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Report

## U. S. A.

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## Review of Developments on Radio Measurement Methods and Standards 1954-1957

Since the XIth General Assembly, significant improvements with respect to frequency standards and radio frequency measurements have been made in the United States. The following represents a group of reviews of the most significant advances. These were prepared by Messrs. W. D. George, H. Lyons, R. G. Fellers, A. B. Giordano, M. Sucher and W. E. Chapin, T. E. Tice and R. H. George.

### 1. — Frequency and Time Interval Measurements and Standards

A new IRE standard on piezoelectric crystals was published (1). The standard specifies nomenclature and practical methods of measuring the various quantities associated with piezo-electric vibrators.

Research and Development on quartz resonators continued to yield new and useful improvements in the field of frequency control, measurements, and standards. Quartz crystal units which were constant to 3 parts in $10^{10}$ per day at 65° C and had a minimum Q of four million at this temperature were developed (2).

Investigations were underway on the aging rates and other characteristics of quartz crystal units when operated at relatively constant temperatures in the range from about 2° K up to about 250° K. Theoretical considerations and measurements indicated a substantial reduction in aging at the lower temperatures; also, at certain low temperatures the Q was substantially increased and the temperature coefficient of frequency was reduced (3, 4).

Standard frequencies broadcast from WWV and WWVH were increased in accuracy from a part in 50 million to a part in 100 million; also the stability of the frequencies broadcast was increased to about 1 part in a billion at WWV, and to 5 parts in a billion at WWVH. The time signals at both stations were changed to agree closely with the newly defined UT2, determined by the U. S. Naval Observatory (5).

The operation of an experimental standard frequency transmitting station on 60 kc/s was commenced by the National Bureau of Standards Boulder Laboratories. An important use of the transmission has been the regular intercomparison at Cruft Laboratory Harvard University of the U. S. A. and the UK standard frequency broadcasts (6).

A better understanding was had of measuring instruments and techniques and improved instruments were made available (7, 8). A practical limitation to sensitivity in the instrumentation with which high precision oscillators were compared was not yet reached.

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Great progress has been made in the field of primary, atomic standards of frequency and time. This work has proceeded principally along three directions.

First, the line widths associated with collision and Doppler large broadening in gases resulted in intensive efforts to find techniques leading to high-Q spectrum lines. The original absorption methods were therefore largely superseded except for work of Shimoda in Japan. The first high-Q method was the cesium, atomic beam, magnetic resonance method developed at the National Bureau of Standards. This resulted in a preliminary value for the cesium, zero-field transition frequency of 9192.63 188 ± 0.00003 Mc/s. The cesium beam method was further developed at M. I. T. and the National Company resulting in the first commercially available atomic clock and frequency standard named the « atomichron » with a stability of 5 parts in $10^{10}$. Further refinements of this method are under study.

Second, a new beam technique using ammonia was developed at Columbia University. This resulted in operation of a Maser (an acronym for Microwave Amplification by Stimulated Emission of Radiation) which used the emission of ammonia rather than absorption to make a self-excited oscillator at the frequency of the 3.3. $NH_3$ transition. The Maser consists of an atomic sample, which is not in thermal equilibrium, contained in a cavity. The sample is, of course, first excited so that it will not be in thermal equilibrium. In the ammonia beam maser this is accomplished by sending the beam through an electrostatic focusser which separates the excited from the ground state molecules by inducing dipoles in the molecules because of the Stark effect. The molecules emit their energy into the cavity causing the field to build up and induce more emission. The maser is thus a regenerative amplifier and oscillates when the total power emitted equals the losses. It is the most coherent generator ever developed with a spectral purity of a part in $10^{12}$ or so. With a stable cavity design the maser serves as a frequency and time standard.

Third, a maser cavity technique using a gas is under development at Princeton University. This uses rubidium vapor at a very low pressure so as to greatly reduce collision broadening. Doppler broadening is reduced by filling the cavity with argon at about 1 mm pressure ; the argon serves as a buffer gas to, so to speak, make the rubidium atoms « stand still ». The collisions with the buffer gas result in very little broadening because of the nature and weakness of the interactions between argon — a noble gas — and rubidium in which the magnetic dipole hfs transitions are used. Thermal equilibrium is destroyed by optically « pumping » the rubidium by irradiating with rubidium resonance radiation.

Additional progress has been made with electronic stabilization and control methods, particularly the phase locking technique at M. I. T. Also solid state masers using spin resonance systems have been successfully developed as amplifiers and oscillators of extremely low noise. These open up a whole new field of application — atomic amplifiers — and might play a role in frequency and time standards either as very coherent generators or as low noise amplifiers of beam type masers.

To sum up, significant progress has been made towards the goal of practical atomic standards as well as a possible new international, primary standard. Most of the details must be left for the references.

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## 2. — Impedance Measurements

Contributions to the field of impedance measurements during the three year period from January 1, 1954 to January 1, 1957 have followed several lines. Considerable work has been done on the problems of analyzing errors and defects in present systems