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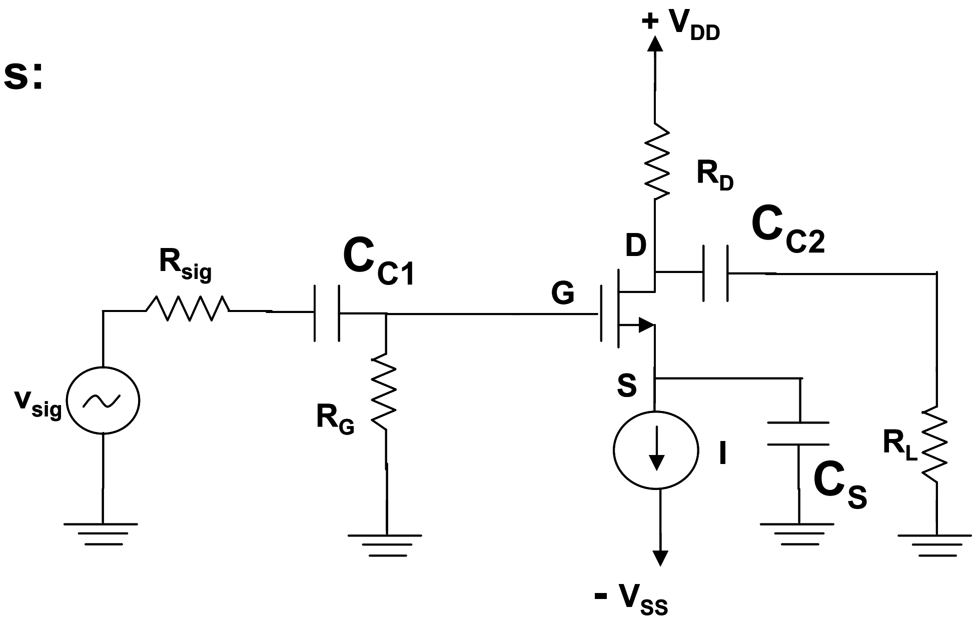
Mansoor Shaukat

Single-Stage Integrated Circuit Amplifier
(Part 2)

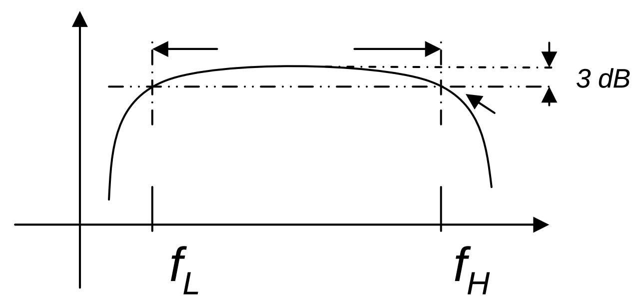
- Common-Source Amplifier : High Frequency Response!

Common-Source Amplifier : High Frequency Response

- The circuit is:

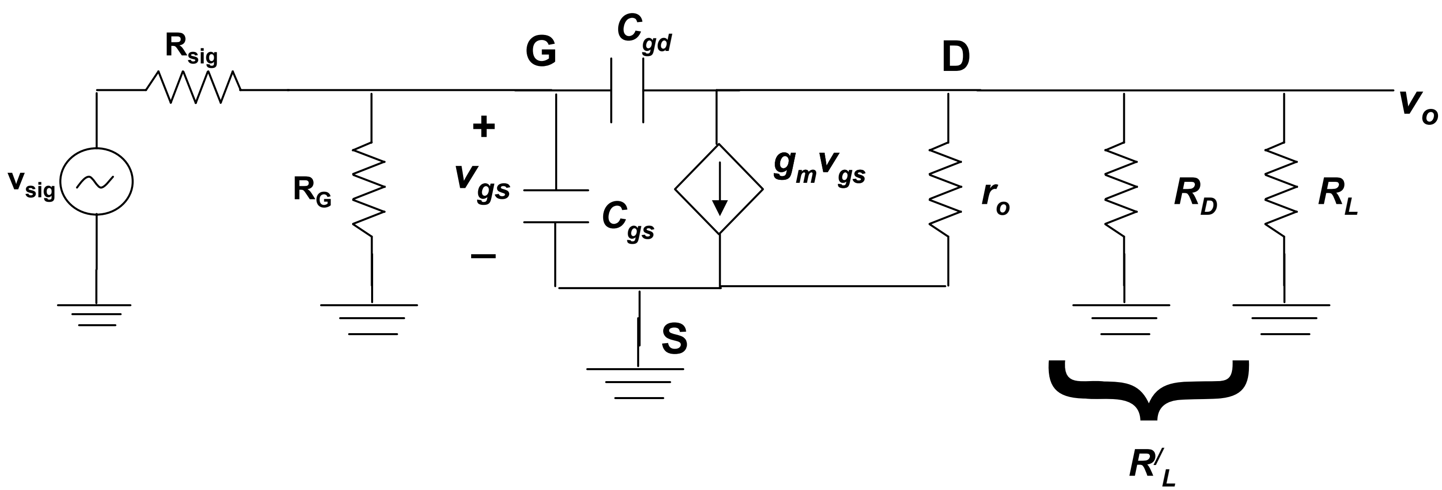


- The MOSFET is replaced by its high-frequency model to determine the gain or the transfer function at f_H.
- At these frequencies (high) C_{C1}, C_{C2}, and C_S will be behaving as perfect short circuits.
- ..contd.

