

**PRAIRIE VIEW A&M UNIVERSITY
ROY G. PERRY COLLEGE OF ENGINEERING
DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
ELEG 4304- Electronics II
FALL 2021**

I. COURSE DESCRIPTION IN ABET FORMAT

II ASSESSMENT RESULTS FOR CURRENT AND PAST THREE PERIODS

Program Outcomes Assessed in Course

Assessment Summary of Class Semester Averages for Outcomes

End of Semester Course Outcomes Assessment Reports

II. TESTS

Summary of Topics covered by Test

Original Test Questions & Master Solution/grading scheme used

(Summary of topics can be a separate page or include on the assignment itself)

Above Average (Graded original work)

Average (Graded original work)

Below Average (Graded original work)

III. QUIZZES

Summary of Topics covered by Quiz

Original Quiz Questions & Master Solution/grading scheme used

Above Average (Graded original work)

Average (Graded original work)

Below Average (Graded original work)

IV. HOMEWORK ASSIGNMENTS

Summary of Topics covered by Homework

Original Homework Questions & Master Solution/grading scheme used

Above Average (Graded original work)

Average (Graded original work)

Below Average (Graded original work)

V. LABORATORY REPORTS

Summary of Topics covered by lab

Laboratory Handout/Instructions and Grading Scheme

Above Average (Graded original work)

Average (Graded original work)

Below Average (Graded original work)

VI. PROJECT

Summary of Topics Covered by Project

Project Problem Statement and Grading Scheme

Above Average (Graded original work)

Average (Graded original work)

Below Average (Graded original work)

[Include any other evaluation used and omit any method above method (Test, Quizzes, Homework, Laboratory and Project reports) that was not used]

Course Description

in ABET Format

Please use the following format for the course syllabi (2 pages maximum in Times New Roman 12 point font)

1.	Course number and name:	ELEG 4304 ELECTRONICS - II
2.	Credits and contact hours:	3 credit hours; 3 contact hours
3.	Instructor's or course coordinator's name:	Dr. Mohan Ketkar
4.	Textbook: Title:	MICROELECTRONIC CIRCUITS
	Author:	A.S. Sedra and K.C. Smith
	Publisher, Year & Edition:	Oxford University Press, 8 th Edition
	a. Other Supplemental material	1. J.O. Attia, "Circuits and Electronics: Hands-on learning with Analog Discovery" 2. Handouts 3. Electronics Circuits books in the library
5.	Specific course information	
	a. Brief description of the content of the course (catalog description)	Design and analysis of single and multistage amplifiers, difference amplifier, frequency response of amplifiers. Feedback concepts. Analysis and design using discrete and integrated circuits.
	b. Prerequisites or Co-requisites	ELEG 3304 or ELEG3043 Minimum Grade of C
	c. *Indicate whether a required, elective, or selected elective (as per definition provided) course in the program	Required
6.	a. Specific goals for the course specific outcomes of instruction (e.g. The student will be able to explain the significance of current research about a particular topic.) <i>Students will be able to:</i>	b. Explicitly indicate which of the student outcomes listed in Criterion 3 or any other outcomes are addressed by the course. <i>The specific goals for the course specific outcomes listed on the left column will address the following student learning outcomes:</i>
	1. Understand the characteristics of operational amplifiers and should be able to design electronic circuits using operational amplifiers	
	2. Understand the operational characteristics of diodes, MOSFETs, and BJTs	
	3. Be conversant with basic electronic circuits such as rectifiers, inverting amplifiers, non-inverting amplifiers, integrators, differentiators, clipping and clamping circuits.	

	4. Recognize and analyze various MOSFET and BJT amplifier circuits 5.	
	6. Use PSPICE or MATLAB to solve electronic circuits' problems 7.	
	8. Design, construct, test electronic circuit that satisfies multiple constraints	Outcome 2 An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
7	Brief list of topics to be covered	Review of Electronic devices Transistor Amplifiers Building Blocks of Integrated Circuit Amplifiers Differential and Multistage Amplifiers Output Stages and Power Amplifiers Frequency Response of Amplifiers Feedback Amplifiers

***Required** courses are required of all students in the program, **elective** courses (often referred to as open or free electives) are optional for students, and **selected elective** courses are those for which students must take one or more courses from a specified group

II ASSESSMENT RESULTS FOR CURRENT AND PAST THREE PERIODS

Program Outcomes Assessed in this course

Outcome 1:

An ability to identify, formulate, and solve complex engineering problems (CEP) by applying principles of engineering, science, and mathematics.

Outcome 6:

An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.

Assessment Summary of Class Semester Averages for Outcomes (Should be provided for Fall 2019 through Spring 2022 Assessment Period)

Outcomes	2
Semester	Semester Class Average (%)
Fall 2021	78.2
Fall 2020	
Fall 2019	80.2
Comments on Trend of Data (Improving or deteriorating)	The average has trended upwards to above 80%. The instructor emphasized the importance of technical writing skills and how the design reports' grades can improve their overall grades. The performance has been consistently above target.

*Expected Semester Class Average = 70% (or as defined by the program)
Ideal Semester Class Average = 70% (or as defined by the program)

End of Semester Course Assessment Report

This summary contains the following Information

1. Performance Statistics

- Total number of students in class
- The class average performance (**stated as %**) in each course outcome assessed in this class and the **two previous times course was assessed**.
- The acceptable class average for the class in each outcome area as set by your Department. **You cannot use any number of your choice**
- Percentage of students who scored below the expected average in each outcome.

2. Implementation Summary

- Brief summary of plans implemented during the semester based on last assessment report

3. Perceived Problems

- Instructor's **critical evaluation** of perceived problems that affected students' performance. **Realistic problems should be identified throughout the semester and summarized in this section of the report.**

4. New Plans for Addressing Problems

- Instructor's plans for addressing the perceived problems the next time the class is taught. **These should be specific enough for another instructor to implement. Most of these should be things that, you, the instructor can implement to help students to improve. Be creative.**

5. Overall Trend over last three assessment periods

- Instructor's summary of overall performance trend for each outcome measured over the last three periods.

5. Were Expectations Met?

Answer **YES** if the **class average was above the expected average** and the **stated percentage of students** scored at or above the expected average, else answer NO.

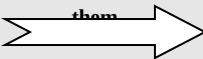
END OF SEMESTER COURSE OUTCOME ASSESSMENT REPORT

ELEG 4043 ELECTRONICS II

FALL 2021 SEMESTER

Report Prepared by: Dr. Mohan Ketkar

Report Date: December 15, 2021

Semester	Analysis Type	Number of Students	Outcome 2			
			Expected Class Average	Expected Percent of students at or above average	Class Average	% Students meeting Expected Average
Fall 2021	Direct	22	75	70	78.2	86
Fall 2019	Direct	20	75	70	80.3	95
Implementation Summary	Items implemented from previous report or after meeting previous instructor		There is no data from previous year's report since the criteria have changed.			
Perceived Problems	Perceived problems are directly related to the PC and the sub items under them 		This was the semester with face-to-face mode of operation after three semesters of online operation. Major problems were inability to gather relevant information and cite references. The time given for the project completion was little, short. Students were unable to complete analysis on software and building and optimizing the performance. Project based on topics from initial chapters will give students enough time.			
Plans for Addressing Problems	Plans for address specific measures to address PC and their sub areas 		All of the plans suggested for the sub-outcomes will address the problems encountered for this outcome.			
Overall Trend over Periods	Ascertain if there were improvements over previous 		Students' performance was above the expected average.			
Were Expectations Met?			YES			

Course Grades downloaded from Canvas

	Student	Test 1 (155204)	Test 2 (155461)	Test 3 (155462)	Course design Project(s) (155451)	Final Exam (155452)	Participation and attendance Current Score	Tests Current Score	Course design Project(s) Current Score	Final Exam Current Score	Current Score	Current Grade
1		85	70	60	90	89	88	77.5	90	89	84.5	A
2		85	80	20	80	66	80	82.5	80	66	76.8	B
3		95	90	65	95	76	100	92.5	95	76	88.8	A
4		85	85		80	74	100	85	80	74	82.2	C
5		35	50	70	80	35	64	60	80	35	56.9	A
6		85	90		80	50	92	90	80	50	76.17	B
7		20	30	5	75	60	69	25	75	60	49.9	C
8		38	65	25	80	25	79	51.5	80	25	52.02	C
9		50	30	80	75	20	80	65	75	20	55	C
10		80	45	70	90	45	100	75	90	45	71.5	B
11		40	55	60	60	66	56	57.5	60	66	60.4	C
12		70	90	35	85	80	100	80	85	80	83	A
13		70	85	94	90	40	85	89.5	90	40	74.3	B
14		50	80	35	80	76	84	65	80	76	73.2	B
15		50	40	20	85	51	96	45	85	51	59.9	C
16		65	65	50	80	64	76	65	80	64	68.8	B
17		35	40	15	80	68	92	37.5	80	68	60.6	C
18		62	55	20		0	80	58.5		0	39.25	F
19		50	60			0	36	60		0	34.55	F
20		42	70	65	85	69	96	67.5	85	69	74.3	B
21		60	55	50	85	73	68	57.5	85	73	68.7	B
22		65	60	25	85	71	92	62.5	85	71	72.5	B
23		75	55	45	80	65	62	65	80	65	67.7	B

Electronics II

FALL 20201

Title of Assignment: TEST 1

TOPICS COVERED IN TEST 1

Test 1 covered the following topics:

1. MOSFET Amplifiers
2. BJT Amplifiers
3. Circuit Models
4. Voltage Gain calculations

ELEG4304 Fall 2021**Test # 1**

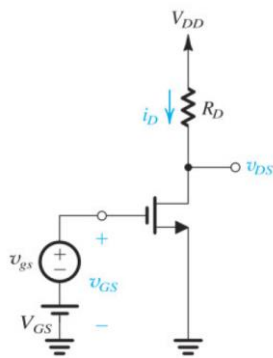
September 16

Question #	Max Points	Obtained
I	30	
II	40	
III	30	
Total points	100	

Closed book, Closed notes.

No cell phone allowed. No sharing of calculators.**After finishing your test, scan all pages into a pdf file.****Upload your file on canvas under Test # 1.****Handover your test to the instructor.**

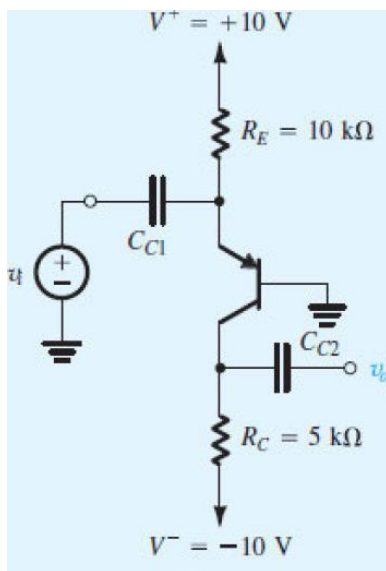
- I. For the amplifier let $V_{DD} = 5\text{ V}$, $R_D = 10\text{ k}\Omega$, $V_t = 1\text{ V}$, $k'_n = 20\text{ }\mu\text{A/V}^2$, $W/L = 20$, $V_{GS} = 2\text{ V}$, and $\lambda = 0$.



- Find the dc current I_D and the voltage V_{DS}
- Find g_m
- Find the voltage gain
- If $v_{gs} = 0.2 \sin \omega t$ volts, find v_{ds} assuming that the small-signal approximation holds. What are the minimum and maximum values of V_{DS} ?

- II. For the following circuit:

- Determine the type of the transistor and type of configuration of this amplifier



- Assuming β of 100, determine V_E , I_E , I_C , and V_C
- Determine g_m , r_e , and r_π
- Sketch ac equivalent circuit (use T model)
- Calculate the gain A_v

III A CE amplifier circuit utilizes a BJT with $\beta = 200$ biased at $I_C = 0.5\text{ mA}$; it has a collector resistance $R_C = 10\text{ k}\Omega$. Find g_m , R_{in} , R_o , and A_{VO} . If the amplifier is fed with a signal source with a resistance of $10\text{ k}\Omega$, and a load resistance $R_L = 10\text{ k}\Omega$ is connected to the output terminal, find resulting A_v and G_v . If the peak voltage of the sinewave appearing between base and emitter is to be limited to 5 mV , what v_{sig} is allowed, and what output voltage signal appears across the load.

ABOVE AVERAGE

(Note: All Pages shown in Light Blue should be printed on Light Blue Paper)

ELEG4304 Fall 2021**Midterm Exam**

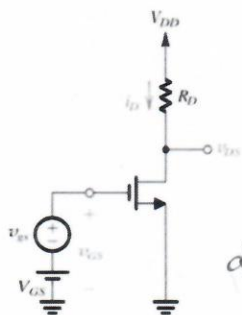
September 16

Question #	Max Points	Obtained
I	30	30
II	40	35
III	30	30
Total points	100	95

Closed book, Closed notes.
No cell phone allowed. No sharing of calculators.

**After finishing your test, scan all pages into a pdf file.
Upload your file on canvas under Test # 1.
Handover your test to the instructor.**

I. For the amplifier let $V_{DD} = 5\text{ V}$, $R_D = 10\text{ k}\Omega$, $V_t = 1\text{ V}$, $k'_n = 20\text{ }\mu\text{A/V}^2$, $W/L = 10$, $V_{GS} = 2\text{ V}$, and $\lambda = 0$.



