THE NATIONAL BUREAU OF STANDARDS ATOMIC TIME SCALE: GENERATION, DISSEMINATION, PRECISION, AND ACCURACY

David W. Allan, James E. Gray, and H. E. Machlan
Atomic Frequency and Time Standards Section
National Bureau of Standards
Boulder, Colorado 80302 USA

The atomic time scale at the National Bureau of Standards, AT(NBS), depends upon an ensemble of continuously operating cesium clocks calibrated occasionally by the NBS primary standard from which the AT(NBS) scale derives its accuracy. The stability of the ensemble between calibrations is of fundamental importance.

The instabilities of each clock in the ensemble are bi-categorized. First, there are deterministic processes that must be considered for each clock; e. g., frequency and time offsets, changes in these offsets, and frequency drift. Changes or drifts in frequency are determined ideally by calibrations with a primary frequency standard. Time offsets or jumps are best determined by referring to the definition of time across the ensemble. Second, there are random fluctuations (non-deterministic). The noise spectrum of these random fluctuations for each clock is deduced by comparing each clock with all the others. This noise spectrum is shown to be reasonably represented by a simple mathematical model, with parameters determined by the random behavior of the clock. These noise parameters are used to provide near optimum filtering of each clock's noise in order to have a best estimate, in the sense of minimum squared error of prediction, of the apparent time and frequency of each clock with respect to the clock ensemble. Knowing the noise spectrum for each clock allows an estimate of the noise of the ensemble, and the long-term fractional frequency stability of AT(NBS) is estimated to be a few parts in 10^{14}.

The inaccuracy of a primary frequency standard may also be bi-categorized. As the parameters which affect the frequency of the primary standard are evaluated, there is associated with each parameter both a bias (possibly zero) and a random uncertainty in our knowledge of its effect. Excellent stability of the time scale allows the possibility of averaging the random portion - in an appropriate weighted sense - of all the frequency calibrations with a primary frequency standard. The random portion is assumed to be characterized by white noise frequency modulation, which will be valid if the uncertainties from one calibration to the next are independent.

The AT(NBS) scale in overview is an ensemble of eight commercial cesium beam clocks maintained independently. The clocks are statistically weighted and filtered to generate a time scale, AT(NBS), with nearly optimum stability. This scale is used as a memory for frequency in utilizing all of the frequency calibrations with respect to the NBS primary frequency standard. These calibrations are then used after appropriate weighting and filtering to determine the proper[1] rate and the accuracy of the AT(NBS) scale. This scale along with the atomic time scales of six other laboratories is used to generate the International Atomic Time Scale, IAT, at the Bureau International de l'Heure (BIH). The IAT scale is then used as the basis for the UTC(BIH) scale, which scale is defined to be an integral number of seconds different from IAT (-10s as of January 1972) and to be within 0.7s of the UT1 earth time scale.

In conjunction with the AT(NBS) proper time scale, we also generate the coordinate time scale, UTC(NBS). This latter scale is kept synchronized (coordinated) to within a few microseconds of the UTC(BIH) scale as well as being mutually coordinated with the UTC(USNO) scale. This coordination is accomplished by small discrete rate changes (of a few parts in 10^{13}) in UTC(NBS) and in UTC(USNO). One second time jumps are made as announced by the BIH for keeping these scales within 0.7s of the UT1 scale.

The UTC(NBS) scale is used as the reference for time and frequency broadcasts of the National Bureau of Standards. The time of this scale and frequencies derived from this scale are currently made available via sundry methods:[2] e.g., the three radio transmitters at Ft. Collins, Colo., WWV, WWVB, and WWVL; the radio transmitters at Kekaha, Kauai, Hawaii, WWVH; portable clocks; the television line-10 time transfer system; telephone, (303) 499-7111; and the experimental ATS-3 satellite, which broadcasts time and frequency information with a format similar to that of WWV and WWVH. The future holds the possibility of having time and frequency made operationally available via an active TV line-1 system, a relay satellite system, and a time code on the Omega transmissions. The precision and accuracy of both the current methods of dissemination as well as some of the promising future methods will be reviewed.

1. Proper is used here in the relativistic sense.
2. Viezbicke, Peter P., NBS Special Publication 236, NBS Frequency and Time Broadcast Services.