Diffraction and polarization of microwaves

Related topics

Diffraction, focal point, linearity, circularly and elliptically polarized waves, transverse waves, polarizer, analyzer, constructive and destructive interference

Principle and task

The equivalence between visible light and microwaves as special cases of the total spectrum of electromagnetic waves can be demonstrated using diffraction and polarization of microwaves as an example. The focusing of microwaves through a plane convex convergent lens is observed and the focal distance of the lens is determined. After that, polarizability of microwaves is demonstrated by means of a metallic grating.

Equipment

Microwave transmitter w. klystron	11740.01	1
Microwave receiving dipole	11740.03	1
Microwave power supply, 220VAC	11740.93	1
Universal measuring amplifier	13626.93	1
Polarisation grid	06866.00	1
Convergent lens, synthetic resin	06872.00	1
Protractor scale with pointer	08218.00	1
Voltmeter, 0.3-300 VDC, 10-300 VAC	07035.00	1
Screened cable, BNC, l 1500 mm	07542.12	1
Connecting cord, 500 mm, red	07361.01	1
Connecting cord, 500 mm, blue	07361.04	1
Connecting cord, 2000 mm, red	07365.01	1
Connecting cord, 2000 mm, blue	07365.04	1
Adapter, BNC-socket/4 mm plug pair	07542.27	1
Tripod base -PASS-	02002.55	1
Barrel base -PASS-	02006.55	1
H-base -PASS-	02009.55	1
Bench clamp -PASS-	02010.00	2
Support rod -PASS-, square, l 250 mm	02025.55	1
Support rod -PASS-, square, l 630 mm	02027.55	4
Right angle clamp -PASS-	02040.55	4
Stand tube	02060.00	1
Meter scale, demo, l = 1000 mm	03001.00	1

Problems

1. Measuring the irradiance of the microwave field behind a converging lens
   - along the optical axis
   - transversally to the optical axis.

Fig.1a: Experimental set-up to determine the focal point of a synthetic resin plastic lens.

