CALIBRATION OF GPS CARRIER-PHASE TIME-TRANSFER EQUIPMENT

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Abstract

GPS carrier-phase time-transfer performance depends on the stability of the delays of the receiving antennas, GPS receivers, cables, amplifiers, and other related electronics. Several groups have studied the effects of the environment on carrier-phase time transfer [1,2]. The United States Naval Observatory (USNO) is also conducting experiments to quantify the effects of temperature and humidity on these hardware components [3]. In this paper we will show a series of network analyzer group-delay measurements of three sets of GPS antenna electronics over a temperature range of –15° C to +45° C covering both the L1 and L2 GPS spectrum.

INTRODUCTION

A GPS antenna system with its associated amplifiers and band-pass filters is typically located outside in an uncontrolled environment. At USNO the seasonal variation in temperature can exceed 50° C. A typical GPS antenna system has a built in low-noise amplifier as well as band-pass filters, which are used to filter out unwanted interfering signals. The group-delay and frequency-response characteristics of band-pass filters tend to be sensitive to changes in temperature. It is, therefore, important to understand the sensitivity of these GPS band-pass filters to varying environmental conditions.

For this experiment we measured the amplitude and group-delay response of three sets of GPS antenna electronics using an Hewlett Packard 8719D network analyzer. These measurements were repeated over a temperature range from –15° C to +45° C in steps of 10 degrees. This 60° C range (+ 5° F to + 113° F) was chosen to represent a typical yearly span of temperatures as measured from the roof of the USNO Time Service building located in Washington, DC. Below is a list of the three amplifiers tested for this report.

A. KW Microwave (KWM FSCM 56216 FLA-I-15015)
B. Allen Osborne Associate (Narrow-band Amplifier with choke-ring)
C. Allen Osborne Associate (Wide-band Amplifier with choke-ring)

It should be pointed out that the exact group-delay response to the complex GPS C/A and P code signal spectrum is not being measured for this paper only the linear response of the amplifiers at discrete frequencies within the GPS spectrum. These results can only be used to derive worst-case temperatures sensitivities.

GROUP DELAY

Group delay is the transmission time through the device under test as a function of frequency. It is defined as the derivative of the phase characteristic with respect to frequency. Since the derivative is essentially the instantaneous slope (or rate of change of phase with respect to frequency), a perfectly linear phase shift results in a constant slope, and therefore a constant group delay. In practice, this phase characteristic typically consists of both linear and non-linear components. The linear component can be attributed to the electrical length of the device under test, and represents the average signal transit time. The non-linear components are interpreted as variations in transit time for different frequencies, and represent a source of signal distortion [4].

The spread-spectrum-modulated GPS C/A and P-code signal is broadcast at the L1 (1575 MHz) and L2 (1226 MHz) frequencies. This bi-phase-modulated signal is band-limited to an approximately 2 to 20 MHz portion of the L-band spectrum. The GPS signal is very weak (-157 dBW) and can be interfered with by near-band signals, such as digital paging systems, UHF TV stations, radar, and other signals transmitting in L-band. As a result, GPS receiving systems employ narrow-band filters to remove these unwanted interfering signals. Figure 1 shows the gain versus frequency response of the three GPS amplifiers tested as part of this experiment.

