COMMON-VIEW TIME TRANSFER USING THE TWO-CHANNEL FAST-SEQUENCING GPS RECEIVER K+K GPS6-2K

P. Hetzel, T. Polewka
Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

W. Klische
K+K Messtechnik GmbH, Braunschweig, Germany

Abstract

Two 2-channel fast-sequencing GPS receivers (Type K+K GPS6-2K made by K+K Messtechnik GmbH, Braunschweig, Germany) have been studied in co-location and in comparison with the NBS-type receivers used at the PTB for the regular GPS CV- time transfer. The new receivers consist of two channels (the "Tracking Channel" and the "Data Channel"), a built-in time interval meter, and PC software. The "Tracking Channel" either continuously tracks a single satellite or sequentially tracks all satellites in view. Both the code phase and the carrier (delta) phase are measured and combined to yield a smoothed reading of the received satellite time. The "Data Channel" reads all the data necessary from the satellites, like almanac, ephemeris, ionospheric model parameters, etc., and acquires new satellites as they arise above the horizon. The PC software currently used generates the "CGGTTS GPS/GLONASS Data Format" in either multichannel mode when observing all satellites in view, or in the traditional single channel mode when tracking a single satellite according to the limited BIPM schedule. The receiver architecture is described, and measurement results obtained from the K+K receivers are compared with the corresponding results determined by NBS-type receivers.

1 INTRODUCTION

In [1] SATMIX time scale comparisons between the PTB (Physikalisch-Technische Bundesanstalt) and the TUG (Technical University Graz) using two single-channel fast-sequencing GPS receivers are described. The time scale differences determined with the SATMIX or Melting Pot Time Transfer method were compared with the corresponding results obtained by the more accurate two-way satellite time and frequency transfer (TWSTFT). Over a period of 1 year the scatter between the two transfer methods amounted to 4 ns, but no significant systematic receiver delay changes of the K+K fast-sequencing receivers were observed. Due to the long-term stability of the receiver demonstrated in this PTB/TUG experiment, an advanced version of this receiver type was developed by K+K Messtechnik: the receiver K+K GPS6-2K in the advanced version now contains two channels, a tracking channel, and a data channel which continuously provides all data transmitted in the GPS data stream. The tracking channel can therefore remain in the fast-sequencing mode (FSM) and does not have to be interrupted for the data readout. In addition to the data channel a time interval counter was incorporated in the receiver which allows measurement of the respective time differences between an external 1PPS reference and the GPS time as received from the satellites. Along with the advanced version, K+K Messtechnik supplies software which allows an external PC to download the data from the two receiver channels via an RS-232 serial interface and to convert them to the CGGTTS format recommended by the BIPM [2].

2 RECEIVER ARCHITECTURE

The advanced K+K GPS6 2K receiver was designed to provide a versatile instrument which can be used as a stand-alone receiver providing 1PPS/GPS or USNO time signals (selectable) and standard frequency, or as a Common-View receiver generating the CGGTTS format recommended by the BIPM. The evaluation of the received data was intentionally made less dependent of the receiver processor and transferred to a standard PC running Windows™. Studies of the data processing with other algorithms than those presently used can therefore easily be done with this receiver structure.

Figure 1 shows the functional block diagram of the advanced receiver version with two channels. Subject to user choice, in FSM (Fast Sequencing Mode) the tracking channel continuously sequences through all satellites in view, or in SSM (Single Satellite Mode) tracks a single satellite only. In either case both PRN code and carrier (delta) phase are coherently measured and combined to yield a smoothed reading of the received satellite time. The relative weights in combining code and carrier phase data are user-selectable. Due to the carrier-phase smoothing, a dwell time for the observation of 160 ms is used for the observation of one satellite.

The sole purpose of the data channel is to read data (almanac, ephemeris, ionospheric correction parameters, etc.) from the satellites and to report these data to the tracking channel. Thus, the tracking channel never needs to interrupt its process of sequentially observing all satellites in view.

All clock and timing signals in the receiver are phase-coherently derived from a single fundamental clock signal at f_0=10.23 MHz generated by the voltage-controlled crystal oscillator VCXO, which in turn is disciplined by the high stability 10 MHz ovened oscillator OCXO. The PLL/Mixer utilizes a three-stage mixing scheme with subsequent integrator to maintain the VCXO signal phase-coherent with the OCXO signal even if the VCXO drifts due to temperature changes or aging of the crystal.

