

About the Set-up of Electric Circuits and the use of Power Supplies, Multimeters and Function Generators

1 Set-up of Electric Circuits

Students who have never or seldom carried out experiments independently often find it difficult to convert a circuit scheme or block diagram into a real electric circuit. The use of power supplies, multimeters and function generators also pose problems in the beginning. This text will describe the principal function and use of the listed instruments. These devices will be treated in more detail through the course of the laboratory course. Two simple circuit schemes are described and photos of the respective real set-ups are shown. For one of the circuits an oscilloscope will be used the function and operation of which will be explained in more detail on a separate laboratory course date.

For detailed photos of the equipment, please direct your attention to the PDF versions of the text. http://physikpraktika.uni-oldenburg.de/download/GPR/pdf/E_Schaltungen_Multimeter.pdf.

2 Power Supplies

For many of the experimental set-ups in the laboratory course, direct voltages¹ (as well as direct currents) with different amplitudes and polarities are used, e.g., + 10 V, - 12 V, + 5 V etc. These voltages can be taken directly from a power supply unit.

Fig. 1 shows a power supply of the type PHYWE that is used in the introductory laboratory course. It is a twin power supply, because it has two separately adjustable outputs. At the left output, voltages between 0 V and 15 V can be adjusted with a maximal current of 5 A. The right output provides voltages between 0 V and 30 V with a maximal current of 2 A.



Fig. 1: Power supply of the type PHYWE. At both outputs (red and blue terminal) a voltage of approx. 10 V is adjusted.

The voltage U and the current I can be adjusted or limited by adjusting the appropriate rotary knob. In most cases, a certain *voltage* is needed for operating a device, e.g. a photodetector. This voltage is adjusted with the knob below the voltage indicator (V) before connecting the power supply with an electrical load. The adjusted voltage can be checked with the voltage indicator. Subsequently, the knob for limiting the current at the same output of the power supply is turned to the right-hand limit stop. This enables the connected consumer later on to draw as much current as necessary for its operation.

Every output of the power supply has two sockets for common laboratory cables. The potential² at the blue terminal is *always* lower than the potential at the red terminal. Comparing the output of the power supply

¹ DC voltage, DC means direct current.

² The (electric) *potential* is a voltage in respect to a fixed point of reference. A point of reference can, for example, be the *earth / ground* denoted by the symbols \equiv or \perp . This is an electrically conductive connection (c.f. power supply in Fig. 2) to the ground. This can be achieved by burying an electrical conductor into the ground and connecting it via cables to the terminal on the power supply. In buildings *grounding* is typically achieved by means of a *foundation earthing system*, to which the *protective grounding* of the household line is connected via a *potential equalization rail*.

with a battery, the blue terminal corresponds to the contact marked “-“, and the red terminal corresponds to the contact marked “+”.

The polarity of the voltage between the two terminals depends exclusively on the selected reference point. Let us assume that a voltage (potential difference) of 10 V is adjusted at the output of the power supply. If we take the red terminal as a reference point, the potential at the blue terminal is 10 V lower. Considering the voltage from this reference point, $U = + 10 \text{ V}$.

Fig. 2 illustrates these relationships by means of a multimeter operated as a voltmeter (more on multimeters cf. Chapter 4).



Fig. 2: On the polarity of the voltage from a power supply. At the left output a voltage of approx. 10 V is adjusted. The left multimeter (type FLUKE) reads a voltage of - 10.02 V, the right one reads a voltage of + 10.01 V³. Reason: The reference point for measuring the voltage (black terminal COM at the multimeter) is connected with the red terminal of the power supply (the one with the higher potential) on the left side and with the blue terminal (the one with the lower potential) on the right side.

The same considerations apply to a battery. Hence, a block battery with a voltage of 9 V can provide a voltage of + 9 V or - 9 V depending on the reference point.

