PHASE DISTRIBUTION ON FIBER OPTIC CABLE

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Abstract

A fiber optics link has been tested for distributing stable phase information at a frequency of 216.98 MHz for the Kickapoo transmitter of the Naval Space Surveillance radar. Laboratory experiments have been carried out with a specially modified laser and no special precautions were taken to minimize reflections. The relative stability of different fibers in the same cable was tested with repeated cycling of the cable temperature. The relative stability of two fibers each 1 km in length over hundreds of hours including temperature changes of 25 kelvins was better than 25 psec peak–to–peak, or about 1 part in 200,000.

INTRODUCTION

The Naval Space Surveillance Kickapoo transmitter near Wichita Falls, Texas is a 10,500–foot long north–south linear array of 2556 dipole radiators which produce a fan–shaped beam at a frequency of 216.98 MHz. This beam covers essentially the entire continental U.S. so that any satellite which penetrates it produces reflections. These are received at multiple sites and the positions and orbits of the satellites deduced. Since its construction 25 years ago, the performance of the array has degraded due to difficulties in maintaining precise phasing of the array. The array is presently phased by returning reference signals through buried coaxial cables which have experienced physical deterioration. The objective of this project was to investigate the feasibility of replacing the phase reference cables with their fiber optic analog.

In order to determine the expected performance of such a system, laboratory experiments were conceived and executed to measure the characteristics of a fiber optic link operating at the transmitter frequency. After extensive consultation with pioneers in this field, a set of components was identified which appeared likely to have the desired stability and ease of handling in both laboratory and field environments. Critical to this study were commercial availability, reliability, and ease of installation and repair by field personnel.

EXPERIMENTAL SETUP

The components chosen included a 1300 nm laser and two receivers, both manufactured by Ortel Corporation. The laser was specially modified to reduce the effect of cable reflections on the output signal. Such reflections have long been observed to have deleterious effects on the phase of the laser output in such systems[1–3]. No additional isolation between the laser and the remainder of the optical system was used. For ease of configuration of the experimental apparatus for making several different measurements, it was decided to connect all optical elements by means of the field–installable AT&T ST connectors. These connectors have moderate return loss (about 30 dB), which is undesirable, but they are easy to install and replace if necessary. Reflections in a field installation could be reduced by fusion splicing if necessary.

The fiber optic cable chosen was of loose–tube construction, built by Siecor Corporation. The advantage of this cable over tight–buffered cable for this application is that the fibers within their large–diameter tubes are not tightly constrained. Thus, when mechanical stresses are imposed by temperature changes, the fiber is free to adjust itself and minimize the stress. This in turn results in smaller changes of the reflection properties than with other constructions. The cable was kept tightly wound on its original drum and placed in an insulated chamber whose temperature could be elevated above ambient by 25 kelvins, an amount sufficient to cause easily measurable changes in the total delay.

The experimental setup for the measurements described here is shown in Figure 1. A 5 MHz signal derived from a hydrogen maser frequency standard was split and sent to two high–stability frequency synthesizers. In the upper path, a generated signal at 216.98 MHz was applied to the modulation input of the fiber optic transmitter. This transmitter is equipped with an internal oven but none of the remainder of the apparatus was temperature–controlled. The optical signal was split in a Gould coupler and sent to two separate fibers in the cable. After the trip through the 1–km cable, the two optical signals were separately detected by identical receivers. The resulting electrical signals were filtered and amplified. Both passive bandpass filters and active crystal–controlled phase–lock loops were used and in the long–term measurements described here there was no measurable difference in the results using different types of filters.

