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A Proposed Far-Field Method for Frequency-Stability Measurements on the DSS 13 Beam-Waveguide Antenna

T. Y. Otoshi
Ground Antennas and Facilities Engineering Section

A method is presented for measuring the frequency stability of the new beam-waveguide (BWG) antenna at DSS 13. This method is relatively inexpensive and primarily utilizes equipment that is already available. Another desirable feature of the method is that a far-field signal will be used for the measurement. In concert with the goal of employing new technology developments, a fiber-optic system will be used at 12 GHz to carry a reference antenna signal to the BWG antenna Ku-band test-package location in the pedestal room.

I. Introduction

This article presents a method for measuring the frequency stability of the antenna optics portion of the new DSS 13 beam-waveguide (BWG) system [1]. The antenna optics portion, hereafter referred to as the antenna, is defined as the portion of the antenna system that includes the main reflector, subreflector, the six mirrors, and the feedhorn assembly located at the final focal point in the pedestal room. The ultimate goal is to develop an accurate far-field method for measuring the frequency stability, group-delay stability, and phase-delay stability of the antenna at X- and Ka-band.

Frequency stability [2] is closely related to group-delay and phase-delay stability in that all three data types are derived from measurements or calculations of small phase perturbations. In the case of frequency stability, measured phase deviations over specified time intervals are converted to fractional frequency deviations of the carrier frequency. In the case of group-delay stability, changes of phase deviations from linear phase characteristics are measured over a specified spanned bandwidth as functions of time. Similarly, in the case of phase-delay stability, the measured changes of phase as functions of time are converted to equivalent pathlength changes for the carrier microwave frequency. Scientists who perform gravity-wave experiments are interested in measurements of frequency stability, while those who perform ranging and very-long-baseline interferometry (VLBI) experiments are interested in group- and phase-delay stability, respectively.

Previously, measurements of the frequency stability of Deep Space Network (DSN) tracking systems did not include the antenna. The methods employed in the past to measure frequency, group-delay, and phase-delay stability of an antenna are discussed in the Appendix. The disadvantages of those methods are also discussed.

The new far-field method discussed here takes advantage of recent advances made in fiber-optic technology. Most of the equipment required for making frequency-stability measurements with this new method is readily available.

II. Methodology

Figure 1 shows a block diagram of the proposed experimental setup, which utilizes far-field transponder and beacon signals available from geostationary satellites at elevation angles between 12 and 47 deg. The method will utilize the already existing Ku-band microwave feedhorn and test package [3] to receive the satellite signals at various focal points of the BWG system at DSS 13. In addition, a phase-detector Allan-deviation measurement instrument [4] and a 10-ft reference antenna, which are already available, will be utilized for this project.

The only new development required is a Ku-band fiber-optic cable system (including modulators, isolators, and amplifiers) that is capable of transmitting the reference antenna signal (12 GHz) over the 50-m distance to the pedestal room. Tests by G. F. Lutes and R. T. Logan [5] of fiber-optic systems at 8.4 GHz demonstrated frequency stability of about 7×10^{-16} for sampling times of 10 sec, which is approximately two orders of magnitude better than the frequency stability of typical hydrogen masers.

One advantage of the proposed method is that it does not require reference signals that are coherent with the station clock. Another advantage is that through the use of a far-field signal propagating through both the test antenna and a reference antenna, phase changes and atmospheric and ionospheric variations tend to cancel out when differenced in the output. Available equipment and state-of-the art technologies are utilized. Furthermore, the experimental setup utilizes fiber-optic technology, which seems to be the way of the future, and is in concert with other DSN–JPL goals.

The initial system will enable measurements of the stability of the BWG system at fixed elevation angles as functions of time and weather conditions (wind, ambient temperatures). Even though the measurements will be made at Ku-band, the information can be extrapolated to other frequencies, provided that the variations are related mostly to mechanical structural deformation. This is just the first step toward getting an accurate measurement of frequency stability of the antenna optics portion of a large antenna.

A variation and possible improvement of the proposed method is to move the reference antenna to the front of the subreflector. Then the possibility exists for using a spacecraft signal or radio sources for phase- and group-delay calibrations at various elevation and azimuth angles.

