

Guiding of microwaves along a Lecher line

Objects of the experiments

- Generating standing microwaves on a *Lecher* line with shorted end.
- Demonstrating the standing wave character of the electric field strength.
- Determining the wavelength λ from the distances between the nodes of the electric field.

Principles

In 1890, E. *Lecher* proposed an arrangement of two parallel round wires for investigating the propagation of electromagnetic oscillations. When a high-frequency electromagnetic field is irradiated into a *Lecher* line, a voltage wave of the shape

$$U_1 = U_0 \cdot \sin\left(2\pi \cdot f \cdot t - \frac{2\pi}{\lambda} \cdot x\right) \quad (I)$$

propagates in the direction x of the wires, whose frequency f and wavelength λ equal those of the irradiated electromagnetic field. Corresponding to the voltage between the wires, a charge distribution arises along the wires, whose displacement leads to a current I through the wires, which propagates like a wave.

Thus an electromagnetic wave propagates along the *Lecher* line. The electric field E between the wires oscillates along with the voltage U . Its field lines run from one wire to the other symmetrically with respect the plane spanned by the wires. The magnetic field B oscillates in line with the current I , the field lines running along closed curves around the wires.

If the two wires are shorted at the end of the *Lecher* line, the voltage U is zero there. A reflected wave U_2 is generated with a phase shift of 180° relative to the incoming wave. The two waves superimpose to form a standing wave, which has the shape

$$U = U_1 + U_2 = -2 \cdot U_0 \cdot \sin\left(\frac{2\pi}{\lambda} x\right) \cdot \cos(2\pi \cdot f \cdot t) \quad (II)$$

if the wave comes in from "the left" and the shorting jumper is at $x = 0$. In this case, the locations of the voltage nodes are

$$x = 0, \frac{\lambda}{2}, -\lambda, -\frac{3\lambda}{2}, \dots \quad (III),$$

i. e., their distances from the end of the line are multiples of $\frac{\lambda}{2}$.

The oscillation nodes of the voltage wave correspond to the oscillation antinodes of the current wave and vice versa.

In this experiment, the propagation of microwaves with a frequency of $f = 9.4$ MHz on a *Lecher* line is investigated. The wires of the line are aligned in parallel one above the other, i. e., the electric field oscillates vertically between the wires and can easily be measured by means of a vertical E-field probe.

The *Lecher* line is shorted at one end by a shorting jumper. Evidence of a standing wave is found by either shifting the shorting jumper with the E-field probe being fixed or by shifting the E-field probe with the shorting jumper being fixed.

The microwaves are transferred onto the *Lecher* line at the other end by means of a bent induction loop, which is held in the horn antenna so that it is penetrated by the magnetic field, which oscillates in parallel to the broad side of the horn antenna.

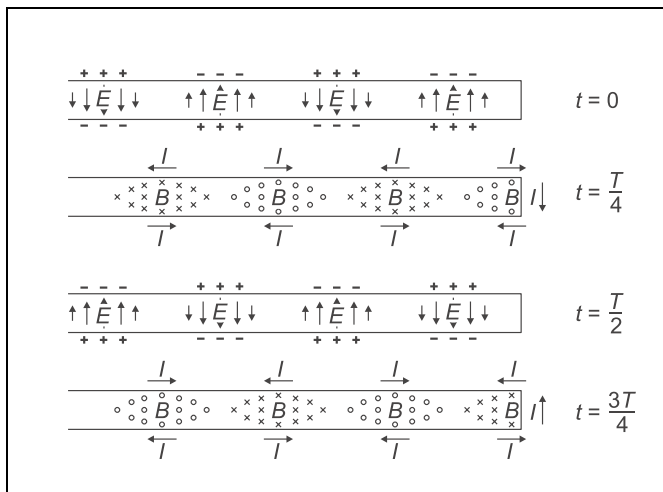


Fig. 1 Standing electromagnetic waves on a *Lecher* line

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, $U \leq 10$ 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 |

- 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.
- Slide the shorting jumper **(c)** on the *Lecher* line, and insert the *Lecher* line in the vertical bores of the PVC body **(d)**.
- Adjust the height of the *Lecher* line according to the height of the high-frequency diode (see experiment P3.7.4.1) in the E-field probe.
- Using adhesive tape, stick the ruler to the table under the *Lecher* line so that the E-field probe can be moved along the ruler in parallel to the *Lecher* line.
- Adjust the height of the horn antenna according to the height of the induction loop **(e)** of the *Lecher* line, and position the horn antenna so that it encloses the induction loop.
- Using the E-field probe, look for a maximum of the received signal U along the *Lecher* line and turn the horn antenna until a maximum signal is achieved.

