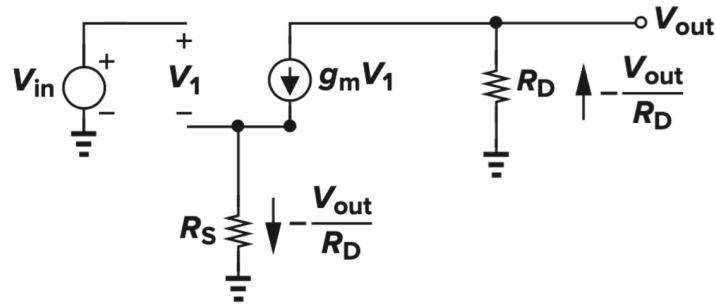


## NX-422 Exercise 4, Implantable Electronics - Solutions

### 1. Small-Signal Model :



$$V_{in} = V_1 + R_S \left( -\frac{V_{out}}{R_D} \right) \quad (1)$$

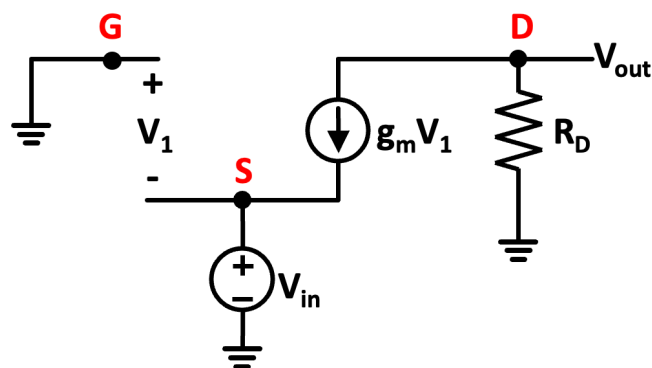
$$g_m V_1 = -\frac{V_{out}}{R_D} \quad (2)$$

Replace  $V_1$  from (2) in (1):

$$V_{in} = -\frac{V_{out}}{R_D g_m} + R_S \left( -\frac{V_{out}}{R_D} \right) = -V_{out} \left( \frac{1}{R_D g_m} + \frac{R_S}{R_D} \right)$$

$$A_V = \frac{V_{out}}{V_{in}} = -\frac{g_m R_D}{1 + g_m R_S}$$

### 2. Common-Gate Amplifier Small-Signal Model:



$$V_{GS} = V_1 = -V_{in}$$

$$V_{out} = -g_m V_1 \times R_D$$

$$V_{out} = -g_m \times (-V_{in}) \times R_D$$

$$A_V = \frac{V_{out}}{V_{in}} = g_m \times R_D$$

3. The Nyquist rate is the minimum sampling frequency required to accurately convert a continuous analog signal into a discrete digital signal, allowing for perfect reconstruction of the original signal without distortion.

$$f_N = 2f_{MAX}$$

**The Nyquist rate for AP recording =  $2 \times 10k = 20 \text{ k Sample/s}$**

Total Power Budget <  $120 \mu\text{W}$  for a single channel

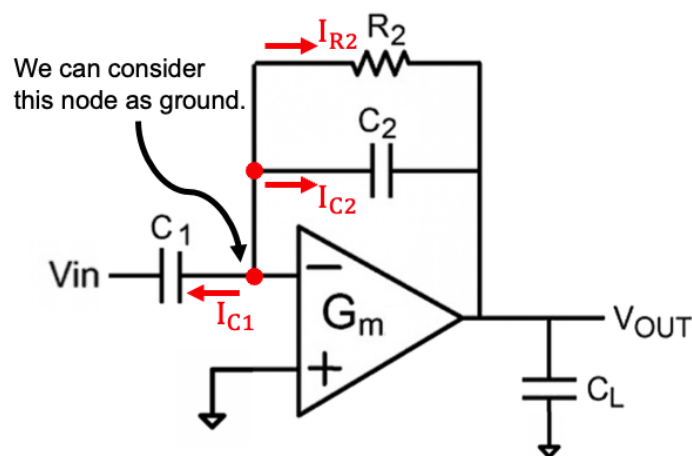
$$120 \mu\text{W} = 7.6 \mu\text{W} + 2 \mu\text{W} + 20\text{kS/s} \times 10\text{bit} \times 3\text{nJ/bit} \times (1/\text{data reduction factor})$$

→ data reduction factor (compression ratio=CR) > 5.4

**Note:** If DSP were consuming power, we need to include the power consumption as we did for AFE and ADC. We need to check if the power consumption is given per channel or for the overall system.

4. Since the OTA has a large gain, we can assume the negative input of the OTA is also ground (the voltage difference between positive and negative inputs is negligible:  $V_{out}/(\text{large gain})$ ).

**From the KCL:**  $I_{C1} + I_{C2} + I_{R2} = 0$  no current flows into the input  $G_m$ .



$$I_{C1} = (0 - V_{in}) \times \frac{1}{Z_{C1}} \text{ where } Z_{C1} = \frac{1}{C_1 s}$$

$$I_{C2} = (0 - V_{out}) \times \frac{1}{Z_{C2}} \text{ where } Z_{C2} = \frac{1}{C_2 s}$$

$$I_{R2} = \frac{0 - V_{out}}{R_2}$$

$$I_{C1} + I_{C2} + I_{R2} = 0$$

$$-V_{in} C_1 s - V_{out} C_2 s - \frac{V_{out}}{R_2} = 0$$

$$-V_{in}C_1s = V_{out}(C_2s + \frac{1}{R_2})$$

$$A_V = \frac{V_{out}}{V_{in}} = -\frac{C_1s}{C_2s + \frac{1}{R_2}} \quad \& \quad |\mathbf{Mid - band Gain}| = |A_M| = \frac{C_1}{C_2}$$