Each 216.98 MHz signal from the fiber optic system was then mixed with a signal at 211.98 MHz derived from a second identical frequency synthesizer. The resulting 5 MHz signals were filtered and amplified, then sent to the NRL frequency standard measurement system. They were compared to the 5 MHz signal derived directly from the maser; it was thus possible to measure the relative phases of the 216.98 MHz signals propagated through separate fibers. The frequency standard measurement system is regularly used for evaluating the performance of high–stability oscillators and has a resolution of 20 psec at a frequency of 5 MHz. The equivalent noise at our frequency is reduced by a factor of 216.98/5, and is thus expected to contribute only 0.5 psec of noise. The system measures a point once per hour.

RESULTS

Many different tests were performed to evaluate separately the stability and noise contributions of the electronics, the fiber optic transmitter/receiver pairs, and the fibers themselves. The noise level of the relative phase measurements using the entire system without including the 1 km cable was about 20 psec peak–to–peak, measured at 216.98 MHz. This noise comes from several sources, including the relative stability of the two frequency synthesizers, temperature variations of the other electronic components, and the 250–foot coaxial cables used to carry the 5 MHz signals from the maser to the experiment room and back to the measurement system.

One measurement sequence covering 48 days of continuous data is shown in Figure 2. The delay measurements of the two separate fiber and receiver channels are superimposed and lie on top of each other; the difference is plotted in the center. The differential delay for the same period is plotted (using 11–point boxcar averaging) on an expanded vertical scale in Figure 3. At about 1130 hours, the heater was turned on and the temperature increased by 25 kelvins; the fiber responded with a time constant of about a day due to being wrapped tightly on its shipping drum. At 1400 hours, the temperature was allowed to drop back to ambient. At about 1250 hours, the building ventilation equipment began to malfunction, with excursions of a few kelvins evident from then until the end of the measurement period.

The total delay through each fiber was about 4.89 microseconds. The change in delay with the controlled temperature change was 1.6 nsec, corresponding to a temperature coefficient of delay of 1.3×10^{-5}/kelvin. The differential delay between the two fibers experienced a maximum excursion of 20 psec peak–to–peak and the effect of the controlled temperature change of the fibers alone is not seen in the differential data. Note, however, that the scatter of the points from the mean is somewhat worse during the period in which the building ventilation was malfunctioning. We conclude that most of the differential delay excursion is caused by changes in the electronics and not by differences in the fibers themselves. If we restrict our attention to the data taken before the building ventilation malfunctioned, and correct for the difference of a factor of 1.0021 in the electrical length of the two fibers, we obtain a differential temperature coefficient of 22 femtosec/kelvin for a combination of the fibers and electronics.

Since the phase stability requirement target for the Kickapoo transmitter is 51 psec, or ±2 degrees of phase at 216.98 MHz, we also conclude that a fiber optic system using the components chosen for this experiment will easily satisfy the requirement. In early 1990, the first cable will be laid at the site for extended testing in the field, which should ultimately lead to a complete system for controlling the transmitter phases.

