Evaluation of an SFP Based Test Loop For A future Upgrade of the Optical Transmission for CERN's Beam Interlock System

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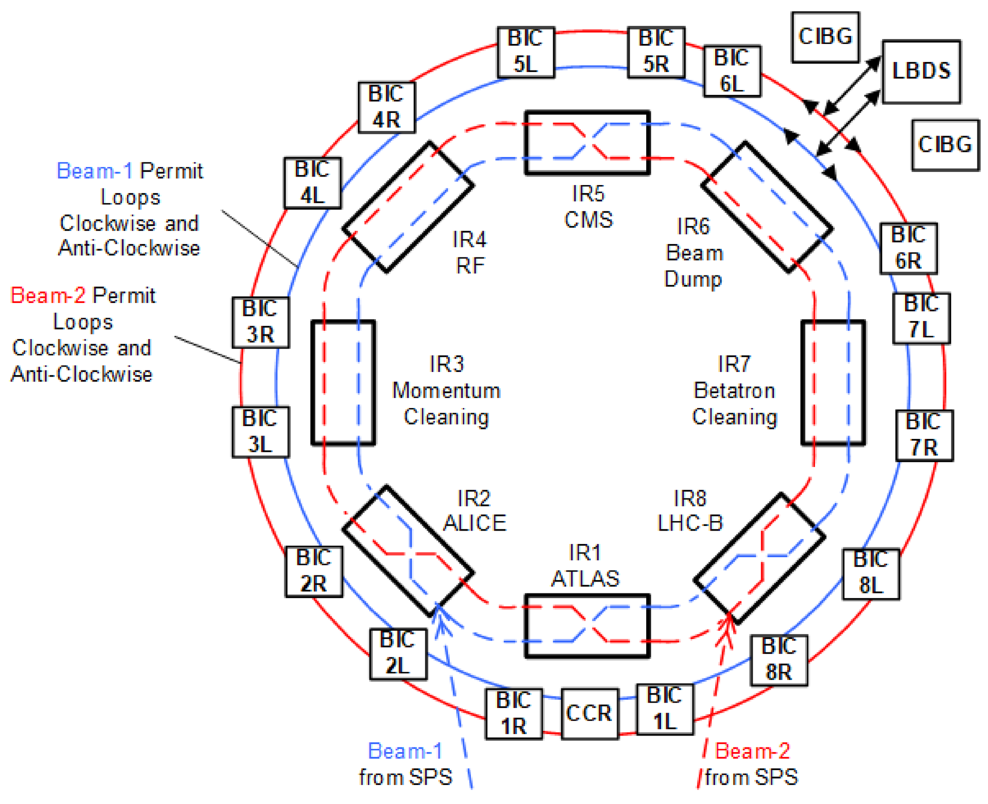
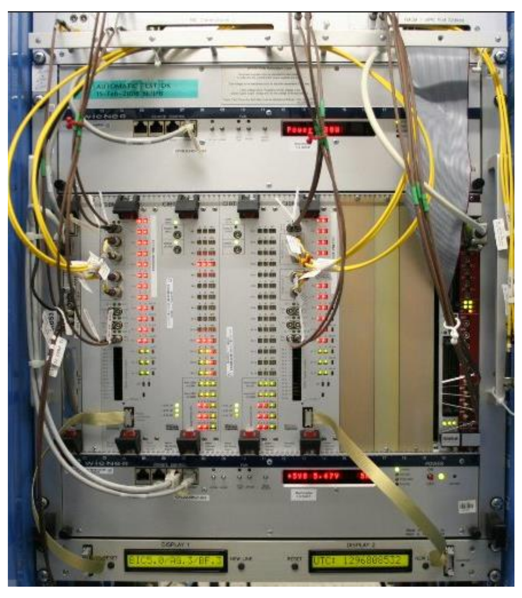
ABSTRACT

The Beam Interlock System (BIS) is the backbone of CERN's machine protection system. The BIS is responsible for relaying the so-called Beam Permit signal, initiating in case of need the controlled removal of the beam by the LHC Beam Dumping System. The Beam Permit is encoded as a frequency signal travelling over a more than 30 km long network of optical fibres all around the LHC ring. The progressive degradation of the optical fibres and the aging of electronics affect the decoding of the Beam Permit, thus potentially resulting in an undesired beam dump event and by this reducing the machine availability. Commercial off-the-shelf SFP transceivers were studied with the aim to improve the performance and continuous monitoring of the optical transmission of the Beam Permit Network. This paper describes the tests carried out in the LHC accelerator to evaluate the selected SFP transceivers and it reports the results of the test loop reaction time measurements during operation. The use of SFPs to optically transmit safety critical signals is being considered as an interesting option not only for the planned major upgrade of the BIS for the HL-LHC era but also for other interlock systems in use at CERN.

