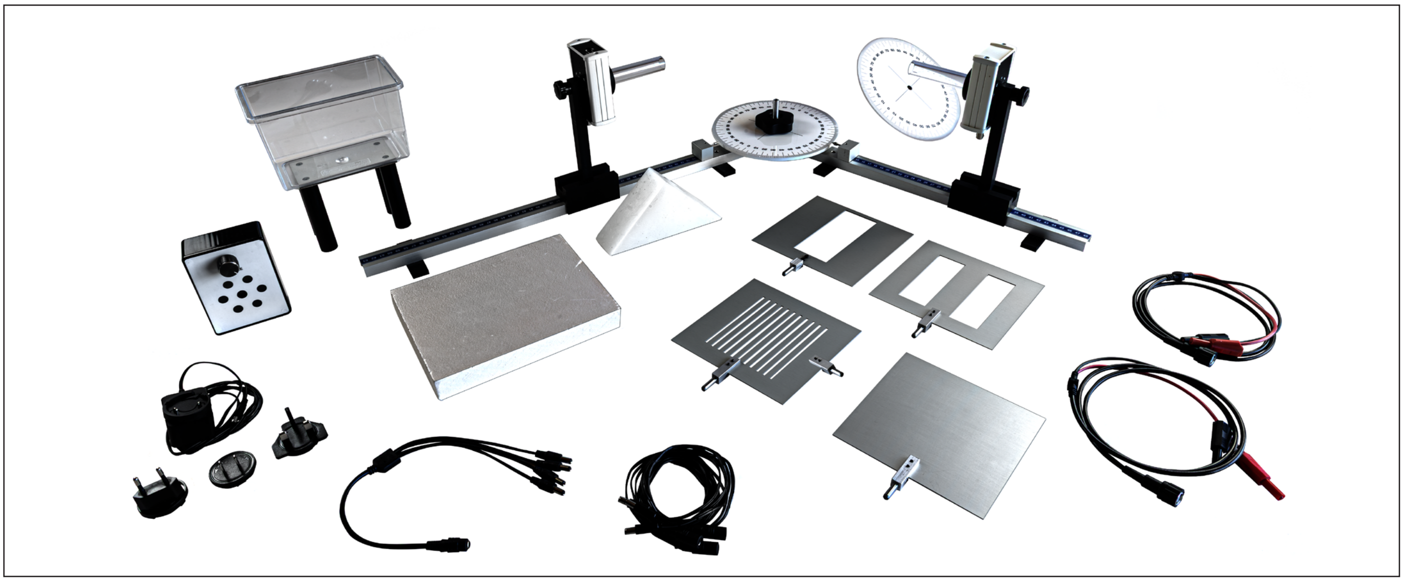
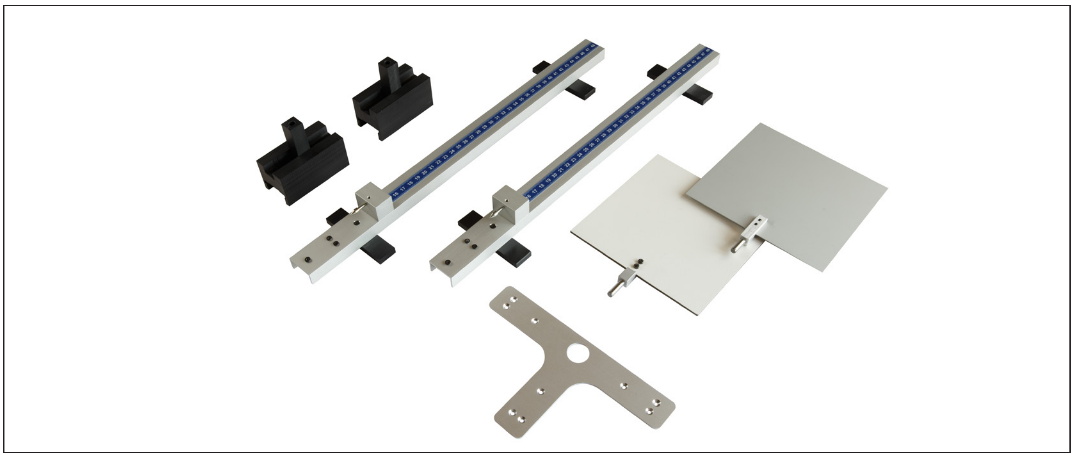
Teaching guide Ver. 4.0.0

Code 5439 / 5437
MICROWAVES OPTICS KIT / MICHELSON INTERFEROMETER





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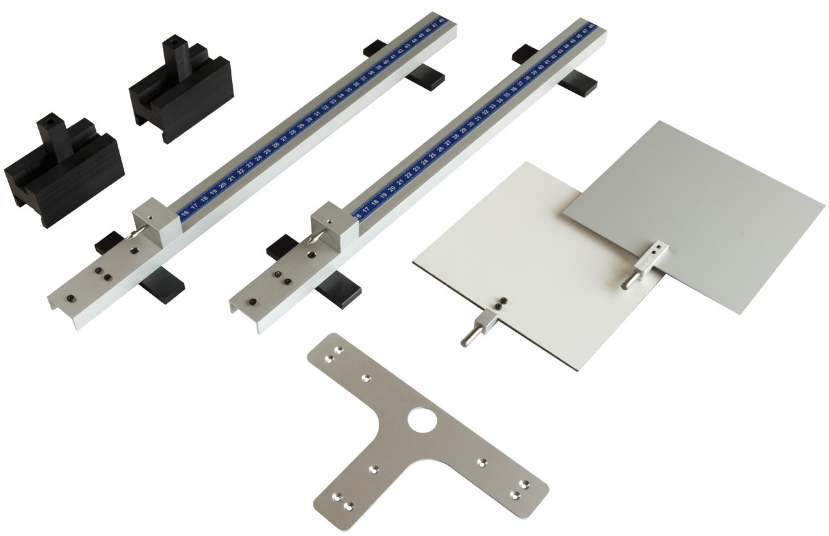
EQUIPMENT SUPPLIED

N.	Description	Code
5439	**MICROWAVES OPTICS KIT**	
1	Microwave transmitter with holder	OFF5019
1	Microwave receiver with holder	OFF5020
1	12 V DC power supply	PS-UNI-12VMP
1	Three-terminal cable for power supply with extensions	OFF4767
1	Articulated track with protractor	OFF5021
1	Loudspeaker	OFF4770
2	BNC - double banana cable	E0277
1	Expanded polystyrene panel	OFF3547
1	Tray	H20
1	Tray support	OFF4772
1	150 x 150 mm metal lamina	OFF5023
1	Protractor with pin	OFF5022
1	Paraffin prism	OFF3559
1	11 slits grating metal sheet	OFF5024
1	Single slit grating metal sheet	OFF5025
1	Two slits grating metal sheet	OFF5026
1	Linear ruler	1116
1	anti-acoustic panel	OFF4794
5437	**MICHELSON INTERFEROMETER**	
1	Rotation plate	OFF5015
2	Movable arm	OFF5028M
2	Lamina holder	OFF5029
1	Lamina with foot	OFF5023
1	White lamina with foot	OFF5030

DESCRIPTION OF EQUIPMENT
5437



EQUIPMENT SUPPLIED

5439

OFF4765 OFF4766

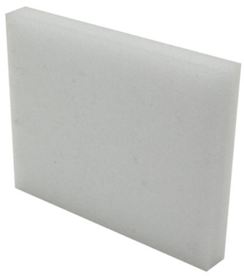
PS-UNI-12VMP

OFF4767

OFF4769

OFF4770

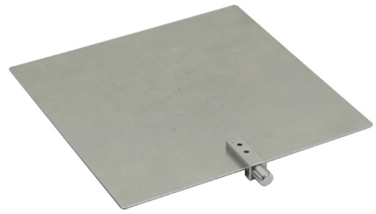
E0277



OFF4794

H20

OFF4772



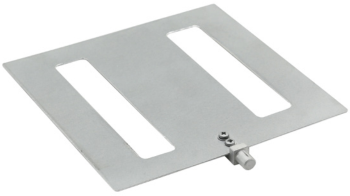
OFF3530

OFF4773

OFF3559

OFF3538

OFF3985



OFF3986

1116

TOPICS

N. performable experiments: 13

ATTENTION

Read this manual carefully for a correct and efficient use of this instrumet.
Make sure that the power supply is compliant.
The transmitter should only be used for physics experiments.
It is not recommended to use this device outside the school laboratory.

A. THEORETICAL INTRODUCTION

1. GENERAL INFORMATION ON ELECTROMAGNETIC WAVES

Monochromatic electromagnetic wave (ie, with a well defined frequency and wavelength) is composed by an electric field (named ***E***) and a magnetic field (named ***B***) mutually perpendicular that oscillate in phase with each other perpendicularly to the propagation direction (Fig.1).

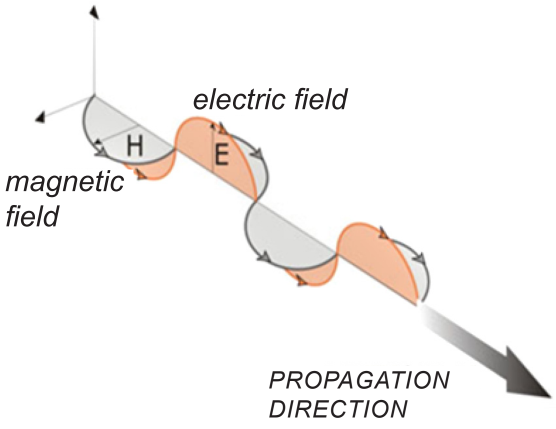


Fig 1

Then an electromagnetic wave actually consists of two components coupled: one electric and one magnetic. A wave of this type is called a polarized plane wave. It is assumed that the polarization plane is the plane in which the electric field oscillates.

In terms of energy, the electromagnetic wave can be assumed as a flow of energy, that in the vacuum propagates at the speed of light in the form of electric and magnetic fields, in a straight line (in homogeneous medium).

Velocity of electromagnetic waves in the vacuum
The speed of electromagnetic waves in vacuum is a very important quantity in physics and it is commonly indicated with *c*: its numerical value is about 300 000 km/s, i.e. $3 \cdot 10^8$ m/s, in scientific notation.

Velocity of electromagnetic waves in non-conductive materials
The speed of electromagnetic waves in a homogeneous, non-conductive and nonferromagnetic material is lower than in the vacuum: $v = c/n$, where n is the so-called index of refraction or refractive index.
The higher is the refractive index, the lower is the propagation speed.
The refractive index, normally a value greater than 1, depends on the properties of the medium, but can assume different values varing the frequency of the wave.

Wavelength
The wavelength is the distance traveled by the wave in the time of a cycle.
In other words, it is the distance between a point in a cycle and the corresponding point in the next cycle (e.g. the distance between two peaks).
The wavelength is usually denoted by the Greek letter λ (lambda) and is measured in meters.

Frequency
The number of wavelengths, or cycles, that pass through a given point, in the unit of time, is called frequency.
The frequency is denoted by the letter *f* or by the Greek letter ν (ni) and is measured in hertz (Hz). It is clear from what has been said above that the frequency and the wavelength are linked to each other through the speed of the wave: $\lambda f = c$ in vacuum and $\lambda f = c/n$ in materials. So:

- at higher frequencies, there are shorter wavelengths;
- at a fixed frequency, the wavelength varies passing from one medium to another with different refractive index.

Amplitude
By amplitude we mean the maximum value that is reached by the oscillation (in analogy to the mechanical case, where we talk about the maximum displacement from the equilibrium position). For example, in the case of a sea wave the amplitude is the maximum height of the wave.
In an electromagnetic wave the amplitudes of the two fields (the electric and the magnetic fields) are not independent, but are linked to each other: in this sense the two fields are coupled.

Intensity

The intensity of an electromagnetic wave is the energy that passes through a unitary area in the unit of time and is measured in W/m^2: this is the energy that crosses a surface of one square meter in every second. It can be shown that the intensity is proportional to the product of the amplitudes of the electric field and of the magnetic field; and since the latter two are proportional to each other, the intensity is proportional to the square of the amplitude of the electric field.

Spectrum of electromagnetic waves

The electromagnetic spectrum is the set of all possible frequencies of electromagnetic radiation. This spectrum is continuous, but a purely conventional and indicative subdivision in various intervals or frequency bands is possible. The possible frequency or equivalently wavelength range goes from zero to infinity, maintaining the relationship of inverse proportionality between the two quantities. (Fig.2).

