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ACCOMPANYING the maintenance of the Nation's primary standard of frequency is a continuing investigation by the National Bureau of Standards of methods for improving the constancy and reliability of the standard. Some modifications incorporated within the last few years include the use of resonator crystals to sustain the accuracy of the standard, more sensitive and reliable temperature controls, and precise clock mechanisms to monitor time signals. The use of new and improved components has resulted in a reduction in the number of replacement parts and represents a considerable saving of time normally required for preventive maintenance procedures.

The NBS primary standard of frequency is the foundation upon which are based all time and frequency transmissions from the Bureau's radio broadcasting stations WWV in Beltsville, Maryland, and WWVH, Maui, Hawaii. From these stations, standard radio frequencies of 2.5, 5, 10, 15, 20, and 25 Mc are transmitted continuously, night and day, with accuracies of 2 parts in 100 million. Two standard audio frequencies, 600 and 440 cycles (the standard musical pitch A above middle C) are broadcast on all of the radio carrier frequencies; every five minutes they are interrupted for intervals of 1 minute. A pulse of 0.005-second duration occurs on each carrier frequency at intervals of 1 second. The time intervals, as transmitted, are accurate within $\pm$(two parts in 10^8+1 microsecond). An announcement of radio propagation conditions, pertinent only to transmission paths in the North Atlantic area, is broadcast in code on each of the standard radio frequencies.

The National Bureau of Standards primary standard of frequency consists of nine crystal-controlled oscillators and eight quartz crystal resonators. Three of the oscillators are located at the Beltsville installation of WWV—one acting as the main oscillator for all of the transmitters, the second as the standby, and the third as a spare. The remaining six oscillators and the eight quartz crystal resonators are maintained at the Bureau's Washington laboratories. All of the crystal-controlled oscillators are kept in continuous operation and the best ones—those having the least amount of deviation from 100 kc for the immediately preceding six months period or longer—are the units from which the standard frequency is determined.

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BS PRIMARY STANDARD OF FREQUENCY

The oscillators are controlled by specially made GT-cut quartz crystals; the resonant frequency of each crystal is 100 kc. In an investigation of the crystals, it has been observed that generally their performance curves (frequency vs amplitude) have a flat region within which the crystal frequency is relatively constant. When the driving current reaches a value of about 150 microamperes, the frequency decreases sharply. In view of this fact, the driving current applied to the crystal units of the newer NBS oscillators is less than 100 microamperes. A decided improvement in performance occurs and is especially evident when the newer oscillators are compared with the older oscillators with driving currents of over 500 microamperes. Increased short-time stability and over-all reliability has also been achieved.

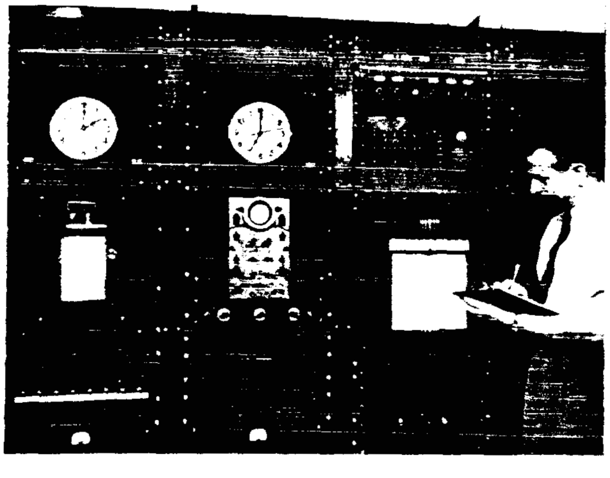
The eight resonator crystals have been part of the frequency standard for about one and a half years. Each resonator's frequency is used in the analysis of the accuracy and constancy of the other nine oscillators. All eight crystals, each also with a resonant frequency of 100 kc, are installed in a single temperature-controlled oven. They do not incorporate additional components such as tubes, resistors, or capacitors. They are not driven continuously but are used only once a day as part of a balanced-bridge network for comparison with one of the standard oscillators. Furthermore, the current driving the crystals is only ten microamperes.

Once a day the value of each resonator crystal and each standard oscillator is determined. First, a precision variable oscillator is adjusted to the frequency of one of the resonators. The variable oscillator is then compared with one of the standard oscillators, and the beat or difference frequency is counted on an electronic frequency counter with a precision of the order of parts in 10^{10}. The variable oscillator is readjusted to the second resonator crystal and again compared with the same standard oscillator. The difference frequency between these two oscillators is again recorded. This procedure is continued until data are available indicating the amount of frequency deviation present between the standard oscillator and each of the resonator crystals. One of the remaining eight oscillators is used as a reference against which all of the other oscillators are compared. Thus, data are available for precise determination of any changes, relative to the system, which may occur in any oscillator or resonator in the system.

