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

Cathode ray oscilloscope, digital storage oscilloscope, and function generator

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

References:

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/2/ EICHLER, H. J., KRONFELDT, H.-D., SAHM, J.: „Das Neue Physikalische Grundpraktikum“, Springer-Verlag, Berlin u.a.
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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, ... In order to perform the following experiments successfully, a thorough knowledge of the oscilloscope is imperative. . The experiments described in this document are divided into two laboratory sessions.

2 Theory

2.1 Cathode ray oscilloscope

2.1.1 Working principle

The functional principle of the cathode ray oscilloscope has been described in many physical textbooks. Therefore we will not give a detailed theoretical description here, but confine ourselves to presenting two principle *functional diagrams (block diagrams)* and the corresponding brief descriptions of these circuits.

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),placed at a distance d_a from the *cathode* is kept at a high positive voltage U_A of up to a few 1000 Volts. Thereby an electrical field $\mathbf{E}_A$ develops between K and A with the magnitude:

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

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

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

(2) $F_A = e\,E_A$

This force accelerates the electrons in the direction of the anode. After travelling through the pierced 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.

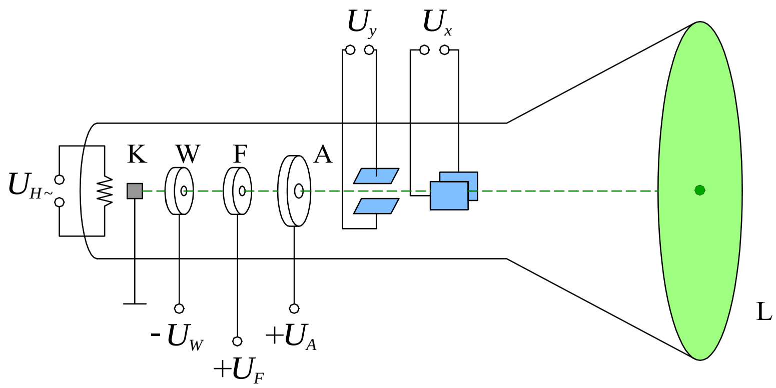


Fig. 1: Schematic set-up of a cathode ray oscilloscope tube. For symbols refer to the text. The dashed green line represents the electrons' trajectory for $U_X = U_Y = 0$.

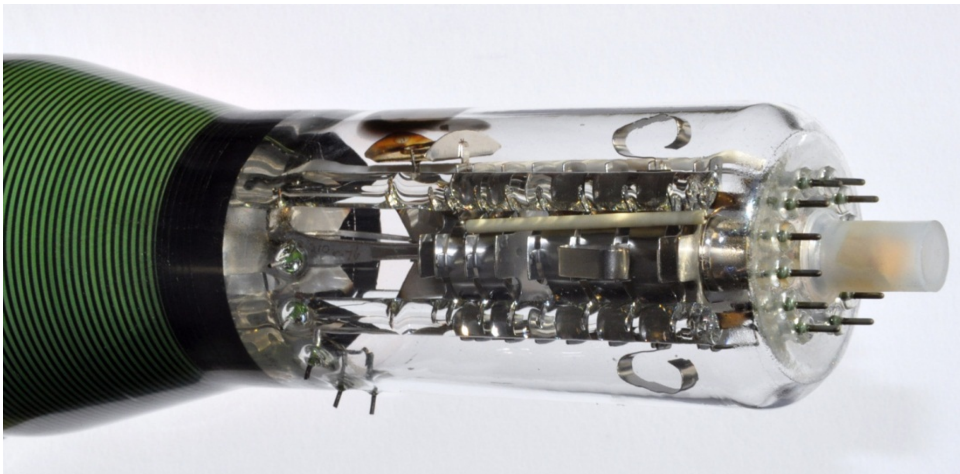


Fig. 2: Photograph of the back-end of an cathode ray oscilloscope tube. It shows the complex structure of the electrodes for forming and controlling the electron beam. The connecting contacts for the different electrodes can be seen at the end of the tube and on the left side of the casing.

The intensity of the point of light can be varied using a negative voltage U_W on 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.

Question 1:

- Could the intensity of the light dot be controlled by means of U_W if all electrons emitted by the cathode had the same kinetic energy? Which qualitative statement can therefore be made on the frequency distribution of kinetic energies of the emitted electrons?

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 places 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.

