Post Office Quartz Oscillators for Use in Time and Frequency Standardisation Abroad

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In 1953 the Post Office was asked to supply several quartz crystal oscillators to America and Canada for use as time and frequency standards. This article stresses the growing importance of such standards, and briefly describes the uses and principles of calibration of oscillator clocks at an observatory. The article concludes with a description of the installations carried out in America and Canada.

INTRODUCTION

THE last two decades have witnessed rapid expansion in the fields of electronics, radio navigational aids, radar and telecommunications, these arts having received especial impetus from the impact of the last war. Each new development has been quickly followed by demands which have required large-scale production of units, and systems. Large-scale manufacture and operation has, in the main, only been achieved by the exercise of economies in materials and time, which in their turn have required more rigid control on all permissible working tolerances. Considering the field of communications, many channels are now provided economically on either cable or radio links, by the maximum loading of the allocated band of the frequency spectrum; this has required a better knowledge and stricter control of operational frequency. Similar conditions apply in air transport and military air operations, where both time and frequency have to be accurately known. Laboratories of either government or commercial establishments, developing high-precision electronic equipment, time pulse techniques, or quartz crystals, require accurate knowledge of frequency and time, as do also the astronomical observatories in studying the movements of the solar and star systems of the galaxy.

The common factors in the above activities are time and frequency, and an ever-increasing demand arises throughout the world for high-precision reference standards of these factors. The importance attached to such standards by all the leading powers can be seen in the establishments which they have set up in various countries, operating by international agreement, to radiate standard reference frequencies and time signals. Great Britain is responsible for providing a standard frequency coverage over Western Europe and North Africa. These transmissions are radiated for the National Physical Laboratory from the Post Office Radio Station at Rugby, as are also daily time signals under the control of the Royal Greenwich Observatory. The United States of America provides standard frequency and time service transmissions from the National Bureau of Standards station at Beltsville, Maryland, with another station covering the Pacific zone situated at Maui, Territory of Hawaii; other time signals under the control of the U.S. Naval Observatory at Washington are radiated from Annapolis, Maryland, Mare Island, California, the Canal Zone and Pearl Harbour. Canada and Australia emit time signals, and standard frequency services are maintained by Italy, South Africa, Japan and Belgium. It will be evident, therefore, that the system is already extensive; it is also expanding, and much effort is constantly being applied to improve the accuracy of all signals transmitted.

The British Post Office has been concerned with the development of high-grade quartz-crystal-controlled oscillators for many years and maintains a Primary Frequency Standard at its Dollis Hill establishment. Such high-stability oscillators can be employed with equal facility as either frequency or time standards and, in the past, equipments embodying these oscillators have been supplied to the National Physical Laboratory, Teddington, and observatories of the United Kingdom and Commonwealth. The most recent orders for a number of oscillators for clock control were placed with the Post Office in 1953 by the U.S. Naval Observatory in Washington, the Dominion Observatory of Canada and the National Research Council of Canada. In order that advantage of Post Office experience could be obtained, the author was assigned the job of superintending the installation work abroad and, with the equipment, travelled to Washington in air transport provided by the U.S. Naval authorities. The Canadian authorities arranged for their equipment also to be flown across using a Royal Canadian Air Force plane. The work of installation in America and Canada required a period of five weeks, during which time five quartz oscillators were set in operation. Arrangements such as these for the overseas installation of quartz oscillators, undoubtedly a tribute to the Post Office, are something of a precedent, and as such have prompted this article.

Many Post Office engineers will be already acquainted with the use of crystal-controlled oscillators on coaxial cable and carrier systems, but the more specialised uses in observatories are less known; as two of the establishments in America and Canada are observatories, it is thought that a brief survey of their function in frequency standardisation could usefully precede a description of the overseas itinerary.

