

# A COMPARISON OF SEVERAL GPS DATA REDUCTION METHODS

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## Abstract

*For several years, discussions have been ongoing about how to analyze GPS time information in order to get the most accurate and precise time comparison between two locations. Many similar studies were done several years ago before the constellation was dominated by Block II satellites. With the Block II satellites and the use of Selective Availability (S/A), time comparisons have lost some precision and accuracy. This paper presents the results of research that was performed to find not only the best of several time comparison methods, but also to determine to what degree precision and accuracy have declined due to S/A.*

## Introduction

The U.S. Naval Observatory (USNO) has been monitoring the GPS time signals for more than 15 years, and through the years, the timing community has been discussing the best reduction methods for those signals. GPS is to date the most accurate and precise navigation and timing system available. We in the timing community are constantly trying for better and, to that end, it was decided that a comparison study should be made of three easily implemented reduction methods. The object was to find the accuracy attainable, the pitfalls, and the effects of Selective Availability (S/A) on each method.

## Data

The data used in this study were collected on an STel model 502 single frequency GPS receiver (SFR) at USNO in Washington, D.C. and at the Naval Observatory Time Service Substation (NOTSS) in Miami, FL. This receiver produces both a GPS and a UTC time value. Each data point used in the reduction was the result of a linear fit through approximately 130 six-second data points referred to the beginning of the track period. The use of 13 minute periods of data insures that the entire GPS message containing the ionospheric and UTC time corrections was received<sup>[1]</sup>.

## Reduction Methods Used

It was decided that three distinct time comparison methods should be compared. The first would use the UTC time correction as transmitted by the GPS satellites. This is the most easily obtained information and can be easily reduced to a relatively high level of accuracy when compared to LORAN and other timing sources. The second method would use common view data points. In this method, two locations monitor the same satellite simultaneously. Each receives a GPS time (or UTC time) from the satellite versus a local reference. Simple subtraction will yield the difference between the two locations. For official timing in the US, one of those locations is USNO in Washington, D.C., and the other location is the point to be synchronized. The third method of reduction would use a "melting pot" of data points. In this method, each location monitors either the most visible satellite (in the case of a single channel receiver) or all satellites possible (in the case of a multi-channel receiver). The individual GPS time versus the local standard's time comparisons are "lumped" together over a period of time. The linear fit solution of these points is considered the offset of the GPS time from the local standard's time. Subtracting one local standard's offset time from the other yields the time difference between the two locations. Again, for official timing in the US, one of those locations is USNO in Washington, D.C., and the other location is the point to be synchronized. The "melting pot" method is similar to the satellite hopping method<sup>[2]</sup> and has been employed by USNO for over 15 years<sup>[3]</sup>.

In this study, it was recognized early that the common view method would be better for short distances between locations, but that it could have a problem over great distances due to geometric and ionospheric considerations. Aside from the coordination efforts and personnel needed to employ common view schedules at various locations, there is also the problem of local schedule demands that can prevent a fully optimized common viewing. Because this research could not interrupt ongoing operations, common view data values were taken whenever they could be obtained. This varied from under 60% to over 80% of the total number of data points collected at a location. It was also recognized that the "melting pot" method would have an accuracy problem if there were not enough data points to fit a curve. A preliminary item of research was to find how many data points were needed to get a valid solution to the "melting pot" linear fit solution. It was found that at least 70 data points per 48-hour period were consistently needed to obtain a result with less than one sigma deviation. A third problem was how to compare a solution that produced many time difference values (common view method) with one that would produce one time difference value per day (melting pot). It was found that the common view method produced scattered results (although not as much as the other methods). A linear fit of those common view points produced a higher level of accuracy and a way to compare common view data reduction one-on-one with "melting pot" reduction.

The linear fit solution method was chosen over more complex methods (e.g., Vondrak's<sup>[4]</sup>) because it was found to be the simplest method that would produce a reasonable result consistently. More elaborate methods were tried and found to agree with Winkler<sup>[5]</sup>, that the more complex methods produced results that were no more accurate and, occasionally, less accurate. Data filtering for the linear fit solution was a two-step process. First, a coarse filter removed the obviously bad values (i.e., a value one microsecond off from its expected value). A first pass through the linear fit program was then performed, with slope and sigma

values calculated. All points exceeding two sigma were then deleted from the reduction and all remaining points linear fitted for a second time. The result from this second pass is the reported value.

Block II results were compared to Block I results to see the degradation due to S/A. Then the results for the common view and "melting pot" reduction methods were compared to decide which is better.

## Results

Method 1) Use the UTC time as transmitted by the satellites. This information can be used in several ways.

a) One satellite is observed for a brief time. The time difference between this transmitted UTC time value and the local time standard is taken as the offset between the local standard and UTC(USNO). (UTC(USNO) is the standard by which the GPS is compared.) This one-shot method can vary more than 60 nanoseconds, when using only Block I satellites or Block II with S/A off, and more than 300 nanoseconds, when Block II satellites are used with S/A on (see Fig. 1).

b) Several satellites are observed for extended periods of time. The running linear fit solution (a 48-hour period was used here) of the difference between the UTC time transmitted from these satellites and the local time standard is taken as the offset between the local standard and UTC(USNO). This linear fit method, using only Block I satellites, can vary more than 20 nanoseconds (see Fig. 2) with an rms of 10 to 20 nanoseconds (see Fig. 3). When using Block II satellites with S/A enabled, the difference can vary more than 30 nanoseconds (see Fig. 4) with an rms of 60 to 80 nanoseconds (see Fig. 5).

