Raman distributed temperature measurement at CERN high energy accelerator mixed field radiation test facility (CHARM)

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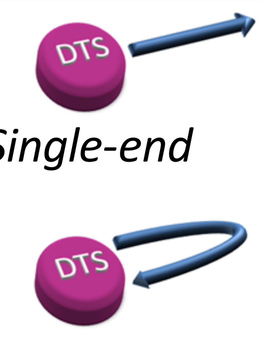
ABSTRACT: In this paper we present a validation of distributed Raman temperature sensing (RDTS) at the CERN high energy accelerator mixed field radiation test facility (CHARM), newly developed in order to qualify electronics for the challenging radiation environment of accelerators and connected high energy physics experiments. By investigating the effect of wavelength dependent radiation induced absorption (RIA) on the Raman Stokes and anti-Stokes light components in radiation tolerant Ge-doped multi-mode (MM) graded-index optical fibers, we demonstrate that Raman DTS used in loop configuration is robust to harsh environments in which the fiber is exposed to a mixed radiation field. The temperature profiles measured on commercial Ge-doped optical fibers is fully reliable and therefore, can be used to correct the RIA temperature dependence in distributed radiation sensing systems based on P-doped optical fibers.

DOUBLE-END RAMAN BASED DISTRIBUTED TEMPERATURE SENSING (RDTS)

- **Raman DTS** used in a wide variety of applications ranging from Oil&Gas industry to the transportation and energy sectors.
- **Double-ended RDTS** are suitable for temperature sensing in **harsh environments** given their capability to compensate for **Wavelength Dependent Losses** (WDL).



- In double-end configuration AS and S traces are alternately acquired in forward and backward directions and properly averaged, providing inherent **correction of WDL and local losses**.

$$T(z) \equiv \left\{ \frac{1}{T_{ref}(z)} - \frac{k_B}{h\Delta\nu} \ln\left[\frac{R^{loop}(z,T)}{R^{loop}_{ref}(z,T_{ref})\Delta loss} \right] \right\}^{-1}$$

Corrected temperature profile:

- Not affected by WDL => not tilted
- Robust to harsh environments and highly reliable

CERN HIGH ENERGY ACCELERATOR MIXED FIELD FACILITY (CHARM) – EXPERIMENTAL SETUP

- 24 GeV/c beam focused on a copper target generating a **mixed radiation field** composed of protons, neutrons, pions, photons, muons and other particles.
- Particle energy spectra representative of space, ground level and accelerator environments.
- **Dose rates** ranging from a few µGy/s up to a few tens of mGy/s.
- Irradiation aerea kept at constant and uniform temperature by means of a ventilation system.

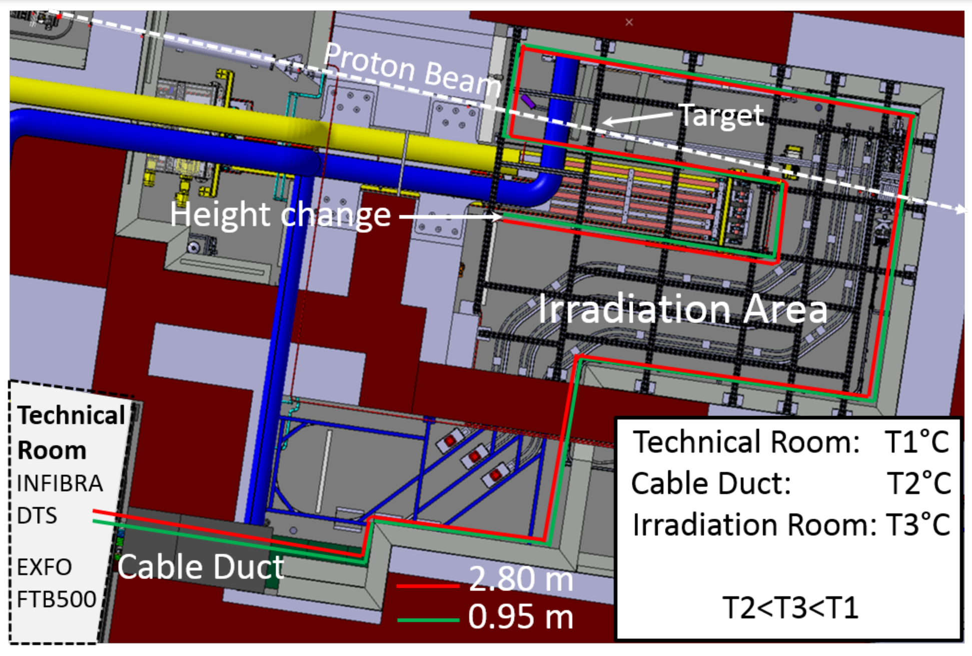


Fig.1 : 2D view of the CHARM facility including the path of the radiation tolerant MM fiber and radiation sensitive SM fiber

- A set of **radiation tolerant** and **radiation sensitive fibers** installed following a 115 m long path in the facility.
- The path runs at 95 cm and 280 cm from the ground, back and forth.
- The fibers are exposed to a large variety of dose rates.
- **Max total accumulated dose** of **1.25 kGy** reached after 24 hours of irradiation, at positions 50 m and 180 m when passing close to the target.