- Find the dc current I_D and the voltage V_{DS}
- Find g_m
- Find the voltage gain
- If $v_{gs} = 0.2 \sin \omega t$ volts, find v_{ds} assuming that the small-signal approximation holds. What are the minimum and maximum values of V_{DS} ?

$$\begin{aligned} a) \quad I_D &= \frac{1}{2} k_n (V_{ov})^2 \\ &= \frac{1}{2} (20 \frac{\mu\text{A}}{\text{V}^2}) (10) (2\text{V} - 1\text{V})^2 \\ &= \frac{1}{2} (200 \frac{\mu\text{A}}{\text{V}^2}) (1\text{V}^2) = 100 \mu\text{A} \end{aligned}$$

$$I_D = 100 \mu\text{A}$$

$$V_{DS} = V_{DD} - (100 \mu\text{A}) (10,000) = 5\text{V} - 1\text{V} = 4\text{V}$$

$$V_{DS} = 4\text{V}$$

$$b) \quad g_m = k_n (V_{ov}) = (20 \frac{\mu\text{A}}{\text{V}^2}) (10) (2\text{V} - 1\text{V}) = (200 \frac{\mu\text{A}}{\text{V}^2}) (1\text{V}) = 200 \frac{\mu\text{A}}{\text{V}}$$

$$g_m = 200 \frac{\mu\text{A}}{\text{V}}$$

$$c) \quad A_v = -g_m R_D = -200 \frac{\mu\text{A}}{\text{V}} \cdot (10,000 \Omega) = -2 \frac{\text{V}}{\text{V}}$$

$$A_v = -2 \frac{\text{V}}{\text{V}}$$

$$d) \quad \text{if } v_{gs} = 0.2 \text{ V}_p \text{ then } v_{ds} = (0.2 \text{ V}_p) \cdot 2 = 0.4 \text{ V}_p$$

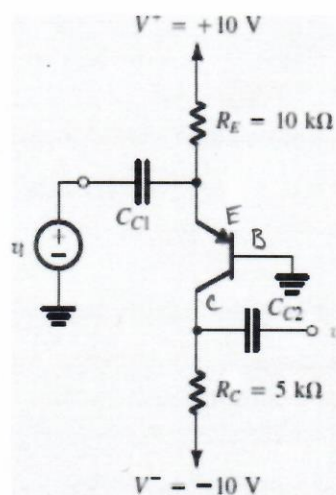
$$v_{ds} = 0.4 \text{ V}_p$$

$$V_{DS \text{ max}} = 4\text{V} + 0.4\text{V} = 4.4\text{V}$$

$$V_{DS \text{ min}} = 4\text{V} - 0.4\text{V} = 3.6\text{V}$$

30

II. For the following circuit:



- Determine the type of the transistor and type of configuration of this amplifier
- Assuming β of 100, determine V_E , I_E , I_C , and V_C
- Determine g_m , r_e , and r_π
- Sketch ac equivalent circuit (use T model)
- Calculate the gain A_v

a) PNP (BJT) type transistor in a common Base configuration

b) $V_{EB} = 0.7 \text{ volts}$ $V_B = 0V \therefore V_E = 0.7V$

$$I_E = \frac{(10 - 0.7)V}{10,000\Omega} = 9.30 \mu A$$

$$\alpha = \frac{100}{101} = 0.9901$$

$$I_C = \alpha I_E = 920.792 \mu A$$

$$-10 = V_C - I_C R_C$$

$$-10 + I_C R_C = V_C$$

$$V_C = -10 + (920.792 \mu A)(5,000\Omega) = -5.396V$$

$$V_C = -5.396V$$

c) $g_m = \frac{I_C}{V_T} = \frac{920.792 \mu A}{25 \text{ mV}} = 36.832 \frac{\text{mA}}{\text{V}}$

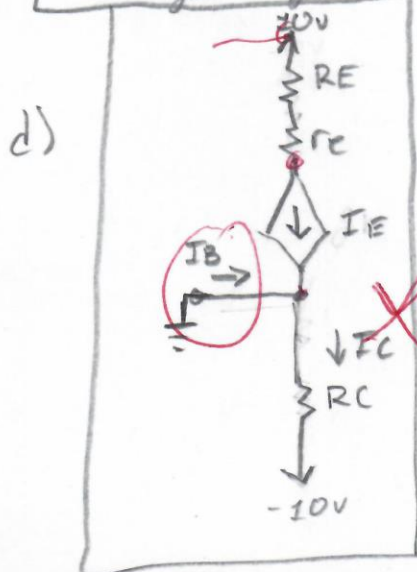
$$r_e = \frac{1}{g_m} = 27.151 \Omega$$

$$r_\pi = \frac{\beta}{g_m} = \frac{100}{36.832} = 2715.054 \Omega$$

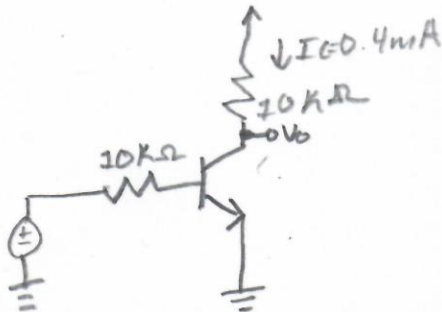
d) $A_v = \frac{V_o}{V_i} = \frac{V_o}{V_E} = \frac{V_C}{V_E} = \frac{-5.396V}{0.7V} = -7.709$

$$A_v = -7.709$$

35



III A CE amplifier circuit utilizes a BJT with $\beta = 160$ biased at $I_C = 0.4 \text{ mA}$; it has a collector resistance $R_C = 10 \text{ k}\Omega$. Find g_m , R_{in} , R_o , and A_{VO} . If the amplifier is fed with a signal source with a resistance of $10 \text{ k}\Omega$, and a load resistance $R_L = 10 \text{ k}\Omega$ is connected to the output terminal, find resulting A_v and G_v . If the peak voltage of the sinewave appearing between base and emitter is to be limited to 5 mV , what v_{sig} is allowed, and what output voltage signal appears across the load.



$$g_m = \frac{I_C}{V_T} = \frac{0.4 \text{ mA}}{25 \text{ mV}} = 16 \frac{\text{mA}}{\text{V}}$$

$$R_{in} = r_{\pi} = \frac{V_T}{I_B}$$

$$I_B = \frac{I_C}{\beta} = \frac{0.4 \text{ mA}}{160} = 2.5 \mu\text{A}$$

$$R_{in} = \frac{25 \text{ mV}}{2.5 \mu\text{A}} = 10 \text{ k}\Omega$$

$$R_o = R_C = 10 \text{ k}\Omega$$

$$A_{VO} = -g_m R_C = -\left(16 \frac{\text{mA}}{\text{V}}\right)(10 \text{ k}\Omega)$$

$$A_{VO} = -160 \text{ V/V}$$

$$A_v = -\left(16 \frac{\text{mA}}{\text{V}}\right)(10 \text{ k}\Omega \parallel 10 \text{ k}\Omega) = -\left(16 \frac{\text{mA}}{\text{V}}\right)(5 \text{ k}\Omega) = -80$$

$$A_v = -80 \text{ V/V}$$

$$G_v = \frac{-\beta(R_C \parallel R_L)}{R_{sig} + r_{\pi}} = \frac{-160(5000)}{(10000) + (10000)} = -40$$

$$G_v = -40 \text{ V/V}$$

$$V_{BE \text{ max}} = 5 \text{ mV}$$

$$V_{BE} = \frac{r_{\pi}}{R_{sig} + r_{\pi}} \cdot V_{sig} = \frac{1}{2} V_{sig}$$

$$V_{BE} = \frac{1}{2} V_{sig} \text{ if } V_{BE \text{ max}} = 5 \text{ mV}$$

$$V_{sig \text{ max}} = 10 \text{ mV}$$

$$V_L = G_v \cdot V_{sig \text{ max}} = (10 \text{ mV})(-40) = -400 \text{ mV}$$

$$V_L |_{V_{sig \text{ max}}} = -400 \text{ mV}$$

30

AVERAGE

ELEG4304 Fall 2021**Midterm Exam**

September 16

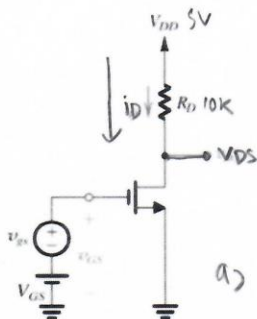
Question #	Max Points	Obtained
I	30	25
II	40	35
III	30	25
Total points	100	85

Closed book, Closed notes.

No cell phone allowed. No sharing of calculators.

**After finishing your test, scan all pages into a pdf file.
Upload your file on canvas under Test # 1.
Handover your test to the instructor.**

I. For the amplifier let $V_{DD} = 5\text{ V}$, $R_D = 10\text{ k}\Omega$, $V_t = 1\text{ V}$, $k'_n = 20\text{ }\mu\text{A/V}^2$, $W/L = 10$, $V_{GS} = 2\text{ V}$, and $\lambda = 0$.



- Find the dc current I_D and the voltage V_{DS}
- Find g_m
- Find the voltage gain A_v
- If $v_{gs} = 0.2 \sin \omega t$ volts, find v_{ds} assuming that the small-signal approximation holds. What are the minimum and maximum values of V_{DS} ?

$$a) I_D = \frac{1}{2} k'_n \frac{W}{L} (V_{GS} - V_t)^2$$

$$I_D = \frac{1}{2} \cdot 20\text{ }\mu\text{A} \cdot 10 \cdot (2 - 1)^2$$

$$I_D = 0.0001\text{ A}$$

$$V_{DS} = V_{DD} - I_D R_D$$

$$= 5 - (0.0001)(10\text{ k}\Omega)$$

$$V_{DS} = 4\text{ V}$$

$$b) g_m = \frac{2 I_D}{V_{GS} - V_t} = \frac{2 \cdot 0.0001}{(2 - 1)} = 0.0002\text{ A/V}$$

$$c) A_v = -g_m R_D = -2\text{ V/V}$$

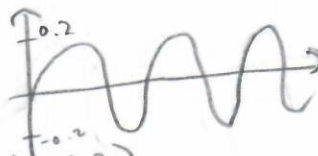
$$d) \frac{V_{ds}}{V_{gs} - V_t} = \frac{V_o}{V_i} = |A_v|$$

$$V_{ds\min} = -V_{gs} A_v = -(0.2 \sin \omega t) \cdot (-2)$$

$$V_{ds\min} = +0.4 \sin \omega t\text{ V}$$

$$V_{ds\max} = +V_{gs} A_v = (0.2 \sin \omega t) \cdot (-2)$$

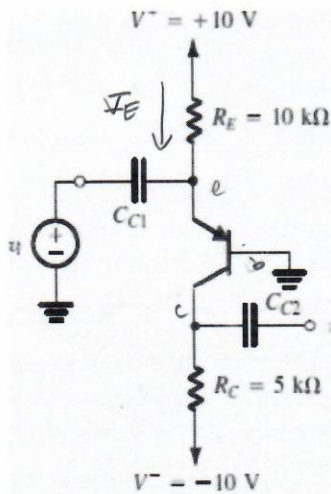
$$V_{ds\max} = -0.4 \sin \omega t\text{ V}$$



25

II. For the following circuit:

a) Determine the type of the transistor and type of configuration of this amplifier



- b) Assuming β of 100, determine V_E , I_E , I_C , and V_C
 c) Determine g_m , r_e , and r_π
 d) Sketch ac equivalent circuit (use T model)
 e) Calculate the gain A_v

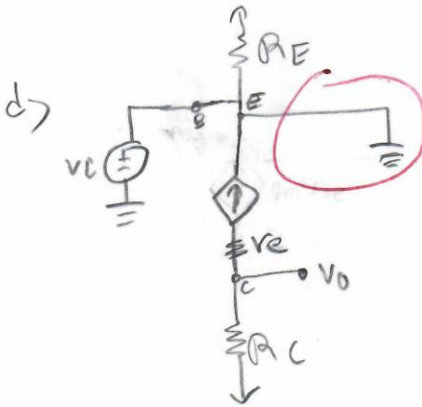
a) BJT, CCS

b) $V_E = 0.7V$
 $I_E = \frac{V_{DD} - V_E}{R_E}$
 $I_E = \frac{10 - 0.7}{10K} = 0.00093A$

$I_C = I_E \alpha$, $\alpha = \frac{\beta}{1+\beta} = \frac{100}{101} = 0.99$

$I_C = (0.00093) \left[\frac{100}{1+100} \right] = 9.21 \times 10^{-4}A$

$V_C = -10 - R_C I_C$
 $V_C = -14.6V$



c) $g_m = \frac{I_C}{V_T} = \frac{9.21 \times 10^{-4}A}{25mV} = 3.68 \times 10^{-2}A/V$

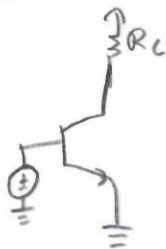
$r_e = \frac{V_T}{I_E} = 26.88\Omega$

$r_\pi = \frac{\beta}{g_m} = \frac{100}{3.68 \times 10^{-2}} = 2715.05\Omega$

e) $A_v = \frac{I_C}{V_T} R_C = 184.2V/V$

35

III A CE amplifier circuit utilizes a BJT with $\beta = 160$ biased at $I_C = 0.4 \text{ mA}$; it has a collector resistance $R_C = 10 \text{ k}\Omega$. Find g_m , R_{in} , R_o , and A_{vo} . If the amplifier is fed with a signal source with a resistance of $10 \text{ k}\Omega$, and a load resistance $R_L = 10 \text{ k}\Omega$ is connected to the output terminal, find resulting A_v and G_v . If the peak voltage of the sinewave appearing between base and emitter is to be limited to 5 mV , what v_{sig} is allowed, and what output voltage signal appears across the load.

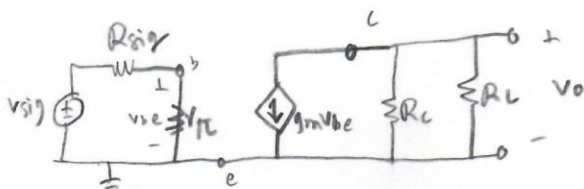


$$\beta = 160$$

$$I_C = 0.4 \text{ mA}$$

$$R_C = 10 \text{ k}\Omega$$

$$a) g_m, R_{in}, R_o, A_{vo}$$



$$g_m = \frac{I_C}{V_T} = \frac{0.4 \text{ mA}}{25 \text{ mV}} = 0.016 \text{ A/V}$$

$$R_{in} = r_{\pi} = \frac{\beta}{g_m} = \frac{160}{0.016} = 10 \text{ k}\Omega$$

$$R_o = R_C = 10 \text{ k}\Omega$$

$$A_{vo} = -g_m R_C = (-0.016)(10 \text{ k})$$

$$A_{vo} = -160 \text{ V/V}$$

$$b) A_v = -g_m (R_C \parallel R_L)$$

$$A_v = (-0.016) \left(\frac{10 \text{ k} \cdot 10 \text{ k}}{10 \text{ k} + 10 \text{ k}} \right)$$

$$A_v = -80 \text{ V/V}$$

$$G_v = +A_v \cdot \frac{r_{\pi}}{r_{\pi} + R_{sig}} = (-80) \left(\frac{10 \text{ k}}{10 \text{ k} + 10 \text{ k}} \right)$$

$$G_v = -40 \text{ V/V}$$

$$c) \frac{V_{be}}{v_{sig}} = \frac{1}{A_v} \rightarrow v_{sig} = \frac{V_{be}}{|A_v|}$$

$$\frac{5 \text{ mV}}{+80 \text{ V/V}} = 0.0625 \text{ mV}$$

$$\frac{V_o}{v_{sig}} = |A_v|$$

$$V_o = v_{sig} |A_v|$$

$$V_o = 0.0625 \text{ mV} \cdot 40$$

$$V_o = 2.5 \text{ mV}$$

25

BELOW AVERAGE

ELEG4304 Fall 2021**Midterm Exam**

September 16

Question #	Max Points	Obtained
I	30	30
II	40	0
III	30	30
Total points	100	60

Closed book, Closed notes.

