# EDURAC SUMMARY AND EXECUTIVE SUMMARY

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Expose

This document represents the summary and the executicve summary of the project EDURAC.

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# Contents

# 1 Executive Summary

In a joint GSTP research effort between Germany and France in the project EDURAC a radiation tolerant Erbium-doped fiber optical frequency comb has been developed and verified. The achievement represents a cornerstone for the future application of frequency comb technologies in space, enabling various quantum optics applications for navigation, gravimetry, earth observation, and ranging in future missions. The frequency comb tolerated an accumulated dose of 1 kGy at a dose rate of 10 mGy/s, without significant degradation of its operability and signal strength. The achieved radiation hardness corresponds to at least 10 yrs of operation in a mid-earth orbit. A key element to this success has been the development of specialty doped fibers by iXblue and the subsequent design and manufacturing of fiber optical combs by Menlo Systems, based on its proprietary Figure-9 technology. The comb's fiber verification has been achieved using both, passive and active, fiber laser arrangements investigated under Gamma irradiation. For such tests radiation facilities by the Fraunhofer INT institute in Euskirchen, Germany, have been used. The final radiation hardness  qualification took place at the calibrated Cobalt-60 source located at ESA's ESTEC facilities in Noordwijk. The irradiated prototypical frequency comb optics module has been assembled and packaged using low outgassing technologies and components in a flight representative package. The system is designed for low size (0.5 l volume), weight(0.5 kg). Operating power requirements of a 'spacecomb' are expected to be in the range of 20-50 W, depending on its application, payload integration, and mission requirements.

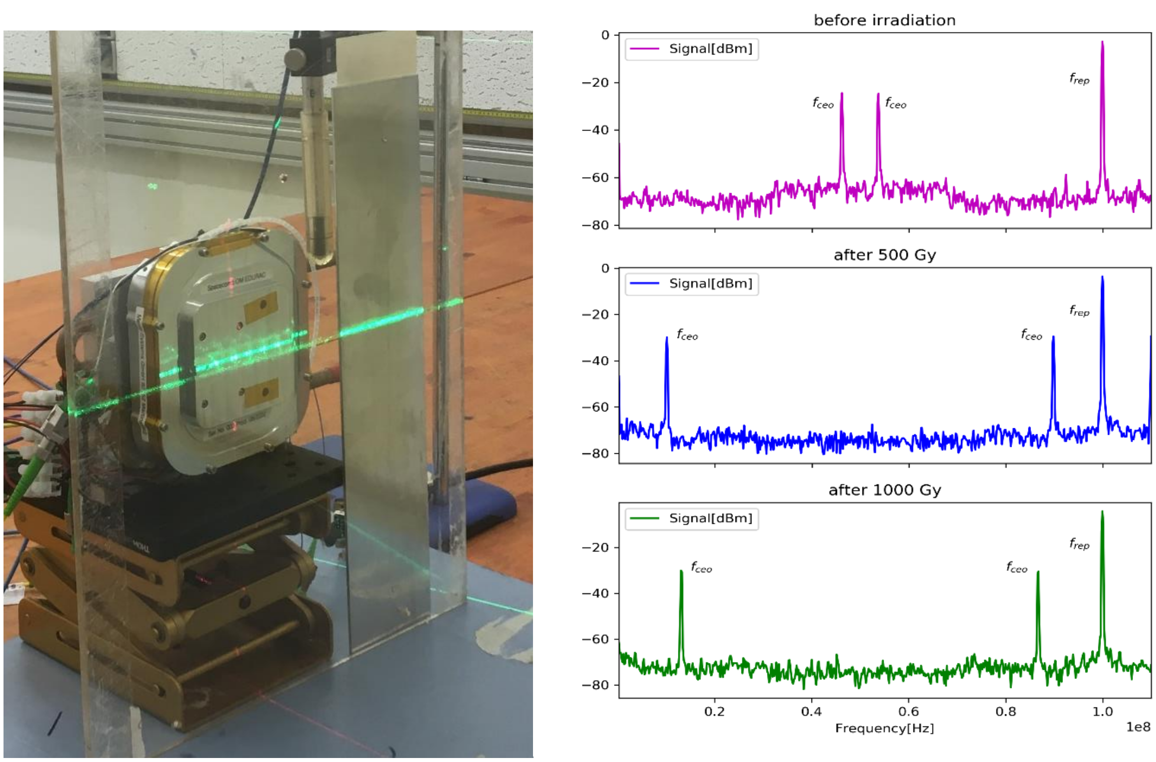


**Figure 1: Left: irradiation of the comb module placed in front of ESTEC's Co-60 source, the alignment laser beam and calibrated dosemeter next to the module are also visible.  Right: Comb's fundamental frequencies RF signal in dBm measured at 100 kHz RBW, detected before irradiation, after 500 Gy, and after 1000 Gy. Radio signal power was essentially unaffected by irradiation.**

## 2 Summary

In a joint GSTP research effort between Germany and France in the project EDURAC a radiation tolerant Erbium-doped fiber optical frequency comb has been developed and verified. The frequency comb has tolerated an accumulated dose of 1 kGy at a dose rate of 10 mGy/s, without significant degradation of its operability and signal strength. Such a radiation hardness corresponds to at least 10 yrs of operation in a mid-earth orbit. A key element to this success has been the development of specialty doped fibers by iXblue, in the present case designing Erbium doped polarization maintining fibers with a controlled low dispersion, high gain up to 35 dB, and 6-8 times improved radiation tolerance. With such fibers the subsequent design and manufacturing of fiber optical combs by Menlo Systems was possible based on its proprietary Figure-9 technology. The resulting fiber comb turned out to be highly efficient, requiring less than 0.7 W of total optical pump power. Thus, pumping can be provided by three 350 mW uncooled 980 nm pump diodes. The comb optics includes Menlo Systems high bandwidth control actuators for the comb's two fundamental frequencies, the repetition rate and the carrier-envelope offset frequency, and the system is ready for being locked to optical or radio frequencies. The frequency comb lines are of low noise, the resulting integrated phase-noise of the stabilized offset beat (100 Hz-1 MHz) is below 80 mrad, which is as good as standard laboratory combs by Menlo Systems. The comb's environmental verification has been achieved using both, passive and active, fiber laser arrangements, operated under Gamma irradiation. Radiation facilities have been provided by the Fraunhofer INT institute in Euskirchen, Germany. The final irradiation test took place at the calibrated Cobalt-60 source located at ESA's ESTEC facilities in Noordwijk, applying two times an accumulated dose of 500 Gy to the system. The irradiated prototypical optics module has been assembled and packaged using low outgassing technologies and components in a flight representative package. The module has low size (0.5 l volume) and weight(0.5 kg). Including losses by thermal stabilization and control electronics the complete system power requirements of a 'spacecomb' based on this optics module are expected to be in the range of 20-50 W, depending on the application, payload integration, and mission requirements. Our achievement represents a cornerstone for the future application of frequency comb technologies in space, enabling various quantum optics applications for navigation, gravimetry, earth observation, and ranging in future missions. In a next step a system based on this technology will be provided for an in-orbit-deployment on the BARTOLOMEO platform within the COMPASSO mission of the DLR, where the frequency comb will be used to compare the stability of two Iodine stabilized reference lasers with ground based precision optical references via a bidirectional laser link.