INTERIM RESULTS FROM THE CHARACTERIZATION TESTING OF THE ENGINEERING DEVELOPMENT (EDM) RUBIDIUM CLOCKS FOR SATELLITE APPLICATIONS

Edward D. Powers, Jr.
Fredrick Danzy
Naval Research Laboratory
Code 8321
4555 Overlook Avenue, Southwest
Washington, D.C. 20375–5000

Abstract

This paper presents some interim results from the environmental testing program to evaluate the Engineering Design Model (EDM) of the EG&G Spaceborne Rubidium Clock. This effort is in support of the GPS BLOCK IIR program and is intended to characterize the performance of EG&G design for BLOCK IIR satellite applications. Two EG&G EDM units are currently under test at NRL's Clock Test Facility to measure the long–term frequency stability, drift, and frequency versus temperature characteristics.

INTRODUCTION

The Global Positioning System (GPS) provides users with precise position and timing information, and will have a constellation of 21 satellites, with 3 on orbit spares, expected to be completed by the mid 1990's. It is anticipated that GPS BLOCK IIR (Replacement) satellites will be needed during the second half of this decade. The GPS BLOCK IIR satellites will carry two EG&G Rubidium Atomic Frequency Standards (AFS) and one Kernco Cesium AFS.

Because the AFS is of such importance to GPS, an AFS development program was begun for the GPS program. An alternative source rubidium AFS project was started by the GPS Program Office and Rockwell in 1979 to insure the supply of space–qualified AFS's. As part of this program EG&G built two prototype Rubidium AFS's, units 1 and 2[1, 2]. These two units were later modified[3]. In 1987, NRL and EG&G presented a paper describing the results of testing done at NRL on these two prototype units[4]. The data presented demonstrated a frequency stability and drift rate better than that of any other Rubidium AFS ever tested at NRL.

Several years later in support of the GPS IIR program, EG&G built two additional rubidium AFS's, units 3 and 4. EG&G implemented several design changes in units 3 and 4. These changes included elimination of the synthesizer and a rearrangement of sub–assemblies which have lead to a more compact design. Units 3 and 4 output frequency, 13,401,343 Hz, is the 510th sub-multiple of the 6,834,682,000 Hz rubidium transition frequency. This allows for elimination of the synthesizer. NRL is doing detailed developmental testing on these four rubidium AFS's in support of the GPS BLOCK IIR program. The purpose of this testing is to assist EG&G, the spacecraft manufacturer, and the GPS Program Office in refining the design and to document the performance of the AFS in the expected space environment. The interim test results of the GPS BLOCK IIR Rubidium AFS are reported in this paper.

NRL CLOCK TEST FACILITY

The Naval Research Laboratory (NRL) has served as the primary development and test facility for all GPS AFS's since the initial concept of GPS. In 1985, the NRL Clock Test Facility was completed and includes a fully-automated 48 channel dual-mixer phase measurement system which records both phase and 900 analog measurements every hour[5]. Shorter-term phase measurements are made using a 12 channel dual mixer system with a 30 channel analog data logger. The primary frequency reference NRL for all phase measurements is one of 5 Hydrogen Masers at NRL[6]. For space environmental testing, NRL has 12 Thermally-controlled high Vacuum Chambers (TVAC). Additional measurements made at the NRL Clock Test Facility include phase noise, spectral purity, vibration, and AC and DC magnetic fields susceptibility measurements.

FREQUENCY STABILITY TESTING

The GPS BLOCK IIR Rubidium AFS's frequency stability specification is defined in terms of Allan Variance[7]. The frequency stability requirement is for performance better than $3.0 \times 10^{-12}/t^{1/2} + 5.0 \times 10^{-14}$ with the frequency drift removed, while operating in a vacuum of less than 1×10^{-5} torr, at a constant temperature. The frequency drift should be less than 5.0×10^{-14}/day after 30 days of continuous operation under constant environmental conditions in vacuum. This performance specification equals the typical performance shown by EG&G units 1 and 2 in testing done at NRL[4]. The development goal is the for long-term frequency stability to be better than 1.0×10^{-14} at sample times greater than one day.

