Electricity

Electromagnetic oscillations and waves
Microwaves

Directional characteristic and polarization of microwaves in front of a horn antenna

Objects of the experiments

- Measuring the transverse and longitudinal field distribution of microwaves in front of a horn antenna.
- Demonstrating the polarizability of microwaves and determining the polarization of the emitted microwaves.

Principles

Properties of microwaves:

Microwaves are electromagnetic waves with frequencies between 300 MHz and 300 GHz and wavelengths between 1 m and 1 mm. Although the frequencies are below those of visible light by more than 3 orders of magnitude, many properties of microwave radiation can be compared with those of visible light.

For instance, microwaves can be polarized the same way as light waves. If the electrical field oscillates in a fixed plane, this is called linear polarization. Such a linear polarization can be created or analyzed by means of a polarizer. If a linearly polarized wave with the electric field amplitude E_0 impinges on a polarizer that is rotated against the direction of polarization of the wave by the angle ϑ, the field component

$$E(\vartheta) = E_0 \cos \vartheta \qquad \text{(I)}$$

will pass the polarizer. Therefore the intensity of the wave is

$$I(\vartheta) = I_0 \cos^2 \vartheta \qquad \text{(II)}$$

behind the polarizer. In optics, Eq. (II) is known as the Malus law.

There is a marked difference between the generation of microwaves and light waves. Microwaves are generated in a waveguide and emitted into free space via an extended antenna. At a sufficiently large distance, the antenna can be regarded as a pointlike source. At this distance the electric and the magnetic fields of the microwave oscillate perpendicularly to each other and to the direction of propagation (far field). Both fields decrease inversely proportionally to the distance, their ratio being constant:

$$E_0 \sim B_0 \sim \frac{1}{r} \qquad \text{(III)}$$

At distances below the limit

$$r_D = 2 \cdot \frac{D^2}{\lambda} \qquad \text{(IV)},$$

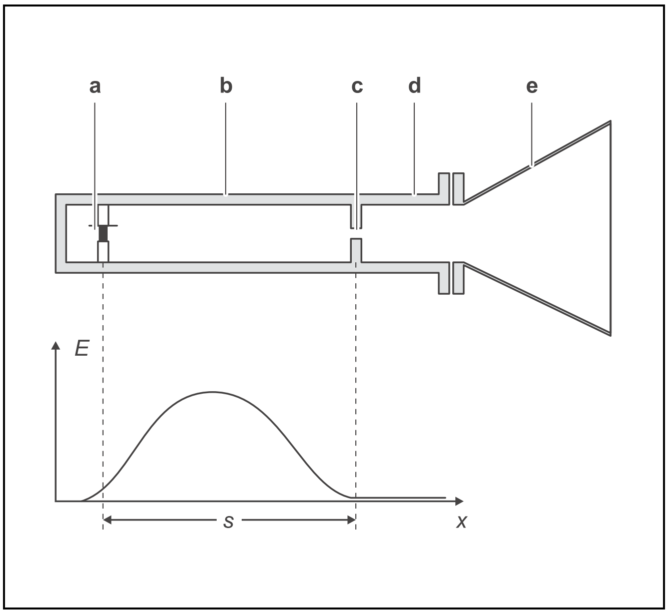
D: greatest transverse dimension of the antenna, λ: wavelength

the field distribution of the radiated wave is more complex (near field). Only in waves radiated perpendicularly to the antenna, the direction of propagation and the electric and magnetic field are perpendicular to each other.

Microwave source:

In this experiment, a Gunn oscillator is used as a microwave source. It operates at a frequency of 9.4 MHz and releases a power of approx. 10 mW via a connected horn antenna (see Fig. 1). The oscillator is a short section of a rectangular waveguide with a small ceramics body being held by a brass post immediately in front of the back. In the ceramics body, there is a semiconductor element with a negative differential resistance. This so-called Gunn element plays the active role in generating oscillations of the electric and magnetic field. On the opposite side, the waveguide is closed by a pinhole diaphragm, through which part of the generated microwave power escapes. A horn antenna is coupled to the closed cavity via another waveguide section. The microwave power is emitted into free space by the antenna.

