# A SYSTEM TO COMPARE AND EVALUATE THE QUALITY OF PRECISE FREQUENCY AND TIMING SYSTEMS

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**Abstract**

*Larger scientific and commercial sites like military test ranges or satellite ground stations very often use several sets of independently operating PTFS (Precise Timing & Frequency Systems). Very often these systems are separated by several hundreds of meters and synchronized to different sources that make it difficult to compare the quality in terms of on-time accuracy and frequency precision between these independent systems.*

*This paper describes a "tool" to measure and evaluate up to eight independently operating PTFS by measuring the differences between the 1pps-signals and the phase relations of frequencies. This "tool" is designed for a satellite ground station with six independent PTFS, most of them based on GPS receivers using UTC as time scale. The PTFS are located on a campus; the distance between the systems is up to several hundred meters.*

*The frequency part of the "tool" continuously measures the phase difference between the multiple frequencies of the external PTFS, which must not necessarily be of the same nominal frequency and outputs the data to a PC. The accuracy of the measurement is about 10 to 50 ps. The timing part of the system compares the difference between 1 pps signals with an accuracy of 100 ps and also outputs the data to the same PC. This unit has some more functions – distribute the information to external sites for monitoring and alarm functions as well as act as an NTP-server.*

*The data derived from the system can be used as well for immediate control, as well for long- term evaluation of the behavior of each independent PTFS.*

## THE PROBLEM

At a modern satellite ground station, a scientific research laboratory or a military test range, there are usually a lot of different time and frequency sources to be found, all of them a part of a single system, dedicated to a specific task.

Very often it turns out that the "single, specific task" is not so single. Just an example: A satellite ground station contains six different subsystems, each of them controlling a single satellite at a specific position. All of these control systems are delivered at different times and each of them represents the latest technology at time of delivery (better to say, at time of quote, but this does not really matter here). Thus, each of the stations have another generation of computer systems, software and, very often, time and frequency generators. We will not go very far back in time and will assume they are all synchronized to a common time scale by GPS or, perhaps, one of the terrestrial radio systems like Omega, Loran C, DCF 77, or other long-wave radio systems.

Comparing the different time and frequency systems, significant differences can soon be found. The differences can be so big that, at one of our customers sites, data which have been sent to a satellite, then transferred to the next satellite and from there to the customer could not been decoded at the final user at the usual speed due to a small frequency difference between the two control stations of the two satellites. Our customer lost a lot of money – commercial high data rate links are expensive, we are talking about thousand of dollars within a few minutes.

He asked us about a solution that constantly measures the frequency and time difference between all of his "islands," and we designed the system described here.

# A POSSIBLE SOLUTION

As said above, each of the satellite control centers contains a PTFS which outputs 10 and/or 5 MHz, 1 pps, and IRIG-B. We are continuously monitoring the main frequency outputs, usually 10 MHz, and the on-time pulse, which is a 1-pps digital signal. One of the stations is used as dedicated reference station.

Phase difference linearly changes with time, as long as the drift rate of two frequencies is constant. Thus, the phase difference of two nominally identical frequencies forms a more or less linear curve. The gradient of the curve is a measure of the ratio of the two frequencies.

The six satellite control facilities are located at one campus, but the distances between the single centers is up to several hundred meters. To avoid crosstalk and common mode problems, the 10 MHz (usually a sine wave) is formed into a square wave and both signals, the 1 pps as well, are transferred as balanced outputs via simple CAT 7 twisted pair lines as used in Ethernet or similar network environments.

The system contains four parts: the phase comparator part for detecting frequency anomalies, the 1pps comparator for detecting timing errors, the computer overhead, and a laptop as a man-machine interface for programming the system and displaying the results.

# PHASE COMPARISON

The phase comparison is done by two four-channel comparator boards supplied by a small German company named K+K. The principle of these boards was described by Kramer and Klische [1]. We are using modified boards, because we presently relate to the basic frequencies of 10, 5, and 1 MHz. We have built a phase-lock loop into the input to avoid spurious signals that may arise through the distribution path.

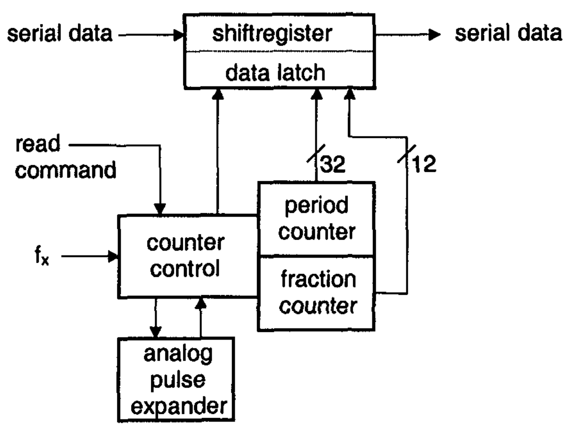


Figure 1. Beat frequency counter (one channel).

All frequencies are sampled with a synchronous strobe signal, named "read command" in Figure 1; each of the boards compares four inputs to the 10 MHz reference input, even if the input frequencies are not 10 MHz. The reference input is also used as a clock source of the board, thus assuring all internal frequencies are derived from the same source, thus being phase-coherent.

The theoretical solution of the phase difference is 50 ps or better than 0.2 degrees related to 10 MHz.

## TIME COMPARISON

The time comparison boards compare up to eight 1-pps inputs, one of them is used as reference input. The theoretical solution of the timing board is also 50 ps.

## OVERHEAD

The overhead consists of a single board computer with all kinds of interfaces, RS232, Ethernet, USB, etc. Its operating system is Linux. It collects the data from the frequency and time boards described above and forms a data stream to the laptop via a USB port.

## DATA STORAGE

The actual data are derived at a rate of 1 to 20 samples per second. They are stored and displayed for a programmable time (we usually use 60 to 100 seconds), then the data are condensed by a factor of 5 to 30 and stored. In case of a failure or significant anomaly, the actual data several seconds before and after the failure are stored. After a few hours, the data are again condensed and stored in a separate file. This file shall be archived in the customers central system. As already said, the above times are programmable by the customer.

## ETHERNET CONNECTION

We have added an Ethernet access into our Alarm & Control Unit, which is the core of our dual redundant frequency and time systems. So we also have added a program to display the status informations of the external "islands" to get a whole picture of the status of all systems at a single site.

We also get "raw" time information via NTP into the laptop, which helps to compare the central station with distant stations via the Internet or fixed networks (this is, of course, a total different quality of comparison, but it is at least an exchange of health and status data and provides a lot of trust for the operations manager).

## DISPLAY

As a display we use the TFT-display of a laptop computer, but any other display can be used, too. As we are using LabView as the data-handling program, we are limited to the possibilities of this program, but we found that this is not really a limitation.


Figure 2. A simplified picture showing the comparison of two external channels with a reference signal – phase 0 shows the warm up of an oscillator, thus the big phase shift; phase 1 shows a cesium standard compared with the reference cesium (see also First Results).

## ERRORS

The error sources are:

- propagation delay between the reference inputs at the comparison boards:
  a fixed value, no problem.

- propagation delay between the different sites, frequency:
  a fixed value, so no problem. The phase difference between the different 10-MHz signals can be ±50 ns; this is also within the on-time difference of the GPS receivers, so we have to live with it anyhow.

- propagation delay between the different sites, 1 pps
  is a fixed value, so no problem; to enhance the resolution of the display, we can subtract/add any number of nanoseconds.

- crosstalk, 1 pps
  Crosstalk at the 1-pps input is a problem, because it leads always to a wrong measurement. We try to avoid this by using differential signals with high common-mode rejection and also using CAT7 cables that provide single shielded twisted pairs plus an additional common shield. The display program is also able to suppress this type of errors, if desired.

- crosstalk 10 MHz
  It is almost the same problem as with the 1-pps signal described above. We have decided to use narrow phase-lock loops in the inputs, because it is the task of the system to see long-term variations better than very-short-term anomalies (at least as they do not exceed certain limits).

The system is not designed to be a phase-noise-measuring device! We can, off course, handle the inputs to customers' specifications.

## FIRST RESULTS

We have used the prototype of the system to compare two Precise Time and Frequency Reference systems we had to deliver to a military project. The systems have been based on cesium standards. To get "meaningful" (in case of the monitoring system, not the PTFS), we had to use the warm-up phase to measure phase degradations, but this worked very well. The results of these tests can be seen in Figures 2 (above) and 3 and 4 (below).

We also used a DCF77-driven system as reference source because it should be less stable than GPS-driven systems. The results are surprising; the short-term stability was better than anticipated, while the short-term stability of a GPS-based system was less good.

## REFERENCES


[1] G. Kramer and W. Klische, 2001, "Multi-channel synchronous digital phase recorder," in Proceedings of the 2001 IEEE International Frequency Control Symposium and PDA Exhibition, 6-8 June 2001, Seattle, Washington, USA (IEEE Publication 01CH37218), pp. 144-151.


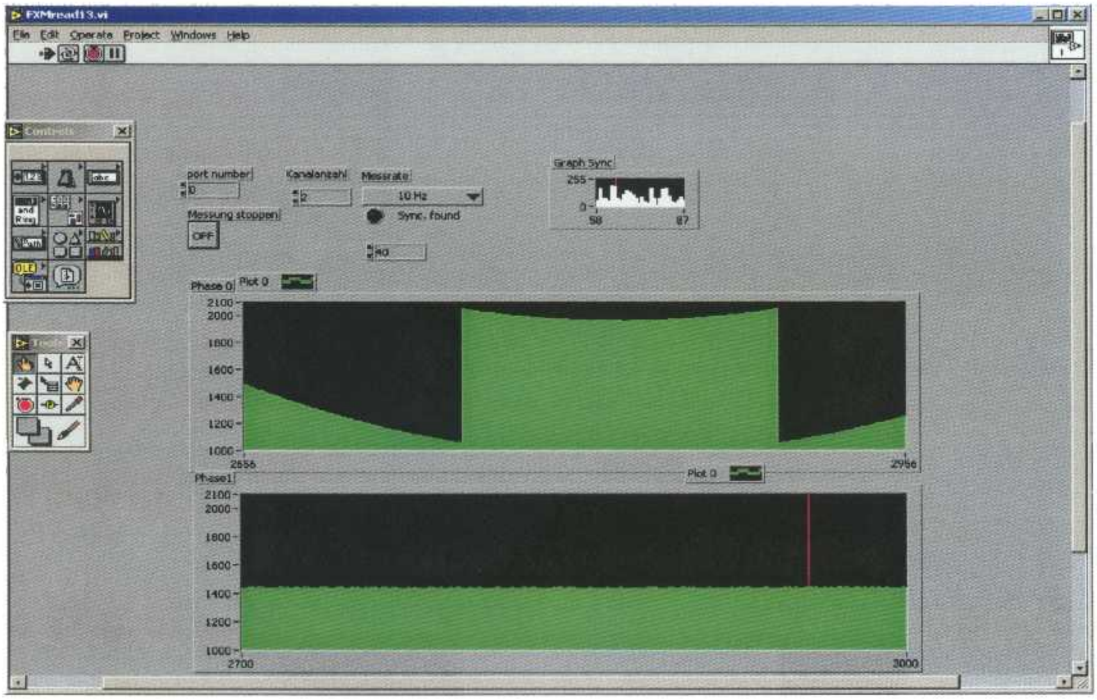


Figure 3

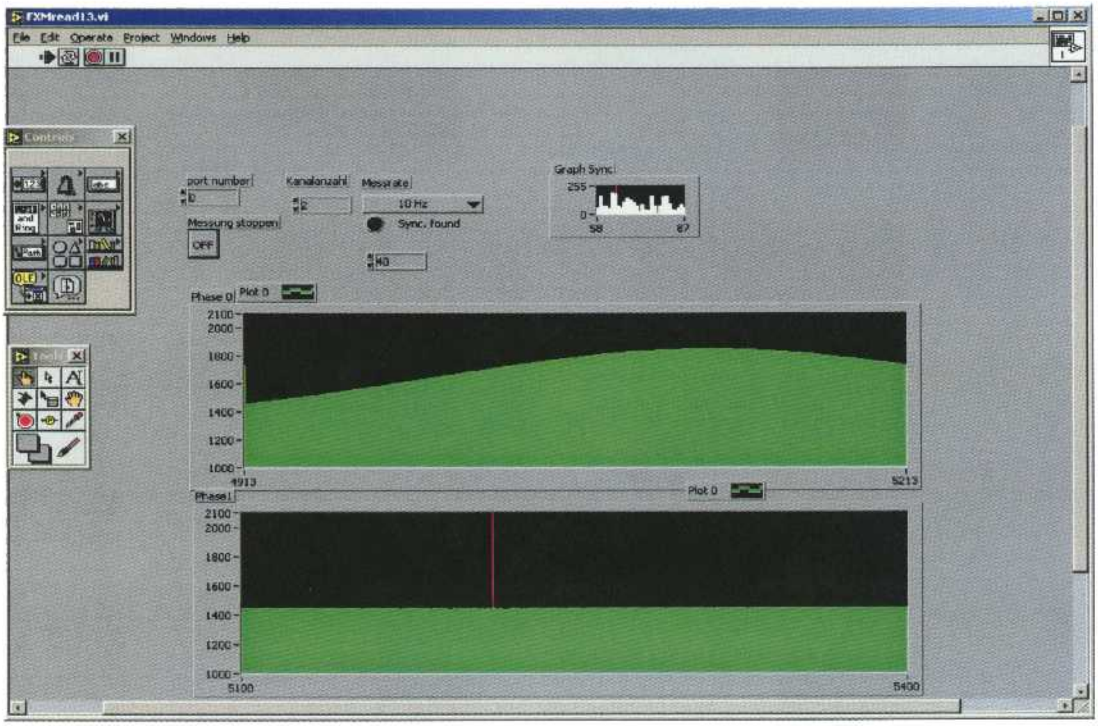
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Figure 4