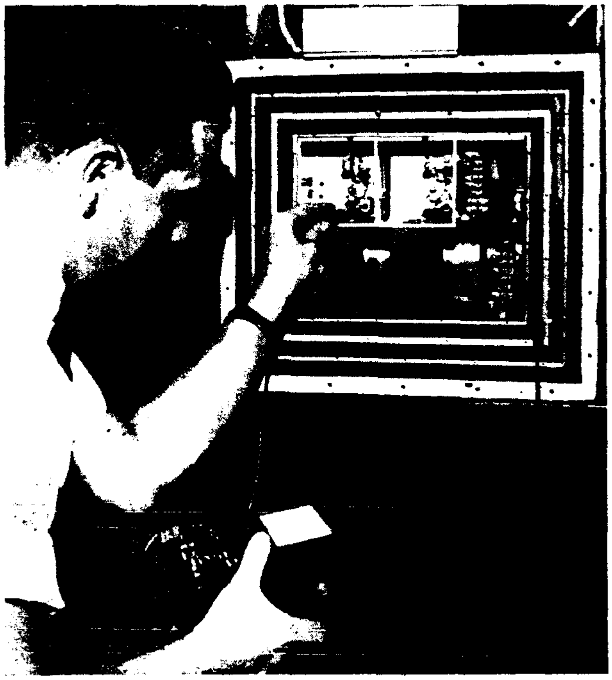
The reference oscillator is also instrumental in obtaining a continuous record of the frequencies of the three standard oscillators at the WWV installation. Automatically the main, standby, and spare oscillators are successively switched at preset intervals to a low power VHF transmitter. The signals are beamed to the NBS laboratory in Washington, and the received signals are compared with the signals derived from the reference oscillator.

A more precise and reliable temperature control of the ovens enclosing the oscillators has been developed. The oven essentially consists of four concentric cubical chambers: the center chamber holds the oscillator unit, and the space of the next and outer chamber is filled with felt insulation. An air-chamber containing mat heaters separates the insulated chambers. The outer heater, designed for coarse temperature control, is controlled by a simple mercury thermostat.

Control of the inner heater, designed to respond to very small changes in temperature, is achieved by use of a network in which the heater element is part of the sensing circuit. In effect, one pair of arms of a resistance bridge is made up of wire with a high temperature coefficient and the other pair of wire of negligible temperature coefficient. Current through both pairs of wires supplies the necessary heat. An oscillatory circuit composed of the bridge connected between the input and output of a high gain amplifier—essentially a



Frequency monitoring equipment. Two racks at left contain spark chronograph and chronoscope used to measure time differences between any two standard-controlled clocks to precision of ±0.02 millisecond. Third rack from left contains automatic beat frequency recorder for intercomparing primary frequency standards. Automatic switching unit (top panel) connects each of six oscillators sequentially to dual electronic frequency counter (next panel below). Recording frequency meter with sensitivity of ±1 part in 10^{10} provides permanent record of frequency differences between standards. Remainder of rack contains power supplies, proportional voltage generator that converts count summation to recorded voltage, and dual frequency multiplier and demodulator providing difference frequencies between oscillators.



Temperature control compartment containing crystal and temperature-sensitive components of one of nine crystal-controlled oscillators of NBS primary standard of frequency. Compartment is made up of four concentric cubical chambers. Quartz-crystal unit of osillator is contained in electronically controlled cylindrical oven (at back of center chamber). A special resistance bridge-feedback amplifier arrangement maintains temperature constant to 0.001 deg C. Unit on top of oven contains vacuum-tube amplifier portion of oscillator.

feedback loop—controls the temperature. When the temperature is near the desired value—the bridge is slightly unbalanced—the amplifier is in a stable condition. As the outer temperature of the oven decreases, the bridge becomes further unbalanced and the amplitude of the output oscillations increases so as to supply more current to the bridge wires and, consequently, more heat to the oven. This condition continues until the temperature regains the operating assigned value. Under normal room conditions, the temperature is controlled to better than 0.001 degree C.

The temperature-control oven for the eight resonator crystal units is constructed with six concentric cubical chambers. All eight crystals are enclosed in the one oven, and the temperature control is achieved with mercury thermostats connected to both inner and outer heaters. Inner temperature variation is less than 0.005 degree C for average variations in room temperature. The standard oscillators at the NBS transmitting station in Beltsville are installed in a room approximately six feet on a side built about 25 feet below the ground. The complete room is temperature and humidity controlled.