Fig. 1 Internal structure of the microwave source and distribution of the electric field *E* in the dominant mode of the cavity oscillation
a Gunn element, **b** cavity, **c** pinhole diaphragm,
d waveguide, **e** horn antenna



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 I	737 27
1 voltmeter, DC, $U \leq 10$ V . . . . e.g.	531 100
2 saddle bases	300 11
2 BNC leads, 2 m long	501 022
1 pair of cables, 100 cm, black	501 461
additionally recommended:	
1 set of microwave absorbers	737 390
additionally recommended:	
ruler or graph paper	

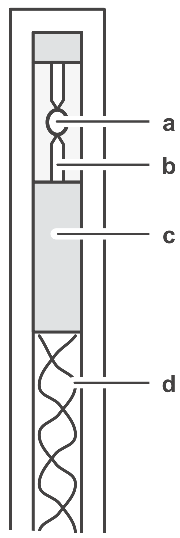


Fig. 2 Internal structure of the E-field probe
a high-frequency diode,
b dipole antenna,
c graphite layers,
d twisted Cu wires

In the cavity, standing electromagnetic waves can arise, whose wavelengths are determined by the dimensions of the cavity. If the cavity is made smaller, the wavelength becomes shorter and the frequency is increased. The frequency can also be changed by introducing a dielectric pin.

In the dominant mode, the resonance frequency is given by

$$f = \frac{c}{2} \cdot \sqrt{\frac{1}{s^2} + \frac{1}{b^2}} \qquad \text{(V)}$$

c: velocity of light, b: cavity width
s: cavity length (here: distance between the pinhole diaphragm and the Gunn element, see Fig. 1)

For $s = 22$ mm and $b = 23$ mm, $f = 9.4$ GHz is obtained and there from $\lambda = 33$ mm. If the relevant dimension of the antenna is $D = 80$ mm, the limit $r_D = 400$ mm results for the far field.

Measuring the field strength:

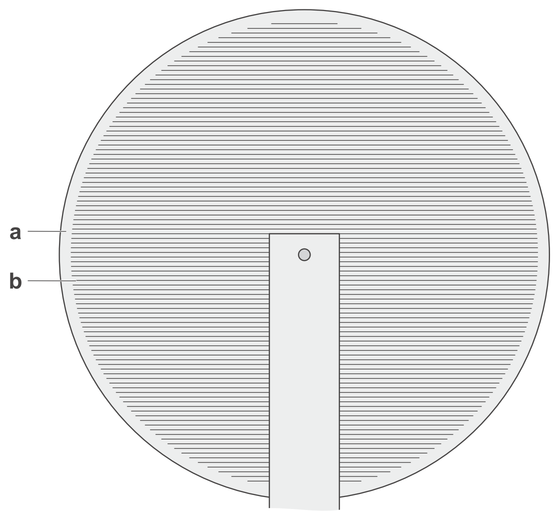
An E-field probe (see Fig. 2), which does not affect the field distribution, is used to measure the electric field strength in the microwave field in a single point. In the probe, short wires, which are soldered to a high-frequency diode, act as dipole antennas for microwaves. A high-resistance layer made of graphite taps the received signal. The copper wires in the lower part of the probe are twisted so as to avoid magnetically induced voltages.

Strictly speaking, the E-field probe measures the electric field's component that is parallel to the longitudinal axis of the probe and rectifies the signal. As the diode characteristic is not linear, the output signal is approximately proportional to the square of the field component. The Gunn power supply is equipped with an integrated amplifier for the output signal of the E-field probe.

Polarization grating:

A polarization grating which is designed like a printed circuit on a board is used as a polarizer for microwaves. Stripes of tin-plated copper prevent formation of an electric field parallel to the stripes due to their high conductivity. The electric field can only build up perpendicularly to the metal stripes.

Fig. 3 Internal structure of the polarization grating
a carrier, **b** metal stripe



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.
- Before positioning anything in the experimental setup, always disconnect the Gunn oscillator.