The OCXO is continuously phase-controlled by the microprocessor such that the 10 MHz signal is phase- locked to the received satellite signals. Therefore, no input of an external reference clock signal is required and the system can also be operated as a stand-alone GPSDO (Disciplined Oscillator). The time constant to control the OCXO is user-selectable depending on its stability (300 s for the two prototypes studied here).

The receiver unit supplies the antenna/down-converter unit with DC and the 9th harmonic of the VCXO signal (92.07 MHz). In the down converter the 92.07 MHz signal is multiplied once more by 16 to generate a 1473.12 MHz signal, which is then mixed with the pre-amplified antenna signal to yield the first intermediate frequency (IF) of 102.3 MHz. In a second stage this 102.3 MHz IF is mixed again with 92.07 MHz resulting in a second IF signal at 10.23 MHz, which is fed down to the receiver unit for further processing. In both units diplexers are used as separating/combining filters to enable the use of a single coax cable for supplying the converter unit with DC and the 92.07 MHz signal, and returning the 10.23 MHz IF signal to the receiver.

In the data and tracking channels, the 10.23 MHz IF signal is filtered, amplified, and then correlated with the digitally generated PRN code. The resultant "de-spread" signal is narrow-band filtered and mixed with f_0 to yield a third IF of nominally DC, which in fact is a low frequency signal (up to a few kHz) exhibiting the sum of the frequency deviation f_0 - f_{GPS} and the Doppler shift due to the satellite motion. This signal is passed through a digitally controlled continuous phase shifter with subsequent D/A converter, allowing the microprocessor to establish a numerically phase-locked loop (PLL), thereby tracking the carrier phase with high resolution.

The PRN code generators of both channels are clocked with the f_0 signal, while numerically controlled phase shifters allow adjustment of the PRN code phase to the satellite range and to

compensate for the Doppler shift as determined by the carrier tracking loop while tracking a satellite.

Finally, the f_0 signal is divided down to yield the 1PPS output signa,l which represents either GPS system time or UTC(USNO). The f_0/1 Hz divider is set by the software to secure proper timing. In addition, the 1PPS can be delayed or advanced with 1 ns resolution to compensate for cable delays. Due to the phase coherence of the VCXO and the OCXO signals, the 1PPS output has a fixed phase relationship to the 10 MHz output signal, with <1 ns jitter.

The receiver unit includes a built-in time interval counter (TIC) which is basically an instrument of its own, except that it reports the measured TI data to the data channel via a standard RS-232 serial interface. The TIC is started by 1PPS from a local 1PPS reference clock and stopped by 1PPS/GPS as generated from the receiver. The 10 MHz OCXO signal serves as time base signal. Internal arming circuitry ensures proper operation even with asynchronous, possibly coincident pulses. Resolution is 50 ps, accuracy typically 500 ps.

Once per second all data obtained in the two channels and the TIC necessary for the common-view processing are transmitted to the PC: date, time, position, the TIC measurement result, the current OCXO time and frequency control-loop errors, azimuth, elevation, model parameters of the ionospheric and tropospheric delay, satellite-clock correction, almanac, ephemeris, the differences between the GPS time as received from a single satellite, and the averaged time as received from all satellites in view. Although the system is designed to allow for any kind of data processing in the PC, the current PC software version supports the Common View Time Transfer using the BIPM format as described in "Technical Directives for Standardization of GPS Time Receiver Software" [2] and "CGGTTS GPS/GLONASS Data Format Version 02" [3]. In the PC software, the user can choose between the fast sequencing mode (tracking all satellites in view according to the regular International GPS Tracking Schedule, like a multichannel receiver), or the single-satellite mode (tracking satellites according to the limited BIPM Tracking Schedule, like a single-channel receiver).

3 MEASURING ARRANGEMENT FOR THE STUDY OF SEVERAL GPS RECEIVERS

Figure 2 shows the block diagram of the measuring arrangement for studies of two K+K type receivers KK1 and KK2. In co-location with three NBS-type receivers, the GPS time as received with KK1 and KK2 has been compared with the corresponding results obtained by three NBS-type receivers NBS, TTR5, and TTR6. The caption of Figure 2 specifies which receiver types and models are assigned to the abbreviations KK1, KK2, NBS, TTR5, and TTR6. Each receiver includes a time-interval meter to determine the time difference between a local reference pulse and the GPS time received. In this study all measurements are related to the common reference UTC(PTB)/1PPS distributed to the receivers by the distribution amplifier DA.