3 Function Generators

Function generators (FG) serve to produce alternating voltages⁴ of different forms, amplitudes, and frequencies. Alternatively, direct voltages can be added to these alternating voltages, which are then called a *DC Offset*. The most common form of a signal at the output of an FG is a sinusoidal alternating voltage $U(t)$, which can be described mathematically as follows:

$$(1) \quad U(t) = U_0 \sin(\omega t) + U_{\text{DC}}$$

with the following meaning:

t :	time
U_0 :	amplitude
$\omega = \frac{2\pi}{T}$:	angular frequency; T : periodic time
U_{DC} :	DC-Offset

³ The deviations by 0.01 V between the indicated voltages are caused by the limited measuring accuracy of the multimeters.

⁴ *AC voltage*, AC means alternating current.

Fig. 3 shows such an alternating voltage together with other typical output voltages of function generators.

Fig. 4 shows the front views of two function generators used in the introductory laboratory course. The form (Function: sinus, square, delta, sawtooth voltage), the frequency (Freq), the amplitude (Ampl) and the direct voltage (DC-Offset) of the signal are adjusted with the switches and adjustable knobs. Further possible adjustments are described later on during this lab course.

The signal output occurs via the terminal Output. The terminals are two-pole BNC terminals⁵. The inner conductor of such a terminal represents one pole, the external contact the other pole (further details in Chapter 5.2).

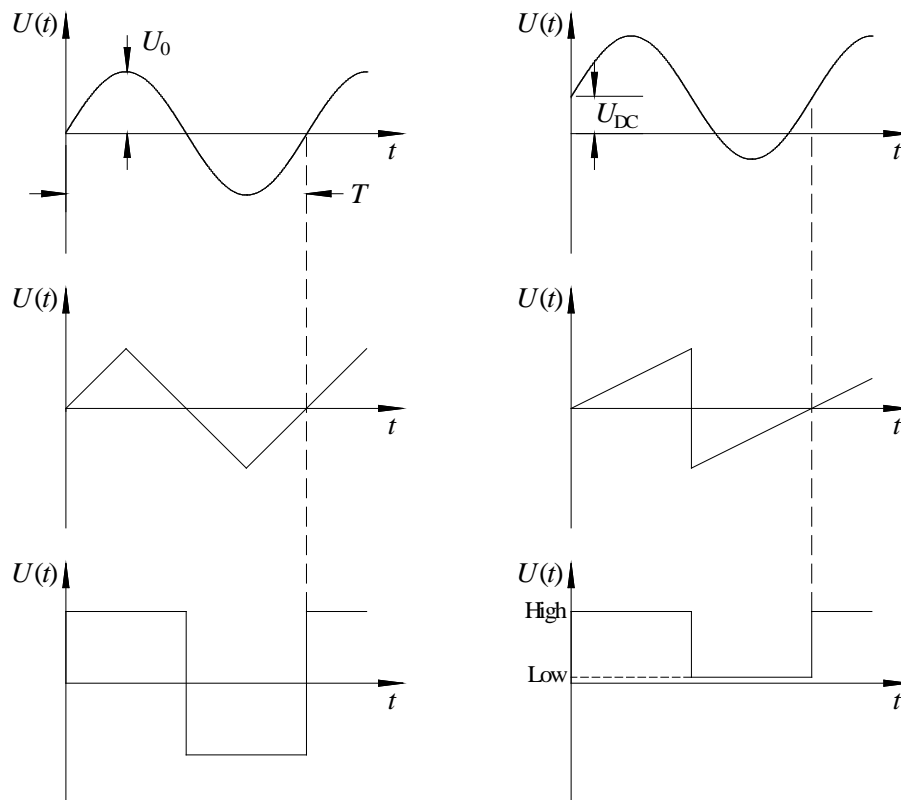


Fig. 3: Typical output signals of function generators. *Top left* sinusoidal alternating voltage without DC-offset, *top right* sinusoidal alternating voltage with DC-Offset. *Centre left* delta voltage, *centre right* sawtooth voltage. *Bottom left* square-wave voltage. *Bottom right* TTL signal⁶.

⁵ Originally, BNC is the name of a product of the company AMPHENOL and means "Bayonet NEILL CONCELMAN".

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 $0 \text{ V} \leq U < 0.4 \text{ V}$, state *High* if $2.4 \text{ V} < U \leq 5.0 \text{ V}$ is valid for an *output signal* of a device. *Low* if $0 \text{ V} \leq U < 0.8 \text{ V}$, *High* if $2.0 \text{ V} < U \leq 5.0 \text{ V}$ is valid for an *input signal* of a device.