Figure 1 shows frequency stability data with and without drift removed collected from unit 3. This test took place over a 107-day period in TVAC at a constant temperature of 28 C. Also shown in figure 1 is NRL reference maser's long-term frequency stability and the phase measurement systems noise floor. Figure 2 shows a normalized frequency offset plot of unit 3. A peak-to-peak deviation of 80 nanoseconds can be seen in figure 3 which is a drift removed phase plot with a frequency drift of -4.45×10^{-14}/day removed. Unit 4 when tested under similar conditions exhibits comparable performance.

TEMPERATURE SENSITIVITY TESTING

An integral part of the planned GPS BLOCK IIR satellite operation incorporates a computer model used to remove the fluctuations in phase due to frequency offset, frequency drift and frequency fluctuations due to thermal changes on board the satellite. Because no active temperature control of the

Rubidium AFS is planned, the exact thermal sensitivity of the AFS must be well understood for this computer model to remove these sensitivity.

Initial temperature sensitivity measurements were made on unit 4 in which the temperature was changed every 6 hours in 5 degree C steps, from 10 C to 35 C and then back to 10 C. Frequency changes ranging from less than 1.0 X 10 -13/C up to 5.0 X -13/C can be seen in figure 4.

Later, EG&G modified unit 4 so that its operating temperature range more closely matched that of the preliminary predicted thermal profile of the spacecraft. Figure 5 shows the results of the latest thermal sensitivity testing done on unit 4 after modification. This test profile called for the temperature to be changed every 8 hours in 0.5 C steps from 15.5 C to 21.5 C and then back to 15.5 C. Analyzing the data from figure 5 points out that between 17.5 C to 21.5 C, the frequency changes were less than 5.0 X 10 -14 /C, while the change in frequency between 15.5 C to 17.5 C was as great as 3.3 X 10 -13/C.

Unit 3 was subjected to a 12–hour thermal cycle with a 3 C peak–to–peak deviation. This 12–hour thermal cycle was chosen to roughly simulate a 12–hour temperature cycle due to the GPS orbit. Temperature sensitivity ranged from 4.0 X 10 -13/C at 17 C to less than 1.0 X 10 -13/C at 27 C.

FUTURE TESTING

Because on–orbit modeling of the EG&G Rubidium AFS is such a vital part of the GPS BLOCK IIR satellite operation concept, a thorough understanding of how closely the clock can be characterized on the ground prior to launch is imperative. The variability between AFS's manufactured will need to be investigated to see the impact it will have on this model.

The best test for evaluating the thermal sensitivities of the Rubidium AFS would be to use the exact thermal profile expected in space. When the GPS BLOCK IIR spacecraft manufacturer completes their predicted thermal profile analysis for the spacecraft, NRL will use this information to derive new tests that more closely corresponds to what the Rubidium AFS will see in space. Additional testing will include a detailed look at the temperature sensitivity of the Rubidium AFS over a much wider range, the repeatability the temperature sensitivities over time, and a detailed analysis of the effect of temperature on drift.