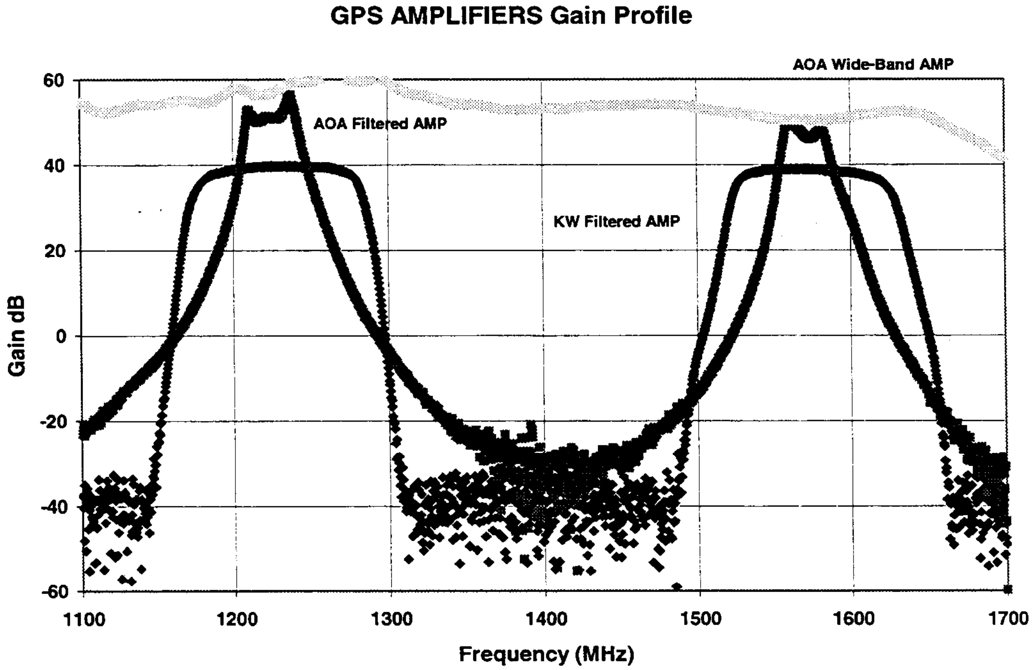

Figure 1. Amplifier gain response measured over 600 MHz.

AMPLIFER GROUP-DELAY MEASUREMENTS OVER TEMPERATURE

Each of the GPS amplifier group delays was measured over a –15° C to +45° C temperature range in 10 C degree steps. Figures 2 and 3 show the group-delay characteristics of these three sets of amplifiers/filters measured at both the L1 and L2

GPS frequencies respectively. Figures 4, 5, and 6 show the group delay measured at exactly the L1 (1575 MHz) and L2 (1226 MHz) GPS frequencies over a 375 KHz bandwidth for each of the three amplifiers tested. Because L1 to L2 group delay difference is used to compute a correction for the GPS signal as it passes through the earth's ionosphere, the resulting ionosphere error is also shown on the right axis of Figures 4, 5, and 6. These graphs show the differential delay between the L2 and L1 multiplied by the ionosphere correction factor (1.546). This ionosphere correction factor is a result of the dispersive nature of the ionosphere for which the group delay is proportional to the square of the frequency. Figures 7, 8, 9, and 10 show the change in group delay as a function of frequency and temperature for both the KW amplifier and the AOA narrow-band amplifier. The data shown are normalized to the measured group delay at 45° C. Presenting the data in this way accentuates the change in the shape of the group-delay characteristics of each of the amplifiers as temperature and frequency are changed.

AOA Wide-Bandwidth Amplifier

The AOA wide-band antenna electronics have a gain of between 50 and 60 dB with a frequency response that covers most of the L-band spectrum (59 dB at GPS L1 and 51 dB at GPS L2). The AOA wide-band electronics do not contain narrow-band filters, and are, thus, susceptible to interference. The major advantage of this amplifier for time-transfer applications is that the amplifier response is nearly linear with frequency, which should result in the amplifier being insensitive to environmental effects.

The group-delay measurements of the AOA wide-band GPS amplifier are shown in Figure 4. The average group delay is around 4.5 ns and fluctuates by about 1 ns over a 60° C temperature range.

AOA Narrow-Bandwidth Amplifier

In Washington DC area, in the mid-1990's, a digital paging service started broadcasting around 960 MHz. Some GPS receivers making L2 measurements and using wide-band non-filtered amplifiers, like the AOA wide-band amplifier, experienced signal interruptions. The Naval Research Laboratory (NRL) developed a simple quarter-wave stub, tuned to notch out this 960 MHz interfering signal. NRL also worked with AOA to develop a new set of GPS antenna electronics with narrow band L1 and L2 filters that removed all near-band interfering signals. A later generation of this antenna filter is now widely used in most of the AOA geodetic product lines and is typically shipped with a choke-ring antenna.

These AOA narrow-band antenna electronics have a gain of 46 dB at the GPS L1 frequency and 51 dB at L2. As illustrated in the gain response curves shown in Figure 1, the AOA narrow-band filters surround both of the GPS L1 and L2 frequencies with sharp cut-off frequencies of +/- 10 MHz. While these filters greatly reduce the effect of interfering signals, they also contribute to a greater instability due to the filters' sensitivity to environmental effects. In Figures 2 and 3, note the 10s-of-ns delay change in group delay measured over both the GPS L1 and L2 spectrum.

