This version: 2000-08-25

LABORATORY
on
ANALOG ELECTRONICS

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First version 1997

1 Measurements on simple circuits

2 Filters and RC-circuits

3 Power supply circuits

4 The Usage of Operational Amplifiers

5 Simulations in Electronics Workbench

6 Design of Transistor Amplifiers

7 Continuation of laboratory work no 6

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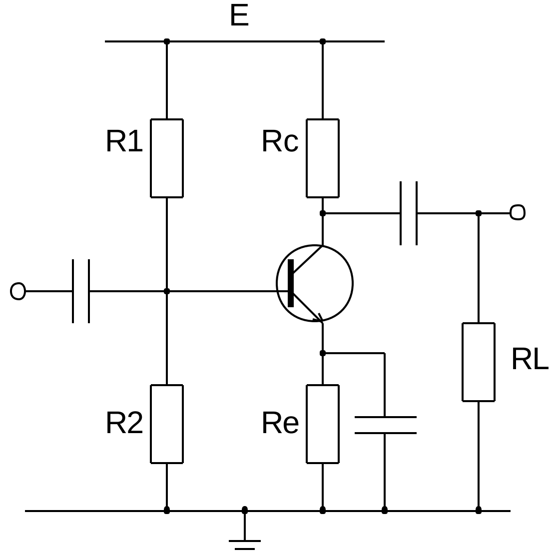

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Allmänna instruktioner för Laborationer i Elektronik

1. Rapportskrivande och regler för godkännande

- Lämna endast in en rapport per laborationsgrupp.
- Inlämning av laborationer görs under kursens gång och senast 14 dagar efter kursslut. Nästa tillfälle för rättning av labbar är första veckan på vårterminen för höstens kurser. För vårterminens kurser gäller att laborationer som inlämnas senare än 14 dagar efter kursslut rättas i början av september.
- Skriv med en prydlig handstil eller skriv på dator.
- Diagram ska vara lättlästa och ha tydliga enheter och axelmarkeringar.
- Studenter som lämnar in labresultat skall alltid vara beredda på att muntligen redovisa laborationen.
- Det är också tillåtet att skriva rapporten på engelska.

2. Allmänna mätinstruktioner och ordningsregler

- För att mäta strömmen som flyter genom kretsen, anslut amperemetern **i serie**.
- För att mäta spänning mellan två punkter i kretsen, anslut voltmetern **parallellt**.
- Det är också möjligt att mäta strömmen indirekt genom att mäta spänningen över en resistor.
- Kontrollera komponenterna innan du använder dem. De ligger inte alltid i rätt låda. Använd RLC-metern för att kontrollera resistanser, spolar och kapacitanser.
- Lägg tillbaka komponenter i **rätt** låda när du är färdig och ställ tillbaka använda instrument på rätt plats innan du går. **Städa efter dig** och lämna labbplatsen som du skulle vilja finna den nästa gång du labbar.
- Släng alltid komponenter som helt tydligt är trasiga, t. ex. där ett ben saknas. Om du inte har något yttre bevis för att komponenten är trasig, pröva med att byta ut den mot en som ska vara identisk. Om den utbytta komponenten fungerar, släng den gamla.
- Vissa multimetrar har olika ingångar för ström- och spänningsmätning. Det innebär att det inte räcker att bara koppla om mellan ström och spänning.
- Oscilloskopets instumentingångar har gemensam instrumentjord. Detta medför att ett tvåkanaligt oscilloskop i allmänhet endast kan mäta två potentialnivåer utifrån en gemensam referensnivå (gemensam punkt) i kopplingen. Andra mätkopplingar medför kortslutningar i kretsen. Dessutom är instrumentjorden ofta ansluten till oscilloskopets skyddsjord vilket även gäller för andra kringutrustningar. Detta medför att ingående apparaters instrumentjordar därför en gång för alla kopplas ihop i en punkt i kretsen för att undvika kortslutningar.
- Tänk på att elektrolytkondensatorer måste polariseras rätt och inte överskrida maximalt tillåten spänning. Annars kan de **explodera**.
- Både oscilloskop och multimetrar kan ställas in i dc- mode eller ac-mode. För oscilloskopet gäller att dc-mod visar signalen som den är, medan ac-mod tar bort en eventuell likspänningsnivå. Detta sker genom att en kondensator kopplas in. Multimentern visar medelvärdet i dc-mod. I ac-mod visas rms-värdet om signalen är sinusformad efter det att en eventuell likspänningsnivå har tagits bort. Oscilloskopet ska i normala fall vara inställt i dc-mod – även när insignalen är en växelspänning.
- Observera att Philipsprobar ska användas till Philipsoscilloskop och Tektronicsprobar till Tektronicsoscilloskop.

3. Speciella mätinstruktioner för digitalteknik

- Digitala utgångar får inte kopplas ihop (om det inte är frågan om open-collector-grindar).
- Lämna inga ingångar oanslutna till digitala kretsar

List of components to be used

Measurements on simple circuits

Resistors:	1 kΩ, 2 kΩ, unknown resistance
Diode:	1N4002
Software:	Electronic Workbench subcircuit “Vdiff”

Filters and RC-circuits

Resistors:	5 kΩ
Capacitor:	6.8 nF
Inductor:	150 mH
Software:	Matlab script “rlc.m”

Power supply circuits

Resistor:	330Ω/5W
Capacitor:	100 μF (Box with capacitor and fuse inside)
Diode:	1N4002
Zener diode:	BZX85/C15
Transformer	Tufvasson PFS 60N
Full wave rectifier	B40C1500

The Usage of Operational Amplifiers

Resistors:	10 kΩ, 50 kΩ, 100 kΩ
Diode:	1N4148
Zener diode:	BZX55-C6V2
Op amp:	LM741

Simulations in Electronic Workbench

Software:	Electronic Workbench subcircuit “butter2”

Design of Transistor Amplifiers

Resistors:	100 Ω, several resistors in the kΩ−range
Transistors:	2N3904
Capacitor:	100 μF

1 Measurements on simple circuits

You don't need to hand in any report for this first laboratory task, just make sure that the laboratory master is aware of that you have completed your tasks.

1.1 Resistance measurements

The laboratory master will supply you with an unknown resistor. Your task is to determine the resistance in three different ways.

(a) The Resistance can be determined by checking the colour code of the resistor. Read chapter 3.2.3 in Söderkvist (or Physics handbook chapter T-3.1 or Paperback on a ELFA catalogue) and determine your unknown resistance accordingly.

(b) Use a multimeter to measure the resistance.

(c) Connect a dc voltage source with a voltage of E = 5 V in series with the resistance and a multimeter. Use the Dual Display Multimeter to measure the voltage U across the resistor and the current I flowing through it. Determine the resistance $R = U / I$

Do you get the same results in all three cases?

Þ ***Summary: Determine** the unknown resistance in three different ways.*

Laboratory master's sign ……………………...

1.2 DC measurements on a linear simple circuit

Connect the circuit shown in Figure 1.1. Connect the regulated DC supply as the input voltage. Connect the Dual Display Multimeter to measure the voltage across the resistor and also the current flowing through it.

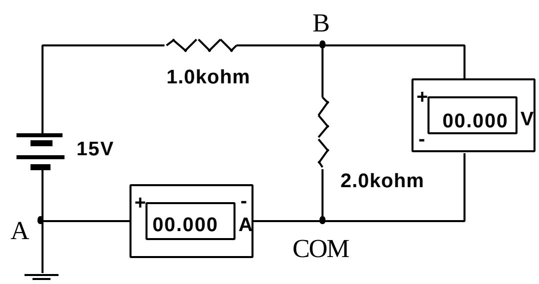

Figure 1.1

Hint: Connect the instrument common point **COM** as indicated, measure the component voltage at point B and the component current through point A. The measured current will then be of opposite sign compared to the voltage.

