Making visible the invisible interference pattern

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Abstract

The two slits experiment is often used to explain the basic principle of interference of light. The position of the interference pattern depends on the phase difference of light from the slits. This experiment is used to explain our interference experiments with Michelson interferometer with the mirrors far from equidistant position. We propose an experiment where the distance between the interference fringes can be determined when the interference pattern disappears completely for a naked eye. We used a semiconductor laser with two fast photodiodes as sensors. The distance between invisible interference fringes was determined by observing the amplitude of the summed fluctuating signal as a function of distance between the sensors. The basic understanding of the phenomenon can be achieved using multimedia models such as sound equivalent of two slits experiment and animated drawings.

Introduction

The interference of light can be observed by naked eye only using coherent sources. In the following we will show how interference phenomena can be observed also with incoherent sources, using relatively modest equipment which is usually available in school laboratories. The experiments were already described [see (Verovnik & Likar, 1988), (Verovnik et al, 1992) and (Verovnik & Likar, 1999)]. Later on, we further developed the idea using Michelson interferometer since the relevant experimental parameters are better controlled (Verovnik & Likar, 2004).

In Michelson interferometer the full contrast of the interference pattern is achieved when the mirrors are in symmetrical positions with respect to the beam-splitter. The contrast vanish completely when the path difference of the arms is much bigger then the coherence length of the light.

It is generally believed the interference pattern is lost completely in this case. We will show how the information about the distance between invisible interference fringes can be measured.

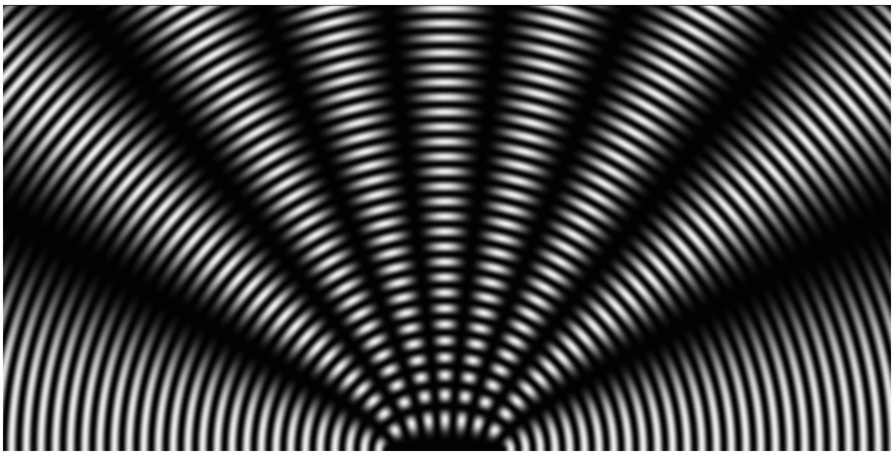
Instead of using relatively complicated mathematical description, we have now developed some of the multimedia materials which enable the basic understanding of the experiment and its outcome. Among them is sound equivalent of the double slit experiment, where the relative phase of sound sources is changing with time. In some cases, to support the explanation of the experiments, the static drawings and illustrations do not give sufficient clarity. For this reason we developed several animated drawings which enable clear understanding of the phenomena. Using this material we expect that students are familiar with the basics of Young's double slit experiment and Michelson interferometer.

The sound equivalent of the double slit experiment

For the motivation and for better understanding further steps, the following experiment is advised. In the classroom two loudspeakers within the distance of about one meter will emit the sine-wave tones, one with the frequency of 800 Hz and the other one at 801 Hz. Asking students what we will hear, they usually give the right answer - beating with the frequency of one Hz. We can put additional question, concerning the energy: Each of the loudspeakers is emitting continuously the sound energy. This can be proved by putting the ear close to each of loudspeakers. Where does the energy go at the moments of silence? The answer is not trivial.

