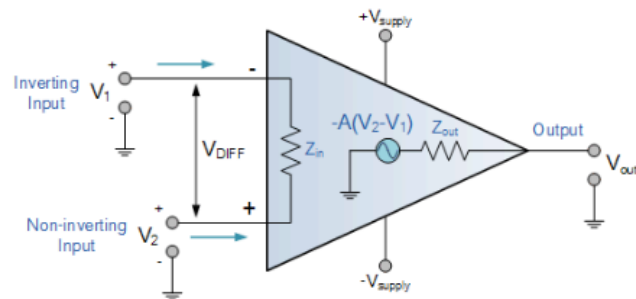




An-Najah National University
Faculty of Engineering
Electrical Engineering Department

Electronic Circuits Lab Manual
10641314



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2018/2019



Department Name : Electrical Engineering Department
Course Name: Electronic Circuits lab **Number:10641314**
Report Grading Sheet

| | | | |
|---|-------------------|-------------------|---------------|
| Instructor Name: | | Experiment #: | |
| Academic Year: 2018/2019 | | Performed on: | |
| Semester: | | Submitted on: | |
| Experiment Name: | | | |
| Students: | | | |
| 1- | | 2- | |
| 3- | | 4- | |
| 5- | | 6- | |
| Report's Outcomes | | | |
| ILO _2_ =(50) % | ILO _3_ =(25) % | ILO _5_ =(25) % | ILO __ =() % |
| Evaluation Criterion | | Grade | Points |
| Abstract answers of the questions: "What did you do? How did you do it? What did you find?" | | | |
| Introduction Sufficient, Clear and complete statement of objectives. | | | |
| Theory Presents sufficiently the theoretical basis. | | | |
| Apparatus/ Procedure Apparatus sufficiently described to enable another experimenter to identify the equipment needed to conduct the experiment. Procedure sufficiently described. | | | |
| Experimental Results and Calculations Results analyzed correctly. Experimental findings adequately and specifically summarized, in graphical, tabular, and/or written form. | | 4 | |
| Discussion Crisp explanation of experimental results. Comparison of theoretical predictions to experimental results, including discussion of accuracy and error analysis in some cases. | | 3 | |
| Conclusions and Recommendations Conclusions summarize the major findings from the experimental results with adequate specificity. Recommendations appropriate in light of conclusions. Correct grammar. | | 1 | |
| References Complete and consistent bibliographic information that would enable the reader to find the reference of interest. | | | |
| Appendices Appropriate information, organized and annotated. Includes all calculations and raw data Sheet. | | | |
| Appearance Title page is complete, page numbers applied, content is well organized, correct spelling, fonts are consistent, good visual appeal. | | 2 | |
| Total | | 10 | |

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Department of Electrical Engineering**Electronic Circuits Lab (10641314)****Total Credits** 1**major compulsory****Prerequisites** P1 : Electronic Circuits 1 (10641214)**Course Contents**

Electronics lab has been prepared to equip the students with the necessary practical and theoretical knowledge of electronic principles. During the lab the students become very familiar with , Types of Diodes, Rectifier diode, Half wave rectifier, Bridge rectifier, On state and off state characteristic of zener diode, Testing the layering and rectifying of bipolar transistor, Characteristic of the transistor, Depletion layer Fets, Characteristic of the Fets, Multistage amplifier, Differential amplifier, Push pull output amplifier, Operational amplifier

| | Intended Learning Outcomes (ILO's) | Student Outcomes (SO's) | Contribution |
|---|---|--------------------------------|---------------------|
| 1 | Basic Knowledge of Principles of Electrical circuits and analysis Knowledge | A | 25 % |
| 2 | Ability to take measurements deferent type of Electronic circuits | B | 25 % |
| 3 | An ability To function and work the experiments as team | D | 20 % |
| 4 | An ability to identify, formulate, and solve electronics circuits problems | A | 20 % |
| 5 | An ability ORCAD methods to solve electronics circuits engineering analyses and design. | K | 10 % |

Textbook and/ or References

1. Electronic circuits lab Manual 2. Lab manual, Machines manuals and several handouts throughout the semester.

| Assessment Criteria | Percent (%) |
|----------------------------|--------------------|
| Projects | 10 % |
| Laboratory Work | 60 % |
| Final Exam | 30 % |

Course Plan

| Week | Topic |
|-------------|--|
| 1 | Exp1: Introduction – PSpice (ORCAD) |
| 2 | Exp 2: Junction Diodes and applications (Rectifier) |
| 3 | Exp 3: Zener diodes and applications |
| 4 | Exp 4: Bipolar Transistor |
| 5 | Exp 5: Unipolar Transistors (Junction Field-Effect Transistor) |
| 6 | Exp 6: Course Project: Soldering and disordering skills and build circuits |
| 7 | Exp 7: Basic Amplifier Circuits with Bipolar Transistors |
| 8 | Exp 8A: Operational Amplifier: Inverting Amplifier Non-Inverting Amplifier |

| | |
|----|--|
| 9 | Exp 8B: Dynamic Behavior of an Op-Amp |
| 10 | Exp 9: Op-amp circuits serving as Adder and Differential Amplifier |
| 11 | Exp 10: Multistage Amplifier |
| 12 | Exp 11: Differential Amplifier |
| 13 | Exp 12: Push-Pull-Amplifier |
| 14 | Final Exam |

Lab Safety Guidelines

- 1) Be familiar with the electrical hazards associated with your workplace.
- 2) You may enter the laboratory only when authorized to do so and only during authorized hours of operation.
- 3) Be as careful for the safety of others as for yourself. Think before you act, be tidy and systematic.
- 4) Avoid bulky, loose or trailing clothes. Avoid long loose hair.
- 5) Food, beverages and other substances are strictly prohibited in the laboratory at all times. Avoid working with wet hands and clothing.
- 6) Use extension cords only when necessary and only on a temporary basis.
- 7) Request new outlets if your work requires equipment in an area without an outlet.
- 8) Discard damaged cords, cords that become hot, or cords with exposed wiring.
- 9) Before equipment is energized ensure, (1) circuit connections and layout have been checked by a laboratory technician and (2) all colleagues in your group give their assent.
- 10) Know the correct handling, storage and disposal procedures for batteries, cells, capacitors, inductors and other high energy-storage devices.
- 11) Experiments left unattended should be isolated from the power supplies. If for a special reason, it must be left on, a barrier and a warning notice are required.
- 12) Equipment found to be faulty in any way should be reported to the laboratory technician immediately and taken out of service until inspected and declared safe.
- 13) Never make any changes to circuits or mechanical layout without first isolating the circuit by switching off and removing connections to power supplies.
- 14) Know what you must do in an emergency, i.e. Emergency Power Off
- 15) For microwave and antenna trainer:
 - a. You should, whenever possible, remove the power from the gun oscillator before placing yourself in front of transmitting antenna.
 - b. For your safety, do not look directly into the waveguides or horn antennas while power is being supplied by the gun oscillator. Because, although the microwave is invisible, it can be dangerous at high levels or long exposure times.
- 16) For fiber optics trainer:
 - a. Do not look inside the connector of the Optical Sources when these are operating. Although nothing can be seen, as the emitted wavelength should be out of the visible range, it can be dangerous for your sight.

- b. Do not bend the optical cables with too narrow curves, as the fiber inside should cut off or damage. The minimum curving ray is around 2 cm;
- c. Sometimes clean the connectors' head with a cotton wad soaked with alcohol;

Electrical Emergency Response

The following instructions provide guidelines for handling two types of electrical emergencies:

1. Electric Shock:

When someone suffers serious electrical shock, he or she may be knocked unconscious. If the victim is still in contact with the electrical current, immediately turn off the electrical power source. If you cannot disconnect the power source, depress the Emergency Power Off switch.



IMPORTANT:

Do not touch a victim that is still in contact with a live power source; you could be electrocuted.

Have someone call for emergency medical assistance immediately. Administer first-aid, as appropriate.

2. Electrical Fire:

If an electrical fire occurs, try to disconnect the electrical power source, if possible. If the fire is small and you are not in immediate danger; and you have been properly trained in fighting fires, use the correct type of fire extinguisher to extinguish the fire. When in doubt, push in the Emergency Power Off button.

NEVER use water to extinguish an electrical fire.

Lab Report Format

Following the completion of each laboratory exercise, a report must be written and submitted for grading. The purpose of the report is to completely document the activities of the design and demonstration in the laboratory. Reports should be complete in the sense that all information required to reproduce the experiment is contained within. Writing useful reports is a very essential part of becoming an engineer. In both academic and industrial environments, reports are the primary means of communication between engineers.

There is no one best format for all technical reports but there are a few simple rules concerning technical presentations which should be followed. Adapted to this laboratory they may be summarized in the following recommended report format:

- ABET Cover Page
- Title page
- Introduction
- Experimental Procedure
- Experimental Data
- Discussion
- Conclusions

Detailed descriptions of these items are given below.

Title Page:

The title page should contain the following information

- Your name
- ID
- Experiment number and title
- Date submitted
- Instructors Name

Introduction:

It should contain a brief statement in which you state the objectives, or goals of the experiment. It should also help guide the reader through the report by stating, for example, that experiments were done with three different circuits or consisted of two parts etc. Or that additional calculations or data sheets can be found in the appendix, or at the end of the report.

The Procedure

It describes the experimental setup and how the measurements were made. Include here circuit schematics with the values of components. Mention instruments used and describe any special measurement procedure that was used.

Results/Questions:

This section of the report should be used to answer any questions presented in the lab hand-out. Any tables and /or circuit diagrams representing results of the experiment

should be referred to and discussed / explained with detail. All questions should be answered very clearly in paragraph form. Any unanswered questions from the lab hand-out will result in loss of points on the report.

The best form of presentation of some of the data is graphical. In engineering presentations a figure is often worth more than a thousand words. Some simple rules concerning graphs and figures which should always be followed. If there is more than one figure in the report, the figures should be numbered. Each figure must have a caption following the number. For example, "*Figure 1.1:DSB-SC* " In addition, it will greatly help you to learn how to use headers and figures in MS Word.

The Discussion

It is a critical part of the report which testifies to the student's understanding of the experiments and its purpose. In this part of the report you should compare the expected outcome of the experiment, such as derived from theory or computer simulation, with the measured value. Before you can make such comparison you may have to do some data analysis or manipulation.

When comparing experimental data with numbers obtained from theory or simulation, make very clear which is which. It does not necessarily mean that your experiment was a failure. The results will be accepted, provided that you can account for the discrepancy. Your ability to read the scales may be one limitation. The value of some circuit components may not be well known and a nominal value given by the manufacturer does not always correspond to reality. Very often, however, the reason for the difference between the expected and measured values lies in the experimental procedure or in not taking into account all factors that enter into analysis.

Conclusion:

A brief conclusion summarizing the work done, theory applied, and the results of the completed work should be included here. Data and analyses are not appropriate for the conclusion.

Notes

Typed Reports are required. Any drawings done by hand must be done with neatness, using a straightedge and drawing guides wherever possible.

Freehand drawings will not be accepted.

EXPERIMENT # 1

Introduction – PSpice (ORCAD)

I. Opening PSpice

II. Drawing the circuit

- A. Getting the parts
- B. Placing the Parts
- C. Connecting the Circuit
- D. Changing the Name of the Part
- E. Changing the Value of the Part
- F. Making Sure You Have a GND
- G. Voltage and Current Bubbles

III. Voltage Sources

- A. VDC
- B. VAC
- C. VSIN
- D. VPULSE

IV. Analysis Menu

- A. DC Sweep
- B. Bias Point Detail
- C. Transient


V. Probe

- A. Before you do the Probe
- B. To Start the Probe
- C. Graphing
- D. Adding/Deleting Traces
- E. Finding Points

VI. Measuring DC Analysis

VII. Exercise

I. Opening PSpice

- Find PSpice on the C-Drive. Open Schematics or you can go to PSpice A_D and then click on the schematic icon .
- You will see the window as shown in Figure 1.

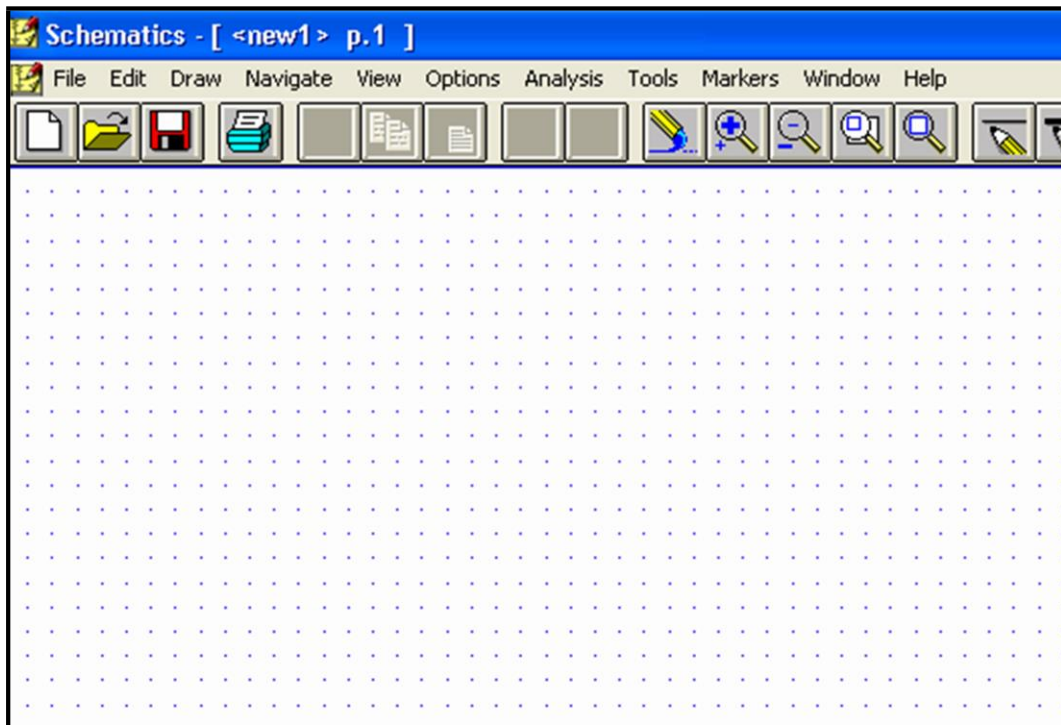



Figure 1

II. Drawing the circuit

A. Getting the Parts

- The first thing that you have to do is get some or all of the parts you need.
- This can be done by
 - Clicking on the 'get new parts' button , or
 - Pressing "Control+G", or
 - Going to "Draw" and selecting "Get New Part..."
- Once this box is open, select a part that you want in your circuit. This can be done by typing in the name (part name) or scrolling down the list until you find it.

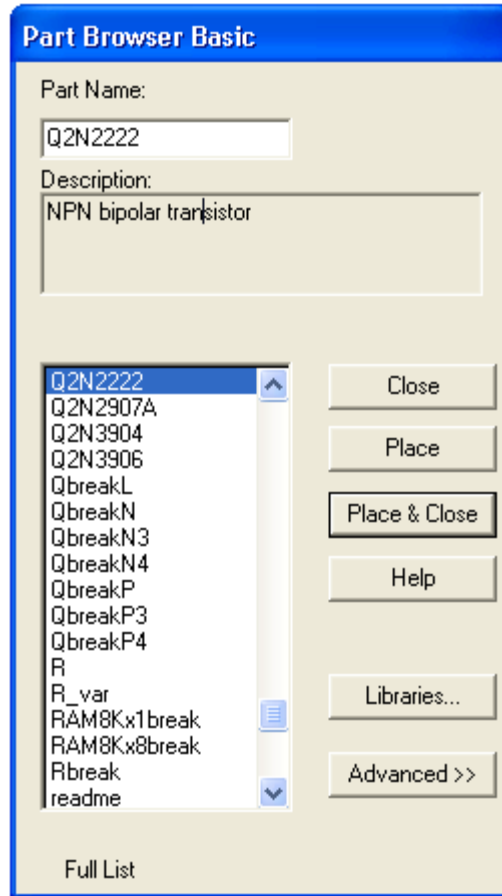


Figure 2

- An important prerequisite to building a schematic is the availability of the necessary parts (in the form of symbols) for assembly. Schematics have an extensive symbol libraries and a fully integrated symbol editor for creating your own symbols or modifying existing symbols. For the labs you will be using the existing symbols.
- Some common parts are:
 - o r - resistor
 - o C - capacitor
 - o L - inductor
 - o d - diode
 - o GND_ANALOG or GND_EARTH -- this is very important, you **MUST** have a ground in your circuit
 - o VAC and VDC
 - o Q2N – bipolar transistor
 - o VSIN –Transient sine voltage source
- Upon selecting your part (you will also see description of the part below part name and you can see the symbol of that part when you click on **advanced** in the above figure), click on the place button (you will see the part attached to the


mouse pointer) then click where you want it placed (somewhere on the white page with the blue dots), if you need multiple instances of this part click again, once you have selected that part right click your mouse the part will not be attached to the mouse pointer. Don't worry about putting it in exactly the right place, it can always be moved later.

- If you want to take a part and close then you just select the part and click on **place& close**.
- Once you have all the parts you think you need, close that box. You can always open it again later if you need more or different parts. (The parts you have selected will be listed on the menu bar for quick access)

B. Placing the Parts

- You should have most of the parts that you need at this point.
- Now, all you do is put them in the places that make the most sense (usually a rectangle works well for simple circuits). Just select the part (It will become Red) and drag it where you want it.
- To rotate parts so that they will fit in you circuit nicely, click on the part and press "Ctrl+R" (or Edit "Rotate"). To flip them, press "Ctrl+F" (or Edit "Flip").
- If you have any parts left over, just select them and press "Delete".

C. Connecting the Circuit

- Now that your parts are arranged well, you'll have to attach them with wires.
- Go up to the tool bar and
 - o select "Draw Wire"  or
 - o "Ctrl+W" or
 - o go to "Draw" and select "Wire".
- With the pencil looking pointer, click on one end of a part, when you move your mouse around, you should see dotted lines appear. Attach the other end of your wire to the next part in the circuit.
- Repeat this until your circuit is completely wired.
- If you want to make a node (to make a wire go more then one place), click somewhere on the wire and then click to the part (or the other wire). Or you can go from the part to the wire.
- To get rid of the pencil, right click.
- If you end up with extra dots near your parts, you probably have an extra wire, select this short wire (it will turn red), then press "Delete".

- If the wire doesn't go the way you want (it doesn't look the way you want), you can make extra bends in it by clicking in different places on the way (each click will form a corner).

D. Changing the Name of the Part

- You probably don't want to keep the names C1, C2 etc., especially if you didn't put the parts in the most logical order. To change the name, double click on the present name (C1, or R1 or whatever your part is), and then a box will pop up (Edit Reference Designator) see Figure 3. In the top window, you can type in the name you want the part to have.

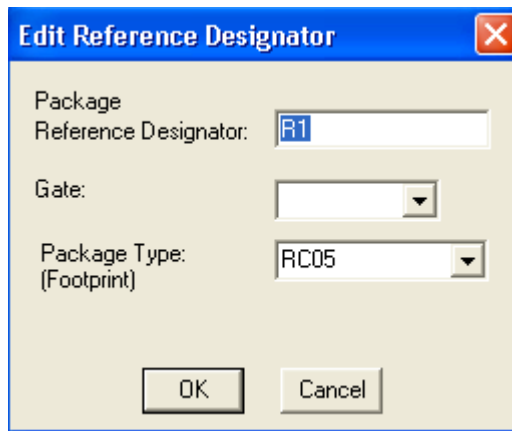


Figure 3

- Note that if you double click on the part or its value, a different box will appear.

E. Changing the Value of the Part

- If you only want to change the value of the part (if you don't want all your resistors to be 1K ohms), you can double click on the present value and a box called "Set Attribute Value" will appear see Figure 4. Type in the new value and press OK. Use u for micro as in uF = microFarad.

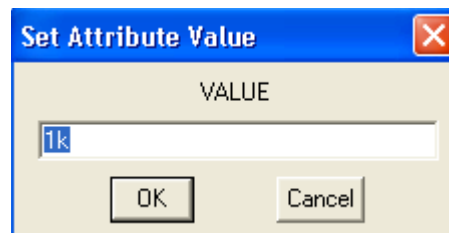




Figure 4

F. Making Sure You Have a GND

- This is very important. You cannot do any simulation on the circuit if you don't have a ground. If you aren't sure where to put it, place it near the negative side of your voltage source.

G. Voltage and Current Bubbles

- These are important if you want to measure the voltage at a point or the current going through that point.
- To add voltage or current bubbles, go to the right side of the top tool bar and select "Voltage/Level Marker" (Ctrl+M)  or "Current Marker" . To get either of these, go to "Markers" and either "Voltage/Level Marker" or "Current Marker".

III. Voltage Sources

A. VDC

- This is your basic direct current voltage source that simulates a simple battery and allows you to specify the voltage value.

B. VAC

- A few things to note about the alternating current source, first PSpice takes it to be a sine source, so if you want to simulate a cosine wave you need to add (or subtract) a 90° phase shift. There are three values which PSpice will allow you to alter, these being:
 - o **ACMAG** which is the RMS value of the voltage.
 - o **DC** which is the DC offset voltage
 - o **ACPHASE** which is the phase angle of the voltage
- Note that the phase angle if left unspecified will be set by default to 0°

C. VSIN

- The SIN type of source is actually a damped sine with time delay, phase shift and a DC offset (see Figure 5). If you want to run a transient analysis you need to use the VSIN see how AC will effect your circuit over time. Do not use this type of source for a phasor or frequency sweep analysis, VAC would be appropriate for that.

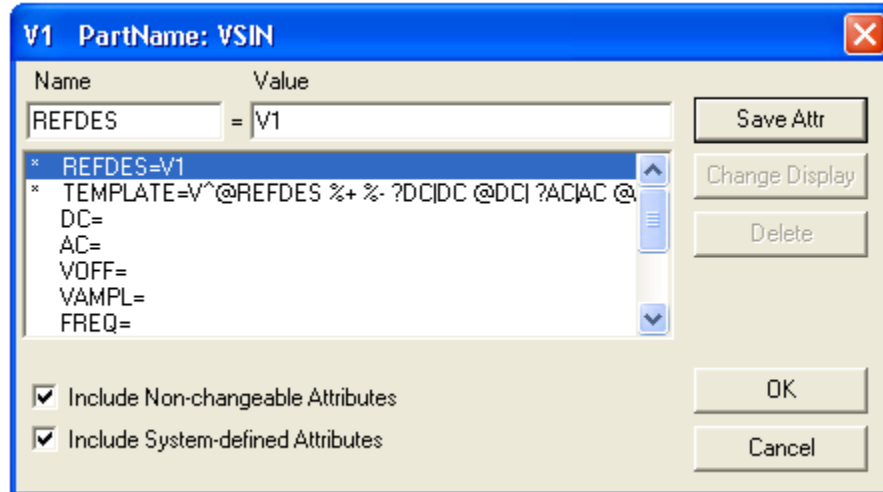


Figure 5

- o **DC** the DC component of the sine wave
- o **AC** the AC value of the sine wave
- o **VOFF** is the DC offset value. It should be set to zero if you need a pure sinusoid.
- o **Vamplitude** is the undamped amplitude of the sinusoid; i.e., the peak value measured from zero if there were no DC offset value.
- o **FREQ** is the frequency in Hz of the sinusoid.
- o **TD** is the time delay in seconds. Set this to zero for the normal sinusoid.
- o **DF** is the damping factor. Also set this to zero for the normal sinusoid.
- o **PHASE** is the phase advance in degrees. Set this to 90 if you need a cosine wave form.
- Note that the normal usage of this source type is to set **VOFF**, **TD** and **DF** to zero as this will give you a 'nice' sine wave.

D. VPULSE

- The VPULSE is often used for a transient simulation of a circuit where we want to make it act like a square wave source. It should never be used in a frequency response study because PSpice assumes it is in the time domain, and therefore your probe plot will give you inaccurate results. Details of VPULSE are (see Figure 6):
 - o **DC** the DC component of the wave.
 - o **AC** the AC component of the wave.
 - o **V1** is the value when the pulse is not "on." So for a square wave, the value when the wave is 'low'. This can be zero or negative as required. For a pulsed current source, the units would be "amps" instead of "volts."
 - o **V2** is the value when the pulse is fully turned 'on'. This can also be zero or negative. (Obviously, V1 and V2 should not be equal.) Again, the units would be "amps" if this were a current pulse.
 - o **TD** is the time delay. The default units are seconds. The time delay may be zero, but not negative.

- o **TR** is the rise time of the pulse. PSpice allows this value to be zero, but zero rise time may cause convergence problems in some transient analysis simulations. The default units are seconds.
- o **TF** is the fall time in seconds of the pulse.
- o **TW** is the pulse width. This is the time in seconds that the pulse is fully on.
- o **PER** is the period and is the total time in seconds of the pulse.
- This is a very important source for us because we do a lot of work on with the square wave on the wave generator to see how various components and circuits respond to it.