Measure the current I flowing through the 2 kΩ-resistor and the voltage U across the resistor. Draw U as a function of I for U ranging from –4 V to 4 V in steps of 0.5 V.

Þ ***Summary: Draw U(I)** for the 2 kW-resistor.*

Laboratory master's sign ……………………...

1.3 DC measurements on a non-linear simple circuit

- *Static method for measurement of diode characteristics*: using the multimeter

Semiconductor diodes are examples of component with a non-linear relation between current and voltage. The diode characteristic curve is described in Söderkvist chapter 3.5.3 and chapter 3.2 in Jaeger.

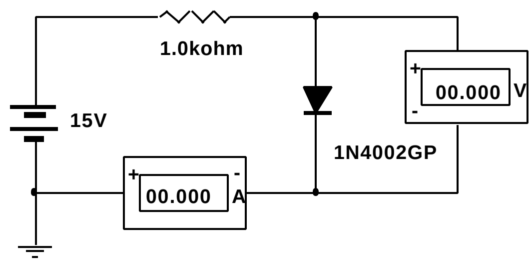

Figure 1.2

Connect the circuit shown in Figure 1.2 using the 1N4002 diode. Measure the current I flowing through the diode and the voltage *U* across the diode. Draw *U* as a function of *I* for *U* ranging from –4 V to 4 V. Estimate the value of the dynamic resistance for the diode when the current I is 0.5 mA.

Hint: Be aware of, that for some regions you might need more points to be able to draw the characteristic accurately.

Þ ***Summary: Draw the diode characteristic curve I(U)*** *as measured using the multimeter. Estimate R_d for the specified operating point.*

Laboratory master's sign ……………………...

1.4 AC measurements on a non-linear simple circuit

- *Dynamic method for measurement of diode characteristics*: using the oscilloscope

The measurement in experiment 1.3 can be performed in a more handy way by using the oscilloscope and AC voltage.

Connect a circuit according to the drawing below. Use a sine-wave generator with the amplitude 5 V as input voltage source.

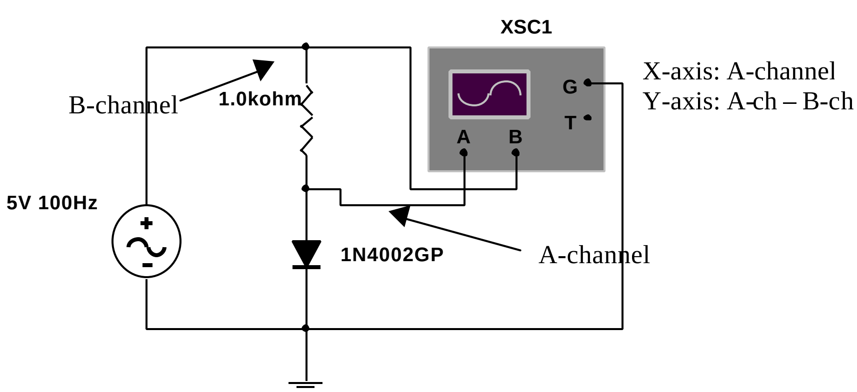

Figure 1.3

Use the A-channel of the oscilloscope to measure the voltage over the diode and the B-channel to measure the total input voltage. Adjust the oscilloscope to get a proper view of the two AC-voltages. Switch the oscilloscope sweep mode to **X-Y**. Use the “add” and the “invert” functions to get channel 1 – channel 2. The voltage over the resistor is proportional to the current floating through the diode. Remember that the channels should have identical gain.

Observe the characteristics of the diode on the oscilloscope screen and draw it on a paper. The scale of the drawing is connected to the gain of the oscilloscope channels. If the scale for channel A is 1V/div, the horizontal scale is 1V/div. If the scale is 1V/div for channel B, the vertical scale is 1V/1kΩ = 1mA/div. Change the output voltage of the sine wave generator and the gain in the channels (keeping the same gain in both channels), in order to observe the different parts of the characteristic. Estimate the dynamic resistance for the diode when the current I is 0.5 mA.

Þ ***Summary: Draw the diode characteristic curve I(U)*** *as observed on the oscilloscope. The slope and threshold voltage should clearly be identifiable in the figures, so be careful when drawing the characteristics. Estimate* R_d *for the specified operating point.*

Laboratory master’s sign ……………………...

1.5 Introduction to the simulation program Electronics Workbench

Electronics Workbench is an electronics simulation program. It is possible to perform most measurements that could be performed on real components. This is done using realistic models for the components and with no risk of destroying the components. It is also easier to see whether the circuit has been connected together in a correct way. The purpose of this exercise is to give an introduction to the program. The program is relatively easy to use, but use the on-line help function or ask the laboratory master if anything is unclear. The program can be found in the *elwork* folder.

a) Get familiar with the program. Find the solutions to problems 1-12 and 1-24 in the Söderkvist exercise book using the program. Show your circuits to the laboratory instructor.
b) Connect the circuit of experiment 1.2 using the program. Do this for U_{in} = -5 V, 2 V and 7 V. Try to find out on your own how to change the value of a component, how to give the component a name, how to wire components and how to rotate a component. Make sure that you know how to use the V-meter and the A-meter and the multimeter. Get familiar with the favourites bin
c) Connect the circuit of experiment 1.4 using the program. Connect the oscilloscope and get familiar with. You don’t have to do any calculations. Set the colour of the connection to channel A to be red and the connection to channel B to be blue. (To get the voltage between any two points and not only relative to ground, you need the subcircuit Vdiff, supplied by the laboratory master.)

Þ *Requested: Show your circuit to the laboratory master and show that you have understood how to use the instruments.*

Laboratory master’s sign ……………………...

2 Filters and RC-circuits

2.1 A measurement of filter circuits using sine wave voltage

Basic filter theory is described in Söderkvist chapter 2.11.

a) Connect the circuit shown in Figure 2.1.

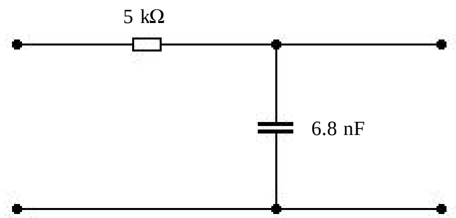

Figure 2.1

Connect the sine-wave generator with the amplitude of about 10 V as the input voltage. Measure the amplitude of the output voltage using the oscilloscope. Use the results to calculate $|H(f)| \equiv \hat{U}_{ut} / \hat{U}_{in}$ in the frequency range 1 kHz - 10 kHz in steps of 1 kHz. Estimate the ”cut-off” frequency of this circuit, i.e. the frequency at which $|H(f)| \approx 0.707$.

What kind of filter is it (Low pass - LP, High pass – HP, Band pass – BP or Band stop – BS)?

Þ ***Summary: Draw** ½**H(f)**½ º $\hat{U}_{ut} / \hat{U}_{in}$, f =1, 2, …, 10 kHz. **Type of filter? Estimate** f_c.*

Build the opposite type of filter using the same components as in (a). Draw your circuit and perform your measurements just as in (a).

Þ ***Summary: Draw** ½**H(f)**½ º $\hat{U}_{ut} / \hat{U}_{in}$, f =1, 2, …, 10 kHz**. Estimate** f_c**.***

Replace the capacitor in Figure 2.1 by an inductor with an inductance L = 150 mH.

Þ ***Summary: Draw** ½**H(f)**½ º $\hat{U}_{ut} / \hat{U}_{in}$, f =1, 2, …, 10 kHz. **Type of filter? Estimate** f_c.*

Now connect the 6.8 nF capacitor in series with the 150 mH inductance. The resonance frequency of a band pass filter is the frequency at which $|H(f)|$ reaches its maximum. The resonance frequency of a band stop filter is the frequency at which $|H(f)|$ reaches its minimum. What type of filter is this? Estimate the resonance frequency of the filter.

