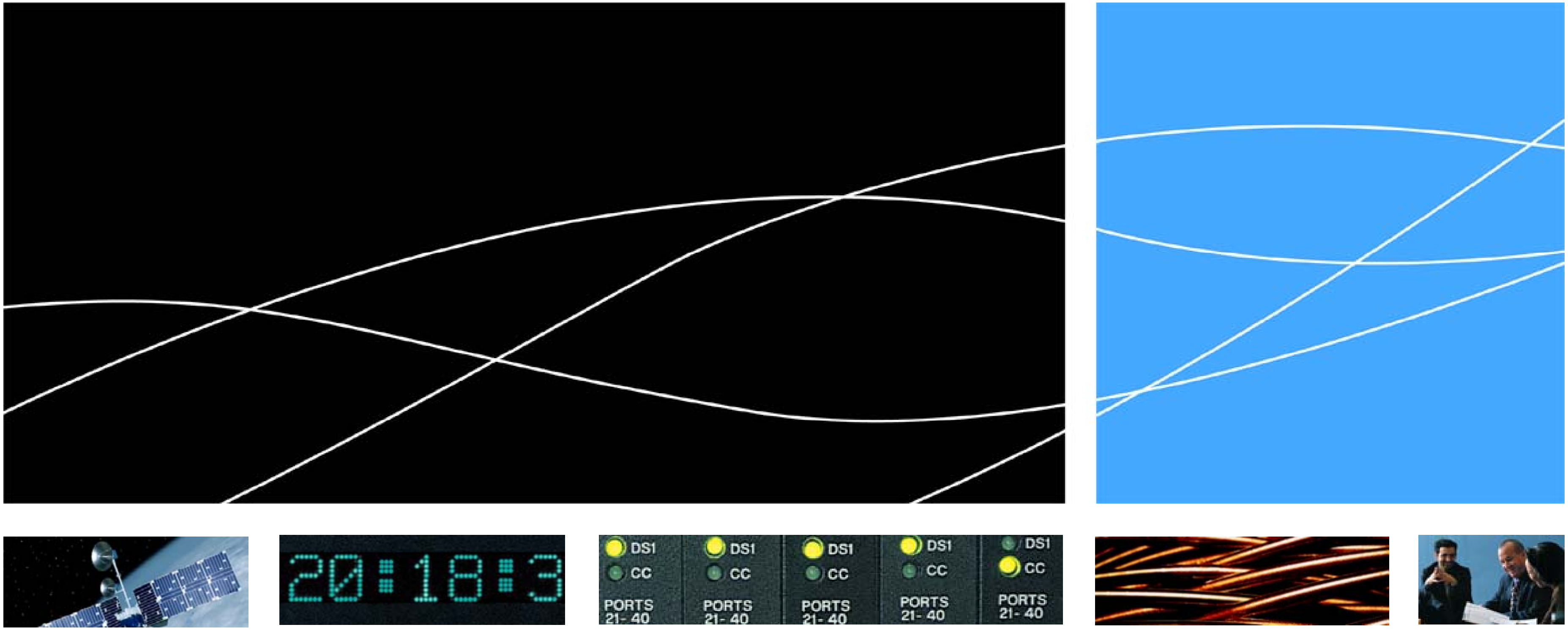


Synchronization Measurement and Analysis

Symmetricom®

Measurement & Analysis: Outline

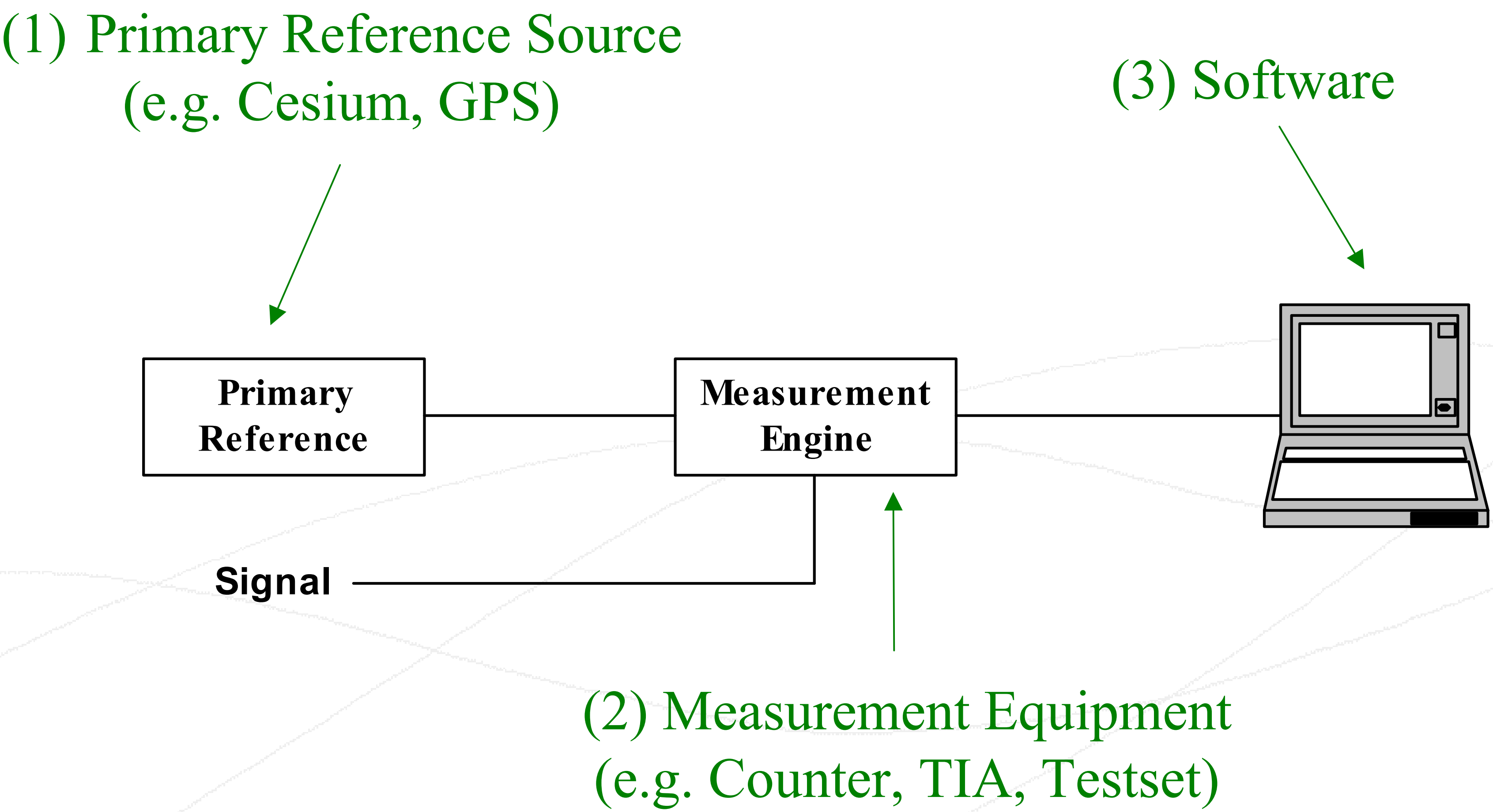
1. Measurement of Phase ←
2. Analysis
3. Measurement Examples

Synchronization Measurement Equipment

- Some kind of phase detector or phase measurement device is needed

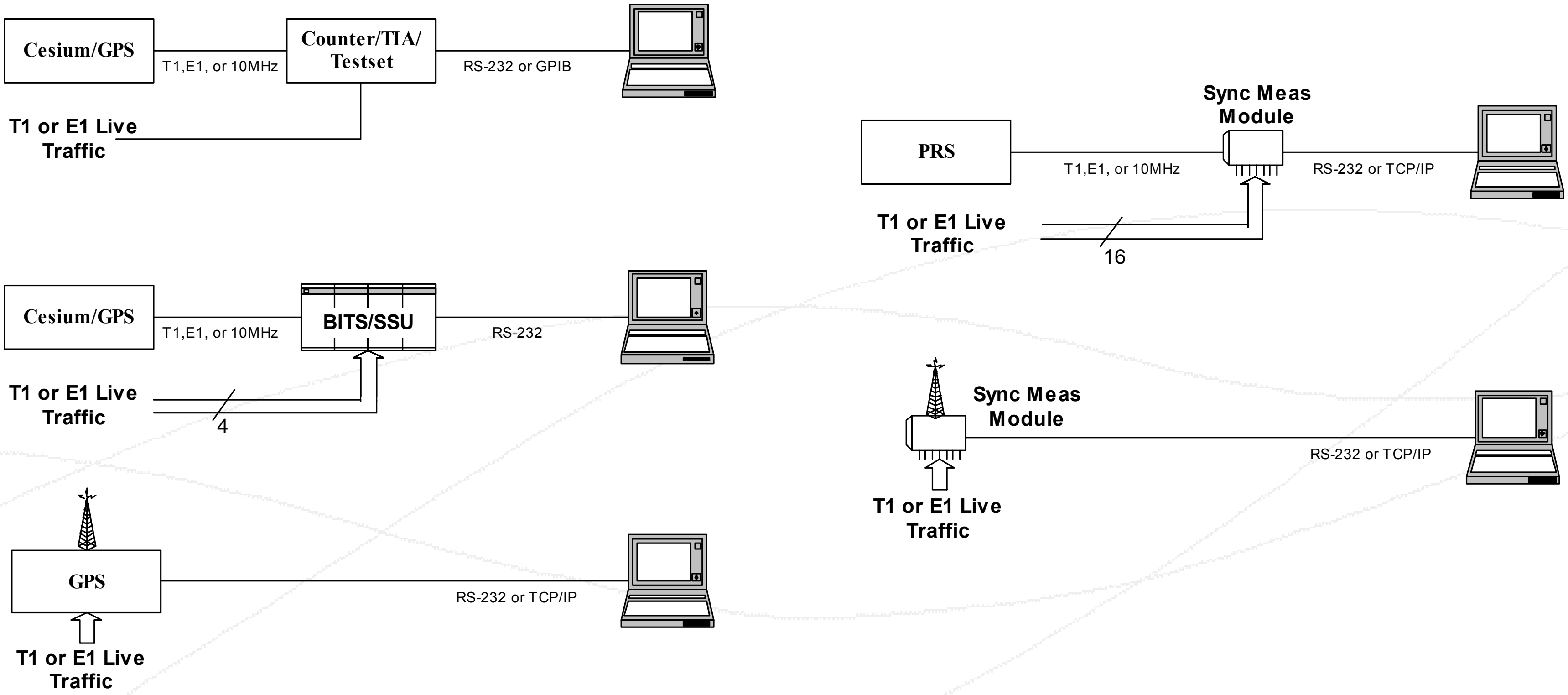
- Phase measurements can be made using:
  - Frequency/time interval counters } Focus for our discussion
  - Time interval analyzers
  - Dedicated test-sets
  - BITS/SSU clocks with built-in measurement capability
  - GPS receivers with built-in measurement capability
  - Sync measurement module

Sync Measurement Block Diagram



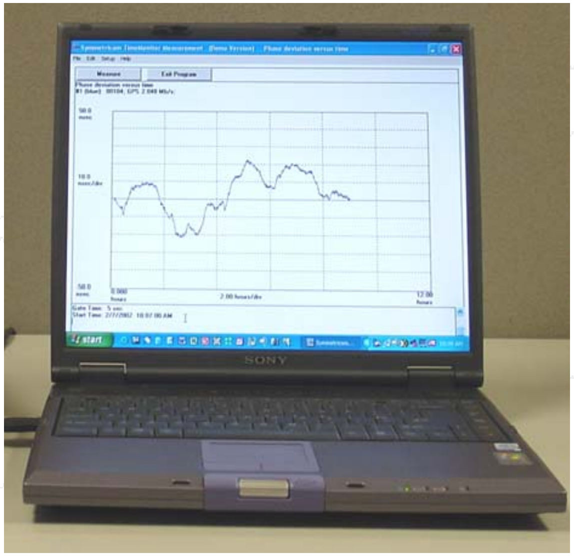
Sync Measurement Example Configurations

Five Example Measurement Equipment Configurations



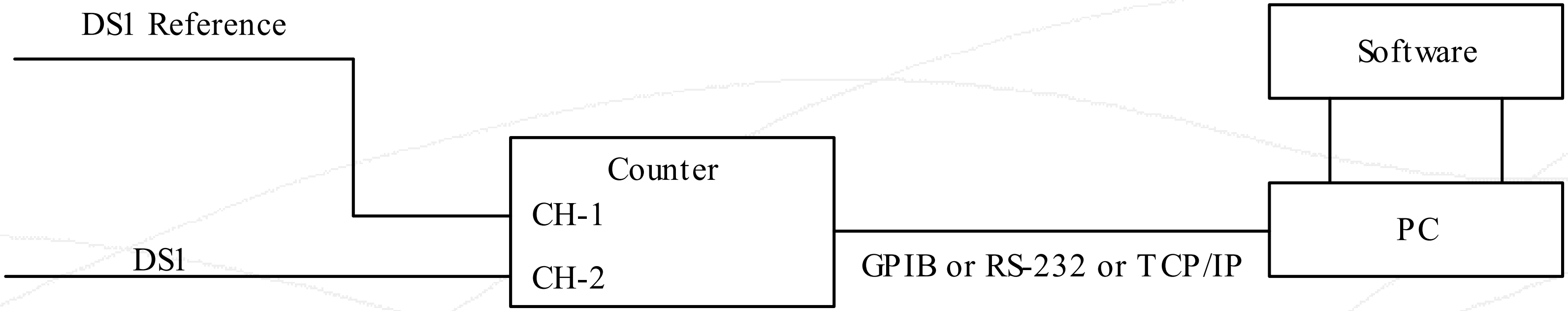
Measuring Jitter/Wander with a Counter

- Jitter & Wander Measurement Setup
  - Computer
  - Software
  - Off-the-shelf counter (or counters)



Measuring Jitter/Wander with a Counter

Counter Jitter/Wander Measurement
Basic Block Diagram



Measuring Phase with a Counter: TI 1 to 2 → Phase

Symmetricom®

- Using a reference signal at the same frequency (or submultiple) of the signal of interest, a counter can be used to measure phase (TIE) directly.
- Software can take care of data clock recovery (no data clock recovery hardware required), phase rollover, and any other processing required to convert the counter measurements to phase.
- Thus an inexpensive counter can be used to measure phase on signals such as traffic bearing DS1s directly.

Phase Digitizing with Counter

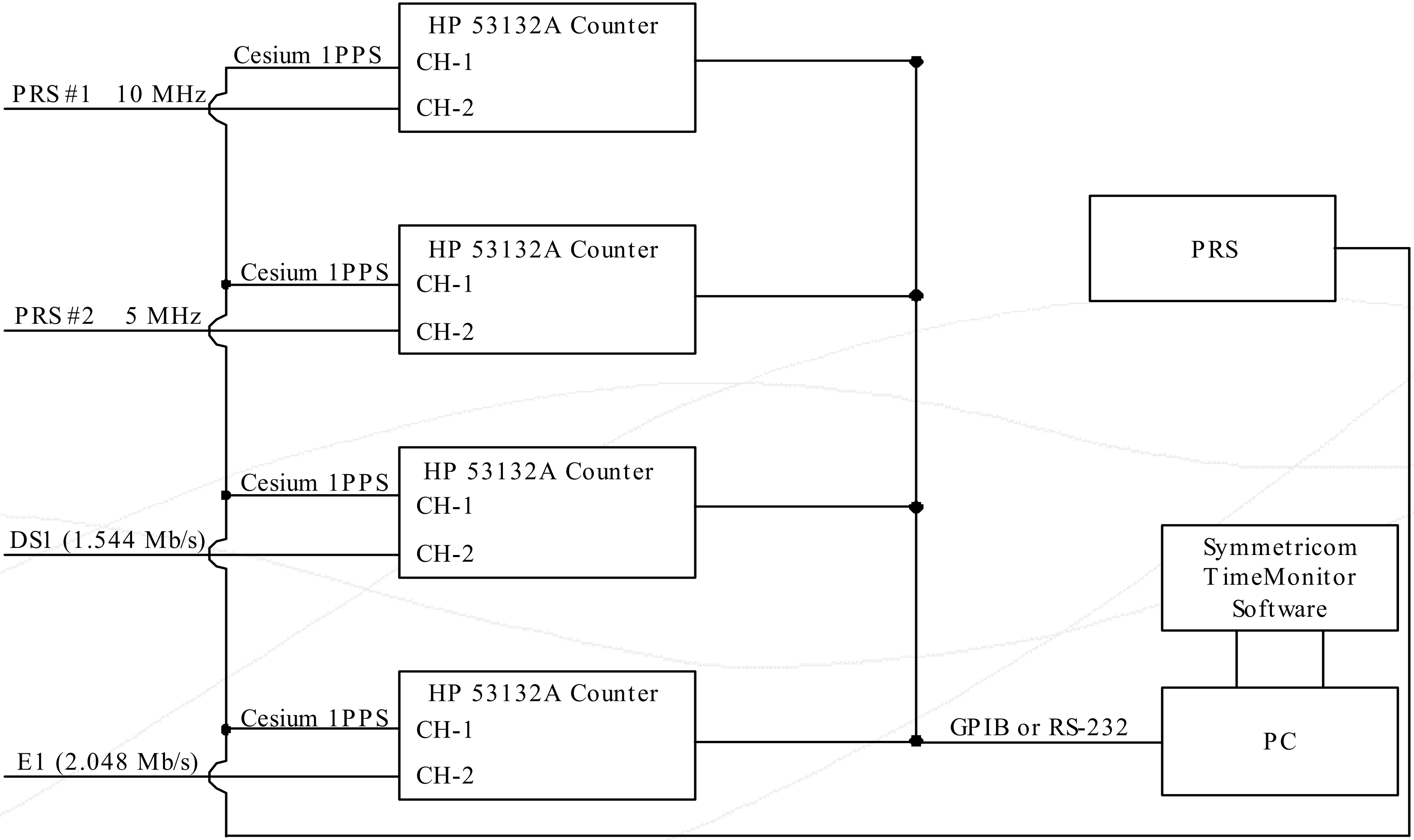
- Any signal rate

- T1/DS1 (1.544 M)
- E1 (2.048 M)
- DS2 (6.312 M)
- DS3 (44.76 M)
- 64 kbit

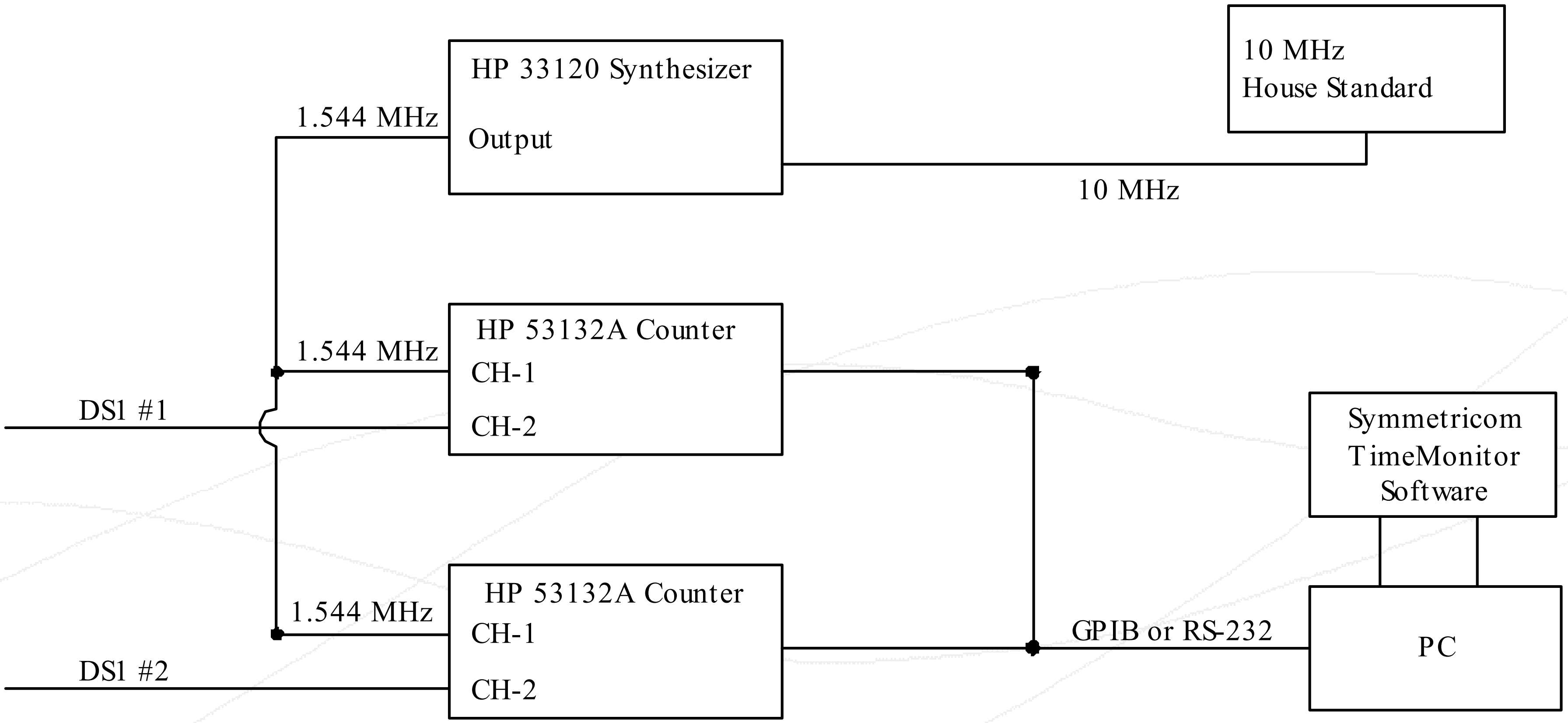
- 1 PPS
- 10 MHz
- STS-1/OC-1 electrical (51.84 M)
- 140 Mb/s Tributary (139.264 M)
- STS-3/STM-1/OC-3 electrical(155.52 M)

- Clock or data signal (software does data clock recovery): measure DS1, E1, DS3 signals directly

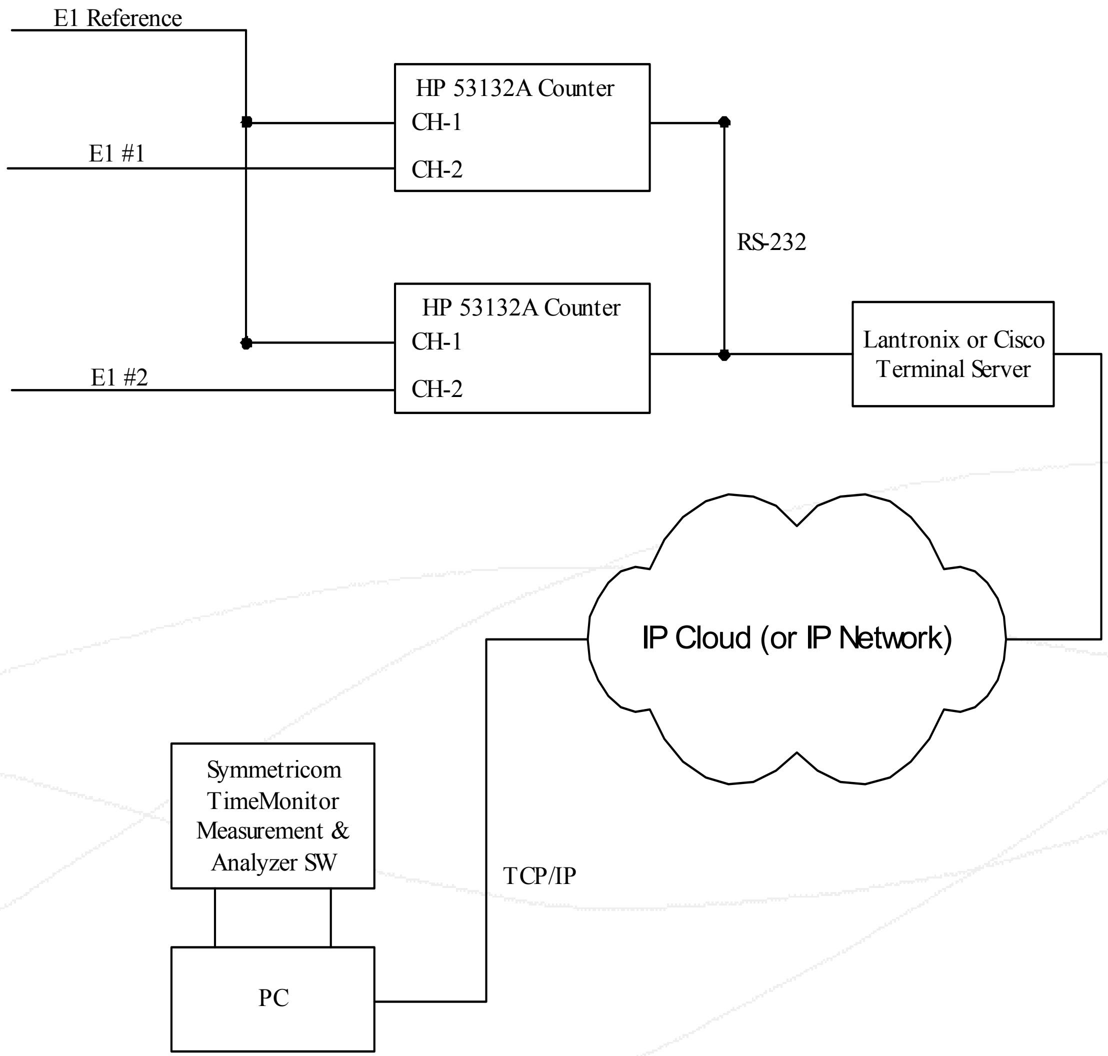
Counter Measurement Block Diagram #1



Counter Measurement Block Diagram #2

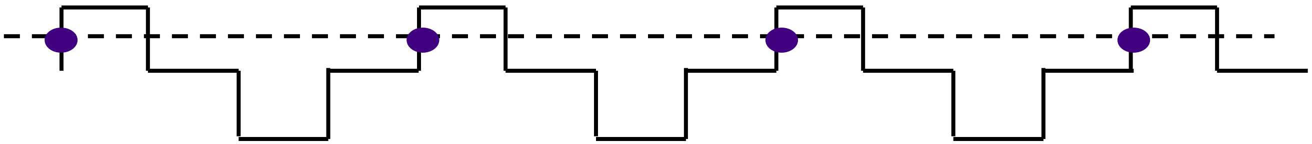


Counter Measurement Block Diagram #3

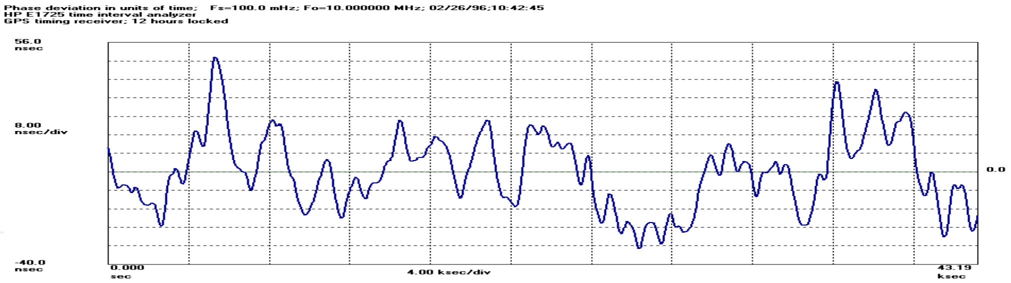


Synchronization Measurements w/ Phase Digitizing: 3 step process

1. Timestamps

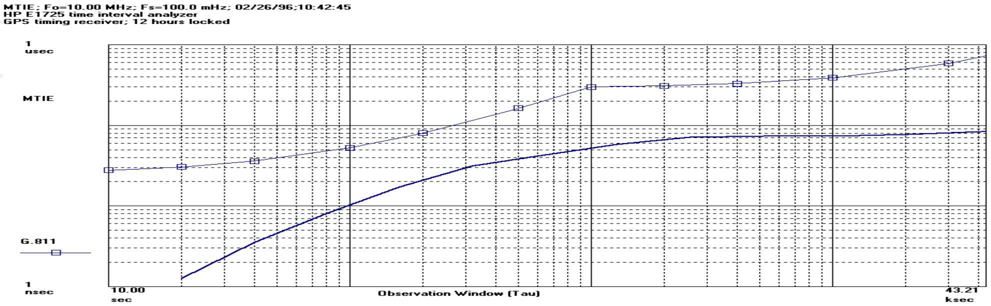


2. Phase


Phase deviation in units of time; Fs=100.0 mHz; Fo=10.000000 MHz; 02/26/96;10:42:45
HP E1725 time interval analyzer
GPS timing receiver; 12 hours locked

Phase Deviation or TIE

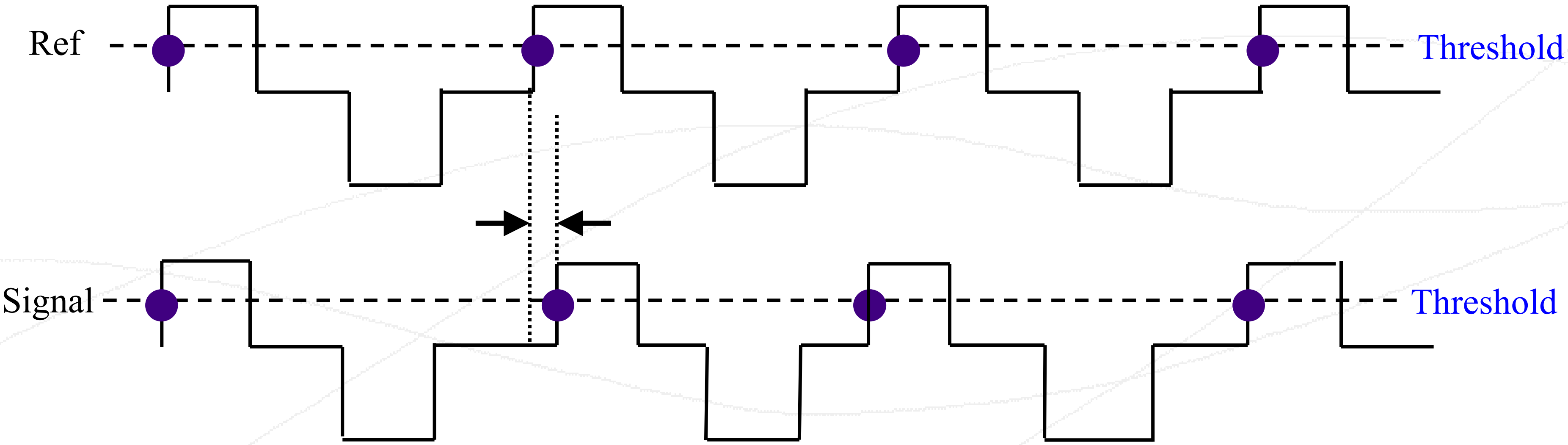
3. Analysis


MTIE; Fo=10.00 MHz; Fs=100.0 mHz; 02/26/96;10:42:45
HP E1725 time interval analyzer
GPS timing receiver; 12 hours locked

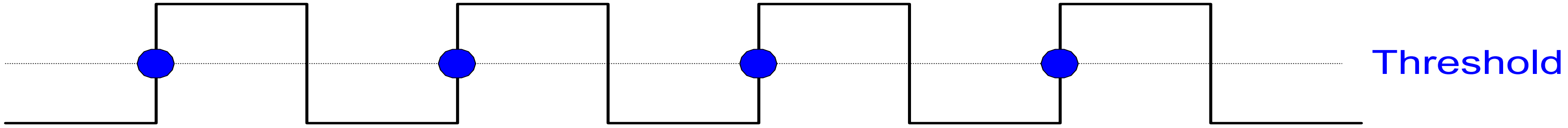
MTIE, TDEV, Allan Variance, Frequency, PPSD, etc.

Phase Digitizing with a Time Interval Counter

A time interval counter is used to time threshold crossings of a signal very precisely. This process is unaffected by amplitude modulation.



