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Laser Safety in the CMS Tracker Optical Links

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Abstract

Laser safety issues are addressed for the CMS Tracker analogue and digital optical link systems. These systems operate with low-power 1310nm light that is normally confined to optical fibre channels. The system and its components are classified according to the International Electrotechnical Commission (IEC) Laser Safety guidelines, for periods of test and development, assembly and installation, as well as for final operation and subsequent maintenance. Recommendations for labelling, access requirements, safe-working practices and eye protection are also derived from the IEC standards. The general issue of laser safety training is also addressed.

The contents of this document will be reviewed if there are any changes in the Standards or system specifications. The most up-to-date information will be available at http://edms.cern.ch/document/338505/1.

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1. Introduction

1.1 System

Approximately 40000 uni-directional analogue optical links, and ~2500 bi-directional[1] digital optical links will be used to readout and control the CMS Tracker[1]. The basic elements of the optical link system are illustrated in Fig. 1 and the architecture of the (analogue) system is outlined in Fig. 2.

Both analogue and digital optical links for the CMS Tracker share the same basic components, namely 1310nm edge-emitting lasers coupled to p-i-n photodiodes via single-mode optical fibre. To enable installation and facilitate testing there are three break-points in the optical links at three patch-panels: the distributed patch-panel, located at, or close to, the detector modules inside the Tracker, the in-line patch-panel in the HCAL crack, and the back-end patch-panel at the FED (or FEC) crates in the counting room.

The optical fibre is in the form of buffered single-way fibre inside the Tracker volume, between the laser (or photodiode) and the distributed patch-panel, ruggedized 12-way ribbon between the distributed and in-line patch-panels, and then dense 96-way multi-ribbon cable from the in-line patch-panels to the FED (or FEC) patch panels. The single-way fibre connections at the distributed patch-panel will be MU to SMU, and the fibre-ribbon connections will use 12-way MFS connectors in the in-line patch-panel and 12-way MPO connectors in the back-end patch-panel.

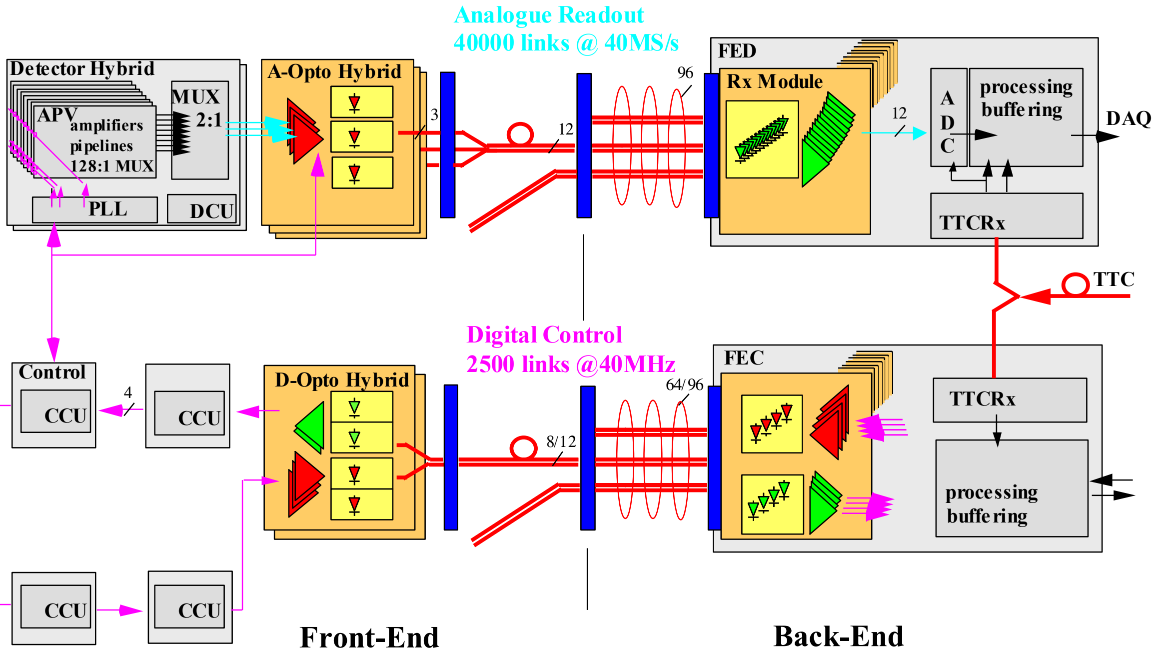

Fig. 1: Schematic outline of analogue and digital optical link systems for the CMS Tracker.

In this document the analogue link is considered in greater detail than the digital link since some elements of the digital link, such as the FEC optical interface, still remain to be defined. However, it is expected that the hazard levels and necessary working practices and precautions with respect to laser safety will be the same for both analogue and digital link systems, since they share many common components.

[1] Although the digital links are considered bi-directional, there will be only a one-way transmission of light in any given fibre and separate fibre channels carry the signals to and from the Tracker.