EXPERIMENTAL SETUP

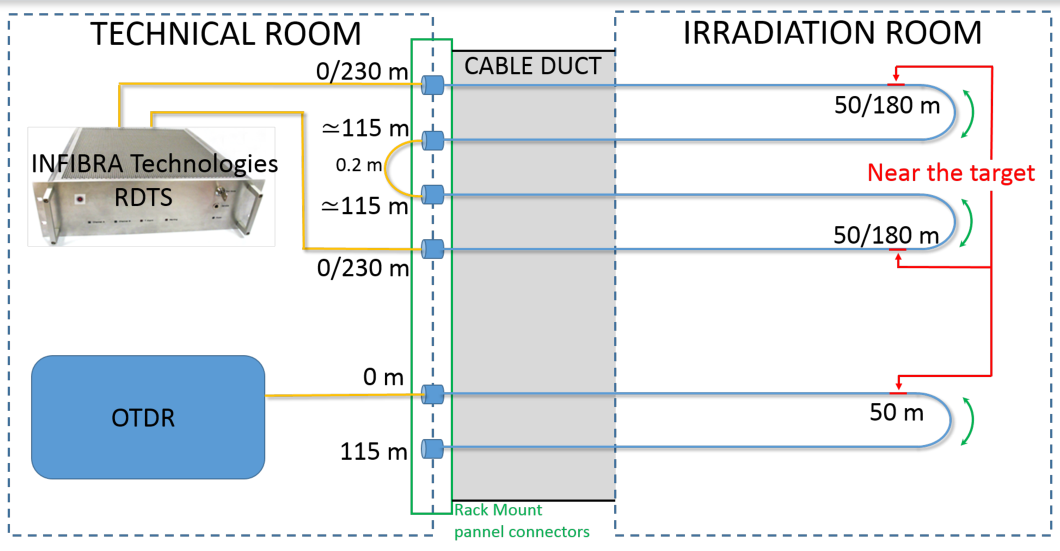


Fig.2 : RDTS control unit, EXFO FTB500 OTDR and the fibers' setup

- RDTS from INFIBRA Technologies S.r.l operating at 1064 nm for temperature sensing
  - **Draka radiation tolerant MM GI (50/125 µm)** MaxCap Bendbright
- EXFO FTB-500 OTDR used for the radiation sensing
  - **Draka radiation sensitive, P-co-doped SMF**