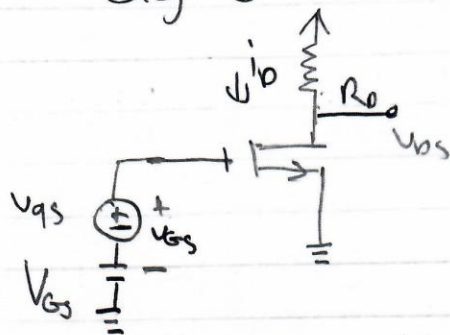
No cell phone allowed. No sharing of calculators.**After finishing your test, scan all pages into a pdf file.****Upload your file on canvas under Test # 1.****Handover your test to the instructor.**

9/16/21 Adeola Okeowo

Eleg 4304 Fall 2021 Test # 1A

Find the dc current I_D and the voltage V_{DS}

1a



$$V_{DD} = 5V, R_D = 10k\Omega, V_t = 1V, k_n = 20\mu A/V^2$$

$$W/L = 10, V_{GS} = 2V, \lambda = 0$$

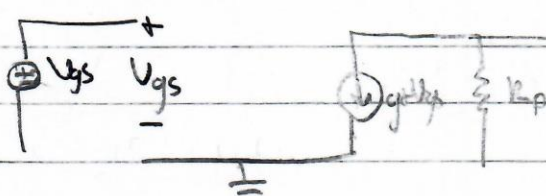
$$I_D = \frac{k_n}{2} \left(\frac{W}{L} \right) (V_{GS} - V_t)^2 = \frac{20}{2} \cdot (10) \cdot (2 - 1)^2 = 100\mu A$$

$$V_{DS} = V_{DD} - I_D R_D = 5 - (10)(0.1) = 4V$$

b $g_m = \frac{\partial I_D}{\partial V_{GS}} = \frac{2I_D}{V_{GS} - V_t} = \frac{200\mu A}{1V} = 2 \times 10^{-4} A/V$

* Finding g_m

c



Finding voltage gain

$$V_o = -R_D g_m V_{gs}$$

$$\frac{V_o}{V_{gs}} = -g_m R_D = -(2 \times 10^{-4} A/V)(10 \times 10^3) = -2 A/V$$

d) If $V_{gs} = 0.2 \sin \omega t$ volts, find v_{ds} assuming that the small signal approximation holds. What are the minimum and maximum values of V_{DS}

$$V_{gs} = 0.2 \sin \omega t \quad V_{ds} = V_D$$

$$A_v = V_{ds} / V_{gs} \rightarrow V_{ds} = A_v \cdot V_{gs} = (-2)(0.2 \sin \omega t)$$

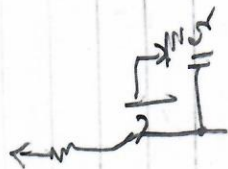
$$V_{ds} = -0.4 \sin \omega t$$

$$V_{ds \max} = V_{gs} + V_{ds} = 4 - 0.4 = \underline{\underline{3.6V}}$$

$$V_{ds \min} = V_{gs} - V_{ds} = 4 - (-0.4) = \underline{\underline{4.4V}}$$

30

2 type of transistor and type of configuration of this amplifier
 a $\beta_{ac} \approx 100$ $V_E = ?$ $V_C = ?$ $V_B = ?$ $V_C = ?$



0

3 BJT

$$\beta = 160$$

$$I_C = 0.4 \text{ mA}$$

$$R_C = 10 \text{ k}\Omega$$

$$R_{in} = ? \quad g_m = ? \quad R_o = ? \quad A_{vo} = ?$$

$$R_E = 10 \text{ k}\Omega$$

$$A_v = ? \quad G_v = ?$$

$$V_{\pi} = 5 \text{ mV}$$

$$V_{sig} = ? \quad V_o = ?$$

$$R_i = r_{\pi}$$

$$g_m = \frac{I_C}{V_T} = \frac{0.4}{25} = 16 \text{ mA/V}$$

$$r_{\pi} = \beta / g_m = 160 / 0.016 = 10 \text{ k}\Omega = R_i$$

$$R_o = R_C = 10 \text{ k}\Omega$$

$$A_{vo} = -g_m R_C = -(16)(10) = -160 \text{ V/V}$$

$$A_v = A_{vo} \cdot \frac{R_C}{R_C + R_E} = -160 \cdot \frac{10,000}{10,000 + 10,000} = -80 \text{ V/V}$$

$$A_v = -80 \text{ V/V}$$

$$G_v = A_v \cdot \frac{R_i}{R_i + R_{sig}} = -80 \cdot \frac{10,000}{10,000 + 10,000} = -40 \text{ V/V}$$

$$V_{\pi} = V_{sig} \cdot \frac{R_i}{R_i + R_{sig}} \Rightarrow V_{sig} = \frac{V_{\pi} (R_i + R_{sig})}{R_i}$$

$$V_{sig} = \frac{(0.005)(10,000 + 10,000)}{10,000} = 10 \text{ mV}$$

30

$$V_o = |G_v| V_{sig} = (40)(10 \times 10^{-3}) = 0.4 \text{ V}$$

ELEG4304 Fall 2021**Test # 2**

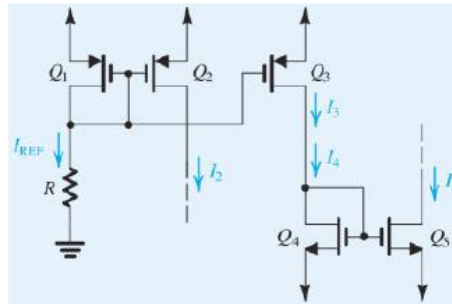
October 14

Question #	Max Points	Obtained
I	40	
II	30	
III	30	
Total points	100	

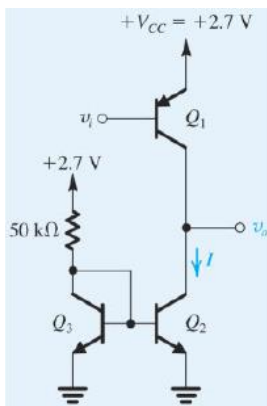
Closed book, Closed notes.

No cell phone allowed. No sharing of calculators.**After finishing your test, scan all pages into a pdf file.****Upload your file on canvas under Test # 1.****Handover your test to the instructor.**

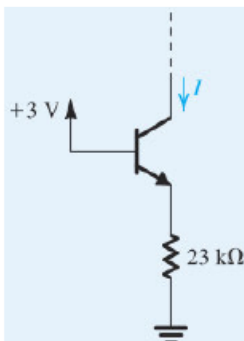
- I. The current-steering circuit below is fabricated in a CMOS technology for which $\mu_n C_{ox} = 400 \mu\text{A}/\text{V}^2$, $\mu_p C_{ox} = 100 \mu\text{A}/\text{V}^2$, $V_{tn} = 0.5 \text{ V}$, $V_{tp} = -0.5 \text{ V}$, $V'_{An} = 5 \text{ V}/\mu\text{m}$, and $V'_{Ap} = 6 \text{ V}/\mu\text{m}$. If all devices have $L = 0.5 \mu\text{m}$, design the circuit so that $I_{REF} = 20 \mu\text{A}$, $I_2 = 80 \mu\text{A}$, $I_3 = I_4 = 60 \mu\text{A}$, and $I_5 = 100 \mu\text{A}$. Use the minimum possible device widths needed to operate the current source Q_2 with voltages at its drain as high as $+1.0 \text{ V}$ and to operate the current sink Q_5 with voltages at its drain as low as -1.0 V . Use the power supply $\pm 1.2 \text{ V}$. Specify the widths of all five devices and the value of R . Find the output resistance r_{o2} of the current source Q_2 and the output resistance r_{o5} of the current sink Q_5



- II. Transistor Q_1 in following circuit is operating as a CE amplifier with an active load provided by transistor Q_2 , which is the output transistor in a current mirror formed by Q_2 and Q_3 . (Note that the biasing arrangement for Q_1 is *not* shown.) Neglecting the finite base currents of Q_2 and Q_3 , and assuming that Q_1 and Q_2 have five times the area of Q_3 , find the value of I_{REF} and I . If Q_1 and Q_2 are specified to have $|V_A| = 16 \text{ V}$, find the total resistance at the collector of Q_1 . Find g_{m1} and $r_{\pi 1}$ assuming that $\beta_1 = 80$. Find R_{in} , A_v , and R_o .



- III. For the constant-current source circuit shown, find the collector current I and the output resistance. The BJT is specified to have $\beta = 80$, $V_{BE} = 0.7 \text{ V}$, and $V_A = 16 \text{ V}$. If the collector voltage undergoes a change of 2 V while the BJT remains in the active mode, what is the corresponding change in collector current? (Note the change is dependent on r_o and R_{OUT} , so need to find that first)



ABOVE AVERAGE

(Note: All Pages shown in Light Blue should be printed on Light Blue Paper)

ELEG4304 Fall 2021**Test # 2**

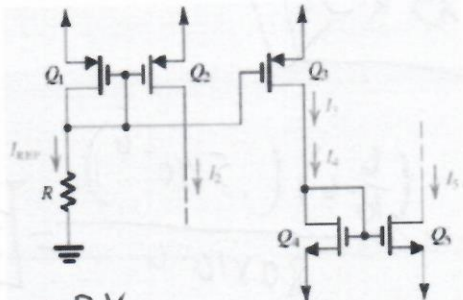
October 14

Question #	Max Points	Obtained
I	40	35
II	30	30
III	30	25
Total points	100	90

Closed book, Closed notes.
No cell phone allowed. No sharing of calculators.

**After finishing your test, scan all pages into a pdf file.
Upload your file on canvas under Test # 1.
Handover your test to the instructor.**

- I. The current-steering circuit below is fabricated in a CMOS technology for which $\mu_n C_{ox} = 400 \mu\text{A}/\text{V}^2$, $\mu_p C_{ox} = 100 \mu\text{A}/\text{V}^2$, $V_{tn} = 0.5 \text{ V}$, $V_{tp} = -0.5 \text{ V}$, $V'_{An} = 5 \text{ V}/\mu\text{m}$, and $V'_{Ap} = 6 \text{ V}/\mu\text{m}$. If all devices have $L = 0.5 \mu\text{m}$, design the circuit so that $I_{REF} = 20 \mu\text{A}$, $I_2 = 80 \mu\text{A}$, $I_3 = I_4 = 60 \mu\text{A}$, and $I_5 = 100 \mu\text{A}$. Use the minimum possible device widths needed to operate the current source Q_2 with voltages at its drain as high as $+1.0 \text{ V}$ and to operate the current sink Q_5 with voltages at its drain as low as -1.0 V . Use the power supply $\pm 1.2 \text{ V}$. Specify the widths of all five devices and the value of R . Find the output resistance r_{o2} of the current source Q_2 and the output resistance r_{o5} of the current sink Q_5 .



Given:

$$\begin{aligned} \mu_n C_{ox} &= 400 \mu\text{A}/\text{V}^2 & V_{tp} &= -0.5 \text{ V} \\ \mu_p C_{ox} &= 100 \mu\text{A}/\text{V}^2 & V'_{An} &= 5 \text{ V}/\mu\text{m} \\ V_{tn} &= 0.5 \text{ V} & V'_{Ap} &= 6 \text{ V}/\mu\text{m} \end{aligned}$$

$$\begin{aligned} L &= 0.5 \mu\text{m} & I_3 &= I_4 = 60 \mu\text{A} \\ I_{REF} &= 20 \mu\text{A} & I_5 &= 100 \mu\text{A} \\ I_2 &= 80 \mu\text{A} \end{aligned}$$

Solution:

$$V_{DS2} = V_{GS2} - V_{tp} \Rightarrow V_{DS \max} = V_{GS} - V_{tp}$$

$$(1 - (-1.2)) = V_{GS2} - V_{tp}$$

$$\therefore V_{GS2} = -0.7$$

$$V_{GS2} = -0.7$$

$$V_{GS1} = V_{GS2} = V$$

$$\text{For } Q_1, I_{D1} = \frac{1}{2} \mu_p C_{ox} \frac{W_1}{L_1} (V_{GS1} - V_{tp})^2$$

$$I_{D1} = I_{REF}$$

$$20 \times 10^{-6} = \frac{1}{2} (100 \times 10^{-6}) \frac{W_1}{L_1} (-0.7 - (-0.5))^2$$

$$\frac{W_1}{L_1} = 10$$

$$W_1 = 5 \mu\text{m}$$

$$W_2 = 4 W_1 \Rightarrow 4(5 \mu\text{m})$$

$$W_2 = 20 \mu\text{m}$$

$$I_3 = 2.5 I_{REF}$$

$$W_3 = 2.5 W_1 \Rightarrow 2.5(5)$$

$$W_3 = 12.5 \mu\text{m}$$

$$I_3 = I_4 \Rightarrow \frac{W_3}{W_4} = \frac{I_n}{I_p}$$

$$W_4 = 12.5 \mu\text{A} \frac{100}{400}$$

$$W_4 = 3.125 \mu\text{m}$$

$$V_0 = [-1.0 - (-1.2)]$$

$$V_0 = V_{GS5} - V_{tn}$$

$$V_0 = -0.2$$

$$V_{GS5} = -0.2 + (0.5)$$

$$V_{GS5} = 0.3$$

$$100 \times 10^{-6} = \frac{1}{2} (400 \times 10^{-6}) \left(\frac{W_5}{L_5} \right) (0.3 - 0.5)^2$$

$$W_5 = 6.25 \mu\text{m}$$

35

$$V_{AQ} = V_{SS} + V_{GS2}$$

$$1.2 - .7 = V_{AQ}$$

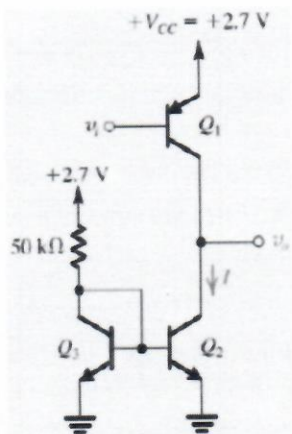
$$V_{AQ} = .5V$$

$$R = \frac{.5}{20 \times 10^{-6}} \Rightarrow \boxed{R = 25 \text{ k}\Omega}$$

$$r_{O2} = \frac{V_{A'P2} L}{I_2} \Rightarrow r_{O2} = \frac{\left(\frac{6}{10} \cdot 6\right) (.5 \times 10^{-6})}{80 \times 10^{-6}} = \boxed{37.5 \text{ k}\Omega}$$

$$r_{O5} = \frac{V_{A'P5} L}{I_5} \Rightarrow r_{O5} = \frac{\left(\frac{5}{10} \cdot 6\right) (.5 \times 10^{-6})}{100 \times 10^{-6}} = \boxed{25 \text{ k}\Omega}$$

- II. Transistor Q_1 in following circuit is operating as a CE amplifier with an active load provided by transistor Q_2 , which is the output transistor in a current mirror formed by Q_2 and Q_3 . (Note that the biasing arrangement for Q_1 is not shown.) Neglecting the finite base currents of Q_2 and Q_3 , and assuming that Q_1 and Q_2 have five times the area of Q_3 , find the value of I_{REF} and I . If Q_1 and Q_2 are specified to have $|V_A| = 16\text{ V}$, find the total resistance at the collector of Q_1 . Find g_{m1} and $r_{\pi 1}$ assuming that $\beta_1 = 80$. Find R_{in} , A_v , and R_o .