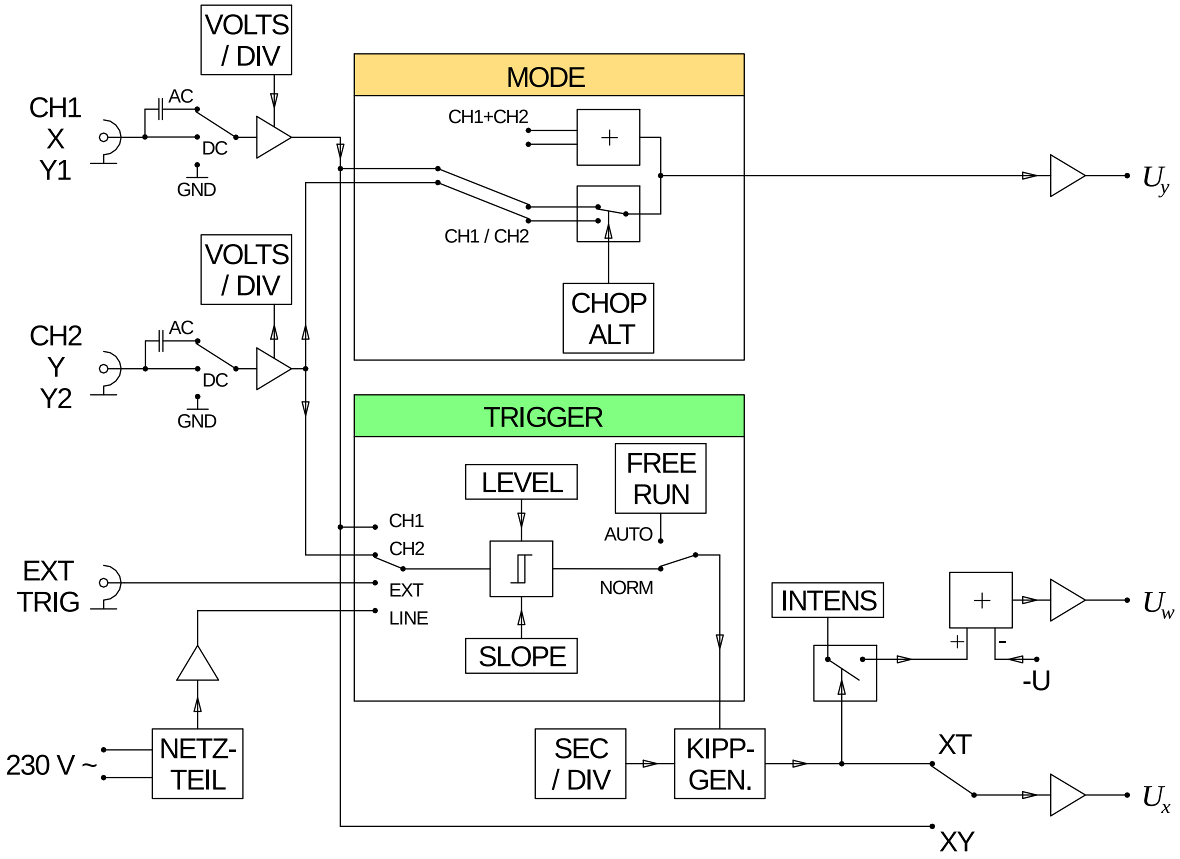


Fig. 3: Block diagram of the most important functional units of a cathode ray oscilloscope. For symbols refer to text and Fig. 4.

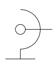
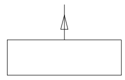
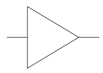
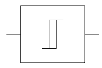
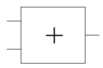
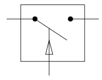
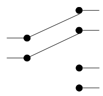
	BNC-Buchse - innen: Signalleitung - außen: Massekontakt		Einheit zur Einstellung von z.B. - Verstärkungsfaktor in VOLTS/DIV - Zeitablenkung in SEC/DIV - Triggerschwelle (LEVEL) - Triggerflanke (SLOPE) - Mode (CHOP/ALT) - Intensität (INTENS)
	Verstärker		Schwellwertdiskriminator erzeugt Ausgangsimpuls, wenn Eingangsspannung > Schwellwert
	Additionsverstärker		Elektronisch gesteuerter Schalter
	Umschalter (2-fach)		

Fig. 4: Explanation of block diagram elements.

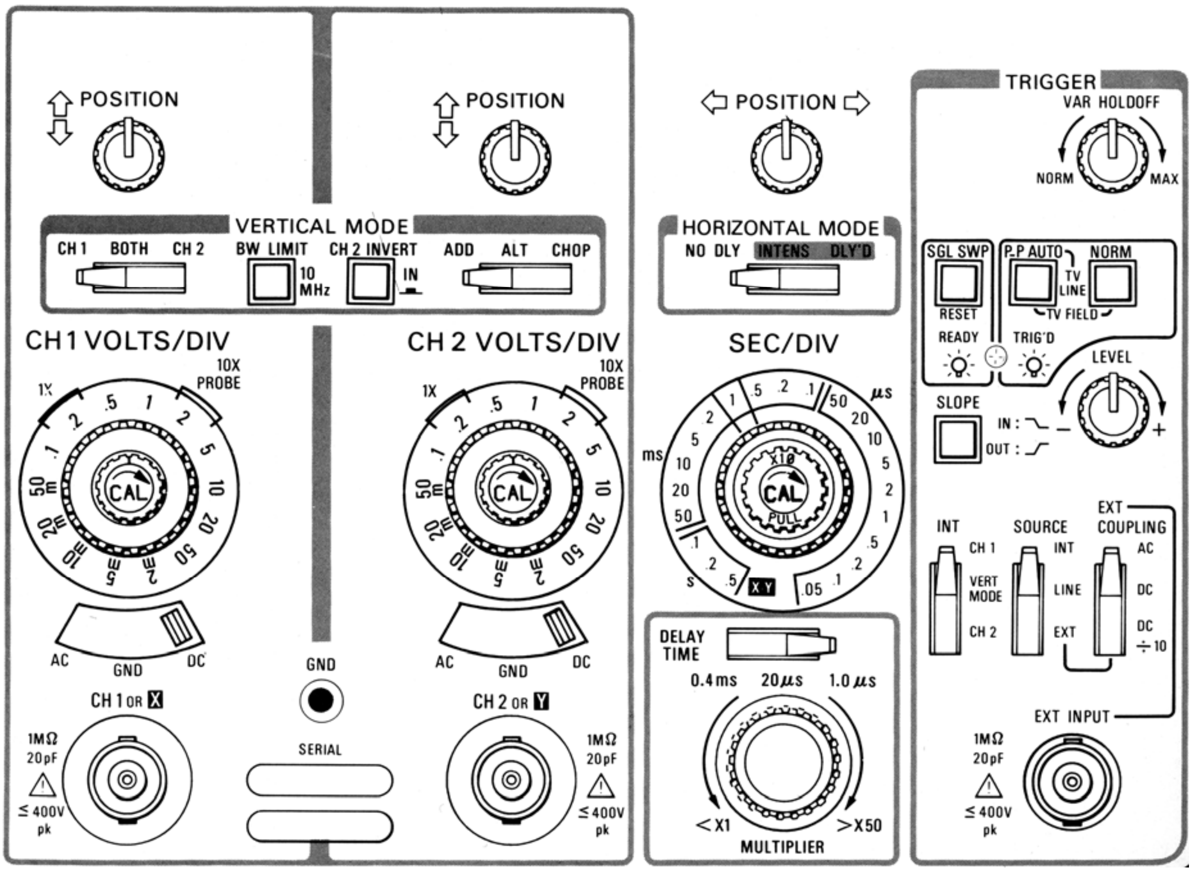


Fig. 5: Front view of the control units of the cathode ray oscilloscope TEKTRONIX 2213A (source: TEKTRONIX-Manual).

Fig. 3 shows the most important (*not all*!) functional units for controlling the different elements of the oscilloscope tube. In Fig. 4the function of the elements in the block diagram are explained. Fig. 5shows the front view of the control units of a typical cathode ray oscilloscope.

The cathode ray oscilloscope represented in Fig. 3and Fig. 5is 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. When the DC[3] mode of the channel's input switch is adjusted the input signal arrives directly at the input amplifier, in the AC[4] mode only its alternating voltage component; 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, which determines how many volts (VOLTS) from the input signal cause a cathode ray deflection of a certain unit length (DIVision, usually 1 cm).

Question 2:

- The vertical size of a signal can be altered on the oscilloscope screen with the VOLTS/DIV knob. How can the horizontal and vertical *position* of the cathode ray be shifted? Which functional and operational components would have to be added, and in which positions, to the block diagram (Fig. 3)?

2.1.2 XY- and XT-operation

The oscilloscope can operate in different modes depending on the setting of the switch of the MODE function group:

– In XY *operation* the signal course will be displayed in $Y(X)$. To produce this, the signal from input CH1 (X) is passed via an amplifier as voltage U_X to the X deflection plate, while the signal from input CH2 (Y) is passed via an amplifieras voltage U_Y to the Y deflection plate.
– The XT *operational mode* displays signals as a function of time t: $Y_1(t)$, $Y_2(t)$, or $Y_1(t) + Y_2(t)$. To produce this, the signals CH1 ($Y_1(t)$) and CH2 ($Y_2(t)$), respectively arrive at the Y deflection plate after amplification, while a sweep generator produces a *saw tooth voltage* which serves as a deflection voltage U_X for the horizontal deflection of the cathode ray (s.Fig. 6). The sweep generator together with its components (e.g. SEC/DIV switch) is also called *time-base*.

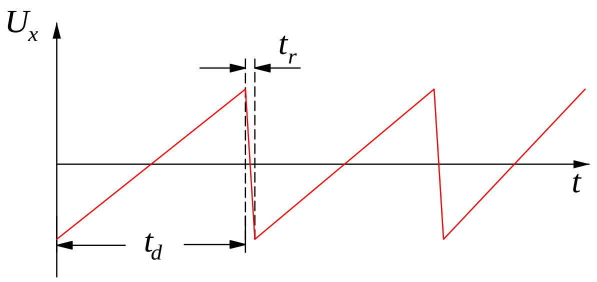


Fig. 6: Saw tooth voltage from the sweep generator. During time t_d the cathode ray moves with constant speed from left to right, and during time t_t it moves from right to left, back to the start of the image.

Question 3:

- The time t_e -needed for the cathode ray to cover a distance of one unit length (1 DIV) in the horizontal direction on the oscilloscope screen is determined by the time-base switch (SEC/DIV) in the XT mode. What is the connection between this time and the time t_d of the saw tooth voltage when the screen width is set to m DIVisions? (Formula!)

[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.

Question 4:

- During the time t_r the cathode ray will not arrive at the luminescent screen – why not? How can this be achieved (hint: U_W)?

2.1.3 Two channel operation

In the alternating (ALT) or in chopped (CHOP) mode it is possible to have an apparently instantaneous display of $Y_1(t)$ and $Y_2(t)$in XT operation:

– In the ALT mode, the cathode ray shows the signal $Y_1(t)$ in its first pass, and in the next pass the signal $Y_2(t)$, then again $Y_1(t)$, followed by $Y_2(t)$ and so on. Due to the time of persistence of the phosphorus on the screen the observer has the impression that both signals are present simultaneously in case of short time periods t_d.

– In the CHOP mode, a high-frequency periodic alternating switch-over between the signals is achieved during each pass of the cathode ray (c.f. Fig. 7).

In ADD mode, the sum of signals $Y_1(t) + Y_2(t)$ is displayed.

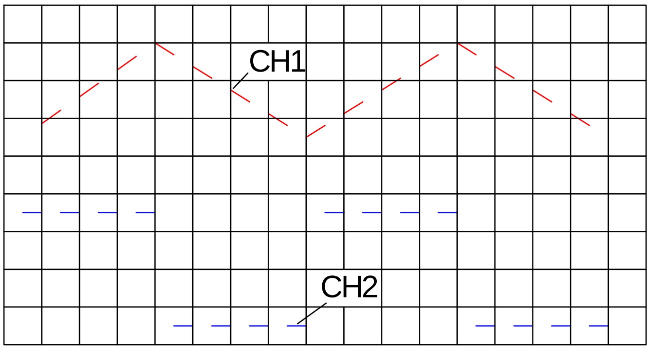


Fig. 7: Schematic signal display of a two-channel oscilloscope in chopped mode. Top: triangular voltage on CH1 (red), bottom: square voltage on CH2 (blue). The signals are displayed in alternation with a very high switching-frequency giving the appearance that both signals appear uninterrupted.