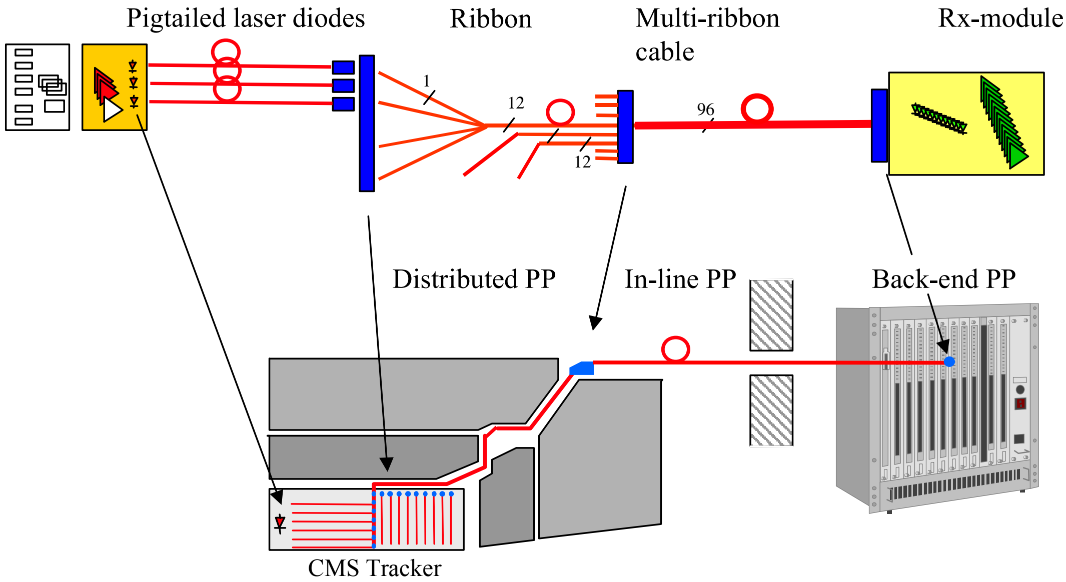

Figure 2: Schematic optical link architecture. Only the analogue read-out system is shown here.

1.2 Preamble

The information provided in this document focuses on safety requirements relating *only to the CMS Tracker optical link systems operating at 1310nm wavelength.* The contents therefore cannot necessarily be directly applied to other optical links, or laser systems, within CMS or elsewhere. Every group involved in using lasers, optical links, or other potentially hazardous optoelectronic equipment must address individually the specific concerns related to laser safety in their particular systems.

The laser safety requirements and recommendations in this document are derived from the current IEC standards 60825-1[2] and 60825-2[3] concerning safety of laser products and safety of optical fibre communication systems respectively. These standards are continuously reviewed and 60825-1 is in the process of being updated[4]. The use of the latest complete version[2] of 60825-1 is considered acceptable at least until the recent changes have been fully included[5]. The safety standard for optical fibre systems, 60825-2, remains valid until 2003, when it will be either updated or withdrawn.

Unfortunately there is currently some degree of confusion with regard to the safety classification of fibre optic systems such as the CMS Tracker Optical links. If the current standards in Refs. [2] and [3] are used, as in this document, then the system contains elements that have a hazard level greater than Class 1, generating some specific requirements. However, in future, when the proposed revisions of 60825-1 in Ref. [4] have been fully consolidated, all of the components in the CMS Tracker optical link systems will be Class 1, or Hazard Level 1. This change of hazard classification is due to a significant relaxation of the various factors involved in the calculation of the accessible exposure limits (AEL), particularly effective at the wavelength of 1310nm.

We have had extensive discussions with the CERN/TIS/RP Laser Safety Officer, regarding the Tracker optical links systems, and on how to interpret the CERN Rules document IS-22. It is recognized that the CERN rules require complete overhaul, as they have not followed the evolution of the IEC standards and are inappropriate for assessments of large and distributed fibre-based communication systems such as those in the CMS Tracker. The laser safety issues presented here for the Tracker optical link systems have therefore been examined separately by TIS/RP and accepted on the condition that they are kept fully informed of the implementation of laser safety practices within the project.

Given the envisaged changes in both the IEC Standards and the CERN Rules, the present document therefore only serves as a temporary measure, drawing attention to laser safety issues and satisfying the requirement to inform all people working with the Tracker optical links of the hazard classifications and subsequent recommendations under the current safety Standards.

The laser safety issues in the CMS Tracker Optical links will be periodically reviewed and modified as required. The latest version of the document will be available at: http://edms.cern.ch/document/338505/1

The subsequent layout of this document is as follows: in Section 2, the hazard classification is determined for the components and for the full optical link system. The specific safety requirements that arise from this hazard classification are then outlined in Section 3. These include the necessary warning signs and labels, the need for limited access to the locations in the final system and in development labs where component classification exceeds Hazard Level 1. The requirements for training and eye-protection are also presented.

2. Hazard classification

Laser safety is usually categorized in terms of a hazard level classification, related to the potential of the laser source to cause harm. The hazard level is determined by the optical power level that is potentially accessible, under all reasonably foreseeable circumstances. The classification is strongly dependent upon the wavelength of the radiation and various other factors such as the nature of the radiation source, i.e. its size, whether it is collimated or divergent, as well as the time-dependence of the radiation. It should be emphasized that the potential damage to the eye or skin tissue varies enormously depending upon these factors. In addition, the classification is also affected by the potential exposure times and the type of tissue exposed.

The different hazard classes are listed below. Each is limited according to an accessible emission limit (AEL). For eye-safe lasers the AEL is related directly to the maximum permissible exposure (MPE), which is the threshold for permanent eye or skin tissue damage. For more powerful lasers or systems, the AEL is related to the potential to cause eye or tissue damage by reflection of the radiation, and to the potential of the source to cause a fire.

Class 1 is considered as safe to use without restrictions.

Class 2 is related to visible wavelengths where 'blink-aversion' protects the user from significant danger.