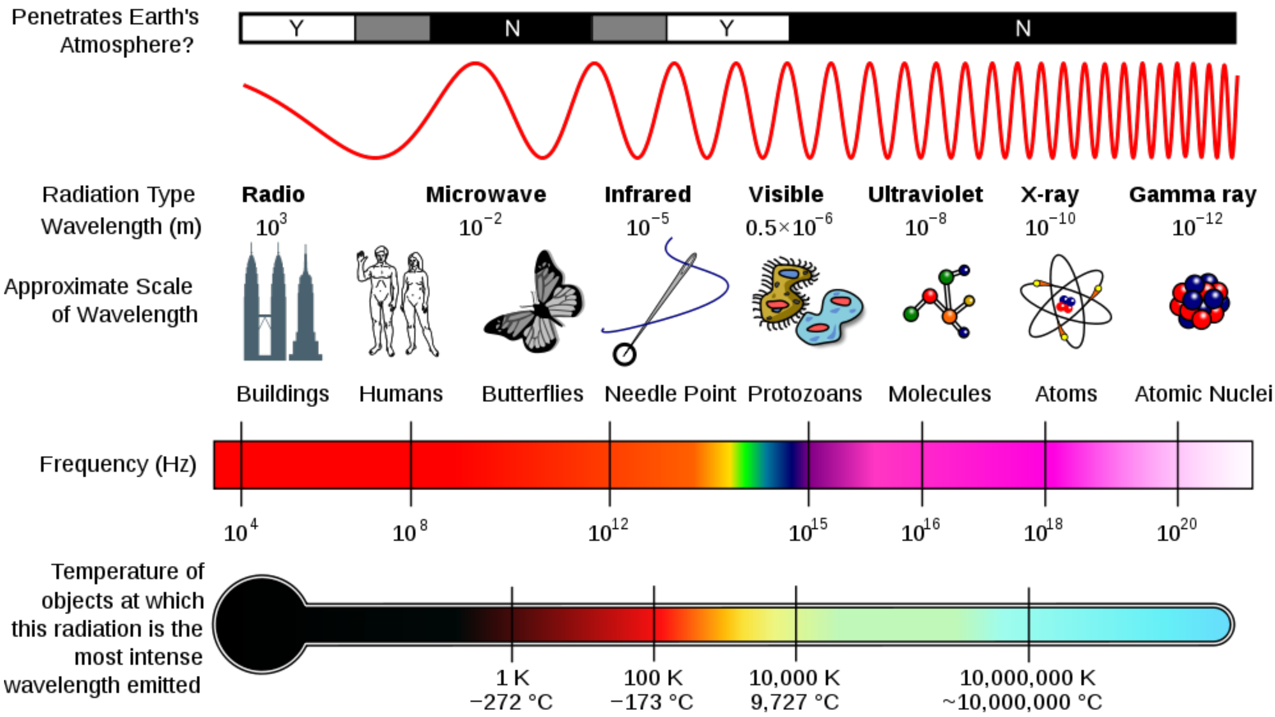


Fig. 2

2. MICROWAVES

Microwaves are electromagnetic radiation with a wavelength between radio waves and infrared radiation. Although we tend to consider them separate from radio waves, the microwaves are included in the UHF and EHF parts of the radio spectrum, but they have specific characteristics due to their high frequency.

The boundary between the microwaves and the neighboring radiation ranges is not clear and can vary according to the different fields of study. The microwaves (Table 1) are between 0.1 m (frequency of about 2-3 GHz) and 1 mm (frequency of about 300 GHz). Above 300 GHz, the absorption of electromagnetic radiation is so intense that the atmosphere can be considered opaque at these frequencies.

However, it returns transparent again in the infrared and visible light areas. When radiations pass through a material, they generate oscillations of small amplitude of ions whose motion, as by friction, causes the heating of the material itself. This thermal effect is called diathermy and is used for therapeutic purposes in medicine to heat limited areas of the human body. Not reaching too high temperatures, they can cure arthritis, bursitis, muscle sprains and traumatic damages in general. The following table lists the division into bands according to the Radio Society of Great Britain (RSGB).

Band name	Frequency range
L	1 – 2 GHz
S	2 – 4 GHz
C	4 – 8 GHz
X	8 – 12 GHz
K_u	12 – 18 GHz
K	18 – 26 GHz
K_a	26 – 40 GHz
Q	30 – 50 GHz
U	40 – 60 GHz
V	50 – 75 GHz
E	60 – 90 GHz
W	75 – 110 GHz
F	90 – 140 GHz
D	110 – 170 GHz

Tab 1

3. DANGERS ARISING FROM EXPOSURE TO MICROWAVES

Although microwaves are widely used since the mid-twentieth century, their potential danger is still under discussion. Beyond this, a risk is well documented regarding the use of magnetron. The cornea of the eye is not crossed by blood vessels that can cool it and could be overheated if hit by microwave, also because it is not transparent to these wavelengths. For this reason, exposure to microwaves, exactly how to sunlight, can increase the incidence of cataracts in later life. There are no protections against the microwaves like the sunglasses against the sun.
A microwave oven with defective door can be a source of risk. It should therefore avoid using damaged equipment and check eventually the stray field with special tools. For the same reason it is good to avoid being in the place of the antenna emission of powerful aircraft radars, as well as look directly and closely the anti-theft sensors that use radar technology. Direct exposure to microwaves may also seems to generate interactions with the brain, causing irritability and headaches. NASA research in 1970 showed that this can be caused by thermal expansion of the inner ear parts.

Figure 3 shows the symbol used to warn users of the dangers associated with the use of microwaves.

Fig.3

4. Amplitude modulation

An electromagnetic signal can be modulated in three ways: amplitude, frequency and phase. These modulations are made by a second signal (called “modulating”) which is multiplied by the first (defined as a carrier). It is thanks to this technique that it was possible to transmit the information contained in the modulating signal at great distances without the use of electric cables. In amplitude modulation, the amplitude of the carrier wave varies proportionally to the amplitude of the modulating wave. As a consequence, the modulated signal has the same frequency as the carrier wave, while its amplitude is maximum at the positive peaks of the modulating wave, and the amplitude is minimal at the negative peaks of the modulating wave (Fig. 4).

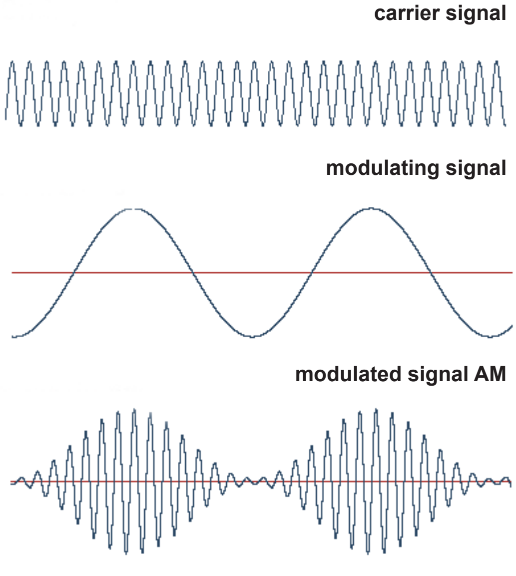


Fig. 4

B. MICROWAVES OPTICS KIT

The microwave optics kit is composed of a transmitter, a receiver, a loudspeaker, an articulated rail and other components.
This kit can be used for performing various experiments on microwaves: it is possible, first of all, to demonstrate that microwaves have the same characteristics as light waves and cause the same phenomena of reflection, refraction, interference, diffraction, etc.

1. TRANSMITTER, DESCRIPTION

The transmitter complete with support, base and power cable is shown in figure 5.
The switch at the top allows you to modulate the carrier wave with the internal signal (IM) if moved to the right, or with an external signal (EM) if moved to the left.

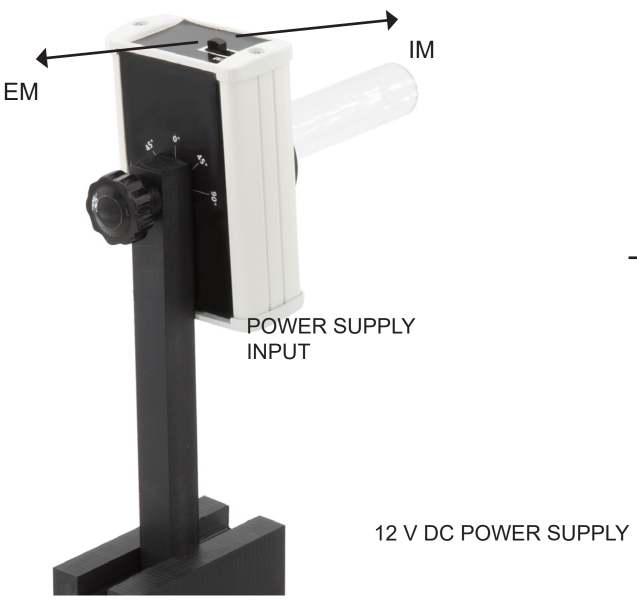


Fig. 5

Fig. 6

The input of the power supply and the input of the external modulation signal are placed in the lower part of this instrument, as shown in figure 6.

2. TRANSMITTER, TECHNICAL DATA

Power supply: 12 V - 1,5 A DC
Frequency of the carrier wave: f_p = 10,5 GHz
Wavelength of the carrier wave: λ = 2,85 cm
Shape of the internal modulating signal: square wave
Frequency of the internal modulating signal: f_m = 676 Hz
Allowed frequency range of the external modulating signal: 100 Hz - 20 MHz
Maximum amplitude allowed for the external modulating signal: 5 V peak to peak

NOTE

For the power supply, use one of the terminals of the the code OFF4767 cable.

To insert the external modulation signal from a function generator, use the code E0277 cable.

3. RECEIVER, DESCRIPTION

The receiver, complete with base and power cable is shown in figure 7.
The BNC socket, placed in the lower part of the instrument, allows to transfer the received signal to the loudspeaker or to a detector instrument (such as a tester or oscilloscope).

Fig. 7

12 V DC POWER SUPPLY

4. RECEIVER, TECHNICAL DATA

Power supply: 12 V - 1,5 A DC
Maximum operational distance: 0 – 1,5 m

5. LOUDSPEAKER, DESCRIPTION

The loudspeaker shown in Figure 8 is the instrument that transforms into an acoustic signal the electrical signal obtained after the demodulation performed by the receiver.

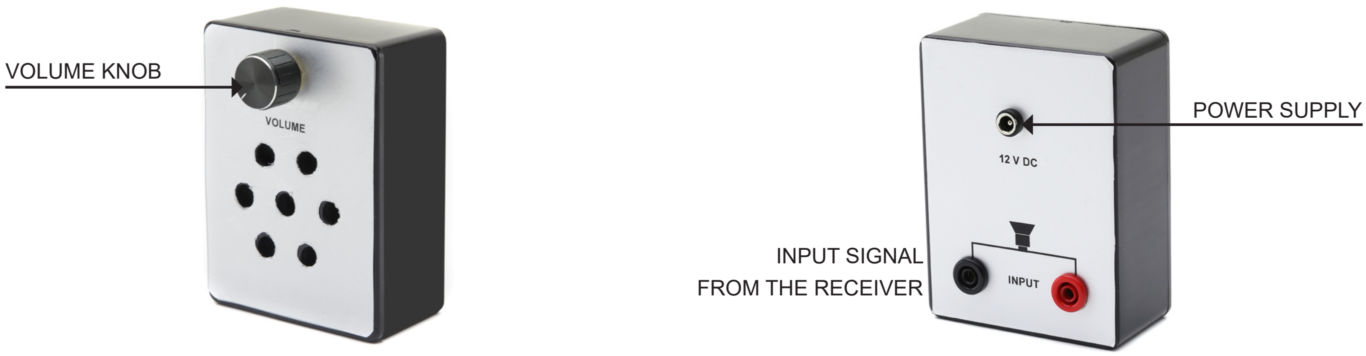


Fig. 8

This signal is taken from the BNC socket of the receiver and it is transferred, with the cod. E0277 cable, to the two bushings arranged in the back part of the loudspeaker where it is amplified as shown in figure 9. Its amplitude can be adjusted by acting on the knob shown in figure 8.