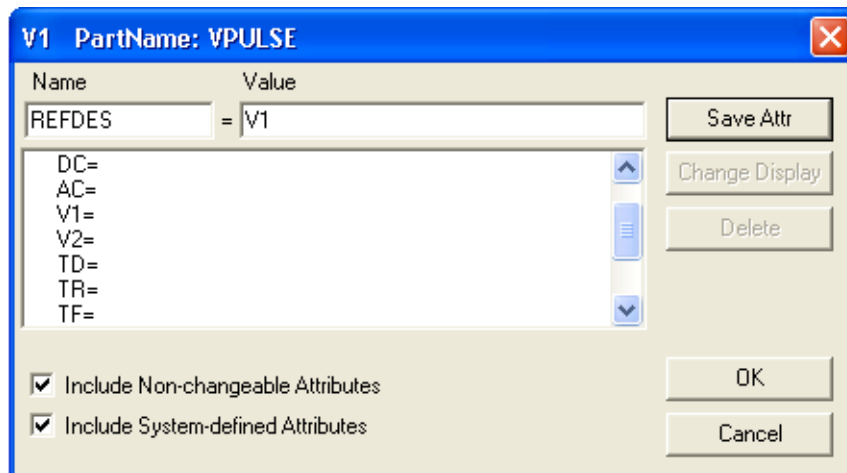


Figure 6

IV. Analysis Menu

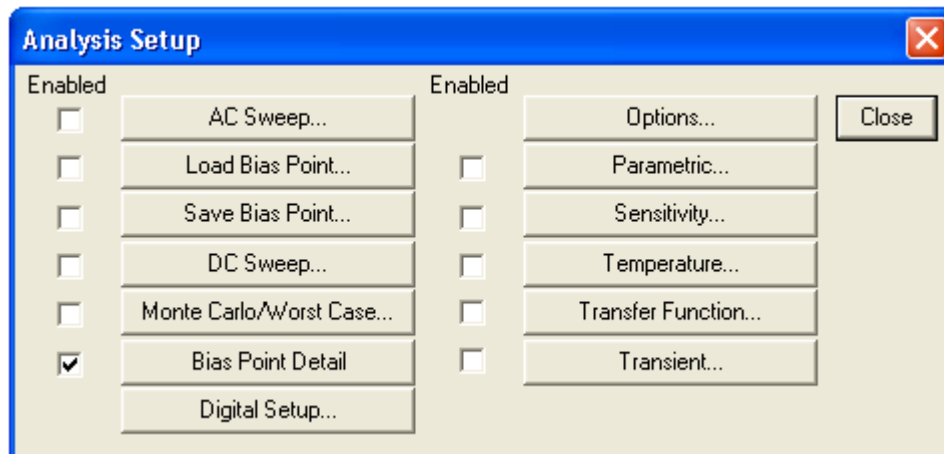



Figure 7

To open the analysis menu click on the  button.

A. DC Sweep

- The DC sweep allows you to do various different sweeps of your circuit to see how it responds to various conditions.
- For all the possible sweeps,
 - o voltage,
 - o current,
 - o temperature, and
 - o parameter and global
- You need to specify a start value, an end value, and the number of points you wish to calculate.
- For example you can sweep your circuit over a voltage range from 0 to 12 volts.

The main two sweeps that will be most important to us at this stage are the voltage sweep and the current sweep. For these two, you need to indicate to PSpice what component you wish to sweep, for example V1 or V2.


- Another excellent feature of the DC sweep in PSpice, is the ability to do a nested sweep.
- A nested sweep allows you to run two simultaneous sweeps to see how changes in two different DC sources will affect your circuit.
- Once you've filled in the main sweep menu, click on the nested sweep button and choose the second type of source to sweep and name it, also specifying the start and end values. (Note: In some versions of PSpice you need to click on **enable nested sweep**). Again you can choose Linear, Octave or Decade, but also you can indicate your own list of values, example: 1V 10V 20V. **DO NOT** separate the values with commas.

B. Bias Point Detail

- This is a simple, but incredibly useful sweep. It will not launch Probe and so give you nothing to plot. But by clicking on **enable bias current display** or **enable bias voltage display**, this will indicate the voltage and current at certain points within the circuit.

C. Transient

The transient analysis is probably the most important analysis you can run in PSpice, and it computes various values of your circuit over time

- Choose **Analysis...Setup** from the menu bar, or click on the Setup Analysis button  in the toolbar. The Analysis Setup dialog box opens.

- Click on the **Transient** button in the Analysis Setup dialog box. The Transient dialog box opens.
- Two very important parameters in the transient analysis are (see Figure8):
 - o **print step**
 - o **final time.**

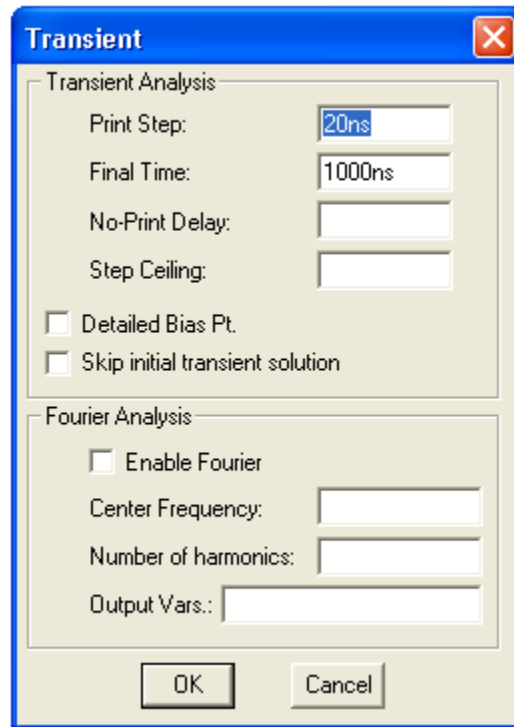



Figure 8

- The ratio of **final time: print step** (Keep print step atleast $1/100^{\text{th}}$ of the final time) determines how many calculations PSpice must make to plot a wave form. PSpice always defaults the start time to zero seconds and going until it reaches the user defined final time. It is incredibly important that you think about what print step you should use before running the simulation, if you make the print step too small the probe screen will be cluttered with unnecessary points making it hard to read, and taking extreme amounts of time for PSpice to calculate. However, at the opposite side of that coin is the problem that if you set the print step too high you might miss important phenomenon that are occurring over very short periods of time in the circuit. Therefore play with step time to see what works best for your circuit.
- You can set a step ceiling which will limit the size of each interval, thus increasing calculation speed. Another handy feature is the Fourier analysis, which allows you to specify your fundamental frequency and the number of harmonics you wish to see on the plot. PSpice defaults to the 9th harmonic unless you specify otherwise, but this still will allow you to decompose a square wave to see it's components with sufficient detail.

A. Before you do the Probe

- You have to have your circuit properly drawn and saved.
- There must not be any floating parts on your page (i.e. unattached devices).
- You should make sure that all parts have the values that you want.
- There are no extra wires.
- It is very important that you have a ground on your circuit.
- Make sure that you have done the Analysis Setup and that only the things you want are enabled.


B. To Start the Probe:

- Click on the Simulate button on the tool bar  (or Analysis, Simulate, or F11).
- It will check to make sure you don't have any errors. If you do have errors, correct them.
- Then a new window will pop up. Here is where you can do your graphs.

C. Graphing:



- If you don't have any errors, you should get a window with a black background to pop up.
- If you did have errors, in the bottom, left hand side, it will say what your errors were (these may be difficult to understand, so go To "View - Output File").

D. Adding/Deleting Traces:

- PSpice will automatically put some traces in. You will probably want to change them.
- Go to Trace - Add Trace or  on the toolbar. Then select all the traces you want.
- To delete traces, select them on the bottom of the graph and push Delete.

E. Finding Points:

- There are Cursor buttons that allow you to find the maximum or minimum or just a point on the line. These are located on the toolbar (to the right).

- Select which curve you want to look at and then select "Toggle Cursor"  .
- Then you can find the max, min, the slope, or the relative max or min (relative max).  is find

VI. Measuring DC Analysis

- If you want to measure DC levels you can use two parts to view these levels.

These parts are placed on the schematic drawing the same way any other part is placed. VIEWPOINT is a voltage viewing point, which will show the value after the circuit is simulated. You place VIEWPOINT on a node. IPROBE is a current probe, which will show the value after the circuit is simulated. You need to put this part between two parts, so that current flowing in that branch can be measured. If you have measurements that are time-varying (i.e. a sinusoid) then you need to run Probe.

VII. Exercise

Read Pspice Tutorial before you start this Session:

Parts to be used in the PSpice:

| Part Name | Pspice Name |
|-------------------|-------------|
| Resistor | R |
| Diode | D1N4148 |
| Zener Diode | D1N750 |
| DC source | VDC |
| Electrical Ground | EGND |

Diode Characteristic: (TUTORIAL)

1. Click on Start \propto Program \propto MicroSim Eval 6.3 \propto Schematic
2. Open the Draw menu by clicking once on the Draw menu. Choose Get New Part, and then Browse.
3. Get part DC battery VDC from the source.slb library
4. Get part resistance R from the analog.slb library
5. Get part diode D1N4002 from the eval.slb library.
6. Get part earth ground AGND from the port.slb library.
7. To Rotate the part first select it, then press Ctrl-R.
8. Draw and complete the diode circuit shown in Figure 1 in which $R = 200\text{m}\Omega$. You can click the left mouse on the device or element and choose Attributes from the Edit menu. Alternatively, you can change the attributes of any devices or elements by double clicking the left mouse and giving new values.
9. Analyze the circuit of Figure 1 by choosing Analysis from Schematic menu.
 - Click once on the Analysis menu and then choose Setup menu.

- Choose the analysis type – DC Sweep and give the sweep information: sweep name – VDD, start value – 0V, Sweep end value – 0.8V, and Sweep increment –0.01.

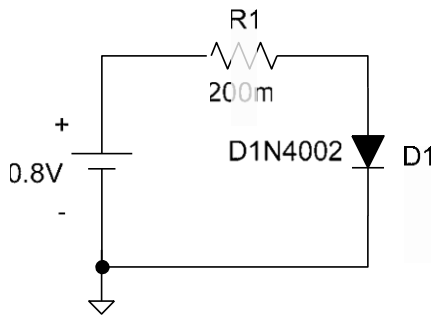


Figure 1

- Run the simulation by choosing Simulate from the Analysis menu.
- After successful simulation, PSPICE will automatically run Probe and move to Probe menu. Choose Add from the Trace menu of Probe and select the plot variable, the diode current. e.g. I(D1).
- Repeat the same procedure for reverse bias by selecting diode D1N750, changing the polarity of the dc source, and changing the sweep values. Attach a copy of the probe output and schematic with this output.

EXPERIMENT # 2

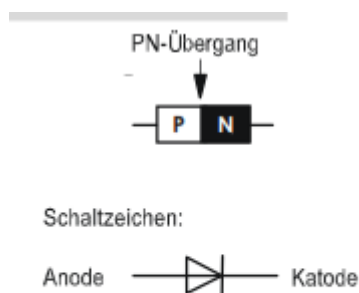
Junction Diodes and applications (Rectifier)

2.1 Effects of the p-n-junction of diodes

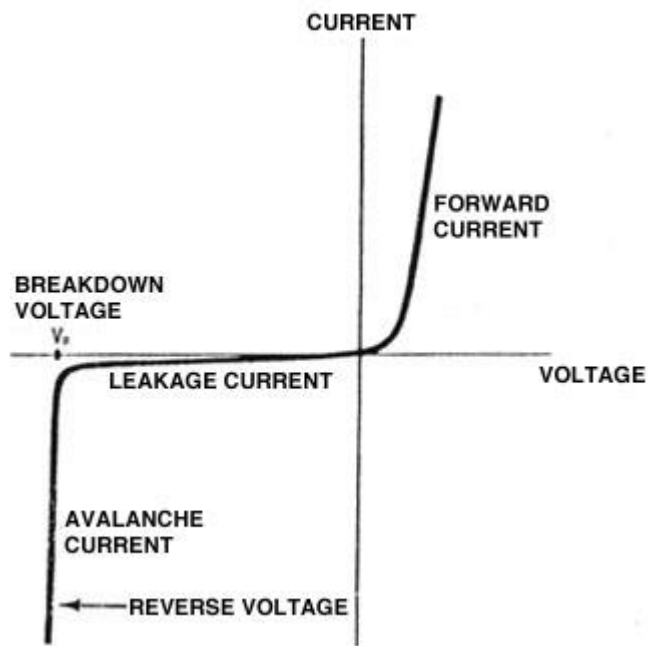
2.1.1 Basics

Diodes are two poles semiconductors. The semiconductor diode consists of a semiconductor crystal (silicon, germanium), one side is n-doped, the other one is p-doped. At the p-n-junction there is a barrier layer. The different doped layers are equipped with ohm contacts and could be connected to other components.

When voltage is applied, the barrier effect could be increased or nullified. The semiconductor diode allows current flow in one direction and blocks the other one. The diode has following the circuit symbol in pic. 1.1.



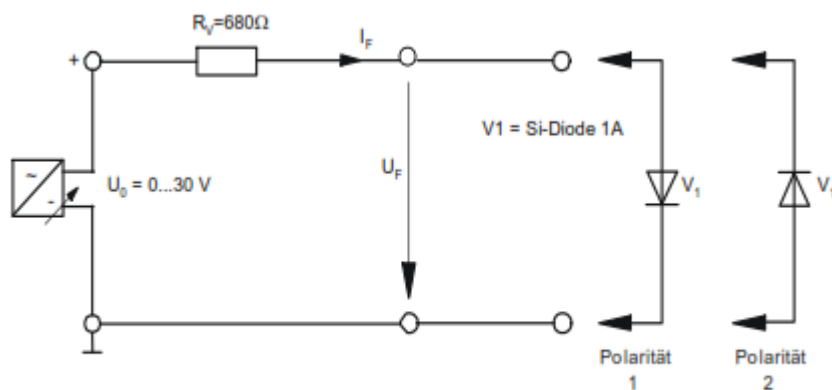
pic. 1.1



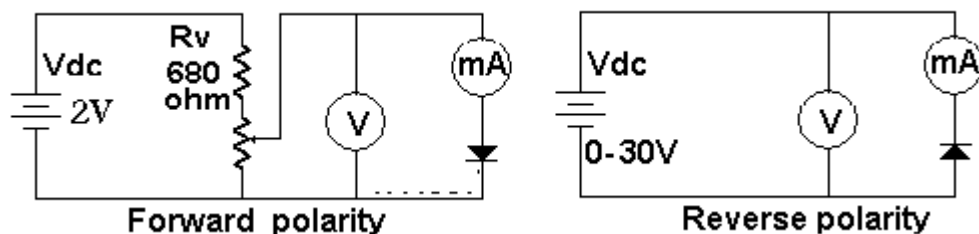
2.1.2 Tests

Test

Examine the effect of the rectifier diode's p-n-junction on the current flow in relation to the applied voltage and its polarity.



pic. 1.2



Exercise:

Test proceeding:

- One by one apply following voltages U_F according to chart 1.1 to the diode's polarity 1 (pic. 1.2) and measure the respective conducting current I_F . Fill the values in chart 1.1. Use the current error circuit.
- Then change the polarity of the diode (polarity 2) and repeat same test with the voltage values of chart 1.2., remove the series resistor. ($680\ \Omega$) and set the voltage directly at the power supply. Use the voltage error circuit for this measurement. An exact measurement of the reverse current I_R requires a highly sensible multimeter ($100\ \text{nA}$).
- For construction of the diode characteristic curve use the values of both charts and fill in the diagram pic. 1.3.

| U_F [V] | 0 | 0,1 | 0,2 | 0,3 | 0,4 | 0,5 | 0,6 | 0,65 | 0,7 | 0,75 |
|------------|---|-----|-----|-----|-----|-----|-----|------|-----|------|
| I_F [mA] | | | | | | | | | | |

chart 1.1

| U_R [V] | 0 | 2,5 | 5 | 10 | 15 | 20 | 25 | 30 |
|------------|---|-----|---|----|----|----|----|----|
| I_R [nA] | | | | | | | | |

chart 1.2

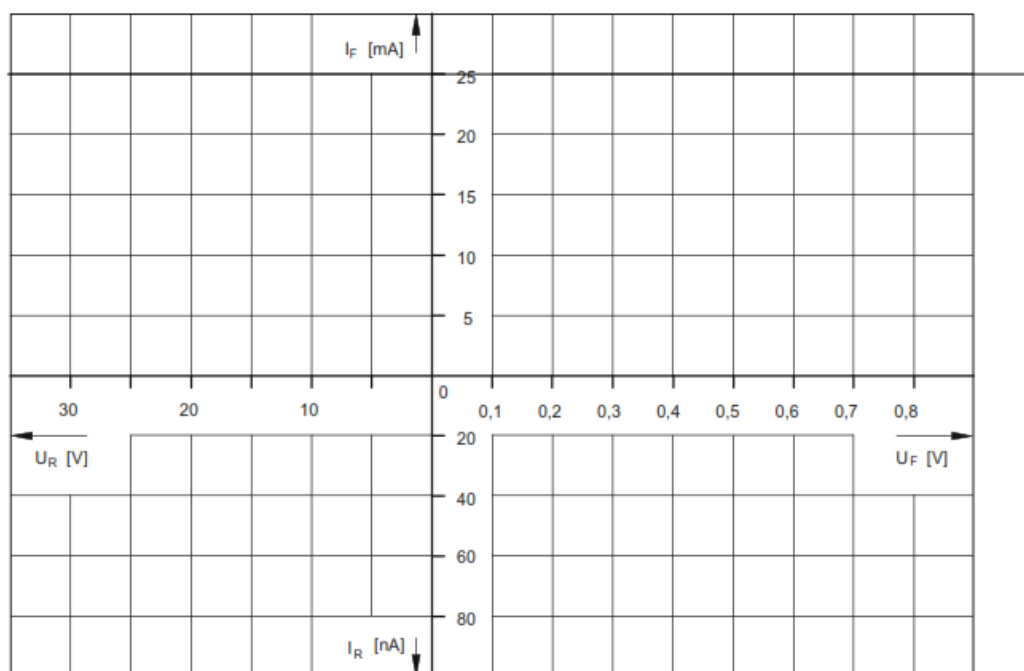


chart 1.3

Test:

What is the name of the voltage, when the diode gets conductive?

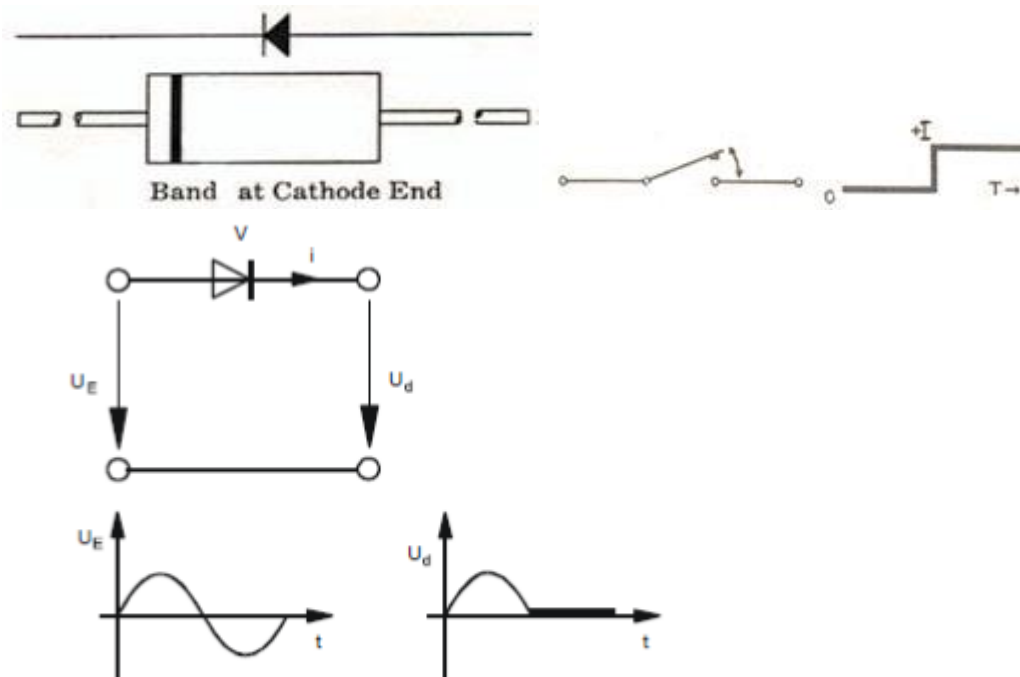
Answer:

2.3 Single Pulse Center Tapped Circuits M1

2.3.1 Basics

If a semiconductor diode is integrated to a circuit, current flow is only possible at one polarity of the applied voltage (bias direction).

When polarity is reversed the blocking function is effective and no current will flow. If AC voltage is applied to such a circuit, it is only conductive at the half wave with the respective polarity. The other half wave is blocked. Current within the circuit will flow only in one direction.



pic. 1.5 M1 single pulse center tapped circuit

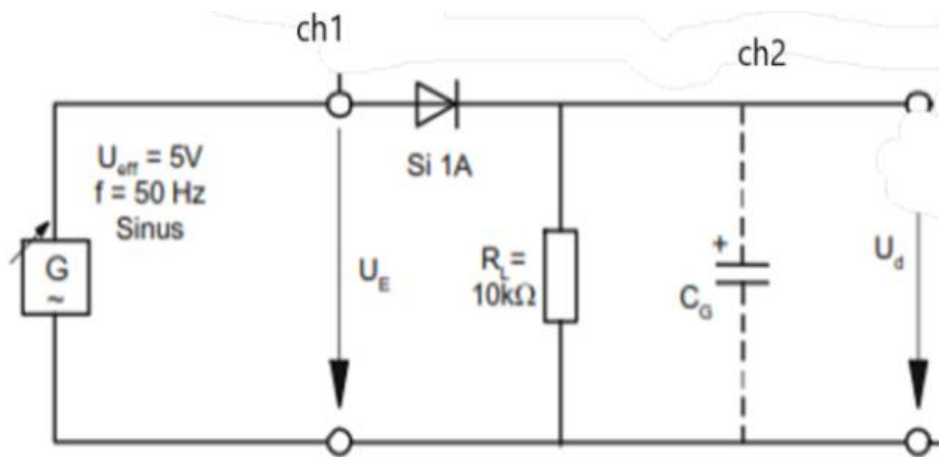
2.3.2 Tests

Test

Examine the rectifying effect of a semiconductor diode within a single pulse center tapped circuit M1 with a multimeter and an oscilloscope.

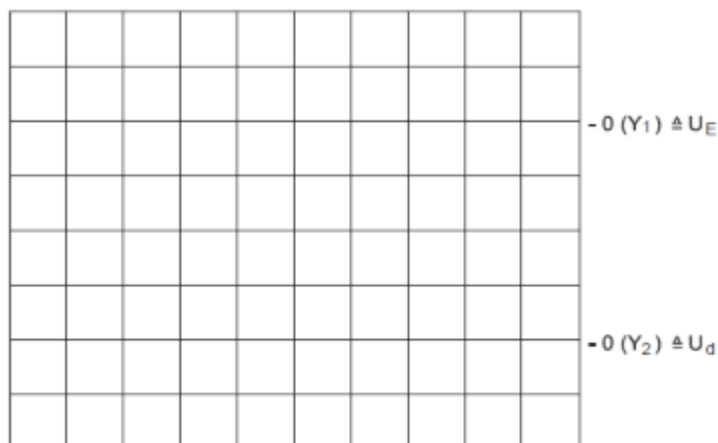
Test proceeding

- Set-up the circuit in pic. 1.6 Without smoothing capacitor.
- Measure the input voltage U_E and the DC voltage U_d with the multimeter and calculate the ratio between U_d and U_E .



pic. 1.6

- Measure the input voltage U_E and the DC voltage U_d with the oscilloscope and draw the curve in pic. 1.7.
- Determine by help of the oscilloscope picture in pic. 18.7 the peak-peak-value and the frequency of the ripple U_{Br} .
- **Note:** Ripple is the AC portion of a pulsating DC voltage U_d



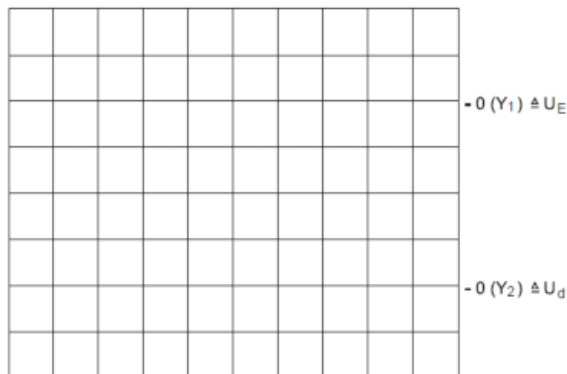
pic. 1.7

Then connect the smoothing - capacitor C_G according to chart 1.3 in parallel to load resistance and repeat your measurements.

Please regard the polarity when connecting the electrolytic capacitors! Fill all determined values in chart 1.3.

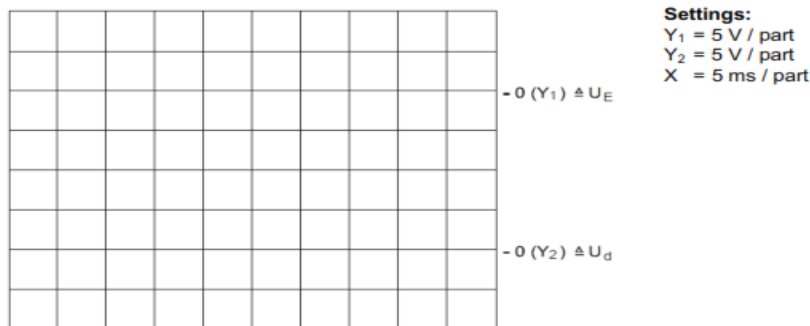
| C | non | $10\mu F$ | $100\mu F$ |
|-----------------------|-----|-----------|------------|
| $V_{inp\ eff}(V)$ | 5V | | |
| $V_d\ (V)$ | | | |
| $\frac{V_{inp}}{V_d}$ | | | |
| Ripple= V_{pp} | | | |
| F out | | XXXX | XXXX |

- Draw the curve for the input voltage U_E and the DC voltage U_d , with smoothing capacitor $10\ \mu\text{F}$ into the chart in pic. 1.8.



pic. 1.8

- Reverse the diode within the circuit in pic. 1.4, measure the voltages U_E and U_d without smoothing capacitor.
- Draw the curves for both voltages into the chart 1.9



pic. 1.9

Test 1: What is the frequency of the ripple U_{Br} ?