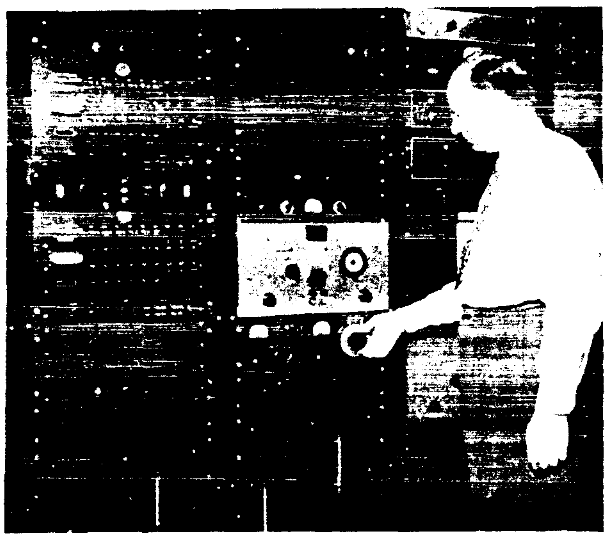
Each of the frequency standards is equipped with individual power supplies and includes improved filters to permit better regulation and control. The supplies all have plate and filament batteries that are continuously float-charged, and in the event of an a-c power failure they can carry the full load for many hours.

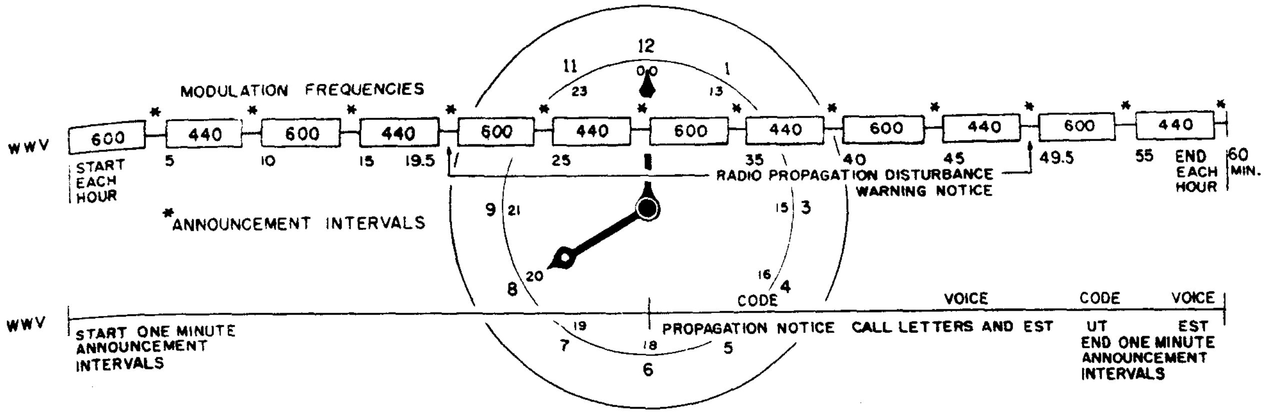
In order to monitor accurately the time signals generated by the frequency standard, one of the NBS standard oscillators is used to drive a synchronous clock. The 100 kc output of each oscillator is electronically divided to a frequency suitable for driving a spark chronograph and chronoscope. The instruments are designed so that the driving oscillator may be compared with the time signals of the other five oscillators in the Washington laboratory and those at the WWV installation to differences as small as 20 millionths of a second.

The time differences or variations in each clock are reported each day to the U. S. Naval Observatory and are used in evaluation of the mean solar time. The Observatory issues weekly corrections to the WWV signals with reference to mean solar time. Quarterly corrections for the slight deviations in absolute time and frequency as broadcast by WWV are also available from the Bureau.

One of the principal uses of the WWV transmission of standard frequencies is that of calibration of precision oscillators. The system commonly employed is demonstrated by the manner in which the WWVH (Hawaii) transmissions are synchronized with those from WWV. Three oscillators are used to give accurate results. One oscillator unit is adjusted to one of the standard frequency transmissions from WWV. Each of the other two oscillators is compared with the

NBS primary resonator frequency standard. Rack at right contains temperature controlled oven (constant to 0.001 deg C) in which resonator crystals are located (panel with two thermometers). Rack also includes special bridge for comparing oscillator with quartz resonator crystals, precision adjustable oscillator (operator is shown making adjustment), power supplies, and high gain, narrow band receiver. Rack at left contains dual electronic counters for counting frequency differences between oscillators. Also included is additional temperature controlled compartment for use in measuring experimental resonator crystals.