LHC BEAM PERMIT LOOPS



Layout of the Beam Permit Loops



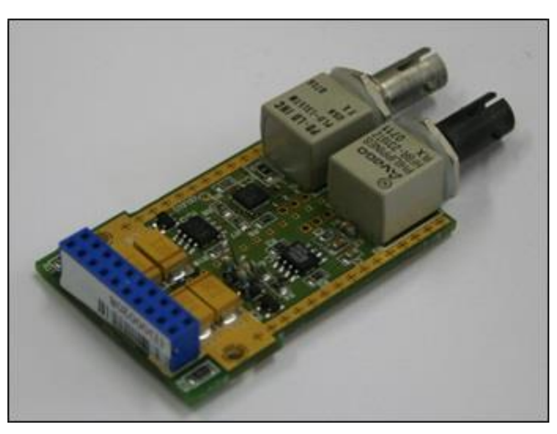
BIS-OP crate

The Beam Permit Loops are one of the most critical parts of the BIS. They carry beam dump requests from the User Systems to the LHC Beam Dump System (LBDS). Its working principle is simple: the Beam Permit is encoded as a frequency signal and sent over optical fibres around the LHC ring. When one of the Users opens the loop, the frequency is interrupted, resulting in the activation of the LBDS.

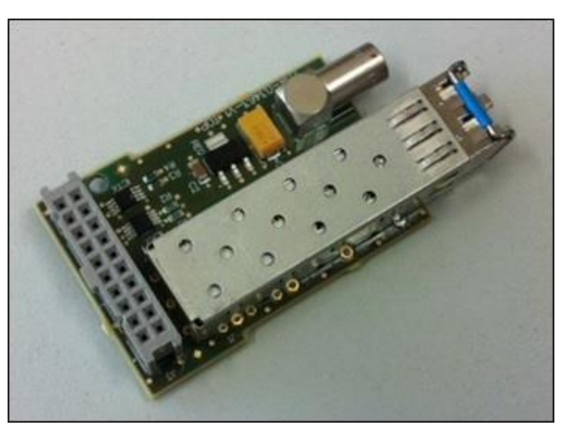
LIMITATIONS OF THE PRESENT OPTICAL TRANSCEIVERS

- low optical budget and lack of gain compensation over temperature variations;
- absence of diagnostics regarding the RX/TX power, operating temperature, bias current, etc;
- erratic operation in DC mode. Switching from a frequency to a DC level signal, i.e. during a beam dump event, provokes an undesired ringing of the Beam Permit signal which could coincide with the Beam Permit loop frequency momentarily;

Commercial SFPs were tested to address the above-mentioned limitations.



ELED based transceiver



SFP based transceiver

Characteristics	CIBO	CIBSFP
Max TX Power	−17.5 dBm	−3 dBm
Max RX Sensitivity	−24 dBm	−20 dBm
Monitoring Functions	No	Yes
Tx Wavelength	1310 nm	1310 nm
Fibre Type	Single Mode	Single Mode
Data Rate	up to 150 Mb/s	up to 1.25 Gb/s

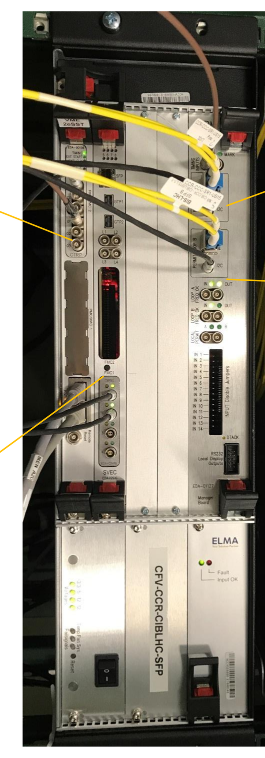
EXPERIMENTAL SETUP BASED ON SFPs

A Beam Interlock Loop based on SFPs (BIS-SFP) was laid out in parallel to the operational LHC BIS (BIS-OP), consisting of 17 ELMA VME64x crates which host the interlock boards. The goal was to validate the correct performance of the system, to check the dual frequency approach and to compare the reaction time against the operational BIS.