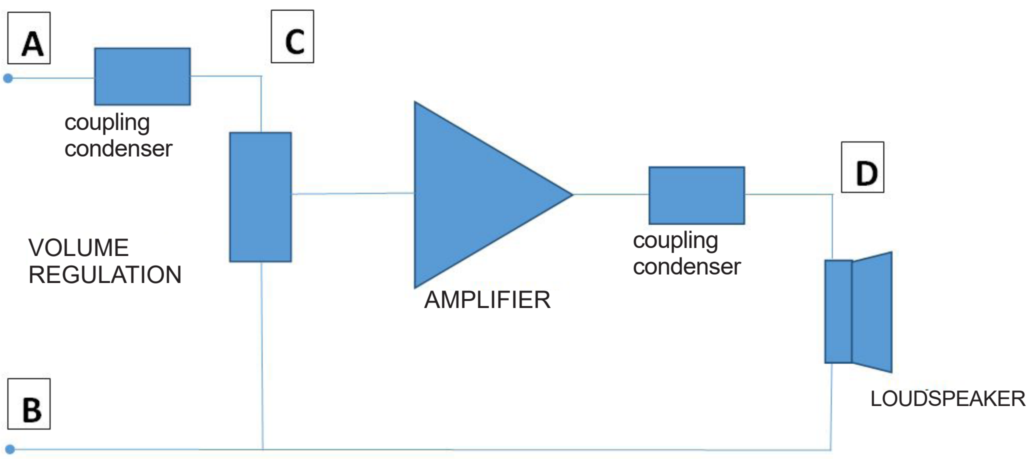


Fig. 9

6. HOW TO MOUNT THE RAIL

a) Hook the short arm (with the connection flange) to the long one with the pivot (Fig.10).

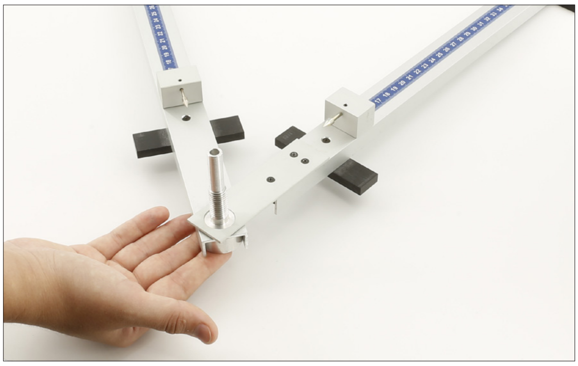


Fig. 10

b) Put the washer in the pivot (Fig. 11).

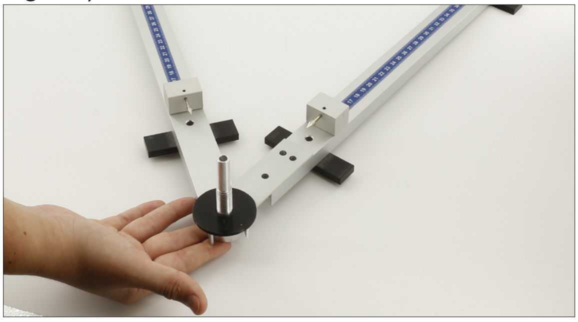


Fig. 11

c) Insert the protractor on the pivot, at 0° (Fig. 12).

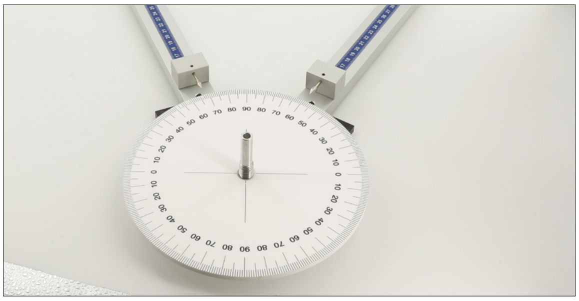


Fig. 12

d) Screw the black PVC yoke onto the pin (Fig. 13).

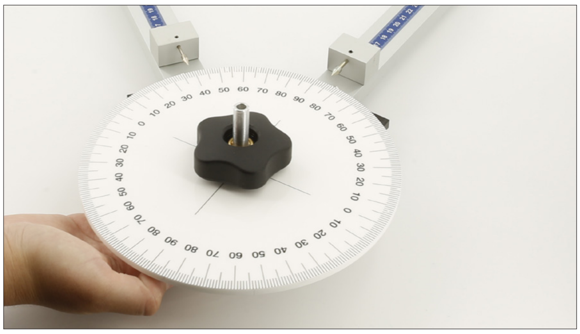


Fig. 13

At the end of the assembly the right arm must be able to rotate independently of the left one.

C. PERFORMABLE EXPERIMENTS

EXPERIMENT N.1: Operational test

Equipment required: rail; transmitter; receiver; loudspeaker; three-ways cable;
power supply 12 V; receiver - loudspeaker connection cable.

- Align the receiver horn with the transmitter horn.
- Set the internal modulation of the transmitter.
- Turn the speaker volume knob all the way to the left.
- Arrange the system as shown in picture 14.
- Connect the power supply.
- Turn the volume control slowly: you should hear a fixed frequency sound of 550 Hz with increasing amplitude.

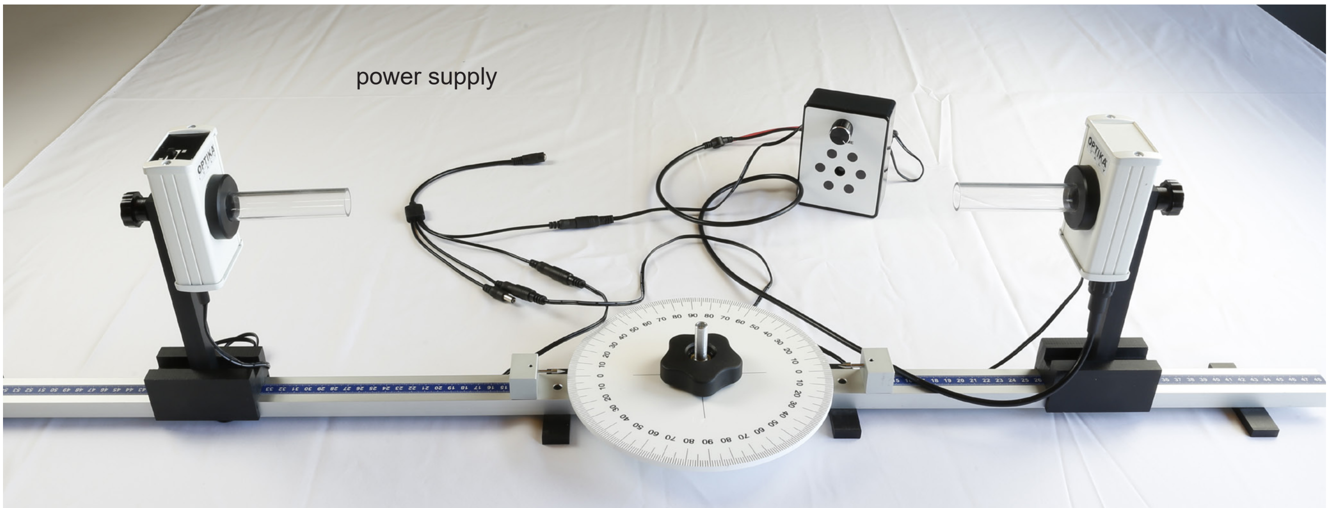
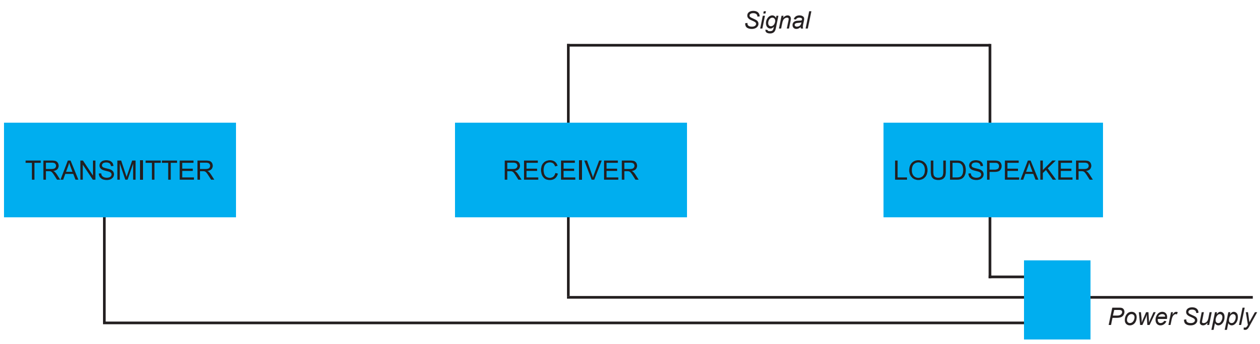


Fig. 14



The signal may be disturbed by the proximity of other bodies capable of absorbing, reflecting or refracting microwaves. Signal distortions are also introduced by the simple approach of a hand to the apparatus: as we will see in the first experiences, in fact, the human body is able to absorb and reflect the microwaves. For this reason it is useful to stay as far as possible from the apparatus during the measurements.
At the same time it is advisable to free the space around the system from every object and appliance and to keep the system at a proper distance from the walls.

EXPERIMENT N.2: Transmission and absorption of microwaves by polystyrene panel

Equipment required: as for experience N.1; polystyrene panel.

Theoretical references

Absorption and transmission of microwaves give important qualitative information about the physical properties of substances that interact with electromagnetic waves.
Let's take into account, for example, the absorption.
When crossing a layer of thickness *x,* it is observed that the intensity of the transmitted radiation follows the Lambert's law:

$$I = I_0 \cdot e^{-kx} \qquad (1)$$

where *k* is the absorption coefficient of the material at a known frequency.
If, for a given frequency, a material has *k* = 0, then it has zero absorption. Of course, the same material can be transparent at certain frequency and absorbs other ones. It is known that electrical insulators are generally transparent to microwaves and visible light, instead they strongly absorb ultraviolet radiation.
It is a common experience that solid insulators such as diamond, quartz and kitchen salt are transparent crystals. If the insulating material is an ionic crystal, we can observe a strong absorption in the infrared region. The first type of absorption is due to the electrons of the solid, the second one is due to the oscillations of the ions.
Semiconductors absorb visible light.This is the reason why silicon solar cell panels appear black. An high absorption coefficient is associated with an high reflectivity. Metals absorb and reflect on the whole spectrum, even in the far infrared and in the microwave region.

How to perform the experiment

For performing this experience, you should arrange the system as in picture 14, the transmitter and the receiver are both 25-30 cm far from the center of rotation of the rail.
Turn the volume knob slightly to the right to obtain a sound that can be heard at a distance of a few meters.

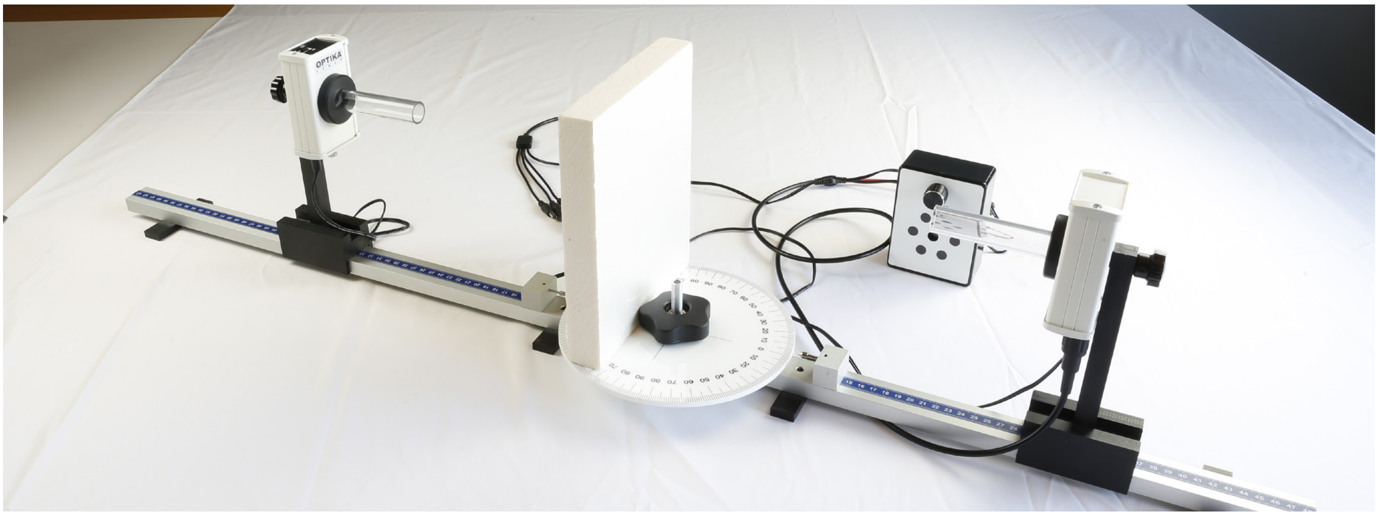


Fig. 15

Now place in the middle the supplied polystyrene panel and observe that there is no attenuation of the signal (Fig. 15). If necessary, repeat the test by sending the received signal to a measuring instrument.

EXPERIMENT N.3: Transmission and absorption of microwaves by water

Equipment required: as for experience N.1; plastic tray with its support.