Hint: The signal at the TTL-OUT connector of the FG TOELLNER 7401 does *not* comply with this norm.



Fig. 4: Front views of two function generators used in the laboratory. *Top*: AGILENT 33120A, *bottom*: TOELLNER 7401. At the FG TOELLNER the frequency of the output signal is the product of the value adjusted at the switch FREQ RANGE (in this case 100 Hz) and the multiplier adjusted at the rotary knob FREQUENCY (1 Hz). At the represented setting therefore $f = 1 \times 100 \text{ Hz} = 100 \text{ Hz}$.

4 Multimeters

Multimeters⁷ (Fig. 5) can be used for measuring different electric values depending on the position of switches, as indicated by their name. The most important values are the following (stated with typical designations found on the control switches):

Direct voltage:	V =, DC V
Alternating voltage:	V ~, AC V
Direct current:	A =, DC A
Alternating current:	A ~, AC A
Resistance:	Ω
Capacity:	μF

When measuring AC voltages or currents, the multimeters display the *effective value* (index “eff”). The effective value of an AC current or voltage is equivalent to the DC value providing an equal amount of electrical power. The connection between the effective value and the amplitude of sinusoidal AC signals without a DC-offset (Index “0”) is given by:

$$(2) \quad U_{\text{eff}} = \sqrt{\frac{1}{T} \int_0^T U^2(t) dt} = \frac{1}{\sqrt{2}} U_0$$

$$I_{\text{eff}} = \sqrt{\frac{1}{T} \int_0^T I^2(t) dt} = \frac{1}{\sqrt{2}} I_0$$

⁷ This name is also used in German.



Fig. 5: Front views of seven multimeters used in the laboratory. *Top* from left to right: MONACOR DMT-3010, ABB METRAWATT M2012, FLUKE 112, AGILENT U1251B, METRALINE DM 62; *centre*: KONTRON DMM 3021; *bottom*: AGILENT 34405A.

The electrical network in Germany has an effective voltage of $U_{\text{eff}} \approx 230 \text{ V}$. This value is usually printed on the type-decals of electrical devices.⁸ Using the above formula, the amplitude is

$$U_0 \approx \sqrt{2} \times 230 \text{ V} \approx 325 \text{ V}$$

For AC measurements, a correct effective value is only obtained for signals with frequencies within a certain interval. In addition, the signal form (sinus, delta, square etc.) has to be considered for interpreting the measured value. Details are found in the reference manual of the measuring device.

Before using a multimeter, the quantity to be measured has to be adjusted with the control switch. Only thereafter may the cables be connected to the input terminals.


The labelling of the input terminal (the potential of which represents the reference potential for voltage measurements) is vendor specific. The most common designations are:

Reference potential: ● COM, COMMON, LO, LOW, 0, ⊥

The colour of this terminal is usually black.

⁸ In many cases the deprecated value of 220 V can still be found on the decals.

The second terminal, to which the comparison voltage is fed, is sometimes termed:

Comparison potential:  HI, HIGH, +

However, often only the units of the quantities to be measured are given there, as e.g.: V, Ω etc. The colour of this terminal is usually red.

For measuring currents, a terminal different from that used for measuring voltages and resistances is used in most instruments together with the COM-terminal. This terminal, also red in most cases, is labelled:

Current measurement:  mA, A

Many instruments provide separate contact terminals for high currents up to 10 A.

The multimeters used in the introductory laboratory course are digital multimeters, which can provide a display-accuracy determined by the number of digits existing in the reading. The leftmost digit usually only shows a 0 or 1 and is therefore counted as half digit. For example, the instrument of the type AGILENT U1251B is a 4 ½-digit multimeter, while the AGILENT 34405A is a 5 ½-digit multimeter. This means: The first digit can only show 0 or 1, while the other 4 or 5 digits can show the numbers 0 - 9.

