L A B O R A T O R I U M   U K Ł A D Ó W   L I N I O W Y C H

Laboratory of analog linear circuits

Basic configurations of bipolar transistor 4 A

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1. Introduction

This exercise enables measurement and comparison the parameters of the basic configurations of the bipolar transistor.
This are respectively:
A – Common emitter configuration (CE),
B – Common emiter with bypassed resistance in emitter (CE-RE),
C – Common collector configuration, the so called emitter follower (CC),
,
D – Common base configuration (CB).
Different configurations are selected using a rotary switch that toggles through the relay systems. Individual circuits are made in such a way as to ensure identical conditions for the powering of transistors.The differences between the parameters of the amplifiers so mainly due to the different configurations of the transistors, enabling a qualitative comparison of the circuits. For independence from the parameters of measuring instruments and quality of connections, each of the amplifier has a built-in input and output buffer with a gain equal to 1.

As an exercise, measurements are: to strengthen in the middle of bandwidth, input and output resistances, the lower and upper 3dB cut-off frequencies and amplitude frequency response beyond the bandwidth of the amplifier.

Prior to the exercise, refer to the theory about the operation of the bipolar transistor as a linear amplifier (posted it in this paper).Teacher is obliged to check the preparation for the exercise.

2. Measurements

For each of the circuits A, B, C and D:

a) Measure the upper and lower cut-off frequency (f_{L3dB}, f_{H3dB}). The measurement should be performed as follows:
- set the effective voltage of the input signal so as to obtain its output value for the circuit: A = 800 mV, 300 mV B = 300mV, D =300 mV. In the case of the C set the input voltage 300 mV.
- decrease (for measuring the lower 3-decibel frequency or increase (for measuring the upper cut-off) frequency). For a circuit A the output voltage should be equal to $800mV/\sqrt{2} \approx 565mV$ for the circuits B and D - $300mV/\sqrt{2} \approx 212mV$

b) Determine the central frequency $f_0 = \sqrt{f_{L3dB} \cdot f_{H3dB}}$ and measure the gain in the midrange v_O/v_S.

c) Measure the input resistance (signal input frequency should be equal to central frequency).

d) Measure the output resistance (signal input frequency should be equal to central frequency).

e) Measure the amplitude frequency characteristics in the range from 40Hz to 2MHz in the pitch frequency of 1, 2, 4, 7, 10 (ie. for example. to 10Hz, 20Hz, 40Hz, 70Hz, 100Hz, ...).

The measured characteristics should be applied to the chart. The vertical axis should be gain expressed in logarithmic measure, ie., The horizontal axis (signal frequency) should be logarithmic.

Examples of measurement tables

	CE	CE-RE	CC	CB
v_0/v_{in} [V/V]				
R_{in} [kΩ]				
R_{out} [kΩ]				
f_{3dBL} [Hz]				
f_{3dBH} [kHz]				

f [Hz]	**40**	**70**	**...**	f_{L3dB}	f_0	f_{L3dB}	**...**	**1M**	**2M**
v_o/v_{in}									

3. Description of results

For circuits CE, CE-RE, CC and CB should be calculated theoretically:
- operating points of transistors
- small signal gains v_O/v_{in},
- the upper and lower cut-off frequencies,
- input and output resistances.

The results of the calculations should be placed in such a way that you can easily compare with measurements, eg. in a common table.
For each circuits draw the measured frequency characteristics of the gain module and apply to them the results of calculations (ie. the gain in the middle of the band and upper and lower cut-offs.
Place your own conclusions and observations. Compare deals between themselves and comment on compliance calculations with the measurements.

4. Theory

In the exercise are made four amplifiers labeled A-D.
All circuits have built-in input and output buffers. These buffers are identical and they are presented in the following table:

Parameter	Unit	Value
Gain	V/V	1
Input resistance R_{BUF}	MΩ	1
Output resistance R_{0BUF}	Ω	≈0
Input capacitance C_{BUF}	pF	20
Frequency limit	MHz	4

For each transistor of the circuits A-D, operating points to be determined on the assumption that the base current I_B is negligibly small, and that the base-emitter voltage V_{BE} is fixed at 0.7V.