Given:

$$|V_A| = 16\text{ V}$$

$$\beta_1 = 80$$

$$r_{\pi 1} = \frac{\beta}{g_{m1}} \quad g_{m1} = \frac{I}{V_T}$$

$$g_{m1} = \frac{.2 \times 10^{-3}}{25 \times 10^{-3}} = 8 \frac{\text{mA}}{\text{V}}$$

Solution:

$$Q_2 = 5Q_3$$

$$I_{REF} = \frac{+2.7\text{ V} - V_{BE}}{50\text{ k}\Omega} \Rightarrow \frac{2.7 - 0.7}{50\text{ k}\Omega} = .04\text{ mA}$$

$$r_{\pi 1} = \frac{80}{8 \times 10^{-3}} = 10\text{ k}\Omega$$

$$I_B = I_{REF} = 0.04\text{ mA}$$

$$Q_2 = 5Q_3 \Rightarrow 5(I_B)$$

$$I = 5(.04) = .2\text{ mA}$$

$$|V_A| = 16\text{ V}$$

$$r_{o1} = \frac{10}{I} = \frac{16}{.2} = 80\text{ k}\Omega$$

$$r_{o2} = \frac{V_A}{I} = \frac{16}{.2} = 80\text{ k}\Omega$$

$$R_{o2} \parallel r_{o1} \parallel r_{o2} = \frac{80 \times 80}{80 + 80} = 40\text{ k}\Omega$$

$$r_{\pi} = R_{in} = 10\text{ k}\Omega$$

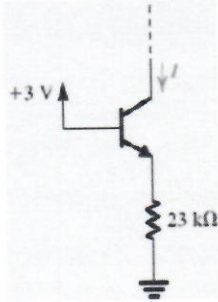
$$R_o = 11\text{ k}\Omega = 40\text{ k}\Omega$$

$$A_v = -g_m (R_o \parallel R_{oc}) = -8 \times 10^{-3}$$

$$A_v = -320 \frac{\text{V}}{\text{V}}$$

30

- III. For the constant-current source circuit shown, find the collector current I and the output resistance. The BJT is specified to have $\beta = 80$, $V_{BE} = 0.7 \text{ V}$, and $V_A = 16 \text{ V}$. If the collector voltage undergoes a change of 2 V while the BJT remains in the active mode, what is the corresponding change in collector current? (Note the change is dependent on r_o and R_{OUT} , so need to find that first)



Given
 $\beta = 80$
 $V_{BE} = 0.7$
 $V_A = 16 \text{ V}$

$$I_E = \frac{3 - V_{BE}}{23 \text{ k}} = \frac{3 - 0.7}{23 \text{ k}} = 0.1 \text{ mA}$$

$$I_C = \frac{\beta}{\beta + 1} (I_E) = \frac{80}{80 + 1} (0.1 \text{ mA})$$

$$I_C = 9.878 \times 10^{-5}$$

$$g_m = 0.004$$

$$r_o = \frac{V_A}{I_C} = \frac{16}{9.878 \times 10^{-5}} = 161.976 \text{ k}\Omega$$

$$\Delta I_C = I_{SE} \left(\frac{V_{DE}}{V_T} + \frac{V_{DC}}{V_D} \right) \left(1 + \frac{1}{\beta} \right) I_C$$

$$\left(\frac{2}{25 \times 10^{-3}} - 3 \right) \left(1 + \frac{1}{80} \right) (9.878 \times 10^{-5})$$

$$\Delta I_C =$$

25

AVERAGE

ELEG4304 Fall 2021**Test # 2**

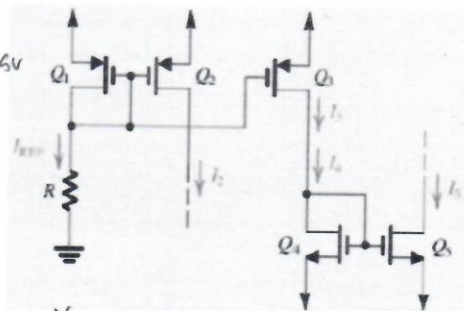
October 14

Question #	Max Points	Obtained
I	40	30
II	30	30
III	30	20
Total points	100	80

Closed book, Closed notes.

No cell phone allowed. No sharing of calculators.**After finishing your test, scan all pages into a pdf file.****Upload your file on canvas under Test # 1.****Handover your test to the instructor.**

- I. The current-steering circuit below is fabricated in a CMOS technology for which $\mu_n C_{ox} = 400 \mu\text{A}/\text{V}^2$, $\mu_p C_{ox} = 100 \mu\text{A}/\text{V}^2$, $V_m = 0.5 \text{ V}$, $V_{tp} = -0.5 \text{ V}$, $V'_{An} = 5 \text{ V}/\mu\text{m}$, and $V'_{Ap} = 6 \text{ V}/\mu\text{m}$. If all devices have $L = 0.5 \mu\text{m}$, design the circuit so that $I_{REF} = 20 \mu\text{A}$, $I_2 = 80 \mu\text{A}$, $I_3 = I_4 = 60 \mu\text{A}$, and $I_5 = 100 \mu\text{A}$. Use the minimum possible device widths needed to operate the current source Q_2 with voltages at its drain as high as $+1.0 \text{ V}$ and to operate the current sink Q_5 with voltages at its drain as low as -1.0 V . Use the power supply $\pm 1.2 \text{ V}$. Specify the widths of all five devices and the value of R . Find the output resistance r_{o2} of the current source Q_2 and the output resistance r_{o5} of the current sink Q_5 .



Given: $\mu_n C_{ox} = 400 \mu\text{A}/\text{V}^2$

$\mu_p C_{ox} = 100 \mu\text{A}/\text{V}^2$, $V_{tn} = 0.5 \text{ V}$, $V_{tp} = -0.5 \text{ V}$
 $V'_{An} = 5 \text{ V}/\mu\text{m}$, $V'_{Ap} = 6 \text{ V}/\mu\text{m}$

$V_{DS2} = V_{GS2} - V_{tp} \Rightarrow V_{DS2, \text{max}} = V_{GS2} - V_{tp}$
 $\Rightarrow V_{GS1} = V_{GS2} = -0.7 \text{ V}$

For Q_1 , $I_{D1} = \frac{1}{2} \mu_p C_{ox} \frac{W_1}{L_1} (V_{GS1} - V_{tp})^2$

$20 \times 10^{-6} = \frac{1}{2} \times 100 \times 10^{-6} \left(\frac{W_1}{0.5 \times 10^{-6}} \right) (-0.7 + 0.5)^2$

$W_1 = 5 \mu\text{m}$

For $Q_2 \Rightarrow \frac{1}{2} \mu_p C_{ox} \frac{W_2}{L_2} (V_{GS2} - V_{tp})^2 = 4 \times \frac{1}{2} \mu_p C_{ox} \frac{W_1}{L_1}$, Since

$I_3 = 2.5 I_{REF} \Rightarrow W_3 = 2.5 W_1 \Rightarrow W_3 = 12.5 \mu\text{m}$
 $I_3 = I_4 \Rightarrow \frac{W_3}{W_4} = \frac{I_3}{I_4} \Rightarrow W_4 = 12.5 \times \frac{100}{140} \Rightarrow W_4 = 8.93 \mu\text{m}$

For Q_5 , $V_{DS5} = V_{GS5} - V_{tn}$ For $\downarrow V_0 \Rightarrow [-1.0 - (1.2)] = V_{GS5} - 0.5$
 $I_5 = 100 \times 10^{-6} = \frac{1}{2} \times 400 \times 10^{-6} \times \left(\frac{W_5}{0.5 \times 10^{-6}} \right) (0.7 - 0.5)^2 \Rightarrow W_5 = 6.25 \mu\text{m}$

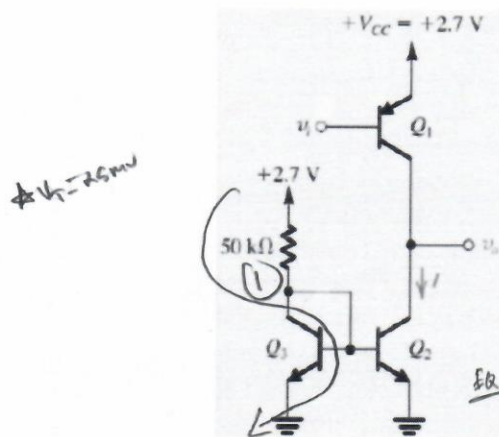
$R = \frac{V_{GS2}}{I_{REF}} = \frac{0.3}{20 \times 10^{-6}} \Rightarrow R = 15 \text{ k}\Omega$

$r_{o2} = \frac{V'_{Ap} L}{I_2} = \frac{(6/10^{-6}) \times 0.5 \times 10^{-6}}{80 \times 10^{-6}} \Rightarrow r_{o2} = 3.75 \text{ k}\Omega$

$r_{o5} = \frac{V'_{An} L}{I_5} = \frac{(5/10^{-6}) \times 0.5 \times 10^{-6}}{100 \times 10^{-6}} \Rightarrow r_{o5} = 2.5 \text{ k}\Omega$

30

- II. Transistor Q_1 in following circuit is operating as a CE amplifier with an active load provided by transistor Q_2 , which is the output transistor in a current mirror formed by Q_2 and Q_3 . (Note that the biasing arrangement for Q_1 is *not* shown.) Neglecting the finite base currents of Q_2 and Q_3 , and assuming that Q_1 and Q_2 have five times the area of Q_3 , find the value of I_{REF} and I . If Q_1 and Q_2 are specified to have $|V_A| = 16 \text{ V}$, find the total resistance at the collector of Q_1 . Find g_{m1} and $r_{\pi 1}$ assuming that $\beta_1 = 80$. Find R_{in} , A_v , and R_o .



KVL in path 1

$$2.7 - (50 \text{ k}\Omega)(I_0) - 0.7$$

$$I_0 = \frac{2.7 - 0.7}{50 \text{ k}\Omega} = 0.04 \text{ mA} \quad \checkmark$$

$$I = 5 \times I_0 = 5 \times 0.04 \text{ mA} = 0.2 \text{ mA} \quad \checkmark$$

Q_1 and Q_2 specified to have $|V_A| = 16 \text{ V}$

$$r_{o1} = r_{o2} = \frac{|V_A|}{I} = \frac{16 \text{ V}}{0.2 \text{ mA}} = 80 \text{ k}\Omega \quad \checkmark$$

EA circuit



total resistance @ $Q_1 = r_{o1} \parallel r_{o2}$

$$= (80 \text{ k}\Omega) \parallel (80 \text{ k}\Omega)$$

$$= 40 \text{ k}\Omega \quad \checkmark$$

$$g_{m1} = \frac{I_C}{V_T} = \frac{I}{V_T} = \frac{0.2 \text{ mA}}{25 \text{ mV}}$$

$$g_{m1} = 0.008 \Rightarrow 8 \text{ mS} \quad \checkmark$$

$$r_{\pi 1} = \frac{\beta_1}{g_{m1}} = \frac{80}{8 \times 10^{-3}} = 10 \text{ k}\Omega \quad \checkmark$$

$$R_{in} = r_{\pi 1} = 10 \text{ k}\Omega$$

$$R_o = r_{o1} \parallel r_{o2} = (80 \text{ k}\Omega) \parallel (80 \text{ k}\Omega)$$

$$R_o = 40 \text{ k}\Omega \quad \checkmark$$

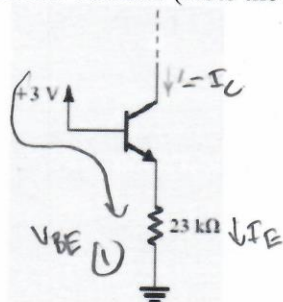
$$A_v = -g_{m1} (r_{o1} \parallel r_{o2})$$

$$= (-8 \times 10^{-3}) (40 \times 10^3)$$

$$A_v = -320 \text{ V/V} \quad \checkmark$$

30

- III. For the constant-current source circuit shown, find the collector current I and the output resistance. The BJT is specified to have $\beta = 80$, $V_{BE} = 0.7$ V, and $V_A = 16$ V. If the collector voltage undergoes a change of 2 V while the BJT remains in the active mode, what is the corresponding change in collector current? (Note the change is dependent on r_o and R_{OUT} , so need to find that first)



KVL LOOP 1

$$3 - V_{BE} - (I_E)(23k\Omega) = 0$$

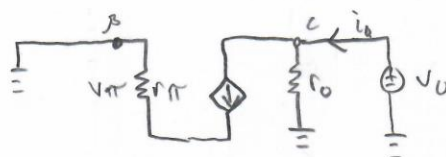
$$I_E = \frac{3 - V_{BE}}{23k\Omega} = \frac{3 - 0.7}{23k\Omega} = 0.1mA$$

$$I_C = \left(\frac{\beta}{\beta + 1} \right) I_E$$

$$I_C = \left(\frac{80}{80 + 1} \right) 0.1$$

$$= 0.099mA$$

Small signal circuit



$$V_E - V_{BE}$$

$$KCL @ emitter \quad \frac{V_{BE}}{r_E} + g_m V_{BE} + \frac{V_O - (-V_{BE})}{R_E} = 0$$

$$R_{out} = r_o = \left(\frac{V_A}{I_C} \right) = \frac{16V}{0.099mA} = 161.61k\Omega$$

20

BELOW AVERAGE

ELEG4304 Fall 2021**Test # 2**

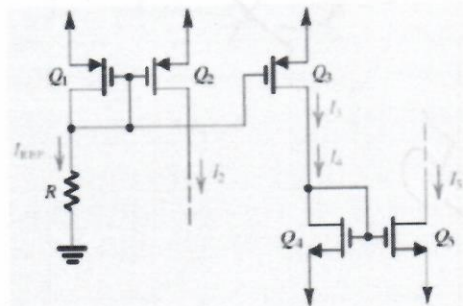
October 14

Question #	Max Points	Obtained
I	40	25
II	30	15
III	30	10
Total points	100	50

Closed book, Closed notes.
No cell phone allowed. No sharing of calculators.

**After finishing your test, scan all pages into a pdf file.
Upload your file on canvas under Test # 1.
Handover your test to the instructor.**

- I. The current-steering circuit below is fabricated in a CMOS technology for which $\mu_n C_{ox} = 400 \mu\text{A}/\text{V}^2$, $\mu_p C_{ox} = 100 \mu\text{A}/\text{V}^2$, $V_{tn} = 0.5 \text{ V}$, $V_{tp} = -0.5 \text{ V}$, $V'_{An} = 5 \text{ V}/\mu\text{m}$, and $V'_{Ap} = 6 \text{ V}/\mu\text{m}$. If all devices have $L = 0.5 \mu\text{m}$, design the circuit so that $I_{REF} = 20 \mu\text{A}$, $I_2 = 80 \mu\text{A}$, $I_3 = I_4 = 60 \mu\text{A}$, and $I_5 = 100 \mu\text{A}$. Use the minimum possible device widths needed to operate the current source Q_2 with voltages at its drain as high as $+1.0 \text{ V}$ and to operate the current sink Q_5 with voltages at its drain as low as -1.0 V . Use the power supply $\pm 1.2 \text{ V}$. Specify the widths of all five devices and the value of R . Find the output resistance r_{o2} of the current source Q_2 and the output resistance r_{o5} of the current sink Q_5



$$\begin{aligned} \mu_n C_{ox} &= 400 \mu\text{A}/\text{V}^2 \\ \mu_p C_{ox} &= 100 \mu\text{A}/\text{V}^2 \\ V_{tn} &= 0.5 \text{ V} \quad V_{tp} = -0.5 \text{ V} \\ V'_{An} &= 5 \text{ V}/\mu\text{m} \quad V'_{Ap} = 6 \text{ V}/\mu\text{m} \\ L &= 0.5 \mu\text{m} \end{aligned}$$

$$V_{DS1} = V_{GS2} - V_{tp} \rightarrow V_{DS1 \max} = V_{GS2} - V_{tp} \quad V_{GS1} = V_{GS2} \\ (1.0 - 1.2) = V_{GS2} - (-0.5)$$

$$V_{GS2} = (-0.2 - 0.5) \quad V_{GS2} = -0.7 = V_{GS1}$$

$$I_{D1} = \frac{1}{2} \mu_p C_{ox} \left(\frac{W_1}{L_1} \right) (V_{GS1} - V_{tp})^2$$

$$W_1 = \frac{(20 \times 10^{-6})(2)(0.5 \times 10^{-6})}{(100 \times 10^{-6})(-0.7 + 0.5)^2}$$

$$W_1 = 5 \mu\text{m}$$

$$I_2 = 80 \mu\text{A} = 4 I_{REF}$$

$$\frac{1}{2} \mu_p C_{ox} \frac{W_2}{L_2} (V_{GS2} - V_{tp})^2 = 4 \left(\frac{1}{2} \right) \mu_p C_{ox} \frac{W_1}{L_1} (V_{GS1} - V_{tp})^2$$

$$W_2 = 4 W_1$$

$$W_2 = 20 \mu\text{m}$$

$$I_3 = 2.5 I_{REF} \Rightarrow W_3 = 2.5 W_1 = 12.5 \mu\text{m}$$

$$I_5 = I_{D1} \Rightarrow \frac{W_5}{L_5} = \frac{\mu_n C_{ox}}{\mu_p C_{ox}} = W_4 = \frac{W_3 \mu_p C_{ox}}{\mu_n C_{ox}}$$

$$= \frac{(12.5)(100)}{400}$$

$$= 3.125 \mu\text{A}/\text{V}^2$$

For Q_5

$$-(0.8) - (-1) = V_{GS5} - 0.5 \quad V_{GS5} = 0.7 \text{ V}$$

$$100 = \frac{1}{2} (400) \frac{W_5}{0.5 \times 10^{-6}} (0.7 - 0.5)^2 \rightarrow W_5 = \frac{(100 \times 10^{-6})(2)(0.5 \times 10^{-6})}{(400 \times 10^{-6})(0.7 - 0.5)^2}$$

$$= 6.25 \mu\text{m}$$



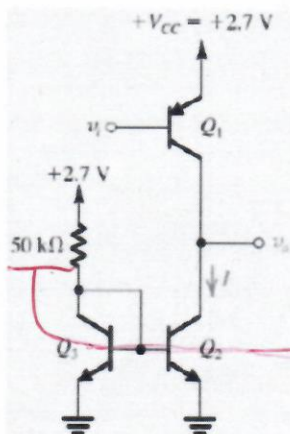
$$R = \frac{V_{O1}}{I_{REF}} = \frac{0.3}{20 \times 10^{-6}} = \boxed{15 \text{ k}\Omega}$$

$$r_{o2} = \frac{(16)(0.5)}{80 \mu\text{A}} = \boxed{3.75 \text{ k}\Omega}$$

$$r_{o5} = \frac{(16)(0.5)}{100} = \boxed{30 \text{ k}\Omega}$$

25

- II. Transistor Q_1 in following circuit is operating as a CE amplifier with an active load provided by transistor Q_2 , which is the output transistor in a current mirror formed by Q_2 and Q_3 . (Note that the biasing arrangement for Q_1 is *not* shown.) Neglecting the finite base currents of Q_2 and Q_3 , and assuming that Q_1 and Q_2 have five times the area of Q_3 , find the value of I_{REF} and I . If Q_1 and Q_2 are specified to have $|V_A| = 16$ V, find the total resistance at the collector of Q_1 . Find g_{m1} and $r_{\pi 1}$ assuming that $\beta_1 = 80$. Find R_{in} , A_v , and R_o .



$$\beta_1 = 80$$

$$I_{REF} = ? \quad I = ?$$

$$g_{m1} = ? \quad r_{\pi 1} = ?$$

$$R_{in} = ? \quad A_v = ? \quad R_o = ?$$

$$I_3 = \frac{2.7 - 0.7}{80 \times 10^{-3}} = 25 \mu A$$

$$\frac{I_2}{I_3} = \frac{A_2}{A_3} = \frac{5A}{A} = 5$$

$$I_2 = I = 5I_3 = 125 \mu A$$

$$r_{o1} = \frac{16}{200 \times 10^{-6}} = 80 k\Omega$$

$$r_{o2} = \frac{16}{200 \times 10^{-6}} = 80 k\Omega$$

$$r_{\pi 1} = \frac{\beta}{g_{m1}} = \frac{80}{5 \times 10^{-3}} = 16 k\Omega$$

$$g_{m1} = \frac{I_{C1}}{V_T}$$

$$= \frac{200 \times 10^{-6}}{25 \times 10^{-3}} = 8 mA/V$$

$$R_{in} = r_{\pi 1} = 16 k\Omega$$

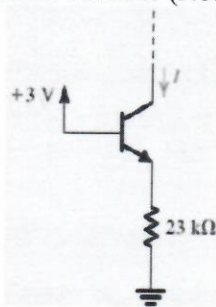
$$R_o = \frac{80 \times 80}{80 + 80} = 40 k\Omega$$

$$V_o = (5 \times 10^{-3}) (v_{in}) (40 \times 10^3)$$

$$A_v = -200$$

15

- III. For the constant-current source circuit shown, find the collector current I and the output resistance. The BJT is specified to have $\beta = 80$, $V_{BE} = 0.7 \text{ V}$, and $V_A = 16 \text{ V}$. If the collector voltage undergoes a change of 2 V while the BJT remains in the active mode, what is the corresponding change in collector current? (Note the change is dependent on r_o and R_{OUT} , so need to find that first)



$$I = ? \quad R_{out} = ? \quad r_o = ?$$

$$\beta = 80 \quad V_{BE} = 0.7 \text{ V}$$

$$V_A = 16 \text{ V}$$

KVL

$$3 - V_{BE} = (I_E)(23 \text{ k}\Omega) \rightarrow I_E = \frac{3 - 0.7}{23 \text{ k}\Omega} = 1 \text{ mA}$$

$$I_C = \frac{\beta}{\beta + 1} I_E \rightarrow \frac{80}{80 + 1} \times 1 \text{ mA}$$

$$= 0.99 \text{ mA}$$

$$\frac{V_{\pi}}{r_{\pi}} + g_m V_{\pi} + \frac{0 - (-V_{\pi})}{R_E} = 0 \quad V_{\pi} = 0$$

$$R_{out} = \frac{V_A}{I_C} = \frac{16}{0.99} = 16.16 \text{ k}\Omega$$

10

Electronics II

FALL 2021

Final Exam

Final covered the following topics:

1. CMOS Amplifiers
2. Frequency Response
3. Miller effect and Open circuit Time constant method
4. Feedback amplifiers

ELEG4304 Fall 2021**Final Exam**December 2nd, 2021

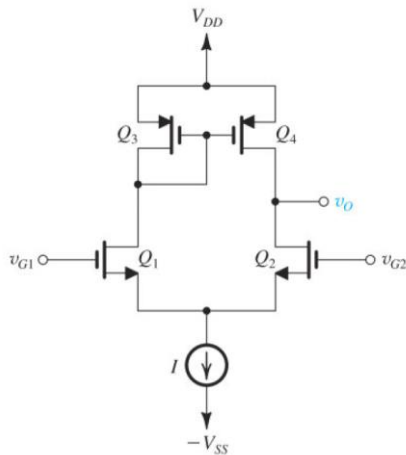
Question #	Max Points	Obtained
I	25	
II	25	
III	25	
IV	25	
Total points	100	

Closed book, Closed notes.

No cell phone allowed. No sharing of calculators.

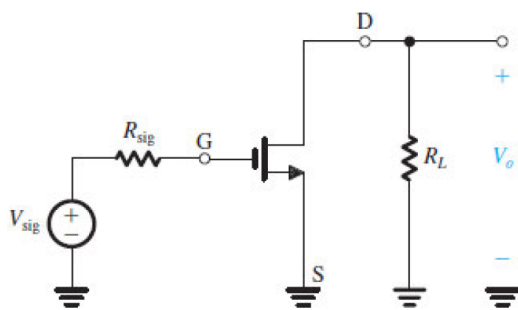
I. An amplifier is fabricated in a CMOS technology for which

$$\mu_n C_{ox} = 2 \mu_p C_{ox} = 200 \mu\text{A/V}^2, (W/L)_n = 100, \text{ and } (W/L)_p = 200, V_{An} = |V_{Ap}| = 20 \text{ V}, \text{ and } I = 800 \mu\text{A}.$$



- Describe the type of amplifier and function of each transistor.
- Calculate V_{ov} for Q_1 and Q_2 .
- Calculate short circuit transconductance for differential input, G_{md}
- Calculate R_o
- Calculate the differential voltage gain, A_d

II.



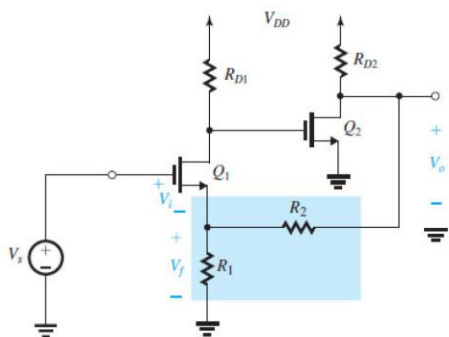
Consider the MOS amplifier fed with a signal source having an internal resistance $R_{sig} = 20 \text{ k}\Omega$. The amplifier has $R_L = 10 \text{ k}\Omega$, $g_m = 2 \text{ mA/V}$, $r_o = 20 \text{ k}\Omega$, $C_{gs} = 20 \text{ fF}$, $C_{dg} = 5 \text{ fF}$.

- Sketch high frequency equivalent circuit
- Find the mid-band gain, A_M
- Using Miller effect determine C_{eq} and C_{in}
- Determine the upper 3 -dB frequency f_H
- Find frequency of transmission zero, f_z

III. Consider a bipolar active-loaded CE amplifier having the load current source implementation with a *pnp* transistor. Let the circuit be operated at a 1 mA bias current. The transistors are specified as follows: $\beta(npn) = 200$, $V_{An} = 130 \text{ V}$, $V_{Ap} = -50 \text{ V}$, $C_\pi = 16 \text{ pF}$, $C_\mu = 0.3 \text{ pF}$. The amplifier is fed with a signal source having a resistance of $36 \text{ k}\Omega$.

- Determine A_M
- Determine C_{in}
- Determine f_H using the Miller effect
- Determine f_H using the open-circuit time constants
- Determine the Gain-bandwidth product.

IV. For the following feedback amplifier circuit



- Identify the type of mixing-sampling
- Find expression for β_f and ideal value of A_f
- Sketch the circuit breaking the loop between drain of Q_1 and gate of Q_2
- Find expression for closed loop gain $A\beta_f$
- If $g_{m1} = g_{m2} = 4 \text{ mA/V}$, $R_{D1} = R_{D2} = 10 \text{ k}\Omega$, $R_1 = 1 \text{ k}\Omega$, $R_2 = 9 \text{ k}\Omega$, determine β_f , $A\beta_f$, A , and A_f

ABOVE AVERAGE

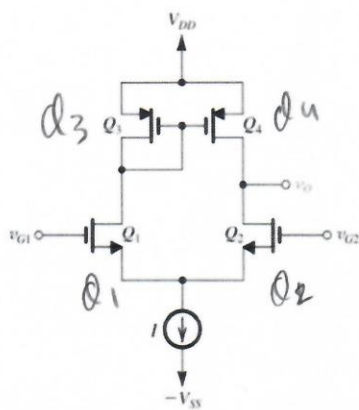
(Note: All Pages shown in Light Blue should be printed on Light Blue Paper)

ELEG4304 Fall 2021**Final Exam**December 2nd, 2021

Question #	Max Points	Obtained
I	25	22
II	25	25
III	25	25
IV	25	17
Total points	100	89

Closed book, Closed notes.
No cell phone allowed. No sharing of calculators.

I.



Known:

$$k'_n = 200 \mu\text{A/V}^2$$

$$k'_p = 100 \mu\text{A/V}^2$$

$$(W/L)_n = 100$$

$$(W/L)_p = 200$$

$$V_{An} = V_{Ap} = 20\text{V}$$

$$I = 800 \mu\text{A}$$

$$I_D = 400 \mu\text{A}$$

An amplifier is fabricated in a CMOS technology for which $\mu_n C_{ox} = 2 \mu_p C_{ox} = 200 \mu\text{A/V}^2$, $(W/L)_n = 100$, and $(W/L)_p = 200$, $V_{An} = |V_{Ap}| = 20\text{V}$, and $I = 800 \mu\text{A}$.

- Describe the type of amplifier and function of each transistor.
- Calculate V_{ov} for Q_1 and Q_2 .
- Calculate short circuit transconductance for differential input, G_{md}
- Calculate R_o
- Calculate the differential voltage gain, A_d

a) Current mirror MOS
~~2 stage differential amp~~
~~• Q_1 & Q_2 are mirrors and NPN~~
~~• Q_3 & Q_4 are mirrors and PNP~~

$$R_o = V_A / I$$

$$A_d = G_{md} \cdot R_o$$

$$G_{md} = I / V_{ov}$$

$$b) I_{D1} = \frac{1}{2} k'_n \left(\frac{W}{L} \right)_n V_{ov}^2$$

$$\sqrt{\frac{2I_D}{k'_n \left(\frac{W}{L} \right)_n}} = V_{ov} = \sqrt{\frac{2 \cdot 400 \times 10^{-6}}{200 \times 10^{-6} \cdot 100}} = 0.2\text{V}$$

$$V_{ov1} = V_{ov2} = 0.2\text{V}$$

$$c) G_{md} = \frac{I}{V_{ov}}$$

$$V_{ov3} = V_{ov4} = \sqrt{\frac{2 \cdot I_{D3}}{k'_p \left(\frac{W}{L} \right)_p}} = \sqrt{\frac{2 \cdot 400 \times 10^{-6}}{100 \mu \cdot 200}} = 0.2$$

$$V_{ov1} = V_{ov2} = V_{ov3} = V_{ov4}$$

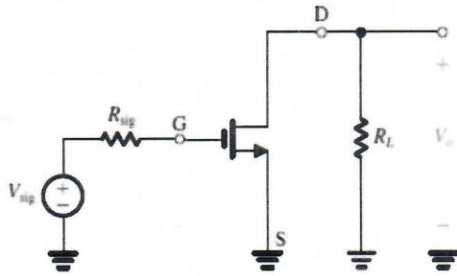
$$G_{md} = \frac{800 \mu\text{A}}{0.2\text{V}} = 0.004 \text{ A/V}$$

$$d) R_o = \frac{V_A}{I} = \frac{20}{800 \times 10^{-6}} = 25 \text{ k}\Omega$$

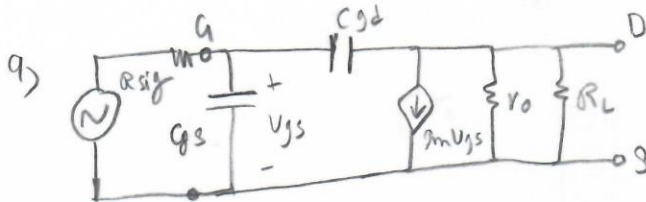
$$e) A_d = G_{md} R_o = 4 \text{ m A/V} \cdot 25 \text{ k}\Omega = 100 \text{ V/V}$$

22

- II. Consider the MOS amplifier fed with a signal source having an internal resistance $R_{sig} = 20 \text{ k}\Omega$. The amplifier has $R_L = 10 \text{ k}\Omega$, $g_m = 2 \text{ mA/V}$, $r_o = 20 \text{ k}\Omega$, $C_{gs} = 20 \text{ fF}$, $C_{dg} = 5 \text{ fF}$.



- Sketch high frequency equivalent circuit
- Find the mid-band gain, A_M
- Using Miller effect determine C_{eq} and C_{in}
- Determine the upper 3-dB frequency f_H
- Find frequency of transmission zero, f_z



Known:

$$R_{sig} = 20 \text{ k}\Omega$$

$$R_L = 10 \text{ k}\Omega$$

$$g_m = 2 \text{ mA/V}$$

$$r_o = 20 \text{ k}\Omega$$

$$C_{gs} = 20 \text{ fF}$$

$$C_{dg} = 5 \text{ fF}$$

b)

$$A_M = -g_m R'_L$$

$$R'_L = r_o \parallel R_L = (20 \text{ k}) \parallel (10 \text{ k}) = 6.67 \text{ k}\Omega$$

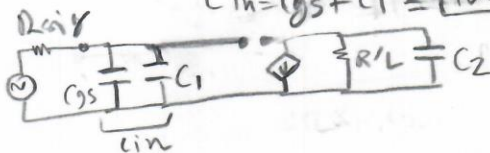
$$A_M = -2 \text{ mA/V} \cdot 6.67 \text{ k}\Omega = -13.33 \text{ V/V}$$

c)

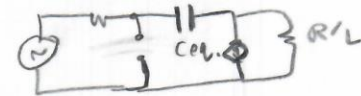
$$C_1 = C_{dg} (1 - A_M) = (5 \times 10^{-15}) (1 + 13.33) = 71.67 \text{ fF}$$

$$C_2 = C_{dg} (1 - 1/A_M) = 5.38 \text{ fF}$$

$$C_{in} = C_{gs} + C_1 = 90.67 \text{ fF}$$



$$C_{eq} = C_{gs} + C_{dg} (1 + g_m R'_L)$$



$$R'_L = 6.67 \text{ k}\Omega$$

$$C_{eq} = 20 \text{ fF} + 5 \text{ fF} (1 + 2 \text{ mA/V} \cdot 6.67 \text{ k}\Omega) = 91.7 \times 10^{-15} \text{ or } 91.7 \text{ fF}$$

d)

$$f_{H1} = \frac{1}{2\pi R_{sig} C_{in}} = \frac{1}{2\pi \cdot 20 \text{ k} \cdot 90.67 \text{ f}} = 86.71 \text{ MHz}$$

$$f_{H2} = \frac{1}{2\pi R'_L C_2} = \frac{1}{2\pi \cdot 6.67 \text{ k} \cdot 5.38 \text{ f}} = 4.44 \text{ GHz}$$

$$f_H = \min(f_{H1}, f_{H2}) = f_{H1} = 86.71 \text{ MHz}$$

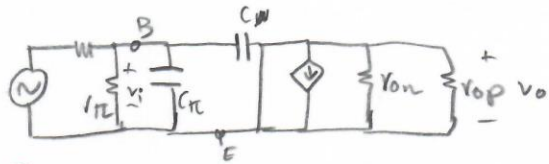
e)

$$f_z = \frac{g_m}{2\pi C_{dg}} = 63.67 \text{ MHz}$$

25

III. Consider a bipolar active-loaded CE amplifier having the load current source implementation with a *pnp* transistor. Let the circuit be operated at a 1 mA bias current. The transistors are specified as follows: $\beta(npn) = 200$, $V_{AN} = 130$ V, $V_{AP} = -50$ V, $C_\pi = 16$ pF, $C_\mu = 0.3$ pF. The amplifier is fed with a signal source having a resistance of 36 k Ω .

- Determine A_M
- Determine C_{in}
- Determine f_H using the Miller effect
- Determine f_H using the open-circuit time constants
- Determine the Gain-bandwidth product.



$$a) A_M = \frac{-r_\pi}{r_\pi + R_{sig}} \cdot g_m R'_L = -176.15 \text{ V/V}$$

$$R'_L = r_{on} \parallel r_{op} = 36.11 \text{ k}\Omega$$

$$R'_{sig} = r_\pi \parallel R_{sig} = 4.40 \text{ k}\Omega$$

$$g_m = \frac{I_C}{V_T} = \frac{1 \text{ mA}}{25 \text{ mV}} = 40 \text{ mS/V}$$

$$r_\pi = \beta / g_m = 200 / 40 \text{ m} = 5 \text{ k}\Omega$$

$$r_{op} = V_{AP} / I_C = 50 / 1 \text{ mA} = 50 \text{ k}\Omega$$

$$r_{on} = V_{AN} / I_C = 130 / 1 \text{ mA} = 130 \text{ k}\Omega$$

$$b) C_{in} = C_\pi + (C_\mu (1 + g_m R'_L))$$

$$= 16 \times 10^{-12} + 0.3 \times 10^{-12} (1 + 40 \text{ m} \cdot 36.11 \text{ k}) = 450 \text{ pF}$$

$$c) f_H = \frac{1}{2\pi C_{in} R'_{sig}} = 80.45 \text{ kHz}$$

$$d) T_H = C_\pi R'_{sig} + (C_\mu R_N + C_L R'_L) = (16 \text{ pF})(4.4 \text{ k}) + (0.3 \text{ pF})(6.4 \text{ M}\Omega) + 0 = 2 \times 10^{-6} \text{ s}$$

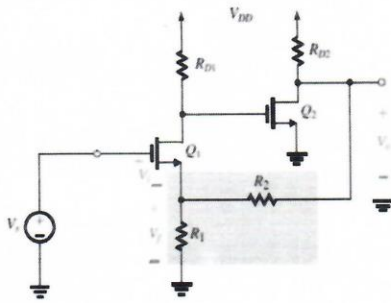
$$R_N = R'_{sig} (1 + g_m R'_L) + R'_L = (4.4 \text{ k})(1 + 40 \text{ m} \cdot 36.11 \text{ k}) + 36.11 \text{ k} = 6.4 \text{ M}\Omega$$

$$e) f_H = \frac{1}{2\pi T_H} = \frac{1}{2\pi \cdot 2 \times 10^{-6} \text{ s}} = 80 \text{ kHz}$$

$$f) \text{GBP} = |A_M| \cdot f_H = (176.15)(80 \text{ k}) = 14 \text{ MHz}$$

25

IV. For the following feedback amplifier circuit

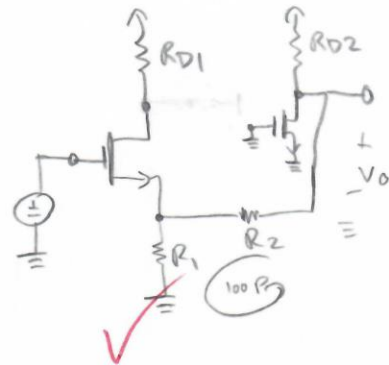


- Identify the type of mixing-sampling
- Find expression for β_f and ideal value of A_f
- Sketch the circuit breaking the loop between drain of Q_1 and gate of Q_2
- Find expression for closed loop gain $A\beta_f$
- If $g_{m1} = g_{m2} = 4 \text{ mA/V}$, $R_{D1} = R_{D2} = 10 \text{ k}\Omega$, $R_1 = 1 \text{ k}\Omega$, $R_2 = 9 \text{ k}\Omega$, determine β_f , $A\beta_f$, A , and A_f

a) Voltage series
voltage mixing - sampling

$$b) \beta_f = \frac{V_f}{V_o} = \frac{R_1}{R_1 + R_2}$$

$$A_{f, \text{ideal}} = \frac{1}{\beta} = 1 + \frac{R_2}{R_1}$$



$$c) V_i = V_o = V_f$$

$$\frac{V_o}{V_f} = g_m (R_1 + R_2) \parallel R_D = A_{\beta}$$

$$R_D = R_{D1} \parallel R_{D2} = 10 \text{ k} \parallel 10 \text{ k} = 5 \text{ k}\Omega$$

$$\frac{V_o}{V_f} = A_{\beta} = g_m (R_1 + R_2) \parallel (R_{D1} \parallel R_{D2})$$

$$d) \beta_f = \frac{1 \text{ k}\Omega}{1 \text{ k}\Omega + 9 \text{ k}\Omega} = 100 \times 10^{-3}$$

$$A_{f, \text{ideal}} = 10 \text{ V/V}$$

$$A\beta_f = (4 \text{ mA/V}) (10 \text{ k} \parallel 5 \text{ k}) = 13.32 \text{ V/V}$$

$$A = \frac{A\beta_f}{\beta_f} = 133 \text{ V/V}$$

AVERAGE

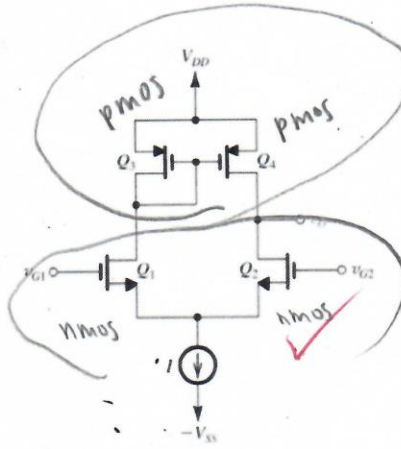
ELEG4304 Fall 2021**Final Exam**December 2nd, 2021

Question #	Max Points	Obtained
I	25	20
II	25	21
III	25	25
IV	25	05
Total points	100	71

Closed book, Closed notes.

No cell phone allowed. No sharing of calculators.

I.



An amplifier is fabricated in a CMOS technology for which $\mu_n C_{ox} = 2 \mu_p C_{ox} = 200 \mu A/V^2$, $(W/L)_n = 100$, and $(W/L)_p = 200$, $V_{An} = |V_{Ap}| = 20 V$, and $I = 800 \mu A$.

- Describe the type of amplifier and function of each transistor.
- Calculate V_{ov} for Q_1 and Q_2 .
- Calculate short circuit transconductance for differential input, G_{md} .
- Calculate R_o .
- Calculate the differential voltage gain, A_d .

$$K'_n = 200 \mu A/V^2 \quad W/L_n = 100$$

$$K'_p = 100 \mu A/V^2 \quad W/L_p = 200$$

$$I_{d_{1,2,3,4}} = \frac{800 \mu A}{2}$$

$$I_{d_{1,2,3,4}} = 400 \mu A$$

$$K_n = (200 \times 10^{-6}) (100) = \frac{1}{50}$$

$$K_p = (100 \times 10^{-6}) (200) = \frac{1}{50}$$

$$|V_{ov}| = \sqrt{\frac{I_d}{K_n}} \Rightarrow \sqrt{\frac{800 \times 10^{-6} / 2}{1/50}} = 0.141 V$$

$$g_{md} = \frac{I_d}{|V_{ov}|} = \frac{400 \times 10^{-6}}{0.141} = 2.837 \times 10^{-3} A/V$$

$$r_o = \frac{V_{An}}{I_D} = \frac{20 V}{400 \times 10^{-6}} = 50 K$$

$$R_o = (50 K \parallel 50 K) = 25 K \Omega = R_o$$

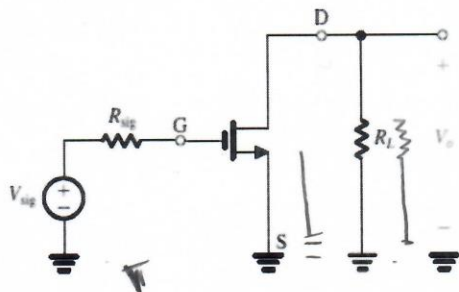
$$A_d = -g_m (R_o)$$

$$A_d = -(2.837 \times 10^{-3}) (25 K)$$

$$A_d = 70.925 V/V$$

20

- II. Consider the MOS amplifier fed with a signal source having an internal resistance $R_{sig} = 20 \text{ k}\Omega$. The amplifier has $R_L = 10 \text{ k}\Omega$, $g_m = 2 \text{ mA/V}$, $r_o = 20 \text{ k}\Omega$, $C_{gs} =$



20 fF, $C_{dg} = 5 \text{ fF}$.

- Sketch high frequency equivalent circuit
- Find the mid-band gain, A_M
- Using Miller effect determine C_{eq} and C_{in}
- Determine the upper 3-dB frequency f_H
- Find frequency of transmission zero, f_z

$$\begin{aligned} R_{sig} &= 20 \text{ k}\Omega \\ R_L &= 10 \text{ k}\Omega \\ g_m &= 2 \text{ mA/V} \\ r_o &= 20 \text{ k}\Omega \\ C_{gs} &= 20 \text{ fF} \\ C_{dg} &= 5 \text{ fF} \end{aligned}$$

$$R_o = 10 \text{ k}$$

high Fre

$$C_{gd} = 5 \text{ fF}$$

2.2m

$$(b) A_M = \frac{V_o}{V_s} = -g_m (r_o \parallel R_L)$$

$$= -(2 \text{ mA/V}) \left(\frac{20 \text{ k} \cdot 10 \text{ k}}{30 \text{ k}} \right) = -13.33 \text{ V/V}$$

$$A = -13.33 \text{ V/V}$$

$$(c) C_1 = C_{dg} (1 - A_M) = 5 (1 - 13.33) = 71.5 \text{ fF}$$

$$C_2 = C_{dg} \left(1 - \frac{1}{A_M} \right) = 5 \left(1 - \frac{1}{13.33} \right) = 5.4 \text{ fF}$$

$$C_{in} = C_{gs} + C_1 = 20 + 71.5 = 91.5 \text{ fF}$$

$$C_{eq} = C_1 + C_2 = 76.9 \text{ fF}$$

$$f_{H1} = \frac{1}{2\pi R_{sig} C_{in}} = \frac{1}{2\pi (20 \text{ k}) (91.5 \text{ fF})} = 86.9 \text{ MHz}$$

$$f_{H2} = \frac{1}{2\pi (R_L \parallel r_o) C_2} = \frac{1}{2\pi (10 \text{ k}) (5.4 \text{ fF})} = 4.4 \text{ GHz}$$

$$\text{upper } f_H = \min(f_{H1}, f_{H2}) = 86.9 \text{ MHz}$$

21

III. Consider a bipolar active-loaded CE amplifier having the load current source implementation with a *pnp* transistor. Let the circuit be operated at a 1 mA bias current. The transistors are specified as follows: $\beta(\text{nnp}) = 200$, $V_{An} = 130 \text{ V}$, $V_{Ap} = -50 \text{ V}$, $C_\pi = 16 \text{ pF}$, $C_\mu = 0.3 \text{ pF}$. The amplifier is fed with a signal source having a resistance of $36 \text{ k}\Omega$.

- Determine A_M
- Determine C_{in}
- Determine f_H using the Miller effect
- Determine f_H using the open-circuit time constants
- Determine the Gain-bandwidth product.

$$R_{sig} = 36 \text{ k}\Omega$$

$$I = 1 \times 10^{-3} \text{ A}$$

A_M

$$g_m = \frac{I_C}{V_T} = \frac{1 \text{ mA}}{25 \text{ mV}} = 40 \text{ mA/V}$$

$$\beta(\text{nnp}) = 200$$

$$R'_{sig} = r_\pi \parallel R_{sig} \quad r_\pi = \frac{\beta}{g_m} = \frac{200}{40 \text{ mA/V}} = 5 \text{ k}\Omega$$

$$\frac{5 \cdot 36}{41}$$

$$R'_{sig} = 4.39 \text{ k}$$

$$r_\lambda = \frac{V_{An}}{I} = \frac{130 \text{ V}}{1 \text{ mA}} = 130 \text{ k}$$

$$r_{pp} = \frac{V_{Ap}}{I} = \frac{-50}{1 \text{ mA}} = 50 \text{ k}$$

$$R_{sig} = \frac{\beta}{\beta}$$

$$R'_L = (r_\lambda \parallel r_{pp}) = \frac{(130 \text{ k} \cdot 50 \text{ k})}{180 \text{ k}} = 36.1 \text{ k}\Omega$$

$$-176 \text{ V/V} = A_M = \frac{r_\pi}{-r_\pi + R'_{sig}} \cdot g_m \cdot R'_L \Rightarrow \frac{5 \text{ k}}{-5 \text{ k} + 36 \text{ k}} \cdot (40 \times 10^{-3}) \cdot (36.1 \text{ k})$$

$$b) C_{in} = C_\pi + C_\mu (1 + g_m R'_L)$$

$$(16 \times 10^{-12}) + (0.3 \times 10^{-12}) (1 + 40 \times 10^{-3} \cdot 36.1 \times 10^3) = 450 \text{ pF}$$

$$c) f_H = \frac{1}{2\pi C_{in} R'_{sig}} = \frac{1}{2\pi (450 \text{ pF}) (5 \text{ k})} = 86.4 \text{ kHz}$$

$$r_\pi = R'_{sig} = 5 \text{ k}$$

$$6.38 \text{ MHz}$$

$$R_M = R'_{sig} (1 + g_m R'_L) + R'_L = 6.38 \text{ MHz}$$

$$5 \text{ k} (1 + 40 \text{ m} \cdot 36.1 \text{ k})$$

$$T_M = C_\pi r_\pi + C_\mu R_M + C_L R'_L$$

$$T_M = 2164.7 \text{ ns}$$

$$f_H = \frac{1}{2\pi T_M} = 73.5 \text{ kHz}$$

$$2\pi \cdot 2164.7 \text{ ns}$$

$$d) f_z = \frac{g_m}{2\pi C_M} = \frac{40}{2\pi \cdot 0.3 \text{ pF}} = 21.29 \text{ kHz}$$

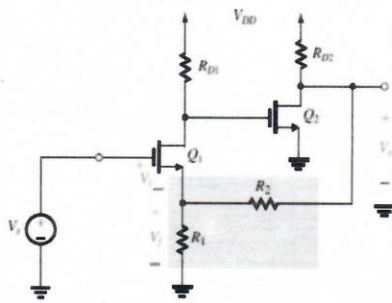
$$GBP = A_m F_H$$

$$(176) (73.5 \text{ kHz})$$

$$= 12.9 \text{ MHz}$$

25

IV. For the following feedback amplifier circuit



- Identify the type of mixing-sampling
- Find expression for β_f and ideal value of A_f
- Sketch the circuit breaking the loop between drain of Q_1 and gate of Q_2
- Find expression for closed loop gain $A\beta_f$
- If $g_{m1} = g_{m2} = 4 \text{ mA/V}$, $R_{D1} = R_{D2} = 10 \text{ k}\Omega$, $R_1 = 1 \text{ k}\Omega$, $R_2 = 9 \text{ k}\Omega$, determine β_f , $A\beta_f$, A , and A_f

(a) voltage sampling + voltage mixing

$$g_{m1} = g_{m2} = 4 \text{ mA/V}$$

$$R_D = R_{D2} = 10 \text{ k}$$

$$R_1 = 1 \text{ k}$$

$$R_2 = 9 \text{ k}$$

$$\beta =$$

$$(b) \beta_f = \frac{V_F}{V_O} =$$

$$V_F =$$

05

BELOW AVERAGE

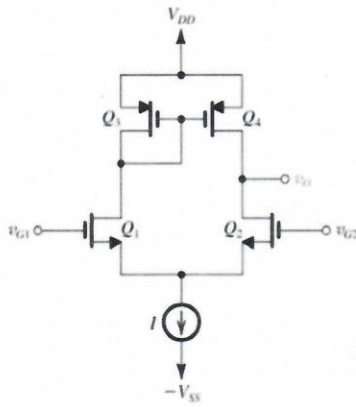
ELEG4304 Fall 2021**Final Exam**December 2nd, 2021

Question #	Max Points	Obtained
I	25	21
II	25	0
III	25	25
IV	25	05
Total points	100	51

Closed book, Closed notes.

No cell phone allowed. No sharing of calculators.

I.



An amplifier is fabricated in a CMOS technology for which $\mu_n C_{ox} = 2 \mu_p C_{ox} = 200 \mu\text{A/V}^2$, $(W/L)_n = 100$, and $(W/L)_p = 200$, $V_{An} = |V_{Ap}| = 20 \text{ V}$, and $I = 800 \mu\text{A}$.

- Describe the type of amplifier and function of each transistor.
- Calculate V_{ov} for Q_1 and Q_2 .
- Calculate short circuit transconductance for differential input, G_{md}
- Calculate R_o
- Calculate the differential voltage gain, A_d

~~X~~ stage current mirror amplifier
nnp & Pnp ~~X~~

$$\frac{I}{2} = I_{D1} = I_{D2} = I_{D3} = I_{D4} = 0.4 \text{ mA}$$

$$K_n = (W/L)_n k'_n = 100 \cdot 0.2 = 20 \text{ mA/V}$$

$$K_p = (W/L)_p k'_p = 200 \cdot (0.2/2) = 20 \text{ mA/V}$$

$$|V_{ov}| = \sqrt{I_D / K_n} = \sqrt{0.4 / 20} = 0.2 \text{ V}$$

$$g_m = I_D / V_{ov} = 0.4 / 0.2 = 4 \text{ mA/V}$$

$$g_{md} = g_m = 4 \text{ mA/V}$$

$$R_o = r_{o1} || r_{o2}$$

21

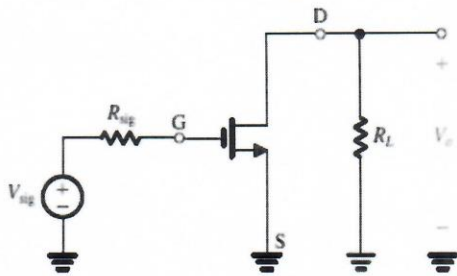
$$r_{o1} = r_{o2} = \frac{V_{An}}{I_D} = \frac{20}{0.4} = 50 \text{ k}\Omega$$

$$R_o = 50 \text{ k}\Omega || 50 \text{ k}\Omega = \frac{(50 \times 50)}{(50 + 50)} = 25 \text{ k}\Omega$$

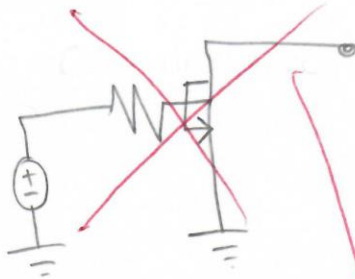
$$A_d = (G_{md}) \cdot (R_o) = (4 \text{ mA/V}) (25 \text{ k}\Omega)$$

$$A_d = 100 \text{ V/V}$$

- II. Consider the MOS amplifier fed with a signal source having an internal resistance $R_{sig} = 20\text{ k}\Omega$. The amplifier has $R_L = 10\text{ k}\Omega$, $g_m = 2\text{ mA/V}$, $r_o = 20\text{ k}\Omega$, $C_{gs} = 20\text{ fF}$, $C_{dg} = 5\text{ fF}$.



- Sketch high frequency equivalent circuit
- Find the mid-band gain, A_M
- Using Miller effect determine C_{eq} and C_{in}
- Determine the upper 3-dB frequency f_H
- Find frequency of transmission zero, f_z



III. Consider a bipolar active-loaded CE amplifier having the load current source implementation with a *pnp* transistor. Let the circuit be operated at a 1 mA bias current. The transistors are specified as follows: $\beta(npn) = 200$, $V_{An} = 130 \text{ V}$, $V_{Ap} = -50 \text{ V}$, $C_\pi = 16 \text{ pF}$, $C_\mu = 0.3 \text{ pF}$. The amplifier is fed with a signal source having a resistance of $36 \text{ k}\Omega$.

- Determine A_M
- Determine C_{in}
- Determine f_{H1} using the Miller effect
- Determine f_H using the open-circuit time constants
- Determine the Gain-bandwidth product.

$$g_m = \frac{I_C}{V_T} = \frac{1 \text{ mA}}{25 \text{ mV}} = 40 \text{ mA/V}$$

$$r_{\pi} = \frac{\beta_{npn}}{g_m} = \frac{200}{40} = 5 \text{ k}\Omega$$

$$r_{\lambda} = \frac{V_{An}}{I} = \frac{130 \text{ V}}{1 \text{ mA}} = 130 \text{ k}\Omega$$

$$r_{pp} = \frac{V_{Ap}}{I} = \frac{-50 \text{ V}}{1 \text{ mA}} = -50 \text{ k}\Omega$$

$$\begin{aligned} C_{in} &= C_{\pi} + C_{\mu} (1 + g_m R'_L) \\ &= 16 \text{ pF} + 0.3 \text{ pF} (1 + 40 \text{ mA/V} \cdot 36.1 \text{ k}\Omega) \\ &= 450 \text{ pF} \end{aligned}$$

$$F_t = \frac{g_m}{2\pi C_{\mu}} = \frac{40 \text{ mA/V}}{2\pi \cdot 0.3 \text{ pF}} = 21.2 \text{ GHz}$$

$$GBP = A_M f_H = (-176)(73.5 \text{ kHz}) = 12.9 \text{ MHz}$$

25

$$\begin{aligned} F_H &= \frac{1}{2\pi T_{\pi}} \\ &= \frac{1}{2\pi (2164.7)} \\ F_H &= 73.5 \text{ kHz} \end{aligned}$$

$$\beta_{npn} = 200 \quad V_{Ap} = -50 \text{ V}$$

$$V_{An} = 130 \text{ V} \quad C_{\pi} = 16 \text{ pF}$$

$$C_{\mu} = 0.3 \text{ pF}$$

$$R_L = (r_{\lambda} \parallel r_{pp}) = \frac{(130 \cdot 50)}{(130 + 50)}$$

$$R_L = 36.1 \text{ k}\Omega$$

$$A_M = \frac{-r_{\pi}}{r_{\pi} + R_{sig}} \cdot g_m R'_L$$

$$A_M = \frac{-5 \text{ k}}{5 \text{ k} + 36.1 \text{ k}} (40 \text{ mA/V})(36.1 \text{ k})$$

$$A_M = -176 \text{ V/V}$$

$$\begin{aligned} R'_{sig} &= r_{\pi} \parallel (R_{sig}) \\ &= 5 \text{ k} \parallel 36 \text{ k} \end{aligned}$$

$$R'_{sig} = 4.39 \text{ k}\Omega$$

$$F_H = \frac{1}{2\pi C_{in} R'_{sig}} = \frac{1}{(2\pi)(450 \text{ pF})(4.39 \text{ k})}$$

$$F_H = 80.6 \text{ kHz}$$

$$r_{\pi} = R'_{sig} = 4.39 \text{ k}\Omega$$

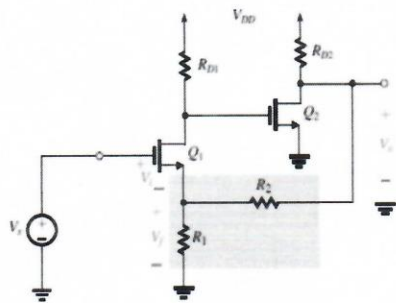
$$\begin{aligned} R_M &= R'_{sig} (1 + g_m R'_L) + R'_L \\ &= (4.39 \text{ k})(1 + (40)(36.1 \text{ k})) + 36.1 \end{aligned}$$

$$R_M = 6.38 \text{ M}\Omega$$

$$\begin{aligned} C_{Tn} &= C_{\pi} r_{\pi} + C_{\mu} R_M + C_L R'_L \\ &= (16 \text{ pF})(4.39 \text{ k}) + (0.3 \text{ pF})(6.38 \text{ M}) + (5 \text{ pF})(36.1 \text{ k}) \end{aligned}$$

$$C_{Tn} = 2164.7$$

IV. For the following feedback amplifier circuit



- Identify the type of mixing-sampling
- Find expression for β_f and ideal value of A_f
- Sketch the circuit breaking the loop between drain of Q_1 and gate of Q_2
- Find expression for closed loop gain $A\beta_f$
- If $g_{m1} = g_{m2} = 4 \text{ mA/V}$, $R_{D1} = R_{D2} = 10 \text{ k}\Omega$, $R_1 = 1 \text{ k}\Omega$, $R_2 = 9 \text{ k}\Omega$, determine β_f , $A\beta_f$, A , and A_f

Output voltage sampled and coupled to input in series

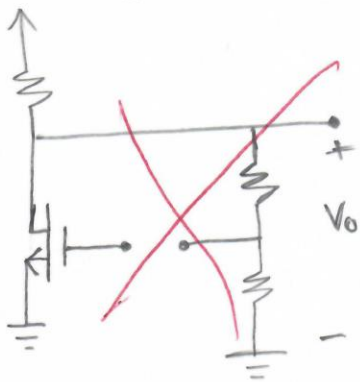
Voltage-sampling & Voltage mixing Feedback

$$\beta = \frac{V_F}{V_O} \quad V_F = \frac{R_1}{R_1 + R_2} V_O$$

$$\beta = \frac{R_1 V_O}{(R_1 + R_2) V_O} = \boxed{\frac{R_1}{R_1 + R_2}}$$

Sketch

Breaking loop at gates



05

Expression for closed loop
Gain $A\beta_f$

$$V_O = g_m (R_1 + R_2) \parallel R_D$$

$$\frac{V_F}{V_O} = g_m \left[\frac{(R_1 + R_2) R_D}{R_D + R_1 + R_2} \right] \cdot \frac{R_1}{(R_1 + R_2)} V_O$$

$$A\beta_f = g_m \left[\frac{R_D R_1}{R_D + R_1 + R_2} \right]$$

**ELECTRICAL & COMPUTER ENGINEERING
OUTCOMES SPECIFIC ASSIGNMENT COVER SHEET**

ELEG4304 ELECTRONICS II

FALL 2021

Instructor: Dr. Mohan Ketkar

Title of Assignment

Design of Class AB Power Amplifier

Outcome 2

An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factor

X	Involves identifying the specific needs to be met by defining/understanding the problem and developing plans for the project to satisfy the need
X	Involves conducting a review of the literature and performing preliminary design by generating alternative ideas/solutions and applying creativity
X	Involves performing detailed engineering design leading to specification and fabrication/selection of components for system being designed.
	Involves consideration of one or more of the following (Please check those involved in this assignment.)
	☐ Public health
	X Safety and welfare
	☐ Global factors
	☐ Cultural factors
	☐ Social factors
	☐ Environmental factors
	X Economic factors
	Involves fabrication and testing of model or prototype

Brief justification of the suitability of assignment for the outcome

Students will select circuit configuration from the various circuits studied and expected performance. Implementation of Safety and protection features are required. Students will design the amplifier to meet given specifications. Utilize circuit simulation to evaluate performance such as power level, distortion, and frequency response. Students will also perform a sensitivity analysis for critical components.

ELEG 4304 Fall 2021

Course Design Project

In this project you are going to design a Class AB audio power amplifier to meet desired specifications. Once you have designed, you will need to run simulation using MultiSim and optimize your design. You will need to refer to Ch 12 of the text and other references to design your circuit which has additional safety features.

Your project report should include the design, schematics, figures, tables, pictures, simulation results, conclusions, and references. Length of the report should not be less than 12 pages including cover sheet.

You must upload your report on Canvas and Taskstream by November 23rd midnight.

Class AB Audio Power Amplifier specifications:

Design a Class AB Audio Power Amplifier with following specifications. The additional requirements are safety, environmental impact, and economical aspects of your design. Choice of design/selection of parts should include short circuit protection and thermal runaway and minimal impact on environment when parts get recycled.

Power Output: At least 5 Watts in $6.2\ \Omega$ fixed load□

Overall Efficiency greater than 50%

Distortion must be less than 0.5 %

Use dual power supply (e.g., $\pm 6\text{ V}$). Specify the power supply rating you selected.

Transistors available 2N3904, 2N3906, TIP31C, TIP 32C

Op-Amp available LM 741.

Diodes: 1N4001, 1N4148

Sensitivity: Input signal $100\text{ mV}_{\text{RMS}}$ across $10\text{ k}\Omega$ for full output power.

Frequency range: 20 Hz to 20 kHz

Note you may need to use multistage configuration. Search the literature to come with most economical configuration.

Run simulations on your design using MultiSim. Redesign to meet or exceed the expectations.

Present your design with specifications of each component. Please estimate the cost the amplifier based on retail prices of each part.

Extra Credit: To build your design and test. Parts will be made available.

ELEG4304 ELECTRONICS II
FALL 2021

John Barrett

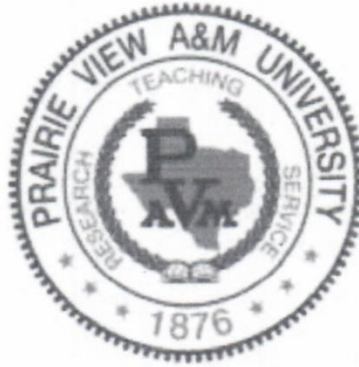
GRADING SCHEME FOR ASSIGNMENT

Item	Points achieved	Maximum Points
1. <i>Design objectives and constraints</i> • Plan of the project • Involve safety and economic features	30	30
2. <i>Literature review and preliminary design</i> • Simulation results	5	5
3. <i>Circuit design</i> • Calculations and simulations • Include safety and economic considerations	15	15
4. <i>Conduct experiments and/or simulation</i> • Collect data to show that your designed circuit <u>meets</u> the design specifications	15	20
5. <i>Analysis and interpretation of results</i> • Present data in tabular form or graphical form. • Use of appropriate statistical method to analyze the results.	15	15
6. <i>Discussion of results and Conclusions</i> • Draw appropriate conclusions	10	10
7. <i>General write-up of report</i> Grammar and adequacy of graphs and figures Proper labeling of graphs and figures Proper references	5	5
8. <i>Composite Grade</i>	95	100

95
100

Excellent Report
Multiple designs to decide
final design

Prairie View A&M College
of Electrical & Computer Engineering



Electronics II

ELEG 4304

Course Design Project ✓

Fall 2021

By: John Barrett ✓

Prof: Mohan Ketkar

Design of a class AB Audio Amplifier

Design Criteria:

Operational Range
Efficiency
Power Delivery
Distortion

20 Hz – 20 kHz
50% or greater
Minimum of 5 Watts to a 6.2 ohm load
Less than 0.5%

The design must also include short circuit protection and thermal runaway prevention.

Parts Available:

Transistors: 2N3904, 2N3906, TIP31C, TIP32C

Op-amps: LM 741

Diodes: 1N4001, 1N4148

Resistors: Any

Thermal Runaway:

Thermal runaway occurs when the heat generated causes electrical parameters to change in such a way that even more heat is produced, leading to a positive feedback loop of heat. To stop thermal runaway in this amplifier circuit two resistors of very low value are placed at the outputs of the power transistors (see figure 1).

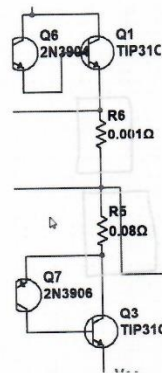


Figure 1:
Thermal Run-
away Preven-
tion Resistors

Short-Circuit Protection:

To protect the circuit in case the output is accidentally short circuited to ground. A voltage sensing transistor is placed across the thermal runaway resistor (see figure 2). This is so that when the large current is drawn during the short circuit scenario a large voltage is then produced between the emitter and the base. This causes the transistor to start conducting which then lowers the current at the base of the darlington pair output. This is essentially acting as a current limiting device.

Protection/Safety

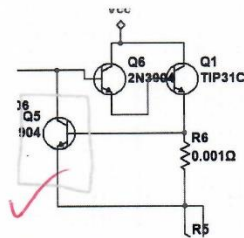


Figure 2: Short-Circuit Protection Transistor

Design 1:

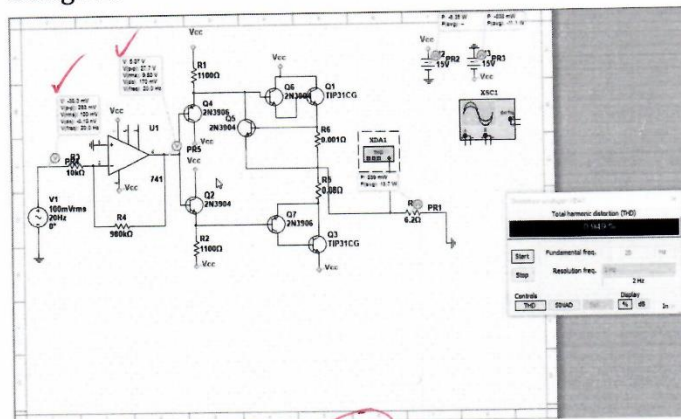


Figure 3: Design 1 Operating at 20 Hz

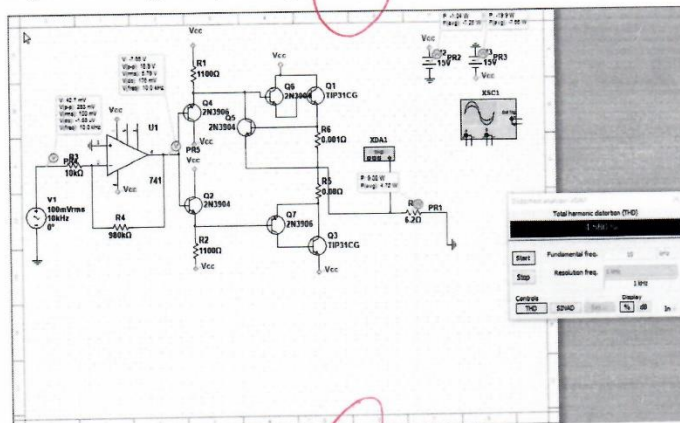


Figure 4: Design 1 Operating at 10 kHz

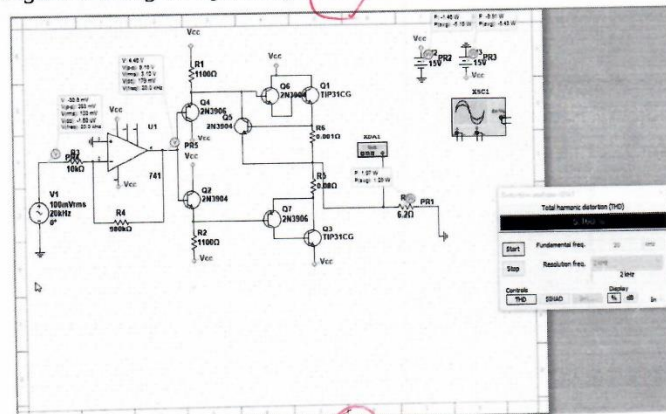


Figure 5: Design 1 Operating at 20 kHz

Results:

Table 1: *Results gathered using a 6.2 ohm load*

Frequency (Hz)	P(supply) (W)	P(load) (W)	Efficiency (%)	Distortion (%)
20	21.7	13.7	63.13	0.949
10k	14.81	4.72	31.87	4.56
20k	10.59	1.29	12.18	5.16

Should have checked for more frequencies

Discussion:

In design 1 the amplifier does not get below 0.949% distortion and then gets more and more distorted as the frequency increases. This same picture of the amplifier getting worse the higher the frequency can also be seen in the efficiency of the amplifier. As the problem seems to get worse the higher the frequency, it points to something not being able to keep up with the higher frequency switching. The most likely culprit is the op-amp. So in design 2 switching the op-amp out with a high speed switching transistor, in a common emitter voltage amplifier form as the pre-amp stage, the 2N3904, will perform better.

Design 2:

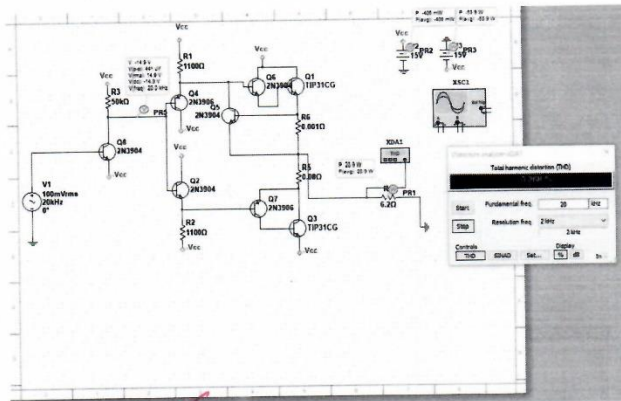


Figure 6: Design 2 Operating at 20 kHz

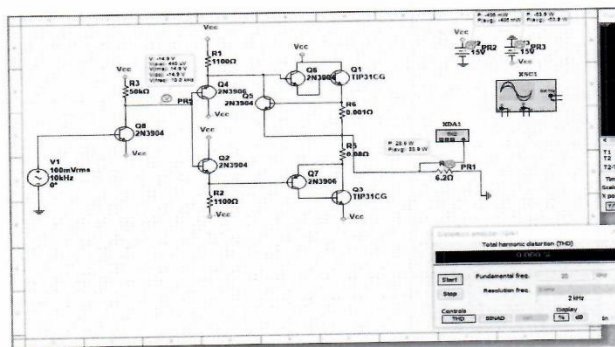


Figure 7: Design 2 Operating at 10 kHz

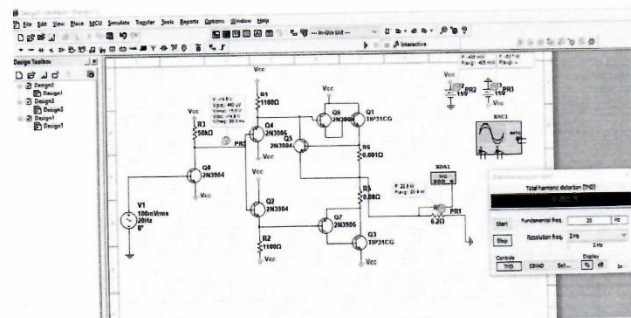


Figure 8: Design 2 Operating at 20 Hz

Results:

Table 2: *Results gathered using a 6.2 ohm load*

Frequency (Hz)	P(supply) (W)	P(load) (W)	Efficiency (%)	Distortion (%)
20	54.306	28.9	53.217	0.265
10k	54.306	28.9	53.217	0.000
20k	54.306	28.9	53.217	0.268

Discussion:

Just changing the op-amp out from design #1, to the 2N3904 high speed switching transistor, improved the overall performance to such a degree that it does not just meet the design minimums but exceeds them in every category. Design #2 delivers almost six times the minimum required power to the 6.2 ohm load. Design #2 maintains a 53% efficiency across the operational range. Design #2 never exceeds a distortion greater than 0.268% over its operational range.

Conclusion:

As predicted the LM 741 was not able to keep up with the high speed switching. Replacing it with the 2N3904 in a common emitter voltage amplifier configuration made the amplifier work as needed. The resistors in the pre-amp stage and the biasing stage are common values, this means they are cheap and easy to get. However the values for the thermal runaway resistors are more uncommon and thus are more expensive. The thermal runaway resistors need to have as small a value as possible so that they do not absorb power that should be going to the load. Therefore, even though they are more expensive they can't really be replaced. The cost of the working design (design 2) comes out to be:

Part	Part #	Number Required	Price per part for order of 100
50 ohm resistor	<u>RC0402JR-0750RL</u>	1	\$0.007
1.1 kohm resistor	<u>ERJ-UP3F1101V</u>	2	\$0.086
1 mohm resistor	<u>PML100HZPJV1L0</u>	1	\$0.575
80 mohm resistor	<u>ERJ-B2CFR082V</u>	1	\$0.20
2N3904	<u>2N3904TF</u>	3	\$0.167
2N3906	<u>2N3906TF</u>	2	\$0.161
TIP31C	<u>TIP31C</u>	2	\$0.489
Total:			\$2.791

Design Methodology:

I took a practical approach to designing this amplifier circuit. Firstly I took the theory such as voltage/power amplification, short circuit protection, thermal runaway prevention methods and laid them out in the order that they would be required. Then I started with an approximate value of the resistors, this gets around where the amplifier needs to be performing. An example would be from design 1 I knew that I needed to start with at least a 62-65x amplification on the pre-amp stage. After getting roughly where you need to be then you start tuning the amplifier by adjusting the resistors until the distortion, power delivery, and efficiency are where you can accept them. This makes the design process less easier as some of the values that are helpful in calculations are not easily obtained from the data sheets available for the parts. An example of this is the current gain on the 2N3904 you must interpolate the approximate value from a logarithmic graph, this is really unhelpful as it is for only one value of I_B .

Sources:

- [1] <https://www.mouser.com/>
Mouser helped me find the prices for the various components so that I could take into consideration the price of each component.
- [2] ON Semiconductor, "General Purpose Transistors," 2N3906 datasheet, Rev. 4, Feb. 2010.
- [3] ON Semiconductor, "General Purpose Transistors," 2N3903 & 2N3904 datasheet, Rev. 9, Aug. 2021.
- [4] STMicroelectronics, "Power Transistors," TIP31C datasheet, Rev. 1, Apr. 2006.
- [5] STMicroelectronics, "Power Transistors," TIP32C datasheet, Rev. 2, Nov 2006.
- [6] National Semiconductor, "Operational Amplifier," LM741 datasheet, Aug 2000.

Very Good references