When explaining the importance of relative phase between the two sources the animation of interference field in front of the loudspeakers contributes substantially to the understanding of this phenomenon. Namely the whole pattern is turning in one direction so that at any selected point in the field the intensity is changing with one cycle per second (Fig. 1).

Fig. 1. Animation showing the turning of the interference field when the frequency of the loudspeakers at the bottom (not seen) differ for 1 Hz.



Double slit experiment and Michelson interferometer

In original Young's double slit experiment, for stable interference pattern constant phase difference of the light coming from each slit is important. Using two independent light sources instead two slits results in random changes of the phase difference and consequently in random changes of the position of the interference pattern. Slow detectors such as human eye can not follow fast movements of the pattern so the screen is seen as uniformly illuminated. Fast detectors such as photodiodes can detect the fluctuations of light at certain conditions.

We used Michelson interferometer since the control of interference pattern is relatively easy. De-coherence of two light beams can be achieved by increasing the length of one arm far beyond the coherence length of the laser light used. The phase difference of the light beams is then rapidly changing in a random way. This results in rapid random movement of the interference pattern on the screen. The interference pattern is blurred completely for the naked eye which detects only the average illumination of the screen.

Measuring fluctuations using two detectors

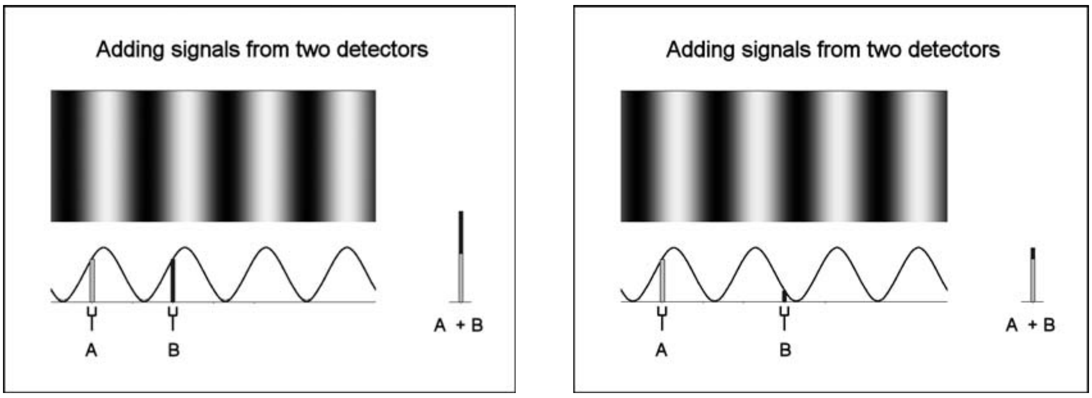
Instead using one detector, which measures random changes of intensity when the pattern is moving randomly, we used two detectors. Now the degree of correlation of the measured signals between the two detectors depends on the distance between them. The degree of correlation can give the information about the distance between invisible interference fringes. This can be a bit difficult to imagine and here again the animated drawings can help.

We present two animations with two extreme positions of the detectors. In Fig. 2a the distance between the sensors is equal to the distance between the neighboring interference fringes on the screen. In the animation the pattern moves uniformly to the right together with the sinusoidal shaped diagram but the position of the sensors is fixed. The height of the bars above the sensors follows the corresponding intensity at each moment. In this case time development of both signals is completely correlated. Both intensities reach the maximum at the same time and the same happens with the minimum and all intermediate values. By adding these two signals, the fluctuations are twice as big as with one single sensor. This is shown with the bar at the right side of the animation screen.

In Fig. 2b the distance between the sensors is increased to one and half distance between the interference fringes. The animation now shows no fluctuation in added signal. When the signal from one sensor increases, the other one decreases and vice versa.

The average magnitude of fluctuations is changing when the distance between the sensors changes, but the average added signal stays the same at all distances. By measuring the fluctuations of the added signal the distance between invisible interference fringes can be determined. It is simply equal to the change of distance between two neighboring positions where the fluctuations are at minimum or maximum.

