# Electronics I. laboratory measurement guide

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## *2. Measurement: Bipolar transistor current generator and amplifiers*

These measurements will use a single (asymmetric) voltage supply. Use one of the controllable outputs of the power supply unit. Set up approx. 30mA current limit before starting the measurements and keep it throughout the session. We are using a BC337 type NPN transistor in TO-92 package (***figure 2.1*** left). A potentiometer (variable resistor) will be needed for some measurements (***figure 2.1*** right).

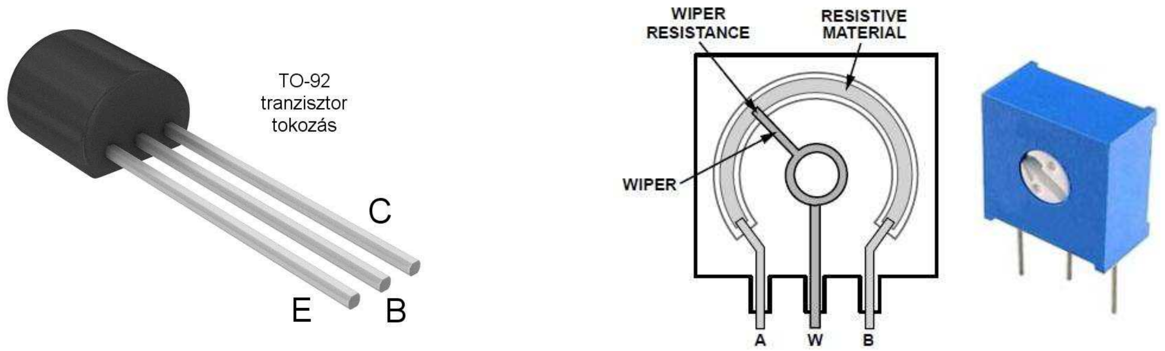


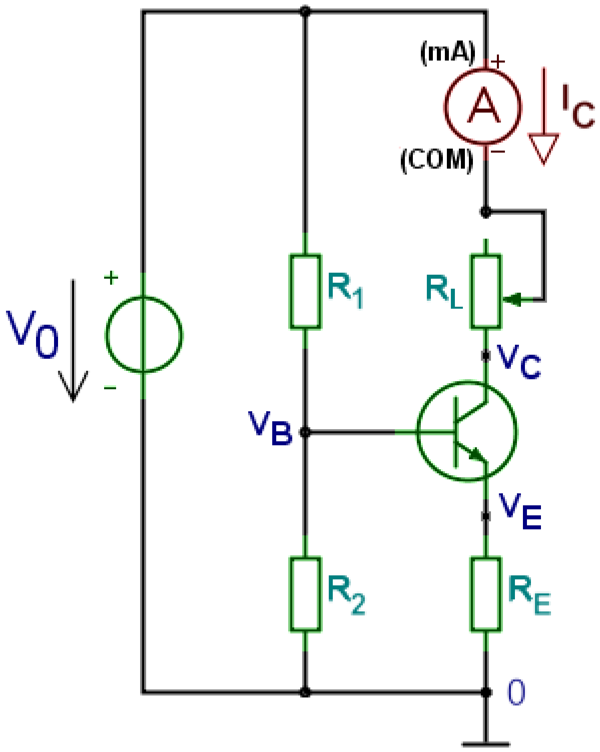

*Figure 2.1 Left: BC337 transistor pinout; Right: potentiometer structure and pinout*

### <u>2.0 Mandatory homework:</u>

**1/a.** Calculate the expected current $I_C$ of the current generator circuit in **exercise 2.1** (***figure 2.2***)! The β of the transistor is sufficiently large.
**1/b.** Calculate the operating point (DC) parameters ($I_E$,$V_B$, $V_E$) if the load is $R_L$=2kΩ!
**1/c.** Calculate the maximum allowed value of the load resistor!
**2/a.** Calculate the operating point DC parameters of the common emitter (CE) amplifier in **exercise 2.2** ($I_E$,$V_B$, $V_C$, $V_E$, $V_{CE}$, $V_{BE}$)!
**2/b.** Calculate the voltage gain ($A_V$) of this circuit with matched load!
**2/c.** Calculate the voltage gain of this circuit if $C_E$ emitter capacitor is removed!
**2/d.** Calculate the input dynamic resistance ($r_{in}$) of the circuit (using β=100; „worst case")! (Remember that transistors have large manufacturing variation. The β parameter of this transistor is between 100...600 according to its datasheet.)

