

Refraction of microwaves

Objects of the experiments

- Confirming the refraction law for microwaves.
- Demonstrating the focussing effect of a collective lens for microwaves.

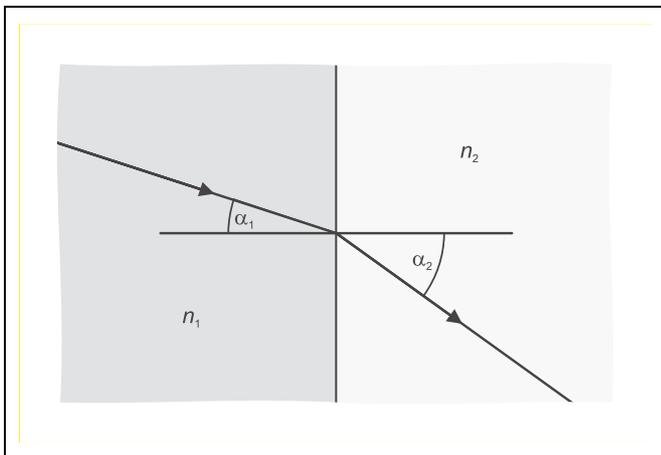
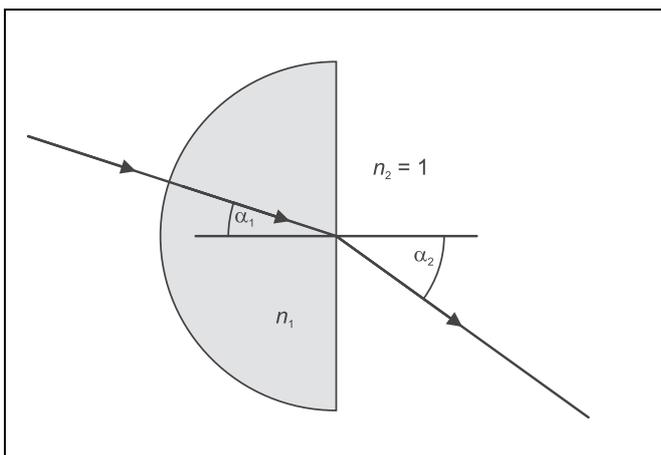


Fig. 1 Change of the direction of propagation at the interface between two media having different refractive indices

Fig. 2 Measuring arrangement with half-cylinder for determining the refractive index n_1



Principles

Like other waves, microwaves change their direction when they pass from one medium into another one if they do not penetrate the interface between the two media perpendicularly. This phenomenon is a consequence of the different wave velocities in the media. It is called refraction.

The refraction law discovered by *W. Snellius* reads:

$$\sin \alpha_1 = \frac{c_1}{c_2} \cdot \sin \alpha_2 = \frac{n_2}{n_1} \cdot \sin \alpha_2 \quad (I)$$

α_1 : angle of incidence, α_2 : angle of emergence, c_1, c_2 : wave velocities, n_1, n_2 : refractive indices

Refraction occurs in the medium with the smaller refractive index away from the normal to the interface (see Fig. 1).

In the experiment, refraction of microwaves at a half-cylinder filled with quartz sand is investigated (see Fig. 2). The microwave ray impinges vertically on the outer surface, which has a circular curvature, so that no refraction takes place there. Refraction does take place at the flat outer surface in the direction of air as medium, whose refractive index n_2 equals 1 to a good approximation.

In optics, refraction is taken advantage of for manufacturing lenses, which are suited to generate optical images. For the focal length f of a thin collective lens whose boundary surfaces are given by two spherical surfaces with the radii of curvature r_1 and r_2 , the following relation holds:

$$\frac{1}{f} = (n - 1) \cdot \left(\frac{1}{r_1} + \frac{1}{r_2} \right) \quad (II)$$

Such lenses can also be constructed for microwaves. In this experiment, the focussing effect of a collective lens filled with quartz sand and having the radii of curvature $r_1 = r_2 = 227$ mm is investigated.

Setup

Remarks:

Measuring results may be distorted by reflection of the microwaves from vertical surfaces of objects close to the experimental setup:

Choose the direction of transmission of the horn antenna so that reflecting surfaces are at a distance of at least 4 m.

If possible, use microwave absorbers to build up a reflection-free measuring chamber.

Apparatus

1 Gunn oscillator	737 01
1 large horn antenna	737 21
1 stand rod, 245 mm, with thread	309 06 578
1 Gunn power supply with amplifier	737 020
1 E-field probe	737 35
1 physics microwave accessories II	737 275
1 voltmeter, DC, $U \leq 10\text{ V}$ e.g.	531 100
2 saddle bases	300 11
2 BNC cables, 2 m	501 022
1 pair of cables, 100 cm, black	501 461
<i>additionally recommended:</i>	
1 set of microwave absorbers	737 390

If several experiments with microwaves are run at the same time, neighbouring Gunn oscillators can interfere: Try to find a suitable arrangement of the experiments. In this case, use of microwave absorbers is mandatory to set up separate reflection-free measuring chambers.

