EARLY IN-ORBIT PERFORMANCE OF GPS BLOCK IIR RUBIDIUM CLOCKS

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Abstract

The first Block IIR GPS navigation satellite, placed in orbit on July 22, 1997, carried a new generation of rubidium clocks. Since then, two of these clocks have been activated, and both are performing well. This paper reports on those early results, and compares the in-orbit performance with ground acceptance test data.

EG&G has delivered about two-thirds of the 66 Rubidium Atomic Frequency Standards (RAFS) needed for the Block IIR GPS program. Composite frequency and time stability plots are presented for all delivered units, and more detailed acceptance test stability data are shown for the two RAFS that are operating on-board SVN43. In addition, similar life test data are shown for the two units that are undergoing life testing at NRL.

In-orbit stability and drift data are presented for RAFS S/N 005 and 006 using all available 15-minute precise ephemeris/clock data from the National Imagery and Mapping Agency (NIMA). RAFS S/N 006 was turned on 8/13/97 and was used as the active clock until 9/26/97. RAFS S/N 005 was turned on 8/22/97 and became the active clock on 9/26/97 at the beginning of a 2-month extended navigation test. Both are showing excellent stability and early drift stabilization.

INTRODUCTION

The first successfully launched Block IIR GPS navigation satellite was placed in orbit on July 22, 1997 carrying a new generation of rubidium clocks. Since then, two of these clocks have been activated, and both are performing well. This paper reports on those early results, and compares the in-orbit performance with ground acceptance test data.

RAFS PRODUCTION STATUS

EG&G has delivered about two-thirds of the 66 Rubidium Atomic Frequency Standards (RAFS) units needed for the Block IIR GPS program. Each of the 21 Block IIR space vehicles has three RAFS, two RAFS are undergoing ground life testing at the Naval Research Laboratory (NRL), and one unit is a spare. Composite Allan and time deviation plots showing the stability of all delivered units are shown in Figures 1 and 2. All units show negative drift with logarithmic stabilization that settles to below -1×10^{-13}/day in 1-2 months, and have a typical stability of $\sigma_y(\tau) = 2\times10^{-12}\tau^{-1/2} + 2\times10^{-14}$.

NRL LIFE TEST DATA

RAFS S/Ns 028 and 030 have been undergoing life testing under thermovac conditions at the Naval Research Laboratory since April, 1997. Both units are performing well and are displaying excellent stability and drift stabilization, as shown in the table below.[3], [4] The stability value shown is the τ=1 day Hadamard deviation (which removes the linear frequency drift).

RAFS S/N	Drift, pp10^{14}/day	Stability, pp10^{15}
028	-8.1	5.6
030	-6.5	7.5

NIMA DATA

The National Imagery and Mapping Agency (NIMA) provides precise ephemeris and clock data for the GPS constellation at their Web site.[5] These data are in the SP3 enhanced format and are organized into daily files by GPS week and day number (see on-line information). The early non-operational data for SVN43/PRN13 can be downloaded via ftp from special files.[6] The NIMA precise ephemeris data are also used by NRL to generate reports regarding the in-orbit performance of GPS clocks.[7]

RAFS S/N 006

Figure 3 shows about 39 days of τ=15 minute NIMA frequency data for RAFS S/N 006 from 8/18/97 to 9//25/97, which covers the complete period from when these data became available to when tuning tests were conducted just prior to switching to RAFS S/N 005. The record shows the negative aging and logarithmic stabilization that is typical of all of these Rb clocks. A $y(t)=a\cdot\ln(bt+1)$ log fit to the frequency data allows the deterministic aging to be separated from the stochastic noise, and uses the entire record to determine the aging slope at the end, only -8.25×10^{-14}/day. A detailed inspection of the data shows a considerable amount of sharp phase noise and spikes, and some daily variations that are indicative of orbital effects.

Figure 4 shows the RAFS S/N 006 frequency residuals after the log fit is removed. The quality of the trend removal is excellent, and the residuals show the noise and diurnal variations more clearly. These residuals are then used to analyze the clock stability.

