Carl von Ossietzky University Oldenburg – Faculty V - Institute of Physics
Module Introductory laboratory course physics – Part I

Oscilloscope and Function Generator

Keywords:
Anode, cathode, cathode ray tube, electron deflection, deflector plates, trigger, AC/DC coupling, direct voltage, alternating voltage, frequency, radian frequency, period, amplitude, phase, phase difference, peak and effective value of alternating voltages, LISSAJOUS figures, harmonic oscillation, peak and effective values of alternating voltage.

Measuring program:
Representation of function generator signals, trigger level and trigger slope, temporal course of the light intensity of a light bulb and a fluorescent lamp, peak and effective value of the line voltage, investigation of a damped harmonic voltage signal, duration of a light flash, frequency stability of a stroboscope, LISSAJOUS figures.

References:
/1/ WALCHER, W.: „Praktikum der Physik“, Teubner Studienbücher Physik, Teubner-Verlag, Stuttgart
/2/ EICHLER, H. J., KRONFELDT, H.-D., SAHM, J.: „Das Neue Physikalische Grundpraktikum“, Springer-Verlag, Berlin among others
/3/ GERTHSEN, C. u.a.: „Physik“, Springer-Verlag, Berlin among others

1 Introduction

The oscilloscope counts among the important measuring instruments in experimental physics. It makes it possible to observe and to measure quantitatively the course of an electric voltage U_y as a function of time t or as a function of voltage U_x in „real-time“. The temporal course of all physical quantities that can be converted to an electrical voltage using a suitable sensor can be displayed with an oscilloscope[1]. There are few restrictions regarding the amplitude and frequency of the measurable signals: if you are prepared to spend enough money, you will certainly find an oscilloscope which meets the requirements.

During the introductory laboratory course, too, the oscilloscope is a frequently used measuring instrument. In some experiments it is a fundamental component of the experimental set-up and yields the quantitative data required for the analysis. In other experiments it is used for qualitative control, i.e., whether a circuit has been correctly set up and is operative, if a sensor is providing the correct signal, etc. In order to perform the experiments in the laboratory course successfully, a thorough knowledge of the oscilloscope is imperative.

Until some years ago, cathode ray oscilloscopes were still in use. This equipment has been replaced predominantly by digital storage oscilloscopes nowadays. We are also working with digital storage oscilloscopes in this experiment and in the lab course, too. Nevertheless, the principle of the cathode ray oscilloscope is briefly represented in the theoretical part, because some basic functional principles of oscilloscopes can thus be explained easily and clearly.

2 Theory

2.1 Cathode Ray Oscilloscope

Fig. 1 shows the schematic set-up of an oscilloscope tube, the real shapes of the single components are considerably more complex (Fig. 2). The grounded *cathode* K (0 V) is heated indirectly by a heating spiral (heating voltage U_H) until thermal electron emission. The *anode* (A), drilled in its centre, is placed at a distance d_a from the *cathode*. Between A and K a positive high voltage U_A of up to a few 1000 Volts is applied. Thereby an electrical field $\mathbf{E}_A$ arises between K and A with the magnitude:

(1) $$E_A = \frac{U_A}{d_A},$$

exerting a force $\mathbf{F}_A$ on the electrons (having charge e) with the magnitude

(2) $$F_A = e\, E_A$$

[1] Details will be presented in the experiment "*Sensors for Force, Pressure,…*".

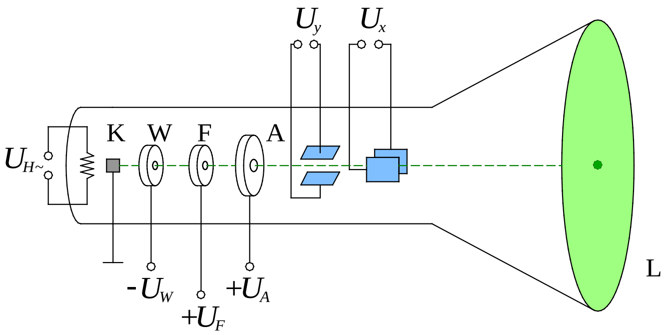


Fig. 1: Schematic set-up of a cathode ray oscilloscope tube. For symbols refer to the text. The dashed green line represents the electrons' trajectory for $U_x = U_y = 0$.

Fig. 2: Photograph of the back-end of an cathode ray oscilloscope tube. It shows the complex structure of the electrodes for forming and controlling the electron beam. The connecting contacts for the different electrodes can be seen at the end of the tube and on the right side of the casing.

This force accelerates the electrons in the direction of the anode. After travelling through the hole in the anode the electrons hit the luminescent screen, causing them to slow down and excite the phosphor in the screen to fluorescence. This causes a visible point of light, the size of which can be minimized with the help of the voltage U_F across the focussing device.
The intensity of the point of light can be varied using a negative voltage U_W between K and the WEHNELT *cylinder* W. The electrical field $\mathbf{E}_W$, resulting from U_W is oriented in the opposite direction of $\mathbf{E}_A$, thus decelerating the electrons. Because of this, only electrons having sufficient kinetic energy can reach the anode.

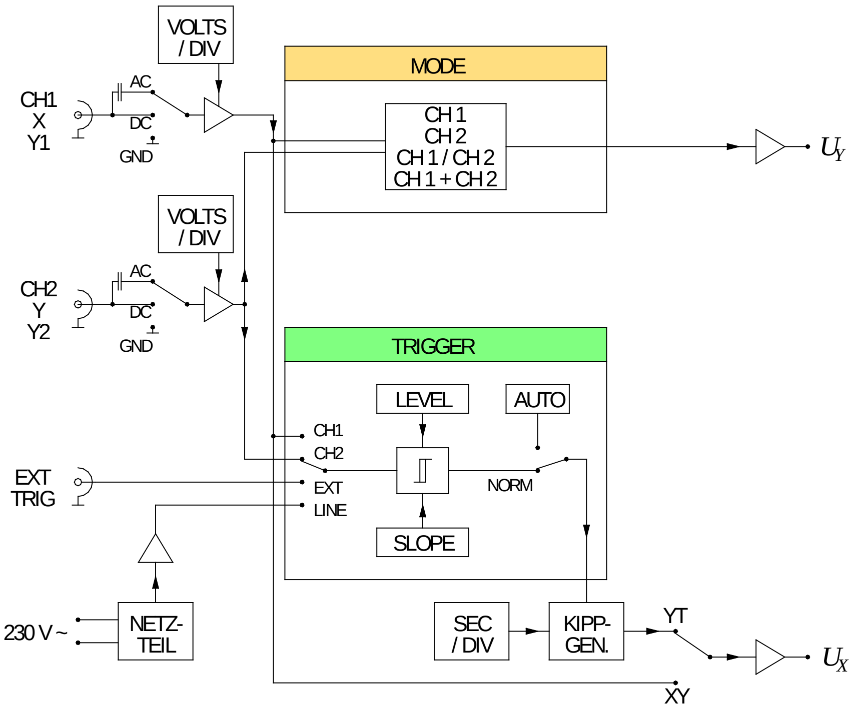


Fig. 3: Block diagram of the most important functional units of an oscilloscope. For symbols refer to text and Fig.4.