The group-delay measurements of the AOA narrow-band GPS amplifier at 1575 MHz and at 1226 MHz are shown in Figure 5. The group delay varies between 25 to 29 ns over the temperature range –15° C to 45° C. Figures 7 and 8 show the change in group delay as a function of both temperature and frequency. Because the AOA narrow-band filter changes shape and group delay as a function of both frequency and temperature, several nanoseconds of delay change could be expected, due to the 60° C seasonal temperature changes at USNO.

KW Microwave Phase-Stable Narrow-Bandwidth GPS Amplifier

The KW microwave antenna electronics have a nearly flat amplitude and phase response at both the GPS L1 and L2 frequencies. The KW microwave amplifier was designed with a 100 MHz bandwidth and rejects unwanted signals by 80 dB +/- 100 MHz from the surrounding GPS L1 and L2 signals. As shown in Figures 2 and 3, the KW microwave amplifier group-delay response is flat to better than 1.0 ns across the entire GPS spectrum.

Figure 6 shows the group delay at the L1 and L2 frequencies. The resulting ionosphere error is shown on the secondary axis at the right. The net effect of these errors is expected to be less than 0.5 nanosecond. Figures 9 and 10 demonstrate how little the group delay changes as a function of both temperature and frequency.

NETWORK ANALYZER GROUP DELAY MEASUREMENTS AT L2

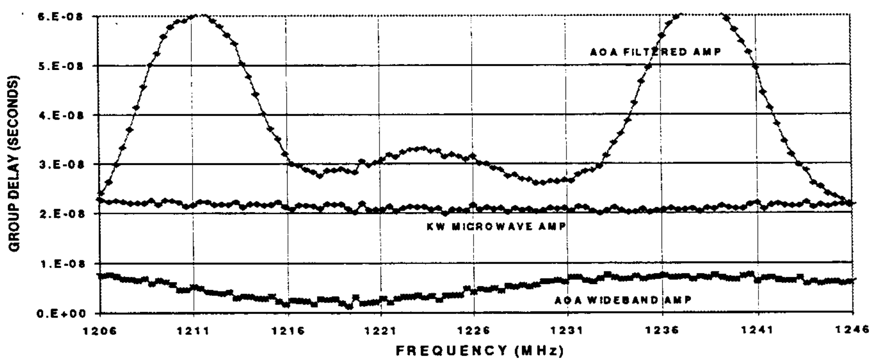

Figure 2

NETWORK ANALYZER GROUP DELAY MEASUREMENTS AT L1

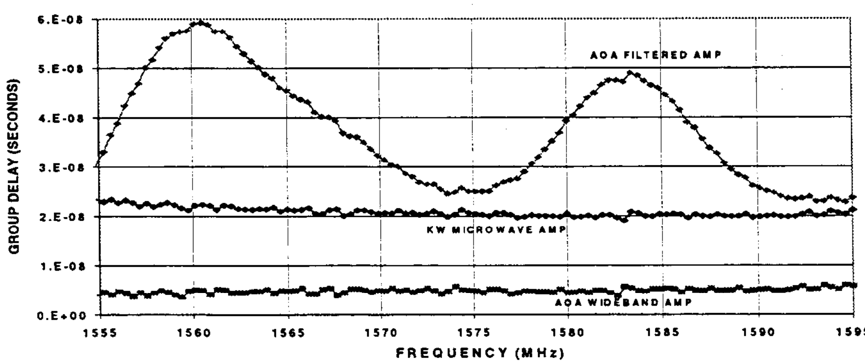

Figure 3

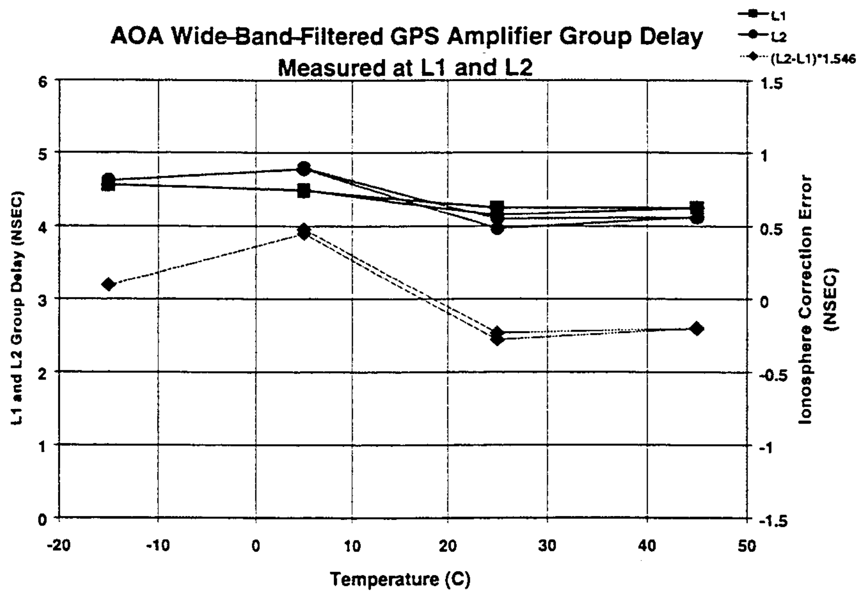

Figure 4

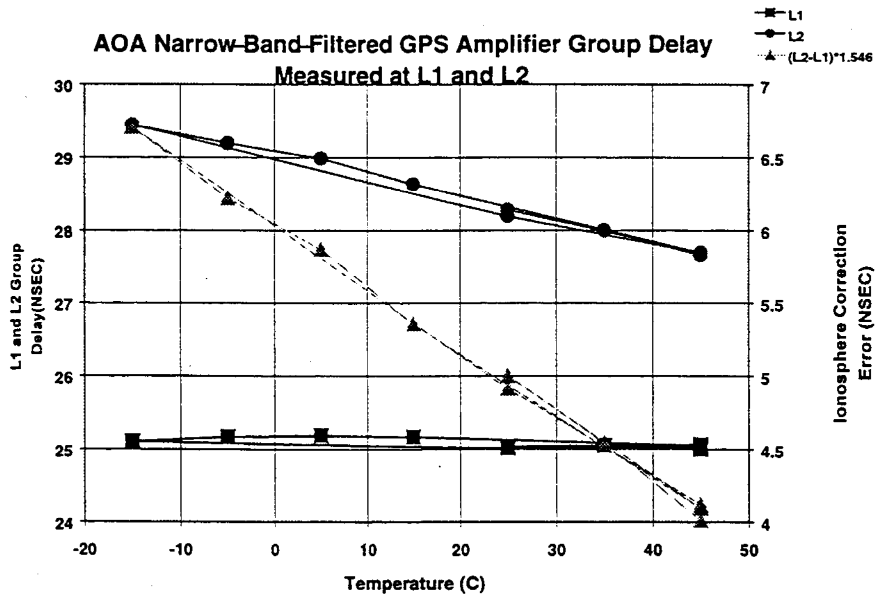

Figure 5

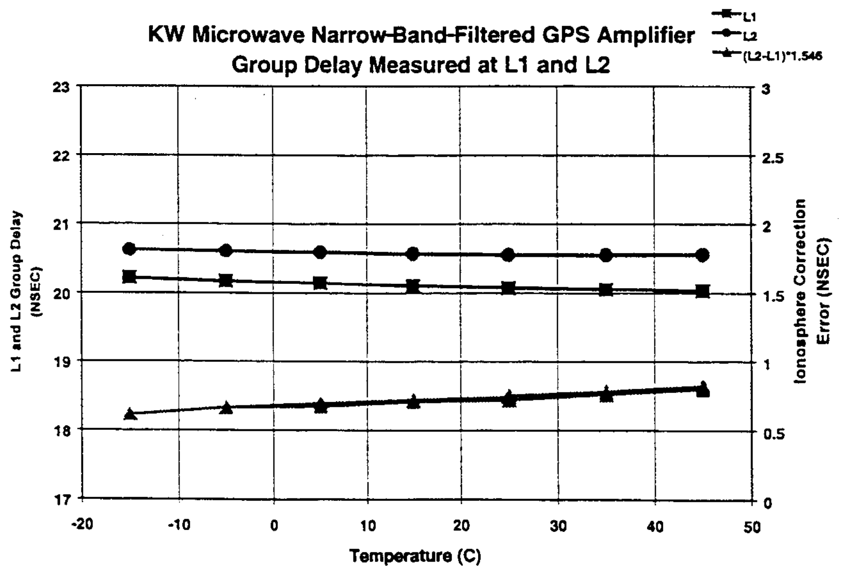

Figure 6

CONCLUSION

Temperature changes can cause GPS antenna amplifiers with narrow-band filters to have nanoseconds-level changes in group delay. To approach sub-nanosecond-level time transfer, either more stable filters or temperature-controlled filters will be required. The KW microwave narrow-band electronics package has a temperature response