TÉCNICO LISBOA

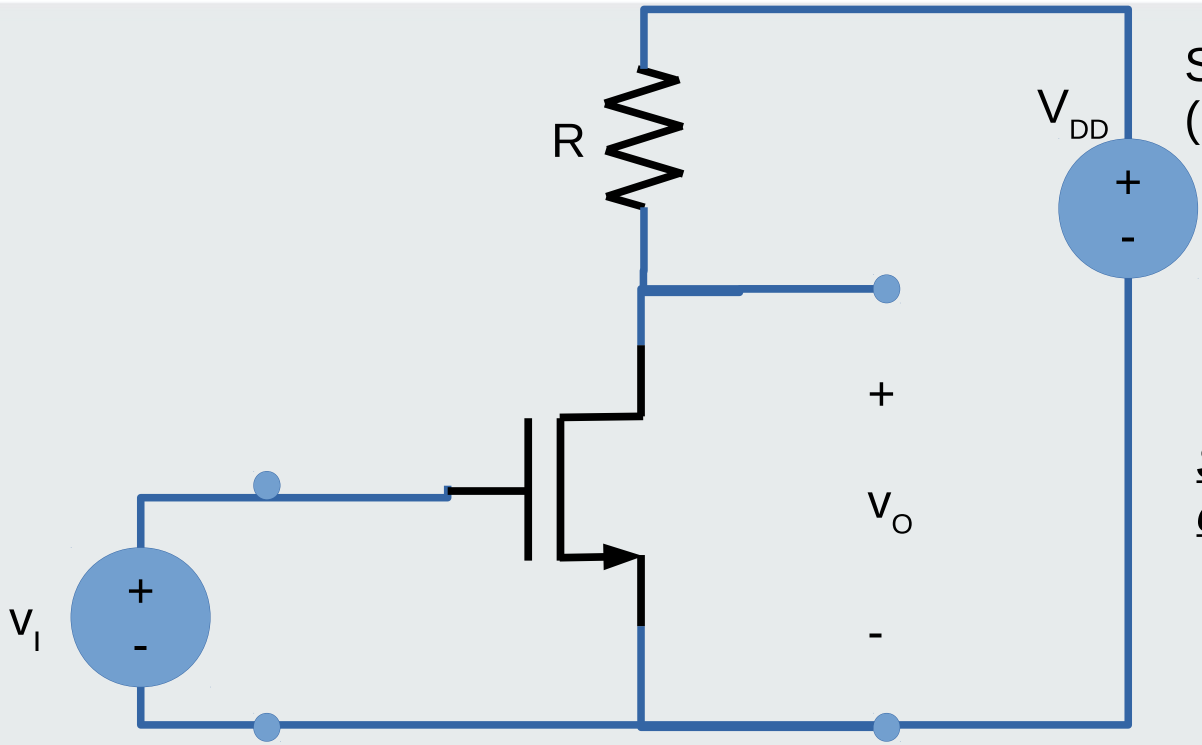
Circuit Theory and Electronics Fundamentals

Lecture 20: MOS Amplifiers

- Common source amplifier
  - OP, Gain, input and output impedances
- Common drain amplifier
  - OP, Gain, input and output impedances

The common source amplifier

Goal: amplify voltage



Supply voltage
(active circuit)

Superposition of DC and AC components

$$v_I = V_I + v_i$$
$$v_O = V_O + v_o$$

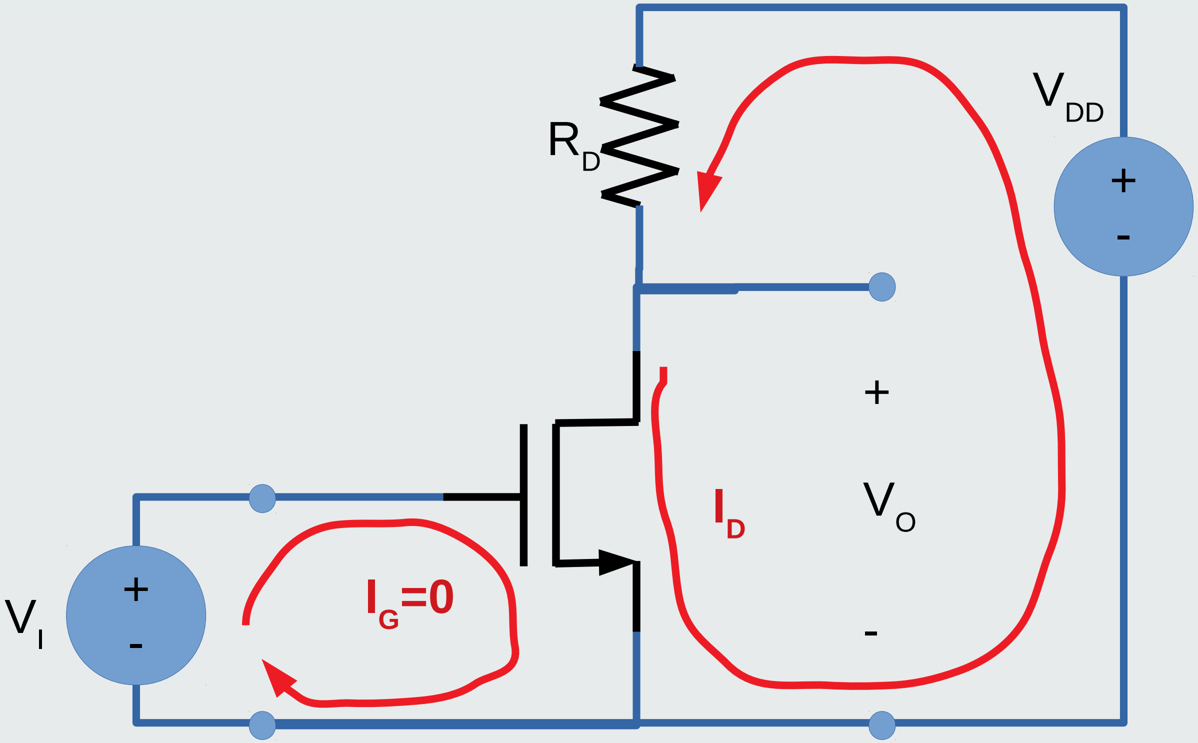
Common (to input and output) Source

Separate DC (operating point) and AC (incremental) analyses

Transistor must operate in the Saturation Region:

$$v_O = v_{DS} > V_{GS} - V_T$$

The common source amplifier Operating Point (OP) analysis



Supply voltage (active circuit)

Common (to input and output) Emitter

Mesh analysis

$$\begin{cases} -V_I + V_{GS} = 0 \,(mesh\, G) \\ R_D I_D + V_O - V_{DD} = 0 \,(mesh\, D) \end{cases}$$