Repeat the previous experience using the plexiglass tray without water (Fig. 16).

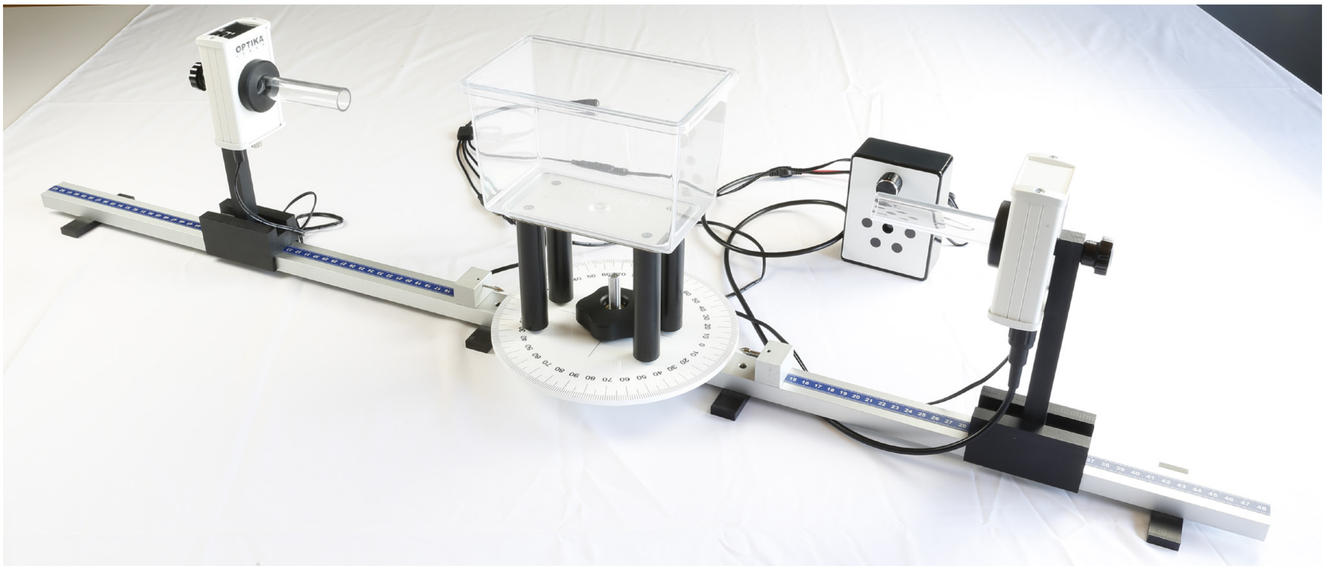


Fig. 16

Also in this case no signal attenuation is recorded. You can try again with other electrically insulating materials (for example wood, cork, etc.) but the result will be the same: the insulating materials let the microwaves go through. It should be noted that depending on the type of material, a partial, more or less evident, reflection of the microwaves may occur.
Try now filling the tray with water (in the picture it is faintly colored to show it). Place the tray according to its longer side as shown in figure 17.

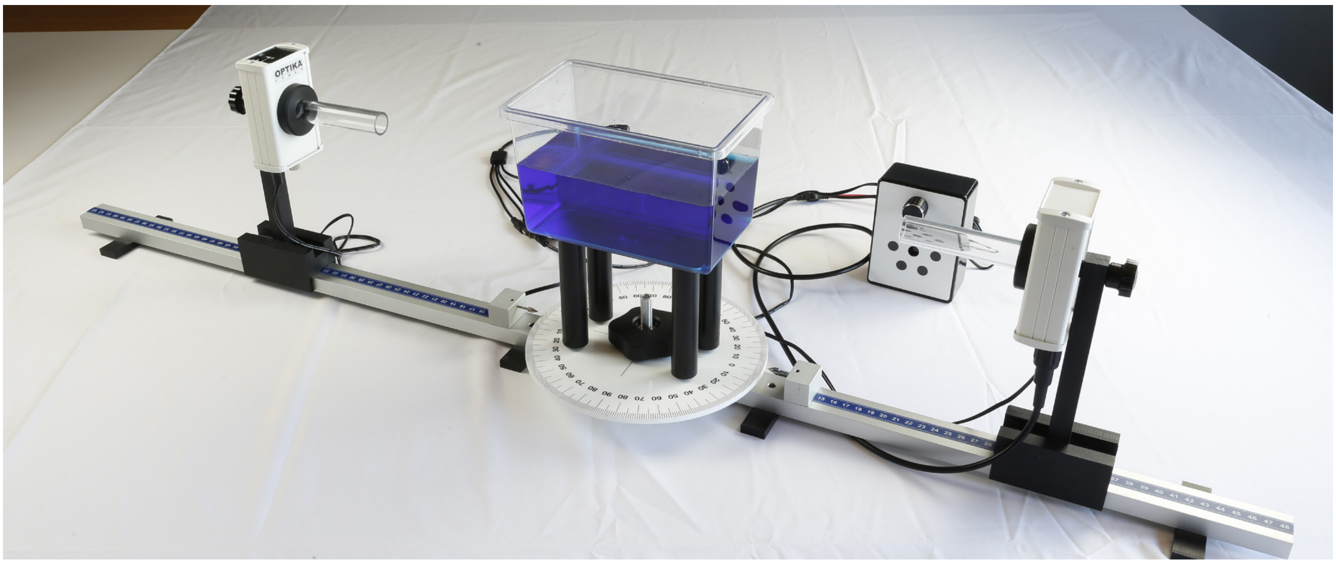


Fig. 17

The signal is totally absent; the microwaves were absorbed by the water. The law that describes this phenomenon of absorption is: $I = I_0 \cdot e^{-k\,x}$.
This means that the water layer does not allow microwaves to reach the receiver. It is precisely for this reason that submarines and boats do not use radar, since the latter is based on the transmission and reception of microwaves, but sonar, which works at much lower frequencies.
Check if the same thing happens even when the microwaves cross the short side of the tray.

EXPERIMENT N.4: Transmission and absorption of microwaves by the human body

Equipment required: as for experience N.1.

A further confirm that the microwaves are absorbed by water can be seen by placing the hand between the transmitter and the receiver as in figure 18. Also in this case the signal is almost totally attenuated. The explanation of the phenomenon lies in the fact that, on average, the 75% of the human body is made of water.

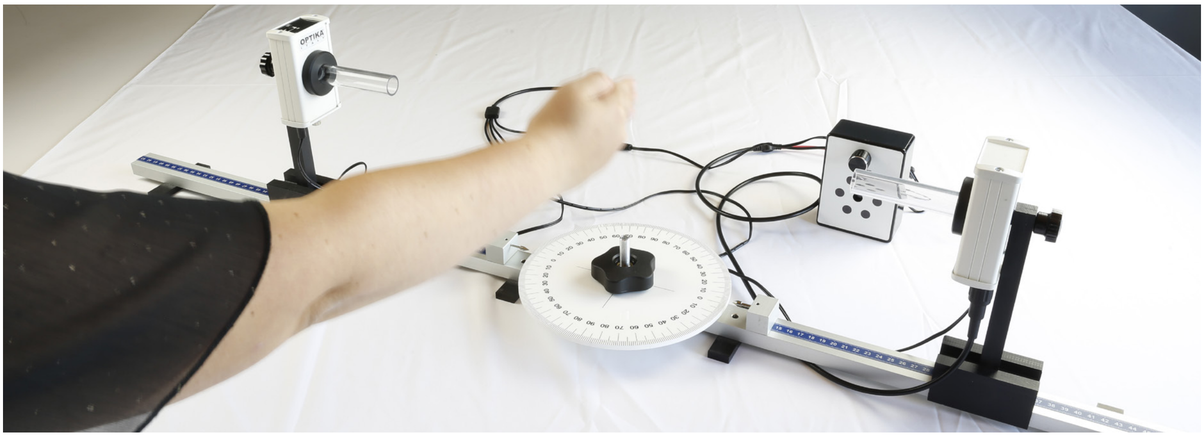


Fig.18

The peak of water absorption is at the frequency of 2,450 GHz.
By emitting electromagnetic energy at the same vibration frequency of the water molecule, the phenomenon of electromagnetic resonance occurs. In such conditions, the total absorption of electromagnetic energy by the water is induced, obtaining the maximum possible heating.
This explains why a microwave oven, with a power of a few hundred watts, is able to heat in a few moments a food that, in a traditional oven, requires tens minutes of heating to reach the same temperature level. In the microwave oven the methods of diffusion of heat in the food are different: while in the traditional oven the heat attacks the surface of the food and then, by conduction, the heat also spreads inside (which entails the greatest “burn” of the surface), with the microwave oven the heat spreads very homogeneously. In fact it is the internal matter (water in this case) to collect the electromagnetic energy and to transmit it around itself.

EXPERIMENT N.5: Transmission and absorption of microwaves by a metal body

Equipment required: as for experience N.1; a metal plate.

Repeat the previous experience by placing a metal plate between the transmitter and the receiver as shown in figure 19. In these conditions there is no microwaves passage and the signal is totally absent.

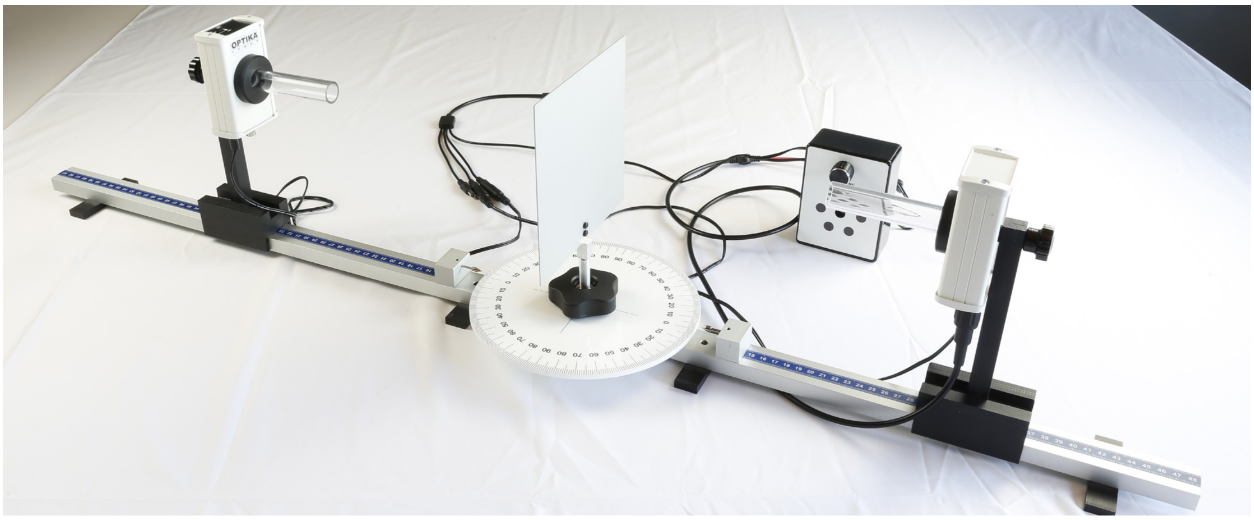


Fig. 19

EXPERIMENT N.6: Microwaves reflection

Equipment required: as for experience N.5.

Arrange the system as shown in figure 20.
The reflecting plate must be aligned with the zero of the protractor while the branch on which the transmitter is arranged must form an angle of 45° with the zero of the protractor.

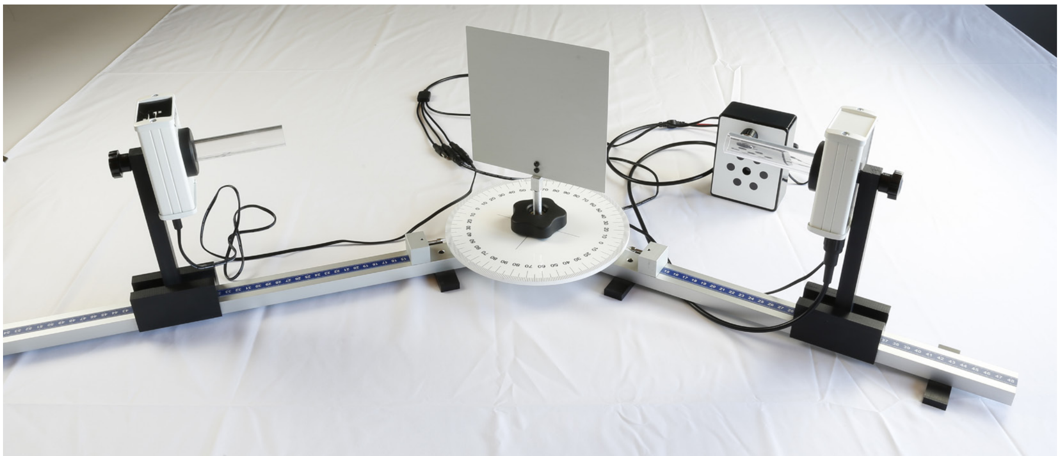


Fig. 20

Switch on the devices and select the internal modulation. Adjust the volume of the received signal just below the audibility threshold. Then, while holding the left branch of the guide, slowly rotates the right one. You will notice that the received signal increases in intensity and becomes maximum when also the angle formed by the left branch with the zero of the protractor is 45°. This proves that the signal reflected by the plate is maximum when the angle of reflection is equal to the angle of incidence (Fig. 21).

