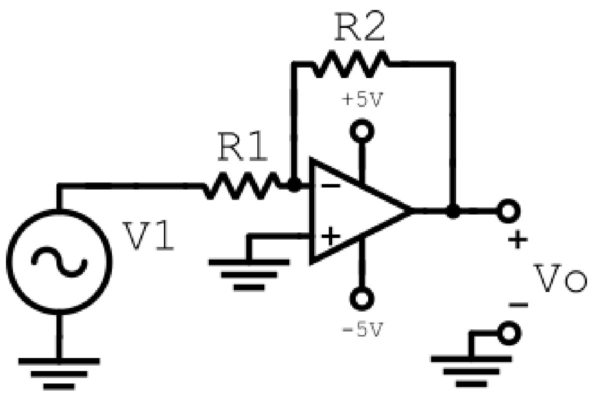
Question 1 (20 minutes - 2 points)

Answer the following questions **with justification**.

a. Given the following circuit, calculate the peak-to-peak amplitude and the average value of the output voltage Vo.



Data:

Peak-to-peak amplitude of V1 = 2 Vpp

Average value of V1 = 0 V

Frequency of V1 = 1 kHz
R1=1 kΩ
R2=2 kΩ
Operational Amplifier:
Ri→∞
Ro=0
Av→∞
GBW=10MHz
Offset voltage Vio=100 mV
Offset current Iio=0 A
Bias current Ib =0 A

Peak-to-peak value of Vo:
2*2=4 Vpp
Average value Vo:
0*2+0.1*3=0.3 V

Justification:

$V1=1\cdot\sin(2\cdot\pi\cdot1000\cdot t)$ V
$Vo= -R2/R1\cdot Vi + (1+R2/R1)\cdot Vio = -2\cdot\sin(2\cdot\pi\cdot1000\cdot t) + 0.3$ V with a maximum of 2.3 V and a minimum of -1.7 V, always between +5 V and -5 V

b. What does 'Slew Rate' mean in an operational amplifier? Provide an example where the amplifier output is limited by this effect.

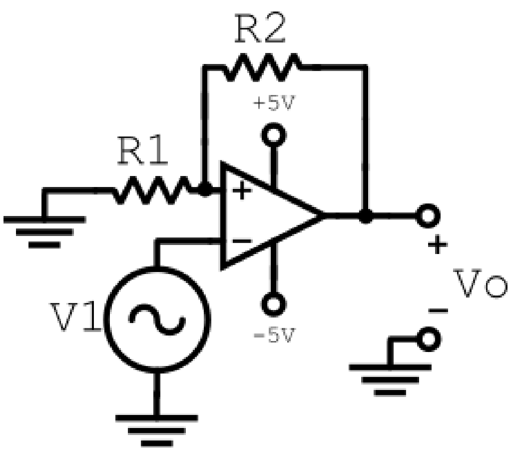
It is a rate that defines the maximum slope of the amplifier's output voltage. Typically, it appears when the input voltage is large and changes rapidly. For example, when we try to pass a square wave with an amplitude close to the supply rails through a buffer or voltage follower. At the output, a finite rise and fall slope will be observed, equal to the slew rate, instead of the square wave's vertical edges.

c. Choose and comment on an advantage of using negative feedback in an electronic amplifier.

One advantage is that it precisely fixes the low-frequency gain of an amplifier. By negatively feeding back, the input voltage or current is compared with another voltage or current proportional to the output, producing an error voltage or current that is amplified. This way, the amplifier remains controlled against internal or external disturbances. The low-frequency gain is determined by the feedback rather than by the amplifier. The precision will depend on how accurate the feedback is.

Other advantages that could be discussed: increases the bandwidth of very slow amplifiers, reduces distortion in non-linear amplifiers, improves input and output impedances.

d. Explain the function of this circuit, indicating if it is an amplifier, a comparator, or a filter.