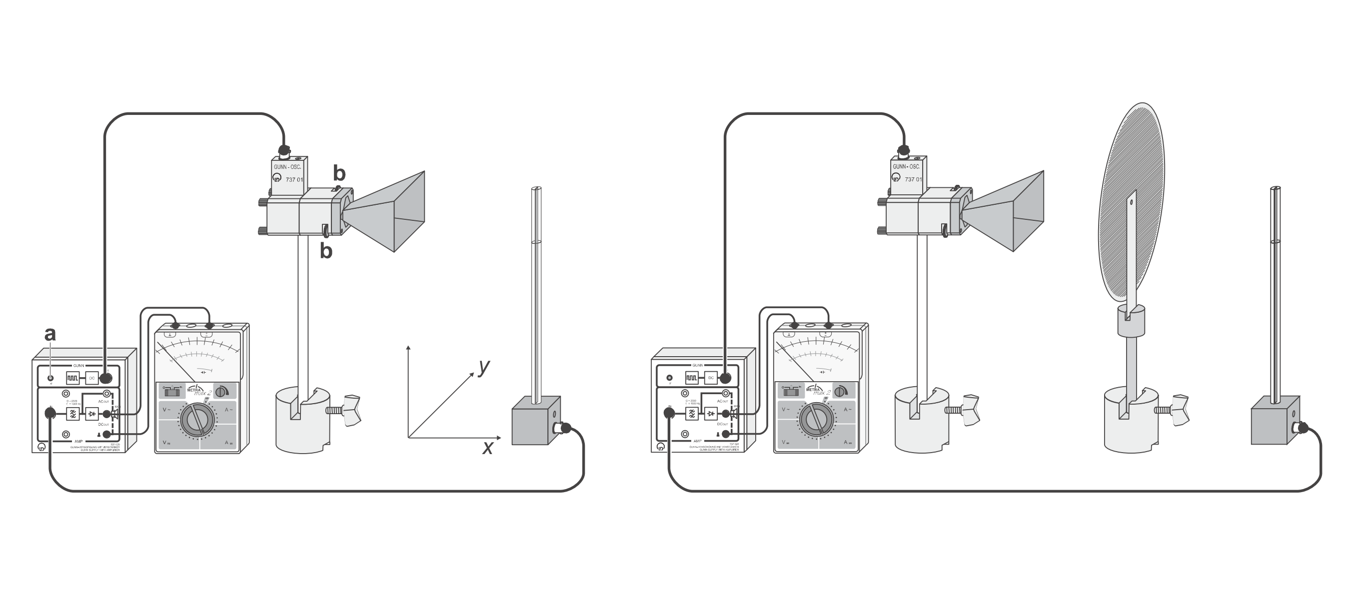


Fig. 4 Experimental setup
left: for measuring the field distribution in front of the horn antenna
right: for determining the polarization

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.

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. 4.

– For measuring distances, make an 800 mm long rule by sticking together scale paper, or use a ruler.

– 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.

Carrying out the experiment

a) Transverse field distribution:
– Set up the E-field probe in front of the horn antenna at the distance x_0 = 100 mm.
– Vary the position of the E-field probe between y = –200 mm and +200 mm in steps of 40 mm. For each case read the received signal U and take it down.
– Repeat the measurement for the distance x_0 = 200 mm.

b) Longitudinal field distribution:
– Set up the E-field probe in front of the centre of the horn antenna (y_0 = 0 mm).
– Measure the received signal U between x = 100 mm and 820 mm in steps of 40 mm and take it down.

c) Polarization:

first:

– Hold the E-field probe vertically and then horizontally in front of the horn antenna, and measure the received signal U in both cases.

next:

– Set up the E-field probe in front of the centre of the horn antenna (distance approx. 300 mm), and place the polarization grating into the field between the horn antenna and the E-field probe.
– Rotate the polarization grating from $\varphi = 0°$ to 180° in steps of 10°. Each time measure the received signal U and take it down.

then:

– Rotate the horn antenna with the Gunn oscillator into the vertical, screw the stand rod into the corresponding thread, and set up the horn antenna at the previous distance from the polarization grating and the E-field probe.
– Again rotate the polarization grating from 0° to 180° in steps of 10°. Each time measure the received signal and take it down.

