Transfer of a 1486.3 MHz frequency standard over installed fibre links for local oscillator distribution with a stability of 1 picosecond.

R. McCool, M. Bentley, M.K. Argo, R. Spencer , S. Garrington
The University of Manchester, Jodrell Bank Observatory, Macclesfield, SK11 9DL, UK.
roshene.mccool@manchester.ac.uk

Abstract

Details of a local oscillator distribution system over 110 km of installed fibre with an r.m.s. stability of, 1 ps in 1 second, 2 ps in 1 minute and 4 ps in 10 minutes.

Introduction

This paper provides details of an experiment, conducted at Jodrell Bank Observatory, to measure changes in the one-way and round trip transport delay of a 1486.3 MHz signal transmitted over varying lengths of, installed, standard single mode fibre. The motivation for this work comes from a desire to produce a fibre-based system to maintain coherence in a distributed radio interferomter.

Current L-Band link system

The MERLIN telescope (Multi-Element Radio Linked Interferometer) [1], based at Jodrell Bank, achieves coherent operation using a frequency standard transmitted over microwave links. This system is locally known as the 'L-band Link' (LBL). A Sigma-Tau hydrogen maser source provides the frequency standard for the LBL. Hydrogen Masers have typically been used as master clocks in radio astronomy applications because they have excellent frequency stability (1 x 10^{-13}) and can maintain this stability over periods of hours.

Pulsed 1486.3 MHz signals, distinguished by different pulse lengths, are transmitted 88 times per second, to each outstation. Terminal equipment at the outstations contain excellent quality crystal oscillators that use the 1486.3 MHz signal to lock a 5MHz frequency standard. The difference in the go and return phase values is measured in a phase comparator and recorded. The use of a common frequency, the short timescales and the dispersionless transmission medium, ensure that reciprocity applies and that changes in the returned phases are double the one-way changes. A correction, equal to, the difference on the go and return phase values, halved, is applied to data received from the different antennas. This corrects for the variable delay between antennas at distances of hundreds of kilometres from a central correlator. Tests in the laboratory and astronomical observations have confirmed that the LBL detects changes of delay at ~ 1 ps level over periods of time extending to many hours.

A fibre based LBL system

The LBL system has been working reliably for over 20 years. However, with the advent of a fibre network upgrade to the UK based radio telescope, e-MERLIN [2] there is a motivation to use the fibre network and reduce the costs associated with the microwave links. In addition, microwave links are not considered practical for future radio telescopes, such as the SKA (Square Kilometre Array), where the concentration of antenna would create unacceptable complexity and produce interference in the radio astronomy.

Although transmissions in an optical fibre suffer dispersion the same TDM technique might offer the prospect of a comparable accuracy over fibre provided that similar-enough optical wavelengths are used in the two directions. The specification for radio astronomy with MERLIN is that the fibre link should be reciprocal to:

- Within 1 ps over a 1 second timescale (equivalent to 8º of phase at 22 GHz) – this is to keep signal loss at less than 1% over timescales less than a typical correlator integration period.
- 2 ps over timescales of 1 minute, to keep coherence loss to a few percent whilst integrating on a calibration source.
- 10 ps over a timescale of 10 minutes in order to maintain the linear phase variation between calibrator points.

The pre-existing, radio based LBL system was adapted to measure changes in the round trip delay in installed fibre of up to 110 km long. The objective was to establish if, in an LBL over fibre system, reciprocity would still apply.

Phase measurements

The experiment used existing LBL terminal equipment connected to optical transmitters and receivers separated by optical circulators and a fibre link. The fibre link is part of the MERLIN fibre network and is, in part buried and, in part laid in troughs along the railway lines. Links of 28.6 km and 110.8 km of fibre were tested in this way. Figure 1. shows the experimental set-up.

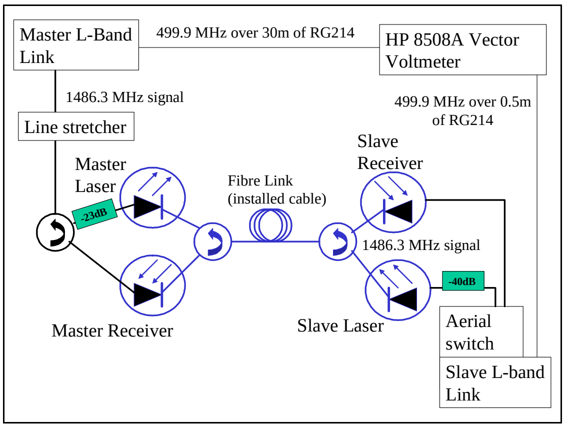

Figure 1. Experimental set-up for a fibre LBL.

A link with no optical components, or fibre, was used to establish the instability error in the LBL equipment and the measurement set up. This measurement removed the effects of the optical system from the results.

A pulsed 1486.3 MHz signal, locked to the maser, is sent from the LBL over RF cable to a directly modulated laser, with no thermal control. This laser has a specified central wavelength of 1550.31nm at 23°C. The signal is then transmitted over a link of installed optical fibre. The receiver at the end of the link is connected to an RF aerial switch that connects the oscillators in the LBL terminal equipment unit that lock to the received signal.

A 499.9 MHz signal locked to the recieved signal is connected to the HP8508A Vector Voltmeter. The phase difference between the original, maser locked, signal and the output of the terminal equipment, gives a value of the phase delay of the one way link.

At the terminal LBL equipment the locked signal is switched to the oputput. The output is connected to another laser. This laser has a specified central wavelength of 1550.85nm at 23°C. The pulsed 1486.3 MHz signal is then sent back over the same link of fibre. At the other end of the fibre link, the signal, is detected by a receiver. This RF signal is connected to the LBL. The LBL calculates the difference in the go and return phases. This value is the round trip phase delay. In the case of an ideal reciprocal system the round trip delay value, halved, should equal the one-way path delay, as measured by the vector voltmeter. Any differences between the two values will indicate the size of the error in the correction added to data at the correlator, or, in other words the stability of the LBL.

Results

The difference between the round trip phase delay, halved, and the one way phase delay was calculated and converted from degrees of phase to seconds. The Allan deviation [3] was calculated and plotted for 0 km, 28.6 km and 110.8 km fibre links. The Allan Deviation plot is shown in figure 2.

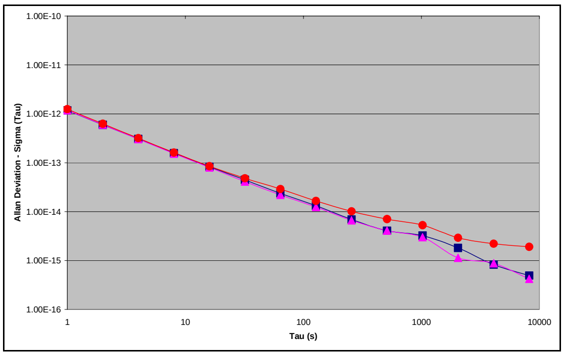

Figure 2. An Allan deviation plot of LBL stability over; 0 km (■), 28.6 km (▲) and 110 km (●)

The results of the experiment show achieved r.m.s. stabilities of:

- 1 ps over 1 second,
- 2 ps over 1 minute and
- 4 ps over 10 minutes.

For sampling intervals of between one second and one minute the stability is the same irrespective of fibre length. This suggests that the short term instability seen in the results is due to terminal equipment and measurement error, rather than a fibre effect. The system is reciprocal over these timescales. Over long term sampling intervals the length of the fibre does effect the stability and this is thought to be due to drift in the wavelength of the lasers and a subsequent change in dispersion related delay difference.

Conclusions

These findings are encouraging and indicate that a fibre based LBL system can achieve the stabilities of 1 ps in 1 second, required for radio astronomy observations at 22 GHz. Further work will look at the stability performance of thermally controlled lasers and longer distance links.

References

[1] Thomasson P., MERLIN, Quarterly Journal of The Royal Astronomical Society, p413-431, Vol 27, 1986.

[2] McCool R. et al., Enhancing the Sensitivity of Radio telescopes Using Fiber-Optic Networks, URSI Radio science bulletin, No 317, June 2006.

[3] Allan D. W., Time and Frequency (Time-Domain) Characterization, Estimation and Prediction of Precision Clocks and Oscillators., IEEE Transactions on Ultrasonics, Ferroelectrics and frequency control, Vol. UFFC-34, No 6, November 1987.