The NBS-type receivers performed 48 selected satellite observations per day according to the limited tracking schedule recommended by the BIPM. The K+K type receivers did the same when operated in the SSM. In the FSM they observed all satellites in view covering all 89 daily track intervals according to the regular International GPS Tracking Schedule of the BIPM. As the artificially limited tracking schedule is a sub-schedule of the regular International GPS Tracking Schedule and the full track length of 13 minutes is the same in both cases, the results obtained from a receiver in SSM should be the same as those obtained in FSM if only data are selected which correspond in track time.

4 MEASUREMENT RESULTS

Figures 3 and 4 show the daily mean values of the differences ΔT(GPS) between the GPS time T(GPS) received with various receivers, e.g. NBS - KK2 stands for:

$$NBS - KK2 \equiv [UTC(PTB) - T(GPS(KK2))] - [UTC(PTB) - T(GPS(NBS))] = \Delta T(GPS).$$

To avoid overlapping curves, arbitrary constants C have been added to Δt(GPS). Figure 3 shows the receiver delay changes of KK2, TTR5, and TTR6 related to NBS. The noise of the NBS-type receivers for succeeding days is lower than that of KK2; however, systematic receiver delay changes of about 3 ns can be seen for NBS-TTR5 and up to 11 ns for TTR6. Omitting the data points when KK2 was operated in FSM, the standard deviation of a daily value from the mean of NBS-KK2 over the period shown amounts to 1.5 ns. The changeover from SSM to FSM, however, results in a shift of about 10 ns. As can be seen in Figure 4, the data for NBS-KK1 show a similar behavior when changing over from SSM to FSM. From MJD 52165 to MJD 52177, both receivers behave as expected when operated in SSM. Attempts to understand the reason for the delay shifts have been made (minor software modifications and corrected antenna coordinates). Unfortunately, data for KK2 are missing between MJD 52217 and MJD 52225 due to a hardware failure of the down-converter. But as can be seen from the last values, the changeover behavior from SSM to FSM of both receivers seems to have been improved, though the scatter of the data points is still too high. Figure 5 gives the timing instabilities of the receivers TTR5, TTR6, and KK2 related to NBS and calculated from the data of Figure 3.

5 CONCLUSION AND FUTURE WORK

In SSM operation the K+K type receiver can be used for common-view time transfer achieving a delay instability of about 1.5 ns. An apparent shift of the receiver delays and an increased scatter of the GPS time received caused by changing from SSM to FSM could not yet be removed completely. Future work will, therefore, focus on finding and removing the cause of the apparent phase shifts of the received GPS signals when changing from SSM to FSM and vice versa. Another important part of the work will be to further reduce the receiver noise. Special attention will be devoted to a careful study of the impact of various parameters within the GPS receiver software, in particular the relative weight of carrier Doppler frequency and PRN code phase in the carrier-smoothing algorithm and the time constant of the OCXO control routines.

6 REFERENCES

[1] P. Hetzel, D. Kirchner, T. Polewka, and H. Ressler, 2000, "SATMIX Time-Scale Comparison Using a Single-Channel Fast-Sequencing GPS Receiver with Carrier-Phase Smoothing," in Proceedings of the 31st Annual Precise Time and Time Interval (PTTI) Systems and Applications Meeting, 7-9 December 1999, Dana Point, California, USA (U.S. Naval Observatory, Washington, DC), pp. 383-392.

[2] BIPM Report 93/6, 1993, "Technical Directives for Standardization of GPS Time Receiver Software."

