaded), moisture absorption, pull force max 30/10N, damping @850nm < 10dB/km good resistance to oil gasoline, acids and alkalis, UV-resistant CTI 600	Pull force low, Small temperature range, good resistance to oil gasoline, acids and alkalis, moisture absorption large damping, compatible with FSMA, ST, FC, V-Pin connector.

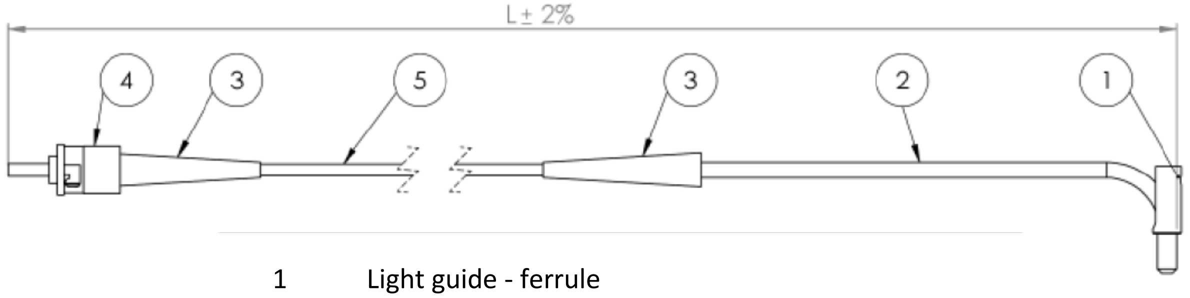
Table 7. Applicable optical fiber and their characteristics

4.7.1 Conclusion for choosing the right optical fiber

The optical fiber to be used depends on the application. The main criterion is the temperature range. For air cooled systems temperatures of higher than 100°C can occur so the HCP-M0200T-A01ZS cable needs to be used. For systems with harsh environment, the V-4Y 1K200/230 2.15 mm cable should be used because it offers good resistance to oil gasoline, acids and alkalis. However, its temperature range of -20 to 70°C needs to be considered (higher temperature capability e.g. 105°C available on request).

4.8 Overview for applicable optical fiber cable sets

Optical fiber sets are built from light guide (thyristor side), optical fiber and connector (optical coupler side or Laser Diode side).



1 Light guide - ferrule
2 Light guide - bended metal tube
3 Bend protection
4 ST connector
5 Optical fiber (PCF)

Figure 15. Optical fiber set

For LTT triggering, Infineon listed PCF or GOF sets should be used. The LTT qualification was mainly done with a 200µm optical fiber, a SPL-PL90 Laser diode with a ST connector housing (SPL PL90A) [14] [18] and a light guide for the LTT. The light guide is optimized for the Infineon LTTs. It needs to be very precise (very low mechanical tolerances) in order to obtain the best optical coupling perform which is achieved by accurately centering the optical fiber on the LTTs optical gate.

Figure 16. Plastic Cladded Fiber set (light guide, glass optical fiber (FRNC jacket) and metal ST connector)

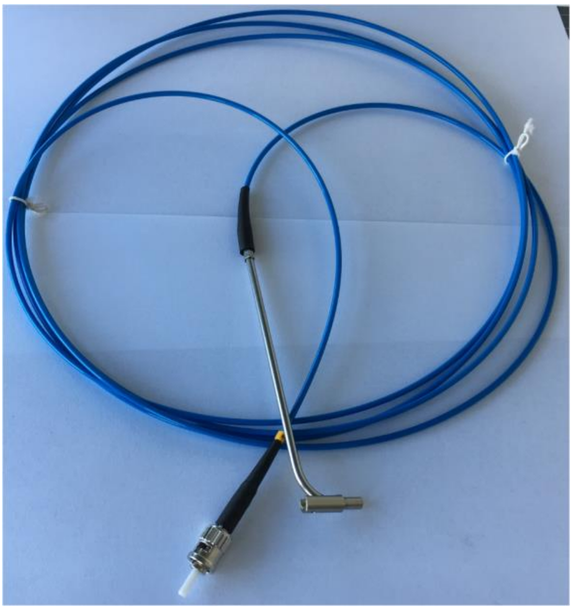


Figure 17. Plastic Cladded Fiber Set (light guide, glass optical fiber (PA jacket) and ceramics ST connector

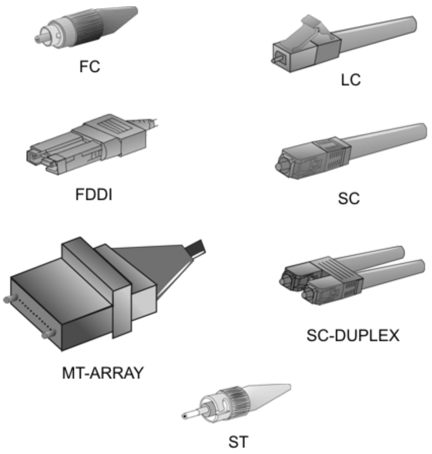


Figure 18. Well known optical connector

Figure 19. Ceramics ST connector

Figure 20. Ceramics FC connector

Figure 21. V-Pin Connector (Blue) from OFS for 200/230µm HCS

The V-Pin connector is compatible with Broadcom Versatile Link (HFBR).

4.9 Listed optical fiber sets

Type designation	Type	Length	Disc diameter	Optical Fiber	Connector	SAP, Remark
		[m]	[mm]	Type	Type *)	
LWL R10 LR50-L1400A	PCF	1.4	76	HCP-M0200T-A01ZS	ST	25945
LWL R10 LR50-L3000A	PCF	3	76	HCP-M0200T-A01ZS	ST	25078
LWL R10 LR50-L4200A	PCF	4.2	76	HCP-M0200T-A01ZS	ST	26661
LWL R10 LR50-L6000A	PCF	6	76	HCP-M0200T-A01ZS	ST	1107098
LWL R10 LR50-L15000A	PCF	15	76	HCP-M0200T-A01ZS	ST	27973
LWL R10 LR87-L3000	PCF	3	150-172	V-4Y 1K200/230 2.15mm	ST, ceramics	1105951
LWL R10 LR87-L3000A	PCF	3	150-172	HCP-M0200T-A01ZS	ST	25025
LWL R10 LR97-L3000	PCF	3	202	V-4Y 1K200/230 2.15mm	ST, ceramics	1104211

Table 8. Listed optical fibers sets

*) Variants of this optical fibers with the FC connector are available on request

5 Applicable optical transmitter

In general, Laser or LED diodes are applicable. LEDs are cheaper than Laser Diodes. LEDs may be applicable for short distances; whereas, Lasers are good choice for long distances and assures long term stability. The trigger circuit design and the required optical fiber depend on chosen optical transmitter.