Timestamps: 1 MHz signal



Perfect mathematical reference (constant carrier)	0 µs	1 µs	2 µs	3 µs
Real signal measurement	0 µs	1.001 µs	1.997 µs	3.005 µs
ϕdev (time)/TIE	0 nsec	- 1 nsec	+ 3 nsec	- 5 nsec
ϕdev (degrees)	0°	- 0.36°	+ 1.08°	- 1.8°
ϕdev (UI)	0 UI	- 0.001 UI	+ 0.003 UI	- 0.005 UI

Phase Modulation Signal Model

$$v(t) = a(t) \cdot \sin\left(\phi(t)\right)$$

$$\phi(t) = \omega_o \cdot t + \theta(t)$$

$$\phi(t_i) = \omega_o \cdot t_i + \theta(t_i) = n_i \cdot 2\pi$$

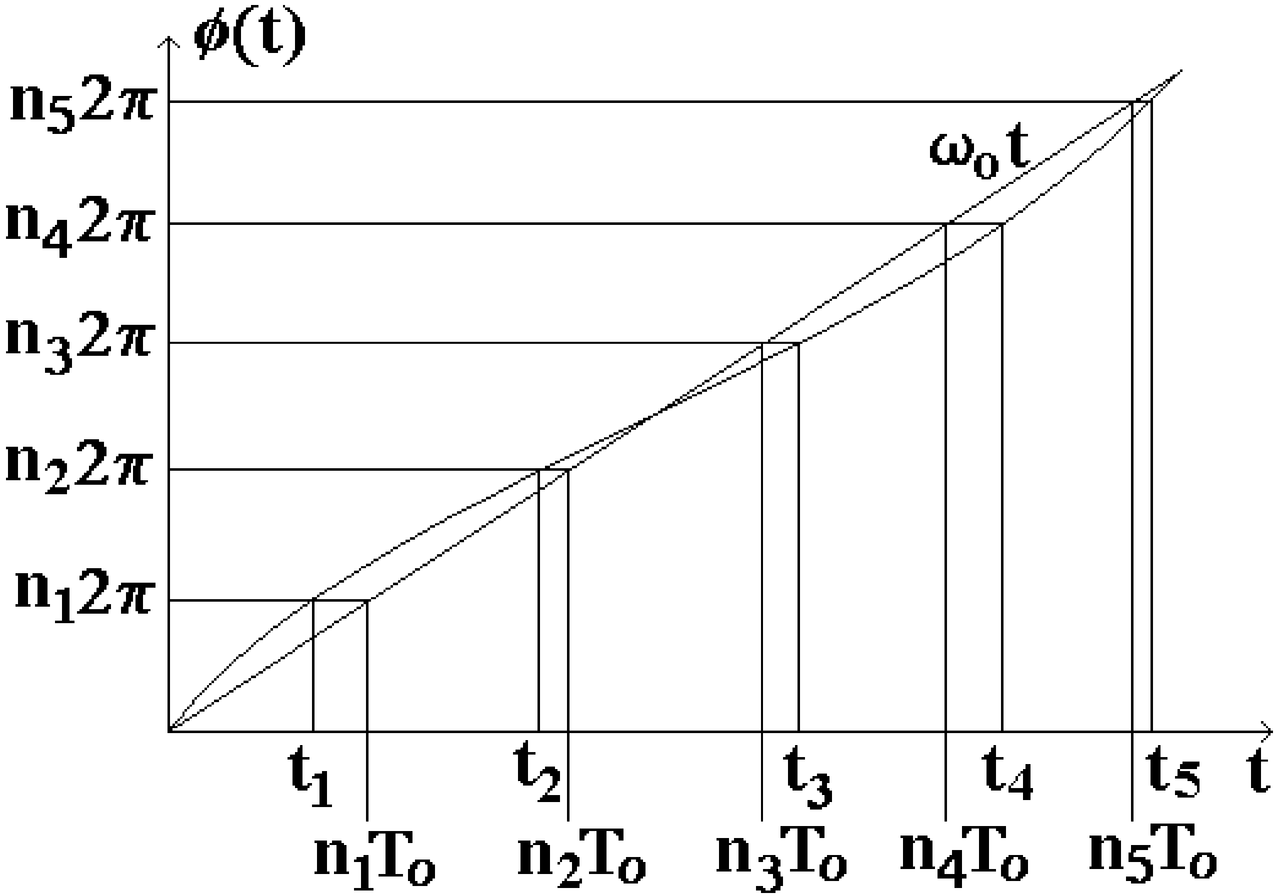
Phase deviation or TIE →

$$\theta(t_i) = n_i \cdot 2\pi - \omega_o \cdot t_i = \omega_o \cdot \left(n_i \cdot T_o - t_i\right)$$

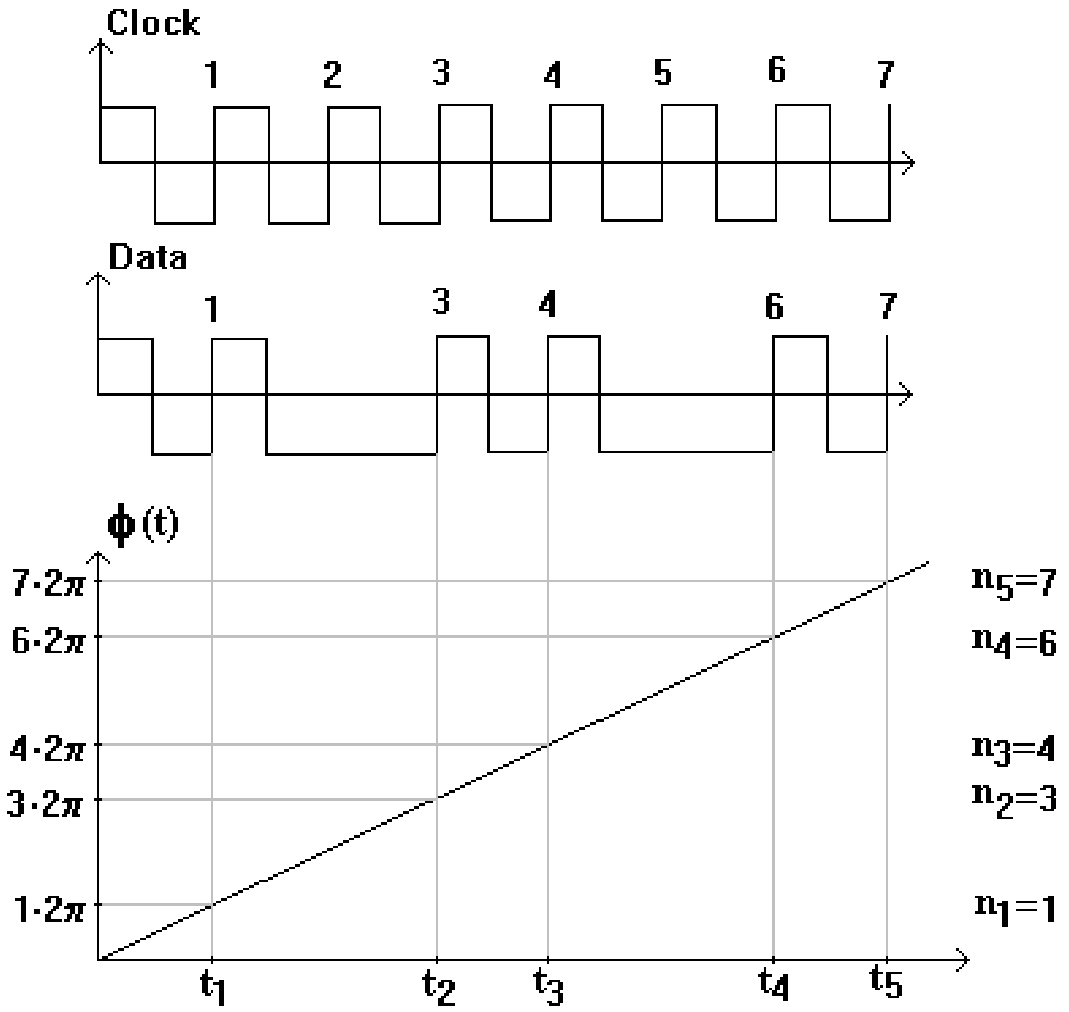
Reference frequency

Phase vs. Time

Phase deviation (TIE) is the difference between these two curves



Data Signal Phase vs. Time



Measurement & Analysis: Outline

1. Measurement of Phase
2. Analysis ←
3. Measurement Examples

Interpretation of Measurement Results

- For synchronization measurements, the measurement analysis used primarily is:
  - Phase (TIE)
  - Frequency (fractional frequency offset)
  - Frequency accuracy
  - MTIE
  - TDEV

All are derived from phase

- MTIE and TDEV analysis shows comparison to ANSI, Telcordia/Bellcore, ETSI, & ITU-T requirements

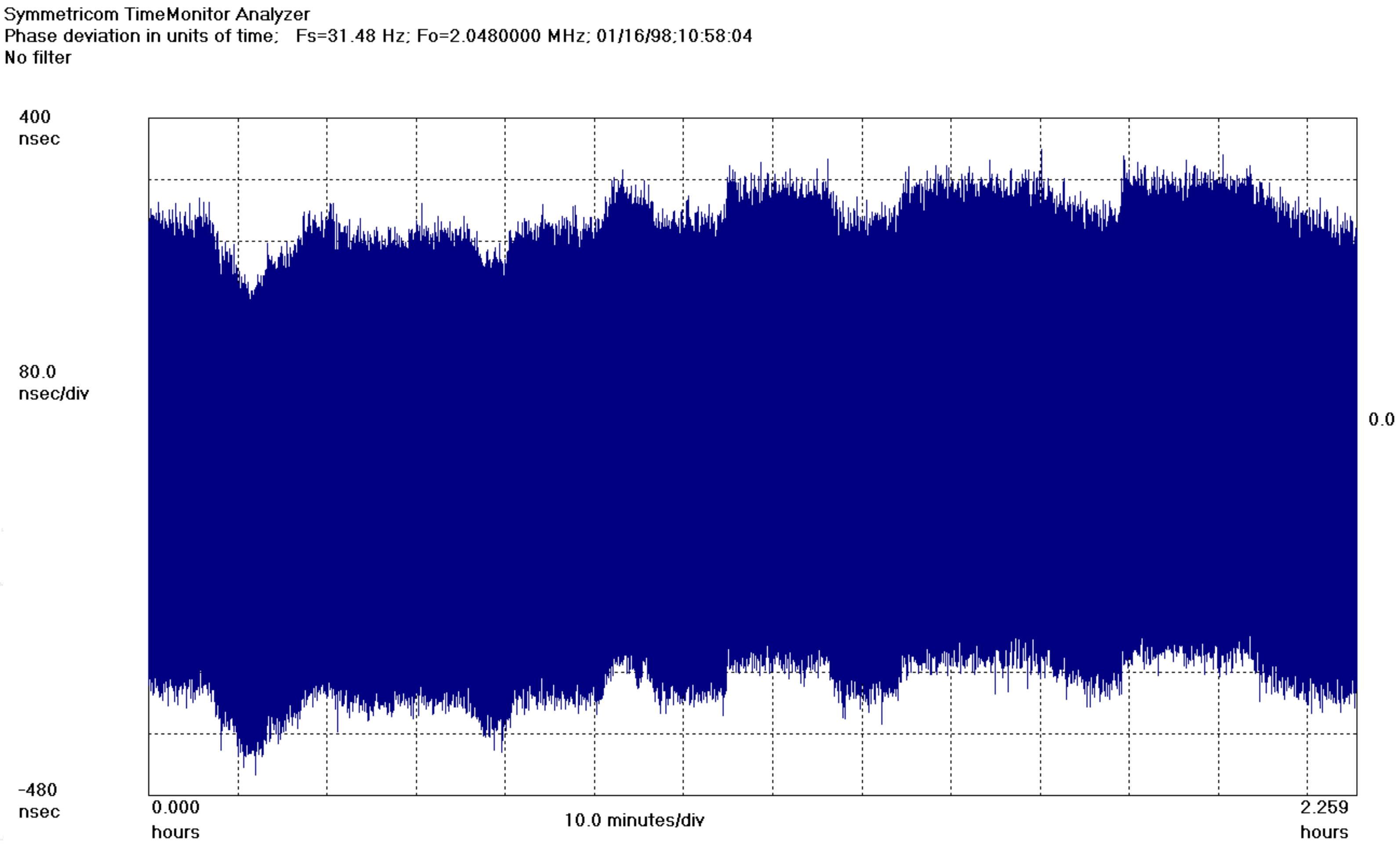
The Importance of Phase (TIE)

1. ***Analysis***: Frequency/MTIE/TDEV etc. derived from phase
2. ***Check:*** Verify measurement is properly made
    - Sudden (point-to-point) large movements of phase are suspect. For example, if MTIE fails the mask, it could be a measurement problem. Phase will help to investigate this.
    - Large frequency offset is easily seen: Is the reference OK? Is the equipment set to use the external reference?
3. ***Timeline:*** The processed measurements don't show what happened over time. Is the measurement worse during peak traffic times? Is the measurement worse in the middle of the night during maintenance activities?

- ▶ Sync Audit reports: 80% - 90% of the plots are phase plots

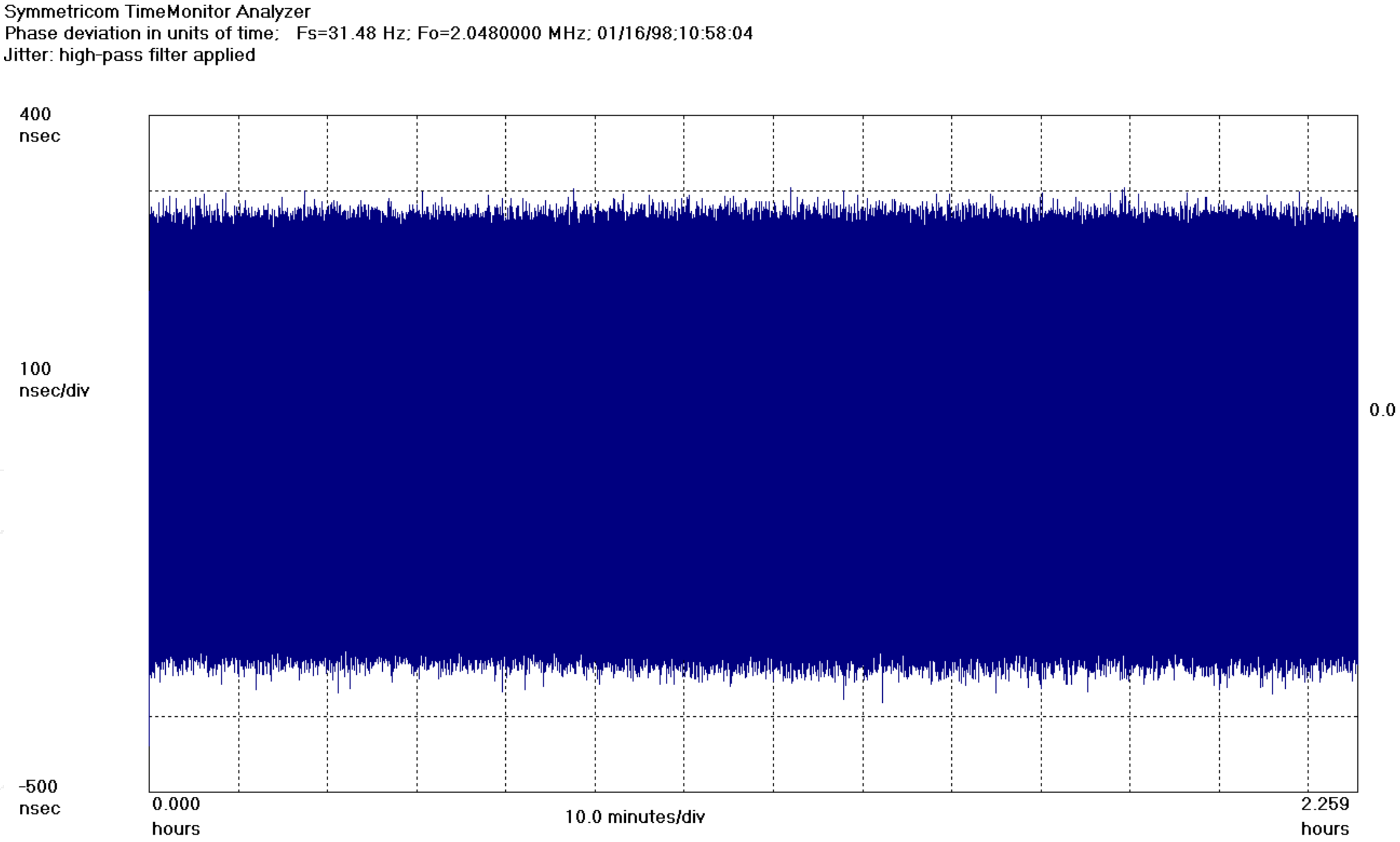
Analysis from Phase: Jitter & Wander

Signal with jitter and wander present



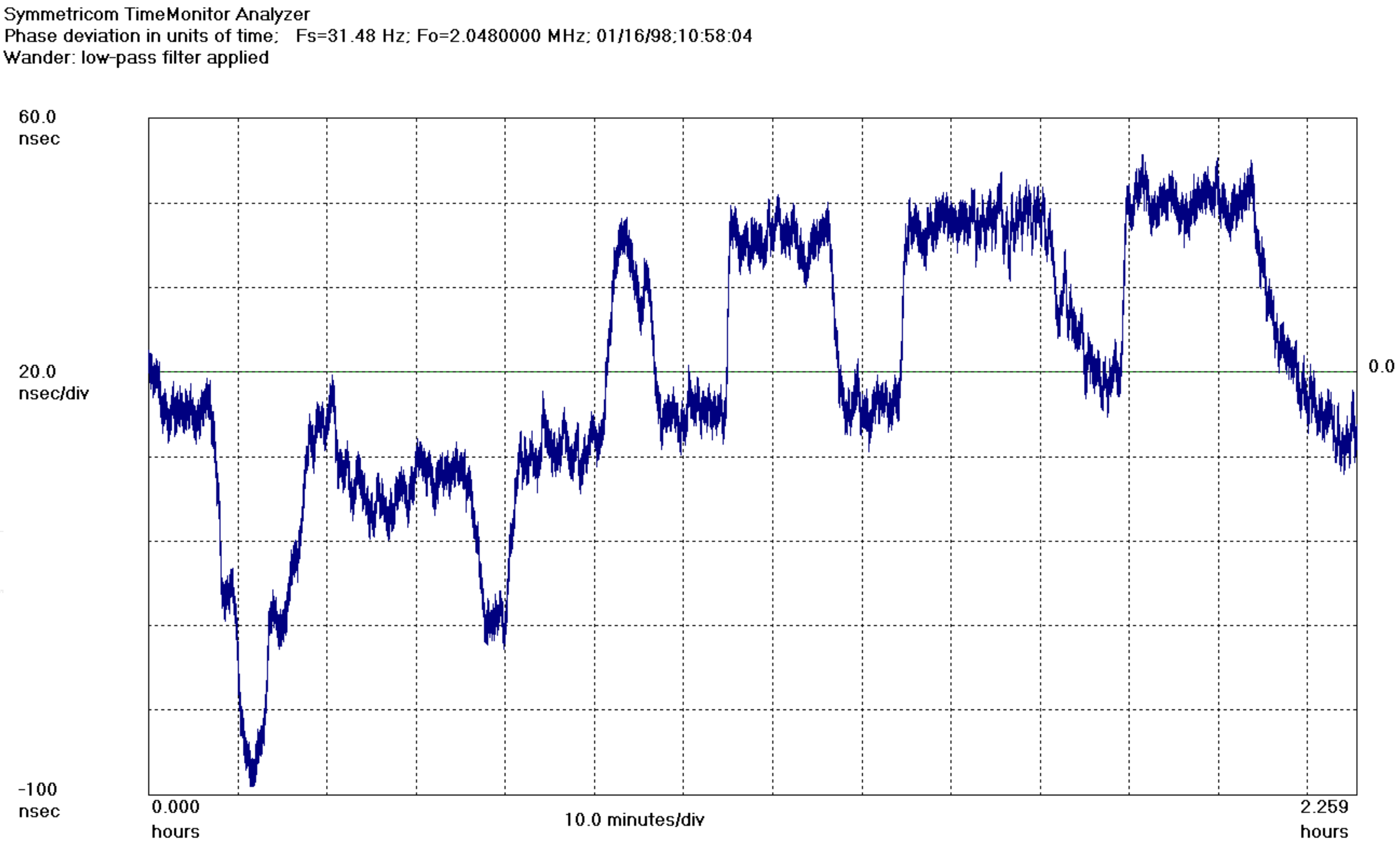
Analysis from Phase: Jitter

Jitter: Filter out low-frequency components with high-pass filter
Jitter = 740 nsec peak-to-peak = 1.52 UI peak-to-peak (E1)



Analysis from Phase: Wander

Wander: Filter out high-frequency components with low-pass filter

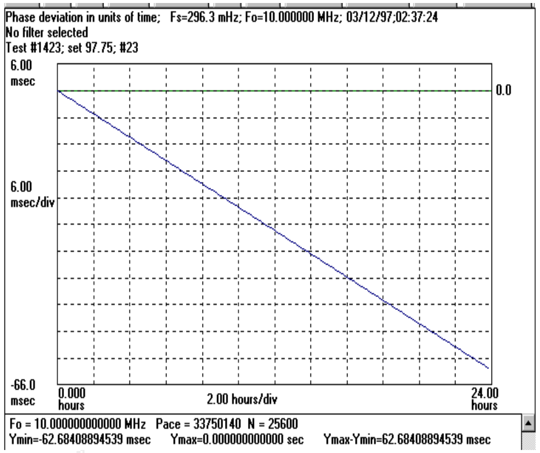


Analysis from Phase: Frequency

- Recall the relationship between frequency and phase:

$$\omega = \frac{d\phi}{dt}$$

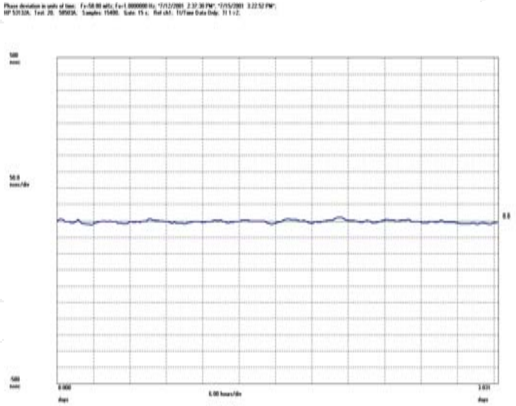
- Important point: Frequency is the slope in the phase plot


Phase deviation in units of time; Fs=296.3 mHz; Fo=10.000000 MHz; 03/12/97;02:37:24
No filter selected
Test #1423; set 97.75; #23

Fo = 10.000000000000 MHz Pace = 33750140 N = 25600
Ymin=-62.68408894539 msec Ymax=0.000000000000 sec Ymax-Ymin=62.68408894539 msec

Frequency offset present

No offset: ideal phase plot (flat)



Analysis from Phase: Frequency

Timestamps(μs):	0	1.001	1.997	3.005	4.002	4.999	6.003
ϕ dev (ns):	0	-1	+3	-5	-2	+1	+3

Phase deviation slope

$$\Delta\phi\text{dev} = \Delta N\cdot T_o - \Delta t = (\Delta N - f_o\,\Delta t)/\,f_o$$

$$\text{fdev} = f - f_o = \Delta N\,/\,\Delta t - f_o = (\Delta N - f_o\,\Delta t)/\,\Delta t = \Delta\phi\text{dev}\cdot f_o/\,\Delta t$$

$$\text{ffoff} = \text{fdev}/f_o$$

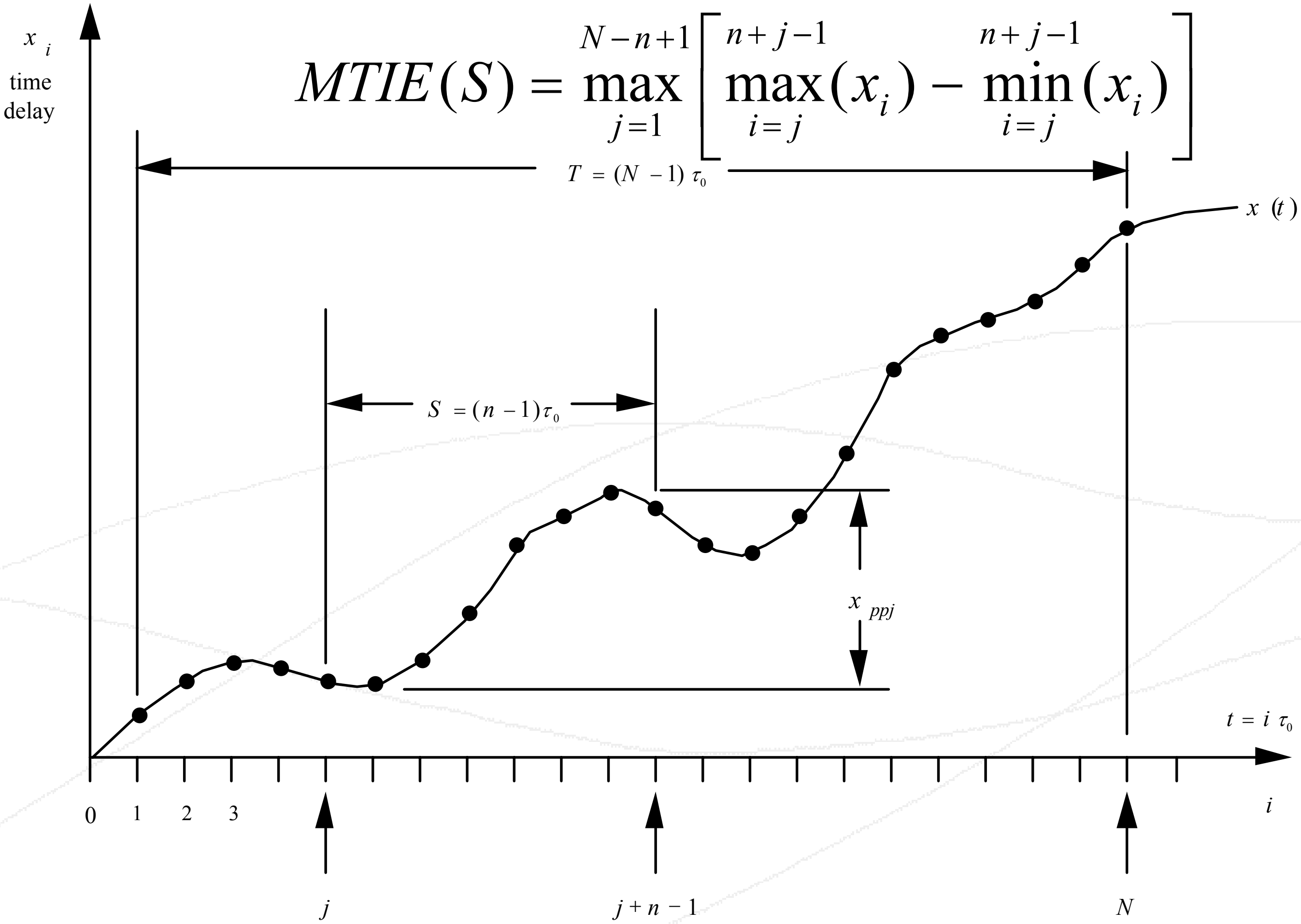
For example, take the average fdev over the first 3 cycles:

Frequency Deviation $= -\ 5\text{nsec}\cdot 10^6\text{Hz}/3.005\mu\text{sec} = -1.7$ kHz

Fractional Frequency Offset = -1.7 kHz/1MHz = -1.7 parts per thousand

Analysis from Phase: MTIE

$$MTIE(S) = \max_{j=1}^{N-n+1}\left[\max_{i=j}^{n+j-1}(x_i) - \min_{i=j}^{n+j-1}(x_i)\right]$$



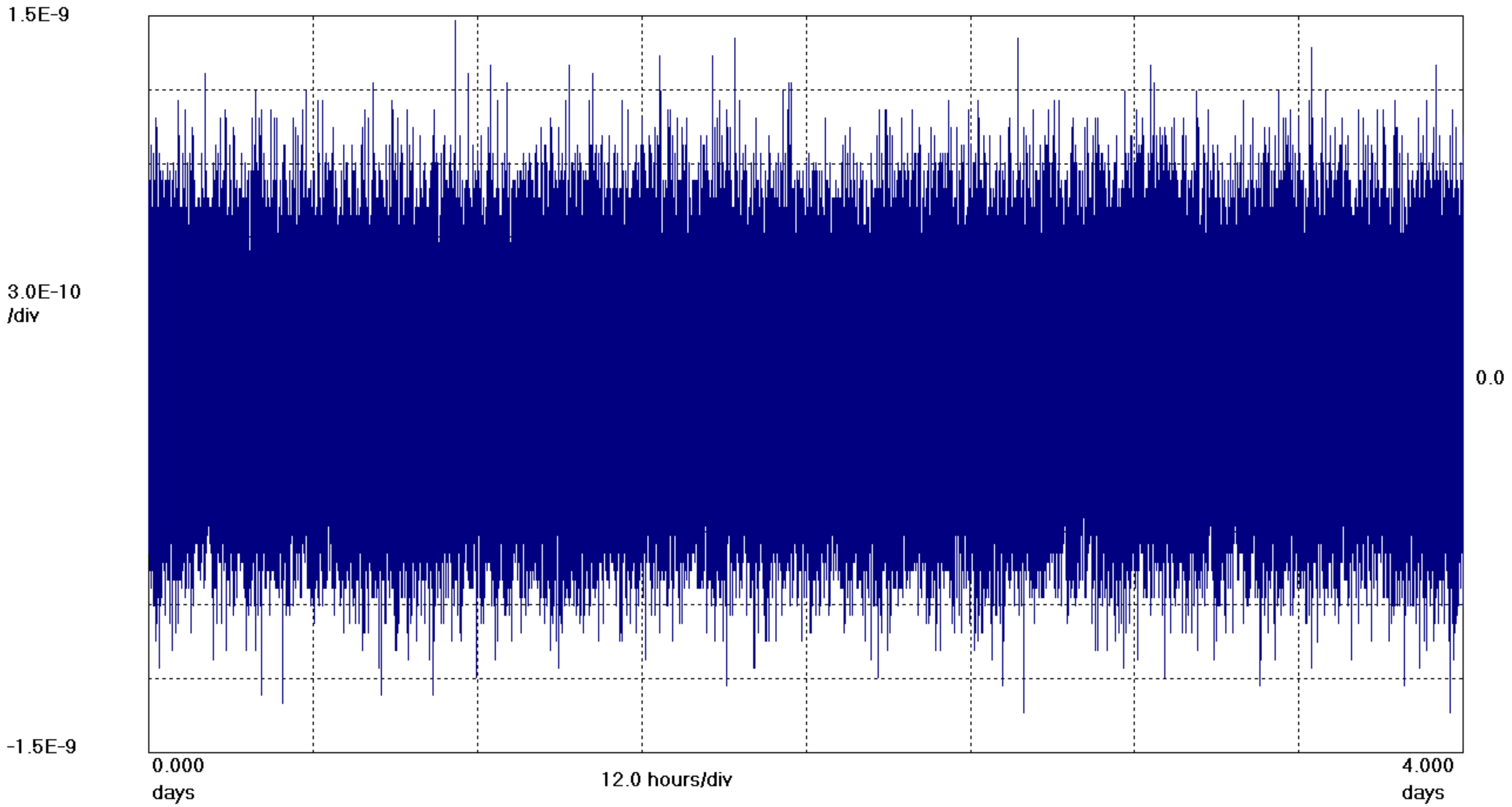
Measurement Analysis: Frequency

Symmetricom

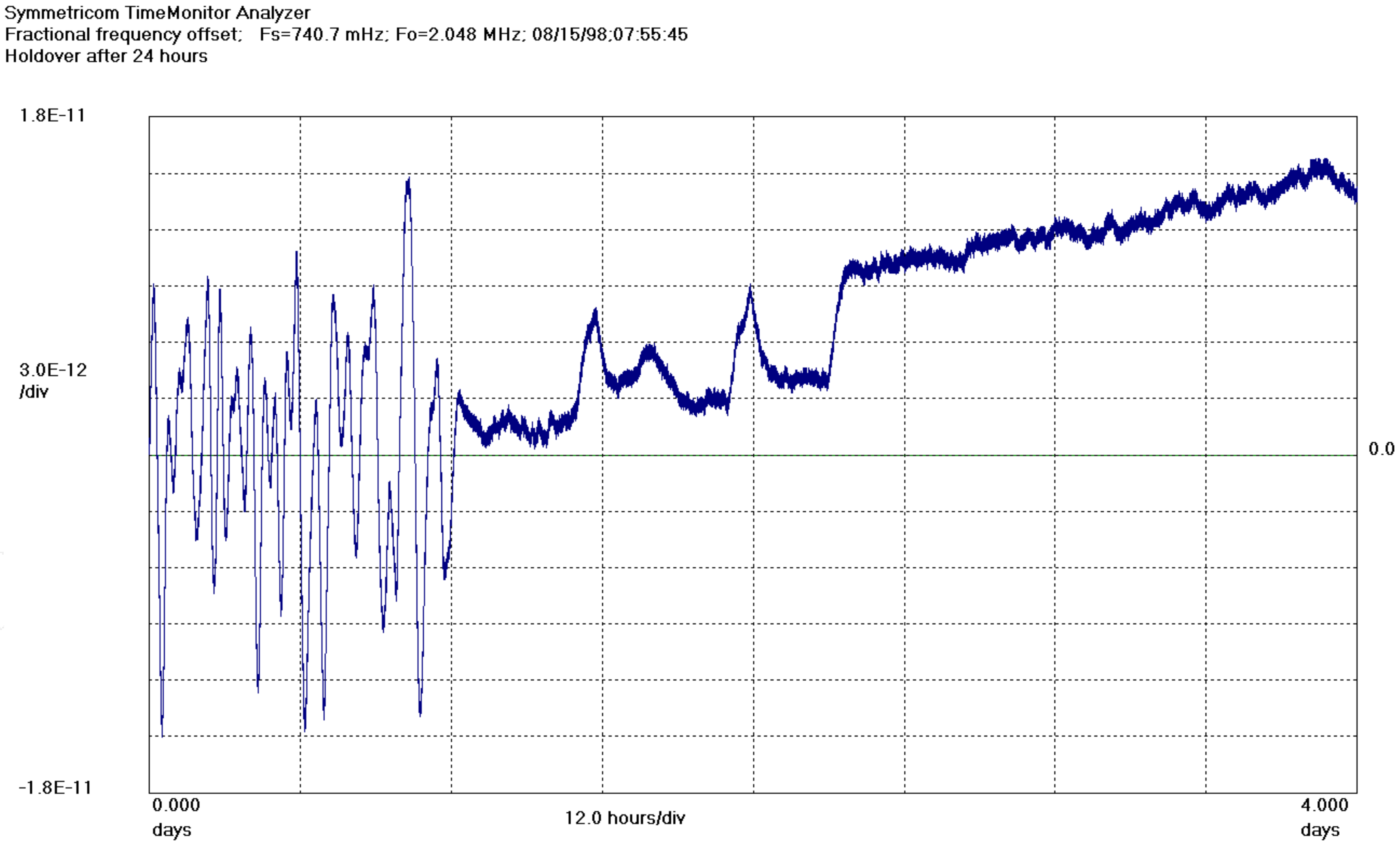
- Dynamic frequency: FDEV/FFOFF
  - Instantaneous frequency plotted over time
  - Fractional frequency offset is a normalized version of frequency deviation
  - Limited resolution as measurement interval decreases
- Frequency accuracy
  - Derived from longer term measurement
  - Phase slope calculation (least-square-fit)
  - Example: PRS 1 part in 10^{11} requirement
- To sum up: a tradeoff exists between precision of frequency result and pinpointing when it occurred