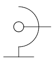
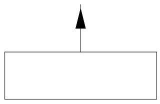
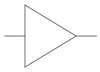
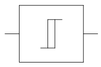
	BNC-socket connector - inside: signal line - outside: ground contact		Unit to adjust e.g.. - amplification factor in VOLTS/DIV - time base in SEC/DIV - trigger level (LEVEL) - trigger slope (SLOPE) - intensity (INTENS)
	Amplifier		Threshold value discriminator generates output signal if input voltage > threshold value

Fig. 4: Explanation of block diagram elements.

The *X* and *Y* deflector plates (blue in Fig. 1) each form a parallel-plate capacitor and are used for horizontal and vertical deflection of the electron beam. If a deflection voltage U_Y is applied to the *Y*-deflector plates (separated by a distance d_Y), an electrical field $\mathbf{E}_Y$ will form between the plates. The magnitude E_Y of this field is given by:

$$E_Y = \frac{U_Y}{d_Y}, \tag{3}$$

exerting a force $\mathbf{F}_Y$ on the electrons during their transit with a magnitude

$$F_Y = e\,E_Y = e\,\frac{U_Y}{d_Y} \tag{4}$$

The electrons are thus deflected up or down by some amount, depending on the amplitude and sign of applied voltage U_Y , causing them to contact the screen at different positions in the vertical direction. The above explanation can be applied analogously to the *X*-deflector plates, which are used to deflect the electrons in the horizontal direction.

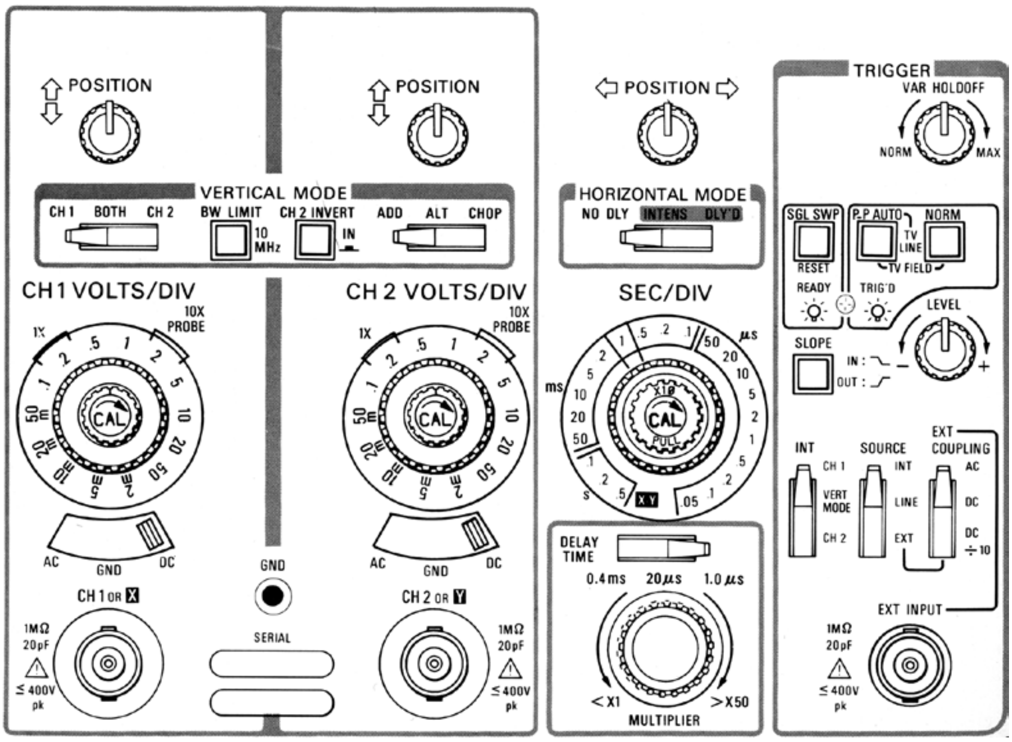


Fig. 5: Front view of the control units of the cathode ray oscilloscope TEKTRONIX 2213A (Source: TEKTRONIX-Manual).

Fig. 3 shows the most important (*not all*!) functional units for controlling the different elements of the oscilloscope tube. In Fig. 4 the function of the elements in the block diagram are explained. Fig. 5 shows the front view of the control units of a typical cathode ray oscilloscope.
The cathode ray oscilloscope represented in Fig. 3 and Fig. 5 is known as a "2-channel oscilloscope" with two signal inputs. The inputs are provided as BNC-terminals and are called channel 1 (often denoted as CH1 or X or Y1), and channel 2 (CH2 or Y or Y2). In addition a BNC-input terminal for an external trigger signal (EXT INPUT or EXT TRIG[2]) is available.
In the DC[3] mode of the channel's input switch the input signal is connected directly to an input amplifier, in the AC[4] mode only its alternating voltage component[5]. In the GND (ground) mode the input signal is set to ground potential.
The amplification factor is varied and set with the VOLTS/DIV knob of the input amplifier, which determines how many volts (VOLTS) from the input signal cause a cathode ray deflection of a certain unit length (one DIVision, usually 1 cm). Thus the VOLTS/DIV setting determines the vertical *size* of a signal on the oscilloscope screen. On the other hand, the horizontal and vertical *position* of the signal on the screen is varied by the POSITION knob, by which a positive or negative direct voltage of variable magnitude is added to the deflecting voltages U_Y und U_X.

2.1.1 XY- and YT-Operation

The oscilloscope can operate in different modes depending on the settings of the *function group* MODE:

- In XY operation the signal course $U_y(U_x)$ will be displayed. To produce this, the signal from input CH1 (X) is passed via an input amplifier as voltage U_X to the X deflection plate, while the signal from input CH2 (Y) is passed via an input amplifier as voltage U_Y to the Y deflection plate.
- The YT operational mode displays signals as a function of time t: $U_{y1}(t)$, $U_{y2}(t)$ or $U_{y1}(t) + U_{y2}(t)$. To produce this, the signals from CH1 and CH2, respectively arrive at the Y deflection plate after amplification. A *sweep generator* produces a *saw tooth voltage* with period t_d, which serves as a deflection voltage U_X for the periodic horizontal deflection of the cathode ray (cf. Fig. 6). The sweep generator together with its components (SEC/DIV switch among other) is also called *time-base*.
- In the YT operational mode, the time t_s the cathode ray takes to travel over a distance of one division (1 DIV) in horizontal direction is set with the time-base switch (SEC/DIV). For a panel width of m DIVisions we obtain $t_d = m\, t_e$.

