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Performance of a 12-GHz Fiber-Optic System for Beam-Waveguide Antenna Stability Testing

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A 12-GHz fiber-optic system is a critical part of a test configuration that has been proposed for measuring the fractional frequency stability of the DSS-13 beam-waveguide (BWG) antenna. This fiber-optic system is used to carry Ku-band (12-GHz) signals from a reference antenna to the DSS-13 BWG pedestal room. Tests performed only on the fiber-optic system portion of the overall test configuration showed that the 12-GHz fiber-optic system (installed at DSS-13) has a frequency stability of about 1.1 × 10^{-16} for sampling time τ = 1000 sec for a nighttime run. This preliminary result establishes the lowest noise floor that can probably be achieved for the test configuration that will be used to measure the frequency stability of the DSS-13 BWG antenna.

I. Introduction

In a previous article [1], a new method for measuring the frequency stability of the DSS-13 BWG was presented. Figure 1 shows the proposed test configuration. The method requires the use of far-field signals in the 11.7- to 12.2-GHz region from geostationary satellites, a stable reference antenna, and a phase detector Allan variance measurement instrument [2]. By receiving the far-field signals simultaneously with a reference antenna and the 34-m antenna under test, the phase variations common to both paths cancel at the output of a mixer contained in the Allan variance measurement instrument [2]. An assumption is made that the time delay difference between the reference and test antennas is much less than the reciprocal of the smallest bandwidth of the signal after filtering. For example, if the bandwidth of the 12-GHz test signal is 1 MHz after filtering, the time delay difference between the test and the reference antennas must be much less than 1 microsecond. To enable accurate determination of the stability of the test path to parts in 10^{15}, it is desired that the path from the reference antenna to the Allan variance machine be very phase stable with fractional frequency stabilities on the order of one or two parts in 10^{16}. The employment of a 12-GHz fiber-optic system makes it possible to meet this stringent frequency stability requirement.

The purpose of this article is to present preliminary results of measurements that were made on the 12-GHz fiber-optic portion of the overall measurement system that will ultimately be employed to test the BWG antenna.

II. Reference Path Test Configuration

Figure 2 shows the 10-ft reference antenna that was developed for this project. This 10-ft reference antenna is located in an outdoor environment and mounted on a solid concrete pad about 30 m from the center of the 34-m antenna (Fig. 3).

A 12-GHz fiber-optic system, installed at DSS 13, is used to carry the output of the reference antenna to a point near the F3 focal point in the pedestal room (see Fig. 1). The 12-GHz fiber-optic system consists of a transmitter, 150 ft of fiber-optic cable, a receiver, and associated amplifiers and short lengths of phase stable cables. The purpose of the transmitter is to receive the 12-GHz signal, use it to modulate a laser beam and then transmit it toward the receiver via the fiber-optic cable. About a 150-ft length of fiber-optic cable goes underground from the reference antenna into the pedestal room to the F3 focal point location where the Ku-band test package [3] is installed. The purpose of the receiver is to demodulate the 12-GHz signal on the laser beam. Short lengths of phase stable microwave cables are used to connect the receiver output to the Allan variance machine.

The new far-field method takes advantage of recent advances made in fiber-optic technology. Tests by Lutes and Logan [4] on a fiber-optic system at X-band (8.4 GHz) have demonstrated that a differential frequency stability of 7×10^{-16} has been obtained for sampling times of 10 sec. This stability value is about two orders of magnitude better than the frequency stability of typical hydrogen masers. The short-term stability is limited by the signal-to-noise ratio of the output signal.

For the proposed BWG antenna stability measurement method to yield useful and accurate data, it is desirable for the described 12-GHz reference path to have a fractional frequency stability of better than 1×10^{-16} or 2×10^{-16} for $\tau = 1000$ sec. It was demonstrated by Conroy [2] that the phase detector Allan variance instrument has a noise floor level of about 1×10^{-17} for $\tau = 1000$ sec. Therefore, the frequency stability of the reference path basically sets the noise floor of the measurement system. It is desirable that the reference path be 10 times more stable than the BWG antenna path stability to be measured.