Schematic diagram showing services offered by NBS Radio Broadcasting Station WWV. At start of each hour, a 600-cycle tone is heard for four minutes. This is interrupted by a 1-minute announcement period in which Eastern Standard Time is announced in voice and Universal Time in code. At conclusion of announcement period, a 440-cycle tone is transmitted for four minutes. Announcements are repeated for new time and then followed by 4-minute 600-cycle tone. A pulse of 0.005-second duration at intervals of one second is broadcast simultaneously with audio notes. At 19½ and 49½ minutes past the hour, radio propagation disturbance warnings are transmitted in code.

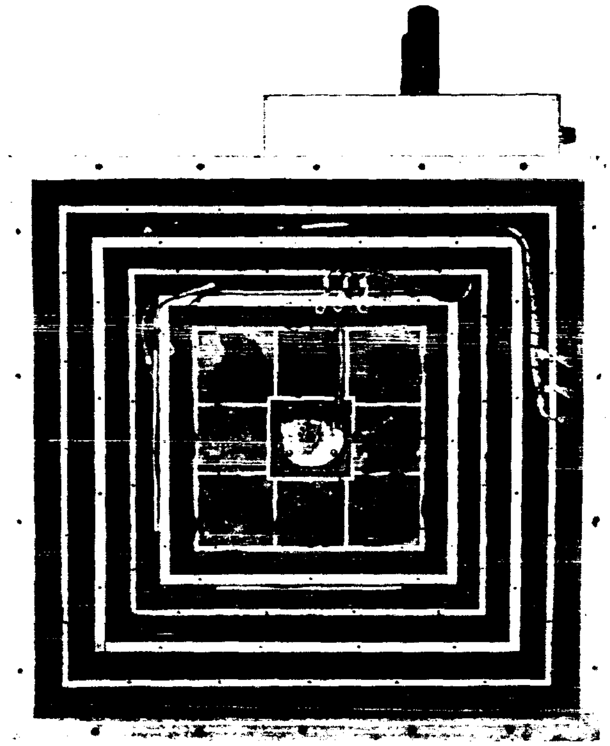
first, and the difference in frequency between them is measured. A better average of the deviation from the WWV transmissions is achieved by this method than the one which would be possible if only one oscillator was involved.

One of the major continuing projects of the Bureau's frequency standard laboratory is the development of more precise quartz oscillators. Another is the investigation of the use of atomic- and molecular-resonance standards as a means for obtaining higher accuracies. Reference to such invariant standards would greatly simplify the maintenance of precise frequency and time standards.

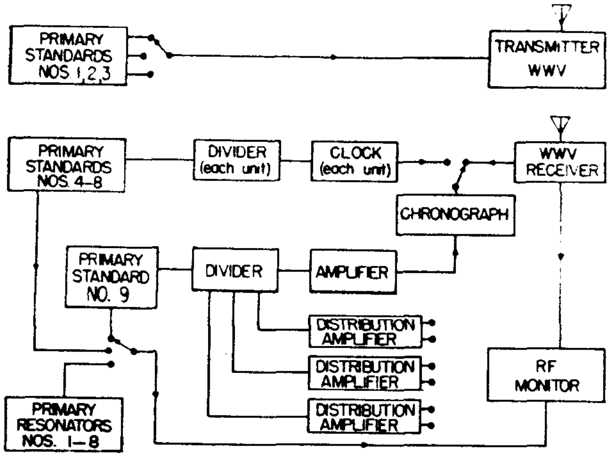
NBS Automatic Announcing System

Accompanying the improvements in the NBS Standard of Frequency is a complete change in the method of reproducing the announcements transmitted by Radio Station WWV. Formerly, the hour, minute, and propagation announcements were sent in code or voice from separate machines. The complete voice message was recorded on magnetic tape, and no portion was used twice during the day. The present method utilizes motion picture film sound track, a photoelectric scanning system, synthesis of the message, and electronic amplification as a means for providing voice and code announcements.

The new system of making WWV announcements, specially developed to NBS specifications by the Audichron Company of Atlanta, Georgia, is similar to equipment used in many municipal telephone exchanges that include time announcements as part of their service. The NBS system is designed to announce "Station WWV. When the tone returns, Eastern Standard Time is ———". It also gives the Universal Time in code and, once every half hour, the radio propagation forecast for the next 12 hours. The sound is reproduced by scanning photographic film with a narrow beam of light. The light passing through the film is reflected onto a photoelectric cell, and the electrical impulses thus produced are amplified to supply the speech input equipment. The voice announcement films are mounted on three drums which are actually cylindrical mirrors: one contains the preliminary announcements,



Temperature control compartment containing resonator crystals of primary standard of frequency. Oven is made up of six concentric cubical chambers. Partitioned center chamber contains eight quartz-crystal resonators and switch for connecting each crystal to external measuring circuit. Box on top of oven contains heater controls and power-supply line filters.