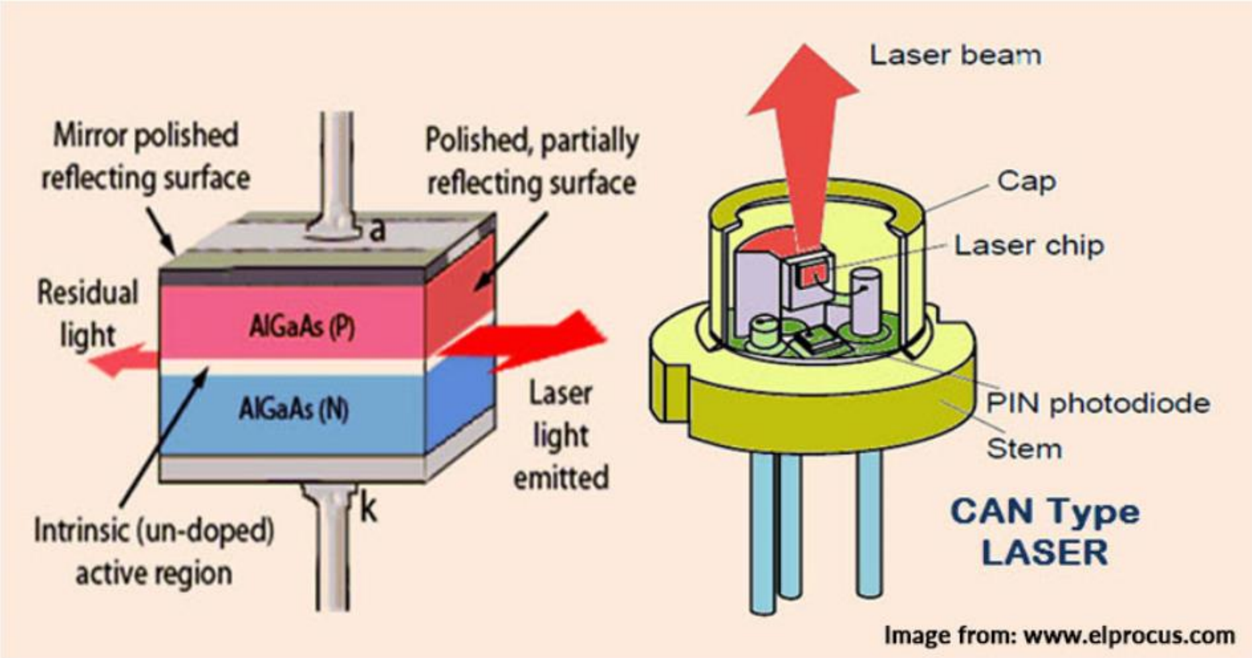


Figure 22. Laser Diode

5.1 Overview for applicable optical transmitter

The applicable laser class for each type of diode needs to be checked! The required safety measures needs to be applied.

The laser diodes SPL PL 90 comply with the following laser classes:

If the laser diode is correctly terminated with the fiber optic cable the control system complies with laser class 1. No operational hazard.

With open operation of the laser diode or in case of a broken fiber optic cable, the system equates to the laser class 3b according to IEC 60825–1. In this case hazard of operation exists due to invisible radiation. Direct or indirect exposure to the eyes or skin is to be avoided.

For triggering LTTs the diodes below listed can be used. The LTT qualification was mainly done with the SPL-PL90 Laser diode from OSRAM Opto Semiconductors [14]. It is a diode that is good for pulsed loads and was originally designed for telecommunications. The trigger characteristics of the LTT series have been adapted to the characteristics of existing laser diodes. As an example for a laser driver board the LFTD18 is equipped with this diode [16].

Type designation	Type	Load type	Wavelength	Mechanics	Figure	Remark
			[nm]			
SPL-PL90	Laser	Pulsed load (100ns), 25W	905	Radial T1 3/4, Core, 5.9mm diameter	Figure 23	In production
SPL-PL90A **) (SPL-PL90-ST)	Laser	Pulsed load (100ns), 25W	905	ST connector	Figure 24	In production
SPL-PL90_3 *)	Laser	Pulsed load (100ns), 75W	905	Radial T1 3/4, Core, 5.9mm diameter	Figure 23	
SPL-PL90-3-ST **)	Laser	Pulsed load (100ns), 75W	905	ST connector	Figure 24	In production
WSLR-808-180m-M-PD *****)	Laser	Continuous load, 0.18W	808	ST connector	Figure 26	In production
SPL-2F94	Laser	Continuous load, 1.5W	940	TO220+FC connector		Withdrawn
SPL-2F81-2S	Laser	Continuous load, 1.5W	808	TO220+FC connector		Withdrawn
LU1064T100 ****)	Laser	Continuous load, 10W	1064	Fiber Ferrule	Figure 28	In production
SMB1N-760D-02 ***)	LED	Continuous load	760	SMD, PA9T	Figure 27	In production

Table 9. Applicable optical transmitter

*) The SPL-PL90_3 contains three chips in series. The forward voltage drop is about three times higher than a single SPL-PL90.
**) The SPL-PL90A and SPL-PL-3-ST coming with a light power test certificate.
***) The SMB1N-760D-02 is a surface mount AlGaAs High Power LED with a typical peak wavelength of 760nm and a radiation of 400mW. It comes in a SMD package (PA9T) with silver plated soldering, a copper heat sink, and is molded in silicone resin.
****) The LU1064T100 [25] is a good choice for a high number of LTTs which needs to be triggered synchronously by use of optical splitters (see chapter 0)
*****) The WSLR-808-180m-M-PD is a good choice for triggering W1C circuits with pulse trains.