Answer:

Test 2: What happens if the diode in circuit pic.1.6 is reversed in polarity?

Answer:

Test 3: At which connector of the diode is the plus pole of the obtained DC voltage U_d ?

Answer:

Test 4: State the value of blocking voltage affecting the diode with smoothing capacitor CG?

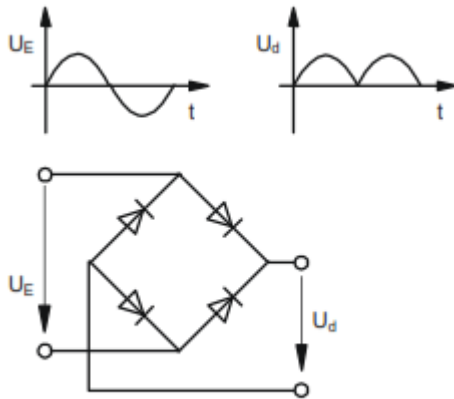
Answer:

Test 5: What influence does the smoothing capacitor have on the peak-peak-value of the ripple?

2.4 Two-Pulse Bridge Circuit

2.4.1 Basics

At the single pulse center-tapped circuit M1 only a half wave of the AC voltage is used. Disadvantage is the small portion of DC voltage with high ripple. This disadvantage is avoided in the two-pulse bridge B2, as polarity of the opposed half-wave is changed and added to the DC voltage?

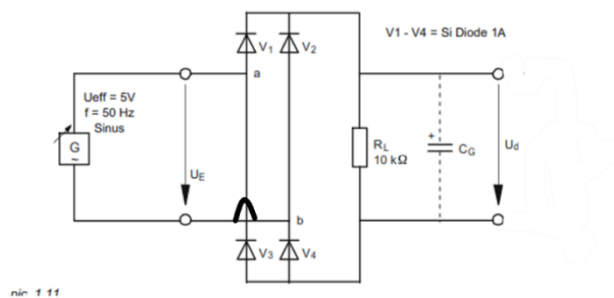


pic. 1.10 B2 Two-pulse Bridge Circuit

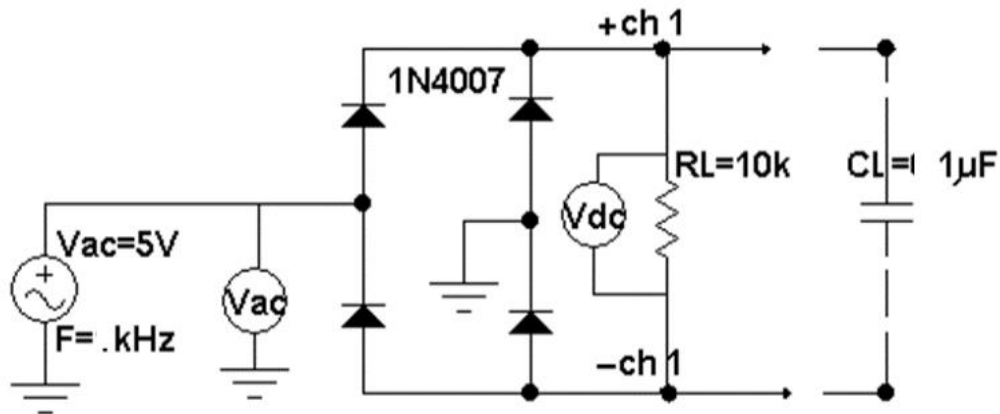
2.4.2 Tests

Test

Examine by help of the oscilloscope and multimeter the characteristics of two-pulse bridge B2.

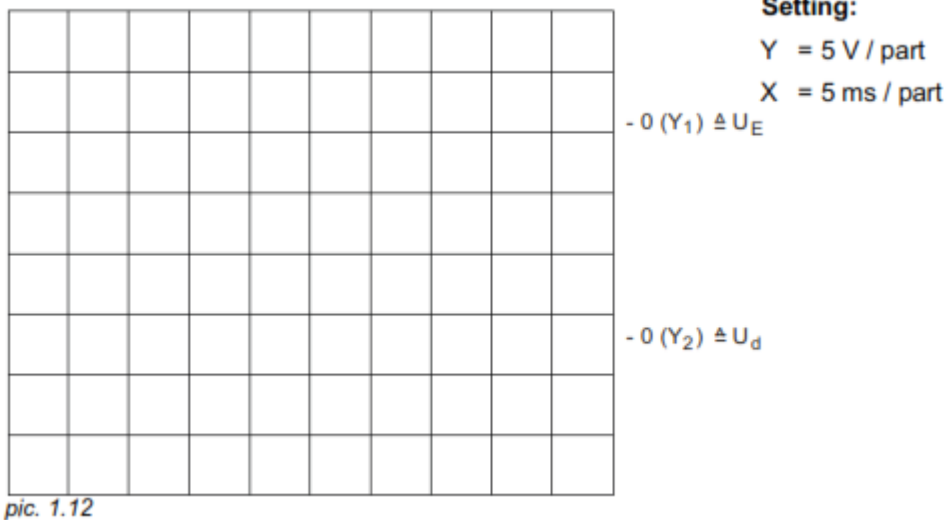


pic. 1.11



Test proceeding:

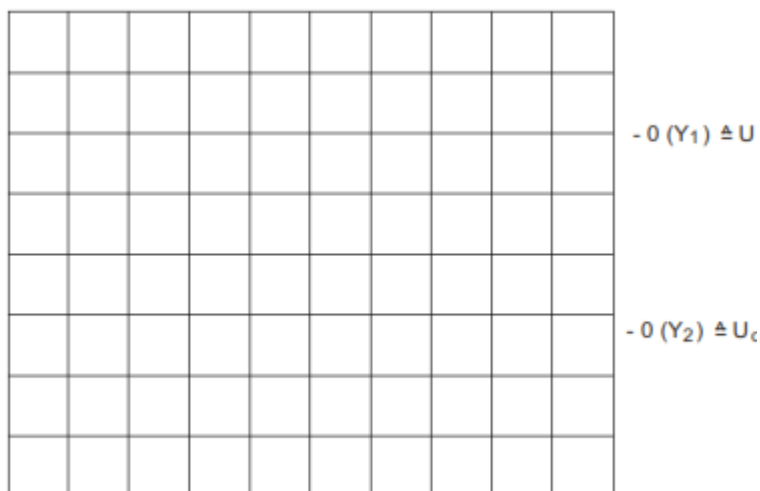
- Set-up the circuit in pic. 1.11 Without smoothing capacitor. Measure input voltage U_E and DC voltage U_d with your multimeter and determine the ratio U_d
- Measure with the oscilloscope all the input voltages U_E to U_E . and DC voltages U_d and draw the curve into pic. 1.12.
- Determine by help of the oscilloscope curve in pic. 1.12 the peak-peak-value and the frequency of ripple voltage U_{Br} .
- **Note:** Ripple voltage is the portion of AC voltage within pulsating DC voltage U_d .



- Then one by one connect the smoothing capacitors C_G in parallel to the load resistor R_L according to chart 1.5 and repeat your measurements.
- **Please regard** the polarity when connecting the electrolytic capacitor!
- Fill the determined values in chart 1.5.

| | | | |
|------------------------|-----|-----------|------------|
| C | non | $10\mu F$ | $100\mu F$ |
| $V_{in\text{ eff}}(V)$ | 5V | | |
| $V_d (V)$ | | | |
| $\frac{V_{in}}{V_d}$ | | | |
| Ripple= V_{pp} | | | |
| F out | | | |

- Draw the curve for the input voltage U_E and the DC voltage U_d with smoothing capacitor $10\mu F$ in chart 1.13.



pic. 1.13

Test 1: What is the ratio between DC voltage U_d and the applied effective input voltage U_E (without smoothing capacitor)?

Answer:

Test 2: What is the frequency of the ripple voltage U_{Br} ?

Answer:

EXPERIMENT # 3


Zener diodes and applications

3.1 Conducting and blocking characteristics of Z-Diodes

3.1.1 Basics

Z-Diodes are silicon-semiconductor diodes, with conduction curve similar to rectifier diodes. In comparison to rectifier diodes, the Z-diode has a lower breakdown voltage within stop – or reverse band (Z-Voltage). When exceeding the breakdown voltage, current increases steeply in reversed direction (Zener effect). In opposite to the rectifier diodes, Z-diodes are utilized in reversed direction.

To protect from overload, a resistor is connected in series to the Z-diode, its value is calculated as follows:

$$R_V = \frac{U_b - U_Z}{I_Z + I_L}$$


U_b = applied operating voltage

U_Z = Zener-voltage of the utilized diode-type

I_Z = average acceptable Z-current

I_L = current affecting the load resistance R_L in parallel to the Z-diode

Circuit Symbol

pic. 2.1

Due to its characteristics the Z-diodes are used for voltage stabilization and voltage limitation.

3.2 DC Voltage Limitation with Z-Diodes

3.2.1 Basics

Because of the steep increasing current in the reverse band of a Z-diode, it is used for limitation of DC voltage.

Therefore a resistor, at which the difference between the unstable input voltage and the limited output voltage drops, is connected in series to the Z-diode.

Limited output voltage is equal to the Z-voltage and is depending on the Z-diode type.

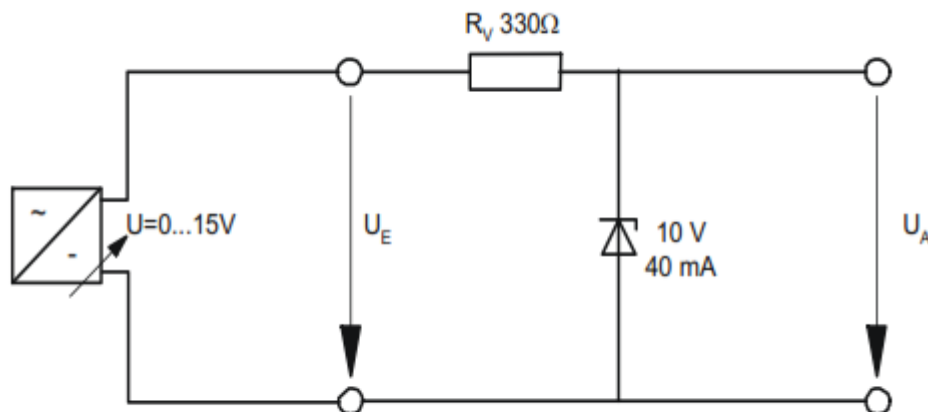
3.2.2 Tests

Test 1

Examine the relationship between output voltage and input voltage at a limiter circuit with Z-diodes.

Test proceeding:

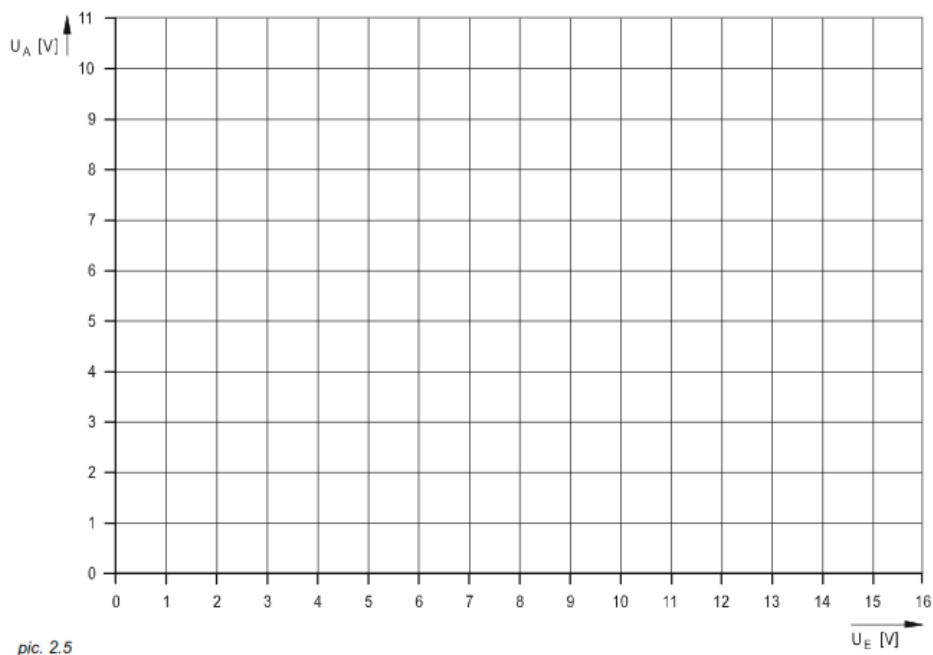
- Set-up the circuit in pic. 2.4. One by one set to DC voltages U_E according to chart 2.1.auf.
- Measure the respective output voltages with the multimeter and fill in chart 2.1.
- Graphically present the relation between output voltage and input voltage within the diagram 2.5.



pic. 2.4

| U_E [V] | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|-----------|---|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|
| U_A [V] | | | | | | | | | | | | | | | | |

chart 2.1

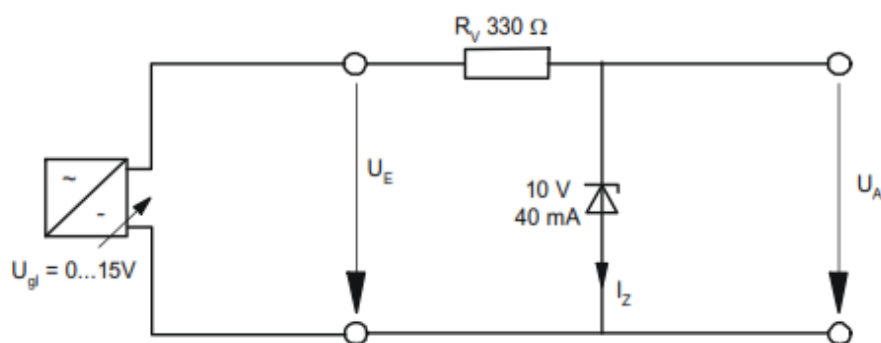


Test 2

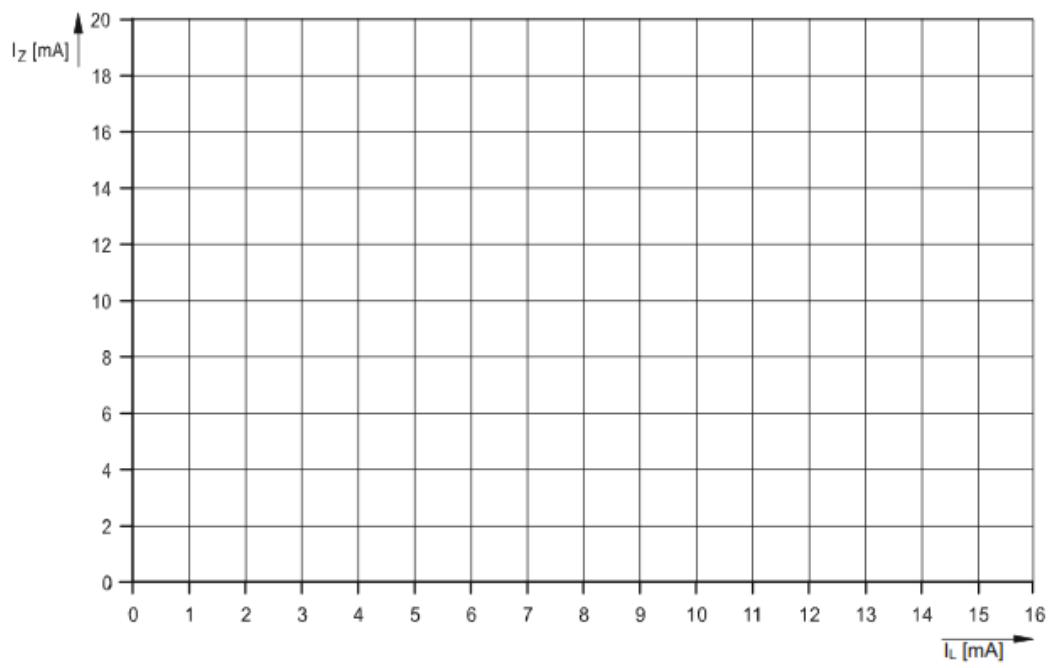
Examine the relationship between Z-current I_Z and input voltage

Test proceeding:

- Set-up the circuit in pic. 2.6. One by one set the DC voltages U_E according to chart 2.6.
- Measure the respective Z-currents I_Z with the multimeter and fill the current values in chart 2.2.
- Graphically present the relation of Z-current I_Z and input voltage U_E in the diagram pic. 2.7.



| $U_E(V)$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|-----------|---|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|
| $I_Z(mA)$ | | | | | | | | | | | | | | | | |



pic. 2.7

Test 3

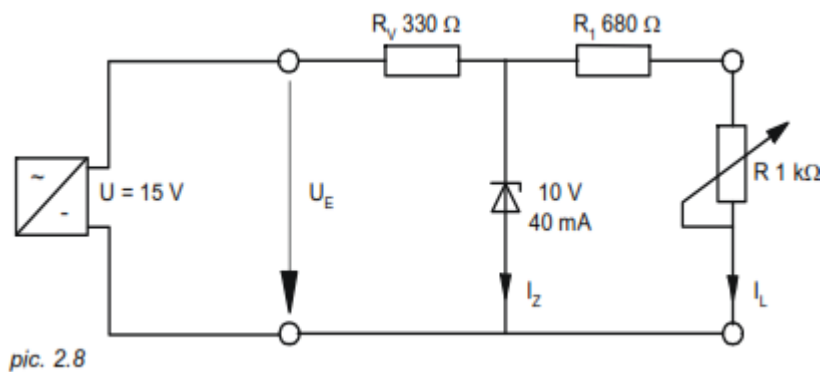
Measure the effects of load current I_L on Z-current

Test proceeding:

- Set-up the circuit in pic. 2.8. Adjust the potentiometer to the load currents I_L according to chart 2.3.

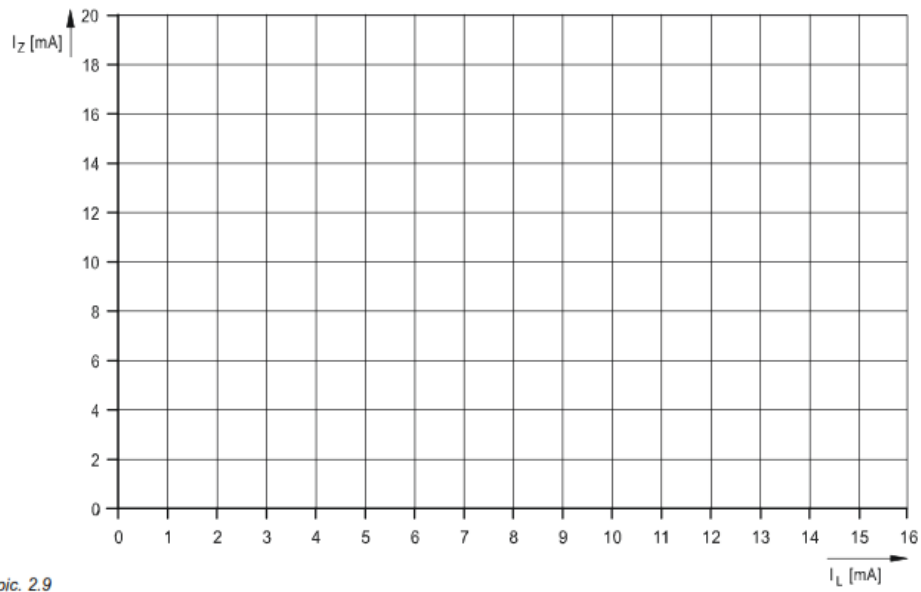
Note:

- Increase the resistor R_1 to 1 k Ω , 2,2 k Ω , 4,7 k Ω and 10 k Ω , use low load current.



- Graphically present the relation between Z-current I_z and load current I_L within the diagram pic. 2.9.

| $I_L(\text{mA})$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|------------------|---|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|
| $I_z(\text{mA})$ | | | | | | | | | | | | | | | | |



Test 1: What condition is needed that the output voltage remains constant in a limiter circuit with Z-diode?

Answer:

Test 2: When does Z-current I_Z flow?

Answer:

Test 3: Under which condition is the limiting effect maintained although under load?

Answer:

3.3 AC Voltage Limiting and Overvoltage Protection with Z-Diodes

3.3.1 Basics

If the voltage applied to a Z-diode is less than Z voltage, no current is flowing. Current only flows if the value of Z voltage is reached or exceeded. Therefore this component could be used to protect other parts (e. g. MOS-components) from over voltage.

To avoid a rectifying effect due to low threshold voltage, two Z-diodes are connected in opposite, thus a polarity independent voltage limitation is received.

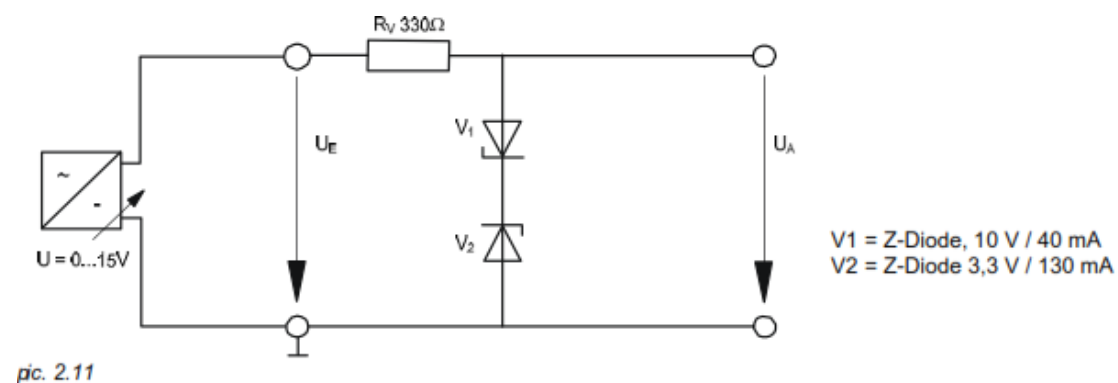
3.3.2 Tests

Test 1

Statically record the curve $U_A = f(U_E)$ of two in opposite directed Z-diodes.

Test proceeding:

- Set-up the circuit in pic. 2.11. One by one set to DC voltages U_E according to chart 2.6.
- Measure the respective output voltage U_A with your multimeter and fill in chart 2.6.
- Then reverse the poles of input voltage V_E and go on with your measurements. Note the respective output voltages V_A in chart 2.7.



pic. 2.11

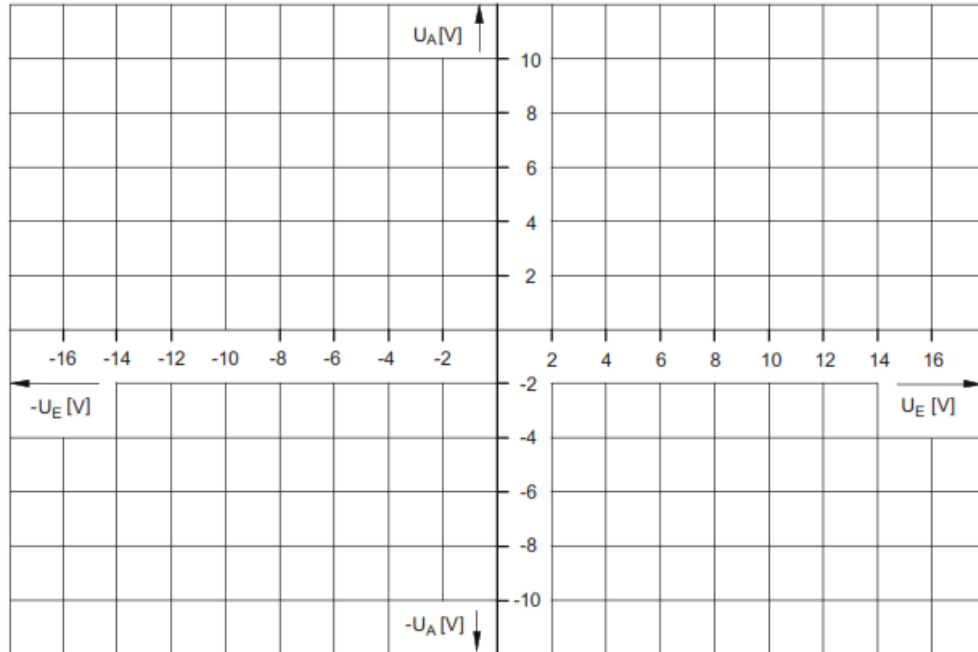
- Graphically present the relation between output voltage U_A and input voltage U_E in chart 2.6.

| $U_E [V]$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|-----------|---|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|
| $U_A [V]$ | | | | | | | | | | | | | | | | |

chart 2.6

| $-U_E$ [V] | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|------------|---|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|
| $-U_A$ [V] | | | | | | | | | | | | | | | | |

chart 2.7



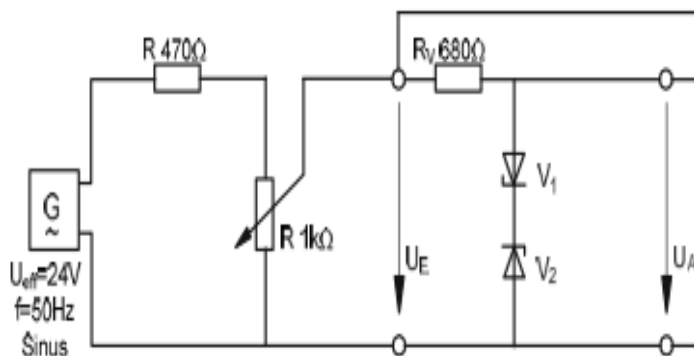
pic. 2.12

Test 2

Examine with your oscilloscope the voltage limiting effect of two opposite directed Z-diodes.