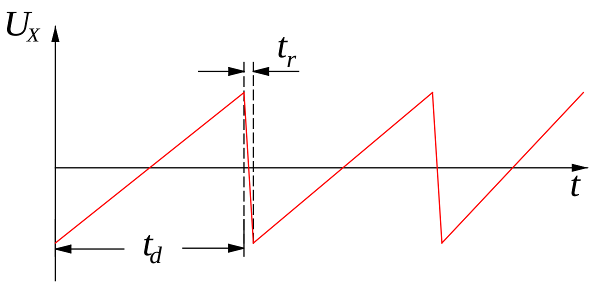


Fig. 6: Saw tooth voltage from the sweep generator. During time t_d the cathode ray moves with constant speed from left to right, and during time t_r it moves from right to left, back to the start of the image. By reducing U_W it is achieved that the beam does not reach the screen during the retrace.

2.1.2 Synchronization (Triggering)

In order to produce a stationary image of a periodic signal $U_y(t)$ with period T on the screen, $U_y(t)$ has to be synchronised with the horizontal deflection voltage $U_X(t)$. This process of synchronisation is called *triggering*. It is controlled by the *function group* TRIGGER. Fig. 7 demonstrates the triggering by means of an example for the case $T \geq t_d + t_r$. The sweep generator produces the next period of the saw tooth voltage $U_X(t)$ first when the input voltage $U_y(t)$ equals the threshold voltage U_L (TRIGGER LEVEL) and the slope (SLOPE) of $U_y(t)$ has the sign adjusted on the trigger switch SLOPE ("+" in the case represented in Fig.

[2] Expressions set in ARIAL correspond to the labels found on the faceplate of the oscilloscope.
[3] DC: *direct current*; here, „DC" is the acronym of direct voltage coupling.
[4] AC: *alternating current*; here, „AC" is the acronym of alternating voltage coupling.
[5] Details on direct and alternating voltages cf. chapter "*About the set-up of electric circuits*" in this script.

7). The signal will be *triggered* only if both conditions are met, this means that the cathode ray goes once across the oscilloscope screen from left to right, and waits for the next trigger event.
The elements of the function group TRIGGER determine whether the oscilloscope is operated in the NORMal trigger mode, or in the in AUTO trigger mode:

– In NORMal mode, it can be decided on which signal triggering (synchronization) occurs. Possible is the INTernal triggering on a signal at CH1 or CH2, on an EXTernal signal which the oscilloscope is supplied with from the EXT INPUT / TRIG socket or the line voltage (LINE).

– In AUTO mode, a triggering as in NORMal mode takes place in case the input signal meets the triggering requirements, otherwise the next period of the saw tooth voltage is also produced without triggering. In this operational mode the cathode ray can be made visible if the channel switch is set to GND. In this case $U_y(t) = 0$ so that no trigger condition ($U_y > U_L$) for starting the electron beam can be met at all.

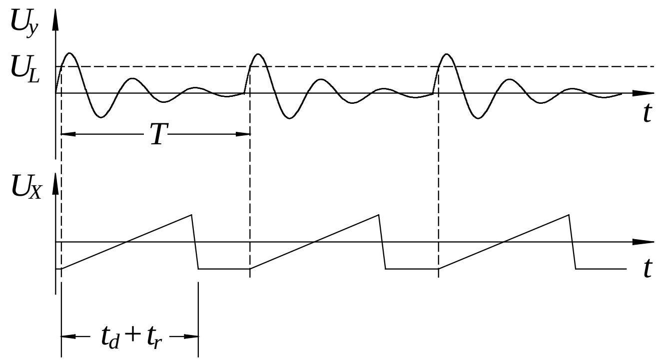


Fig. 7: Signal triggering. Top: input signal $U_y(t)$, bottom: sweep generator signal $U_x(t)$. U_L: Trigger level.

Question 1:
- What does it mean for the triggering of the oscilloscope if the TRIGGER switch is set to
  a) NORM, EXT, „-“,
  b) NORM, CH1, „+”?

Question 2:
- Two sinusoidal voltages $U_{y1}(t)$ and $U_{y2}(t)$ may be visible on the oscilloscope screen. How can the periods T , the frequencies f, and the angular frequencies ω of the signals be determined? What is the formal relationship between these values? How can the amplitudes $U_{y1,0}$ and $U_{y2,0}$ of the voltage signals be determined?

Question 3:
- Assuming that the signals $U_{y1}(t)$ and $U_{y2}(t)$ have equal frequencies, but one is shifted sideways compared to the other i.e. phase-shifted. How can the phase shift φ (in degrees) of the two signals be determined (formula)?

2.2 Digital Storage Oscilloscope

2.2.1 Basics

A digital storage oscilloscope (short: digital oscilloscope) is basically nothing else but a computer containing the following special components besides the usual units like CPU, internal / external memory, bus system and software:

– A panel with rotating switches (e.g. SCALE LEVEL,…) and buttons (e.g. CH1/2 MENU, TRIGGER MENU, CURSOR,…), cf. Fig. 9, by which the software is controlled (instead of keyboard and mouse).
– A unit to acquire and digitize voltage signals that are connected to the BNC-terminals CH1, CH2 and EXT TRIG.

– An LCD screen for the display of the acquired signals, the output of measured values and set-up parameters as well as the representation of the menus for controlling the device (cf. Fig. 10, Fig. 11, Fig. 12).

The analogue input signals are converted into digital signals by means of an *analogue/digital converter* (A/D converter). For this reason, only some basic terminology will be explained in the following.
The conversion *analogue* $\rightarrow$ *digital* does not happen continuously, but at discrete periodic times, the so-called *sampling points* (Fig. 8). The frequency at which a signal is scanned is determined by the *sampling rate* or *sampling frequency* f_a; its reciprocal value is the *sampling interval* T_a. The higher the sampling rate f_a, that is the smaller T_a, the more precisely the temporal course of the input signal can be represented. For the equipment used in the laboratory course the maximum sampling frequency f_a is 1 GHz .

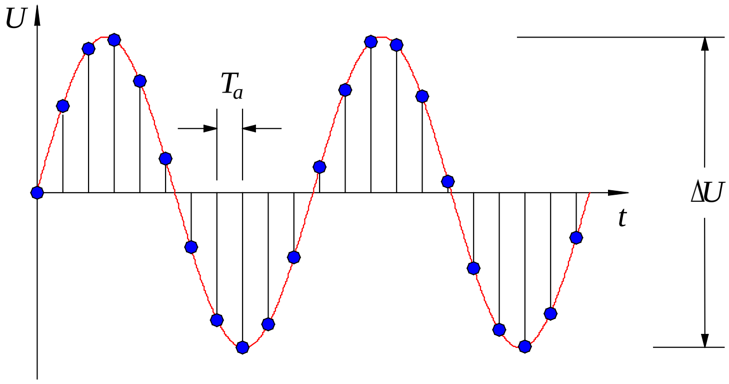


Fig. 8: Sampling of a sinusoidal signal (red). The sampling points (blue) are separated by time intervals of length $T_a = 1/f_a$. ΔU is the maximum voltage difference in the represented signal.

