PHASE COMPENSATED FIBRE-OPTIC LINKS FOR THE LEP RF REFERENCE DISTRIBUTION

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Introduction

The positioning of the RF accelerating stations at LEP necessitates precise phase synchronisation over many kilometers. For LEP Phase I, the RF stations are situated at four locations, one either side of the diametrically opposite interaction points numbers 2 and 6 [1]. The master RF frequency generator is situated in the main control room, together with associated equipment, and signal transmission to the RF stations is via 1.3 μm monomode fibre optic links. There is a total of six fibre optic cables for RF transmission. Two cables from the control room terminate in surface buildings at interaction points 2 and 6 (with lengths 5.4 km and 7.9 km respectively). At both of the surface buildings, two cables descend to the RF stations either side of the interaction points (each cable approximately 500 m). The cables contain eight monomode fibres. One is used for the transmission of the phase stabilized RF reference and one for transmission of the bunch repetition frequency. The others are used for returning signals from the RF stations to the control room for monitoring purposes. Transmission delay variations occur due to fibre temperature changes and dispersion. The two long cables are laid in trenches together with 66 kV power cables, and temperature changes are a result of load variations on the high tension cables as well as climatic changes. The total estimated delay variations for the longest link is about 8 ns. A feedback system was therefore developed to compensate for fibre optic transmission delay variations and results from a laboratory prototype have been presented [2]. The system has now been installed and tested at LEP and is described in the following sections.

The LEP accelerating structure consists of coupled accelerating/storage cavity assemblies. They are excited at both their resonant frequencies, f_1 and f_2, spaced by 90 kHz, twice the bunch repetition frequency. These two frequencies are generated locally at each RF station from the received RF reference and bunch frequency signals. The RF distribution frequency is $(f_1 + f_2)/4$, 176.127 MHz. This frequency was chosen in order that the 180° phase ambiguity resulting from the feedback system could be removed by frequency doubling the received reference to 352.254 MHz.

Phase stabilization system

Feedback phase stabilization of a fibre optic link requires returning a fraction of the received light back to the transmitting end of the link. It was