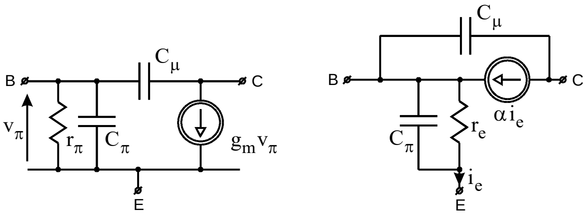

Fig. 1. Small Signal circuit substitute π type and T-type of the bipolar transistor.

Small Signal analysis should be adopted V_T = 25 mV. Data transistor BC237: β=160, C_π=4.5pF, f_T=150MHz.

Small signal parameters are:

$$g_m = \frac{I_C}{V_T} \qquad r_\pi = \frac{\beta}{g_m} \qquad \alpha = \frac{\beta}{\beta+1} \qquad r_e = \frac{r_\pi}{\beta+1}$$

$$C_\pi = \frac{g_m}{2\pi \cdot f_T} - C_\mu$$

4.1 Circuit A:

It is an amplifier in the configuration of the common-emitter (CE).

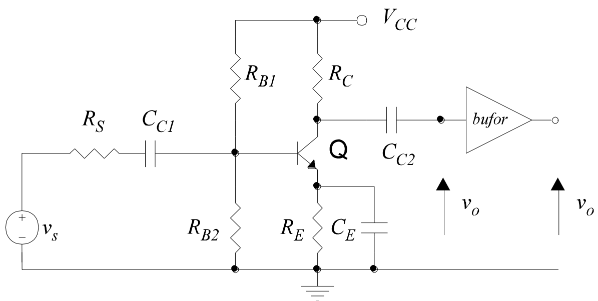

Fig. 2. Amplifier configuration diagram of a common-emitter (CE).

4.1.1 Operating point

is calculated by neglecting the base current:

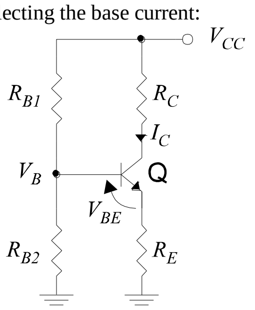

Fig. 3. The circuit diagram for counting of the operating point.

$$V_B = V_{CC}\frac{R_{B2}}{R_{B1}+R_{B2}} \tag{1}$$

$$I_C \approx \frac{V_B - V_{BE}}{R_E} \tag{2}$$

$$V_{CE} = V_{CC} - (R_C + R_E)I_C \tag{3}$$

4.1.2 Small Signal analysis:

Midrange:

The small signal substitute schematic in the medium frequency range (bandpass) is formed assuming that the coupling and shunt capacitances constitute a short circuit for AC signal, while the parasitic capacitances of the transistor are dilation.

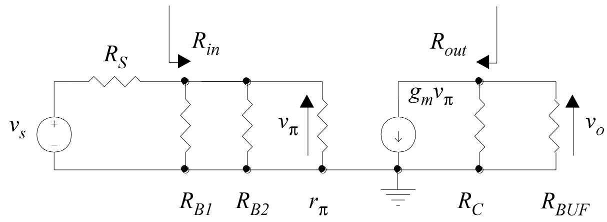

Fig. 4. A substitute small signal scheme of the amplifier in a CE of Fig. 2 for the medium frequency range.

$$R_{in} = R_{B1} \| R_{B2} \| r_\pi \tag{4}$$

$$R_{out} = R_C \tag{5}$$

$$v_0 = -g_m v_\pi (R_C \| R_{BUF}) \tag{6}$$

$$v_\pi = v_s \frac{R_{in}}{R_{in}+R_S} \tag{7}$$

$$\boxed{\frac{v_0}{v_s} = -\frac{R_{in}}{R_{in}+R_S} g_m (R_c \| R_{BUF})} \tag{8}$$

High frequencies:

Upper cut-off frequency is determined based on the time constants associated with the respective capacities of the parasitic transistor. These constants are calculated for the parasitic capacitance on the assumption that the other parasitic capacitances are the opening.

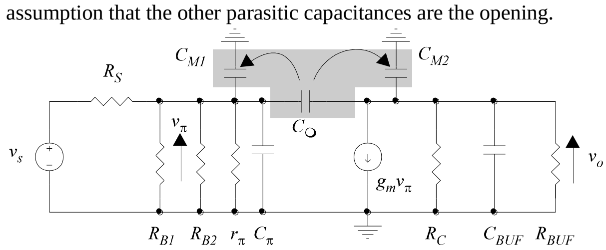

Fig. 5. A substitute small signal scheme of the amplifier in a CE of Fig. 2 to determine the upper cut-off frequency

Time constants:

Using the Miller theorem can replace the capacity C_π of the transistor on the capacity of C_{M1} and C_{M2}.

$$K = \frac{v_0}{v_\pi} = -g_m R_C \| R_{BUF} \tag{9}$$

$$C_{M1} = C_\mu (1-K) \tag{10}$$

$$C_{M2} = C_\mu \left(1 - \frac{1}{K}\right) \tag{11}$$

Then we determine the time constants associated with individual capacities:

$$\tau_{H1} = (C_{M1} + C_\pi)(R_S \| R_{in}) \tag{12}$$

$$\tau_{H2} = (C_{M2} + C_{BUF})(R_C \| R_{BUF}) \tag{13}$$

The approximate value of the upper cut-off frequency is defined by the formula:

$$\boxed{f_{H3dB} \approx \frac{1}{2\pi \cdot (\tau_{H1} + \tau_{H2})}} \tag{14}$$

Low frequencies:

The lower cut-off frequency is determined based on the time constants associated with the respective coupling capacitances or shunts (calculating time constants for each capacity, the other must be regarded as a short circuit).

Parasitic capacitances of the transistor are treated as openings.

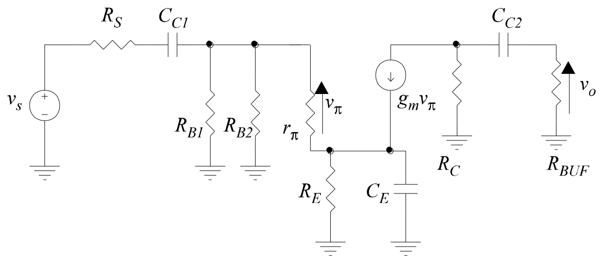

Fig. 6. A substitute small signal scheme of the amplifier in a CE of Fig. 2 to determine the lower cut-off frequency

Using the above equivalent circuit each time constants are equal:

$$\tau_{L1} = C_{C1}(R_S + R_{in}) \tag{15}$$

$$\tau_{L2} = \frac{C_E R_E}{1 + g_m R_E} \tag{16}$$

$$\tau_{L3} = C_{C2}(R_C + R_{BUF}) \tag{17}$$

The approximate value of the lower cut-off frequency is defined by the formula:

$$\boxed{f_{L3dB} \approx \frac{1}{2\pi}\left(\frac{1}{\tau_{L1}} + \frac{1}{\tau_{L2}} + \frac{1}{\tau_{L3}}\right)} \tag{18}$$

4.2 Circuit B:

This is the amplifier in a common emitter configuration with not bypassed R_{E1} resistance in the emitter (CE-RE).

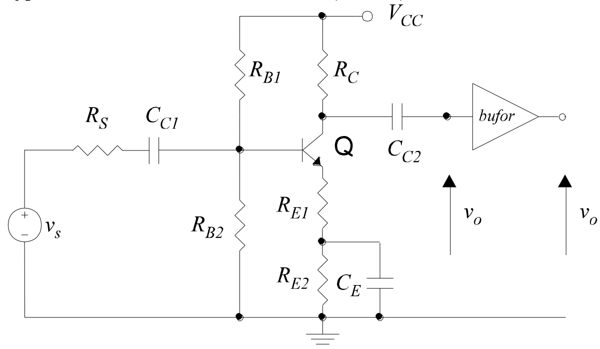

Fig. 7. Amplifier configuration diagram of a common-emitter with not bypassed resistance R_{E1} (CE-RE).

4.2.1 Operating point

calculated as for the A (in the formulas I_C and V_{CE} instead R_E is the sum of R_{E1} + R_{E2})

4.2.2 Small Signal analysis:

Mitrange:

Substitute small signal schematic in the medium frequency range (bandpass) is formed assuming that the coupling capacitances and shunts constitute a short circuit for AC signals, while the parasitic capacitance of the transistor are dilation.

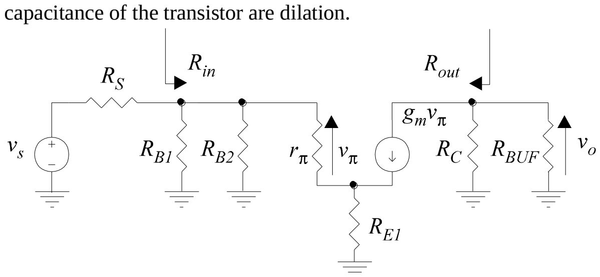

Fig. 8. The substitute small signal scheme of the amplifier in a CE-RE shown in Fig. 7 for the medium frequency range.

$$R_{in} = R_{B1} \| R_{B2} \| (r_\pi + (\beta+1)R_{E1}) \tag{19}$$

$$R_{out} = R_C \tag{20}$$

$$v_0 = -g_m v_\pi (R_C \| R_{BUF}) \tag{21}$$

$$v_\pi = v_s \cdot \frac{R_{in}}{R_{in} + R_S} \cdot \frac{r_\pi}{r_\pi + (\beta+1)R_{E1}} \tag{22}$$

$$\boxed{\frac{v_0}{v_s} = -\frac{R_{in}}{R_{in} + R_S} \cdot \frac{r_\pi}{r_\pi + (\beta+1)R_{E1}} \cdot g_m (R_c \| R_{BUF})} \tag{23}$$

High frequencies

Upper cut-off frequency is determined based on the time constants associated with the respective capacities of the parasitic transistor. These constants calculated for the parasitic capacitances on the assumption that other parasitic capacitances are the openings.

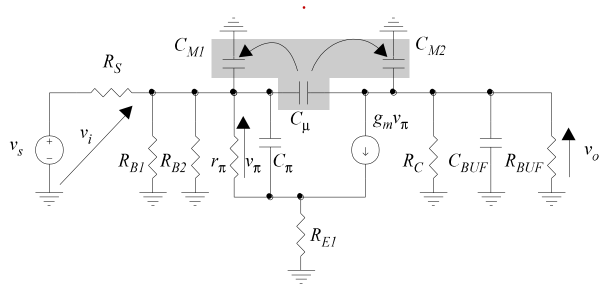

Fig. 9. Substitute small signal diagram of the amplifier in a CE-RE shown in Fig. 7 to determine the upper cut-off frequency.

Time constants:

Using the Miller theorem can replace the capacity C_π of the transistor on the capacities of C_{M1} and C_{M2}.

$$K = -\frac{\alpha \cdot R_C \| R_{BUF}}{r_e + R_{E1}} \tag{24}$$

$$C_{M1} = C_\mu (1 - K) \tag{25}$$

$$C_{M2} = C_\mu \left(1 - \frac{1}{K}\right) \tag{26}$$

Then we determine the time constants associated with individual capacities:

$$\tau_{H1} = C_{M1}(R_S \| R_{in}) \tag{27}$$

$$\tau_{H2} = C_\mu \left(r_\pi \| \frac{R_{E1} + R_S \| R_{B1} \| R_{B2}}{1 + g_m R_{E1}} \right) \tag{28}$$

$$\tau_{H3} = (C_{M2} + C_{BUF})(R_C \| R_{BUF}) \tag{29}$$

The approximate value of the upper cut-off frequency is determined by the formula:

$$\boxed{f_{H3dB} \approx \frac{1}{2\pi \cdot (\tau_{H1} + \tau_{H2} + \tau_{H3})}} \tag{30}$$

Low frequencies:

The lower cut-off frequency is determined based on the time constants associated with the respective shunts or coupling capacitances (calculating time constants for each capacity, the other must be regarded as a short circuit). Parasitic capacitances of the transistor are treated as openings.