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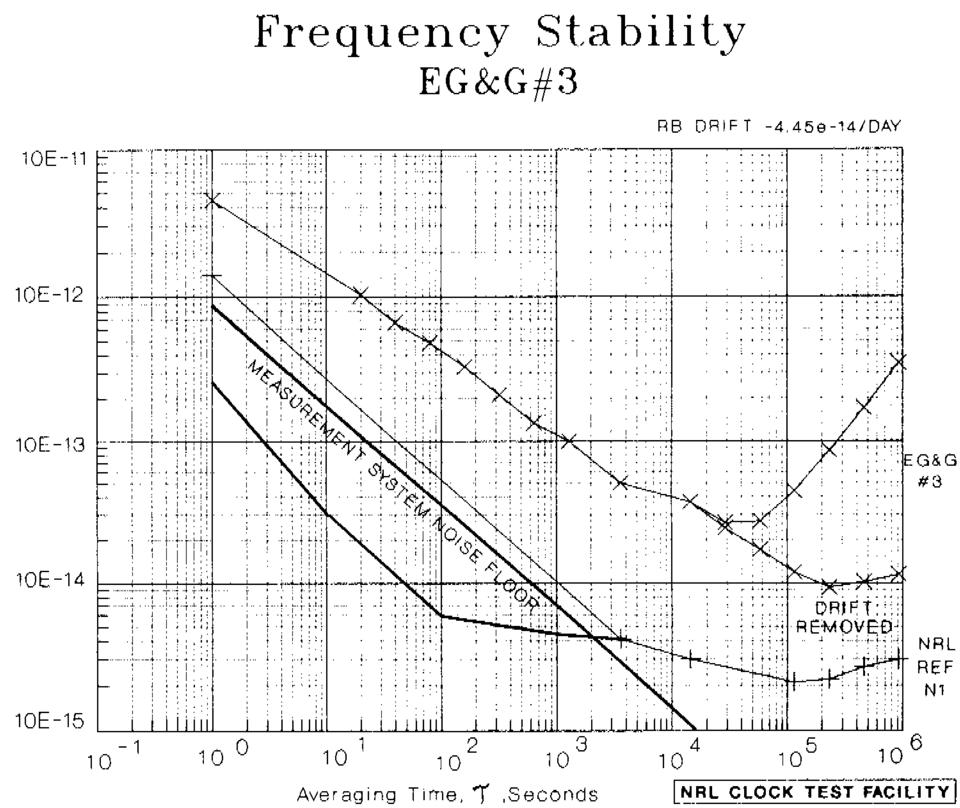