Figure 5 shows the RAFS S/N 006 frequency stability as measured during factory acceptance testing and by the NIMA in-orbit data for the complete SVN43 time keeping system (TKS). The order-of-magnitude increase in noise at short averaging times is due mainly to the coarse phase meter resolution, while the extra noise at intermediate averaging times is due mainly to VCXO noise and temperature sensitivity.[1] It is also somewhat higher than measured during ITT acceptance testing[2], perhaps because the actual orbital temperature variations are larger than predicted. The RAFS temperature sensitivity is negligible. The overall stability is near that of the RAFS itself at averaging times of 1 day and longer.

Figure 6 shows the RAFS S/N 006 time stability. The 1-day time deviation, $\sigma_x(\tau)$ or TDEV, is probably the single best indicator of clock performance in the GPS application. This value, 0.79 nsec or 0.24 meter, is excellent, and well within the 1.40 meter error budget allocation.[2]

RAFS S/N 005

Figures 7-10 show similar data for RAFS S/N 005, which was turned on 8/22/97 and selected as the on-line clock on 9/26/97. NIMA tracking data for S/N 005 began on 9/27/97 and continued until 10/16/97, when it ended because of side effects of an extended navigation test that is expected to continue through 12/7/97. RAFS S/N 005 had a drift of -1.12×10^{-13}/day at the end of this record and a stability essentially identical to that of S/N 006. The 1-day TDEV for this clock was also similar, 0.59 nsec.

CONCLUSIONS

The first of a new generation of space-qualified rubidium clocks has been launched and their early performance is excellent.

ACKNOWLEDGEMENTS

The work on these high performance rubidium clocks has been underway for over 20 years, beginning at General Radio in 1975 and continuing at EG&G since 1980. Many persons and organizations have contributed to and supported this work, including the U.S. Air Force, Rockwell/Boeing, ITT, GE/Lockheed Martin, the Naval Research Laboratory and Aerospace Corporation.

REFERENCES

[1] A. Wu, "*Performance Evaluation of the GPS Block IIR Time Keeping System*", Proceedings of the 28th Annual Precise Time and Time Interval (PTTI) Applications and Planning Meeting, December 3-5, 1996, pp. 441-453.

[2] H. Rawicz and R. Smid, "*GPS Block IIR Accuracy Verification*", Proceedings of the ION GPS-97 Conference, pp. 377-385.

[3] J.A. Buisson, "*RAFS Life Test Analysis Update No. 28-29*", Naval Research Laboratory, October 22, 1997.

[4] J.A. Buisson, "*RAFS Life Test Analysis Update No. 30-29*", Naval Research Laboratory, October 22, 1997.

[5] http://164.214.2.59/geospatial/products/GandG/sathtml/.

[6] ftp://164.214.2.59/pub/sat_out/nimwwwwd.13, where wwww is the GPS week # and d is the day.

[7] J.A. Buisson, "*NAVSTAR Analysis Update No. 43-3*", Naval Research Laboratory, October 14, 1997.

