Time Standards

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THE POSSIBILITY of embodying our unit for time in a physical constant is attractive. We can measure time, and its reciprocal, frequency, with the greatest precision of any physical quantity. For example, we can compare the ratio of the average frequencies of two oscillators over concurrent time intervals with as great a precision as we choose. The limit is set by how long the oscillators will operate and how many cycles we wish to count, but such comparisons are pointless if the frequencies of the oscillators are not relatively stable over the interval involved. Conversely, we may measure time with equal precision by counting cycles of a particular oscillator, assuming its frequency is constant.

There is a serious problem in measuring time accurately. We can lay two meter bars side-by-side and compare their lengths. If, by subsequent comparisons, we find their lengths have not changed relatively we have confidence that our length standards have not changed. But there is no way to lay two time intervals side-by-side; we must rely on the stability of an oscillator to compare time intervals. Man-made oscillators show drifts in frequency with respect to each other, and since oscillators are not passive things like meter bars and kilogram weights, we expect them to drift.

To obtain a good standard for time and frequency we adopted first an astronomical constant, the rotational frequency of the earth, which had been regarded as constant since the days of Joshua. Man-made oscillators were used to interpolate for shorter intervals of time and the second was defined as 1/86400 of a mean solar day. As the apparent solar day varies throughout the year due to eccentricity of the earth's orbit, astronomers kept track of time by observing star transits, in relation to which earth's rotation is much more uniform.

Precise astronomical observations revealed that this standard was not good enough. The frequency of rotation of the earth is changing with respect to the revolutions of the moon about the earth and the earth about the sun, when allowance is made for perturbations of the revolution time. All planetary motions are in substantial accord. In addition to a gradual slowing down, which is to be expected from tidal friction, there are erratic fluctuations in rotational speed. For this reason astronomers carry out their more precise calculations in *ephemeris time*, which is based on planetary motions.

With the improvement of quartz-crystal oscillators, seasonal fluctuations in the earth's rotation with respect to the stars have appeared. Though the oscillator frequencies drift, they drift monotonically, allowing us to measure these seasonal fluctuations, which amount to 1 part in 10^8. Correcting for this seasonal fluctuation, astronomers have established a more uniform time scale, called UT2, good to 1 part in 10^9, tied in with the earth's rotation, and hence subject to effects of long-term changes.

So we see that even the smoothed rotation frequency of the earth is not good enough for a standard. Accordingly the second was redefined in 1956 by the International Committee on Weights and Measures as 1/31556925.9747 of the tropical year 1900.0 at 12 hours ephemeris time. Why this strange definition? Why not take the sidereal year or the anomalistic year? The lengths of all these years change in known, highly regular ways, so that specification of any epoch was necessary. We chose the tropical year, which is the time between two successive passages of the center of the sun across the celestial equator in the same sense, because accurate tables were already available for its variation, based on the epoch 1900.

The need for a better standard of time became urgent during the past decade with the improvement in microwave techniques. Microwave terms in the spectra of molecules and atoms were being measured with increased precision. The Bureau began to explore these phenomena as the basis for constructing more stable oscillators. Before 1952 Lyons and his co-workers at the Bureau had measured the microwave resonance in the ground state of the cesium atom with a precision of 1 part in 10^7. Essen and his co-workers at the National Physical Laboratory a few years later increased this precision to a few parts in 10^{10}. It is likely that greater precision can be attained in measuring the cesium frequency and also other atomic frequencies such as those of rubidium, as was indicated by recent work of Bender and Beaty of the Bureau and Chi of the Naval Research

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Laboratory. As the frequencies of these resonances depend on energy levels of the atoms involved, and as, in the case of the cesium, independent experiments have agreed to within the limits of precision, we may presume that they can serve well as standards for time and frequency.

How can we relate these resonance frequencies to the defined unit of time, the ephemeris second? As the second is defined by an event which occurred over 50 years ago we must measure the resonance frequencies in terms of current values of the UT2 second, and then, through observations on the moon, relate the UT2 second to the ephemeris second. This was done recently, based on four years of observation of the moon, showing that the ephemeris second corresponds to 9,192,632,770±20 cycles of the cesium frequency. This is much less precise than the defined value of the second or the precision with which the cesium resonance can be observed.