Figure 23. SPL-PL90, SPL-PL90_3 Laser diode (pulsed load)

Figure 24. SPL-PL90A Laser diode (SPL-PL90 with housing and ST connector)

advanced optics solutions

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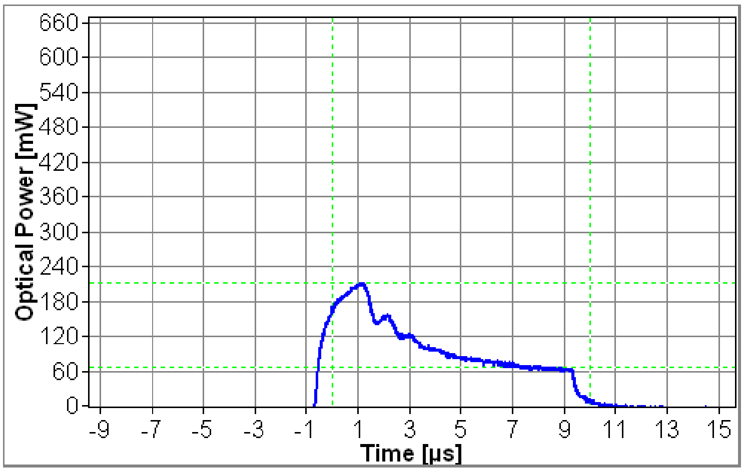
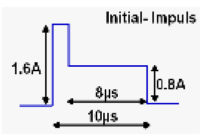
WWW: www.aos-fiber.com

Report LTT Cable

Report-No.:	KS1504190004	Date:	15.04.2019
PO-No.:	0100252474	Time:	10:21:07
Operator.:	Jacobi	Cable-No.:	Ref.
Customer.:	388/2847	Type:	R10 LR50 L6000
Batch-No.:	M1902202	Connector:	ST



	Responsivity [A/W]:		0.00350	
	Pulse Width [µs]:	10	Level [mA]	0.7
	Power [mW]:	213	Pulse energy [nWs]	957

Notes:	Measured @905nm Cable length= 6m Loss<-0.0dB resp. <0.0%
Sign:	

Figure 25. Test certificate for SPL-PL90A

Figure 26. WSLR-808-180m—M-PD Laser diode (ST connector, continuous load)

Figure 27. SMB1N-760D-02 Red High Power LED, 760nm, 400mW

Figure 28. LU1064T100 Industrial Laser Diode, 940nm, 10W [25]

5.2 Behavior of the optical transmitter

Using the SPL PL 90 diode, it will be shown which currents the laser diode should be operated at to ensure that the thyristor switches on safely. The behavior of other optical transmitter must be investigated during qualification.

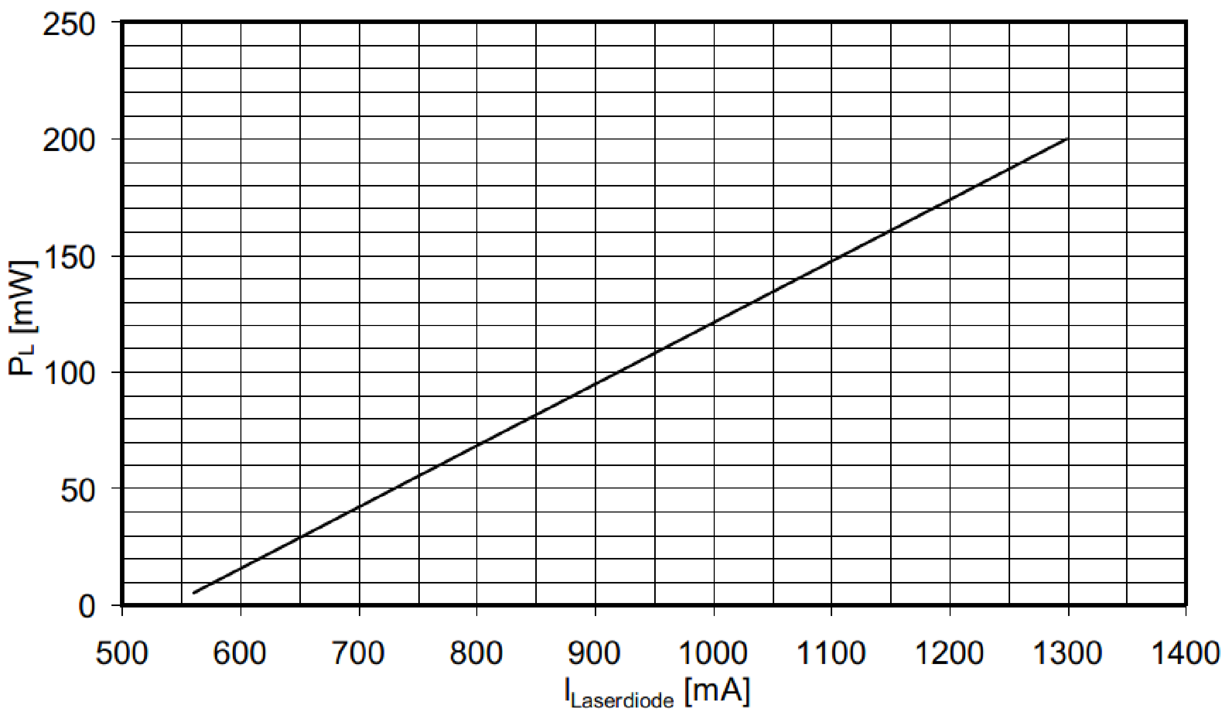


Figure 29. SPL PL90 Laser Diode typical dependency of light power and control current

From Figure 29 it can be seen that the typical emitted light power for a 0.8A diode current is about 70mW. This is a typical value which is required due to aging and degradation effects. See chapter 6 for details about useful life.

Also, the emitted light power depends strongly on the optical transmitter temperature. The behavior of laser diode SPL-PL90 is shown in Figure 30. The chosen trigger technology needs to be checked during the trigger circuit qualification. Each connector adds some attenuation. The optical waveguide should have as few connection points as possible.