ACKNOWLEDGEMENTS

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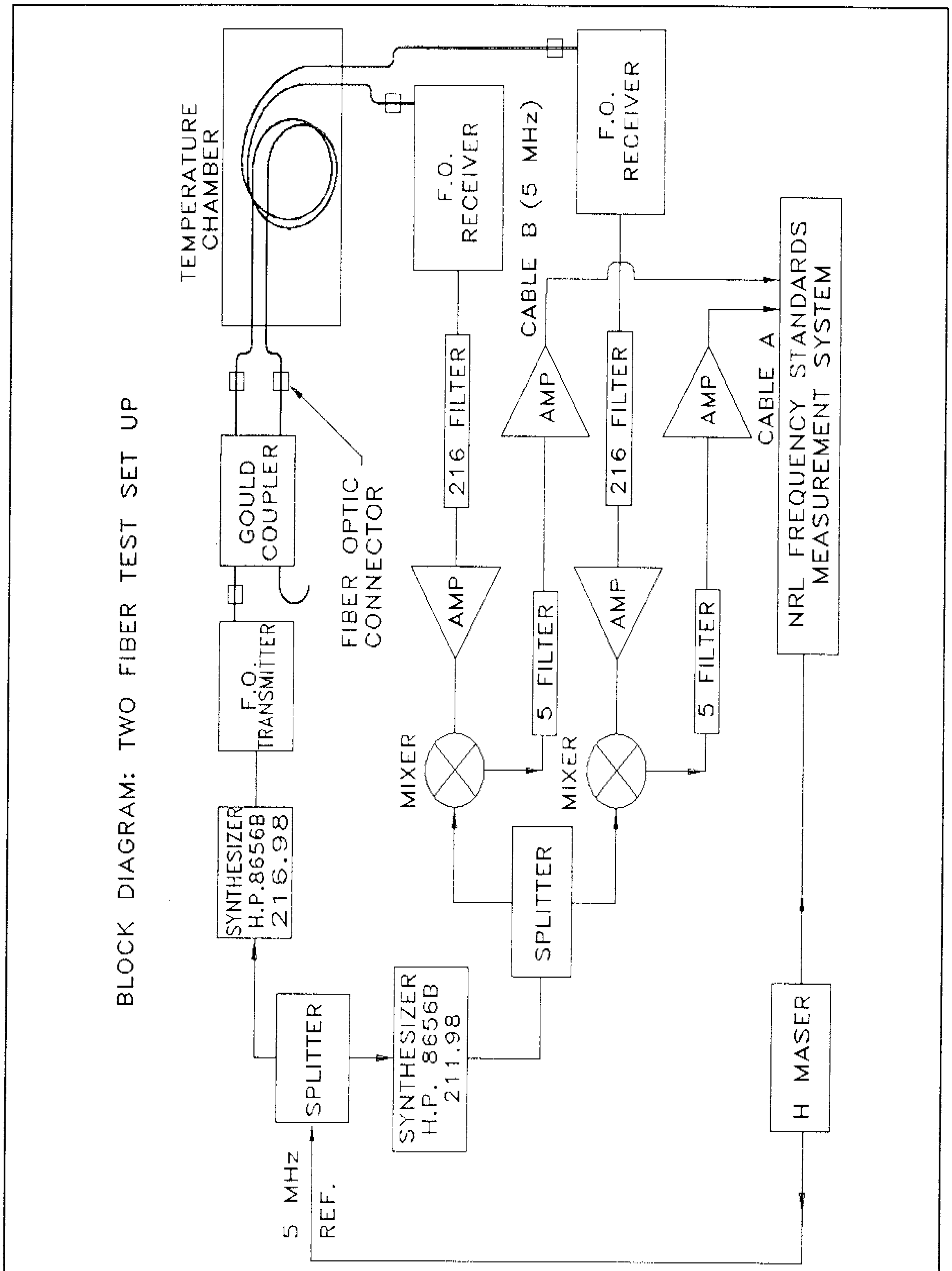

Figure 1 Experimental setup for the measurements.

