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Phase stabilization over a 3 km optical link with sub-picosecond precision for the AWAKE experiment

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The Advanced Wakefield Experiment (AWAKE) project aims at studying the proton-driven plasma wakefield acceleration technique for the first time. For that purpose, a testing facility is currently being built at CERN at the former CNGS (CERN Neutrinos to Gran Sasso) facility. The proton beam at an energy of 400 GeV from the Super Proton Synchrotron (SPS) is used to accelerate an electron beam to the GeV scale over ten meters of plasma. Previous experiments using electron and positron beam drivers showed acceleration gradients up to 50 GV/m: three orders of magnitude higher than RF cavities currently used.

The wakefield acceleration principle requires very precise synchronization between the driver (proton) beam, a laser pulse seeding an instability in a rubidium plasma and the witness (electron) beam. By design, the reference frequency (2997.9 MHz) of the electron beam and the laser repetition rate (88.2 MHz), used for generating the plasma, are derived locally at the AWAKE site and, therefore, the corresponding achievable timing errors are very small. However, the low-level RF (LLRF) system controlling the proton beam of the SPS accelerator needs to synchronize its reference frequency (400.8 MHz) to the plasma (laser) and electron references. Even though the SPS LLRF system is located about 3 km away from the laser and electron beam electronics, the maximum phase drift between the three references has been specified to be in the sub-picosecond range, in order to achieve the maximum energy transfer from the driver to the witness beam.

Since 2014, phase drift measurements over long optical fiber links have been performed to validate the optical medium for reference signal transmission with low phase drifts. In addition, a phase drift measurement logging system has been set up, storing continuously outside temperature and phase difference between a local reference signal and a copy of the same signal sent over a 6 km optical fiber loopback.

In order to cope with the requirements of the AWAKE experiment, we have designed a custom VME board that includes optical transceivers for the synchronization signals to be sent/received, a phase-error discrimination stage and a digital control part embedded in a Xilinx Spartan-6 FPGA. High quality delay lines are used to compensate changes in the phase drift of the optical medium. The delay lines are set using coarse and fine tuning. A real-time control algorithm only performs coarse steps when the SPS proton beam is not present in between acceleration cycles. In addition, an evolved algorithm to compensate for power supply noise and variations of board temperature conditions has been developed.

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