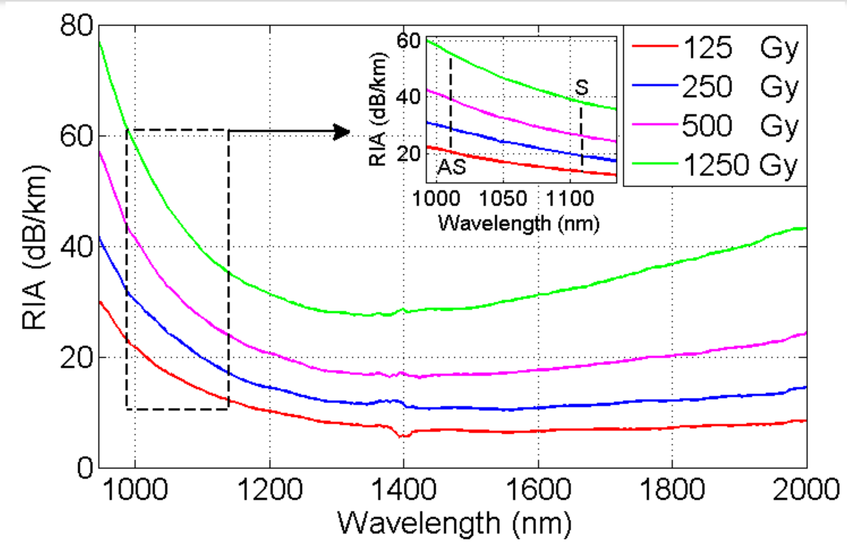


Fig. 3: Draka MM characterization, dose rate 0.23 Gy/s

RESULTS OF DISTRIBUTED TEMPERATURE MEASUREMENTS IN A MIXED FIELD RADIATION ENVIRONMENT

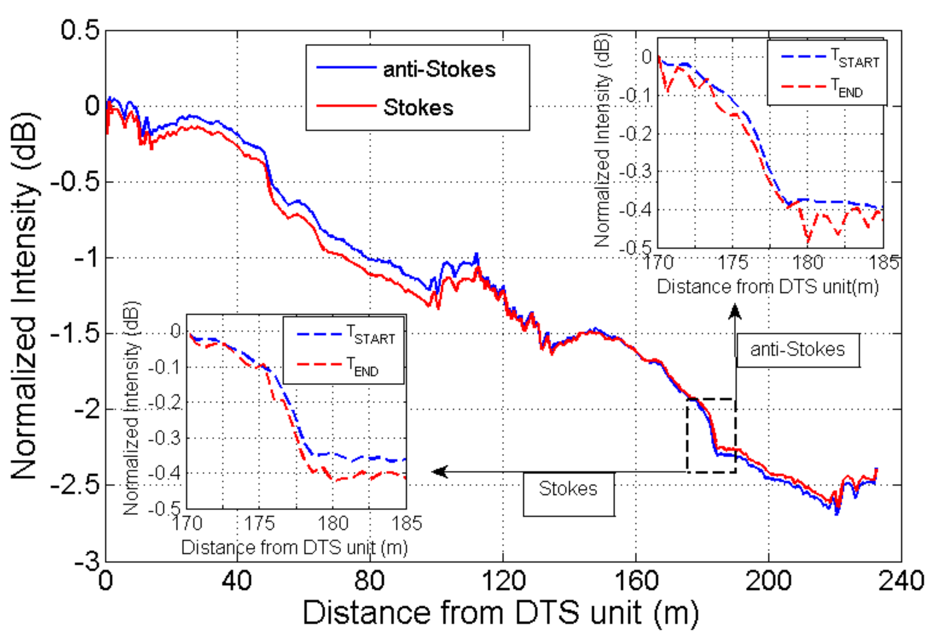


Fig 4: Normalized intensity in the P-doped SMF at different times during irradiation

- Significant **WDL** and **differential RIA** (~ 14dB/km) observed between Stokes and anti-Stokes well compensated
- No temperature variations even in the higher exposed test positions where dose levels range from 600 Gy to 1250 Gy (see insets) and strong radiation gradients are present

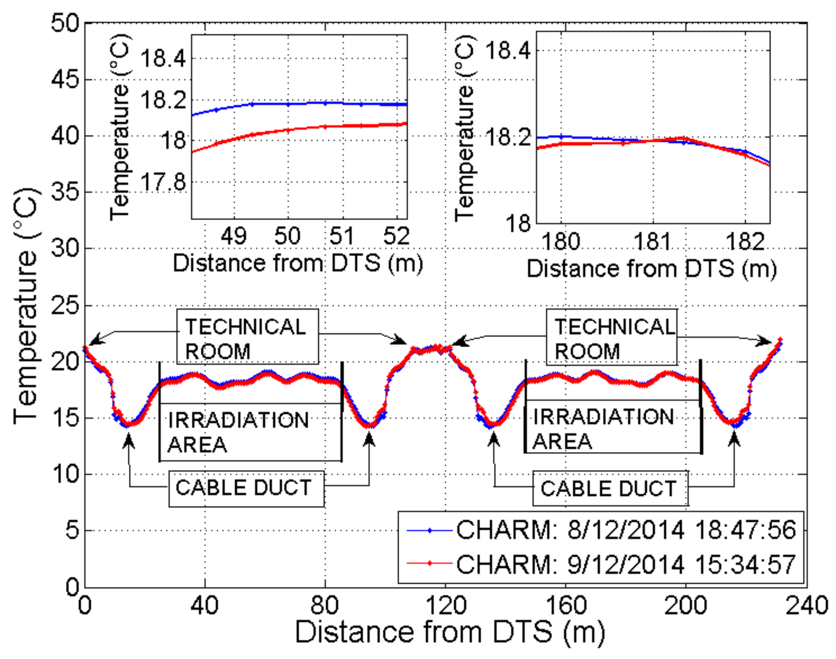


Fig 5: Temperature profiles along the Draka MMF at the beginning and end of irradiation

- 1°C temperature variation can lead to 1% of RIA variation depending on the fiber
- Locally, temperature variations of several tens of degrees can be observed in the Large Hadron Collider (LHC)

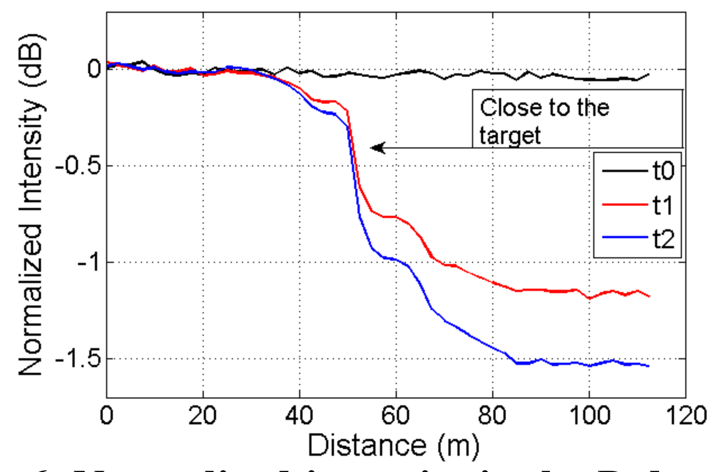


Fig 6: Normalized intensity in the P-doped SMF at different times during irradiation

CONCLUSIONS: In conclusion, we have demonstrated the effectiveness of Raman DTS technology based on radiation tolerant Ge-doped MM optical fibers to accurately measure temperature distributions in harsh environments affected by mixed field radiation. The temperature profiles achieved on Ge-doped optical fibers can then be used to correct the RIA temperature dependence in distributed dosimeters based on P-doped fibers.

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OFS24, 28 September – 2 October, 2015. Curitiba, Brazil