Crystal Clock for Accurate Time Signals

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DEMAND for time interval signals accurate to a microsecond in navigation, seismology, and geological surveys, led to the development of the crystal clock, utilizing electronic circuits instead of conventional clock mechanisms. Developed by the National Bureau of Standards, the crystal clock is now broadcasting one-second time pulses throughout the world—the only continuous time signal service provided by any country. One or more of the frequencies broadcast continuously (5, 10, and 15 megacycles per second and 2.5 Mc. at night) may be received on the usual short-wave radio receiver. These highly-accurate time signals, which proved of great assistance to the Armed Forces in World War II, are now providing an expanding peacetime service to industry, scientific laboratories, and schools.

The heart of the Bureau's crystal clocks consists of a flawless crystal of quartz with series resonance frequency of approximately 100,000 or 200,000 cycles per second. By electron-tube circuits the crystal is continuously oscillated and the resulting frequency is divided with no loss of accuracy to 60 cycles per second. This 60-cycle frequency supplies power to a synchronous motor which, through gear trains, drives contacts that give intervals of one minute, five minutes, and thirty minutes to control the automatic announcement equipment of the transmitters. The motor also operates a one-second contact which opens an electrical gate and allows a highly accurate seconds pulse to be broadcast.

The accuracy of the seconds pulse does not depend on the closing time of the contact. The accuracy is determined by the crystal oscillator frequency which controls a square-wave generator and the adjustment of this generator which supplies voltage to an amplifier during alternate 1/200th second intervals. A standard 1000-cycle frequency is fed into the amplifier so that the output consists of groups of five cycles of 1000-cycle frequency spaced 1/200th second apart. During the time when no signal is being passed by the amplifier, the seconds contact is closed and it is opened during the next no signal period. Therefore, the seconds pulse consists of five cycles of 1000-cycle frequency given once each second, supplying a seconds pulse 1/200th second long.

The absolute accuracy of the frequency of the crystal oscillator is at present within a few parts in one hundred million. Although the seconds pulses are obtained by exact division of the quartz plate frequency, owing to possible phase shifts and other difficulties, the pulses are accurate to one part in one million. In other words, the length of a one-second interval as broadcast is accurate to one microsecond. An interval of one minute or larger is accurate to a few parts in one hundred million.

However, to supply an accurate time interval is one thing; to supply a time signal with a high absolute accuracy is quite another. The Bureau depends upon the Naval Observatory to supply the absolute time and differences between this and the time signals broadcast from the Bureau's radio station WWV at Beltsville, Maryland. As these differences are based upon data obtained both before and after radio time signal has been transmitted, it is necessary to extrapolate continually the data from a known correct value two or more weeks in the past. For this reason there are days when the error to the absolute value of the broadcast time may be as great as 0.02 second.

The quartz crystal of the clock is cut to a certain size and at an angle to the axis of the mother crystal to give the desired frequency and temperature coefficient. Each clock also has a driver circuit arrangement and frequency-dividing equipment. The rate of the crystal clock depends on the temperature, pressure, and humidity of the air around the quartz plate, and the operating voltage of the circuit supplying the frequency-conditions which call for extremely accurate control. Pressure and humidity are maintained by sealing the quartz plate in a glass or metal enclosure; temperature is held constant by placing the quartz plate and certain important parts of the circuit arrangement in a constant-temperature oven.

There are certain similarities and differences in the crystal clock and the conventional pendulum clock. Each is affected by changes in pressure and temperature; but these conditions may be controlled. The pendulum clock, however, is affected by changes in the gravitational constant to such an extent that changes in water level in the ground, or the tides when the clock is near the seashore, may result in a measurable change in rate. Such changes in gravity produce no noticeable effect on the rate of the crystal clock. It is possible to compare crystal clocks at high frequencies to determine erratic behavior accurately. This has not been done with pendulum clocks.