As a preliminary step for evaluating the overall measurement system, the 12-GHz fiber-optic system (minus the reference antenna) was tested. The test block diagram is shown in Fig. 4. A 12-GHz signal from a frequency synthesizer is sent to a 10-dB coupler. One of the outputs from the coupler goes directly to the reference port of the Allan variance phase detector. The other output goes to the 12-GHz fiber-optic transmitter unit. An AM-optical signal emitted by the transmitter unit is sent to the reference antenna's outside environment via approximately 150 feet of fiber-optic cable. At the end of this cable, a fiber-optic connector is used to join this cable to another 150-ft length of fiber-optic cable going back to the receiver.[1] The modulated optical signal is demodulated by the receiver and the 12-GHz output signal is amplified by an external amplifier and routed to the test port of the Allan variance instrument. Thus, the configuration being tested is the 12-GHz fiber-optic system with a 300-ft length fiber-optic cable, part of which is exposed to outside temperature variations.

III. Test Results

The first test was made with the signal generator (see Fig. 4) being driven by its own internal free-running frequency reference. A second test was made with the signal generator being driven by a portable Cesium reference standard.

Figure 5 shows the Allan deviation results for the first test, which was run during both daytime and nighttime hours. Two 9-hour runs were made. Allan deviations for the day and night runs were, respectively, 4.9×10^{-16} and 1.1×10^{-16} for $\tau = 1000$ sec. It can be seen in Fig. 5 that a strange hump (a departure from linearity) occurred for the daytime run. This departure from linearity on the log-log plot can be explained by examining the corresponding phase versus time plot shown in Fig. 6. It can be seen in the plot that the phase change since the start of the test varied from 0 to 20 deg and then to about -5 deg over the duration of the test. Whenever there is a large departure from linear behavior in the phase curve slope, the Allan deviation will correspondingly be affected. The cause of the phase change in Fig. 6 can be explained by examining the weather data curve in Fig. 7. There is a strong correlation between the measured phase change (Fig. 6) and the outside air temperature change (Fig. 7). During the daytime hours, the outside temperature varied between 23.9 and 30 deg C. Examination of Fig. 6 shows that the phase varied from 0 to about -18 deg for the nighttime run. The outside air temperature varied between 22.4 and

[1] The transmitter and receiver modules, which incorporate features based on JPL research, were purchased from the Ortel Corporation of Alhambra, California.

24.6 deg C. The reason why the Allan deviation curve was more linear for the nighttime run than the daytime run is that the nighttime run phase-versus-time curve is nearly linear.

During the measurements, phase-versus-time data are stored in computer data files. The Allan deviation is computed from the phase data by using equations given in [2].

Even though most of the fiber-optic cable goes underground to a stable thermal environment, about 10 feet of the cable were exposed to the outside weather environment. The test results shown in Figs. 5 and 6 show that the fiber-optic cable is somewhat sensitive to outside air temperature changes and, for best results, the entire cable length needs to be in a thermally stable environment. After the tests described in this article were completed, the portion of fiber-optic cable exposed to the weather at the reference antenna location was wrapped with thermal insulation material.

Figure 8 shows the test data for the period when the signal source was driven by 5 MHz from a portable Cesium frequency standard. The Allan deviations for the daytime and nighttime runs were, respectively, about 4.5×10^{-16} and 3.5×10^{-16} for sampling times of 1000 sec. Figure 9 shows the corresponding phase-versus-time plot for the daytime run. Unfortunately, the phase-versus-time data for the nighttime run could not be saved due to a glitch that prevented the data file from being closed. Figure 10 shows the corresponding temperature data for the same time period. The air temperature changed from 26 to about 30 deg C for the daytime test. Even though the temperature variation was about as large as for the first set of tests (Figs. 5–7), the phase change was much smaller. The smaller variation of phase is attributed to the use of a more stable frequency source to perform the tests. These test results indicate that the Allan variance result depends upon the stability of the frequency source when there is a differential path length difference between the reference and the test paths. For this test, the differential path length was 300 feet of cable, whose velocity of propagation is about 66 percent of that for free space. Thus, a 300-ft length of this fiber-optic cable corresponds to a phase delay of approximately 460 nsec.