Block diagram of NBS primary standard of frequency.

another the hours, and a third the minutes. The code machine has three similarly mounted films that contain the hours, minutes, and the propagation information. From these records, the machine "builds up" or composes the complete message in the proper sequence. An identical announcing system is provided for standby operation in case of failure of the main unit.

Each set of three drums is mounted on a common axis. Above each set of drums is a carriage supporting a photoelectric cell and light source. The surface of each drum is highly polished, so that the image of an exciter filament lamp, focused on the sound striations on the film, is reflected upon the photocell contained in the scanning head. The strips of motion picture film are wound spirally upon the cylindrical mirrors, which revolve at 30 revolutions per minute. Synchronous motors drive the drums and derive their operating voltages directly from the NBS frequency standard. Thus the drum revolutions are always in step with the signals transmitted by WWV, which precisely synchronizes the announcements with the tone-break periods.

The scanning head is made to follow the film strip by a cam follower running on a spiral groove milled into the surface of the main cam. The spiral groove is endless, but the lead at one end is cut at a smaller angle than the rest of the cam so that the carriage remains nearly stationary for a few seconds at the beginning of each sweep cycle and then scans in both directions. A complete cycle of the machine is exactly 10 seconds.

Each strip of film has one part of a time announcement recorded on it. Because WWV transmits time announcements every five minutes (288 different announcements per day), the film carrying the minutes needs only the words 5, 10, 20, etc. The minute drums are wound with 24 strips of film, two for each 5-minute interval in the hour. The first 2 strips have no sound photographed on them while the last 2 strips carry "fifty-five." The first strip on the hour film is blank, and the last reads "twelve." The preliminary voice announcement, "Station WWV . . . . ," is recorded on a single strip. The same photocell responds to a tape containing the AM and PM announcements, which are selected by a solenoid-operated shutter. The code films containing the propagation notices are scanned by a photocell which can be displaced manually to the proper film strip with the latest information. This operation is performed every 6 hours.

Suppose, for example, that the next announcement will be 3:45 PM EST. The scanning head is at one end of the carriage. At 3:44:40 the photocell begins to scan the film containing the preliminary announcement. At 3:44:41 the photocell responds to "Radio Station WWV. When the tone returns, Eastern Standard Time is ———." By this time (3:44:46) the scanning head has reached the film carrying the hour, and the word "three" is fed into the amplifying system. The operation continues so as to carry the scanning head to the minute film so that "forty-five" can be heard. In the proper time sequence, the output from the film containing "PM" is also put in the system. Thus, by 3:44:50, the hour, minute, and meridian position have been announced. Meanwhile, the scanning head on the code machine has reached a position so that at 3:44:50.5, the Universal Time is broadcast in code in the same manner as was the voice announcement. By 3:44:55.5, the code announcement is concluded, and the carriage above the voice drums is in a position to reproduce "3:45 PM." Both the code and voice announcements are completed from about two- to three-quarters of a second before 3:45:00.

At 19½ and 49½ minutes past the hour, a radio propagation notice becomes part of the code announcement. This announcement—either "N" (normal), "U" (unsettled), or "W" (disturbed) and a number (3 to 7 signifying poor to good propagation conditions for the next 12 hours)—begins exactly at 3:19:30 and 3:49:30, for example, and is followed by the voice and code announcements described above.

The scanning-revolving mechanisms are arranged so that when 60 minutes have expired, the hour drum is advanced to the film containing the next hour. The photocell responds to the reflected light at all times. An electronic alarm system is available that utilizes this between-announcement scanning voltage. If the voltage is not of a predetermined value, the alarm will be set off and the announcement system will be automatically switched to the standby unit.

Besides being completely automatic, the NBS announcing system makes it possible to broadcast information more reliably than with tape methods. A further refinement planned for the near future is the incorporation of means for operating the synchronous motors directly from commercial power lines. Frequency control of the voltage supplying the synchronous motors will be achieved by phasing networks that will keep the time announcements exactly in step with the frequency standard.

For additional information concerning NBS time and frequency transmissions, see Standard frequencies and time signals from WWV and WWVH, *NBS letter circular, LC 1009. For information on accurate monitoring of time signals, see* New spark chronograph and chronoscope, *NBS Technical News Bulletin, Vol.* ***35****, 1, 14 (Jan. 1951).*