To get a better picture of the effects of S/A, we subtract the Block I linear fit result from the Block II result. This results in showing that S/A will affect the UTC timing by more than  $\pm 20$  nanoseconds (see Fig. 6).

With either of these methods, the data are dependent on the GPS Master Control Station (MCS) to upload in a timely manner the current UTC offset to the satellites. Currently, these corrections are uploaded once every 24 hours. However, these uploads may not be frequent enough to meet the needs of some locations.

Method 2) A time comparison between two locations can be made. Time offset data are collected at the standard (USNO) and at the location desiring time synchronization. By simple subtraction, the time offset between USNO and the remote site is found. This comparison can be done in several ways. To compare the various methods, avoid the problem of the MSC's failure to upload the UTC correction to the satellites simultaneously, and respond to local monitoring requirements, the GPS time transmitted by the satellites was used.

a) One satellite is simultaneously observed at both locations for a brief time. Values of USNO minus satellite time and local clock minus satellite time are obtained. Subtraction of the second from the first will yield USNO minus local clock. The values obtained from this one simultaneously observed satellite (single point common view) method can vary more than 20 nanoseconds, depending on which satellite is observed, when using only Block I satellites (see Fig. 7), to more than 40 nanoseconds, when Block II satellites are used with S/A enabled (see Fig 8).

b) One satellite is simultaneously observed at both locations for a brief time. Values of USNO minus satellite time and local clock minus satellite time are obtained. Subtraction of the second from the first will yield USNO minus local clock. This one simultaneously observed satellite value is then linear-fitted with other values over a specified period of time (48 hours were used here). This linear fitting of common view values method using Block I satellites can vary more than 5 nanoseconds (see Fig 9), with an rms of 2 to 10 nanoseconds (see Fig. 10). When Block II satellites are used with S/A enabled, the difference can vary more than 10 nanoseconds (see Fig. 11), with an rms of 5 to 10 nanoseconds (see Fig. 12).

Again, to get a better picture of the effects of S/A, we subtract the Block I linear fit result from the Block II result. This results in showing that S/A will affect the linear fitting of common view points by more than +/- 5 nanoseconds (see Fig. 13).

c) All satellites in view at each location are observed. Only a small amount of effort, if any, is made to observe the same satellite simultaneously at each location. The clock minus GPS time values from USNO and clock minus GPS time values from the local clock are linear-fitted separately. Then subtracting the second from the first, one obtains USNO minus local clock. The result is a "melting pot" of satellites' linear fit time transfer between two locations. This "melting pot" linear fit method using only Block I satellites can vary by more than 10 nanoseconds (see Fig. 14), with an rms of 10 to 25 nanoseconds (see Fig. 15). When using Block II satellites with S/A enabled, the difference can vary more than 20 nanoseconds (see Fig. 16), with an rms of 80 to 110 nanoseconds (see Fig. 17).

Yet again, to get a better picture of the effects of S/A, we subtract the Block I linear fit result from the Block II result. This shows that S/A affects the linear fitting of "melting pot" points by more than  $\pm 10$  nanoseconds (see Fig. 18).

This concludes the comparison of the effect of Selective Availability on time synchronization of a clock to UTC(USNO). However, a comparison of common view versus "melting pot" must yet be done to determine the better analysis method.

For Block I satellites, the "melting pot" solution minus a linear fit of the common view points is less than  $\pm 20$  nanoseconds (see Fig. 19). But, a running five-day average is less than 15 nanoseconds (see Fig. 20). A running 60-day average shows the difference in the two methods is less than 10 nanoseconds (see Fig. 21). Using Block II satellites, the difference will vary by  $\pm 20$  nanoseconds (see Fig. 22). Again, by averaging the differences over a period of time, the average difference is much less. For a five-day running average, the difference can be over 10 nanoseconds (see Fig. 23). When a 60-day running average is performed, the average

difference is less than 10 nanoseconds (see Fig 24).

## Conclusions

The level of accuracy and precision needed at a location will determine how best to synchronize a local clock to UTC(USNO). If the tolerance is more than half a microsecond (500 nanoseconds), the local clock can be set according to the UTC time transmitted by any satellite (Block I or II). For closer tolerance, data reduction methods must be employed and time comparisons must be made between USNO and the remote clock.

A one-time comparison using one satellite will yield an error of more than 40 nanoseconds for Block II satellites with S/A enabled. Linear fitting of several common view time comparisons will yield an error of more than 10 nanoseconds, with an rms of over 10 nanoseconds, for Block II satellites with S/A enabled. A "melting pot" time comparison will yield a tolerance of more than 20 nanoseconds, with an rms of over 100 nanoseconds, for Block II satellites with S/A enabled. The linear-fitted common view solution is within 10 nanoseconds difference from the "melting pot" solution when averaged over 60 days. Although the "melting pot" method is more than ten times noisier, it is far less work to implement. Exact viewing schedules do not have to be loaded into each GPS receiver. The "melting pot" method requires many data points to maintain its accuracy (70 to 80 passes per 48-hour period), whereas the common view method needs considerably fewer data points (at least five to ten per 48-hour period) to maintain its high level of accuracy. The analysis of common view points also requires that the data reduction program do a considerable amount of verification and resynchronization of those data points whose collection times do not exactly match. As a result, the initial programming takes longer to develop and the program execution takes fractionally longer than the "melting pot" analysis.