Þ ***Summary: Draw** ½**H(f)**½ º $\hat{U}_{ut} / \hat{U}_{in}$, f =1, 2, …, 10 kHz. **Type of filter? Estimate** f_{res}.*

Change to a parallel connection of L = 150 mH and C = 6.8 nF.

Þ ***Summary: Draw** ½**H(f)**½ º $\hat{U}_{ut} / \hat{U}_{in}$, f =1, 2, …, 10 kHz. **Type of filter? Estimate** f_{res}.*

2.2 Measurements on a RC-circuit

RC-circuits are treated in Söderkvist chapter 3.3.3.

Use the same circuit as in Figure 2.1, but replace the sine-wave by a square-wave with the amplitude of about 10 V. Observe the waveform of the output voltage. Choose the generator frequency in such a way that the asymptotic part of the exponential waveform of the output voltage is fully developed. Measure carefully:

$t_{(10\%)}$ - the time when the output signal reaches 10% of the amplitude,
$t_{(63\%)}$ - the time when the output signal reaches 63% of the amplitude,
$t_{(90\%)}$ - the time when the output signal reaches 90% of the amplitude.

Calculate the time constant t of the circuit using three methods:

$$t = R \cdot C \qquad t = t_{(63\%)} \qquad t = \frac{t_{(90\%)} - t_{(10\%)}}{2.2}$$

Calculate the average value of t and the maximum error in percents.

Þ ***Summary: Calculate*** *t* ***using (a) R and C, (b)*** $t_{(63\%)}$***, (c)*** $t_{(10\%)}$ ***and*** $t_{(90\%)}$.

Replace the capacitance in Figure 2.1 by an inductor with inductance L = 150 mH. The analytical expression for the time constant in the RL circuit is $t = L / R$.

Þ ***Summary: Calculate*** *t* ***using (a) R and L, (b)*** $t_{(63\%)}$***, (c)*** $t_{(10\%)}$ ***and*** $t_{(90\%)}$.

2.3 Measurements of complex power

(a) **Measurement**. Use the same circuit as in Figure 2.1. Connect a sine-wave generator with the amplitude 10 V as input voltage. Use the first channel of the oscilloscope to measure the input voltage and the second channel to measure the voltage over the capacitance. Use the add and invert functions of the oscilloscope to get channel 1 – channel 2, i.e. the voltage over the resistor. The voltage over the resistor can then be used to get the current as $i(t) = u_R(t) / R$. Measure the phase shift between the current and voltage. Perform these measurements in the frequency range 1 kHz to 10 kHz in steps of 1 kHz.

Theory. Calculate the impedance of the circuit, and draw the complex representation of the circuit impedance for the frequencies f = 1 kHz, 5 kHz and 10 kHz. Calculate the active power P and reactive power Q of the circuit for these frequencies.

Þ ***Summary: Draw X(f) º Û***$_C$***(f)/Î(f) and*** *j (f), f=1, 2, …, 10 kHz;* ***Calculate Z(f), P(f), Q(f)****, f = 1, 5 and 10 kHz*

(b) Place an inductance L = 150 mH in series with the capacitor in figure 2.1 Measure the voltage over C and L.

Start MATLAB on the PC. Activate the MATLAB-script `rlc.m`. , by choosing it on the menu “File/Run Script...”. The script will give you a graphic view of the phase and size of the voltage for each component in a serial resonance circuit. Use the script to verify your calculations.

Þ ***Summary: Draw X(f) º Û***$_C$***(f)/Î(f) and*** *j (f), f=1, 2, …, 10 kHz;* ***Calculate Z(f), P(f), Q(f),*** *f = 1, 5 and 10 kHz*

Formulas

Ohm's law	U = R I
Sinusoidal signals	$u(t) = \hat{u} \sin(\omega t + \varphi_U) \Leftrightarrow U = \hat{u} e^{j\varphi U}$
'Ohm's law for ac'	U = Z I, where $\lvert Z \rvert = \hat{U} / \hat{I}$ and $\arg Z = \varphi_U - \varphi_I$
Capacitive impedance	$Z = 1/j\omega C$
Inductive impedance	$Z = j\omega C$
Complex power	$P + jQ = U I^* = Z \lvert I \rvert^2 = \lvert U \rvert^2 / Z^*$

3 Power supply circuits

3.0 Introduction

The three basic constituents of a power supply circuit are the *transformer*, the *rectifier bridge* and the *electrolyte capacitor.* In this experiment, we examine how these different parts influence the output voltage as well as the load's influence. In all cases set the oscilloscope to dc-mode to observe the general appearance of the output voltage. In case of a reasonably good rectification, the voltage is roughly constant with small variations, the 'ripple'. Set the oscilloscope to ac-mode in order to observe the ripple voltage. Note that it is not possible to measure the RMS-value using a conventional voltmeter, if the voltage is not sinusoidal.

3.1 Half wave rectifier

Connect the diode 1N4002 between the output of the transformer and a 330Ω/5W resistor load (see Figure 3.1).

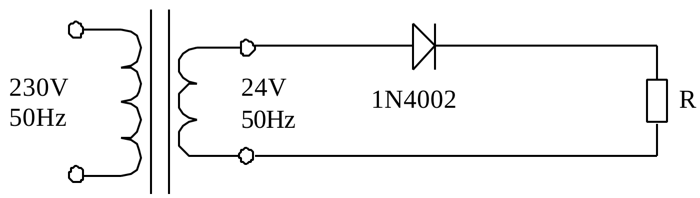

Figure 3.1

Observe and measure the load voltage using the oscilloscope. Draw the observed waveform. Calculate the average and RMS (root-mean-square) values. Calculate the output power in this case. Turn the diode in the opposite direction. Observe and measure the load voltage using the oscilloscope. Draw the observed waveform. Calculate the average and RMS (root-mean-square) values. Calculate the output power in this case.

Þ ***Summary: Draw U(t)*** *as seen on the oscilloscope.* ***Calculate U_m and U_{RMS}****. Do this with the* <u>*diode in both directions*</u>*.* ***Calculate P_{out}****.*

3.2 Half wave rectifier with filtering capacitance

Connect the capacitance C = 100µF (***with fuse and*** **SHIELD** ***supplied by the laboratory teacher***) in parallel to the load R=330Ω/5W (as shown in Figure 3.2).

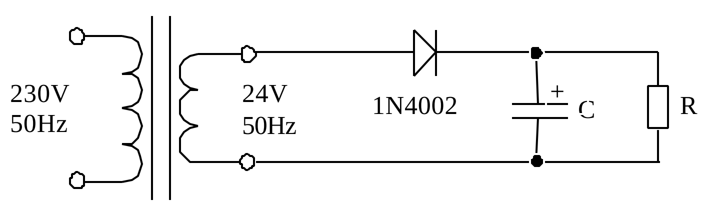

Figure 3.2

Þ ***Summary: Draw U(t)*** *as seen on the oscilloscope.* ***Calculate U_m and U_{RMS}****. The signal can be approximated to a ramp function in the calculations. Do this* <u>*with*</u> *and* <u>*without*</u> *the load.* ***Calculate P_{out}****.*

3.3 Full wave rectifier

Connect the full wave rectifier (built using four diodes 1N4002) between the output of the transformer and the load R=330Ω/5W (as in Figure 3.3).

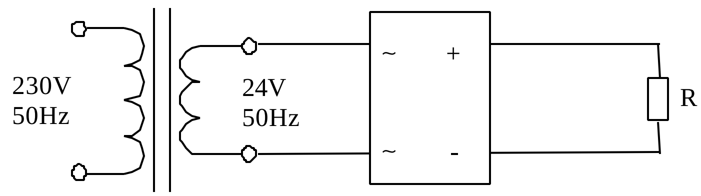

Figure 3.3

Observe and measure the load voltage using the oscilloscope. Draw the observed waveform. Calculate the average and RMS values as well as the load power.

Þ ***Summary: Draw U(t)*** *as seen on the oscilloscope.* ***Calculate*** U_m ***and*** U_{RMS}. ***Calculate*** P_{out}.