According to the *sampling theorem* the highest possible sampling frequency f_a simultaneously determines the maximum frequency f_s of a harmonic input signal that can be acquired by a digital storage oscilloscope. For a correct signal recording the condition

$$f_a > 2\, f_s \qquad (5)$$

must be fulfilled, otherwise errors will occur (aliasing).[6]

In order to determine the voltage value at a sampling point as precisely as possible, an A/D converter with the highest possible *resolution* is required, which is given by the number n of available bits. n bits allow for a relative accuracy of $1/2^n$ for voltage measurements. For the types used in the laboratory course $n = 8$, that is $2^8 = 256$ different voltage values can be acquired. Two examples for illustration:

– For an amplifier adjustment of 1 V/DIV at the SCALE switch (VOLTS/DIV switch) and 8 Divisions in vertical direction input signals with maximum voltage differences of 1 V/DIV × 8 DIV = 8 V can be displayed. Single voltage values can then be measured with a precision (resolution) of $8\text{ V}/2^8 \approx 30$ mV. Therefore, voltage differences in the input signal smaller than 30 mV cannot be *resolved*.
– For an amplifier adjustment of 20 mV/DIV and 8 Divisions input signals with maximum voltage differences of ΔU = 20 mV/DIV × 8 DIV = 160 mV can be displayed. The resolution for the measurement of single voltage values then is $160\text{ mV}/2^8 \approx 0{,}63$ mV.

For measurements with highest resolution it is therefore important to amplify the input signals by correct adjustment of the SCALE switch so high that they cover approximately the entire screen in vertical direction.

Question 4:

a) With what accuracy can a sinusoidal AC voltage with an amplitude of $U_0 = 2$ V and a frequency of $f = 50$ Hz be measured at a VOLTS / DIV setting of 2 V / DIV?
b) With which VOLTS / DIV setting, based on the sinusoidal AC voltage from a), can the accuracy be improved by a factor of 4?

[6] More information about the sampling theorem and the aliasing will be given later on in the experiment "*Fourier analysis*".

Another quantity determining the quality of a digital oscilloscope is the maximum number *N* of sampled values that can be stored. *N* = 2,500 for the types used in the laboratory course. The representation of the measured values occurs on a 7 inch (800 x 480 pixels WVGA TFT color display.

Fig. 9: Front view of the digital oscilloscope TEKTRONIX TBS 1102B EDU.

Signal *storage* is done continuously in a digital oscilloscope. The last *N* sampled values of the signal are *always* available in the memory. However, the signals are only *presented* upon triggering. The continuous storage of the signal offers the advantage that parts of signals can be presented prior to triggering (*pre-triggering*). Hence, the time of triggering is found in the horizontal centre of the screen in the standard setting of the oscilloscope (Fig. 10). Using the HORIZONTAL POSITION knob this time can be shifted to the left or right side.

As alternative oscilloscopes the TEKTRONIX models TDS 1012B, TDS 1012 and TDS 2012C are used. All models have the option of data storage on an SD card or a USB flash drive.

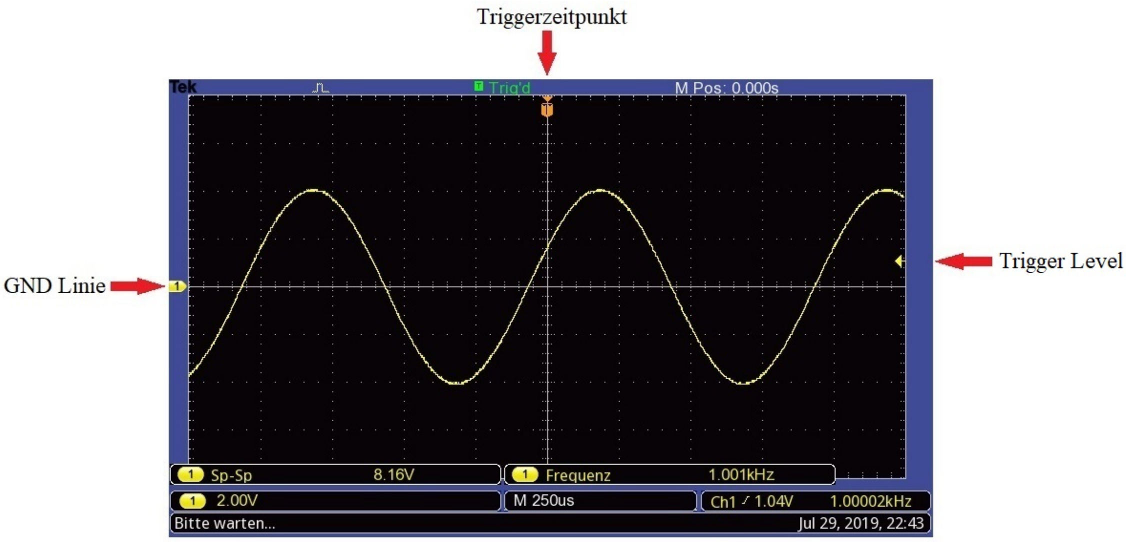


Fig. 10 Screenshot of the digital oscilloscope TEKTRONIX TBS 1102B - EDU measuring a sinusoidal alternating voltage on CH1. By activating the function MEASURE (MESSUNG) the peak-peak-value U_{SS} of the voltage (8.16 V) and its frequency (1.001 kHz) are displayed on the right side of the screen. At the bottom, the setting of the parameter VOLTS/DIV (CH1 2.00V) and SEC/DIV (M 250µs), as well as the value of the TRIGGER LEVEL (⁄ 1.04 V) are shown. The sign ⁄ means that triggering occurs on a part of the signal having positive SLOPE. The downward arrow shown at the top of the screen marks the time at which the signal was triggered. The arrow pointing to the left at the right screen border shows the TRIGGER LEVEL and the rightward arrow on the left screen border (with the digit 1) gives the 0 V-line (GND) of CH1.

2.2.2 Menu Control

Many functions of the digital oscilloscope are controlled by menus. After pressing a button like MENU (CH1 MENU), MEASURE, ACQUIRE, DISPLAY etc. a menu appears in the right column of the screen with five fields arranged one below the other. As an example, Fig. 11 shows the menu after pressing the button CH1 MENU. The entries in the individual fields can be changed by pressing the button on the right of the fields. For example, repeated pressing of the button besides the field COUPLING results in a change of the signal coupling: DC → AC → GND → DC → AC → GND →… Further menus are shown in Fig. 12.