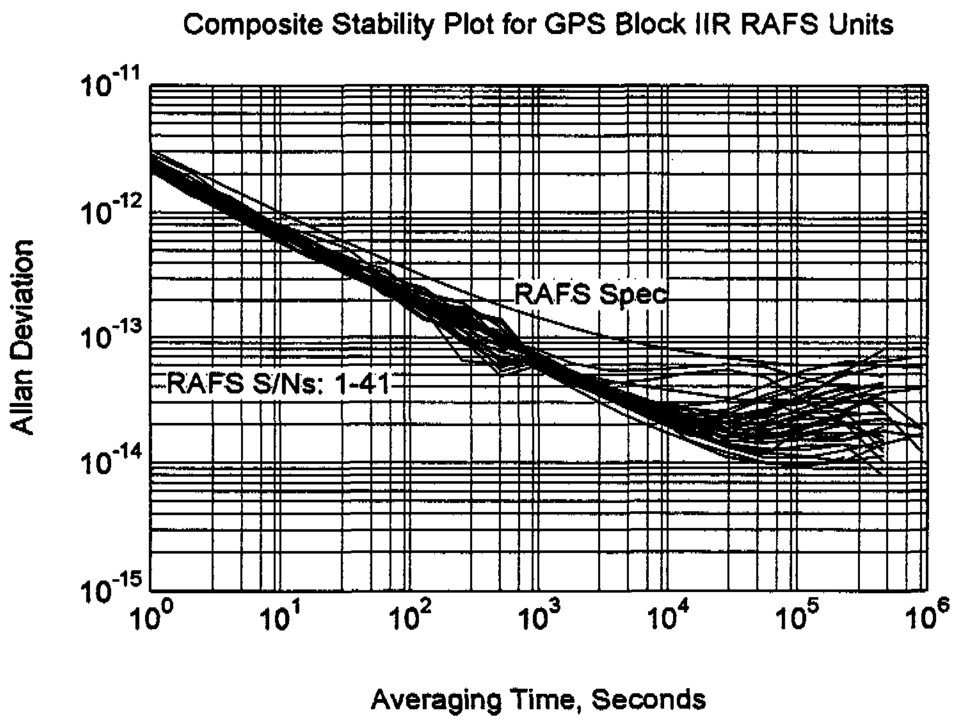

Figure 1 RAFS Composite Frequency Stability Plot

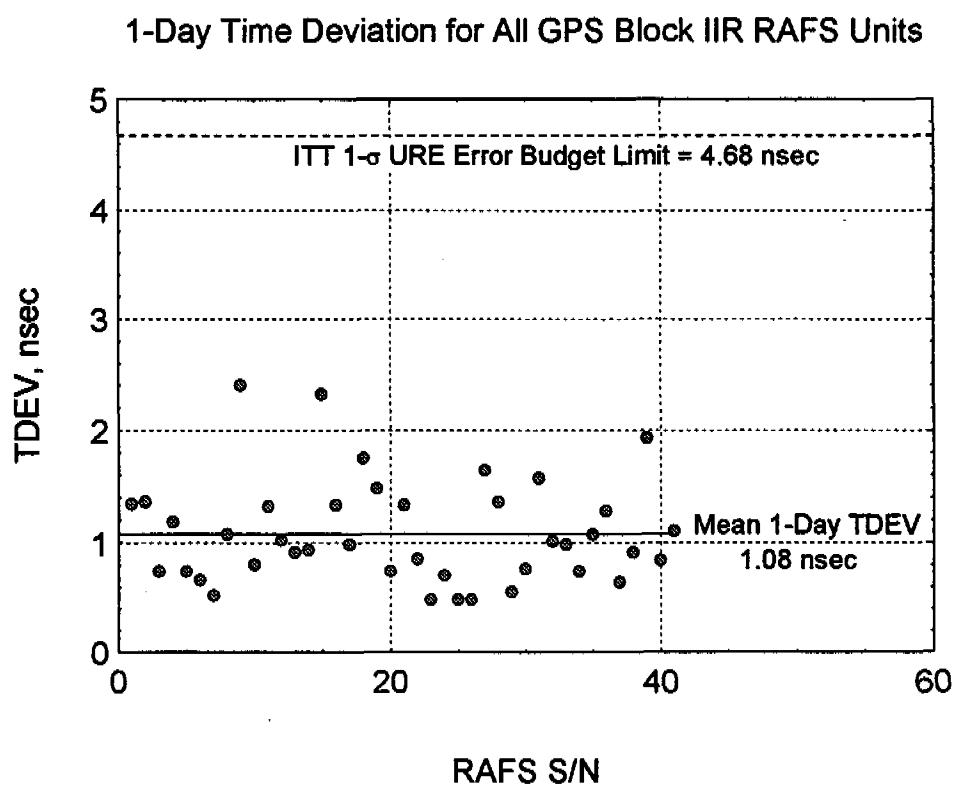