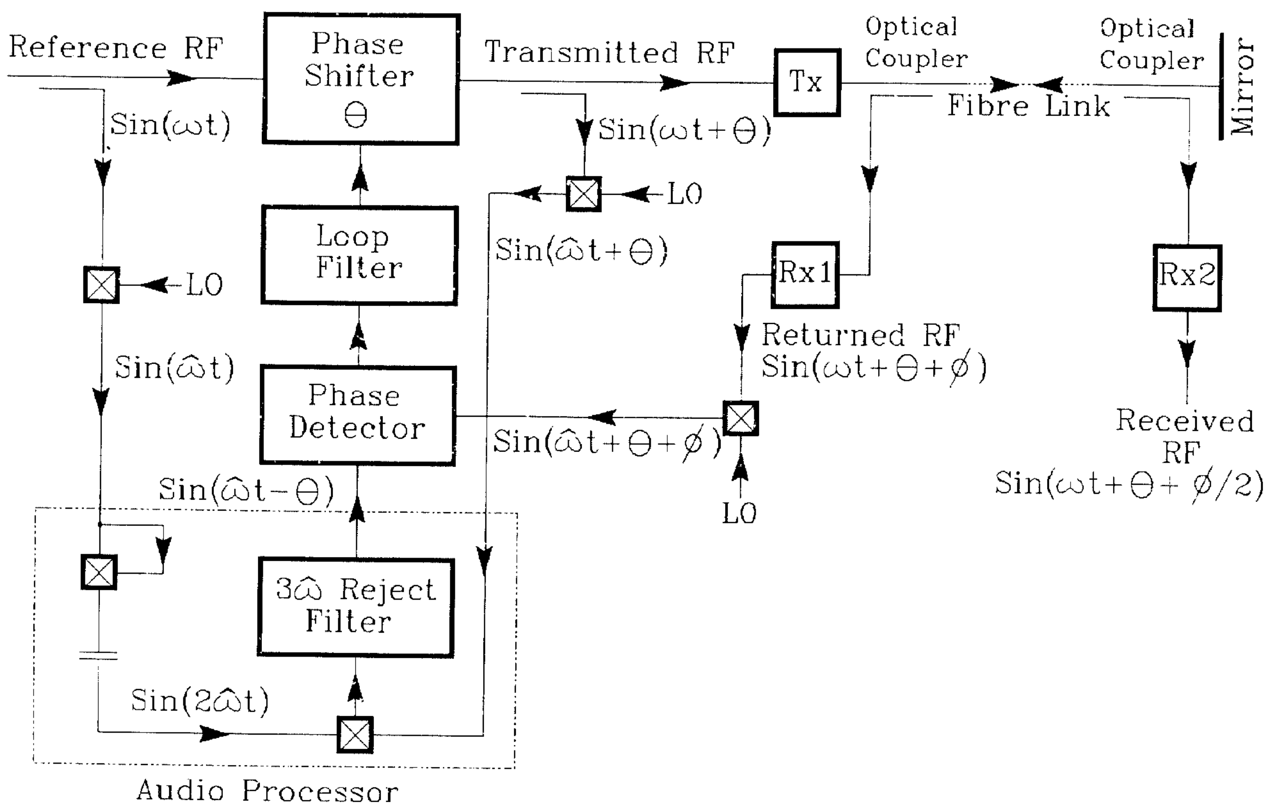

Figure 1 Fibre optic phase feedback system

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at first envisaged to use a second fibre for the return signal. However, tests of a 1 km length of cable containing eight fibres revealed differences of up to 3% in the delay/temperature characteristics of the fibres over a temperature range of 10°C to 30°C. Consequently, to ensure precise tracking of the forward and return paths, bidirectional fibre transmission has been employed. The operation of the system is explained with reference to figure 1. The reference RF signal passes through a voltage controlled phase shifter and then modulates the laser transmitter. The laser output is launched over the link via an optical coupler. At the receiving end, part of the signal is demodulated and part is reflected back down the line to a receiver at the transmitting end. The returned RF undergoes twice the link delay changes which need correction and, in coaxial cable compensation systems, the returned RF is routed through the phase shifter before phase comparison with the reference RF. In the present scheme, this problem is circumvented with the use of audio processing at an intermediate frequency (IF) within the loop, resulting in much simplified RF circuitry. The use of an audio IF has the additional advantage of facilitating phase detection. The signals at various points in the system are indicated in figure 1 where, for simplicity, constant amplitudes and phase shifts have been omitted. ω is the RF and $\hat{\omega}$ the audio IF. θ is the phase introduced by the phase shifter and ϕ the round-trip fibre phase shift. A local oscillator (LO), $\sin(\omega t - \hat{\omega}t)$, mixes the reference RF, the transmitted RF and the return RF down to the IF, $\hat{\omega}$. Via a process of audio mixing and filtering, the signal $\sin(\hat{\omega}t - \theta)$ is produced. It is this signal which is phase compared to 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 RF phase equal to that of the reference. It should be noted that this method shares a drawback of other feedback phase stabilization schemes, namely: a 180° ambiguity in received phase.

In fact, the complete system is more complicated than has been outlined above. The additional circuitry is needed because of leakage of the laser output directly into the return receiver via the coupler at the transmitting end. This direct component is removed from the returned RF signal at the output of receiver 1 using a system of RF switching, or chopping (figure 2). Directly prior to transmission, the RF signal is chopped with a duty cycle < 50 % at a frequency which is an odd harmonic of the reciprocal of twice the round-trip fibre delay. The laser is then unmodulated when the modulated light returns and the unwanted RF is removed from the output of the return receiver with a second chopper in antiphase with the first. At the receiving end, the RF sidebands are removed by means of a phaselocked loop incorporating a voltage controlled quartz oscillator. The loop also serves to improve the signal to noise ratio.

An additional problem was a result of the modulated light reflected from the mirror entering the laser which, during that time, is unmodulated. It was observed that the returning modulated light remodulates the laser output, giving rise to unwanted RF bursts between the required bursts at the output of receiver 2. As the level of remodulation is not great, the problem could be simply solved by means of an optical attenuator at the laser output. A 4 dB attenuator is required for the longest LEP link.

Performance

The six feedback systems for LEP RF reference distribution are now installed and operational. The lasers employed are GaInAsP/InP giving an output of -1 dBm into the pigtail. The receivers contain a PIN photodetector with a GaAs FET transimpedance amplifier. The mirror consists of an aluminium coating on one of the fibres of the 10:1 coupler. A 20 kHz IF is employed and the chopping frequencies are between 100 kHz and 150 kHz (duty cycle 40%). The audio mixing is achieved with precision analogue multipliers. The phase feedback loop has a bandwidth of 10 Hz and a d.c. gain of 3000. For each phase shifter, the control voltage is connected to an analogue to digital converter so that the closed loop phase shift can be monitored by computer. The complete RF reference transmission system installed in the surface building at point 2 is shown in figure 3.