Measuring example

a) Transverse field distribution:

Table 1: received signal $U(x_0, y)$ (transverse distribution)

	x_0 = 100 mm	x_0 = 200 mm
$\frac{y}{\text{mm}}$	$\frac{U}{\text{mV}}$	$\frac{U}{\text{mV}}$
–200	14	75
–160	22	235
–120	160	520
–80	820	1200
–40	2920	2200
0	5000	2700
40	3750	2100
80	1150	1040
120	245	490
160	52	220
200	19	75

b) Longitudinal field distribution:

Table 2: received signal $U(x, 0)$ (longitudinal distribution)

$\frac{x}{\text{mm}}$	$\frac{U}{\text{mV}}$
100	5000
140	3800
180	2850
220	2450
260	1750
300	1680
340	1120
380	1075
420	940
460	830
500	570
540	660
580	520
620	490
660	450
700	440
740	340
780	320
820	270

c) Polarization:

Horn antenna horizontal, E-field probe vertical:
U = 1800 mV

Horn antenna horizontal, E-field probe horizontal:
U = 14 mV

Table 3: Received signal $U(\varphi)$ behind the polarization grating with the E-field probe being aligned vertically

	horizontal horn antenna	vertical horn antenna
$\frac{\varphi}{\text{grd}}$	$\frac{U}{\text{mV}}$	$\frac{U}{\text{mV}}$
0	49	10
10	59	64
20	115	210
30	190	350
40	370	420
50	600	360
60	940	245
70	1260	100
80	1430	21
90	1500	7
100	1430	42
110	1220	115
120	920	200
130	605	290
140	350	320
150	165	305
160	77	195
170	42	70
180	38	10

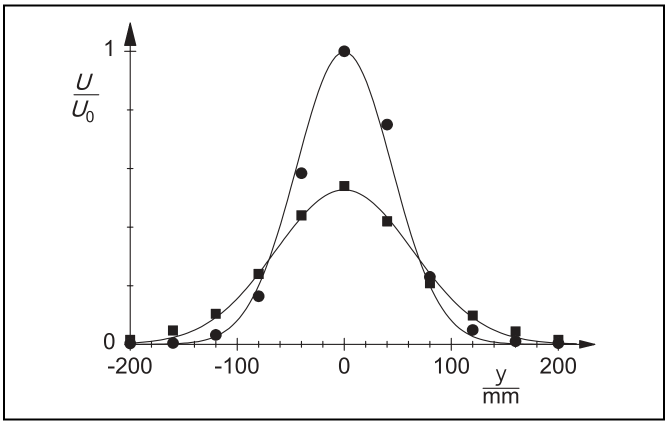


Fig. 5 Transverse distribution of the normalized received signal in front of the horn antenna (● : x_0 = 100 mm, ■ : x_0 = 200 mm)

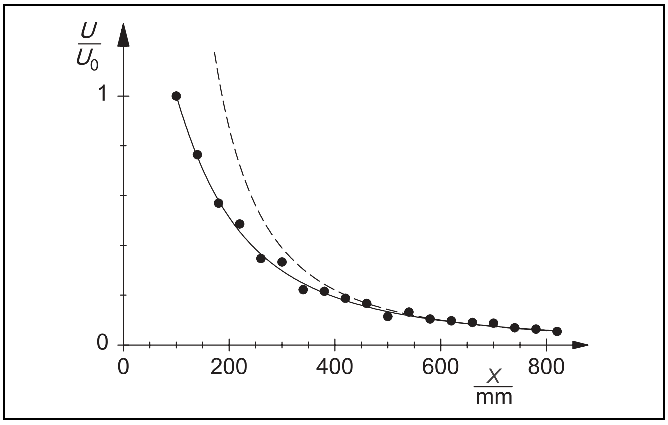


Fig. 6 Longitudinal distribution of the normalized received signal in front of the horn antenna