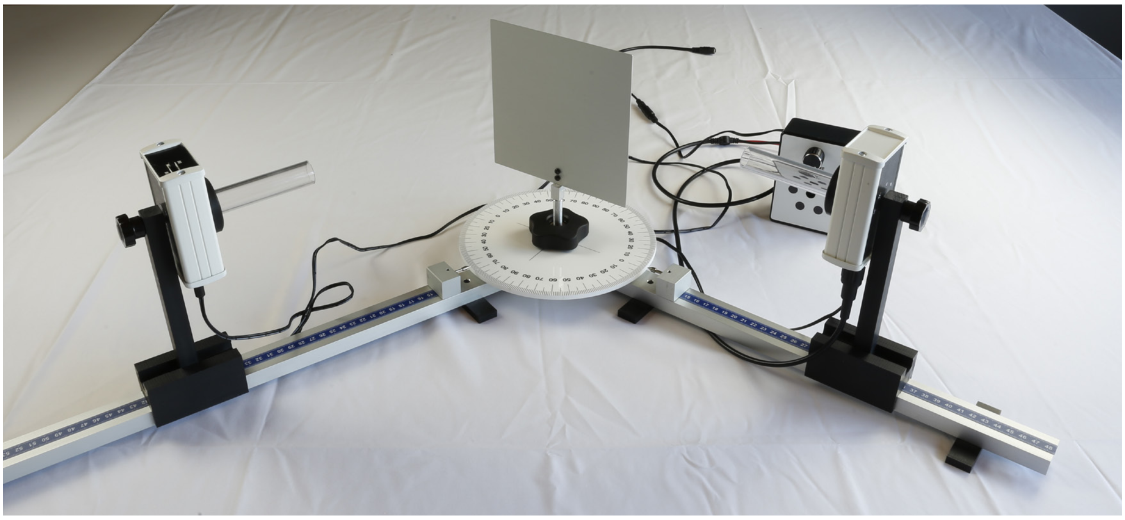


Fig. 21

EXPERIMENT N.7: Microwaves refraction

Equipment required: as for experience N.1; a protractor with pin; paraffin prism.

As an optical prism is able to produce the refraction of light, so even a paraffin prism produces a refractive effect on the microwaves that follows the same optical laws as the refraction of light rays. For this experience arrange the system as shown in figure 22. It is advisable to place the transmitter 25 cm far from the prism in order to minimize the microwaves reaching the receiver without passing through the prism, which must be arranged as shown 23.
In this position the angle at the vertex is $A = 45°$, while the value of the angle of incidence i can be read on the upper goniometer. Choose, for example, $i = 30°$.

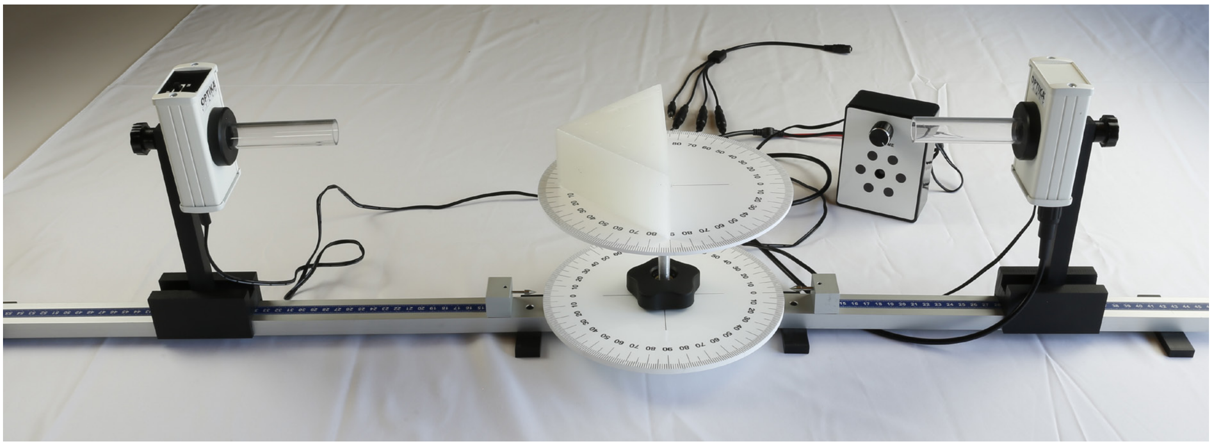


Fig. 22

If the receiver is aligned with the transmitter, it receives no signal because the wave beam sent by the transmitter is deviated from the prism. Holding the left branch, slowly rotate the right one and take note of the position at which the signal reaches the maximum value (Fig. 24). You can thus evaluate the total deviation angle δ, taking into account the position, on the lower protractor, of index of the branch on which the receiver is placed.

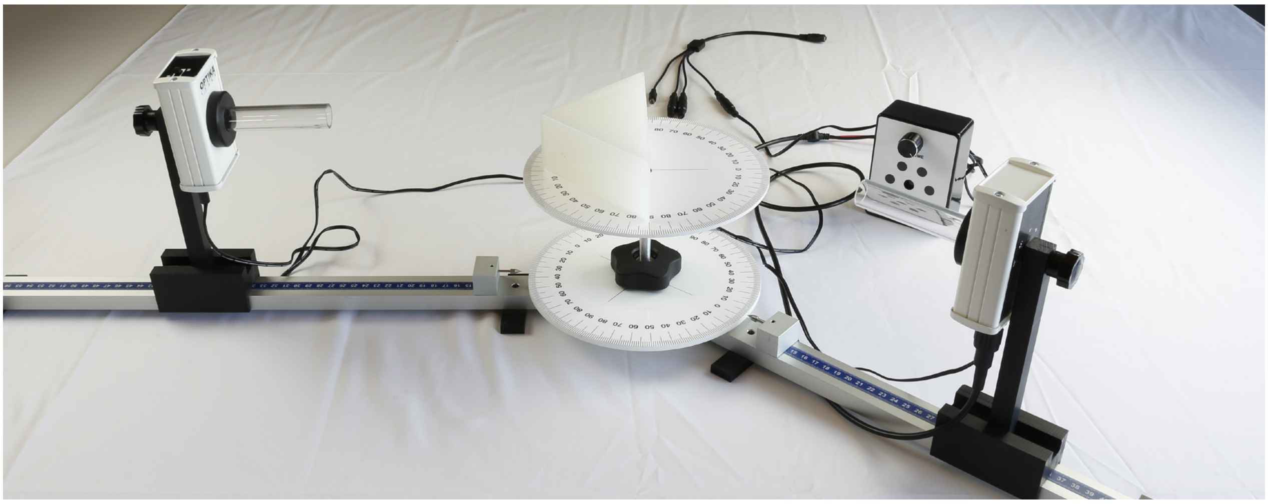


Fig. 24

From geometric considerations, we have that

$$\delta = i + e - A \qquad (2)$$

Using this formula, knowing the values of *i, A,* δ, you are able to calculate the value of the angle *e.* (Fig. 25).

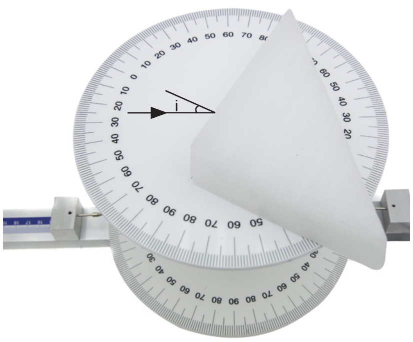


Fig. 23

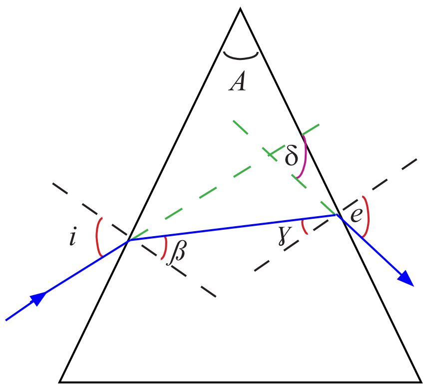


Fig. 25

EXPERIMENT N. 8: Total reflection of the microwaves

Equipment required: as for experience N.7.

The refraction index is a quantity that depends, at a given temperature, both on the material and on the wavelength of the incident radiation. Paraffin is a variable mixture of alkanes ($C_n H_{2n+2}$), characterized by refractive indices ranging from 1 to 1.4. The purpose of this experience is to determine the refractive index of the supplied paraffin at a frequency of 10.5 GHz, which will approximately have a value included between 1 and 1.4.
In this experience we use the phenomenon of total reflection in the passage of a wave from a propagation medium with a refractive index n to the air. The index of refraction n is linked to the limit angle l from the following relation:

$$n = 1 / \text{sen}(l) \qquad (3)$$

For this reason, we should know the value of l to calculate the value of n.
Arrange the system as shown in Figure 22 and place the prism as shown in Figure 26. The wave reaches the prism in a perpendicular direction, so it is not deflected. It then continues in the same direction and reaches the inclined face of the prism according to an angle of 45° (Fig. 27).

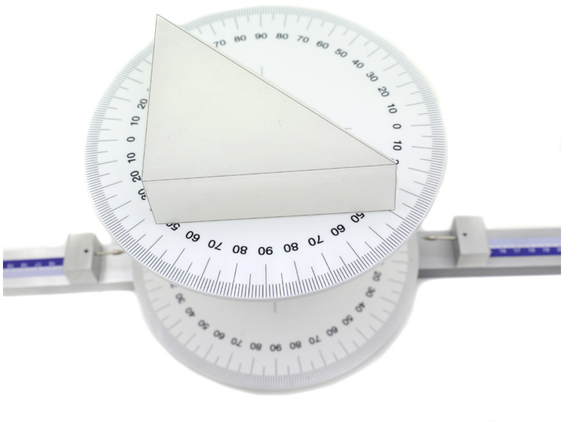


Fig. 26

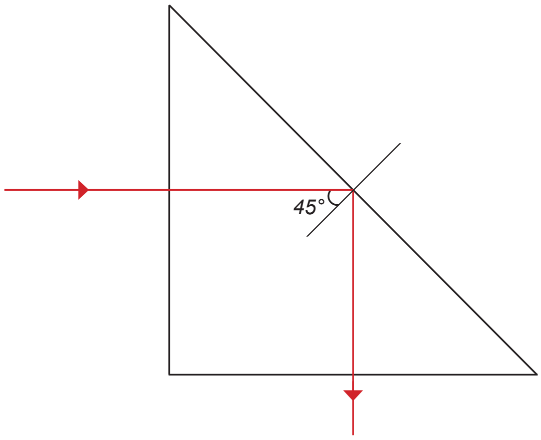


Fig. 27

If this angle is greater than the limit angle, then the ray is totally reflected, otherwise it is refracted.
To check it, holding the left arm of the rail, slowly rotate the right one. You can thus verify that the signal is maximum when the arm is rotated of about 90°, in the direction of the totally reflected ray (Fig. 28). This means that l is slightly less than 45°, which corresponds to a refractive index of about 1.4.