2.1.4 Synchronization (Triggering)

In order to produce a stationary image of a periodic signal *Y(t)* with time period *T* on the screen, *Y(t)* has to be synchronised with the saw tooth voltage of the sweep generator. This process of synchronisation is called *triggering*. Fig. 8demonstrates 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 first when the input voltage *Y(t)* equals the threshold voltage U_L (TRIGGER LEVEL) and the slope (SLOPE) of *Y(T)* has the sign adjusted on the trigger switch SLOPE ("+" in the case represented inFig. 8). 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.

Question 5:

- What would the image on the oscilloscope look like without triggering (i.e. without synchronization) during the time interval $3\times(t_d + t_r)$? (Sketch for the case that the duration of the screen's afterglow is large compared to $3\times(t_d + t_r)$.)

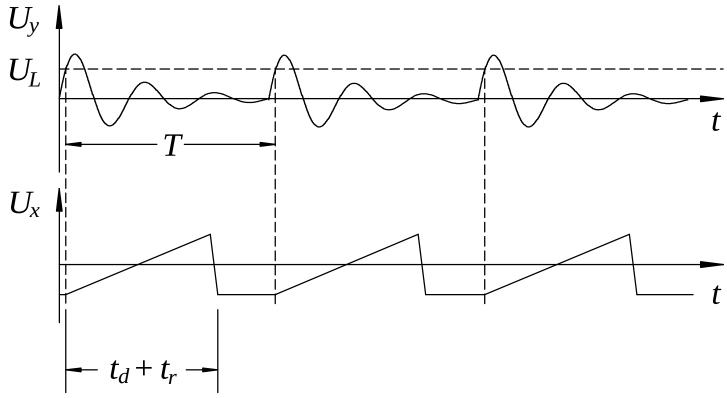


Fig. 8: Signal triggering. Top: input signal $U_y(t)$, bottom: sweep generator signal $U_x(t)$. U_L:Trigger level.

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 the line voltage (LINE) or on an EXTernal signal which the oscilloscope is supplied with from the EXT INPUT / TRIG socket. 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 (FREE RUN) mode the cathode ray can be made visible if the channel switch is set to GND, so that no trigger condition for starting the electron beam can be met at all.

Question 6:

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

Question 7:

- Two sinusoidal courses of voltage $Y_1(t)$ and $Y_2(t)$ may be visible on the oscilloscope screen. In which mode is the oscilloscope operating? How can the periods lengths 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_o of the voltage signals be determined?

Question 8:

- Assuming that the signals $Y_1(t)$ and $Y_2(t)$ 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

In practice it is often necessary to present and measure single impulse courses instead of continuous or periodic signals. For example, it may be necessary to measure the temporal course of the light intensity of a laser pulse using a photo detector, which converts a light intensity into a voltage. In such cases oscilloscopes are required which can store a signal once it has been recorded. Previously, cathode ray oscilloscopes were used, first storing the signal on a special storage layer as a charged image and then continuously transmitting it to the luminous layer. Such instruments are being superseded by digital storage oscilloscopes nowadays in nearly all applications.

In a digital storage oscilloscope (briefly: digital oscilloscope), the analogue input signals are first converted into digital signals by means of an *analogue/digital converter* (A/D converter). Details of this conversion process will be treated in the experiment „*Data Acquisition and processing with the PC*". For this reason, only some basic terminology will be explained in the following.

The conversion *analogue* → *digital* does not happen continuously, but at discrete periodic times, the so-called *sampling points* (Fig. 9). 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 , the more precisely the temporal course of the input signal can be represented. For the equipment used in our laboratory course the maximum sampling frequency f_a is 1 GHz .

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

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

must be fulfilled, otherwise errors will occur (aliasing).[5]

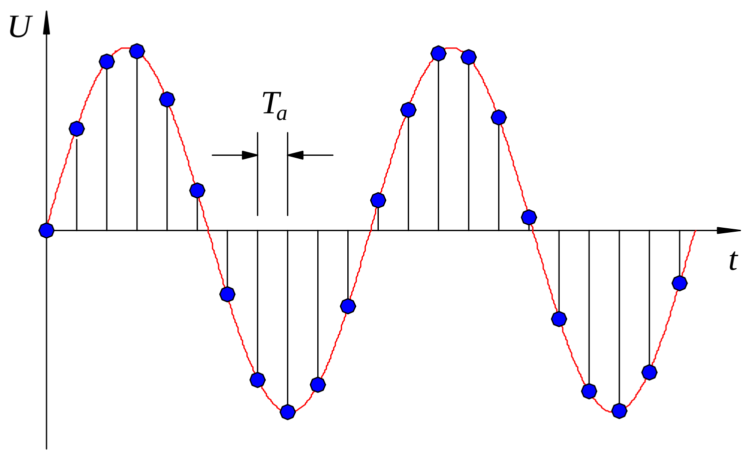


Fig. 9: Sampling of a sinusoidal signal (red). The sampling points (blue) are separated by time intervals of length $T_a = 1/f_a$.

In order to determine the signal amplitude 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 amplitude measurements. For the types used in the laboratory course $n = 8$. For an oscilloscope set to an amplification of 1 VOLTS/DIV and having a precision of 8 Divisions in the vertical, the resolution is $1\ \text{V/DIV} \times 8\ \text{DIV} / 2^8 \approx 30\ \text{mV}$. Voltage differences in the signal to be displayed smaller than 30 mV can not be *resolved* (displayed) in this case. For an amplification of 20 mV/DIV, however, a resolution of $(20\ \text{mV/DIV} \times 8\ \text{DIV} / 2^8) \approx 0{,}63\ \text{mV}$ is obtained.