Frequency: Point-by-point

Symmetricom TimeMonitor Analyzer
Fractional frequency offset; Fs=740.7 mHz; Fo=2.048 MHz; 08/15/98;07:55:45
Holdover after 24 hours



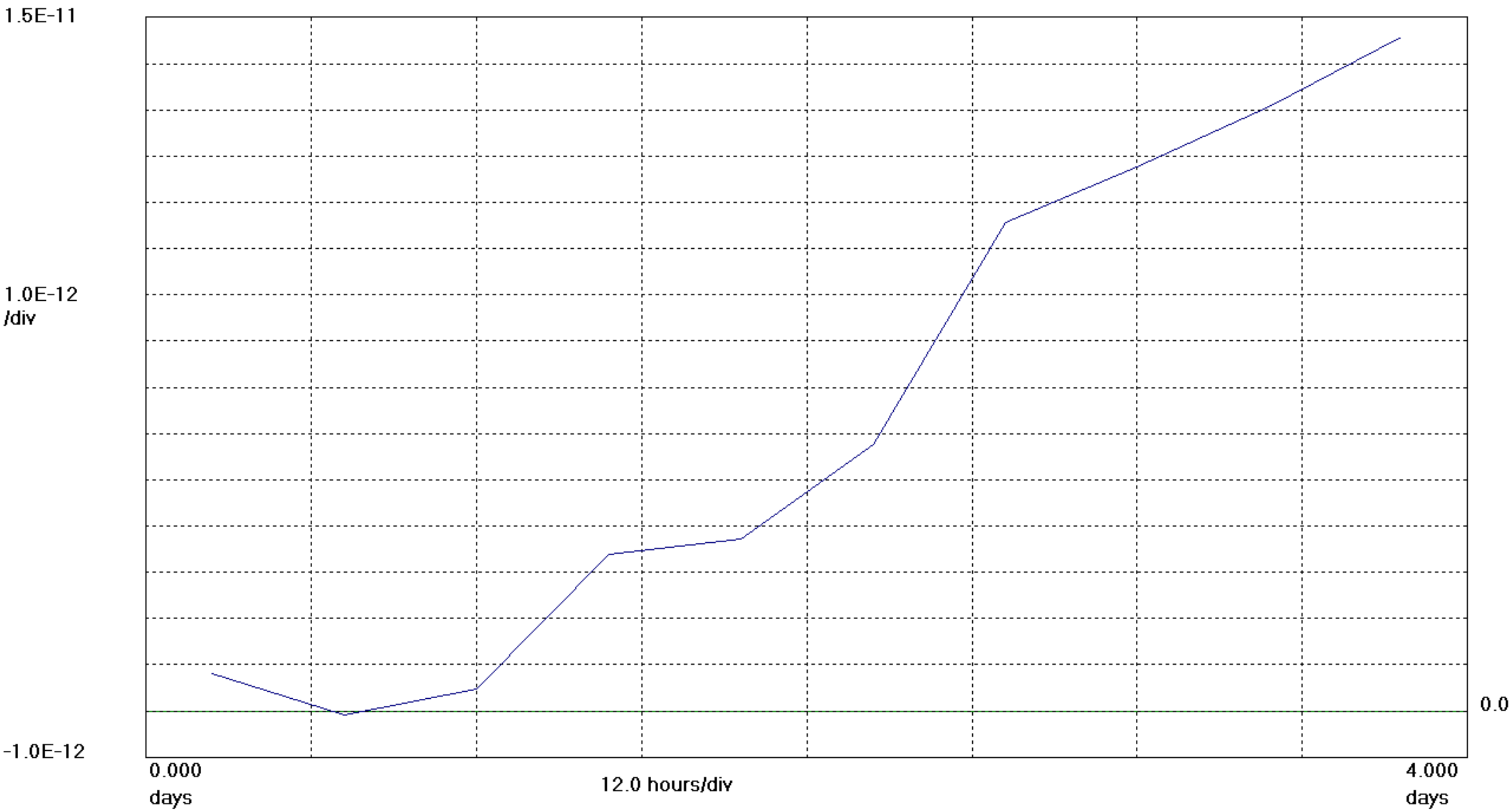
Frequency: w/ Low Pass Filter



Symmetricom TimeMonitor Analyzer
Fractional frequency offset; Fs=740.7 mHz; Fo=2.048 MHz; 08/15/98;07:55:45
Holdover after 24 hours

Frequency: Segmented LSF

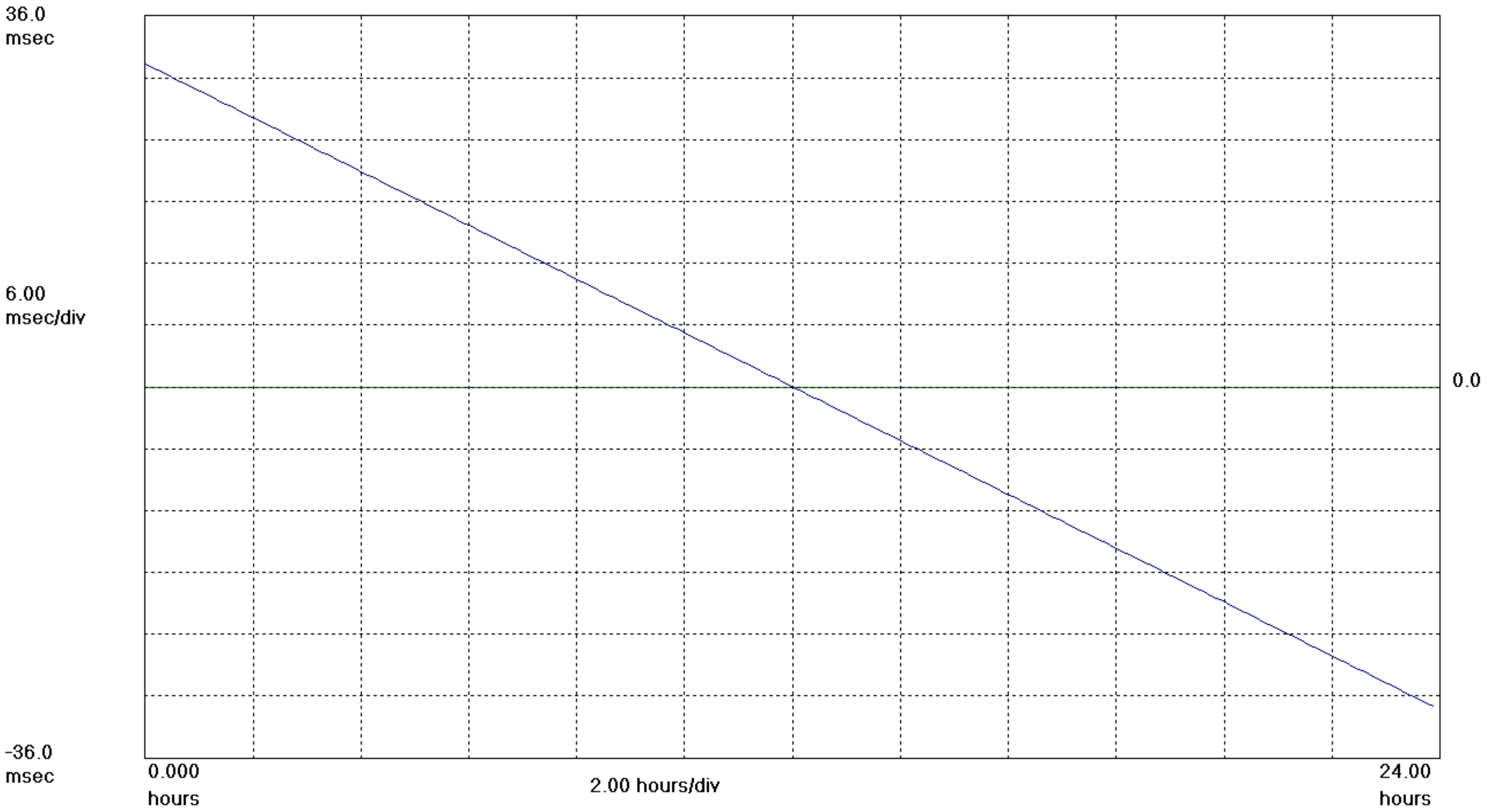
Symmetricom TimeMonitor Analyzer
Least square fit fractional frequency offset vs. time; N=10; 08/15/98;07:55:45
Holdover after 24 hours



Frequency: Offset Present

0.7 ppm on double oven quartz oscillator

Symmetricom TimeMonitor Analyzer
Phase deviation in units of time; Fs=296.3 mHz; Fo=10.000000 MHz; 03/12/97;02:37:24
Test #1423; set 97.75; #23; Fo offset = -7.255E-7; Fo reference = 10.000000000000 MHz

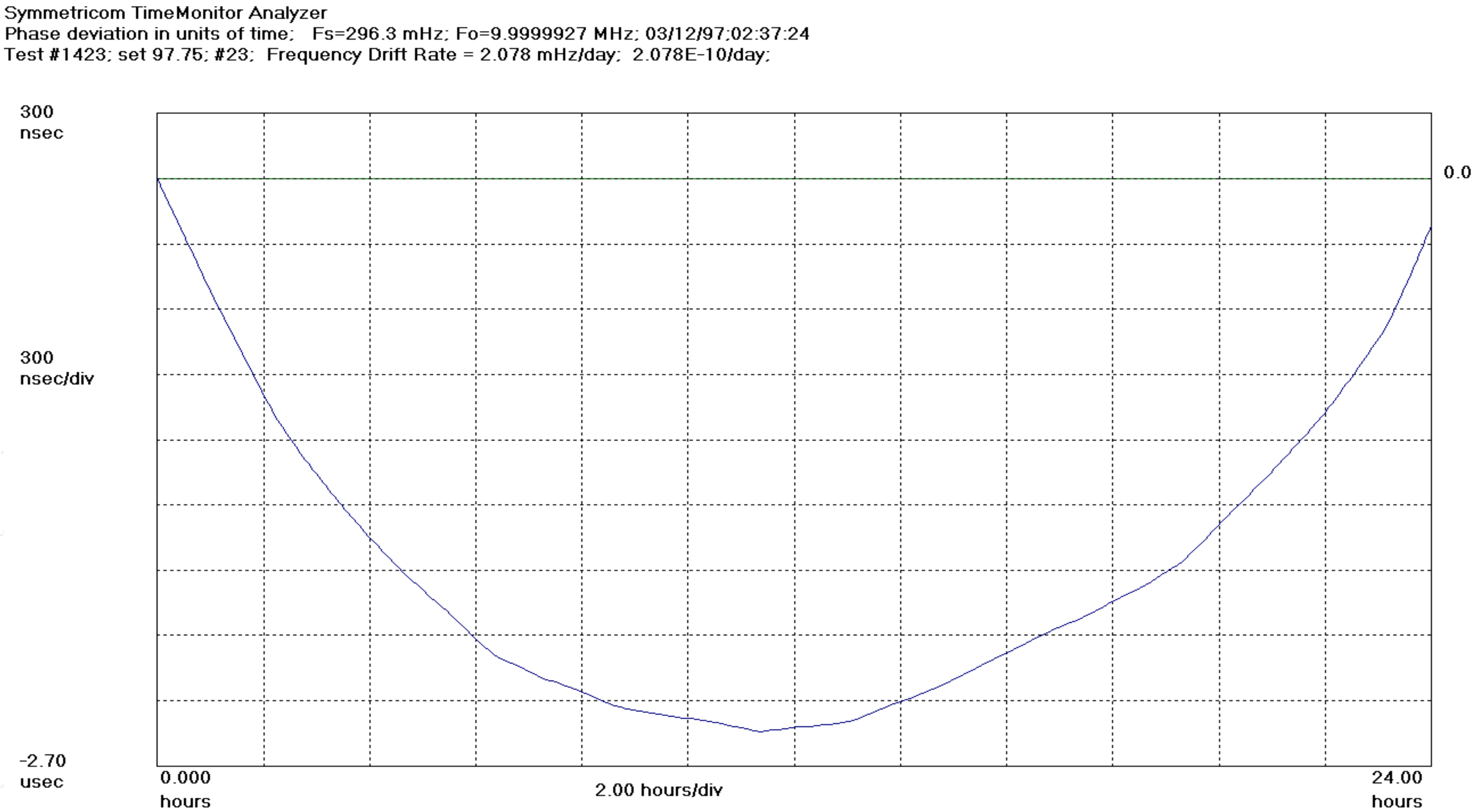


Frequency: Offset Removed

Frequency offset removed

Phase deviation quadratic shape shows presence of linear frequency drift

Frequency drift is 2 mHz per day or $2 \cdot 10^{-10}$ per day



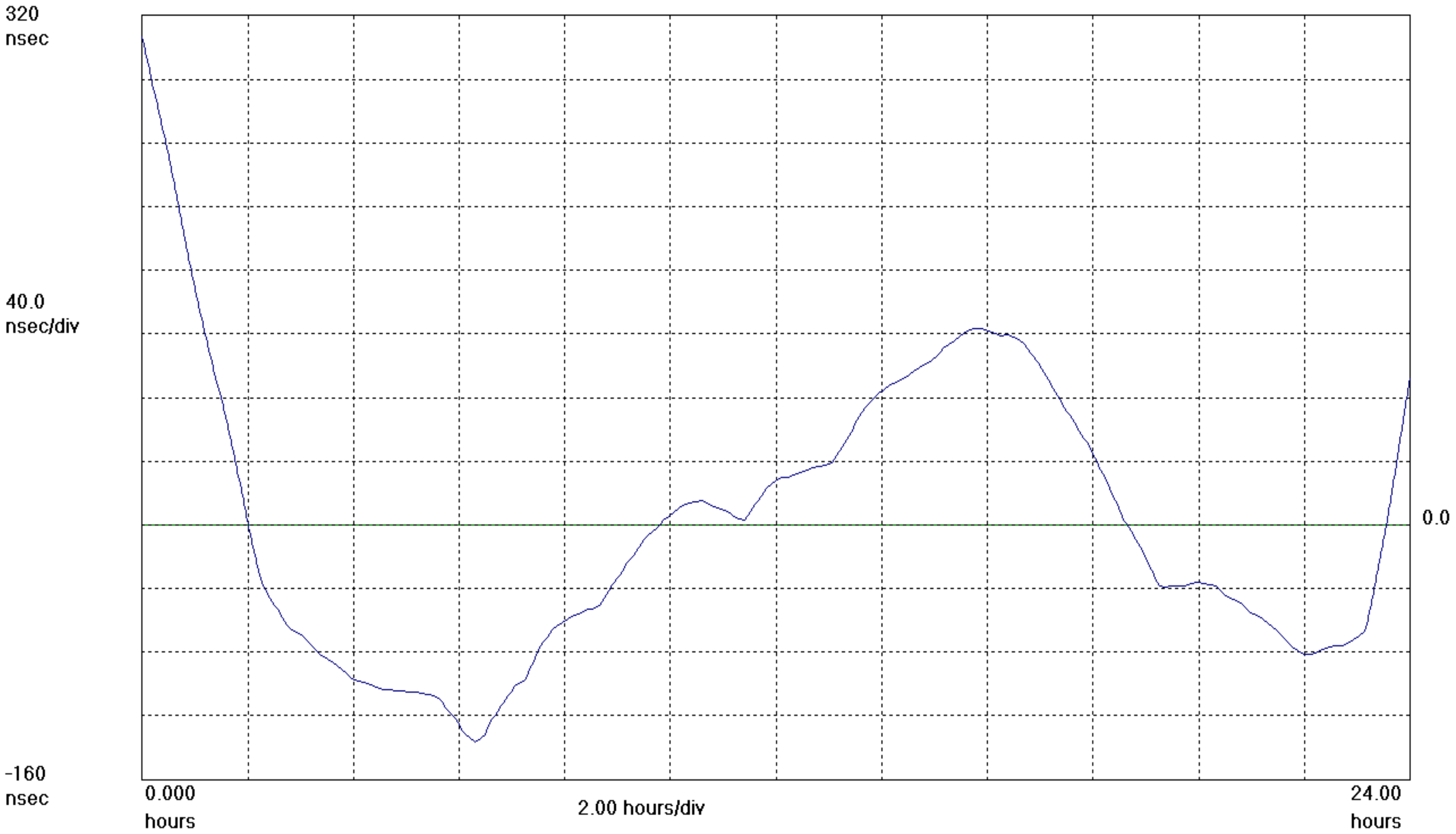
Symmetricom TimeMonitor Analyzer
Phase deviation in units of time; Fs=296.3 mHz; Fo=9.9999927 MHz; 03/12/97;02:37:24
Test #1423; set 97.75; #23; Frequency Drift Rate = 2.078 mHz/day; 2.078E-10/day;

Frequency: Drift Removed

Symmetricom

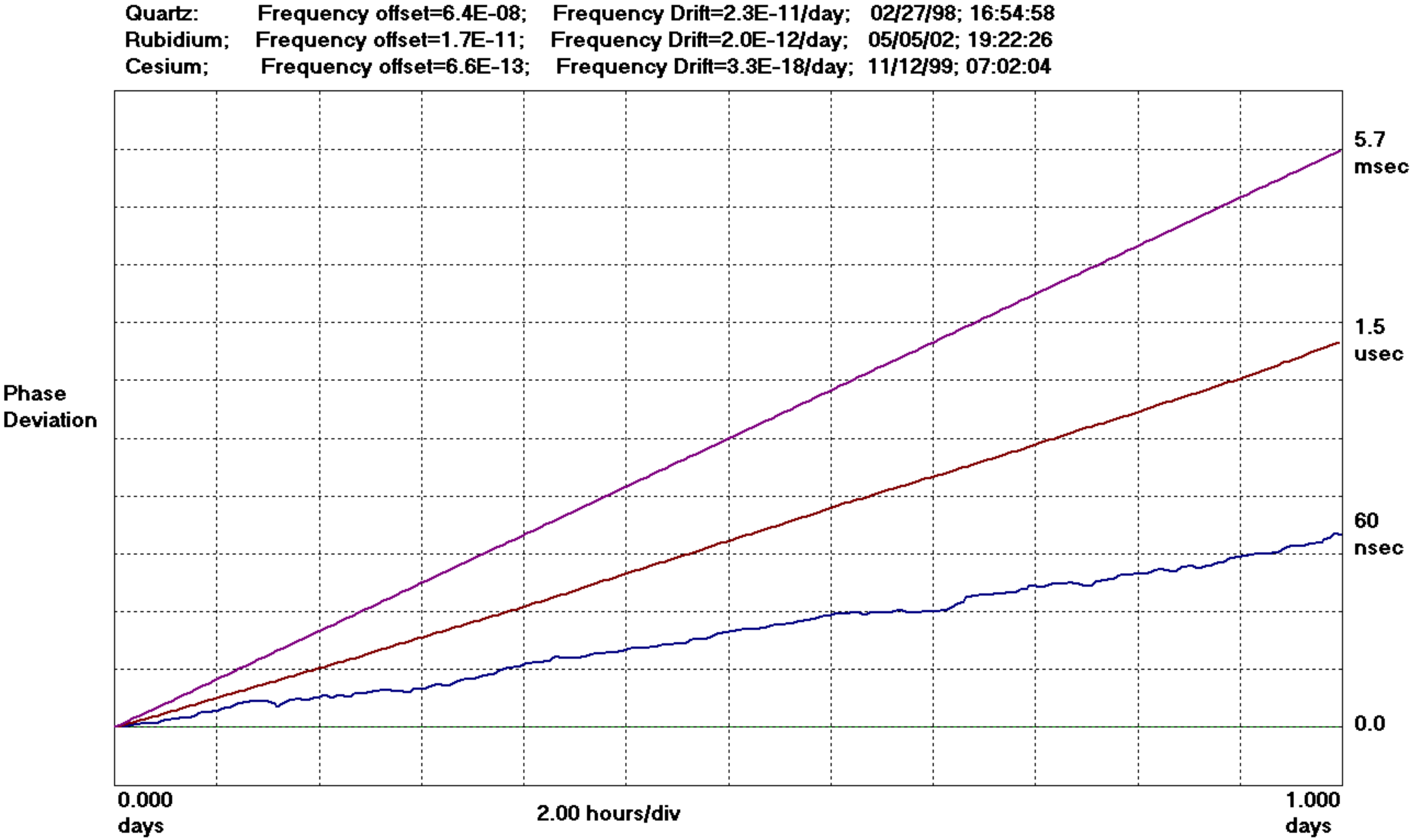
Phase deviation fit to quadratic shows residual phase movement

Symmetricom TimeMonitor Analyzer
Phase deviation in units of time; Fs=296.3 mHz; Fo=9.9999927 MHz; 03/12/97;02:37:24
Test #1423; set 97.75; #23; Frequency Drift Rate = 2.078 mHz/day; 2.078E-10/day;



Frequency Accuracy and Stability

Quartz, Rubidium, and Cesium



Quartz: Frequency offset=6.4E-08; Frequency Drift=2.3E-11/day; 02/27/98; 16:54:58

Rubidium; Frequency offset=1.7E-11; Frequency Drift=2.0E-12/day; 05/05/02; 19:22:26

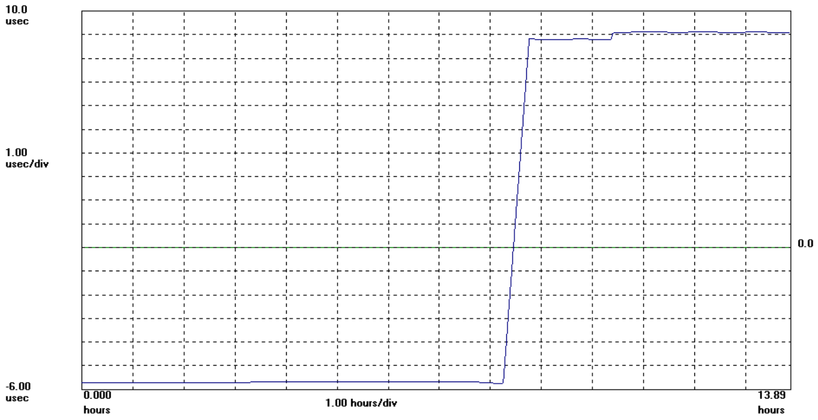
Cesium; Frequency offset=6.6E-13; Frequency Drift=3.3E-18/day; 11/12/99; 07:02:04

Synchronization Measurements

- Both MTIE and TDEV are measures of wander over ranges of values from very short-term wander to long-term wander
- MTIE is a peak detector: shows largest phase swings for various observation time windows
- TDEV is a highly averaged, “rms” type of calculation showing values over a range of integration times

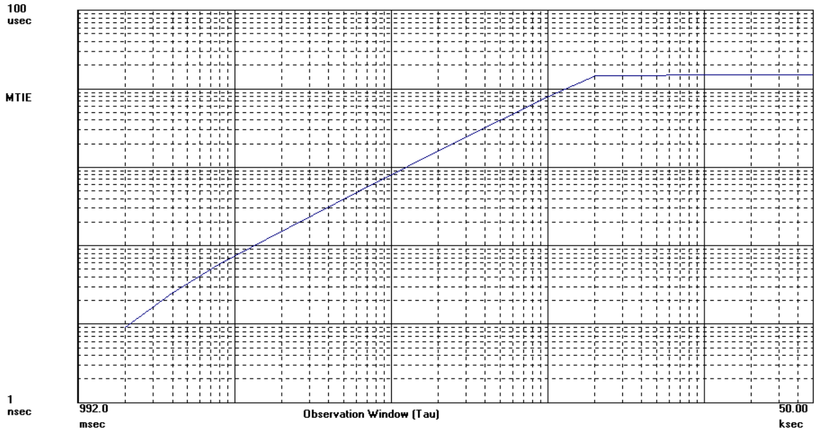
MTIE: shows a step in phase

Phase



Phase steps upwards 15 μsec about 8 hours into the measurement

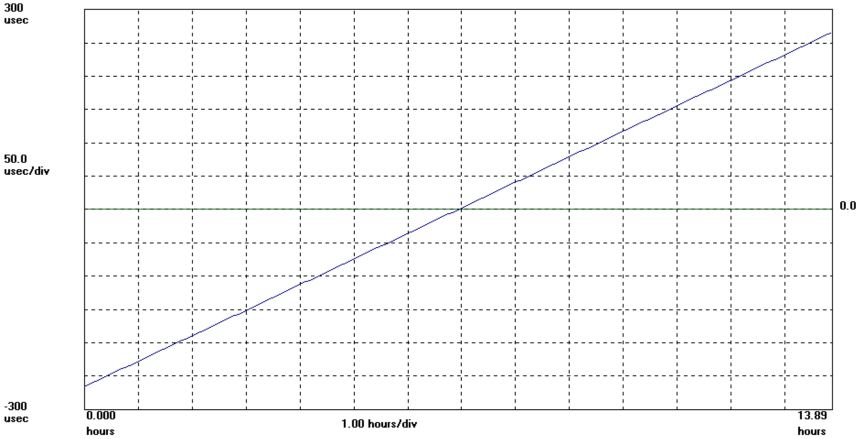
MTIE



MTIE flattens after a certain tau value (moving from left to right)

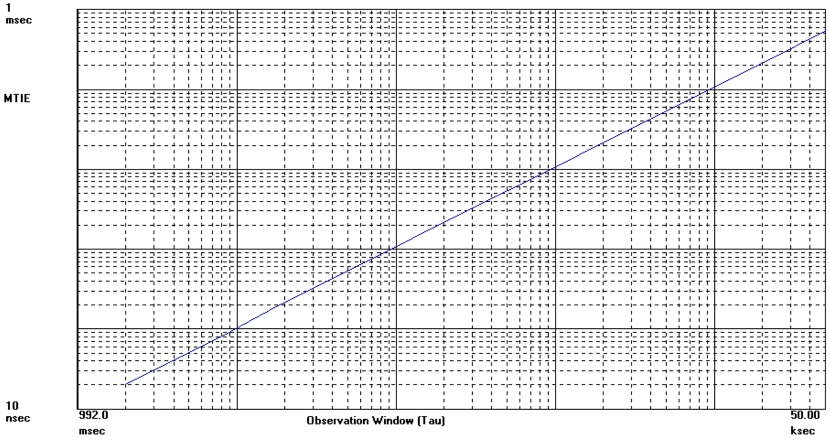
MTIE: shows a frequency offset

Phase



A frequency offset is seen as a constant slope in phase

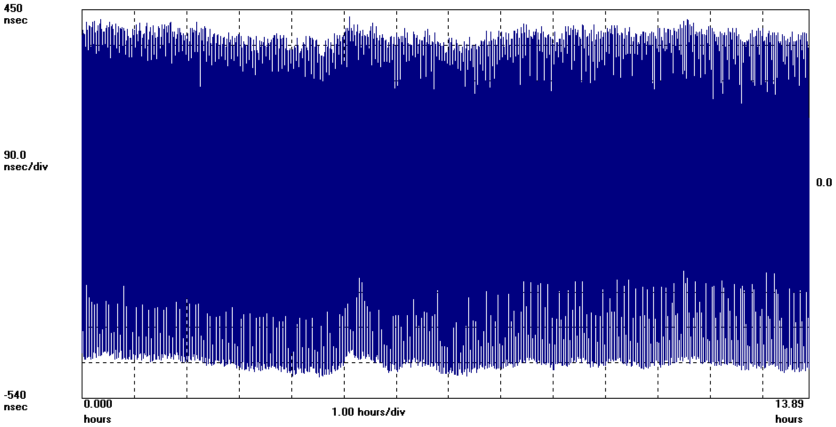
MTIE



MTIE constantly increases with increasing observation time

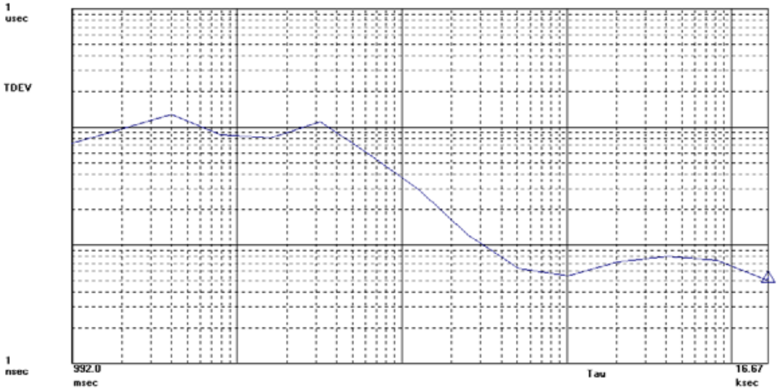
TDEV: shows a phase modulation consistent throughout measurement