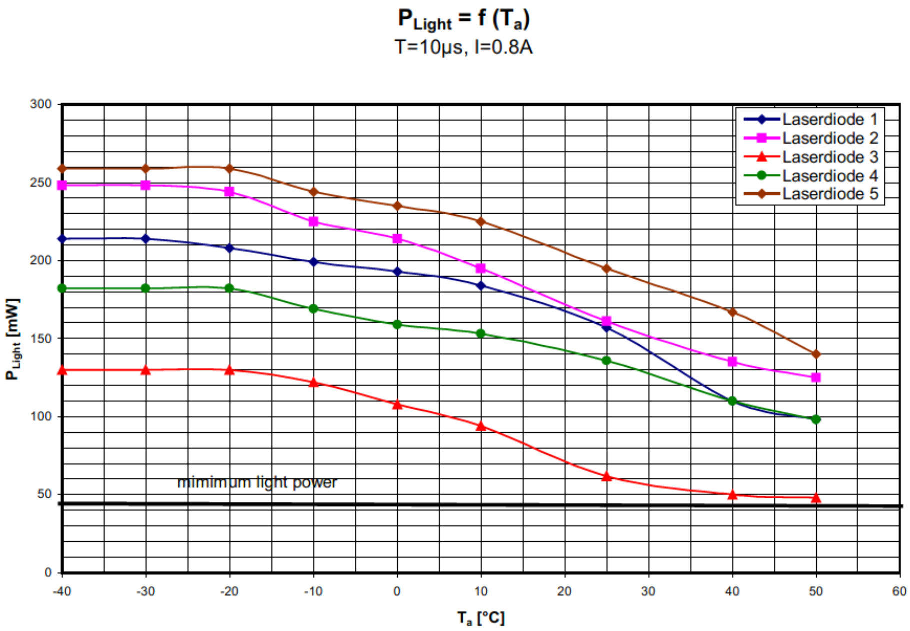


Figure 30. Emitted light power vs. ambient temperature for SPL-PL90

Under worst case conditions (50°C ambient temperature on the PCBA with the LFTD18 and a laser diode SPL-PL90 at its lower tolerance limit) the emitted light power may be about 50mW only. The selection of laser diodes in accordance to Figure 30 is recommended and often required (e.g. for series or parallel operated thyristors and high di/dt applications).

All SPL-PL90A Laser Diodes from Infineon are shipped with a test report. With this, correct selection is possible.

6 The optical transmitter

6.1 Driving the optical transmitter

For critical applications like series or parallel connected LTTs or applications with high di/dt, the dynamic behavior of the emitted light power is critical. Similar to ETTs, LTTs turn-on with a strong trigger pulse is required [5].
Figure 31 and **Error! Reference source not found.** shows the dynamical behavior of the emitted light power for some typical trigger pulses.

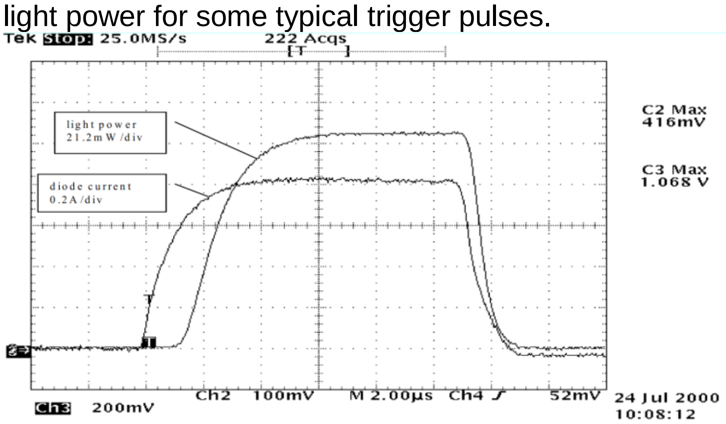


Figure 31. Dynamical behavior of emitted light power by triggering with 0.8A

For all application, it must be checked whether a delay time of about 2 µs can be tolerated (for this example). Especially for thyristors connected in series, synchronous turn on of all thyristors is required. With a stronger light trigger pulse the delay time can be reduced.

To control light-triggered thyristors, we recommend a current pulse for the SPL PL90 Laser diode as shown in Figure 32. Depending on application continuous triggering may be required. In that case we recommend controlling the laser diode with a pulse train of approximately 6 kHz. The resulting operating temperature of the laser diode needs to be checked. Alternatively the WSLR-808-180m-M-PD Laser diode [15] can be applied.

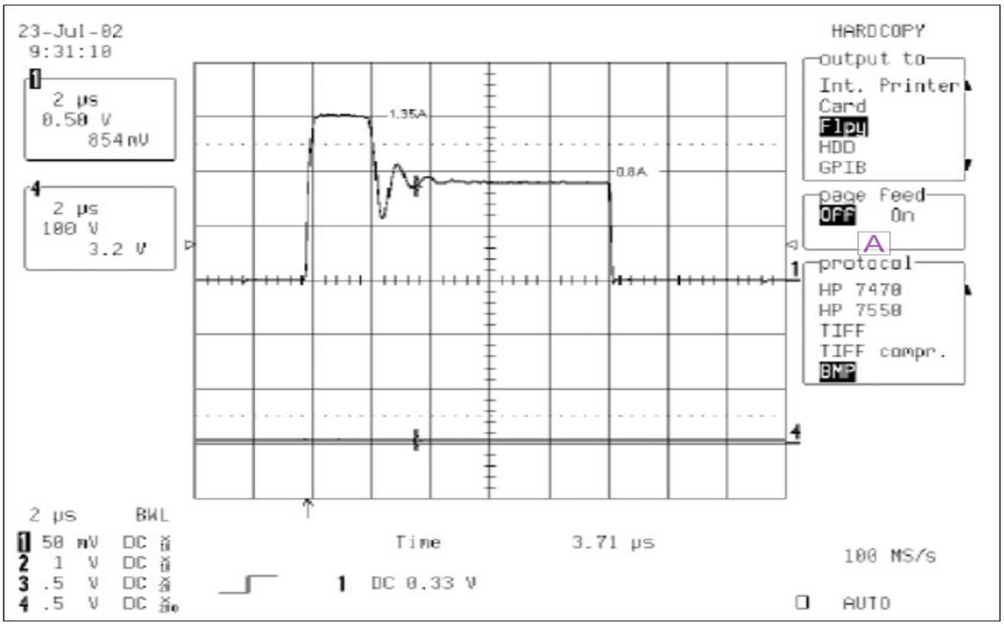


Figure 32. Recommended current pulse for SPL PL90 Laser diode

If the anode current rise time is not known, repetitive optical triggering during the planned conduction time is necessary (e.g. 180° conduction time for a W3C circuit). It can be realized by a 6 kHz pulse train which will refresh the internal gate current. If the thyristors turns off after initial triggering, the triggering conditions needs to be fulfilled again (minimum anode cathode voltage, latching current etc.). This requirement can still be realized with the SPL-PL90 Laser diode.