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

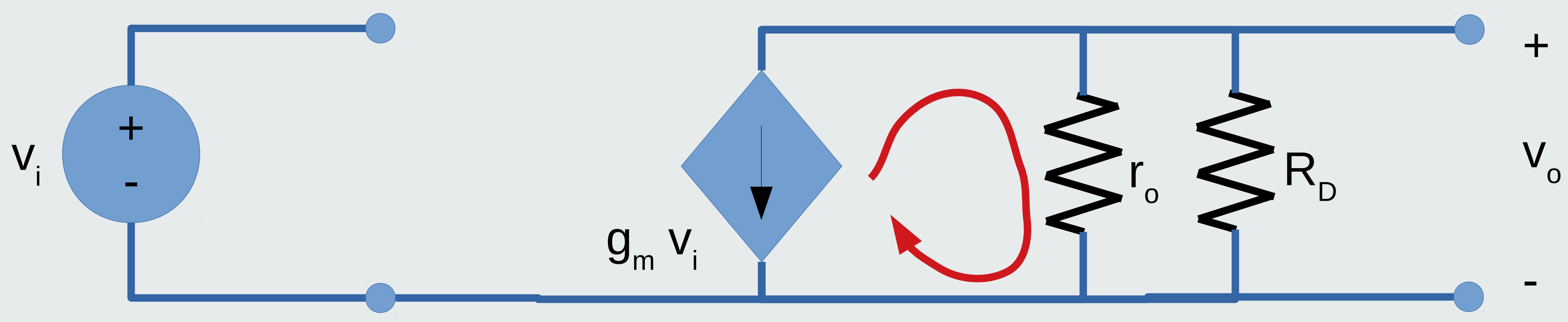
$$I_D = k(V_I - V_T)^2$$

$$V_O = V_{DD} - R_D k (V_I - V_T)^2$$

Non linear model!

<u>Saturation Region</u> condition: $v_{DS} = V_O > v_{GS} - V_T = v_I - V_T$

The common source amplifier
Incremental analysis: gain



<u>Compute incremental parameters after OP</u>

$$g_m = \frac{2 I_D}{V_I - V_T}$$

$$r_o \approx \frac{\lambda^{-1}}{I_D}$$

$$v_o = -g_m (r_o || R_D) v_i$$

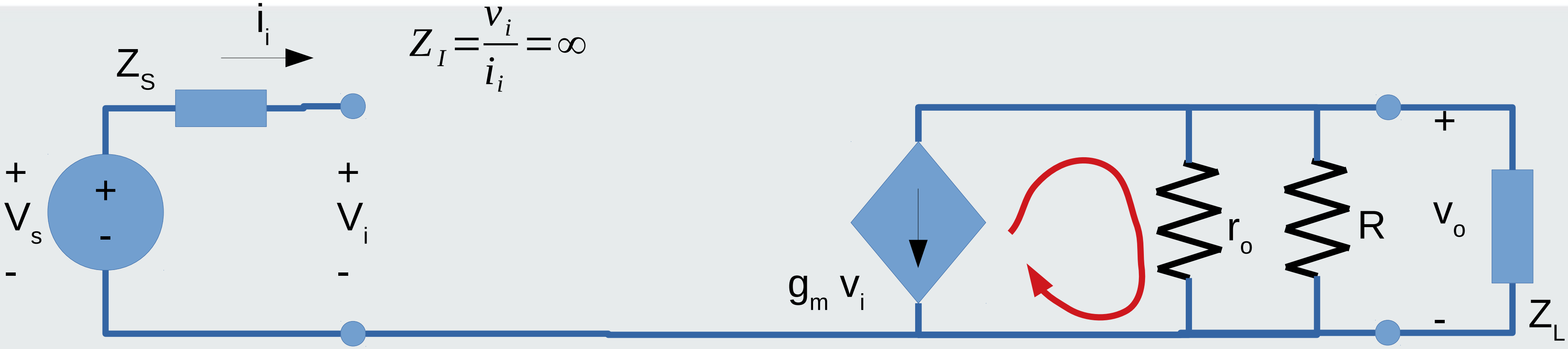
$$A_V = \frac{v_o}{v_i} = -\frac{g_m}{\cancel{\frac{1}{r_o}} + \frac{1}{R_D}} \approx -g_m R_D$$

Gain is negative and moderately high (I_D compared to v_I-v_T)

Gain is temperature Dependent due to V_T!

ID increases with the temperature

The common source amplifier
Input impedance



$$Z_I = \frac{v_i}{i_i} = \infty$$

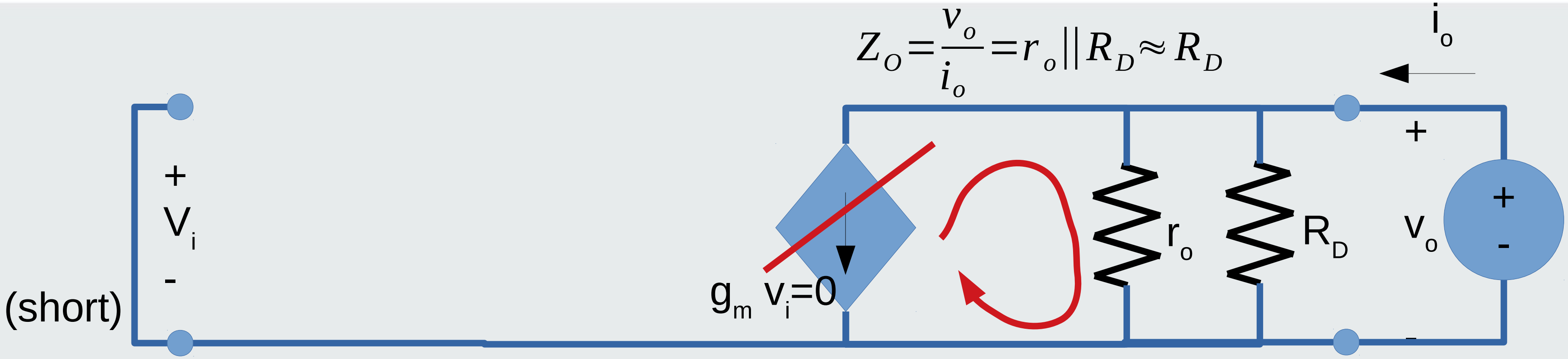
Apply
Input
Voltage

Measure
Input
Current

- If you are the source S you are happy to know that Z_I is infinite – in practice there’s a small impedance due to the gate capacitance
- In the above circuit Z_I is independent of the load , which is good!
- A wide range of sources can be connected
- However a very high gate voltage v_S may damage the thin oxide gate
- By convention, Z_I is often given for when the load is absent (short-circuit for current and open-circuit for voltage)

