LABORATORY OF ELECTRONICS			
Script exercise No.: **1B**	Consecutive exercise No.:	Lab team members: 1. 2. 3.	
Subject: Operational amplifier (dynamic characteristics)		DEAN GROUP:	LAB GROUP:
Planned lab exercise execution date:	Real lab exercise execution date:	Lab exercise report submission date:	
		Grade:	

2.1. Measurements of a differential pair (circuit A)

2.1.1. Differential input mode measurements, $f = 1kHz$; measurements of the harmonic distortion h :

DIFF/CM released, KRE released (V_{we} – input voltage; V_{wy} – output voltage)

$V_{we}\ [mV]$	5	10	15	20	25	30	35	40	45	50
h [%]										

Note: The input voltage meter measures the RMS (Root Mean Square) voltage value but the oscilloscope - the maximum value. In order to compare them for example multiply by $\sqrt{2}$ the value of the input voltage meter reading.

Measurement of the differential mode gain K_{uDIFF} and input resistance R_{in} , $f = 1kHz$:

$V_{we}\ [mV]$	$V_{wy}\ [V]$	$K_{uDIFF} = V_{wy} / V_{we}\ [V/V]$	measured R_{in}: $V_{wy'}\ [V]$
10			

2.1.2. Common input mode measurements, $f = 1kHz$; measurement of the common mode gain K_{uCM} and input resistance R_{in} :

DIFF/CM pressed, KRE released

$V_{we}\ [V]$	$V_{wy}\ [V]$	$K_{uCM} = V_{wy} / V_{we}\ [V/V]$	measured R_{in}: $V_{wy'}\ [V]$
1			

2.2. Measurements of the magnitude frequency response of the amplifier (circuit B) for resistor feedbacks 10k/10k and 1k/10k, $K_u = V_{wy} / V_{we}$

10k/10k				1k/10k			
$V_{we}\ [mV]$	25			$V_{we}\ [mV]$	20		
f [kHz]	V_{wy} [mV]	K_u [V/V]	$20\cdot\log\lvert K_u\rvert$	f [kHz]	V_{wy} [mV]	K_u [V/V]	$20\cdot\log\lvert K_u\rvert$
0.11				0.11			
1.0				1.0			
20.0				2.0			
50.0				3.0			
100.0				5.0			
125.0				6.0			
150.0				8.0			
200.0				10.0			
250.0				12.0			
300.0				14.0			
400.0				16.0			
500.0				18.0			
-				20.0			
-				30.0			
-				40.0			
-				50.0			
-				75.0			
-				100.0			
-				200.0			
-				400.0			
$f_{H3dB}\ [kHz]$				$f_{H3dB}\ [kHz]$			
$f_T\ [kHz]$ dla $V_{wy} = 25\ mV$				$f_T\ [kHz]$ dla $V_{wy} = 20\ mV$			

Measurements of the 3dB cutoff frequencies and the unity-gain frequencies:

f_{L3dB} - lower 3dB cutoff frequency, i.e.: $K_u(f_{L3dB}) = 0.707 \cdot K_u(f{=}1kHz)$,

f_T - unity-gain frequency, i.e.: $V_{wy}(f_T) = V_{we}$ or $K_u(f_T) = 1$.

3. Elaboration of the results

1) Plot a graph of nonlinear distortion h as the function of the input voltage V_{we} for the circuit A (differential input mode).

2) For a differential pair calculate analytically the operating point of transistors, the small-signal gain and the input resistance.

For the calculations assume: $V_{CC} = 12V$, $V_{EE} = -12V$, $V_{BE} = 0.7V$, $V_T = 25mV$, $\beta = 120$, $R_{EE} = 10\ k\Omega$, $R_E = 100\ \Omega$, $R_C = 5.1\ k\Omega$, $R_{SZER\,DIFF} = 5.1\ k\Omega$, $R_{SZER\,CM} = 1500\ k\Omega$, $R_{GEN} = 50\ \Omega$, $R_{BUF} = 1000\ k\Omega$

Operating point: $I_{EE} = \frac{-V_{EE} - V_{BE}}{R_{EE} + \frac{R_E}{2}} = ...$, $\alpha = \frac{\beta}{\beta+1} = ...$, $I_C = \alpha \cdot 0.5 \cdot I_{EE} = ...$, $V_C = V_{CC} - R_C I_C = ...$.

Auxiliary calculations:

$g_m = \frac{I_C}{V_T} = ...$, $r_\pi = \frac{\beta}{g_m} = ...$, $r_e = \frac{r_\pi}{\beta+1} = ...$

For the calculations use the following formulas:

Differential input mode	Common input mode
Input resistance (theory) R_{IN}	
$R_{INDIFF} = 2(\beta+1)(R_E + r_e)$	$R_{INCM} = \frac{1}{2}(\beta+1)(2R_{EE} + R_E + r_e)$
Input resistance (measured) R_{IN}	
$R_{INDIFF} = 2\frac{V_{wy'}}{V_{wy} - V_{wy'}} \cdot R_{SZER} - R_{GEN}$	$R_{INCM} = \frac{V_{wy'}}{V_{wy} - V_{wy'}} \cdot R_{SZER} - R_{GEN}$
Small-signal gain K_u	
$K_{uDIFF} = \frac{R_{INDIFF}}{R_{INDIFF} + 2R_{GEN}} \cdot \frac{\alpha \cdot R_C \cdot R_{BUF}}{R_C + R_{BUF}} \cdot \frac{1}{r_e + R_E}$	$K_{uCM} = \frac{R_{INCM}}{R_{INCM} + 2R_{GEN}} \cdot \frac{\alpha \cdot R_C \cdot R_{BUF}}{R_C + R_{BUF}} \cdot \frac{1}{2R_{EE} + r_e + R_E}$

Compare the calculation results with the results of measurements in the table below:

	Differential input mode		Common input mode	
	theory	measured	theory	measured
$R_{IN}[k\Omega]$				
K_u				

Moreover, calculate the Common Mode Rejection Ratio coefficient: $CMRR = 20\log\frac{K_{uDIFF}}{K_{uCM}} = ...$

3) Plot the measured characteristics of the amplifier $20 \cdot \log|K_u|$ for feedback resistors 10k/10k, 1k/10k on separate graphs (linear vertical axis, logarithmic horizontal axis). Mark the 3dB cutoff frequency and the unity-gain frequency.

Write your own conclusions and observations for all measurements in the exercise. Compare circuits and write comments on differences between calculations and measurements.