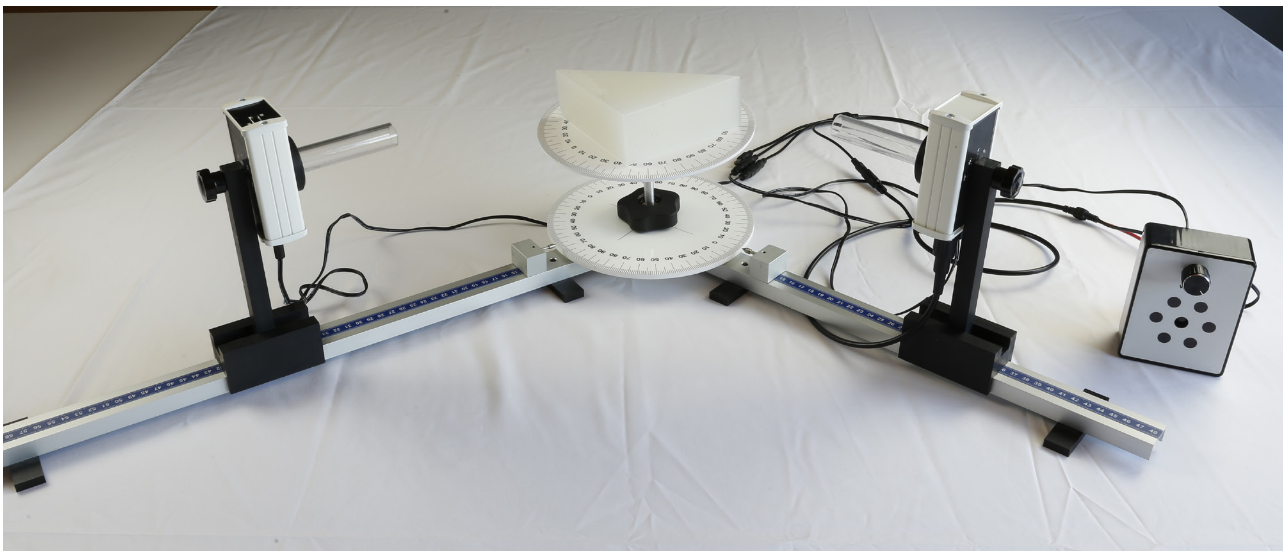


Fig. 28

EXPERIMENT N. 9: Microwaves polarization

Equipment required: as for experience N.1; connection cable loudspeaker - tester and tester (not supplied).

As has been pointed out in the theoretical introduction, an electromagnetic wave with a well defined frequency, is constituted by the set of two fields: an electric field (E) and a magnetic field (B), perpendicular to each other. If the electric vector and, consequently, also the magnetic vector, oscillate always in the same direction, the electromagnetic wave is polarized (Fig. 29).

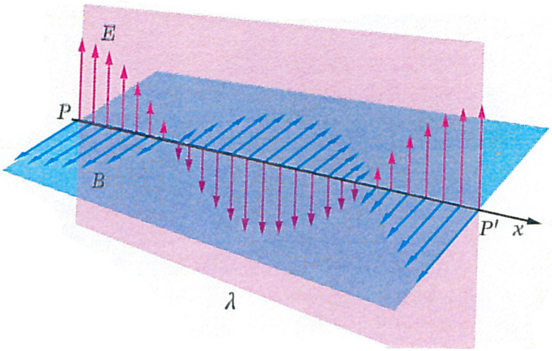


Fig. 29

Fig. 30

Fig. 31

To determine if the electromagnetic waves produced by the transmitter are polarized, you can perform the following experience. At the back of the transmitter there is a protractor, shown in figure 30. Slightly unscrewing the handwheel, it is possible to rotate the transmitter up to 90° in both directions of rotation, as shown in figure 31.
Now arrange the system as shown in figure 32, set the internal modulation and adjust the volume of the received signal to a medium value. If you rotate the transmitter slowly, you will see that when it is placed almost perpendicular to the receiver, the signal is extinguished, as the receiver includes a polarization filter.
By connecting the receiver output to a tester, set for alternating voltage measurements, you can verify that, within experimental errors, the intensity of the received signal is proportional to the cosine of the angle of rotation (Fig. 32).

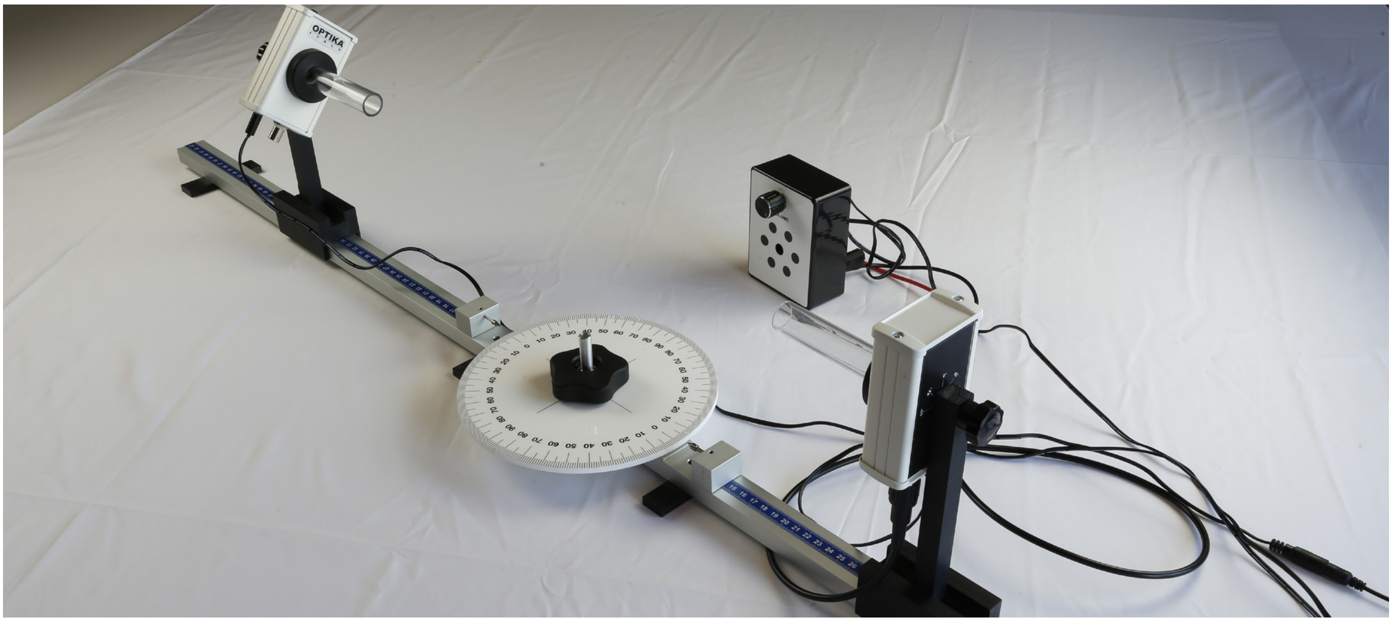


Fig. 32

EXPERIMENT N.10: Microwaves polarization plane

Equipment required: as for experience N.1; 11 slits grating metal lamina.

The previous experience has shown that electromagnetic wave, produced by the transmitter, is linearly polarized, ie both the electric and the magnetic vector oscillate always in the same direction.
With the following experience, you can determine the direction of oscillation. Set up the system as shown in figure 33 and, when the internal modulation is activated, adjust the intensity of the acoustic signal to an average value.

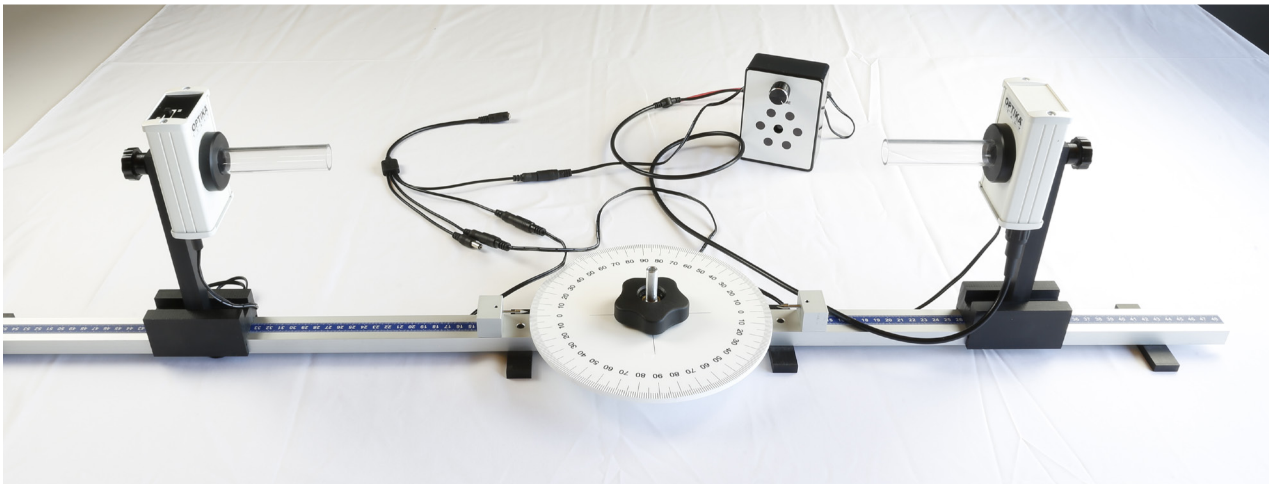


Fig. 33

Then, place the 11 slits grid between the transmitter and the receiver as shown in figure 34. You will notice that the acoustic signal maintains its intensity.

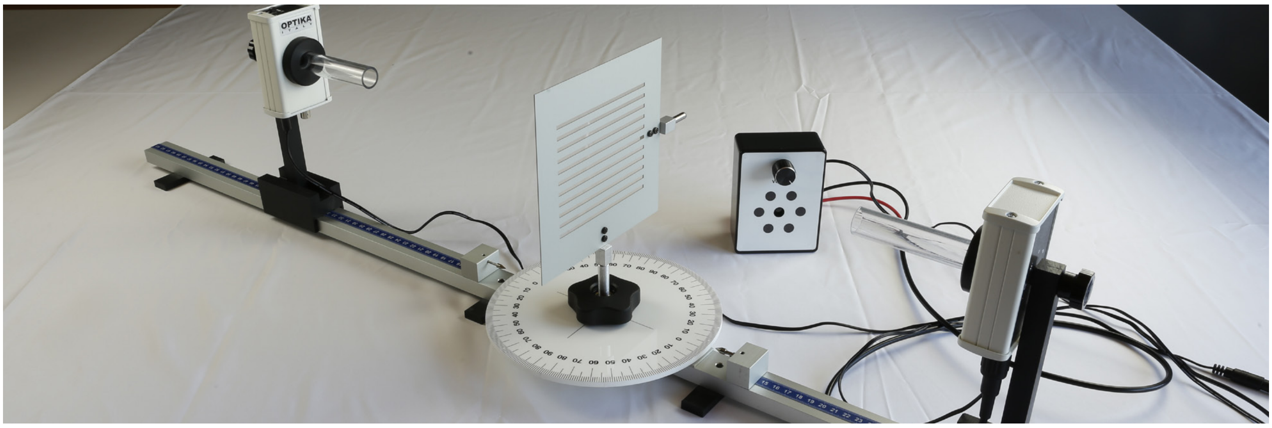


Fig. 34

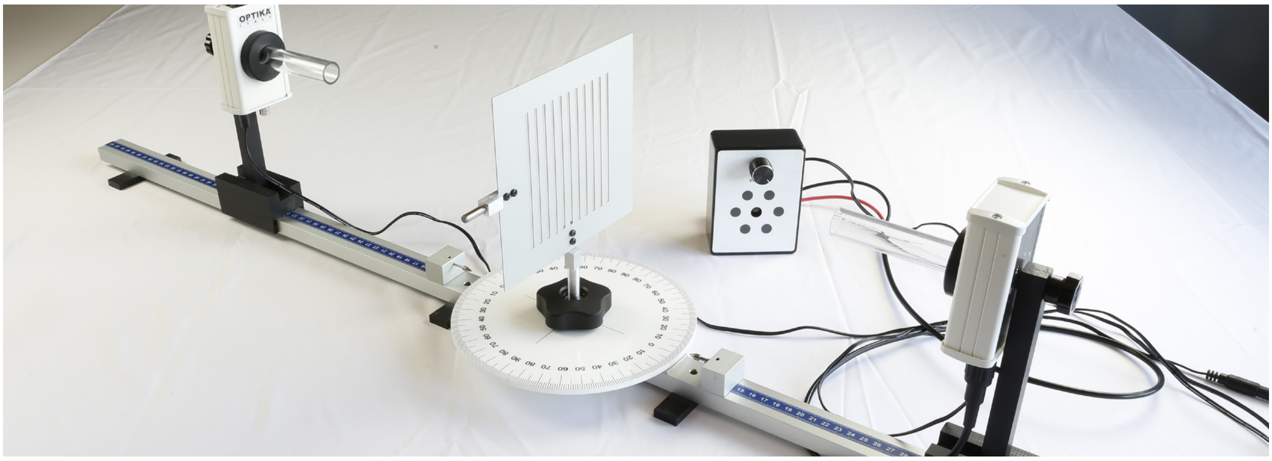


Fig. 35

By turning the grid 90° degrees, as shown in figure 35, the acoustic signal is extinguished. Remembering what is explained in the introduction, it is possible to conclude that the electric vector of the wave produced by the transmitter oscillates in a horizontal plane.

