# Radiation effects on COTS laser-optimized graded-index multimode fibers exposed to intense gamma radiation fields

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## ABSTRACT

We report on experimental measurements of the radiation effects on COTS laser-optimized graded-index multimode fibers exposed to intense gamma radiation fields. Measurements at room and cold temperatures of the radiation-induced attenuation losses at 850 nm for two dose rates (450 Gy/h and 157 Gy/h) and for a total dose of 1000 Gy are presented for several fibers from different manufacturers.

**Keywords:** Radhad fiber, gamma radiation, radiation-induced attenuation, photobleaching

## 1. INTRODUCTION

Optical communication is the next trend for communications in space. Complex and high throughput processor architectures and novel payload instruments, such as High Resolution SAR, Hyper Spectral Imagers and High Speed High Resolution Cameras place new demands for existing data handling architectures on telecommunication and science satellites. Very high speed data links with data rates of at least 1-10 Gbps are needed for these future applications. This leads to increasing interest in exploring the benefits of optical signals as the preferred transmission technology for future space flight missions.

The European Space Agency (ESA) has initiated the SpaceFibre study to investigate the use of fibre optic links for intra-satellite high-speed data communications [1]. A fiber optic link offers many potential advantages for intra-satellite communications due to its reduced weight, size and power consumption, spark immunity and tolerance against electromagnetic interferences. The findings of the SpaceFibre study are to be included as an extension to the existing and widely used SpaceWire ECSS-E-50-12A standard, a unified standard for intra-satellite networks. The performance requirements of the SpaceFibre link are set to 1-10 Gbps data rate over a link length of 100 meters with a bit error rate less than $10^{-12}$ for a mission lifetime of 10 to 15 years.

The SpaceFibre development team is composed of the Prime contractor Patria (Finland, interface electronics, protocol definition), VTT (Finland, fiber optic transmitter and receiver), INO (Canada, optical fiber), Fibrepulse (Ireland, fiber optic connectors and assemblies), Gore electronics (Germany, optical fiber jacket) and the University of Dundee (UK, SpaceWire protocol).

In this paper, the radiation hardness of some high performance optical fibers is determined. The best performing fiber will be recommended to the SpaceFibre study. Many parameters like the radiation dose rate, the test temperature and the coupled optical power are taken into account. Data extrapolations to typical dose rates in the space environment are presented.

## 2. THE SPACE RADIATION ENVIRONMENT

It is well known that optical fibers are sensitive to gamma radiations [2]. The main noticeable effect is an increase of the fiber attenuation losses. The radiation-induced attenuation (RIA) of the fiber is dependent on two key parameters, the radiation dose rate, expressed in Gray per hour (Gy/h), and the total irradiation dose (TID) experienced by the fiber over the mission lifetime. For the SpaceFibre study, the target TID is 1000 Gy (100 krads).

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Once in space the optical fiber must withstand various dose rates of radiations. The typical background radiation level is 0.06 Gy/h and this level can increase up to 20 Gy/h during solar flare events [3]. This means that one must take into account the impact of these RIA losses over the entire mission lifetime to determine the power budget of the communication link.

## 3. FIBER REQUIREMENTS

The selected optical fiber for the SpaceFibre study will have to be radiation hardened (radhard) and capable of 10 Gbps transmission capacity over a length of 100 meters. In order to meet these requirements, it is valuable to know some facts about the chemical composition and the waveguide characteristics of the desired fiber.

First, the fiber must operate in the 850-nm communication window because of the good radiation hardness and performance of VCSEL lasers at that wavelength. Unfortunately, the RIA losses of optical fibers at 850 nm are typically 10 times higher (on the dB scale) compared to losses at 1300 nm. Phosphorous doping, mainly used to ease the refractive index profiling of the fiber, must also be avoided as it has been well documented as not acceptable for use in the space environment due to its very high radiation sensitivity [4].

Second, the singlemode fiber must be avoided due to large laser to fiber alignment tolerances. The step-index multimode fiber must be avoided too due to bandwidth limitations. With its 50-micron core diameter and large NA, the laser-optimized graded-index multimode fiber (LOGIMF) is the only option that can meet the bandwidth and light coupling requirements of the SpaceFibre study. This type of fiber is widely available on the market as a COTS (commercial off the shelf) component, but its radiation hardness needs to be determined.