Figure 1

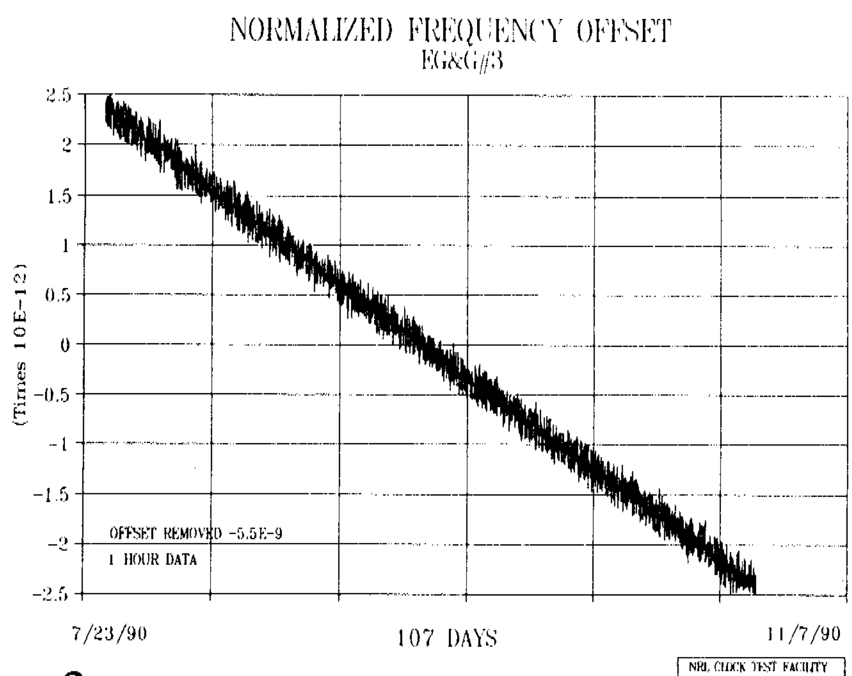

Figure 2

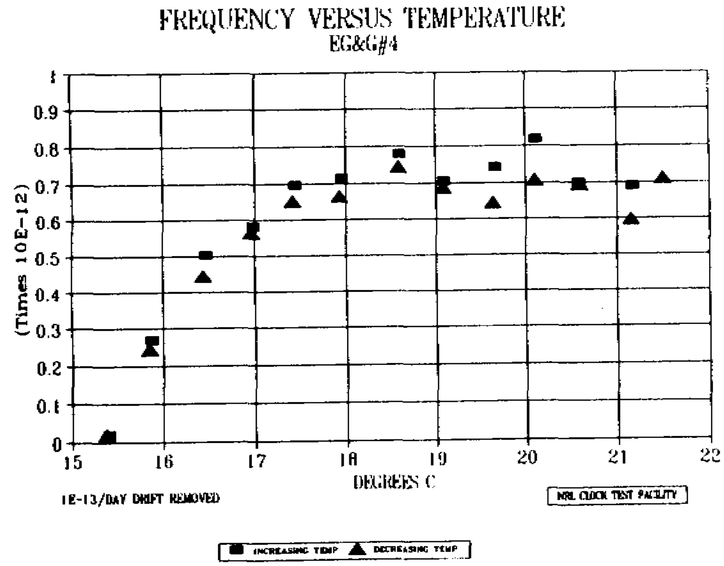

Figure 5

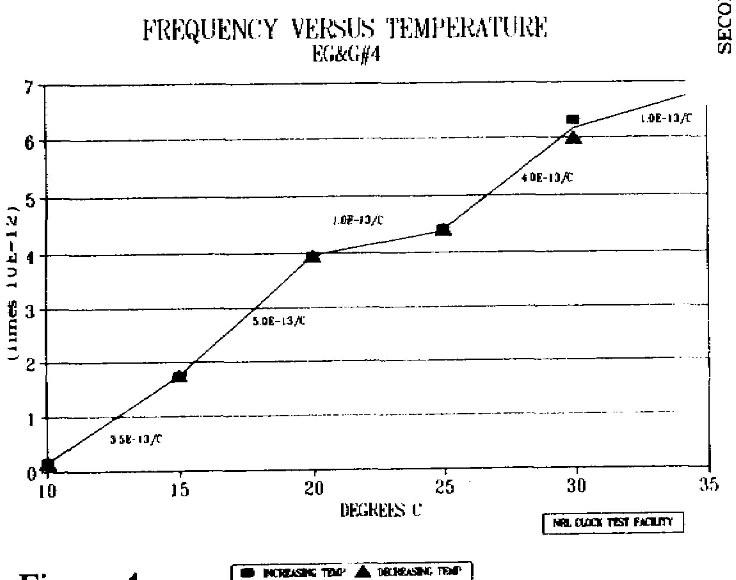

Figure 4

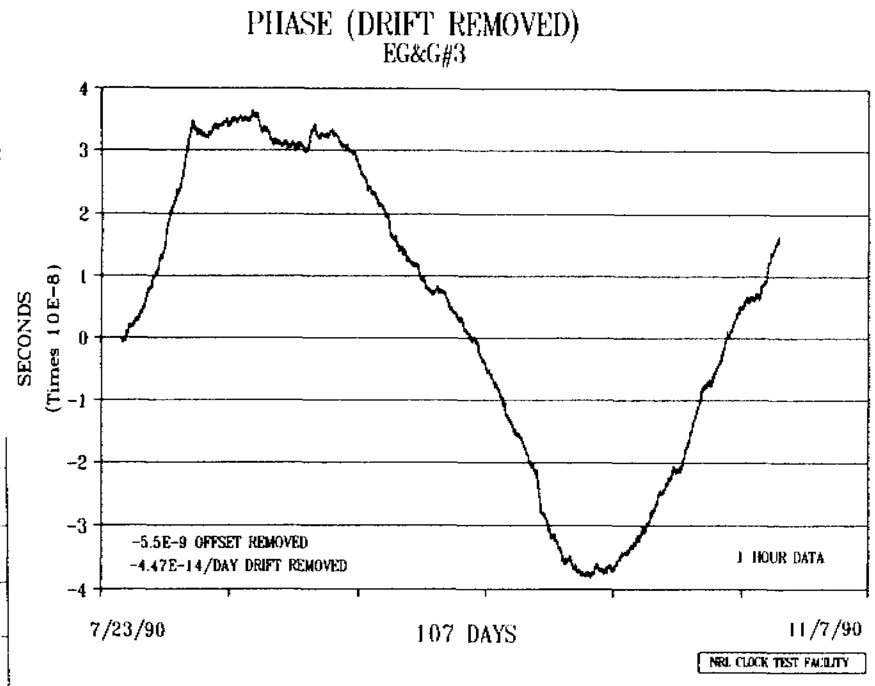

Figure 3