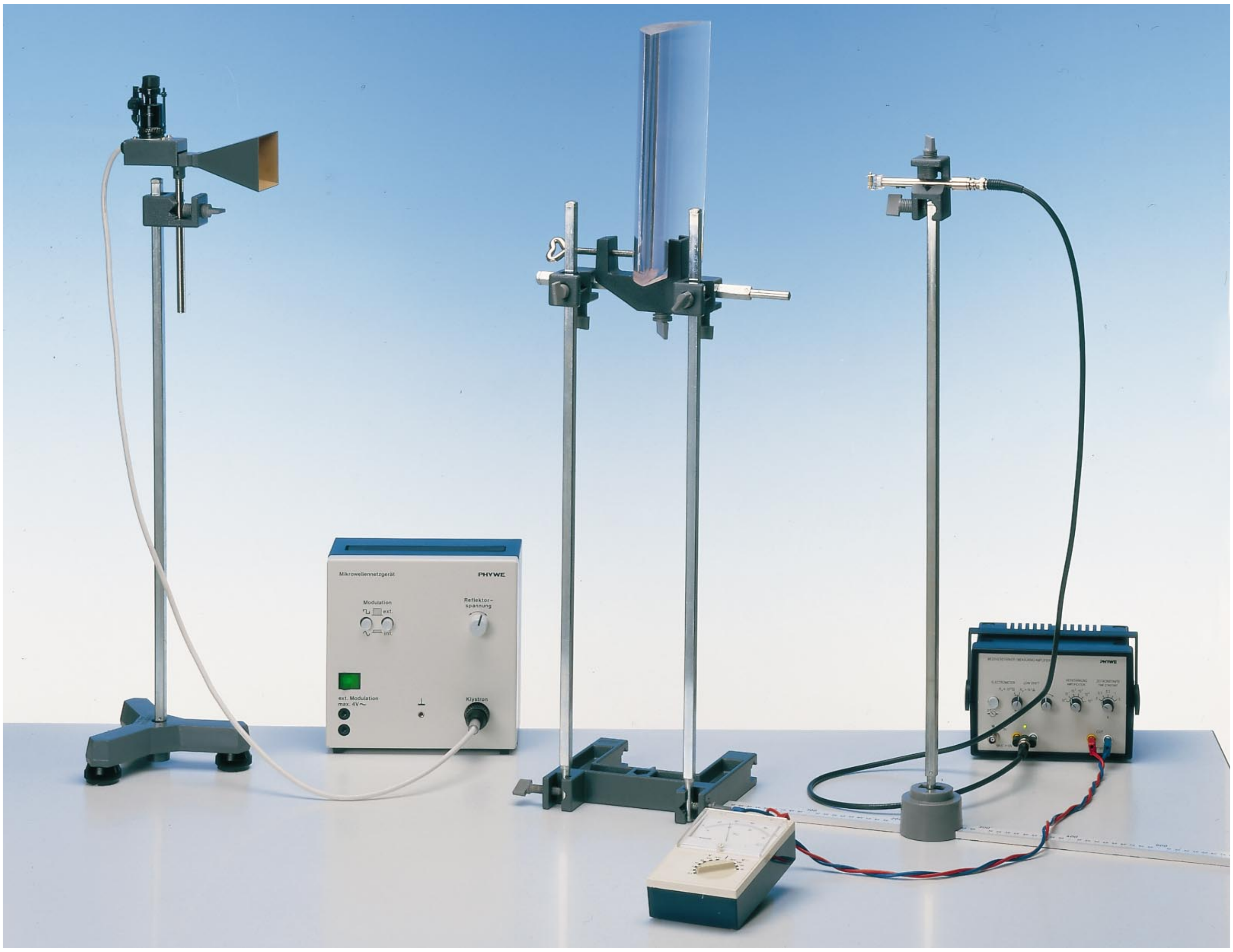
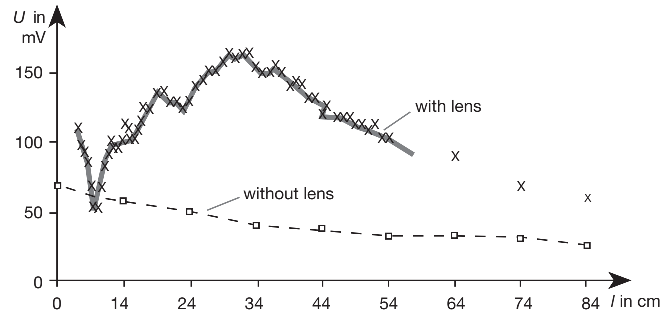


Fig. 2: Intensity of radiation as a function of the distance between the lens and the receiving dipole.



Determination of the focal length of a synthetic resin converging lens and comparison of the results with the distribution of irradiance when no lens is used.

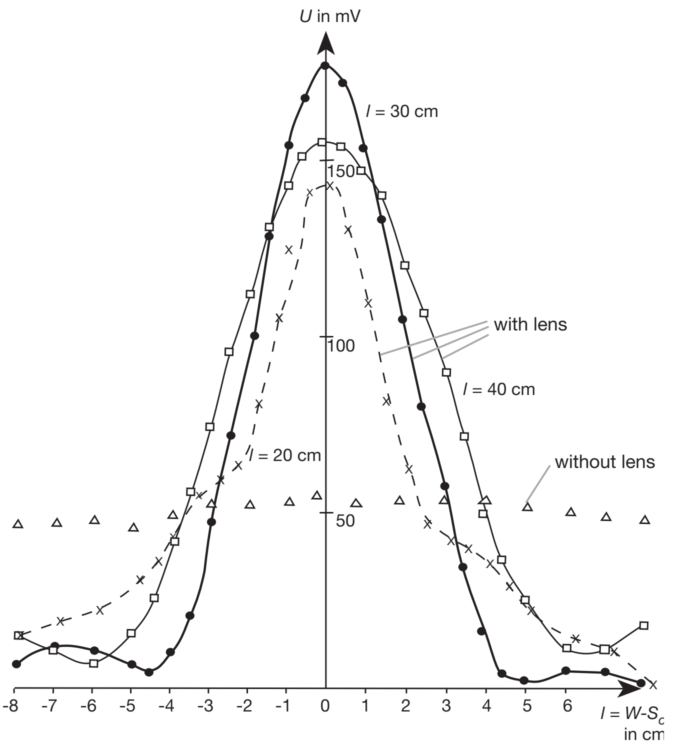
2. Measurement of the irradiance transmitted through a metal grating as a function of the angle between the direction of polarization and the grating bars.

