Interference Fringes Produced by Superposition of Two Independent Maser Light Beams

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Optical interference effects are normally only observed with photons in coherent superposition states. Such states can be brought about with the help of beam splitters or induced optical transitions. It has been said that "each photon then interferes only with itself. Interference between different photons never occurs"[1]. However, transient interference effects have been demonstrated with two completely independent microwave beams[2]. Such effects, which are analogous to optical beats from incoherent sources[3-5], are immediately understandable in classical terms, for the amplitude and phase of each beam remains constant for a time short compared with the reciprocal frequency spread, $1/\Delta\nu$ (the coherence time). While it is true that in this case the ensemble average of the radiation intensity at different space points gives no indication of interference, the ensemble average is not relevant to any one short-time observation.

Interference effects ought to be observable also with two independent light beams, provided: (*a*) the photons in the two beams are not in orthogonal spin states; (*b*) the observation is made in a time shorter than the reciprocal total frequency spread, $1/\Delta\nu$, of the two beams, so that all the received photons may be regarded as falling into the same cell of phase space; (*c*) the mean number of photons received on a coherence area in a coherence time[6], that is, the mean occupation number of each cell of phase space or the photon degeneracy parameter, δ - is much greater than 1.

As has been shown[7,8], for light from typical thermal sources δ is always much less than unity and reaches the value 1 only when the source temperature approaches 10^5 °K. On the other hand, δ is usually very large for optical maser beams[8], and this suggests the use of masers for the experiment[9]. We wish to report observation of interference fringes produced by the superposition of two independent beams of ruby maser light.

The experimental arrangement is shown in Fig. 1. Two light beams from two independent ruby masers are aligned with the help of two adjustable 45° mirrors and superposed on the photocathode of an electronically gated image tube[10]. The tube is magnetically focused and the image produced on the output fluorescent screen is photographed. The effective separation, d, of the two virtual (incoherent) sources is defined by two slits and the expected fringe spacing, x, is, as usual, given by

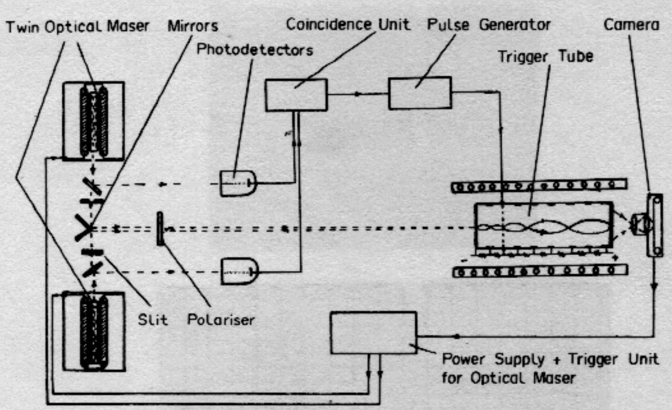


Fig. 1. Outline of the apparatus for recording transient interference fringes

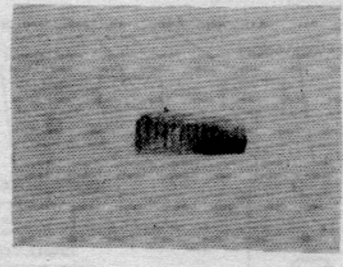
$$x = \lambda D/d \tag{1}$$

where λ is the wave-length and D the slit-to-cathode distance. The two rubies are rotated until the polarization planes of the two beams are parallel and a linear polarizer is introduced as a further precaution. A narrow-band optical filter attenuates most of the pumping radiation.

The flash tubes exciting the two masers are triggered simultaneously; but, as the maser emission from ruby is in the form of a series of random 'spikes' of approximately ½ μsec duration, two light beams are only occasionally emitted in coincidence. The image tube is therefore normally gated-off by a negative bias voltage applied to the grid. Two monitor photodetectors feeding into a coincidence circuit determine when two maser beams emerge in coincidence, and then cause the image tube to be gated-on by a positive pulse of selected duration (30-500 nsec) applied to the grid.

The two rubies used in the experiment are 5·7 cm long, of diameter 6 mm (0.02 per cent Cr, 60° orientation) and have silver-coated plane ends. They are surrounded by four straight xenon flash tubes in a configuration of the type described by Miles and Edgerton[11]. Under excitation of a few per cent above the threshold for maser action (approx. 200 joules) the rubies deliver about 20-40 'spikes', which leads to an average spike coincidence rate of about one per xenon flash. Provision is made for preventing double exposures resulting from double coincidences by paralysing the electronic gate for some hundreds of μsec after each exposure.

Fig. 2 shows a photograph of interference fringes obtained in a 40-nsec exposure, together with a micro-photometer tracing across the negative. The measured fringe spacing is 0.277 ± 0.003 mm, while the corresponding value calculated from equation (1) with D = 180 ± 0.5 cm, d = 4.51 ± 0.03 mm, λ = 6943 Å, is 0.277 ± 0.003 mm. The number of distinguishable fringes is about 23, which is rather less than the number expected from the ratio of slit spacing (4.51 mm) to slit width (about 0·3 mm). However, the high granularity



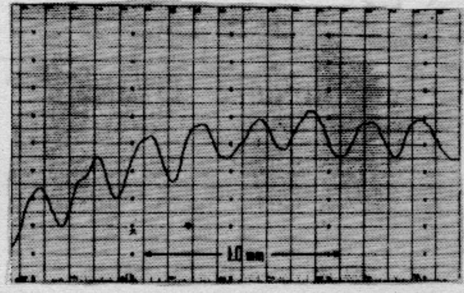


Fig. 2. An example of fringes recorded: (a) photograph; (b) microphotometer tracing.

of the film makes small variations of photographic density difficult to detect.

The maximum measured fringe visibility of the pattern is about 15 per cent. As in conventional interference experiments with coherent light beams, the visibility is partly determined by the ratio of the two light intensities, but in this case it is strongly dependent on the exposure time.

The approximate relation is easily calculated classically. Let us represent the two beams at some point in the superposition plane by the complex analytic random functions[12] $V_1(t - \frac{1}{2}\tau)$ and $V_2(t + \frac{1}{2}\tau)$, where $c\tau$ represents an optical path difference varying systematically from point to point. Then the resultant wave amplitude at any point of superposition is:

$$V(t) = V_1(t - \tfrac{1}{2}\tau) + V_2(t + \tfrac{1}{2}\tau) \qquad (2)$$

and, if $I_1(t) = |V_1(t)|^2$ and $I_2(t) = |V_2(t)|^2$ are the instantaneous intensities, the resultant intensity is:

$$I(t) = I_1(t - \tfrac{1}{2}\tau) + I_2(t + \tfrac{1}{2}\tau) + 2R[V_1^*(t - \tfrac{1}{2}\tau)\, V_2(t + \tfrac{1}{2}\tau)] \qquad (3)$$

Now $V_1(t)$ and $V_2(t)$ can be expressed in the form[12]:

$$\left.\begin{aligned} V_1(t) &= \sqrt{I_1(t)}\,\exp[2\pi i\nu_1 t + i\phi_1(t)] \\ V_2(t) &= \sqrt{I_2(t)}\,\exp[2\pi i\nu_2 t + i\phi_2(t)] \end{aligned}\right\} \qquad (4)$$

are describable in completely classical terms.

We thank Professor J.D. McGee and Dr. W.L. Wilcock for helpful suggestions. The work was supported financially by a grant from the Department of Scientific and Industrial Research.

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