# LOCAL OSCILLATOR DISTRIBUTION USING A GEOSTATIONARY SATELLITE

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**Abstract.** A satellite communication system suitable for distribution of local oscillator reference signals for a widely spaced microwave array has been developed and tested experimentally. The system uses a round-trip correction method to remove effects stemming from atmospheric fluctuations and radial motion of the satellite. This experiment was carried out using Telstar-5, a commercial Ku-band geostationary satellite. For this initial experiment, both earth stations were located at the same site to facilitate direct comparison of the received signals. The local oscillator reference frequency was chosen to be 300MHz and was sent as the difference between two Ku-band tones. The residual error after applying the round trip correction has been measured to be better than 3psec for integration times ranging from 1 to 2000 seconds. For integration times greater than 500 seconds, the system outperforms a pair of hydrogen masers with the limitation believed to be ground-based equipment phase stability. The idea of distributing local oscillators using a geostationary satellite is not new; several researchers experimented with this technique in the eighties, but the achieved accuracy was 3 to 100 times worse than the present results. Since then, the cost of both leased satellite bandwidth and the Ku-band ground equipment has dropped substantially and the performance of various components has improved. An important factor is the leasing of small amounts of satellite communication bandwidth. We lease three 100kHz bands at approximately one hundredth the cost of a full 36MHz transponder. Further tests of the system using terminals separated by large distances and comparison tests with two hydrogen masers and radio interferometry is needed.

**Key words:** Two Way Satellite Time Transfer, TWTT, TWSTT, Local Oscillator, LO, distribution, Hydrogen Maser

## 1. Introduction

In a synthesis array system, the angular resolution of the image is directly proportional to the longest baseline in the array. Therefore, an array such as the SKA must have several long baselines if high angular resolution is a design parameter. In an array in which all antennas are at a single site, all local oscillators can be derived from a single Hydrogen Maser frequency standard. However, when the antennas are placed long distances from one another, it becomes much more difficult to keep the local oscillators coherent. Unfortunately, any phase instability in the local oscillators translates directly into the received data. For instance, if there is a 10° phase drift in a local oscillator at a given site, then the down-converted data will have a 10° phase drift as well. In addition, there is a phase shift caused by turbulence in the atmosphere [1]. If atmospheric phase instabilities are the dominant source of phase noise in the measurements, then this disturbance can be calibrated out by the use of one or more phase calibration sources [2]. What this means is that the local oscillators used in Very Long Baseline Interferometry (VLBI) must succumb to very stringent stability requirements between calibrations.

The Very Long Baseline Array (VLBA) is equipped with a separate Hydrogen Maser at each antenna. In the case of the VLBA, where there are only eleven antennas, the cost of the Hydrogen Masers is not great enough to be a limiting factor. However, for a larger array, such as the SKA, equipping hundreds of antennas (or clusters of antennas) with their own Hydrogen Maser would impose too large of a cost burden. Therefore, it makes sense to evaluate alternative ways in which local oscillators can be distributed to a sparse array of antennas. In this paper an experiment in which a commercial geostationary satellite was used to distribute a LO signal will be described.

## 2. Two Way Time Transfer (TWTT)

Sending a LO signal through a satellite has several advantages over the use of Hydrogen Masers. First of all, the cost the system is significantly lower than the Hydrogen Maser alternative. This is in part due to the satellite television industry. It is now possible to buy 'off the shelf' low noise blocks (LNB), block upconverters (BUC), and antennas. Each of these components are high quality and cost a fraction of what they would have cost prior to the satellite television boom. Perhaps a more important factor is the fact that the satellite companies have started leasing small amounts of bandwidth inside certain transponders. What this means is that you can now lease 100kHz of a 32MHz transponder for about 1/320$^{th}$ the price of the full transponder. Since the LO signal is a very narrow band signal by nature, this new leasing policy is quite an important breakthrough. There is also a significant performance advantage of the satellite distribution system over the classical Hydrogen Maser approach in that an absolute frequency reference is transferred. Therefore, unlike a Hydrogen Maser, the frequency of the transferred reference will not drift.