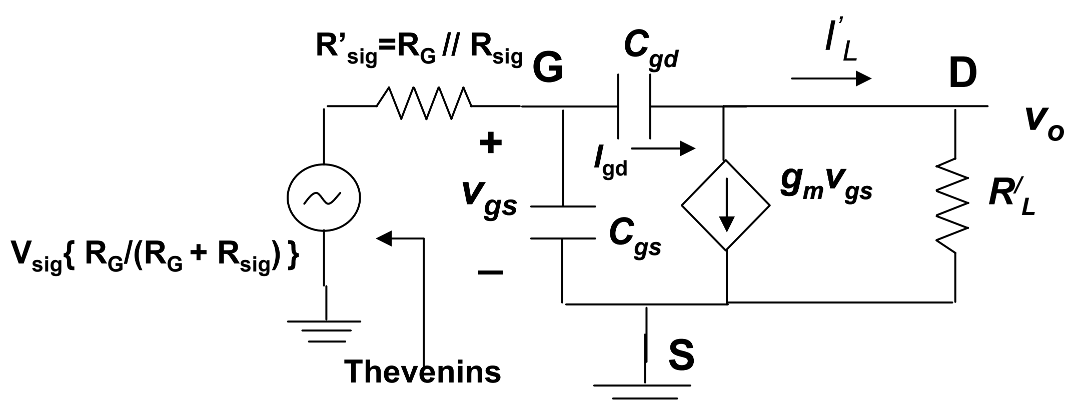


Common-Source Amplifier : High Frequency Response…contd

- So the circuit becomes:

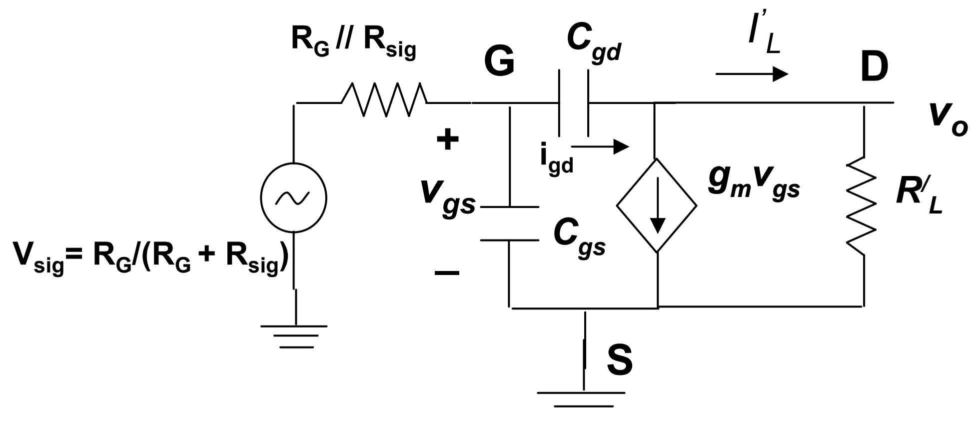


- To deal with the bridging capacitor C_{gd} consider the following circuit:

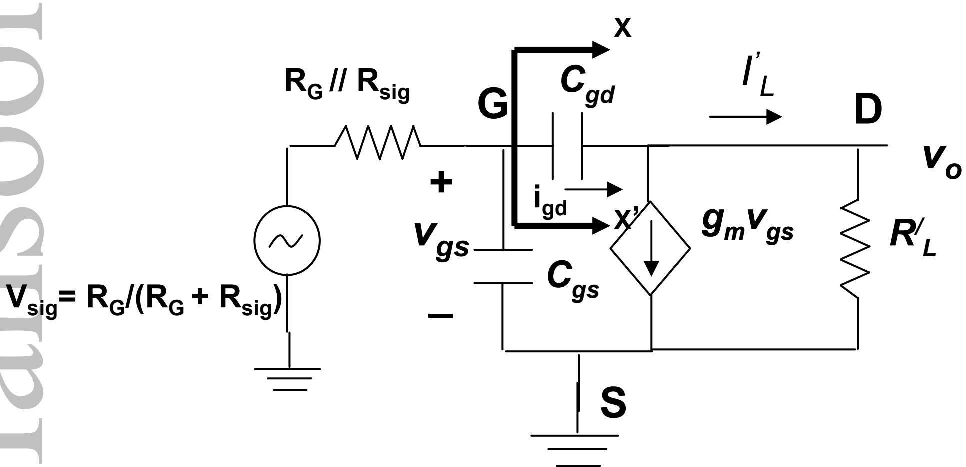


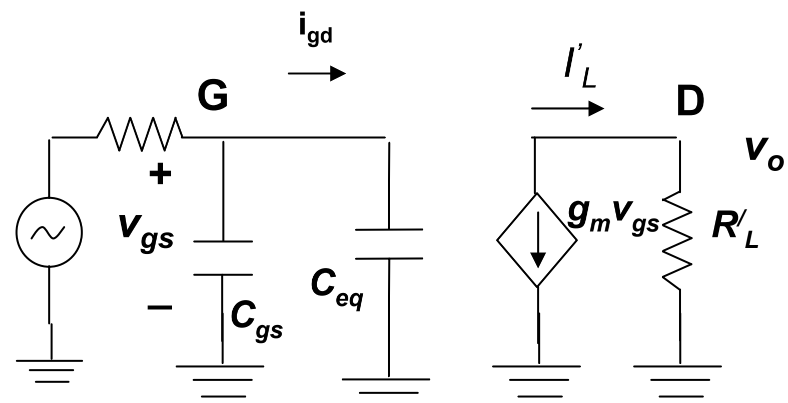
Common-Source Amplifier : High Frequency Response…contd

- So KCL at o/p node is: $I_{gd} = g_m V_{gs} + I'_L$
- Or $I'_L = I_{gd} - g_m V_{gs}$
- At and near f_H $I_{gd} << g_m V_{gs}$
- So $I'_L = - g_m V_{gs}$
- And $v_O = - g_m V_{gs} R'_L$



- Because I = sCV
- So $I_{gd} = sC_{gd} (v_{gs} - v_o)$
- Or $I_{gd} = sC_{gd} (v_{gs} - (- g_m V_{gs} R'_L)$
- And $I_{gd} = sC_{gd} (1 + g_m R'_L) V_{gs}$
- Now consider:





- Now $I_{gd} = sC_{gd}(1 + g_m R'_L)\, v_{gs} = sC_{eq}V_{gs}$
- Which means $C_{eq} = C_{gd}(1 + g_m R'_L)$
- So output voltage across C_{gs} :

$$v_{gs} = \left(\frac{R_G}{R_G + R_{sig}} v_{sig} \right) T_F$$

And : $$T_F = \frac{v_o}{v_i} = \left(\frac{1}{1 + \frac{s}{w_o}} \right)$$ where $w_o = 1/C_{in}R'_{Sig}$

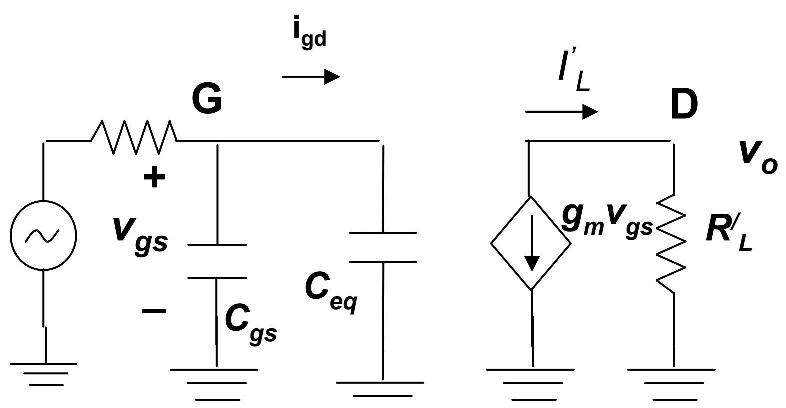
3 dB or corner freq

- Hence:

$$v_{gs} = \left(\frac{R_G}{R_G + R_{sig}} v_{sig} \right) \left(\frac{1}{1 + \frac{s}{w_o}} \right)$$

Here $C_{in} = C_{gs} + C_{eq} = C_{gs} + C_{gd}(1 + g_m R'_L)$

And $R'_{Sig} = R_{Sig} \,//\, R_G$



- …contd!

Common-Source Amplifier : High Frequency Response…contd

- **Hence with:**

$$v_{gs} = \left(\frac{R_G}{R_G + R_{sig}} v_{sig} \right) \left(\frac{1}{1 + \frac{s}{w_o}} \right)$$

- **We know $v_O = -g_m v_{gs} R'_L$ or $v_{gs} = -v_O / g_m R'_L$**
- **So $v_{gs} = -v_O / g_m R'_L$** $= \left(\frac{R_G}{R_G + R_{sig}} v_{sig} \right) \left(\frac{1}{1 + \frac{s}{w_o}} \right)$
- **So hi-freq gain of CS amplifier:**

$$\frac{v_o}{v_{sig}} = -\left(\frac{R_G}{R_G + R_{sig}} \right) g_m R'_L \left(\frac{1}{1 + \frac{s}{w_o}} \right)$$