## 4. TEST SETUP

The optical fiber irradiation tests are performed at the Canadian Irradiation Centre (Laval, Québec) using a Gammacell GC-220 unit (Cobalt$^{60}$ chamber). This unit gives an average dose rate of 450 Gy/h during the first set of tests and 429 Gy/h during the last set of tests 8 months later. It allows the insertion of a lead attenuator to reduce the dose rate by 65%.

The fibers are wounded on a 10-cm diameter aluminum spool. As illustrated in figure 1, two types of spool are used for the tests, the spool on the left is used at room temperature and the spool on the right is used for the low temperature irradiation tests.

Fig. 1. Pictures of the spools used for the irradiation tests. The spool on the left is used for the room temperature test and the spool on the right can be temperature-controlled.

The temperature-controlled spool is shorter in height compared to the other one in order to allow the bending of the cooling tubes, as they loose flexibility at cold temperature. A thermal pad has been added underneath the fiber in order to keep efficient thermal transfer between the fiber and the aluminum spool.

For each test a 100 meter fiber sample is rolled up on a spool. Initially, only a few microwatts of light at 850 nm (EXFO FLS-300) are coupled in the fiber to avoid photobleaching effect during irradiation. Then, to study the photobleaching effect, around 10 mW of laser power are coupled in the fiber. The measurements are taken in realtime using a power meter connected to a computer.

## 5. MEASUREMENT RESULTS

Six different fibers, all germanium-doped only, have been irradiated, with four of them being LOGIMF. Draka Comteq (The Netherlands) has provided three versions of its MaxCap 300 laser-optimized fiber: a standard, a radhard and a radhard-optimized. A standard laser-optimized telecom fiber and a graded-index radhard fiber came from two other manufacturers. The last one is a germanium-doped graded-index multimode fiber manufactured by INO for comparison purposes.

Figure 2 shows the attenuation losses of the radhard graded-index fiber, before and after exposure to gamma irradiation (TID = 1000 Gy), as a function of the wavelength. Higher radiation sensitivity at shorter wavelengths is clearly noticeable, the attenuation losses at 850 nm increase by 18 (157 Gy/h) to 24 (450 Gy/h) times after irradiation but only by 5.8 times at 1300 nm for both dose rates.

| | 1300 nm (dB/km) | 850 nm (dB/km) |
|---|---|---|
| Before irradiation | 1.24 | 2.3 |
| After a dose rate of 157 Gy/h | 7.2 | 129.6 |
| After a dose rate of 450 Gy/h | 7.2 | 171.3 |

Table. 1. Attenuation losses of the radhard graded-index fiber at 850 and 1300 nm before and after irradiation.

Figures 3 and 4 show the RIA measurements of all six fibers taken at room temperature at dose rates of 157 and 450 Gy/h respectively. After a TID of 1000 Gy, the RIA varies from 4 to 9 dB at 157 Gy/h and 7 to 16 dB at 450 Gy/h. The Draka MaxCap 300 radhard-optimized fiber (fiber A) shows the best performance with a RIA at 450 Gy/h lower than 8 dB after a TID of 1000 Gy while losses of the other fibers are well above 11.5 dB. All fibers except the Telecom radhard fiber (fiber F) and the INO fiber (fiber D) show some saturation behavior at high TID, the fibers D and F are still in the linear regime (on a log scale) of their RIA losses. Regarding the annealing of the fibers once irradiation has stopped, almost all fibers demonstrate good attenuation losses recovery except for the fibers D and F that show very low recovery.

Figure 5 shows the RIA losses measured at -17 $^{o}$C for the standard telecom and the Draka MaxCap 300 radhard-optimized fibers. For comparison the room temperature RIA measurement of the Draka fiber has been added in the figure. As expected, germanium-doped fibers are very sensitive at cold temperature [5], the losses increasing at more than 45 dB after a TID of 1000 Gy. On the other hand, annealing was excellent when the fiber temperature returned to room temperature. This test demonstrates also a clear advantage for the radhard fiber compared to the standard fiber.