Tests and analyses will be performed to determine the effects of such parameters as differential delays, signal modulations (AM and FM) and bandwidth.

IV. Conclusions

Preliminary test results have been obtained on the 12-GHz fiber-optic portion of the test configuration that will be employed to test the BWG antenna frequency stability. These results indicate that the best performance that can be achieved with this test configuration is about 1.1×10^{-16}. It is expected that under wind conditions, the stability of the BWG antenna will be at least an order of magnitude worse.

The test results presented in this article indicate that microwave fiber-optic systems can be useful for many antenna applications, such as carrying microwave signals from the antenna reflector surface areas down to ground level.

A small part of the degradation of performance of the 12-GHz fiber-optic system, whose results were presented in this article, might be attributable to the external amplifiers and rf cables used in the test. Also, the differential delay between the reference and the test port might have introduced some degradations even though a Cesium standard was used. These effects are being investigated.

Acknowledgments

J. Garnica, L. Smith, J. Ney, and the DSS-13 crew fabricated and assembled the reference antenna shown in the photograph. R. Logan assisted in the checkout of the 12-GHz fiber-optic system.

References

[1] T. Y. Otoshi, "A Proposed Far-Field Method for Frequency-Stability Measurements on the DSS 13 Beam-Waveguide Antenna," *TDA PR 42-107*, vol. July–September, Jet Propulsion Laboratory, Pasadena, California, pp. 81–87, November 15, 1991.

[2] B. L. Conroy and D. Le, "Measurement of Allan Variance and Phase Noise at Fractions of a Millihertz," *Rev. Sci. Instruments*, vol. 61, no. 6, pp. 1720–1723, June 1990.

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[4] G. F. Lutes and R. T. Logan, "Status of Frequency and Timing Reference Signal Transmission by Fiber Optics," *Proceedings of the 45th Annual IEEE Symposium on Frequency Control*, Los Angeles, California, pp. 679–686, May 29–31, 1991.