In certain applications, turning on the thyristors with a turn-on pulse of 10 µs will not ensure a safe triggering. For example, if the latching current is not reached during the pulse or the thyristor current drops below the holding current. To ensure the correct operation of LTTs in these applications, tests were carried out with an extended trigger pulse.
This extended light pulse leads to increased aging of the diode. To reduce losses and increase service life, the continuous current of the trigger pulse was lowered to 700mA. By preselecting the laser diodes, one can ensure that the thyristor still switches on safely despite the lower current. With lower trigger energy, the turn-on time of the thyristor increases.
The use of a church tower pulse (current increased in the laser diode in the first 2 µs to 1.35A) ensures a quick turn-on, while the subsequent "roof" of 0.7A keeps the thyristor in the conductive state. The trigger pulse was increased from 10µs to approximately 110µs (see Figure 33).

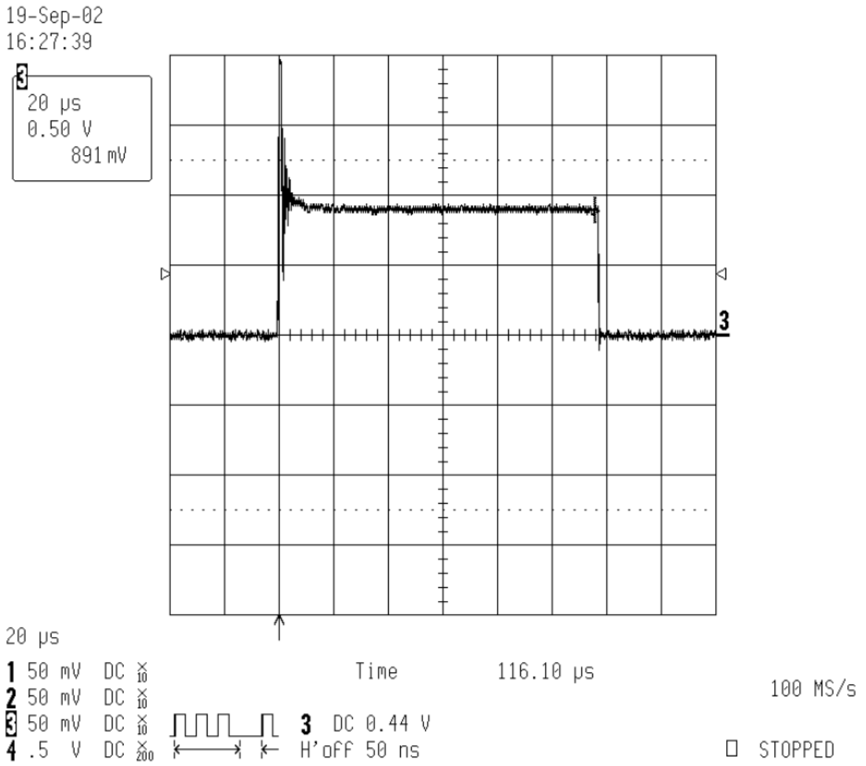


Figure 33. Extended current pulse through the laser diode (1,35A/0,7A-110µs)

With this extended trigger pulse, continuous operation with the SPL-PL90 is not possible. The losses are too high which means the operating temperature of the laser diode will be too high. For this kind of triggering a Laser diode like WSLR-808-180m-M-PD [15] can be used. It is a diode for continuous operation with less losses.

See section 6.2.4 for information on the useful life of a laser diode.

6.2 Useful life

6.2.1 Degradation

The diode's intrinsic reliability time describes the wear out period of the component at the end of the product cycle. It is based on increased aging of the material. This continuous change over time is generally measurable and is referred to as degradation. For LEDs, the most significant degradation parameters are the changes in brightness or wavelength. Other parameters such as forward voltage drop generally play a lesser role. During operation, LEDs experience a gradual decrease in luminous flux which is measured in Lumens. As a rule, this is accelerated by increasing the operating current and temperature of the LED even it is driven within specifications. The term "Lumen maintenance" (L) is used in connection with the degradation of light in LEDs. This describes the remaining luminous flux over time with respect to the original luminous flux of the LED. Due to continuous degradation, a failure criterion must be established in order to obtain a correct evaluation of the LED failure. The point in time at which the luminous flux of the LED reaches the failure criterion is then described as the failure time or lifetime of the LED. As a rule, the failure criterion is determined by the application. Typical values are 50% (L50) or 70% (L70) which depend on the relative light output versus time curve shown in Figure 34, [4].

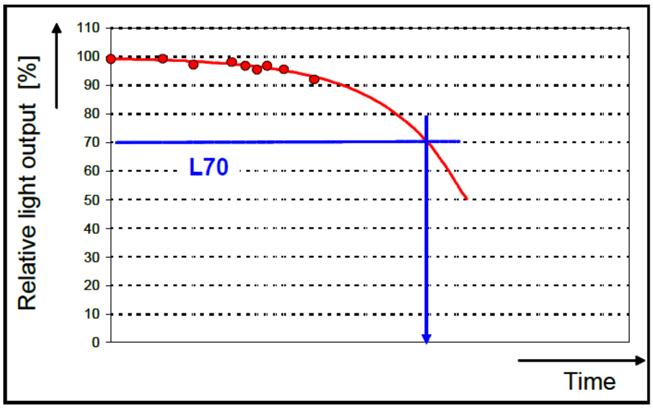


Figure 34. Degradation curve

6.2.2 Statistical wear out

This is not in scope of this application note and needs to be covered separately.

6.2.3 Evaluation of useful life for a real application

Following is an example for estimating the useful life of the SPL-PL90 laser diode in a W1C or W3C circuit.
The load current depends on the application load situation. The load current can be very high and it can also be very low. Therefore, the application requires pulse train during the conduction period e.g. 10ms [5].
The pulse pattern is as recommended in chapter 6.1 which is 1.35A / 0.8A, 10µs, 6kHz.