Figure 6 shows the photobleaching test results performed on the Draka MaxCap 300 radhard-optimized fiber. Two 100-m fibers were irradiated at the same time on the same spool, with one fiber shined with only a few microwatts of power and the other fiber was shined with 7 mW of laser light at 850 nm. The fiber with high power coupled in the core has its RIA losses cut by half on a dB scale compared to the low power fiber.

## 6. EXTRAPOLATION RESULTS

The fibers were exposed to gamma radiation intensity levels that are not typical of the space environment. The tests at two dose rates were conducted for the purpose of data extrapolation at dose rates corresponding to solar flare events (20 Gy/h) and the background radiation level (0.06 Gy/h) [6]. Figure 2 shows the RIA measurements, fits and extrapolations of the Draka MaxCap 300 radhard-optimized fiber. The RIA after a TID of 1000 Gy becomes as low as 0.05 dB for the background radiation dose rate and 1.4 dB during solar activity. This demonstrates that if the fiber temperature is kept around 20 $^{o}$C, the fiber should not be a major concern in the power budget of the communication link for a mission lifetime of at least 10 years.

## 7. CONCLUSION

Commercial off the shelf standard and radhard laser-optimized graded-index multimode fibers with transmission capacity of up to 10 Gbps over several hundreds of meters and operating in the 850-nm communication window have been exposed to gamma radiations. Measurements of the radiation-induced attenuation show losses varying from 7 to 16 dB when the fibers are exposed to a dose rate of 450 Gy/h and for a total irradiation dose of 1000 Gy. When considering the typical dose rates in space, radiation-induced attenuation losses can be as low as 0.05 to 1 dB. Measurements at -17 $^{o}$C show much higher sensitivity of germanium-doped fibers to cold temperatures, losses increasing to more than 45 dB after a TID of 1000 Gy for the Draka MaxCap 300 radhard- optimized fiber, the best performing fiber in our tests.

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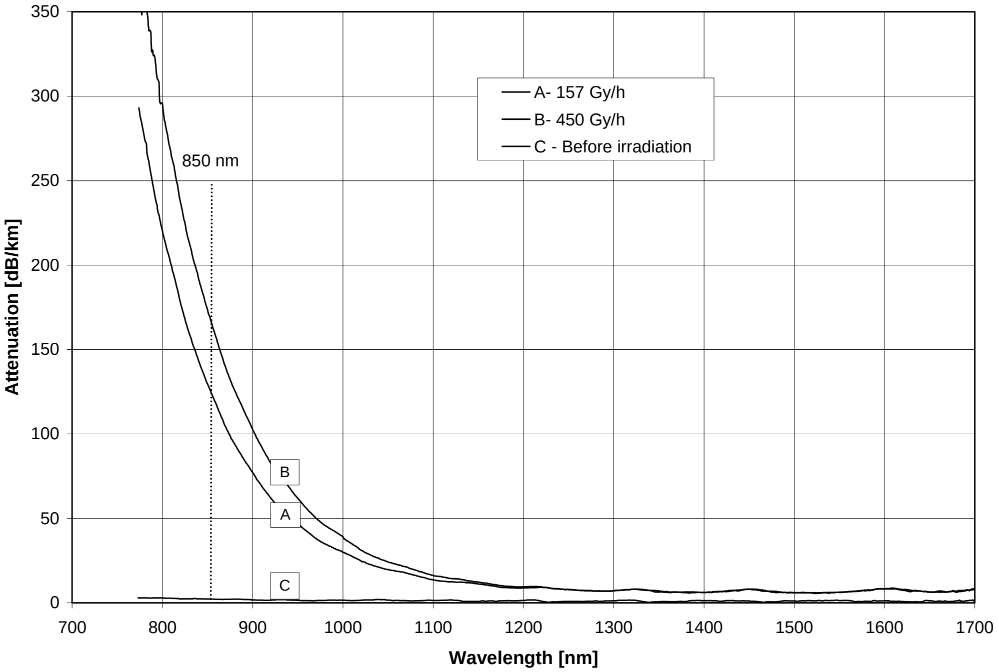

Fig. 2. Telecom radhard fiber attenuation versus wavelength before and after gamma irradiation. The total irradiation dose is 1000 Gy.