Using the equivalent circuit of Fig. 10, the individual time constants are equal:

$$\tau_{L1} = C_{C1}(R_S + R_{in}) \tag{31}$$

$$\tau_{L2} = C_E \left(R_{E2} \left\| \left(R_{E1} + \frac{r_\pi + R_{B1} \| R_{B2} \| R_S}{\beta + 1} \right) \right. \right) \tag{32}$$

$$\tau_{L3} = C_{C2}(R_C + R_{BURF}) \tag{33}$$

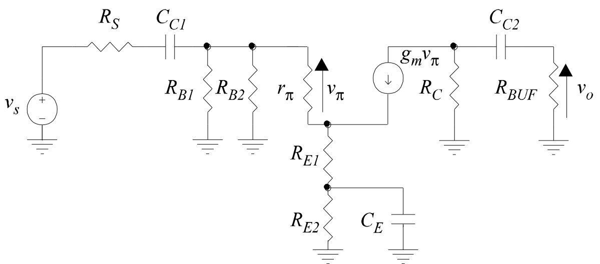

Fig. 10. A substitute small signal scheme of the amplifier in a CE-RE shown in Fig. 7 to determine the lower cut-off frequency.

The approximate value of the lower cut-off frequency is given by:

$$f_{L3dB} \approx \frac{1}{2\pi}\left(\frac{1}{\tau_{L1}}+\frac{1}{\tau_{L2}}+\frac{1}{\tau_{L3}}\right) \tag{34}$$

4.3 Circuit C:

This is a common amplifier in the configuration of the collector (CC), ie. emitter follower.

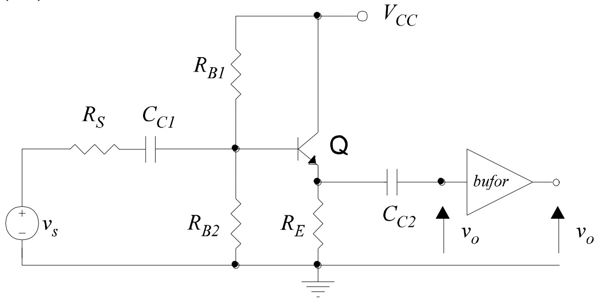

Fig. 11. The configuration diagram of the amplifier in the common collector (CC).

4.3.1 Operating point

as calculated for the circuit A.

4.3.2 Small signal analysis

Mitrange

Substitute small signal schematic in the medium frequency range (bandpass) is formed assuming that the coupling capacitances and shunts constitute a short circuit for AC signal, while the parasitic capacitances of the transistor are dilation.

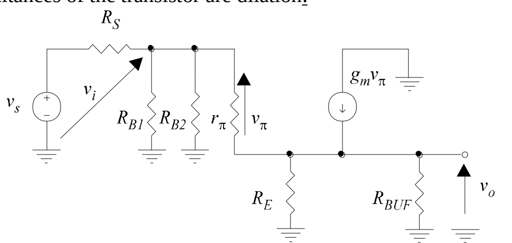

Fig. 12. A substitute small signal scheme of the amplifier circuit CC shown in Fig. 11 for the medium frequency range.

$$R_{in} = R_{B1}||R_{B2}||\left(r_\pi + (\beta+1)(R_E||R_{BUF})\right) \tag{35}$$

$$R_{out} = R_E||\left(\frac{r_\pi + R_S||R_{B1}||R_{B2}}{\beta+1}\right) \tag{36}$$

$$v_0 = v_i \cdot \frac{(\beta+1)(R_E||R_{BUF})}{r_\pi + (\beta+1)(R_E||R_{BUF})} \quad (37$$

$$v_i = v_s \cdot \frac{R_{in}}{R_{in}+R_S} \tag{38}$$

$$\frac{v_0}{v_s} = \frac{R_{in}}{R_{in}+R_S} \cdot \frac{(\beta+1)(R_E||R_{BUF})}{r_\pi + (\beta+1)(R_E||R_{BUF})} \tag{39}$$

High frequencies:

Upper cut-off frequency is determined based on the time constants associated with the respective capacities of the parasitic transistor. These constants calculated are for the parasitic capacitances on the assumption that the other parasitic capacitances are the openings.

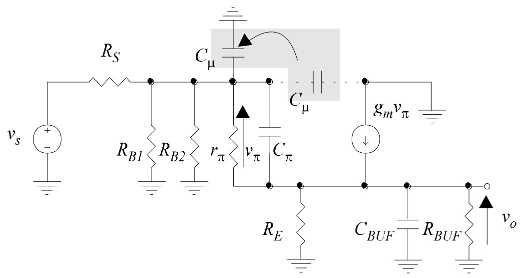

Fig. 13. A substitute small signal scheme of the amplifier circuit CC shown in Fig. 11 to determine the upper cut-off frequency.

In the CC circuit there is no Miller capacitance!
time constances

$$\tau_{H1} = C_\mu (R_S||R_{in}) \tag{40}$$

$$\tau_{H2} = C_\pi\left(r_\pi||\frac{R_E||R_{BUF} + R_S||R_{B1}||R_{B2}}{1+g_m(R_E||R_L)}\right) \tag{41}$$

$$\tau_{H3} = C_{BUF}\left(R_{BUF}||R_{out}\right) \tag{42}$$

The approximate value of the upper frequency limit is determined by the formula:

$$f_{H3dB} \approx \frac{1}{2\pi\cdot(\tau_{H1}+\tau_{H2}+\tau_{H3})} \tag{43}$$

Lower frequencies:

The lower cut-off frequency is determined based on the time constants associated with the respective shunts or coupling capacitances (calculating time constants for each capacity, the other must be regarded as a short circuit). Parasitic capacitances of the transistor are treated as the openings.

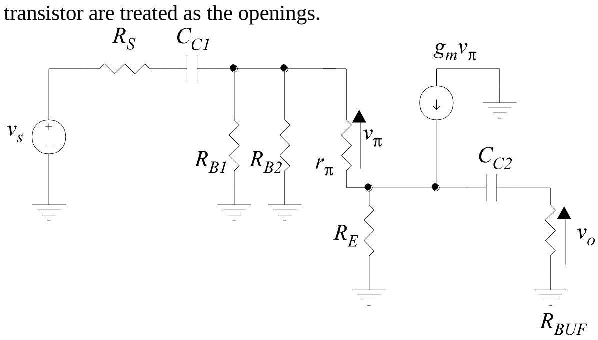

Fig. 14. A substitute small signal scheme of the amplifier circuit CC shown in Fig. 11 to determine the lower cut-off frequency.

Using the above equivalent circuit each time constants are equal:

$$\tau_{L1} = C_{C1}(R_S + R_{in}) \tag{44}$$

$$\tau_{L2} = C_{C2}(R_{out} + R_{BUF}) \tag{45}$$

The approximate value of the lower cut-off frequency is given by:

$$f_{L3dB} \approx \frac{1}{2\pi}\left(\frac{1}{\tau_{L1}}+\frac{1}{\tau_{L2}}\right) \tag{46}$$

4.4 Circuit D:

This is the amplifier in the configuration of common base (CB).

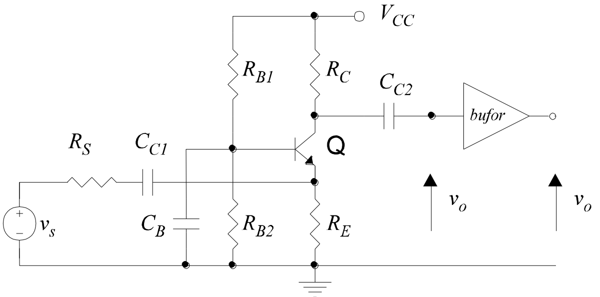

Fig. 15 Diagram of the amplifier configuration common base (CB).

4.4.1 Operating point
as calculated for the circuit A.

4.4.2 Small signal analysis
Mitrange
Substitute small signal schematic in the medium frequency range (bandpass) is formed assuming that the coupling capacitances and shunts constitute a short circuit for AC signal, while the parasitic capacitances of the transistor are dilation.

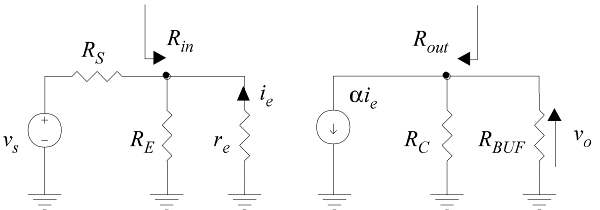

Fig. 16. A substitute small signal scheme of the amplifier circuit CB shown in Fig. 15 for the medium frequency range.

$$R_{in} = R_E || r_e \quad (47)$$

$$R_{out} = R_C \quad (48)$$

$$v_0 = -\alpha \cdot i_e (R_C || R_{BUF}) \quad (49)$$

$$i_e = -\frac{R_{in}}{R_{in} + R_s} \cdot \frac{1}{r_e} \cdot v_s \quad (50)$$

$$\boxed{\frac{v_0}{v_s} = \frac{R_{in}}{R_{in} + R_s} \cdot \frac{\alpha}{r_e} \cdot (R_C || R_{BUF})} \quad (51)$$

High frequencies:
Upper cut-off frequency is determined based on the time constants associated with the respective capacities parasitic transistor. These constants are calculating for the parasitic capacitance on the assumption that the other parasitic capacitances are the openings.

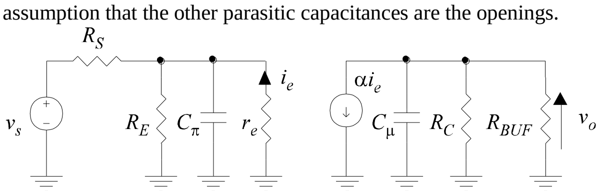

Fig. 17. A substitute small signal scheme of the amplifier circuit CB shown in Fig. 15 to determine the upper cut-off frequency.

For RF there is no effect on the multiplication of the capacitance (Miller effect)
time constants:

$$\tau_{H1} = C_\pi (R_S || R_E || r_e) \quad (52)$$

$$\tau_{H2} = (C_\mu + C_{BUF}) \cdot (R_C || R_{BUF}) \quad (53)$$

The approximate value of the upper frequency limit is determined by the formula:

$$\boxed{f_{H3dB} \approx \frac{1}{2\pi \cdot (\tau_{H1} + \tau_{H2})}} \quad (54)$$

Lower frequencies:
The lower cut-off frequency is determined based on the time constants associated with the respective shunts or coupling capacitances (calculating time constants for each capacity, the other must be regarded as a short circuit). Parasitic capacitances of the transistor are treated as the openings.

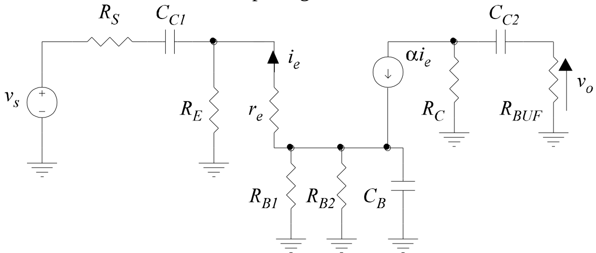

Fig. 18. A substitute small signal scheme of the amplifier circuit CB shown in Fig. 15 to determine the lower cut-off frequency.

Using the above equivalent circuit each time constants are equal

$$\tau_{L1} = C_{C1}(R_S + R_{in}) \quad (55)$$

$$\tau_{L2} = C_B \left[R_{B1} || R_{B2} || \left((r_e + R_E || R_S) \cdot (\beta + 1) \right) \right] \quad (56)$$

$$\tau_{L3} = C_{C2}(R_C + R_{BUF}) \quad (57)$$

The approximate value of the lower cut-off frequency is given by:

$$\boxed{f_{L3dB} \approx \frac{1}{2\pi} \left(\frac{1}{\tau_{L1}} + \frac{1}{\tau_{L2}} + \frac{1}{\tau_{L3}} \right)} \quad (58)$$

4.5 Measurement of the input resistance of the amplifiers

Input resistance is measured using additional resistor R_S' connected in series with the internal resistance R_S. of the generator. During normal operation, it is shorted by the switch located on the front panel. After pressing the button marked with the following connecting resistor $\boxed{R_{in}}$ in series with R_S,, which reduces the gain.