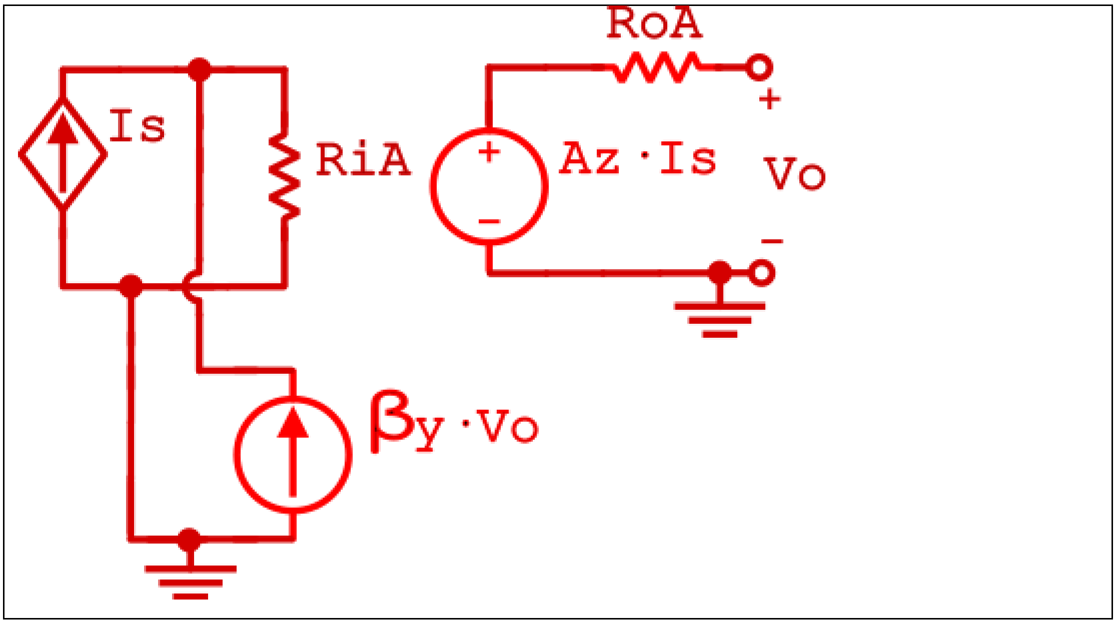


Datos:
Peak-to-peak amplitude of V1 = 2 Vpp
Average value of V1 = 0 V
Frequency of V1 = 1 kHz
R1=1 kΩ
R2=2 kΩ
Operational Amplifier:
Ri→∞
Ro=0
Av→∞
GBW=10MHz
Offset voltage Vio=0 V
Offset voltage Iio=0 A
Bias current Ib =0 A

In this case, it is a comparator. V1 is compared to one-third of Vo, resulting in a comparator with memory or hysteresis loop. The comparison threshold depends on the previous output state, which can be +5V or -5V. The output is always saturated at +5V or -5V because the amplifier gain is infinite.

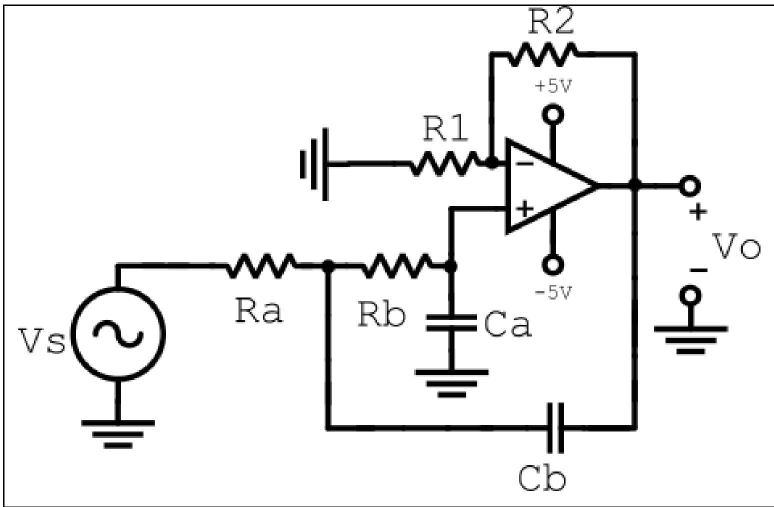
e. Draw the small-signal model of a transimpedance amplifier with negative feedback, showing the input and output impedances of the non-feedback amplifier, and the