In addition to the actual measured value (numerical value), further data are displayed in some instruments, e.g., the unit of the measured quantity (mA, A, mV, ...), the type of signal (AC, DC), the measuring range (100 mV, 100 Ω ,...) etc.

For measuring resistances, a multimeter provides an internal constant test current I_T , which flows from the red terminal through the resistance to be measured at the black terminal. By internal measurement of the voltage U over the resistance R the displayed value of $R = U/I_T$ is obtained. The test current has to be kept low as possible in order to avoid a heating of the resistance. Details on resistance measurements are given in the experiment “*Measuring Ohmic resistances ...*”.

For measuring capacities, the capacitor is fed with a constant charging current I_L . The capacity C can be determined by measuring the voltage U over the capacitor at two times t_1 and t_2 . Details on capacity measurements are given in the experiment “*Measuring capacities ...*”.

5 Examples of Wirings

5.1 Voltage Divider

Fig. 6 shows the circuit scheme of a voltage divider with the resistances R_1 and R_2 connected to a constant voltage source (*power supply*) with the terminal voltage U . The symbols used in the schematic are explained in the Appendix. The current through the resistances is measured using an *ammeter* A, the voltage at the resistance R_2 is measured using the *voltmeter* V.

Fig. 7 shows a photo of an actual set-up. *Resistance decades* are used, where the required resistances can be adjusted by means of slide switches (right side $R_1 = (100 + 10) \Omega$, left side $R_2 = 200 \Omega$; accuracy $\pm 1 \%$ each). Multimeters are used to measure currents and voltages. The electric connection between the equipment and components is realized by means of common *single-wire laboratory cables* provided (blue and red cables in Fig. 7) with *laboratory plugs* (“*banana plugs*”) at their ends. The equipment and components themselves are provided with *sockets* fitting these plugs.

For a supply voltage $U = 4.8 \text{ V}$, the current I flowing through the resistor is

$$(3) \quad I = \frac{U}{R} = \frac{4,8 \text{ V}}{(110 + 200) \Omega} \approx 15,5 \text{ mA}$$

It is expected that the ammeter’s display will show this value. In reality, the display reads 15.38 mA. The deviation is caused by the limited accuracy of the resistors in the resistance decade, the voltage setting on the power supply, and the limited accuracy of the ammeter itself.

The voltage U distributes over the resistors with a ratio

$$(4) \quad \frac{U_1}{U_2} = \frac{R_1}{R_2} = \frac{110 \Omega}{200 \Omega} = 0,55$$

By using

$$(5) \quad U = U_1 + U_2$$

it follows by combination of Eq. (4) and (5) that U_2 equals:

$$(6) \quad U_2 = \frac{U}{1 + \frac{R_1}{R_2}} = \frac{4,8 \text{ V}}{1,55} \approx 3,10 \text{ V}$$

In practice, the voltmeter displays a value of -3.04 V. The deviation is, once again caused by the tolerance of the resistors, the power supply, and the limited accuracy of the multimeter. The negative sign appears, because the COM-terminal of the multimeter is connected to the higher potential at the resistor R_2 (red wire).

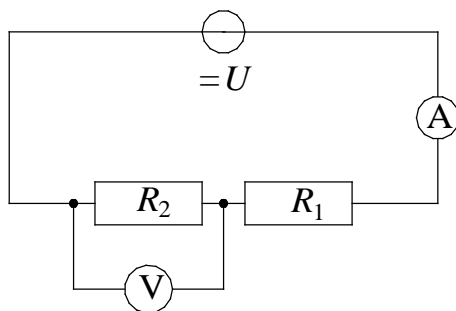


Fig. 6: Block diagram of a voltage divider with the resistances R_1 and R_2 , constant voltage source with terminal voltage U , voltmeter V, and ammeter A.