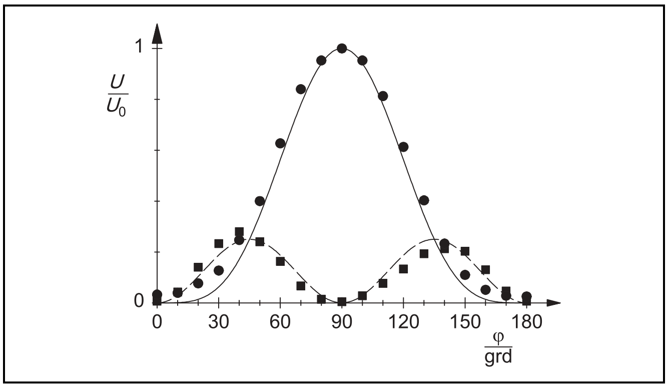


Fig. 7 Normalized received signal behind the polarization grating with the E-field probe being aligned vertically
● : horizontal horn antenna (measured values)
—— : vertical polarization (calculated values)
■ : vertical horn antenna (measured values)
– – – : horizontal polarization (calculated values)

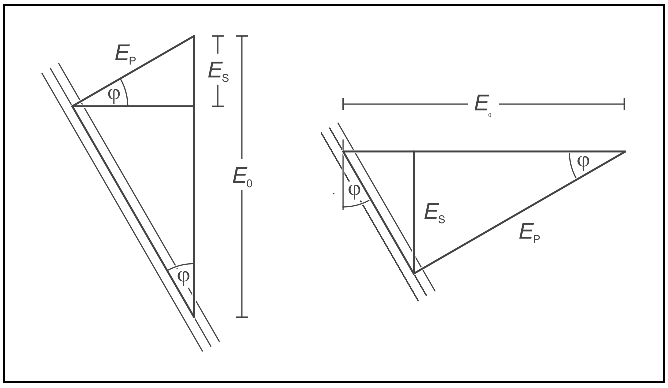


Fig. 8 Calculation of the components of the electric field

Evaluation

a) Transverse field distribution:

In Fig. 5, the values from Table 1 have been normalized to $U_0 = U$(100 mm, 0 mm) for the graphic representation.

b) Longitudinal field distribution:

The values of the longitudinal field distribution represented in Fig. 6 also are normalized to $U_0 = U$(100 mm, 0 mm).

For distances x > r_D = 400 mm, the quadratic hyperbola – drawn as a dashed line in the graph – is in good agreement with the measured data, i.e., in that region the far-field approximation $U \sim E^2 \sim \frac{1}{x^2}$ or $E \sim \frac{1}{x}$ holds.

c) Polarization:

The received signal is approximately zero if the E-field probe is aligned horizontally in front of the horizontal horn antenna. That means, the waves transmitted by the horn antenna are linearly polarized perpendicularly to the broad side of the horn antenna.

In Fig. 7, the measured values from Table 3 – normalized to the value $U_0 = U(90°)$ measured when the horn antenna is aligned horizontally – are plotted. The curves drawn in the graph were calculated according to the following consideration (see Fig. 8):

If the waves behind the horn antenna are polarized perpendicularly, the component $E_P = E_0 \cdot \sin\varphi$ of the electric field will pass the polarization grating perpendicularly to the metal stripes if φ is the angle between the metal stripes of the polarization grating and the vertical. The E-field probe, which also is aligned vertically, then measures the component $E_S = E_P \cdot \sin\varphi = E_0 \cdot \sin^2\varphi$ and generates the received signal $U = U_0 \cdot \sin^4\varphi$ (solid line in Fig. 7).

If the waves are polarized horizontally, the electric field behind the polarization grating will be $E_P = E_0 \cdot \cos\varphi$.
Then the E-field probe measures the component $E_S = E_P \cdot \sin\varphi = E_0 \cdot \cos\varphi \cdot \sin\varphi$ and generates the received signal $U = U_0 \cdot \cos^2\varphi \cdot \sin^2\varphi$ (dashed line in Fig. 7).

A comparison of the measurement with the calculation confirms that the waves transmitted by the horn antenna are polarized perpendicularly to the broad side of the horn antenna.

Results

Microwaves can be polarized and thus are transverse waves. The electric field in front of the horn antenna is linearly polarized perpendicularly to the broad side of the horn antenna.

The signal transmitted from the horn antenna decreases if the distance increases. For great distances the electric field of the signal is inversely proportional to the distance.

The received signal of the E-field probe is proportional to the square of the electric field component of the microwaves parallel to the axis of the probe.