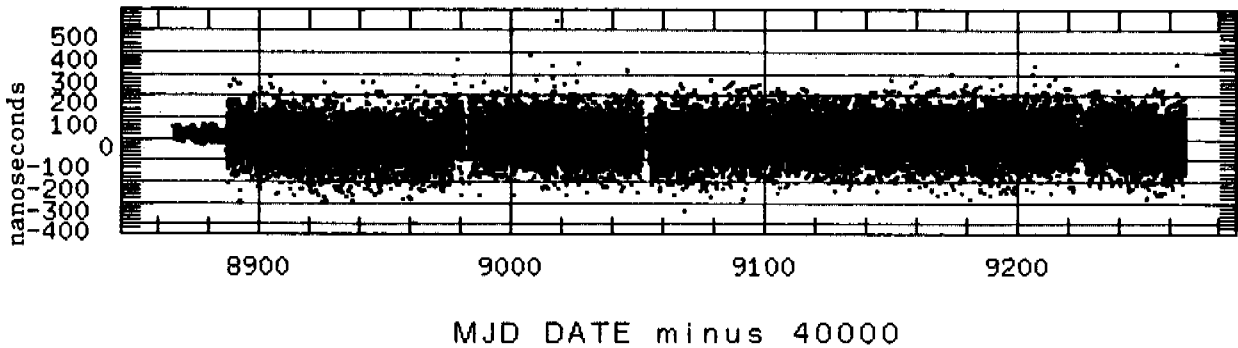
The final judgement of whether performing the extra work in programming and maintaining common view time comparison is offset by the lower noise level of the results must be left to the individual centers of operations. Each center's procedure is governed by its own allowable tolerances.

## References

- [1] Miranian, M. and Klepczynski, W. , "*Time Transfer via GPS at USNO*", Proceedings of ION GPS-91, pp. 215 – 222
- [2] Dewey, W.P., "*Disciplined Rubidium Oscillator with GPS Selective Availability*", Proceedings of the 24<sup>th</sup> Annual Precise Time and Time Interval Applications and Planning Meeting, 1992, pp. 163 – 167
- [3] Winkler, G.M.R. (USNO), private communication, 1993
- [4] Vondrak, J., "*A Contribution to the Problem of Smoothing Observational Data*", Bulletin of the Astronomical Institutes of Czechoslovakia, vol. 20, pp. 349 – 355
- [5] Winkler, G.M.R., "*Introduction to Robust Statistics and Data Filtering*", 1993 Frequency Control Symposium Tutorials, June 1993

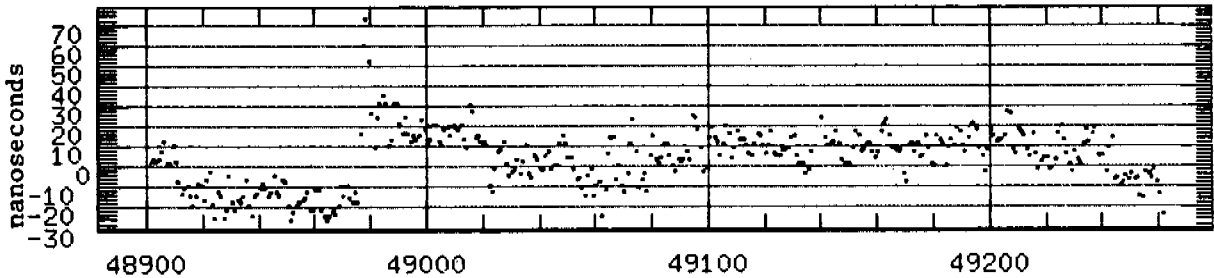
**USNO MC MINUS GPS UTC TIME RAW DATA**

(Fig. 1)



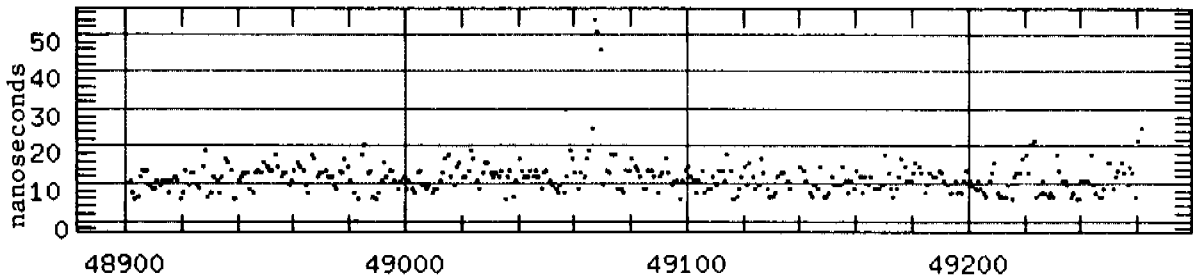
**USNO MC - BLOCK I UTC TIMES, 48-HOUR LINEAR FITTED**

(Fig. 2)



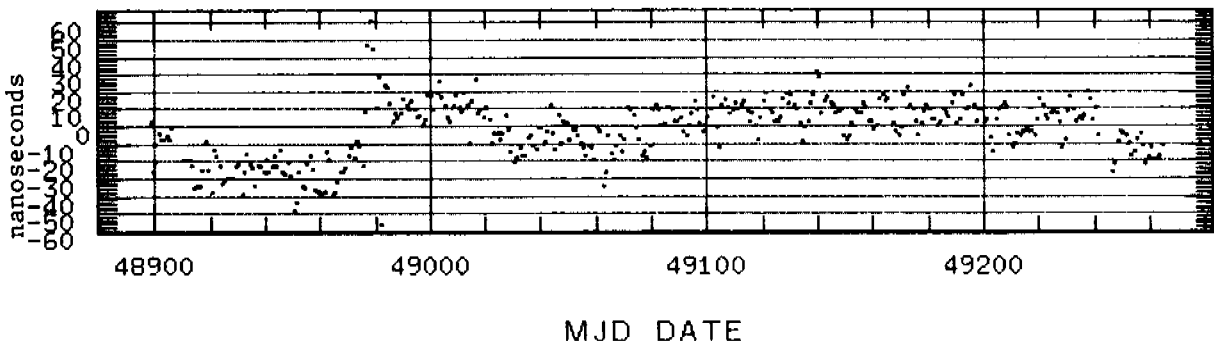
**USNO MC - BLOCK I UTC TIMES, LINEAR FIT RMS**

(Fig. 3)



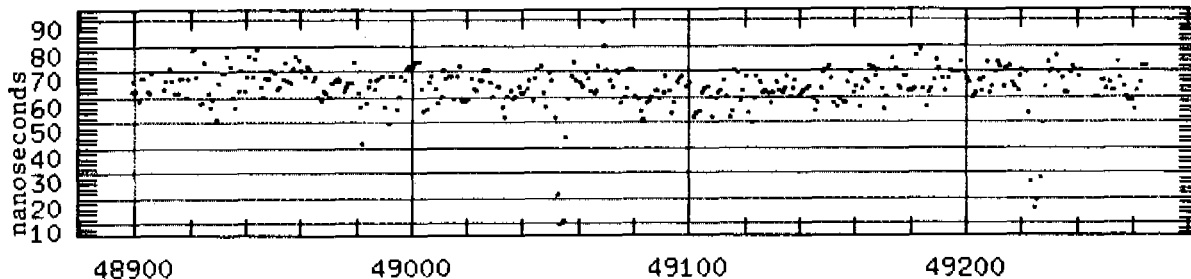
**USNO MC - BLOCK II UTC TIMES, 48-HOUR LINEAR FITTED**

(Fig. 4)



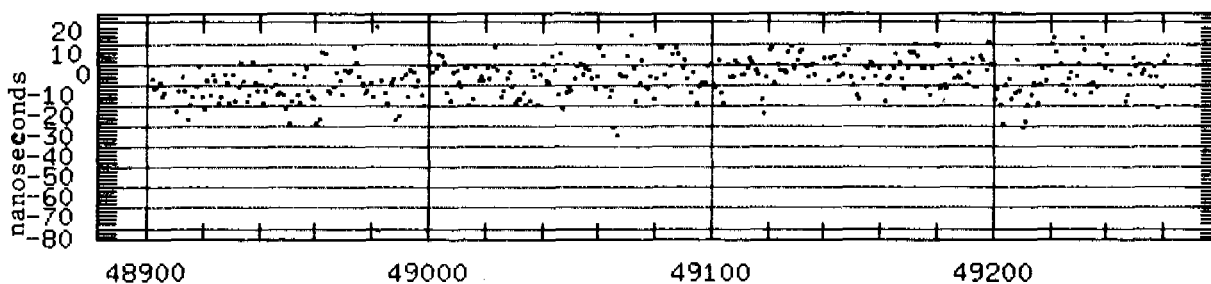
USNO MC - BLOCK II UTC TIMES, LINEAR FIT RMS

(Fig. 5)



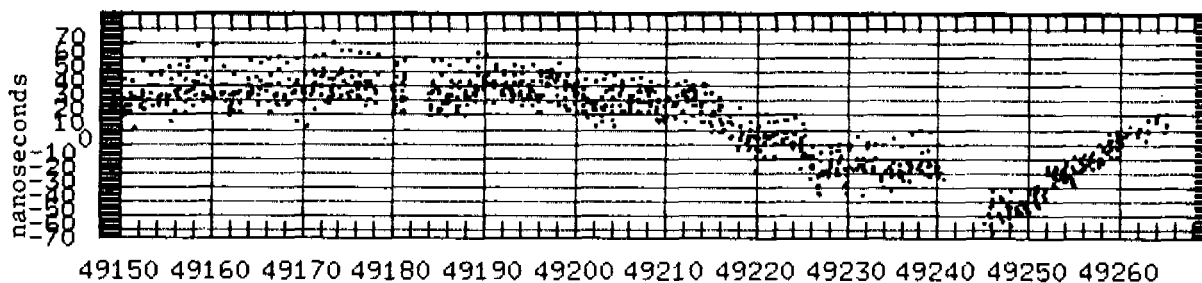
BLOCK II MINUS BLOCK I LINEAR FITTED UTC TIMES

(Fig. 6)



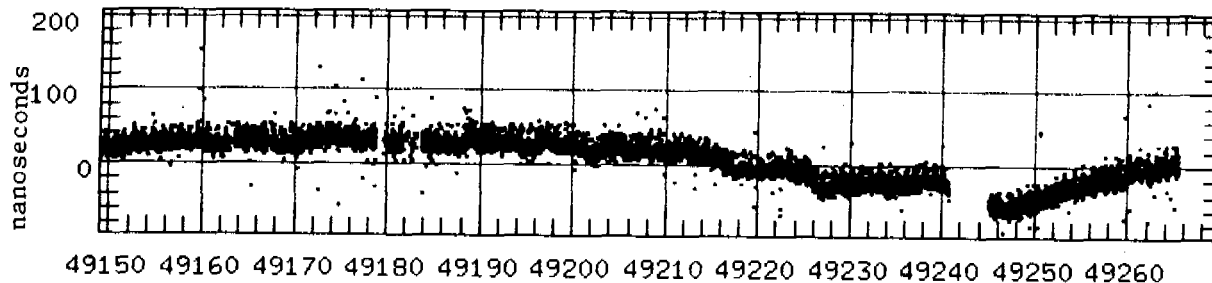
USNO MC - NOTSS VIA SINGLE BLOCK I COMMON VIEW POINTS

(Fig. 7)



USNO MC - NOTSS VIA SINGLE BLOCK II COMMON VIEW POINTS

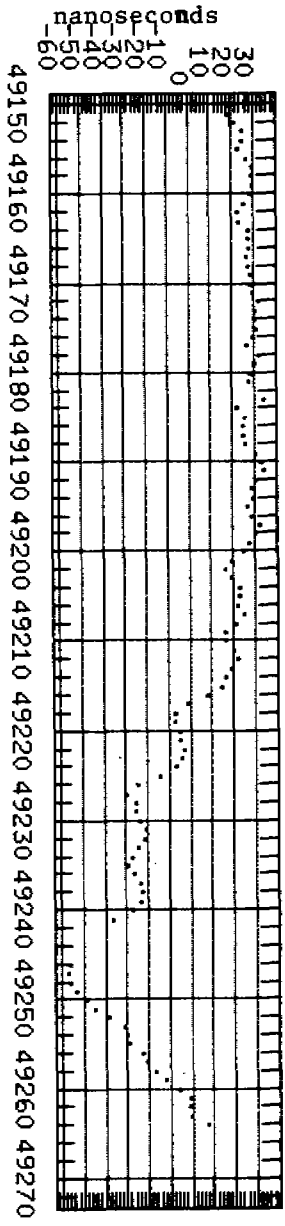
(Fig. 8)



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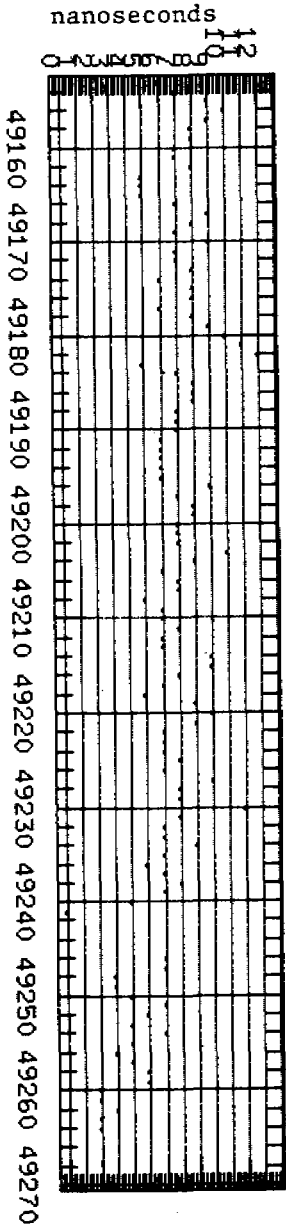
USNO MC - NOTSS VIA FITTED BLOCK I COMMON VIEW POINTS

(Fig. 9)



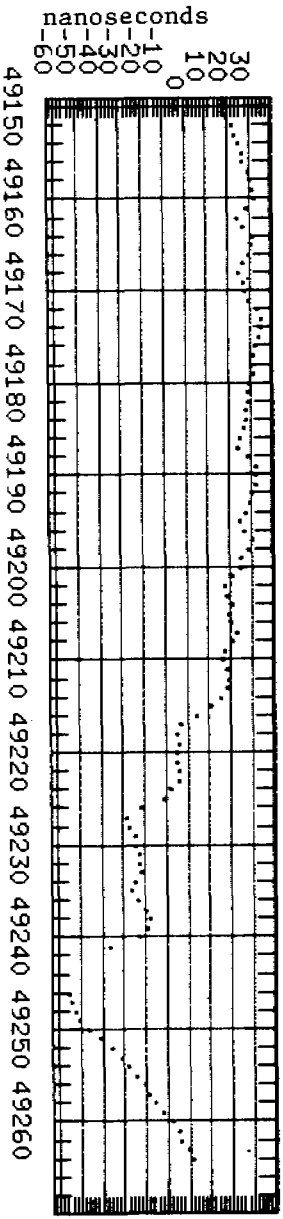
USNO MC - NOTSS FITTED BLOCK I COMMON VIEW POINTS RMS

(Fig. 10)



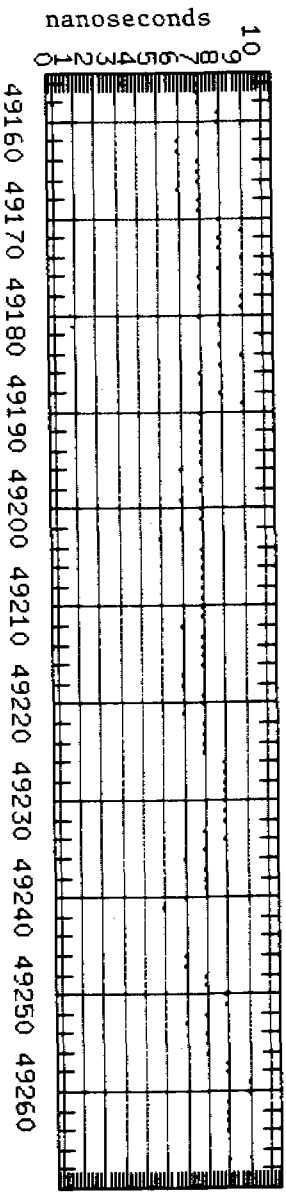
USNO MC - NOTSS VIA FITTED BLOCK II COMMON VIEW POINTS

(Fig. 11)