EXPERIMENT N.11: Diffraction of microwaves due to a slit

Equipment required: as for experience N.1; one slit grating metal lamina.

When a wave reaches an obstacle, with a slit slightly wider than the wavelength, the phenomenon of diffraction occurs. Beyond the slit, the energy does not spread uniformly, but presents maximum points alternate to minimum points. This strange distribution is explained by the Huygens-Fresnel principle, according to which all the points of the slit belonging to the same wave front behave like coherent wave sources. this means that in a generic point of the space beyond the slit the intensity will be the result of the overlapping of these elementary waves. On the screen there will be an alternation of maximum intensity points and minimum intensity points. You can check it with the system shown in figure 36. Make sure that the transmitter is no more than 30 cm far from the center of the rail.

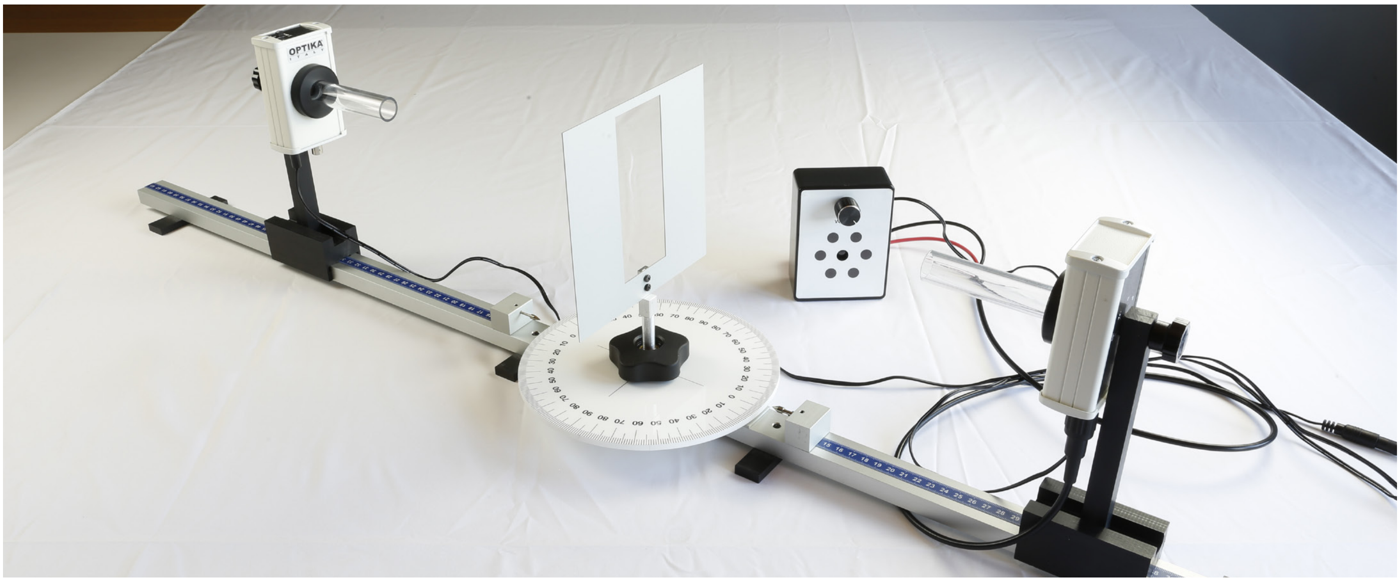


Fig. 36

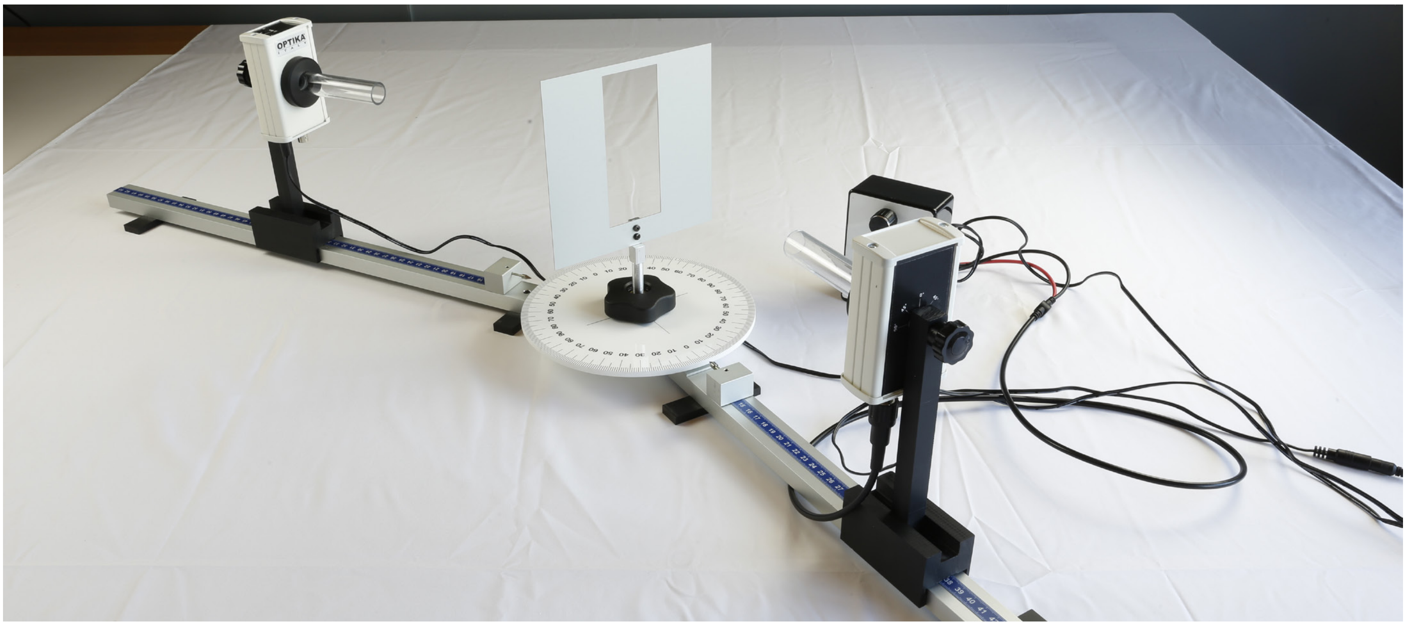


Fig. 37

In the central position the intensity is maximum, but moving the receiver slowly, a sequence of minimums and maximums is detected. It can be shown that the angular distance between the central maximum and the first minimum satisfies the following relationship:

$$sen\ \alpha = \pm \frac{\lambda}{d} \qquad (4)$$

where *α* is the displacement angle of the receiver, *λ* is the wavelength and *d* is the width of the slit.
Being *λ* = 2,85 cm and *d* = 5 cm, the first minimum must be at the angle of rotation of the receiver of about 34° (Fig. 37).

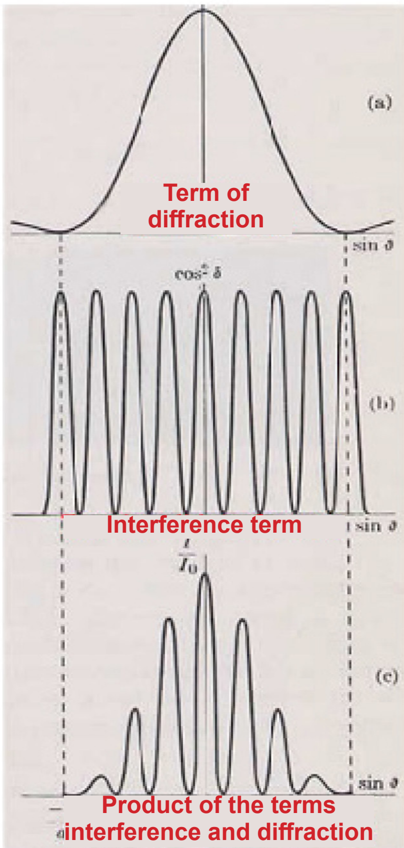


Fig. 38

EXPERIMENT N.12: Diffraction of microwaves due to a double slit (Young's experiment)

Equipment required: as for experience N.1; two slits grating metal lamina**.**

If we now use the two slits grating metal lamina as shown in Figure 38, the radiation diffracted by each slit will interfere with each other.
This is the Young's experiment. The effect obtained is a superposition of two phenomena: the interference between the elementary waves produced by the two slits and the diffraction obtained from each of the two slits (Fig. 39).
First set the transmitter and receiver in the positions indicated in the previous experience, replacing the single slit grating metal lamina with with the one with two slits. In this situation, the received signal is maximum, as the two elementary waves travel the same distance.

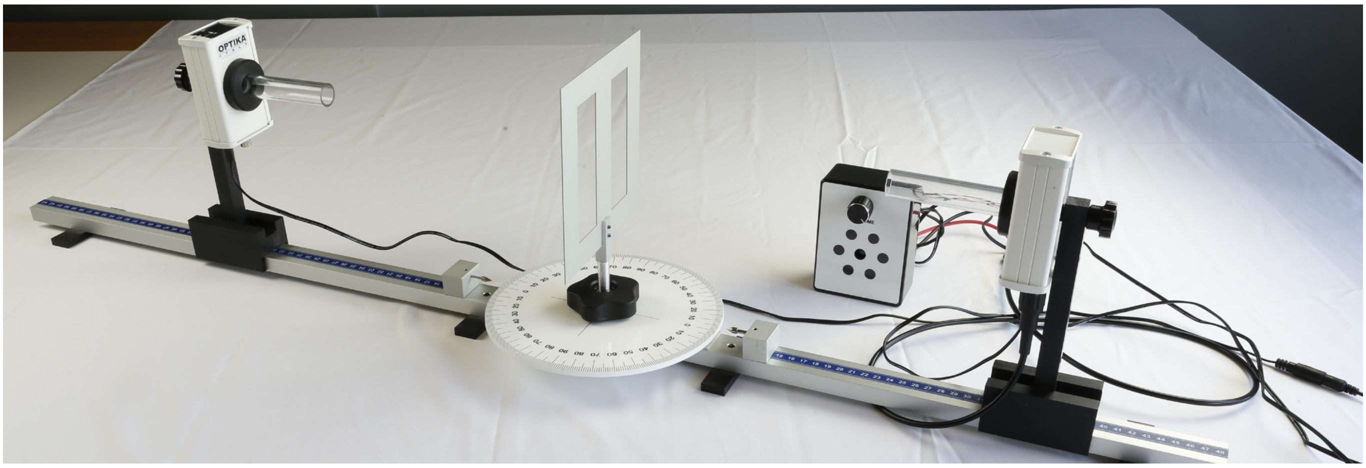


Fig. 38

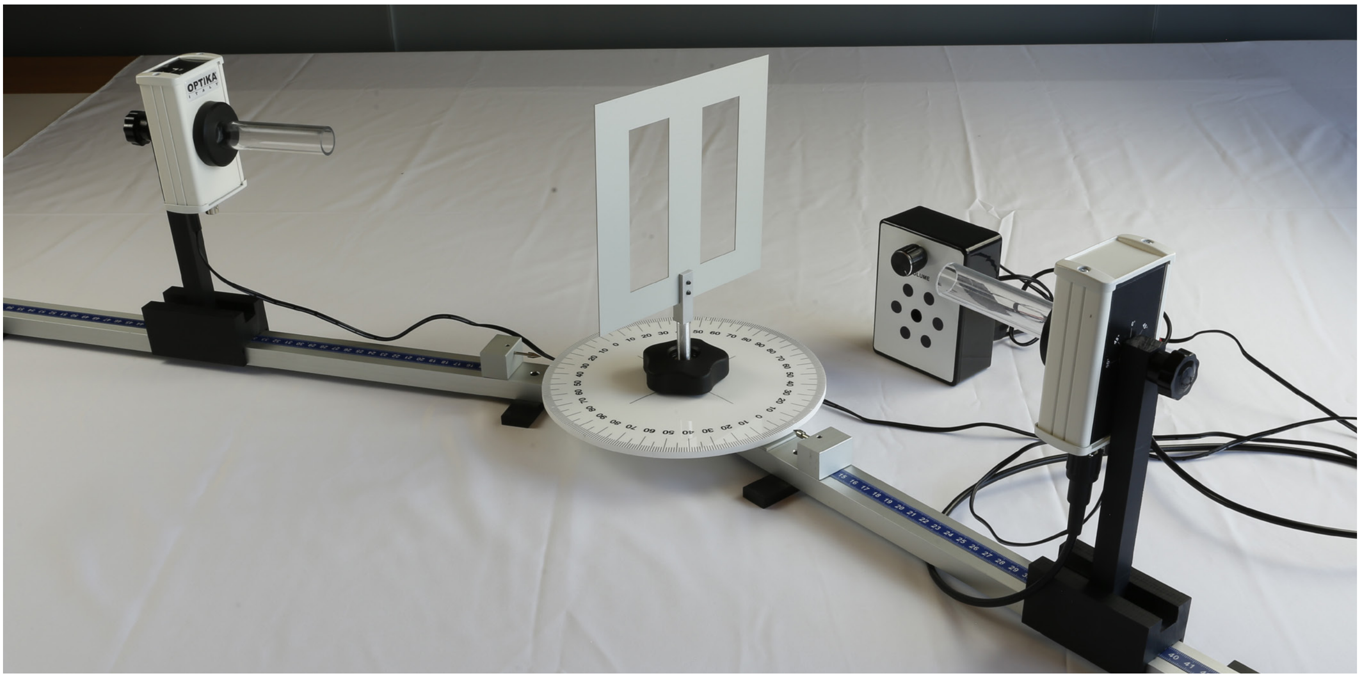


Fig. 40

By rotating the receiver, it is possible to study the result of this overlap for different angles (Fig. 40). If *a* is the distance between the two slits, the first order maximum of the interference figure is given by the following relation:

