MODELING AND OPTIMUM UTILIZATION OF HIGH PERFORMANCE CLOCKS

David W. Allan and James A. Barnes

A minimization of the frequency deviations for the frequency standards in high performance clocks has been a common goal of their manufacturers. The standards in general use are typically based on atomic resonances in hydrogen, rubidium, or cesium or on a quartz crystal resonance. It is our intent to give models which generally characterize these deviations. The most detailed models have been developed for commercial cesium clocks.

The models are based on both the random and non-random frequency deviations that we and others have observed in numerous high performance clocks. Reported elsewhere are some aspects of characterizing the model of these deviations [1,2]. The non-random deviations typically include inaccuracies in the time and/or frequency of a clock, a systematic frequency drift, and infrequent steps in its time and/or frequency. The random deviations for sample times of the order of a second and longer are usually well characterized by spectral densities of a power law type, and in those instances where the distribution of the random deviations have been measured it has been found to be normal (i.e., Gaussian).

Once a good mathematical model was deduced, there resulted two obvious benefits: First, the model and reasoning led to physical interpretations as to why the frequency deviations were occurring and hence to what the possible cures might be or to what might be the methods of reducing the deviations in a clock. Second, given a good model, numerous mathematical inferences arose as to how to process the data; i.e., a) how to minimize time dispersion or to optimally predict a clocks time at some future date, b) how to best calibrate a clock, c) how to detect abnormal behavior in a clock such as the steps and drift, and d) how to both design and test time scale algorithms in order to generate the most uniform and accurate time scale from a clock ensemble.

Specifically, we have observed that commercial frequency standards have frequency drifts of a few parts in 10^{-13} per year [1,2]. Using sensitive detection routines, as outlined in the test, we have measured the magnitude of the effects by optimally filtering the noise (random deviations) of these standards. After ascertaining the magnitudes of some of the frequency drifts and steps, we found a close correlation of some of these with the servo control voltage which

David W. Allan and James A. Barnes are with the National Bureau of Standards, Boulder, Colorado 80302 USA.

frequency locks the internal quartz oscillator's frequency to the cesium resonance (see Fig. 1). We will discuss some of the implications of these findings.

We have found it very useful to computer simulate these deviations. Methods were developed to accomplish this simulation for both the random and non-random deviations, and these methods have proved to be very useful tools for testing time scale algorithms and hence for minimizing time dispersion in a clock ensemble, for testing methods of detecting frequency drift and steps, as well as for providing optimum time prediction routines. Many of the above techniques are applicable in several single clock applications.

An important conclusion is that only clock simulation provides an objective evaluation for the rationale behind and the execution of a time scale algorithm. The models developed were tested against real clock performance to verify their appropriateness, and we have found good agreement.

REFERENCES

1. "The National Bureau of Standards Atomic Time Scale: Generation, Stability, Accuracy and Accessibility," by David W. Allan, J. E. Gray and H. E. Machlan, Chapter 9 of NBS Monograph 140, Time and Frequency: Theory and Fundamentals (in press).

2. "Performance, Modeling, and Simulating of Some Cesium Beam Clocks," David W. Allan, D. J. Glaze, H. E. Machlan, A. E. Wainwright, Helmut Hellwig, J. A. Barnes, and James E. Gray, Proceedings of the 27th Ann. Symp. on Freq. Control, Ft. Monmouth, N.J., pp. 334-346 (1973).

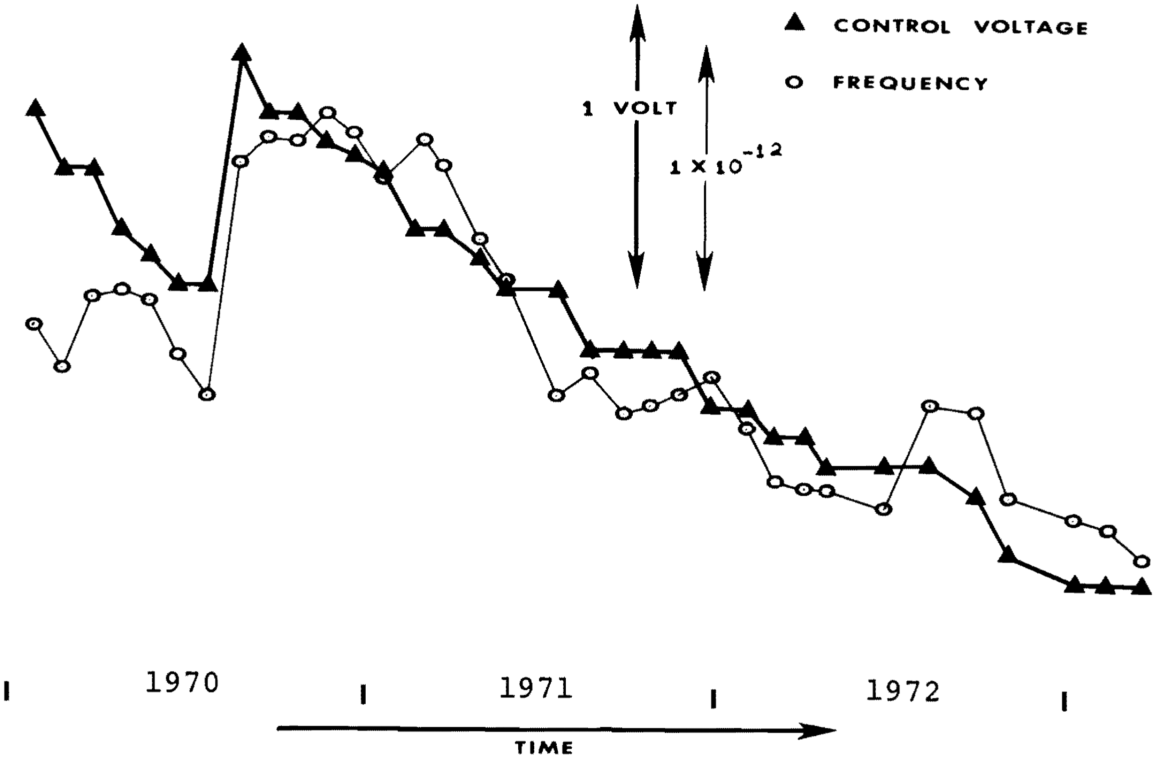

Fig. 1. Correlation of Frequency Standards with Control Voltage on Cesium 324