Class 3A refers to laser sources that are naked-eye safe, i.e. safe provided that optical instruments are not used. In the case where optical instruments are used then the total accessible power is limited to at most five times the MPE. This classification is particularly relevant for sources having divergent beams.

Class 3B and **Class 4** are for components and systems that can expose users to radiation well above the thresholds for physical injury. The main difference is that Class 3B lasers will cause retinal damage through direct intrabeam exposure, or specular reflections, whereas Class 4 can cause retinal damage even through diffuse reflections and may also present a fire hazard.

Hazard Levels 1, 2, 3A, kx3A, 3B and 4 are the corresponding classifications for *fibre-optic systems*, as opposed to laser or LED sources. This different nomenclature reflects the fact that the laser source may be far distant from an accessible element of the fibre-optic system where there may exist a potential risk. For fibre-optic systems used in Controlled or Restricted areas, there is also a special classification, kx3A, that has greater accessible optical power than Hazard Level 3A but does not present a significantly greater risk to *trained workers* to require the usual classification as Hazard Level 3B.[2]

The hazard classification of a laser, LED, or fibre-optic system system, is made by, first of all, calculating the accessible power that passes through an aperture placed a certain distance from the light source, fibre-end or connector face. The diameter of the aperture and its distance from the source are also given in the standards and there is a nominal exposure time used in the calculation. For the CMS Tracker optical link systems operating at 1310nm, the apertures are 7mm, representing a fully dilated eye-pupil, or 50mm, representing an optical instrument. The distance of the aperture is typically 100mm from the source, though this can vary depending upon the source size, representing the human ability to focus on an object at the given distance. The choice of aperture in the calculation depends upon whether the AEL is expressed in terms of radiant power (units of joules) or as radiant intensity, or irradiance (units of joules/square-metre). The exposure time used in

[2] In hazard level kx3A 'k' is not a calculable constant.

the calculation for AEL for the CMS Tracker system is 100s.

For the calculation of the apparent size of the source, the angular subtense α is determined for a distance of 100mm and the value is then limited (by truncation) to the range $\alpha_{min}<\alpha<\alpha_{max}$, where α_{min}=11mrad and α_{max}=100mrad. The lower limit is fixed by the exposure times used in the calculation, in our case 100s. A relaxation factor of α/α_{max} is then applied in the AEL calculation to increase the AEL in proportion to the increase in size of the source.

The hazard classification is now presented for the components used in the CMS Tracker optical link systems.

2.1. Lasers and optohybrids

2.1.1. Lasers

The 1310nm lasers that will be mounted inside the Tracker, as delivered in a package pigtailed with single-mode fibre, are individually Class 3A, since they are capable of a relatively large optical power output when driven with a sufficiently strong current source (I>150mA). The lasers are therefore eye-safe for I<150mA and if I>150mA, they are eye-safe as long as optical instruments are not used to view the light source.

2.1.2. Optohybrids

On the CMS Tracker optohybrids the maximum laser current, including modulation amplitude in both analogue and digital link systems, and even in case of laser driver failure, is limited to around 65mA. The power emitted from a given fibre can therefore be no more than 3.25mW, based upon the maximum specified laser efficiency of 50µW/mA. The optohybrid is therefore Hazard Level 1 since the Class 1 AEL for emission from a single-mode fibre at 1310nm wavelength is 9.2mW. The calculation of this AEL is given in Appendix A.1. The lasers, when assembled onto the optohybrid, also become Class 1 components due to the limitation of the laser driver current.

2.2. Passive elements: Optical fibres, fibre-cables and connectors

All completely connected optical links could, according to 60825-1, be denoted as Class 1, from the point of view of users, since the optical power is completely contained in the fibre channels. However, according to 60825-2, the hazard classification must also take into account the potential exposure to laser radiation that can occur if a connection is opened, or if a fibre is broken, whilst the system is energized. This is most likely to occur during development, installation and later maintenance of the system.

Within the CMS Tracker optical links there are three patch-panels where laser radiation is potentially accessible to users[3]. Firstly there is the distributed patch-panel, mounted inside the Tracker, housing single-way connections with MU-type termination. Secondly there is the in-line patch-panel in the HCAL crack, where 12-way MFS fibre-ribbon connectors will be used. Finally there is the back-end (FED) patch panel that will use 12-way MPO fibre-ribbon connectors. In addition to the patch-panels there is always some chance that an energized single fibre, 12-way fibre ribbon, or 96-way multi-ribbon cable could be broken, thus exposing personnel to laser radiation. These conditions are considered now in greater detail.

Note that we are considering only the connector interfaces in the analogue optical link system since the digital link interfaces at the FEC are still to be fully defined. It is very unlikely that greater hazard levels will exist in the digital link system, so the information given here should be sufficient to cover both systems.

2.2.1 MU-connectors at the distributed patch-panels

In the case of opening a single-way MU-connection whilst the attached laser is being driven at the maximum current of 65mA, the maximum optical power emitted from the open fibre is ~3.25mW. As for the preceding example of the laser diode on the optohybrid (Sect. 2.1) this is within the Hazard Level 1 AEL of 9.2mW at 1310nm.

2.2.2 Fibre-ribbon connectors at the in-line and back-end patch-panels

In the worst-case of opening an energized 12-way ribbon connector there could be 12 fibres each transmitting

[3] It should be noted that for each type of patch panel, there will be many instances, e.g. the 'distributed' patch panel is located at many points within and around the Tracker volume. The in-line patch-panels will consist of 2x16 separate modules mounted around the circumference of the HCAL crack. The back-end patch-panel refers to all the FED analogue optical input connections on the front-panels of FED cards (as well as ribbon-connector points on the FECs).

