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TRANSMISSION OF A STABILIZED RF PHASE REFERENCE OVER A MONOMODE
FIBRE-OPTIC LINK

E. Peschardt and J. Sladen

ABSTRACT

A scheme is presented for the stabilization of an RF phase reference transmitted across a fibre-optic link. Using a mirror, part of the received light is returned along the same fibre to the transmitting end where half the round trip fibre delay variations are compensated.

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INTRODUCTION

Where it is necessary to distribute an RF phase reference over long distances, a stabilization scheme is often required to compensate for delay variations of the transmission line. In the past these schemes have been employed in coaxial systems.^{1,2} However, with the advent of monomode fibre-optic systems, it can be considerably more economical to use fibre links for transmission of the reference. This is the case for the RF reference distribution at the Large Electron Positron collider (LEP), currently being constructed at CERN, which will be installed in an underground ring tunnel of approximately 27 km circumference. Particle acceleration is accomplished using RF energy at 352 MHz and stabilization of the phases between accelerating stations is necessary if the maximum acceleration is to be attained. In the first phase of operation, two accelerating stations will be equipped, located near two diametrically opposite points of the LEP ring. The RF reference will be sent from a main control room to each station over monomode 1.3 μm links. Transmission delay variations arise primarily due to temperature changes in the cable ducts but are also caused by laser wavelength variations.

For the longest link (8 km) the estimated delay variation is about 1000° at 352 MHz. A phase stabilization system must reduce this to a few degrees.

In this paper, the phase feedback scheme for the LEP fibre-optic links is presented. With a mirror and an optical coupler, part of the received light is returned along the same fibre to a receiver at the transmitting end. This ensures that the delay variations in the go and return paths are equal. Unlike the feedback schemes developed for coaxial systems, the RF signal passes through the compensating phase shifter in only one direction. This simplifies the RF system at the expense of involving some audio processing. However, as the RF signals would normally be mixed down to an audio intermediate frequency (IF) for ease of phase detection, this is not a serious drawback.

Experimental results for a 352 MHz system are given. The test link consisted of 2.4 km of monomode fibre which was temperature-cycled in an environmental chamber to produce large open loop phase variations.

PHASE FEEDBACK SYSTEM

The proposed feedback system is shown in Fig. 1. Various constant phase shifts and amplitudes are not indicated for clarity. The reference RF input passes through a voltage-controlled phase shifter giving a phase shift θ . This signal modulates a laser and is transmitted (via optical coupler 1) over the fibre link. At the receiving end the signal is split in coupler 2. Part of the signal enters receiver 2 and, with a mirror, is returned along the link to receiver 1 at the transmitting end. The total round trip RF phase shift is ϕ . The reference RF, $\sin(\omega t)$, the transmitted RF, $\sin(\omega t + \theta)$, and the returned RF, $\sin(\omega t + \theta + \phi)$, are mixed down to the audio IF, $\hat{\omega}$. After a process of audio mixing and filtering, the signal $\sin(\hat{\omega} t - \theta)$ is obtained. This signal is phase compared with the return IF signal $\sin(\hat{\omega} t + \theta + \phi)$ so that the closed loop maintains $\theta = -\phi/2 + n\pi$ (n integer) and keeps the received phase constant.

Clearly, coupler 1 must have good directivity to isolate the direct laser output from receiver 1. Couplers with directivity of 50 dB are readily available and, if spliced to the transmitting fibre, would give sufficient isolation for many applications. However, this level of isolation would not be maintained if the coupler and fibre were joined with a connector. In order to relax the isolation requirement at coupler 1, the experimental system described below employs a scheme of RF switching (chopping). Directly before transmission, the RF signal is chopped with a duty cycle $< 50\%$. The chopping frequency must be an odd harmonic of the reciprocal of twice the round trip fibre delay, so that the laser is unmodulated when the modulated light returns. In this way, the unwanted RF at receiver 1 output can be removed with a second chopper in antiphase with the first. A phaselocked loop is now required to regenerate the carrier from the output of receiver 2.

Experimental Verification

The configuration was essentially identical to Fig. 1 apart from the inclusion of the RF choppers, one at the transmitter input and the second at the output of receiver 1. The GaInAsP/InP laser launched -4 dBm into the 1.3 μm monomode pigtail and the receivers were germanium avalanche photodiodes. The 2.4 km of monomode fibre was covered in

a loose buffer jacket and consisted of two 1.2 km bobbins joined with a splice. Couplers 1 and 2 had coupling ratios of 1:1 and 1:10 respectively. They were joined to the transmitter, receivers and fibre link with connectors and the mirror was fixed against a connectorized pigtail of coupler 2. The isolation between the transmitter and receiver 1 was 27 dB (optical) and the input power at receiver 1 was -26 dBm. The chopping frequency was 123 kHz with a 40% duty cycle. A lowpass filter removed the chopper sidebands from the IF of 20 kHz. A 10 Hz feedback loop with a d.c. gain of 3000 was employed. The phase between the reference RF and the received RF was monitored with a vector analyser. The RF was 352 MHz.

The fibre was temperature-cycled in an environmental chamber over the range -10°C to 53°C. Below -10°C the attenuation increased sharply. At 53°C the phase shifter was at the limit of its characteristic. Open loop measurements showed a 1140° RF phase shift over the temperature range. The delay increase above 40°C was much higher than that explained by glass thermal expansion and was most likely caused by fibre strain due to the large difference in thermal expansion coefficients between the fibre and the plastic buffer jacket. Between 0°C and 53°C the attenuation was stable within ± 0.2 dB. At -10°C the attenuation had increased by 1 dB.

In the closed loop the 1140° phase variation was reduced to 2.5°. Some of this error was believed to be due to the reflected light entering the laser and modulating the output. This gives rise, at the receiving end, to an unwanted RF signal between the required RF bursts. To confirm this, a third chopper was placed at the output of receiver 2, phased to pass only the wanted bursts. The above temperature test was repeated and the closed loop error was reduced to 1.5°. The problem of far end reflections entering the laser could be overcome more simply by the use of an optical isolator at the laser output.

CONCLUSIONS

We have demonstrated a system for the phase stabilization of an RF signal transmitted over a fibre-optic link. The RF signal passes through a variable phase shifter only in the forward direction and audio processing in the loop doubles the phase shifter component of the loop phase

error. Consequently, in the closed loop, the phase shifter compensates for only half of the phase variations due to the go and return paths. As part of the received light is returned along the same fibre, delay variations in each path are equal and the accuracy of the scheme is assured.

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References

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Fig. 1. Phase feedback system for fibre-optic link