3.4 Full wave rectifier with filtering capacitance

Connect the capacitance C=100μF (***with fuse and*** **SHIELD** ***supplied by the laboratory instructor***) in parallel to the load R = 330Ω/5W (shown in Figure 3.4).

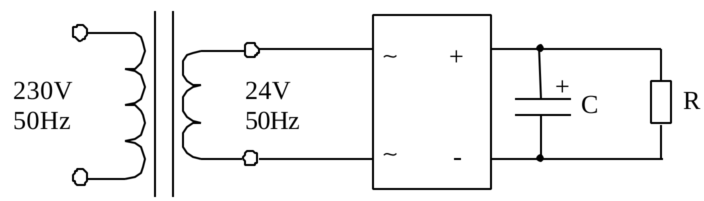

Figure 3.4

Observe and measure the load voltage using the oscilloscope. Draw the observed waveform. Calculate the average and RMS values as well as the load power.

Þ ***Summary: Draw U(t)*** *as seen on the oscilloscope.* ***Calculate*** U_m ***and*** U_{RMS}. ***Calculate*** P_{out}.

3.5 The Zener diode as a voltage stabiliser

A Zener diode can be used as a voltage stabiliser to further improve the performance of the rectifying circuits. The serial resistance R_S in Figure 3.5 needs to be chosen in such a way that the maximum power dissipation (1.3 W) of the Zener diode BZX85/C15, is not exceeded. Calculate R_S in such a way that the maximum power dissipation (which occurs when $R \to \infty$) is 1 W.

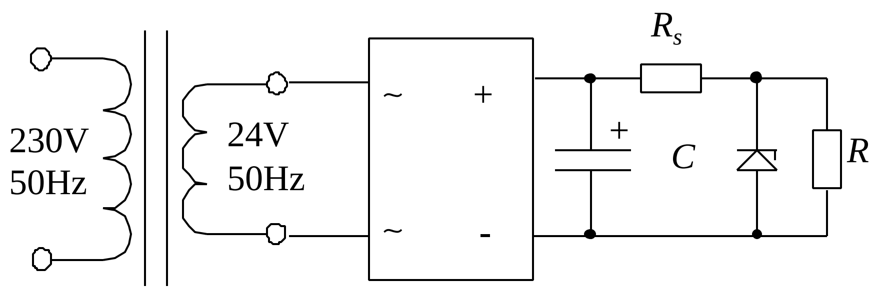

Figure 3.5

Also calculate the maximum power dissipation in the serial resistance R_S (which occurs when $R \to 0$) and choose a resistor that can stand this power dissipation. Measure the Zener diode voltage and current for $R = \infty$. Use the oscilloscope for the measurement and measure the maximum ripple voltage. Connect the load R=330Ω/5W. Measure the voltage and current as well as the maximum ripple voltage.

Use the results to calculate the dynamic resistance of the diode.

Þ ***Summary: Determine R_s*** *to limit power dissipation.* ***Calculate P_{max}*** *for R_s.* ***Draw U(t)*** *as seen on the oscilloscope.* ***Calculate U_m and U_{RMS}.*** *Do this <u>with</u> and <u>without</u> the load.* ***Calculate R_d.***

Formulas

$$U_{mean} = \overline{U} = \frac{1}{T}\int_0^T u(t)dt$$

$$U_{RMS} = U = \sqrt{\frac{1}{T}\int_0^T u^2(t)dt}$$

$$P = U \cdot I = (U_{RMS} \cdot I_{RMS})$$

$$R_d = \frac{\Delta U}{\Delta I} = \lim_{r \to \infty} \frac{U_{R=\infty} - U_R}{I_{R=\infty} - I_R}$$

Hint: To simplify the integrals, the period of the functions can be chosen to:

- Sinusodial functions: Use a period of $2 \cdot \pi$
- Ramp functions: Use a period of 1

This makes the calculations as simple as possible but will not affect the result.

4 The Usage of Operational Amplifiers

Linear and non-linear circuits,

References: *Söderkvist* chapter 4.11, page 369-374, 377-378, *Jaeger* chapter 12

4.1 First view of the operational amplifier

a) Connect the circuit of Figure 4.1.

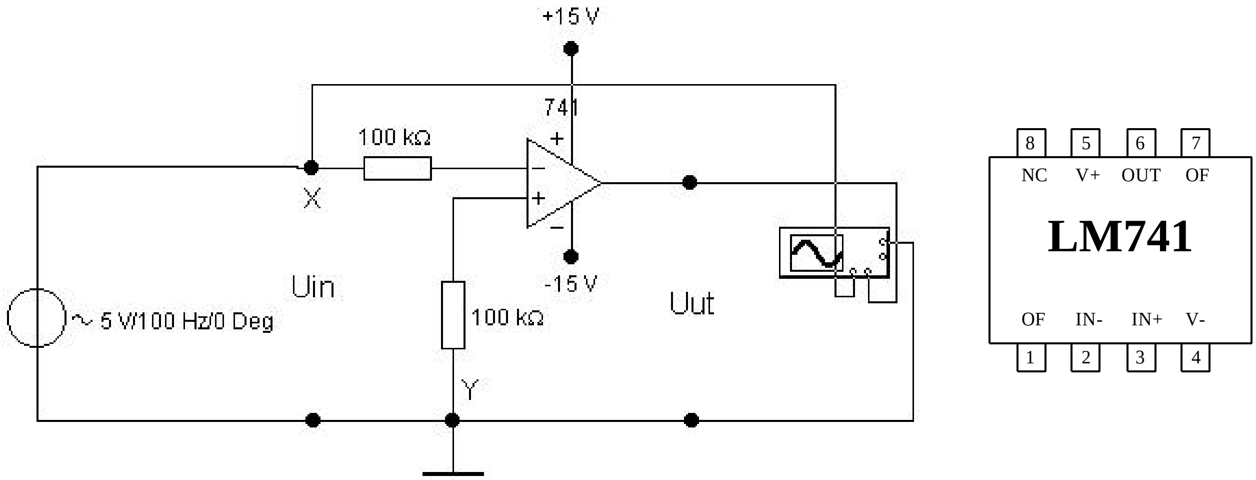

Figure 4.1

Connect the sine-wave generator as an input voltage $U_{in,}$ setting the frequency to about 100 Hz, and amplitude to about 5V. Connect the channel 1 of the oscilloscope to the voltage U_{in} and CHANNEL 2 to U_{out}. Switch the oscilloscope sweep mode to **X-Y** in order to get the voltage U_{in} as a sweep for the x-axis. Observe the characteristic U_{out} = f (U_{in}) of the connected op-amp. Changing the output voltage of the sine wave generator and the gain in channels try to observe the active part of the characteristic. Draw the characteristic (with the scales on axes).

Þ ***Requested:*** *Draw* $U_{out} = f(U_{in})$.

b) Exchange the inputs of the amplifier (point "X" to the ground and point "Y" to U_{in}). Observe the transient characteristic of this connection. Draw the characteristic

Þ ***Requested:*** *Draw* $U_{out} = f(U_{in})$. *Explain the difference between the previously measured and the present one.*

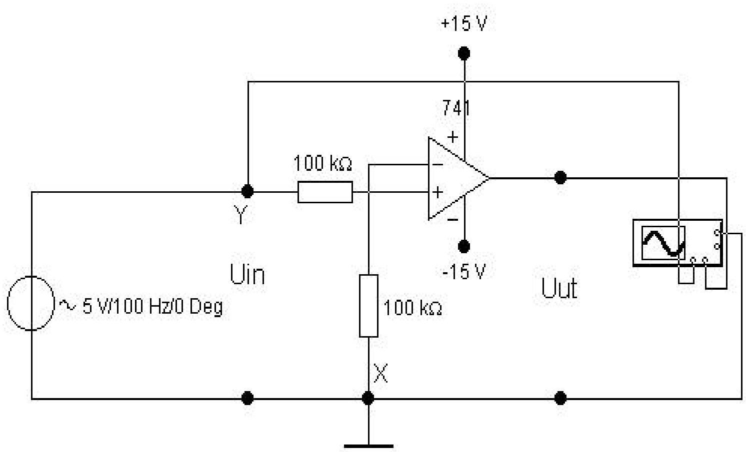

Figure 4.2

4.2 Op-amp with feedback – linear circuits

a) Now connect point "X" to U_{out} instead of the ground as shown in Figure 4.3. Observe the transient characteristic of this connection. Calculate the gain of the constructed amplifier.