Phase



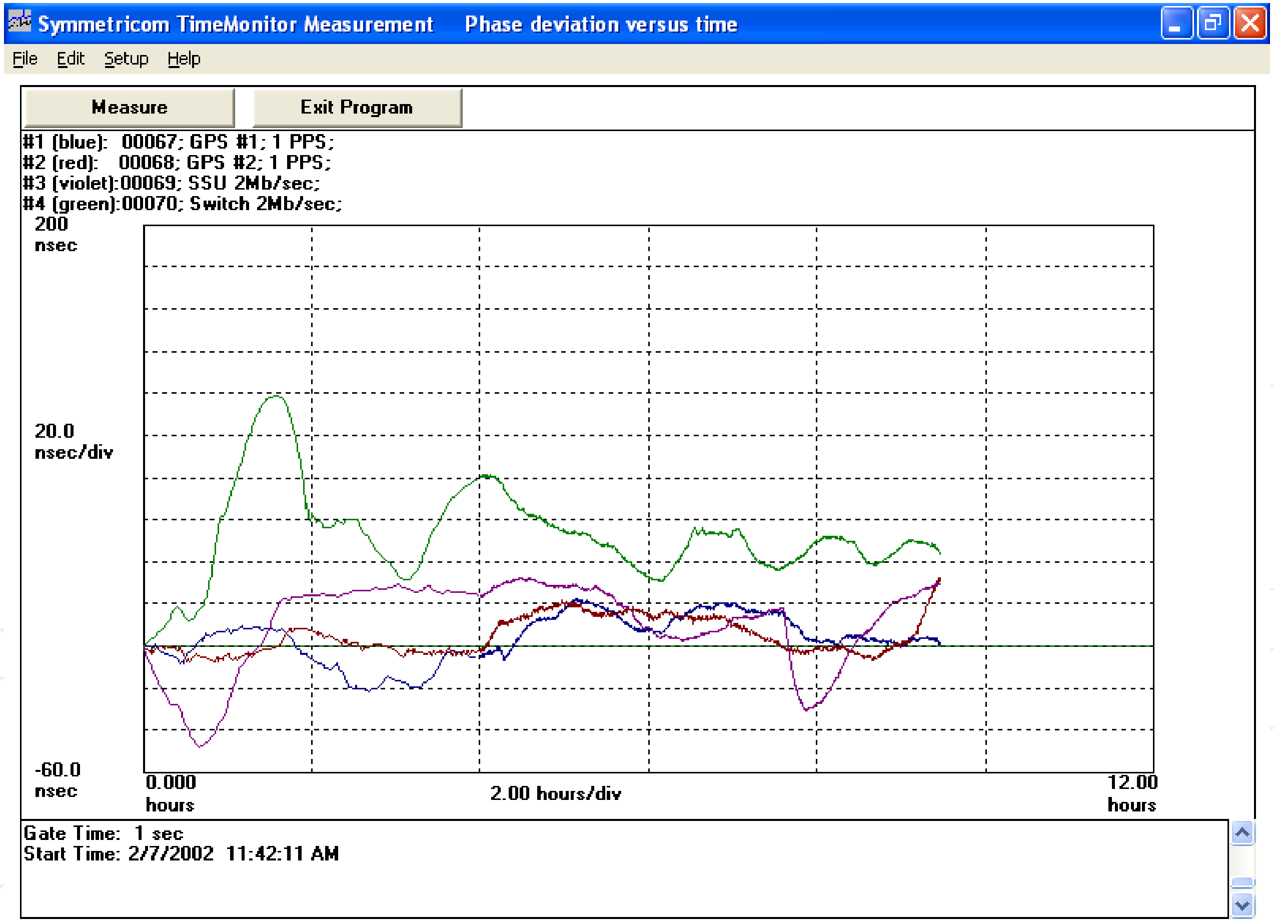
Phase shows large swings in the short term but is flat in the long term

TDEV



TDEV is elevated for shorter term wander (left) but relatively reduced for longer term (right)

Measurement Demo



#1 (blue): 00067; GPS #1; 1 PPS;
#2 (red): 00068; GPS #2; 1 PPS;
#3 (violet):00069; SSU 2Mb/sec;
#4 (green):00070; Switch 2Mb/sec;

Gate Time: 1 sec
Start Time: 2/7/2002 11:42:11 AM

Measurement & Analysis: Outline

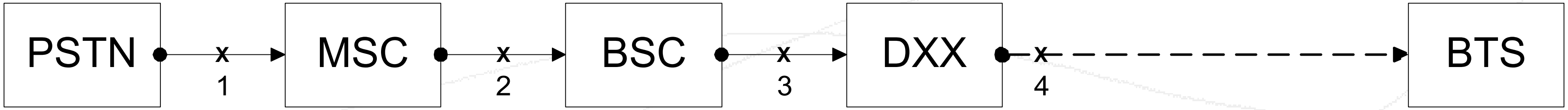
1. Measurement of Phase
2. Analysis from Phase
3. Measurement Examples ←

Sync Measurement #1: Network Element Cascading

Symmetricom

Sync degradation with cascading: PSTN-MSC-BSC-DXX

GSM Mobile Telephone Operator



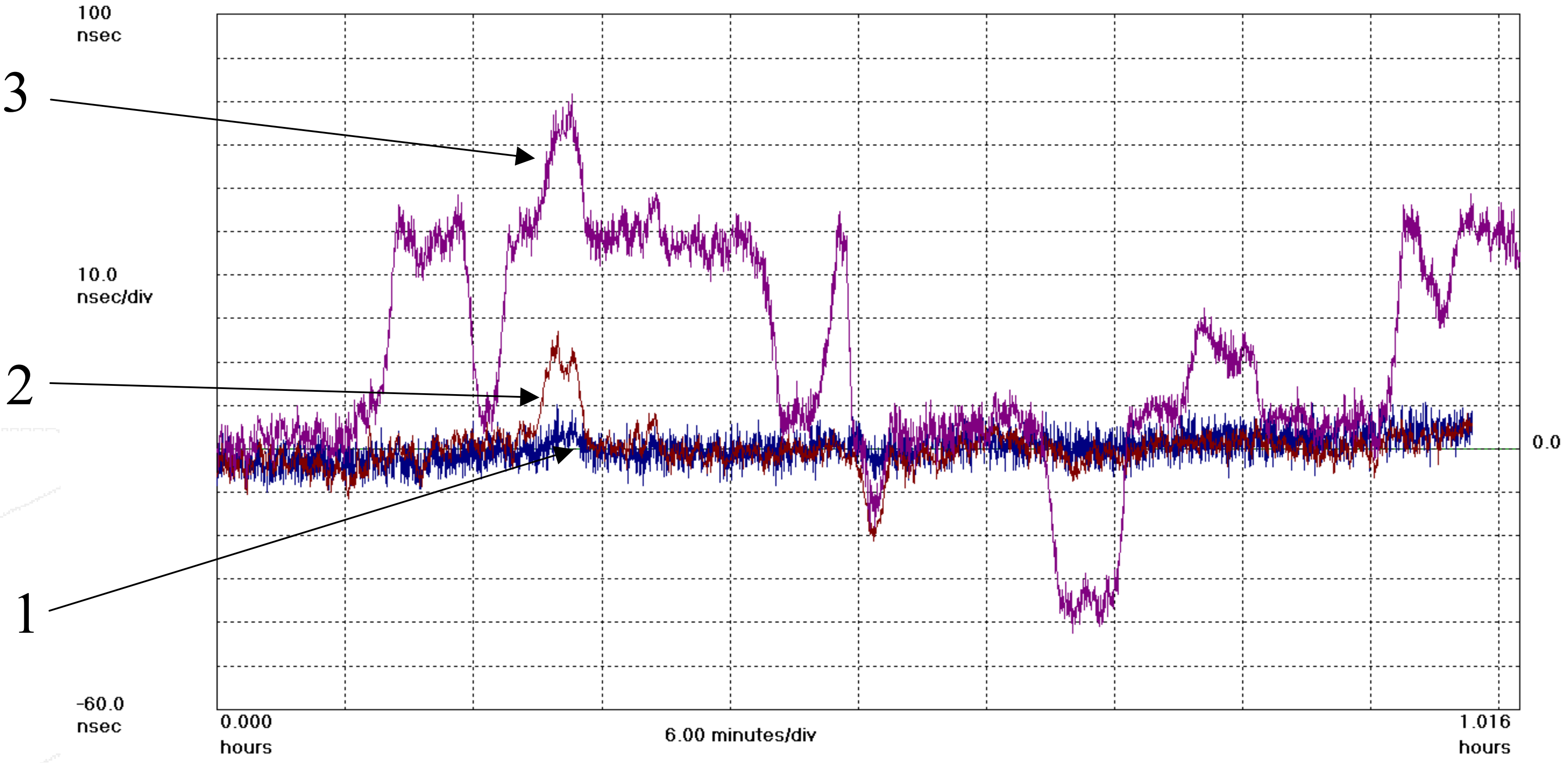
x: measurement points

Sync Measurement #1: Network Element Cascading

Symmetricom

Sync degradation with cascading: PSTN-MSC-BSC-DXX
21 nsec to 48 nsec to 124 nsec to 682 nsec peak-to-peak TIE

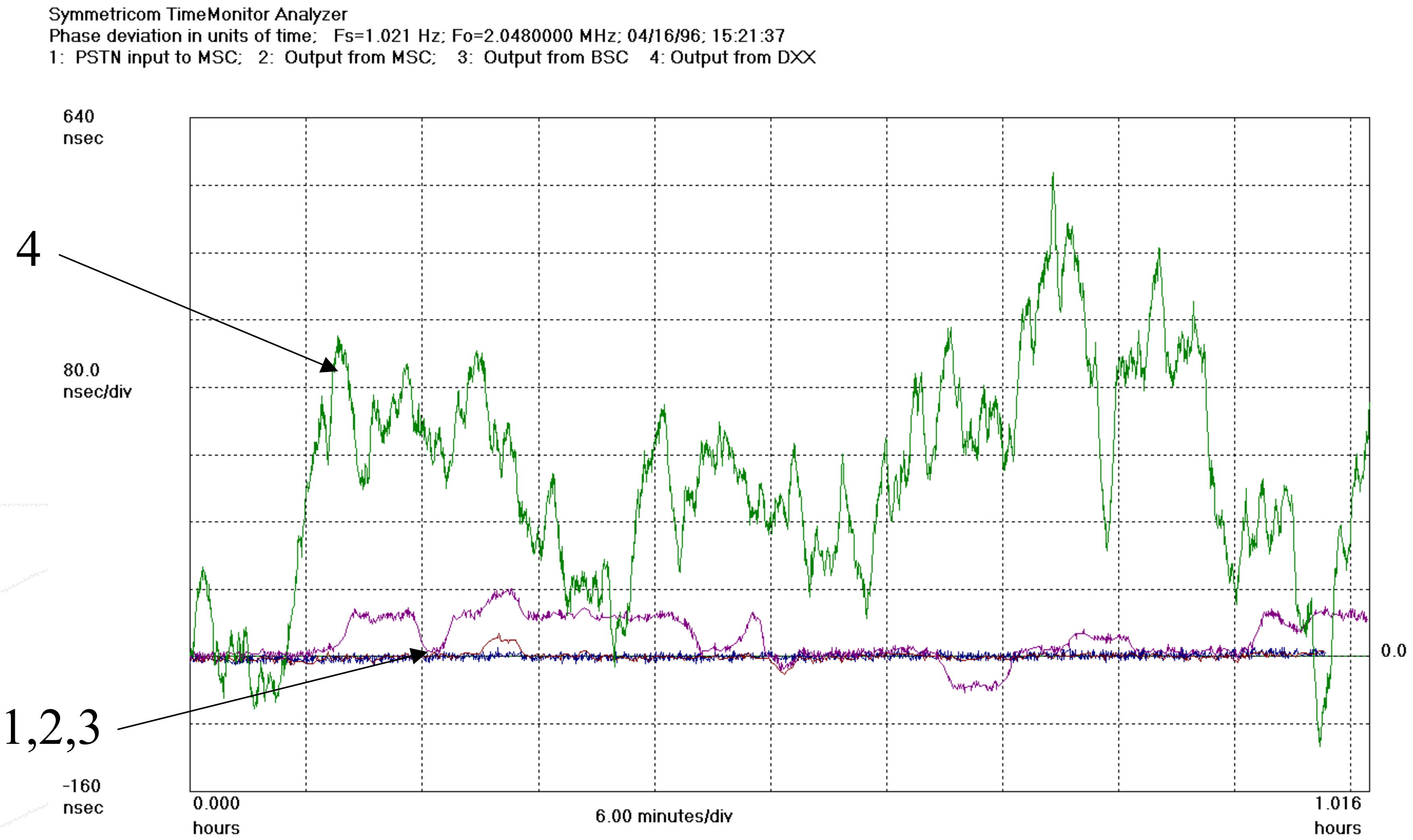
Symmetricom TimeMonitor Analyzer
Phase deviation in units of time; Fs=1.021 Hz; Fo=2.0480000 MHz; 04/16/96; 15:21:37
1: PSTN input to MSC; 2: Output from MSC; 3: Output from BSC



Sync Measurement #1: Network Element Cascading

Symmetricom

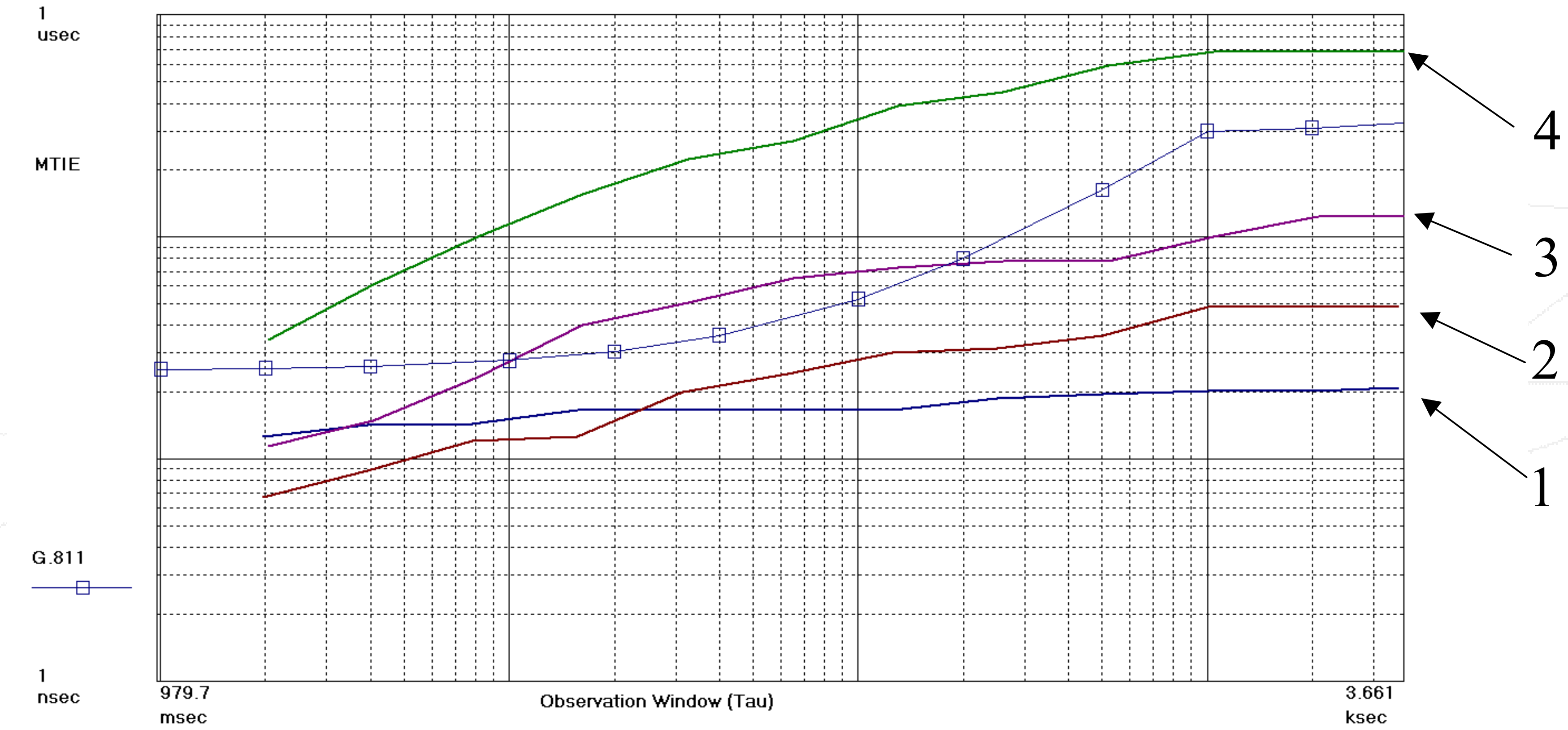
Sync degradation with cascading: PSTN-MSC-BSC-DXX
21 nsec to 48 nsec to 124 nsec to 682 nsec peak-to-peak TIE



Sync Measurement #1: Network Element Cascading

Sync degradation with cascading: PSTN-MSC-BSC-DXX MTIE

Symmetricom TimeMonitor Analyzer
MTIE; Fo=2.048 MHz; Fs=1.021 Hz; 04/16/96; 15:21:37
1: PSTN input to MSC; 2: Output from MSC; 3: Output from BSC 4: Output from DXX

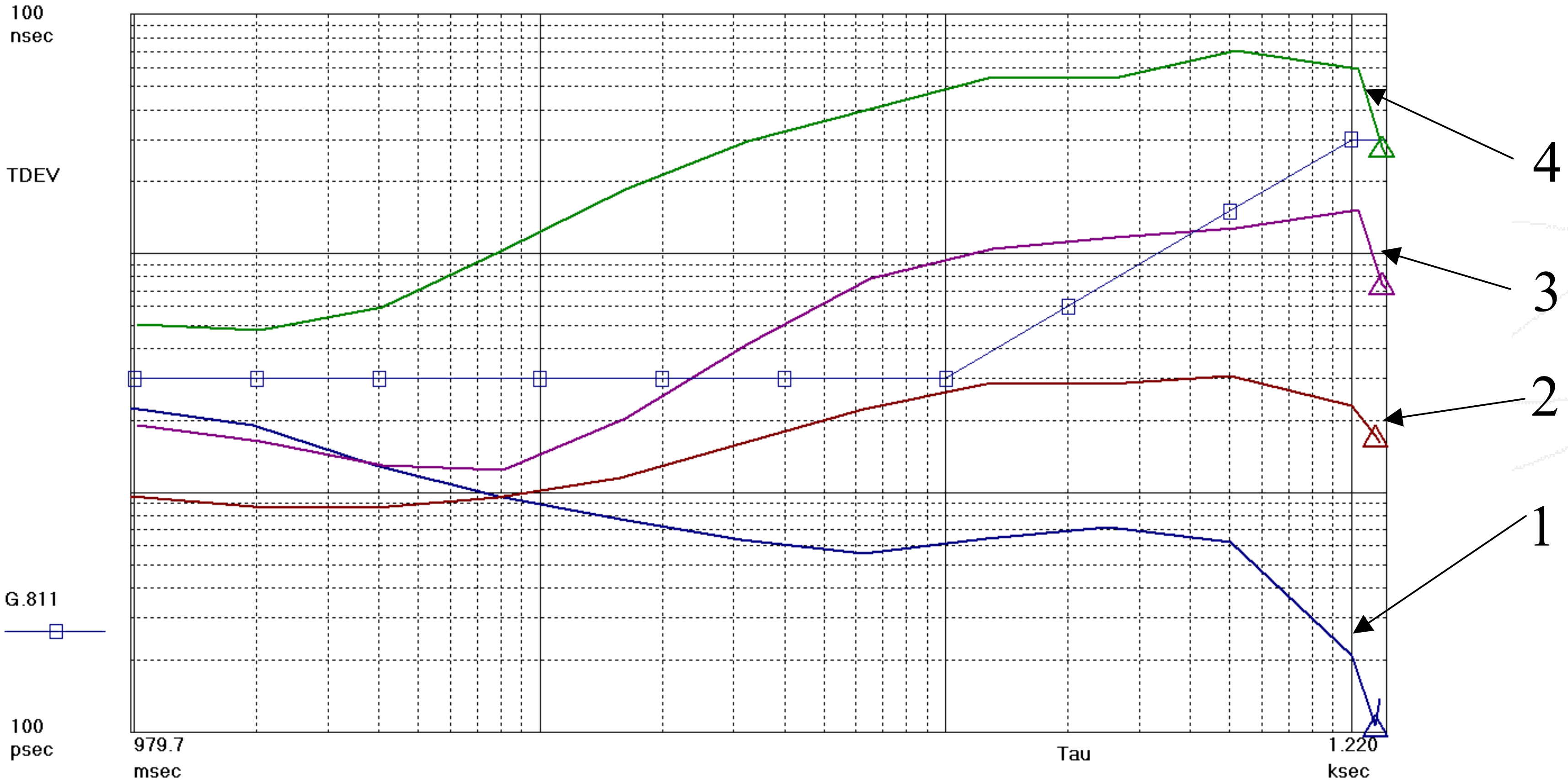


Sync Measurement #1: Network Element Cascading

Symmetricom

Sync degradation with cascading: PSTN-MSC-BSC-DXX TDEV

Symmetricom TimeMonitor Analyzer
TDEV; No. Avg=1; Fo=2.048 MHz; Fs=1.021 Hz; 04/16/96; 15:21:37
1: PSTN input to MSC; 2: Output from MSC; 3: Output from BSC; 4: Output from DXX



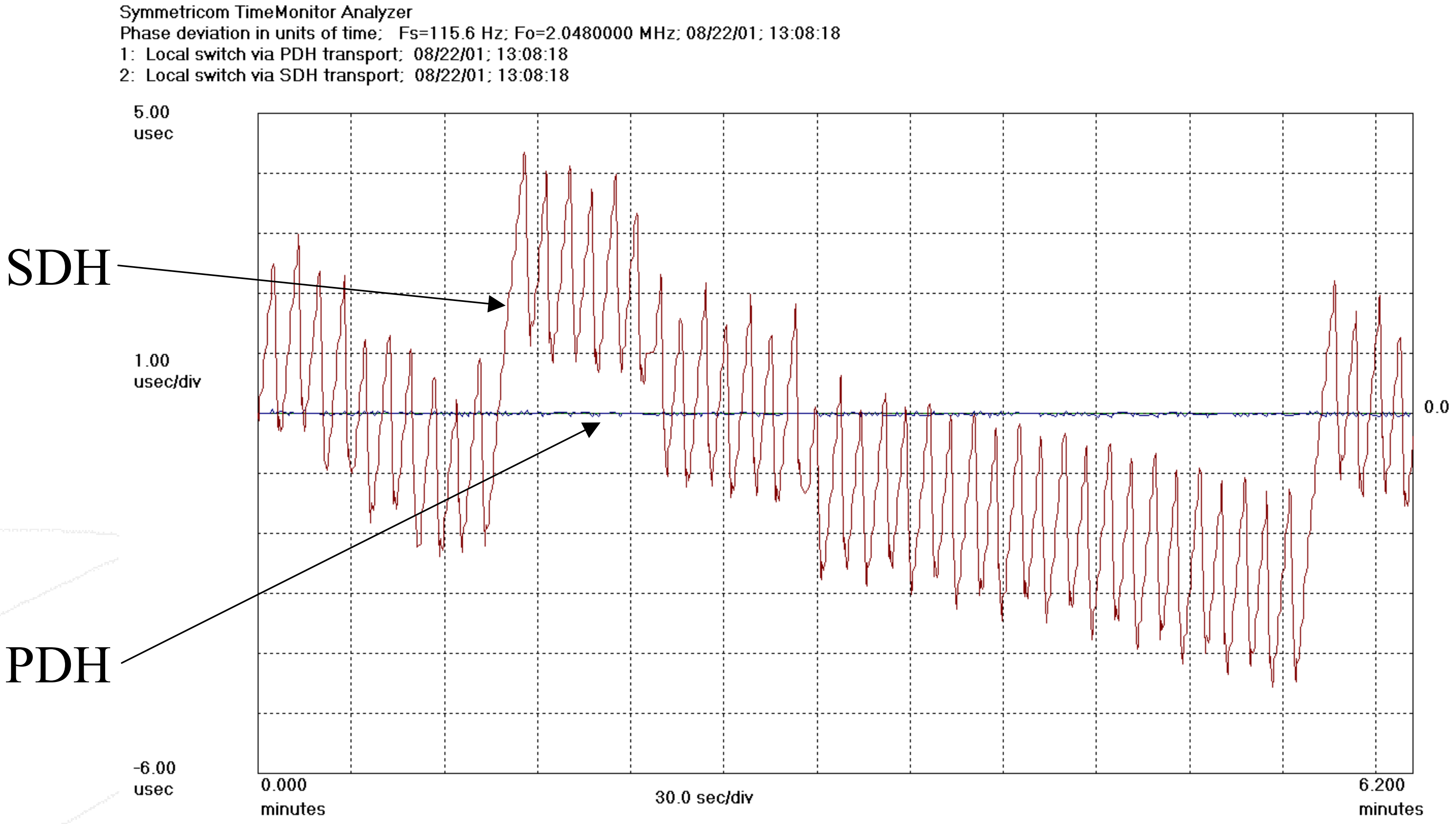
Sync Measurement #2:
SDH vs. PDH Transport

MSC PSTN timing: PDH vs. SDH transport

x: measurement points

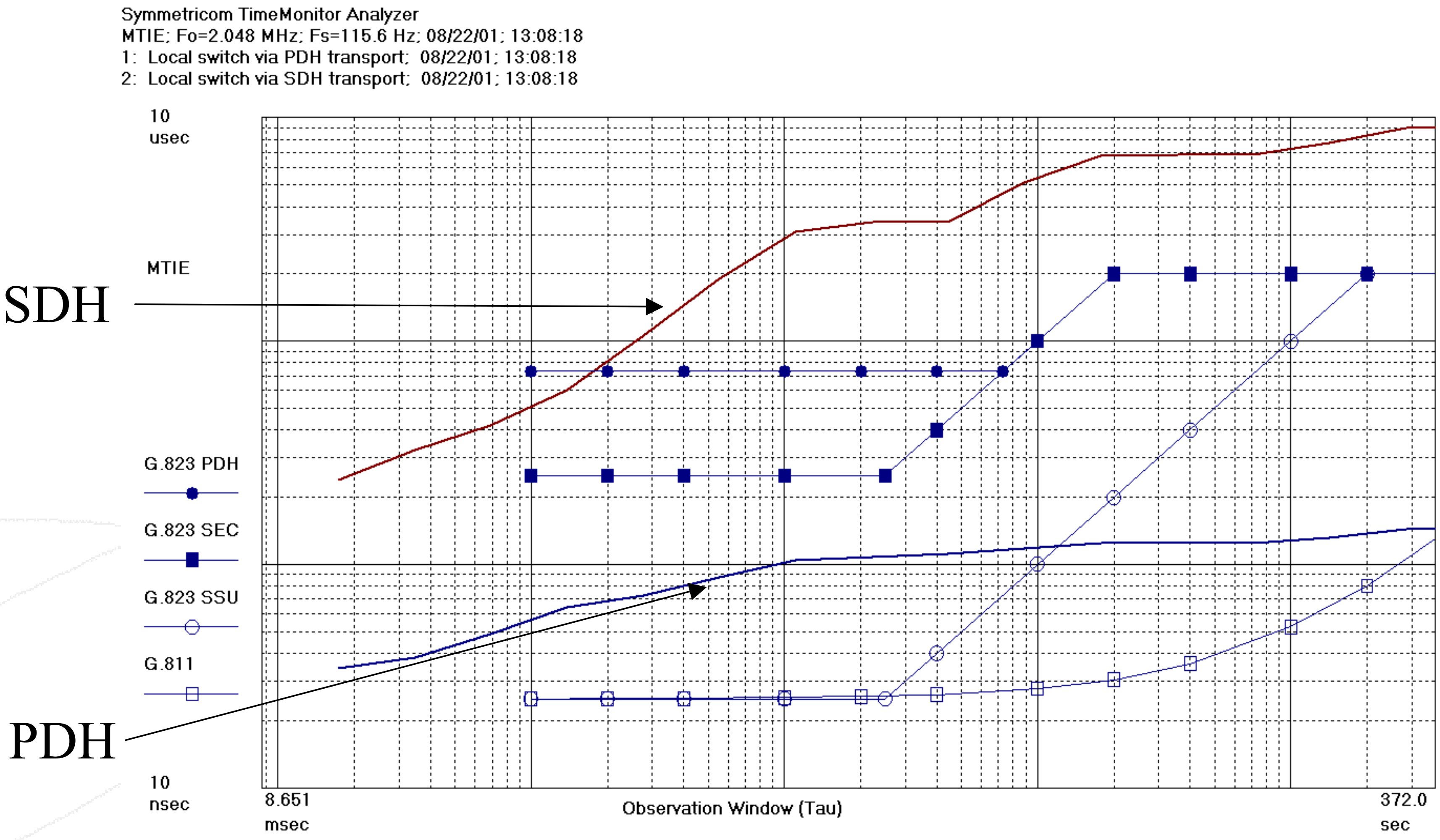
Sync Measurement #2: SDH vs. PDH Transport

PDH vs. SDH transport



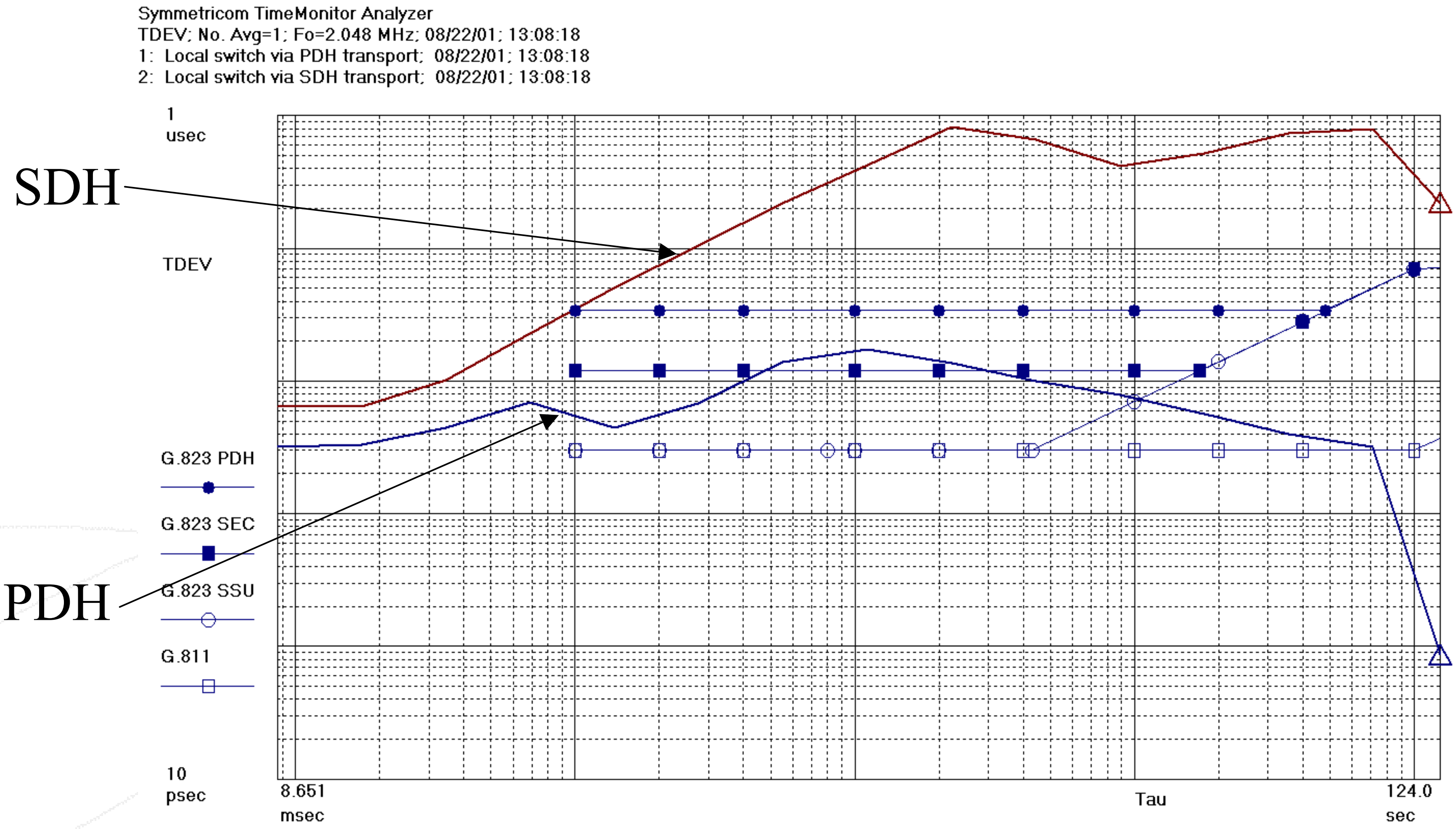
Sync Measurement #2:
SDH vs. PDH Transport