USNO MC - NOTSS FITTED BLOCK II COMMON VIEW POINTS RMS

(Fig. 12)

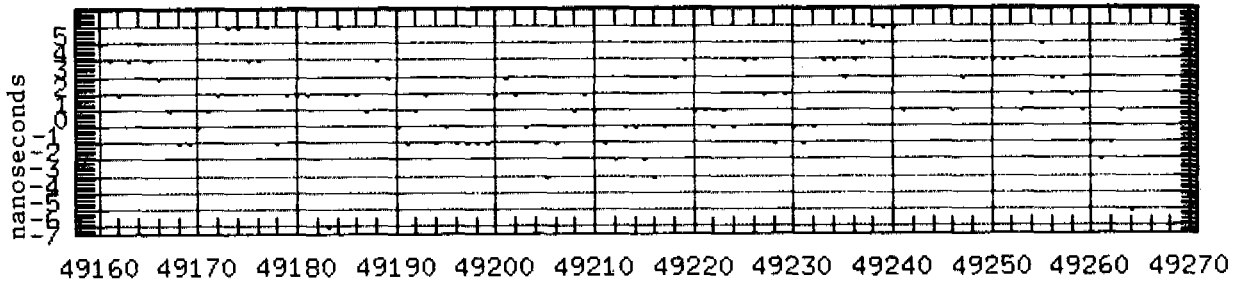


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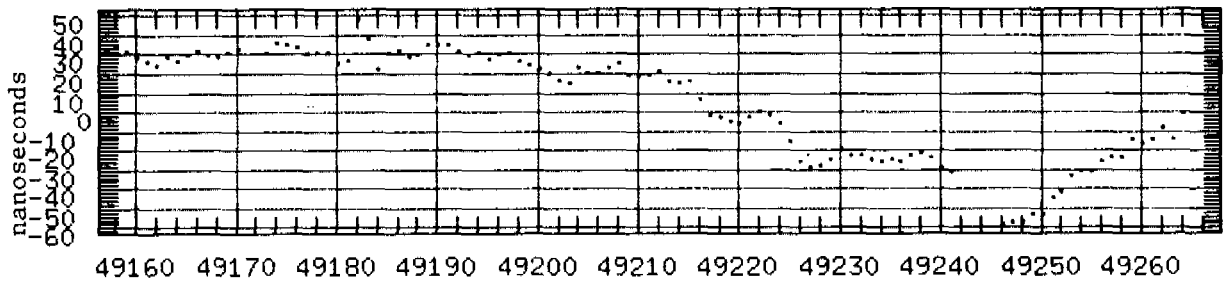
**BLOCK II - BLOCK I FITTED COMMON VIEW POINTS**

(Fig. 13)



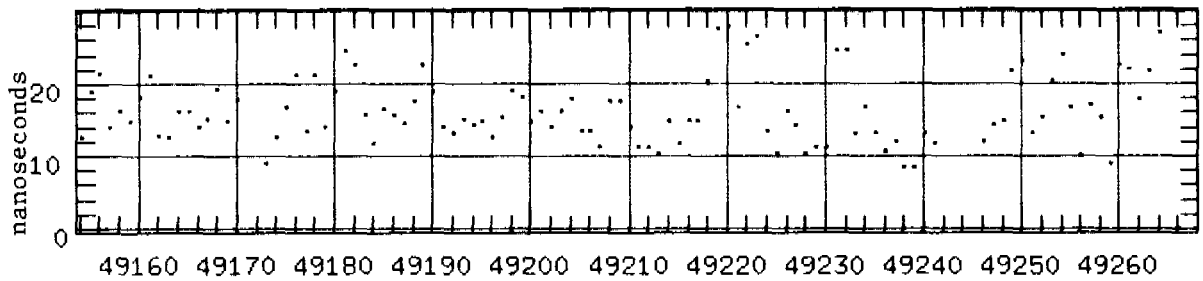
**USNO MC - NOTSS BLOCK I MELTING POT LINEAR FIT**

(Fig. 14)



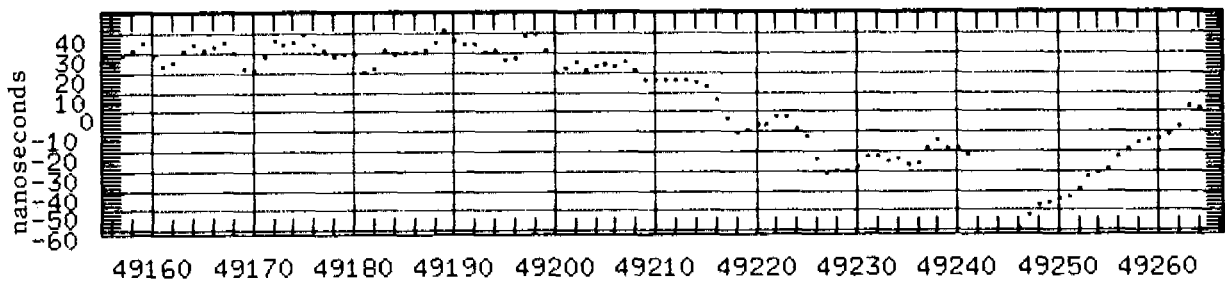
**USNO MC - NOTSS BLOCK I MELTING POT LINEAR FIT RMS**

(Fig. 15)



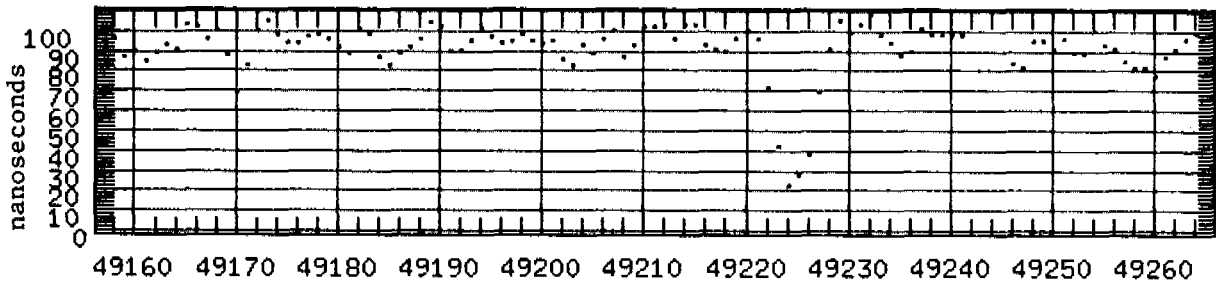
**USNO MC - NOTSS BLOCK II MELTING POT LINEAR FIT**

(Fig. 16)

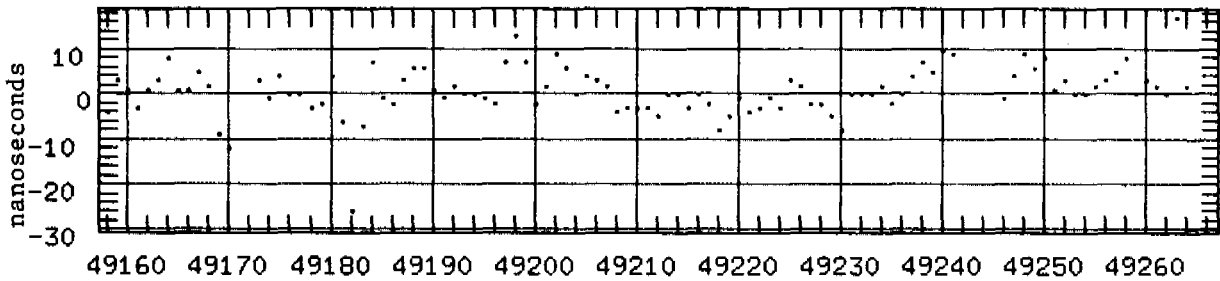


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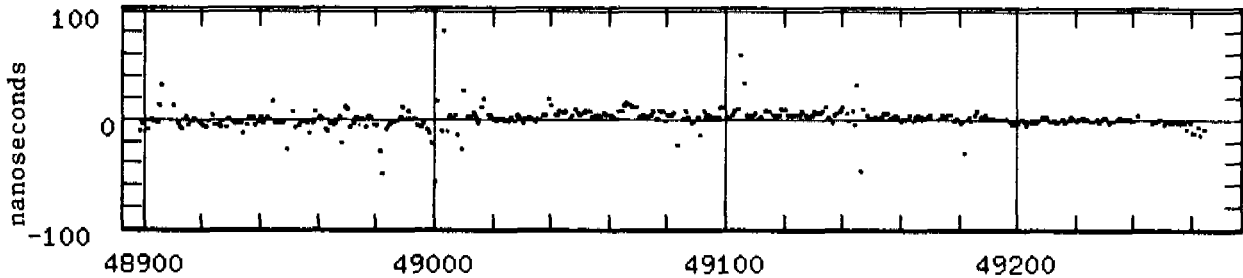
USNO MC - NOTSS BLOCK II MELTING POT LINEAR FIT RMS  
(Fig. 17)



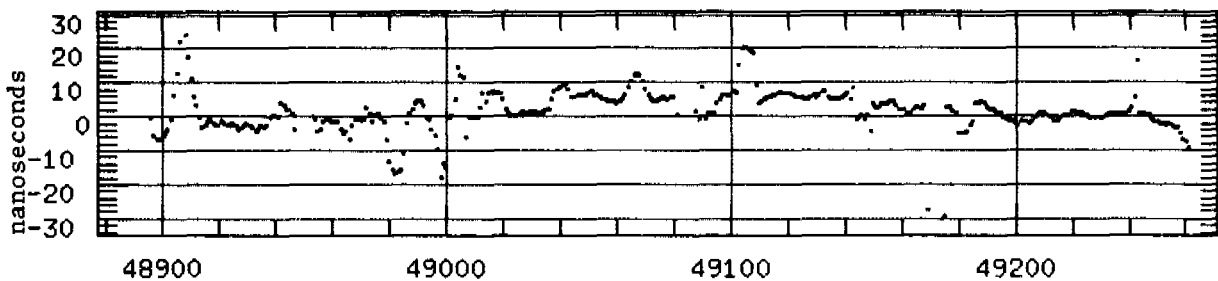
BLOCK II - BLOCK I MELTING POT LINEAR FIT POINTS  
(Fig. 18)



USNO MC - NOTSS BLOCK I MELTING POT - COMMON VIEW  
(Fig. 19)

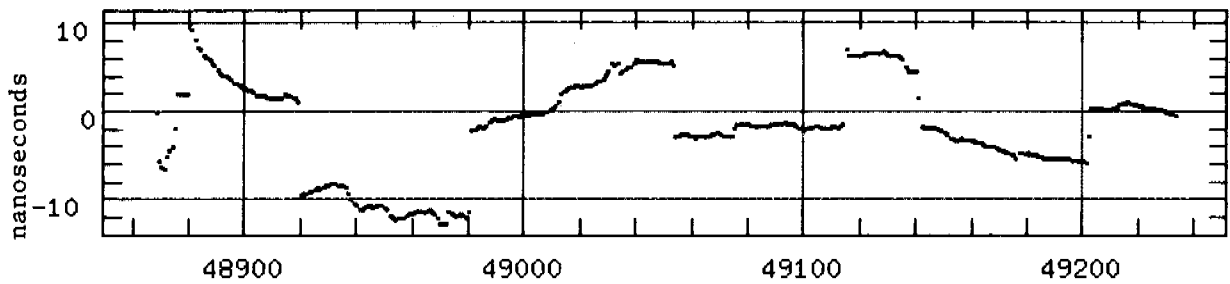


USNO MC - NOTSS BLOCK I MELTING POT - COMMON VIEW  
(Fig. 20)

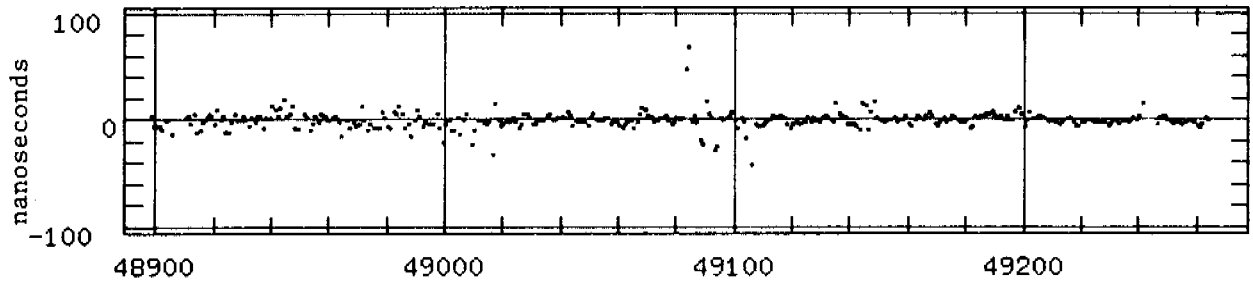


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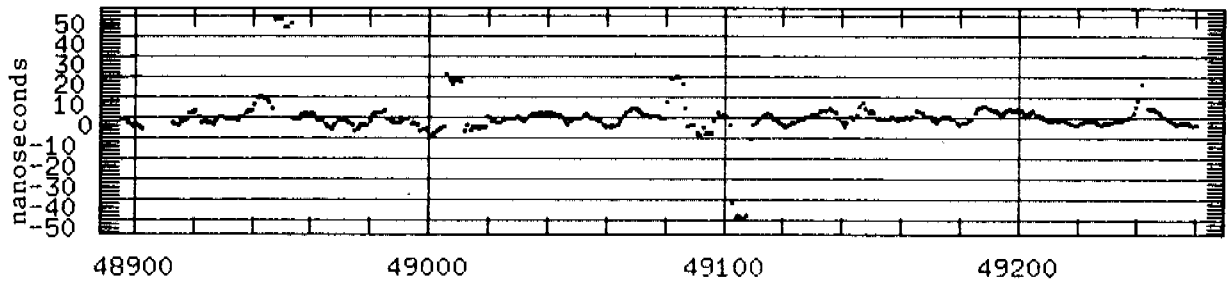
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(Fig. 21)



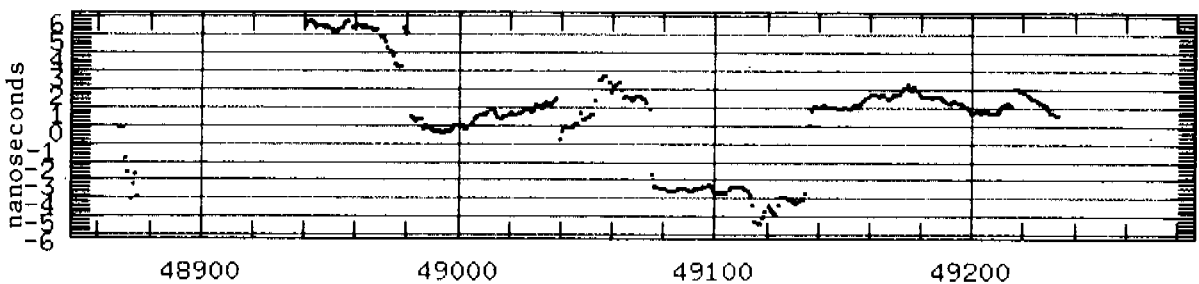
USNO MC - NOTSS BLOCK II MELTING POT - COMMON VIEW  
(Fig. 22)



USNO MC - NOTSS BLOCK II MELTING POT - COMMON VIEW  
(Fig. 23)



USNO MC - NOTSS BLOCK II MELTING POT - COMMON VIEW  
(Fig. 24)



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