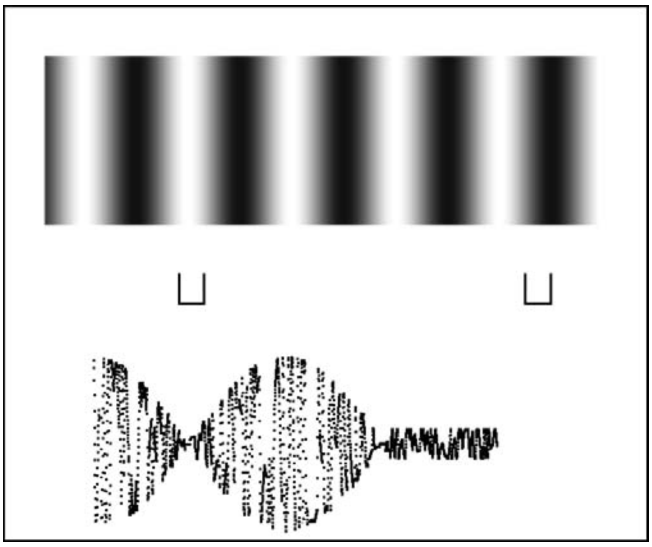
Fig. 2. The two animations where interference patterns together with the diagrams below are moving uniformly to the right. The sensors A and B are fixed. a - The distance between the sensors are equal to the distance between the two neighboring fringes. The added intensities fluctuate. b - The distance is equal to one and half of the distance between the fringes. The added intensities do not fluctuate.



a b

The next interactive animation (Fig. 3) represents one more step closer towards the real measurement. Now the interference pattern moves randomly and the distance between the sensors can be controlled by pressing a key on the computer keyboard. The alternating component of the added signal is plotting simultaneously at the bottom of the screen.

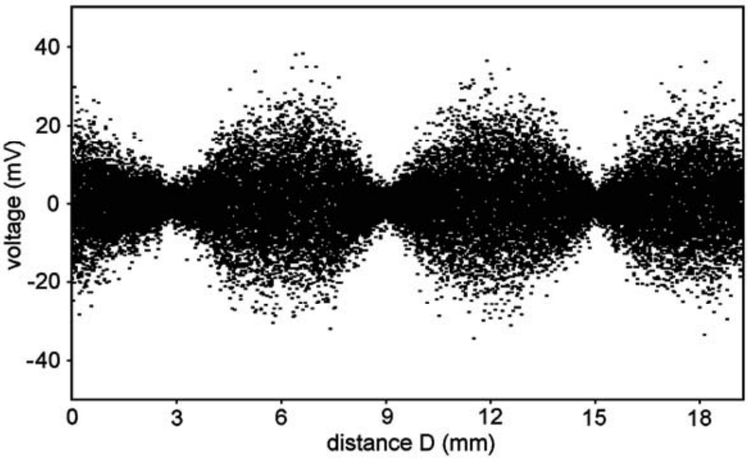
Fig. 3. Interactive animation with random movable interference pattern. The distance between the sensors can be controlled by pressing a key on the computer keyboard. The alternating component of the added signal is plotting simultaneously at the bottom of the screen.



The experiment

The experiment itself is already described (Verovnik & Likar, 2004) and is therefore not theoretically and technically discussed here. The most important is the outcome which is presented in Fig. 4.

Fig. 4. Fluctuations of the measured signal changes periodically with increasing distance between the two light sensors - photodiodes. The period (about 6 mm) is equal to the distance between the fluctuating (invisible) interference fringes.



Conclusion

We believe the experiment and didactic multimedia material described here is of considerable didactic value. It demonstrates new possibilities for explaining the interference experiments with incoherent light sources which are usually not part of the curriculum. Indirectly these kinds of experiments demonstrate that the photons from different sources always interfere. Similar experiment we performed with the light from two independent lasers. The basic understanding of the experiment and its outcome can be achieved by the use of presented didactic multimedia models in relatively short time.

List of references

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