amplification and feedback circuit gains. Assume the feedback circuit does not load the amplifier, or that such loading effects are included in the amplifier's impedances and gain.



Question 2 (40 minutes - 4 points)

Given the low-pass Sallen Key filter in the figure:



Datos:
R2=1.5 kΩ
Ra=Rb=R=1 kΩ
Ca=Cb=C=1.6nF
Operational Amplifier at low frequency:
Ri→∞
Ro=0
Av→∞

El filtro tiene una respuesta en frecuencia dada por:

$$\frac{Vo}{Vs}(j\omega) = \frac{K \cdot (\omega_o)^2}{(j\omega)^2 + \frac{\omega_o}{Q}(j\omega) + \omega_o^2} = \frac{K/(RC)^2}{(j\omega)^2 + \frac{3-K}{RC}(j\omega) + \frac{1}{(RC)^2}}$$

donde K es la ganancia en DC del circuito.

Se pide:

1. Calculate R1 to set a DC gain of 5/2.
2. Calculate the quality factor Q.
3. Calculate the natural frequency of the poles in Hz. Determine whether they are real or complex conjugate poles.
4. Calculate the filter gain at the natural frequency of the poles and express it in dB.
5. Calculate the output voltage if the input voltage has the following expression:

$$Vs = 0.1 \cdot sen(2 \cdot \pi \cdot 1MHz \cdot t)$$

6. Does the previous result change if the amplifier has an offset voltage of 100mV at the input? If so, calculate it.
7. Which amplifier would you choose to implement this filter: one with a GBW=10kHz or one with a GBW=10MHz? Justify your answer.
8. Could the same frequency response be implemented with a passive filter? Comment on your answer.

(2)

1) $k = 1 + \frac{R_2}{R_1} = \frac{5}{2} = 1 + \frac{3}{2} \Rightarrow \frac{R_2}{R_1} = \frac{3}{2} \Rightarrow \boxed{R_1 = \frac{2}{3} R_2 = 1k\Omega}$

2) $\boxed{Q = \frac{1}{3 - \frac{5}{2}} = 2}$

3) $\boxed{f_o = \frac{1}{2\pi RC} = 99'5\,kHz}$

4) $\frac{V_o}{V_e}(j\omega)\Big|_{\omega=\omega_0} = \left| \frac{k\cancel{\omega_0^2}}{\cancel{(j\omega_0)^2} + \frac{\omega_0}{Q} j + \cancel{\omega_0^2}} \right| = k \cdot Q = \frac{5}{2} \cdot 2 = 5$

$\simeq \boxed{14\,dB}$

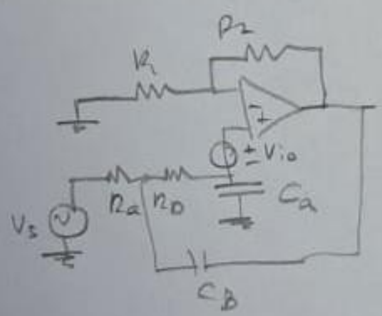
5) Cuando $f = 1MHz \Rightarrow$

$$\frac{V_o}{V_s} = \frac{k \cdot (2\pi \cdot 99'5kHz)^2}{[j(2\pi 1MHz)]^2 + \frac{2\pi \cdot 99'5kHz}{2} j\, 2\pi 1MHz + (2\pi \cdot 99'5kHz)^2} =$$

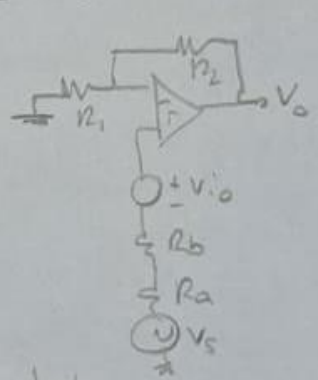
$$= -0'024 - 0'001j \simeq 0'024_{180^\circ} \simeq -0'024$$

$V_o = -0'024 \cdot 0'1 \,sen(2\pi \cdot 1MHz\, t) = -2'4\,mV\, sen(2\pi \cdot 1MH$

6)



en DC:



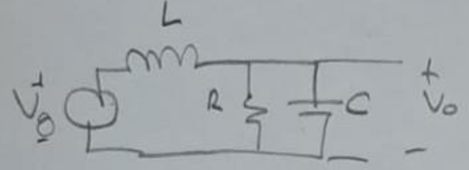
Tenemos que queda en serie y por tanto:

$V_{io} K = 100mV \cdot 2'5 = \underline{2'5V}$ a la salida

$V_o = 2'5V - 2'4mV\, sen(2\pi \cdot 1MHz\, t)$

7) Uno de GBW = 10MHz ya que el de 10kHz no es suficiente para dar cabida a la respuesta en frecuencia dada, con la pala a 99'5 kHz.

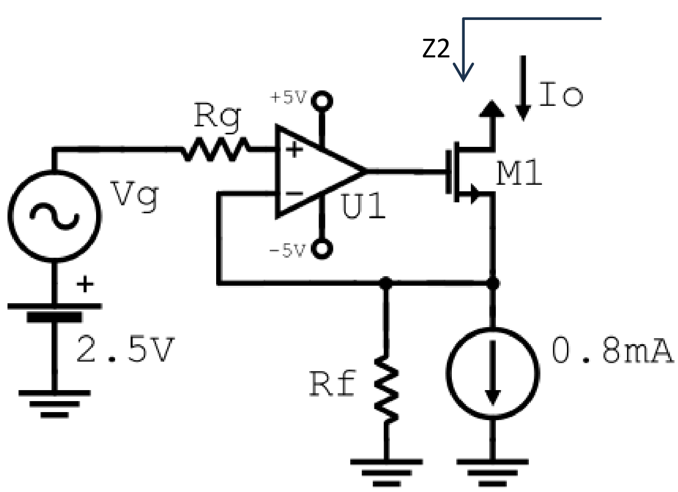
8) Un filtro pasivo no tiene ganancia de tensión. Se podría implementar con un circuito como:



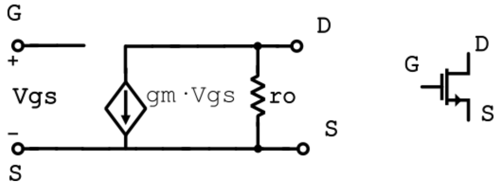
pero con ganancia = 1.

Question 3 (40 minutes - 4 points)

The circuit in the figure is a simplified diagram of a voltage-to-current converter. It has a series-series feedback thanks to the Rf resistor.



- Rg=50 Ω, Rf =10 k Ω
- Datos de U1:
  Voltage amplifier with
  Ri=100 M Ω
  Av=100
  Ro=10 k Ω
- M1 data:
  MOSFET transistor.
  Consider the following model:



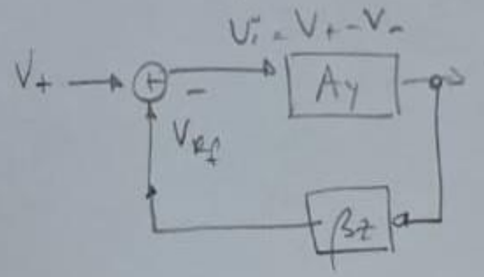
Con gm=10 μA/V, ro=10 k Ω

<u>Tasks:</u>

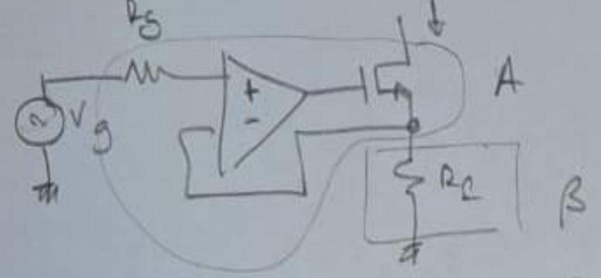
1. Demonstrate that there is negative feedback in this circuit and identify the amplification and feedback networks.
2. Draw the small-signal model of the circuit. Use the transistor model provided in the figure.
3. Calculate the gain of the β network.
4. Use the previous result to calculate an approximate value for Io/Vg assuming the loop gain (Aβ) is sufficiently large.
5. Draw the small-signal model of the A network, including all loading effects (Network A').
6. Calculate a more realistic value of Io/Vg and compare it with the result obtained in 4. Consider that in network A', the gain is 500 μA/V and the output impedance is 20 kΩ.
7. Calculate the impedance Z2.
8. Indicate whether the output node should be a high or low impedance node and comment on the result obtained in 7.

3

1) Si $I_o \uparrow \Rightarrow V_{R_f} \uparrow \Rightarrow V_- \uparrow \Rightarrow \downarrow V_i = V_+ - V_- \Rightarrow V_{gs_{M_1}} \downarrow \Rightarrow I_d \downarrow$

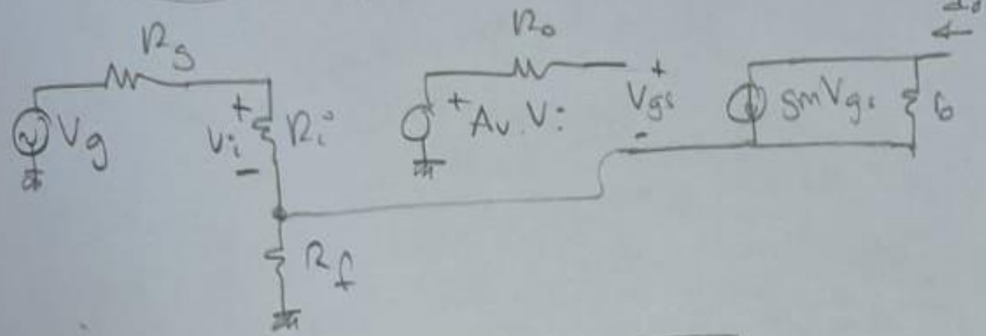


Serie - serie
Compara tensión y muestrea corriente.

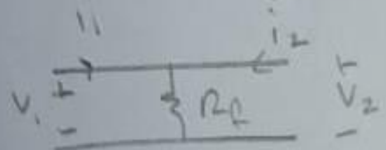


(Fuentes de DC ignorados)

2)



3)



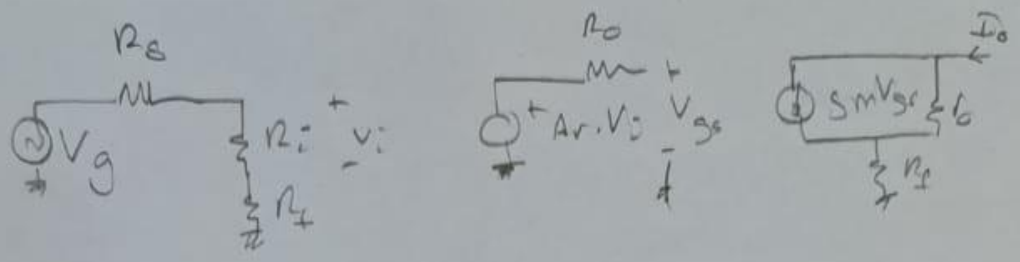
$$\boxed{\beta_z = \frac{V_1}{i_2}\Big|_{i_1=0} = R_f} = 10\,k\Omega$$

parámetros z

$$\begin{pmatrix} V_1 \\ V_2 \end{pmatrix} = \begin{pmatrix} z_{11} & \beta_z \\ \times & z_{22} \end{pmatrix} \begin{pmatrix} i_1 \\ i_2 \end{pmatrix}$$