CHRONOMETERS

The duties of an observatory are many and varied, but one of their main functions is the maintenance of a time service. Prior to the introduction of quartz clocks, the passage of time was marked at the observatory by pendulum clocks; in these, the swing of the pendulum may have had a period of half, one, or two seconds, corresponding respectively to frequencies of two, one, or a half, oscillations per second. The periods marked by these oscillations were integrated via the clock escapements to indicate periods of minutes and hours, on dials. In the quartz clock the slow beat of the pendulum has been replaced by an oscillation rate of 100,000 per second produced by a vibrating quartz crystal. The periods defined by each crystal oscillation, more accurate in time than those of the pendulum, may be integrated by electronic means to measure periods of minutes and hours, as in the case of the pendulum clock. Fig. 1 shows in block schematic form the way this can be

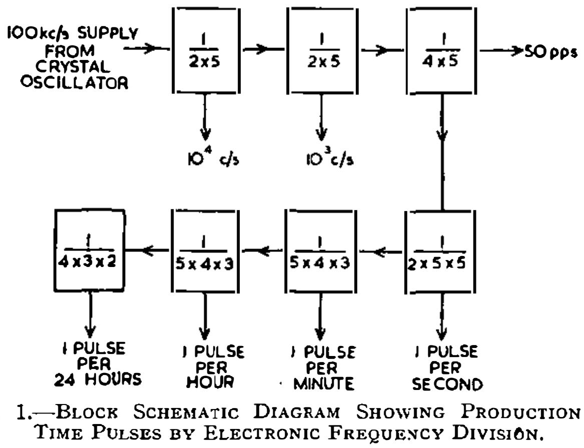

FIG. 1.—BLOCK SCHEMATIC DIAGRAM SHOWING PRODUCTION OF TIME PULSES BY ELECTRONIC FREQUENCY DIVISION.

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achieved using a chain of electronic dividers driven by the 100 kc/s crystal. Division down to 50 c/s would probably be effected by multivibrator-type dividers, from which frequency it is simple to continue down to seconds, minutes and even days by counter-type dividers, probably employing cold cathode gas triode valves. Some establishments may use the 1,000 c/s supply to control a phonic motor clock from which second and minute pulses are obtained from cam-operated contacts. The accuracy of this arrangement is, however, inferior to the electronic chain.

TIME AND FREQUENCY STANDARDISATION

In checking the frequency of an oscillator in cycles per second or the time-keeping properties of a quartz clock, reference has to be made to the fundamental unit of time, and for this information recourse is made to data issued by one of the astronomical observatories already referred to. In Great Britain the Royal Greenwich Observatory is responsible for the determination of standard time and the emission of time signals.

The basis of time measurement at an observatory is, in general, the period of rotation of the Earth, and although this period is now known to vary cyclically throughout the year, no error in principle will be involved if for the purpose of this description the Earth's rotational period is considered to be uniform. Consider an observer on the equator noting the position of the sun overhead and at the same time starting some type of chronometer; if he now waits until the sun appears again in the same position overhead and then notes his chronometer reading, the time difference so observed corresponds roughly to 24 hours. In practice, instrumental measurements are effected which eliminate the human and positional errors which would be present in the rough observation described. For instance the sun is not used as the marker in space, because the disc subtends a comparatively large arc at the observational point and hence does not provide a precise point reference; also, because of the sun's closeness to the Earth when considered on an astronomical basis, the daily progress of the Earth in its orbit round the sun means that the Earth would rotate through an angle of more than 360° during the period between observations. To counter these sources of inaccuracy, the measurements are effected against certain selected stars, which are so distant that they provide a point source of light for reference, and do not show any apparent shift in space when viewed from either end of the Earth's orbit. The time so determined is known as sidereal time, and requires modification by a constant factor if solar, or sun, time is to be expressed.