Þ ***Requested:*** *Draw $U_{out} = f(U_{in})$. Calculate the gain. Explain the difference between the previously measured and the present one.*

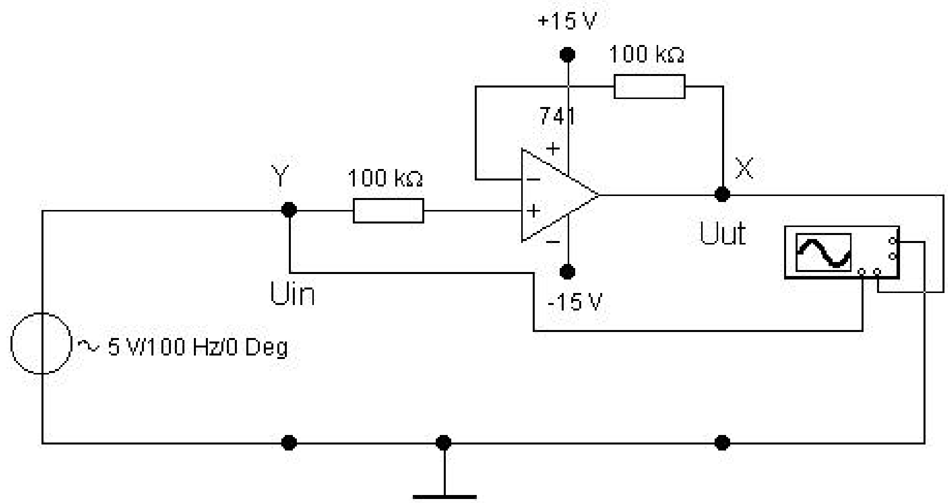

Figure 4.3

b) Change the circuit to the one shown in the Figure 4.4. It should be noted that the common agreement among the op-amp users is to not include the supplying pins of op-amps in the schematic drawings, assuming that their connections to power supplies are obvious). **Don't remove the 15 V supply pins!!!**

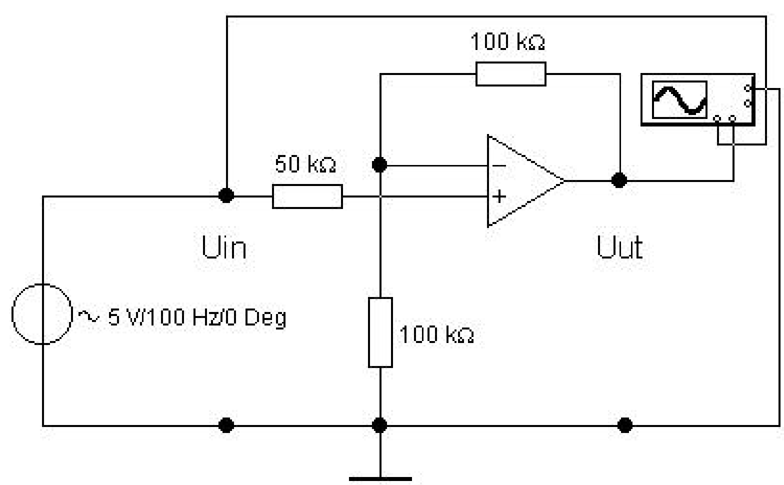

Figure 4.4

Observe the transient characteristic of this connection.

Þ ***Requested:*** *Draw $U_{out} = f(U_{in})$. Explain the difference between the previously measured and the present one.*

c) Change the circuit to the one shown in Figure 4.5.

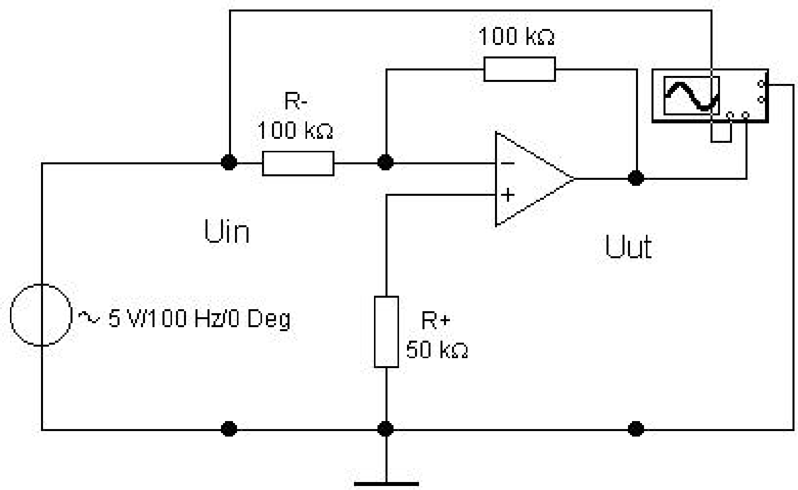

Figure 4.5

Observe the transient characteristic of this connection.

Þ ***Requested:*** *Draw $U_{out} = f(U_{in})$. Explain the difference between the previously measured and the present one.*

Change the resistances *R+* and *R-* to 10 kΩ. Observe the transient characteristic of this connection.

Þ ***Requested:*** *Draw $U_{out} = f(U_{in})$. Explain the difference between the previously measured and the present one.*

Change the circuit to the one shown in Figure 4.6.

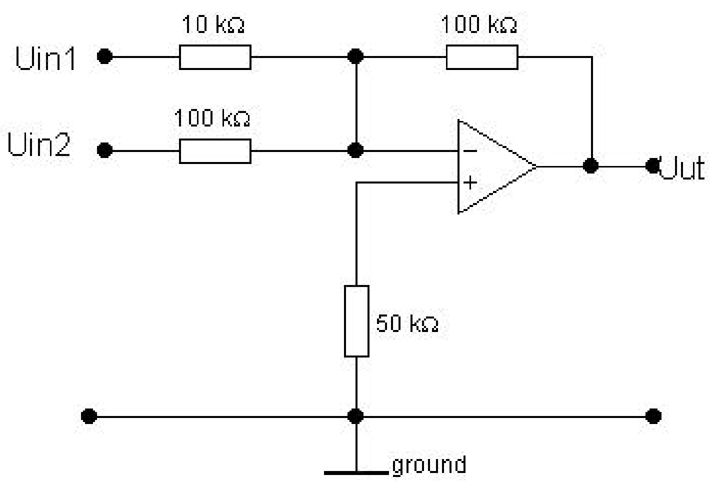

Figure 4.6

Connect the <u>sine-wave generator</u> as an input voltage U_{in1}. Use a 100 kΩ potentiometer connected between –15 V and +15 V supplies as U_{in2}. Observe the characteristics, i.e. the U_{out} = f (U_{in1}) curve, for a few different U_{in2} voltages. Calculate the gain of the constructed amplifier for U_{in1} and U_{in2}.

Þ *Requested: Draw $U_{out} = f(U_{in1})$ for a few U_{in2}. Explain the difference between gains.*

4.3 Op-amp with feedback – non-linear circuits

a) Connect the circuit of Figure 4.7.