However, despite the advantages inherent to the use of a satellite LO distribution, there are several significant challenges which must be dealt with in order to use such a system. When sending a local oscillator signal through a satellite to a remote base-station, a phase shift will occur due to the electrical path length, the earth station hardware, and the satellite hardware. This phase shift will have time dependence and cannot be computed accurately enough to permit interferometry. To combat this effect, a two-way time transfer technique was originally suggested by Yen et al. [3].

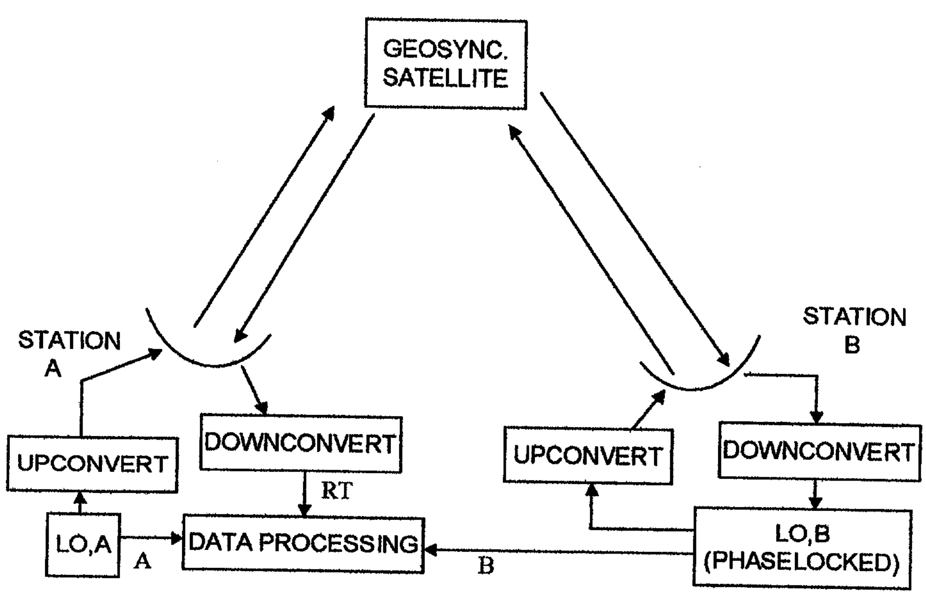


*Figure 1.* Two Way Time Transfer Block Diagram

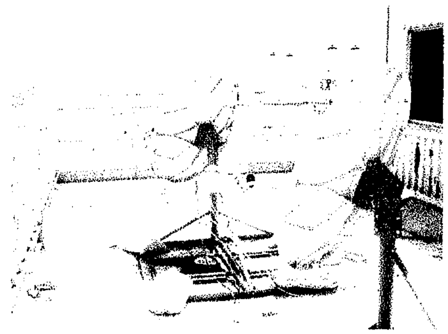

*Figure 2.* Photograph of transmit/receive setup

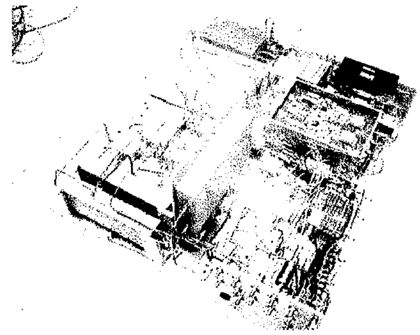

*Figure 3.* Station A Electronics

A block diagram of a two-way time transfer system is presented in figure 1. This experiment was conducted using the Telstar-5 Satellite. The oscillator located at station-A serves as the master LO and is a 5MHz VCXO that is multiplied to 300MHz. The master local oscillator will hereby be referred to as LO-A. The 300MHz frequency standard is transmitted from station-A to station-B as the difference of two Ku band CW tones. Differential transmission of the LO is necessary to remove the effects of any phase noise which would otherwise be introduced by the down-conversion oscillator onboard the satellite. At station-B, the 300MHz signal is recovered using a narrow-band phase lock loop (PLL) which serves as a tracking filter. The tracking filter has an equivalent double sideband (DSB) noise bandwidth of approximately 1Hz. The output of this PLL serves as LO-B, the transferred local oscillator. The phase error in a PLL is dependent on both the SNR of the input signal and the loop bandwidth of the PLL. This quantity can be written explicitly [5]:

$$\Delta\phi_{RMS} = \sqrt{\frac{BL}{SNR_i}}, \tag{1}$$

where BL is the equivalent single sideband (SSB) loop noise bandwidth and $SNR_i$ is the ratio of input signal to the noise in a 1Hz bandwidth. .