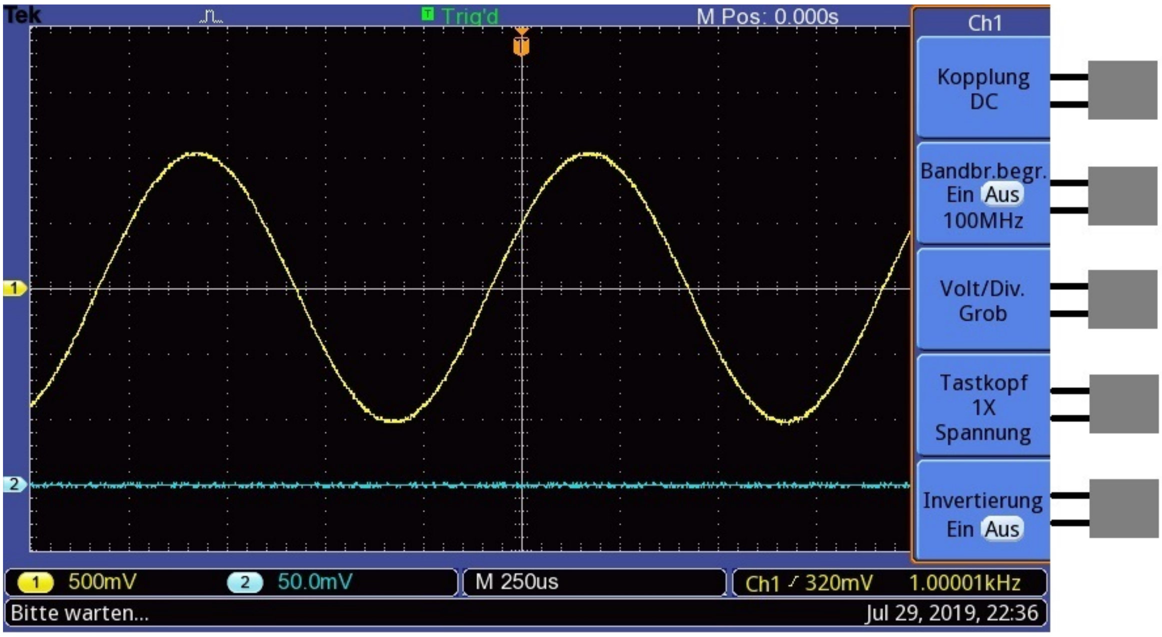


Fig.11: Menu on the screen (right column) after pressing the button CH1 MENU. On the right, the buttons for changing the menu selection in the individual fields.

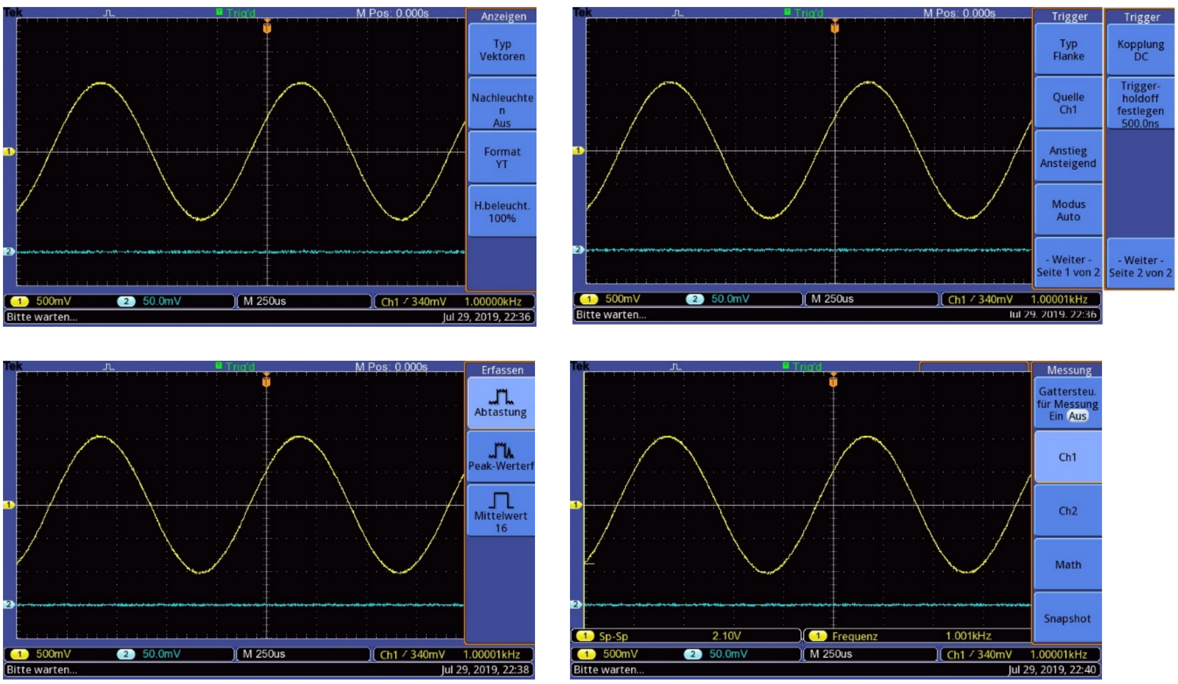


Fig.12: Menus after pressing different function buttons. The following menus are presented from left to right and from top to bottom: Menu UTILITY → ANZEIGEN (DISPLAY) (Switching between YT- and XY-mode among others), menu TRIGGER, menu ACQUIRE and menu MEASURE.

2.2.3 Quantitative Measurements

An important advantage of digital oscilloscopes compared to analogue instruments is the possibility of internally executing some calculations on the stored data. Thus peak values of signals, temporal and amplitude differences, time periods, signal frequencies etc. are easy to measure.

For measuring parameters of *periodic* signals (period, frequency, amplitude etc.) the menu MEASURE is well suited. The results are displayed in the bottom margin of the screen, respectively. Fig. 10 and Fig. 12 bottom right show examples.

Non-periodic signals or single voltage and time values can be measured with the help of the CURSOR menus (Fig. 13). With two horizontal cursors (*voltage cursor*) voltage values and voltage differences can be measured, with two vertical cursors (*time cursor*) time values and time differences. The cursors can be shifted by the MULTIPURPOSE knob (MULTIFUNCTION knob).[7] The measured values belonging to the cursor positions are presented in the respective fields on the right margin of the screen.

