Interference not only in Surveying[1]

Anna BARAŃSKA, Poland

Key words: interference, the speed of light, Galilean transformation, Michelson interferometer

SUMMARY

Interference - the phenomenon of the a new, spatial pattern of the wave formation as a result of overlapping (superposition) of two or more waves. Usually refers to the interaction of waves that are correlated because they come from the same source or because they have the same or nearly the same frequency. Interference of waves consistent (coherent) gives a spatially constant wave amplitude distribution.
Utilisation interference phenomena – examples:

1. Precise measurement of the distance from the source to the detector wave – interference rangefinders, gravity meters. Measurement of displacement and shape of objects.
2. Holography - a technique for obtaining spatial images with the method of reconstruction of the wave.
3. Noise suppression by means of generating sound waves in opposite phase to the noise produced by a device.
4. In telecommunication - the division of the area of the so-called cell communication network in order to obtain the possibility of an independent transmission of signals (UMTS technology).

STRESZCZENIE

Interferencja - zjawisko powstawania nowego, przestrzennego układu fali w wyniku nakładania się (superpozycji) dwóch lub więcej fal. Zazwyczaj odnosi się do interakcji fal, które są skorelowane dlatego, że pochodzą z tego samego źródła lub dlatego, że mają takie same lub prawie takie same częstotliwości. Interferencja fal spójnych (koherentnych) daje stały przestrzennie rozkład amplitudy fali.
Wykorzystanie zjawiska interferencji – przykłady:

1. Precyzyjny pomiar długości drogi od źródła do detektora fali – dalmierze interferencyjne, grawimetry. Pomiary przemieszczeń i kształtu obiektów.
2. Holografia – technika uzyskiwania obrazów przestrzennych metodą rekonstrukcji fali.
3. Tłumienie hałasu za pomocą układu generującego fale dźwiękowe w przeciw fazie do hałasu wytwarzanego przez jakieś urządzenie.
4. W telekomunikacji – podział obszaru tzw. komórki sieci komunikacyjnej w celu uzyskania możliwości niezależnego przekazu sygnałów (technologia UMTS).

[1] The task within statutory researches in Department of Geomatics, AGH University of Science and Technology, Krakow, Poland

Interference not only in Surveying

Anna BARAŃSKA, Poland

1. INTRODUCTION

Interference is a physical phenomenon in which a new, spatial wave pattern is formed as a result of overlapping (superposition) of two or more waves. This term generally refers to the interaction of waves, which are correlated because they come from the same source or because they have the same, or nearly the same, frequency. Coherent wave interference (coherent, i.e. having the same frequency, length and being in the same phase) gives a spatially constant wave amplitude distribution.

During the superposition of the light coming from two sources other than lasers, or even from different positions of the same source, we do not observe interference. To induce it, the waves must be coherent, i.e. their phase difference can not depend on time. Such light waves from normal (not laser) sources are obtained by splitting the light coming from a single source into two or more beams. The radiation in each of them comes from the same atoms of the source and, due to their common origin, these beams are coherent. To split the light into coherent beams, the phenomena of reflection or refraction of light may be used.

The phenomenon of interference is used in a variety of fields. Examples include as follows:

- measuring the distance from the source to the wave detector – interferometric laser rangefinders, gravimeters; measuring displacements and shape of objects,
- holography – spatial imaging technique by wave reconstruction method,
- noise reduction by means of a system generating sound waves in antiphase to the noise produced by a device,
- in telecommunications – division of the so-called communication network cell in order to facilitate independent signal transfer (UMTS technology).

2. ALBERT ABRAHAM MICHELSON - A SHORT BIOGRAPHY

Fig. 1. Albert Abraham Michelson

Albert Abraham Michelson was an American physicist of Polish origin. The main points of his biography:

- born in 1852 at Strzelno in Kuyavia (region in Poland),
- lived in the USA since 1855,
- in the years 1889-1929 Professor of American universities: Case School of Applied Science in Cleveland, Clark University in Worchester, University of Chicago,
- member of the National Academy of Sciences in Washington,
- The Nobel Prize in 1907 for the construction of high-precision optical instruments (including the so-called Michelson interferometer) and measurements with their use,
- the second American Nobel Prize winner, and the first one in the field of science.