The varying magnetic field of microwaves can induce voltages in cable loops:
Avoid cable loops.

The experimental setup is illustrated in Fig. 3.

- Attach the Gunn oscillator to the horn antenna with the quick connectors **(b)**.
- Align the horn antenna horizontally, screw the 245 mm long stand rod into the corresponding thread and clamp it in a saddle base.
- Connect the Gunn oscillator to the output OUT via a BNC lead. Connect the E-field probe to the amplifier input and the voltmeter to the output DC OUT of the Gunn power supply.
- Set up the E-field probe in front of the centre of the horn antenna.
- Set the modulation frequency with the frequency adjuster **(a)** so that the multimeter displays maximum received signal.
- Prepare the angular scale **(c)** on a circle with a diameter of 20 mm.
- Mount the half-cylinder with the PVC adaptor on the stand rod 180 mm, and clamp it in a saddle base.
- Carefully pour approx. 1.5 kg of quartz sand into the half-cylinder. Then put the half-cylinder on the angular scale just prepared.
- Set up the Gunn oscillator with horn antenna at an angle of incidence $\alpha_1 = 0^\circ$ near the half-cylinder, which is filled with quartz sand, and align the antenna so that its axis is directed towards the centre of the circle.
- Set up the E-field probe on the opposite side at $\alpha_2 = 0^\circ$. Then look for the maximum of the received signal U .
- If necessary, correct the alignment of the horn antenna and the hollow cylinder until the maximum is found exactly at $\alpha_2 = 0^\circ$.

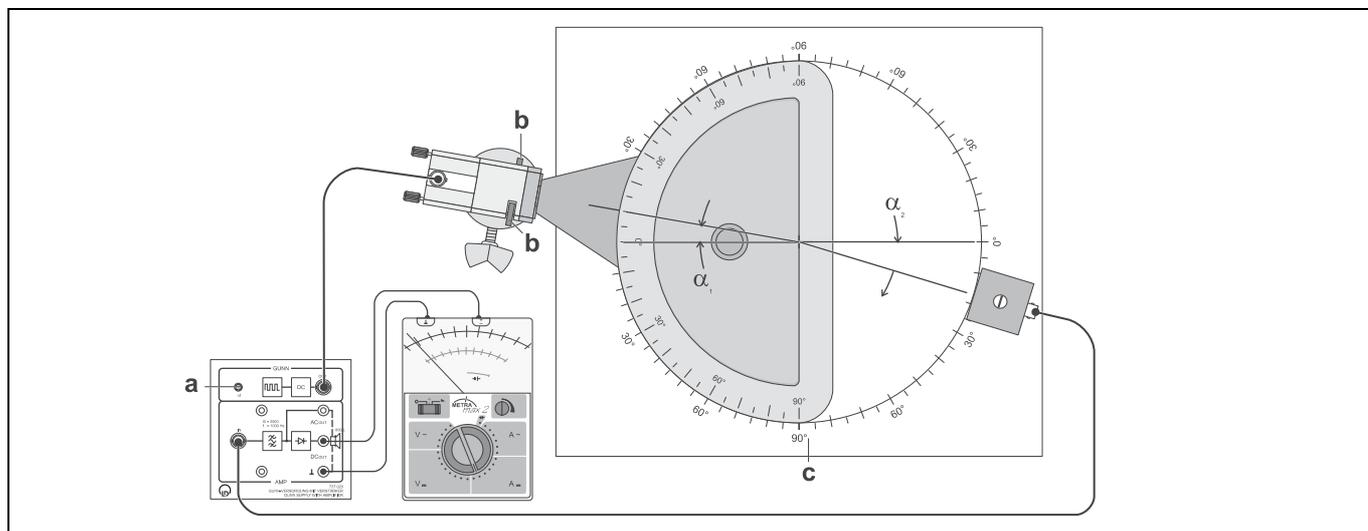


Fig. 3 Experimental setup for investigating the refraction of microwaves (view from above)

Safety notes

Attention, microwave power! The microwave power released from the Gunn oscillator is approx. 10–15 mW, which is not dangerous to the experimenter. However, in order that students are prepared for handling microwave systems with higher power, they should practise certain safety rules.

- Never look directly into the transmitting horn antenna.

Carrying out the experiment

a) Checking the refraction law:

- Set up the Gunn oscillator at an angle of incidence $\alpha_1 = 10^\circ$ so that the antenna is directed towards the centre of the circle of the half-cylinder.
- Using the E-field probe, look for the maximum of the received signal U , and take its position down as angle of refraction α_2 .
- Adjust other angles of incidence α_1 , and repeat the procedure.