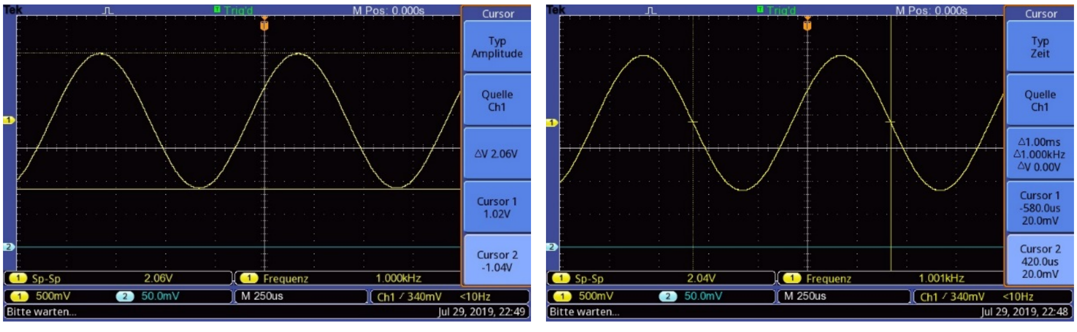


Fig. 13: CURSOR-menus. Left: two voltage cursors (type Amplitude), marking the maximum (CURSOR 1.02 V) and the minimum (CURSOR 2, -1.04 V) of the signal at CH1. ΔV shows the voltage difference between both cursor values (2.06 V). Right: two time cursors (type Time), marking the start (CURSOR 1, - 580 µs) und the end (CURSOR 2, 420 µs) of a period of the signal at CH1. Δt shows the time difference between both cursor values (1.000 ms).

2.2.4 Storage of Single Signals

Another advantage of digital oscilloscopes compared to analogous devices is the possibility of acquiring and storing single signals, for example voltage pulses at the output of a photodiode after irradiation with a short light flash. Using the menu TRIGGER the conditions can be set (LEVEL, SLOPE,…) for a single signal acquisition. By pressing the button RUN / STOP or SINGLE SEQ, respectively, the oscilloscope is then set to a waiting mode (display READY in the top menu row). Acquisition starts when the input signal meets the trigger conditions *after that*. Due to the pre-triggering (cf. Chap. 2.2.1) even the signal course is then visible just before the trigger event.

3 Experimental Procedure

Equipment:

Digital oscilloscope TEKTRONIX TBS 1102B – EDU (alternative: TEKTRONIX TDS 1012 / 1012B / 2012C / TBS 1102B, 2 function generators (TOELLNER 7401 and AGILENT 33120A / 33220A), signal former, stroboscope, optical flash (METZ 44AF-1), photo detector (Si photo element SIEMENS BPY64P), incandescent lamp and fluorescent lamp in light-tight box, high resistance voltage divider 100:1 for dividing the line voltage.

Hints:

Details about handling the instruments, especially the oscilloscopes, must be taken from the available manuals if required. The usage of manuals (German and English manuals) is one of the educational objectives of a laboratory course!

The experiments are performed using the function generator (FG) TOELLNER 7401. The function generator AGILENT 33120A / 33220A is used only in the experiment 3.10. Sometimes it can be helpful to press the AUTOSET button on the oscilloscope. The device then analyzes the input signal and displays it with settings derived from it.

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[7] With the oscilloscope type TDS 1012, the cursor is moved using the POSITION buttons and with the oscilloscope types TDS 1012B / 2012C with a separate rotating knob.

3.1 Generating a Point

A stationary point shall be generated in the centre of the oscilloscope screen. For this purpose, the oscilloscope must be set to XY mode (menu UTILITY → ANZEIGEN (DISPLAY)).[8] Which operational elements are used to change the vertical and horizontal position of the point?

3.2 Generating a Vertical Line

In the XY mode a vertical line with a length of 6 DIVisions shall be generated in the centre of the screen. For this purpose an appropriate signal from the function generator (OUTPUT terminal) must be connected to the *Y* channel. Which operational elements of the oscilloscope and function generator can be used to influence the length and the position of the line? (Try all possibilities!)

3.3 Output Signals of a Function Generator

In the YT-mode the different output signals of the function generator (sine, triangle, square-wave signal) shall be represented one after the other. Vary the frequency, the amplitude and the offset voltage (DC-OFFSET) at the FG and observe the related signal changes on the oscilloscope. To observe changes when varying the offset voltage, the oscilloscope has to be adjusted to DC coupling (CH1/2 MENU). Together with the output signal of the FG, represent the signal at the socket TTL OUT[9]. Document the output signal for all three signal-forms together with the TTL-signal either with a screen shot (cf. Appendix, Chap. 4). State the minimal and maximal voltage levels of the TTL-signal and its phase position relative to the output signals (sine, triangle, square-wave signal).

3.4 Trigger Level and Trigger Slope

The function generator (DC-OFFSET OFF) is connected to channel CH1 of the oscilloscope. On the screen an image according to Fig. 14 is generated, i.e. a "sinusoidal signal with baseline". The amplitude of the sinusoidal signal shall be 1 V, its frequency 2 kHz and exactly one period is to be made visible on the screen. Triggering is done in NORMal mode (TRIGGER MENU), the trigger position shall be at the left image margin.

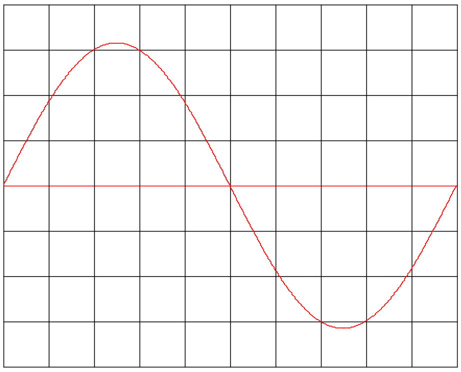

Fig. 14: Oscilloscope diagram of a sinusoidal signal (red) with baseline (red). Each square has a size of 1 DIV × 1 DIV.

The sinusoidal signal is to start on the left margin one by one with an argument (phase angle) of 0°, 45°, 90°, 135°, 180°, 225°, and 270° without changing the adjustment of the HORIZONTAL POSITION on the oscilloscope. How to adjust the LEVEL (PEGEL) and the SLOPE (FLANKE) of the trigger unit? (Representation of results in tabular form; calculate the trigger level for the respective phase angle, adjust it at the oscilloscope, and enter it in the table).

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8 For alternative models: menu Display

9 Cf. the explanations on the output signals of a FG in the chapter "*About the set-up of electric circuits*" in the script describing the experiments.

3.5 Quantitative Measurement of a Voltage Signal

With the help of a photo-detector, it is possible to convert the temporal course of a light intensity $I(t)$ into a proportional voltage signal $U(t)$. The temporal course of the light intensity of an light bulb and that of a fluorescent lamp (Fig. 15), connected to the mains (50 Hz alternating voltage), is to be measured with the available photo-detector (frequency, amplitude, signal form). Special attention is to be paid to the characteristic differences between the signals of both lamps.

For this purpose the photo-detector is placed on the aperture of the lamp box and the respective lamp is switched on. $I(t)$ comprises a constant part I_{DC} and a distinctively smaller, temporally varying part I_{AC}. Only the voltage signal which belongs to part I_{AC} is displayed on the oscilloscope.

Question 5:
- Why does $I(t)$ comprise a direct component I_{DC}?

