Lecture 21, Nov 29, 2023

Multi-Stage Amplifier Example

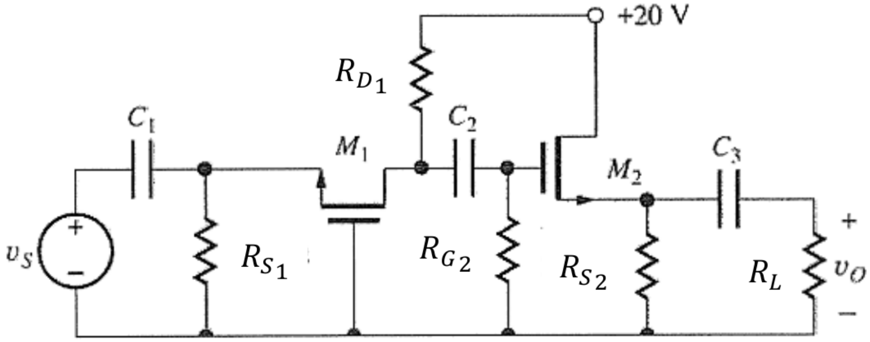

Figure 1: Multi-stage amplifier.

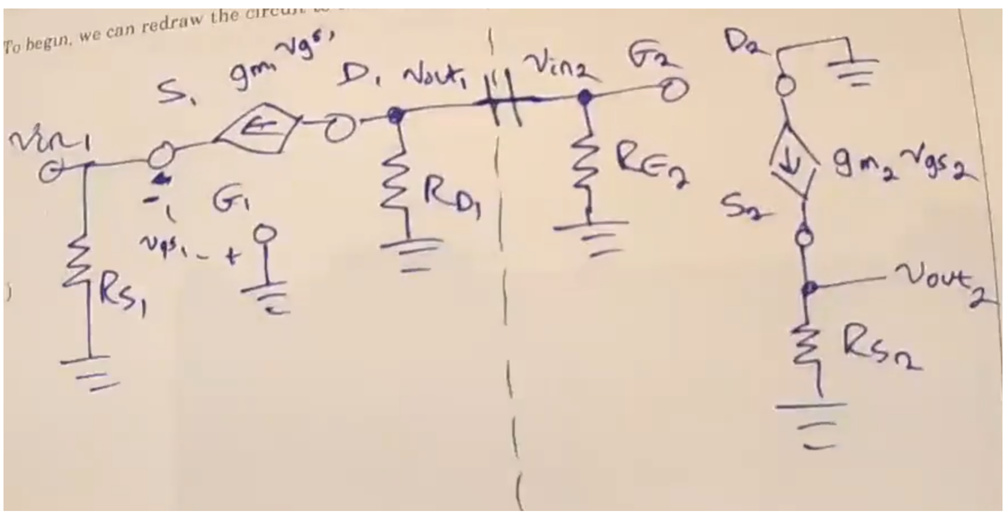

Figure 2: Amplifier in small signal domain.

- Typically, for a multi-transistor amplifier, we can look at positions of the capacitors to draw dividing lines
  - Everything to the right of C_1 and the left of C_3 is the actual amplifier
  - C_2 divides the two individual amplifier stages
- Because we have a model for loading effects, we can analyze each stage separately
- The first stage is a common-gate amplifier, while the second stage is a common drain amplifier
- For a common-gate amplifier, as we have derived, $A_{v_{g_1}} = g_{m_1} R_{D_1}, R_{IN_1} = R_{S_1} \parallel \dfrac{1}{g_{m_1}}, R_{OUT_1} = R_{D_1}$
  - We can see that the standard results do not change if we draw this out in small signal domain
- For the common-drain amplifier:
  - Redraw the circuit using a T-model
  - For R_{out}:
    - Assuming $v_{in} = 0$, the gate is grounded
    - $R_{out} = R_{S_2} \parallel \dfrac{1}{g_{m_2}}$
    - Source resistors tend to be small (kilohms or smaller), but $\dfrac{1}{g_m}$ is usually in the range of ohms to tens of ohms, so the second term will dominate

    * This gives us an output resistance in the range of tens of ohms or smaller, which is good
  - For R_{in}, we simply have R_{G_2}, since no current flows into the gate
    * We can easily make R_{in} relatively large
  - For A_{v_0}:
    * We can write a node equation at v_{out_2}
    * $\frac{v_{out_2}}{R_{S_2}} - g_{m_2}v_{gs_2} = 0$ where $v_{gs_2} = v_{in_2} - v_{out_2}$
    * $A_{v_0} = \frac{g_{m_2}R_{S_2}}{g_{m_2}R_{S_2} + 1}$
    * Note since typically $g_{m_2}R_{S_2} \gg 1$, the gain is close to unity; in fact, the gain cannot ever be greater than 1
  - This configuration is often called a source-follower – typically, it follows the voltage at the source without amplification, but increases the available power that can be output
- The common-gate amplifier amplifies the voltage, while the common-drain amplifier amplifies the power
- Now we can solve for the input/output resistances and voltage gain for the whole circuit
  - R_{in} for the whole circuit is simply R_{in_1}
  - R_{out} for the whole circuit is simply R_{out_2}, assuming an input voltage of zero
  - We don't have information about the source and load, so we will find the open circuit gain A_{v_0} for the whole circuit
  - $A_{v_0} = A_{v_{0_1}} A_{v_{0_2}} \frac{R_{in_2}}{R_{in_2} + R_{out_1}}$
  - In general, for multiple stages, the overall input resistance is the input resistance of the first stage; the overall output resistance is the output resistance of the last stage; the voltage gain is the product of all voltage gains, with a resistor divider between each pair of stages