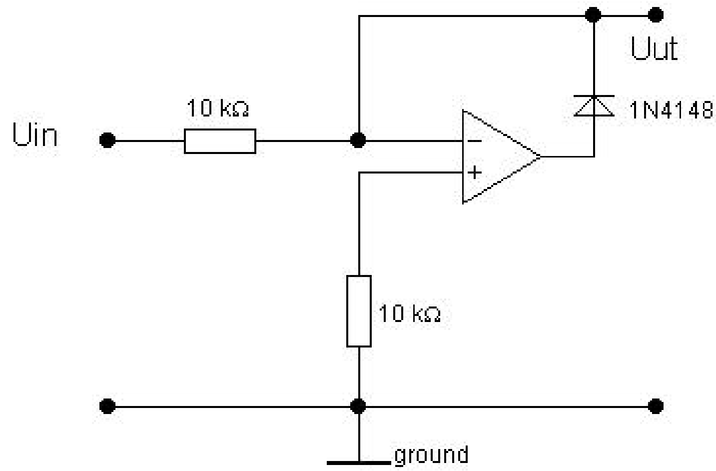

Figure 4.7

Observe and draw the transient characteristic of this connection. Switch the diode to the opposite direction. Observe and draw the transient characteristic of this connection. Any ‘normal’ diode can be used if the 1N4148 diode is not available. How does the circuit work, i.e. why do you get the results you get? Is it really an ideal diode without threshold voltage?

Þ ***Requested:*** *Draw $U_{out} = f(U_{in})$. Answer the questions.*

b) Construct the circuit of Figure 4.8. If the Zener diode BZX55-C6V2 is not available, use any other Zener diode with a Zener voltage below 15 V.

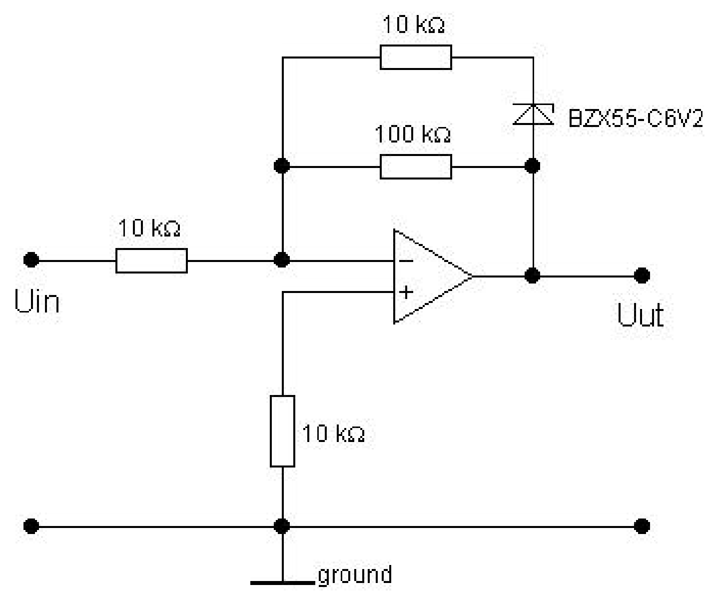

Figure 4.8

Þ ***Requested:*** *Draw $U_{out} = f(U_{in})$ for the diode in both directions.*

5 Simulations in Electronics Workbench

You don't need to hand in any report for this laboratory task.

5.0 Introductions

Electronics Workbench is an electronics simulation program. It is possible to perform most measurements that could be performed on real components. This is done using realistic models for the components and with no risk of destroying the components. It is also easier to see whether the circuit has been connected together in a correct way. The purpose of this experiment is to give an introduction to the program. The program is relatively easy to use, but use the on-line help function or ask the laboratory master if anything is unclear.

5.1 General instructions

- The program can be found in the *elwork* folder.
- Always remember to connect ground to at least one point of your circuit.
- Changing the label of for example a diode is not the same as changing the model of the diode.
- Choose Analysis/Analysis options…/Instruments from the menu in order to stop the oscilloscope after each sweep or to get shorter time steps for the Oscilloscope and shorter frequency steps for the Bode plotter.
- By switching between A- and V-mode it is possible to use the multimeter to measure open circuit voltage and short circuit current with the same instrument.
- The bode-plotter needs an ac source to be included somewhere in the circuit. The frequency setting of the ac source does not matter, but a frequency sweep will be generated according to the settings of the bode plotter.

5.2 Filters and the Bode plotter

(a) Connect the *RC*-filter of experiment 2.1 and use the bode plotter to observe *H(w)* (both magnitude and phase). Change the scales to make the plot easier to view. Find the cut-off frequency by finding the '–3 dB'-level. What is the asymptotic slope of the filter at high/low frequencies (measured in dB/decade)?
Note: The voltage amplification in dB is defined as $G_{dB} = 20 \log |\hat{U}_{out}/\hat{U}_{in}|$.

Þ ***Requested**: Hand in a printout of the circuit and the bode-plot. Cut-off frequency? Asymptotic slope?*

Laboratory master's sign ……………………...

(b) The subcircuit *butter2*, supplied by the laboratory master, contains a so-called second order Butterworth filter. Use the Bode plotter to determine what asymptotic slope it has.

Þ ***Requested:** Hand in a printout of the circuit and the bode-plot. Determine the asymptotic slope.*

Laboratory master's sign ……………………...

(c) Connect R = 5 kΩ, C = 6.8 nF and L = 150 mH in series just as in experiment 2.1, part 4, with U_{out} being the voltage over *C* and *L*. Use the Bode plotter to determine the resonance frequency f_0. Try to determine as accurately as possible the minimum gain of this band-stop filter?

Þ ***Requested:** Print out the bode plot. Determine f_0 from the plot. Determine minimum gain.*

Laboratory master's sign ……………………...

5.3 Diode limiting circuits

(a) Connect the circuit shown in Figure 5.1 below. How does the circuit work? What will happen if the voltage U_{bias} is changed? How does the resistance R_1 influence the results?

Þ ***Requested:*** *Show the circuit and the results and explain how it works.*

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Laboratory master's sign ……………………...

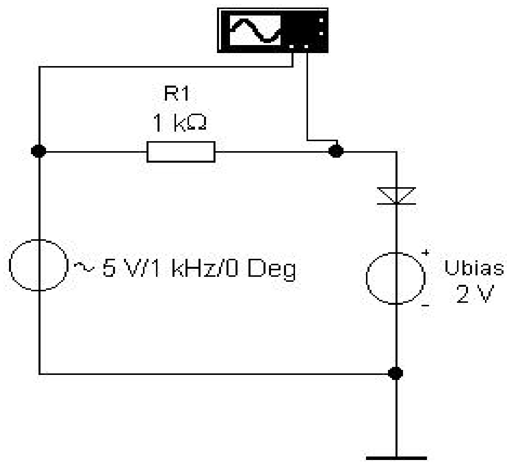


Figure 5.1

(b) How can you make a circuit that clips all voltages below a certain limit? Connect a circuit that clips all voltages below approximately +2.0 V.

Þ ***Requested:*** *Answer the question. Check that your circuit works and include it in your report.*

Laboratory master's sign ……………………...

(c) Connect a 'positively limiting' circuit, clipping at +3.0 V, and a 'negatively limiting' circuit, clipping at -1.0 V, in parallel in order to clip the voltage in both directions.

Þ ***Requested:*** *Design and connect the circuit and include a printout of an oscilloscope trace in your report.*

Laboratory master's sign ……………………...

(d) Connect the circuit shown in Figure 5.2 below. Note that it's not enough to change the labels of the diodes to get different zener voltages.

Þ ***Requested:*** *Include an oscilloscope plot and explain how the circuit works.*

Laboratory master's sign ……………………...