In order to measure the phase shift that is encountered during the transmission path, LO-B is sent back through the satellite to station A. We can call this signal LO-RT, where RT stands for 'round trip.' Now, the phase difference between LO-A and LO-B can be written,

$$\phi_B = \phi_t + \phi_{E,B}, \tag{2}$$

where $\phi_t$ is a phase shift due to the satellite link and $\phi_{E,B}$ is a phase shift due to the station B receiver electronics. The phase difference between LO-RT and LO-A can be written,

$$\phi_{RT} = 2\phi_t + \Delta\phi_t + \phi_{E,B} + \phi_{E,A}, \tag{3}$$

where $\phi_{E,A}$ is a phase shift due to the station-A receiver electronics and $\Delta\phi_t$ is an error term due to non-reciprocity of the link. One source of non-reciprocity is the difference in up-link (14.2 GHz) and down-link (11.9 GHz) frequencies coupled with a difference in dispersion due to the ionosphere at sites A and B; this has not been evaluated in the present experiment.

If the ground based hardware has been designed well, $\phi_{E,A}$ and $\phi_{E,B}$ will be constants which can be determined through calibration. However, $\phi_t$ will not be constant, due to radial motion of the satellite and atmospheric fluctuations. For this initial experiment, station-A and station-B were co-located in order to permit the direct measurement of $\phi_B$. Thus we can define a residual error:

$$\phi_{residual} = \frac{\phi_{RT}}{2} - \phi_B = \frac{\Delta\phi_t}{2} + \frac{\phi_{E,A}}{2} - \frac{\phi_{E,B}}{2} \tag{4}$$

So, if the link is perfectly reciprocal and the earth station hardware does not drift, then the residual error will be a constant with noise determined by equation (1).

## 3. Results

Using digital phase detectors, $\phi_B$ and $\phi_{RT}$ were sampled at 100Hz. After the data was unwrapped, Equation (4) was calculated as a function of time. This data was then used to calculate the Allan Standard Deviation and RMS time error. For a description of the Allan Standard Deviation, see [5]. Results appear in figures 4 and 5.

Similar experiments were carried out in the eighties. Results from Cannon et al. [6] and Ables et al. [7] also appear in the figures. One additional experiment in which results in the 10psec range were produced was carried out by Van Ardenne et al. [8].