When measuring the signals it will appear that they are superimposed by a noise signal of low amplitude. For periodic signals, this noise can be reduced by the mean value method. For this, the mode ACQUIRE → AVERAGE is chosen, in which the mean of signals can be taken over 4, 16, 64 or 128 time intervals of length Δt. Δt corresponds to the width of the time interval displayed on the screen: $\Delta t = 10 \times t_e$, where t_e is the value set by SEC/DIV.

Switch between the acquisition modes SAMPLE (SCAN) and AVERAGE, vary the number of time intervals the means of which are to be taken and document the alterations in the represented signals.

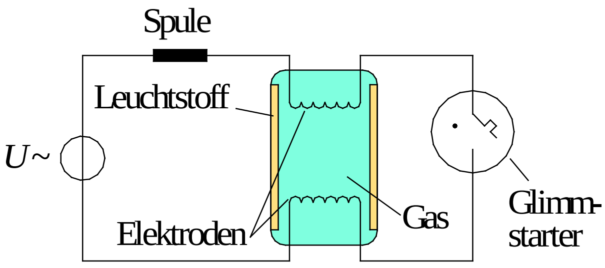

Fig.15: Block diagram of a fluorescent lamp.

Question 5:
- Fig. 16 shows the block diagram of a fluorescent lamp. How does the lamp work in principle? What is the principle difference compared to a incandescent lamp?

3.6 Peak and Effective Value of the Line Voltage

With a high-ohmic voltage divider, the line voltage is divided with two resistors in the ratio 100:1 (Fig. 16; accuracy of the resistances ± 1 %). [10]

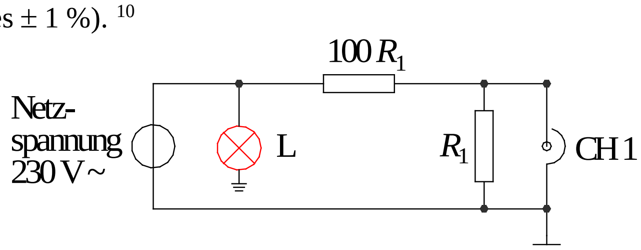

Fig. 16: High-ohmic voltage divider to divide the line voltage with control lamp L (red).

Attention:
- *When connecting the voltage divider to the line voltage the polarity must be observed! With the right polarity the red control lamp L lights up, with the wrong polarity it does not. In this case, the mains plug must be turned around! The oscilloscope must in no case be connected at the wrong polarity!*

[10] A voltage divider instead of a transformer is used in order not to distort the form of the line voltage.

- *For security reasons, only trained staff is allowed to use the described voltage divider (danger of touching the mains voltage at false use of the circuit or in case of cable disruption). Therefore, the cable at the resistor R_1 may only be attached after the circuit has been checked by a supervisor!*

The voltage is measured over the smaller resistor R_1, fed into CH1 of the oscilloscope input and the form, frequency, and amplitude are measured.

Question 7:
- How large is the amplitude (the peak value) of the line voltage, how large is the effective value (assuming sinusoidal form for the line voltage)? How large would be the effective value of a square-wave voltage of the same amplitude?

Question 8:
- Which current (effective value) flows through a heated plate being operated by alternating current and whose specification label reads “230 V / 1.5 kW”? How large is the peak value of the current?

3.7 Investigation of a Damped Periodic Voltage Signal

A rectangle voltage (frequency 10 kHz, amplitude some V) is fed into the input of a signal former. This signal former is treated as a „black box” the function of which is of no interest here. It is only important that there is a voltage signal with a course corresponding to that of a damped harmonic oscillation at the output of the signal former.

Question 9:
- The voltage course $U(t)$ of a damped harmonic oscillation (cf. Fig. 17) with the starting amplitude U_0, the angular frequency ω, and the damping constant α can be written as a function of time t :

(6) $$U(t) = U_0 \cos(\omega t) \mathrm{e}^{-\alpha t}$$

The gradually decreasing amplitudes of the partial oscillations be U_i (i = 1, 2, 3,…, cf. Fig. 18). What course of the function occurs, if the U_i are plotted over i a) linearly and b) logarithmically ? (The i-axis is to be scaled linearly in each case.)

The output signal of the signal former is connected to CH1 of the oscilloscope. Triggering and time-base of the oscilloscope are adjusted such that a complete damped oscillation and the beginning of another one are visible on the screen. Subsequently, the following signal data are measured:

a) frequency of the damped oscillation,
b) voltage amplitudes U_i of the first 5 partial oscillations,

Plot a graph of U_i as a function of i (linearly and half-logarithmically) in your report and compare your results with the expectations according to Question 7.

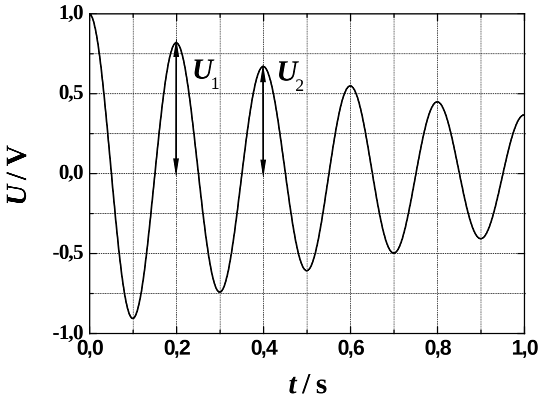

Fig. 17: Damped harmonic oscillation according to Eq. (6). U_0 = 1 V is the initial amplitude, U_1 and U_2 are the amplitudes of the two subsequent oscillations.

3.8 Frequency Stability of a Stroboscope

The task in this part of the experiment is to make quantitative statements about the frequency stability of a stroboscope, whose flashes are converted into voltage impulses by means of a photo-detector. A measure for this frequency stability is the maximum time period ΔT, by which the time interval between stroboscope flashes varies about the mean pulse distance $\overline{T}$ (Fig. 18).

The present task is performed by triggering the oscilloscope on the voltage signal of the photo-detector in NORMal trigger mode. The stroboscope is operated at a frequency of $f \approx 30$ Hz. The deflection time is adjusted such that an interval of length $t_0 \approx 1{,}1\overline{T} \approx 1{,}1/f$ is represented on the screen.

Then the trigger mode is switched to single pulse detection button SINGLE (button SINGLE SEQ for the TDS 1012 / 1012B or trigger mode SINGLE SHOT on the TDS 210/220). Through this is achieved, that after pressing the RUN/STOP button *one* impulse course is stored and presented as it appears following triggering. Before triggering the display reads READY (the oscilloscope waits until the trigger threshold is achieved), and after triggering ACQ COMPLETE (STOP) appears. By means of the time cursors the impulse distance T between the first impulse (on which we trigger) and the second impulse can be measured. The measurement is repeated at least ten times (meanwhile the RUN/STOP key is used again each time) in order to obtain a useful estimated value for the time interval ΔT and to specify it in relation to the mean pulse distance $\overline{T}$.