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 recorded signals in digital oscilloscopes is comparable to the presentation of images in computers. The oscilloscopes are controlled by software. The software parameters (VOLTS/DIV, SEC/DIV etc.) are adjusted via control buttons or keys of the control panel (Fig. 10 and Fig. 11). After

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

pressing some keys, further options may be entered controlled by the menu. The graphic representation of signals is usually achieved by the use of liquid crystal displays (LCD).

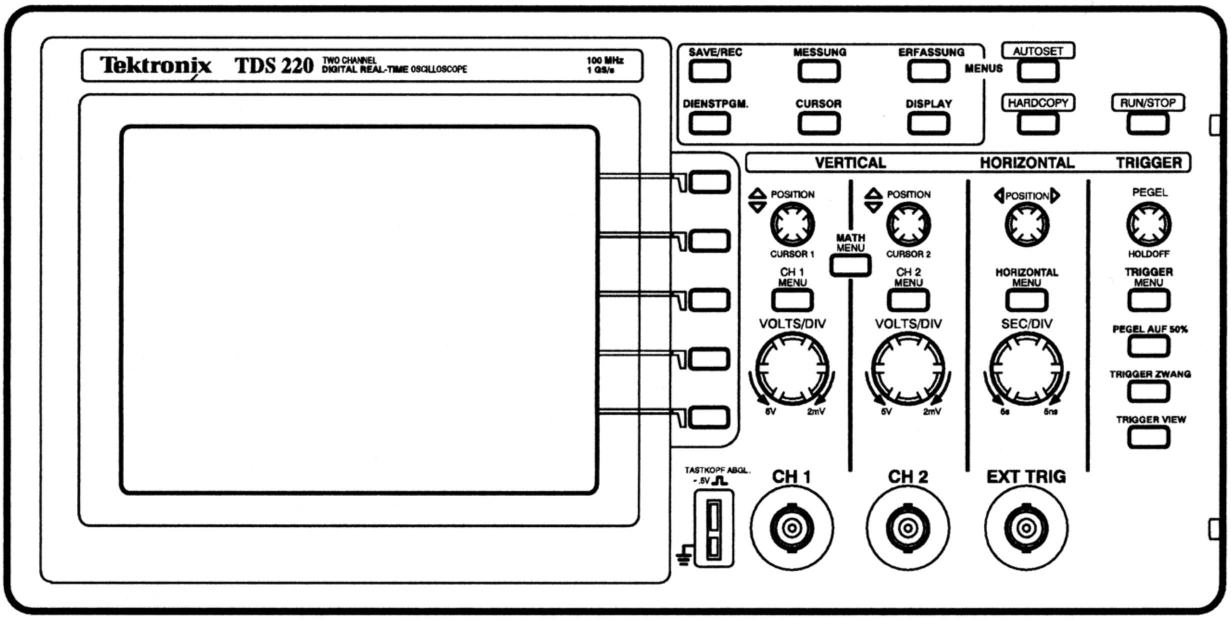

Fig. 10: Front view of the digital oscilloscope TEKTRONIX TDS 220 (Source: TEKTRONIX-Manual).

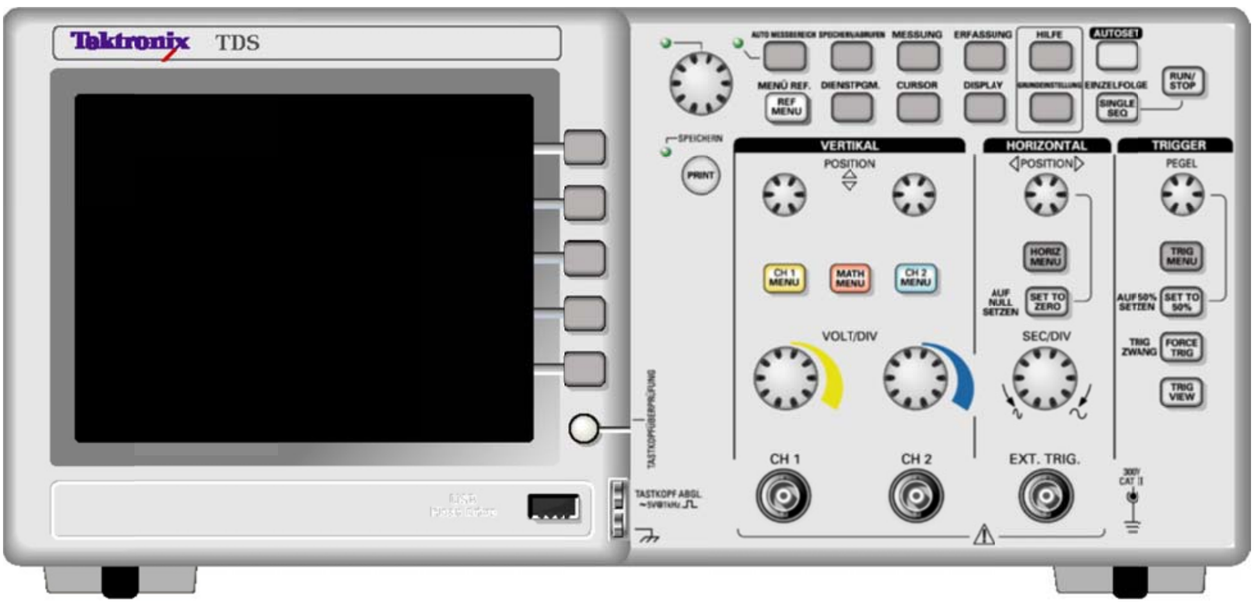

Fig. 11: Frontal view of a digital oscilloscope TEKTRONIX TDS 1012B (Source: TEKTRONIX-Manual). The models TDS 1012 and TDS 1012B support storing data on SD-cards and USB-flash drives respectively.