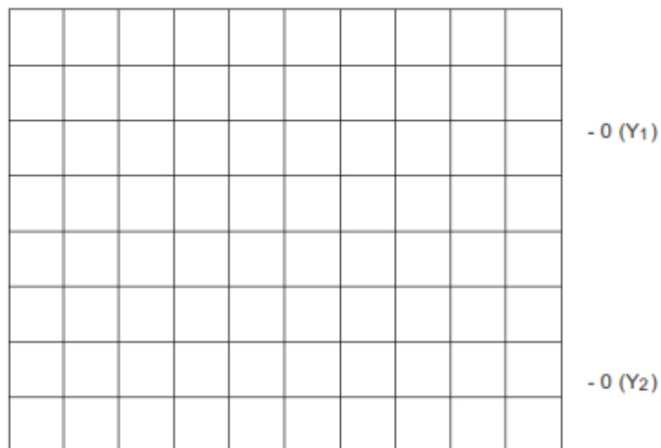
Test proceeding:

- Apply a sine-wave AC voltage $U_{eff} = 10\text{ V}$; $f = 50\text{ Hz}$ to the circuit in pic. 2.14 and set the input voltage to $U_{E\text{ eff}} = 2\text{ V}$ at the potentiometer.



pic. 2.14

- Measure the input voltage U_E and output voltage U_A with your oscilloscope and draw the curve into diagram pic. 2.15.
- Then increase input voltage to $U_{E\text{ eff}} = 10\text{ V}$.
- Repeat your measurements and fill the values into pic. 2.16.



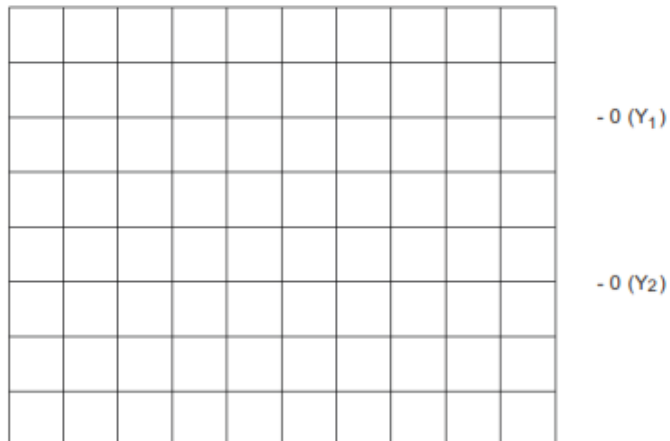
pic. 2.15

Notes:

Y_1 = input voltage U_E
 Y_2 = output voltage U_A

Settings:

X = 5 ms / part
 Y_1 = 2 V / part
 Y_2 = 2 V / part



pic. 2.16

Notes:

Y_1 = Input voltage U_E
 Y_2 = Output voltage U_A

Settings:

X = 5 ms / part
 Y_1 = 10 V / part
 Y_2 = 5 V / part

Test 1: Do you know the application possibilities for a Z-diode?

Answer:

Test 2: State the advantage of two opposed directed Z-diodes?

Answer:

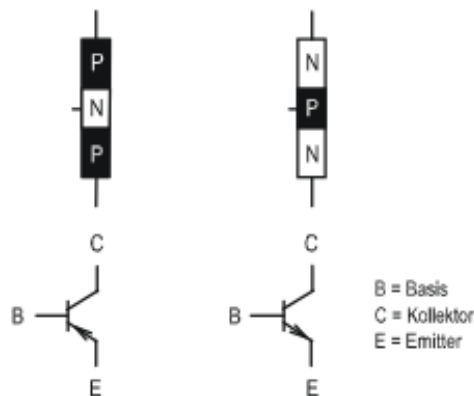
EXPERIMENT # 4

Bipolar Transistor

4.1 Basics

Transistors are 3-layers semiconductor components with two p-n-junctions each. The n-p-n transistors have a thin p-conductive layer between the two n-conductive layers. The p-n-p transistors have a thin n-conductive layer embedded between two p-conductive layers.

The p-n-junction between the mid-layer (base) and the two outer layers (emitter and collector) have rectifying effect, this could be examined likewise to any other rectifier diode.



Test

Examine the effect of the p-n-junctions of a n-p-n transistor on the conductivity in dependence of the supply voltage and its polarity. Repeat same the test with a p-n-p transistor. Note the basic differences to the n-p-n transistor.

Then repeat the measurements with a p-n-p transistor (Art no. 503.130.004) and give your statement for the base/ emitter path and the collector/base path at what polarity the junctions of p-n-p transistors and n-p-n transistors are conductive or blocked. Fill your results in chart 4.6.

| | Polarity | NPN-Type | PNP-Type |
|---|----------------------|----------|----------|
| base/ emitter junction (conductive or blocked) | base + / emitter - | | |
| | base - / emitter + | | |
| collector/ base junction (conductive or blocked) | collector - / base + | | |
| | collector + / base - | | |

chart 4.6

Test 1: Name the basic characteristics of the two p-n-junctions of a transistor.

Answer:

Test 2: What characteristic of the p-n-junction from base and emitter is different from base and collector?

Answer:

Test 3: What needs to be regarded when changing a circuit from n-p-n transistors to p-n-p transistors?

Answer:

4.2 Current Distribution within a Transistor and Control Function of Base Current

4.2.1 Basics

Due to the conductive p-n-junction load carriers from the emitter will be accelerated into the extreme thin basis layer, they will break down the opposing blocked p-n-junction between collector and base, and are biased towards the collector. Base current I_B is less than emitter current I_E by the value of this collector current I_C .

Base current influences the value of the collector current. The relation between those both currents is called the current amplifier ratio B .

$$B = I_E - I_C \qquad B = \frac{I_C}{I_B}$$

Low signal current amplification β is:

$$\beta = \frac{\Delta I_C}{\Delta I_B}$$

The terminal connection of the transistor with negative or positive polarity is given by its layering. With n-p-n transistors base and collector are positive in reference to the emitter, with the p-n-p transistor it is negative.

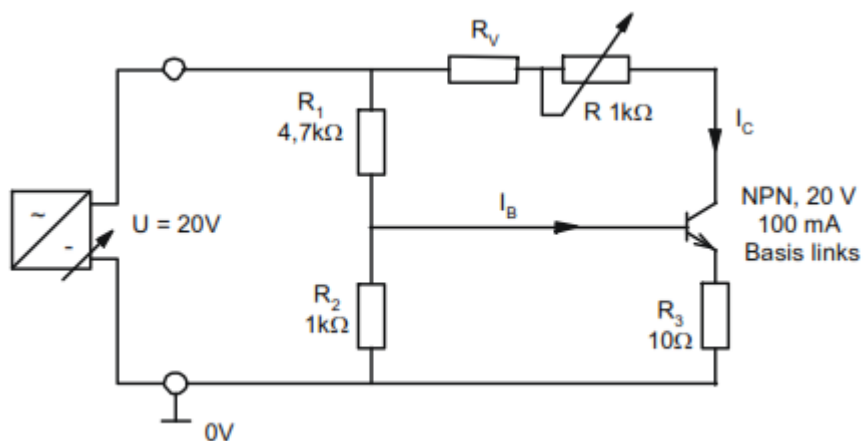
4.2.2 Tests

Test 1

Examine statically the influence of the collector current in reference to the base current. Repeat same test for the n-p-n transistor.

Test proceeding

- Apply DC voltage of $U_{gl} = 20 \text{ V}$ on the circuit in pic. 4.5. Measure the base current I_B with interrupted collector conductance (remove potentiometer) and fill the value in chart 4.7.
- Add potentiometer to the circuit and adjust the collector currents according to chart 4.7. Add the values for the base current into chart 4.7.

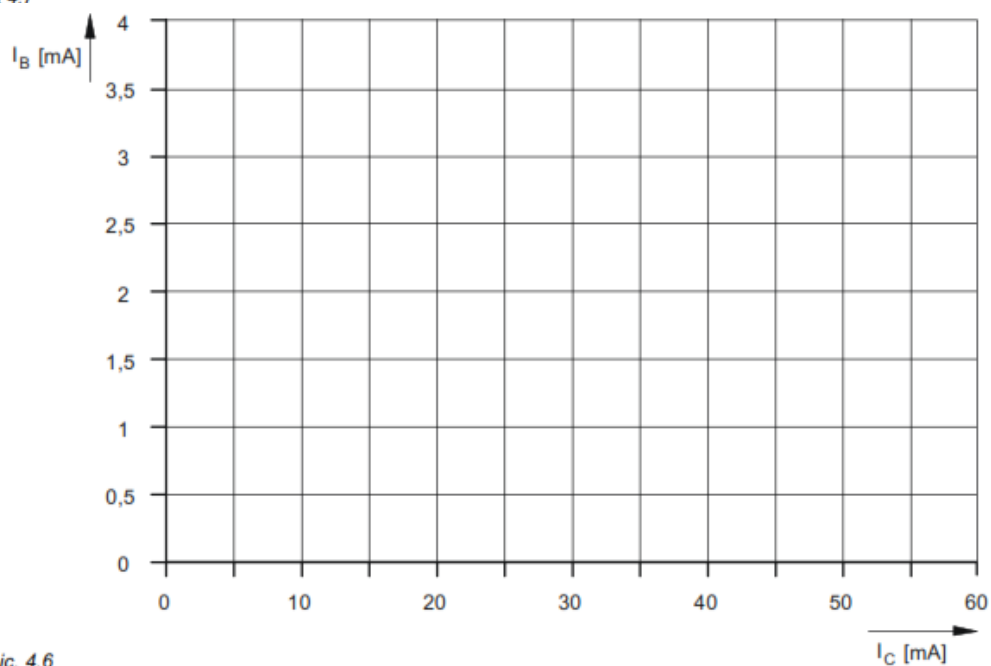


pic. 4.5

- Graphically represent the relation between base current I_B and collector current I_C (with constant base/emitter current) within the diagram pic. 4.6.
 $I_B = (I_C)$, U_{BE} constant

| | | | | | | | |
|-------------------|----------|------|-----|-----|-----|-----|-----|
| $R_V [\Omega]$ | ∞ | 1000 | 680 | 470 | 470 | 330 | 220 |
| $I_C [\text{mA}]$ | 0 | 20 | 25 | 30 | 40 | 50 | 60 |
| $I_B [\text{mA}]$ | | | | | | | |

chart 4.7



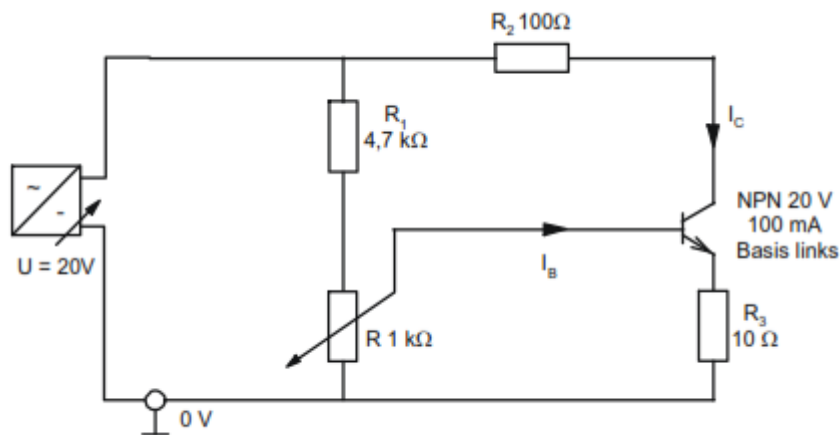
pic. 4.6

Test 2

Examine statically the influence of base current to the collector current. Use n-p-n transistors for this test.

Test proceeding:

- Set-up the circuit in pic. 4.7. Adjust the base current according to the values in chart 4.8.
- Measure the respective collector current I_C and fill the values in chart 4.8.



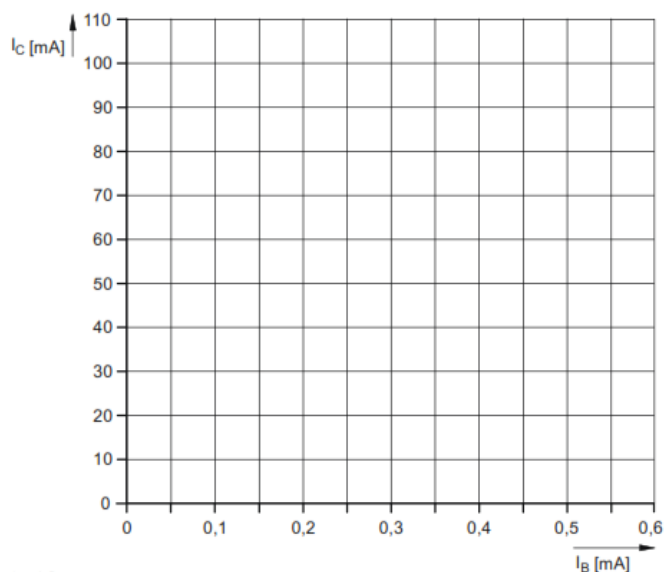
pic. 4.7

- Graphically present the relation between collector current and base current within the diagram pic. 4.8.

$$I_C = f(I_B)$$

| I_B [mA] | 0 | 0,05 | 0,1 | 0,15 | 0,2 | 0,25 | 0,3 | 0,35 | 0,4 | 0,45 | 0,5 |
|------------|---|------|-----|------|-----|------|-----|------|-----|------|-----|
| I_C [mA] | | | | | | | | | | | |

chart 4.8



pic. 4.8

Test 1: What do we learn from the curve in pic. 4.8?

Answer:

Test 2: What is the current amplification factor B at $I_C = 55 \text{ mA}$ (see pic. 4.8)?

Test 3: What is the small signal current amplification β (see pic. 4.8)?

Answer:

$$B = \frac{I_C}{I_B} =$$

Answer: small signal current amplification at

$$\Delta I_C = 40 \text{ mA} - 20 \text{ mA} \quad \beta = \frac{\Delta I_C}{\Delta I_B} =$$

small signal current amplification

$$\Delta I_C = 80 \text{ mA} - 70 \text{ mA} \quad \beta = \frac{\Delta I_C}{\Delta I_B} =$$

4.3 Characteristics of a Transistor

4.3.1 Basics

Characteristics of the transistor could be presented in 4 curves.

Input characteristic

- The input characteristic show the relation between base current I_B and base/ emitter voltage U_{BE} (at short-circuit output).

Output characteristic

- The output characteristic shows the relation between collector current I_C and collector/ emitter voltage U_{CE} with different constant base currents.

Control characteristic

- The control characteristic shows the relation between collector current I_C and base current I_B

Reverse voltage transfer characteristic

- Reverse voltage transfer characteristic show the relation between different constant base currents U_{BE} and respective base/ emitter voltages U_{CE} .

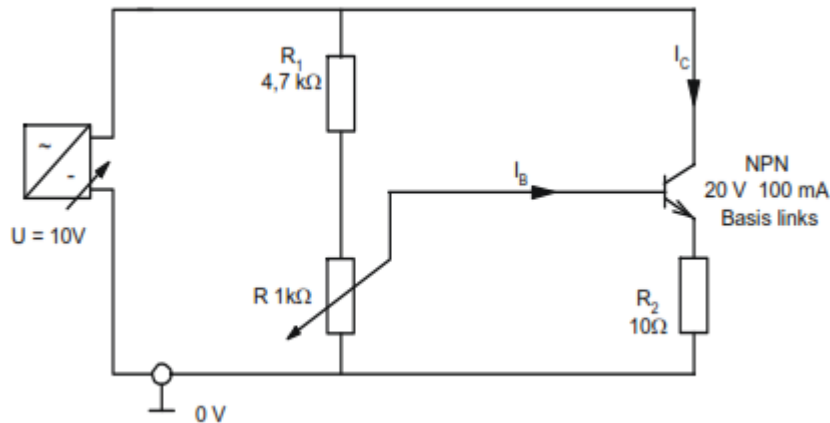
4.3.2 Tests

Test

- Measure the electric characteristics of a transistor and draw the 4 curves of the transistor (4 quadrants presentation).

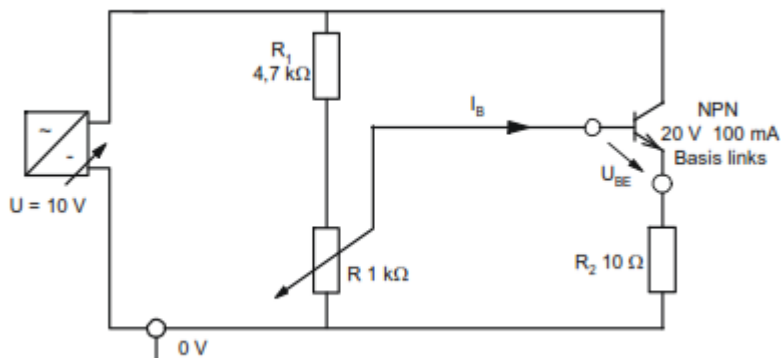
Test proceeding:

- Set-up the circuit in pic. 4.9. One by one adjust the potentiometer to the base currents I_B according to chart 4.9. Measure the respective collector currents I_C and fill in chart 4.9.
- Graphically present the relation between collector current and base currents $I_C = f(I_B)$ in the 2nd quadrant of the diagram pic. 4.13.



pic. 4.9

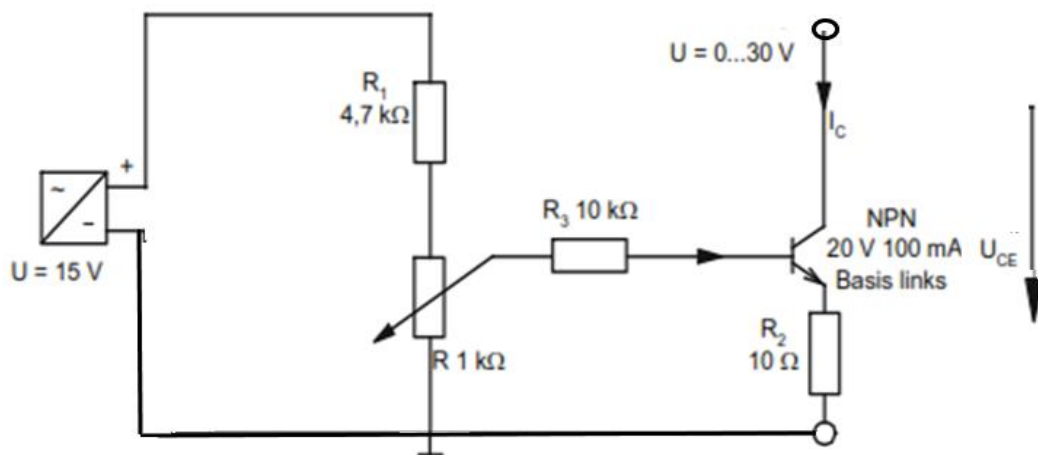
- Note:** At this and following measurements there are high tolerances in the measured values due to component heating. Temperature stabilizing measures are not practicable, as they would basically falsify the characteristic curves. Therefore we recommend reducing the current to zero for about 30 s after each measurement and short action for reading the measured values when current is applied. When drawing the curve the variations within the measurements have to be compensated by interpolating. Modify the circuit according to pic. 4.10, then one by one adjust the potentiometer to base/ emitter U_{BE} currents according to chart 4.10.
- Measure the respective base currents I_B and fill the values in chart 4.1. Graphically present the relation between the base current and the base/ emitter voltage $I_B = f(U_{BE})$ in the 3rd quadrant of the diagram 4.13.



pic. 4.10

□

- Then modify the circuit according to pic. 4.11, then measure the collector current I_C for different base currents I_B and collector/ emitter voltages U_C according to chart 4.11 and fill the values in to chart 4.11. Graphically present the relation between collector current and collector/ emitter current $I_C = f(U_{CE})$ for different base currents in the 1st quadrant of diagram 4.13.



pic. 4.11

- With the circuit according to pic. 4.11, then measure the base/ emitter voltage U_{BE} for different base currents I_B and different collector/ emitter voltages U_{CE} according to chart 4.12 and fill the values in chart 4.12. Graphically present the relation between base/ emitter voltage and collector/ emitter voltage $U_{BE} = f(U_{CE})$ for different base currents in the 4th quadrant of the diagram 4.13.
- Last examine the influence of the resistor R_2 . Therefore adjust the circuit according to pic. 4.9 to a collector current of $I_C = 3\text{ mA}$ bridge the resistor for about 2-3 s and regard the behavior of both ammeters.

Test 1: What is the duty of resistor R_2 within the emitter line?

Answer:

Test 2: Which parameter can control the collector current I_C ?

Answer

Control characteristic

| $U_{CE} = 10\text{ V}$ | | | | | | | | | |
|------------------------|---|----|----|----|----|-----|-----|-----|-----|
| $I_B [\mu\text{A}]$ | 0 | 20 | 40 | 60 | 80 | 100 | 120 | 140 | 160 |
| $I_C [\text{mA}]$ | | | | | | | | | |

chart 4.9

Input characteristic

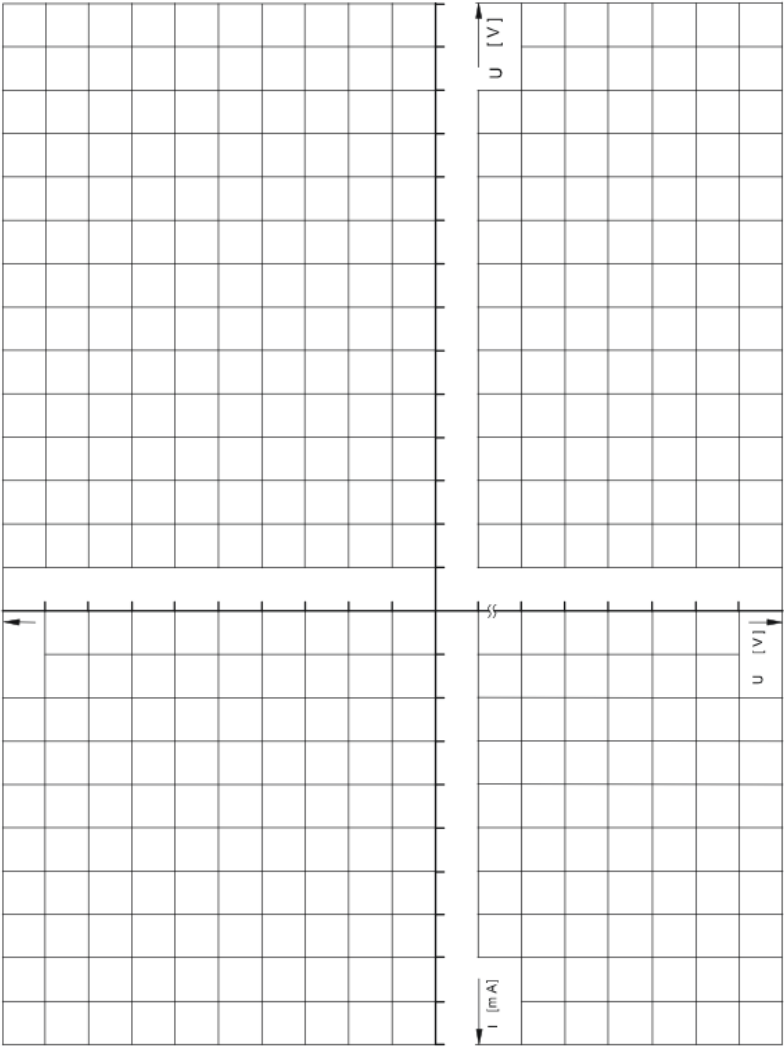
| $U_{CE} = 10\text{ V}$ | | | | | | | | | | |
|------------------------|---|-----|-----|------|-----|----------|----------|----------|----------|----------|
| $U_{BE} [\text{V}]$ | 0 | 0,5 | 0,6 | 0,65 | 0,7 | ca. 0,71 | ca. 0,71 | ca. 0,71 | ca. 0,71 | ca. 0,71 |
| $I_B [\mu\text{A}]$ | | | | | | | | | | |

chart 4.10

Output characteristic

Reverse voltage transfer characteristic

| V _{CE} | | 0 | 0.2 | 0.5 | 2 | 4 | 6 | 8 | 10 | 12 | 14 |
|----------------------------|-----------------|---|-----|-----|---|---|---|---|----|----|----|
| at I _b =20μA | I _c | | | | | | | | | | |
| | V _{BE} | | | | | | | | | | |
| at I _b =40μA | I _c | | | | | | | | | | |
| | V _{BE} | | | | | | | | | | |
| at I _b =60μA | I _c | | | | | | | | | | |
| | V _{BE} | | | | | | | | | | |
| at I _b =80μA | I _c | | | | | | | | | | |



pic. 4.13

EXPERIMENT # 5

Unipolar Transistors (Junction Field-Effect Transistor)

5.1 Control Function of the N-Channel-FET

5.1.1 Basics

Current flow through the channel of a field-effect transistor (Source/ Drain) is controlled by the gate potential. Unlike bipolar transistors, no voltage is required, as long as the p-n-junction between gate and channel is blocked.