We have no hope of relating the atomic resonances to the ephemeris second with much greater precision in the near future. We thus are faced with the fact that atomic constants are much better standards for time and frequency than astronomical constants. Furthermore, as standards they are much more accessible than the astronomical constants, which require long years of observation to compare them precisely with other quantities. Clearly, we are able today to improve our standard for time by selecting one of the atomic resonances and defining the second in terms of it, making the definition such that the new definition will agree as closely as feasible with the present one.

The frequencies broadcast by the Bureau's stations WWV and WWVH are now monitored and kept as constant as possible by reference to the cesium resonance. The intervals between the seconds pulses are maintained in the same way. Therefore the seconds pulses gradually get out of step with mean solar time. When the difference becomes great enough the pulses are shifted by exactly 20 milliseconds to bring them back in. Thus we are already using two kinds of time, atomic time—for the scientists—and mean solar time—for the birds and other diurnal creatures.

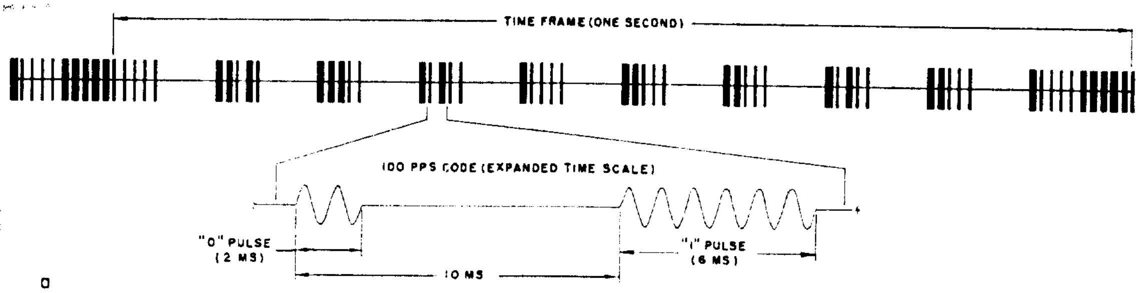
These attempts to improve time and frequency measurement may seem a quest for precision for precision's own sake, a futile pushing of the decimal point. But this is not correct. It is an attempt to establish standards so that we may learn what physics lies beyond the decimal point. For such things have Nobel Prizes been awarded. We have already learned that the earth turns irregularly on its axis. Now we ask, do time scales based on astronomic, atomic, and molecular processes change with respect to each other as some think they might? (The ammonia maser depends on molecular processes for its frequency stability.) Perhaps from these newly achieved precisions and those soon to be achieved we may even be able to resolve experimentally the famous clock paradox of relativity.

Time Code on WWV

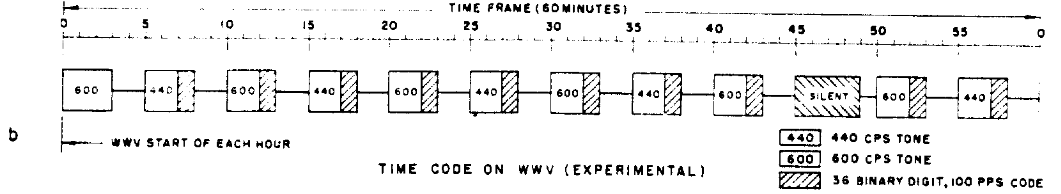
NATIONAL BUREAU OF STANDARDS radio station WWV is now broadcasting an experimental time code of 36 bits at 100 pulses per second (PPS) on 2.5, 5, 10, 15, 20, and 25 Mc.

The code (binary-coded decimal) is broadcast for 1-min intervals and 10 times per hour. Except at the beginning of each hour, it immediately follows the standard audio frequencies of 440 and 600 cps. The latter frequencies are given alternately as below, except the duration is 2 min instead of 3 min when the code is given. A complete time frame is 1 sec.

The code contains time of year information (UT) in seconds, minutes, hours, and day of year.



36 BINARY DIGIT, 100 PPS CODE (1000 CPS CARRIER) (WITHOUT 100 PPS INDEX MARKERS)



TIME CODE ON WWV (EXPERIMENTAL)