6.2.4 Estimated useful life for the laser diode

The degradation depends on the operation temperature. The operation temperature depends on diode current. Design margin was added to the diode current to account for degradation and to cover tolerances (see 5.2 and 6.2.4.1). Please find more details in [24].
(The coupling losses between laser diode, optical fiber and trigger window of the LTT needs to be take also into account).

6.2.4.1 Defining the nominal laser diode current for proper LTT triggering

With:
LTT's minimum optical trigger power: 40mW (acc. to thyristor datasheet)
Tolerances in light power +-50% @ 50°C (according to chapter 5.2Figure 30)
Max degradation planned -> L70 (70% of nom optical power)

Expected emitted light power of the laser diode to cover tolerances and degradation = 40mW*1.5/0.7 = 85.7 mW.
That leads to an operational diode current of about 0.875 A (read from Figure 29).
The value is similar to the recommended trigger pulse (1.35A/0.8A).

6.2.4.2 The power losses for the SPL PL90 Laser diode for the recommended trigger pulse are:

Estimation

Time [µs]	I_F diode [A]	V_F [V]	P_Losses [W]	P_loss_avg [W]	Comment
2	1.35	ca. 1.75	2.363	0.0283	Active, peak current
8	0.8	ca. 1.5	1.2	0.0575	Active, roof current
157	0	0	0	0	Passive, no current
167µs				0.0858	Avarage power losses

(6kHz)					

The LFTD18 is specified with T_op = 0 to 70°C [16]
The laser diode is specified with T_op = -40 to 85°C [14]
R_th_ja of SPL-PL90 = 160 K/W [14]

The temperature rise for the SPL PL 90 laser diode for this load is about:
Delta T_ja_laser_diode = R_th_ja * P_loss_avg
160 K/W * 0.0858 W
13.7 K

Theta j diode = 70 °C + 13.7 K (Assumption T_a = T_op_max_LFTD18 = 70°C)
= 83.7 °C

The temperature increase due to this standard pulse train is ok; therefore, diode will be operated within the specified data.

6.2.4.3 The power losses for the SPL PL90 laser diode for the extended trigger pulse are:

Estimation

Time [µs]	I_F diode [A]	V_F [V]	P_Losses [W]	P_loss_avg [W]	Comment
2	1.35	ca. 1.75	2.363	0.0283	Active, peak current
110	0.7	Ca. 1.5	1.05	0.69	Active, roof current
55	0	0	0	0	Passive, no current
167µs (6kHz)				0.72	Avarage power losses

Selection of the Laser diodes is required
The temperature rise for the SPL PL 90 Laser diode is:

Delta T_ja_diode = R_th_ja * P_loss_avg
160 K/W * 0.72 W
115.2 K

Theta j diode = 70 °C + 115.2 K (Assumption T_a = T_op_max_LFTD18 = 70°C)
= 175.2 °C

The temperature increase due to this extended pulse during continuous operation is too much. Only single pulses are allowed e.g. to drive a pulsed power application [19].
For this requirement the SPL-2F81-2S Laser Diode may work. The heat sink mountable diode is designed for continuous load [15].

6.2.4.4 Estimated useful life for the laser diode

Life time B50/L70 may be 60.000h @ 85°C T_op (see Figure 35) [4].

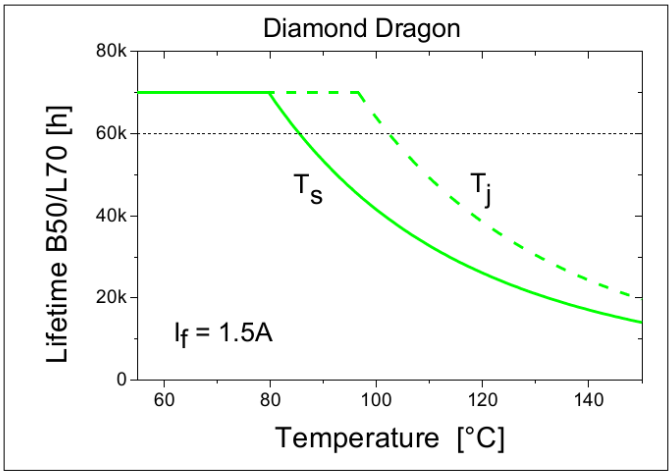


Figure 35. Dependence of lifetime on the junction temperature and solder point temperature for OSRAM Opto Semiconductors's Diamond Dragon product line

The operating temperature for the optical transmitter for the recommended trigger pulse is below 85°C according to 6.2.4.2
The estimated useful life is probably better than 60.000h. That is about 7 years of life when operating 24 hours per day and about 20 years of life when operating 8 hours per day. For more lifetime, the WSLR-808-180m-M-PD diode may be used [24].

6.3 Laser Driver, Optical Coupler and Optical Splitter units

Depending on the application and on the requirement for redundancy, individual or common triggering of the thyristors may be meaningful. Common triggering via optical couplers is useful for series and parallel operated thyristors. An optical coupler allows multiple paralleled optical input signals. If one fails the system can work with the remaining ones. Additionally, the optical coupler can offer a feedback output for the control unit. With a monitoring board for each individual thyristor the functional status for each individual thyristor can be observed. It can identify thyristors that are not switching or are shorted (see chapter 6.3.2.)

6.3.1 Laser Driver units

M&P, Dresden offers a wide range of laser triggering units for LTT's.
The module generates laser light impulses for the control of light triggered thyristors. Applying a signal to the input generates a series of trigger impulses at the power outputs. The current flowing through the laser diode is controlled by the power supply. A failure in the current control circuit or the laser diode activates the error signal of the driver.
Supply voltage for the control unit and driver circuits are provided by an internal switch mode power supply.
Up to 18 Laser diodes capable of controlling 18 thyristors can be triggered simultaneously.
The mother board contains 3 power transistors for driving the laser diodes and the receiving unit. Each power transistor has its own current control and all are triggered simultaneously. Laser diode modules plugged into the mother board contain the Laser diodes. Each diode module contains a maximum of 6 Laser diodes. Each diode module is controlled by a separate power transistor. Control errors (e.g. current value to small or to large) are displayed and memorized.
For the fiber optic input, the HFBRx528 coupler type are used (transmitter: HFBR1528, receiver: HFBR2528). Minimum required pulse width is 20µs. To control the module via these fiber optics, the specifications and recommendations of Broadcom must be followed.
The driver LFTD18P-LRM generates an output pulse packet with the time length of the input signal. Its repetition rate for 10µs wide impulses is 6 kHz ± 5 %. If the width of the input pulse is less than 0.167 ms (1 / 6 kHz) a single impulse is generated. [16].

