A Buried Frequency Standard

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A new type of frequency standard which is free from mechanical and thermal shock and also independent of power supplies (all vital factors in the operation of quartz-oscillator frequency standards) has been set up at the Dollis Hill Radio Station. The standard is located 60 ft below ground level, and it is hoped that in a few months' time it will take its place in the Dollis Hill Standard.

Introduction

In a previous issue of the Journal[1] some details were given of quartz-clock equipment supplied by the Post Office to America and Canada and attention was drawn to the growing importance of such standards, and to the sustained efforts to improve technique. To augment the primary frequency standard maintained in the Radio Experimental and Development Branch of the Engineer-in-Chief's Office, at Dollis Hill, a new type of frequency standard known as a "Quartz-Crystal-Resonator Standard" has been developed. This type of standard differs from the conventional quartz-oscillator standard in that, unlike the oscillator, which is in a continuous state of oscillation, the resonator is only excited at infrequent intervals for sufficient time for its frequency of resonance to be determined.

It is known that, providing the temperature of a crystal resonator is maintained at a constant value, its frequency-time performance is similar to that of its oscillator counterpart. Advantage has also been taken of the temperature stability which exists some feet below the surface of the ground. The effect of the ground on penetration of heat waves generated at the surface may be considered somewhat as a transmission problem; i.e., the waves suffer an attenuation and a phase delay. For instance, at a depth of 30 ft a surface temperature change of 10°C will be attenuated to about 0·4°C, and will be delayed about six months, i.e., when the surface temperature is rising in the summer period, the measured temperature at 30 ft down is falling, corresponding to the previous winter temperature fall. It is only the long-term seasonal temperature changes which penetrate to these depths, the daily surface changes being, in effect, completely filtered out.

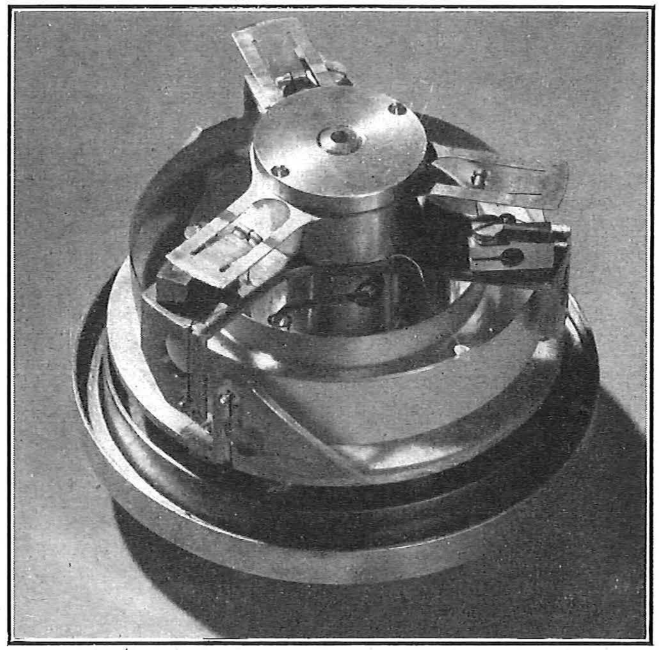
The Post Office has installed a quartz resonator at a depth of 60 ft below ground level, where the maximum temperature change throughout the year is less than one-tenth of a degree centigrade. As this installation is the first of its kind in Great Britain or the Commonwealth, it is thought that some details of the installation will be of interest.

The Quartz-Crystal Resonator

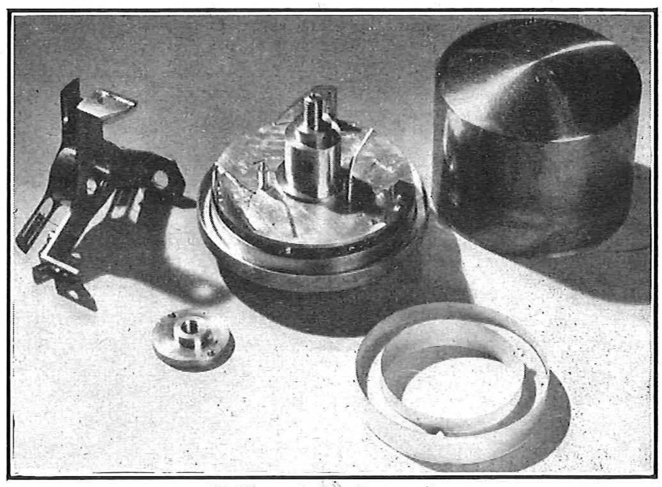
The quartz resonator has been placed at the foot of a 60-ft deep steel pipe of 6 in. internal diameter; the pipe consisting of a number of sections jointed with screwed sockets and each joint made waterproof.

The Crystal.

A 100 kc/s Essen-type ring is used, suitably dimensioned so that the temperature at which its frequency-temperature coefficient is zero corresponds with the temperature at the bottom of the borehole (at Dollis Hill 11·5°C). It is in all respects similar to its oscillator counterpart and is mounted by a silk-thread suspension system in an evacuated container. A photograph of a typical oscillator crystal unit is given in Fig. 1. Resistance thermometer elements are associated with the crystal so that the working temperature can be monitored at all times.



(a) 100 kc/s Z-cut quartz ring, mounted on thread suspension, with cover removed.



(b) Dismantled oscillator unit.

Fig. 1.—Typical Quartz-Crystal Oscillator Unit.

The Resonator Chamber.

Fig. 2 shows the assembly of the resonator chamber which was lowered down the borehole, the crystal element being mounted in the cylindrical container at the base of the assembly. Coaxial cables carrying the h.f. signals and d.c. control cables can be seen entering the chamber at the top, and changeover relays and calibrating resistance elements are seen about the middle of the assembly. Provision is made for checking the degree of vacuum in the crystal holder and for checking the frequency-temperature coefficient of the crystal.

The complete chamber is sealed with carbon dioxide gas at slightly above atmospheric pressure. Four spring feet at each end of the chamber acted as guides on the pipe walls during the lowering operations.

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[1] McClements, J. S. Post Office Quartz Oscillators for Use in Time and Frequency Standardisation Abroad. Vol. 48, p. 26, Apr. 1955.

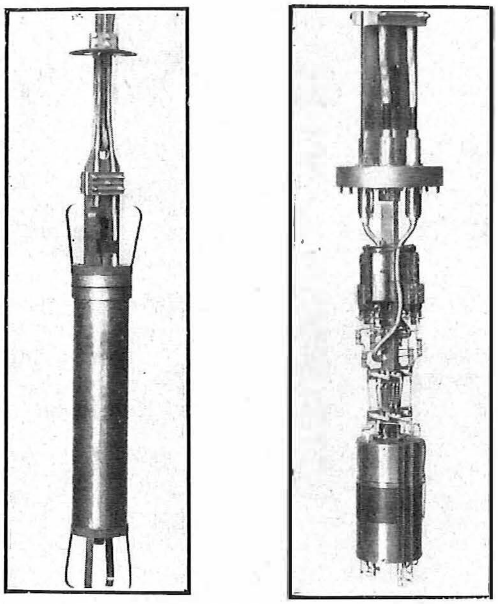


Fig. 2.—The Resonator Chamber.

Lowering Operations.

Fig. **3** shows the complete assembly suspended above the borehole prior to lowering. The container is suspended on a ¼-in. diameter steel-wire rope, to which the cables are also clamped at frequent intervals. At intervals of 10 ft the bore pipe is closed by air baffles, also attached to the supporting cable, which reduce the effect of air convection in the pipe. Because of the delicacy of the crystal element, lowering operations were carried out slowly and carefully, cable clamps and air baffles being fitted as the system was lowered. The performance of the crystal was monitored throughout the lowering operation.