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. 12). Using the HORIZONTAL POSITION knob this time can be shifted to the left or right side.

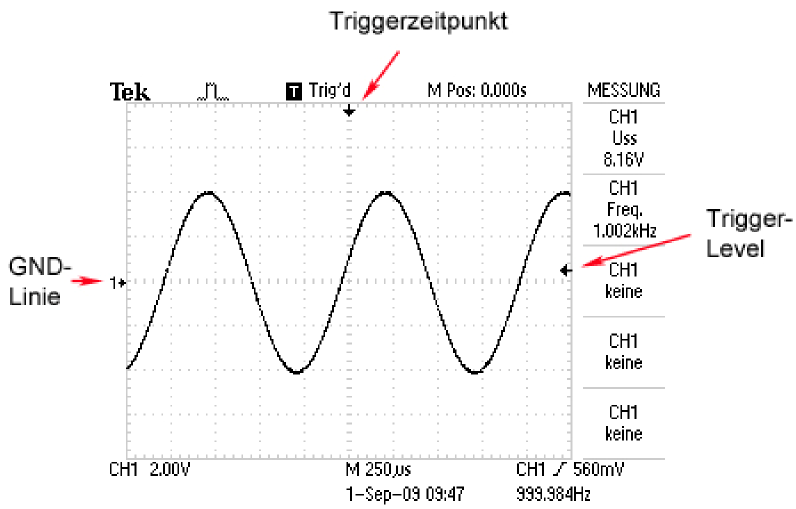

Fig. 12: Screenshot of the digital oscilloscope TEKTRONIX TDS 1012 measuring a sinusoidal alternating voltage on CH1. By activating the function MESSUNG the peak-peak-value U_{SS} of the voltage (8.16 V) and its frequency (1.002 kHz) are displayed on the right side of the screen. At the bottom, the setting oft he parameter VOLTS/DIV (CH1 2.00V) and SEC/DIV (M 250µs), as well as the value of the TRIGGER LEVEL (⁄ 560mV) 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.

Another 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. These functions are controlled by the knob MESSUNG. The results are displayed in the bottom right corner of the screen (seeFig. 12).

For further details on using the devices, please refer to the manuals. The usage will be learned rather quick and without great effort during the laboratory course.

3 Experimental Procedure

Equipment:

Cathode ray oscilloscope (TEKTRONIX 2225/2213A), digital oscilloscope (TEKTRONIX TDS 1012/1012B), 2 function generators (TOELLNER 7401 and AGILENT 33120A), 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

Attention:

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!

In the course of your studies you will have to work with oscilloscopes over and over, which look different and may differ in their operation. Therefore, it would be wrong to become familiar with only one type of oscilloscope during the practical course. On the contrary, it is in your own interest to use different models in order to develop routine in using these devices.

3.1 Experiments with the cathode ray oscilloscope

The experiments are performed using the function generator TOELLNER 7401. The function generator AGILENT 33120A is used only in the experiment 3.1.8.

3.1.1 Producing a luminous point

A well focused (knob FOCUS), stationary luminous point of a low intensity (knob INTENSITY) should be generated in the centre of the oscilloscope screen. For this purpose, the oscilloscope must be set to XY mode (knob SEC/DIV), which switches the internal *X* deflector unit (*sweep generator* / *time base*) off. - Which operational elements are used to change the vertical and horizontal position of the luminous point?

3.1.2 Producing a horizontal line

Now, the luminous point is to travel across the screen at different rates. This is achieved by switching on the XT mode (set the knob SEC/DIV to a numerical value), that means by switching on the time base (TRIGGER in AUTO-mode). At which position of the SEC/DIV switch does a horizontal line appear and why?

3.1.3 Producing a vertical line

A vertical line is produced on the screen by supplying an appropriate signal from the function generator (terminal OUTPUT) to the *Y* channel with the time base switched off (XY-mode). 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!) What must the shape of the function generator signal be (sine, triangle, rectangle) to yield a line with an *equal* degree of brightness over its total length? Why?

3.1.4 Output signals of a function generator

Represent the different output signals of the function generator (FG) TOELLNER 7401 on the oscilloscope in the XT-mode one after the other (sine, triangle, rectangle signal). 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. Together with the output signal of the FG, represent the signal at the socket TTL OUT[6]. Sketch the output signal for all three signal-forms together with the TTL-signal and state the voltage levels and phase relation of the latter relative to the output signal.

3.1.5 Function of the trigger

3.1.5.1 Trigger level and trigger slope

The function generator is connected to one channel of the oscilloscope and an image is generated on the screen according toFig. 13, i.e. a "sinusoidal signal with baseline". The amplitude of the sinusoidal signal is 1 V, its frequency is 2 kHz and exactly one period is to be made visible on the screen. Both the channel input switch and the switch for the trigger coupling are set to AC. Triggering is done in NORMal mode.