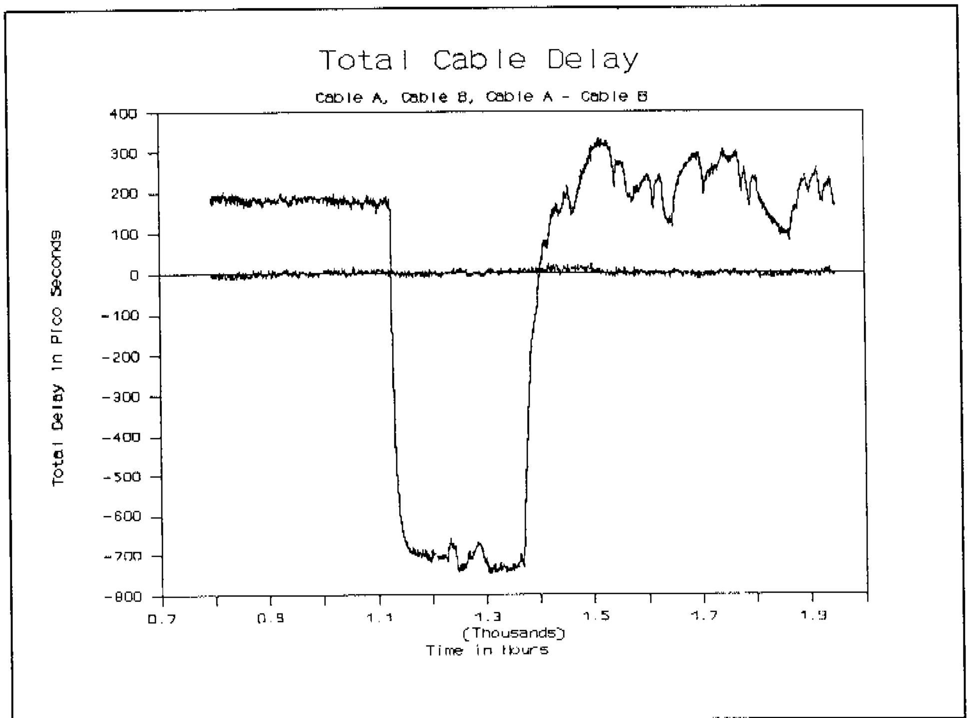

Figure 2 The total delay for two fibers is plotted and almost overlap each other exactly. The difference between the two fibers is also shown.

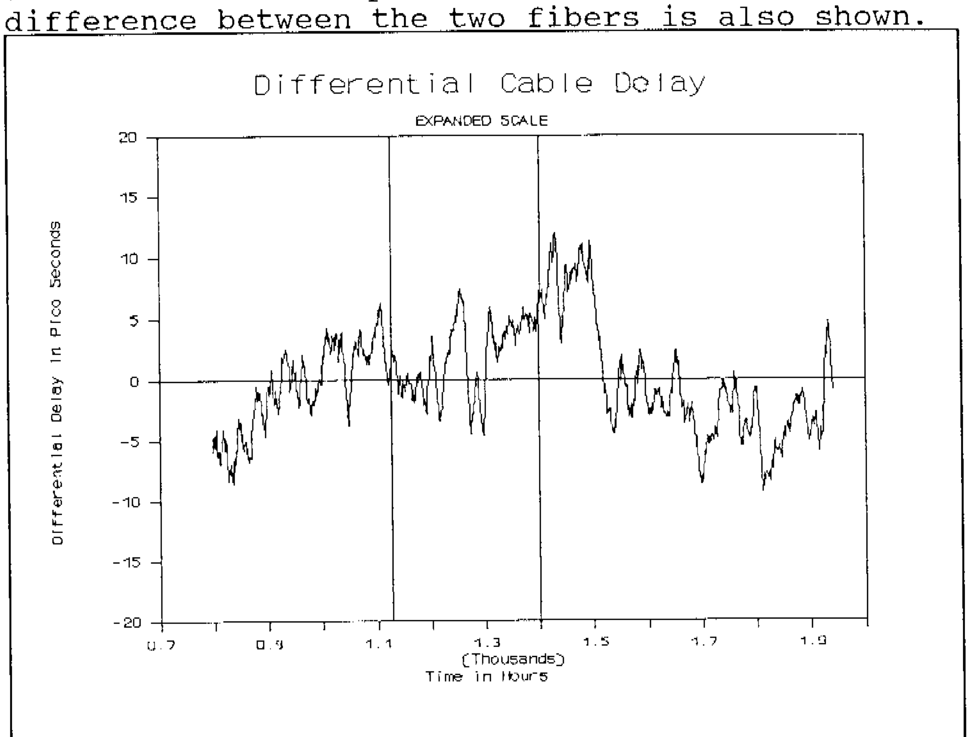

Figure 3 Differential Delay between two fibers with an expanded scale. The two vertical bars are at the times of the temperature change.