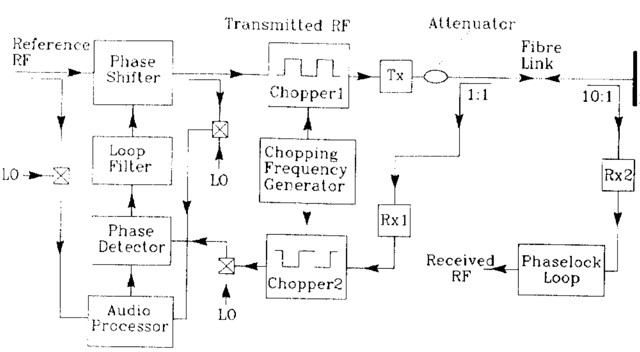

Figure 2 Feedback system with RF chopping

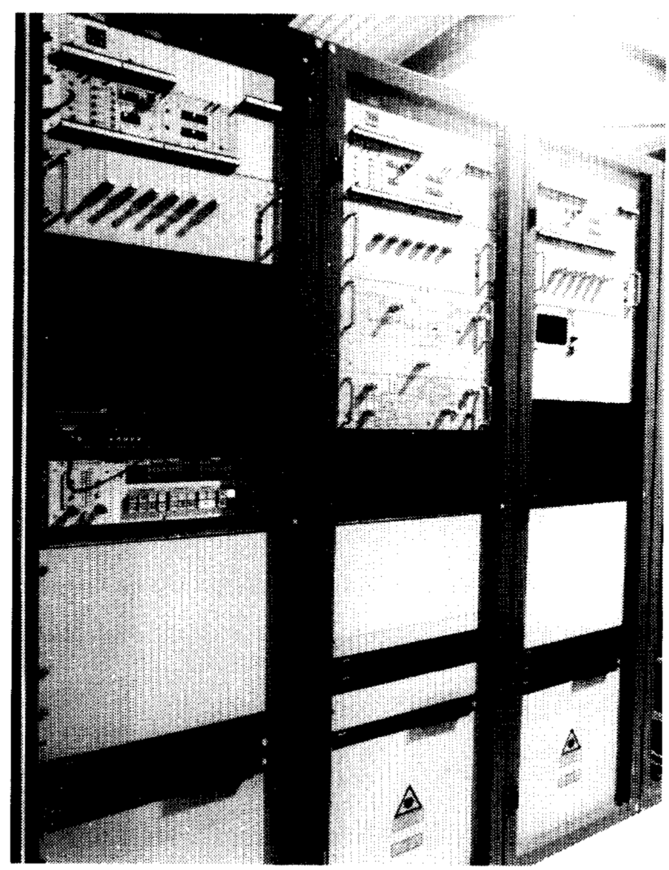

Figure 3 Surface building electronics for phase stabilized transmission system

In order to verify performance of the system in the field, an additional system has been installed over the longest link, returning the reference from the surface building at point 6 to the control room. Since November 1988 the phase of this signal has been checked against the control room reference, and the positions of the feedback phase shifters monitored. The phase shifters have both moved over a range of 120° (at 176 MHz) and the returned phase variations were 2.4°. If this is taken as 1.2° per link, then about half the error is inherent in the feedback system and the rest due to temperature changes in the electronics. Clearly we will need to wait for a few more months to obtain fuller open loop phase variations. However it is not expected that these will significantly increase the observed closed loop error.

When LEP is operational it will be important to monitor the reference transmission system such that faults can be quickly diagnosed, and some means of checking the phases of the received reference at the RF stations is required. Mirroring each link with another phase stabilization system in the opposite direction would be both complicated and costly and is not envisaged. Instead, the received RF signal from each station will be returned over a non-stabilized fibre for phase comparison with the control room reference. The measured phase variations will be approximately opposite to the variations of the phase shifters for the relevant stabilized links. Although this is not a precise check, an indication of serious faults over the transmission system will be obtained. The coaxial switching involved, the phase shifter monitoring and network analyser control will all be automatic.

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References

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[2] Peschardt, E., and Sladen, J.P.H. "Transmission of a stabilized RF phase reference over a monomode fibre optic link", Electronics Letters, 22, No 6, pp. 868-869, 1986.