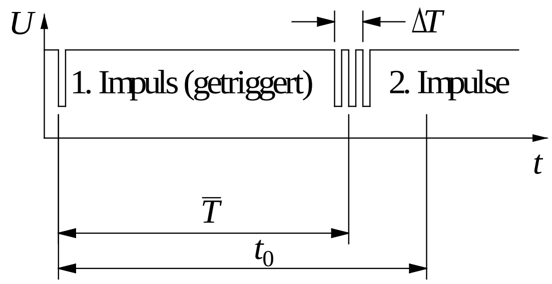

Fig. 18: Oscilloscope diagram of a temporally fluctuating pulse sequence.

3.9 Duration of a Light Flash

The duration of a light flash from a photo flash is to be determined by use of a photo-detector (press button M at the photo flash until the LED above 1/64 is on). The flash is directed onto the photo detector from a distance of about (0.5 – 1) m and activated. The signal of the photo detector is acquired by the oscilloscope using the SINGLE (SINGLE SEQ / SINGLE SHOT) mode.

Since the duration of the flash is short (< 1 ms) and the light intensity of the flash rises and falls rapidly, a sufficiently *fast* detector must be used, more precisely, a photo-detector, capable of measuring light pulses having a short rise and fall time. For the detector used in this laboratory course, this is achieved by connecting a 50 Ω-resistor across the output terminals of the detector and measuring the voltage across the resistor. This method is called a 50 Ω-*termination* of the detector[11].

The duration of the flash to be measured is the 10%-width t_b of the recorded voltage pulse, as defined in Fig. 19. A screenshot (cf. Chap. 4) of the recorded light flash is to be attached to the report.

[11] A 50 Ω-termination can be realized by simply connecting a BNC T-piece to the BNC output jack of the photo detector. A 50 Ω-resistor is then connected to one side of the T-piece, and the input of the oscilloscope to the other.

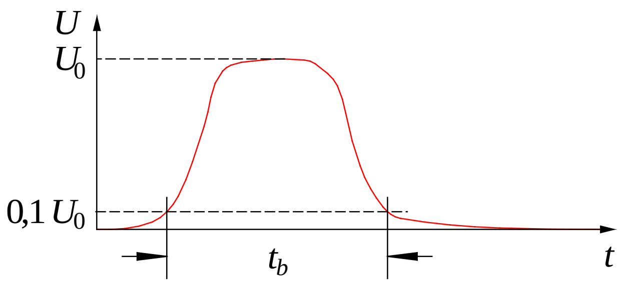

Fig.19: Definition of the 10%-width t_b of a voltage pulse $U(t)$ with the amplitude U_0.

3.10 LISSAJOUS Figures

LISSAJOUS figures result from the superposition of two sinusoidal signals $U_x(t)$ und $U_y(t)$ that are connected to the two input channels of the oscilloscope in the XY mode.

Question 9:

- What does a LISSAJOUS figure look like which results from the superposition of two sinusoidal signals with an amplitude ratio of 1:2 and a frequency ratio of 2:3? (Sketch using `Matlab`. The phase shift between both signals at time $t = 0$ be 0.)

Two sinusoidal alternating voltages from the function generators AGILENT and TOELLNER are to be superimposed on the oscilloscope such that LISSAJOUS figures are generated. The figures shall have approximately the same size in the horizontal and vertical directions. The function generator AGILENT is adjusted to a fixed frequency of f_1 = 50 Hz, while the frequency f_2 of the function generator TOELLNER is varied. It shall be attempted to produce the most constant possible figures for function generator frequencies of f_2 = (25, 50, 100, 150, 200) Hz. The resulting figures are to be sketched and interpreted.

Question 6:

- What could be the reason for the fact that constant figures cannot be generated?

4 Appendix

The following sequence of keys needs to be entered in order to save a screenshot of the digital oscilloscope onto a SD-card or an USB-stick.

Basic settings (only required once):

SAVE/RECALL	→ Action	→ Save image
File format	→ JPG	
Choose directory	→ GPRnn[12]	→ Change directory

Saving an image:

SAVE (Save / PRINT)	→ TEKnnnn.JPG

nnnn is the image number. It is automatically incremented by 1 for each image saved.

[12] nn is the number of the group; select by using the rotating knob on the top left.

Translation of German denotations in figures

German	English
Amboss	anvil
Amperemeter	ammeter
Anschlussbuchse	contact
Anschlusskontakt	contact
Ausgleichsgerade	regression line
außen	external
Außenleiter	outer conductor
BNC-Buchse	BNC socket
BNC-Stecker	BNC plug
Einheiten	units
Einheit zur Einstellung von z.B.	unit for adjusting e.g.
Elektroden	electrodes
Erde	earth potential, ground
Fehler der Summe der Quadrate	error of the sum of the squares
Fläche	surface
Funktionsgenerator	function generator
Gas	gas
Geflecht	mash
Gehäuse	case
getriggert	triggered
Gewichtung, keine Gewichtung	weighting
Gleichung	equation
Glimmstarter	glow starter
globales Minimum	global minimum
GND-Linie	ground line
Impuls (getriggert)	pulse (triggered)
innen	interior
Innenleiter	inner conductor
Innenmessschenkel	inside jaw
Intensität	intensity
Isolierung	insulation
Koaxialkabel	coaxial cable
Laborkabel	laboratory cable
Langname	long name
Leiter	conductor
Leitungskreuzung	line intersection
Leuchtstoff	luminescent material
Licht	light
Lineare Anpassung	linear fit
lokales Minimum	local minimum
Luft	air
Luftzufuhr	air supply
Masse	ground
Massekontakt	ground contact
Mathematik	mathematics
Matrikelnr.	registration number
Menü	menu
Messdaten	measured data
Messhülse	measuring sleeve
Messschiene	measure scale
Messspindel	measure spindle
Messtrommel	no translation
Messung	measurement
Mittelwert	mean value
Monitor	monitor

Nachname	last name
Netzgerät	power supply
Netzspannung	line voltage
Nonius	vernier
Oszilloskop	oscilloscope
Parameter	parameter
Pegel auf 50%	level set to 50 %
Physik	physics
Ratsche	ratched stop
Schaltung	wiring
Schnittpunkt mit der Y-Achse	intersection with the Y-scale
schwarz (Masse)	black (ground)
Spannungsquelle	voltage source
speichern	store
Spitzenwert	peak value
Spule	Coil
Standardfehler	standard error
Steigung	slope
Stromquelle	current source
Tiefenmessschiene	depth measure scale
Triggerflanke	trigger slope
Triggerschwelle	trigger level
Triggerzeitpunkt	trigger time
Trigger Zwang	force trigger
Verbindung	connection
Verstärker	amplifier
Verstärkungsfaktor	amplification factor
vertikal	vertical
Voltmeter	voltmeter
Vorname	first name
Wert	value
Wertigkeit	significance
Widerstand	resistance
Zeitablenkung	time base
Zielgröße	target value