For many years past these stellar observations have been effected using what is known as a "transit telescope." This telescope can swing only in the plane of the meridian. It is the duty of the observer to ensure that for any particular star the instrument is set to catch the star image in its field, and during transit (i.e., the apparent passage of the star across the field), to hold the image bisected by an adjustable reference line. While the transit adjustment is in progress electrical circuits associated with the telescope transmit a series of pulses which are recorded on a tape chronograph; simultaneously, a series of pulses marking minutes and seconds from the local quartz clock of the observatory are impressed on the tape. The time relationship between the local clock and the mean time of transit of the star can now be determined. At the end of another sidereal day a similar relationship can be established for the same star if observational conditions are suitable, and the new comparison will show whether the local clock has gained or lost in time in terms of the Earth's period of rotation, and hence whether the driving crystal frequency is above or below its nominal value. Such measurements are carried out over periods of years, thus enabling the long-term time-keeping properties of the clocks to be established. Because of the relatively large scatter of the transit measurements during any one night, some considerable time must elapse before the trend of clock performance is determined. Once this is established the time service is maintained by extrapolation of the clock performance (confirmed by the use of several clocks), and only small adjustments are made from time to time which tend to steer the clock time in accordance with the trend of astronomical observations. These measurements are the limiting factor on the absolute determination of time, and hence frequency, which at present is of the order of one part in one hundred million (i.e., approximately one millisecond per day). The Royal Greenwich Observatory is bringing into use a new stellar observing device known as a "Photographic Zenith Tube" (PZT); this employs a mercury pool by which the light from the star under observation is reflected on to a photographic plate, thus eliminating setting errors and operators' personal errors. Several images of the star are impressed on the plate, each of which can be fixed in time in terms of the local clocks, and hence an accurate time of the mean transit across the meridian determined. The method should improve accuracy of time determination by one order of 10.

In practice, the determination of time at an observatory is not so simple as described. The work is very exacting and requires much intricate mathematical computation because of the many variable factors involved. Mention has already been made of the variations in rate of the Earth's daily rotation; by modern quartz clock standards these variations are too large to be ignored and the astronomers are adopting a new time system called "Ephemeris Time" which is based on the rotation of the Earth round the Sun. This longer time base is independent of the Earth's short-term variations and hence provides a time reference which is more uniform than that obtainable from daily measurements.

Once the frequency of the crystal oscillator controlling the clock has been determined, other clocks and oscillators can be standardised by direct comparison using frequency measurements or time-pulse technique. By the use of radio transmissions of time signals or standard frequencies, the clocks and oscillators of establishments remote from the observatory can similarly be standardised. It is current practice for each observatory to measure the time signals of other observatories in terms of its own clocks; thus an international monitoring service on time is maintained. The effectiveness of each station is limited by its time and frequency measuring capabilities, and hence a continual search goes on for improved methods and equipment.

THE CRYSTAL OSCILLATORS

The oscillators supplied by the Post Office for Observatory and Frequency Standards use Essen ring-type crystals, of nominal frequency 100 kc/s. The frequency of this type of crystal varies with temperature in accordance with a parabolic law and it is practice to mount the crystal in a thermostatically controlled oven, the temperature of which coincides with the apex temperature of the crystal (i.e., the frequency of the crystal rises to a maximum as temperature is increased and then falls again for further increases in temperature; the point of maximum frequency is known as the "apex" or "turn-over" temperature). Controlling the crystal at this temperature, where the frequency/temperature coefficient is effectively zero, ensures that the oscillator frequency is not affected by changes in ambient temperature. The crystal has a high "Q" value, $\omega L/R$, usually in the region of one and a half to two million, which endows the oscillatory circuit with a large phase/frequency coefficient. This means that only a small frequency change is required to compensate any circuit phase changes; these usually arise from power supply and temperature variations and are kept to a minimum by choice of components. The combined result of the above is an oscillator which is practically independent of changes in temperature and power supplies.

A view of the oscillator with cover removed is shown in Fig. 2. The oven which houses the ring-type quartz crystal is in the centre of the panel, to the left of which is the unit controlling the temperature of the oven. On the right is an amplifier unit which maintains crystal oscillation.

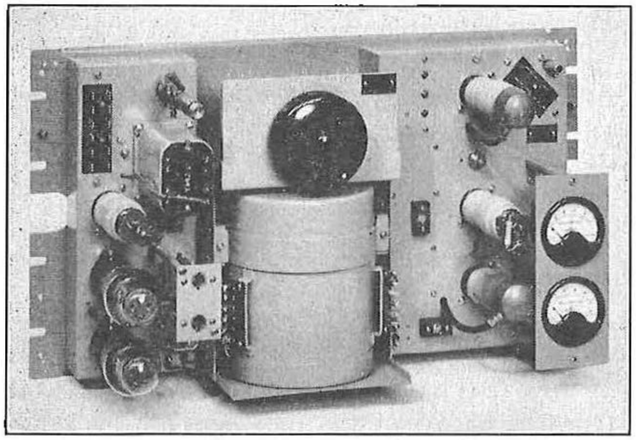

FIG. 2.—THE OSCILLATOR WITH COVER REMOVED.

