2:30-5:30 P.M.—SESSION 2: TIME AND FREQUENCY

Chairman: James A. Barnes
National Bureau of Standards, Boulder, Colorado

2.0: Introductory Remarks by Session Chairman

2.1: An Intercomparison of Hydrogen and Cesium Atomic Frequency Standards

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Early in September, 1965, a group of atomically controlled oscillators was assembled at the National Bureau of Standards in Boulder, Colorado. The main purpose of the two months of experiments was to obtain intercomparisons of the frequencies of the cesium beam, thallium beam, and hydrogen maser with accuracies substantially better than any previously obtained.

The equipment assembled for the experiments included the United States Frequency Standard NBS-III, a cesium beam; another cesium beam device constructed at Hewlett-Packard Company (incorporating a Varian Associates beam tube); two hydrogen masers constructed at the Q. E. D. Division of Varian Associates.

The majority of comparisons among the two masers and the two cesium beam devices was obtained by period measurements of the beat frequencies between pairs of 5 MHz signals synthesized from the various controlling atomic transitions. Data taken at 5 MHz was reduced by computor analysis with input from automatically punched cards.

Results indicated the frequency fluctuations of one maser relative to the other was within a few parts in 10^{13} from one second to several hundred seconds, and the frequencies of the two masers agreed to within one part in 10^{12} for the entire two-month period.

The fluctuations in the frequency of the 5 MHz signal locked to NBS-III as compared to a hydrogen maser decreased with increasing sample time as $\tau^{-1/2}$ for ranging from 100 seconds to five hours. This is in complete agreement with theory. A standard deviation of one part in 10^{13} was obtained for adjacent sample times of two hours. For adequate averaging times ($\tau \geq 200$ seconds), the new total estimated inaccuracy for NBS-III is 1.1×10^{-12} for a *one*-sigma value.

The comparison of NBS-III with the Hewlett-Packard (H-P) cesium beam indicated a standard deviation for the frequency fluctuations of seven parts in 10^{13} for two-hour samples. If one assumes that the figure of one part in 10^{13} quoted above for the comparison of NBS-III and a hydrogen maser is caused primarily by shot noise modulating the frequency of NBS-III, it is possible to calculate the fluctuations on a shorter machine with a different flux of atoms and this is in complete agreement with the experimental results of 7×10^{-13} for two-hour samples as obtained.

The H-P cesium beam being independently aligned, was compared for about two weeks. Assuming NBS-III as the primary standard, the average frequency of the 5 MHz output of the H-P unit was within 9 parts in 10^{13} which is well within the estimated accuracies for the two beams.

A valve for the frequency of the $F=1, M_F=0 \rightarrow F=0, M_F = 0$ hyfine transition of the hydrogen atom under unperturbed conditions has been redetermined with better accuracy in terms of the $F = 4, M_F = 0 \rightarrow F = 3, M_F = 0$ hyperfine transition of Cs 133.

The state-of-the-art for both cesium beams and hydrogen masers has undergone significant improvement. Absolute accuracy in the vicinity of a few parts in 10^{12} for frequency measurements is thus confirmed.