Input characteristic or control characteristic of a FET shows the relation between gate/ source voltage U_{GS} and drain current I_D .

With the characteristic curve steepness S could be determined, which shows the exact voltage amplification

S = Steepness in mA/V

ΔI_D = Change of Drain Current in mA

ΔU_{GS} = Change of Gate/Source Voltage in mA

$$S = \frac{\Delta I_D}{\Delta U_{GS}}$$

5.1.2 Tests

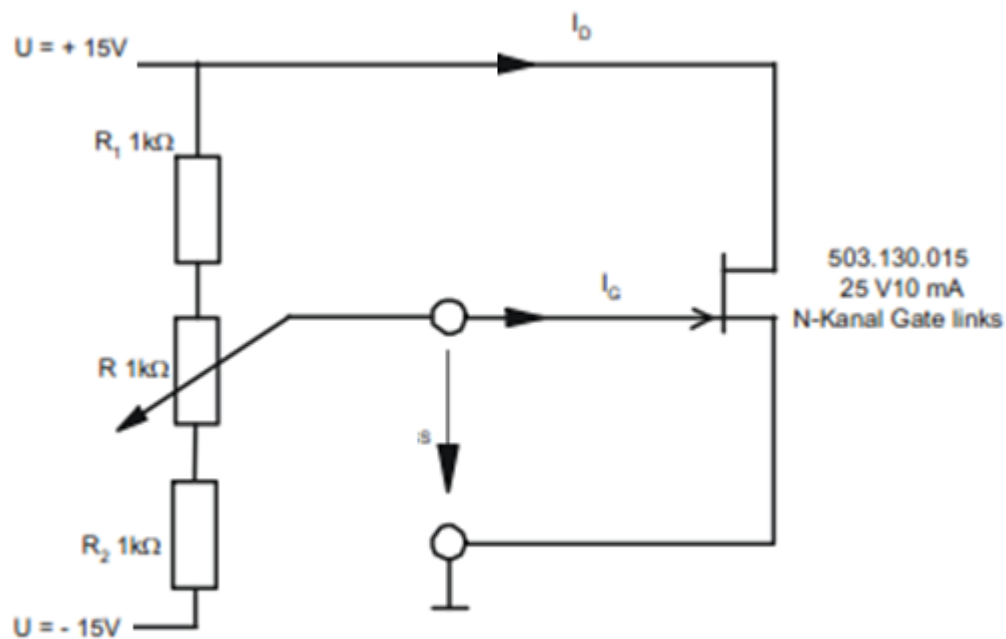
Test

Examine the influence of the gate/ source voltage on the gate current and drain current. Draw the control curve:

$$I_G = f(U_{GS}); I_D = f(U_{GS})$$

Test proceeding:

□ Set-up the circuit in pic. 5.6 and change the gate/ source voltage U_{GS} in steps shown in chart 5.4. Measure each gate current I_G and drain current I_D with your multimeter and fill the values in chart. 5.4 and 5.5.



pic. 5.6

Graphically present the relation between gate I_G current and gate/ source voltage U_{GS} in diagram 5.7.

$$I_G = f(U_{GS})$$

| U_{GS} [V] | -4 | -3 | -2 | -1 | 0 | +0,5 | +0,6 | +0,7 | +0,75 |
|--------------|----|----|----|----|---|------|------|------|-------|
| I_G [mA] | | | | | | | | | |

chart 5.4

$U_{DS} = 15 V$

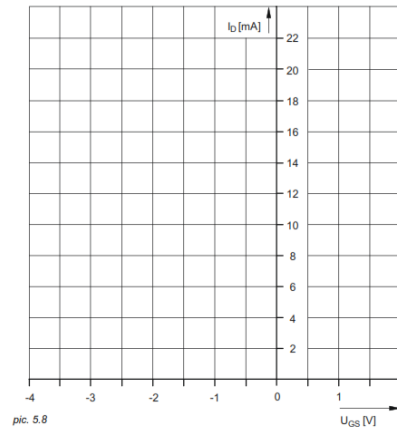
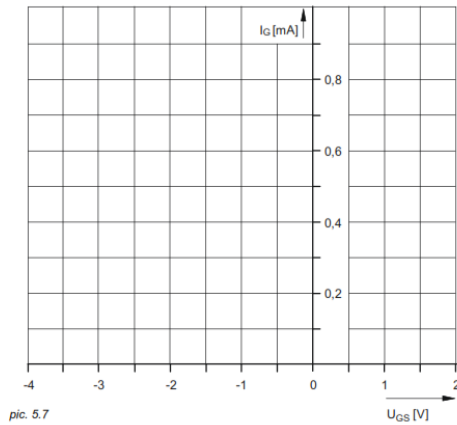
Graphically present the relation between drain current I_D and gate/ source voltage U_{GS} in diagram 5.8.

$$I_D = f(U_{GS})$$

| U_{GS} [V] | -4 | -3 | -2 | -1 | 0 | +0,5 | +0,6 | +0,7 | +0,75 |
|--------------|----|----|----|----|---|------|------|------|-------|
| I_D [mA] | | | | | | | | | |

chart 5.5

$U_{DS} = 15 V$



Test 1: What is the steepness S of a FETs when change of gate/ source voltage is $U_{GS} = 1,0 \text{ V}$ and a respective change of drain current $I_D = 3,8 \text{ mA}$?

Answer:

Test 2: When is the field-effect-transistor controlled without voltage?

Answer:

5.2 Output Characteristics of FETs

5.2.1 Basics

Semiconductor-manufacturers not only state control characteristics of field-effect-transistors, but also output characteristics, showing the relation between drain current and a variety of constant drain/ source voltages.

Output characteristics are stated without working resistance (static values). The practically used working resistance is drawn into the characteristic curve, the graph shows the voltage amplification.

5.2.2 Tests

Test 1

Statically measure the relation between drain current and drain/ source voltage for different gate/ source voltages.

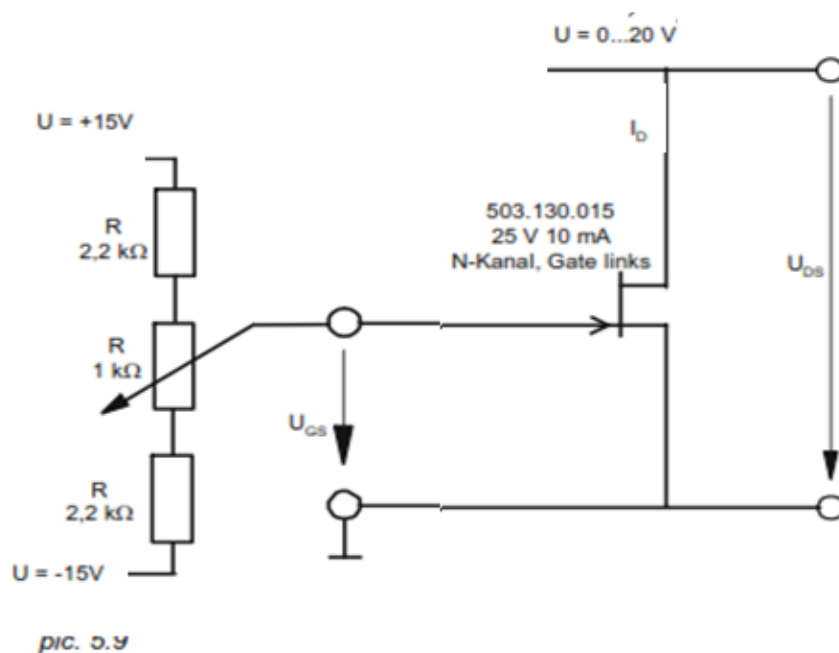
$$I_D = f(U_{DS})$$

Test proceeding:

Set-up the circuit in pic. 5.9, then measure with your multimeter the drain current I_D for each gate/ source voltage U_{GS} and drain/ source voltage U_{DS} according to chart 5.6.

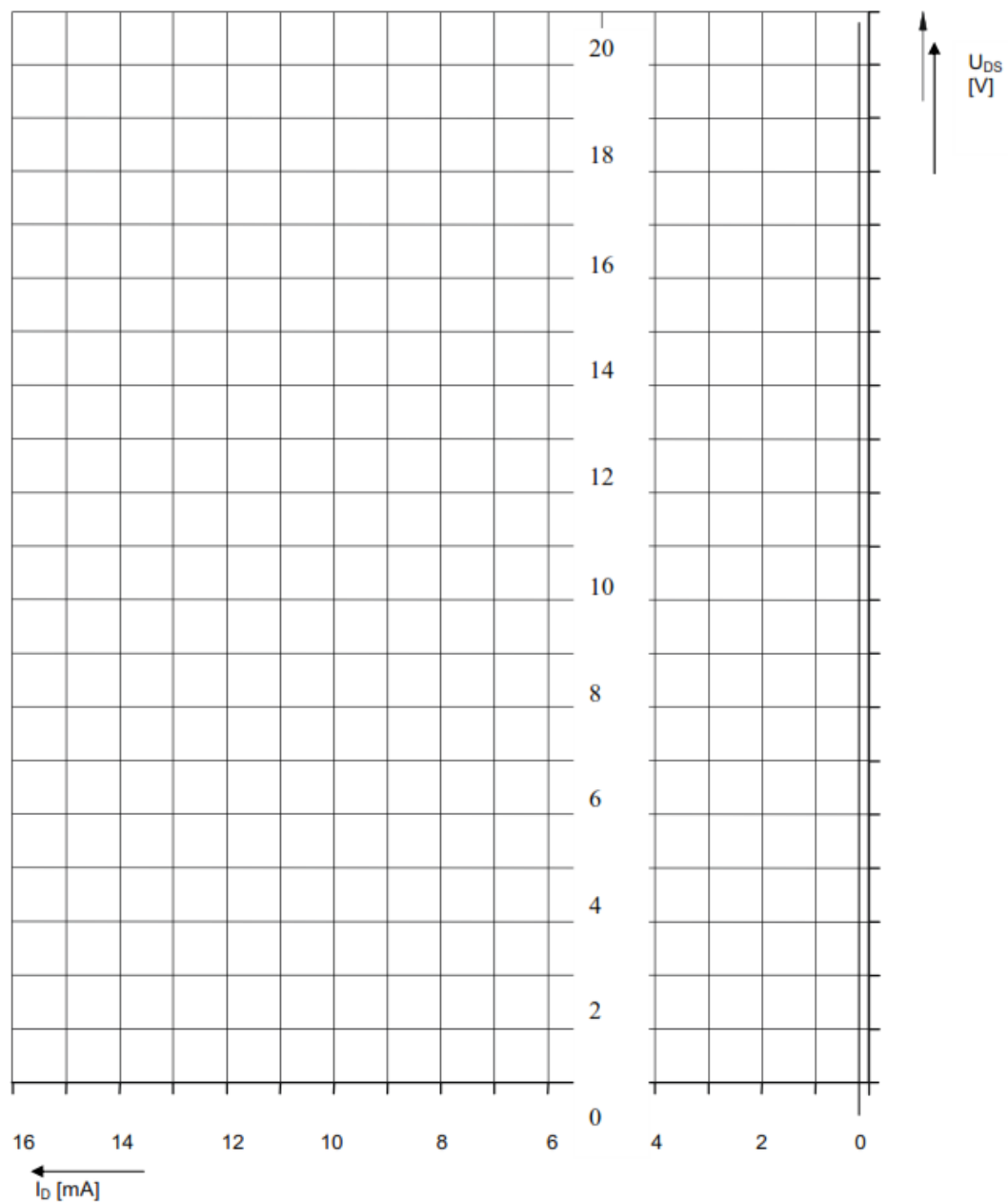
Fill the values for drain current I_D into chart 5.6.

Graphically present the relation between drain current I_D and drain/ source voltage U_{DS} for different gate/ source voltages U_{GS} .



| U_{DS} [V] | 0 | 0,5 | 1 | 1,5 | 2 | 3 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 |
|------------------------------------|---|-----|---|-----|---|---|---|---|---|----|----|----|----|----|----|
| I_D [mA] at $U_{GS} = -1,5$ V | | | | | | | | | | | | | | | |
| I_D [mA] at $U_{GS} = -0,5$ V | | | | | | | | | | | | | | | |
| I_D [mA] at $U_{GS} = 0$ V | | | | | | | | | | | | | | | |
| I_D [mA] at $U_{GS} = 0,5$ V | | | | | | | | | | | | | | | |

chart 5.6



pic. 5.10

Test 2

Examine the influence of working resistance to the field-effect-transistor.

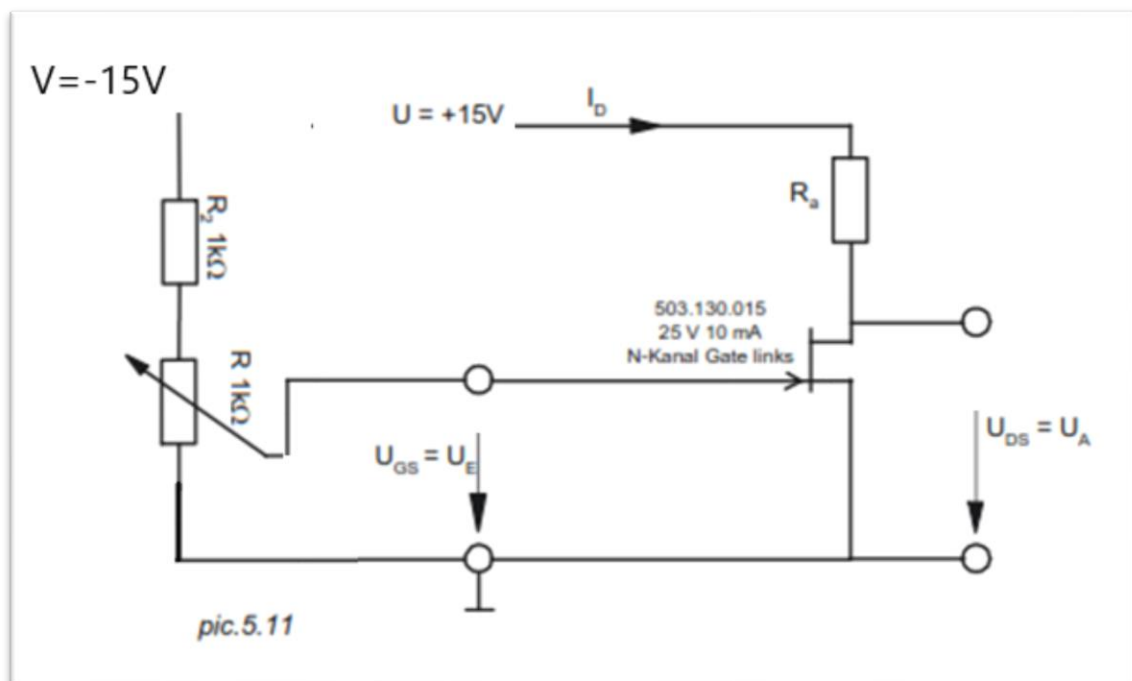
Test proceeding:

- ☐ Set-up the circuit in pic. 5.11 and measure with your multimeter the output voltage U_A for all working resistances R_a and input voltages U_E of chart 5.7.
- ☐ Fill your determined values into chart 5.7.
- ☐ Calculate the amplification v for different working resistances R_a with following equation:

$$v = \frac{\Delta U_A}{\Delta U_E}$$

$$\Delta U_A = U_{A1} - U_{A2}$$

$$\Delta U_E = U_{E1} - U_{E2}$$

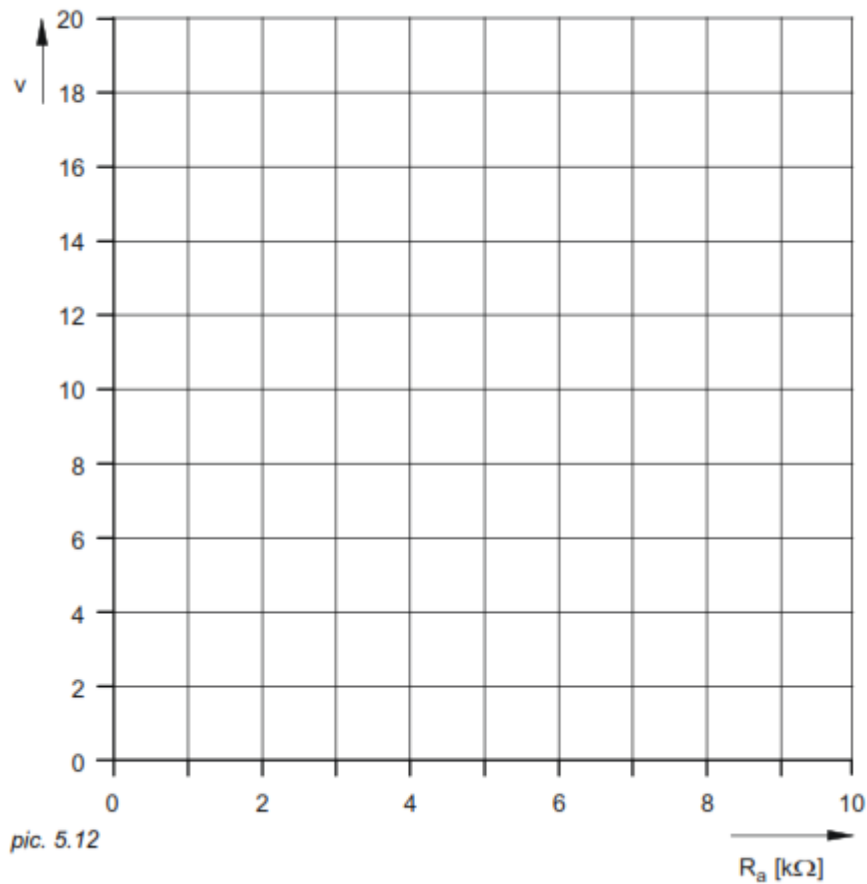


| R_a [kΩ] | 1 | 2 kΩ | 4,7 |
|-------------------------------|-----|------|-----|
| $-U_{E1}$ [V] | 0,5 | 1,0 | 1,5 |
| $-U_{E2}$ [V] | 1,0 | 1,5 | 2,0 |
| U_{A1} [V] | | | |
| U_{A2} [V] | | | |
| ΔU_E [V] | | | |
| ΔU_A [V] | | | |
| $v = \Delta U_A / \Delta U_E$ | | | |

chart 5.7

- Graphically present in chart 5.12 the relation between voltage amplification v and working resistance R_a in chart 5.12

- Draw the graph for the working resistance with $R_a = 2 \text{ k}\Omega$ into the diagram 5.10.



Test 1: How does the amplification factor v react, when working resistance R_a increases?

Answer:

Test 2: What is the amplification factor v at $U_E = -0,5 \text{ V} - (-1,5 \text{ V})$? Diagram in pic. 5.7 may help to find the answer.

Answer:

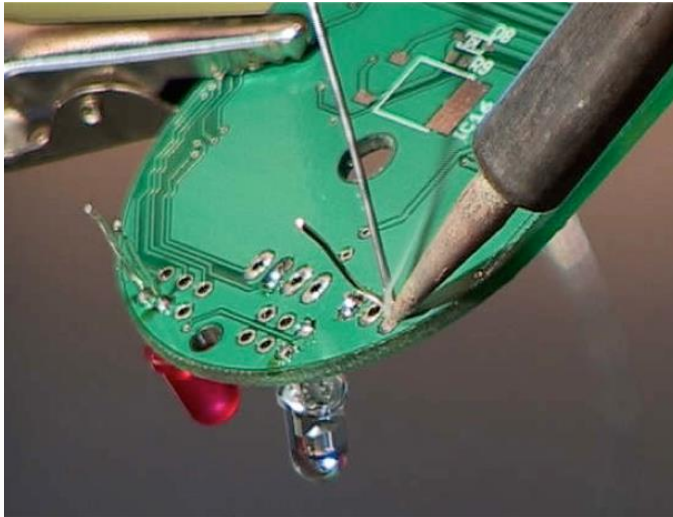
Test 3: What do the negative results for U_A indicate?

Answer:

EXPERIMENT # 6

Course Project: Soldering and disordering skills and build circuits

Soldering



Soldering is an essential skill for prototyping electronics and interactive systems.

Why? First, working with breadboards is hard, and sometimes you'll want your components to fit into other forms. Second, some of your components won't come with terminals or pins that neatly fit into your breadboard. Third, when you start to build more advanced solutions, you'll want to be able to permanently make connections so when you deploy and test your product wires don't come loose easily - hook up wire tends to do that!

Soldering is really important because:

- the breadboard is constraining and when you've build complex circuits,;
- when you need to add complex components sensors or circuits you need to give them terminals
- or large enclosures you might need to be able to break out of it

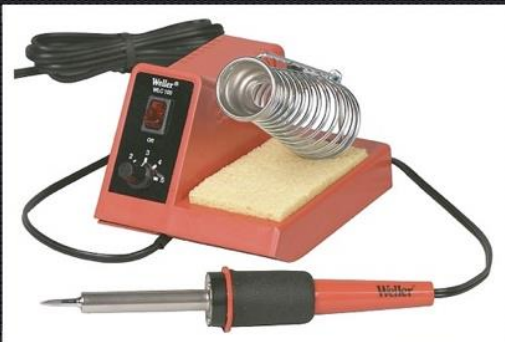
Soldering allows:



- Components to be joined to a PCB (printed component board)
- Sensors to be added to a breadboard
- Components 'reach' to be extended
- Wires to be joined and connected

Tools for soldering

- **The soldering iron:** this heats a metal tip to very high temperatures and allows you to melt metal onto wires or other connections to make permanent connections between wires or circuit boards
- **Solder:** This is what you melt onto your wires to join them using the tip of the soldering iron
- **Wire cutter:** The wire cutter lets you cut wire! It has a series of gauges allowing you to strip back the protective coating on wire easily to expose some wire to make connections.



Soldering iron



Solder



Wirecutter

Tools for Soldering

A guide to soldering

Before you begin soldering, you should make sure your soldering iron's tip is shine. When it is bright and shiny it will transfer heat much better. A dull tip can lead to weakly soldered connections which are prone to breaking and separating.

[If your soldering iron is exceptionally dull, you might need to clean it. There's tip tinner/cleaner in most of the labs you can use.

Before we begin using our soldering iron we'll want to tin it. First turn on the iron and heat it to around by turning the dial.

Hot hot heat

Be careful! The soldering iron gets extremely hot and you can give yourself a nasty burn if you're not careful.

Watch for solder that may drip too.

When tinning, apply a lot of solder, coat the tip of the soldering iron liberally. Once the solder has been applied, just wipe off the excess on the damp sponge. After wiping it off, you should have a tip that's extremely shiny. If its shiny it's ready to use.

Steps for soldering:

1. Turn on / heat up the iron
2. Check the tip of the iron is clean
3. Place the wires/components/board
4. Heat the joint with the iron
5. Feed in solder and it should spread
6. Remove iron, leave to cool (10 secs)
7. All done!



Tips for applying heat

Check your joint

Test your joint by gently pulling (not yanking) the wire and seeing if it is firm and well connected.

If it feels weak, you can easily fix it by reheat the joint and apply some new solder. Don't put hot solder on cold wires. Make sure you heat the both contacts/wire before applying new solder.

Tips and Common Mistakes

- Not enough heat: The joint may look ok, but if the solder didn't melt then you'll have a 'dry/cold' joint. This means it will come apart easily.
- Too much heat: Some components - like LEDs, semiconductors, switches. etc - are sensitive to heat and will get damaged if they are heated too much. Heat transfers along wires and may damage the components. It won't hurt the joint but it's useless if the component won't work any more. If you're soldering to a sensitive component, add a heat sink like an alligator clip to dissipate the heat
- Not enough solder / too much solder: A thin connection can be problematic. It may look OK on the outside, but the connection between the two contacts mightn't actually be made. Flip over the PCB to check if the solder has filled the pin completely
- Moving the joint before you completed complete: This could create a fracture and at some point this could break the joint. It's easily avoided by

clamping your components in place while soldering, fix the board in place or making sure you've a steady hand!

- Dirt or grease on the wire or joint: If a component or wire looks a little dirty, clean it off. Any contaminants or dirt will prevent the solder from sticking and a good connection being made. A bit of sandpaper will work a charm!
- Soldering iron not clean - tip has carbon: Over time the tip will become burnt. This stops the tip heating up properly. You need to make sure that you clean by wiping it on the sponge and that your iron is always shiny.
- Not testing the joint: Apply a little force to check its OK. Don't just assume that because it looks OK it is.

Don't panic

Don't worry if you get it wrong, you can re-apply heat and try to fix it. You can also de-solder (using a suction pump or desoldering wick) to remove the solder you've applied, but it's a bit tricky.

Thankfully, 9 times out of 10 you won't need to desolder

EXPERIMENT # 7

Basic Amplifier Circuits with Bipolar Transistors

7.1 General

Transistors can be operated in different basic amplifier circuits. These circuits are named after which electrode, which acts as a common reference electrode for the input and output signal voltage.