profile that provides a near ten-fold improvement in group-delay stability over the widely used AOA electronics package. It is hoped that the use of the KW Microwave or similar electronics might mitigate the need for complex temperature stabilization. The use of stable antenna electronics or temperature-controlled electronics, phase-stable antenna cables, and good microwave impedance matching techniques [5] should greatly reduce the effect of temperature on GPS carrier-phase time transfer.

FUTURE WORK

We planned to repeat these measurements using data collected from a series of zero-baseline experiments using live GPS signals. This should provide a clearer understanding of the group-delay temperature dependencies of GPS antenna amplifiers and band-pass filters on both code and carrier measurements. We are also planning to replace our antenna electronics with phase-stable antenna electronics.

ACKNOWLEDGMENTS

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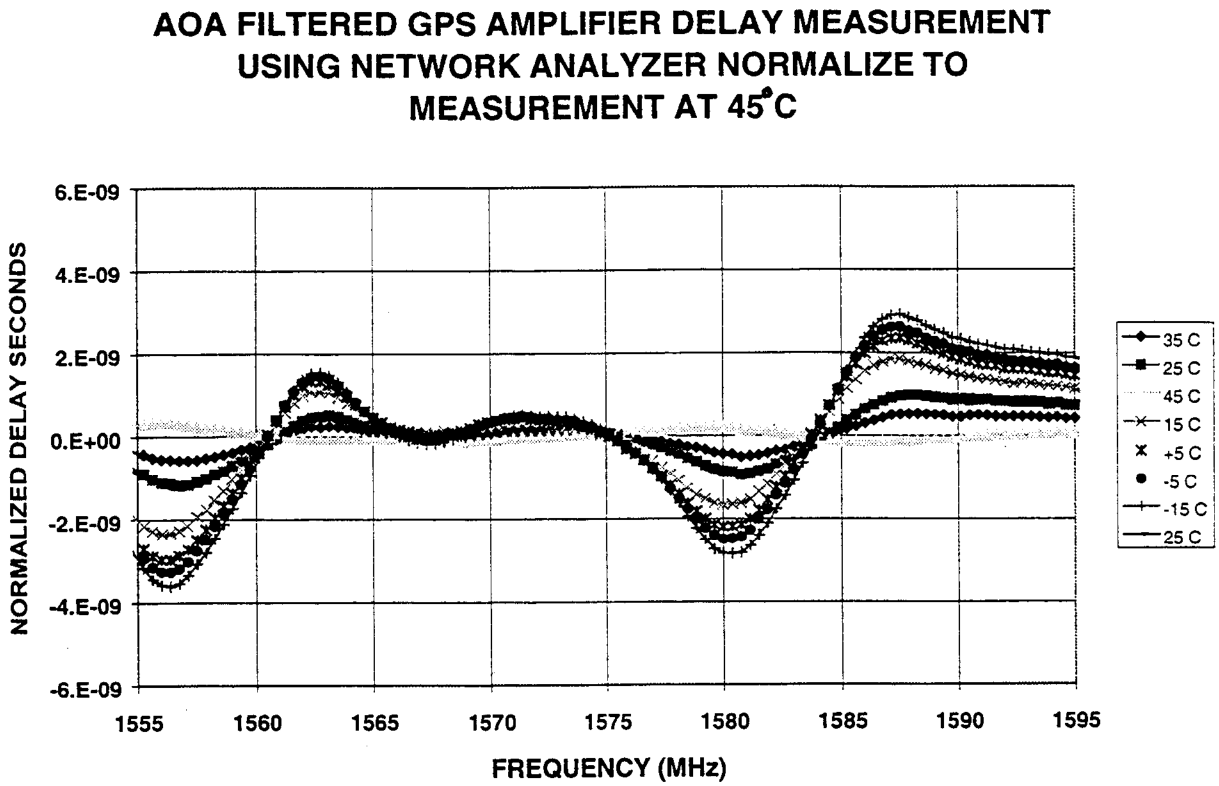