Set-up and procedure

1. The set-up required to determine the focal point of the synthetic resin lens is shown in Fig. 1a. The transmitting and receiving equipment is situated approx. 65 cm above the surface of the table, in order to minimize disturbing interference due to reflection from the surface of the table. The fact that the measuring instruments also may reflect microwaves must be taken into account when positioning the instruments. It is recommended to place the microwave emitter (without amplitude modulation) about 100 cm from the receiving dipole and approx. 80 cm from the front end of the scale, which is attached with a bench clamp. The voltage of the receiving dipole is connected to the “low drift” input of the measurement amplifier. The reflecting voltage of the clystron (ν = 9.45 GHz, corresponding to a wavelength of λ = 3.18 cm) and the orientation of the transmitting antenna are adjusted to the maximum DC voltage signal of the receiving dipole. The receiving dipole must be oriented parallel to the narrow side of the horn antenna (polarization direction) to assure the maximum reception signal. For control purposes it should be checked that the receiving dipole remains on the optical axis when the barrel base is shifted on the measuring scale, e. g. by measuring the distance to the edge of the table. The cylin-

Fig.1b: Experimental set-up

Fig. 3: Profile of the intensity of radiation.



drical lens is centered by shifting it immediately before the measuring scale and perpendicularly to the optical axis, until the maximum DC voltage signal of the receiving dipole (at a distance of approx. 25 cm.) is reached. The obtained distribution of irradiance (proportional to the rectifying diode voltage and to the square of the amplitude of field intensity $|\vec{E}|^2$) along the optical axis is plotted as a function of the distance between the receiving dipole and the cylindrical lens. This experiment is repeated without converging lens at a distance of 10 cm for comparison.

The focusing effect of the converging lens is demonstrated by recording the irradiance profile at a distance of 20 cm, 30 cm and 40 cm of the lens, perpendicularly to the optical axis. The point of reference for the distance measurements is the surface of the convex side of the lens, near which the main planes of the lens (thick lens) are situated. For this purpose, the measuring scale is fixed to the table perpendicularly to the optical axis at the corresponding distances.

2. To check the transmittance of a polarization screen, the converging lens is substituted by a metal grating with its bars oriented perpendicularly to the receiving diode Fig 1b. A semicircular scale is attached to the microwave transmitter (situated approx. 20 cm from the metal grating), which is fixed to a stand tube so that it can pivot. The corresponding pointer is attached to the stand tube, so that it is possible to read the angle of rotation of the microwave transmitter. As the direction of oscillation of the electric field vector is parallel to the narrow side of the funnel, the angle α of inclination of polarization related to the grating bars is given. The angle α of inclination is varied from 0° to 90° in steps of 50 and the corresponding DC voltage signal at the receiving dipole is recorded. It should be made sure that the voltage at the receiving dipole is maximum exactly at the same moment the receiving diode is oriented perpendicularly to the grating bars.