3.25mW. The 12 fibre channels in the ribbon are arranged with a pitch of 250µm and the classification is done taking into account the actual spatial distribution of the light sources in the connector, and their optical divergence, in order to avoid being overly conservative. This is essentially the same as the classification procedure for an extended source, such as an array of lasers, requiring a calculation for each possible α value of the distributed radiation sources, effectively checking for any 'hot-spots' at particular angular subtenses across the ribbon.

For the fibre ribbon classification a separate calculation is therefore made for the individual fibre channels, then groups of two neighbouring fibres, groups of three, and so on up to 12 fibres in a 12-way connector. Due to the definition of α_{min}, a given group of fibres is considered as a single source if $\alpha < \alpha_{min}$ (=11mrad). This is the case for a group of up to 5 neighbouring fibre channels in a 12-way connector. Since there could be up to 3.2mW per fibre channel, it is clear that the AEL of Hazard Level 1 of 9.2mW for a single-mode fibre radiation source is exceeded, therefore we must determine the AEL for Hazard Level 3A (as in Appendix A.2).

In the case of a 12-way connector, the group of all 12 fibre-channels is the most restrictive in terms of AEL, having a limit of 5.1mW/fibre for Hazard Level 3A. Hazard Level 3A is therefore appropriate for the 12-way connectors, both in the in-line patch-panels and the back-end (FED) patch-panels.

2.2.3 Optical fibres, ribbon and multi-ribbon cables

We now consider the case of a broken fibre or broken 12-way or 96-way cable. For a single-way fibre the radiation exposure risk is the same as for opening a MU-connection, which is Hazard Level 1 in the CMS Tracker optical link system. In the case of a broken ribbon it is noted within the IEC Standards that this presents no greater risk than a broken single fibre, due to considerations of reflection and scattering at the fibre ends, and random alignment and movement of the fibre ends. This situation presents a Hazard Level of 1 and the same argument can be extended to a broken multi-ribbon cable where the risk is the same as a single ribbon and therefore a single-fibre channel, i.e. Hazard Level 1.

However, in the case of repairs to a fibre ribbon where the ribbon is cleaved before splicing, it should be noted that the hazard level is not the same as for a broken fibre. Handling a cleaved ribbon presents the same hazard level as an open 12-way connector, which means Hazard Level 3A.

2.3. Hazard level summary for analogue optical link system

Figure 3 summarizes the hazard classification of the complete CMS Tracker analogue optical link system.

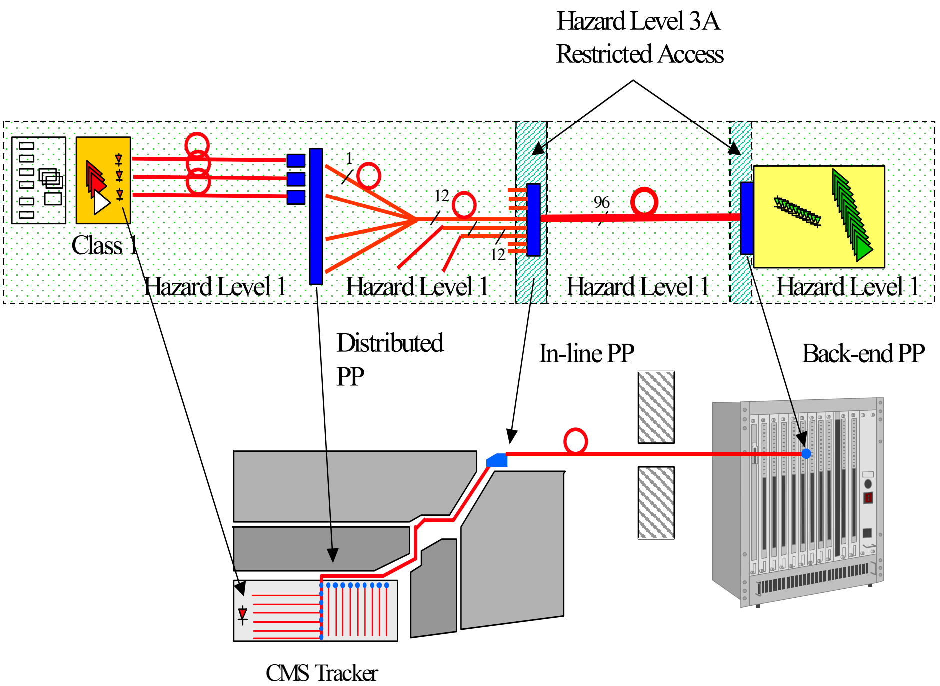

Fig.3: Optical link hazard classification summary. Not shown are the cases for broken fibre or cable, which is Hazard Level 1, and the case of cleaved fibre-ribbons, which is Hazard Level 3A.

3. Laser safety requirements

3.1. Labelling of hardware

The IEC Standards state exactly where and which type of labels must be used throughout a fibre optic system. These recommendations must be followed within the CMS Tracker optical link system to minimize any risk to users and other personnel associated with the optical links. A brief summary of all the requirements is given here, and we again refer the reader to the IEC documents for the complete description of labels and signs.

3.1.1. MU-Terminated laser assemblies and laser test-benches

The lasers, as delivered packaged on silicon submounts with their fibre pigtail and MU-connector, must be labelled Class 3A on the container. This is because the devices are capable of emitting a sufficiently high level of optical power when used with a strong current source.