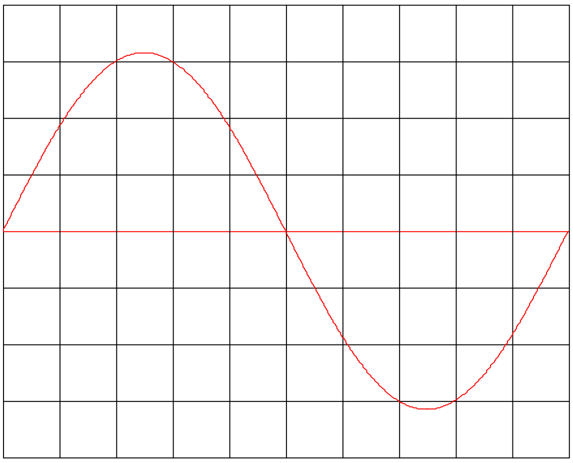

Fig. 13: Oscilloscope diagram of a sinusoidal signal (red) with baseline (red)". Each square has a size of 1 DIV × 1 DIV.

Hint:
With some oscilloscopes an AC trigger coupling is only possible for external triggering. In that case the signal of the function generator has to be connected in parallel to the input channel CH1 and the extternal trigger input of the oscilloscope (EXT INPUT / TRIG) by means of a BNC-T piece.

The sinusoidal signal is to start on the left side of the screen 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. Which operational elements of the trigger unit have to be adjusted to which position? (Representation of results in tabular form; calculate the trigger level for the respective phase angle and enter it in the table).

3.1.5.2 Trigger coupling

The channel input switch is set to DC. The DC-OFFSET of the function generator (sinusoidal signal, frequency 2 kHz, amplitude 1 V) is switched on, and with it, positive and negative direct voltages can be added to the generator signal. How does the picture on the oscilloscope screen change when the DC-OFFSET is varied, when the switch for the trigger coupling is set to AC (note hint in Chapter 3.1.5.1)?

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[6] TTL is the abbreviation of transistor transistor logic. A TTL signal is a logic signal that can take on only two voltage values U: *Low* and *High*. State *Low* if 0 V ≤U < 0.4 V, state *High* if 2.4 V < U ≤≥ 5,0 V is valid for an *output signal* of a device. *Low* if 0 V ≤ U < 0.8 V, *High* if 2.0 V < U ≤ 5.0 V is valid for an *input signal* of a device.

What are the differences, when the switch for the trigger coupling is set to DC? How can these differences be explained?

3.1.6 Alternating / chopped mode

By means of an oscilloscope image like the one in Fig. 13(”sinusoidal signal with baseline“), the difference between the alternating and the chopped representation of a 2 channel oscilloscope is to be investigated. For this purpose the signal frequency is reduced to 200 Hz. With which frequency would the signals be switched between in the chopped mode? (Hint: Use a cathode ray oscilloscope of the type TEKTRONIX 2213A for measuring this frequency (reference value: > 500 kHz))

3.1.7 Quantitative measurement of voltage signals

Preliminary remark:

As soon as the oscilloscope is used for quantitative measurements, i.e., as soon as numerical values for voltage amplitudes, frequencies or time intervals are to be determined, it is important to make sure that the functional switches VOLTS/DIV (input amplifier) and SEC/DIV (horizontal sweep) are in the CALibrated position! It has happened more than once that entire experimental series had to be repeated just because this adjustment had been neglected!

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 incandescent lamp (desk lamp) and that of a fluorescent lamp (50 Hz alternating voltage) is to be measured with the available photo-detector. 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}. The part I_{AC} is displayed on the oscilloscope by means of the photo-detector and is analysed regarding the signal form and frequency. Special attention is to be paid to the characteristic differences between the signals of both lamps.

Question 9:

- Why does $I(t)$ comprise a constant part I_{DC}?

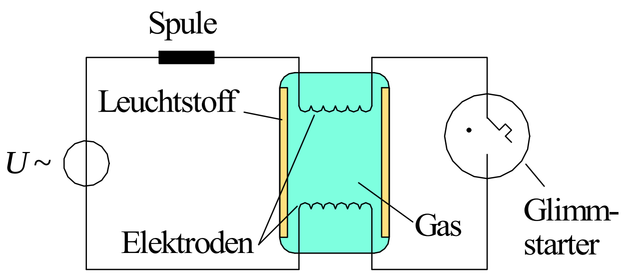

Fig. 14: Block diagram of a fluorescent lamp.

Question 10:

- Fig. 14 shows the block diagram of a fluorescent lamp. How does the lamp work in principle? Which is the fundamental difference from an incandescent lamp?

3.1.8 Lissajous figures

Question 11:

- LISSAJOUS figures result from an appropriate superposition of two sinusoidal signals - how?
- 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 33120A and TOELLNER 7401 are to be superimposed on the oscilloscope such that LISSAJOUS figures are generated which have approximately the same size in the horizontal and vertical directions. The function generator AGILENT 33120A is adjusted to a constant frequency of f_1 = 50 Hz, while the frequency f_2 of the function generator TOELLNER 7401 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 12:
- What could be the reason for the fact that constant figures cannot be generated?

3.2 Measurements with the digital oscilloscope

When the digital oscilloscope has been switched on it first performs a self-test. Afterwards, measurements can be started. After attaching a signal, the mode SAMPLE in the menu AQUIRE is selected. In the menu DISPLAY the TYPe INTERPOLated is chosen.This will connect the voltage values at the sampling points by a line, which enhances signal display. Then the button AUTOSET is pressed. The instrument automatically selects parameters for the vertical and horizontal deflection, which generally cause a signal to appear on the screen. Then a further precision adjustment can be performed on the basis of these parameters.

3.2.1 Quantitative measurement of voltage signals

3.2.1.1 Output signals of a function generator and light intensity of an incandescent- and a fluorescent lamp

Repeat the measurements of chapters 3.1.4 and 3.1.7 with the digital oscilloscope. The frequency and amplitude are measured by means of the horizontal and vertical CURSORs which can be shifted by the POSITION buttons (type TDS 1012) or with a separate knob (type TDS 1012B). The vertical cursor (*time cursor*) provides temporal information, while the horizontal cursor (*voltage cursor*) provides information about the voltage which is presented in the respective fields on the right margin of the screen.