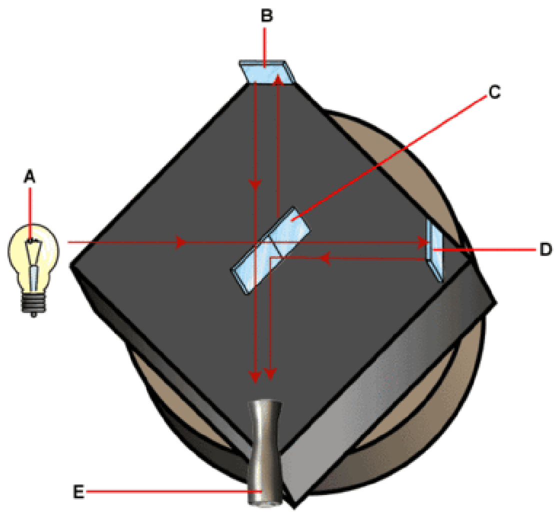


Fig. 2. Michelson interferometer – scheme

A - light source,
C - translucent plate splitting a wave into beams,
B, D - mirrors reflecting light waves,
E - telescope for reading interference pattern.

The most important Michelson's invention, which undoubtedly was the interferometer, enabled its inventor to carry out very accurate measurements of **the speed of light**, as well as other measurements in the field of metrology. In **1887,** Michelson and Edward Morley (American physicist and chemist born in 1838) conducted an experiment proving that **the speed of light did not depend on the motion of the Earth**. This experiment, showing no effect of rotational and orbit movement of the Earth on the speed of light, was of major importance for the later development of Einstein's special theory of relativity. Michelson experiment was supposed to confirm the existence of a hypothetical **aether,** the light carrier. A negative test result became an experimental basis for the theory of relativity.

Michelson and Morley's test results revealed the imperfection of classical mechanics. Galilean transformation failed in the case of Maxwell equations describing electromagnetic waves. According to the calculations based on Newtonian mechanics, the speed of light should depend on the motion of the observer relative to the hypothetical aether, in which electromagnetic waves were to propagate. It turned out, however, that contrary to the predictions of classical physics, the light travels at the same speed, regardless of the reference system. Initially, many physicists believed that such small divergences between the measurement results and the expectations of the mechanics may be eliminated thanks to e.g. more accurate measurements. Few assumed that the newly discovered shortcomings of the classical theory may lead to the formulation of new, more fundamental laws of nature. For Einstein, these inconsistencies in classical physics gave rise to a new theory.

3. THE HISTORY OF MEASURING THE SPEED OF LIGHT

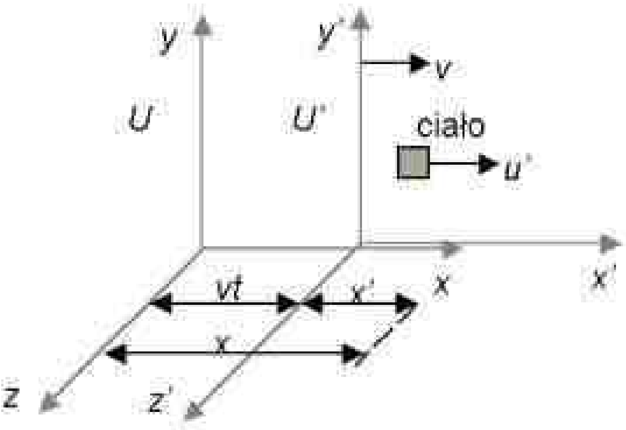


Fig. 3. Galilean transformation imaging for the velocity vector

Galilean transformation of velocity is as follows:

$U = v + u$ for the velocities of the same sense,

$U = v - u$ for the velocities of the opposite sense,

where:

U - velocity of a body in the non-moving frame,

v - velocity of the moving frame,

u - velocity of a body in the moving frame.

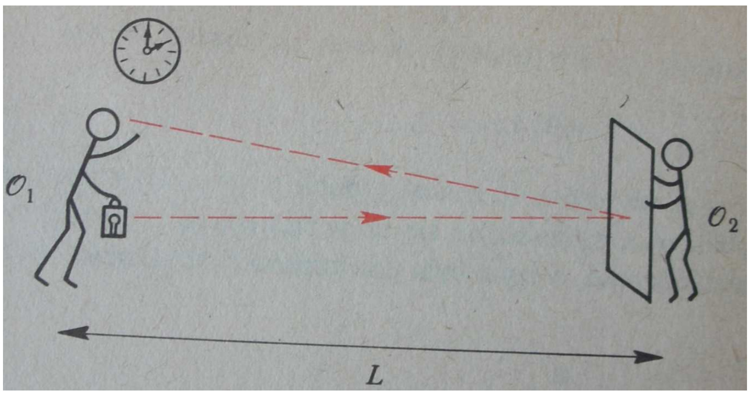


Fig. 4. Galileo's experiment

$$c = \frac{2L}{t}$$

where t - time, after which the observer O_1 notices the light signal sent by him and reflected in a mirror held by the observer O_2.