Within the CMS Tracker optical link system the individual laser diodes are mounted on optohybrids. These components, as well as the fibre-pigtails and MU-connectors are Hazard Level 1, therefore these components do not need individual laser safety labels. A Hazard Level 1 (or Class 1) label on the box or container used for shipping the optohybrids would be useful.

Test-benches that power the lasers using the Tracker optohybrids must also be labelled with Hazard Level 1 labels. In the (unlikely) situation that these lasers are driven individually using a much stronger current sources (>150mA) the test-bench must be labelled with Class 3A labels and signs.

3.1.2. Fibres, ribbons, optical cables, connectors and patch-panels

The single channel fibres, 12 channel ribbons, 12 channel ribbon cable, and 96 channel multi-ribbon cable in this system do not have to have individual laser safety labels, since they are Hazard Level 1 components.

The single-way MU-connectors inside the Tracker do not need to be labelled individually as they are also Hazard Level 1. It is sufficient that the Tracker volume is marked, where appropriate space is available, with a Hazard Level 1 label, stating that laser equipment is contained there.

Ducts containing the CMS Tracker optical link channels that are accessible to any CMS personnel should be labelled with the equivalent of "CMS Tracker Optical Links. Hazard Level 1". If the ducts contain fibre channels that are not part of the Tracker optical links, but are part of other systems, then the labelling must reflect the appropriate hazard class and provide specific details of the hazard.

The accessible locations that present a potential hazard in excess of Level 1 are the patch-panels that house the connectorized fibre ribbon junctions. The individual connectors do not require a warning label, since the accessible locations are limited to the various patch-panels.

For the in-line patch panels in the HCAL crack the patch-panel housings must carry a label for Hazard Level 3A. This label, and the appropriate hazard description label, must remain clearly visible even when the patch panel is opened. In the case of the receivers on the FEDs in the counting room (and for the FECs if 12-way ribbon is used), the crates, or racks, should have a protective cover that is clearly labelled Hazard Level 3A, along with a warning label explaining the nature of the hazard.

3.2. Access limitations to areas housing laser and optical links systems

The parts of the Tracker optical link systems with Hazard Level 3A must have access limited to authorized, trained personnel, in order to minimize risks.

Of the three types of location outlined in the IEC Standards: Unrestricted, Restricted and Controlled, the locations housing the CMS Tracker optical link system where the hazard is Level 3A must be either 'Restricted' or 'Controlled' areas.

Restricted access implies fewer limits than Controlled access. By following the correct guidelines for the appropriate access limitations it is possible to avoid the need for engineering controls such as automatic power reduction, or interlocks, etc., that would be expensive to build into the Tracker optical link systems.

It should be noted that the precise place referred to as being a Restricted or Controlled Area is a very flexible term. It can be an area equivalent to an entire room or laboratory, for example, or only part of a room, or simply the object containing the optical components, e.g. a closed patch-panel housing, or an electronics rack with a door or cover.

The locations that are therefore considered to necessarily be of limited access within the final CMS Tracker optical link systems are:

- The in-line patch-panels situated within the HCAL crack.
- The crates containing the FEDs.
- The crates containing the FECs.

These zones will have (at least) **Restricted Access** and they must satisfy the following requirements:

- The location is marked as being of access only to authorized personnel. Personnel will receive authorization from the area supervisor, having received sufficient training.
- The location is marked clearly with signs warning of the access conditions, at the entry and within the area, giving the hazard class and the nature of the hazard.
- The location is supervised by a trained person, or team of people, identified with the responsibility for checking that the rules for access, and safety recommendations for the use of the laser systems, are followed.
- All of the hazardous objects within the area are labelled correctly.
- Only trained personnel will be allowed to work on the optical link system within the restricted area.
- Eye-protection must be available if the hazard exceeds the maximum permissible exposure (MPE) limit. In this system, with Class 3A as the worst-case, the MPE can only be exceeded if optical instruments are used to view a 12-way connector, or cleaved ribbon. In this case eye-protection should be worn if workers are closer than the safe naked-eye viewing distance, called the 'extended nominal ocular hazard distance' or ENOHD. The ENOHD is calculated for a 12-way connector (or cleaved ribbon) in Appendix A.3.

3.3 Special precautions during link development, installation and maintenance

In the laboratories developing, testing or using the optical link system (with either analogue or digital links), including test-beam areas, or system-test labs, the appropriate access controls must be applied.

In locations where the lasers are tested on the CMS Tracker opto-hybrids without fanning into optical ribbon cables, the hazard is never in excess of Class 1, or Hazard Level 1, and there are no special access requirements. However, it is assumed that, in any case, these work-places are considered as Restricted Areas with no unsupervised access to the public, and that laser operators have also received appropriate safety training.

In laboratories with test-benches for the CMS Tracker optical link system using *ribbonized* optical fibre cables with 12-way connectors there must be access conditions appropriate for Hazard Level 3A.[4] The laboratory, or at least the test-bench, must be designated as a Restricted Area. There must be warning signs attached to the test-bench and labels on the optical connectors and the connector housings, unless an entire patch-panel is being tested. In this latter case only the patch-panel has to be labelled as Hazard Level 3A.

During installation or subsequent maintenance of the optical links at any of the 12-way fibre-ribbon connector patch-panels in the final system, or during any ribbon splicing operations, the area around the object being worked upon will be (temporarily) designated as a Restricted Area. The boundary of the Restricted Area is defined by the ENOHD, given in Appendix A.3. Access to this area will be limited to authorized personnel by the appropriate use of temporary signs. For personnel working within this area, appropriate eye-protection should be worn if it is possible for the accessible power to exceed the MPE.