When measuring the signals of chapter 3.1.7 it will appear that they are superimposed by a random noise signal of low amplitude. For periodic signals, this random 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 and AVERAGE, vary the number of signals the means of which are to be taken and document the alterations in the represented signals.

3.2.1.2 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. 15); accuracy of the resistances ± 1 %). [7]

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!*

- *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!*

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

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

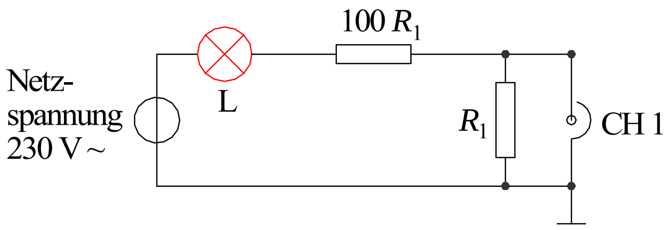

Fig. 15: High-ohmic voltage divider to divide the line voltage with control lamp L (red).

Question 13:

- 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 the effective value of a square alternating voltage of the same amplitude be?

Question 14:

- 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?

3.2.1.3 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 15:

- The voltage course $U(t)$ of a damped harmonic oscillation (see Fig. 16) 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) $$U(t) = U_0 \cos(\omega t) e^{-\alpha t}$$

  The gradually decreasing amplitudes of the partial oscillations be U_i (i = 1, 2, 3,…, c.f. Fig. 16). 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 a channel of the oscilloscope. Triggering and time-base sweep 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 - 10 partial oscillations,

Plot a graph of U_i as a function of i (linearly and half-logarithmically) and compare your results with the expectations according to Question 15.

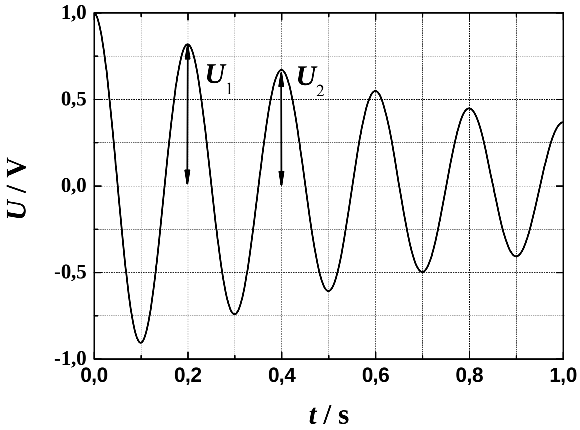

Fig. 16: Damped harmonic oscillation according to Eq. (6). $U_0 = 1$ V is the initial amplitude, U_1 and U_2 are the amplitudes of the two subsequent oscillations.

3.2.2 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. 17).

The present task is performed by triggering the oscilloscope on the voltage signal of the photo-detector in the trigger mode NORMal. The stroboscope is operated at a frequency of $f \approx 30$ Hz. The deflection time is adjusted such that an interval of

$$t_0 \approx 1.1\,\overline{T} \approx \frac{1.1}{f}$$ is represented on the screen.

Then the trigger mode is switched to single pulse detection (key 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 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 $\overline{T}$.

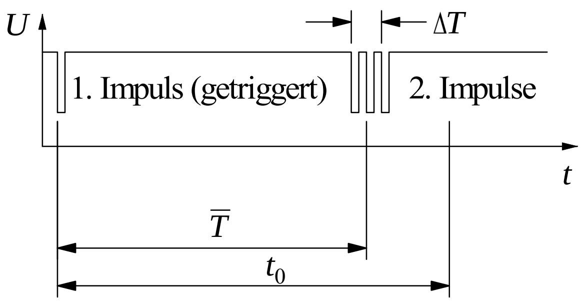

Fig. 17: Oscilloscope diagram of a temporally fluctuating pulse sequence.

3.2.3 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. The flash is aimed at the ceiling of the laboratory, the light scattered by the ceiling reaches the detector. The signal of the photo detector is acquired by the oscilloscope using the 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[8]. The physical importance of this connection method will become clear in the later experiments „*Measurement of capacities…*" and "*Sensors…*".

The duration of the flash to be measured is the 10%-width t_b of the recorded voltage pulse, as defined byFig. 18. A screenshot (cf. Chap. 4) of the recorded light flash is to be attached to the report.

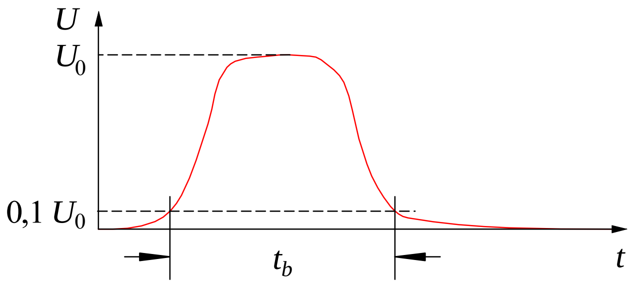

Fig. 18: Definition of the 10%-width t_b of a voltage pulse $U(t)$ with the amplitude U_0.

4 Appendix

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

Basic settings (only required once):

SAVE/RECALL	→ Action	→ Save image
File format	→ TIFF	
Choose directory	→ GPRnn[9]	→ Change directory

Saving an image:

Save	→ TEKnnnn.TIF

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

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[8] 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.

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