The common source amplifier: output impedance

$$Z_O = \frac{v_o}{i_o} = r_o || R_D \approx R_D$$

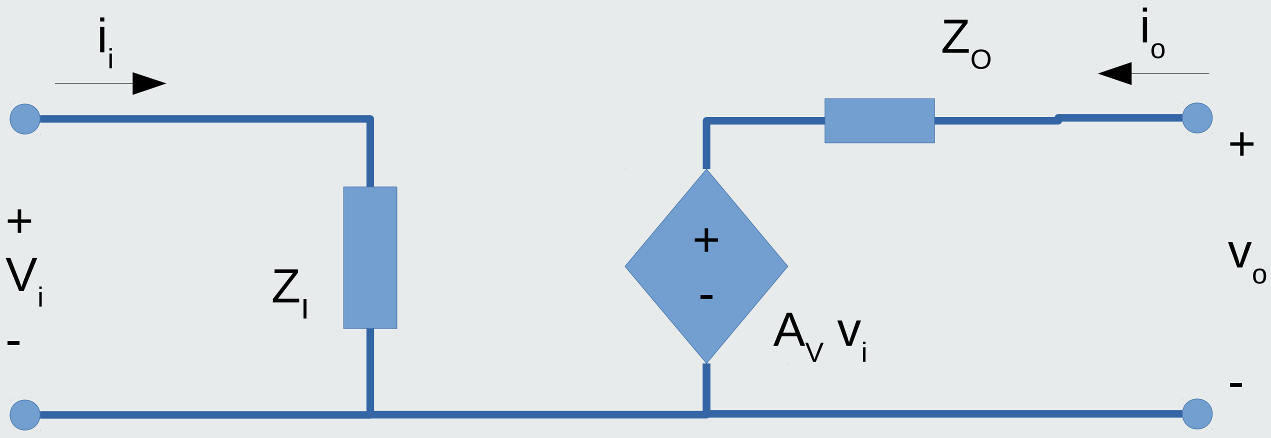


Apply Output Voltage

Measure Output Current

- If you are the load L, you want to know Z_o; if Z_O does not combine with $Z_{L,}$ the connection may fail and damage may occur!
- Z_O is depends on the source S.
- The nature of the dependence must be stated; otherwise you don’t know what you are connecting to.
- By convention, Z_O is given for when the source is off (short-circuit for voltage and open-circuit for current)

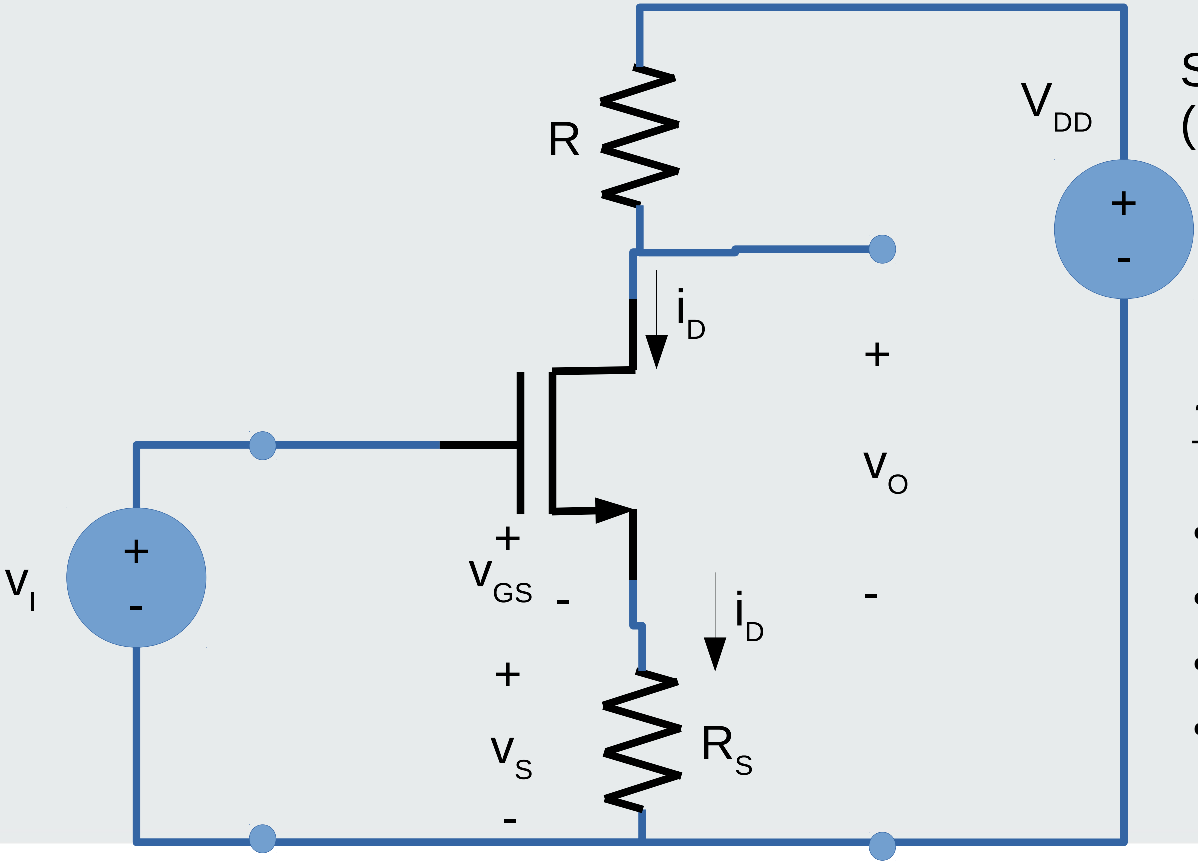
Feed-forward amplifier incremental model



- Amplifier fully characterized by 3 parameters
- Thévenin equivalent at output (A_V, Z_O)
- Equivalent impedance at input (Z_I)

The common source amplifier with degeneration

Goal: linearise DC gain, improve temperature dependency

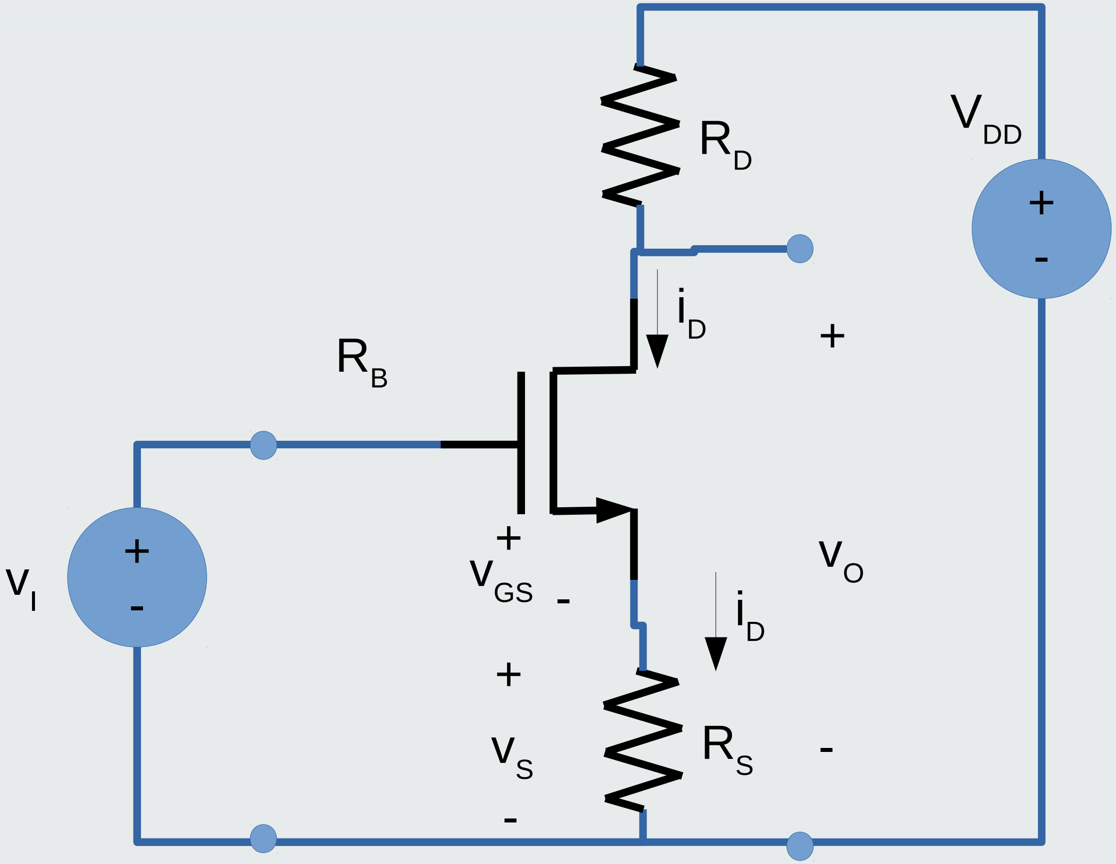


Supply voltage (active circuit)

Temperature stabilisation

- I_D increases with T
- V_S increases
- V_{GS} decreases
- I_D decreases

The common source amplifier with degeneration: OP



$$I_D = k(V_{GS} - V_T)^2$$

$$V_{GS} - V_T = \sqrt{\frac{I_D}{k}}$$

Mesh analysis

$$\begin{cases} -V_I + V_{GS} + R_S I_D = 0 \, (mesh\,G) \\ -R_D I_D + V_{DD} - V_O = 0 \, (mesh\,D) \end{cases}$$

$$\begin{cases} -V_I + V_{GS} + R_S I_D = 0 \\ -R_D I_D + V_{DD} - V_O = 0 \end{cases}$$

$$\begin{cases} -V_I + V_T + \sqrt{\frac{I_D}{k}} + R_S I_D = 0 \\ I_D = \frac{V_{DD} - V_O}{R_D} \end{cases}$$

$$V_{DS} > V_{GS} - V_T$$

Last condition must be verified for Transistor to be saturated.

Imposes upper limit on v_I

The common source amplifier with degeneration: OP

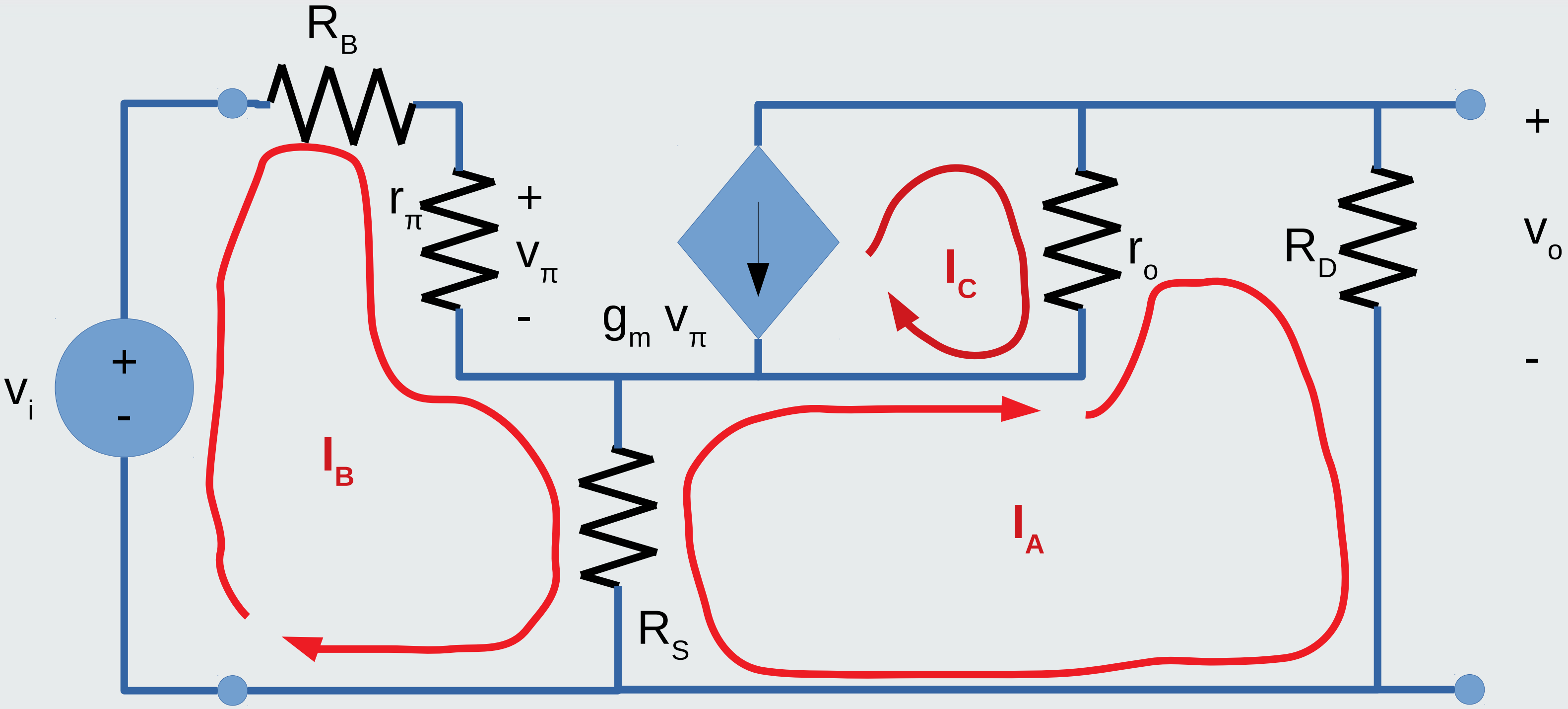
$$\begin{cases} -V_I + V_T + \sqrt{\dfrac{I_D}{k}} + R_S I_D = 0 \\ I_D = \dfrac{V_{DD} - V_O}{R_D} \end{cases}$$

$$V_O = -\frac{R_D}{R_S}(V_I - V_T) - \frac{R_D}{R_S}\sqrt{\frac{4}{k R_S}(V_I - V_T) + \frac{1}{4k^2 R_S^2}} + V_{DD} - \frac{1}{2k R_S}$$

Quadratic but still nasty to solve!

Valid for large signals also. Linear term in v_I more important than term in sqrt(v_I)

The common source amplifier with degeneration: gain (1)



Almost similar to BJT's common emitter with $\begin{cases} r_\pi = \infty \\ R_B = 0 \end{cases} \Leftrightarrow \begin{cases} g_\pi = 0 \\ R_B = 0 \end{cases}$

The common source amplifier with degeneration: gain (2)

$$\frac{v_o}{v_i}=R_D\frac{R_S-g_m r_\pi r_o}{(r_o+R_D+R_S)(R_B+r_\pi+R_S)+g_m R_S r_o r_\pi-R_S^2}$$

$$r_\pi\to\infty, R_B=0\Rightarrow\frac{v_o}{v_i}=-\frac{g_m R_D r_o}{r_o+R_D+R_S+g_m R_S r_o}$$

$$r_o\to\infty\Rightarrow\frac{v_o}{v_i}=-\frac{g_m R_D}{1+g_m R_S}$$

$$g_m R_S\gg 1\Rightarrow\frac{v_o}{v_i}=-\frac{R_D}{R_S}$$

Degenerated common source amp. : input impedance

$$Z_i = \frac{v_i}{i_g}$$

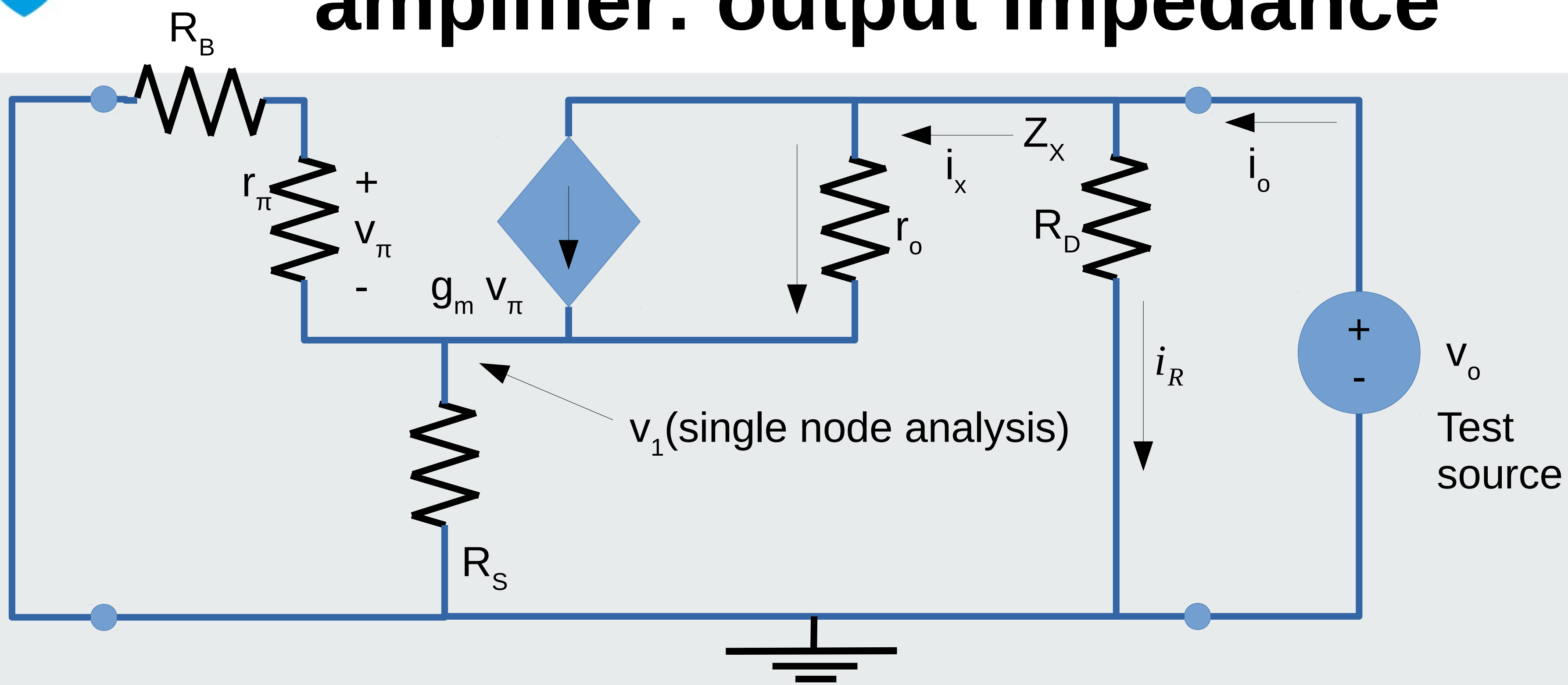
$$i_g = 0$$

$$Z_i = \infty$$

$$Z_i = \frac{1}{j\,\omega C_{gs}}$$

Small parasitic capacitance → high input impedance

Degenerated common source amplifier: output impedance



Almost similar to BJT's common emitter with $\begin{cases} r_\pi = \infty \\ R_B = 0 \end{cases} \Leftrightarrow \begin{cases} g_\pi = 0 \\ R_B = 0 \end{cases}$

Degenerated common source amplifier: output impedance

$$Z_o = R_D || \frac{r_o\left[\left(R_B + r_\pi\right) || R_S\right]}{r_o || r_\pi + R_B || R_S || \frac{r_\pi + R_B}{g_m r_\pi}}$$

$$r_\pi \rightarrow \infty, R_B = 0 \Rightarrow Z_o = R_D || \frac{r_o R_S}{r_o || R_S || \frac{1}{g_m}}$$

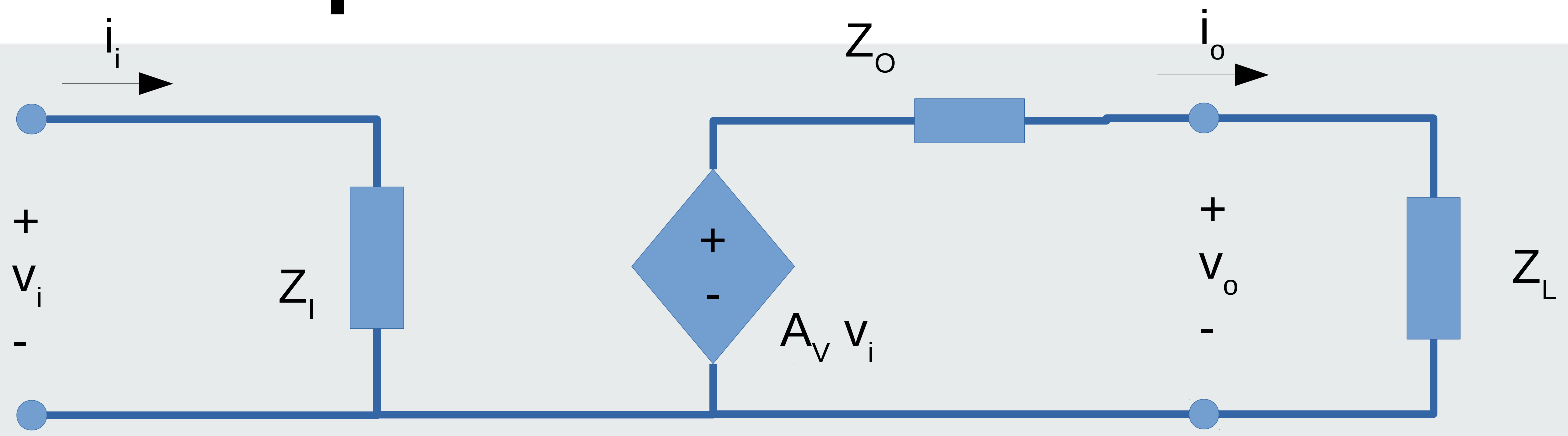
$$Z_o = R_D || r_o R_S \left(\frac{1}{r_o} + \frac{1}{R_S} + g_m\right)$$

$$Z_o = R_D || \left(R_S + r_o + g_m R_S r_o\right)$$

$$r_o \rightarrow \infty \Rightarrow Z_o = R_D$$

A high R_D is important for high gain but makes Z_O high… :-(

Common source amplifier problem



Problem: because Z_O is high, a common load Z_L gets a small voltage only!

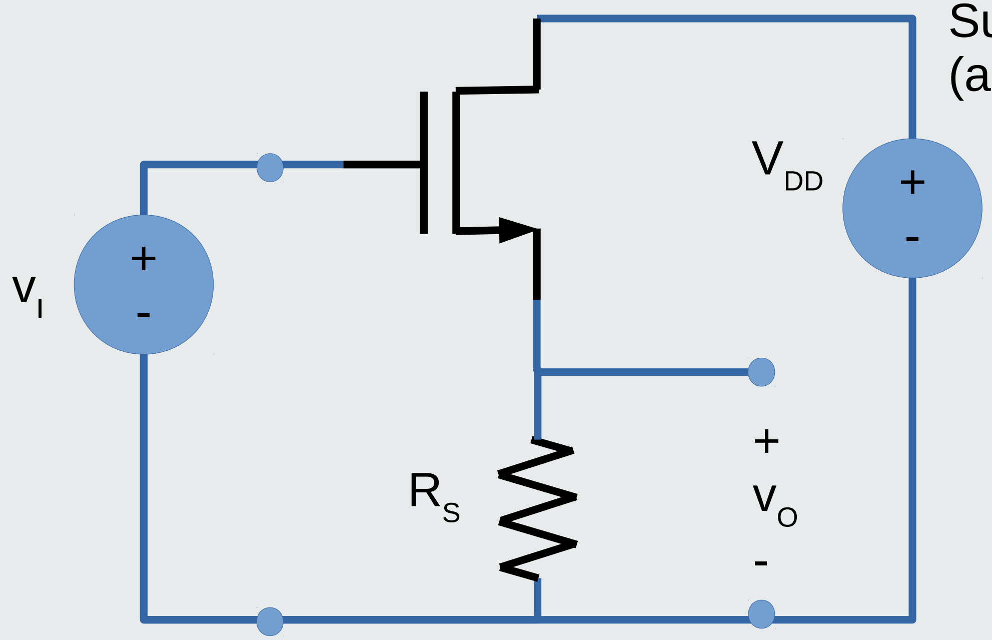
$$v_o = \frac{Z_L}{Z_L + Z_O} A_V v_i$$

This output voltage divider wastes the high voltage gain A_V :-(

The common drain amplifier

Goal: supply enough current to load

Common (to input and output) drain

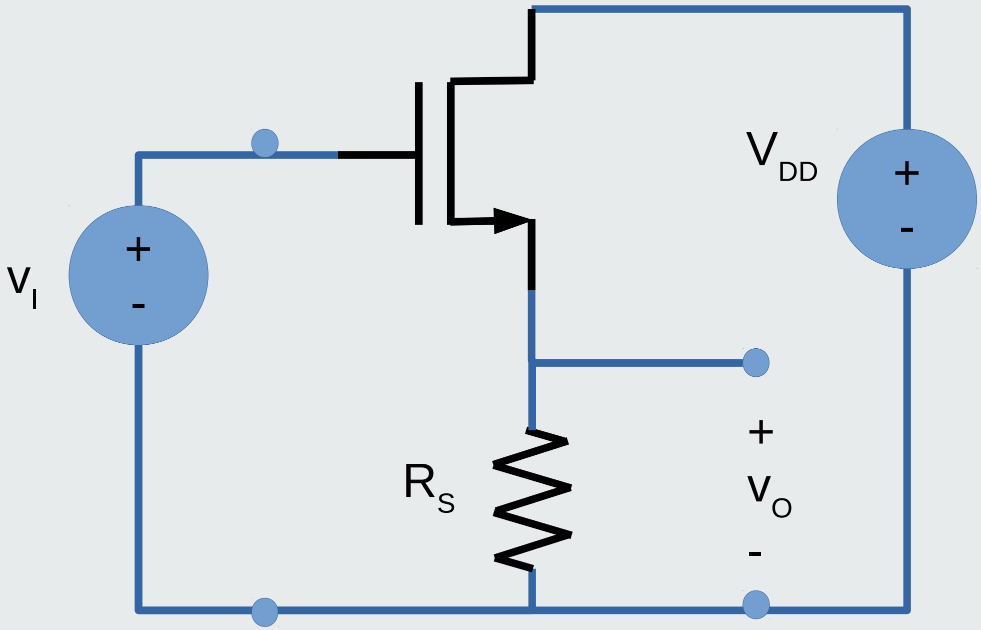


Superposition of DC and AC components

$$v_I = V_I + v_i$$
$$v_O = V_O + v_o$$

Separate DC (operating point) and AC (incremental) analyses

The common drain amplifier: operating point



Mesh analysis

$$\begin{cases} -V_I + V_{GS} + R_S I_D = 0 \\ V_O = R_S I_D \end{cases}$$

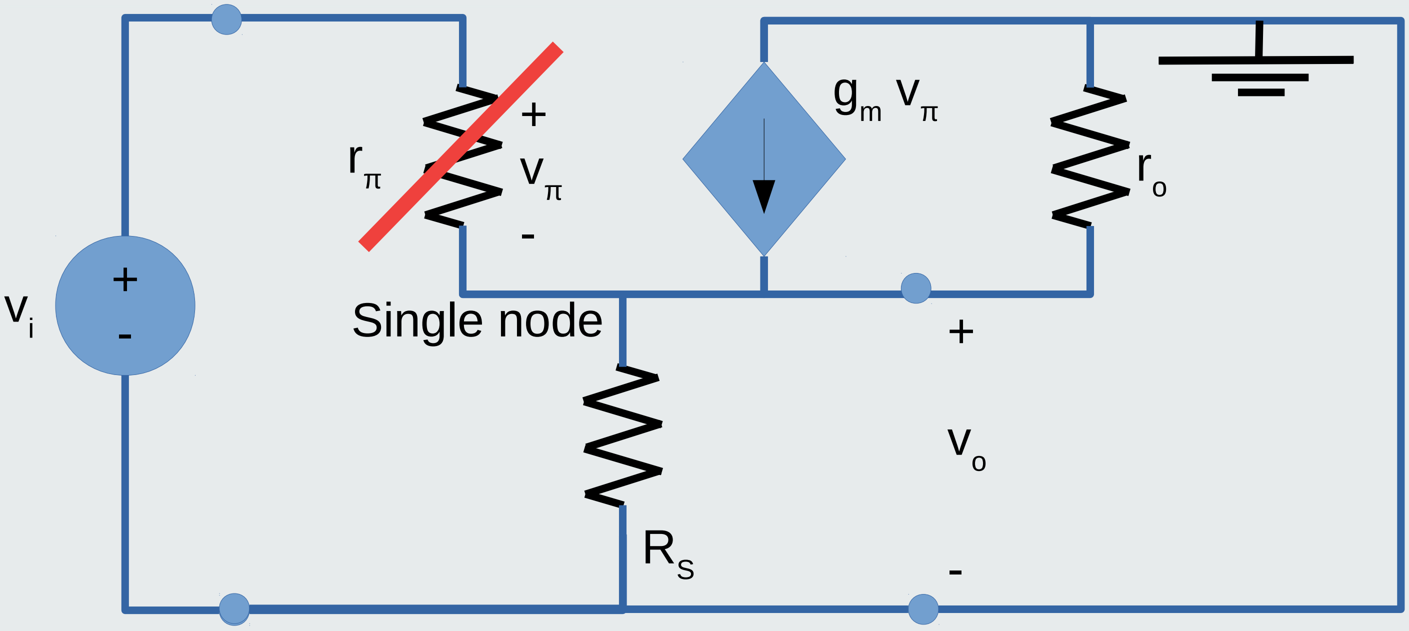
$$V_{GS} - V_T = \sqrt{\frac{I_D}{k}}$$

$$V_O = V_i - V_T + \frac{1}{2}\left(\sqrt{\frac{4}{kR_S}(V_I - V_T) + \frac{1}{k^2 R_S^2}} + \frac{1}{2kR_S}\right)$$

Emitter follows base voltage with constant difference V_{ON}

Source Follower Circuit

The common drain amplifier: voltage gain



$$g_\pi = 0$$

$$g_s = \frac{1}{R_S}$$

$$g_o = \frac{1}{r_o}$$

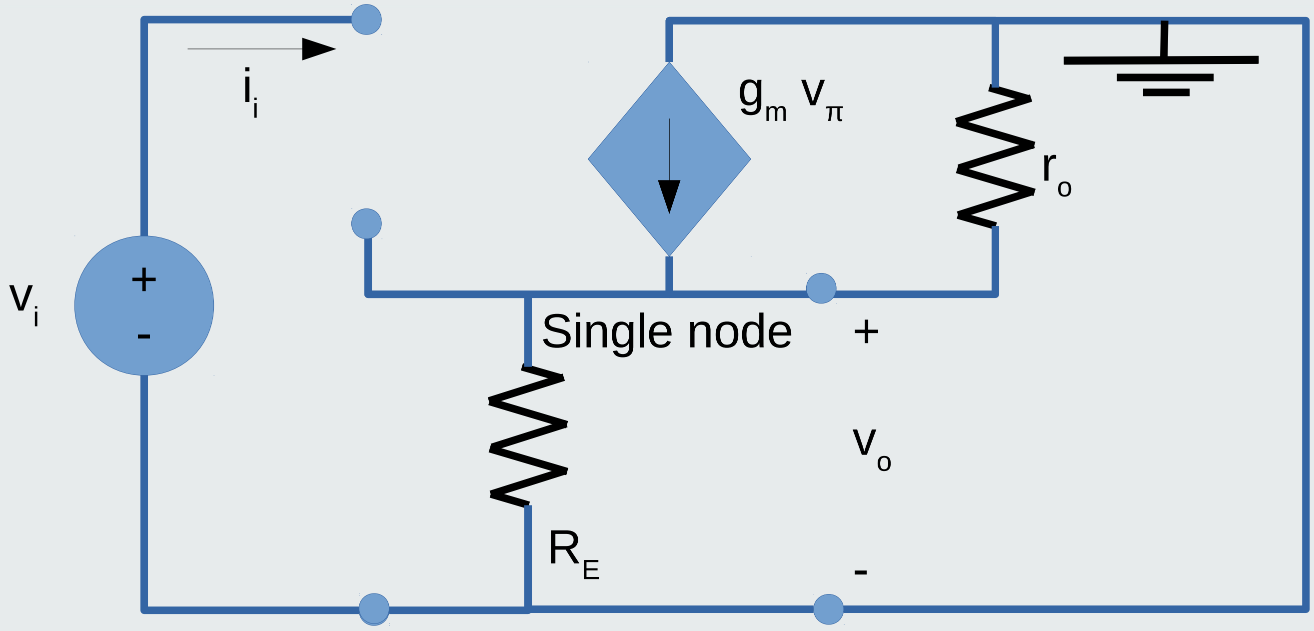
$$g_\pi = 0$$

$$\frac{v_o}{v_i} = \frac{g_m}{g_s + g_o + g_m} \approx 1$$

$$g_s, g_o \ll g_m$$

Use BJT model with infinite input resistance

The common collector amplifier: input impedance



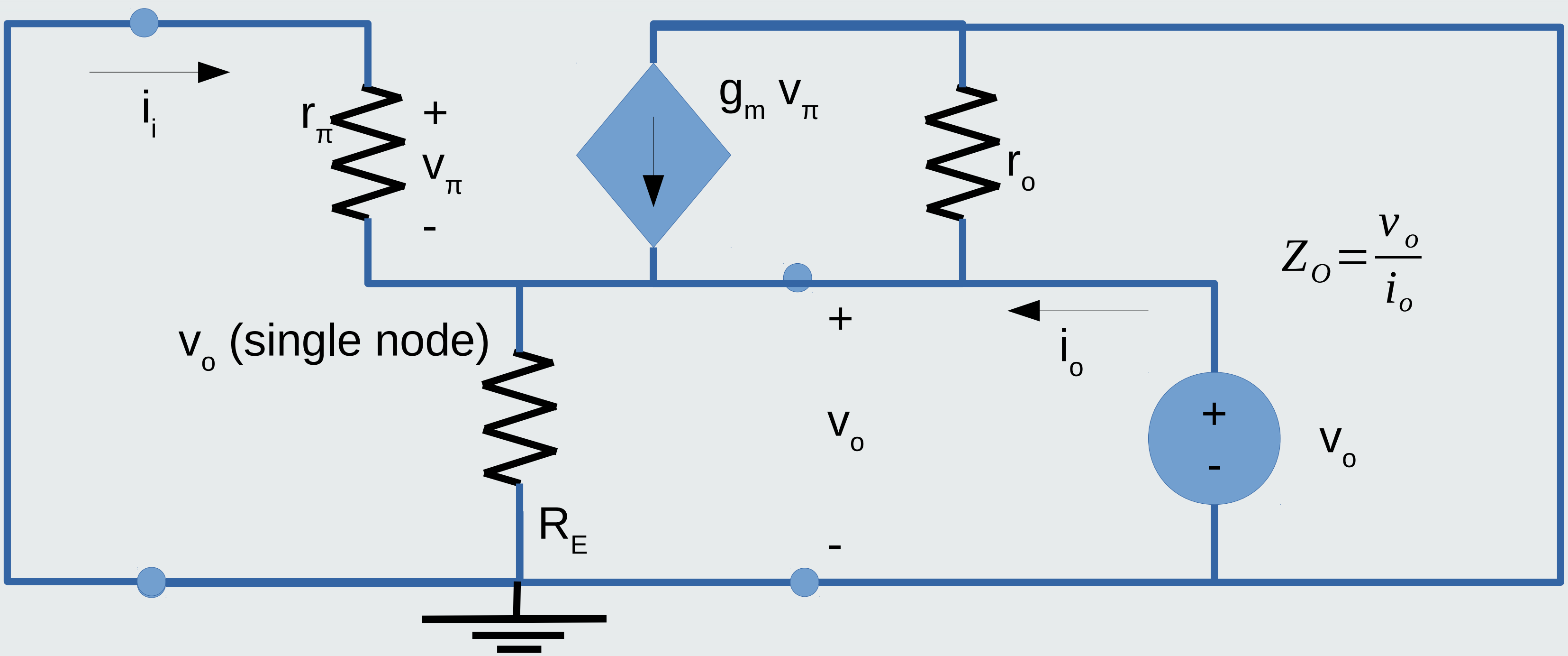
$$Z_I = \frac{v_i}{i_i}$$

$$i_i = 0$$

$$Z_I = \infty$$

Use BJT model with infinite input impedance

The common collector amplifier: output impedance



$$Z_O = \frac{v_o}{i_o}$$

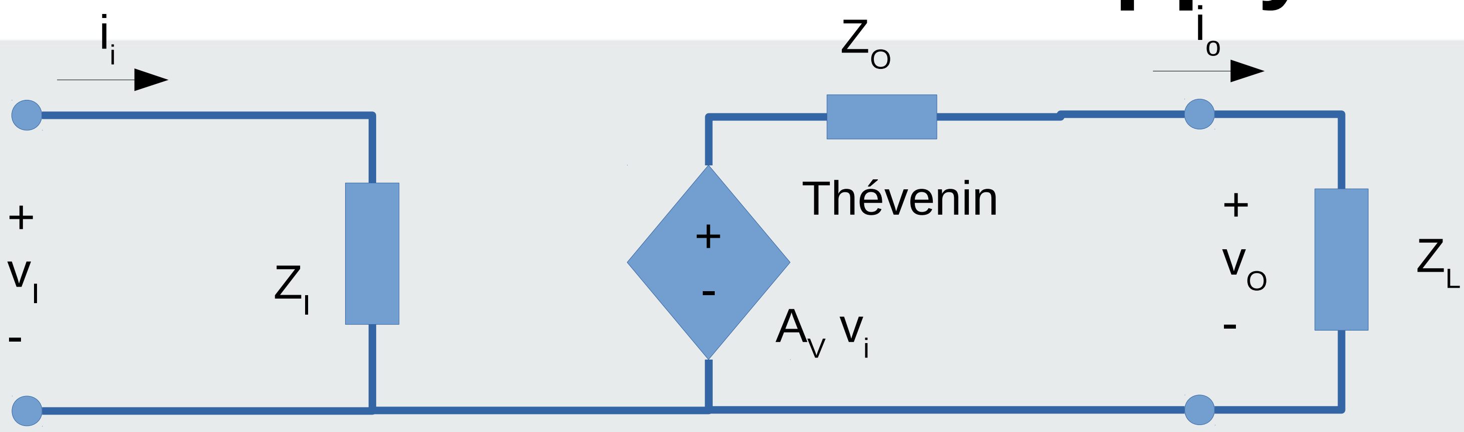
Use BJT model with infinite input resistance

$$g_\pi = 0$$

$$Z_O = \frac{v_o}{i_o} = \frac{1}{g_s + g_o + g_m}$$

$$g_s, g_o \ll g_m \Rightarrow Z_O \approx \frac{1}{g_m}$$ **LOW!**

Common collector amplifier: solves current supply



Common Source

$$v_o = \frac{Z_L}{Z_L + Z_O} A_V v_i$$

Common Drain

$$A_V \approx 1$$
$$Z_O \ll Z_L$$