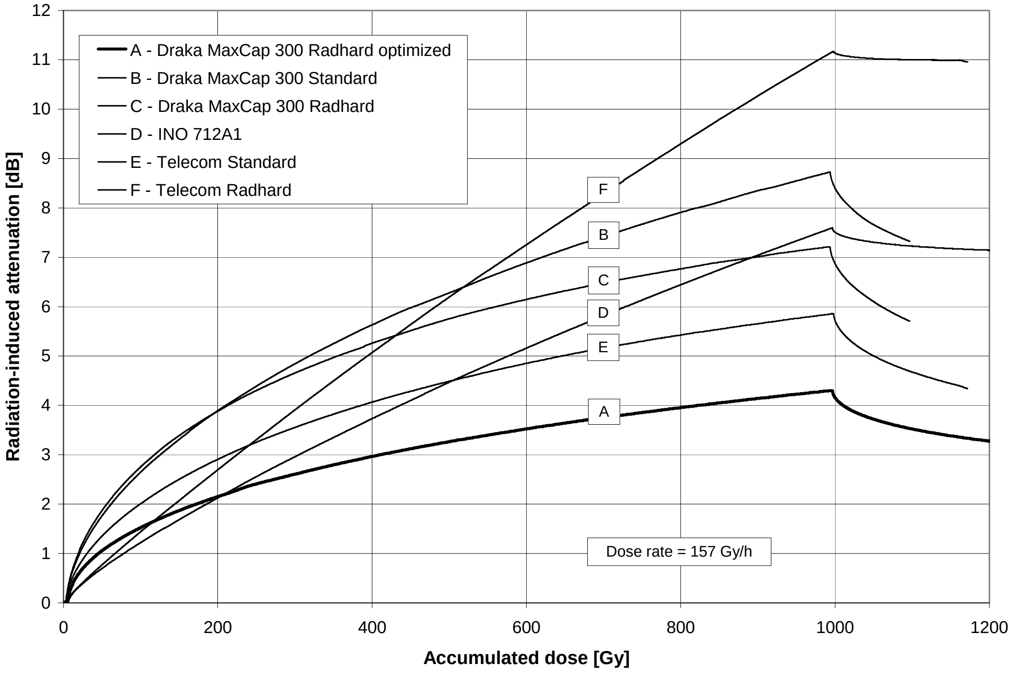

Fig. 3. Radiation-induced attenuation measurements at 850 nm of COTS graded-index multimode fiber samples (100 metres). The average radiation dose rate is 157 Gy/h and the total irradiation dose is 1000 Gy.