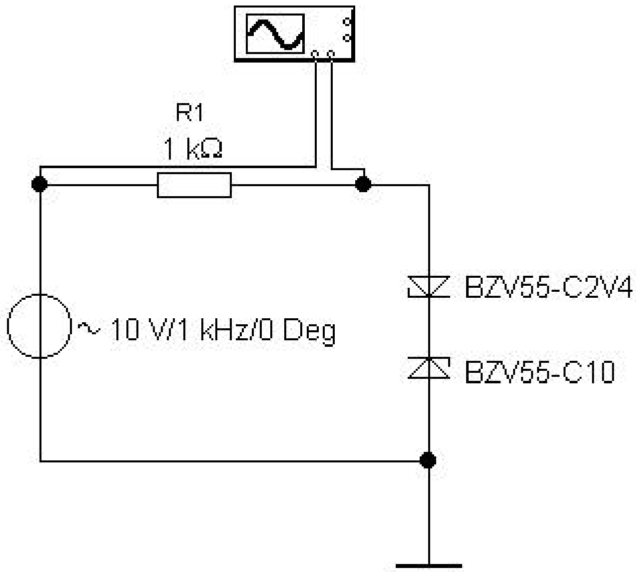


Figure 5.2

5.4 Electronic Current Source

Make a simple electronic current source according to *figure* 3.88, *page* 295 in *Söderkvist* or *figure* 15.67, *page* 781 in Jaeger. Try to design it in such a way that the current is of the order 5 mA. Most important is that the current does not change appreciably with the load. The source should be able to give this current for load voltages up to 4.0 V. Use a 2N3904 transistor. How do the values of the resistors R and R_E influence the function of the current source? What is the internal resistance of the source?

Þ ***Requested:*** *Hand in a print-out of the circuit or show the circuit to the laboratory master. Determine the current and internal resistance. Influence of R and R_E?*

Laboratory master's sign ……………………...

5.5 Transistor-transistor logic (TTL)

The circuit below, in Figure 5.3, shows a standard TTL inverter circuit. A low input voltage should lead to a high output voltage and a high input voltage to a low output voltage. For TTL, input voltages in the interval 0 to 0.8 V are defined as low and input voltages between 2.0 and 5.0 V are high. Output voltage between 0 and 0.4 V are low and output voltages between 2.4 and 5.0 V are considered to be high. Determine the transfer function of the circuit and verify that the output voltage always stays within the limits for the allowed input voltages. Connect a *square-wave generator* with a frequency 100 kHz and observe the output wave form and determine the *propagation delay* of the gate. The propagation delay is time between a designated point on the input pulse (e.g. the 50% point) and the corresponding point on the output pulse.

Þ ***Requested:*** *Determine transfer function. Verify output voltage. Draw output waveform? Determine propagation delay.*

Laboratory master's sign ……………………...

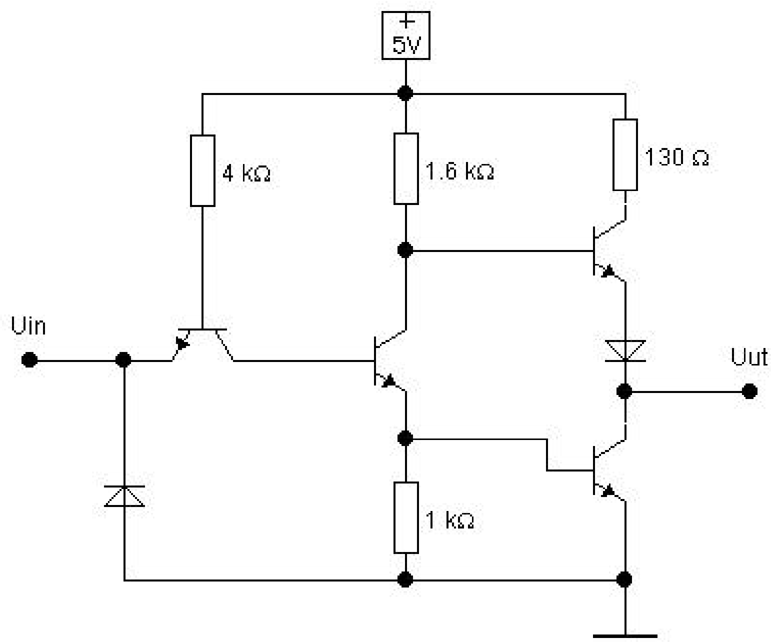


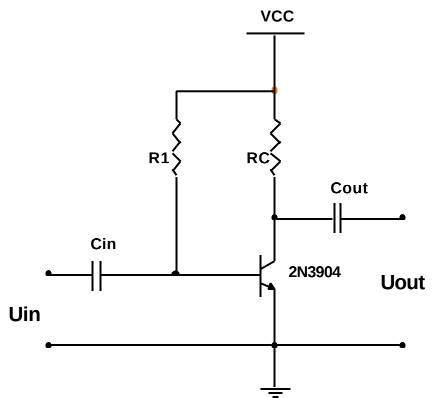
Figure 5.3

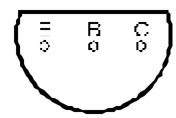
6 Design of Transistor Amplifiers

This task is supposed to be accomplished during two sessions (no 6 and 7).

6.1 Simple CE-stage

a) A simple CE-stage with a transistor and only two resistors is shown in Figure 6.1. Calculate the values of the resistors to achieve U_{OUT} = 7.5. The forward base-emitter voltage drop V_{BE} can be assumed to be 0.7 V and the current amplification factor, *b* is 200 and I_{Cmax} = 200 mA.





2N3904 seen from the connector side.

Figure 6.1

Hint: You have to choose an arbitrary value of I_{CQ} (In the order of 10-50 mA)

Connect the circuit in Figure 6.1, with the resistor you have chosen. Use 100 µF capacitors (for C_{in} and C_{out}) and a 2N3904 transistor. Measure the achieved voltage U_{CEQ}. Does the measured value differ from 7.5 V? Squeeze the transistor between your fingers. Can this affect the output voltage? Why?

Check the value of U_{CEQ} for two other 2N3904 transistors. Explain why the measured voltage of U_{CEQ} can differ.

Build the circuit in Electronic Workbench. What is the output voltage of the simulation?

Þ ***Requested:*** *Calculate resistor values (With calculations). Measure U_{OUT}. Answer questions.*

b) Connect the *sine-wave generator* as the input voltage U_{in}. Set the frequency to about 100 Hz and the amplitude to about 5 V. Connect channel 1 of the oscilloscope to U_{in} and channel 2 to U_{out}. Switch the oscilloscope sweep mode to *X-Y* in order to put the voltage U_{in} as sweep for the x-axis. Observe the transient characteristic U_{out} = f (U_{in}) of the constructed Common Emitter amplifier. Change the output voltage of the sine-wave generator and the gain in the channels in order to observe the different parts of the characteristic. Draw the characteristic (<u>with the scales on axes</u>) and answer where the following regions are in the charatristics:

- Turn-off region
- Saturation region
- Active region?

Calculate the gain of the amplifier using the slope of the transient characteristic. Important information that can be extracted from the characteristics is how large the linear region is for the amplifier.

Þ ***Requested:*** *Draw U_{out} = f(U_{in}) as seen on oscilloscope. Answer questions. Calculate gain. (The gain is defined as the slope of V_{out} = f(V_{in}) in the active region).*

6.2 CE-stage with voltage divider

To achieve circuit stability a voltage divider is to be added in the DC-biasing network.

a) Calculate the values for R_1 and R_2 so that the DC collector current I_C is equal to the previous excercise.

Hint: The base current can be neglected in the claculations if the current in the voltage diveder is more than 10 timer higher than I_B.

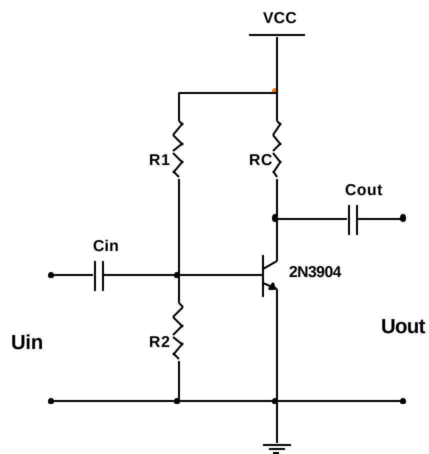


Figure 6.2

Check the value of U_{CEQ} for two other 2N3904 transistors. Are the results any different from the previous exercise? If so, explain why.