Early in 1995, X- and Ku-band far-field signals from Earth-orbiting spacecraft will become available for a Space VLBI Project.[1] These same signals can be used to calibrate the stability of the BWG antenna at various elevation angles with the configuration described above. For this Space VLBI Project, a Soviet spacecraft named Radioastron will be launched and will transmit X- and Ku-band downlink frequencies of 8.473 GHz and 15.06 GHz, respectively. A Japanese spacecraft named VSOP will be launched and will transmit a Ku-band downlink frequency of 14.2 GHz. The worldwide VLBI experiments to be performed with the Soviet and Japanese spacecraft represent an international group effort whose participants include the United States, Japan, the Soviet Union, Western Europe, Canada, and Australia.

III. Concluding Remarks

There is a strong need to develop a far-field frequency-stability measurement technique for measuring antenna effects that does not tie up an additional DSN tracking antenna (fully implemented with phase calibrators, low-noise amplifier, VLBI processors, etc.), as is necessary for the VLBI or the connected-element interferometry (CEI) techniques. The processing from the system proposed in this article is simpler, less expensive, and enables useful data to be obtained in a shorter time frame.

It is suggested that the proposed work be the pioneering effort to uncover major problems in a short time frame, while the VLBI and CEI efforts are carried out in parallel for the long-term solution. Technology developed from this work can be transferred to such other projects as holography and the gravity-wave experiments. An opportunity exists to demonstrate that fiber-optic cables can be used to carry microwave frequencies (X- or Ku-bands) over long pathlengths with only negligible degradation of the signal (both phase and amplitude). The spin-offs from such a joint effort will potentially benefit other projects in the future.

[1] *Orbiting VLBI Subnet C/D Review*, JPL D-8361 (internal document), Jet Propulsion Laboratory, Pasadena, California, April 3, 1991, and *Design Requirements: DSN Orbiting VLBI Subnet*, JPL DM515606A (internal document), Jet Propulsion Laboratory, Pasadena, California, May 16, 1991.

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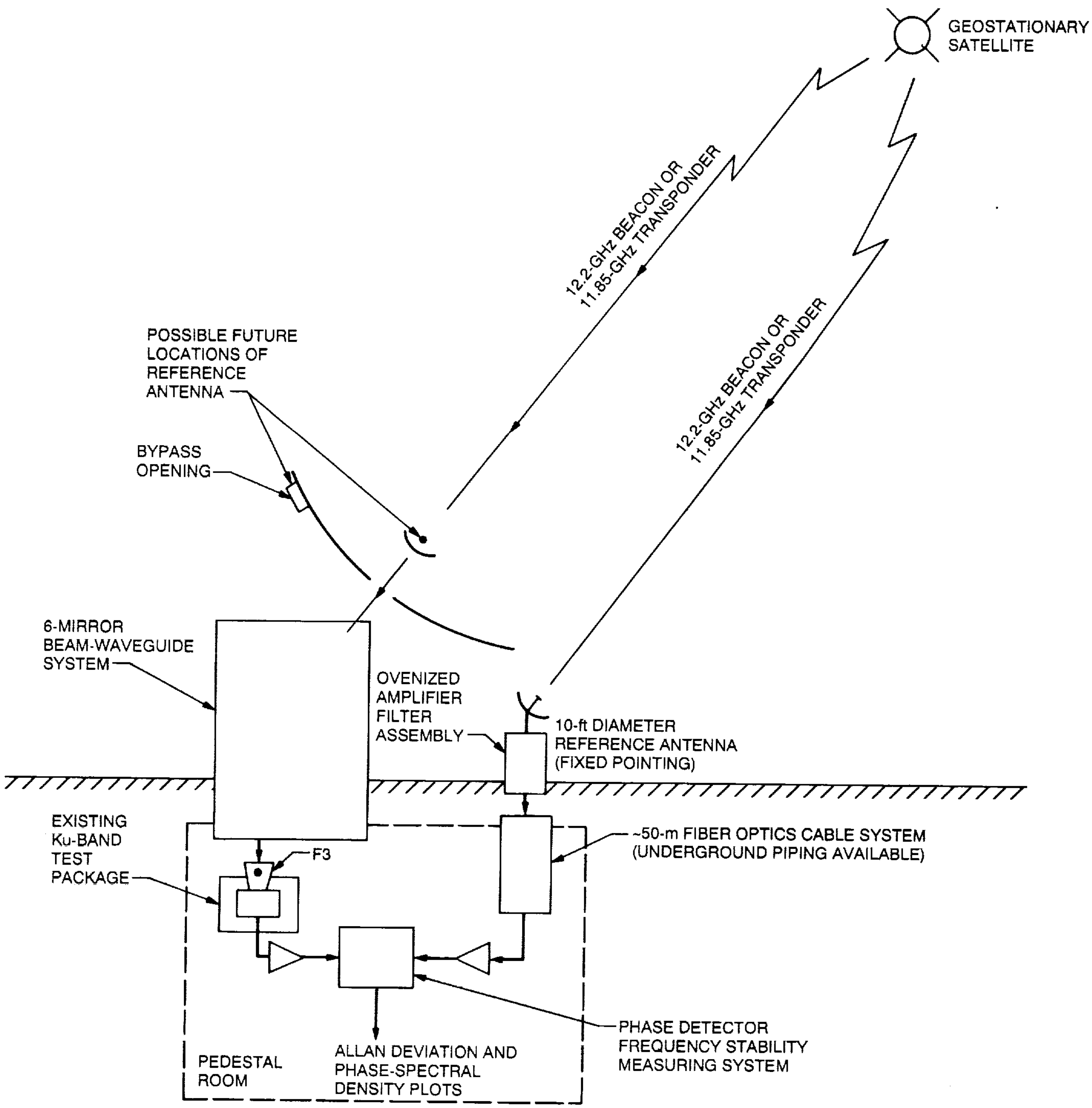