Processor board with timing interface for communication with the control system and accurate timestamping

A dedicated VME board was used to monitor the diagnostics registers from the SFP transceivers via I²C protocol:

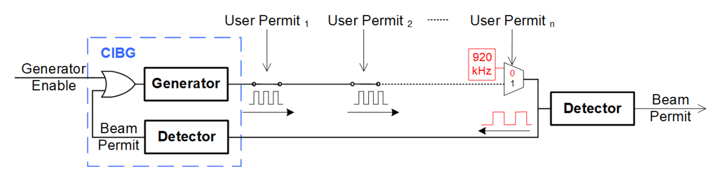
- TX/RX power
- Bias current
- Internal supply voltage
- Operating temperature



BIS-SFP crate

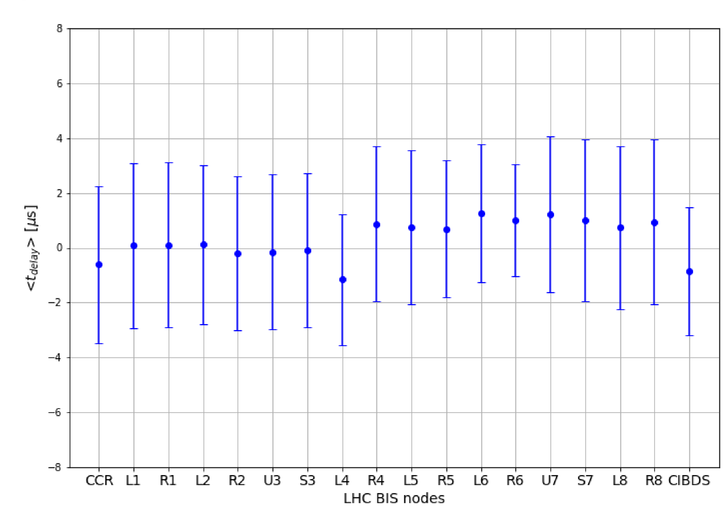
SFP transceivers provide large optical budget and monitoring functions

Dual frequency approach to overcome the limitations of optical transceivers to work with DC signals. The FALSE status of the Beam Permit is not anymore represented by a constant signal but a frequency

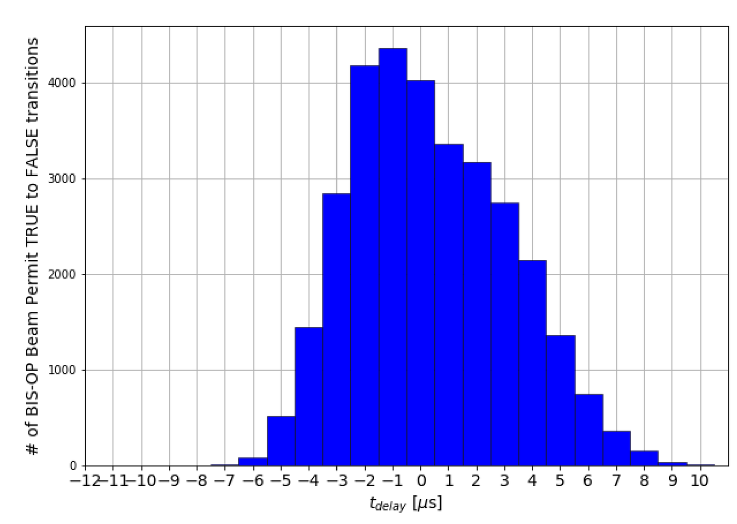


EXPERIMENTAL RESULTS

The overall performance of the SFP-based Beam Permit Loop was evaluated over the period from July 2017 to October 2018, where 1832 beam dump requests were executed. In all cases, the SFP Beam Permit Loop was triggered and neither missed dumps nor spurious triggers were observed. The mean time delay between the optical loops was 0.363 μs with an standard deviation σ of 2.85 μs, which is compatible with the ~ 3.2 μs frequency detection window of the FPGA and other parameters (e.g. fibre length and synchronization difference between BICs).

