Radiation Tests of Optical Fibres: An Overview

By C. Issever, B.T. Huffman, A. Weidberg for the Joint Opto-electronics working group. Comments by J. Troska and K. Gill included.

Common wisdom exists regarding the procedures for testing optical fibres for use in various types of radiation environments. This document is meant to be an overview or summary of that wisdom which is largely collected from other sources. The authors would appreciate any relevant additions to these sources or other information that members of the group might have to add to this document.

Radiation Exposure of Optical Fibres
There seems to be no clear way to predict how radiation will damage optical fibre, consequently the procedures to date have involved actual exposure of test lengths of fibre identical to the production version to levels expected over the fibre’s lifetime.

Radiation exposure takes three forms:
1. Charged hadronic sources. Typically this involves protons from beams, but pions or charged kaons might also be used. This source produces bulk and ionizing damage.
2. Neutral hadronic sources, typically neutrons (but neutral kaons are possible though this author knows of no instance of their use only for radiation testing). This source produces bulk damage almost exclusively.
3. Gamma rays or electrons. This source produces Ionizing damage.

Optical fibres for data transmission are almost universally made of SiO2 (silica) which is doped with various elements to obtain the changes in refractive index for the propagation of optical signals. The common doping element considered at CMS and ATLAS is Ge. ATLAS has a bespoke fibre with a fluorine dopant. Past tests where there was Phosphorous dopant did not turn out well for even low-level radiation environments.

Past experience in tests at both experiments and in a wide range of nuclear and space-based applications indicate that, even in environments with a high level of hadronic radiation, it is the ionizing component of that radiation which effects the performance of optical fibres. This effect is through the creation of discoulouration centres through the fibre reducing transmission efficiency. As a result, all fibres currently in use in the ATLAS and CMS detectors are either pure silica or doped with Ge and Fl.

Sources of gamma rays, providing only ionizing radiation damage, are thus favoured for fibre tests. These sources are often from the decays of radioactive elements with Co60 being a popular source. Such exposures have the benefit of large luminous volumes which can accommodate many meters of fibre in the exposure chamber or target area. Gamma sources have another key benefit of being incapable of activating the test rig or the fibres themselves thus permitting easy transport off the radiation site after the proper contamination surveys.

Tests in a neutron source might point out problems with mechanical stability if high integrated doses can be obtained. There is also concern about the integrity of the fibre buffer and the
mechanical stability of any cabling that will be subjected to high dose rates. These ancillary issues are reasons for neutron-source tests.

**Recommendation:** Tests for radiation hardness at SLHC fluences can be performed in gamma sources alone. But the full integrity of the final cabling structure, including any sheathing, should be exposed to neutrons to check for mechanical stability problems.

**Level of Radiation**

This is dependent on radius but for the purpose of the SLHC we are assuming a nominal exposure of 10 times the LHC equivalent. This corresponds to 3000fb⁻¹ delivered integrated luminosity.

**Recommendation:** A rule of thumb for radii of the order of 30cm from the beam-line is 0.6MGy over the life of the upgrade.

[I need the neutron fluence numbers, would appreciate it if someone would just write a few sentences and send it to me for inclusion.]

**Test procedure in gamma sources**

Several elements are required for testing optical fibres for losses due to radiation damage. Below is a list of the more common elements.

**Source:** This is typically either a laser (VCSEL or edge emitting) or a Light Emitting Diode (LED). LED sources have the advantage that they can sometimes either be tuned or emit light over a broad range of wavelengths so damage can be broadly assessed. Lasers launch a high energy density of light down Multimode (SIMM) and graded Index (GRIN) fibres which might aid bleaching or even annealing effects. Lasers can also provide a high loss tolerance so a longer length of fibre may withstand testing.

It is important that the source’s light output be independently monitored so that power fluctuations can be monitored during the test.

**Detector(s):** Typically these are p-i-n diodes if a test is being performed at high speed or Large Area Photodiodes (LAPD’s) if overall transmission is of interest. LAPD’s can experience temperature dependent effects that take some time to stabilise due to their large packaging and active area.

**Test set-up:** Below is a diagram of a suggested set-up for in-situ optical fibre testing.

The laser supplies light to a fibre splitter which then sends approximately 50% of the optical power down two fibres, the test and the control. (The exact percentage of light launched down the test or control fibres is largely irrelevant but the time-stability of this coupling is very important.)

The test fibre runs into the exposure volume where the length to be tested is coiled. The control fibre makes the same run, as near as possible, but does not coil in the radiation volume, rather it returns directly to the optical detector(s). Ideally there would be one optical detector with some mechanism of switching which fibre’s light output is being recorded on the same optical sensor. However, many sensors show excellent stability characteristics, so continuous monitoring on two different optical receivers might be desired. This is a description of a test
system for a single fibre channel. It is always desirable to replicate this system over many channels to test ribbon fibres and to mitigate the effect of variations within fibre batches and optical coupling into and out of the fibre.

**Important Considerations:** As one can see by bending a bit of plastic located between crossed polarisers, stress causes changes in that medium’s optical properties. Several groups who have performed optical tests have also reported significant effects depending on the bending radius.[ref. NATO Docs. And H. Ooms] Consequently it is important to record the bend radius of the fibre spool during any tests. During any exposures it is recommended that the fibre be subjected to minimal stresses and indeed, even removed from any support if possible. All types of cables foreseen should be tested not only bare fibre (if it is foreseen to make jacketed cable). Coil size should reflect size available in radiation source and be such that it is within fibre bending spec and can be shown not to affect the results of the damage. Attention must be paid to the recommended minimum bend radius from the fibre manufacturer and also account for the likely bending that will be experienced in the final system [reference H. Ooms and M. van Uffelen private communication].

Exposure times and monitoring intervals will depend on the radiation rate of the source and the total dose desired.

**Test set-up: Fibre exposure**

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Fibre Description</th>
<th>Dose received</th>
<th>Fibre length tested</th>
<th>Total loss measured</th>
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<tbody>
<tr>
<td>CMS</td>
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<td>10dB</td>
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<tr>
<td>ATLAS</td>
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References
I need to look these up again formally. For some reason most of them do not have the journal or proceeding where they were published in their headers.


ATLAS Standard Radiation Test Methods, Sub-part of ATC-TE-QA-001.