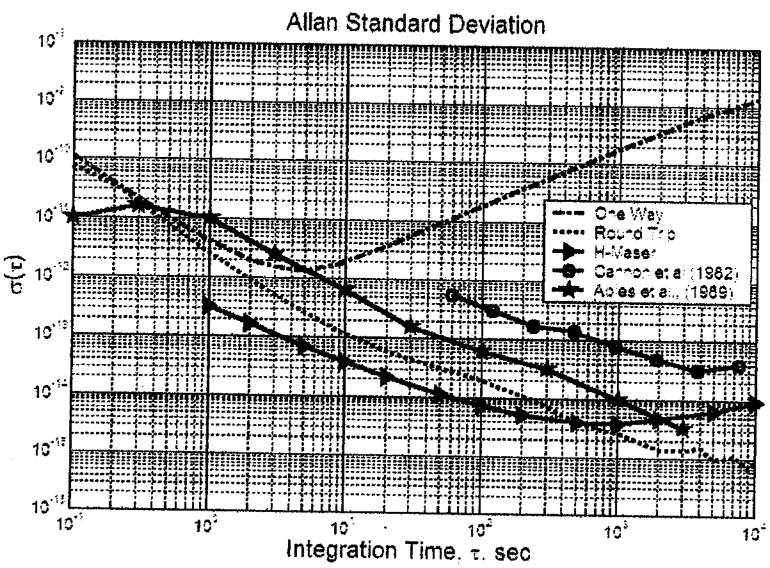


*Figure 4.* Measured Allan Standard Deviation [6], [7]. One way refers to $\phi_B$ and round trip refers to $\phi_{residual}$.

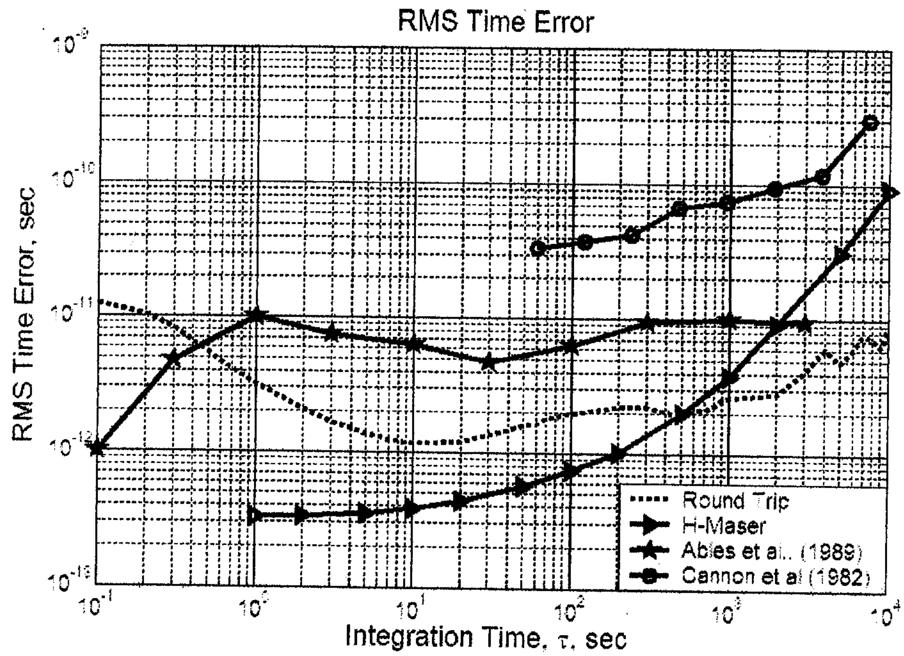


*Figure 5.* Measured RMS time error [6]. [7].

## 4. Conclusions

A TWTT system has been demonstrated in which both terminals were located at the same location. While the results are better than previous results, there is still a need for improvement. There are two clear ways in which the system could be improved. The first improvement is to add a temperature stabilization system to the hardware. It seems that our largest source of error was temperature related effects. In particular, we noticed a ripple in the data that correlated quite well with measured temperature changes in the room. The second way in which the system could be improved is to improve the signal to noise of the link. For this experiment, we transmitted less than ½ watt and used one-meter antennas. Although our contract permitted us to transmit 4 times more power, we simply were unable to increase our power levels without producing unreasonable intermodulation products. Although the results obtained in this experiment look promising, more research is needed. A reasonable next step would be to add temperature control to the system and perform an experiment in which the terminals are significantly separated. Such a test must include hydrogen masers at the two sites and interferometry with astronomical sources to test the long term stability.


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