PDH vs. SDH transport



Sync Measurement #2:
SDH vs. PDH Transport

PDH vs. SDH transport



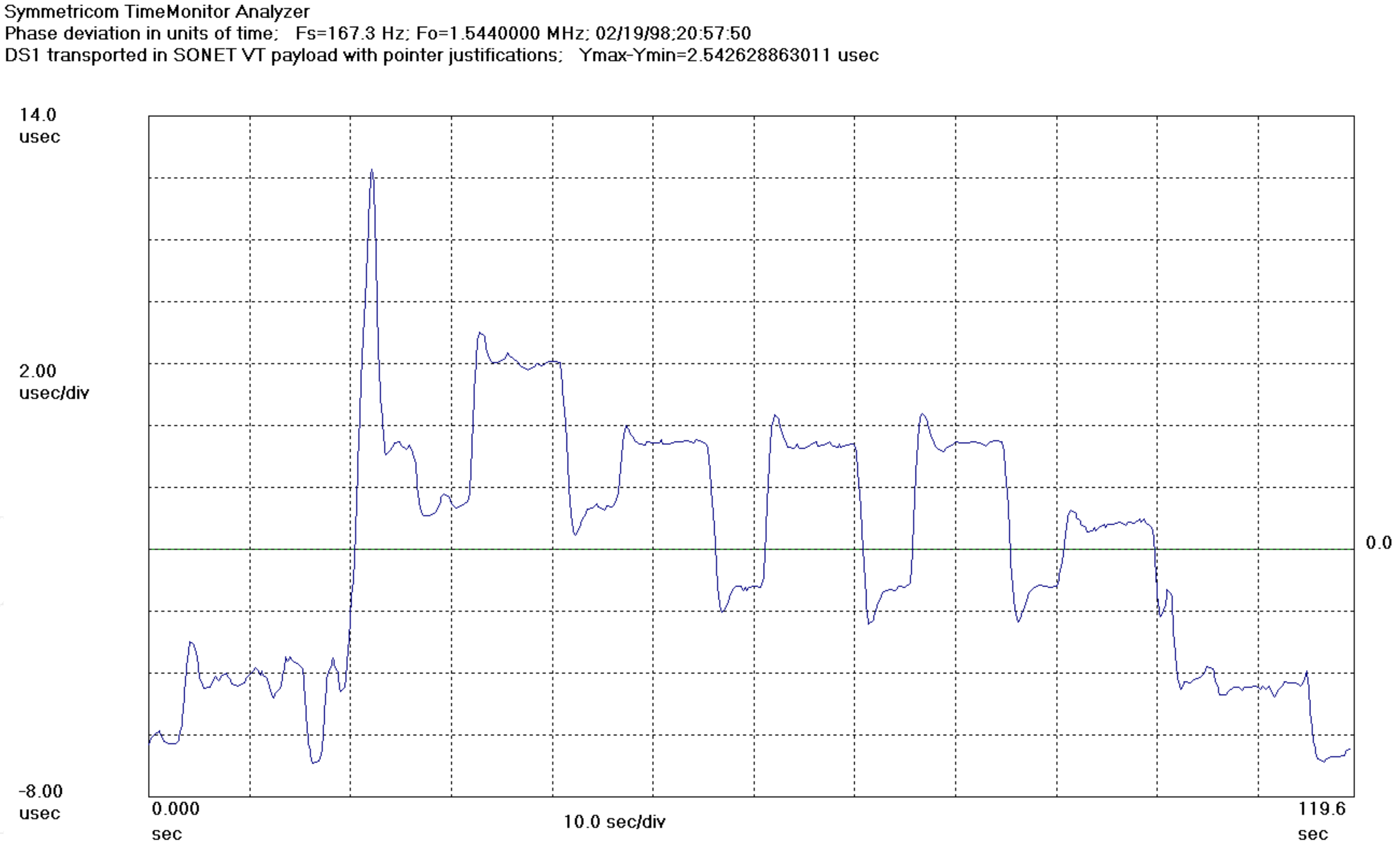
Symmetricom TimeMonitor Analyzer
TDEV; No. Avg=1; Fo=2.048 MHz; 08/22/01; 13:08:18
1: Local switch via PDH transport; 08/22/01; 13:08:18
2: Local switch via SDH transport; 08/22/01; 13:08:18

SDH

PDH

Sync Measurement #3:
SONET vs. PDH Transport

SONET pointer justifications on DS1

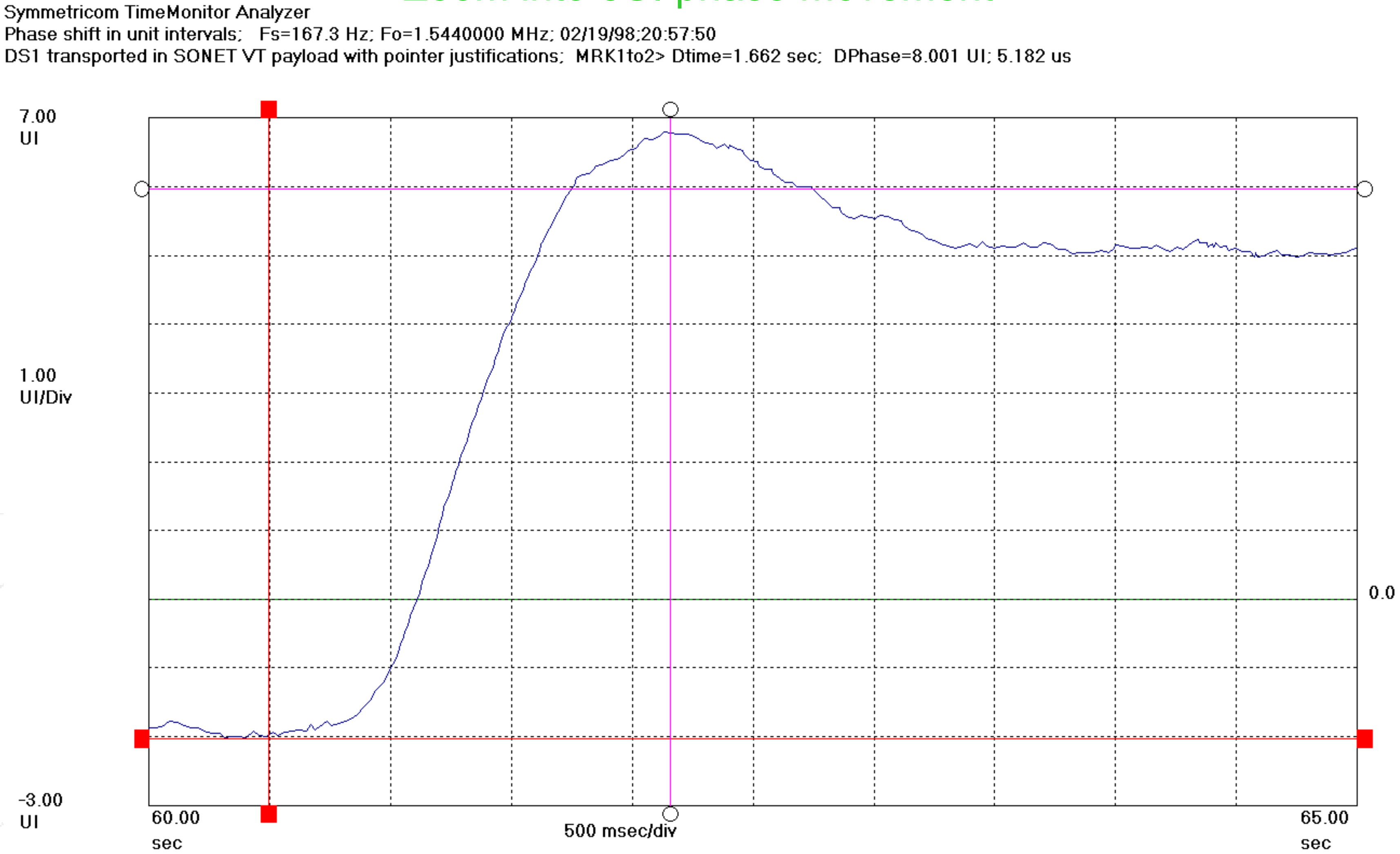


Symmetricom TimeMonitor Analyzer
Phase deviation in units of time; Fs=167.3 Hz; Fo=1.5440000 MHz; 02/19/98;20:57:50
DS1 transported in SONET VT payload with pointer justifications; Ymax-Ymin=2.542628863011 usec

Sync Measurement #3: SONET vs. PDH Transport

SONET pointer justifications on DS1

Zoom into 8UI phase movement

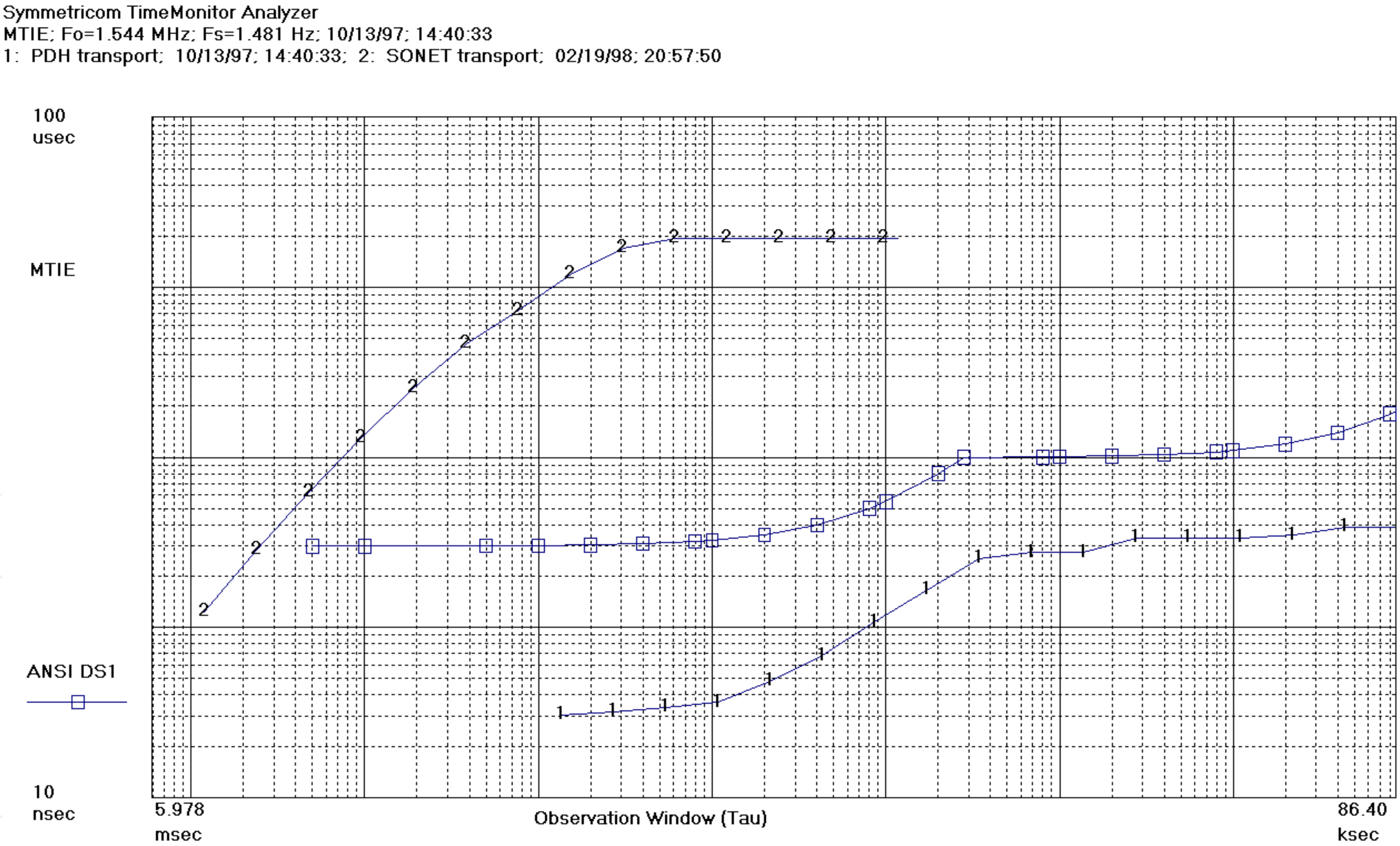


Symmetricom TimeMonitor Analyzer
Phase shift in unit intervals; Fs=167.3 Hz; Fo=1.5440000 MHz; 02/19/98;20:57:50
DS1 transported in SONET VT payload with pointer justifications; MRK1to2> Dtime=1.662 sec; DPhase=8.001 UI; 5.182 us

Sync Measurement #3: SONET vs. PDH Transport

SONET pointer justifications on DS1

SONET vs. PDH transport MTIE comparison

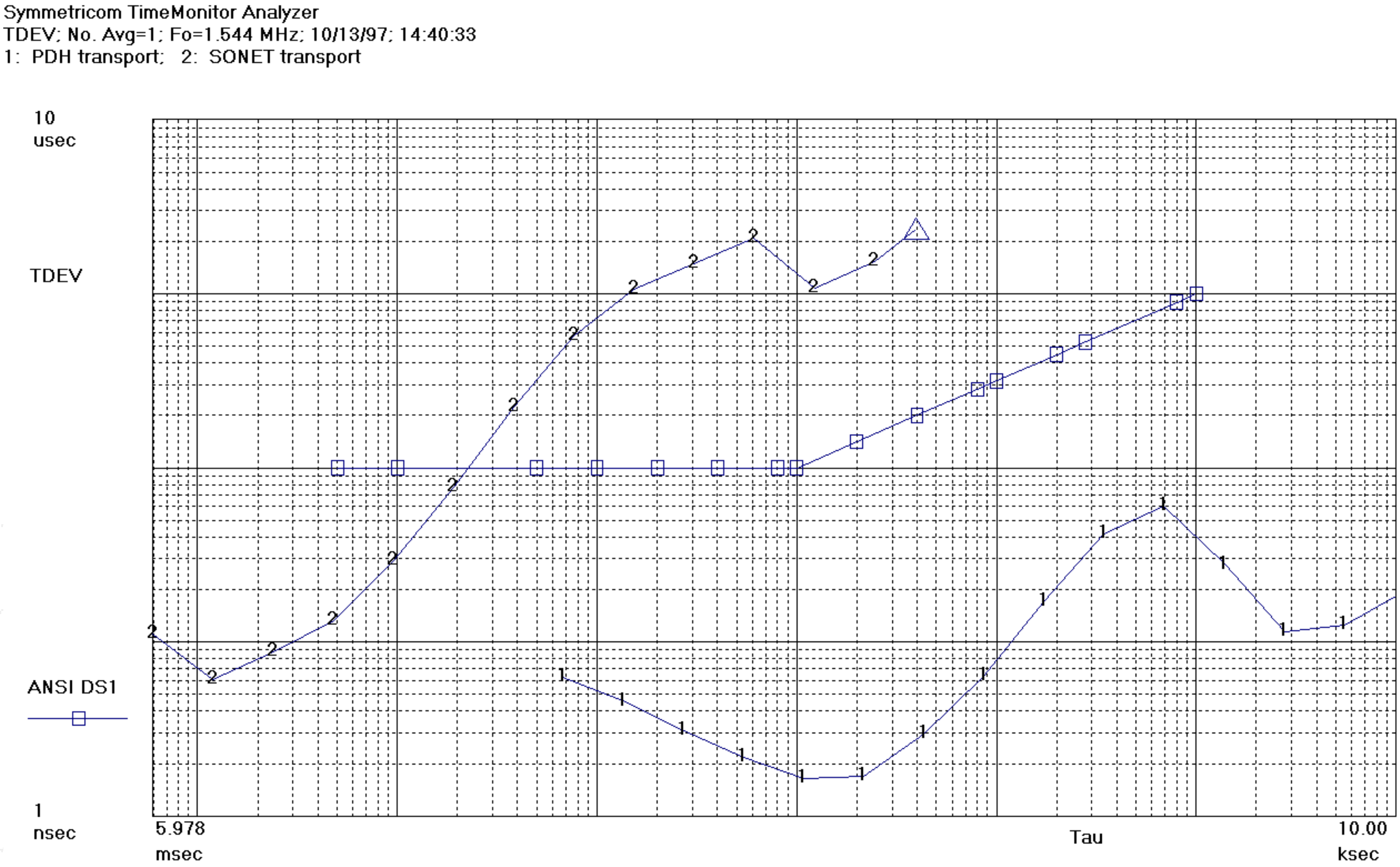


Symmetricom TimeMonitor Analyzer
MTIE; Fo=1.544 MHz; Fs=1.481 Hz; 10/13/97; 14:40:33
1: PDH transport; 10/13/97; 14:40:33; 2: SONET transport; 02/19/98; 20:57:50

Sync Measurement #3: SONET vs. PDH Transport

SONET pointer justifications on DS1

SONET vs. PDH transport TDEV comparison

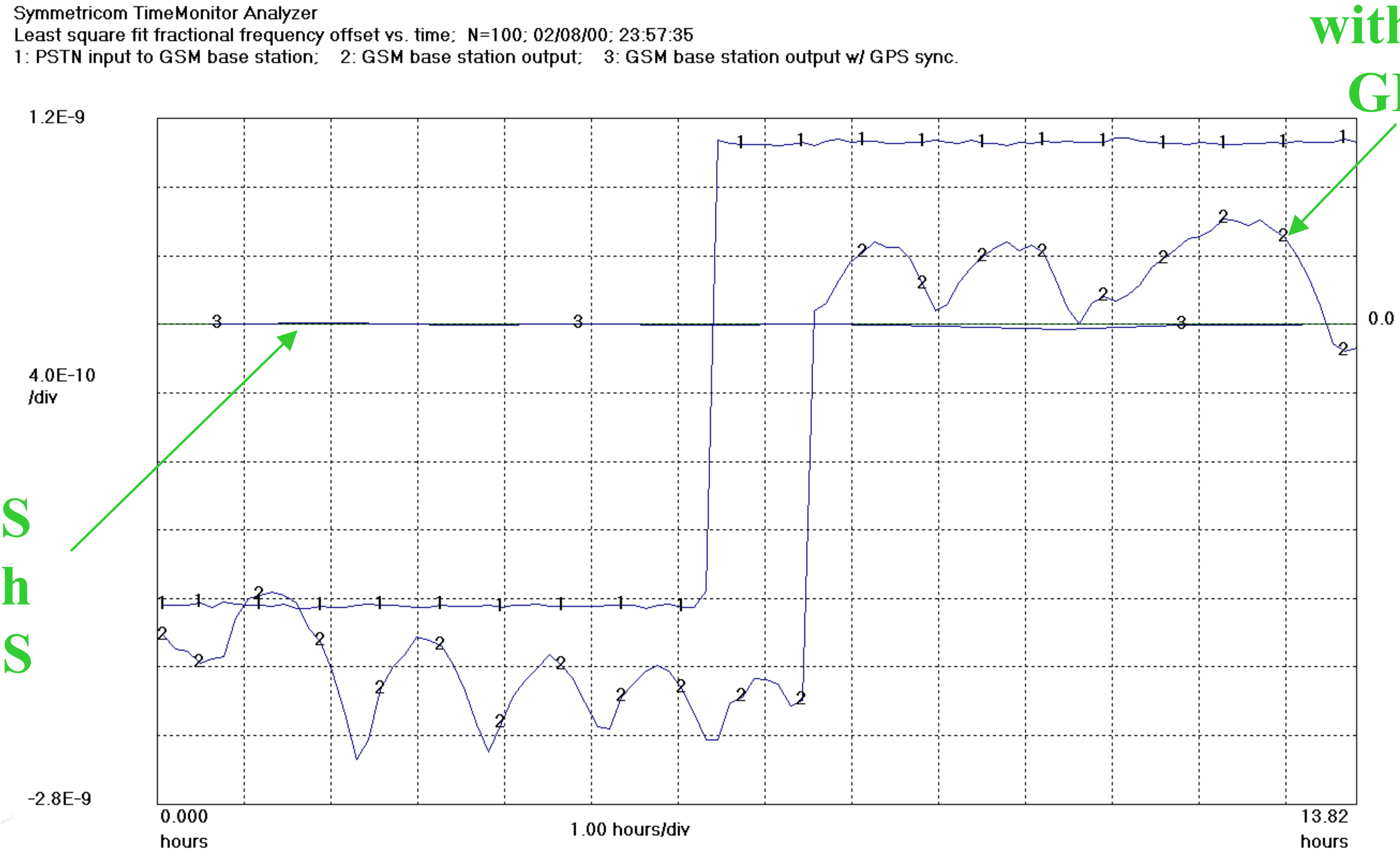


Sync Measurement #4:
GSM BTS: GPS vs. PSTN timing

Symmetricom®

Frequency jump from PSTN at GSM base station

BTS without GPS



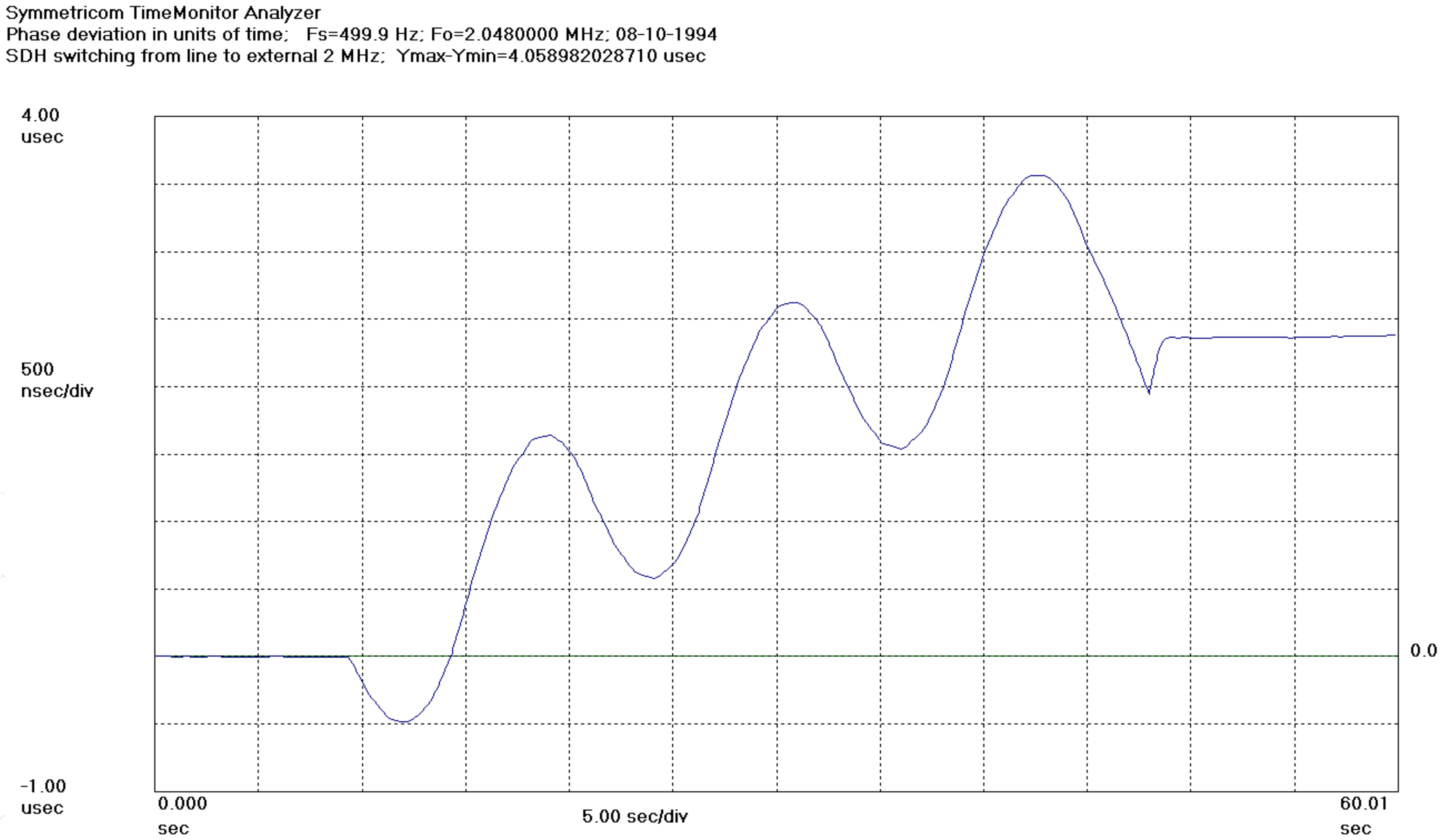
Symmetricom TimeMonitor Analyzer
Least square fit fractional frequency offset vs. time; N=100; 02/08/00; 23:57:35
1: PSTN input to GSM base station; 2: GSM base station output; 3: GSM base station output w/ GPS sync.

BTS with GPS

Sync Measurement #5:
NE Reference Switching

Reference switching

Phase deviation ringing and overall phase shift of 2.4 µsec



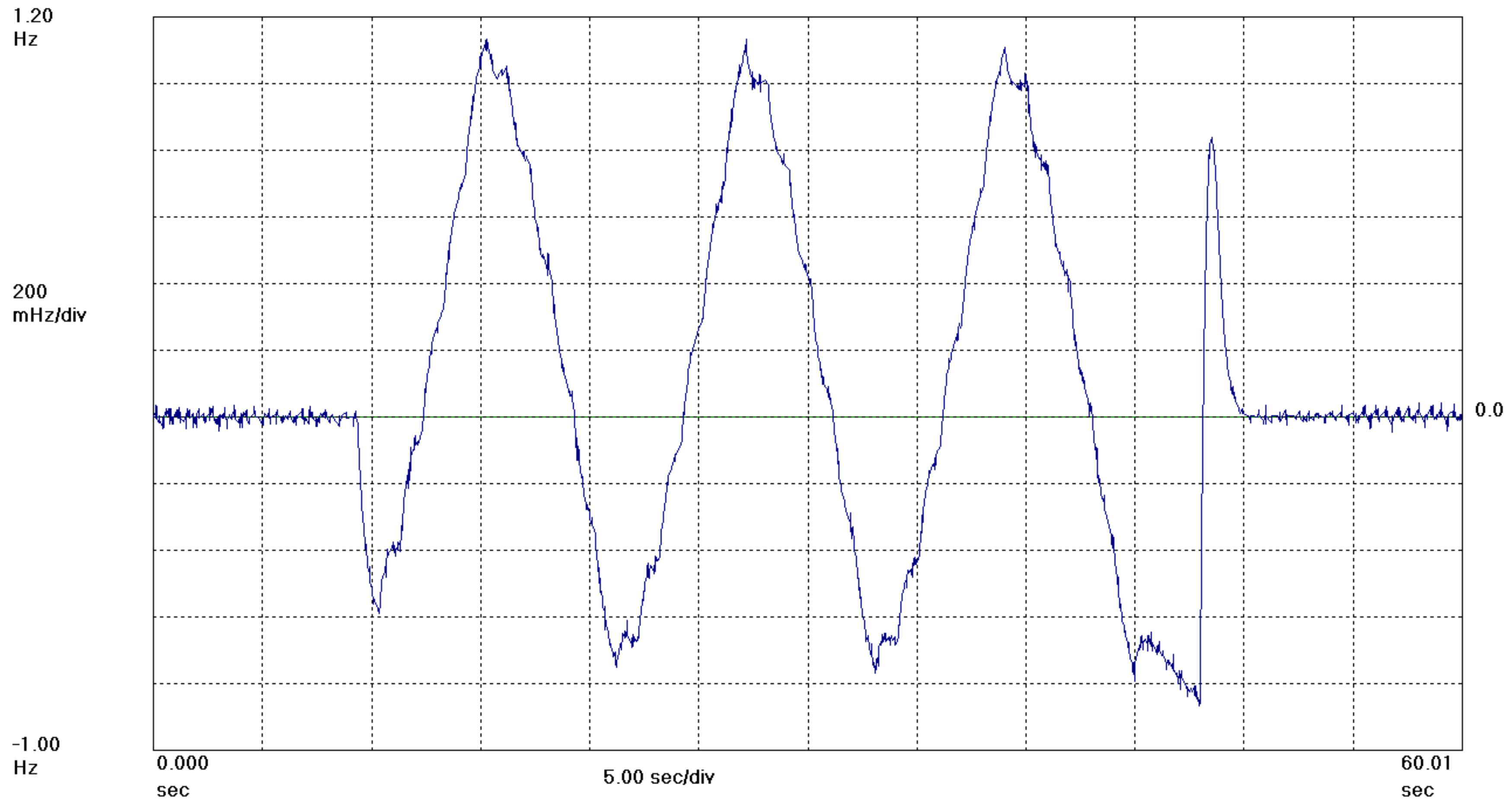
Symmetricom TimeMonitor Analyzer
Phase deviation in units of time; Fs=499.9 Hz; Fo=2.0480000 MHz; 08-10-1994
SDH switching from line to external 2 MHz; Ymax-Ymin=4.058982028710 usec

Sync Measurement #5: NE Reference Switching

Reference switching

Frequency movement +/- 1 Hz

Symmetricom TimeMonitor Analyzer
Frequency deviation from Fo; Fs=499.9 Hz; Fo=2.048 MHz; 08-10-1994
SDH switching from line to external 2 MHz; Ymax-Ymin=2.005233108997 Hz