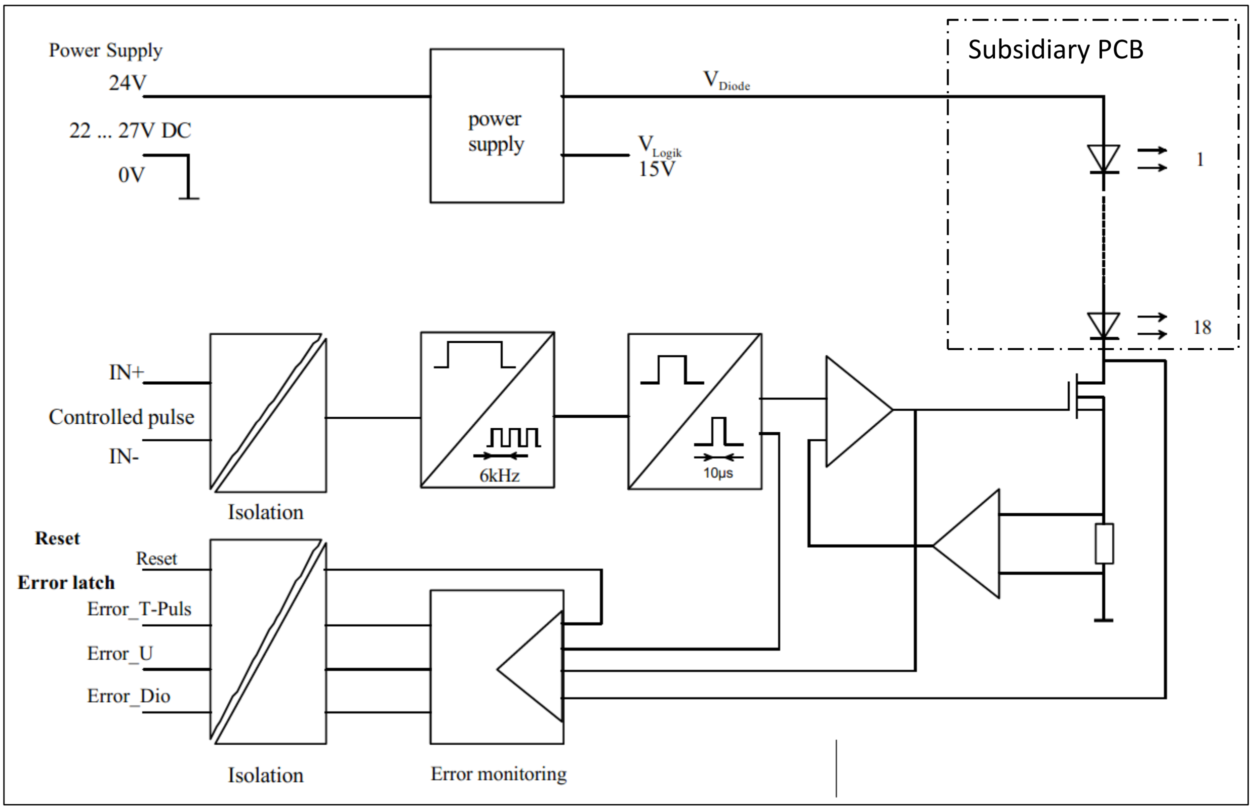
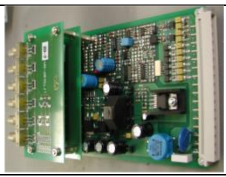
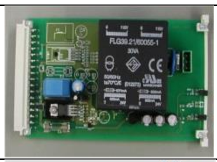
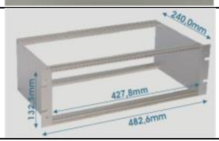


Figure 36. Block diagram of the LFTD18P laser driver unit

Building blocks	Width [TE]	Remark	Picture
LFTD18P-xxxx/6	8	1 channel, with 6 SPL-PL90A Laser Diodes	
LFTD18P-xxxx/12	12	1 channel with 12 SPL-PL90A Laser Diodes	
LFTD18P-xxxx/18	16	1 channel with 18 SPL-PL90A Laser Diodes	
Power Supply	16	Input voltage 24 V DC, 48 V DC, 230V AC etc.	
Rack 3HE, 84TE	84		

Lab Housing 3HE, 32TE	32	For 1 LFTD18P + Power Supply	
Lab Housing 3HE, 40TE	40	For 2 LFTD18P + Power Supply	

Table 10. LFTD18P Laser Driver concept

6.3.2 Thyristor voltage monitoring

With a voltage monitoring board for each individual thyristor the functionality of a system with series connected SCR’s can be observed (optional). It can identify thyristors that are not switching or shorted. The product is still under development at M&P in Dresden, Germany.

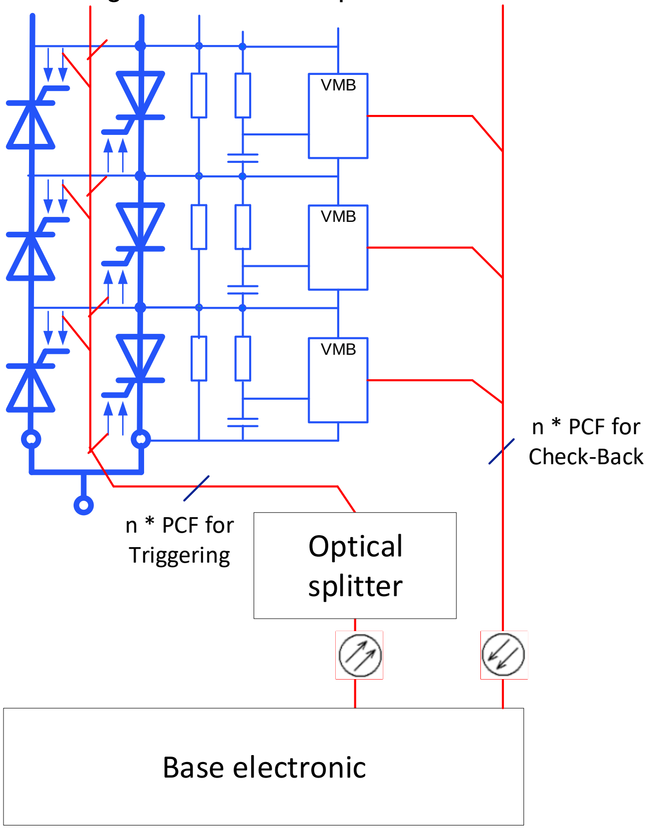


Figure 37. Power stage with series connected thyristors and voltage monitoring boards