At the Bureau the equipment used in comparing the various crystal clocks measures accurately in a few seconds a change of rate equivalent to 1 second in 50 years. During one month, the change in the rate of drift of a good crystal clock may be less than +1 part in one hundred million. Therefore if the clock

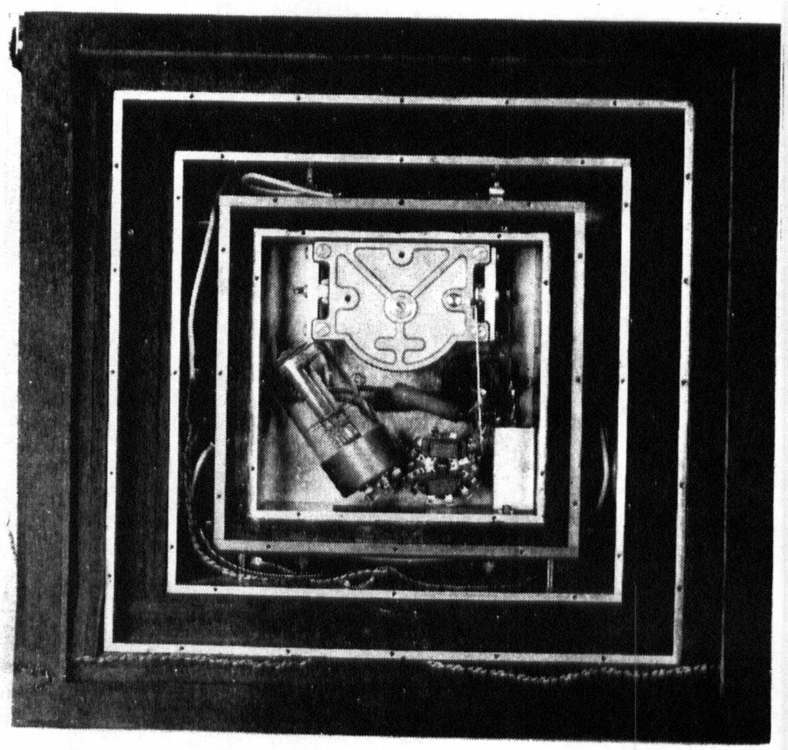

Fig. 1. Interior view of the NBS 100-kc. standard frequency oscillator which provides the constant frequency controlling the crystal clock. Quartz-crystal unit, in evacuated container, and part of oscillator circuit arrangement, are shown in temperature-controlled compartment. Layers of aluminum and felt are used to obtain uniform temperature.

began the year with correct time and zero rate of drift, it would have gained approximately 2 seconds by the end of the year. The short-time variations (10 minutes or less) are less than one part in one billion.

The broadcasting of time by the National Bureau of Standards came as a by-product of the standard frequency broadcast services which were begun in 1922. Intermittent broadcasts during certain hours of the day became continuous after January 1941, with station identification at five minute intervals. The one-second pulses given as a modulation to the transmitted signal were not announced time signals. However, these pulses did mark time intervals which could be used for the timing of events or for determining the rate of a clock.

Owing to the interest of the military forces, the one-second pulses of the crystal clock were brought into close agreement with the Naval Observatory time signals. In February, 1944, the 59th second pulse was omitted to designate the end of each minute. Announcements of Eastern Standard Time in Continental (International Morse) Code have since been added during the announcement period, which occur each five minutes. These announcements are given during an interruption to the standard audio frequencies which start exactly on the hour.

In addition to the continuous accurate time intervals and announcements, the broadcast by radio station WWV provides standard radio frequencies,

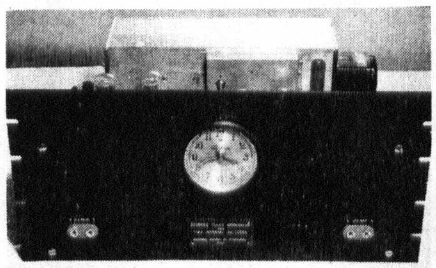

Fig. 2. Front view of the NBS Seconds Pulse Generator and Time Interval Selector.

standard audio frequencies (440 and 4000 cps.), the standard musical pitch (A above middle C), and radio propagation disturbance warning notices.

