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TECHNOLOGY REALIZATION CENTER

Traceability In Production Testing of the Symmetricom 5071A Cesium Clock

Abstract

In the manufacturing of Cesium-based primary frequency standards, the Cesium standard's normal operating frequency must be verified to be within the basic accuracy specifications set for that standard.

At Symmetricom, San Jose site production area, an active "real time" ensemble composed of three High Performance 5071A Primary Frequency Standards is used as a local reference to test production 5071A instruments. Also available at the production area, is a High Performance 5071A Cesium standard, which is designated as House Reference Standard. Daily comparison of time between the Ensemble, House Reference Standard and UTC (NIST) are made, using common view GPS techniques. The data obtained permits continuous tracking of the Ensemble and the House Reference Standard. Continuous measurement of up to 14 units under test is made relative to the Ensemble reference. This permits easy determination of the relative difference between UTC and the standards under test.

Introduction

The goal for the test system is to provide a clean, stable, accurate working reference, physically close to the test units in the production area. This paper discusses each of the elements in the measurement chain between the GPS reference receiver and the frequency standard units under test. Figure 1 shows a block diagram of the frequency reference chain and the production test system.

Symmetricom San Jose Site Ensemble Reference Standard

The ensemble reference standard is located at Symmetricom's San Jose site, referred to herein as "Ensemble". This is an official reference station for the National Institute for Standards and Technology (NIST), based in Boulder, Colorado.

A long-term reference to NIST is maintained by use of a common-view Global Positioning System (GPS) arrangement with NIST and subscription to their daily sampling of the ensemble data. NIST provides a monthly report of these results to provide direct traceability of the San Jose site ensemble to UTC (NIST) [1].

Real-Time Ensemble

Figure 2 shows a block diagram of the real-time ensemble. The term "Real-time" refers to the fact that the production ensemble controller makes continuous, real time adjustments to three high performance 5071A primary frequency standards included in the ensemble. A key point is that the internal Cesium loop operates un-steered, at its natural frequency. The output of each of the three 5071A is precisely steerable in steps of 6.3 parts in 10^{15} by use of an internal high-resolution direct digital frequency synthesizer [2].

In the real-time ensemble, the output signal from each 5071A is phase-compared with the ensemble output signal. This signal is derived from a power summer, which combines the outputs of the three 5071A [3]. The result of these comparisons is sent to the ensemble controller. The ensemble controller determines a frequency offset for each 5071A output, which will bring it in phase with the ensemble output. In order to produce a true average of the three undisturbed frequencies, the controller selects the minimum set of offsets which sum to zero. The three outputs are driven to operate in phase, and at the average frequency of the three 5071A in the ensemble.

A further advantage of power summing is that output frequency stability (Allan Variance) and phase noise are reduced by the square root of N and 10 log N (dB) respectively (where N is the number of sources in the ensemble).

Even though the ensemble provides the working reference for production frequency measurements, it is not kept in a controlled environment. Extensive testing of the 5071A by independent labs shows virtually no change in frequency due to environmental changes [4]. This environmental insensitivity reduces the cost of the test system because neither the ensemble nor the test units need to be environmentally controlled, even though the final test runs for a minimum of six consecutive days. Refer to the 5071A Product Overview for its stability and accuracy specifications over wide ranges of external environmental effects.

The output signal from the real-time ensemble is sent to the measurement system where it provides the reference for accuracy and stability measurements on the newly produced frequency standards. This output is also monitored long-term to UTC (NIST) using the same service described earlier.

Long-Term Stability Measurement System

The measurement system, shown in Figure 3, uses a time interval phase measurement technique to compare the frequency of the test units to that of the ensemble. The time interval counter is used to measure the phase difference between the 5 MHz output from the ensemble and the unit under test.

Each unit under test is sampled every 33.333 seconds. Each sample represents the average of 1000 measurements of the time difference between the local reference and the unit under test. Data reduction from 30 consecutive samples produces an effective time difference for that 1000-second period. Data is acquired on each unit for a total of 6 days, or 518 time difference measurements.

The data thus obtained yields a plot similar to Figures 4 and 5. The data in Figure 4 was derived from a high performance 5071A instrument, whereas the data in Figure 5 came from a standard 5071A instrument.

To precisely determine the relative output frequency of each test unit, a least-squares-fit line is computed from the time-difference data. The frequency offset of the test unit (with respect to the ensemble) is computed from the slope of that line.

In addition to the production frequency standards under test, the system also measures the signal from San Jose site house standard and GPS. These data are reduced in the same manner described above, and stored giving a continuous record of the frequency difference between the ensemble, the house standard and GPS.

Results

The data produced is then further reduced to give frequency measurements traceable to UTC (NIST).

Accuracy

We have shown how production frequency measurements have a traceability chain from UTC (via NIST) to the measurement of 5071A primary frequency standards on the production line. The remaining issue is the accuracy with which the production units can be measured.

Sources of uncertainty in this measurement are the frequency determination from GPS, real time ensemble frequency, and the production measurement system. Our best estimates of these uncertainties are as follows.

GPS

Monitoring GPS for long periods while using the San Jose site ensemble clock as a "flywheel" yields fairly good results. Over a four-week period we are able to determine UTC with an uncertainty of around 100 ns. This translates to a frequency uncertainty of about 4 parts in 10^{14}.

Measurement System

Based on measurements of our production test system, we estimate its measurement uncertainty to be close to 3 parts in 10^{14}.

Local Reference

Finally, the uncertainty contribution of the real time ensemble, as described above, is the square root of 3 better than an individual ensemble unit. For a 6 day averaging time (the duration of the frequency measurement) the ensemble contributes an uncertainty of less than 1.5 parts in 10^{14}.

Using a square-root-of-the-sum-of-the-squares method the total system error is estimated at less than 6 parts in 10^{14}. This level of accuracy is sustainable because of the number of Cesium standards in the system, and the continuous cross checking between the system elements. As presently configured the system provides more than sufficient accuracy to guarantee our present specifications.

Conclusion

Using the systems and methods described above, we can indeed measure the long-term accuracy of all units produced with sufficient precision to guarantee that all units meet a published accuracy specification of $\pm 1x10^{-12}$ for standard performance 5071A and $\pm 5x10^{-13}$ for high performance 5071A clocks, and that this accuracy level can be maintained in a normal production environment.

References

[1] http://tf.nist.gov/timefreq/service/fms.htm

[2] Giffard, Robin P. and Cutler, Leonard S., "A Low-Frequency, High Resolution Digital Synthesizer", Proceedings of the 1992 IEEE Frequency Control Symposium, page 188, IEEE Catalog number 92CH3083-3.

[3] Stem, A., "About Sum of Signals and Possible use in Time and Frequency Systems", Proceedings of the Forty-Fifth Annual Symposium on Frequency Control, pp 659-666, IEEE Catalog number 91CH2965-2.

[4] Johnson, James L. and Kusters, John A., "A New Cesium Beam Frequency Standard Performance Data", Procedings of the 1992 IEEE Frequency Control Symposium, page 143, IEEE catalog number 92CH3083-3.

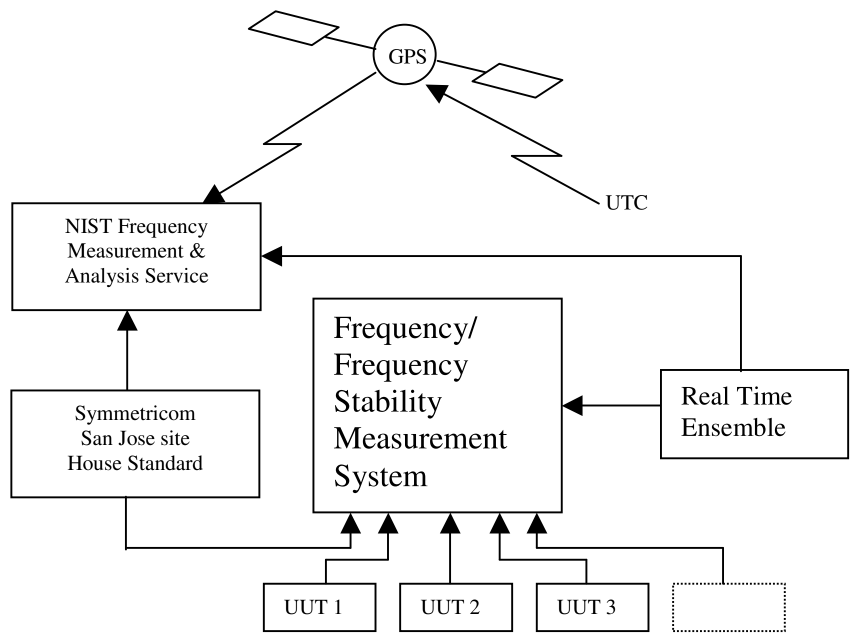

Figure 1. Block diagram of Frequency Standard/Measurement System

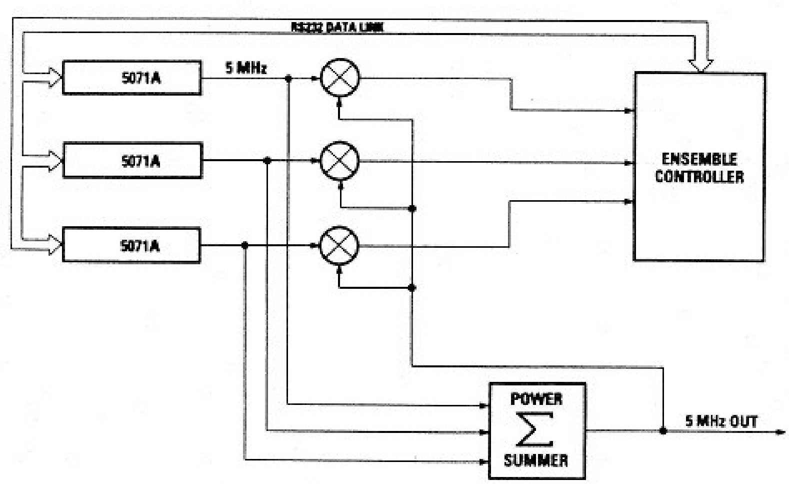

Figure 2. Block Diagram of Production Real-Time Ensemble

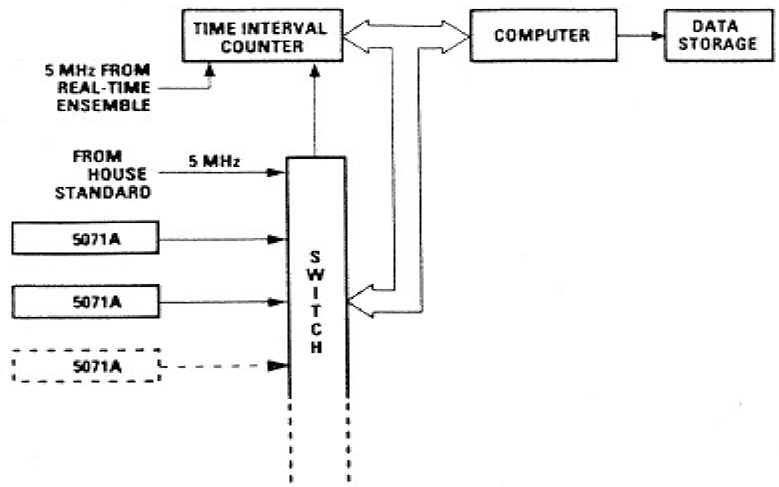

Figure 3. Frequency/Frequency Stability Measurement System

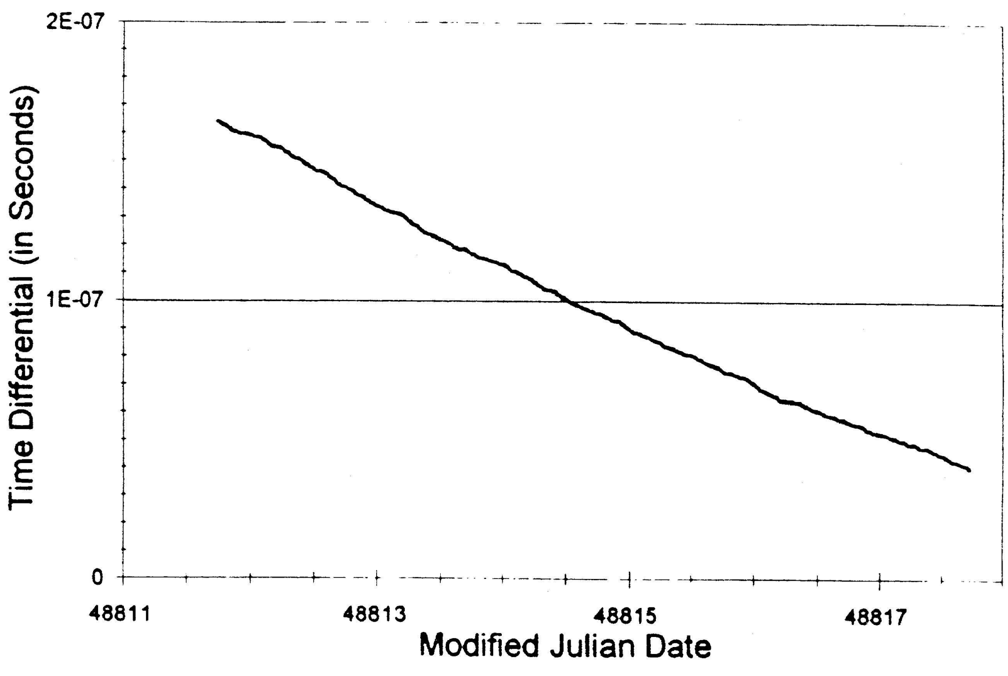

Figure 4. Continuous Phase Plot: 5071A with High Performance Cesium Beam Tube vs. Local Reference

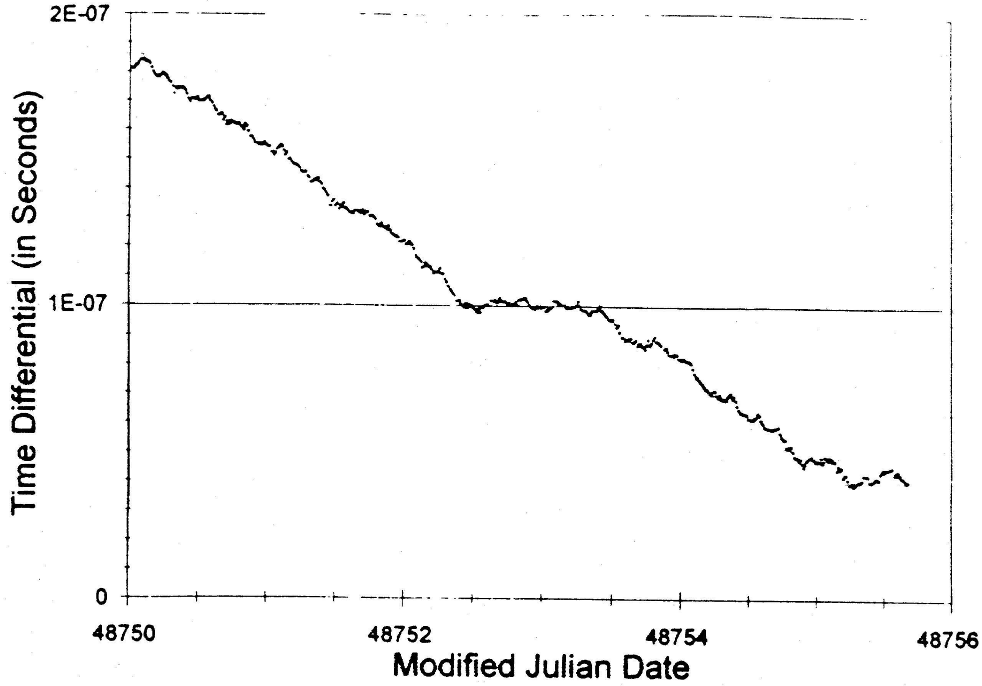

Figure 5. Continuous Phase Plot: 5071A with Standard Cesium Beam Tube vs. Local Reference