



# RAPPORT

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## ***Translation from the original report no. FEmF016992 in Swedish (translation by Pendulum Instruments AB)***

### **Verification of a GPS-controlled frequency standard, Fluke model 910R or Pendulum Model GPS-89<sup>1)</sup> (serial number 758602)**

#### **Introduction**

The 910R/GPS-89 has been verified with respect to accuracy and stability for two different signal outputs: the 1-s pulse output that is based on the GPS-signal (here called GPS 1-pps) and one of the 10 MHz outputs that are based on the internal rubidium clock (here called Rb 10-MHz), the frequency of which is controlled by the GPS-signal.

The 910R/GPS-89 has been verified relative to the Swedish National Time Scale UTC(SP) which is based on a Cesium standard traceable to UTC. The traceability of UTC(SP) is verified continuously through the international cooperation that is coordinated by the International Bureau of Weights and Measures, BIPM, at Sevres, France.

The 910R/GPS-89 traceability to UTC will be discussed at the end of this report.

#### **Installation**

The 910R/GPS-89 was installed at the National Laboratory for Time and Frequency of SP Swedish National Testing and Research Institute, at Borås. The GPS-antenna of the National Laboratory was used.

#### **Measurement method**

Time interval measurements have been made to verify the signals from the 910R/GPS-89. The measurements were made both with the National Laboratory's own measurement program with appurtenant equipment and with the software package TimeView™ that is delivered with the frequency counter used (FLUKE 6681R). The timebase of the frequency counter was the same Cesium standard as UTC(SP) is based on.

At all measurements the time interval measurement was started by UTC(SP) and stopped by GPS 1-pps or Rb 10-MHz.

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<sup>1)</sup> The Fluke model 910R is labelled Pendulum GPS-89 in the Nordic countries

## Result

### *Verifying GPS 1-pps*

#### Measurement 1:

At this measurement GPS 1-pps was measured relative to UTC(SP). Every tenth minute for two weeks a measurement was made. Figure 1 shows the time difference UTC(SP) - GPS 1-pps. The standard deviation is about 30 ns and the average offset about 690 ns. If we compensate for the time delays in the antenna cable (about 320 ns) and the cable to the counter (about 40 ns), and for the time difference UTC(SP) - UTC (about 330 ns), you will get a value for UTC - GPS 1-pps of about 0 ns. The uncertainty in these calculations is approximately  $\pm 50$  ns.

The figures 2 and 3 show relative frequency between UTC(SP) and GPS 1-pps based on data in Figure 1, for 10-min respectively 24-h mean values. For 10-min mean values (see Figure 2) the relative frequency is within about  $\pm 1,5E-10$ . The corresponding number for 24-h mean values (see Figure 3) is about  $\pm 1,0E-12$ . (A positive relative frequency value means that the signal from the 910R/GPS-89 is higher than the frequency of UTC(SP).)

Figure 9 shows the Allan deviation for data in Figure 1. The Allan deviation for 10-min mean value time is about  $8,7E-11$  and about  $6,1E-13$  for 24-h mean value time. The slope of the curve shows that the measurements are dominated by phase noise from the GPS-signal.

#### Measurement 2:

At this measurement GPS 1-pps was measured relative to UTC(SP). One measurement per second was made during 100 s. Figure 4 shows the time difference UTC(SP) - GPS 1-pps minus mean deviation. The standard deviation is about 30 ns. In the figure you can see that GPS 1-pps has a sawtooth characteristic with a period of about 5 s and an amplitude of about  $\pm 50$  ns. This behavior is deterministic and can be compensated for, if necessary, by means of correction values from the GPS-receiver.

### *Verifying Rb 10-MHz*

At this measurement Rb 10-MHz was measured relative to UTC(SP). Phase differences (in seconds) were measured for three different time intervals: 1 s during two hours, 10 s during about 17 hours and 10 min during about 10 days. (At 10 min time interval UTC(SP) was measured relative to the signal at the Rb 1-pps output, which is divided from Rb 10-MHz.) The Figures 5, 6, 7 respectively show measured phase differences. At the last-mentioned measurement the 910R/GPS-89 was set to hold-over mode after a couple of days. This means that the internal rubidium reference was no longer locked to (controlled by) the GPS-signal. After a few days more, the Rb 10-MHz was locked to GPS again.

Figure 8 shows relative frequency between UTC(SP) and Rb 10-MHz based on data in Figure 7, for 24-h mean values. Figure 8 shows that for 24-h mean values, the relative frequency is within about  $\pm 5E-13$ , when the rubidium reference is locked to GPS. After about 3 days in hold-over mode the relative frequency is about  $+2,5E-12$ . After locking the signal to GPS again, it took about 24 hours to get back within  $\pm 5E-13$ . (A positive relative frequency value means that the frequency of the signal from the 910R/GPS-89 is higher than the frequency of UTC(SP).)

Figure 8 also shows the relative frequency between GPS and Rb 10-MHz. These data are collected from the internal monitoring function in the 910R/GPS-89, which continuously supervises and stores relative frequency data between GPS and the internal rubidium reference. The Figure shows that the two measurement series accord within about  $\pm 5E-13$  which is the resolution you get from GPS at a mean value time of about 24 h (see Figure 9).

Figure 9 shows the Allan deviation for data in the Figures 5 and 6. The table below shows the Allan deviation for different mean value times based on data in the Figures 5 and 6, and the specification for the 910R/GPS-89. For measuring times up to about 100 s the comparison is dominated by phase noise from the measurement. For measuring times between 100 s and 5000 s the measurement is dominated by frequency noise from the rubidium reference. For measuring times longer than 5000 s you can see a tendency of frequency drift in the rubidium reference.

$\tau$ /s	Allan deviation	Specification
1	5,2E-11*	3,0E-11
10	1,0E-11	1,0E-11
100	1,4E-12	3,0E-12
1 000	2,8E-13	1,0E-12
10 000	1,8E-13	-

\* The resolution of the measurement system is approx.  $\pm 5E-11$

## Traceability

With traceability we mean an unbroken chain of documented comparative measurements between a reference and the device under test. Within the domain of time and frequency the reference is UTC or some national time scale that is traceable to UTC, e.g. UTC(SP).

The traceability for the 10-MHz output on the 910R/GPS-89 is guaranteed through the continuously documented chain Rb 10-MHz -> GPS -> UTC(USNO) -> (UTC or UTC(SP)). For Rb 10-MHz -> GPS through the internal documenting function, for GPS -> UTC(USNO) through documentation from USNO (United States Naval Observatory) at e.g. [http://192.5.41.239/gps\\_datafiles.html](http://192.5.41.239/gps_datafiles.html), and for UTC(USNO) -> (UTC or UTC(SP)) through BIPM's Circular T at e.g. <ftp://62.161.69.5/pub/tai/publication/>.

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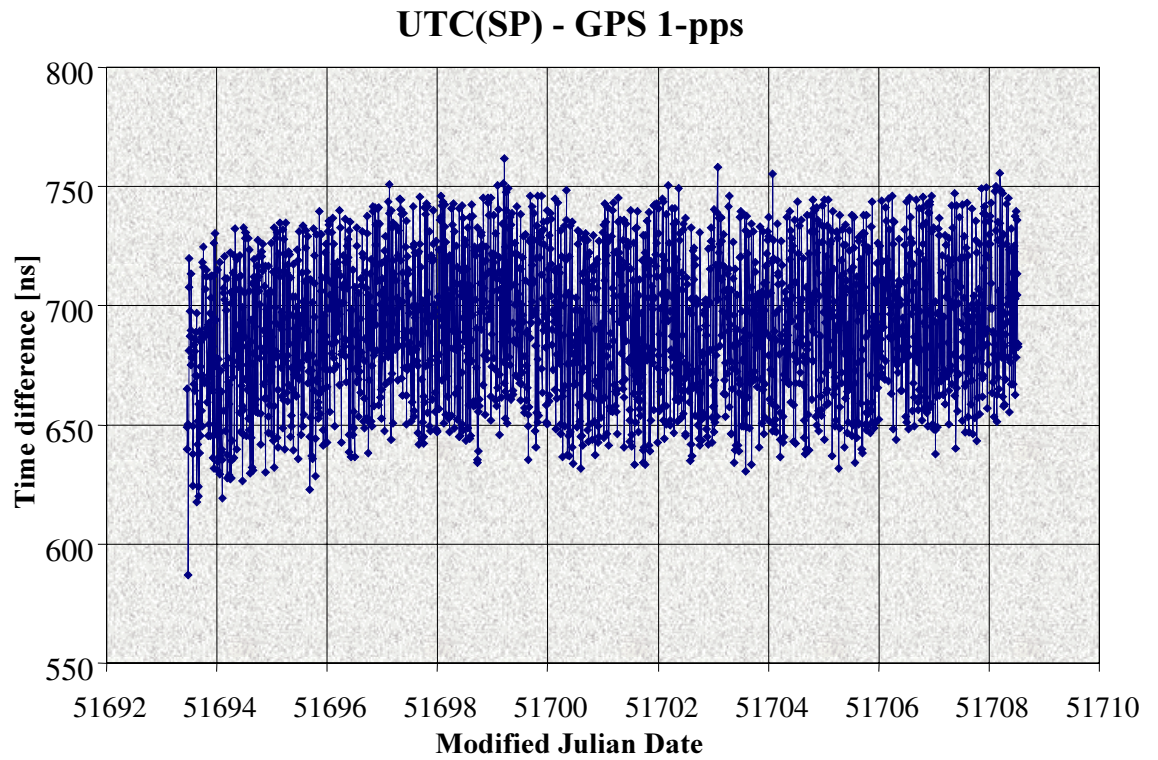


Figure 1: Measured time difference between UTC(SP) and GPS 1-pps + bias

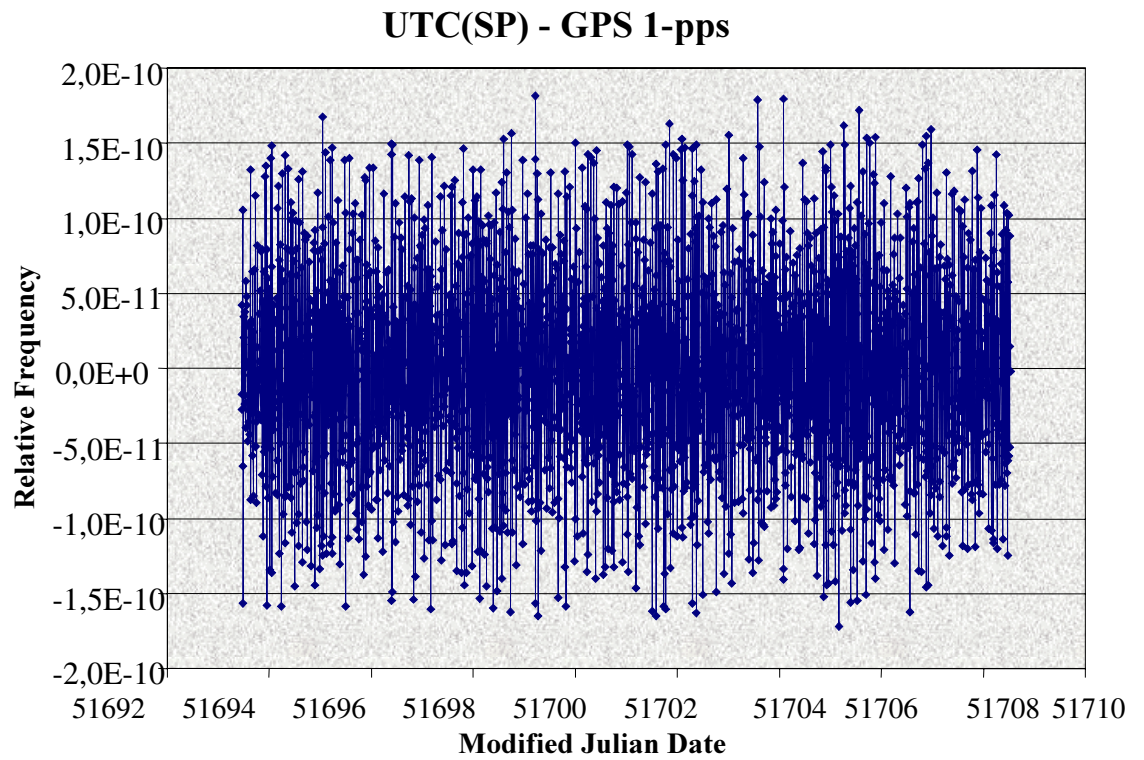


Figure 2: Relative frequency between UTC(SP) and GPS 1-pps (10-m mean values)

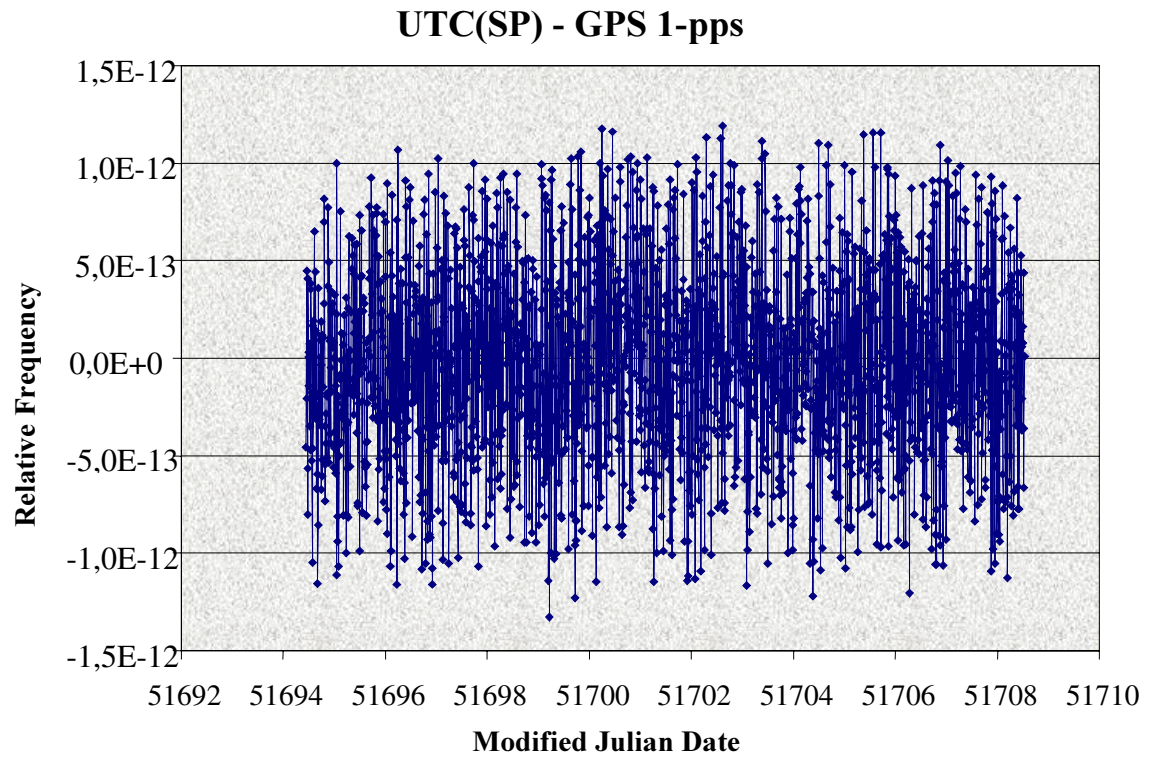


Figure 3: Relative frequency between UTC(SP) and GPS 1-pps (24-h mean values)

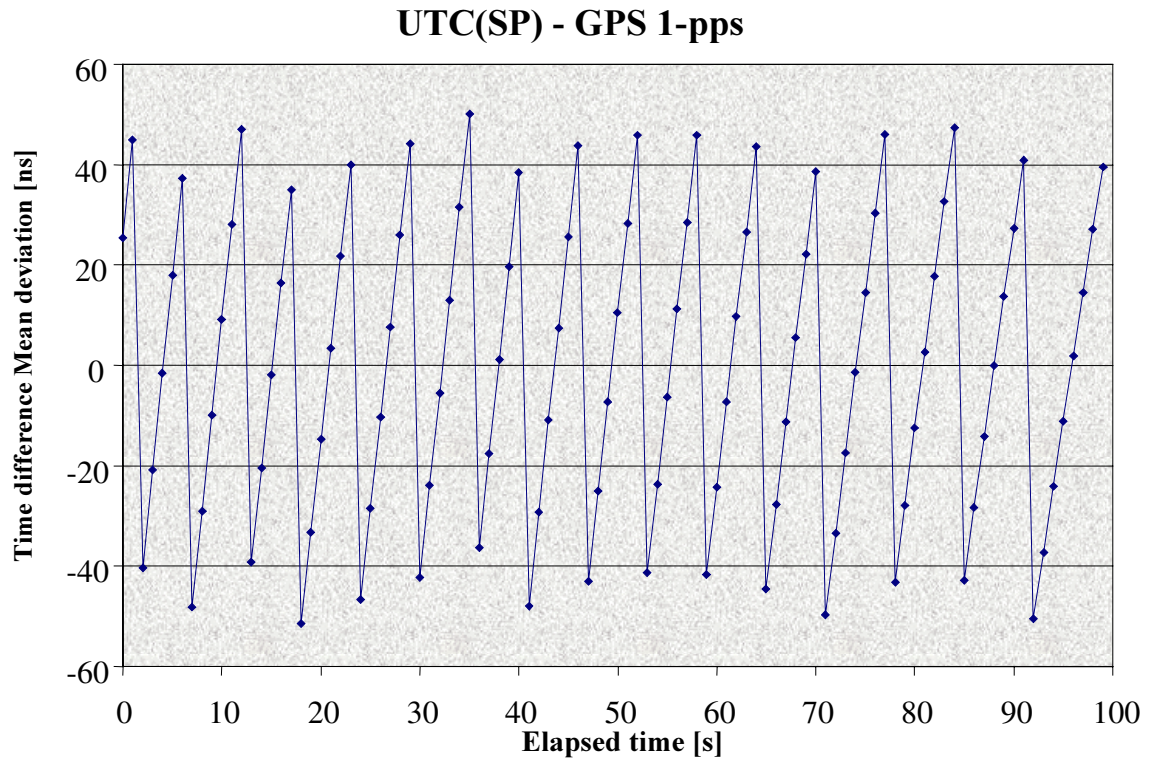


Figure 4: Measured time difference between UTC(SP) and GPS 1-pps – mean deviation

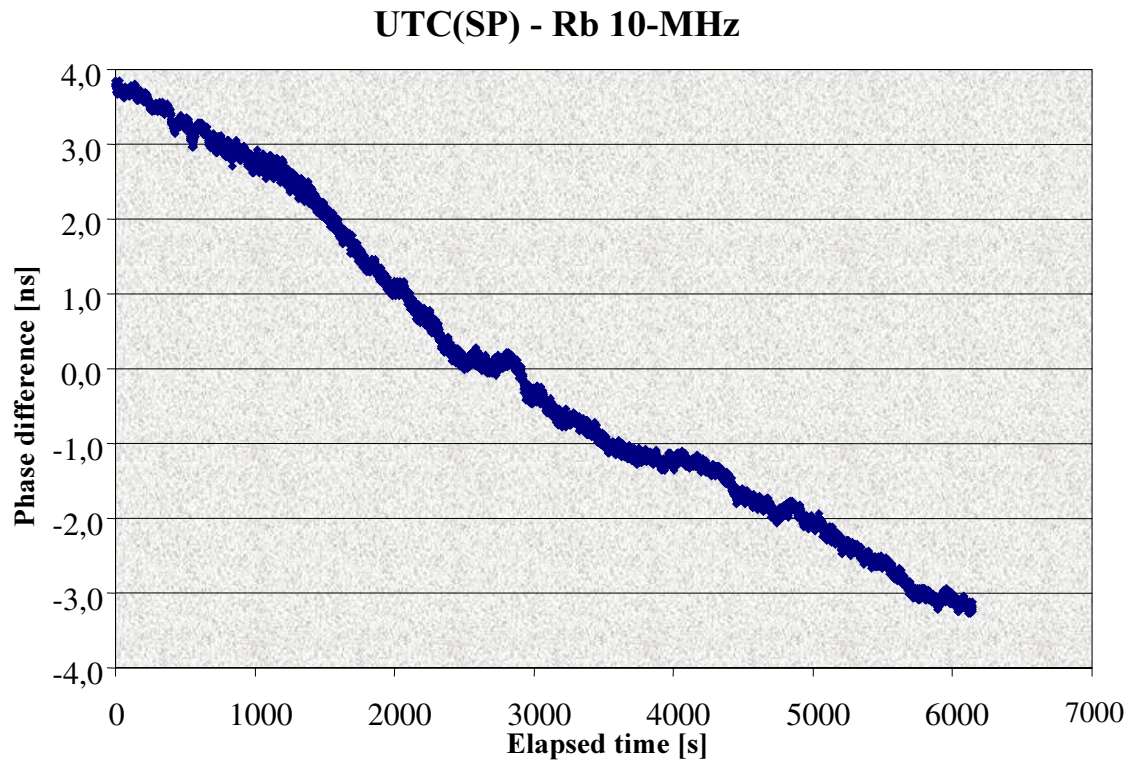


Figure 5: Phase difference between UTC(SP) and Rb 10-MHz (1-s data)

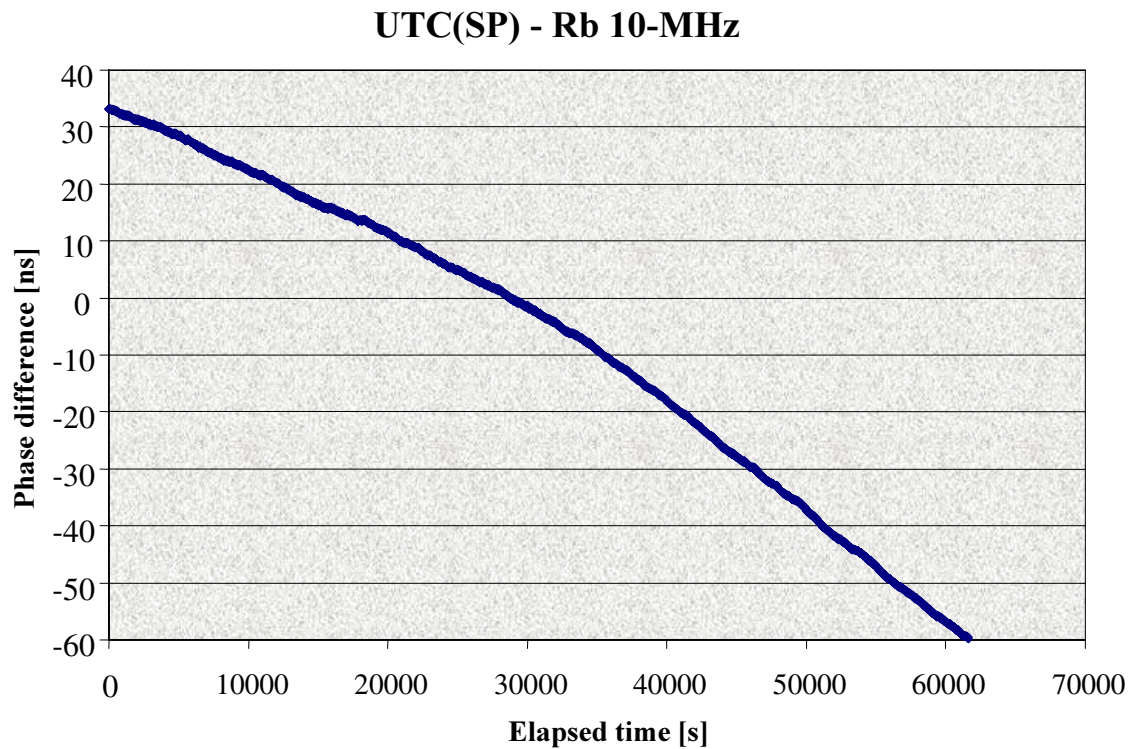


Figure 6: Phase difference between UTC(SP) and Rb 10-MHz (10-s data)

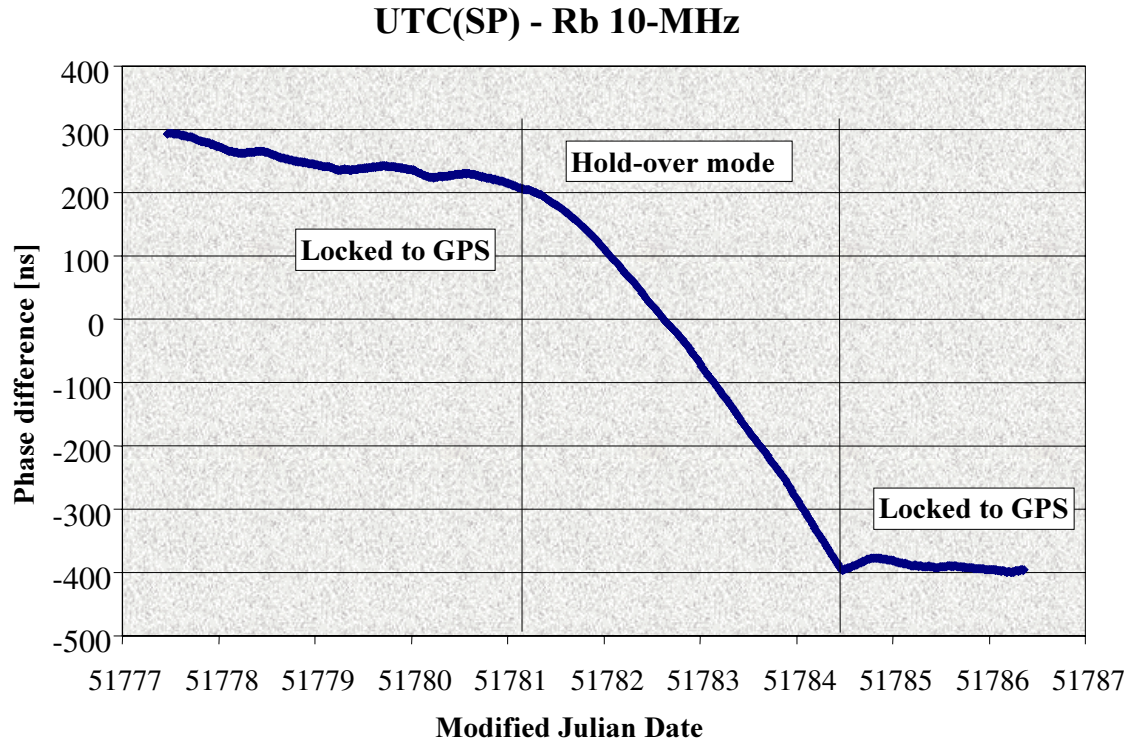


Figure 7: Phase difference between UTC(SP) and Rb 10-MHz (10-min. data)

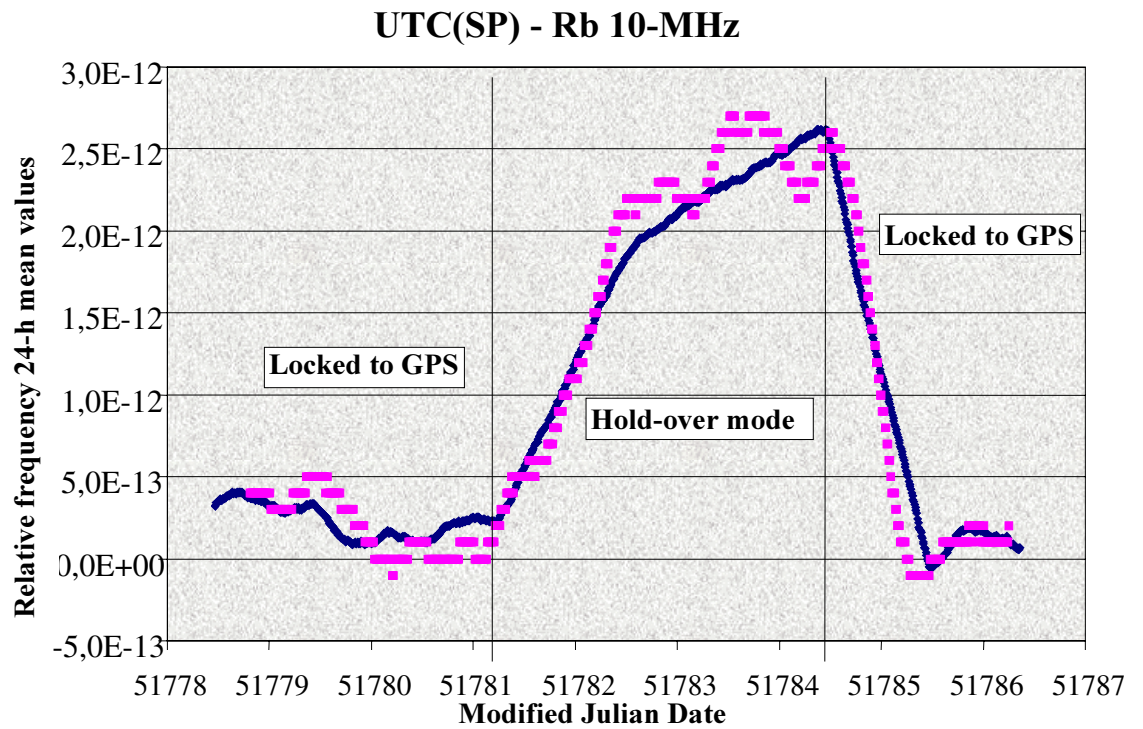


Figure 8: Relative frequency for (dark blue) UTC(SP) - Rb 10-MHz and (purple) GPS - Rb 10-MHz, (24-h mean values)

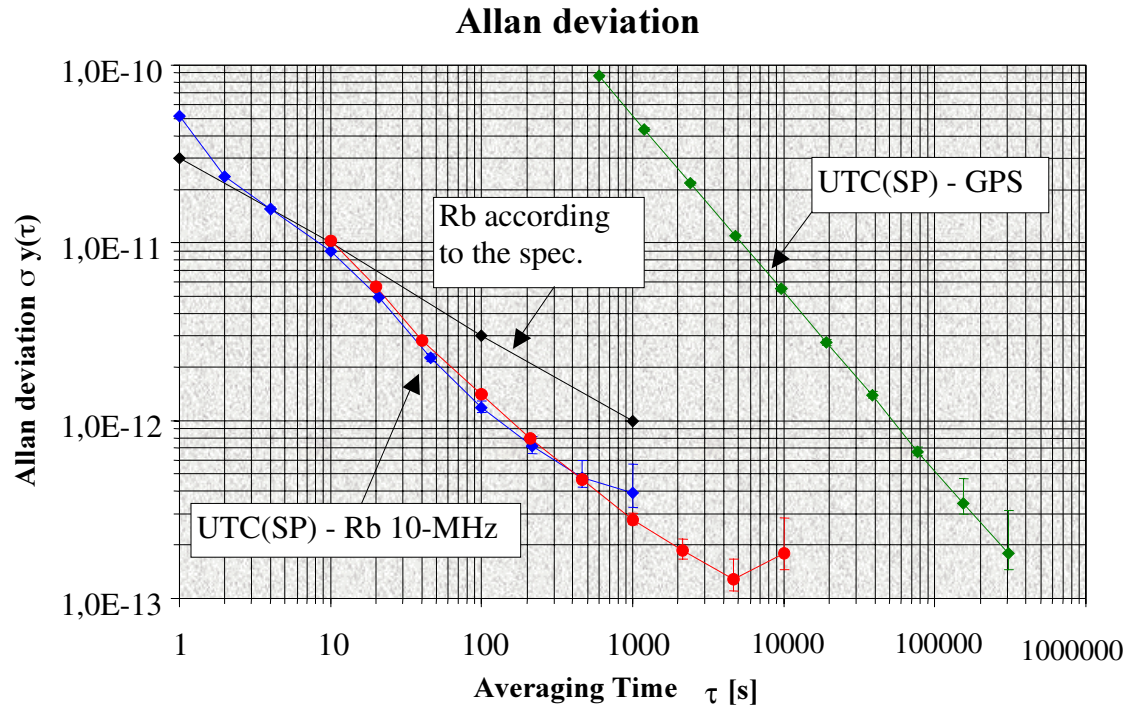


Figure 9: Allan deviation for data in Figure 1 (green), 5 (blue) and 6 (red), and according to the spec.