How is the temperature stability for this circuit, i.e how does the collector-emitter voltage change from start-up with a cold transistor until V_{CE} is stabilised. Explain why.

Build the circuit in Electronic Workbench. What is the output voltage of the simulation?

Þ ***Requested:*** *Calculate resistor values (With calculations). Measure U_{OUT}. Answer questions.*

b) Connect the sine-wave generator and draw the transfer characteristics as for the first amplifier. Compare the transfer characteristics with the previous amplifier. Important characteristics are amplification, voltage swing and the linearity.

Þ ***Requested:*** *Draw $U_{out} = f(U_{in})$ as seen on oscilloscope and compare with other amplifiers. Calculate gain.*

6.3 CE-stage with emitter resistance

A resistor is introduced in the emitter-path to increase the stability.

Calculate the values for R_E and R_C with the assumption the voltage drop over R_E should be 10% of the supply voltage. The operating point for V_{Out} should correspond to the middle of the possible voltage swing.

a) Check the value of U_{CEQ} for two other 2N3904 transistors. Are the results any different from the previous exercise? If so, explain why.

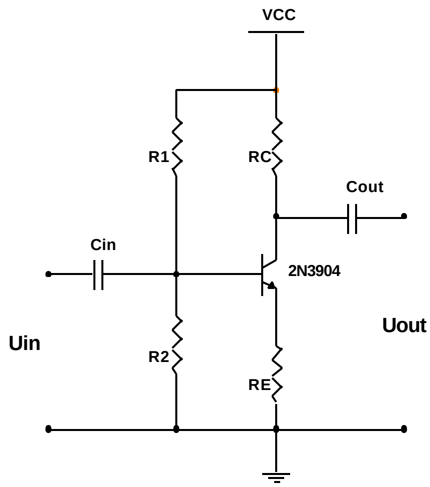


Figure 6.3

How is the temperature stability for this circuit, i.e how does the collector-emitter voltage change from start-up with a cold transistor until V_{CE} is stabilised. Explain why.

Build the circuit in Electronic Workbench. What is the output voltage of the simulation?

Þ ***Requested:*** *Calculate resistor values (With calculations). Measure U_{OUT}. Answer questions.*

b) Connect the sine-wave generator and draw the transfer characteristics. Compare the transfer characteristics with the previous amplifiers. Important characteristics are amplification, voltage swing and the linearity. What have happened to the amplification? Explain why.

Þ ***Requested:*** *Draw $U_{out} = f(U_{in})$ as seen on oscilloscope and compare with other amplifiers. Calculate gain. Answer question.*

6.4 CE-stage with emitter capacitance

A capacitor is added parallel to R_E to increase amplification.

The value for C_E can be selected to 100 μF.

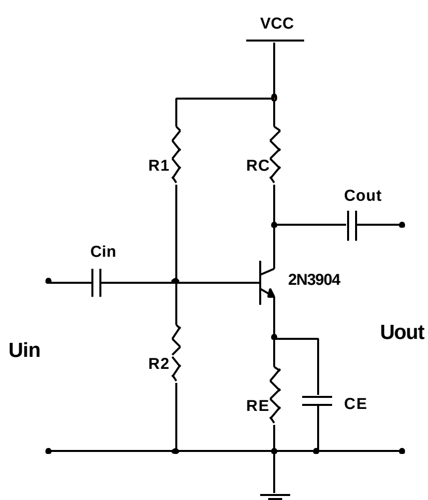


Figure 6.4

Connect the sine-wave generator and draw the transfer characteristics. Compare the transfer characteristics with the previous amplifier. Important characteristics are amplification, voltage swing and the linearity. What have happened to the amplification? Explain why.

What is the influence of the value for C_E? What will happen if the value is lower?
Hint: Think of the experiment Filters and RC-circuits.

Connect a load, R_L=100Ω to the amplifier. How is the voltage amplification changed when the load is connected to the amplifier? Explain why.

Þ ***Requested:*** *Draw* $U_{out} = f(U_{in})$ *as seen on oscilloscope for both with and without a load resistor. Compare with other amplifiers. Calculate gain for both with and without a load resistor. Answer questions.*

Don't disconnect, keep the circuit for a later exercise.

6.5 CC-stage

Construct a common collector amplifier with the transistor 2N2904.

In the CC-amplifier the resistor R_C is not needed but can some times be used to avoid high currents that would destroy the transistor. Here we will not use any resistor R_C. Calculate the values for R_E, R_1 and R_2 for a suitable operating point.

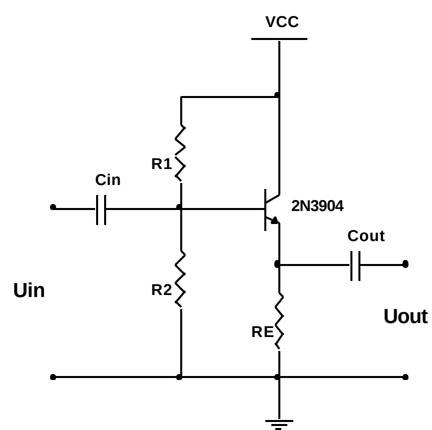


Figure 6.5

Check the value of U_{OUT} for two other 2N3904 transistors. Compare the stability for changes in temperature and changes in devices with other amplifiers.

Connect the sine-wave generator and draw the transfer characteristics. Compare the transfer characteristics with the previous amplifiers. Important characteristics are amplification, voltage swing and the linearity. Why is the amplification so different from previous amplifiers?

Connect a load, R_L=100Ω to the amplifier. **Do not** use a capacitor in the load path! The load will however affect the operating point but it is **not needed** to make any adjustments for this. How is the voltage amplification changed when the load is connected to the amplifier? Explain why.

Þ ***Requested:*** *Draw* $U_{out} = f(U_{in})$ *as seen on oscilloscope for both with and without a load resistor. Compare with other amplifiers. Calculate gain for both with and without a load resistor. Answer questions.*

6.6 Multistage amplifier

Connect the output from the CE-amplifier to the input on the CC-amplifier.

Connect the sine-wave generator to the CE-amplifier and draw the transfer characteristics. Compare the transfer characteristics with the previous amplifiers. Important characteristics are amplification, voltage swing and the linearity. Why is the amplification so different from previous amplifiers?

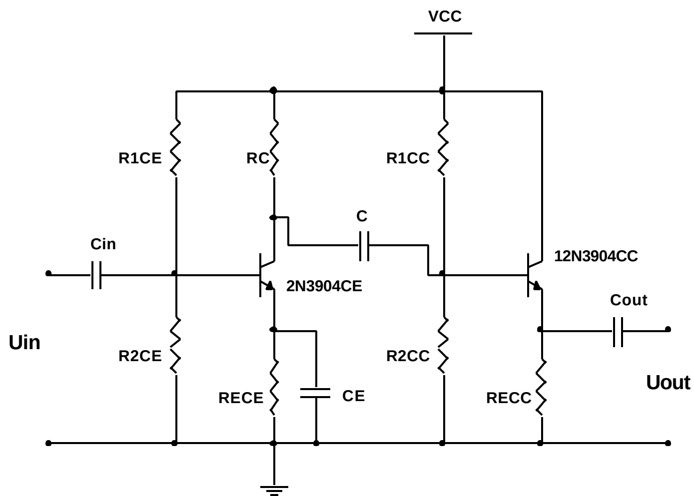


Figure 6.6

Connect a load, R_L=100Ω to the amplifier. **Do not** use a capacitor in the load path! The load will however affect the operating point but it is **not needed** to make any adjustments for this. How is the voltage amplification changed when the load is connected to the amplifier? Explain why.

Þ ***Requested:*** *Draw $U_{out} = f(U_{in})$ as seen on oscilloscope for both with and without a load resistor. Compare with other amplifiers. Calculate gain for both with and without a load resistor. Answer questions.*