## 2.1 Current generator with bipolar transistor:

**2.1.1** Build the circuit according to ***figure 2.2***. The load will be the potentiometer. Measure all the needed resistors with two digits of precision and use these values for calculations.




Components:

**$V_0$ = 15V**
**$R_1$ = 120kΩ**
**$R_2$ = 33kΩ**
**$R_E$ = 1kΩ**
**$R_L$ = 10 kΩ potentiometer**

*Figure 2.2: Current generator circuit*

The ampermeter will measure the collector current $I_C$, which is also the generator's output current (generator current). Measure this in mA setting with 3 decimal digits of precision.

**2.1.2** Measure $I_C$ when $R_L$=0. (Either rotate the potentiometer to 0Ω or short-circuit it with a wire). Compare the measured value to the calculated one!

**2.1.3** Slowly increase resistance of $R_L$ (use a screw driver) until $I_C$ decreases by 10% compared to the original (measured in previous exercise). Now take the potentiometer out of the circuit and measure the resistance between the two pins that were connected. This will be $R_{Lmax}$. Compare it with the calculated value!

**2.1.4** Put back the potentiometer. Set it up to be lower than $R_{Lmax}$. Measure this $R_L$ value and also $V_B$, $V_C$ and $V_E$ node potentials (that is, voltages relative to the reference zero point).

**2.1.5** Measure the output dynamic resistance of the circuit! To do this, connect a voltmeter in parallel with $R_L$. First rotate $R_L$ so that its voltage $V_{RL}$ is about zero; then choose an $R_L$ so that $V_{RL}$ is about 6..7V. Measure both voltage and current to three digits of precision in both cases. It is not necessary to measure $R_L$ itself.

| | $R_{L1}$= | $R_{L2}$= |
|---|---|---|
| $V_{RL}$ | mV | V |
| $I_C$ | mA | mA |

Calculate $R_{L1}$ and $R_{L2}$ from the measured values. Then calculate the output dynamic resistance using the following formula.

$$r_{out} = \frac{\Delta V_{RL}}{\Delta I_C} = \left| \frac{V_{RL2} - V_{RL1}}{I_{C2} - I_{C1}} \right|$$

This value tells us how good a current generator is (how much does its current change if its voltage changes). The bigger, the better (the more constant the current).

## 2.2 Common emitter (CE) amplifier:

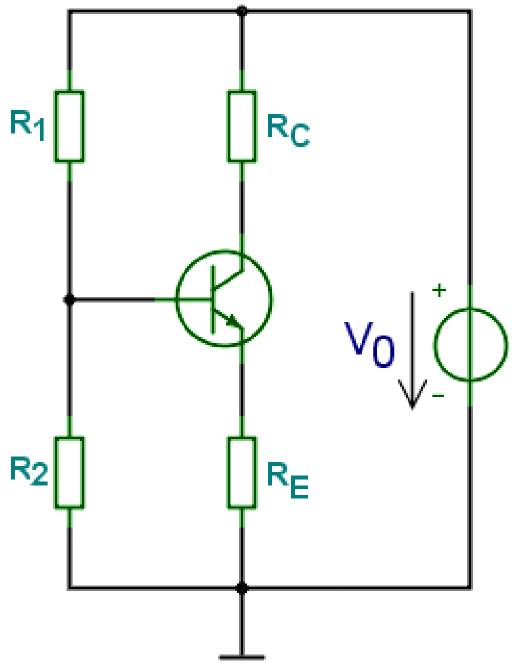



*Figure 2.3: DC part of a CE amplifier*

**Parameters: $V_0$=15V, $R_1$=120kΩ, $R_2$=33kΩ, $R_E$=2kΩ, $R_C$=5.1kΩ**

**2.2.1** You can use parts of the previous current generator circuit in this exercise. The base divider ($R_1$ and $R_2$) are unchanged. Replace $R_E$ with 2kΩ instead of previous 1kΩ and replace potentiometer with a fix $R_C$=5.1kΩ.
Measure all the needed resistors with two digits of precision and use these values for calculations (as resistors have a manufacturing tolerance.)

First build the circuit in ***figure 2.3***. Supply voltage is still $V_0$=15V.

**2.2.2** Measure the operating point DC parameters $V_B$, $V_C$, $V_E$, $V_{BE}$, $V_{CE}$. (Remember: $V_B$ means voltage between base and reference point; $V_{BE}$ means voltage between base and emitter; and so on.) From these values and the measured resistances, calculate $I_C$. Compare with value calculated in homework!

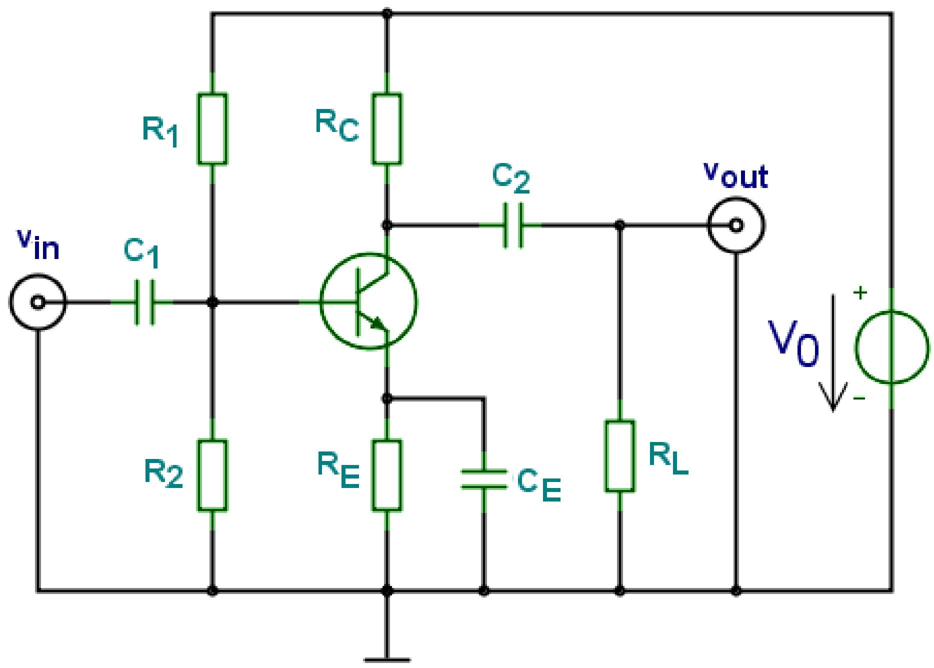


*Figure 2.4: Complete measurement circuit of CE amplifier*

Parameters: same as before, plus: $C_E$=47μF, $C_1$=$C_2$=100nF, $R_L$=5.1kΩ

**2.2.3** Complete the rest of the circuit with the capacitors and load resistor, according to **figure 2.4.** Values: $C_E$ =47μF/35V (it's an electrolytic capacitor which is polarity sensitive, its negative pole is noted on the package, take care when inserting it in the circuit); $C_1$=$C_2$=100nF (ceramic or foil capacitors, these are polarity independent). The load is matched, that is $R_L$=$R_C$. Connect the point marked as $v_{in}$ to the analog output of the function generator and also to the channel 1 (CH1) of the scope (use a T-juntcion and BNC-BNC cable). Connect $v_{out}$ to CH2 of scope.

Setup 5kHz frequency sine wave (with no offset) on the function generator. Turn on the two 20dB attenuators on the function generator (buttons above the BNC connector). Change the amplitude such that the output signal of the amplifier is not visibly distorted (that is, it still looks like a sine wave). **This input amplitude will be in order of mV**, which is very small, therefore setup the scope to trigger on CH2 (the output).

Draw the signal waveforms and measure their parameters (period/frequency, peak-to-peak voltage, phase) and find out the voltage gain ($A_V$). Compare the measured value with those calculated in the homework! Give the $A_V$ values in dB as well.

**2.2.4** Measure the lower and upper limit frequencies. Note the output voltage value at 5kHz. Decrease the frequency (and only that!) of the function generator until the voltage drops to 70% of its original value; this will be the lower limit frequency $f_L$ (the -3dB point). Do the same by increasing frequency (above 5kHz), thus you get the upper limit $f_U$. The difference between the two limits is the bandwidth B.
To measure this, a recommended method is to connect the ouput signal to the voltmeter in AC mode. In this case, don't forget to measure the voltage at 5kHz first, as the voltmeter measures rms values instead of peak-to-peak like the scope.

**3.2.5** Go back to f=5kHz. Remove emitter capacitor $C_E$ and measure $A_V$ gain again. Give a reason for the difference! Here you can increase the input voltage to better see the result (as $A_v$ will be much smaller).

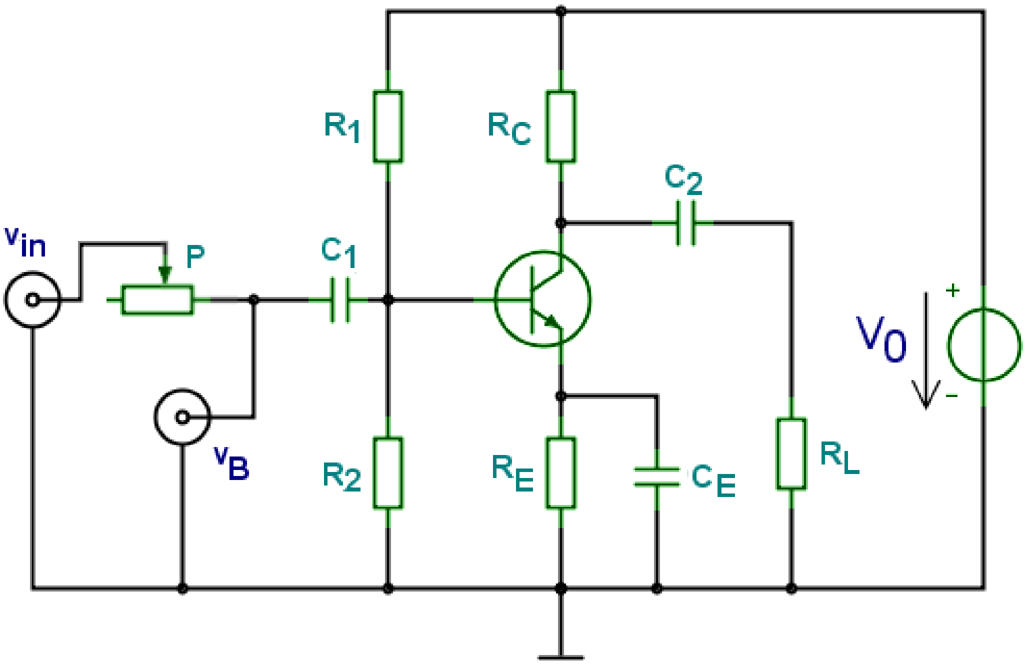



*Figure 2.5 : Measuring the amplifier's dynamic input resistance*

**2.2.6** Put back $C_E$. (If you changed the input voltage, change it back to few mV!) Measure the input dynamic resistance of the circuit. To do this, put a $R_P$=10kΩ potentiometer in series with the input according to ***figure 2.5***. Thus the input resistance of the amplifier and the potentiometer make a voltage divider. Now connect a multimeter in mV setting to $v_{in}$ (that is the function generator's output). Using the multimeter, set up 20mV effective value (this is measured by the multimeter in AC setting) sinewave at 5kHz on the generator. Now remove the multimeter from the $V_{in}$, and put it to the base of the transistor (measure $V_B$, remember in AC mode!). Now change the potmeter until the value measured on $V_B$ is 10mV. Now the potmeter and the input resistance of the amplifier circuit are equal, creating a 50-50% voltage divider. Remove the potmeter and measure its resistance between the two pin that were connected. This will be equal to $r_{in}$.

Compare this value with your homework calculation. Rearrange the formula to find out the real value of beta (β) using the measured $r_{in}$!

## 2.3 Common collector amplifier:

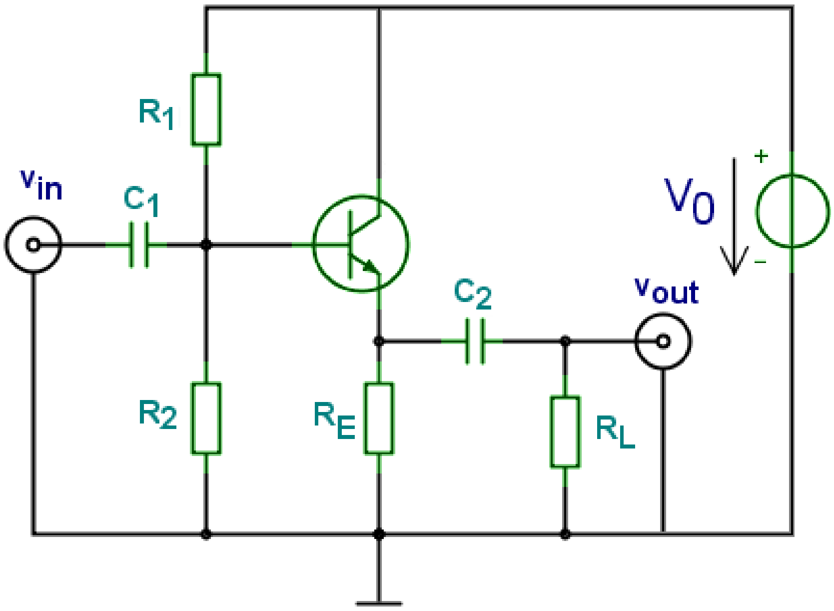



*Figure 2.6: CC amplifier*

Parameters: same as before

**2.3.1** Change our previous CE circuit according to ***figure 2.6*** to get a CC amplifier. Remove / short circuit $R_C$, remove $C_E$ and put $C_2$ to the emitter to get the new output.

**2.3.2** Setup input signal 5kHz, 1V peak-to-peak (Vpp). Measure voltage gain, phase shift and compare with theoretical lessons!

**2.3.3** Measure lower and upper limit frequencies!

## 2.4 Entry test question:

1. Draw the CE transfer and output characteristics of an NPN transistor (note all parameters!)
2. Draw a CE amplifier circuit!
3. How do we measure voltage gain?
4. How do we choose load resistor to get maximum output voltage?
5. How do we calculate voltage and power gain in decibels (dB) ?
6. How do we measure the input dynamic resistance of an amplifier?
7. What is the beta ($h_{21}$) current gain parameter of a transistor?
8. What does the saturation voltage of a transistor mean?
9. What is the lower and upper limit frequency of an amplifier? Draw a graph and explain!
10. What determines the lower frequency limits?
11. What is the role of the emitter capacitor in the CE amplifier and what happens if we remove it?
12. What do you know about the voltage gain, current gain, input and output resistance of the CE amplifier (generally, in orders of magnitude)?
13. What do you know about the voltage gain, current gain, input and output resistance of the CC amplifier (generally, in orders of magnitude)
14.* Draw a current generator using a PNP transistor!