As a general precaution, required by 60825-2, all personnel working on links during development, installation and maintenance should check the operating status and hazard level of the equipment before opening any optical fibre-ribbon connector or cleaving a fibre-ribbon. If possible, live-working, i.e. with light in the fibres, should be avoided. In addition, any laser-based test equipment should be limited to Class 1 or Class 3A. If test

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[4] In laboratories containing development test-benches for the CMS Tracker optical link system that use *ribbonized* optical fibre cables with 24-way connectors there must be access conditions appropriate for Hazard Level kx3A. In this case the laboratory test-bench (or equivalent) must be designated as a Controlled Area, limited only to authorized, trained personnel, with Hazard Level kx3A warning signs attached to the test-bench as well as labels on the optical connectors and/or the connector housings.

equipment with a greater hazard level is to be used, then all accessible fibre ends and connectors should be secured and labelled with the appropriate marking before testing proceeds. It should also be considered that during certain periods of development, installation and maintenance safety labels may not yet have been installed in all locations before work begins on the system.

3.4. Laser safety training

Laser safety should be considered as an integral part of the training for CMS personnel in order to prepare them to be able to safely work with and around the numerous optical link systems, or other optoelectronic components and systems that exist within CMS. Untrained workers present not only a risk to themselves but they are also a risk to other personnel.

The IEC standards contain all appropriate general safety recommendations. Some basic good-practice notes are listed in Table 1 for work on optical fibre systems, taken from 60825-2. Similar laser safety guidelines must be available for reference in all laboratories and locations housing optical link systems. However, it should be noted that referring to those guidelines alone does not represent an acceptable substitute to proper Laser Safety training.

Training must be sufficient to minimize all risks associated with the given class of hazard that is accessible. In the case of the CMS Tracker optical links the worst-case hazards currently envisaged are of level 3A, which defines the minimum training requirement for all link users, who have direct access to the hardware. In the final system, as well as in the testing laboratories, the personnel who are responsible for access to the Restricted and Controlled Areas should compile a list of personnel who are authorized to access these locations.

The responsibility for ensuring adequate Laser Safety training of users lies fundamentally with the users themselves and with their supervisors. Training courses are widely available and it is *not* considered to be the responsibility of the CMS Tracker optical link development team to train users in Laser Safety, or to accompany unauthorized or untrained personnel in Restricted or Controlled Areas.

Table 1: Examples of general good working practices essential to fibre-optic systems

Viewing fibre	Do not stare at fibre-ends or connectors without appropriate eye protection, or point the light source at other people. Do not use any unapproved viewing aid or instrument.
Fibre ends	Fibre-tips should be covered with tape, or another suitable material to avoid sharp ends, and avoid direct exposure to radiation if energized.
Connector ends	Unterminated connector ends should be covered with the appropriate dust-cap.
Test Equipment	The power supply to the optical source should be the last thing connected and the first thing disconnected. Use test equipment of the lowest class necessary.
Ribbon fibres	Do not cleave fibre ribbons unless authorized to do so.
Fibre cut-offs	Dispose of all cut-offs in a suitable container.
Safety Labels	Report all instances of damaged safety labels.
Signs	Area warning signs required for locations exceeding hazard level 3A. Signs may also be displayed in locations of lower classification.

3.5 Eye Protection

In any case where the hazard level is in excess of 3A, or if the MPE is exceeded by working with optical aids on objects with Hazard Level 3A, the use of eye-protection such as safety glasses or goggles is strongly recommended and such equipment must be made available in these areas.

Manufacturers can be consulted directly in order to gather information on these safety products. Essentially, the selection procedure for protective eye-wear in a low power system such as the CMS Tracker Optical Links involves, first of all, a calculation of the level of protection required. This value is given by $\log_{10}(H_0/MPE)$, where H_0 is the level of accessible power at the given wavelength, and MPE is the maximum permissible exposure for that wavelength. The optical density of the safety glasses (or filter) should then be *greater* than the level of required protection at the appropriate wavelength.

DIN and Euronorm (EN) standards[7] specify a label for the protection level as ***X* L *Y*** where *X* is up to 4 letters relating to the code for type of laser: D = continuous wave, i.e. constant power, I = pulsed (~µs to ms), R = Q-switched (~ns), and M = very short pulse(~ps). Then **L *Y*** is the optical density, such that L 5 represents for example a transmittance of 10^{-5}. For applications such as the CMS Tracker optical link systems, laser safety glasses with the specification 'D L3' at 1310nm are readily available, providing a large margin of over-protection, even in the worst-case of optical instruments being used to observe an energized 12-way connector.

3.5 Summary of laser safety requirements

The components and parts of the system that are Class 1 or Hazard Level 1, do not require any special engineering controls, or individual laser safety labels on each part. It is sufficient to add a Class 1 label or Hazard Level 1 label at an appropriate location on a part of the system assembly that contains a Hazard Level 1 component. There are also no access limitations from the point of view of laser safety, to test-areas or parts of the final system containing Class 1 or Hazard Level 1 components. From the point of view of good-practice it is nonetheless preferable if all workers that will access these parts of the system are trained how to handle the fibre-optic and optoelectronic components in the system.

The Hazard Level 3A components and system parts also do not require any special engineering controls as they will only be used in Restricted Areas, where there will be no admittance to unaccompanied, unauthorized people. According to the latest full versions of the IEC Standards[2,3], in the final optical link system the in-line patch-panels and back-end patch-panels will be Restricted Areas and must carry Hazard Level 3A warning signs and appropriate details of the nature of the hazard and user-precautions. The actual fibre-ribbons, and ribbon-connectors do not require individual labels and it is sufficient to label the patch-panel housings or covers. Labels should be visible even when the housing or cover is opened.