Fig. 1. Proposed method for measurement of frequency stability of beam-waveguide portion of DSS 13 BWG antenna.

Appendix

Previous Methods Employed To Measure Frequency, Group-Delay, and Phase-Delay Stability of Antenna Systems

I. Directional Coupler Below Feed Horn

The frequency stability of a transmit–receive system wâs successfully measured [6,7], but the measurements were restricted to the portion of the system below a direction coupler located just below the feedhorn. The coupler method does not test the portion of the system that includes the feedhorn, subreflector, and main reflector.

II. Dish-Mounted Probes

In the past, a ranging system and zero-delay dish-mounted probes were used to measure multipath-caused errors on the group delay of a large antenna [8,9]. Similar dish-mounted probe tests were also performed using VLBI methods and network analyzer techniques.[1,2]

Dish-mounted probes are highly susceptible to multipath errors for both ranging and VLBI. Although time-domain techniques [10] have proved to be successful for separating multipath errors, the dish-mounted probe technique can only yield knowledge of antenna RF stability at a single point on the main reflector surface and not the entire surface.

III. Collimation-Tower Technique

A VLBI method was used to measure the group- and phase-delay stability of the DSS 13 26-m antenna by using a VLBI noise source at the DSS 13 collimation tower and a 6-ft reference antenna mounted at the top edge of the main reflector [11]. A real-time VLBI correlator used to process the data showed good repeatability for a short duration. The disadvantage of the collimation-tower technique is that the collimation tower is not in the far-field and, in fact, is usually at only about 1/10 the required far-field distance. Furthermore, because the collimation tower source is usually located at an elevation angle of ~ 5 deg, this method is very susceptible to errors caused by multipath signals bouncing from the ground into the reference and test antennas. In addition, the multipath signals received by the test and reference antennas do not remain constant over long periods of time.

IV. Far-Field Methods

The Viking and Voyager spacecraft were used as far-field illuminators to determine the group-delay changes due to subreflector defocusing [12,13].[3] The DSN ranging system was used, and group-delay measurements using the ranging system have a precision of ~ 0.5 nsec, which is inadequate for making long-term group-delay stability measurements. Charged particle changes on the uplink and downlink signals are difficult to take into account.

A VLBI technique was used to investigate the effects of antenna structural deformation on measured VLBI group delays of the DSS 14 64-m antenna when using the DSS 13 26-m antenna as the reference antenna [14]. The precision of these measurements is estimated to be about ± 1 cm for a spanned bandwidth of 40 MHz after removing the effects of unwanted multipath reflections between the subreflector and the Mod-3 cone-support platform.

Resch recently proposed using VLBI and CEI techniques (needing phase calibrators and real-time correlators and another antenna, such as the DSS 14 70-m antenna) to test the stability of the DSS 13 BWG antenna.[4] The main disadvantage of this method is that it is difficult to separate out the frequency instabilities of the antenna under test when the stability of the reference antenna (DSS 14) is unknown. Phase calibrators have presented problems in the past for VLBI measurements and may require more development to improve their reliability.

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[3] In [13], subreflector experiments were performed by T. Otoshi.

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