1. Emitter circuit.
2. Collector Circuit.
3. Base Circuit.

7.2 Test

Determine by measurement the electric characteristics of the three basic amplifier circuits:

- Voltage amplification factor V_U
- upper limiting frequency f
- resistance R_E
- output resistance R_A
- phase shift angle φ

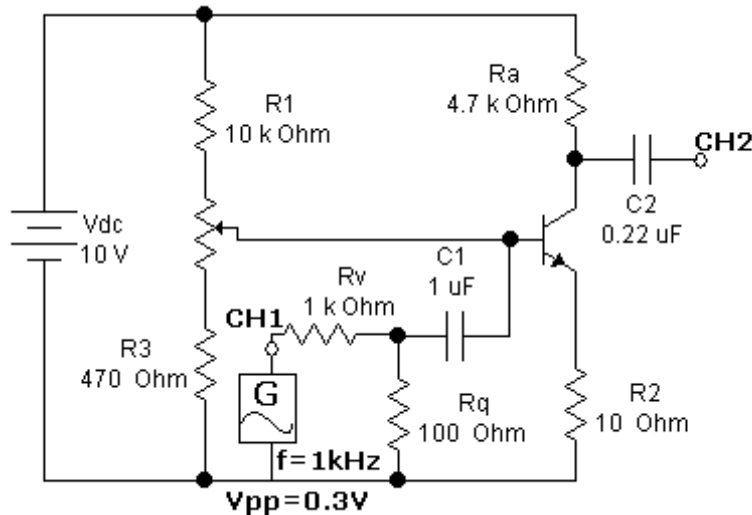
Operate the basic amplifier circuit as pure AC voltage amplifier, for isolation of supply voltage from signal voltage use capacitor C1, C2 and additionally for the base circuit C3.

Test proceeding:

7.2.1 Emitter circuit Tests

1. Apply sine-wave voltage to the input A of emitter circuit in pic. 6.1.:
 $f = 1 \text{ kHz}$, $V_{pp} = 30 \text{ mV}$

Note: For more convenient measurement of the low input voltage, select a voltage divider (RT 1) at the generator output. Thus, input voltage U_E at the measuring point B is $11 \times U_E = 0,33 \text{ V}$. Adjust the operation point of the thyristor with the potentiometer, until undistorted voltage is applied to measuring point C.



2. Measure input – and output voltage with the oscilloscope and draw the curve into diagram pic. 6.4 .Determine the phase shifting between UE and UA and calculate the voltage amplification factor with following equation:

$$\beta = \frac{V_O}{V_I}$$

3. Determine the upper limiting frequency. It is the frequency, when output voltage drops to 70,7% of its maximum value if frequency is increased.
4. Determine the input resistance RE . According to pic. 6.1 connect resistor RV with 470 Ω in series to the input (A). This will affect, that output voltage of value U1 drops to value U2. From both voltages and the familiar series resistor, you can calculate the input resistance RE

:

$$R_I = \frac{R_V}{\frac{V_1}{V_2} - 1}$$

5. Then determine the output resistance RA. Therefore connect the load resistor RL in parallel to output (C to earth), thus output voltage with value U1 drops to value of U2. From both voltages and the familiar load resistor, you can calculate the output resistance with following equation:

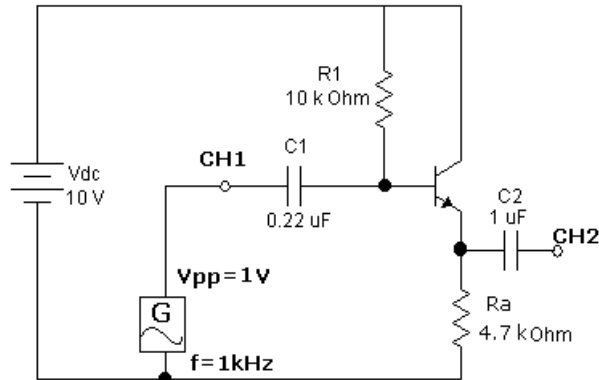
$$R_o = R_L \left(\frac{V_1}{V_2} - 1 \right)$$

- **Note** the determined values in chart 61.

7.2.2 Collector circuit test

- Then set-up the collector circuit in pic. 6.2. Repeat your measurements in the same way. Draw the curve into diagram 6.4 and note your values in chart 6.1.

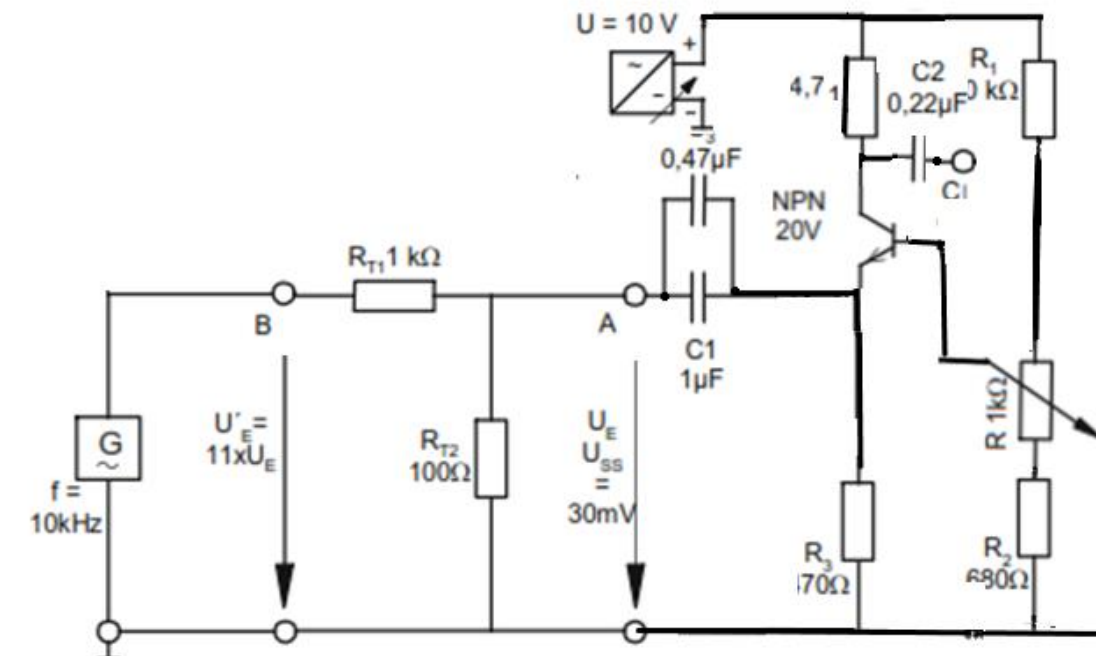
Note: For determination of the upper limiting frequency the function generator should have a frequency range of 5 MHz.



7.2.3 Base circuit test

- Set-up the base circuit in pic. 6.3 and repeat your measurements. Draw the curves in diagram 6.6. and note your values in chart 6.1.

Note: Use the measuring frequency of 10 kHz, as otherwise the reactance of the input coupling capacitor is not low enough in respect to input resistance.

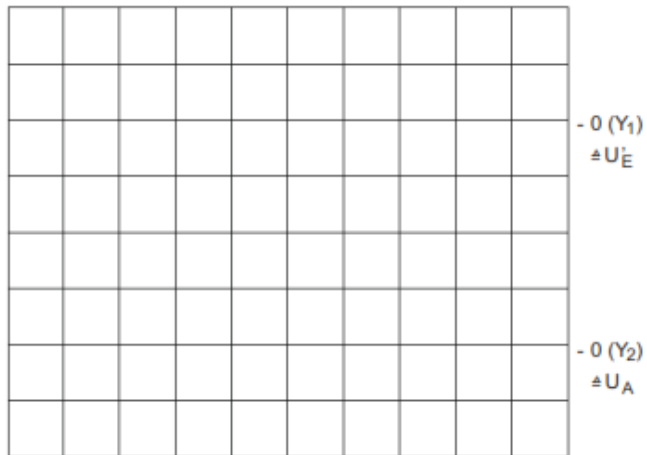


pic. 6.3

Base circuit

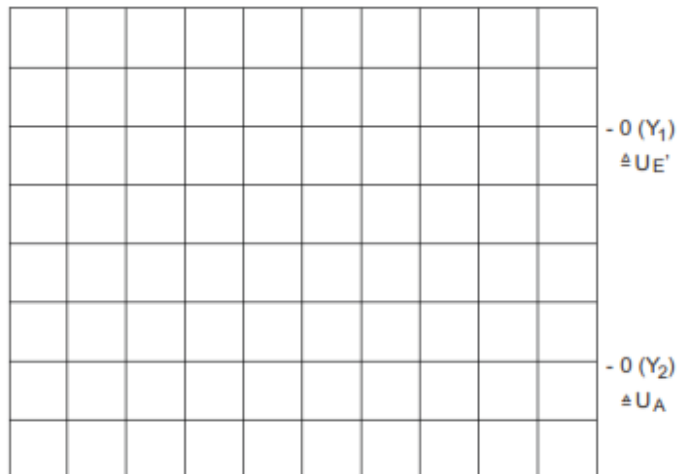
chart 6 1

Settings:
 $Y_1 = 0,1 \text{ V / part}$
 $Y_2 = 1 \text{ V / part}$
 $X = 0,1 \text{ ms / part}$



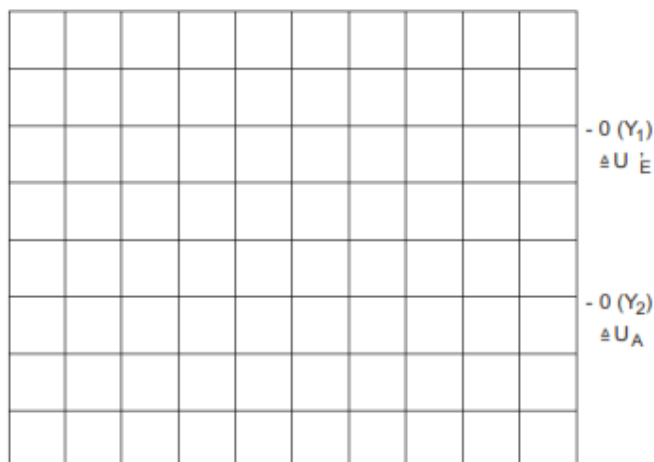
pic.6.4

Settings:
 $Y_1 = 0,5 \text{ V / part}$
 $Y_2 = 0,5 \text{ V / part}$
 $X = 0,1 \text{ ms / part}$



pic. 6.5

Settings:
 $Y_1 = 0,1 \text{ V / part}$
 $Y_2 = 0,2 \text{ V / part}$
 $X = 10 \mu\text{s / part}$



pic. 6.6

Test 1: Which one of the three circuits does have inverting effects?

Answer:

Test 2: For what task do we use the collector circuit due to its characteristics?

Answer:

Test 3: What are the both significant differences between base circuit and emitter circuit?

Answer:

EXPERIMENT # 8A

Operational Amplifier: Inverting Amplifier Non-Inverting Amplifier

Introduction

Operational Amplifiers (op-amp) are ideal DC voltage amplifiers with high ohmic differential input and very high amplification factor.

Op-amps are offered as integrated standard components (e.g. A 741).

In principle all circuit set-ups with single transistors could also be done with op-amps.

Following tests are for examination of the basic characteristics of this kind of components.

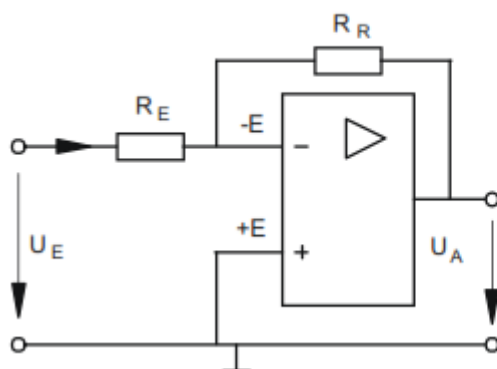
8A.1 Op-Amp serving as inverting Amplifier

8A.1.1 Basics

The inverting amplifier is a circuit that inverts the input voltage at the output. With AC voltage there is a phase shifting of 180° between in- and output voltage. With an inverting amplifier we can either get a gain or loss at the input signal, depending on the resistance of R_R and R_E .

Amplification factor:

$$v = - \frac{R_R}{R_E} \quad \text{or} \quad v = - \frac{U_A}{U_E}$$



*pic. 15.2
Circuit of the op-amp as inverting amplifier*

Calculation could be simplified as follows:

- Within the dynamic range is the difference of both inputs 0.
- Input current I_E within the amplifier is 0.

Amplification factor is $v = -1$ (at $R_R = R_E$), means the amplitude at input and output are the same.

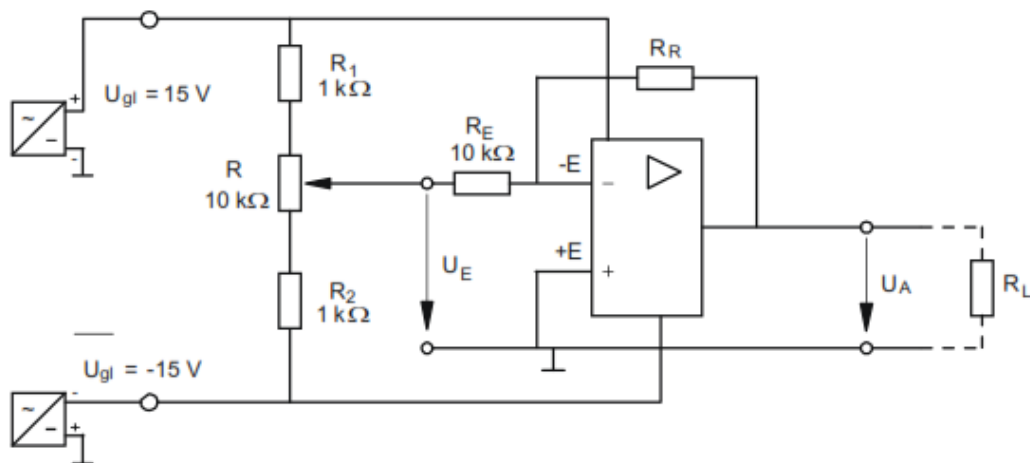
8A.1.2 Tests

Test

Graphically present the relation between output voltage and input voltage and examine in a further test the influence of different load resistors on the output voltage.

Test proceeding:

- Set-up the circuit in pic. 15.3 and measure output voltage U_A for different feedback resistors R_R and input voltages U_E according to chart 8.1 with your multimeter.
- Fill your determined values in chart 23.1. Then graphically present the relation of output voltage U_A to input voltage U_E and feedback resistors R_R .

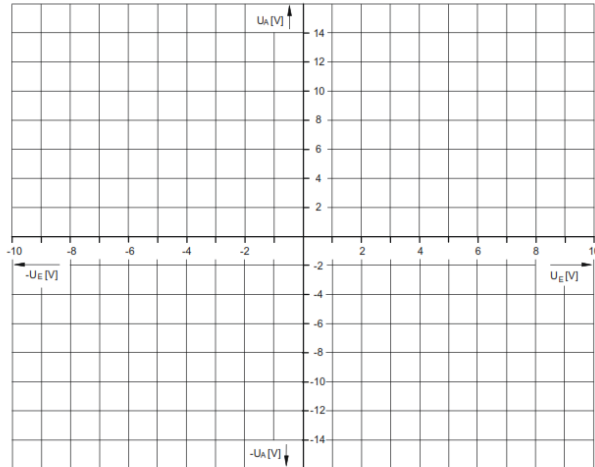


pic. 15.3

| U_E [V]* | -10 | -8 | -6 | -4 | -2 | 0 | 2 | 4 | 6 | 8 | 10 |
|---|-----|----|----|----|----|---|---|---|---|---|----|
| U_A [V] at $R_R = 10 \text{ k}\Omega$ | | | | | | | | | | | |
| U_A [V] at $R_R = 22 \text{ k}\Omega$ | | | | | | | | | | | |

chart 15.1

*To get a linear curve, you have to insert an additional measuring point U_E , at the limiting point of the op-amp.

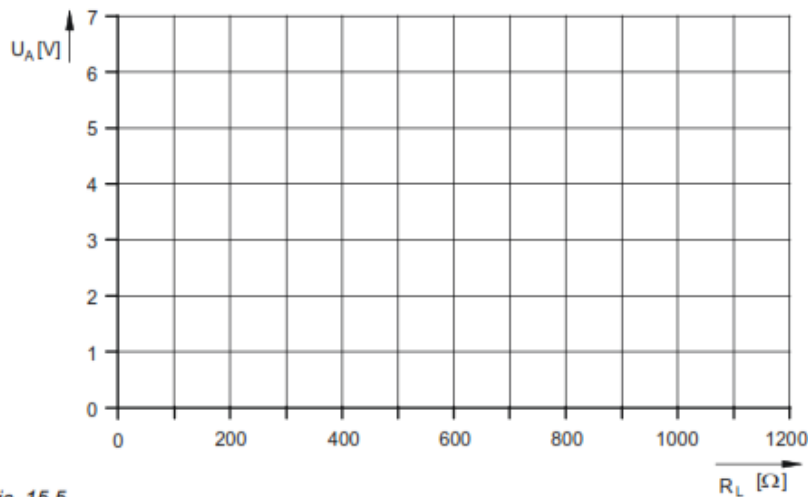


pic. 15.4

- For another test adjust input voltage U_E to -5 V. R_R and $R_E = 10\text{ k}\Omega$. Connect different loads according to chart 15.2. Now measure the respective output voltages U_A
- Fill the determined values in chart 15.2. Then graphically present the relation of output voltage U_A to load resistance R_L in diagram 15.5.

| $R_L [\Omega]$ | 1000 | 680 | 470 | 330 | 220 | 100 |
|------------------|------|-----|-----|-----|-----|-----|
| $U_A [\text{V}]$ | | | | | | |

chart 15.2



pic. 15.5

Test 1: What is the polarity of the input voltage U_E in reference to the output voltage U_A at an inverting amplifier?

Answer:

Test 2: What components specify the amplification factor v at the inverting amplifier?

Answer:

Test 3: What is the amplification factor at $R_R = 10 \text{ k}\Omega$ and $R_E = 1 \text{ k}\Omega$?

Answer:

Test 4: What statement could be given to the characteristic curve pic. 15.5?

Answer:

8A.2 Op-Amp serving as non-inverting Amplifier

8A.2.1 Basics

At the non-inverting amplifier input – and output voltages are of same polarity, with AC voltages phase shifting is 0° .

Like shown in pic. 15.6 input voltage at the not inverted amplifier is applied to input $+E$.

As within the dynamic range the difference between both inputs is 0, also the input $-E$ is voltage supplied.

Use following equation for the amplification factor

:

$$v = 1 + \frac{R_R}{R_E} \quad v = \frac{U_A}{U_E}$$

8A.2.2 Tests

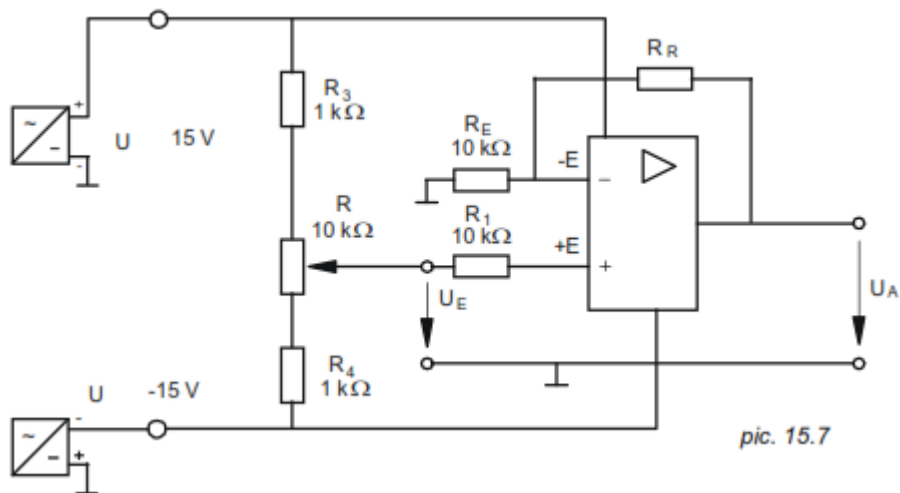
Test

Graphically present the relation of output voltage to input voltage with different feedback resistors.

Test proceeding

☐ Set-up the circuit in pic. 15.7 and measure with your multimeter the output voltages U_A for different feedback resistors R_R and input voltages U_E according to chart 15.3.

☐ Fill the determined values in chart 15.3, then graphically present the relation between output voltage U_A and input voltage U_E as well as the feedback resistors R_R with in the diagram 1.8

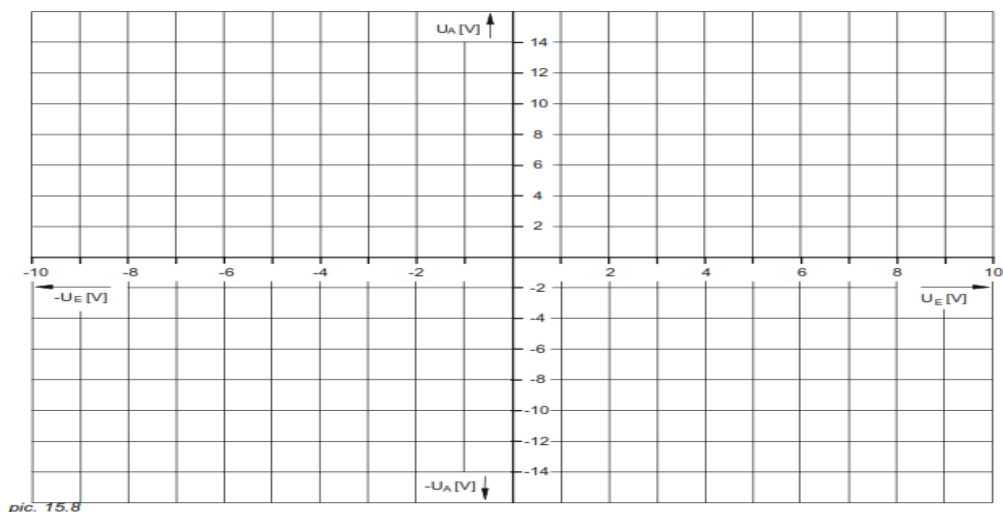


pic. 15.7

| U_E [V]* | -10 | -8 | -6 | -4 | -2 | 0 | 2 | 4 | 6 | 8 | 10 |
|---|-----|----|----|----|----|---|---|---|---|---|----|
| U_A [V] at $R_R = 10 \text{ k}\Omega$ | | | | | | | | | | | |
| U_A [V] at $R_R = 22 \text{ k}\Omega$ | | | | | | | | | | | |

chart 15.3

* To get a linear curve, you have to insert an additional measuring point U_E , at the limiting point of the op-amp.



pic. 15.8

Test 1: What components define the amplification factor?

Answer:

Test 2: What is the output voltage U_A when $R_R = 47 \text{ k}\Omega$, $R_E = 10 \text{ k}\Omega$, $U_E = 2 \text{ V}$?

Answer:

Test 3: What is the polarity of input voltage U_E with respect to output voltage U_A ?

Answer:

EXPERIMENT # 8B

Dynamic Behavior of an Op-Amp

8B.1 Basics

Op-amps are broadband DC voltage amplifiers, not only amplifying DC voltages but also AC voltages in some frequency ranges. Negative feedback caused by external circuitry does not only define the amplification factor but also the bandwidth and the input resistance.

8B.2 Tests

Test

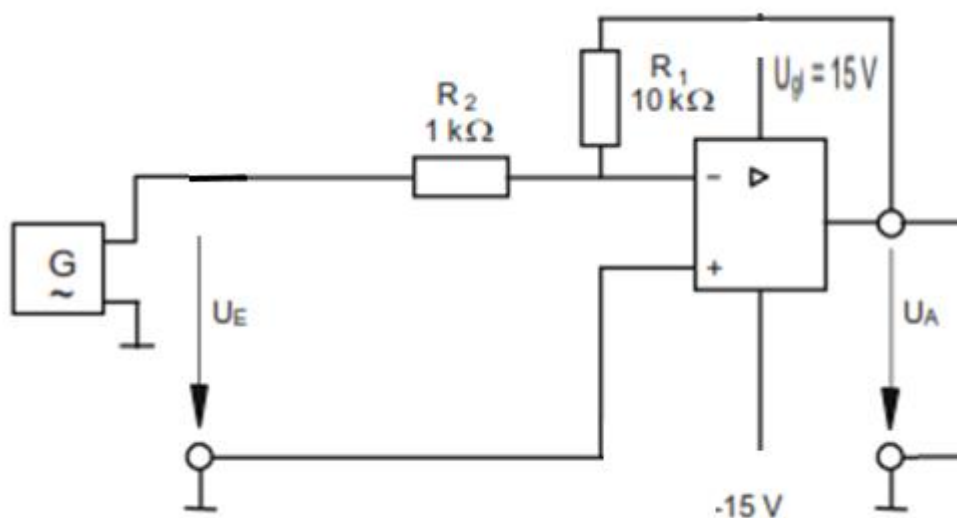
Examine my measuring the behavior of an op-amp when applying sinus voltage

Test proceeding:

□ Apply sinus voltage $U_{ss} = 1 \text{ V}$, $f = 1 \text{ kHz}$ to the input of circuit in pic. 23.16. Measure with the oscilloscope the input voltage U_E and the output voltage U_A , and draw the respective curve into pic. 13.18.

□ Determine the amplification factor v by following equation:

$$v = \frac{U_A}{U_E}$$



• Then determine the upper limiting frequency. It is the frequency, when output voltage drops to 70,7% of its maximum value, if frequency is increases.