Figure 2 RAFS Composite Time Stability Plot

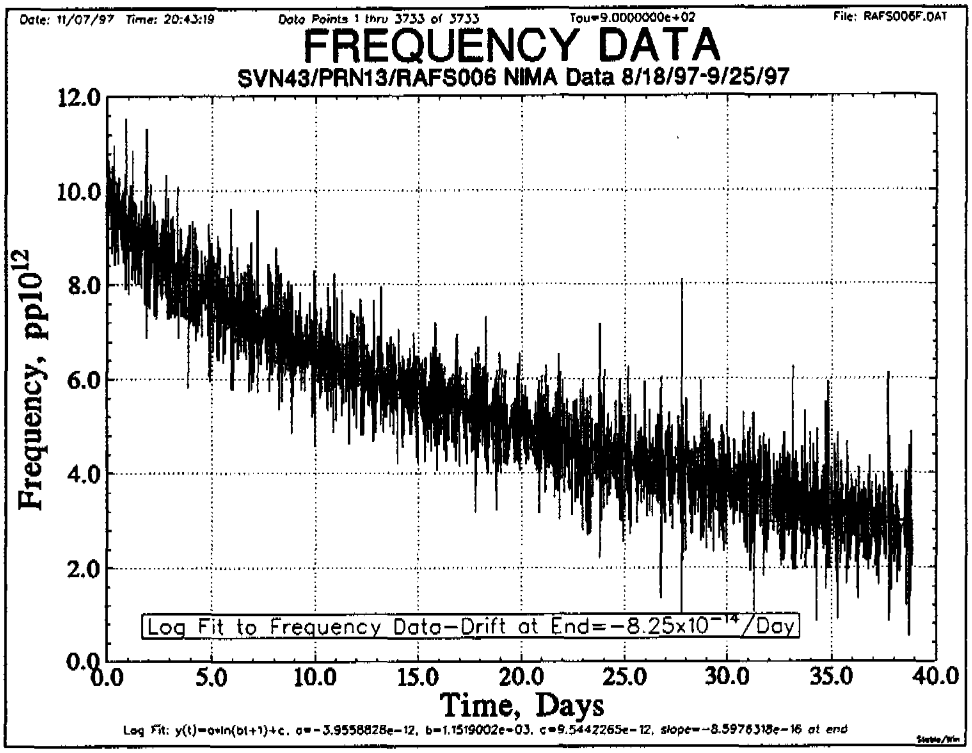

Figure 3 RAFS S/N 006 Frequency Data