[3] BIPM Document, 1998, "CGGTTS GPS/GLONASS Data Format Version 02," submitted to the 7th CGGTTS Meeting, November 1998, Reston, Virginia, USA.
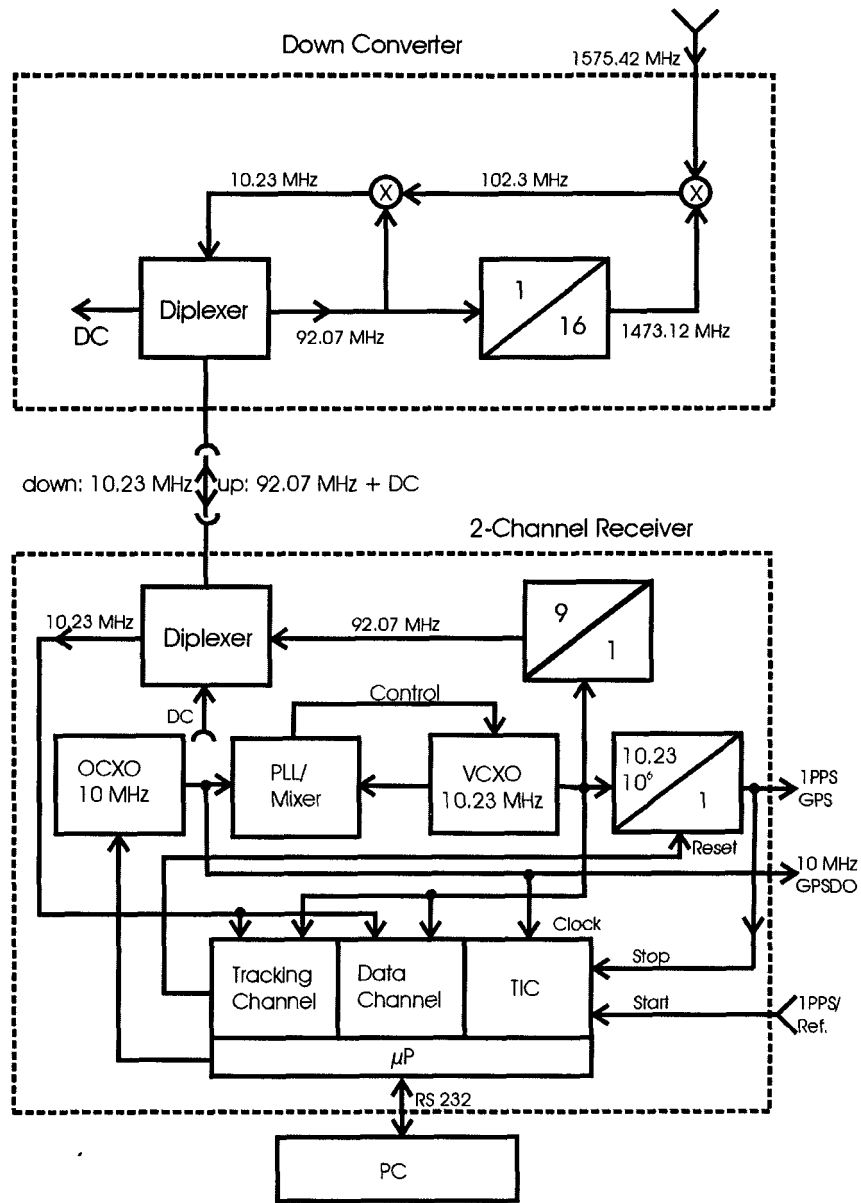
Down Converter

1575.42 MHz

10.23 MHz · 102.3 MHz

X · X

Diplexer

DC

92.07 MHz

1 / 16 · 1473.12 MHz

down: 10.23 MHz / up: 92.07 MHz + DC

2-Channel Receiver

10.23 MHz · Diplexer · 92.07 MHz · 9 / 1

DC

Control

OCXO 10 MHz

PLL/ Mixer

VCXO 10.23 MHz

10.23 / 10⁶ · 1

1PPS GPS

Reset

10 MHz GPSDO

Clock

Tracking Channel

Data Channel

TIC

Stop

Start

1PPS/ Ref.

μP

RS 232

PC

Figure 1: Functional block diagram of the K+K GPS6-2K receiver. The diplexers serving as combining/separating filters allow the use of a single cable for the up- and down-signal. Phase-coherent down conversion of the received GPS signal use harmonics of the 10.23 MHz-VCXO-signal which drives code generators and correlators in the Tracking and Data channel.
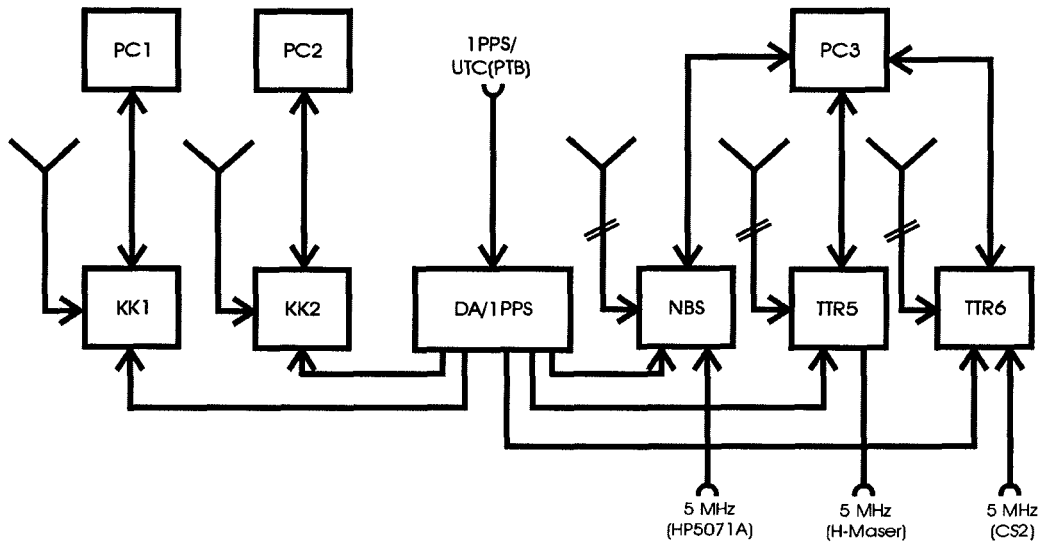
Figure 2: Block diagram of the setup for studies of K+K-type and NBS-type receivers. KK1, KK2: K+K-type receivers, model GPS6-2K, made by K+K Messtechnik GmbH; NBS: Original NBS-type receiver, made by Rockwell Collins; TTR5, TTR6: NBS-type receivers, models TTR5/SN156 and TTR6/SN420, made by Allen Osborne Assoc.; DA: 1PPS distribution amplifier; PC1, PC2, PC3 connected with GPS receivers via RS-232 interface.
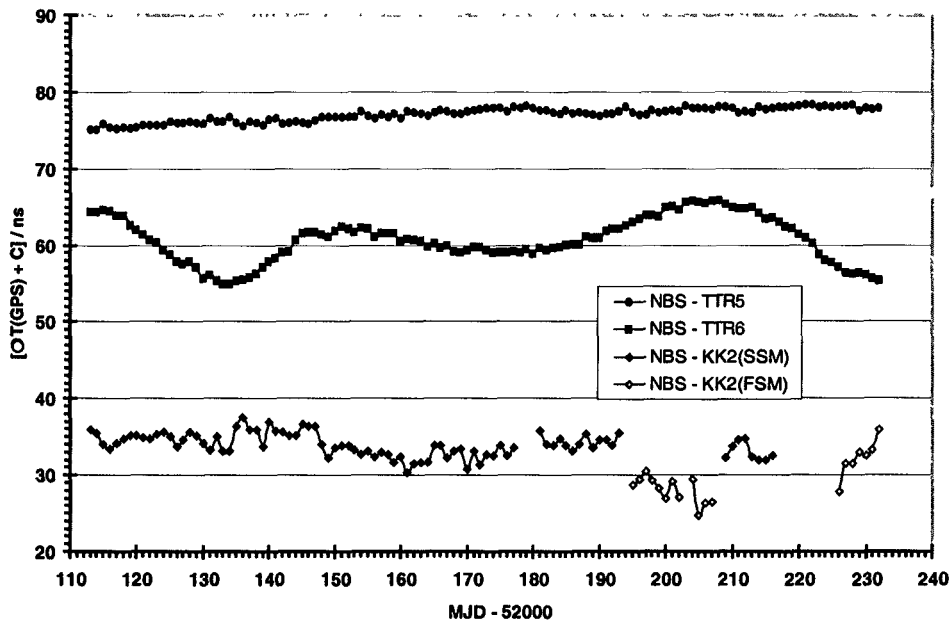

Figure 3: Daily mean values of the differences $\Delta T(GPS) + C$ between the GPS time T (GPS) obtained with the receivers KK2, NBS, TTR5, TTR6.
NBS - KK2 $\equiv$ [UTC(PTB) - T(GPS(KK2))] - [UTC(PTB) - T(GPS(NBS))]
NBS - TTR5 $\equiv$ [UTC(PTB) - T(GPS(TTR5))] - [UTC(PTB) - T(GPS(NBS))]
NBS - TTR6 $\equiv$ [UTC(PTB) - T(GPS(TTR6))] - [UTC(PTB) - T(GPS(NBS))]
Full symbols: Single satellite mode (SSM); open symbols: Fast sequencing mode (FSM). For clarity different constants C added.

154

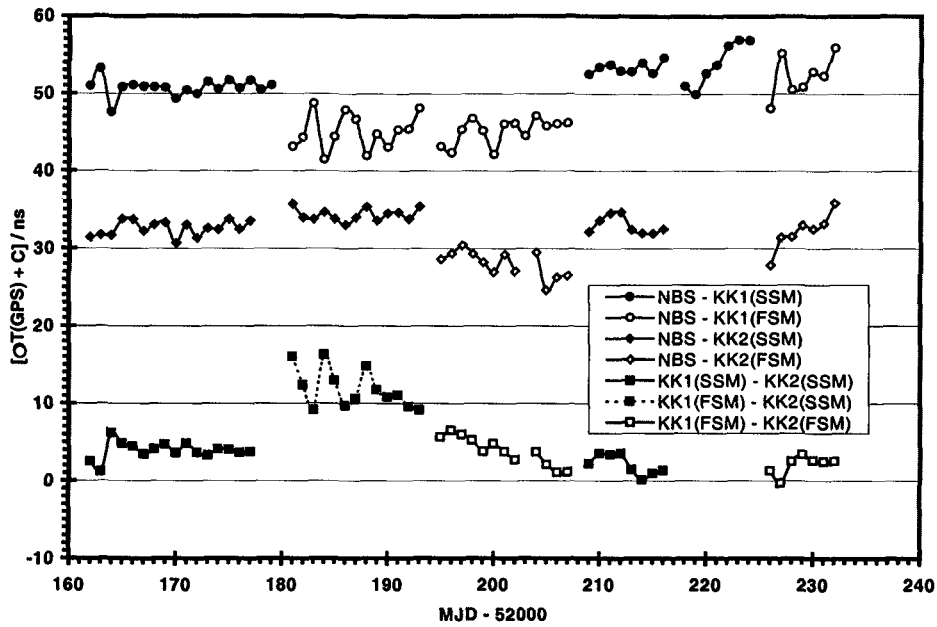Figure 4: Daily mean values of the differences ΔT(GPS) + C (C=Constant) between the GPS time T(GPS) obtained with the receivers KK2, NBS, TTR5, TTR6.

NBS - KK1 ≡ [UTC(PTB) - T(GPS(KK1))] - [UTC(PTB) - T(GPS(NBS))]
NBS - KK2 ≡ [UTC(PTB) - T(GPS(KK2))] - [UTC(PTB) - T(GPS(NBS))]
KK1 - KK2 ≡ [UTC(PTB) - T(GPS(KK2))] - [UTC(PTB) - T(GPS(KK1))]
Full symbols: Single satellite mode (SSM), open symbols: Fast sequencing mode (FSM). For clarity different constants C added.
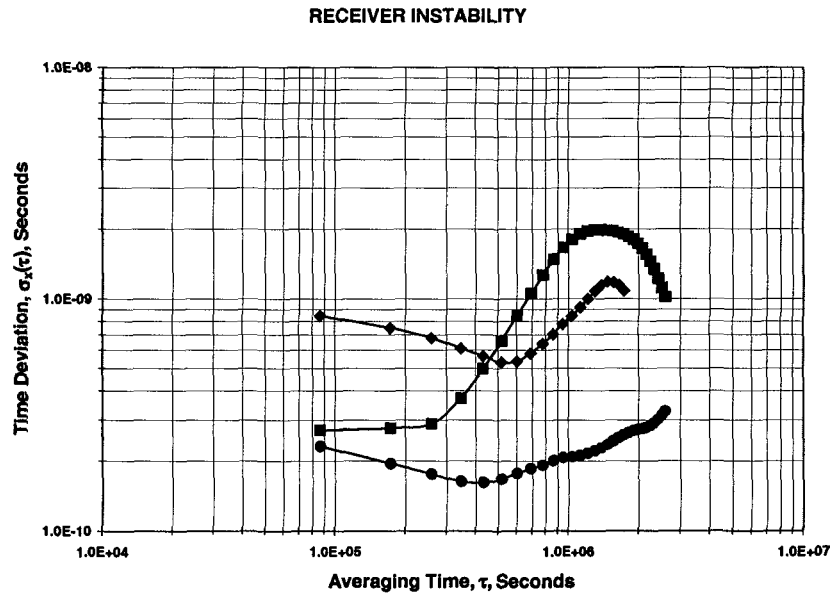
RECEIVER INSTABILITY

Figure 5: Time deviation of NBS-TTR5 (circles), NBS-KK2 (diamonds), and (NBS-TTR6 (squares).