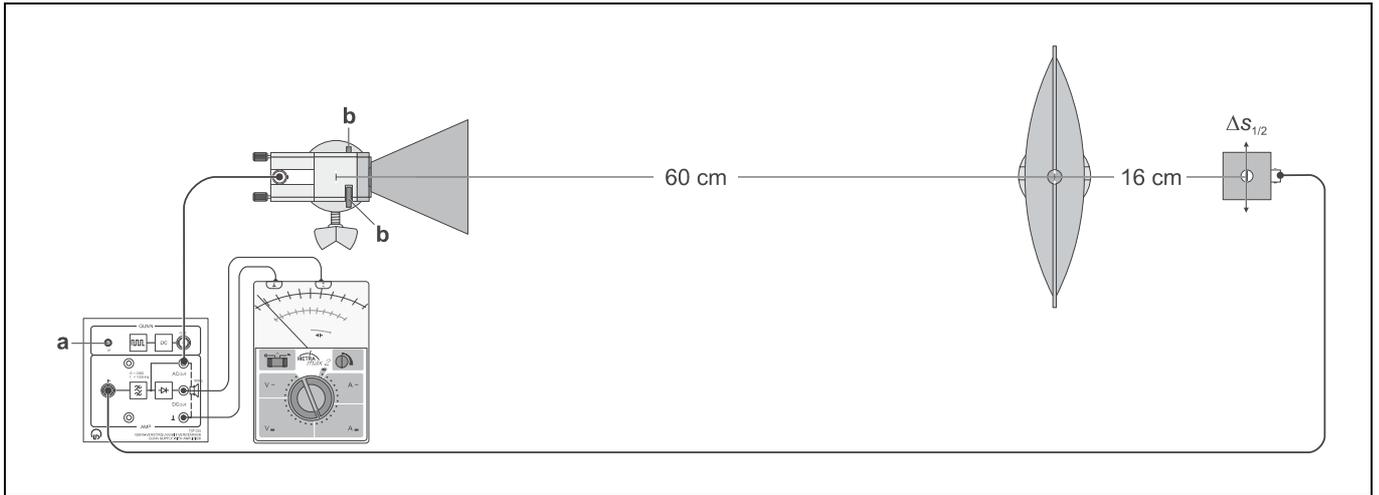


Fig. 4 Experimental setup for checking the focussing effect of a lens

b) Checking the focussing effect of a lens

- Fill the lens with quartz sand, set it up using the holding rod and a saddle base, and place it in the path of ray keeping to the distances indicated in Fig. 4.
- Optimize the alignment of the lens until the received signal U takes its maximum for a straight path of ray.
- Shift the E-field probe perpendicularly to the direction of the ray to the "right" and to the "left", and look for the positions where the received signal is reduced to half the maximum value (the distance between these positions is the half-width $\Delta S_{1/2}$).
- Shift the E-field probe back to the maximum of the received signal.
- Remove the lens from the ray of path, and measure the received signal U without lens.
- Determine the half-width $\Delta S_{1/2}$ of the signal without lens by shifting the E-field probe.

Measuring example

a) Checking the refraction law:

Tab. 1: Angle of incidence α_1 and angle of emergence α_2

Nr.	α_1	α_2
1	-30°	-58°
2	-20°	-38°
3	-10°	-16°
4	0°	0°
5	10°	18°
6	20°	36°
7	30°	60°

b) Checking the focussing effect of a lens:

Tab. 2: Received signal U and half-width $\Delta S_{1/2}$ of the received signal

Aufbau	$\frac{U}{V}$	$\frac{\Delta S_{1/2}}{\text{cm}}$
mit Linse	7.5	5
ohne Linse	0.8	34

Evaluation

a) Checking the refraction law:

Tab. 3: Evaluation of the measuring data from Table 1

Nr.	$\sin \alpha_1$	$\sin \alpha_2$
1	-0.50	-0.85
2	-0.34	-0.62
3	-0.17	-0.28
4	0.00	0.00
5	0.17	0.31
6	0.34	0.59
7	0.50	0.87

The measured values from Table 3 are plotted in Fig. 5. From the slope of the straight line through the origin drawn in the diagram, the refractive index n of quartz sand can be calculated:

$$a = \frac{n_2}{n_1} = \frac{1}{n_1} = 0.575, \text{ and thus } n = n_1 = 1.74$$

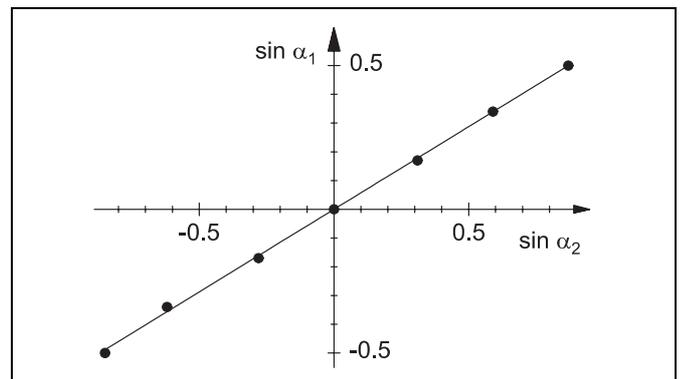


Fig. 5 Plot of the data from Table 3

b) Checking the focussing effect of a lens:

According to Eq. (II) the focal length of the collective lens can be calculated: $f = 163 \text{ mm}$.

The collective lens collects the intensity in a focus, whose distance from the lens equals the focal length to a good approximation and whose half-width is significantly smaller than that of the intensity distribution of the horn antenna.