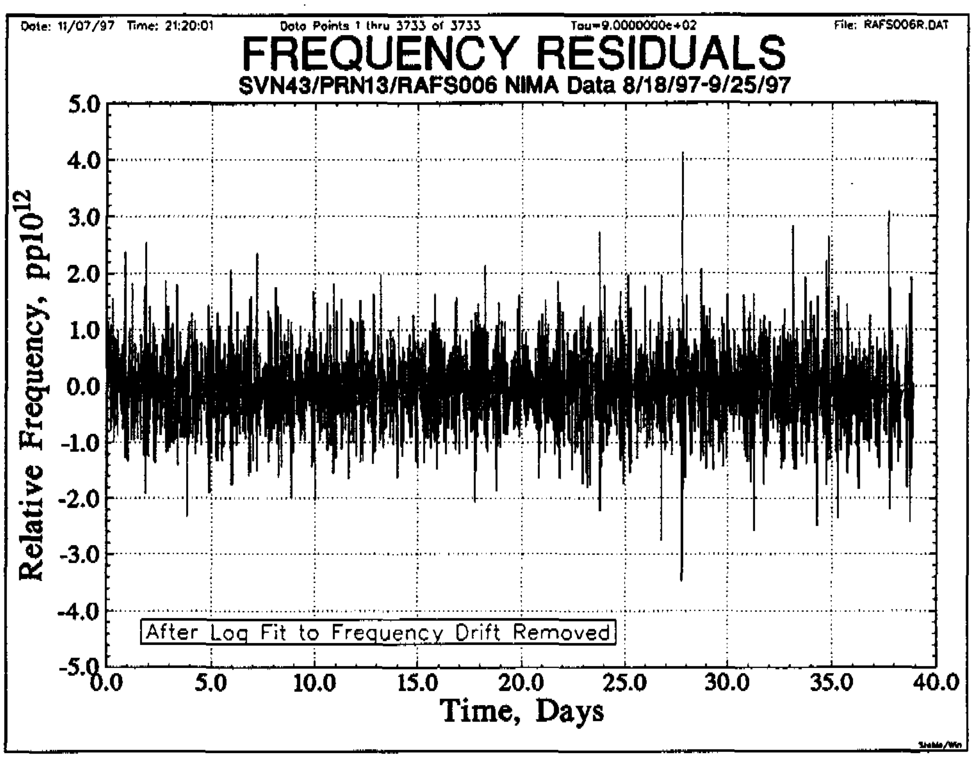

Figure 4 RAFS S/N 006 Frequency Residuals

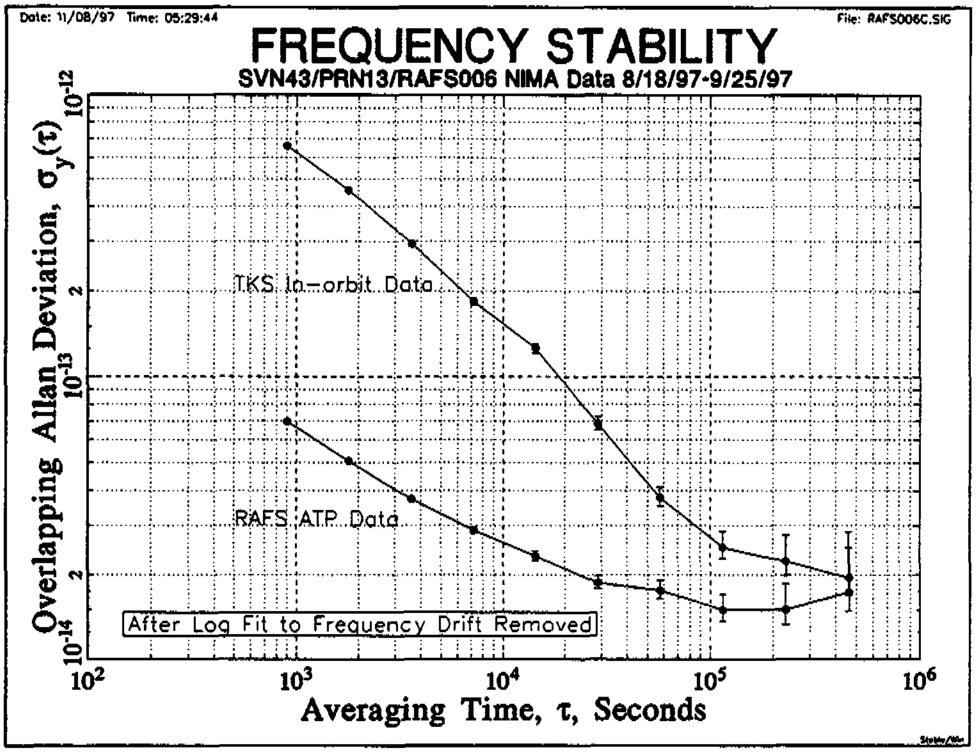

Figure 5 RAFS S/N 006 Frequency Stability