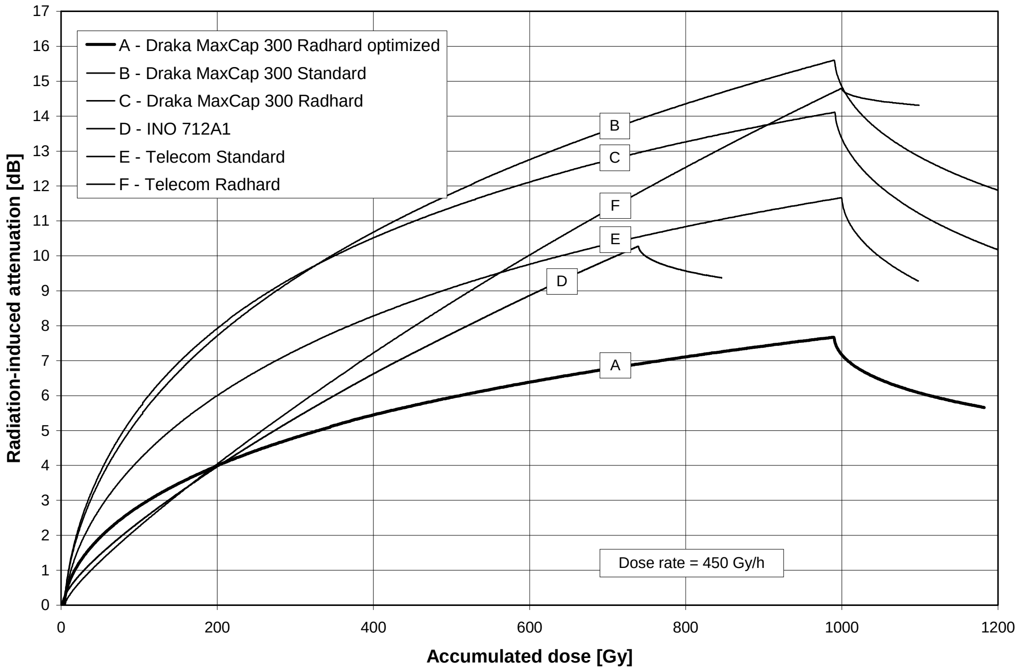

Fig. 4. Radiation-induced attenuation measurements at 850 nm of COTS graded-index multimode fiber samples (100 metres). The average radiation dose rate is 450 Gy/h and the total irradiation dose is 1000 Gy.

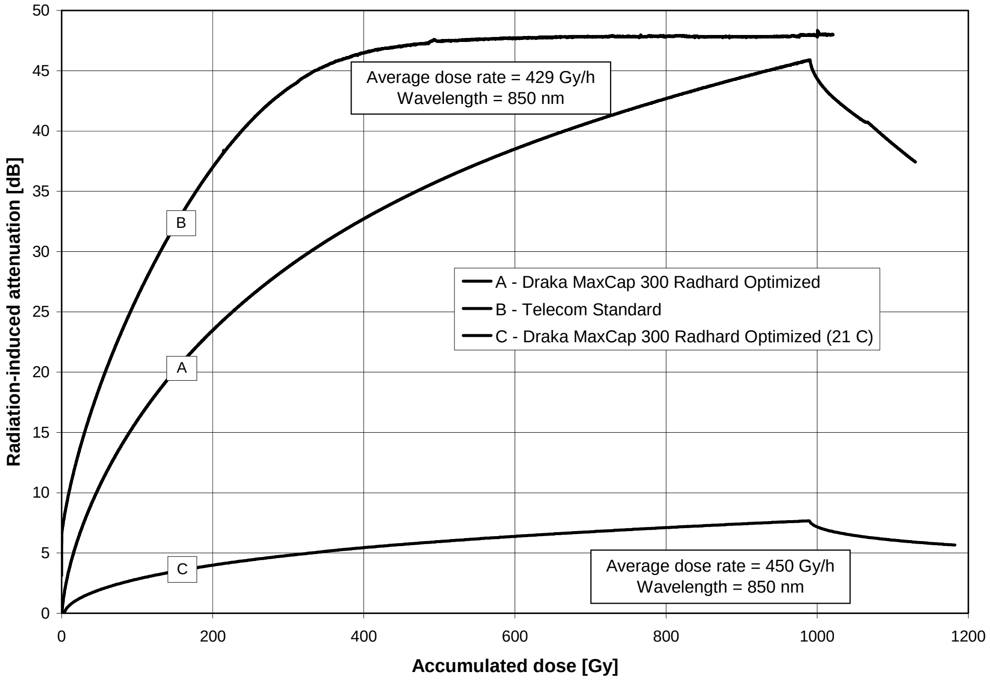

Fig. 5. Radiation-induced attenuation measurements at 850 nm of COTS laser-optimized graded-index multimode fiber samples (100 metres) performed at room temperature (curve C) and at an average temperature of -17 °C (curves A and B). The average radiation dose rate at cold temperature is 429 Gy/h and the total irradiation dose is 1000 Gy.