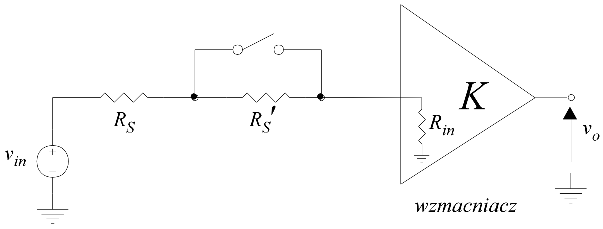

Fig. 19. Method for measurement of input resistance of the amplifier.

Marking as well v_O as v_O' respectively output voltages with a bypassed and opened resistor R_S' get:

$$v_0 = K \cdot \frac{R_{in}}{R_{in} + R_S} \cdot v_{in} \quad (59)$$

$$v_0' = K \cdot \frac{R_{in}}{R_{in} + R_S + R_S'} \cdot v_{in} \quad (60)$$

$$\frac{v_0}{v_0'} = \frac{R_{in} + R_S + R_S'}{R_{in} + R_S} \quad (61)$$

$$\boxed{R_{in} = \frac{v_0'}{v_0 - v_0'} \cdot R_S' - R_S} \quad (62)$$

4.6 Measurement of the output resistance of the amplifiers

Output resistance is measured using additional resistor R_L' switched in parallel with the load resistance of the amplifier R_L, which in the studied circuit is the input resistance R_{BUF} of the buffer

During normal operation R_L', is disconnected. During the resistance measurement accompanied by his switch located on the front panel and marked $\boxed{R_{out}}$.. After pressing the button, adding a resistor R_L', which reduces the gain.

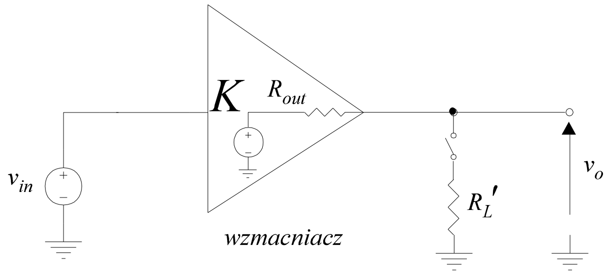

Fig. 20. Method for measurement of output resistance of the amplifier.

Marking as well v_O as v_O' respectively output voltages at the opened and bypassed resistor get:

$$v_0 = K \cdot \frac{R_{BUF}}{R_{BUF} + R_{out}} \cdot v_{in} \tag{63}$$

$$v_{0'} = K \cdot \frac{R_{BUF}||R_L'}{R_{BUF}||R_L' + R_{out}} \cdot v_{in} \tag{64}$$

$$\frac{v_{0'}(R_{BUF}||R_L' + R_{out})}{R_{BUF}||R_L'} = \frac{v_0(R_{BUF} + R_{out})}{R_{BUF}} \tag{65}$$

$$\boxed{R_{out} = \frac{R_{BUF} \cdot R_L'}{\frac{R_{BUF} \cdot v_0'}{v_0 - v_0'} - R_L'}} \tag{66}$$

4.7 The data elements in different configurations arrangement.

Parameter	Units	CE	CE-RE	CC	CB
β	-	160	160	160	160
C_μ	pF	4.5	4.5	4.5	4.5
f_T	MHz	150	150	150	150
R_S	kΩ	1	1	1	0.1
$R_{S'}$	kΩ	1	1	1	1
C_{C1}	nF	68	68	68	68
R_{B1}	kΩ	43	43	43	43
R_{B2}	kΩ	22	22	22	22
C_B	µF	there is no	there is no	there is no	47
R_C	kΩ	6.2	6.2	6.2	6.2
R_E	kΩ	3.13	there is no	3.13	3.13
R_{E1}	kΩ	there is no	0.16	there is no	there is no
R_{E2}	kΩ	there is no	2.97	there is no	there is no
C_E	µF	100	100	100	100
C_{C2}	nF	100	100	100	100
R_{BUF}	MΩ	1	1	1	1
C_{BUF}	pF	20	20	20	20
$R_{L'}$	kΩ	4.7	4.7	4.7	4.7
V_{CC}	V	12	12	12	12

Literature:

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