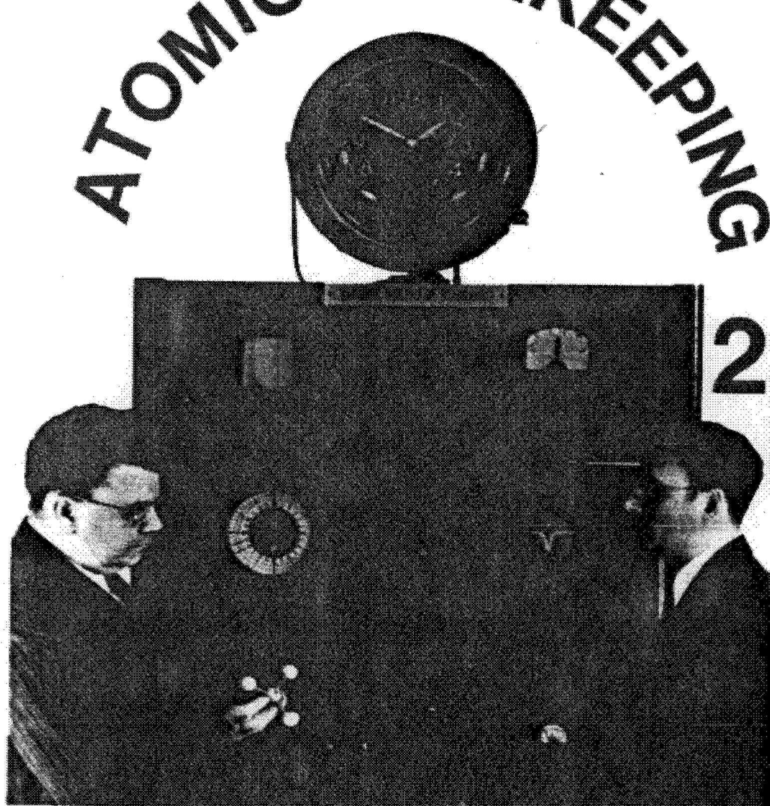
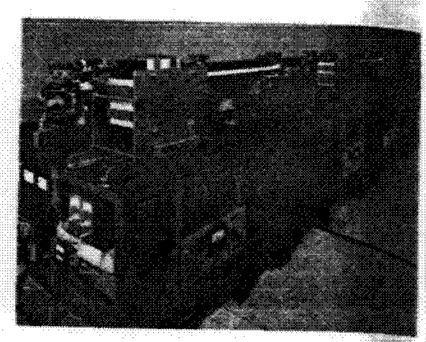
ATOMIC TIMEKEEPING 25 YEARS LATER





In 1949, Dr. Edward Condon, former NBS director, and Dr. Harold Lyons, physicist, announced the first atomic clock, which was based on the ammonia molecule. The present NBS atomic clock, an NBS primary frequency standard, is a cesium-beam device.

ON January 6, 1949, Department of Commerce Secretary Charles Sawyer and several National Bureau of Standards scientists announced to the world a new timekeeping system. Totally independent from the centuries old system of basing time intervals on our revolving earth, this device interrelated oscillations of ammonia molecules to a quartz oscillator's frequency and time system. Although no better in accuracy than astronomical time, which changes due to fluctuations in the earth's revolution, this 1949 device acquired the distinction of being the world's first "atomic clock."

Little did Sawyer or the physicists involved know that their techniques would one day lead to development of several highly refined atomic time and frequency standards. Refinement and application of new techniques by NBS and other standards laboratories have established today's extremely accurate cesium-beam standards. These standards provide a highly stable frequency, which in turn defines the unit of time, the second, which is the most accurate base unit in our international measurement system. Since 1967, the second of time has been internationally defined as "the duration of 9,192,631,770 periods of the radiation corresponding to the transistion between two hyperfine levels of the ground state of the cesium 133 atom."

Today's horologist and the general public are unfamiliar with the physicists' vocabulary describing atomic clocks. Instead of familiar terms like "escapement," "pendulum," balance wheel" and "main spring," atomic clock makers are prone to talk of "hertz," "resonance," "detectors," "atomic beams" and "microwave interaction cavities." Although this technical jargon may be formidable to many, atomic clocks perform the same basic function as the mechanical type clocks used since the start of time measurements. Each counts, or in its own way keeps track of a regular periodic phenomenon, often referred to as a vibration or oscillation. The constant rate and repeated oscillation motion of a pendulum or balance wheel permit an escapement to indicate time in seconds, minutes and hours. Refined time sources offering oscillations as high as nine billion per second are currently used by NBS.