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. 2.

- 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.

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.

Carrying out the experiment**a) Determining the wavelength from the distance between the minima of the field strength:**

- Scan the field with the E-field probe along the line, and mark the positions of the minima of the received signal U .
- Measure the distance Δ , e.g., between the first and the eleventh minimum.

b) Demonstrating the standing wave character of the electric field: (see Tab. 1 on page 3)

- Shift the E-field probe in steps of 2 mm, measure the received signal U , and take it down.

Measuring example**a) Determining the wavelength from the distance between the minima of the field strength:**

Distance between the first and the eleventh minimum:
 $\Delta = 159$ mm

b) Demonstrating the standing wave character of the electric field: (see Tab. 1 on page 3)**Evaluation****a) Determining the wavelength from the distance between the minima of the field strength:**

$\Delta = 10 \cdot \frac{\lambda}{2} = 159$ mm, from which the wavelength is obtained:

$$\lambda = \frac{\Delta}{5} = 32 \text{ mm}$$

From $f = 9.4$ GHz the wavelength in free space follows:

$$\lambda_0 = \frac{c}{f} = 32 \text{ mm} \quad (c = 3 \cdot 10^8 \frac{\text{m}}{\text{s}})$$

Thus the wavelength on the *Lecher* line equals the wavelength in free space.