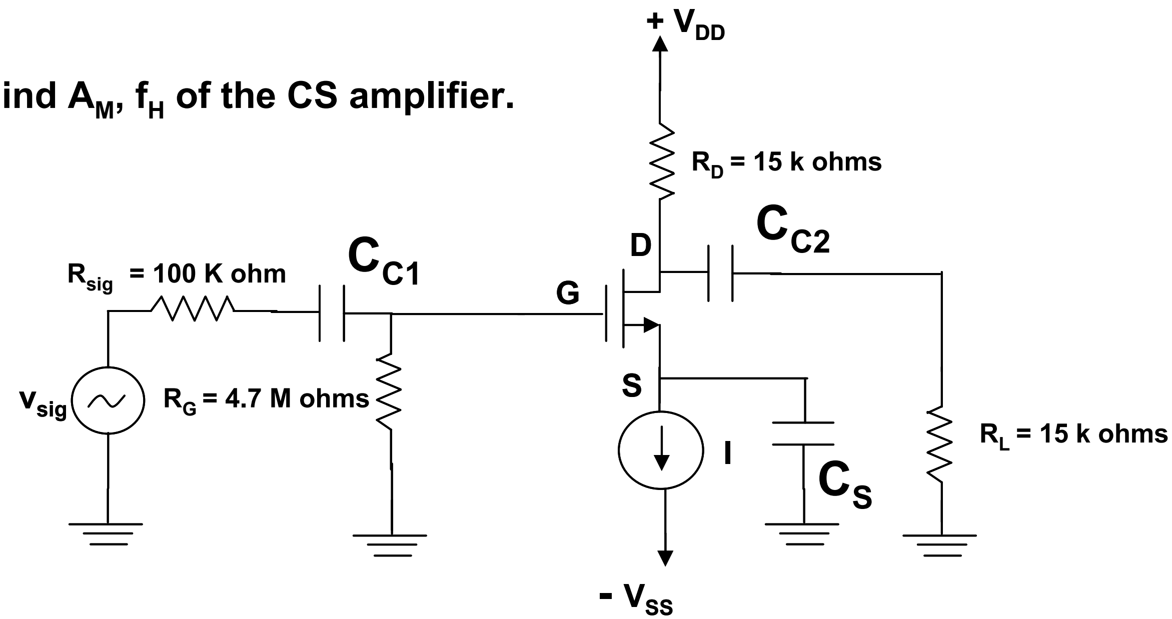
Or: $\frac{v_o}{v_{sig}} = \left(\frac{A_M}{1 + \frac{s}{w_H}} \right)$ **where:** $A_M = -\left(\frac{R_G}{R_G + R_{sig}} \right) g_m R'_L$ **And:** $f_H = \left(\frac{1}{2\pi C_{in} R'_{sig}} \right)$

- **Notice that in the expression for $C_{eq} = C_{gd}(1 + g_m R'_L)$, the factor $(1 + g_m R'_L)$ is known as Miller multiplier and multiplication of C_{gd} by $(1 + g_m R'_L)$ is known as Miller effect.**
- **Example!**

Example : High Frequency Response

- The circuit is:

- Find A_M, f_H of the CS amplifier.



C_{gs} = 1 pF
C_{gd} = 0.4 pF
g_m = 1 mA/V
r_o = 150 kΩ

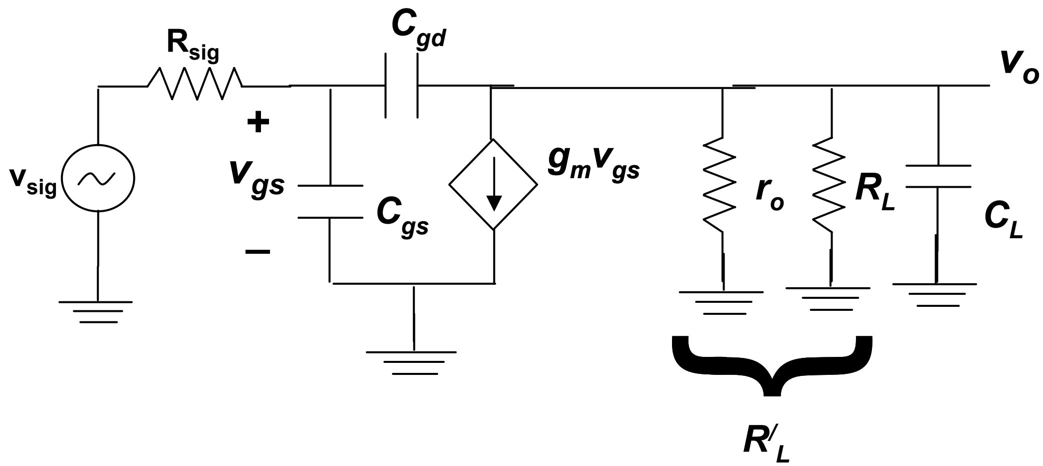
- **Solution:** $A_M = -\left(\frac{R_G}{R_G + R_{sig}}\right) g_m R'_L$ $\quad R'_L = r_o \,//\, R_D \,//\, R_L = 150 \,//15\, //15 = 7.14$ k ohms