Depends On Z_L!

$$A_V' = \frac{Z_L}{Z_L + Z_O} A_V$$

Effective Gain

$$A_V' \approx 1$$

Unaffected by Z_L!

Depends On Z_O!

$$i_o = \frac{v_o}{Z_L} = \frac{A_V}{Z_L + Z_O} v_i$$

Load Current

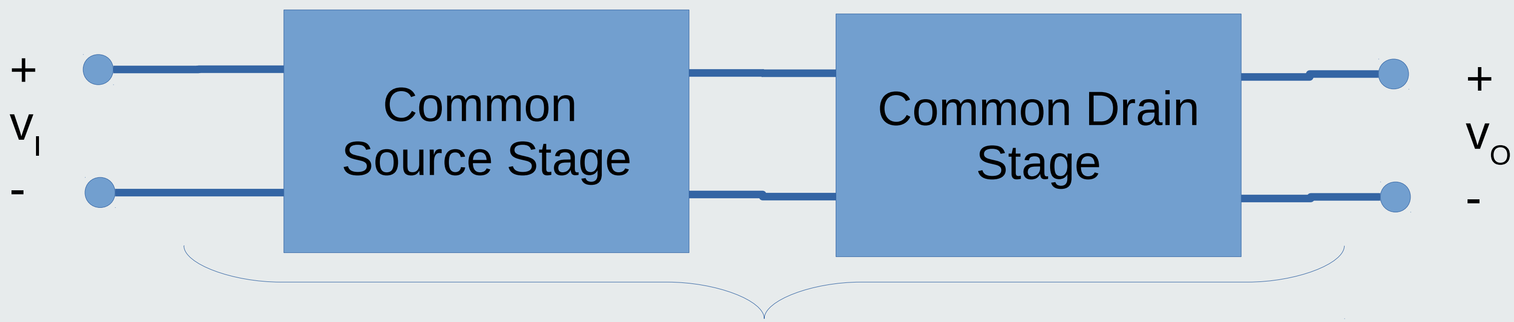
$$i_o = \frac{v_o}{Z_L} = \frac{A_V}{Z_L} v_i$$

Unaffected by Z_O!

Good voltage amplifier

- Input is voltage
- Output is voltage
- Z_I should be high to not degrade input voltage
- Z_O should be low to not degrade output signal
- A_V should be high because we want to amplify

High Z_I, High A_V, High Z_O **High Z_I, Low Z_O, Low A_V**



Good Voltage Amplifier: High A_V, High Z_I, Low Z_O!

Conclusion

- MOSFET amplifiers presented
- Common source amplifier
  - High gain, input and output impedances
  - High output impedance not good for voltage amplifier
- Common drain amplifier
  - Low gain, high input impendance and low output impedances
  - Low gain is not good for voltage amplifier
- Combining common source and common drain stages results in a good voltage amplifier design