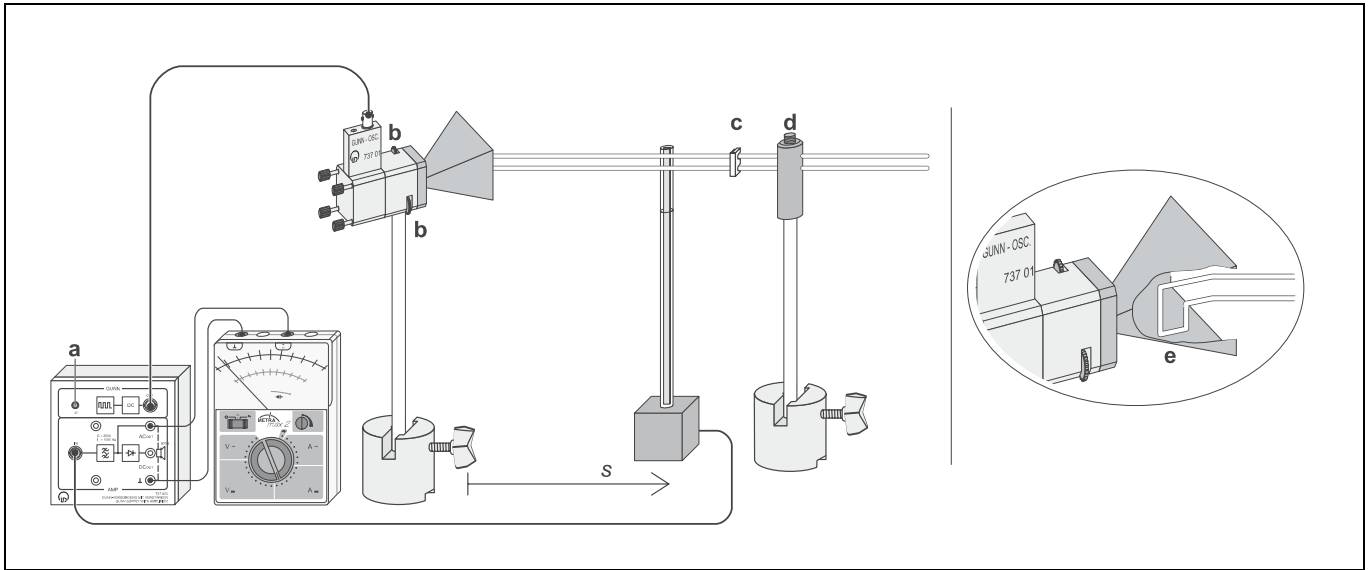


Fig. 2 Experimental setup for guiding microwaves along a Lecher line

Tab. 1: shape of the received signal U along the *Lecher* line

| $\frac{s}{\text{mm}}$ | $\frac{U}{\text{mV}}$ | $\frac{s}{\text{mm}}$ | $\frac{U}{\text{mV}}$ | $\frac{s}{\text{mm}}$ | $\frac{U}{\text{mV}}$ | $\frac{s}{\text{mm}}$ | $\frac{U}{\text{mV}}$ |
|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| 40 | 670 | 90 | 440 | 140 | 330 | 190 | 260 |
| 42 | 690 | 92 | 350 | 142 | 300 | 192 | 170 |
| 44 | 660 | 94 | 320 | 144 | 212 | 194 | 60 |
| 46 | 570 | 96 | 320 | 146 | 105 | 196 | 60 |
| 48 | 480 | 98 | 210 | 148 | 70 | 198 | 150 |
| 50 | 390 | 100 | 175 | 150 | 145 | 200 | 255 |
| 52 | 390 | 102 | 220 | 152 | 245 | 202 | 300 |
| 54 | 490 | 104 | 310 | 154 | 300 | 204 | 320 |
| 56 | 610 | 106 | 360 | 156 | 320 | 206 | 265 |
| 58 | 650 | 108 | 390 | 158 | 265 | 208 | 170 |
| 60 | 580 | 110 | 350 | 160 | 170 | 210 | 75 |
| 62 | 540 | 112 | 275 | 162 | 92 | 212 | 65 |
| 64 | 510 | 114 | 165 | 164 | 70 | 214 | 120 |
| 66 | 390 | 116 | 115 | 166 | 150 | 216 | 270 |
| 68 | 330 | 118 | 182 | 168 | 250 | 218 | 325 |
| 70 | 370 | 120 | 260 | 170 | 300 | 220 | 320 |
| 72 | 440 | 122 | 335 | 172 | 325 | 222 | 260 |
| 74 | 510 | 124 | 350 | 174 | 260 | 224 | 160 |
| 76 | 430 | 126 | 345 | 176 | 165 | 226 | 55 |
| 78 | 390 | 128 | 255 | 178 | 82 | 228 | 45 |
| 80 | 310 | 130 | 155 | 180 | 70 | 230 | 55 |
| 82 | 250 | 132 | 95 | 182 | 145 | 232 | 260 |
| 84 | 240 | 134 | 150 | 184 | 245 | 234 | 325 |
| 86 | 270 | 136 | 235 | 186 | 300 | 236 | 335 |
| 88 | 370 | 138 | 310 | 188 | 320 | 238 | 260 |

b) Demonstrating the standing wave character of the electric field:

Fig. 3 shows a plot of the measured values from Table 1. The minima of the received signal U , i.e. the minima or nodes of the electric field E , are not zero as no ideal reflection takes place at the shorting jumper. For distances of up to $s = 100 \text{ mm}$, the influence of the direct radiation from the horn antenna is clearly seen.

The curve drawn in the diagram was calculated for $\lambda = 32 \text{ mm}$, whereby the fact that the received signal U is proportional to the square of the electric field E was taken into account. (see P3.7.4.1).

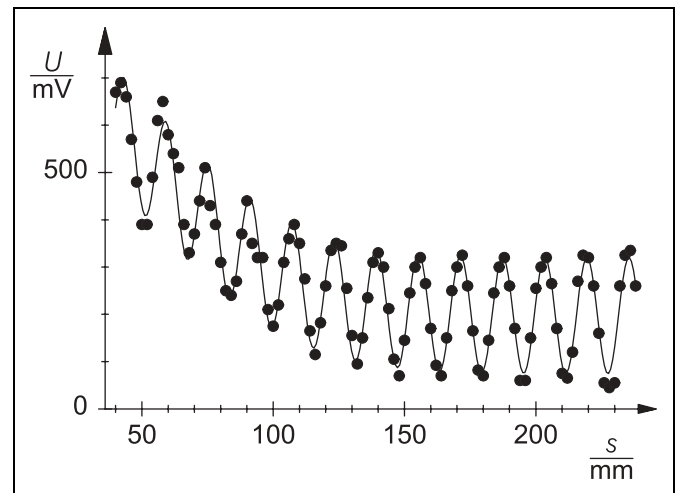


Fig. 3 Standing wave character of the received signal U along the *Lecher* line

Results

By means of a *Lecher* line, microwaves can be guided to an arbitrary place, e.g. perpendicularly to the direction of transmission of the horn antenna.

Reflection at the shorting jumper gives rise to a standing wave on the *Lecher* line.

The wavelength on the *Lecher* line equals the wavelength in free space.