Figure 7

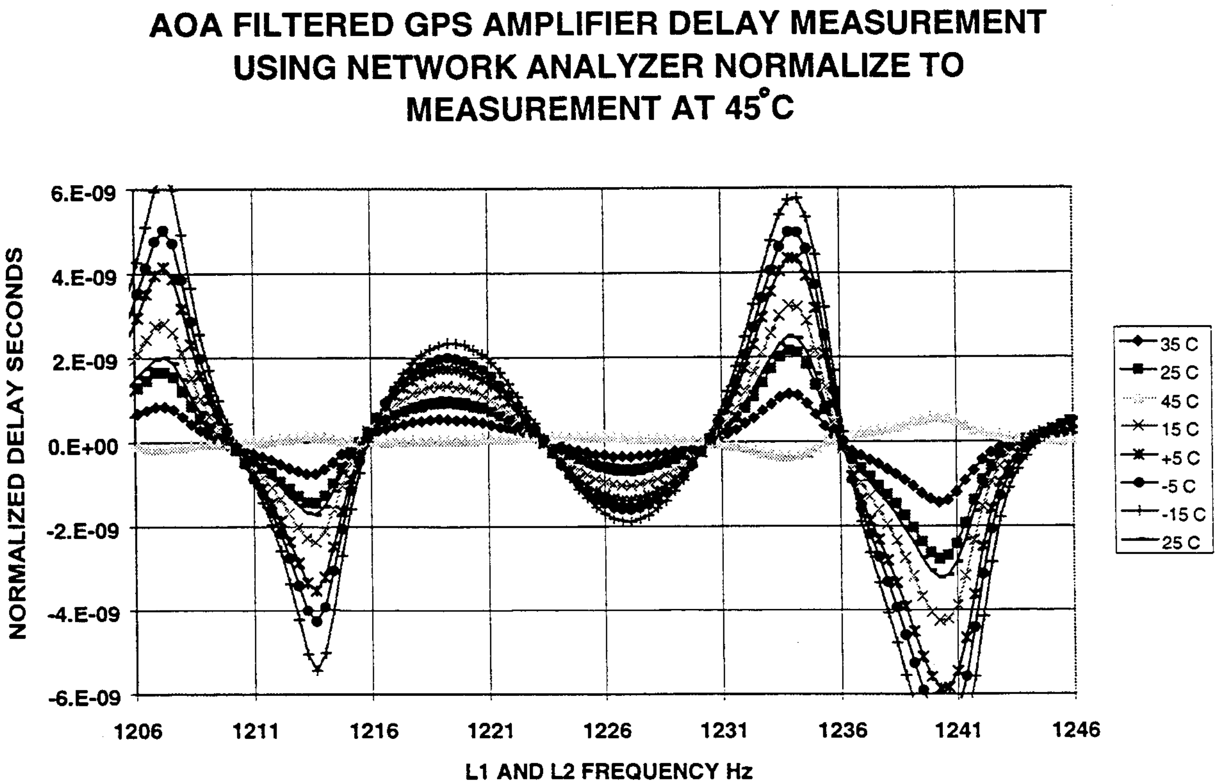

Figure 8

KW MICROWAVE GPS AMPLIFIER DELAY MEASUREMENT USING NETWORK ANALYZER NORMALIZE TO MEASUREMENT AT 25°C

