
Review of developments occurring within the United States in the fields of Radio Measurement Methods and Standards during the triennium 1960 through 1962.

1. Atomic frequency and time interval standards. R. C. Mockler
2. RF and microwave power measurements. G. F. Engen and N. T. Larsen.

Appendix: Measurements standards and calibration laboratories in the United States. C. E. White.

1. Atomic Frequency and Time Interval Standards

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Probably the most noteworthy accomplishment in the period 1960–61–62 has been the development of the hydrogen maser. The HY maser may also have application as a frequency standard, but no serious attempt to evaluate its usefulness to this purpose has been made. A thallium beam is finally under critical test as a frequency standard. Considerable technological development of cesium beams, ammonia masers, and optically pumped gas cells has taken place. Commercial rubidium gas cells of excellent quality are now available, together with much improved new models of commercial cesium beam standards. Techniques have been developed for synchronizing and comparing widely separated clocks by propagated signals. It is now possible to compare atomic frequency standards using VLF transmissions to about 2 parts in $10^{15}$ over large distances.

1.2. Atomic Beam Standards

The hydrogen atomic beam maser has been shown to have an interaction time the order of 1 sec, from which is inferred a spectral line width of about 1 e/s. This is the narrowest line employed in any of the present-day frequency standards. The extreme narrowness of the line reduces very substantially the effects of "frequency pulling" by the resonant cavity on the emission frequency. As a consequence of the large number of collisions taking place within the decay time, there is practically no first-order Doppler shift. Two hydrogen masers at Harvard have demonstrated a relative stability of 1 part in $10^{12}$ over a 12-hr period. A frequency shift of about 1 part in $10^{11}$ exists as a result of interaction with the wall coatings. There is hope of eliminating this shift to a large extent [Goldenberg, Kleppner, and Ramsey, 1960; Goldenberg, Kleppner, and Ramsey, 1961; Kleppner, Goldenberg, and Ramsey, 1962 a and b; Ramsey and Kleppner, 1962; Vessot and Peters, 1962]. Although hydrogen is much more sensitive to a magnetic field than is thallium or even cesium, its narrow line width will allow the field to be reduced to a very low level. However, it remains to be determined just how low this field may be reduced. Intensity may suffer drastically at the desirable field level as a result of "Majorana flop."

NBS has made preliminary measurements on a thallium beam, obtaining precisions of 5 parts in $10^{13}$ in a given day. However, the day-to-day frequency measurements show a standard deviation of the mean of 4 parts in $10^{12}$. This scatter in the day-to-day measurements has been found to be attributable to the rather poor construction of the microwave structure exciting the transition. From the present data it is inferred that significantly higher accuracy can be obtained with thallium as opposed to cesium if a suitable microwave structure is used.
7. Precise Measurements of Distance and of the Velocity of Light Using Lasers

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One of the major accomplishments of the past 3 years in the area of radio science has been the development of coherent sources of light called optical masers or lasers. These devices have greatly extended the range of frequencies over which the techniques developed in the normal radio and microwave ranges can be applied. The most immediate applications appear to be in the areas of basic science, communications, and precise distance measurements.

A number of types of lasers is now available. These include pulsed and continuous optically pumped solid-state lasers, Q-switched solid-state lasers, continuous rf discharge and optically pumped gas lasers, and electron injection semiconductor lasers. The type which appear to be most applicable to precise distance measurement are the Q-switched solid-state laser and the gas laser.

In the Q-switched laser [Hellwarth, 1961; McClung and Hellwarth, 1962] a large inverted population difference between two energy levels of a crystal is produced by optical pumping while the Q of the optical cavity is low. The Q is then rapidly switched to a high value, usually by opening a Kerr cell shutter in the optical path or rotating a 90-degree prism so that its plane of retroreflection becomes perpendicular to a plane reflector forming the other end of the optical cavity. This gives a rapid buildup of power in the cavity and a quick dumping of the inverted population in the crystal. Output pulses as short as 10 nsec with a peak power output of over 50 MW and a narrow output beam width have been obtained [Marshall, Roberts, and Wuerker, 1962]. This type of device appears superior to microwave methods for radar-type measurements of long distances under some circumstances.