- Determine the input resistance R_E . Therefore connect a resistor R_V in series to the input. This will affect a receding of the output voltage from value U_1 to value U_2 . Calculate the input resistance R_E with both voltage values and the given series resistor with following equation:

$$R_E = \frac{R_V}{\left(\frac{U_1}{U_2} - 1\right)}$$

R_E = input resistance in Ω

R_V = series resistor in Ω

U_1 = output voltage with no series resistor

U_2 = output voltage with series resistor

- Then determine the output resistance R_A , by connecting load resistance R_L to earth at the output. This affects a drop of output voltage from value U_1 to value U_2 .
- Calculate the output resistance with both voltage values and the given load resistance with following equation:

$$R_A = R_L \left(\frac{U_1}{U_2} - 1 \right)$$

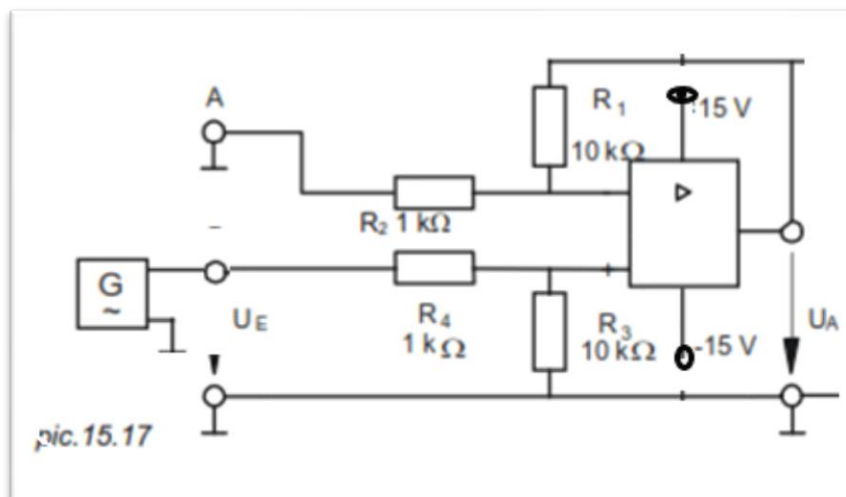
R_A = output resistance in Ω

R_L = series resistance in Ω

U_1 = output voltage with no resistor

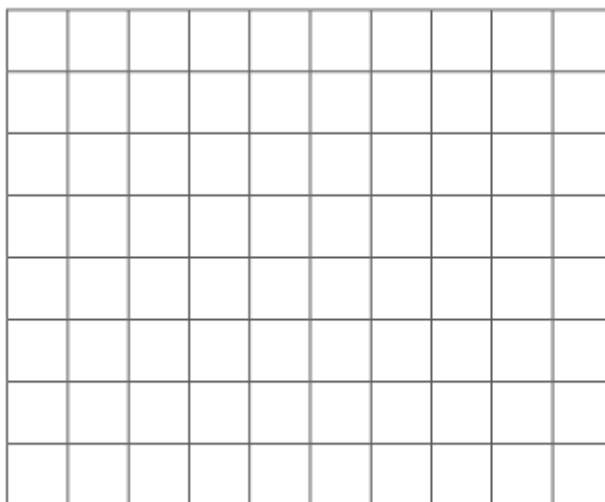
U_2 = output voltage with resistor

- Fill the determined values in chart 15.7.
- Then set-up the circuit in pic. 15.17, apply sinus voltage of $U_{pp} = 1 \text{ V}$; $f = 1 \text{ kHz}$ to the input U_E .



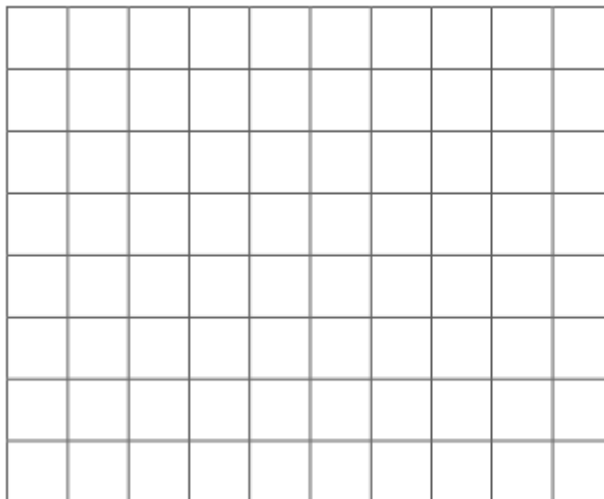
Repeat all measurements and calculations, draw the curves of input- and output voltages into diagram 15.19 and fill your values in chart 15.7.

| | Inverting Input ($R_1 = 10 \text{ k}\Omega$, $R_2 = 1 \text{ k}\Omega$) | Non-inverting Input ($R_1 = R_3 = 10 \text{ k}\Omega$, $R_2 = R_4 = 1 \text{ k}\Omega$) |
|-------|---|---|
| U_E | 1 V | 1 V |
| U_A | | |
| v_U | | |
| f_o | | |
| R_E | ($R_V = 100 \Omega$) | ($R_V = 10 \text{ k}\Omega$) |
| R_A | ($R_L = 100 \Omega$) | ($R_L = 100 \Omega$) |



Settings:
 $Y_1 = 5 \text{ V / part}$
 $Y_2 = 0,5 \text{ V / part}$
 $X = 0,2 \text{ ms / part}$
 $-0 (Y_1)$
 $\pm U_A$
 $-0 (Y_2)$
 $\pm U_E$

pic. 15.18



Settings:
 $-0 (Y_1)$ $Y_1 = 5 \text{ V / part}$
 $\pm U_A$ $Y_2 = 0,5 \text{ V / part}$
 $X = 0,2 \text{ ms / part}$
 $-0 (Y_2)$
 $\pm U_E$

pic. 15.19

- Now disconnect point A in the circuit of pic. 15.17 from reference potential (\perp) and connect to point B. Hence, both inputs are fed by same voltage. Measure the output voltage with your oscilloscope.

Test 1: What is the phase shift angle between input and output voltage?

Answer:

a) When inverting input is used:

b) When non-inverting input is used:

Test 2: The input resistance R_E is similar to what resistance value at the inverting input?

Answer:

Test 3: The input resistance R_E is similar to what resistance value at the non-inverting input?

Answer:

Test 4: Does output resistance R_A is in any relation to the feeding input R_E ?

Answer:

Test 5: What is the value of the output voltage R_A if both inputs of the op-amp are fed by same voltage?

Answer:

EXPERIMENT # 9

Op-amp circuits serving as Adder and Differential Amplifier

9.1 Op-Amp serving as Adder

9.1.1 Basics

at $R_{E1} = R_{E2} = \dots R_{En} = R_E$ is true:
$$U_A = -\frac{R_R}{R_E}(U_{E1} + U_{E2} + \dots + U_{En})$$

at $R_R = R_E$ is true:
$$U_A = -(U_{E1} + U_{E2} + \dots + U_{En})$$

$$U_A = -R_R \left(\frac{U_{E1}}{R_{E1}} + \frac{U_{E2}}{R_{E2}} + \dots + \frac{U_{En}}{R_{En}} \right)$$

9.1.2 Tests

Test

Examine an adder by measurement.

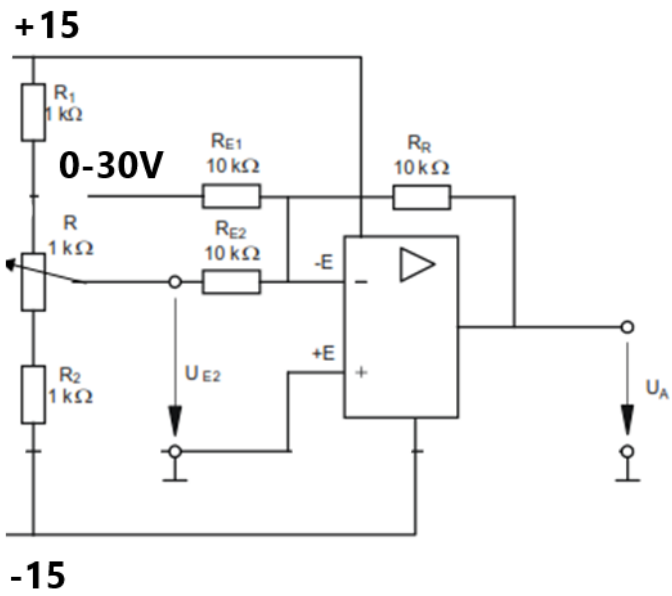
Test proceeding

□ Set-up the circuit in pic. 15.10 and adjust the input voltage to $U_{E2} = 2 \text{ V}$ the input voltage U_{E1} is according to chart 15.4 then measure with the multimeter each output voltage U_A .

Repeat those measurements with input voltage of $U_E = -2 \text{ V}$.

□ Fill the determined values into chart 15.4 and graphically present the relation of U_A and input voltage U_{E1} [$U_A = f(U_{E1})$] in diagram 15.11.

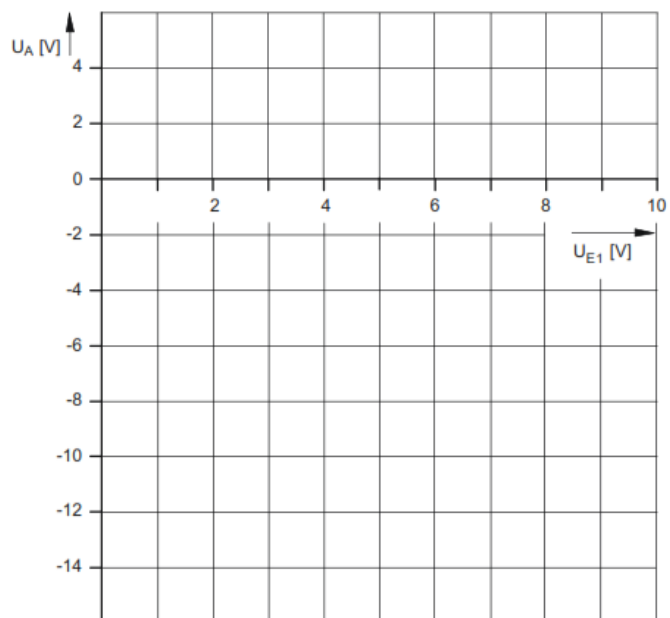
□ Then repeat all measurements for an input resistance of $R_{E1} = 4,7 \text{ k}\Omega$, fill the values for the output $\text{k}\Omega$, voltages U_A in chart 15.5, then draw the curve into the diagram 15.12.



$R_{E2} = 10 \text{ k}\Omega$

| $U_{E1} \text{ [V]}$ | 0 | 2 | 4 | 6 | 8 | 10 |
|---|---|---|---|---|---|----|
| $U_A \text{ [V] at } U_{E2} = 2 \text{ V}$ | | | | | | |
| $U_A \text{ [V] at } U_{E2} = -2 \text{ V}$ | | | | | | |

chart 15.4

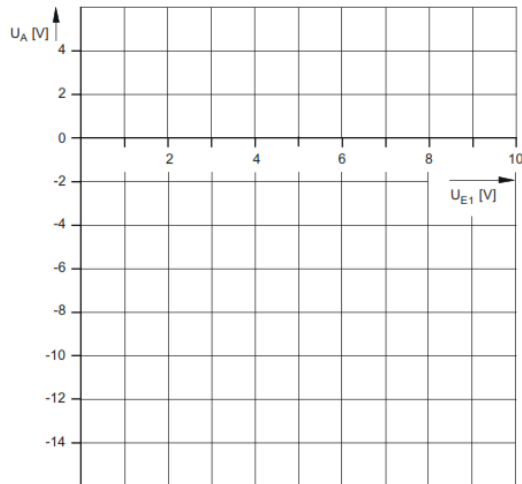


pic. 15.11

$$R_{E1} = 4,7 \text{ k}\Omega$$

| $U_{E1} [\text{V}]^*$ | 0 | 2 | 4 | 6 | 8 | 10 |
|--|---|---|---|---|---|----|
| $U_A [\text{V}] \text{ at } U_{E2} = 2 \text{ V}$ | | | | | | |
| $U_A [\text{V}] \text{ at } U_{E2} = -2 \text{ V}$ | | | | | | |

chart 15.5 * To get a linear curve, you have to insert an additional measuring point U_E , at the limiting point of the op-amp.



pic. 15.12

Test 1: Input currents I_{E1} and I_{E2} have to flow across which resistor?

Answer:

Test 2: What kind of circuit is obtained if only one input is connected?

Answer:

Test 3: What is the output voltage if one input current is positive and the other one negative?

Answer:

9.2 Op-Amp serving as Differential Amplifier

9.2.1 Basics

The differential amplifier is considered to be a subtraction element with amplification. Both input voltages gain with the same amplification factor. For a good common mode rejection the amplification factors for both inputs have to be equal.

Following equation is for the common mode rejection G:

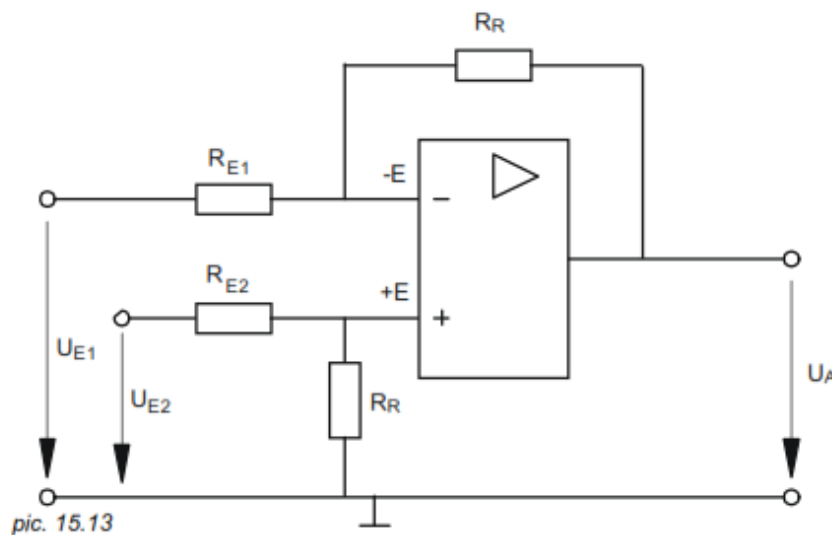
$$G = 20 \log \frac{V}{V_{\text{common mode}}} / \text{dB}$$

At the non-connected amplifier it is $\mu\text{A 741}$ approx. 90 dB.

With subtraction element is $R_E1 = R_E2 = R_E$ and $R_3 = R_R$ output voltage U_A is:

$$U_A = U_{E2} \cdot \frac{R_R}{R_E + R_R} \cdot \frac{R_E + R_R}{R_E} - U_{E1} \cdot \frac{R_R}{R_E} \quad U_A = (U_{E2} - U_{E1}) \cdot \frac{R_R}{R_E}$$

If resistance R_R and both input resistances R_E are totally equal, then only the difference between the two inputs gain by amplification ratio R_R to R_E . Op-amps in differential amplifier circuits are e.g. used for measuring amplifiers.



9.2.2. Tests

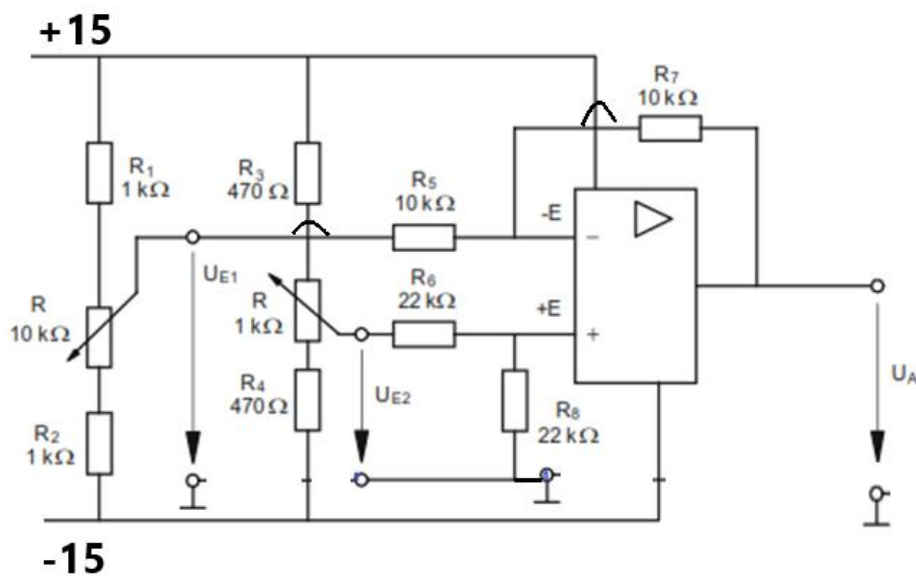
Test

Examine the differential amplifier for common mode rejection by measurement.

Test proceeding

- Set-up the circuit in pic 15.14, then measure for different input voltages U_{E1} and U_{E2}

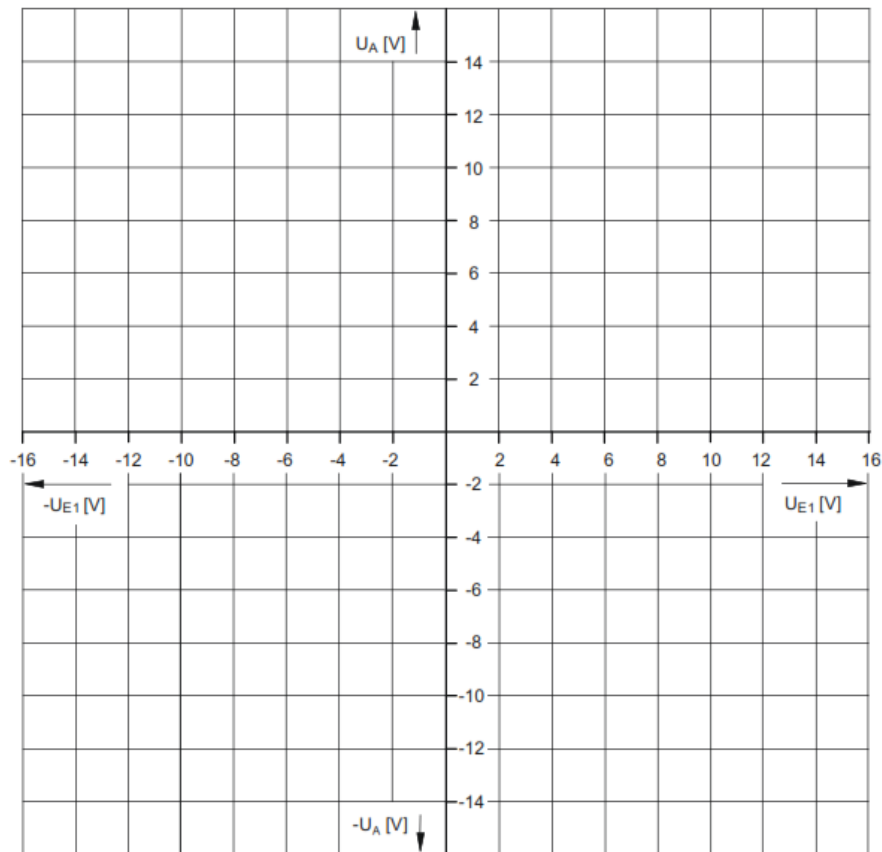
According to chart 15.6 the output voltage U_A . Fill the values for voltage in chart 15.6 and graphically present the relation of output voltage U_A to input voltages U_{E1} and U_{E2} in diagram. 15.15.



| U_{E1} [V]* | -10 | -6 | -2 | +2 | +6 | +10 |
|------------------------------|-----|----|----|----|----|-----|
| U_A [V] at $U_{E2} = -4$ V | | | | | | |
| U_A [V] at $U_{E2} = 0$ V | | | | | | |
| U_A [V] at $U_{E2} = 4$ V | | | | | | |

chart 15.6

* To get a linear curve, you have to insert an additional measuring point U_E , at the limiting point of the op-amp.



pic.15.15

Test 1: When do we obtain a common mode rejection?

Answer:

Test 2: What circuit is considered to be a differential amplifier?

Answer:

Test 3: What output voltage is obtained when both inputs are supplied?

Answer:

EXPERIMENT # 10

Multistage Amplifier

Introduction

If the amplification factor of one transistor is not enough, then more could be connected, thus amplification is multiplied. An exception is the distributed amplifier, used for ultra-high-frequency, here all partial amplification factors are added.

When connecting the single transistors, they have to be coupled in a way that the operation values (collector – and basic-closed-currents, base -/ emitter-pre-load) will not influence one another. For AC voltage amplifiers it is affected by coupling across RC-elements or transformers. At composite amplifiers (for amplification of DC- and AC voltages) all stages are potential-matched and then coupled together.

10.1 Two-Stage AC Voltage Amplifier

10.1.1 Basics

Voltage gain of both transistors in an emitter circuit is fully utilizable. Resistor R_4 and R_6 are for stabilizing the operation point. As input- and output stages are coupled by RC elements, no DC voltage could be transferred. Only AC voltages over a certain frequency will be transferred.

10.1.2 Tests

Test

Measure the curves for input – and output voltages, the partial voltage amplification factors, total voltage amplification factor and the limiting frequencies for a two-stage AC voltage amplifier

Test proceeding:

☐ Apply to the input A of the circuit in pic. 9.13 a sine-wave voltage with a frequency of $f = 1 \text{ kHz}$. Set the voltage to 1 mV .

Note:

For better adjustment of the low input voltage with the oscilloscope, select a voltage divider (R_{T1} / R_{T2}) at the generator output. Input voltage U_E at measuring point B is $1001 \times U_E = 1 \text{ V}$. ☐

- Adjust the operating point of the transistors at the potentiometers $1 \text{ k}\Omega$ and $10 \text{ k}\Omega$, so the maximum and undistorted output voltage is given.
- ☐ Measure with your oscilloscope the curve for the output voltage at the collector of transistor $V_1(U_{A1})$ and the curve for the output voltage at the collector of transistor V_2 .
- ☐ Trigger the oscilloscope with input voltage U_E

- Then measure the amplification factor v_1 and v_2 (U_{A2}), as well as the total amplification factor v_{ges} of both transistors.
- At least measure with constant input voltage the output voltage for different frequencies and note the values in chart 9.4.

- In pic. 9.15 graphically present the dependency of amplification factor v_{ges} from frequency. Maximum amplification factor $v_{ges} = 100\%$.

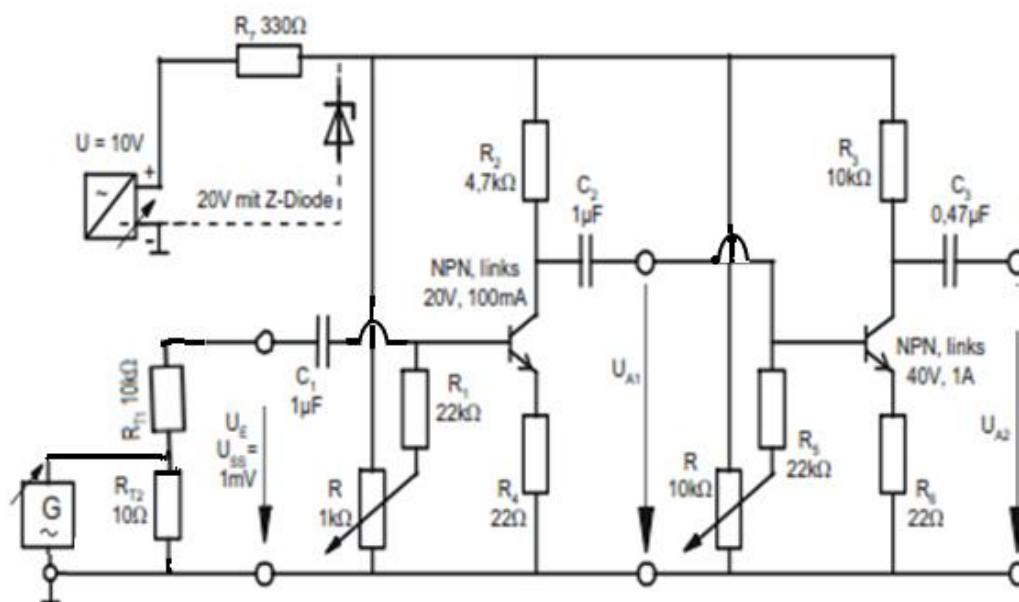
□

Determine then the upper and lower limiting frequency. It is the frequency, when output voltage drops to 70,7% of its maximum value if frequency is increased or decreased.

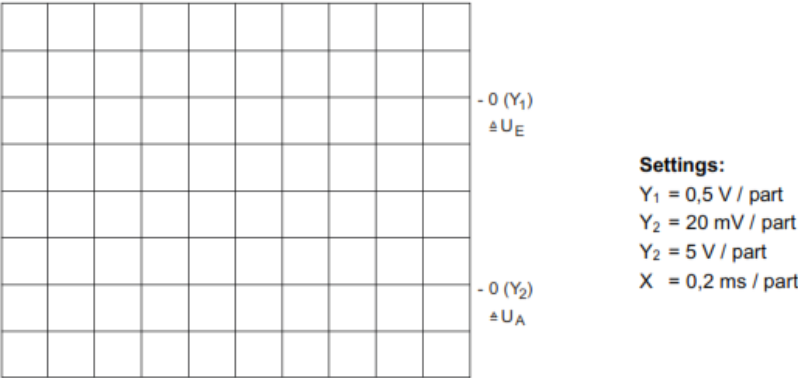
- **Note:** Multistage amplifiers are susceptible for noise from the 50-Hz-power supply (so called ripple voltage) due to the high amplification factor. For keeping this a minimum, all reference potentials of the circuit have to be connected to a single point (see point E pic. 9.13)

(negative pole of the operating voltage, reference point of the function generator and the oscilloscope, base point of R_{T2} , potentiometer $1\text{ k}\Omega$ and $10\text{ k}\Omega$, R_4 , and R_6).