Continuity of power supply is essential for the satisfactory long-term operation of the oscillators as clocks, and some form of stand-by supply to cover mains failure is always necessary. In preparing the oscillators for overseas installation, as much of the circuit testing and alignment as possible was carried out in the laboratory at Dollis Hill, thus leaving the minimum amount of testing at the final location.

INSTALLATION WORK IN AMERICA AND CANADA

American Installation.

The first oscillator was installed at the U.S. Naval Observatory in Washington, transport having been provided on a plane of the Fleet Logistic Air Wing (U.S. Navy). Over the Atlantic the average cruising speed was 330 m.p.h. at a height of 20,000 ft., conditions being very steady, so that no undue precautions were required in stowing the crystals. Two crystals were carried, and in accordance with Post Office practice, the crystal units were housed in ballasted carrying cases as a protection against vibration and shock; these cases contained battery-operated test oscillators which enabled the activity (i.e., quality) of the crystals to be determined at any time. The journey continued by road from the Navy Air Base to Washington, a distance of about 70 miles.

The Naval Observatory buildings are extensive, laboratories, observing domes and workshops ringing the main building which houses the time department. The observing equipment consists of two Photographic Zenith Tubes, arranged to photograph the same star simultaneously, and affording, as a result, a high degree of accuracy.

A special room was allocated at the observatory in which the Post Office crystal oscillators were to be mounted. The room, situated on the main ground floor corridor of the building is provided with a door having a glass inspection panel, through which members of the public (who pass through the observatory in large numbers) can view the new clock-controlling oscillators. The room is arranged to house three oscillators, each of which is mounted on a large block of concrete that floats on helical springs, and so forms an effective shock-proof support. The stand-by power supply for each oscillator is provided by a small D.C./A.C. rotary converter. When the mains supply fails a relay releases and starts up the converter which is powered by batteries; at the same time the input to the oscillator power unit is switched from the mains terminals to the output of the converter, which supplies 115V A.C. (the nominal supply voltage in Washington). The H.T. supply to the oscillator is maintained during the running-up period of the converter by a large reservoir capacitor in the power unit. This method of providing stand-by power is current practice in the Post Office for Frequency Standards.

When the first oscillator had been set up its frequency was checked against existing standards at the observatory and the results showed that little change had taken place in the operating frequency of the oscillator during the journey from England. Subsequent frequency comparisons demonstrated that the Post Office oscillator had considerably higher stability (frequency/time) than those already in use at the observatory. It was intended that the remaining oscillators would be installed by the staff of the observatory, and at the time of writing, a second oscillator has been installed.

Canadian Installations.

After completion of the work at Washington, the author flew to Ottawa carrying one crystal as a spare against four projected installations in Canada. The Canadian apparatus had previously been flown to Ottawa, Ontario, in charge of a Canadian official who also took personal custody of the associated quartz crystal units.

The first installation was made at the Dominion Observatory in Ottawa where the time department of the observatory is equipped with one Photographic Zenith Tube of the same design as at Washington, and several oscillators using GT plate-type crystals. Prior to the introduction of these oscillators, timekeeping had been maintained by pendulum clocks housed in special vaults 20 ft. below ground level. The Post Office oscillator was given the honour of occupying one of these vaults, an ideal situation free from vibration and of even temperature. Stand-by power supplies for the oscillator were provided by battery-operated vibrator units of the type used on the Canadian Pacific railway cars for lighting purposes. On checking the oscillator against the local standards it was found that the frequency was within one part in 10^8 of the value measured at Dollis Hill.

The remaining three oscillators were installed in two departments of the National Research Council of Canada, an organisation with very extensive scope which ranges from research projects undertaken for industry and medicine, to military commitments. Two oscillators were set up at the Physics Division, and one at the Division of Radio and Electrical Engineering. At both divisions the installation work progressed smoothly, but at the time no final arrangements had been made for stand-by power supplies for the oscillators. The behaviour of the oscillators at the Physics Division was excellent and an effective demonstration of the frequency stability was afforded by having two oscillators of the same type together. The installation of the last oscillator at the Radio and Electrical Engineering Division concluded the work done in Ottawa, which in all had taken a little over three weeks.

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