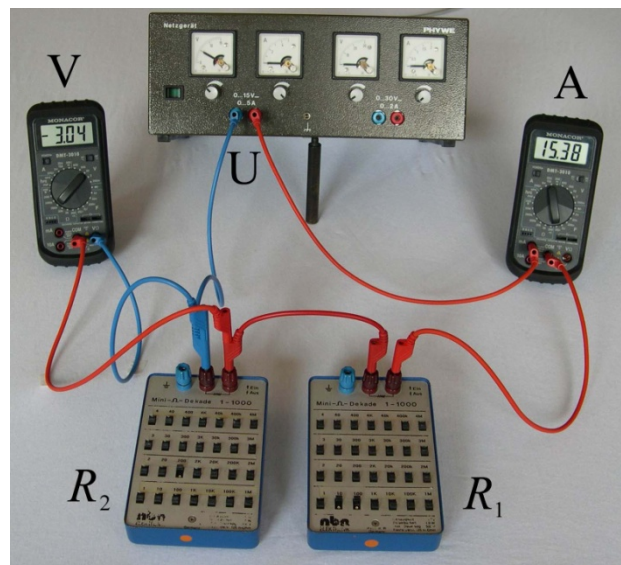


Fig. 7: Real set-up of the circuit corresponding to Fig. 6. The voltage of the power supply is set to 4.8 V.

5.2 Function Generator and Oscilloscope

Fig. 8 shows the block diagram of a function generator FG, which generates a sinusoidal alternating voltage U of an adjustable amplitude and frequency (e.g. 2 V, 1 kHz). A load resistor R (e.g. $R = 1 \text{ k}\Omega$) is connected to the output of the function generator. The output voltage of the FG at this resistance is measured using an oscilloscope OS⁹. Fig. 9 shows a photo of an actual set-up.

In this case, *coaxial cables* are used for the electric connection of the function generator with the oscilloscope (Fig. 11) and the resistance (resistance decade). These cables will be dealt with in more detail in the course of the laboratory course. These cables (Fig. 10) possess one *inner* and one *outer* conductor and are thus *twin-conductor cables*. An insulator is located between the inner and outer conductor, and the

⁹ Details of the oscilloscope are given in the experiment „*Oscilloscope and function generator*”.

outer conductor is surrounded by a plastic sheath. There are *BNC-connectors* at the ends of the cables. The inner pin of the connector is connected with the inner conductor, the outer metal body with the outer one. Via a bayonet lock the connectors are connected to the related *BNC-sockets* of the equipment such as the function generator or oscilloscope.

There are two variants to connect components as e.g. resistance decades to the coaxial cables. We use either cables possessing a BNC-plug on one side and two common laboratory plugs on the other side (Fig. 9, connection of FG and R) or a suitable adapter piece (Fig. 10). With the help of *BNC-T pieces* (Fig. 10) a signal can be fed into two coaxial cables simultaneously (in Fig. 9 the output signal of the FG).

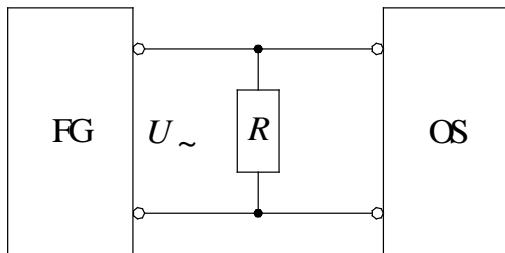


Fig. 8: Block diagram of a function generator FG with output alternating voltage U_{\sim} , load resistor R and oscilloscope OS for measuring the voltage.

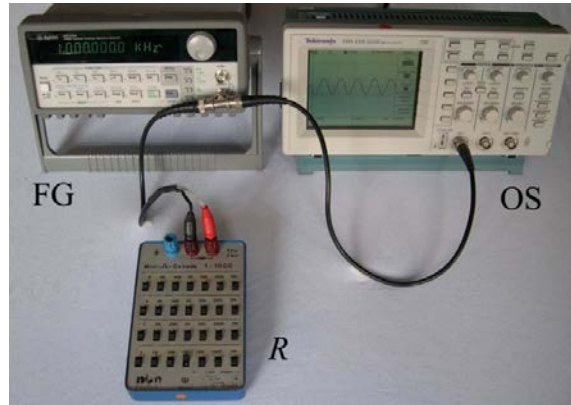


Fig. 9: Real set-up of the circuit corresponding to Fig. 8.