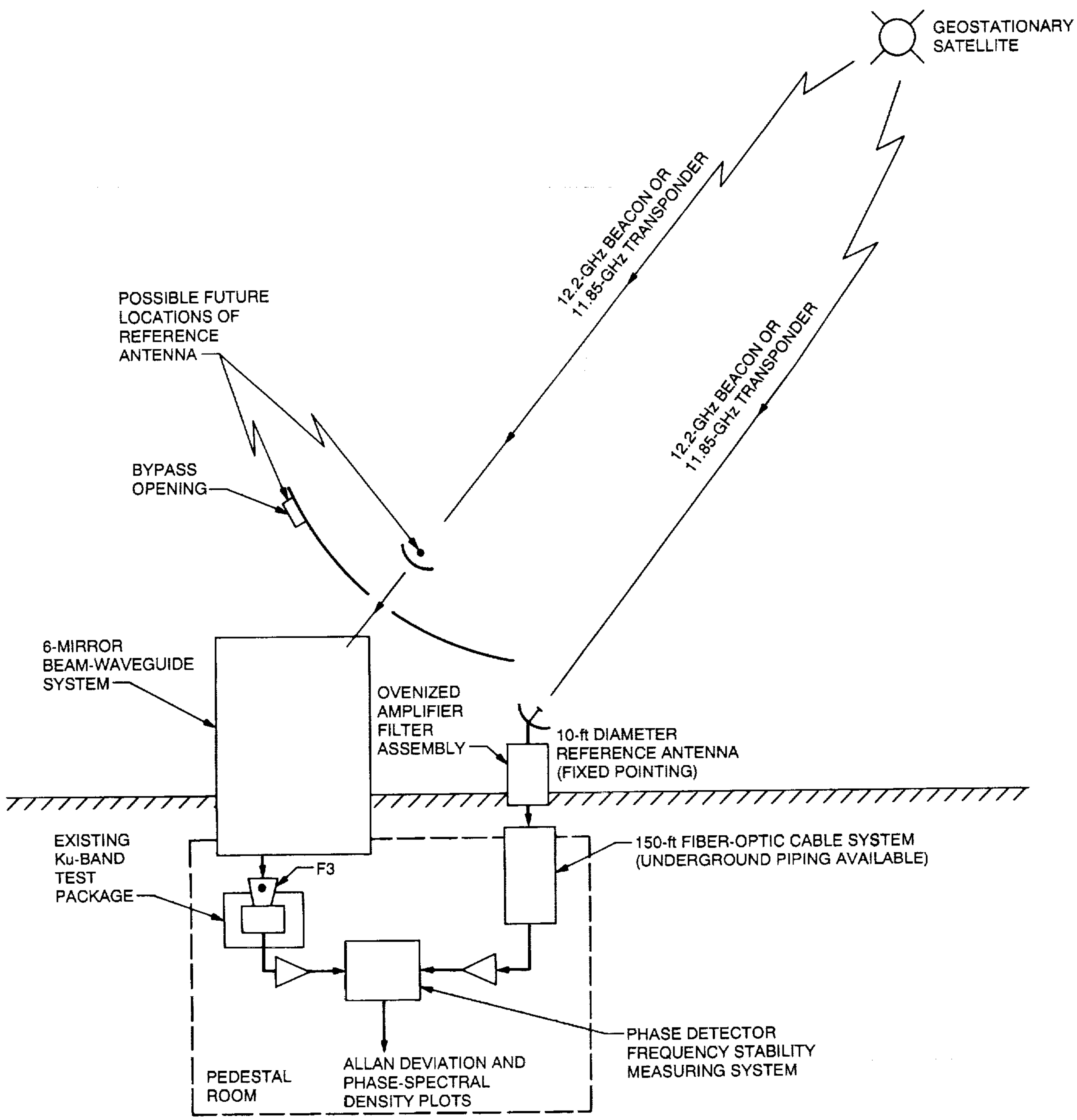

Fig. 1. Test configuration for measurement of the frequency stability of the BWG antenna.

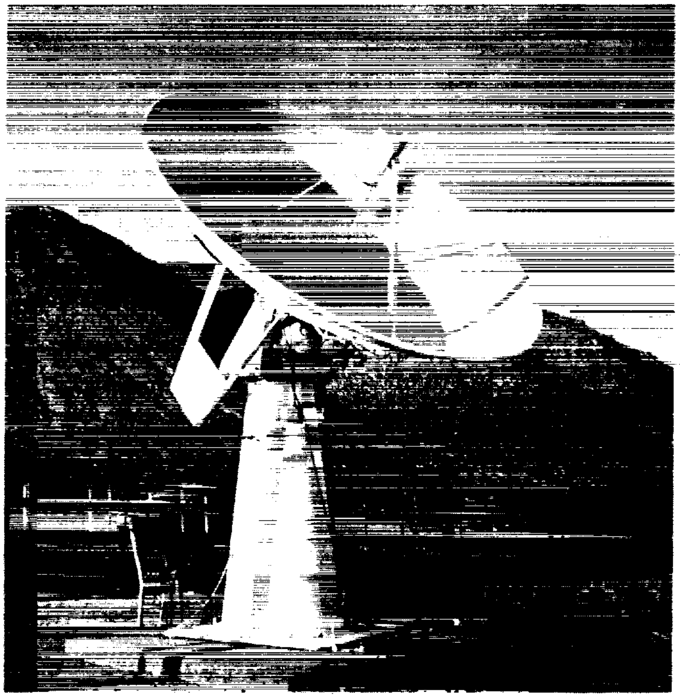

Fig. 2. Newly installed 10-ft reference antenna.

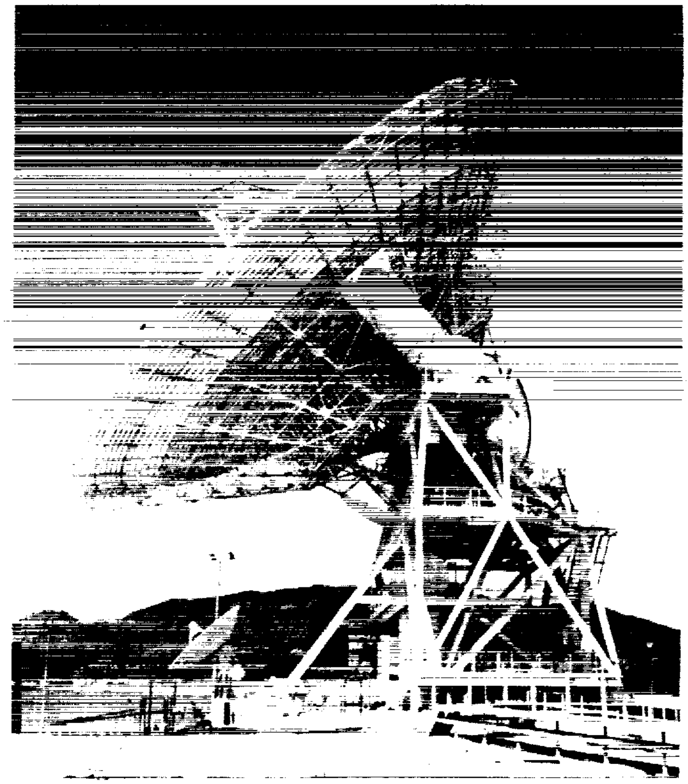

Fig. 3. View of the 34-m antenna and the 10-ft reference antenna pointed at a geostationary satellite at a 46.5-deg elevation angle.

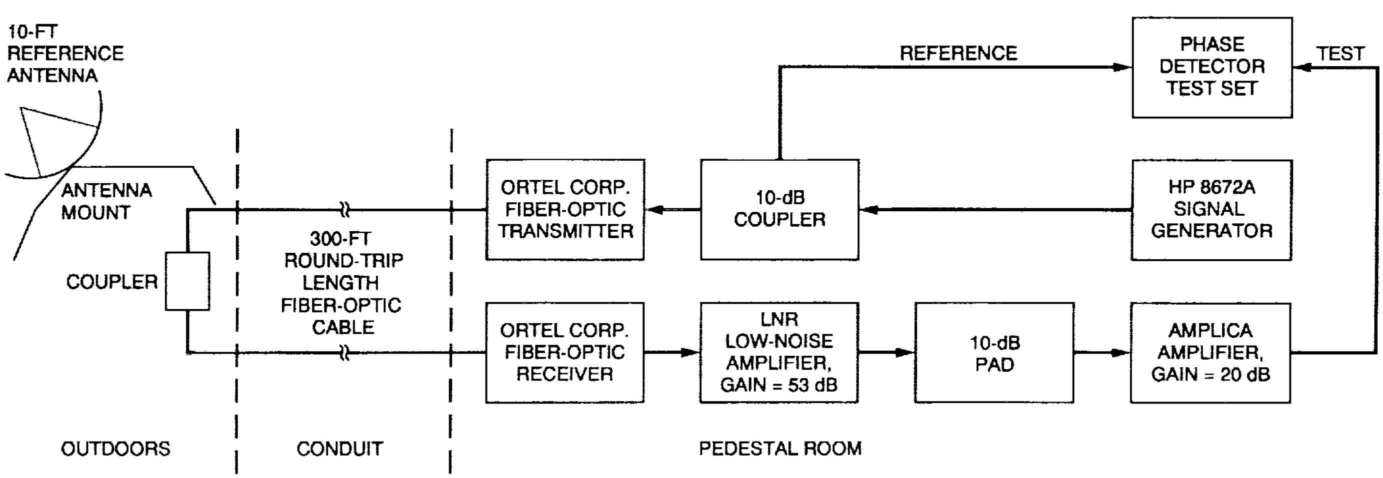

Fig. 4. Block diagram of the measurement setup to test the 12-GHz fiber-optic system that was installed at DSS 13.

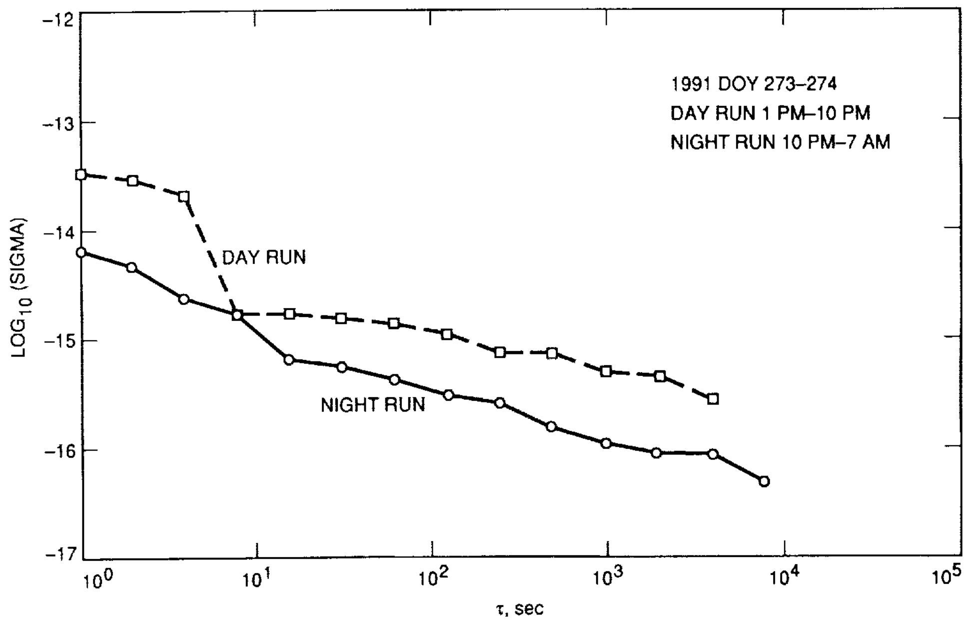

Fig. 5. Allan deviation characteristics of the 12-GHz fiber-optic system for day and night runs on 1991 DOY 273–274. The signal source was free-running. Test frequency was 12.198 GHz.

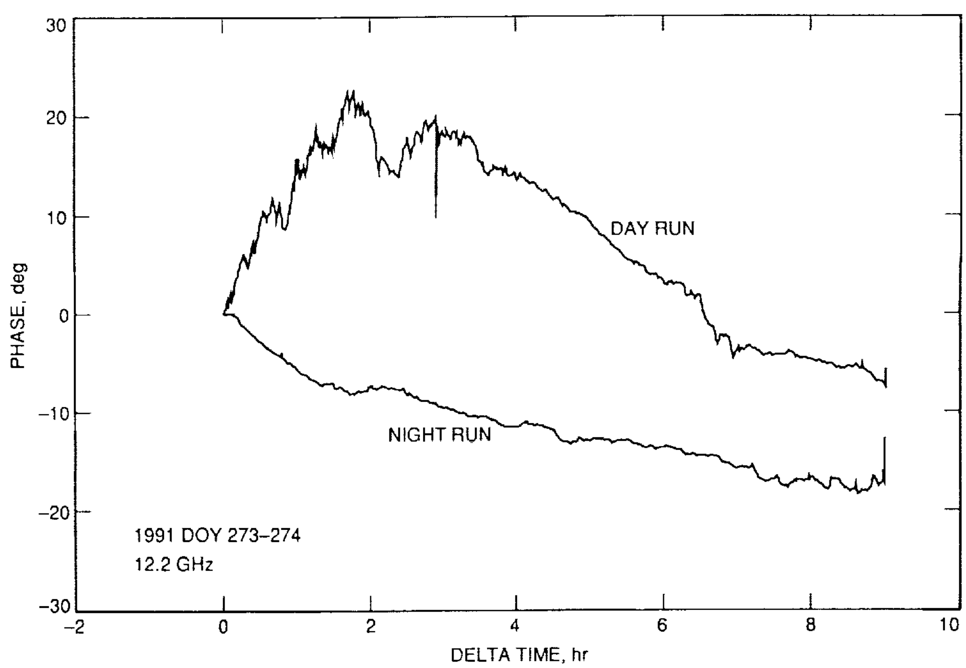

Fig. 6. Phase changes corresponding to the Allan deviation curves shown in Fig. 5.