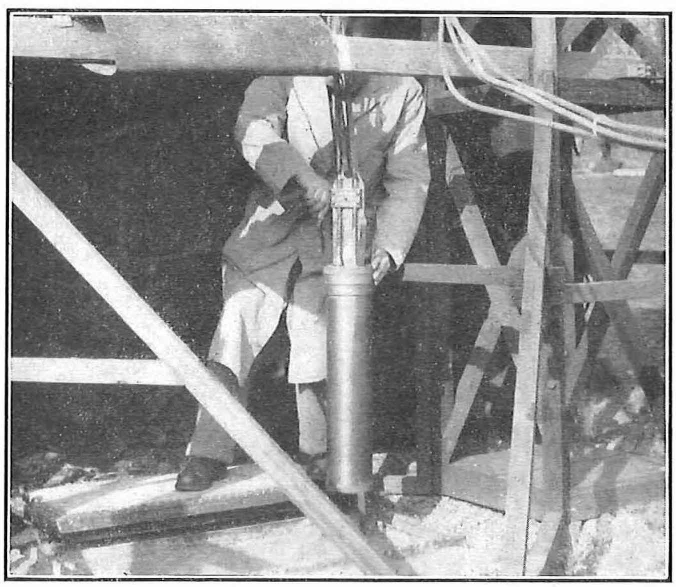


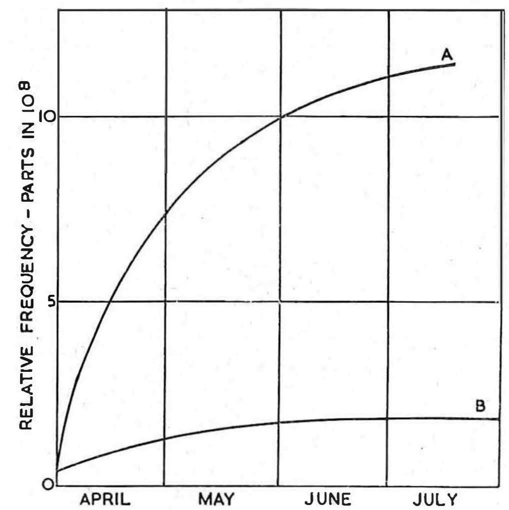
Fig. 3.—Resonator Chamber Suspended Over Borehole Prior to Lowering.

Measurement of Frequency.

Advantage is taken of the fact that at the resonant frequency of the crystal its equivalent electrical circuit is a pure resistance. The overall circuit, including cables, is initially aligned at 100 kc/s with an equivalent resistance simulating the crystal. By means of relays the crystal is then switched into the circuit, and the frequency of the driving generator adjusted until the resistive conditions are again obtained. The frequency of the generator then corresponds with the crystal resonance frequency.

Performance.

When a crystal oscillator is first installed, the frequency changes rapidly with time, compared with the rate of change after some months of operation. This comparatively large frequency change is known as the "preliminary frequency-ageing" of the crystal; the preliminary ageing may persist for three to six months, during which time a total frequency change of 10 parts in 10^8 is not uncommon. A typical ageing curve of a crystal oscillator operating at 50°C is shown in Fig. **4**, curve A. The frequency-time



A—Oscillator operating at about 50°C.
B—Resonator operating underground at 11·5°C.

Fig. 4.—Frequency-Time Performance of Quartz-Crystal Oscillator and Resonator.

performance of the underground resonator since installation is shown in Fig. **4**, curve B, which is a mean curve based on daily measurements and fits the measured data within one part in 10^9 at all points. It will be seen that the preliminary frequency ageing of the resonator was completed in less than two months and the overall frequency change measured up to the beginning of August was less than 1·5 parts in 10^8.

Conclusion

The performance of the first Dollis Hill underground resonator, since it was lowered into the earth in March 1955, is very promising, the rate of frequency change with time already being comparable with the best oscillator frequency standards. As is the case with all frequency standards, however, measurements will continue for many months before performance can be sufficiently established to enable the resonator to be used as an effective standard.