If necessary (ripple of power supply $> 1\text{ mV}$), please increase the output voltage of the power supply to 20V and smooth with R_7 and Z-diode ZPD 10.



pic. 9.13



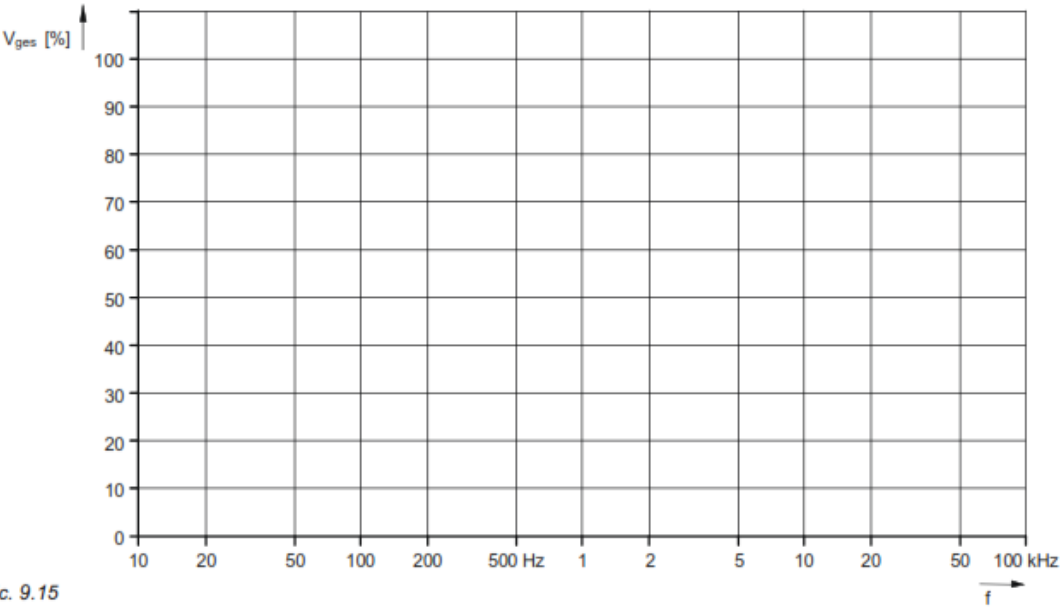
pic. 9.14

| v1 | v2 | vges |
|----|----|------|
| | | |

chart 9.3

| f [kHz] | 0,01 | 0,02 | 0,05 | 0,1 | 0,2 | 0,5 | 1 | 2 | 5 | 10 | 20 | 50 |
|-----------------------|------|------|------|-----|-----|-----|---|---|---|----|----|----|
| U _E [mV] | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| U _A [V] | | | | | | | | | | | | |
| $v = \frac{U_A}{U_E}$ | | | | | | | | | | | | |
| V _{ges} [%] | | | | | | | | | | | | |

chart 9.4



pic. 9.15

Test 1: What is the phase shift between U_E and U_{A1} ?

Answer:

Test 2: What is the phase shift between U_E and U_{A2} ?

Answer:

Test 3: What is the interrelation between the single amplification factor and the total amplification factor?

Answer:

Test 4: What is the lower limiting frequency?

Answer:

Test 5: What is the upper limiting frequency?

Answer:

EXPERIMENT # 11

Differential Amplifier

11.1 Basics

Differential amplifiers increase the difference between two input voltages. Same voltages at both inputs cause no output voltage. Basically the differential amplifier is similar to an emitter-coupled phase inverter. Instead of an emitter resistor, another transistor is utilized for constant voltage supply. It provides that the sum of the both emitter currents within the emitter-coupled circuit remains constant.

Thus, emitter current of one transistor drops the same rate than emitter current at the other increases. Than increases at the other.

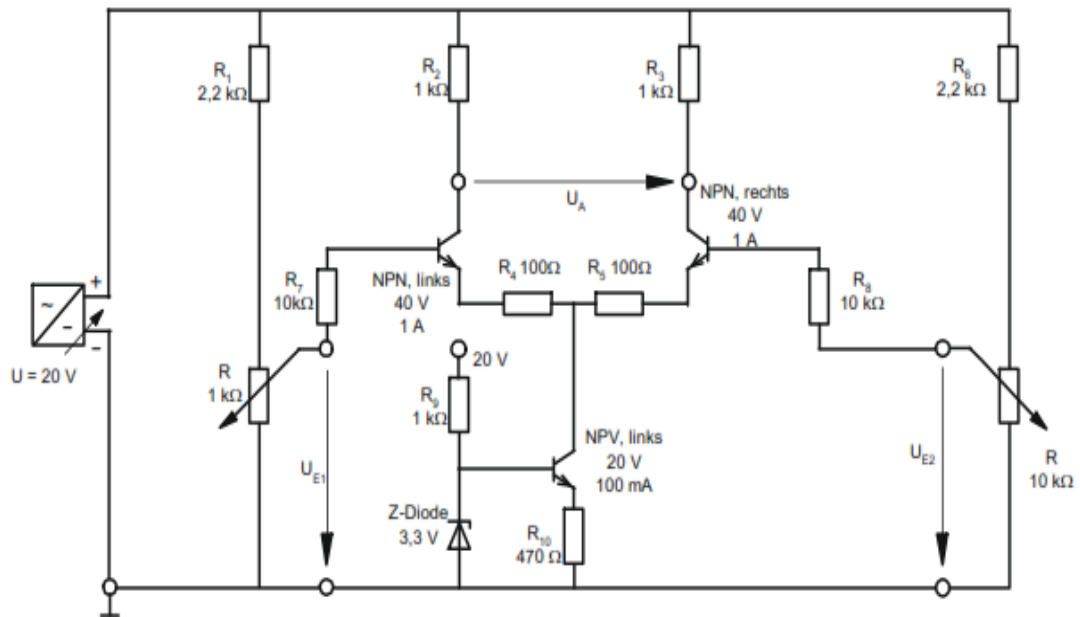
11. 2 Tests

Test

Examine the characteristics of a differential amplifier first for DC voltage and second for superimposed AC voltage.

Test proceeding:

- Apply to circuit 9.26 DC voltage of $U_{gl} = 20 \text{ V}$. Adjust the voltage U_{E2} by potentiometer ($10 \text{ k}\Omega$) to $5,5 \text{ V}$ and keep this constant
- Then step by step change the voltage U_{E1} . Note the respective values of the output voltage in chart 9.8.



pic. 9.26

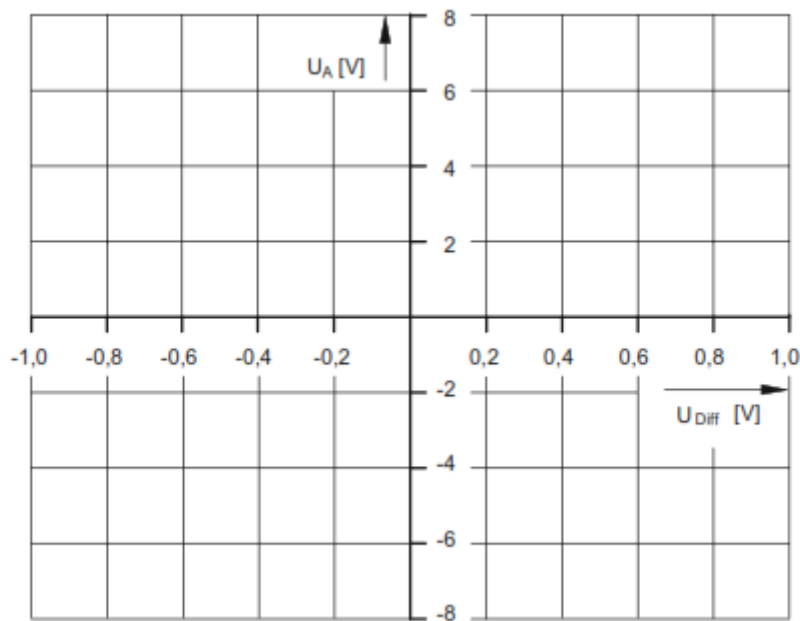
- Calculate the input voltage differentials $U_{E\text{Diff}} = U_{E1} - U_{E2}$ and note the values in chart 9.8.
- Then set the voltage U_{E1} to 5,5 V and keep it constant. Step by step change the voltage U_{E2} and note the respective output voltages in chart 9.9.
- Again calculate the input voltage differentials and note the results in chart 9.9.
- Graphically present in diagram 9.27 the dependency of output voltage from the difference of the input voltages, first for constant voltage U_{E2} , then for constant voltage U_{E1} .

| U_{E1} [V] | 4,6 | 4,8 | 5 | 5,2 | 5,5 | 5,8 | 6 | 6,2 |
|------------------------|-----|-----|---|-----|-----|-----|---|-----|
| U_A [V] | | | | | | | | |
| $U_{E\text{Diff}}$ [V] | | | | | | | | |

chart 9.8 $U_{E2} = 5,5 \text{ V (constant)}$

| U_{E2} [V] | 4,6 | 4,8 | 5 | 5,2 | 5,5 | 5,8 | 6 | 6,2 |
|------------------------|-----|-----|---|-----|-----|-----|---|-----|
| U_A [V] | | | | | | | | |
| $U_{E\text{Diff}}$ [V] | | | | | | | | |

chart 9.9 $U_{E1} = 5,5 \text{ V (constant)}$

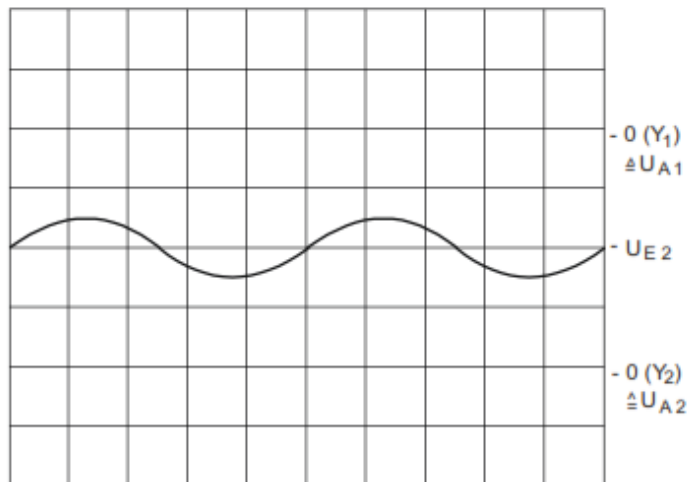


pic. 9.27

Test examine the dynamic characteristics

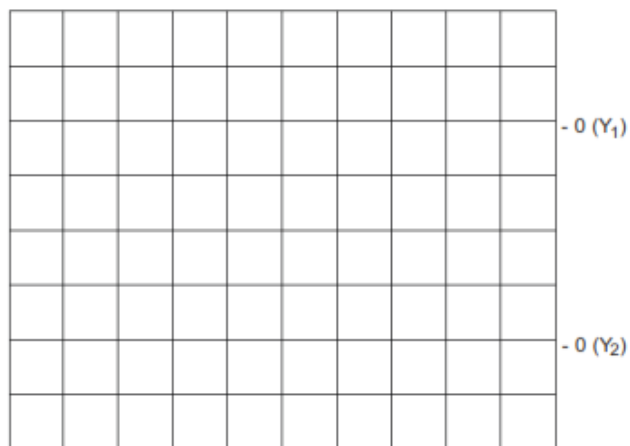
In another test examine the dynamic characteristics of the circuit in pic. 9.28. Therefore adjust both DC input voltages U_{E1} and U_{E2} to 5,5 V ($U_A = 0 \text{ V}$). First superpose input voltage U_{E1} with AC voltage $U_{E\text{ss}} = 0,6 \text{ V}$; $f = 1 \text{ kHz}$. Draw the respective curves for output voltages U_{A1} in diagram 9.29.

Note: To allocate the input voltages, the oscilloscope has to be triggered with the input voltage U_{E1} at the external trigger input. Set the trigger source to “extern”.



pic.9.30

Settings:
 $Y_1 = 1 \text{ V / part}$
 $Y_2 = 1 \text{ V / part}$
 $X = 0,2 \text{ ms / part}$
 $U_{E2} = \text{trigger signal}$



pic. 9.31

Settings:
 $Y_1 = 1 \text{ V / part}$
 $Y_2 = 1 \text{ V / part}$
 $X = 0,2 \text{ ms / part}$
 $U_{E1} = U_{E2} = \text{trigger signal}$

Test 1: What is the output voltage when both inputs are controlled the same?

Answer:

Test 2: In which integrated circuit is the differential amplifier the base circuit?

Answer:

EXPERIMENT # 12

Push-Pull-Amplifier

12.1 Basics

Amplifiers have the task to apply a certain signal to a load resistor. For load resistors there are actuators, which transfer electrical signals into meachanical power (i.e. loud speakers, actuator motors, valves). In todays amplifier technology mostly complementary collector stages are used. In pic. 9.37 you see a its circuit diagram. During the positive half-wave V_1 is conductive and V_2 is blocked, at the negative half-wave it is vice versa. Therefore one after the other half-wave is applied to the load R_L .

Without signal both transistors are blocked, its closed-circuit current is $I_C = 0$.

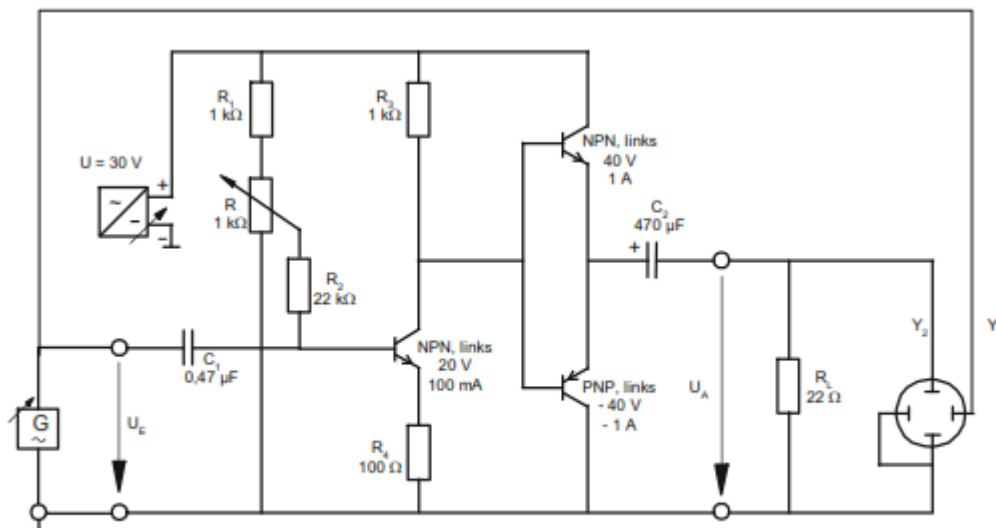
12.2 Tests

Test

Examine by measurement the characteristics of a push-pull-amplifier with complementary transistors.

Test proceeding:

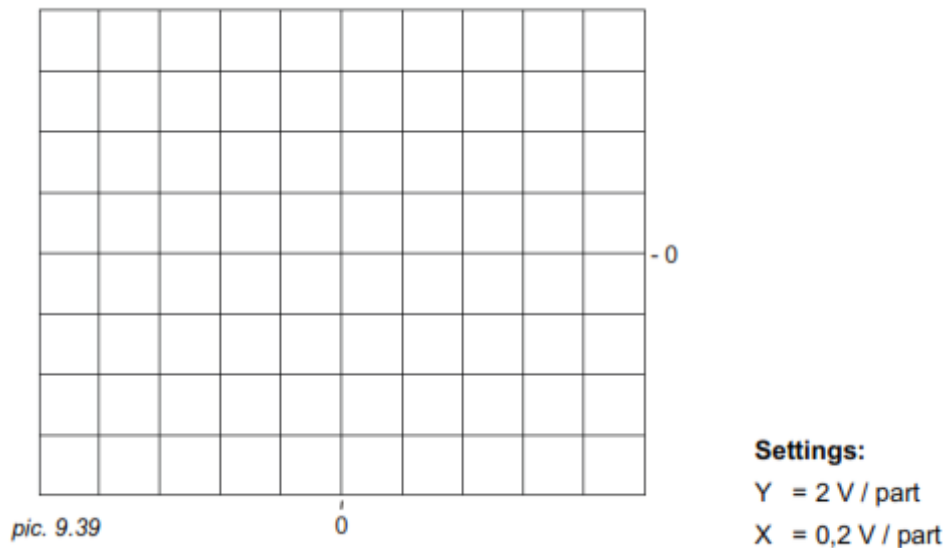
□ Apply a sine-wave voltage of $U_{ss} = 2\text{ V}$; $f = 4\text{ kHz}$ to the input (A) of the push-pull-amplifier according to pic. 9.38 and display the dependency of output voltage to input voltage on the oscilloscope (X/Y-presentation). Adjust the operating point of the transistor V_1 at the potentiometer, so undistorted output voltage is at measuring point C.



pic. 9.38

Caution: Regard the polarity of the electrolytic capacitor!

Note: This open circuit set-up holds the possibility that the circuit energizes itself and starts with high frequent oscillation. If this occurs you have to twist the input signal wire with the ground wire or use an isolated cable. Do not double-ground your measuring devices.



□ Draw the screen shot into diagram 9.39.

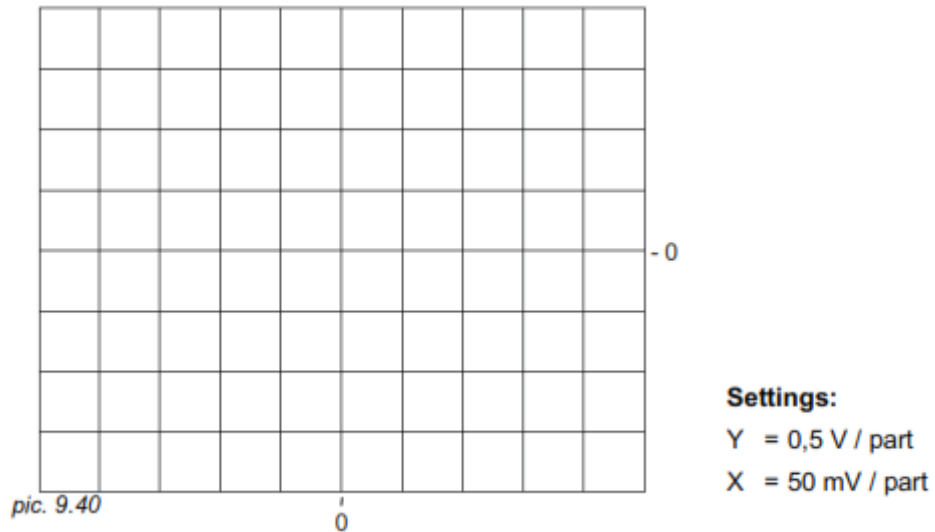
• Calculate by help of the measured voltage the voltage applied to the Note those values together with the values for the load resistor R_L . effective load current in chart 9.12.

| $U_{A \text{ ss}}$ | $U_{A \text{ eff}}$ | P | I_{eff} | φ | R_A | η |
|--------------------|---------------------|-----|------------------|-----------|-------|--------|
| | | | | | | |

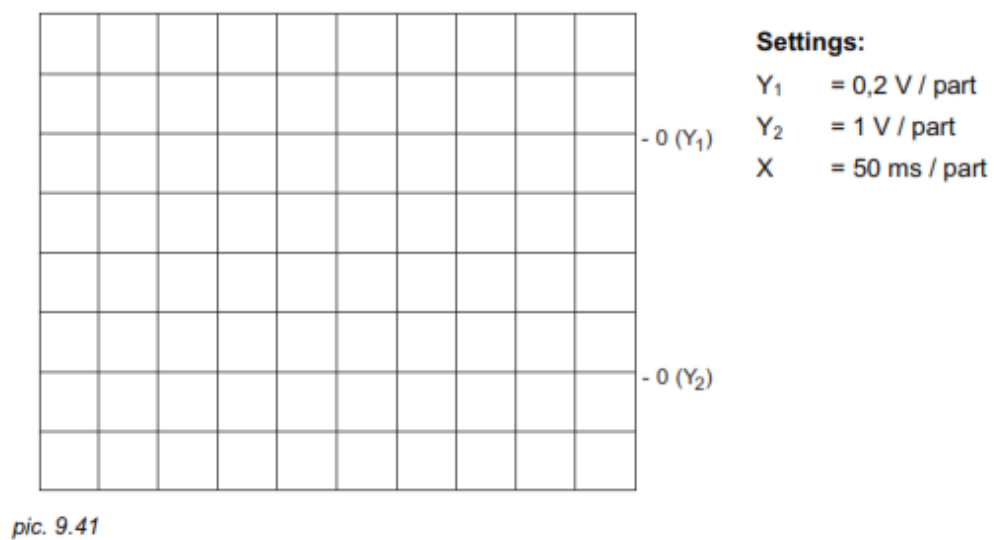
chart 9.12

□

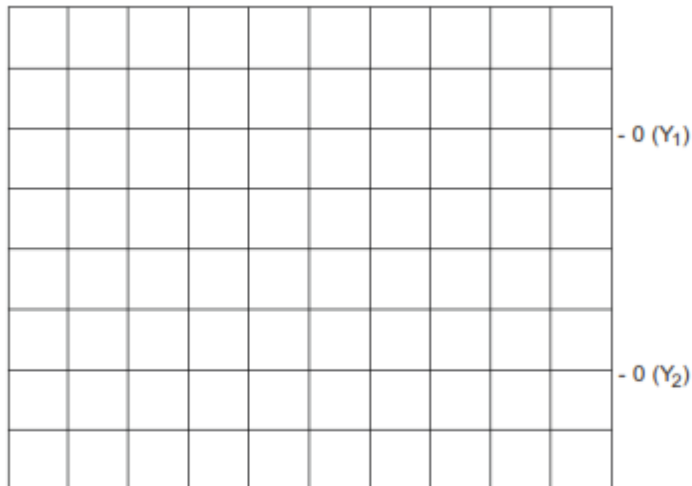
- Calculate the efficiency and note the values in chart 9.12.
- Reduce step by step the input voltage to $U_{\text{ss}} = 0,5 \text{ V}$ and draw the curve (X / Y-presentation) in pic. 9.40.



- Select the two-channel mode with time dependant presentation for the oscilloscope, draw the curve for input- and output voltage in diagram 9.41.



- Then increase the input voltage to $U_{ss} = 2 \text{ V}$ and draw the Oscilloscope-presented curve in diagram 9.42.



Settings:

Y₁ = 1 V / part

Y₂ = 5 V / part

X = 50 ms / part

pic. 9.42

- Measure the open circuit voltage U_A and draw into diagram 9.43.
- Determine the phase shift between U_A and U_E. Note the values in chart 9.12.
- Use following equation for the calculation of the internal resistance at the output side.

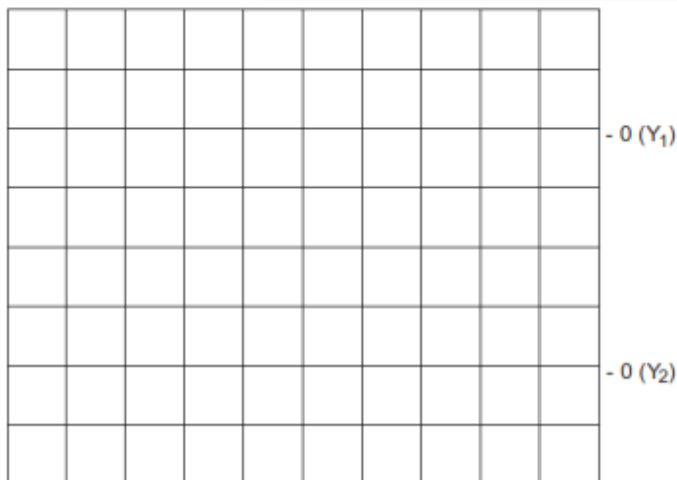
$$R_i = R_L \cdot \left(\frac{U_1}{U_2} - 1 \right) =$$

R_A = output resistance in Ω

R_L = load resistor in Ω

U₁ = output voltage without load resistor

U₂ = output voltage with load resistor



Settings:

Y₁ = 1 V / part

Y₂ = 10 V / part

X = 50 ms / part

pic. 9.43

Test 1: How big is in this circuit the effective output voltage and output power?

Answer: $U_{eff} =$ $P =$

Test 2: Determine the effective load current across the load resistor.

Answer $I_{eff} =$

Test 3: On which parameter depends the operating current that the amplifier consumes from the power supply?

Answer:

Test 4: Determine the input power of the circuit at hand. What is the efficiency of this?

Answer: $P_V =$ $\eta = \frac{P_{ab}}{P_{zu}} =$

Test 5: What is the internal resistance at output side?

Answer:

$$R_i = R_L \cdot \left(\frac{U_1}{U_2} - 1 \right) =$$

Test 6: What is the difference in the curve for low control in respect to high control?

Answer:

Test 7: How is the curve for open circuit output voltage?

Answer: