LABORATORY OF ELECTRONIC CIRCUITS

Laboratory exercise no.: **2**	Consecutive protocol number:	Name and surname: 1. 2. 3.

Title: Negative feedback

Day of week:	Date of the measurements:	Date of elaboration:
	Grade:	

2.1. Measurement of the following parameters of the amplifier for different feedback configurations: low and high 3-dB frequencies (f_{L3dB}, f_{H3dB}), center frequency (f_0), input and output resistances (R_{in}, R_{out}), nonlinear distortions (h). Initial condidtions of the measurements: f_{in} = 18 kHz, V_o = 300 mV_{RMS}

Amplifier's configuration		**A (open loop)**	**B (closed loop 1)**	**C (closed loop 2)**
input voltage V_s	$[mV]$			
f_{L3dB} (at V_o = 300/√2 ≈ 212 mV_{RMS})	$[kHz]$			
f_{H3dB} (at V_o = 300/√2 ≈ 212 mV_{RMS})	$[kHz]$			
center frequency $f_0 = \sqrt{f_{L3dB} \cdot f_{H3dB}}$	$[kHz]$			
gain at center frequency $K_u(f_0)$	$[V/V]$			
output voltage V_o' for R_{in} measurement	$[mV]$			
output voltage V_o' for R_{out} measurement	$[mV]$			
nonlinear distortion h	$[\%]$			

2.2. Measurement of an amplitude characteristic of the amplifier for different feedback configurations (measuerements are conducted by point-by-point method).

Initial condidtions of the measurements: for each amplifier's configuration, set initially f_{in} = 18 kHz, and set V_s at which V_o is 300 mV_{RMS}.

A (open loop)				**B (closed loop 1)**				**C (closed loop 2)**			
f	V_o	K_u	$20 \cdot \log\|K_u\|$	f	V_o	K_u	$20 \cdot \log\|K_u\|$	f	V_o	K_u	$20 \cdot \log\|K_u\|$
$[kHz]$	$[mV]$	$[V/V]$		$[kHz]$	$[mV]$	$[V/V]$		$[kHz]$	$[mV]$	$[V/V]$	
1.0				200 Hz				200 Hz			
2.0				400 Hz				400 Hz			
4.0				700 Hz				700 Hz			
7.0				1.0				2.0			
10.0				2.0				4.0			
18.0				18.0				18.0			
50.0				50.0				50.0			
70.0				100.0				100.0			
100.0				500.0				500.0			
120.0				1 MHz				700.0			
140.0				1.4 MHz				1 MHz			
170.0				1.7MHz				1.2 MHz			
200.0				2 MHz				1.5 MHz			
500.0				3 MHz				2 MHz			

3. Data elaboration

1) Plot the measured characteristics $20\log|K_u|$ on separate graphs (vertical axis is linear, horizontal axis is logarithmic).

2) Calculate operating points of the transistors, the amplifier gain and input and output resistances of the amplifier.

Use the following data: $V_{CC} = 12V$, $V_T = 25mV$, $V_{BE} = 0.7V$, $\beta = 200$, $\alpha = \frac{\beta}{\beta+1}$, $R_{B_1} = 51k\Omega$, $R_{B_2} = 6.2k\Omega$, $R_{C_1} = 8.2k\Omega$, $R_{C_2} = 2.2k\Omega$, $R_{E_1} = 560\Omega$, $R_{E_2} = 1.2k\Omega$, $R_L = 5.1k\Omega$, $R_{F_B} = 18k\Omega$, $R_{F_C} = 36k\Omega$, $R_S = R_{L'} = 1k\Omega$, $R_{S'} = 2k\Omega$

Operating point of the transistor Q1: $V_{B_1} = V_{CC}\dfrac{R_{B_2}}{R_{B_1}+R_{B_2}} = \ldots\ldots\ldots\ldots,\ I_{C_1} = \dfrac{V_{B_1}-V_{BE}}{R_{E_1}} = \ldots\ldots\ldots\ldots,$

$V_{CE_1} = V_{CC} - \left(R_{C_1}+R_{E_1}\right)\cdot I_{C_1} = \ldots\ldots\ldots\ldots,$

Operating point of the transistor Q2: $V_{B_2} = V_{CC} - R_{C_1}\cdot I_{C_1} = \ldots\ldots\ldots\ldots,\ I_{C_2} = \dfrac{V_{B_2}-V_{BE}}{R_{E_2}} = \ldots\ldots\ldots\ldots,$

$V_{CE_2} = V_{CC} - \left(R_{C_2}+R_{E_2}\right)\cdot I_{C_2} = \ldots\ldots\ldots\ldots$

Auxiliary equations:

$g_{m_1} = \dfrac{I_{C_1}}{V_T} = \ldots\ldots\ldots\ldots,\ r_{\pi_1} = \dfrac{\beta}{g_{m_1}} = \ldots\ldots\ldots\ldots,\ r_{e_1} = \dfrac{r_{\pi_1}}{\beta+1} = \ldots\ldots\ldots\ldots,\ R_{1_B} = \dfrac{R_{E_1}\cdot R_{F_B}}{R_{E_1}+R_{F_B}} = \ldots\ldots\ldots\ldots,\ R_{2_B} = R_{E_1}+R_{F_B} = \ldots\ldots\ldots\ldots,$

$g_{m_2} = \dfrac{I_{C_2}}{V_T} = \ldots\ldots\ldots\ldots,\ r_{\pi_2} = \dfrac{\beta}{g_{m_2}} = \ldots\ldots\ldots\ldots,\ r_{e_2} = \dfrac{r_{\pi_2}}{\beta+1} = \ldots\ldots\ldots\ldots\ R_{1_C} = \dfrac{R_{E_1}\cdot R_{F_C}}{R_{E_1}+R_{F_C}} = \ldots\ldots\ldots\ldots,\ R_{2_C} = R_{E_1}+R_{F_C} = \ldots\ldots\ldots\ldots.$

For calculations, please use the formulas in the table below. Attention: for configuration B use R_{1_B} i R_{2_B} for calculations; for configuration C use R_{1_C} i R_{2_C}. You must fill empty fields in the table below.

<table>
<tr><th>A (open loop)</th><th>B (closed loop 1)</th><th>C (closed loop 2)</th></tr>
<tr><td colspan="3">Small-signal gain K_u</td></tr>
<tr><td rowspan="2">$K_u = g_{m_2}\cdot\dfrac{R_{C_2}R_L}{R_{C_2}+R_L}\cdot\dfrac{\alpha\cdot R_{C_1}\cdot r_{\pi_2}}{R_{C_1}+r_{\pi_2}}\cdot\dfrac{1}{r_{e_1}+R_{E_1}}\cdot\dfrac{R_{in}}{R_{in}+R_S}$</td><td colspan="2">$A' = g_{m_2}\cdot\left(\dfrac{1}{R_{C_2}}+\dfrac{1}{R_L}+\dfrac{1}{R_2}\right)^{-1}\cdot\dfrac{\alpha\cdot\left(R_{C_1}\cdot r_{\pi_2}\right)}{R_{C_1}+r_{\pi_2}}\cdot\dfrac{1}{r_{e_1}+R_1}\cdot\dfrac{\left(r_{e_1}+R_1\right)\cdot(\beta+1)}{\left(r_{e_1}+R_1\right)\cdot(\beta+1)+R_{S'}}$
$B = \dfrac{R_{E_1}}{R_{E_1}+R_F},\ K_u = A_f = \dfrac{A'}{1+A'B}$</td></tr>
<tr><td>$A' = \ldots\ldots\ldots\ldots\ldots\ldots,\ B = \ldots\ldots\ldots\ldots\ldots\ldots$</td><td>$A' = \ldots\ldots\ldots\ldots\ldots\ldots,\ B = \ldots\ldots\ldots\ldots\ldots\ldots$</td></tr>
<tr><td colspan="3">Calculation of the input resistance R_{in}</td></tr>
<tr><td rowspan="2">$R_{in} = \left(\dfrac{1}{R_{B_1}}+\dfrac{1}{R_{B_2}}+\dfrac{1}{\left(r_{e_1}+R_{E_1}\right)\cdot\left(\beta_1+1\right)}\right)^{-1}$</td><td colspan="2">$R_i = R_{S'}+(\beta+1)\cdot\left(r_{e_1}+R_2\right),\ R_{if} = R_i\cdot\left(1+A'\cdot B\right),\ R_{in} = \left(\dfrac{1}{R_{if}-R_{S'}}+\dfrac{1}{R_{B_1}}+\dfrac{1}{R_{B_2}}\right)^{-1}$</td></tr>
<tr><td>$R_i = \ldots\ldots\ldots\ldots\ldots\ldots,\ R_{if} = \ldots\ldots\ldots\ldots\ldots\ldots$</td><td>$R_i = \ldots\ldots\ldots\ldots\ldots\ldots,\ R_{if} = \ldots\ldots\ldots\ldots\ldots\ldots$</td></tr>
<tr><td colspan="3">Calculation of the output resistance R_{out}</td></tr>
<tr><td rowspan="2">$R_{out} = R_{C_2}$</td><td colspan="2">$R_0 = \left(\dfrac{1}{R_{C_2}}+\dfrac{1}{R_L}+\dfrac{1}{R_2}\right)^{-1},\ R_{of} = \dfrac{R_0}{1+A'B},\ R_{out} = \dfrac{R_{of}\cdot R_L}{R_L-R_{of}}$</td></tr>
<tr><td>$R_0 = \ldots\ldots\ldots\ldots\ldots\ldots,\ R_{of} = \ldots\ldots\ldots\ldots\ldots\ldots$</td><td>$R_0 = \ldots\ldots\ldots\ldots\ldots\ldots,\ R_{of} = \ldots\ldots\ldots\ldots\ldots\ldots$</td></tr>
</table>

Amplifier's configuration	A (open loop)		B (closed loop 1)		C (closed loop 2)	
	theoretical	measured	theoretical	measured	theoretical	measured
K_u						
$R_{in} = \dfrac{V_o'}{V_o - V_o'}\cdot R_S' - R_S\ [k\Omega]$						
$R_{out} = \dfrac{R_L\cdot R_L'}{\dfrac{R_L\cdot V_o'}{V_o-V_o'} - R_L'}\ [k\Omega]$						
$f_{L3dB}\,[kHz]$	–		–		–	
$f_{H3dB}\,[kHz]$	–		–		–	

For each measurement result, include your conclusions. Compare the above theoretical results with the measurement results of the real circuits.