Gas lasers [Javan, 1959; Faust, McFarlane, Patel, and Garrett, 1962], on the other hand, have much lower output power but run continuously. Their demonstrated spectral purity of a few parts in $10^{11}$ [Jaseja, Javan, Murray, and Townes, 1962], and independent retestability of about 1 part in $10^6$ [Javan] make possible extremely accurate measurements over quite long vacuum paths. With such devices the limitation on path lengths over which interference measurements can be made appears to lie mainly in the problem of finding the whole fringe number or in path stability rather than in the coherence length, as was previously the case. Gas laser output wavelengths of 0.63 μ [White and Ridgen, 1962] to 12.9 μ [Faust, McFarlane, Patel, and Garrett, 1962] have already been obtained. These wavelengths can be supplemented by using beat wavelengths between two laser modes corresponding to different optical transitions as the basic unit of measurement. For example, if the 1.1143-μ [McFarlane, Patel, Bennett, and Faust, 1962] and 1.1177-μ [Javan, Bennett, and Herriott, 1961] transitions in neon are employed, the beat wavelength will be 0.32 mm. Still longer beat wavelengths can be obtained by using two different axial modes for the same optical transition or by using a microwave modulator [Bloembergen, Pershan, and Wilcox, 1960; Pershan and Bloembergen, 1961] to modulate the light output from either a laser or a conventional light source. Quite short beat wavelengths may be obtainable on a pulsed basis with a microwave modulator operated with a high modulation index, but for continuous operation the index which can be used appears to be limited by heat dissipation in the modulator crystal.

Paths of up to 864 m have previously been measured in terms of shorter paths by means of white light fringes with multiple reflections [Fabry and Buisson, 1919; Honkasalo, 1960]. With lasers, measurements over quite long paths can also be done by using automatic fringe counters or by using several different wavelengths and beat wavelengths calibrated with respect to each other over shorter paths in order to obtain the whole fringe number. Probably the simplest method is to use white light fringes to set the long path to an integral multiple of a shorter path for which the whole number of laser fringes is known, and then to measure the long path to the desired fraction of a fringe with a laser source. With such procedures the accuracy of measuring long and stable vacuum paths will probably be limited.
mainly by the uncertainty in the length standards. For a precise measurement of the velocity of the light \( c \) at optical wavelengths, a common method is to use two optical frequencies \( \nu_1 \) and \( \nu_2 \) with a difference \( \Delta \nu \) known in frequency units. The number of beat wavelengths over a distance \( L \) known in length units is measured. If \( n_2 \) and \( n_1 \) are the number of fringes for the two wavelengths, then 
\[
\nu_1 = \frac{2L}{n_1}, \quad \nu_2 = \frac{2L}{n_2}, \quad \Delta \nu = \frac{c}{2L} (n_2 - n_1), \quad \text{and} \quad c = 2L (n_2 - n_1). 
\]
For a given path length \( L \), it is normally advantageous to use as high a difference frequency \( \Delta \nu \) as can be determined accurately so that \( n_2 - n_1 \) will be large. Making \( L \) large is also desirable in order to make \( n_2 - n_1 \) large, as long as the additional path length does not increase the uncertainty in terms of fractions of a fringe to which \( (n_2 - n_1) \) can be measured.

At the National Bureau of Standards an attempt is planned to measure the beat frequency of about 831 Ge/s between the two neon laser lines at 1.1143 and 1.1177 \( \mu \) which were mentioned earlier. The method, which was suggested by Z. L. Bay, is to intensity modulate the beam of a special cathode ray tube at the 831 Ge/s beat frequency by illuminating the photo-cathode spot with both laser lines. If the frequency applied to the horizontal deflection plates is near a subharmonic of the beat frequency, a slowly running intensity modulated pattern will be produced on the face of the tube. For a roughly 10 Ge/s deflection frequency and fairly rapid initial acceleration of the beam, the percentage modulation of the pattern should be adequate for measurement of the running frequency and thereby of the beat frequency [Statz, Paanannen, and Koster, 1962]. If this attempt is successful, the method is intended for use in a velocity of light measurement over a suitable path length.

References

Bay, Z. L., and H. S. Boyne, Private communication.
Fabry, C., and H. Buisset (1919), Indications techniques sur les étaons interferentiels a lames Argentees. J. Physique 39, 80.
Javan, A., Private communication.

White, A. D., and J. D. Rigden (1962), Continuous gas maser operation in the visible, Proc. IRE 50, 1697.

Additional References

Fabry, C. (1923), Les Applications des Interférences Lumineuses, p. 82.
Rigden, J. D., and A. D. White (1962), Simultaneous gas maser action in the visible and infrared, Proc. IRE 50, 2366.