Long-distance fiber-optical transfer of a radio-frequency control signal for radio-astronomy and sensing applications

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Abstract: Passive phase-conjugation enables precise fiber-optical transfer of radio-frequency reference signals over long distances, yielding high long-term stability for radio-astronomy and remote-sensing applications without active path-length stabilization.

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1. Introduction

Long-distance dissemination of highly stable time and frequency standards in the optical, microwave and radio-frequency (RF) domains can be facilitated by optical-fiber networks. Much research [1–3] has addressed means of phase stabilization of the optical-fiber links. Enhanced radio-telescope synchronization for Very Long Baseline Interferometry (VLBI) at radio frequencies is a primary application. Other applications include remote sensing by laser spectroscopy with extremely high accuracy in laboratory, industrial and atmospheric environments.

2. Technique

We have developed a RF transfer technique [4] (Fig. 1) that uses a simple frequency mixing process to achieve algebraic phase conjugation. Slow (>1 s) fluctuations in the optical-fiber path length are passively compensated to ensure that the phase difference between the reference and synchronized sources is independent of the link length. On shorter timescales, a high-quality quartz oscillator, acting as a local "flywheel," is employed at the remote location [4]. This approach allows a high-quality "master" RF reference signal to be transferred without active stabilization to "slave" applications in a remote location (e.g., hundreds of km away).

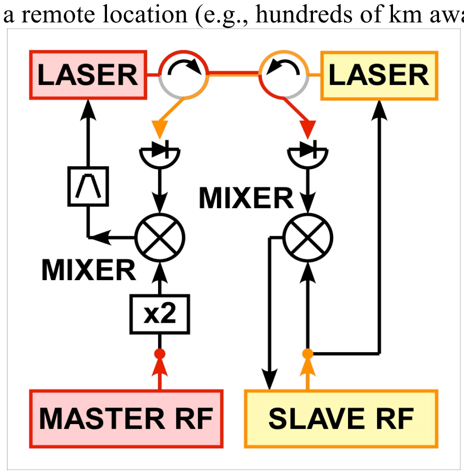

Fig. 1: Simplified schematic of our RF-over-fiber transfer system [4].

3. Experiments

We have realized important applications of our RF-over-fiber technique at the Australia Telescope Compact Array based at Narrabri (NSW), performing VLBI radio astronomy by synchronizing RF timing signals between the telescope receivers *via* ~310 km of installed fiber using two types of experiments.

The first experiment entailed two receiver dishes located side by side to minimize phase fluctuations in received signal due to atmospheric perturbations. Interferometric measurements were made on a strong astronomical source at ~8.6 GHz, with laser-based RF transfer providing frequency synchronization to one of the receivers *via* the ~310-km loop through the fiber-optic link to a remote radio-telescope unit at Mopra (~150 km south of Narrabri) and back. This required independent bidirectional erbium-doped-fiber amplification (EDFA) while sharing the fiber network with other data traffic. Compared to direct H-maser timing, the phase stability for radio-astronomy interferometry was *indistinguishable* from RF transfer *via* the 310-km fiber-optic loop.

A second experiment used the radio telescope at Mopra, with its H-maser timing reference transferred *via* ~155 km of optical fiber to synchronize it with the Narrabri radio-telescope cluster for VLBI measurements. As in the first experiment, VLBI measurements based on a fiber-transferred RF reference demonstrated *the same* level of phase stability as those synchronized using an additional H maser located at Narrabri.

4. Results and discussion

Figure 2 shows the fractional frequency stability of the RF transfer signal as measured in the second experiment on two experimental runs, alongside the stability of two H masers referenced to each other. We find that the fractional frequency-transfer stability for an 80-MHz RF signal is 2×10^{-15} with a 3600-s averaging time through the ~310-km real-world optical-fiber link; this is comparable to the relative stability between two H masers.

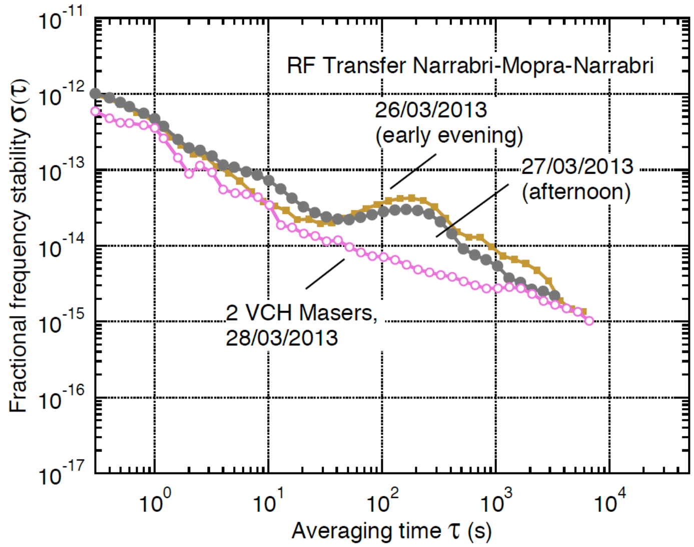

Fig. 2: Allan deviation plots, indicating that the long-term (>1 hour) fractional frequency stability for RF-over-fiber transfer is comparable to that of two separate H masers.

In the course of determining the effectiveness of the fiber-transfer timing, a split-antenna test was used to reduce the effect of atmospheric perturbations. These tests are again a strong validation of the technique, but ongoing work is aimed at suppressing some residual phase fluctuations (on a time scale around ~200 s, as shown in Fig. 2) that affect the transfer stabilization. These phase shifts could arise from thermal drifts in the experimental apparatus, but are more likely due to effects in the 310-km fiber link or to possible phase drifts of different cable paths inside the instrument room at Narrabri.

Our RF-over-fiber approach facilitates fiber-optical dissemination of time and frequency standards over very long (*e.g.*, transcontinental) distances, where the optical round-trip propagation time is significant (*e.g.* ~10 ms per 1000 km) but still within the stability range of the quartz oscillator. RF signals (*e.g.*, referenced to an accurate frequency comb) can then also be remotely transmitted *via* optical fiber to enable calibration of environmental, industrial, and laboratory-based molecular-spectroscopic sensing sites. This obviates the need for a remote frequency reference given that, over hundreds of kilometres, our fiber-optical dissemination system can yield RF frequency stability at least as good as that of a local H maser. In the context of VLBI radio astronomy, our RF-over-fiber approach could well underpin development of technologies to support the Square Kilometre Array.

5. References

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