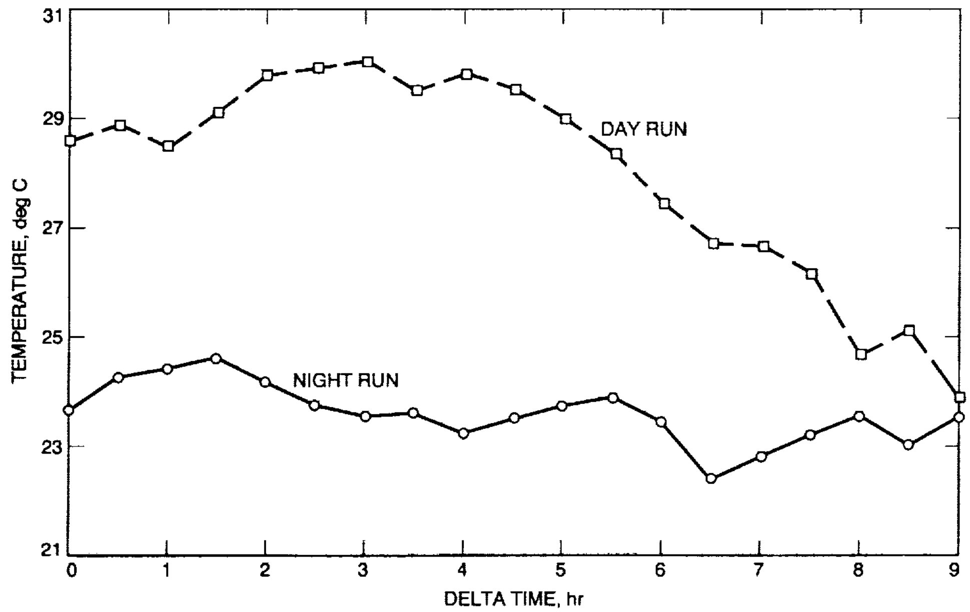

Fig. 7. Outside air temperature during measurements of phase changes shown in Fig. 6.

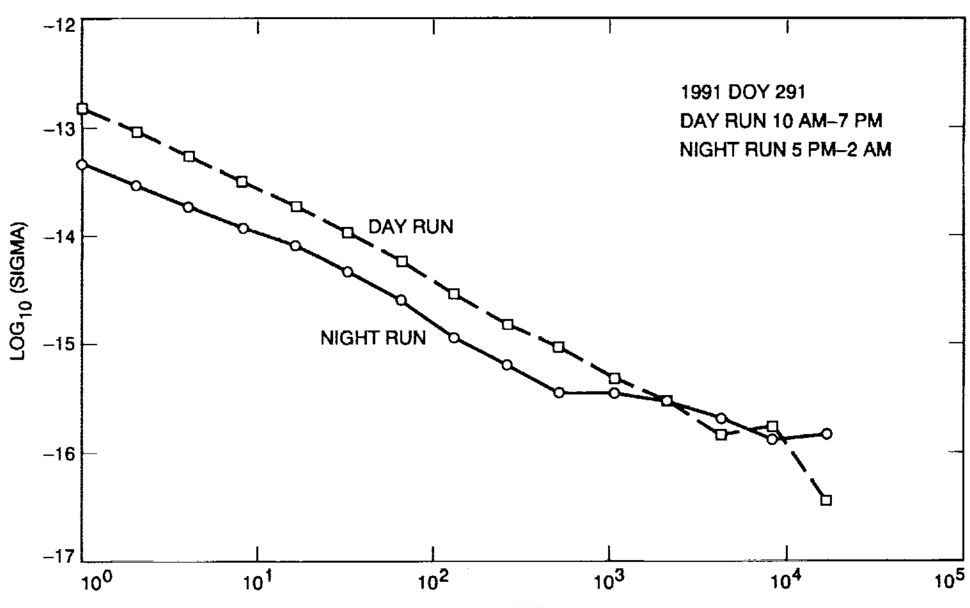

Fig. 8. Allan deviation characteristics of the 12-GHz fiber-optic system for day and night runs on 1991 DOY 291. The signal source was driven by 5 MHz from a portable Cesium reference standard. Test frequency was 12.248 GHz.