Theory and evaluation

1. Diffraction of electromagnetic waves

Similarly to visible light, the speed of propagation of microwaves depends on the material they travel through: combination of Maxwell's equation in dielectric media yields the following result for the phase velocity v_{PH} of an electromagnetic wave in general (c being the speed of light, ϵ the dielectric constant and μ permeability):

$$v_{\mathrm{PH}} = \frac{c}{\sqrt{\epsilon\mu}} \qquad (1)$$

or, with permeability $\mu \approx 1$ (this is the case for non ferromagnetic materials), phase velocity v_{PH} is inversely proportional to the root of the dielectric constant.

$$v_{\mathrm{PH}} = \frac{c}{\sqrt{\epsilon}} \qquad \text{(Maxwell's Relation)} \qquad (2)$$

The dielectric constant ϵ depends both on the type of material as well as on the frequency of the propagating electromagnetic wave.

In case of a microwave (f = 9.45 GHz) the following applies for the absolute diffraction indexes:

$$n := \frac{c}{v_{\mathrm{PH}}} = \sqrt{\epsilon}$$

$$\text{with } n_{\mathrm{air}} < n_{\mathrm{synthetic\ resin}} \qquad (3)$$

At the boundary surface between air and synthetic resin, reflection and diffraction occur just as in geometrical optics: the plane convex cylindrical lens thus acts as a converging lens for microwaves. Therefore, a significantly larger illuminance is observed along the optical axis after the lens (cf. Fig. 2) as would be the case for the same set-up without lens. Due to conservation of energy, illuminance outside the optical axis must be smaller (cf. Fig. 3): the microwaves are bunched together. If the microwaves impinging on the cylindrical lens are approximated by plane waves (this may be done because the distance between transmitter and lens is large as compared to the dimensions of the lens) and neglecting diffraction through the lens, the peak in Fig. 2 represents the focal point of the lens (more correctly the focal line). The focal distance of the lens (related to the main plane) is thus:

$$f = 31 \text{ cm} \pm 3 \text{ cm}.$$

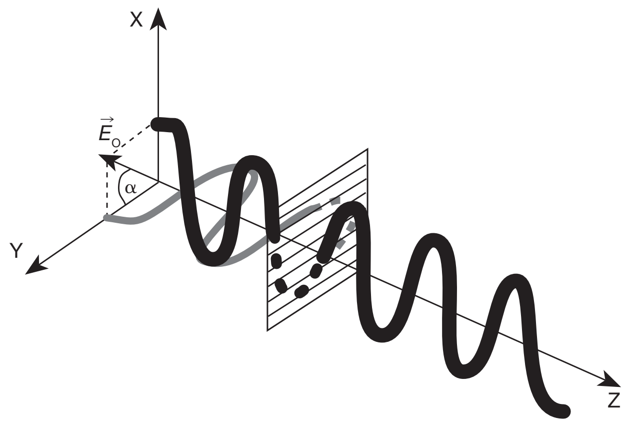
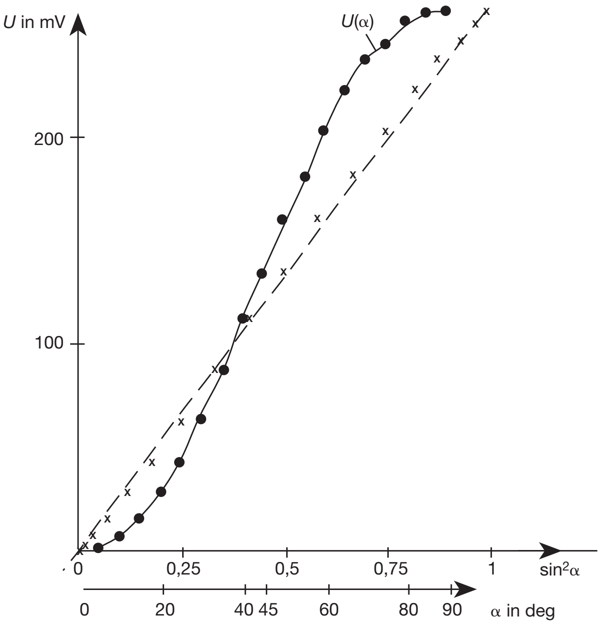


Fig. 4: Transmission through a metal grating.