4) $\dfrac{I_o}{V_g} \simeq \dfrac{1}{R_f} = 0'1\ mS$

5)

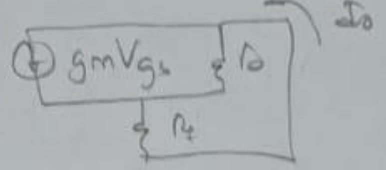


6)

$$A'_y = \frac{I_o}{V_g} = \frac{I_o}{V_{gs}} \cdot \frac{V_{gs}}{V_i} \cdot \frac{V_i}{V_g}$$

$$\frac{I_o}{V_{gs}} = g_m \frac{r_o}{r_o+R_f}$$

(Consideramos el circuito con carga nula. Como la salida es en corriente ponemos un cortocircuito)



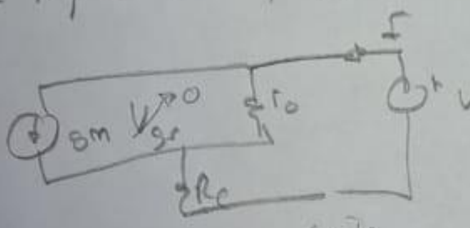
$$\frac{V_{gs}}{V_i} = A_v$$

$$\frac{V_i}{V_g} = \frac{R_i}{R_g+R_i+R_f}$$

$$A'_y = g_m \frac{r_o}{r_o+R_f} \cdot A_v \cdot \frac{R_i}{R_g+R_i+R_f} = 10\mu \underbrace{\frac{10k}{10k+10k}}_{1/2} \cdot 100k \underbrace{\frac{100M}{50+100M+10k}}_{1}$$

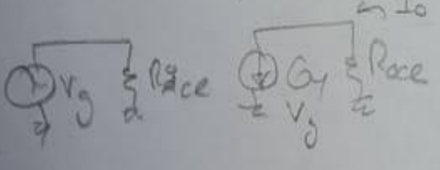
$$= 10\mu \cdot 50 = 500\mu A/V \text{ (Dado en enunciado)}$$

R_{osr}



$$R_{osr} = \frac{V}{I} = R_f + r_o = 20k\Omega$$

(Dado en enunciado)

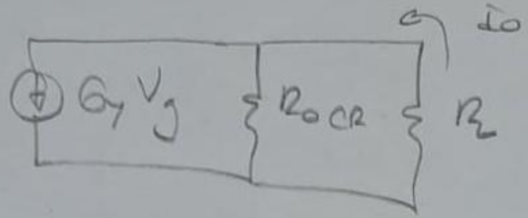


$$\frac{I_o}{V_g} = G_y = \frac{A_y}{1+A_y\beta_g} = \frac{500\mu}{1+500\mu \cdot 10k} = \frac{500\mu}{1+5} \approx 0'08\, mA/V$$

Idealmente era 0'1 mA/V

7) $R_{oCR} = R_{oSR}(1+A\beta) = 20k\Omega \cdot 6 = \boxed{120k\Omega}$

8) Deberá ser un nodo de alta impedancia ya que la salida es en corriente.



$$I_o = G_y V_g \frac{R_{oCR}}{R_{oCR}+R_L}$$

$$\frac{I_o}{V_g} = G_y \frac{R_{oCR}}{R_{oCR}+R_L} \simeq G_y \text{ independiente de } R_L$$

si $R_{oCR} \uparrow\uparrow$

Por tanto debe ser de alta impedancia.