In the first half of the seventeenth century, Galileo conducted the first experimental attempts to verify whether the speed of light is finite. Members of the Italian Academy of Experiments (Accademia del Cimento), which was contemporary of Galileo, tried to conduct his experiment to measure the speed of light, but today it is clear that the experiment could not produce the intended result due to the inevitable experimental outliers, response time errors, etc., too large in relation to the speed of light. However, Galileo's merit was the idea of measuring the speed of light (the wave travelling back and forth), which was and still is used in numerous experiments.

Ole Roemer, a Danish astronomer, was the first to measure the speed of light in 1676, based on fluctuations in orbital cycle around Jupiter of one of its satellites, Io moon. Orbital period is determined from the observations of eclipses of Io by Jupiter. Roemer noted that as the distance between the Earth and Jupiter increased in its orbital motion, the moments of eclipses were delayed, and he concluded therefrom that this resulted from the time needed for the light to cover the Earth's orbit around the Sun.

Although the speed of light calculated in those conditions (214 000 km/s) deviated significantly from the currently adopted one, an important conclusion of the experiment was its finiteness, contrary to the belief represented by the majority of contemporary physicists.

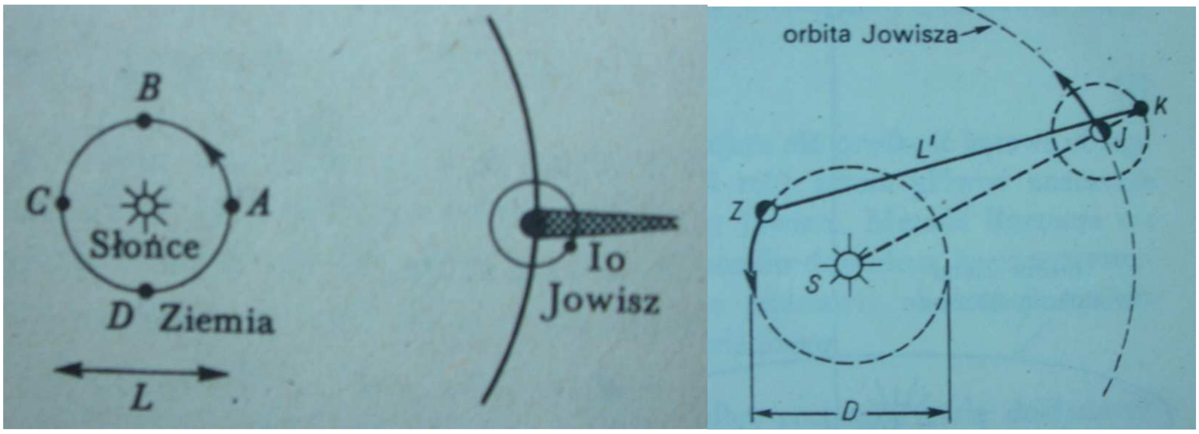


Fig. 5. The Sun (*S*), the Earth (*Z*), Jupiter (*J*), Io (*K*) – relative positions

The next two centuries saw measurements of the speed of light by various methods, which resulted in the values closer to the current value of c = 299 792 458 ± 1,2 m/s.

In those days, until the nineteenth century, it was assumed that, similarly to, for example, the sound waves, the light in order to propagate needs a medium called the aether, penetrating through everything and present everywhere, even in a vacuum. The aether would have to have unusual properties:
1) high resilience due to the large value of c,
2) excellent clarity and permeability, as the planets move without any noticeable resistance.

Each wave has a certain velocity in relation to the medium in which it propagates. Therefore, when measuring *c*, it is necessary to take into account the movement of the Earth relative to the aether.

4. DETAILS OF ALBERT MICHELSON EXPERIMENT

Albert Michelson attempted to detect the motion of the Earth relative to the aether using an interferometer which he had constructed by himself.