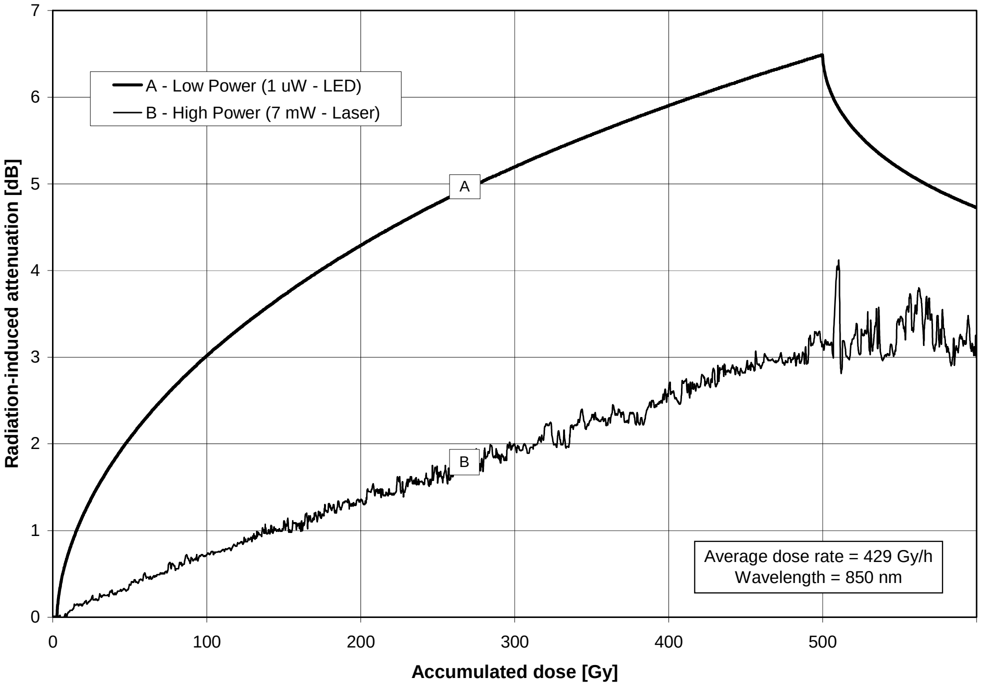

Fig. 6. Photobleaching test for two Draka MaxCap 300 Radhard Optimized fiber samples (100 m) wounded on the same spool with low (curve A) and high (curve B) optical power coupled in the fibers.

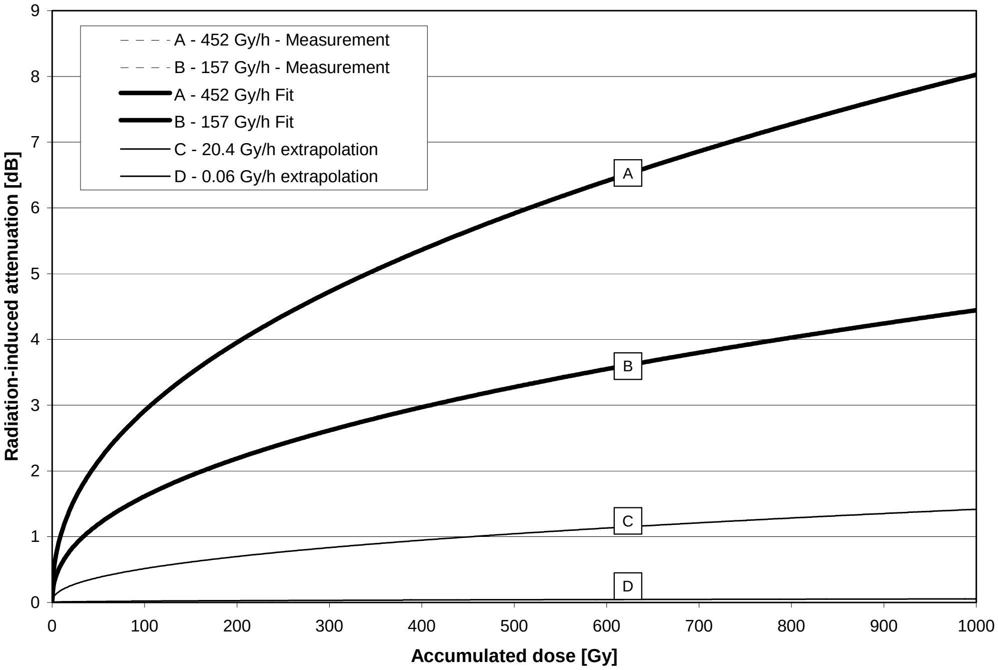

Fig. 7. Attenuation fit and extrapolation of the Draka MaxCap 300 Radhard Optimized fiber samples exposed to gamma irradiation. Extrapolations are at 0.34 & 0.001 Gy/min dose rates.