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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 [Javen, 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^{13} [Jaseja, Javan, Murray, and Townes, 1962], and independent resettability of about 1 part in 10^{9} [Javen] 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 best 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 ν_1 and ν_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_1 and n_2 are the number of fringes for the two wavelengths, then $\nu_2 = n_2 \cdot \frac{c}{2L}$, $\nu_1 = n_1 \cdot \frac{c}{2L}$, $\Delta\nu = (n_2 - n_1) \cdot \frac{c}{2L}$, and $c = 2L \cdot \frac{\Delta\nu}{(n_2 - n_1)}$. 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 Gc/s between the two neon laser lines at 1.1143 and 1.1177 μ 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 Gc/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 Gc/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, Paananen, 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.

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