To be authorized to work on parts of the system with Hazard Level >1, workers must receive appropriate laser safety training, as well as having training of how the system operates.

When working on the parts of the system with Hazard Level 3A, within the area delimited by the ENOHD, eye-protection should be worn if the accessible power can exceed the MPE.

4. Conclusion

The CMS Tracker optical link system has been classified in terms of laser safety under reasonably foreseeable circumstances, consistent with guidelines in the current IEC Standards for laser safety and laser safety in optical fibre systems. The corresponding recommendations for labelling, access controls, eye-protection and laser safety training have also been outlined.

The laser transmitters, when operated standalone with a limited supply current (<150mA), or after being attached to a CMS Tracker optohybrid, do not present any risk to personnel as they are Hazard Level 1. They require no additional engineering, access or labelling requirements apart from a Hazard Level 1 label. In the case of CMS Tracker optical links, these labels can be located at a point in the Tracker where space is available. The optical fibres, ribbon, ribbon cables, and multi-ribbon cables in the system are also Hazard Level 1 and a Hazard Level 1 label should be attached to the cable duct at one or more visible points.

The only elements of the system requiring any particular controls are at the in-line and back-end patch-panels housing the fibre-ribbon connectors. These points are Hazard Level 3A, requiring Restricted Access and signs appropriate to Hazard Level 3A mounted on the patch panel housings or covers. Similar controls and labels will also be required at the FECs if ribbonized fibres are used in these modules.

During installation, commissioning and maintenance of the final system, areas where the laser hazard exceeds Class 1 will become temporarily designated as zones of Restricted Access, if they were not already restricted. At all times during work on potentially live fibres, the Hazard Level will be limited, during test or maintenance to 3A. Appropriate eye-protection will be made available for any work in an area where the accessible power is in excess of the MPE.

In summary the final CMS Tracker Optical link system uses low power levels and the relatively safe wavelength of 1310nm. All the components with Hazard Level 1, or Class 1, are safe to the naked eye and in the parts where the Hazard Level is 3A these elements only present a risk if viewed using optical instruments.

In the laboratories developing and assembling the optical links, where the Hazard Levels may exceed 3A, appropriate controls and best-practices must be established. It is also the individual responsibility of all people in the project to have followed sufficient laser safety training. Only trained personnel will be allowed to work on parts of the system where the access is limited.

This document, its contents and recommendations will be periodically reviewed to reflect any future changes in the IEC standards and/or CERN rules concerning Laser Safety. The updated versions will be archived on EDMS at: http://edms.cern.ch/document/338505/1

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[7] EN 207 – Personal Eye Protection – Filters and Eye Protection for Laser Radiation

Appendix

A.1 Calculation of AEL for Class 1 or Hazard level 1

For Class 1, or Hazard Level 1, the AEL is defined in terms of radiant energy as

$$AEL = 3.5x10^{-3}\, t^{0.75} C_6 C_7 \qquad \text{(units of J)}$$

where t is the exposure time (t=100s for our application) and C_6 and C_7 are correction factors:

$$C_6 = \frac{\alpha}{\alpha_{\min}} \qquad \text{- angular subtense relaxation factor}$$

where α_{min}=11mrad. For a point source, e.g. a laser diode, or single optical fibre, or a one-way connector, $\alpha = \alpha_{min}$, therefore C_6=1.

$$C_7 = 8 \qquad \text{- wavelength correction factor at 1310nm}$$

To calculate the accessible power limit, P_{AEL}, the radiant power from a given source is determined as that passing through a 50mm aperture, placed at 10cm distance from the source. This is simulating the power that could be coupled into an optical instrument:

$$P_{AEL} = 3.5x10^{-3}\, t^{-0.25} C_6 C_7 \qquad \text{(units of W)}$$

Therefore P_{AEL}=9.2mW. Considering a single-mode optical fibre, or MU-connector, as in the current application, 100% of the emitted power will be coupled into a 50mm aperture at 10cm distance, therefore 9.2mW is the accessible emission limit for Hazard Level 1.

A.2 Calculation of AEL for Class 3A or Hazard level 3A

For Class 3A, or Hazard Level 3A, the AEL has two limits, one is defined in terms of radiant energy as

$$AEL_{(1)} = 1.8x10^{-2}\, t^{0.75} C_6 C_7 \qquad \text{(units of J)}$$

and the second is in terms of irradiance as

$$AEL_{(2)} = 90 t^{0.75} C_6 C_7 \qquad \text{(units of J/m}^2\text{)}$$

The first condition leads to a maximum power output from a small source (one with angular subtense $\alpha \leq \alpha_{min}$) of $AEL_{(1)}$=46mW, i.e. five times the MPE and five times the limit for Class 1, or Hazard Level 1.

For the second condition, the irradiance can be related to a maximum power at the 7mm diameter measurement aperture according to

$$P_{2,AEL} = 90 t^{-0.25} C_6 C_7 \times \pi (3.5 \times 10^{-3})^2$$

Therefore $P_{2,AEL}$=8.9mW. However, only a fraction of the light output from a single-mode fibre is coupled into the aperture. The emitted beam is gaussian with a width d_{63} (containing 63% of the power) at a distance r given by

$$d_{63} = \frac{2\sqrt{2} r \lambda}{\pi w_0}$$

where λ is the wavelength and w_0 is the mode-field diameter in the fibre. At r=100mm, with λ =1310nm and w_0 =9μm, this gives d_{63}=13.1mm.

