multipliers, auxiliary frequency-modulated search oscillator, and pulse discriminator circuits. The 100 kc is then divided down to audio frequencies in conventional manner and used to operate a synchronous-motor clock as a time standard. A constancy in frequency of 5 parts in 10^8 has been obtained for periods of several days with this experimental clock when compared with WWV frequency standards. Improvement of this type of standard and the development of more constant types of atomic resonance controlled oscillators are to be expected.

It is shown in the references cited that the sharpness of resonance within individual oscillating molecules is extremely great. Because of collisions of molecules with each other and with the gas cell walls, and the Doppler broadening attributable to natural thermal agitation, the practical working Q of an ammonia gas absorption line ranges between 50,000 and 500,000. This compares favorably with the Q of quartz crystals used in frequency standards which ranges from 100,000 to 1,000,000. It is thus reasonable to hope that a constancy of 1 part in 10^8 to 1 part in 10^9 may be obtained by proper refinements in circuitry and technique. Whether or not this degree of constancy of absolute value can be maintained without or even with precise temperature and pressure regulation remains to be investigated.

Civil time will, no doubt, continue to be defined in terms of the mean solar second, as would ordinary frequency designations. After about 2,000 years, if the earth continues to slow down at its present rate, the mean solar second would be about 1 part in 3 million longer than at present and the accumulated time difference between mean solar time and Newtonian time would amount to about three hours.

Conclusions

Frequency and time standards, using high-precision quartz crystals, are now available which are capable of supplying frequencies and time intervals constant to considerably better than 1 part in 10^8 per day. In order to achieve an accuracy approaching this order, these standards must be frequently checked in terms of standard frequency or time broadcasts. An accuracy of 1 part in 10^8 represents about the limit obtainable in terms of the earth's mean rate of rotation over a 100-day period. Longer periods of averaging can not be expected to give greatly improved accuracy, because of the possibility of slight oscillator frequency deviations and uncertainties in the uniformity of the determinations of the earth's mean rate.

By using ordinary zero beating methods, a remote frequency standard may be adjusted within 1 part in 10^7 to WWV's received frequency. Special offset techniques permit this setting error to be reduced to less than 1 part in 10^8. Changes in the radio propagation medium may cause the received frequency to differ from that transmitted by as much as several parts in 10^7. By averaging a number of determinations made when noon or midnight prevails about halfway between transmitter and receiver, long-distance frequency comparisons can generally be made with a precision of better than 1 part in 10^8.

The intercomparison of two remote oscillators, constant to 1 or 2 parts in 10^9 per day, by means of transmitted time pulses from one or both of the standards, is possible to a precision of a few parts in 10^9 through comparisons of average frequencies over periods of 6 or more days.

The development of atomic or molecular-resonance standards of high constancy and absolute accuracy may greatly simplify the maintenance of precise frequency and time standards. The practical realization of such standards, which seems reasonably probable in the near future, will eliminate the necessity of making highly precise physical measurements in terms of the earth's variable rate of rotation. Such a standard would supply a means of studying more precisely the motions of the earth and other astronomical bodies.

Considerable work is being done to improve the constancy of quartz-crystal frequency standards, especially with regard to aging or frequency drift and improved temperature control methods.

It is probable that frequency and time standards, which have improved by a factor of ten or more per decade in the last thirty years, will continue to reach new orders of accuracy and constancy. However, these improvements in accuracy will probably be referred to a new kind of standard, rather than to the mean solar second.

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CORRECTION

It has been brought to the attention of the editors that the name of Han Chang, co-author of the paper, "The Reactance-Tube Oscillator," which appeared on pages 1330–1332 of the November, 1949, issue of the PROCEEDINGS OF THE I.R.E. was misspelled in his biography on page 1345 of that issue. The editors regret this inadvertent error.