$$sen\ \alpha = \pm \frac{\lambda}{a}$$

MICHELSON INTERFEROMETER

In 1887, Michelson and his colleague Morley attempted to measure the Earth's speed relative to the fixed reference system of the ether, which was imagined to be a very thin matter like air, which neither translates nor rotates, but is only able to oscillate and vibrate locally.
Maxwell's entire electromagnetic theory was based on the aether hypothesis, which demonstrated the wave-like nature of radiation.
Michelson thought it was possible to observe the effect of the Earth's motion relative to the ether. This should have caused an "apparent wind" that promoted or inhibited the propagation of light depending on direction.
Contrary to their hypothesis, the experiment they carried out failed and proved the now established non-existence of the ether.
An interferometer built according to the Michelson-Morley configuration is an instrument by which the phenomenon of interference of identical electromagnetic waves with different optical paths can be observed. The same system also makes it possible to measure their wavelength.

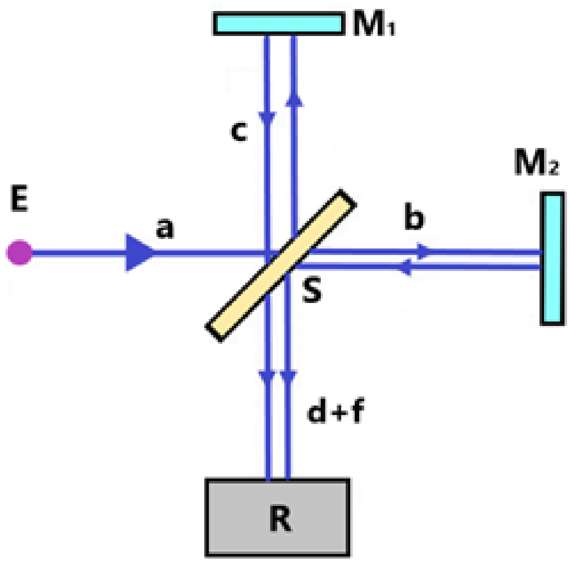


Figure 41

A simplified scheme of the experimental apparatus is shown in Figure 41:
1. A source **E** called the "emitter" sends an electromagnetic wave **a** in the direction of a semi-reflecting lamina **S**, oriented at 45° to the direction of wave propagation.
2. Ideally, the semi-reflecting lamina **S** separates the incident wave **a** into two identical waves **b** and **c**.
3. **b** passes unperturbed through the lamina S, continuing along its original direction, towards a totally reflecting mirror $\mathbf{M_2}$, while c is totally reflected towards a second totally reflecting mirror.
4. **b** and **c** are totally reflected by $\mathbf{M_2}$ and $\mathbf{M_1}$ respectively, being directed back towards the semi-reflecting lamina **S**.
5. At this point, **b** is separated into two identical waves so that one continues unperturbed towards **E** and one is reflected towards a receiver **R**.
6. Similarly, wave **c** is separated into two identical waves, one is reflected back to **E** and one passes unperturbed through the lamina **S** on its way to **R**.
7. In the end, the two waves detected by **R**, denoted as **d** and **f**, interact with each other according to the phenomenon of wave interference.

Depending on the space difference between the $\mathbf{SM_2- M_2S - SR}$ optical path and the $\mathbf{SM_1-M_1S-SR}$ optical path, the interference between **d** and **f** can be destructive or constructive. This difference determines the phase shift of the two waves detected by **R** and thus the type and magnitude of the interference.

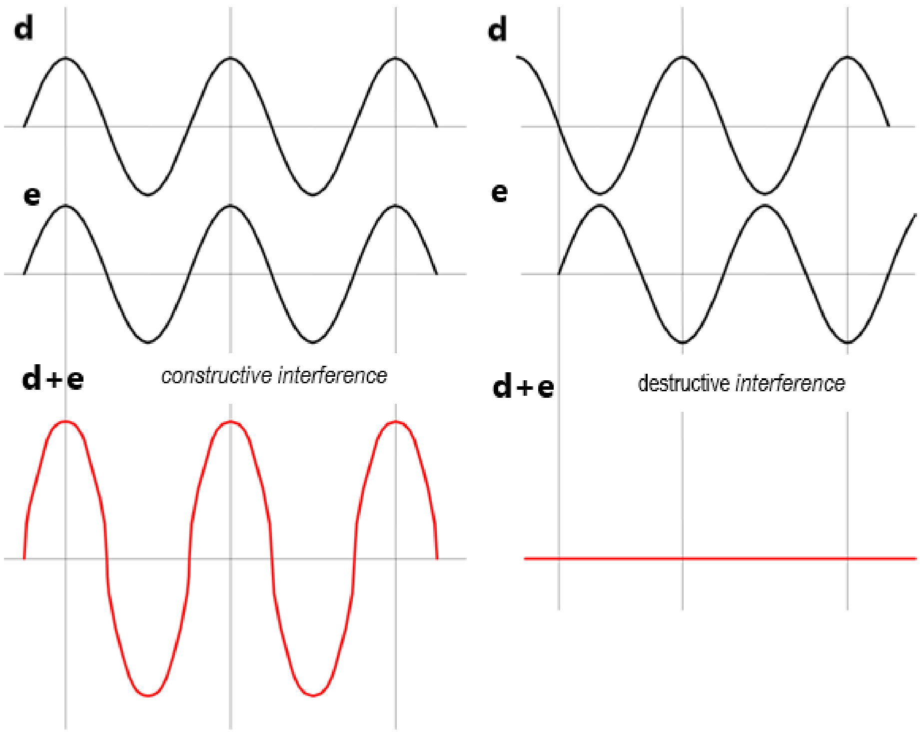


Figure 42

Defined **A** as the amplitude and **I** as the intensity, the following relation holds for electromagnetic waves

$$I = A^2$$

Since the lamina has a reflective power of 50 %, each of the two beams **b** and **c**, referring to Fig. 41, carries half the intensity carried by the original wave **a**, and the relative vibrations will have amplitude:

$$A_1 = \sqrt{I_1} = \sqrt{\frac{I}{2}} = \sqrt{\frac{A^2}{2}} = \frac{A}{\sqrt{2}}$$

After being totally reflected by the $\mathbf{M_1}$ and $\mathbf{M_2}$ mirrors,**b** and **c** hit a second time on the semi-reflecting lamina, thus creating the **d** and **e** beams. The amplitude of these results:

$$A_2 = \sqrt{I_2} = \sqrt{\frac{I_1}{2}} = \sqrt{\frac{1}{2}}\sqrt{\frac{I}{2}} = \sqrt{\frac{1}{2}}\sqrt{\frac{A^2}{2}} = \frac{A}{\sqrt{2}\sqrt{2}} = \frac{A}{2}$$

Where a phase agreement occurs,the amplitude results

$$\frac{A}{2} + \frac{A}{2} = A$$

while where there is phase opposition the amplitude results

$$\frac{A}{2} - \frac{A}{2} = A$$

Constructive interference occurs when waves with the same amplitude and frequency are in phase concordance. Referring to Figure 42, the amplitude of the resulting wave is equal to the sum of the amplitude of the original waves. This occurs when the difference **D** between the two optical paths is equal to an integer multiple of wavelength,

$$D = n\,\lambda$$

(with n=0, 1, 2 …)

Destructive interference occurs when waves with the same amplitude and frequency are in opposition of phase. Referring to Figure 42, the arithmetic sum of the amplitude of the original waves compensates, resulting in a resultant wave of lower or zero amplitude. This occurs when the difference between the two paths is equal to an integer multiple of wavelength + half wavelength

$$\mathbf{D} = (n+1/2)\,\lambda$$

(with n=0, 1, 2 …)

If the receiver does not register any signal, simply move the moving lamina by a distance $\lambda/4$ to increase the corresponding return path of $\lambda/2$ and to change the interference pattern.
In this new arrangement, the beams directed to the receiver will be in phase agreement. This time all the intensity will be recorded by the receiver.

EXPERIENCE 13: Michelson Interferometer

Equipment required: articulated track ; transmitter; receiver; loudspeaker; three-terminal cable; 12V power supply; receiver-speaker connection cable; 1 metal lamina; 1 Michelson interferometer kit.

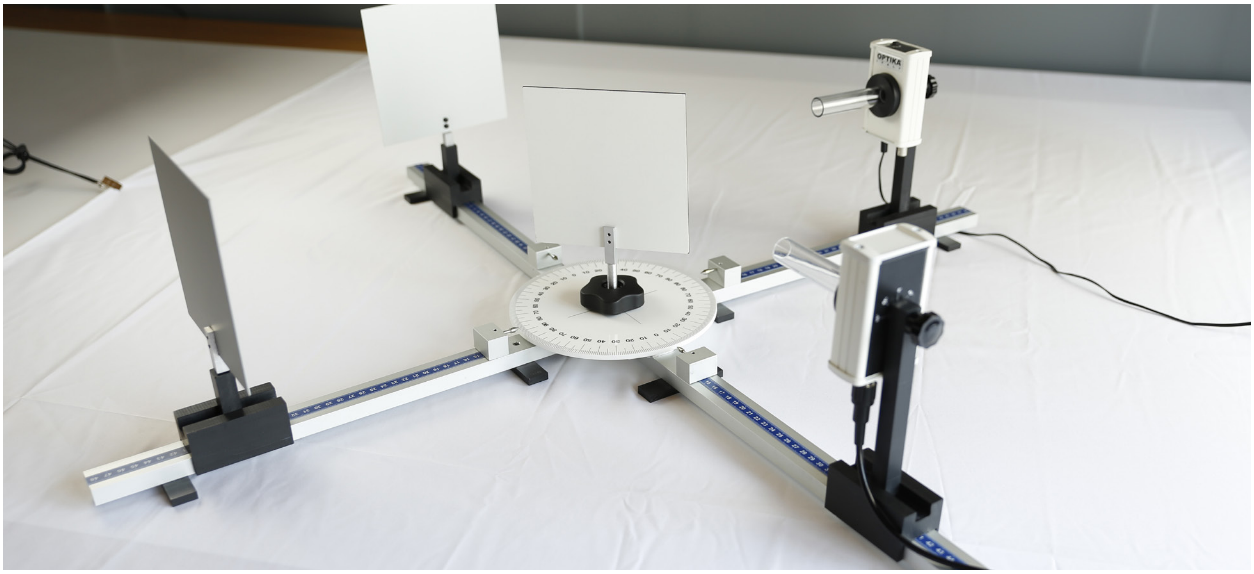


Figure 43

Place the equipment as in figure 43. Special attention should be given to the arrangement of the lamina **S**, which should be oriented approximately 45° to the direction of the emitter.
The previous comments on the interferometer's operation and the interference phenomenon can be verified. Furthermore, the wavelength of the wave beam emitted by the microwave emitter can be determined.
Once the device is ready and started, move one of the two metal lamina $\mathbf{M_1}$ or $\mathbf{M_2}$ (fully reflective screen) until a maximum is obtained.
Then note the current $\mathbf{x_1}$ position of the reflective lamina and slowly move it forward or backward until a new maximum point is obtained.Take note of the new position $\mathbf{x_2}$ of the lamina.
Define **Δx** as the difference between the two positions:

$$\Delta x = |\, x_2 - x_1 |$$

Referring to the above, we obtain:

$$\frac{\lambda}{2} = \Delta x$$

Verify agreement with the known value of λ = 2,85cm.

WARNING

The small differences between the characteristics of the pieces supplied and the designs that represent them, they are justified by the technological update.

OPTIKA SCIENCE ITALY