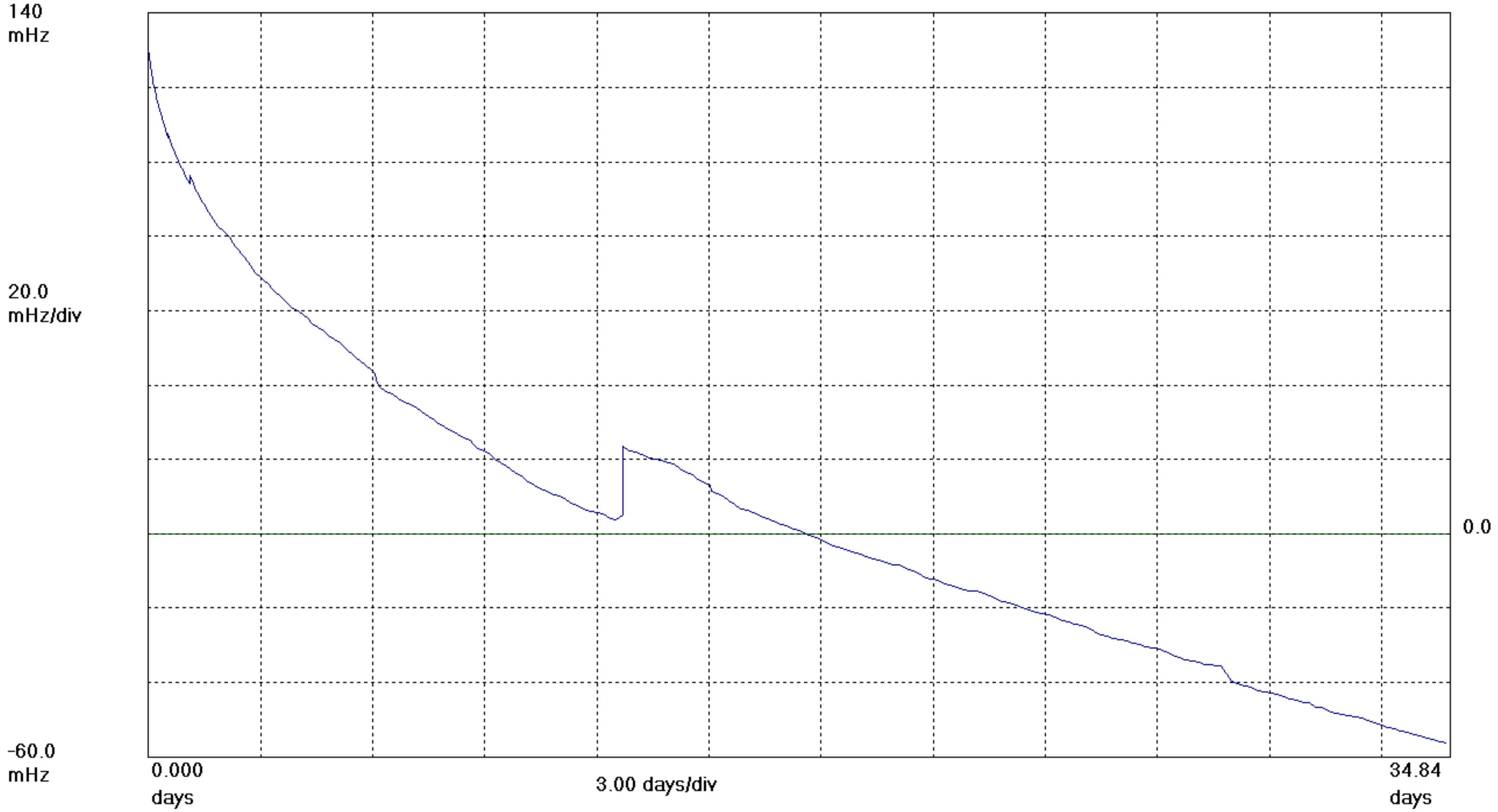


Sync Measurement #6: Oscillator Frequency Jump

Symmetricom

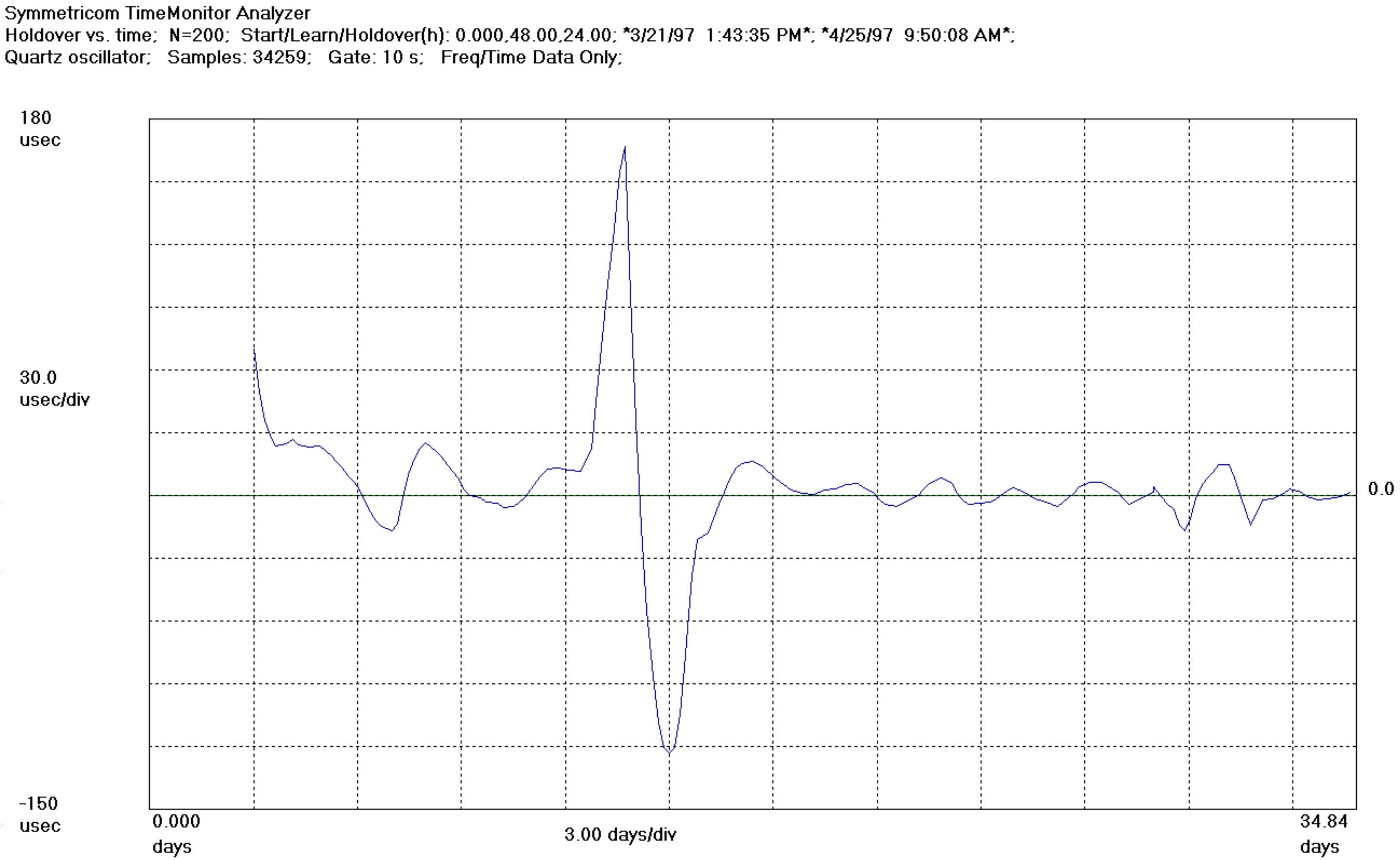
Oscillator frequency jump: effect on holdover

Symmetricom TimeMonitor Analyzer
Frequency deviation from Fo; Fs=11.38 mHz; Fo=10.00 MHz; *3/21/97 1:43:35 PM*; *4/25/97 9:50:08 AM*;
Quartz oscillator; Samples: 34259; Gate: 10 s; Freq/Time Data Only;



Sync Measurement #6:
Oscillator Frequency Jump

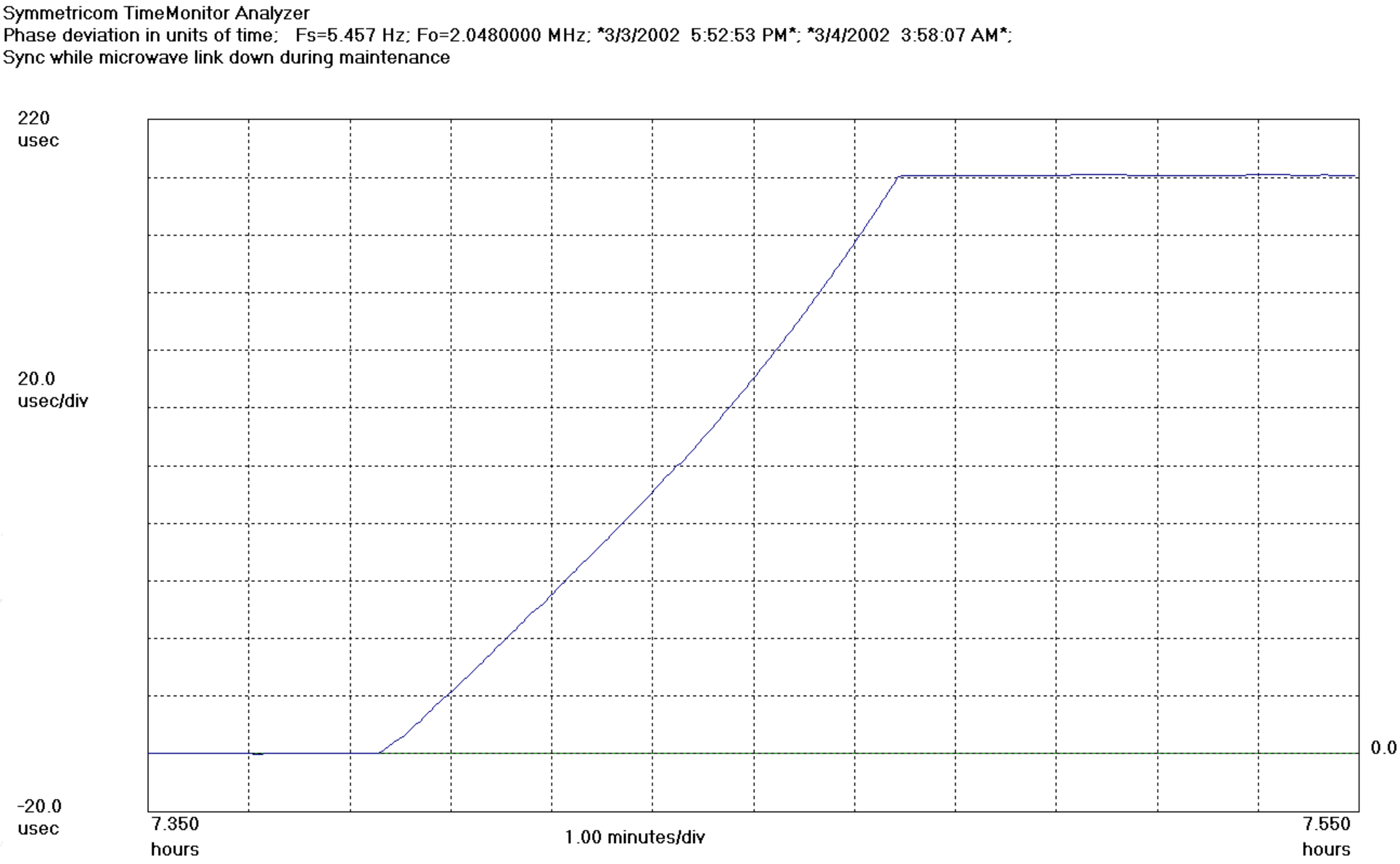
Oscillator frequency jump: effect on holdover
> 150 µsec rather than 1 to 10 µsec



Symmetricom TimeMonitor Analyzer
Holdover vs. time; N=200; Start/Learn/Holdover(h): 0.000,48.00,24.00; *3/21/97 1:43:35 PM*; *4/25/97 9:50:08 AM*;
Quartz oscillator; Samples: 34259; Gate: 10 s; Freq/Time Data Only;

Sync Measurement #7: Microwave Link Down

Microwave link down: 200 µsec over 5 minutes

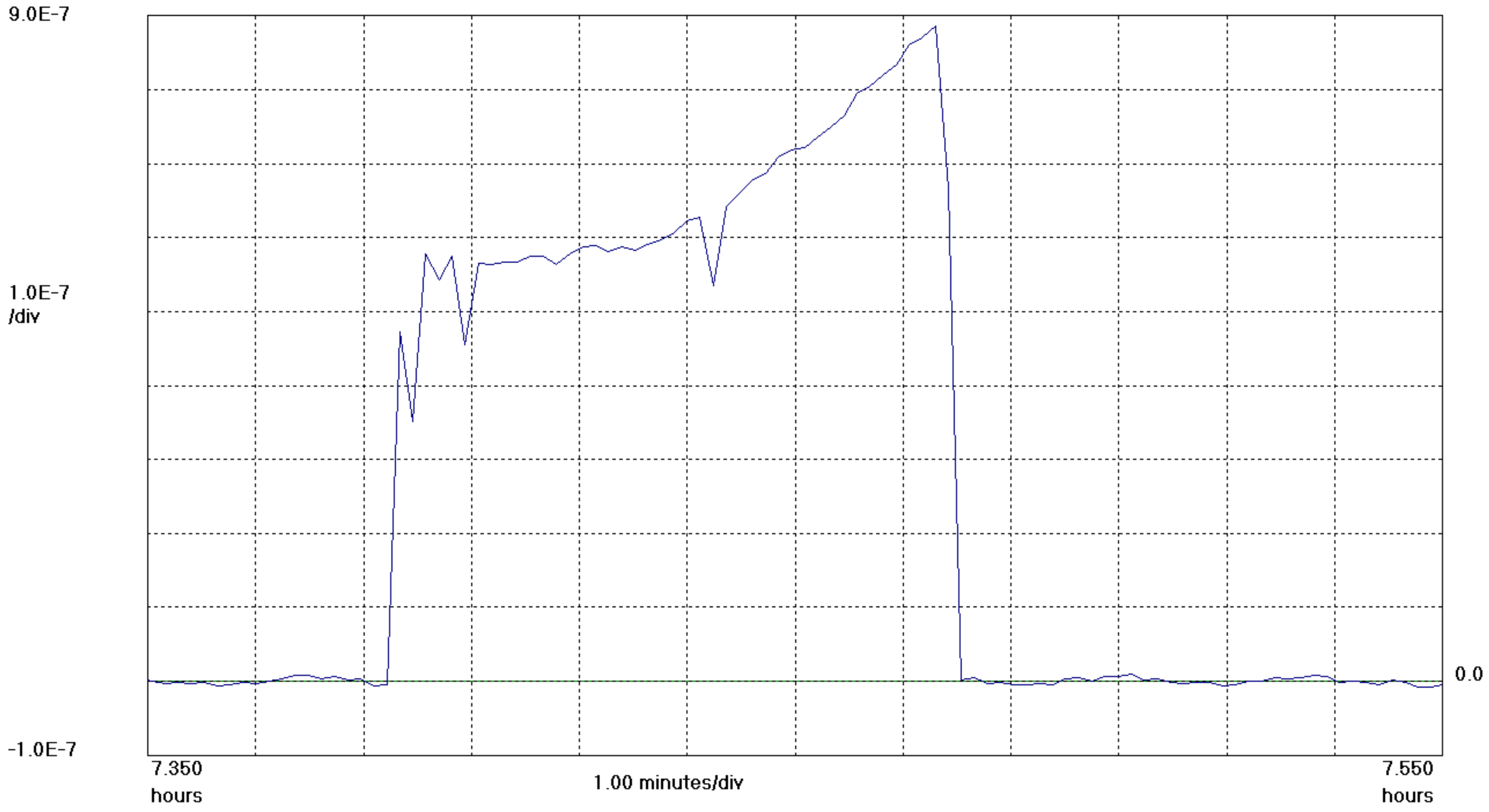


Symmetricom TimeMonitor Analyzer
Phase deviation in units of time; Fs=5.457 Hz; Fo=2.0480000 MHz; *3/3/2002 5:52:53 PM*; *3/4/2002 3:58:07 AM*;
Sync while microwave link down during maintenance

Sync Measurement #7: Microwave Link Down

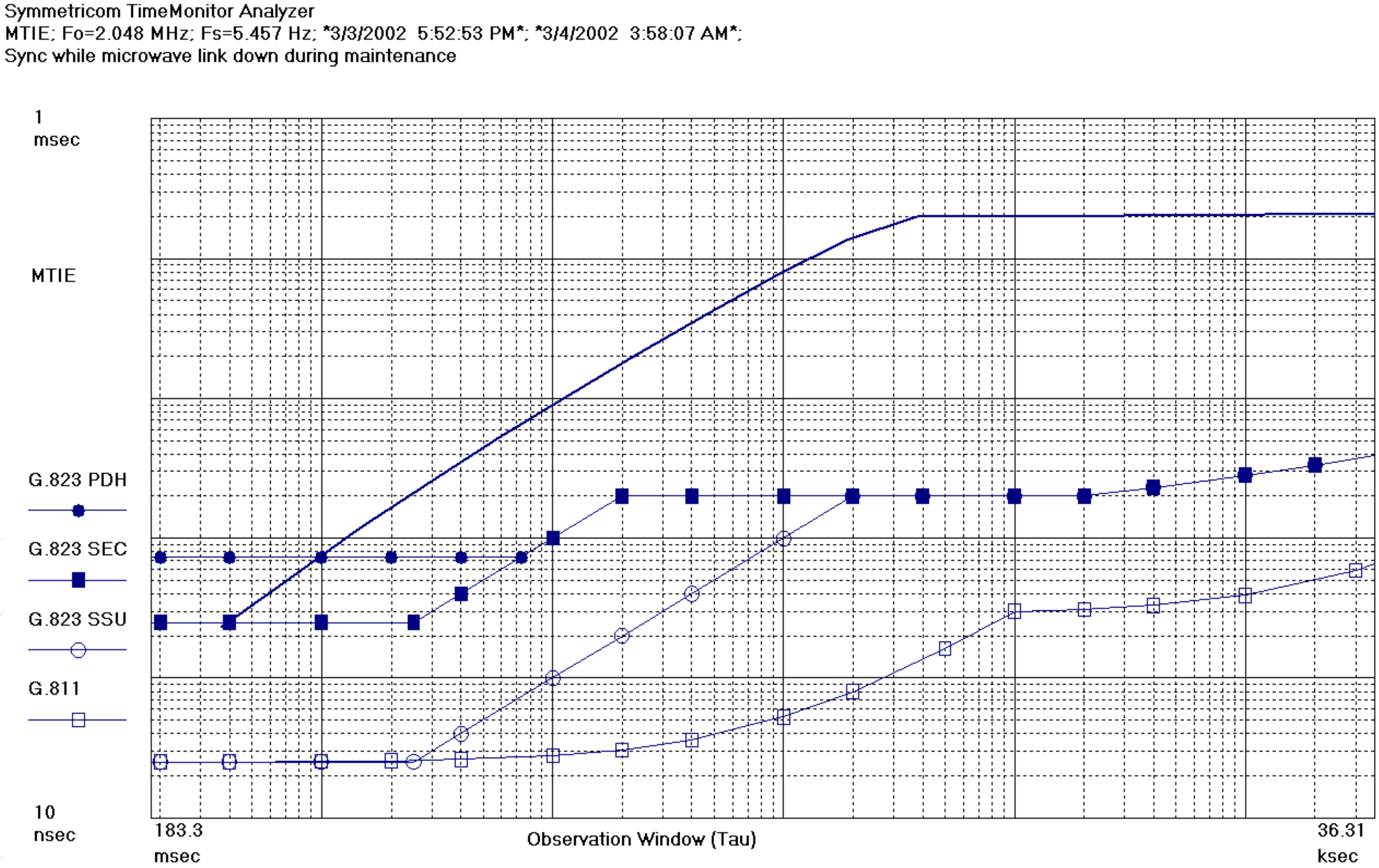
Microwave link down: Frequency offset reaches 1 ppm

Symmetricom TimeMonitor Analyzer
Least square fit fractional frequency offset vs. time; N=5000; *3/3/2002 5:52:53 PM*; *3/4/2002 3:58:07 AM*;
Sync while microwave link down during maintenance



Sync Measurement #7: Microwave Link Down

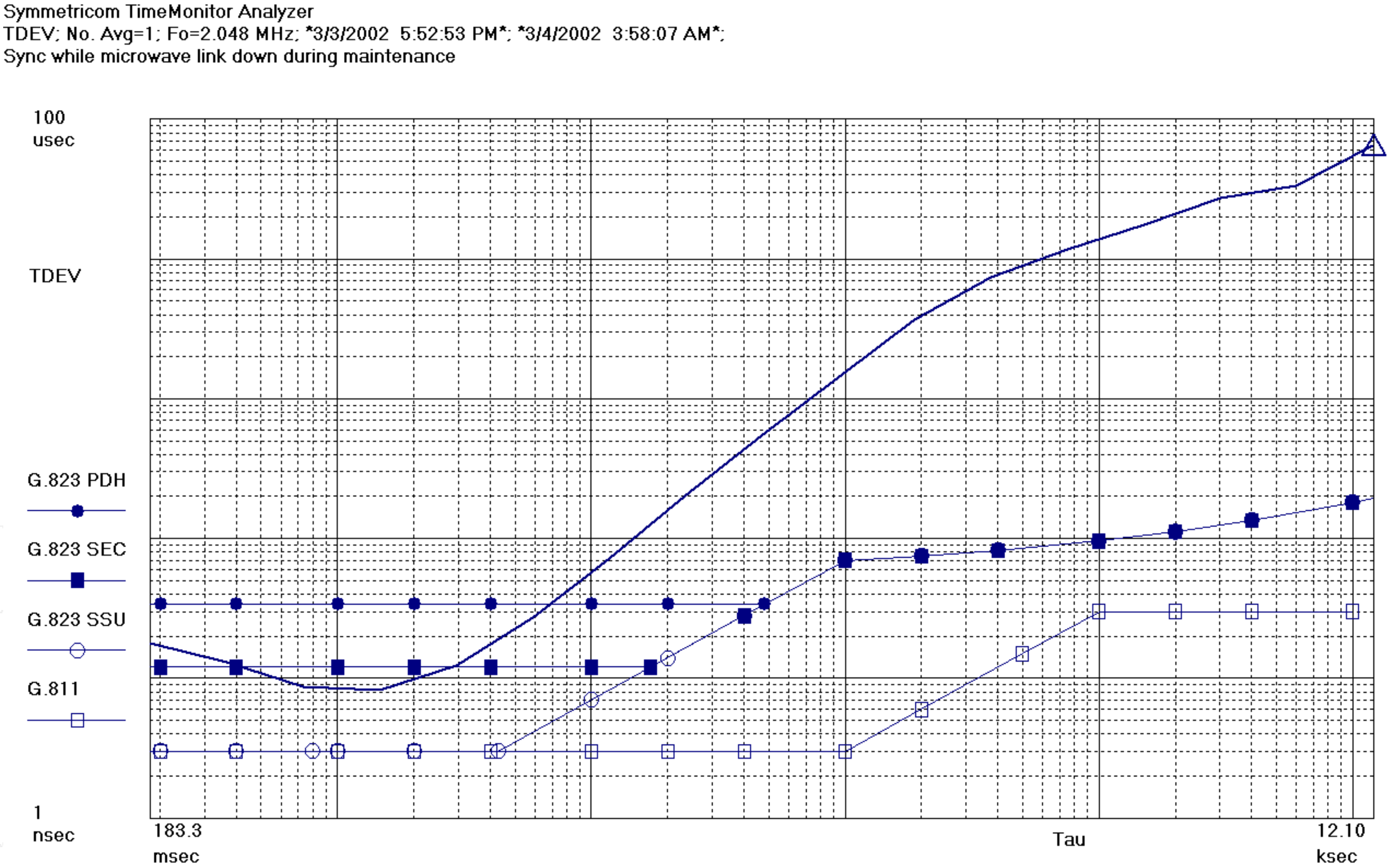
Microwave link down: MTIE network limits exceeded by a large margin



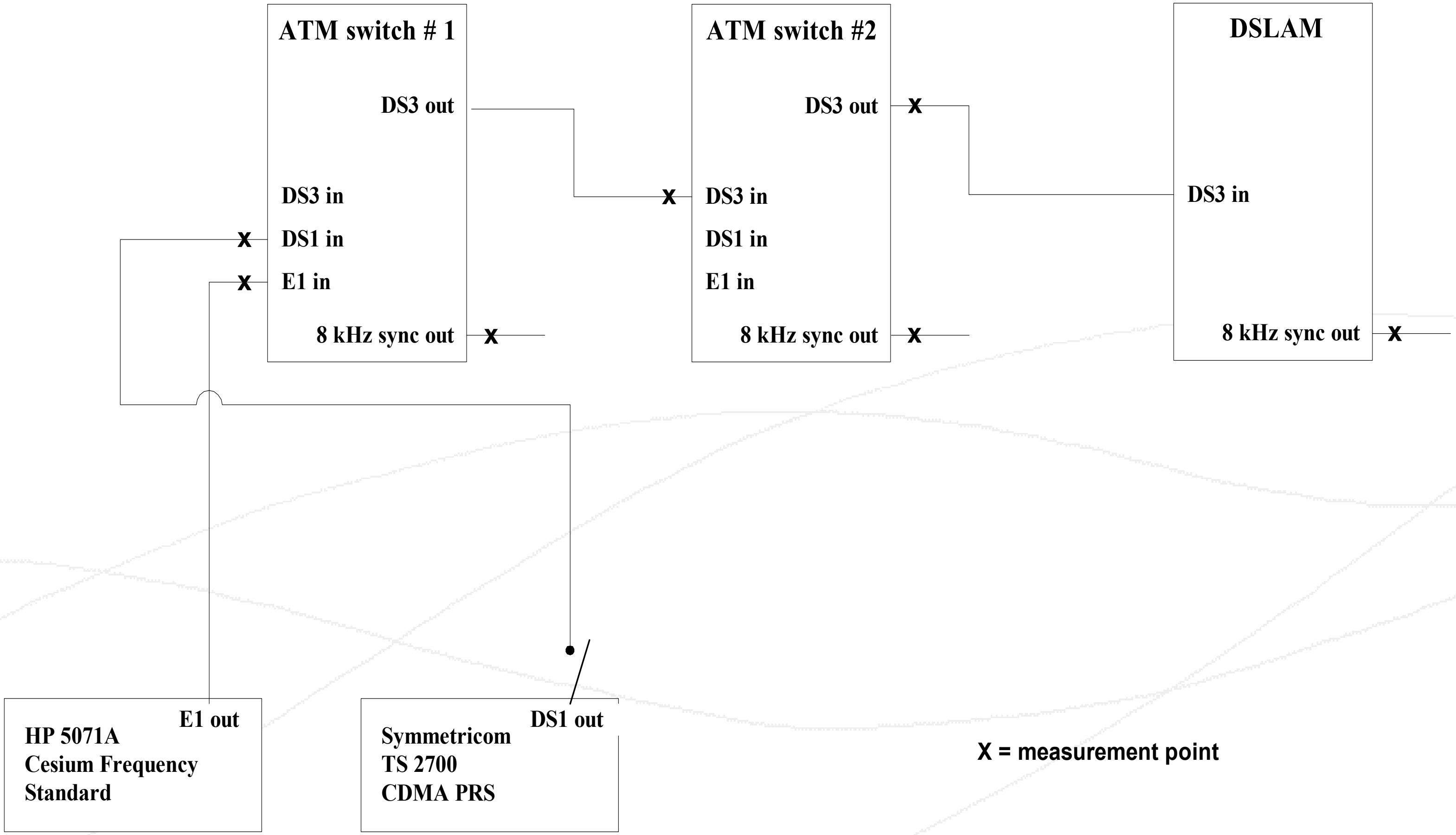
Symmetricom TimeMonitor Analyzer
MTIE; Fo=2.048 MHz; Fs=5.457 Hz; *3/3/2002 5:52:53 PM*; *3/4/2002 3:58:07 AM*;
Sync while microwave link down during maintenance

Sync Measurement #7: Microwave Link Down

Microwave link down: TDEV network limits exceeded by a large margin



Sync Measurement #8: DSL Synchronization



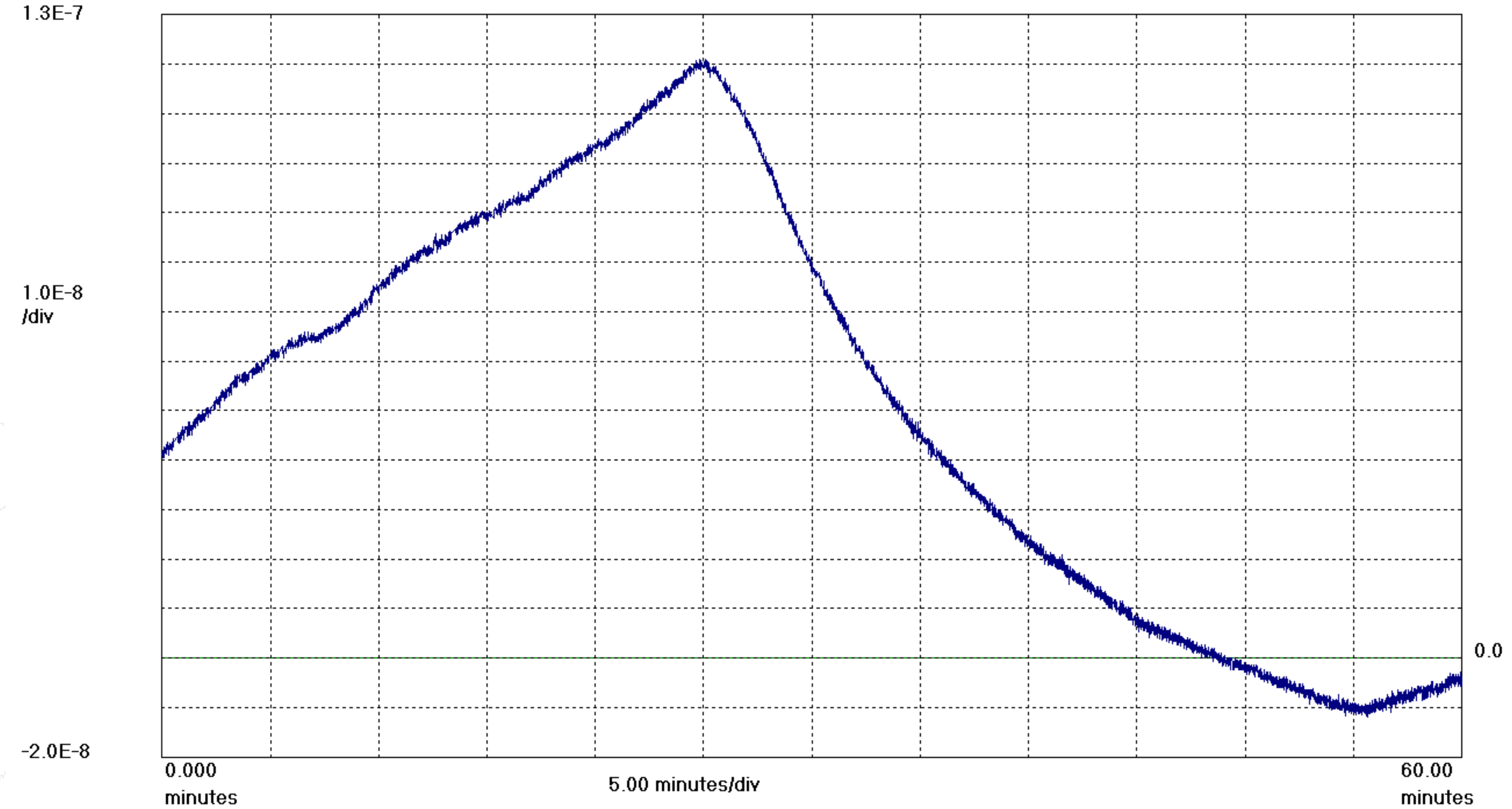
X = measurement point

Sync Measurement #8:
DSL Synchronization

ATM switch internal oscillator

Frequency drifting between –1.2 and 12 parts in 10^8 over one hour

Average frequency offset: 6.0 parts in 10^8



Symmetricom TimeMonitor Analyzer
Fractional frequency offset; Fs=5.000 Hz; Fo=8.000 kHz; 11/10/99; 14:39:16
ATM switch internal clock

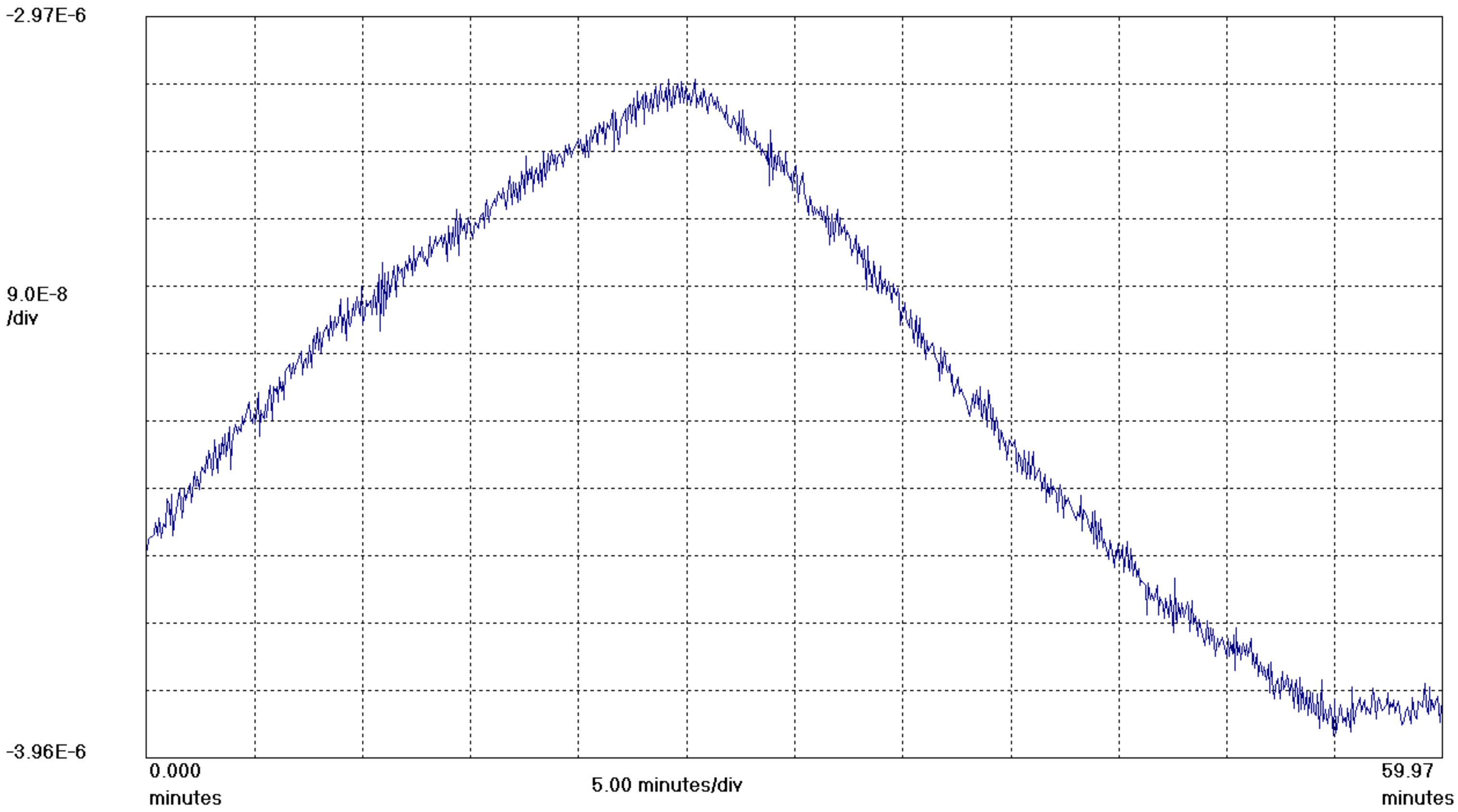
Sync Measurement #8: DSL Synchronization

DSLAM internal oscillator

Frequency drifting between –3 and –4 parts in 10^6 over 1 hour

Average frequency offset: -3.4 parts in 10^6

Symmetricom TimeMonitor Analyzer
Fractional frequency offset; Fs=250.0 mHz; Fo=8.000 kHz; 11/10/99; 14:39:16
DSLAM internal clock

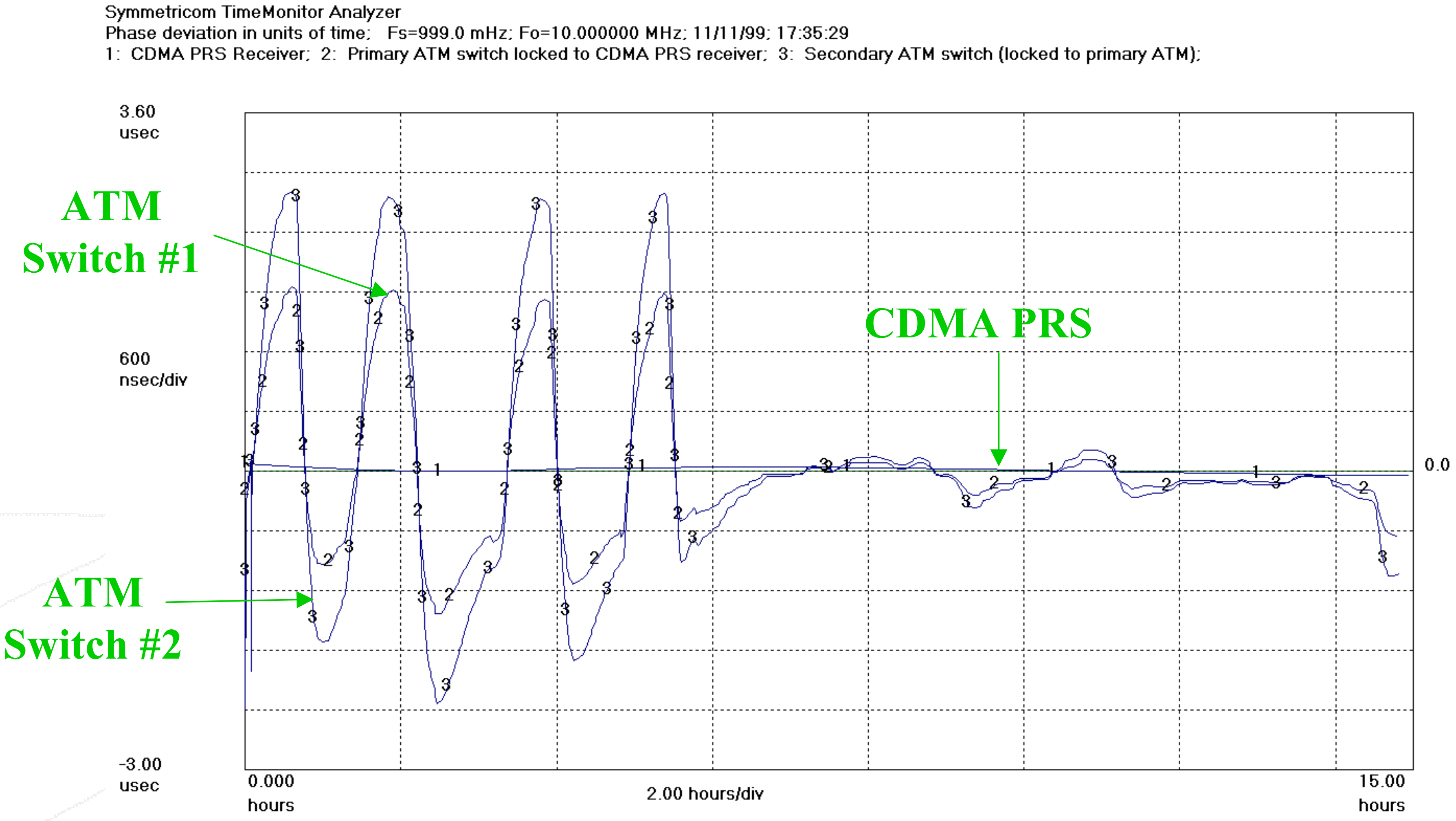


Frequency offset is 2 orders of magnitude worse than the ATM switch internal oscillator

Sync Measurement #8:
DSL Synchronization

Symmetricom®

ATM switch phase-locked loop affected by daytime temperature swings from air conditioning system (ΔT = 20 degrees F)



Symmetricom TimeMonitor Analyzer

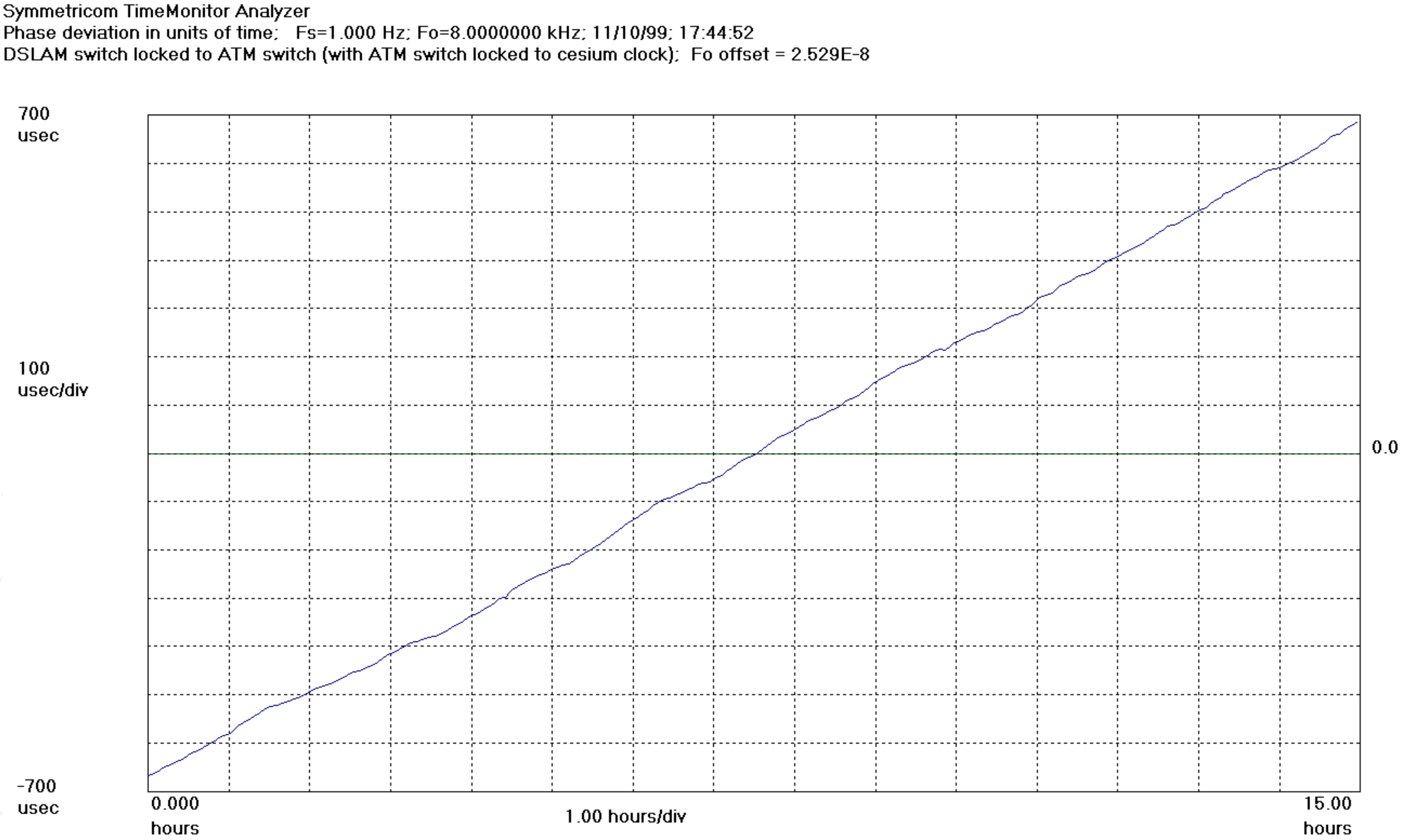
Phase deviation in units of time; Fs=999.0 mHz; Fo=10.000000 MHz; 11/11/99; 17:35:29

1: CDMA PRS Receiver; 2: Primary ATM switch locked to CDMA PRS receiver; 3: Secondary ATM switch (locked to primary ATM);

Sync Measurement #8:
DSL Synchronization

DSLAM w/ External Sync

Does not really synchronize to external signal: 2.5 parts in 10^8 frequency offset!!

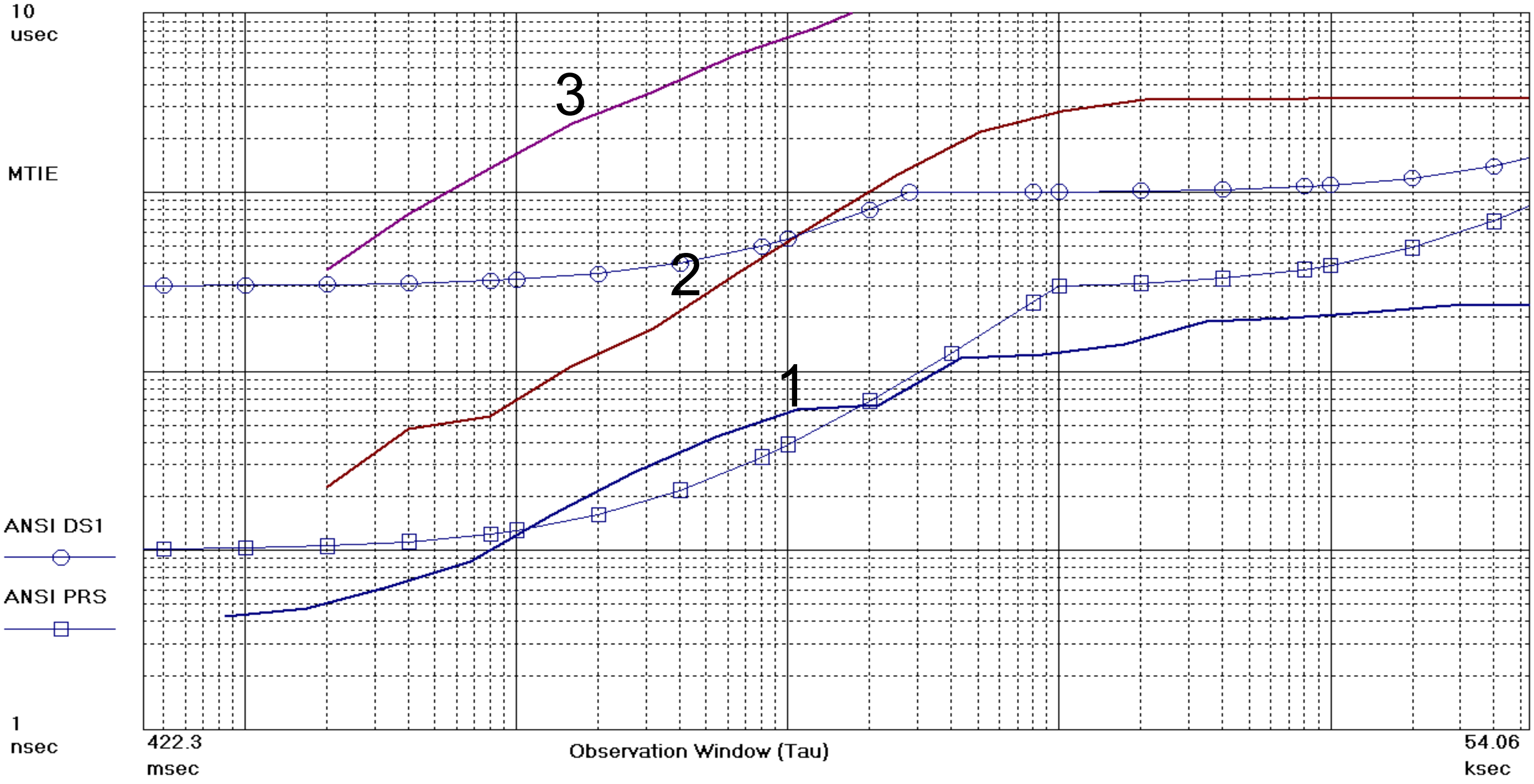


Symmetricom TimeMonitor Analyzer
Phase deviation in units of time; Fs=1.000 Hz; Fo=8.0000000 kHz; 11/10/99; 17:44:52
DSLAM switch locked to ATM switch (with ATM switch locked to cesium clock); Fo offset = 2.529E-8

Sync Measurement #8:
DSL Synchronization

ATM vs. ATM Δ T vs. DSLAM

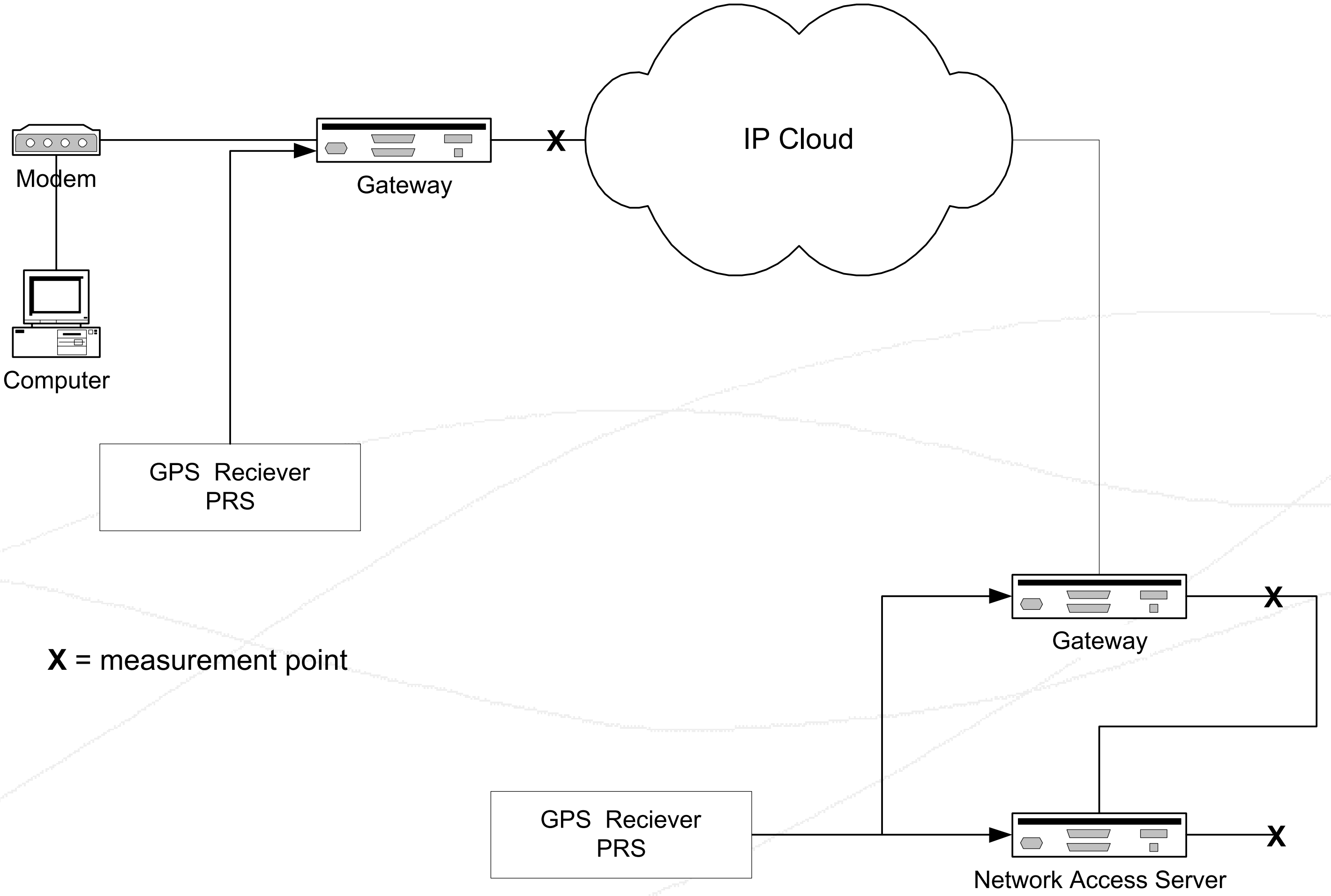
Symmetricom TimeMonitor Analyzer
MTIE; 1: ATM switch locked to PRS with constant temperature
2: ATM switch locked to PRS with temperature fluctuations due to improperly functioning air conditioning system
3: DSLAM switch locked to ATM switch (with ATM switch locked to PRS)



Sync Measurement #9:
IP Synchronization

Symmetricom

Modem over IP fails without synchronization



Modem

Gateway

IP Cloud

Computer

GPS Reciever
PRS

Gateway

GPS Reciever
PRS

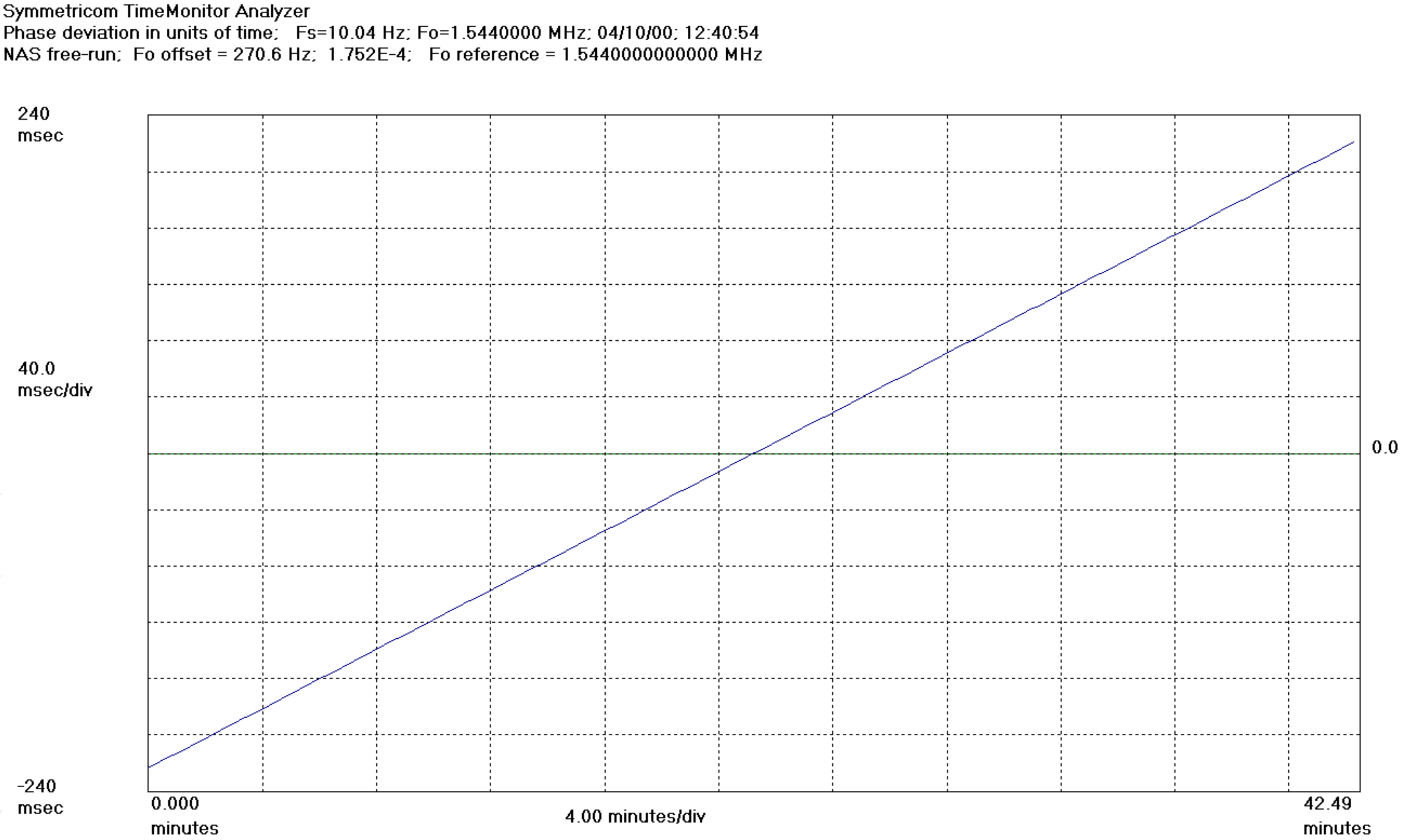
Network Access Server

X = measurement point

Sync Measurement #9:
IP Synchronization

IP network access server internal oscillator

175 ppm: much worse than stratum 4 requirement of 32 ppm



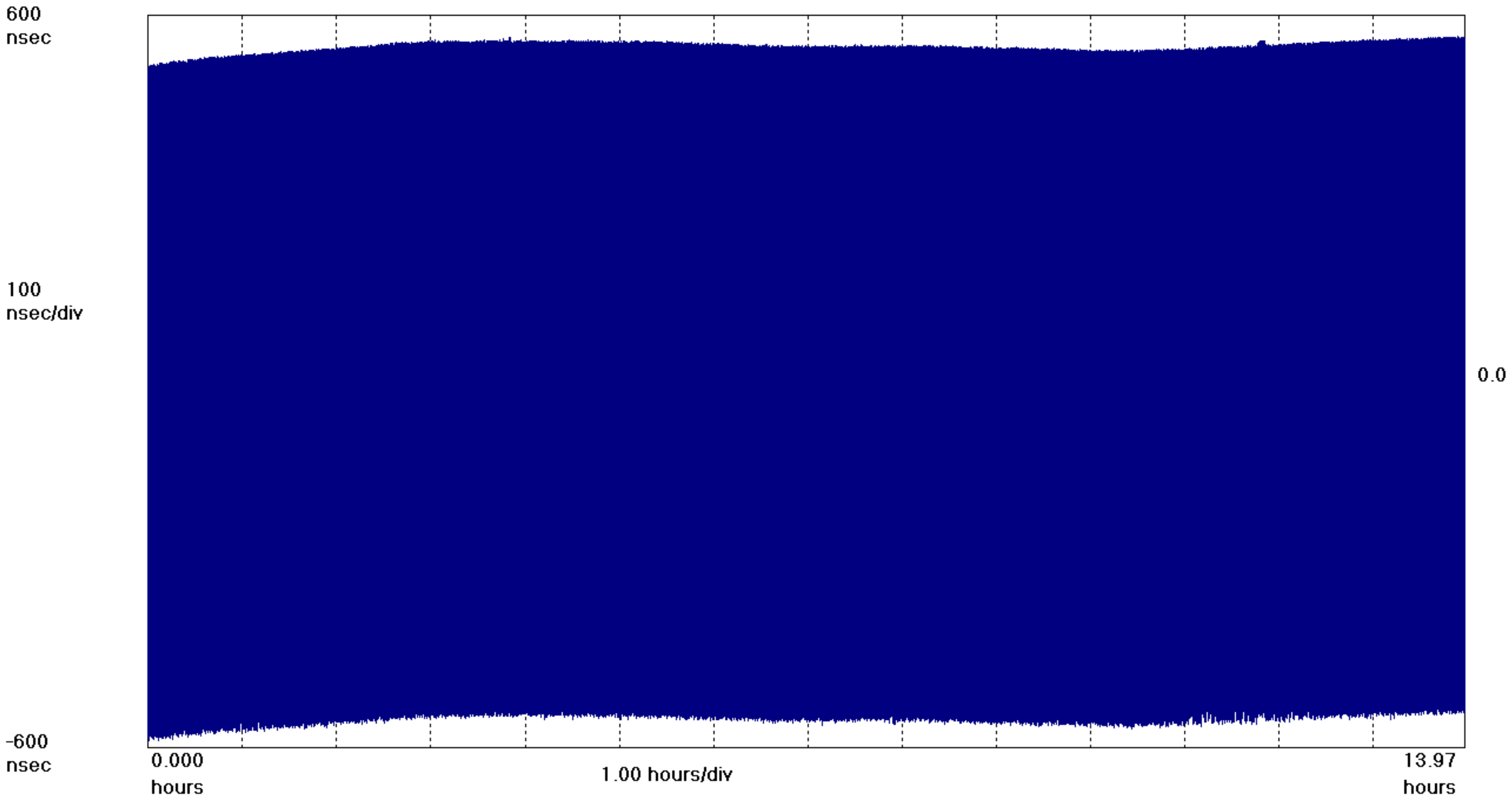
Symmetricom TimeMonitor Analyzer
Phase deviation in units of time;   Fs=10.04 Hz; Fo=1.5440000 MHz; 04/10/00; 12:40:54
NAS free-run; Fo offset = 270.6 Hz; 1.752E-4;   Fo reference = 1.5440000000000 MHz

Sync Measurement #9:
IP Synchronization

IP network access server locked to external PRS reference

Short-term wander at 1.15 μsec peak-to-peak

Symmetricom TimeMonitor Analyzer
Phase deviation in units of time;   Fs=5.089 Hz; Fo=1.5440000 MHz; 04/12/00; 19:02:00
HP E1725 Time Interval Analyzer
Voip1 locked to GPS; Ymax-Ymin=1.154499045697 usec

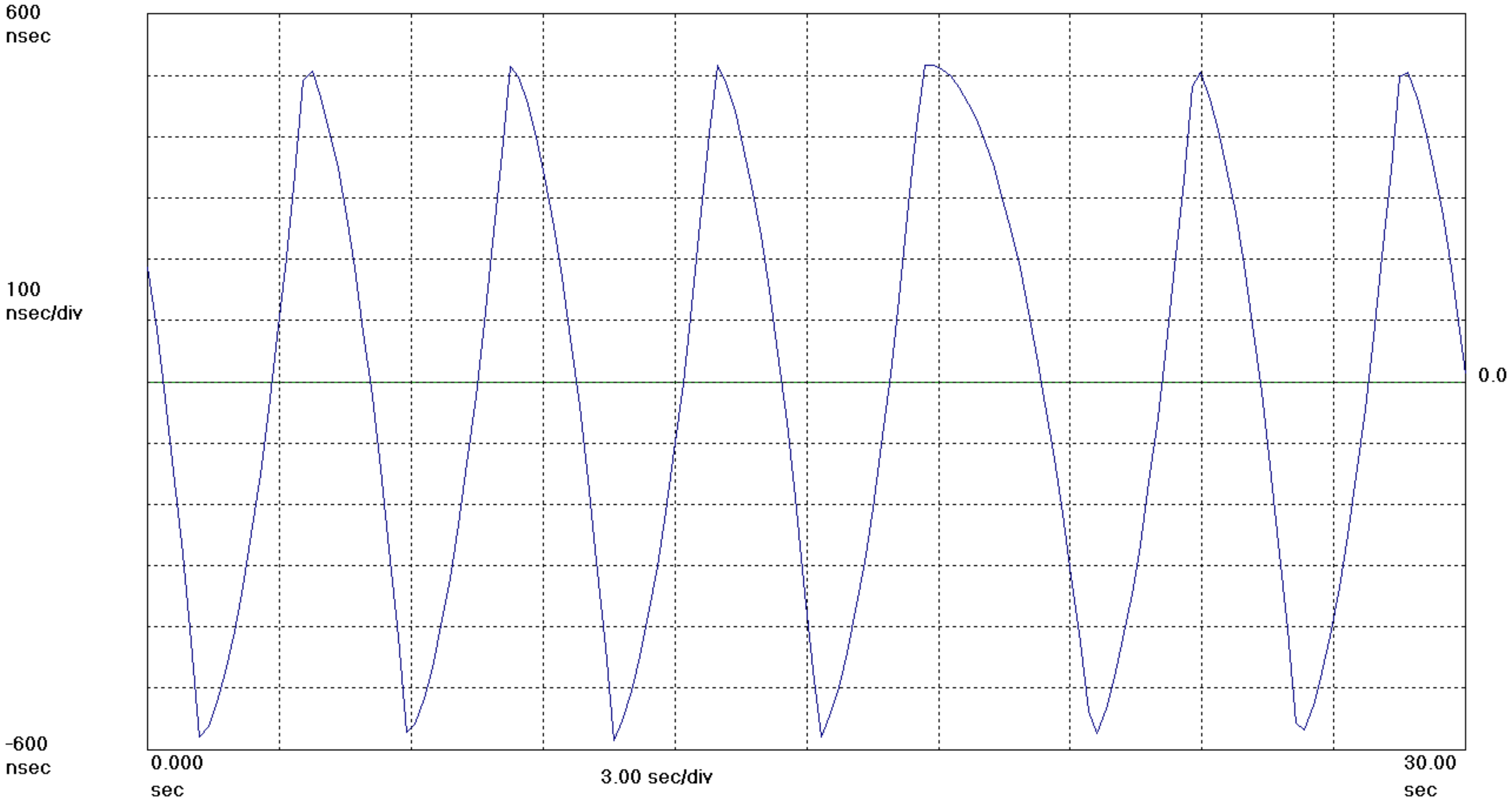


Sync Measurement #9:
IP Synchronization

IP network access server locked to external PRS reference

Zoom into first 30 seconds: wander pattern observed

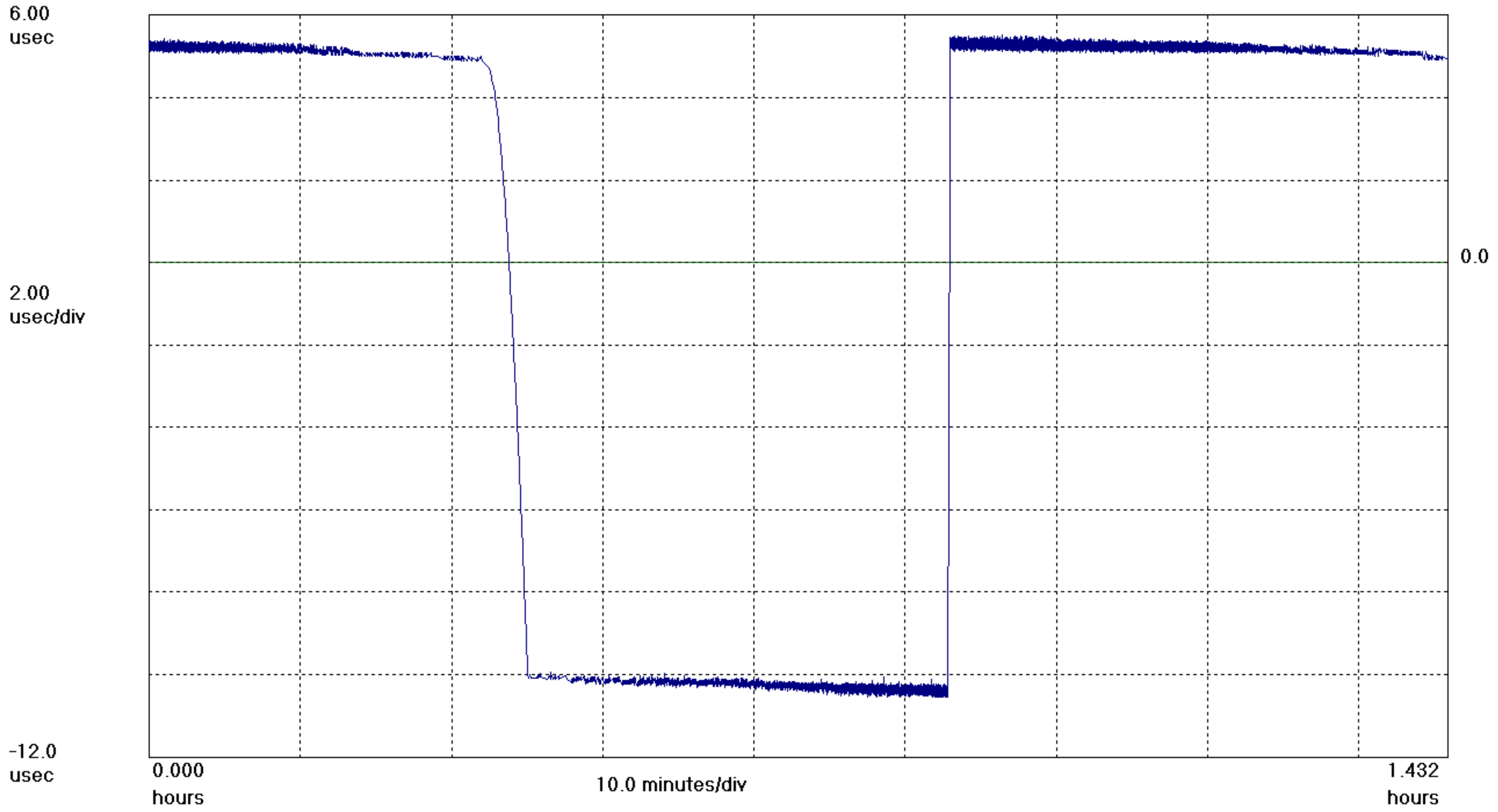
Symmetricom TimeMonitor Analyzer
Phase deviation in units of time; Fs=5.089 Hz; Fo=1.5440000 MHz; 04/12/00; 19:02:00
HP E1725 Time Interval Analyzer
Voip1 locked to GPS; Ymax-Ymin=1.154499045697 usec