6.3.3 Optical coupler and optical splitter

For redundancy and increased reliability it may be helpful to drive a couple of series connected thyristors from one trigger source. For that Leoni Optical Systems offers a wide range of optical components [22].

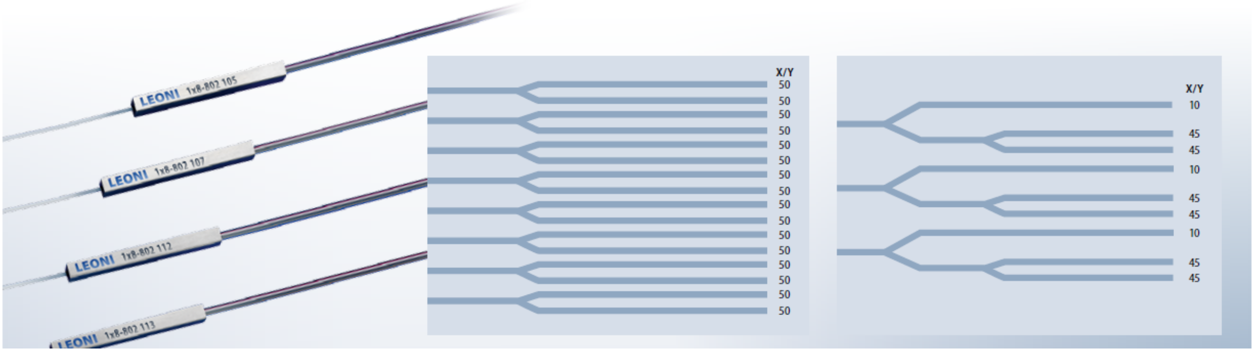


Figure 38. Optical splitter components

Figure 39. Optical splitter units with PCF fiber, 19" rack and ST connectors

7 Conclusion

Using LTTs is very common for medium and high voltage applications. The behavior of optical components needs to be taken into account during the system design.

Aging and maintenance:
The Laser Diodes are subject to aging. Depending on the design, the transmission power of the laser diodes should be checked according to a maintenance plan (depends on operation mode).

Clearance, Creepage and Partial Discharge:
The fiber optic cabling needs to be done correctly or clearance, creepage and partial discharge failures can occur. Light triggered thyristors are usually used for medium and high voltage applications. The optical fibers must not bridge clearance and creepage distances. If applicable, this is also valid for the cooling water distribution, which should be done with suitable materials for medium voltage applications.

Redundancy and Snubber Circuits:
Due to the robust functional design and the short on failure behavior of the LTTs, redundancy for a system is easy to implement. But the detailed design needs to be done from a complete system overview. For example if one series connected LTT is not triggered due to a missing or weak Laser signal, the LTT will turn on via BOD triggering. In that case, the snubber Circuit of that LTT carries a higher load because the thyristor discharges the snubber capacitor from the BOD voltage level. The snubber circuit needs to be designed accordingly. Furthermore it could be helpful getting information about this malfunction via a thyristor voltage monitoring board (see chapter 6.3.2).

8 Table directory

9 Pictures directory

10 Supplier

10.1 Fiber Optic System

AOS, Dresden, Germany
Leoni Fiber Optics, 96524 Neuhaus-Schierschnitz, Germany

10.2 Laser Diodes

OSRAM Opto Semiconductors GMBH, Regensburg, Germany
Lumics GmbH, Berlin, Germany

10.3 Laser Driver

M&P GmbH, Dresden, Germany

11 Brands

Osram, Siemens, Agilent, Leoni Fiber Optics, OFS, AOS, Lumics, FO-Systems GmbH

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14 Sources

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[2] Datasheet for SPL PL90-ST from AOS

[3] Brauchbarkeitsdaueruntersuchungen from M&P GmbH, Dresden, Germany for Infineon.

[4] Application Note AN006, Reliability and Lifetime of LEDs from OSRAM Opto Semiconductors GMBH

[5] Application Note for triggering ETT‘s (AN2018-08) from Infineon Bipolar Technologies GmbH & Co. KG

[6] SWITCHING DIRECT LIGHT TRIGGERED THYRISTORS WITH POLYMER OPTICAL FIBERS from TU Nuremberg, Infineon Bipolar Technologies

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[8] Wikipedia

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[10] Datasheet for optical fiber from FO-Systems GmbH

[11] Standard IEC 60664-1 Insulation coordination

[12] Standard IEC 60664-4 Partial discharge

[13] Standard IEC 60071-2 Insulation coordination – Application guide

[14] Datasheet for SPL-PL90 from OSRAM Opto Semiconductors GMBH

[15] Datasheet for WSLR-808-180m-M-PD from WAVE spectrum

[16] Technical Description Driver for light triggered thyristors LFTD18P –LRM/xx from M&P GmbH, Dresden

[17] ONE major project – ONE cable solution from Leoni GmbH

[18] Datasheet for SPL-PL90A from Infineon

[19] Life time investigation for extended trigger pulse for a pulsed power application from M&P GmbH, Dresden

[20] Application Note, Operating the SPL PLxx Pulsed Laser Diode from OSRAM Opto Semiconductors GMBH

[21] High-voltage Thyristors for HVDC and Other Applications: Light-triggering Combined with Self-protection Functions from Infineon AG, Siemens AG, eupec GmbH & Co.KG

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