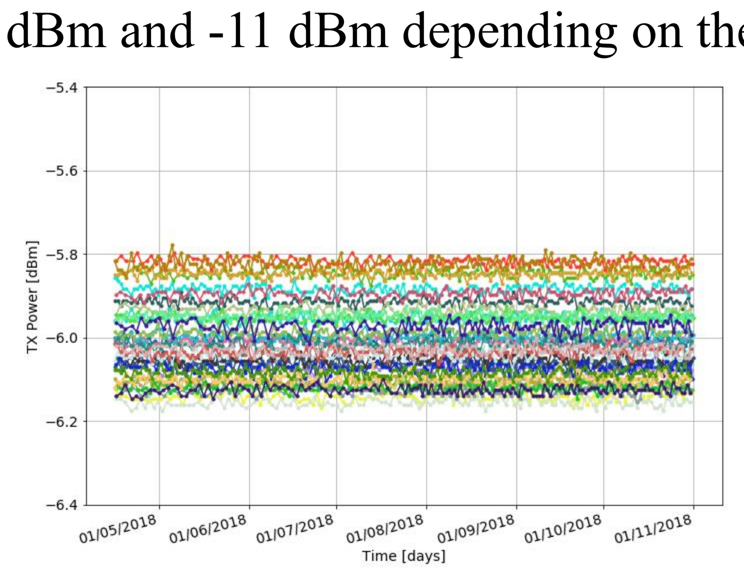


Propagation delay for each SFP node per location

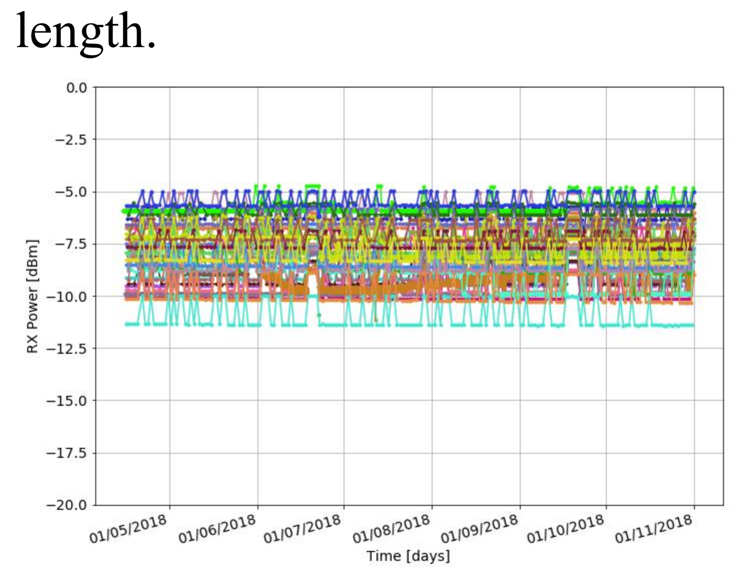


Propagation delay between BIS-OP and SFP-OP

Diagnostics data was remotely read from the SFP registers. The figures below show the power transmitted and received by all SFP transceivers in the loop, which remained constant over several months. The measured average TX power was ˜-6 dBm, while the received power was in the range between ˜-5 dBm and -11 dBm depending on the fibre length.



Power transmitted for each SFP node



Power received for each SFP node

CONCLUSIONS

The use of SFP transceivers has proven to be appropriate for the transmission of safety critical signals at short and long distances along the LHC Beam Interlock System. Test results over more than a year of LHC operation showed a reliable reaction time of the BIS-SFP optical network, using a dual frequency to encode the Beam Permit status. A stress test inducing thousands of dump requests on the BIS-SFP loop will be performed, with the goal to ensure an even higher confidence level in terms of reliability of the system. The collected data demonstrated the justification of using SFPs for several reasons, such as their large power margin to overcome effects of fibre optics degradation, embedded diagnostics capabilities for easier monitoring of the optical network status, and the reduced maintenance needs. As a result, the use of SFPs for the transmission of critical and non-critical information, (e.g. monitoring diagnostics), is being envisaged for future upgrades and applications of the LHC BIS, as well as for other BIS configurations.