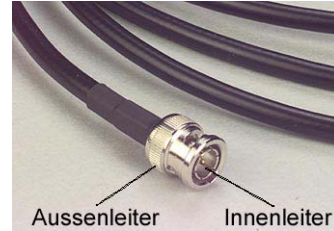
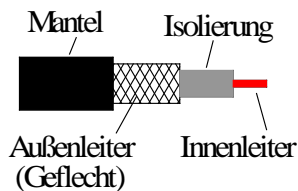


Fig. 10: *Top left:* Schematic of a coaxial cable, *top right:* Coaxial cable with BNC-plug. *Bottom from left to right:* T-piece for coaxial cable with BNC-connectors, fitting piece connecting coaxial cables with BNC-plugs, adapter piece for junction BNC-connector \rightarrow laboratory socket.

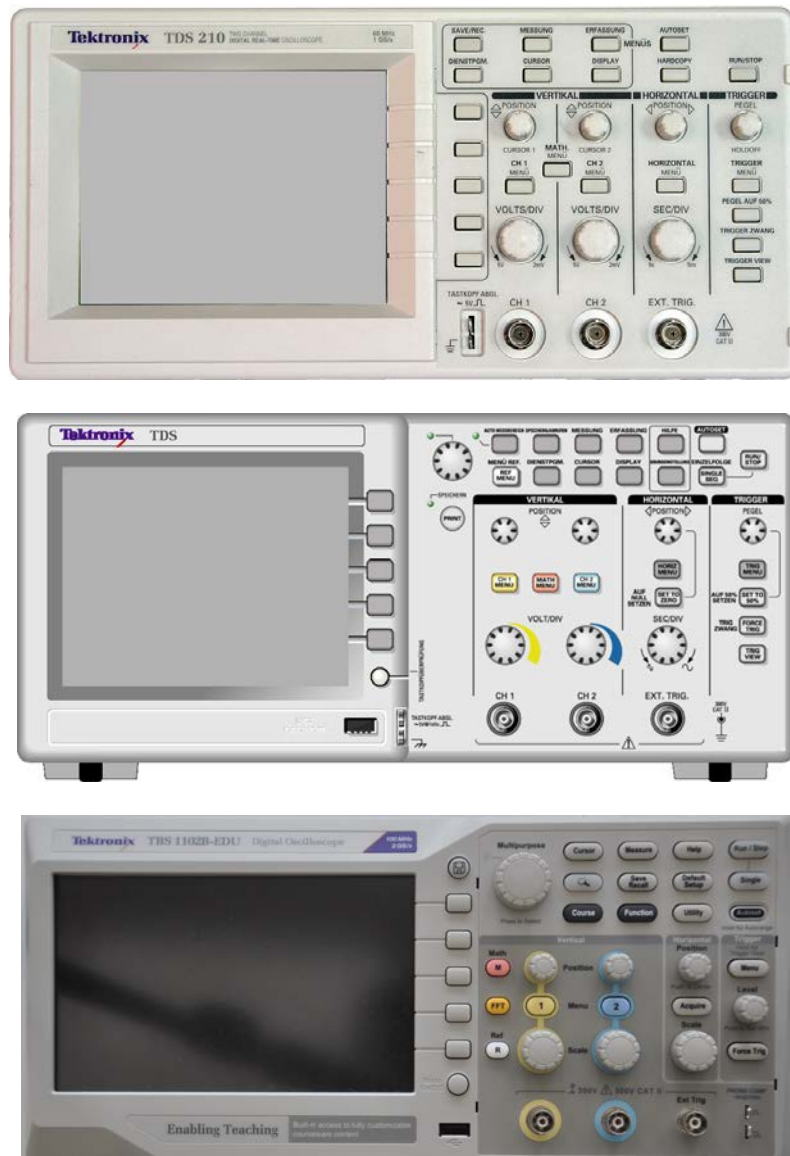


Fig. 11: Front views of three oscilloscopes used in the laboratory. *Top*: Digital oscilloscope TEKTRONIX TDS 210. *Middle*: Digital oscilloscope TEKTRONIX TDS 1012B. *Bottom*: Digital oscilloscope TEKTRONIX TBS 1102B-EDU.

6 Appendix

A selection of circuit symbols in accordance with DIN EN 60617: