OPTICAL LINKS AND RF DISTRIBUTION FOR ANTENNA ARRAYS

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***Abstract*—An array of three antennas has recently been developed at the NASA Jet Propulsion Laboratory capable of detecting signals at X and Ka band. The array requires a common frequency reference and high precision phase alignment to correlate received signals. Frequency and timing references are presently provided from a remotely located hydrogen maser and clock through a combination of commercially and custom developed optical links. The selected laser, photo-detector, and fiber components have been tested under anticipated thermal and simulated antenna rotation conditions. The resulting stability limitations due to thermal perturbations or induced stress on the optical fiber have been characterized. Distribution of the X-band local oscillator includes a loop back and precision phase monitor to enable correlation of signals received from each antenna.**

I. INTRODUCTION

The present day NASA Deep Space Network (DSN) consists of approximately 20 large aperture antennas (ranging from 26m to 70m diameter) on three sites around the world. At each DSN site, each antenna receives coherent, highly stable reference frequency signals from a central atomic frequency standard which may be located up to 30 km from the central frequency reference. For nearly two decades reference signals have been distributed using a variety of modulated optical carrier capabilities. During this time, JPL has developed several state of the art optical transmission systems including the Stabilized Fiber Optic Distribution Assembly (SFODA) which has been operational since 1999 [1,2]. During its development and initial field testing, the SFODA was used to enable connected element interferometry experiments between DSN antennas separated by 30 km [3]. Since becoming operational, the SFODA has been used for radio science activities with the Casinni Spacecraft and, most notably, for gravity wave searches between a specially configured DSN antenna and the Cassini spacecraft [4].

NASA has recently undertaken an ambitious effort to develop the next generation DSN to replace the existing aging network and to meet future demands for increased capacity [5]. One viable approach to significantly increase total antenna collection area and tracking capability is with an array of many smaller antennas that can be commercially produced. A preliminary array design envisions nearly 400 twelve meter diameter antennas at each of the three DSN sites with each antenna capable of receiving signals at X and Ka band. The antennas at each DSN site could be operated coherently for tracking missions or radio sources requiring very large collection aperture (i.e. weak signals), or operated in smaller subgroups to accommodate simultaneous tracking of multiple missions. The design requires multiple, low noise, phase stable, and cost effective optical transport of RF signals. Development is currently ongoing to support both receive only and array uplink scenarios. Most operational scenarios require the preservation or easy calibration of long term phase stability of each optical link to enable phase alignment between different antennas.

II. STABILIZED FIBER OPTICAL DISTRIBUTION

Over the past twenty years JPL has developed several state of the art optical transmission systems to distribute frequency and time references to all 20 large aperture antennas in the DSN. From a frequency performance perspective the most demanding mission has been tracking the Cassini mission both during cruise phase (1997-2004) and after orbit insertion at Saturn (2004-). Ambitious Radio Science experiments in search of low frequency gravity waves used a two-way Doppler link at X and Ka band requiring a very stable frequency reference and distribution capability. Because the specialized Cassini support antenna Deep Space Station 25 (DSS-25) is located 16 km from the atomic frequency standard, the SFODA was developed and implemented to compensate for temperature induced phase fluctuations over the fiber optic link.

In 1999 the SFODA was first installed in the DSN to provide stabilized frequency distribution to the research antenna Deep Space Station 13 (DSS-13) and then subsequently to DSS-25. The basic principal of the SFODA is to measure any induced phase variation over the distribution fiber and compensate it by controlling the temperature on a 4 km reel of optical fiber, as shown in Figure 1. The measured Allan deviation achieved with the SFODA with and without compensation is shown in Figure 2. The SFODA successfully met the very demanding phase and frequency stability requirements of the Cassini Radio Science Mission and enabled multiple sensitive Gravity

Wave searches with NASA's Cassini spacecraft. While in operation for more than 6 years, the SFODA has demonstrated short term stability (1 sec) in the high 10^{-15} range and long term stability (1 day and longer) of 10^{-18} .

III. OPTICAL LINKS AND RF DISTRIBUTION FOR THE JPL ANTENNA ARRAY

For NASA's next generation DSN an array, several hundred antennas will reside at each of the three DSN sites. Each antenna will be connected to a central control site providing common reference signals and signal correlation. Optical signals will be used for link the control center to each antenna for transport of frequency and time references, X band and Ka band, and Monitor and Control (M/C) signals.

Currently a three-antenna network (consisting of two 6-meter and one 12-meter antenna) has been developed at JPL (a.k.a. the array breadboard). For the first array system demonstration, frequency and timing references were provided from the JPL Frequency Standards Laboratory approximately 2.4 km from the antenna sites. The initial optical link used an existing multi-segmented and poorly controlled fiber optic network.

The frequency and timing signal flow block diagram for the array breadboard is shown in Figure 3. The reference signal originates in the JPL Frequency Standards Laboratory from a hydrogen maser frequency standard and sent to the antenna control room using a commercial timing and fiber optic distribution system recently developed for the DSN [7,8]. The time code translator (TCT), distribution amplifier (DA) and pulse distribution amplifier (PDA) convert the timing signal and provide 5,10, and 100 MHz reference frequencies as well as 1, 10, 100, and 1000 pps signals. The fiber optical transmitter (FO TX) sends X band (7.5 GHz, generated from 100 MHz) to the antenna as the local oscillator (LO) source. For the downlink, the X band signal is sent from the antennas to the control room through the optical links. The cable temperature stability, phase differential stability for straight stress and rotation (to simulate the antenna turning) were measured.

The X-band local oscillator signal was generated at the array control center and then distributed to each of the three antennas by fibers mounted in above ground conduits and exposed to large temperature variations. The breadboard frequency and timing system was built using a combination of commercially available and custom developed components. The laser, photo-detector, and fiber components were selected and tested under projected thermal conditions and the effect of induced stress under simulated antenna rotation conditions was characterized. The X-band local oscillator distribution between the three antennas also incorporates a loop back and precision phase monitor to provide phase calibration information for signal correlation.

Since frequency Local Oscillator (LO) distribution from the control center is via optical fiber cable and is monitored through a loop back cable, the fiber performance under thermal and mechanical stress is a critical. In the breadboard design, the phase compensation technique assumes that the round trip phase variation is twice the one way variation. To verify this we measured the thermal stability of single fiber and the differential thermal stability of two fibers in the same cable under identical environmental conditions. In practice, one fiber is used to transfer the primary RF signal and a second fiber in the same cable is used to obtain phase perturbation information needed to compensate the variation fiber length. Figure 4 shows the test results of phase variations and stability for a 1.4 km optical fiber subjected to large temperature variations. Figure 5 shows the differential phase and stability between two fibers in the same test cable and under simultaneous conditions as shown in Figure 4 for a single fiber.

The rotation of the antenna causes stress and effective fiber length changes. To simulate antenna movement and cable wrap effects, we measured the phase stability of a 0.7 km, 4 fiber optical fiber cable while 1 pound weights were applied to stress it. The cable reel was rotated at a constant rotation rate of 18° per minute for 10 minutes and then reversed to its starting position. The cable reel diameter was 15 inches. The test results with 1 pound of stress on the cable are shown in Figure 6.

The breadboard array is now receiving X and Ka signals from the Mars Reconnaissance Orbiter (MRO) spacecraft and the effectiveness of the LO distribution and long term phase monitoring is being evaluated. Long term round trip showing the large monitored phase variations from the control room to Antennas 1 and 2 are shown in Figure 7. A more streamlined approach for signal transport that integrates closed loop phase compensation, though much smaller and less costly than the SFODA, is currently under development [9].

IV. ACKNOWLEDGMENTS

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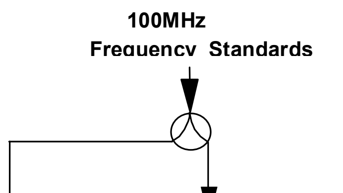

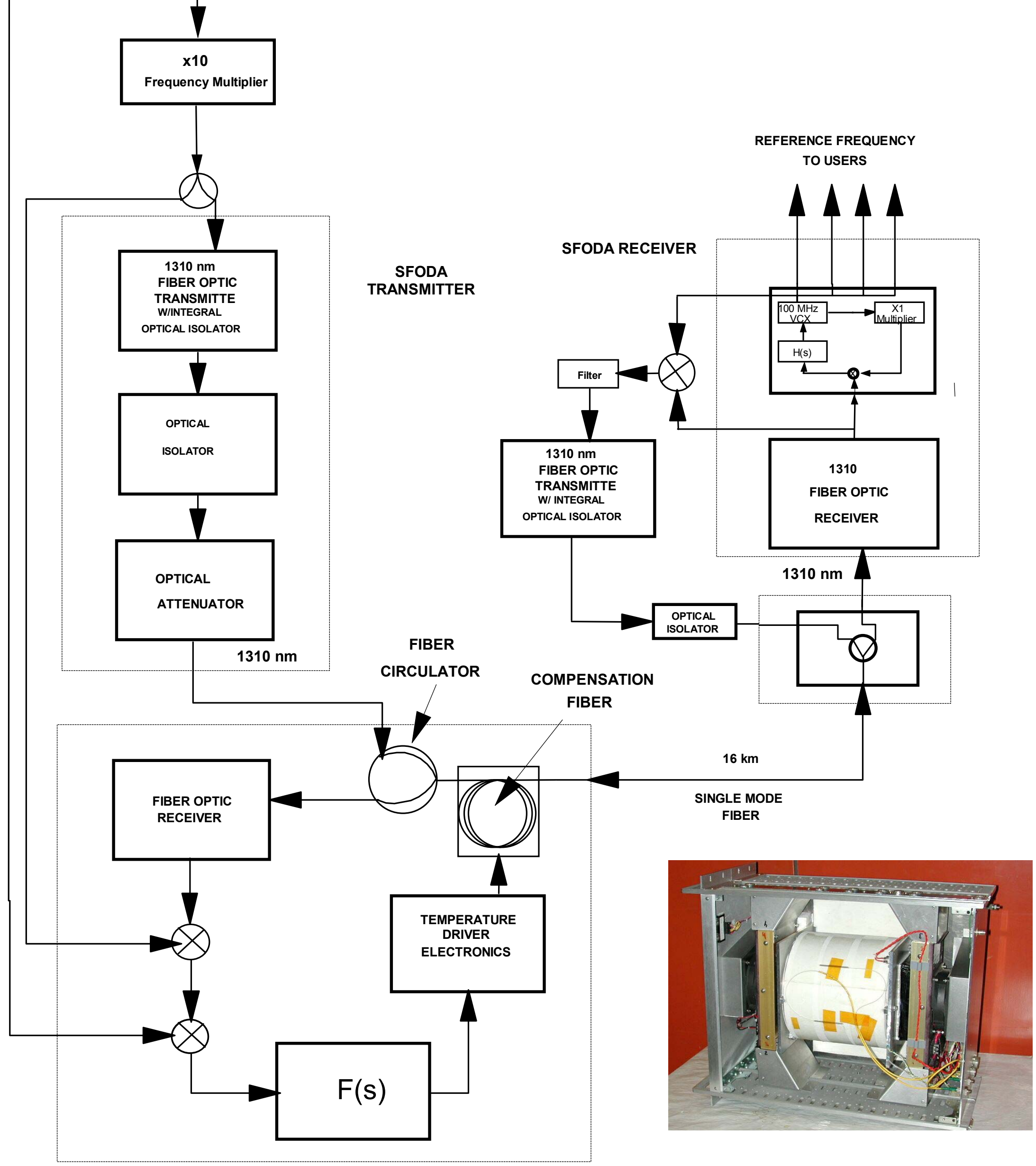

Figure 1. Conceptual Block Diagram of the SFODA. The 4 km compensation fiber reel is shown at the lower right.

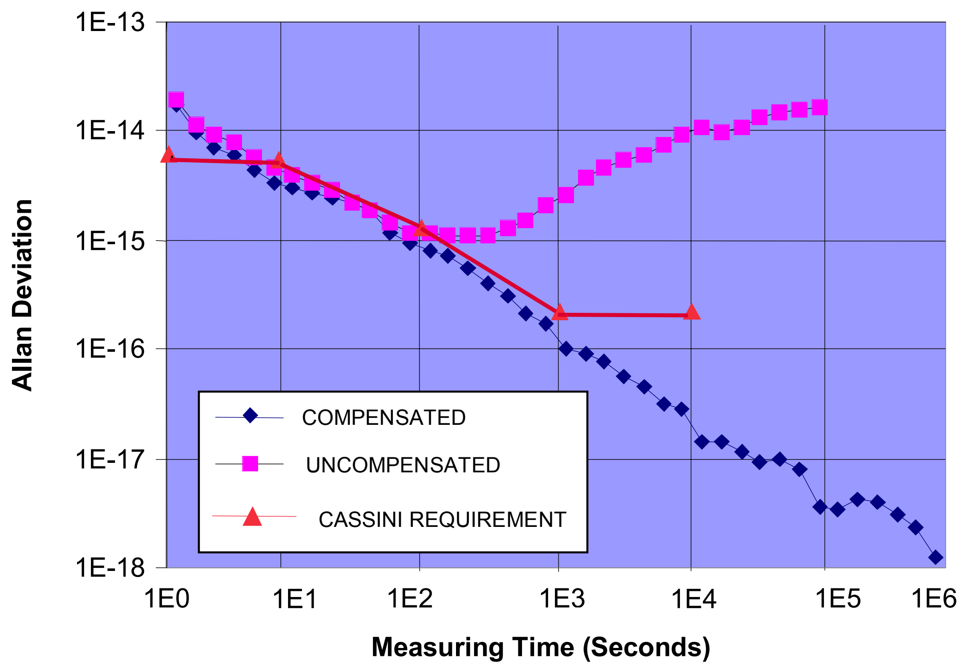

Figure 2. Stability of the Stabilized Fiber Optic Distribution Assembly (SFODA)
(16 km fiber reel in test chamber. 1 second data is degraded by measurement system used in 1999)

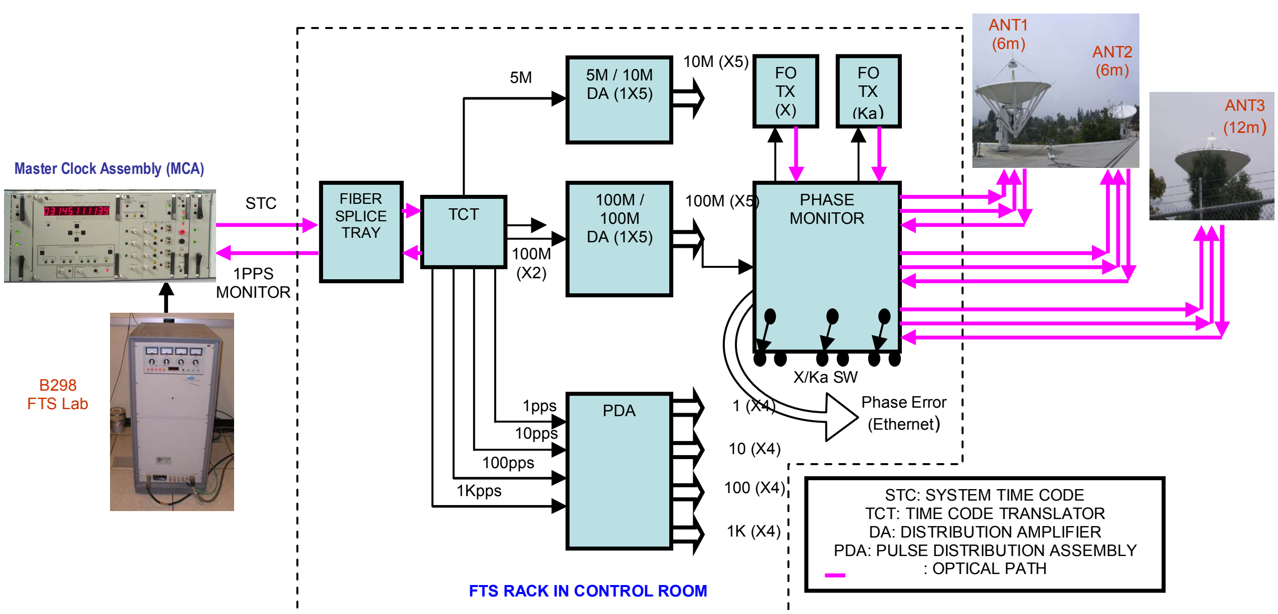

Figure 3. Frequency and Timing References for the DSN Array Breadboard

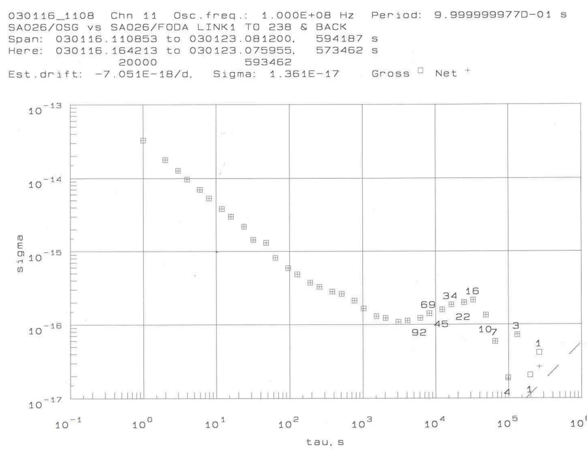

Figure 4: 1.4 km Single Fiber Phase Variation

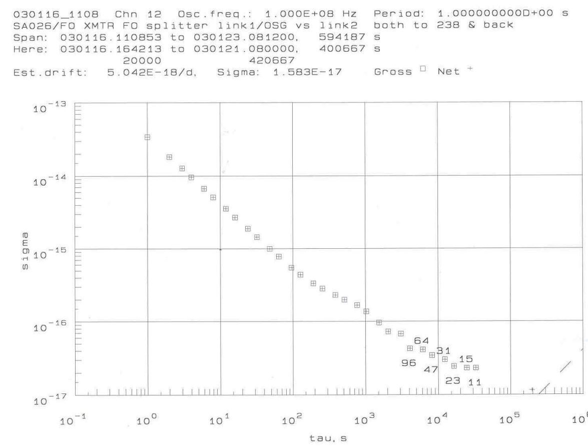

Figure 5: Differential phase variation, two fibers in same cable.

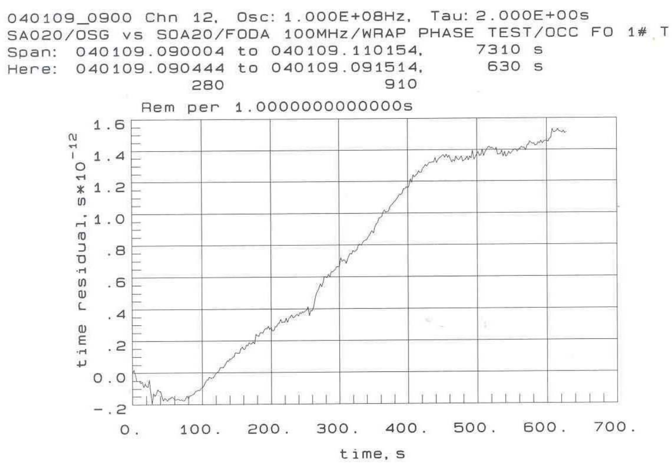

Figure 6. Cable Stress Testing (January 2004), (1 Pound tension, 15” bend diameter, 180° rotation over 10 minute interval)

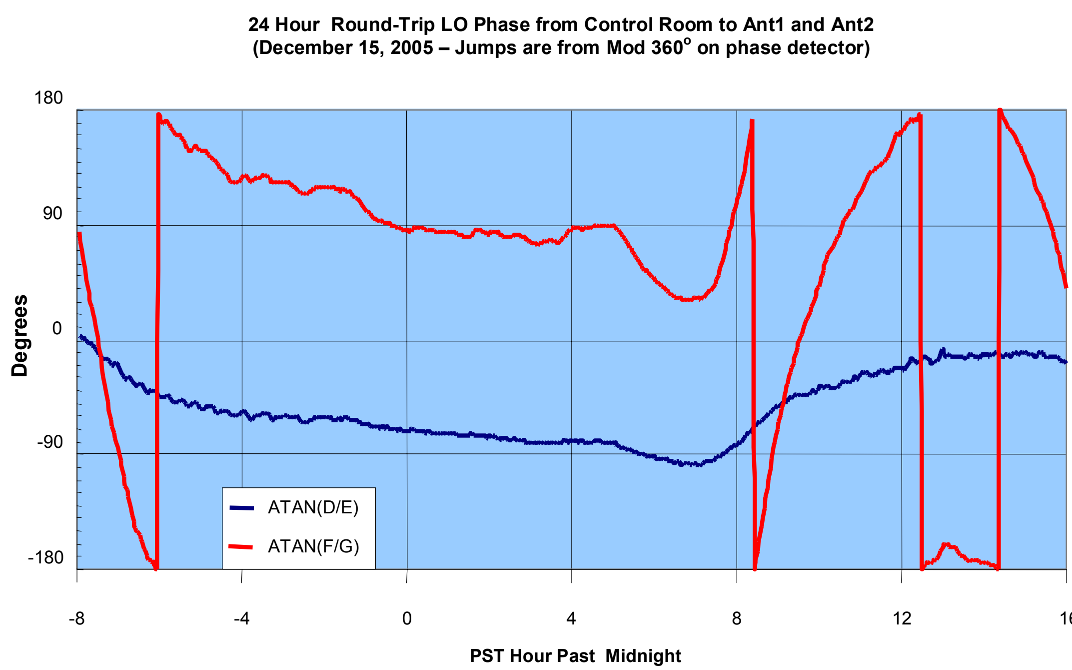

Figure 7. Control Room to Antenna Round-Trip Phase Monitor