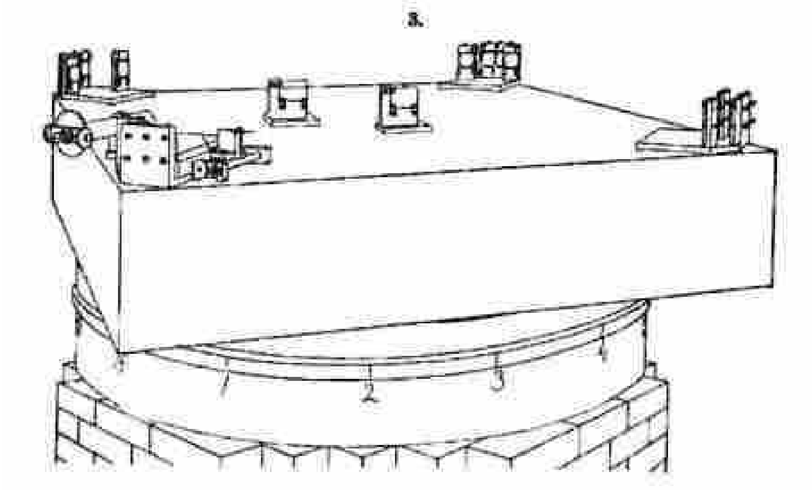
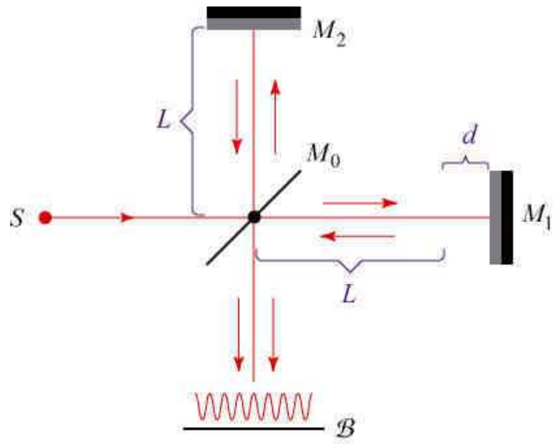


Fig. 6. Albert Abraham Michelson interferometer



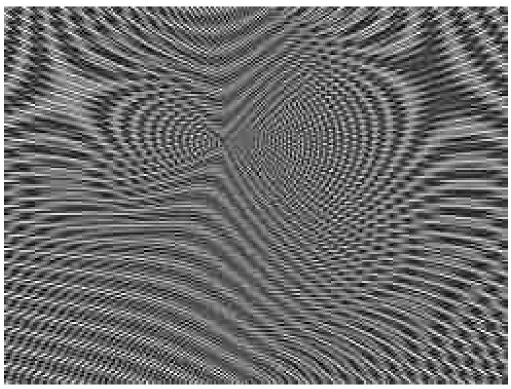


Fig. 7. Scheme of the experiment using Michelson interferometer **Fig. 8.** Interference pattern

Michelson experiment was conducted as follows:

A beam of light comes from the source ***S*** onto a translucent plate $\boldsymbol{M_0}$, where it is split into two beams travelling to the mirrors $\boldsymbol{M_1}$, $\boldsymbol{M_2}$. After being reflected, the waves pass through the plate again, and are directed to the telescope ***B***, in which light and dark fringes are observed - the result of interference of the beams. Interference pattern depends on the difference of beam optical paths, which may vary in sections $\boldsymbol{M_0M_1M_0}$ and $\boldsymbol{M_0M_2M_0}$, due to the mobility of the mirror $\boldsymbol{M_1}$.

Due to the rotational and orbital motion of the Earth, the setting of the interferometer changes, relative to the stationary aether. Let the arm $\boldsymbol{M_0M_1}$ of the length $\boldsymbol{L+d}$ be directed along the Earth's velocity vector relative to the aether: $\vec{v}$, and the arm $\boldsymbol{M_0M_2}$ of the length $\boldsymbol{L}$ - perpendicular to $\vec{v}$. The time difference to be covered by the two beams can be calculated as follows:

$$t_1 = \frac{L+d}{c-v} + \frac{L+d}{c+v} = \frac{2(L+d)}{c \cdot \left(1 - {v^2}/{c^2}\right)} = \frac{2(L+d)}{c}\gamma^2 \tag{1}$$

$$t_2 = \frac{2L}{\sqrt{c^2 - v^2}} = \frac{2L}{c}\gamma \tag{2}$$

where:

$$\gamma = \frac{1}{\sqrt{1 - \left({v}/{c}\right)^2}} \tag{3}$$

therefore:

$$\Delta t = t_1 - t_2 = \frac{2\gamma}{c}(\gamma L + \gamma d - L) \tag{4}$$

Having rotated the interferometer by 90 degrees, the mirrors $\boldsymbol{M_1}$, $\boldsymbol{M_2}$ shall swap roles. Performing similar calculations, we determine the time difference in this position:

$$\Delta t' = \frac{2\gamma}{c}(L + d - \gamma L) \tag{5}$$

Thus, in the field of vision of the telescope, the interference pattern should change. It can be calculated by how much the interference fringes should move, knowing the Earth's orbital velocity $\boldsymbol{v}$ = 30 km/s, the wavelength $\boldsymbol{\lambda} = 6 \cdot 10^{-7}$ m of the yellow light used in the experiment, and the distance between the plate and the mirrors, $\boldsymbol{L}$ = 1.2 m. It was calculated that this shift should be $\boldsymbol{k}$ = 0.04 fringes:

$$k = \frac{c \cdot (\Delta t - \Delta t')}{\lambda} \approx \frac{2L}{\lambda} \cdot \left(\frac{v}{c}\right)^2 \tag{6}$$

when $\boldsymbol{d}$ = 0.

This value is very small, yet observable. However, the shift was negligible, less than 0.01 interference fringes. Repetition of the experiment, over and over again, for many years and for different wavelengths, with increasing the distance to be covered by the light should result in a greater displacement of the interference pattern. However, it was consistently less than 0.01 interference fringes. The shift is proportional to the square of the ratio of the Earth's velocity relative to the aether, to the speed of light (6), and so a negative result of the Michelson-Morley experiment proved that the Earth's velocity relative to the aether is much smaller than its orbital speed. Subsequent use of lasers and masers (these are devices operating like lasers, but emitting radiation in a different frequency range) significantly improved the accuracy of calculations. The conclusion of the zero effect of the Earth's motion relative to the aether on the measured speed of light was confirmed. Thus, **the aether does not exist**, and $\boldsymbol{c}$=const does not depend on the frequency of the wave, the direction of propagation in space, nor on the relative motion of the observer and the source.

5. USING INTERFERENCE IN SURVEYING INSTRUMENTS

The phenomenon of interference is widely used in a variety of surveying instruments. These include, inter alia:

- **absolute gravimeter** to measure the absolute value of the gravity - ballistic gravimeter determining gravity acceleration based on the free fall of a body in a vacuum; the use of a laser interferometer to determine the path of a falling body,
- **electromagnetic interferometric rangefinders** (mobile radio interferometer),
- **interferometric radars** used in remote sensing to create a digital terrain model, as well as in land subsidence monitoring on large areas,
- **laser interferometers** for remote control of industrial surface deformation.

REFERENCES

1. Feynman R.P., Leighton R.B., Sands M., “The Feynman Lectures on Physics”, Volume I, Part. 2, PWN, Warsaw 1974,
2. Kittel C., Knight W.D., Ruderman M.A., “Mechanics”, PWN, Warsaw 1973,
3. Wróblewski A.K., Zakrzewski J.A., “Introduction to Physics”, PWN, Warsaw 1984.

BIOGRAPHICAL NOTES

Name:	Anna Barańska
Employment:	AGH University of Science and Technology in Krakow Poland (from 01.11.2003)
Degree:	Habilitation of Geodetic Sciences (AGH Krakow, 29.09.2011)
Degree:	Philosophy Doctor of Geodetic Sciences (AGH Krakow, 12.06.2003)
Study:	Doctor Study at the Faculty of Mining Surveying and Environment Engineering (AGH Krakow, 10.1998 – 06.2003)
Degree:	Master of Geodetic Science, Specialization: Real Estate Administration (AGH Krakow, 23.06.2000)
Study:	Master Study at the Faculty of Mining Surveying and Environment Engineering (AGH Krakow, 10.1995 – 06.2000)
Degree:	Master of Mathematics, Specialization: Applied Mathematics (Jagiellonian University Krakow, 24.06.1996)
Study:	Master Study at the Faculty of Mathematics and Physics Faculty (Jagiellonian University Krakow, 10.1991 – 06.1996)

CONTACTS

Anna Barańska, D.Sc., Ph.D.
AGH University of Science and Technology
Faculty of Mining Surveying and Environmental Engineering
Department of Geomatics
al. A. Mickiewicza 30
30 – 059 Krakow
POLAND
Tel. + 48 12 617 44 80
Fax + 48 12 617 45 88
E-mail: abaran@agh.edu.pl