Fig. 5: Transmitted radiation intensity as a function of $\sin^2\alpha$ of the angle of incidence.



However, diffraction at the lens (wavelength $\lambda = 3.18$ cm, only a little smaller than the dimensions of the converging lens) as well as interference with reflected waves cause significant deviations from the laws of geometrical optics. This can be recognized from the secondary diffraction peaks in figures 2 and 3.

2. Polarization of electromagnetic waves

Microwaves, as all electromagnetic waves, oscillate transversally and thus have two degrees of freedom related to the direction of polarization. Every linear polarization of a transverse plane wave propagating along the z- axis can thus be divided into two perpendicular components:

$$\vec{E}(\vec{r},t) = E_x \cos(\vec{k}\vec{r} - \omega t)\vec{e}_x + E_y \cos(\vec{k}\vec{r} - \omega t)\vec{e}_y \quad (4)$$

General solutions of Maxwell's equations with a phase shift between the two components are called elliptically polarized waves:

$$\vec{E}(\vec{r},t) = E_x \cos(\vec{k}\vec{r} - \omega t)\vec{e}_x + E_y \cos(\vec{k}\vec{r} - \omega t + \varphi_0)\vec{e}_y \quad (5)$$

The time relationship of the electric field vector $\vec{E}$ for a fixed localization $\vec{r}_0 = 0$ becomes clear for the special case $|E_x| = |E_y|$ and $\varphi_0 = (2n+1)\pi$; n = 0, 1, … :

$$\vec{E}(\vec{r}_0, t) = E_x \begin{pmatrix} \cos(\omega t) \\ \mp \sin(\omega t) \\ 0 \end{pmatrix}$$

The $\vec{E}$ vector of the microwave field (and thus the magnetic field intensity vector $\vec{H}$ perpendicular to this) rotates with the period

$$T = \frac{2\pi}{\omega}$$

with constant amplitude, perpendicularly to the direction of propagation.

The microwaves used in this case are already linearly polarized when they leave the transmitting antenna. The metal grating acts as an analyzer which allows to determine the direction of polarization of the microwaves. If a microwave, whose $\vec{E}$ vector is polarized parallel to the grating bar, impinges on the grating, the free charge carriers in the metal are excited into oscillation by the high frequency field, which in turn produces a microwave field with opposite phase: a stationary wave is built up before the screen, which can be detected by the receiving dipole set up parallel to the grating. The two waves interfere to zero behind the grating, inasmuch as the distance between the grating bars is significantly smaller than the wavelength. This means that the transmitted irradiance vanishes after the grating.

If, on the other hand, the angle between the direction of polarization of the incident microwave and the direction of the grating bars is $\alpha = 90°$, the free charge carriers cannot oscillate freely along the field lines, and in this case the incident microwave passes through the polarizing grating without being weakened.

In the general case (cf. Fig. 4) of a direction of polarization which forms an angle α with the grating, the incident wave is decomposed into a partial wave with a polarization direction parallel to and one with a polarization direction perpendicular to the grating bars, of which only the latter is transmitted. Thus, of the transmitted amplitude E_0, only the following portion reaches the microwave detector:

$$E_{\text{trans}} = E_0 \sin\alpha \quad (6)$$

The received irradiance (proportional to E) of the transmitted microwave correspondingly is:

$$I_{\text{trans}} = I_0 \sin^2\alpha \quad (7)$$

where I_0 is the (maximum) intensity for $\alpha = 90°$ (cf. Fig. 5).

In the case of non polarized, "natural" microwaves, the metal grating can also be used as a polarizer, as only microwaves polarized perpendicularly to the grating bars are found after the grating.

Caution

Although the clystron only has low power, one must avoid looking directly into the microwave.