There are many peacetime uses for frequency and time services other than checking the operation of clocks and other time-pieces. The accurate measurement of time is of importance in seismology, geodesy, and navigation, in other countries as well as our own. The broadcasts are being utilized by many organizations such as schools and universities, scientific laboratories, manufacturers, and users of radio communications equipment; observatories which are widely separated and make automatic recordings of astronomical phenomena and motions of earth; power companies which continuously check the frequency of power generated at widely separated stations; communications companies which regularly transmit photographs by wire or radio; and certain radio broadcast companies which synchronize program features from various countries.

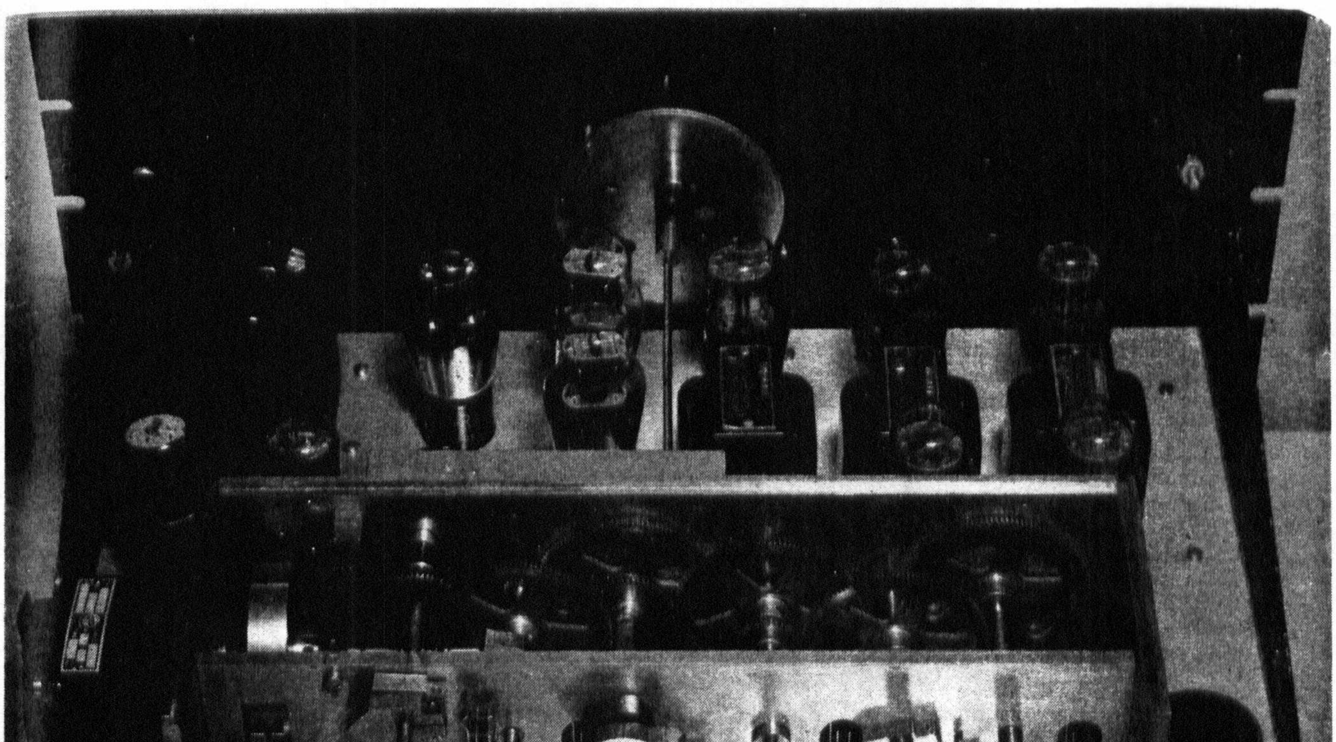

Fig. 3. Rear view of the NBS Seconds Pulse Generator and Time Interval Selector used in the time control equipment of the Bureau's radio station WWV. The one-second contact is made by a cam on the flywheel immediately to the right of the electric motor. The succeeding cams are for the longer time intervals, controlling the announcements for the radio station.