Sync Measurement #10:
HDSL: Unsuitable for Sync Transport

HDSL DS1: 15 µsec phase steps every 30 minutes

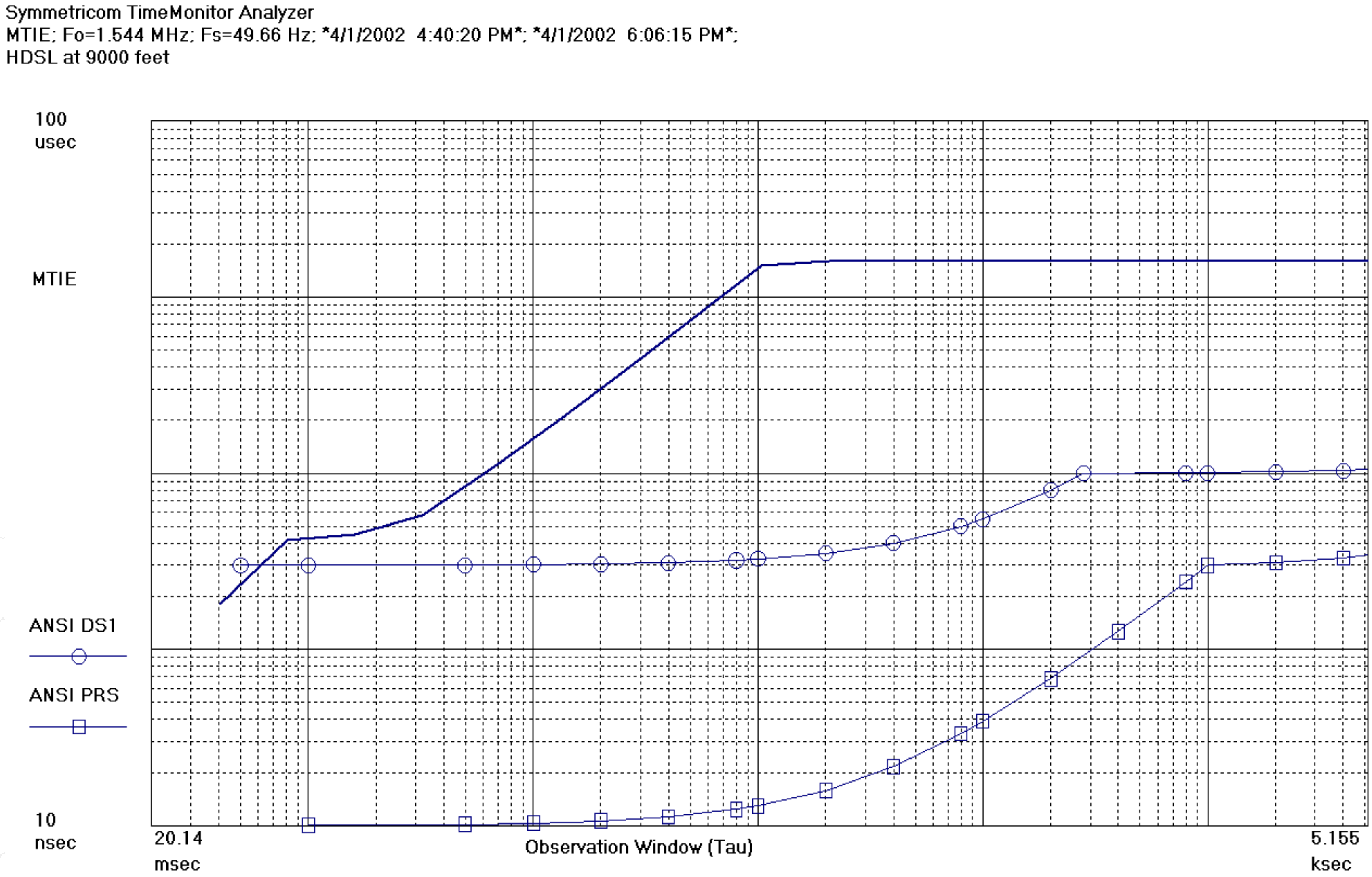
Symmetricom TimeMonitor Analyzer
Phase deviation in units of time; Fs=49.66 Hz; Fo=1.5440000 MHz; *4/1/2002 4:40:20 PM*; *4/1/2002 6:06:15 PM*;
HDSL at 9000 feet



Sync Measurement #10:
HDSL: Unsuitable for Sync Transport

Symmetricom®

HDSL DS1: ANSI T1.101 DS1 MTIE requirement exceeded by a large margin

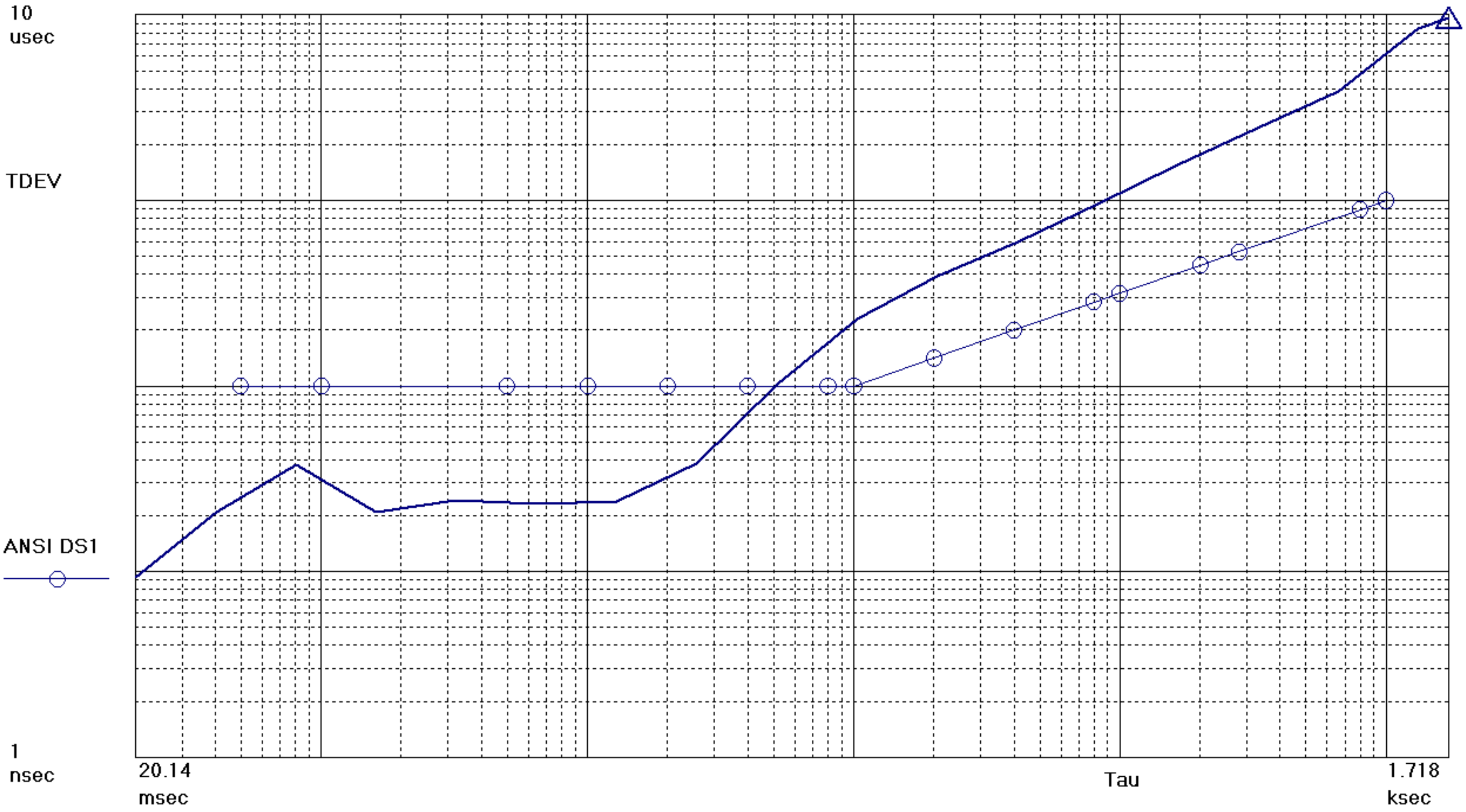


Symmetricom TimeMonitor Analyzer
MTIE; Fo=1.544 MHz; Fs=49.66 Hz; *4/1/2002 4:40:20 PM*; *4/1/2002 6:06:15 PM*;
HDSL at 9000 feet

Sync Measurement #10:
HDSL: Unsuitable for Sync Transport

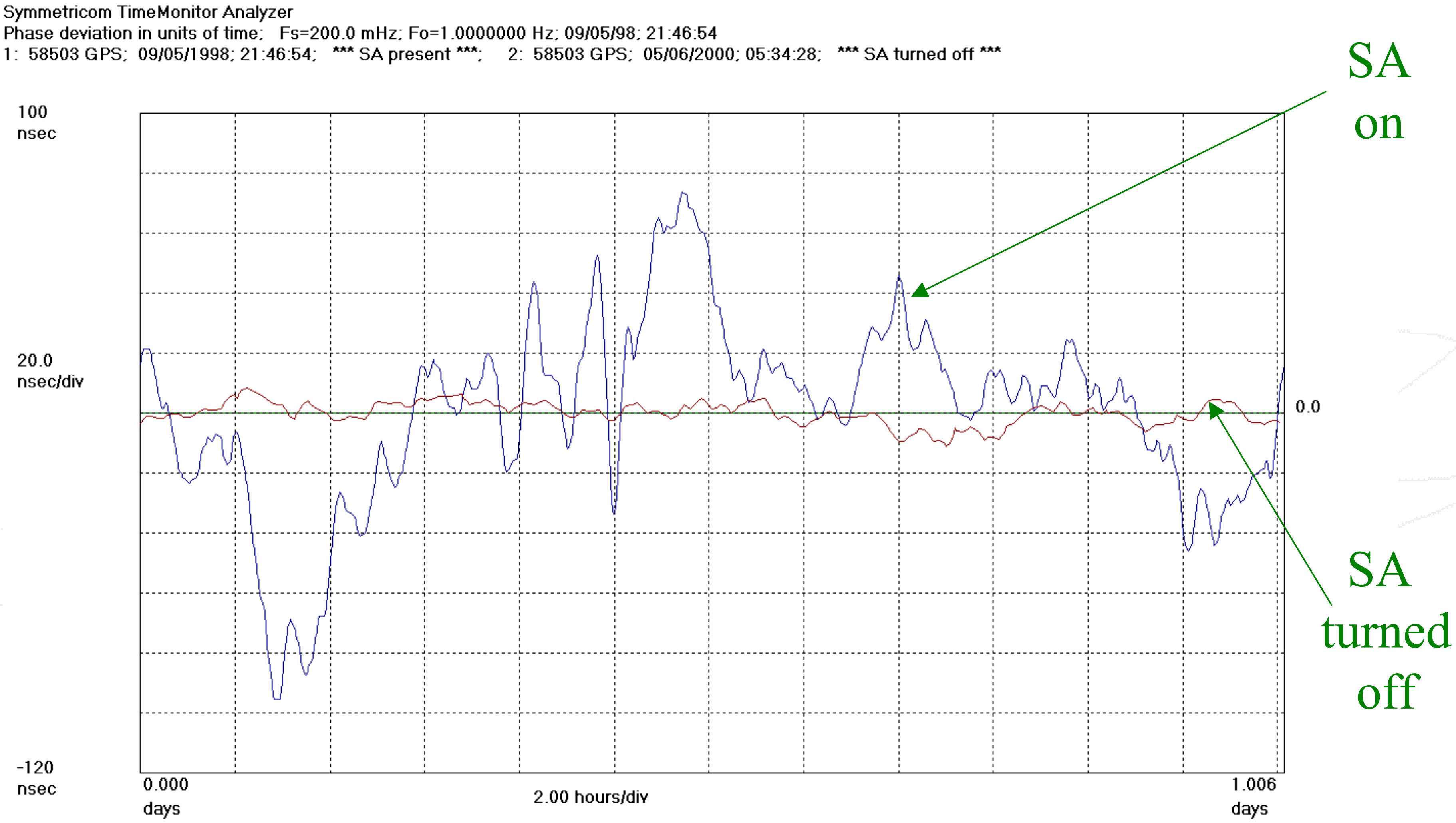
HDSL DS1: ANSI T1.101 DS1 TDEV requirement exceeded by a large margin

Symmetricom TimeMonitor Analyzer
TDEV; No. Avg=1; Fo=1.544 MHz; *4/1/2002 4:40:20 PM*; *4/1/2002 6:06:15 PM*;
HDSL at 9000 feet



Sync Measurement #11:
GPS: Effect of SA Being Turned Off

Effect of turning off SA on GPS receivers



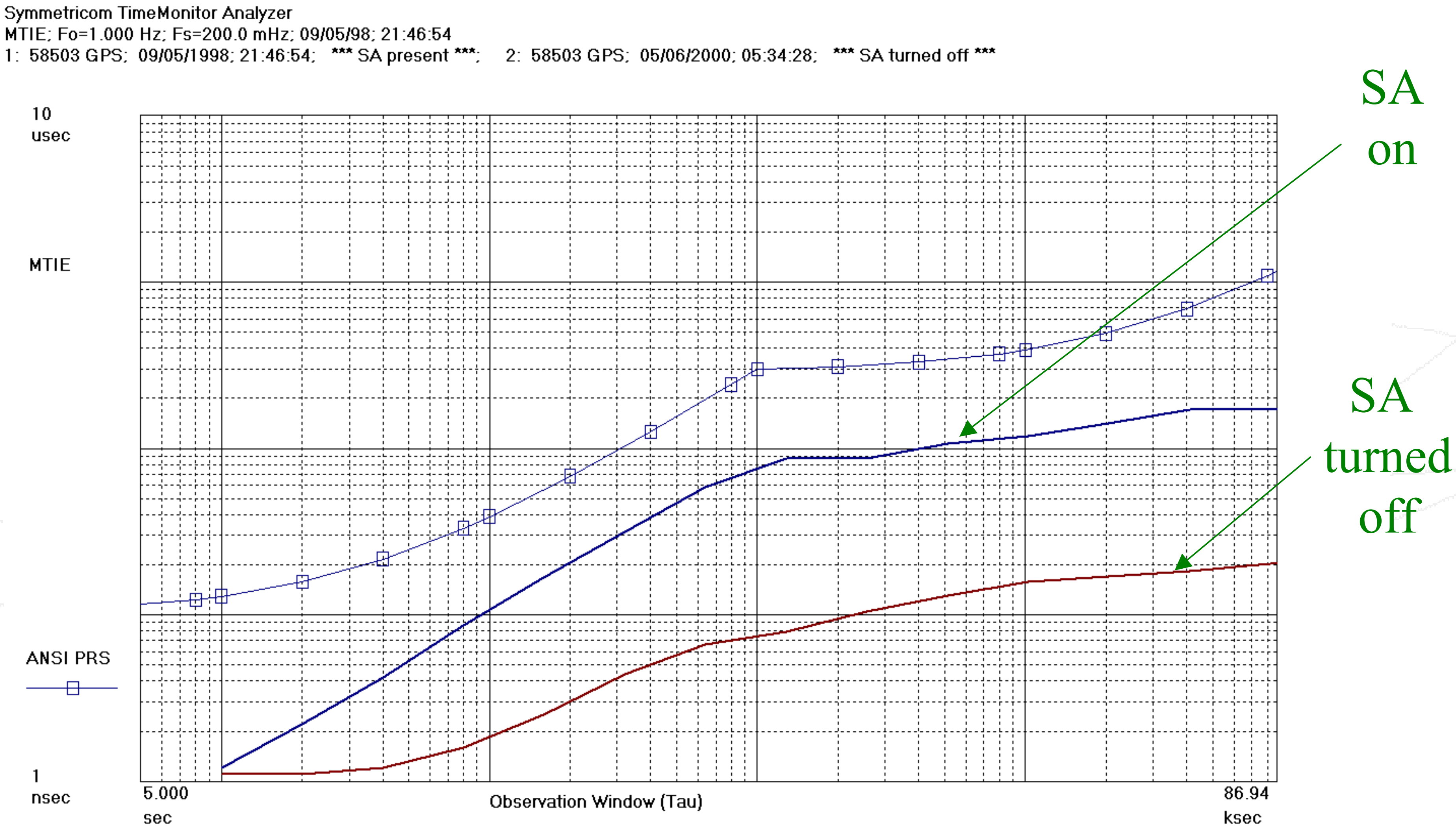
Symmetricom TimeMonitor Analyzer
Phase deviation in units of time; Fs=200.0 mHz; Fo=1.0000000 Hz; 09/05/98; 21:46:54
1: 58503 GPS; 09/05/1998; 21:46:54; *** SA present ***; 2: 58503 GPS; 05/06/2000; 05:34:28; *** SA turned off ***

SA on

SA turned off

Sync Measurement #11:
GPS: Effect of SA Being Turned Off

Effect of turning off SA on GPS receivers: MTIE



Symmetricom TimeMonitor Analyzer
MTIE; Fo=1.000 Hz; Fs=200.0 mHz; 09/05/98; 21:46:54
1: 58503 GPS; 09/05/1998; 21:46:54; *** SA present ***; 2: 58503 GPS; 05/06/2000; 05:34:28; *** SA turned off ***

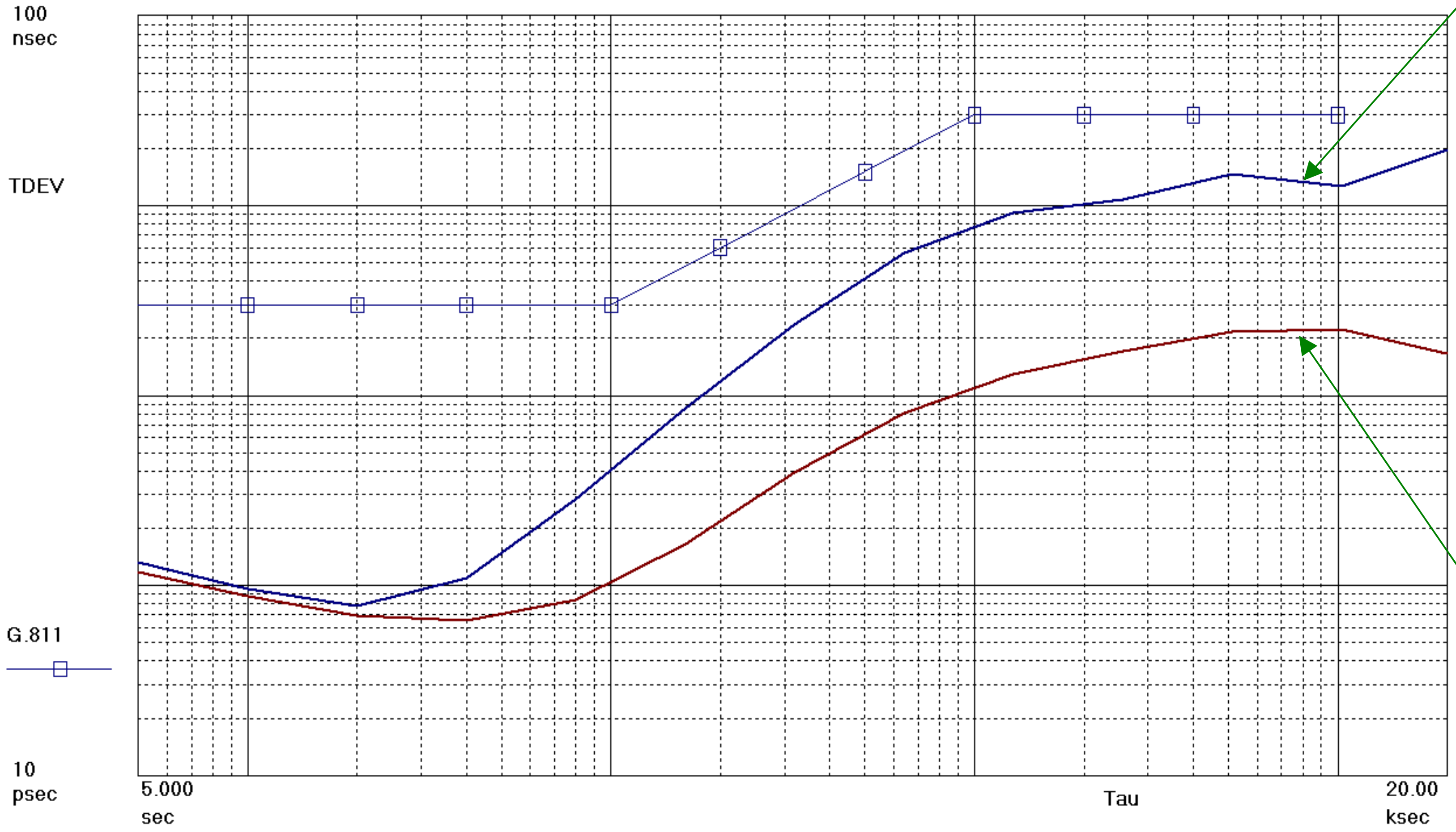
SA on

SA turned off

Sync Measurement #11:
GPS: Effect of SA Being Turned Off

Effect of turning off SA on GPS receivers: TDEV

Symmetricom TimeMonitor Analyzer
TDEV; No. Avg=1; Fo=1.000 Hz; Fs=200.0 mHz; 09/05/98; 21:46:54
1: 58503 GPS; 09/05/1998; 21:46:54; *** SA present ***; 2: 58503 GPS; 05/06/2000; 05:34:28; *** SA turned off ***



SA on

SA turned off

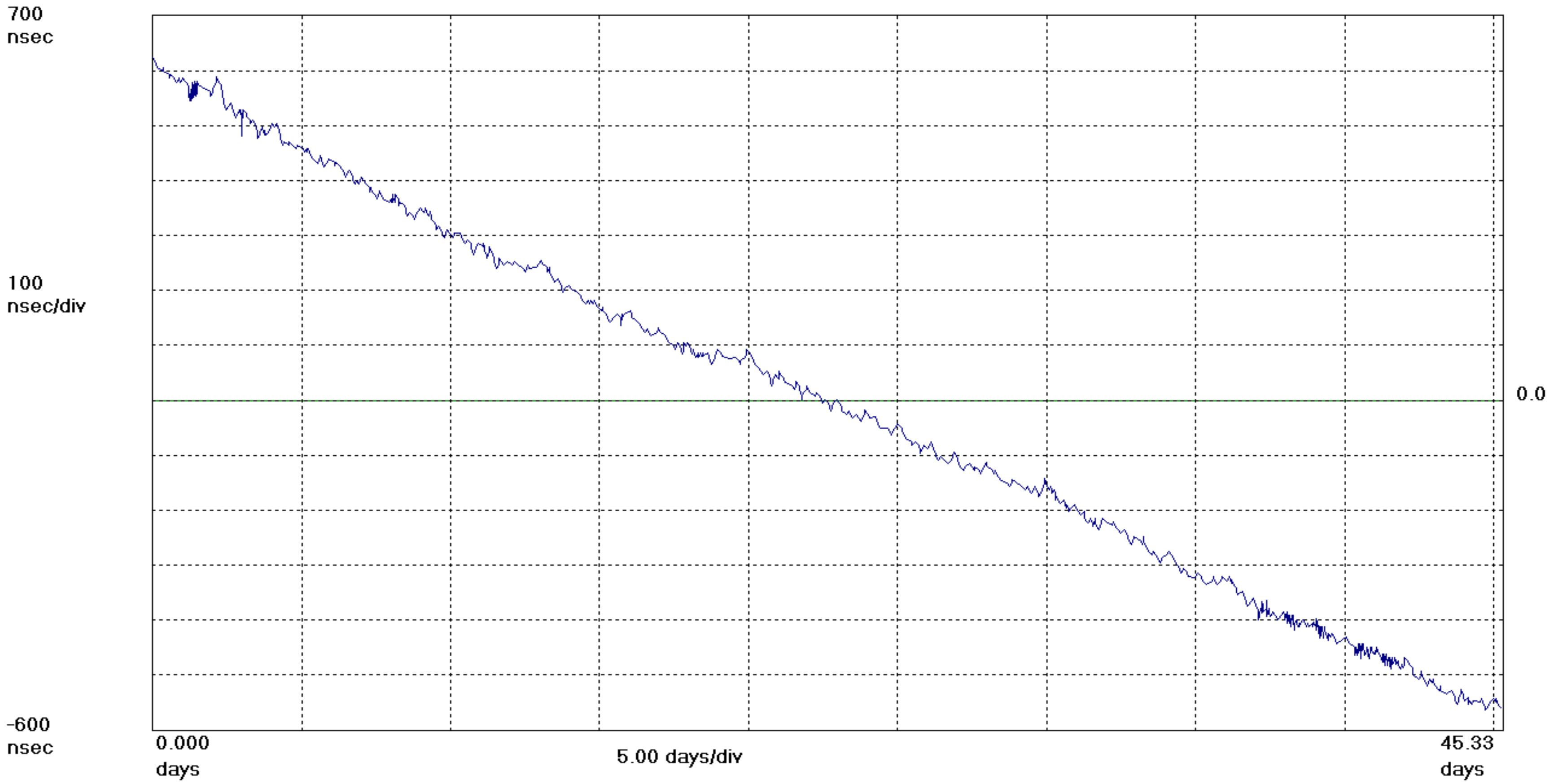
Sync Measurement #12:
GPS vs. Cesium: Measuring Cesium Offset

Measuring cesium clock offset with GPS: -2.7 parts in 10^{13}

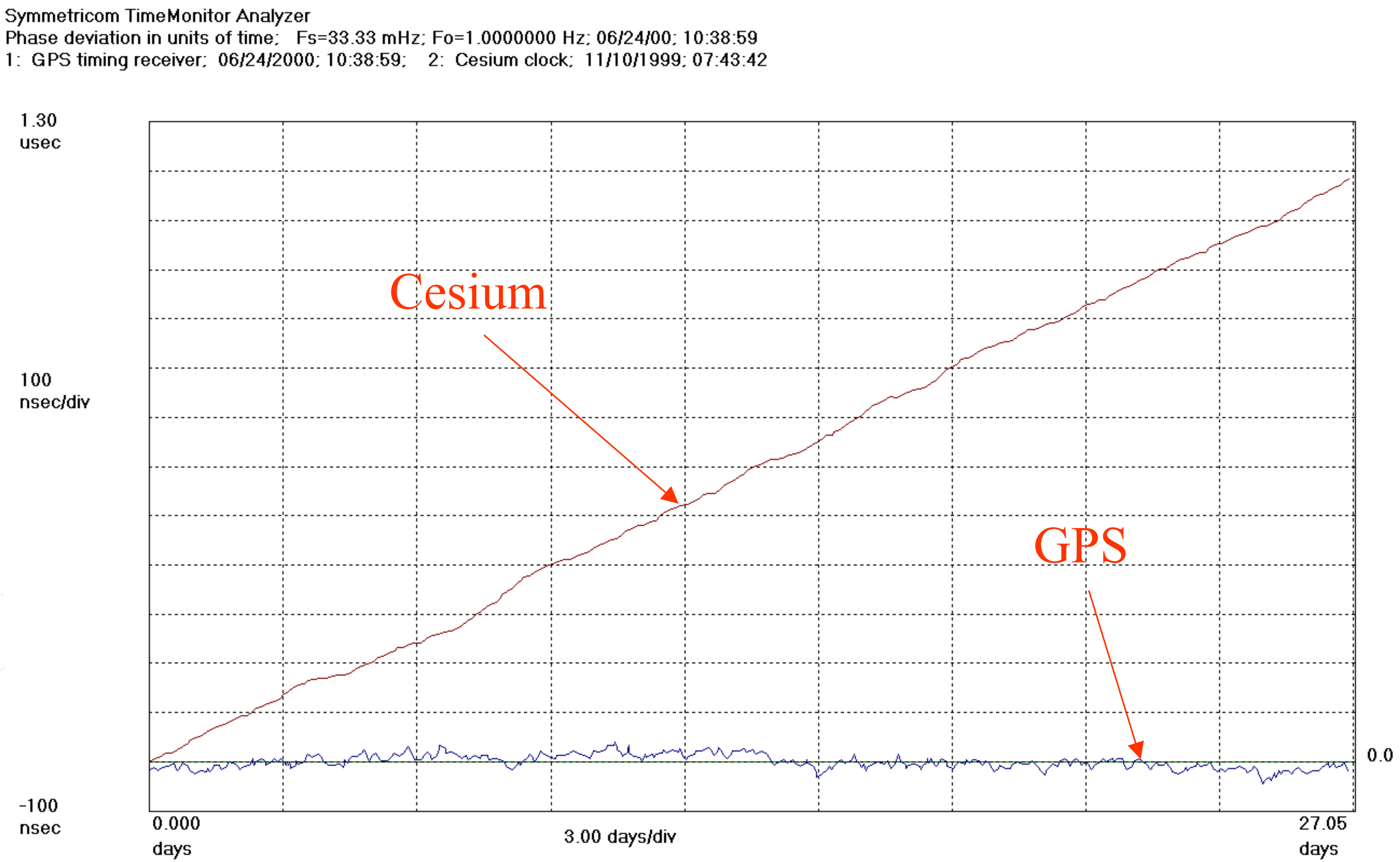
24 hour measurement: cesium can be used to measure GPS

45 day measurement: GPS can be used to measure cesium

Symmetricom TimeMonitor Analyzer
Phase deviation in units of time; Fs=33.33 mHz; Fo=1.0000000 Hz; *6/19/2000 11:09:59 AM*; *8/3/2000 7:07:14 PM*;
HP 53132A time interval counter; GPS receiver measured vs. cesium clock 45 days



Sync Measurement #12:
GPS vs. Cesium



Sync Measurement #12: GPS vs. Cesium

Intersect point at 12.7 hours

Both meet PRS requirements by a large margin