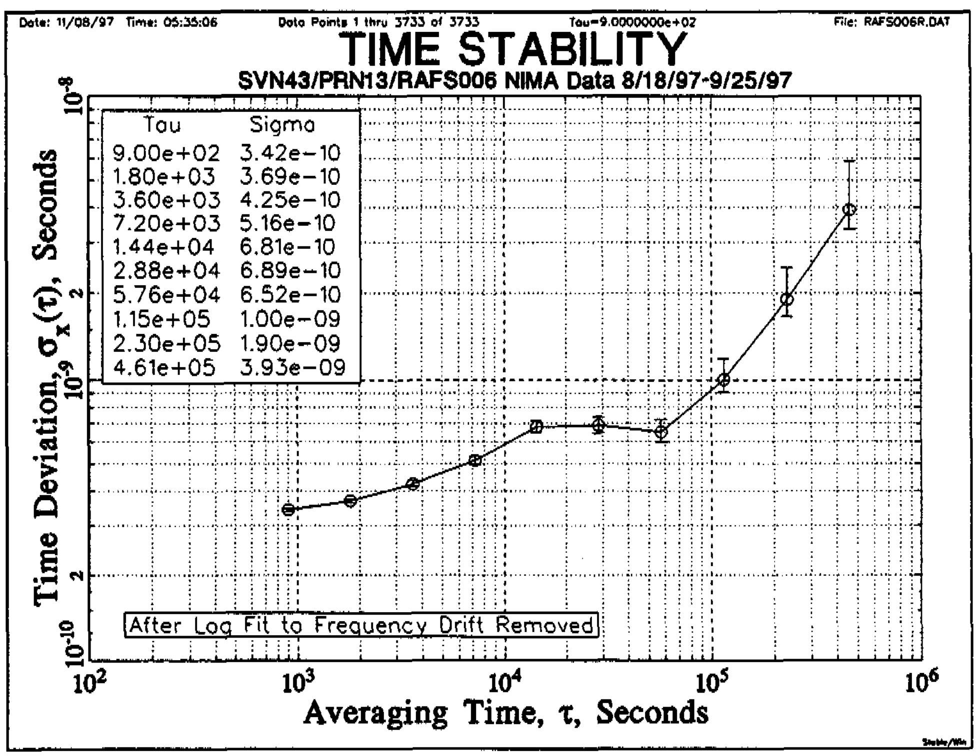

Figure 6 RAFS S/N 006 Time Stability

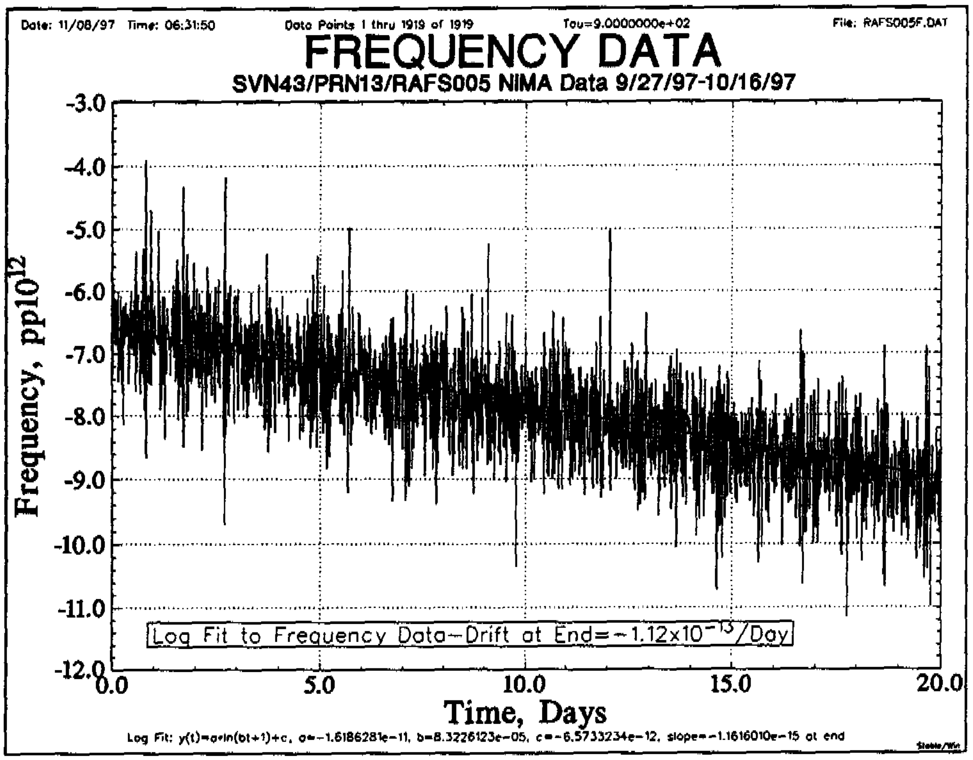

Figure 7 RAFS S/N 005 Frequency Data

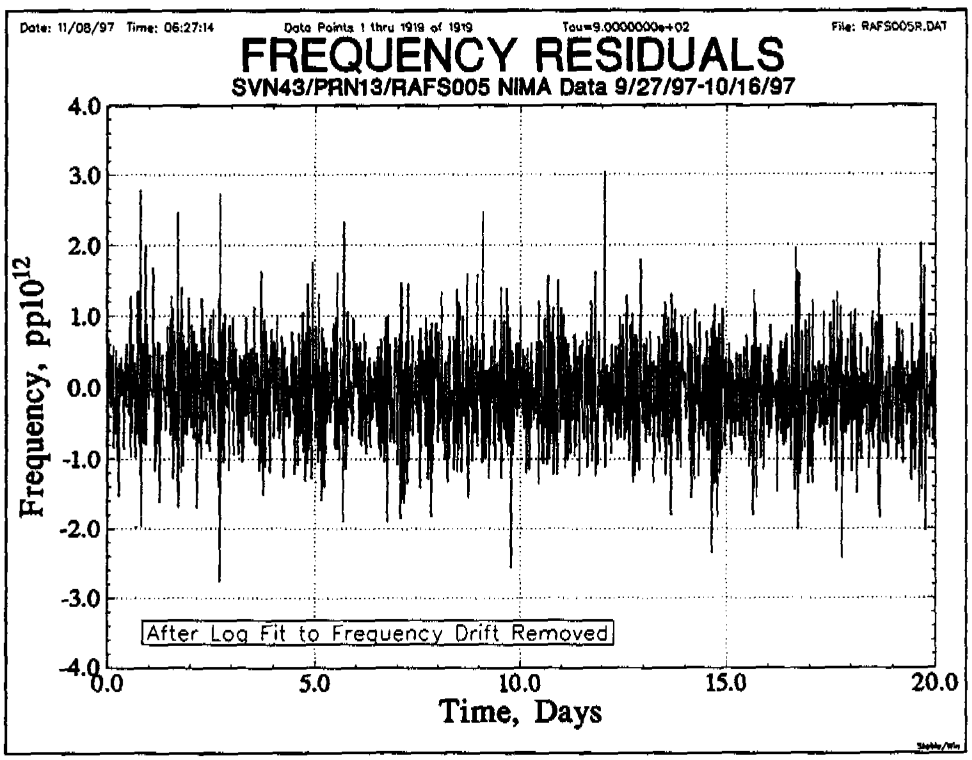

Figure 8 RAFS S/N 005 Frequency Residuals

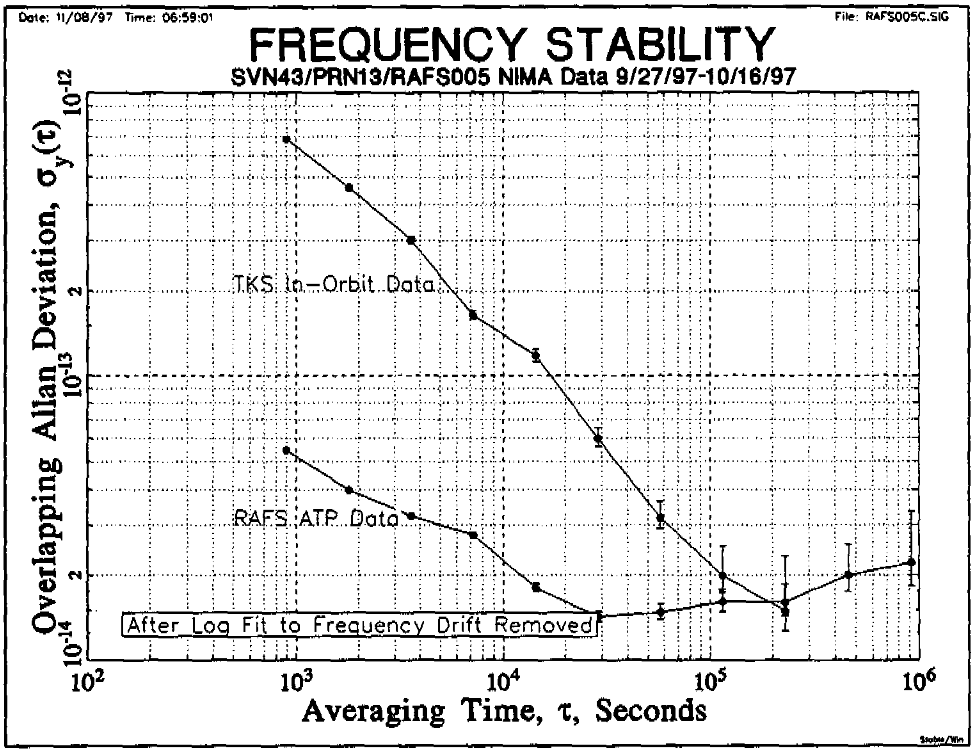

Figure 9 RAFS S/N 005 Frequency Stability

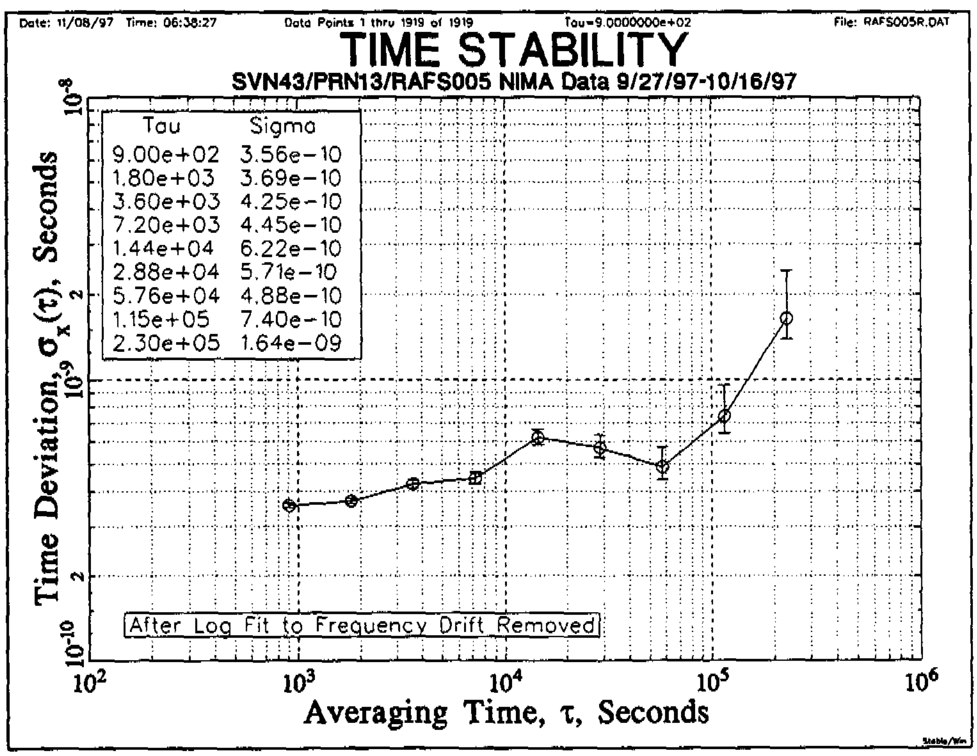

Figure 10 RAFS S/N 005 Time Stability