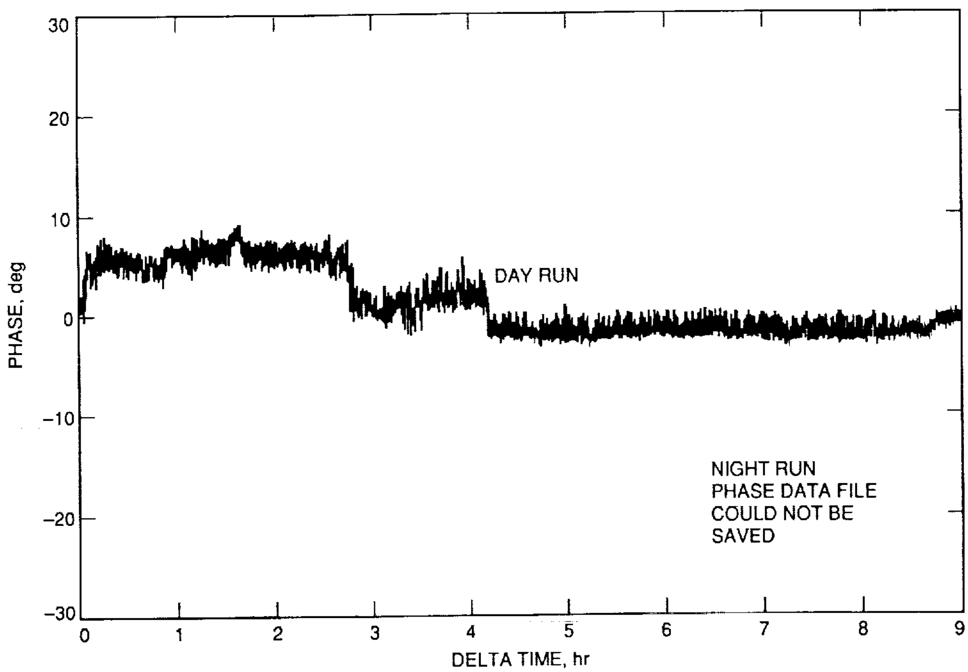

Fig. 9. Phase changes corresponding to the Allan deviation daytime curve shown in Fig. 8.

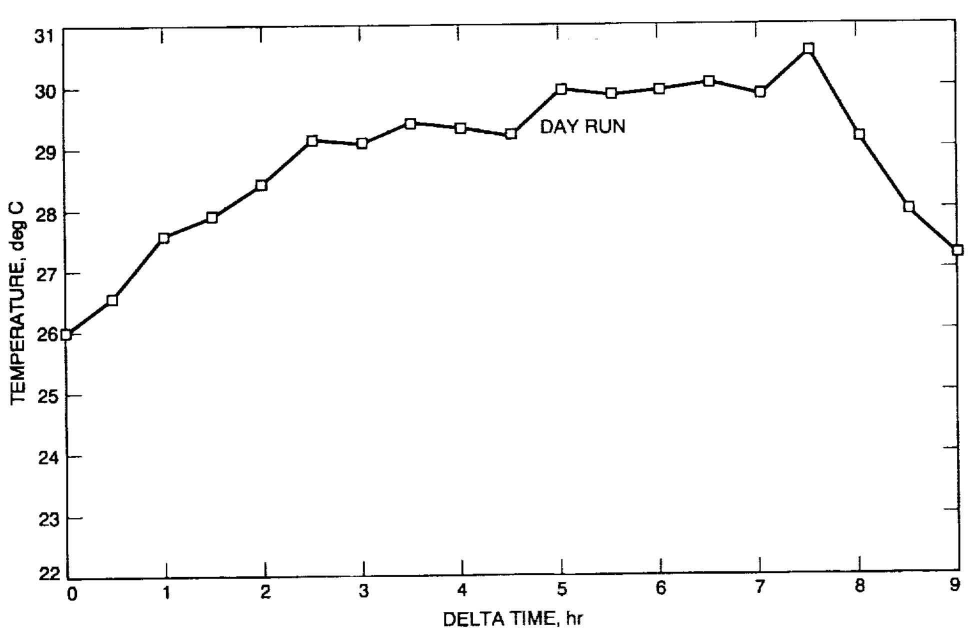

Fig. 10. Outside air temperature during measurements of phase changes shown in Fig. 9.