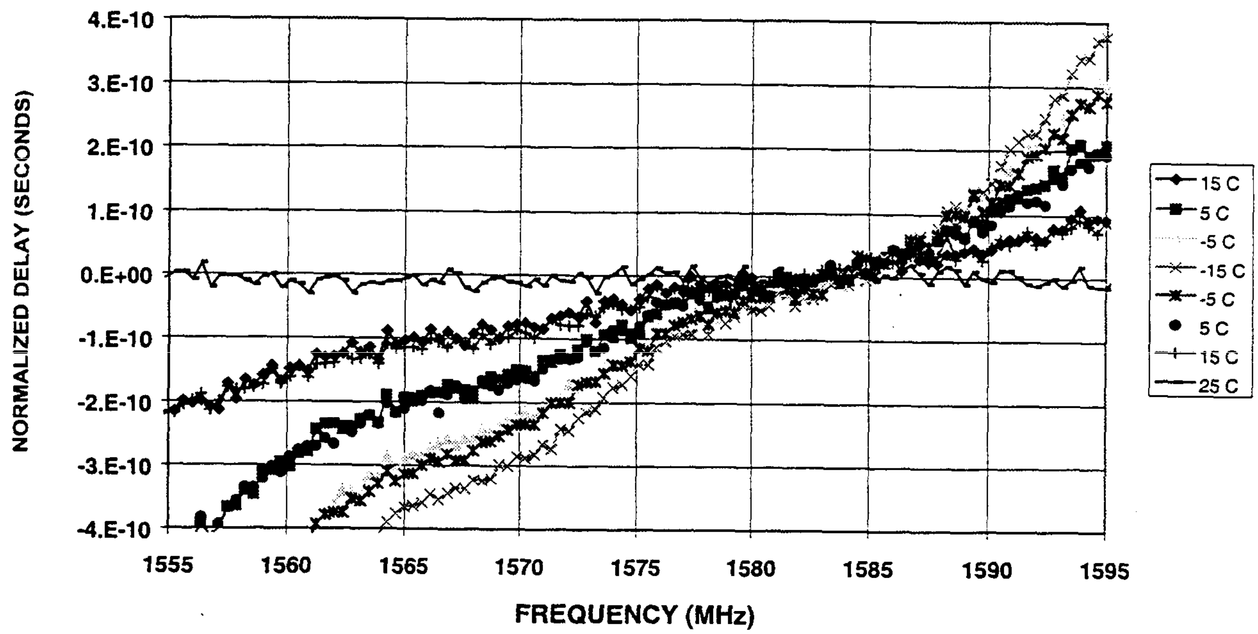

Figure 9

KW MICROWAVE GPS AMPLIFIER DELAY MEASUREMENT USING NETWORK ANALYZER NORMALIZE TO MEASUREMENT AT 25°C

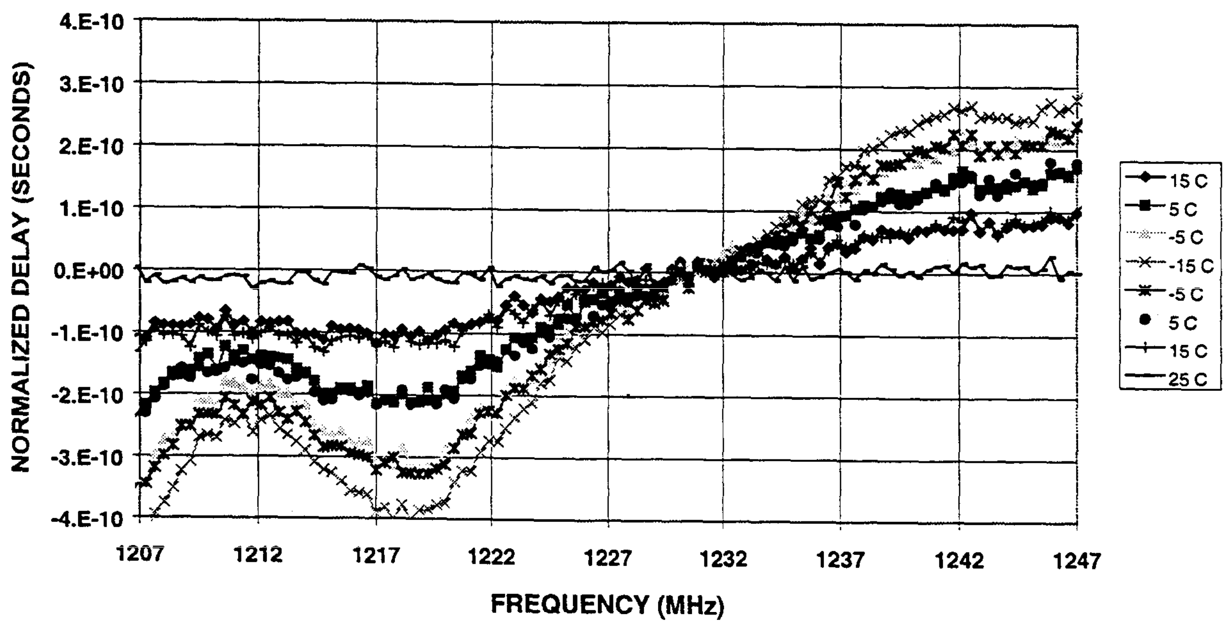

Figure 10