The fraction of light power coupled into an aperture of diameter d_a is then

$$\eta = 1 - \exp\left[-\left(\frac{d_a}{d_{63}}\right)^2\right]$$

Therefore η=24.8% for a 7mm aperture at 100mm distance.

The AEL for the power emitted from the fibre tip, or connector end-face is $P_{2,MAX}$ given by

$$P_{2,MAX} = \frac{P_{2,AEL}}{\eta}$$

giving $P_{2,MAX}$ =35mW. This is a lower value than the limit determined from condition 1, therefore the limit of the power output of a fibre to be within Hazard Level 3A is 35mW.

In the case of the 12-way fibre connectors in the in-line and back-end patch panels, where the hazard exceeds Level 1, here the fibre ribbon must be treated as an extended laser source. In this case there is a linear array of equally powerful sources at 250μm pitch, each fibre channel having a maximum power output of 3.25mW.

The AEL must then be calculated taking into account the angular subtense of each potential grouping of light sources to check for any 'hot-spots'. In the 12-fibre ribbon case, this means checking both Hazard Level 3A radiant exposure and irradiance conditions for groups of 1, 2, 3, 4, and so on, up to a group of 12 fibre channels.

The results of this calculation are given in Table 2. The most stringent requirement is that of the irradiance condition applied to the group of 12 channels, i.e. the whole 12-way connector or cleaved fibre-ribbon. In this case, the AEL per fibre is 5.1mW. Since this is more than the maximum envisaged 3.25mW per channel then the 12-way fibre ribbon connectors in the Tracker Optical Links system are Hazard Level 3A, as are any cleaved fibre ribbons in the final system.

A.3 Calculation of Extended Nominal Ocular Hazard Distance (ENOHD)

For the parts of the system where the Hazard Level is 3A, protective eye-wear should be worn if there is a risk that a worker can be exposed to power levels greater than the maximum permissible exposure (MPE). For Hazard Level 3A, the objects are eye-safe, provided optical instruments are not used. However, if for example an instrument is being used to view a fibre ribbon, or 12-way connector, then the extended nominal hazard distance should be calculated, this is the distance beyond which the MPE is not exceeded.

Considering the light output from a 12-way ribbon, it is reasonable to assume that 100% of the light is coupled into a 50mm aperture at 100mm distance. If each fibre can transmit a maximum power level of 3.2mW then there could be up to 40mW coupled into the aperture.

The MPE is 9.2mW which corresponds to the Hazard Level 1 radiant power AEL. Therefore it is necessary to calculate the distance a 50mm aperture must be placed from a 12-way ribbon connector such that only 9.2mW is coupled into the aperture in the worst-case, i.e. 0.80mW per fibre-channel. This means 25% coupling efficiency.

Using the coupling efficiency equation from the preceding section, the beam width is given by

$$d_{63} = \frac{d_a}{\sqrt{(-\ln(1-\eta))}}$$

therefore d_{63}=93.2mm for η=0.25 and d_a=50mm.

The safe distance d_{ENOHD} is then given by re-arranging the beam-width equation to give

$$d_{ENOHD} = \frac{\pi w_0 d_{63}}{2\sqrt{2}\lambda}$$

such that with w_0=9μm, this means that d_{ENOHD} = 710mm.

Within this distance eye-protection should be worn, as the MPE will be exceeded if optical instruments are being used to view the fibre-ribbon connectors or cleaved ribbon. The ENOHD is also the boundary of the area that should be limited to being a Restricted Area whilst work is being carried out on the in-line or back-end patch panels, or if a 12-way ribbon in the final system is being spliced.

Table 2 . AEL values for 12-way ribbon connectors (or cleaved ribbon) for Hazard Level 3A. In part (a) are the AEL values for the radiant power condition, assuming 100% coupling of light into a 50mm aperture at 100mm distance. In part (b) are the values for the irradiance condition with 24.8% coupling into a 7mm diameter at 100mm distance.

(a)

Number of fibres in group	Angular subtense, α (mrad), limited by α_{min}=11mrad	Relaxation factor, C_6	AEL for group $P_{1,AEL\text{-}Grp}$ (mW)	AEL per fibre $P_{1,AEL}$ (mW)
1	11	1	46.0	46.0
2	11	1	46.0	23.0
3	11	1	46.0	15.3
4	11	1	46.0	11.5
5	11	1	46.0	9.2
6	11.7	1.06	48.9	8.1
7	13.0	1.18	54.4	7.8
8	14.3	1.30	59.8	7.5
9	15.5	1.41	64.8	7.2
10	16.8	1.53	70.2	7.0
11	18.0	1.64	75.3	6.9
12	19.3	1.75	80.7	6.7

(b)

Number of fibres in group	Angular subtense, α (mrad), limited by α_{min}=11mrad	Relaxation factor, C_6	AEL for group $P_{2,AEL\text{-}Grp}$ (mW)	AEL per fibre $P_{2,MAX}$ (mW)
1	11	1	35.0	35.0
2	11	1	35.0	17.5
3	11	1	35.0	11.6
4	11	1	35.0	8.75
5	11	1	35.0	7
6	11.7	1.06	37.1	6.2
7	13.0	1.18	41.3	5.9
8	14.3	1.30	45.5	5.7
9	15.5	1.41	49.3	5.5
10	16.8	1.53	53.5	5.3
11	18.0	1.64	57.4	5.2
12	19.3	1.75	61.2	5.1