Molecular and Atomic Physics

The 1949 ammonia type atomic clock resulted from the perfection of molecular and atomic physics techniques started in the 1920's. Although these techniques were in their infancy in 1920, physicists were striving to learn how matter interacted with electromagnetic energy (microwave, radar). The study of spectral lines, called spectroscopy, broadened. These distinct lines, the result of electromagnetic energy being absorbed or emitted by certain molecules and atoms at very precise frequencies, were discovered. The first atomic clock used the ammonia absorption line to regulate a frequency emitted from a quartz crystal oscillator. This frequency was in turn used to regulate two synchronous clocks, each set and compared to astronomical time. The quartz oscillator provided the clock's short-term stability, the ammonia absorption line the necessary long-term stability.

Cesium Devices

That same year, NBS initiated research and development of a cesium beam atomic device. A consultant to NBS, Professor Polykarp Kusch, an associate with Professor Isidor Rabi of Columbia University, worked on applying Rabi's magnetic resonance technique to a cesium-beam device. As with the ammonia clock, a quartz oscillator's multiplied signal provided the needed microwave signal. Similarities between the ammonia and cesium clock devices more or less ended at this point.

By applying atomic-beam techniques, a very narrow beam composed of cesium atoms was formed. Emitted from an oven, these atoms passed through a pair of magnets, one on each side of a microwave cavity, and completed their path by hitting a detector. The signal at the detector, in turn, controlled the frequency of the quartz oscillator. The oscillator's frequency was controlled to a very narrow limit, resulting in improved frequency stability and accuracy as compared to the ammonia device.

The first successful detection of the cesium transition used as today's definition of the second was observed in NBS-I and reported in 1952.

The National Physical Laboratories (NPL), Teddington, England, constructed the first cesium-beam standard used for periodic calibration of secondary oscillator time sources. This atomic clock, also using a Ramsey type interaction cavity, was in operation by 1955 with an accuracy of one part in one billion (1×10^{-9}).

NBS Atomic Frequency Standards

The NBS Time and Frequency Division in Boulder, Colo., maintains two of the world's most accurate frequency standards. Referred to as NBS-4 and NBS-5, these devices have been completed in the last 2 years, strengthening a quarter-century of NBS involvement in establishing molecular and atomic-beam frequency standards. Since 1960, several generations of NBS cesium-beam devices have provided our Nation and NBS with a primary frequency standard.

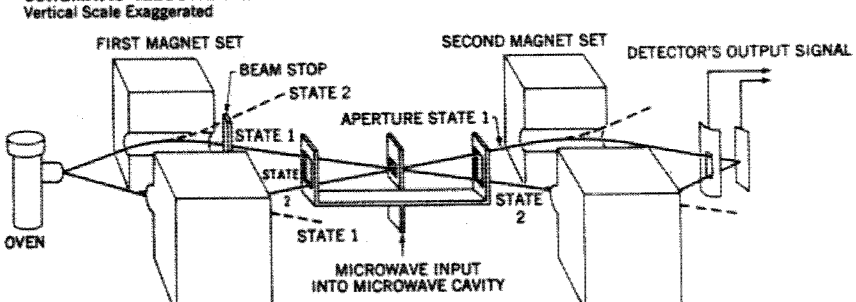
Forming a system in which they mutually support each other, NBS-4 and NBS-5 provide accuracies approximately 100,000 times better than the second of time as measured by our revolving earth. If NBS-5 were allowed to run constantly for one million years without adjustment, it would still be accurate to better than 10 seconds!

Contributing to World Time

NBS atomic clocks are direct contributors to the world's uniform time system, Coordinated Universal Time (UTC), maintained by the Bureau International de l'Heure (BIH) in Paris, France. Since NBS-4 and NBS-5 form the primary NBS standard, their frequencies are periodically used to check and calibrate an ensemble of continually running commercial cesium clocks. This standard and ensemble form the NBS atomic clock system, which generates the necessary atomic time disseminated by several NBS methods.

Time and frequency signals, covering over half the world, are broadcast 24 hours a day from three NBS radio stations: WWV—2.5, 5.0, 10.0, 15.0, 20.0, and 25.0 MHz; WWVB—60 kHz; and WWVH—2.5, 5.0, 10.0, 15.0, and 20.0 MHz. WWV and WWVB transmitters are located near Fort Collins, Colo.; WWVH transmits from the Island of Kauai in the Hawaiian Islands. A time-of-day telephone service is also provided by WWV (303/499-7111) and WWVH (808/335-4214). During the past 2 years, NBS has additionally offered time-of-day signals from a NASA geostationary satellite that covered the North and South American continents and the Atlantic and Pacific Oceans. □

SCHEMATIC ILLUSTRATION OF MAJOR COMPONENTS AND BEAM PATHS OF NBS-5
Vertical Scale Exaggerated



SOLID LINES SHOW OPTIMAL APPLICATION OF THE MICROWAVE FREQUENCY AND POWER TO THE CAVITY TO EFFECT A COMPLETE CHANGE OF ENERGY STATE.