  $g_m R'_L = 1 \times 7.14 = 7.14$ V/V $\quad$ So $A_m = -7$ V/V

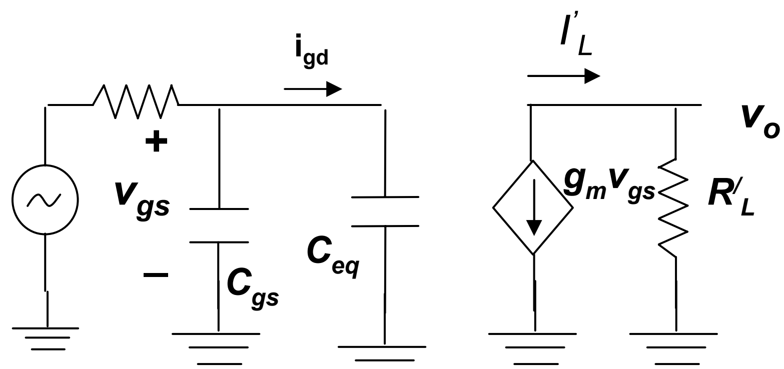
  - **Now $C_{eq} = (1 + g_m R'_L)\, C_{gd} = 3.26$ pF**
  - **And $C_{in} = C_{gs} + C_{eq} = 1 + 3.26 = 4.26$ pF**
  - **Finally $f_H = 1/2\Pi C_{in} (R_{sig} \,//\, R_G) = 382$ k Hz.**
  - **QED?**

Active-Loaded Common Source : High Frequency Response

- **High-frequency equivalent-circuit model of CS amplifier is:**



And when R_{sig} is relatively large and C_L is relatively small,



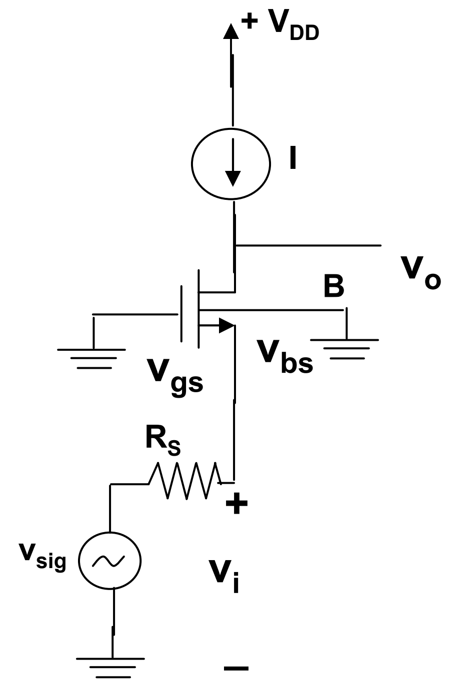
where $C_{eq} = (1 + g_m R'_L)\, C_{gd}$

$$A_M = -g_m R'_L \qquad f_H = \left(\frac{1}{2\pi C_{in} R_{sig}} \right)$$

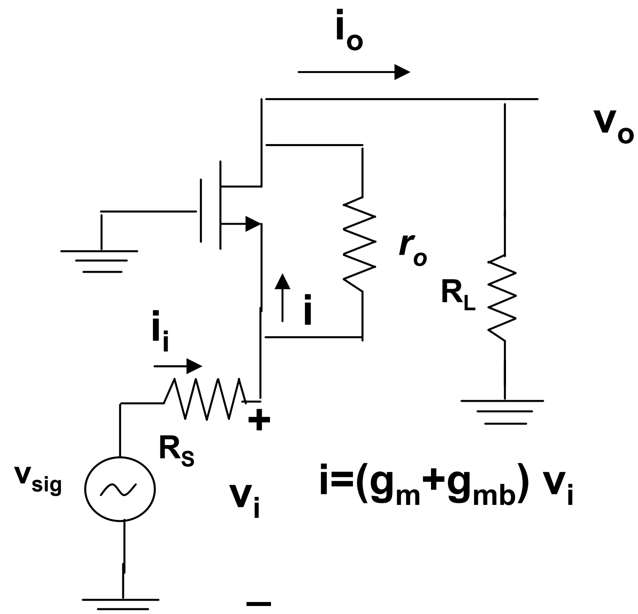
- **QED!**

The CG Amplifier With Active Load

- Consider the following circuit:



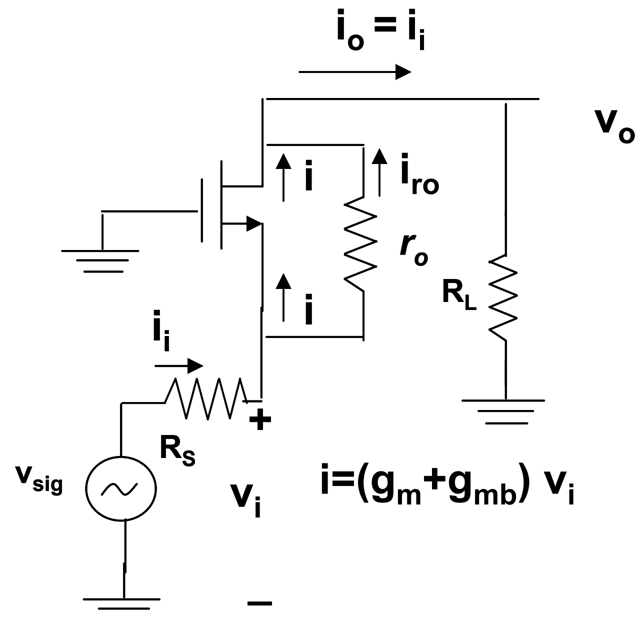
- Body transconductance $g_{mb} = \chi\, g_m$ where $\chi = 0.1$ to 0.2
- Note v_{bs} gives rise to a drain current signal $g_{mb}\, v_{bs}$
- And since both gate and body are grounded, the two voltages are equal.
- For analysis, consider the following circuit:



- Because r_o connects output to input node so R_{in} depends on R_L and R_{out} on R_s.
- …contd!

The CG Amplifier With Active Load…contd

- Now $v_o = i_i R_L$
- At source node $i_i = (g_m + g_{mb}) v_i + i_{ro}$
- Now $$i_{ro} = \frac{v_i - v_o}{r_o} = \frac{v_i - i_i R_L}{r_o}$$
- So $$i_i = (g_m + g_{mb}) v_i + \frac{v_i - i_i R_L}{r_o}$$
- Or $$i_i r_o + i_i R_L = \left[(g_m + g_{mb}) r_o + 1\right] v_i$$
- And $$i_i = \frac{\left[1 + (g_m + g_{mb}) r_o\right] v_i}{r_o + R_L}$$
- Finally $$R_{in} = \frac{v_i}{i_i} = \frac{r_o + R_L}{\left[1 + (g_m + g_{mb}) r_o\right]}$$



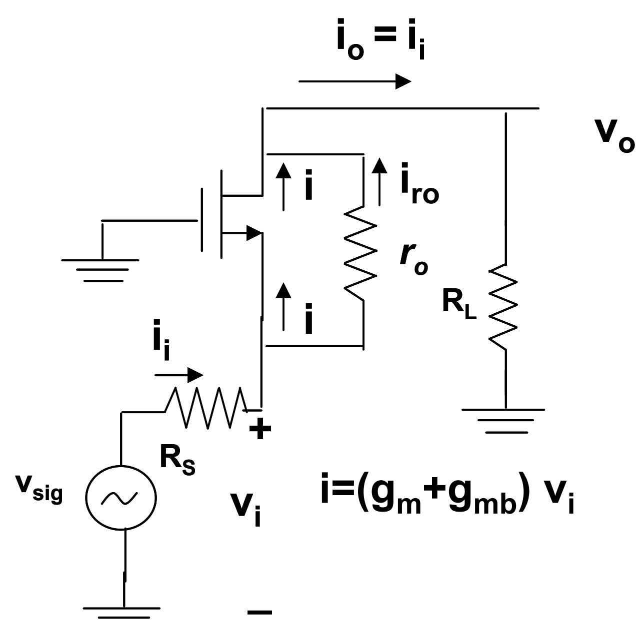
- …contd!

The CG Amplifier With Active Load…contd

- For voltage gain: $v_o = i_o R_L = i_i R_L$ and $v_i = i_i R_{in}$
- So $A_v = v_o/v_{in} = R_L/R_{in}$
- For A_{vo}?
- $ir_o + v_i = v_o$ (because $R_L = \alpha$ so i flows from top to bottom)
- And $i = (g_m + g_{mb})v_i$
- So $v_o = (g_m + g_{mb})v_i r_o + v_i$
- Or $A_{vo} = 1+(g_m + g_{mb})r_o$
- Now

$$R_{in} = \frac{v_i}{i_i} = \frac{r_o + R_L}{\left[1+(g_m + g_{mb})r_o\right]}$$

- Therefore $$R_{in} = \frac{r_o + R_L}{A_{vo}}$$
- Hence $$A_v = \frac{R_L}{R_{in}} = A_{vo}\frac{R_L}{r_o + R_L}$$
- …contd!



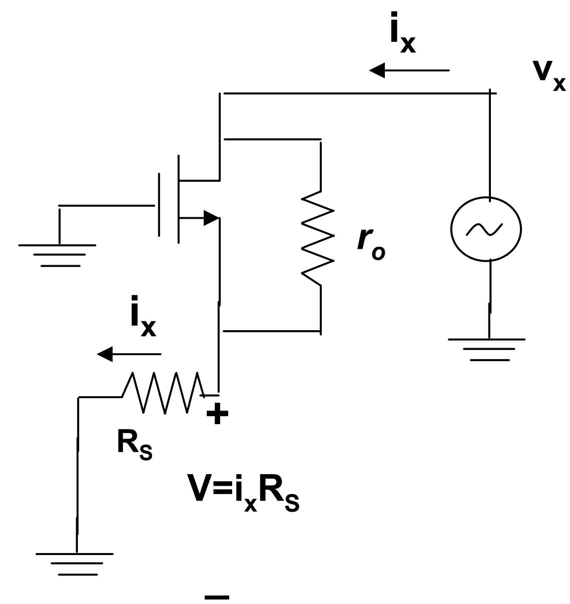
The CG Amplifier With Active Load…contd

- There are two output resistances:-R_o when $v_i = 0$ and R_{out} when $v_{sig} = 0$.
- So $R_o = r_o$
- For R_{out} $$v_x = [i_x + (g_m + g_{mb})v]r_o + v$$
- And

$$R_{out} = r_o + [1 + (g_m + g_{mb})r_o]R_s$$

- Finally

$$R_{out} = r_o + A_{vo}R_s$$



- CB Amplifier with active-load!

The CB Amplifier With Active Load

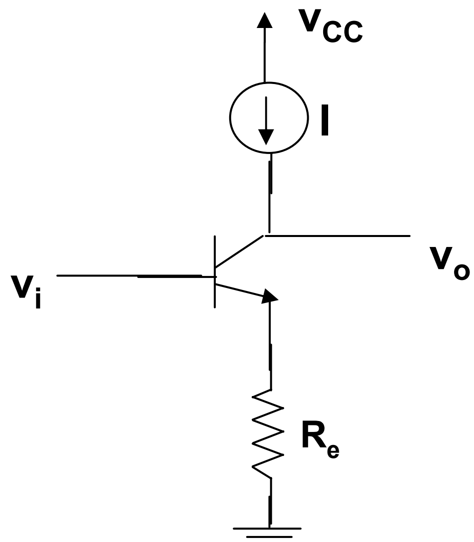
- **Similar treatment as CG but with finite β. Additionally, the base conducts signal current contrary to the behaviour of a MOSFET CG amplifier.**

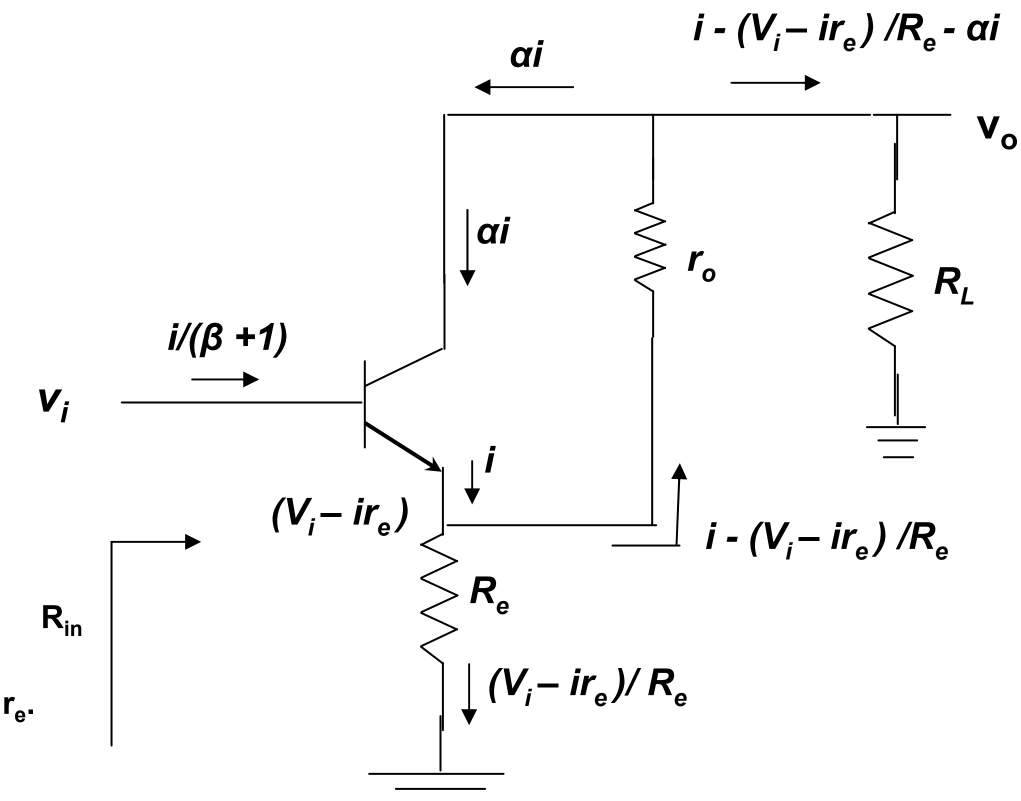
- **Emitter degeneration resistance!**

The CE Amplifier With Emitter Degeneration Resistance

- **Emitter degeneration is more useful in CE amplifier than source degeneration in the CS amplifier.**
  - **Because emitter degeneration increases the input resistance of the CE amplifier.**
  - **Incidentally the input resistance of CS is practically infinite to begin with.**

- **The circuit:**





- **R_e is usually in the range of 1 to 5 times r_e.**
- **The analysis?**
- **$v_o = (V_i - ir_e) - r_o\{i - (V_i - ir_e)/R_e\}$**
- **…contd!**

The CE Amplifier With Emitter Degeneration Resistance…contd

- So $v_o = (V_i - ir_e) - r_o\{i - (V_i - ir_e)/R_e\}$ and $v_o = [\,i - (V_i - ir_e)/R_e - \alpha i\,]R_L$
- And solving these two equations simultaneously gives us $R_{in} = V_i/[i/(\beta + 1)]$
- Or:

$$R_{in} = (\beta+1)r_e + (\beta+1)R_e \frac{r_o + \frac{R_L}{\beta+1}}{r_o + R_L + R_e}$$

- Can be simplified to:

$$R_{in} = (\beta+1)r_e + (\beta+1)R_e \frac{1}{1+\frac{R_L}{r_o}}$$

- Hence inclusion of R_e :
  - Reduces effective transconductance by a factor (1 + gm RL)
  - Increases its output resistance by the same factor
  - Increases input resistance depending on the value of RL.
  - Increases amplifier bandwidth and finally the emitter degeneration resistance Re increases the linearity of the amplifier.

- The CS Amplifier!

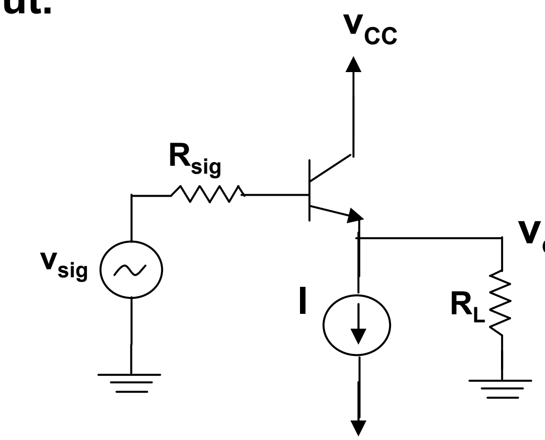
The CS Amplifier With Source Degeneration Resistance

- **The source degeneration resistance introduces negative feedback.**
- **Broadens the bandwidth.**
- **More control over the amplifier.**

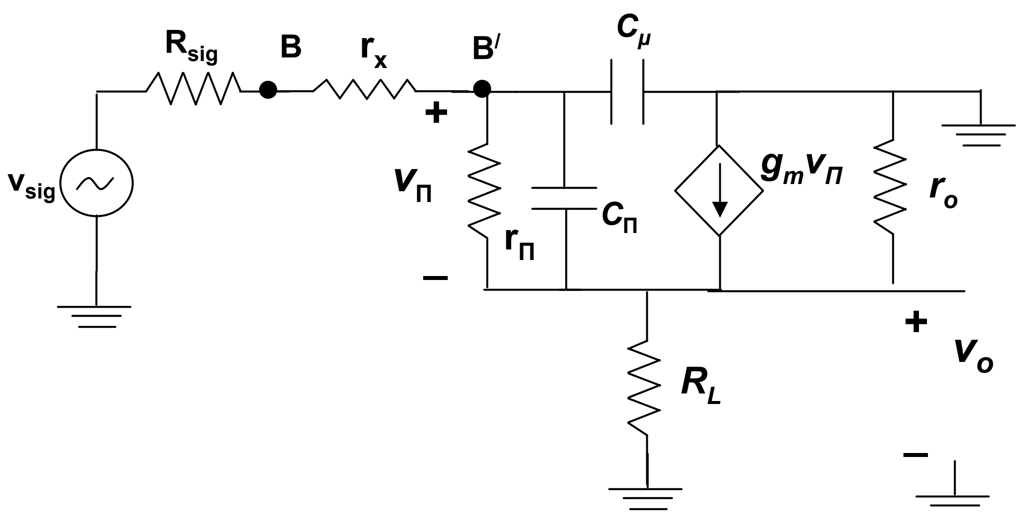
- **The Emitter Follower!**

The Emitter Follower

- The common–collector is also called emitter-follower because the voltage at the emitter follows very closely the voltage at the input.
- The emitter-follower suitable for IC fabrication is:

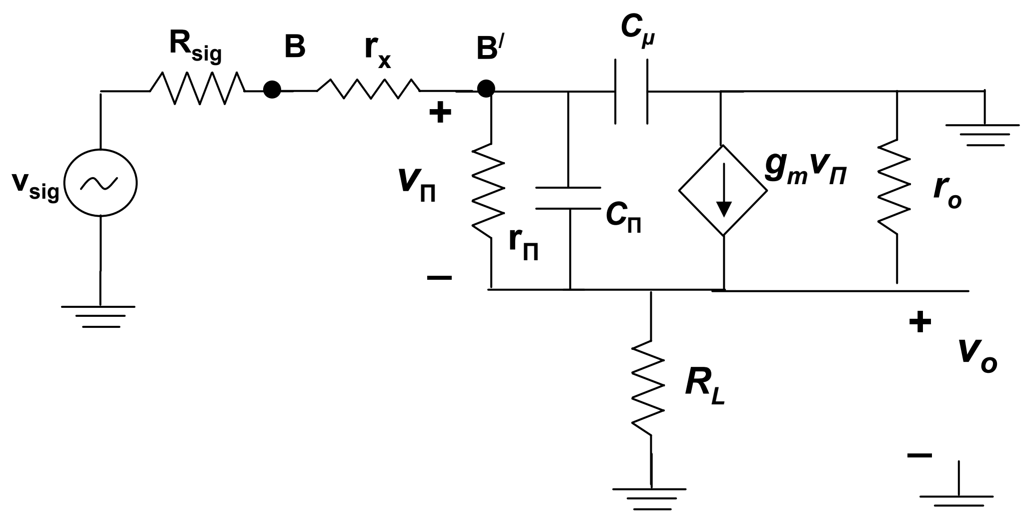


- Low frequency gain, input resistance and output resistance is identical to capacitively coupled version studied earlier.
- The high-frequency circuit is:

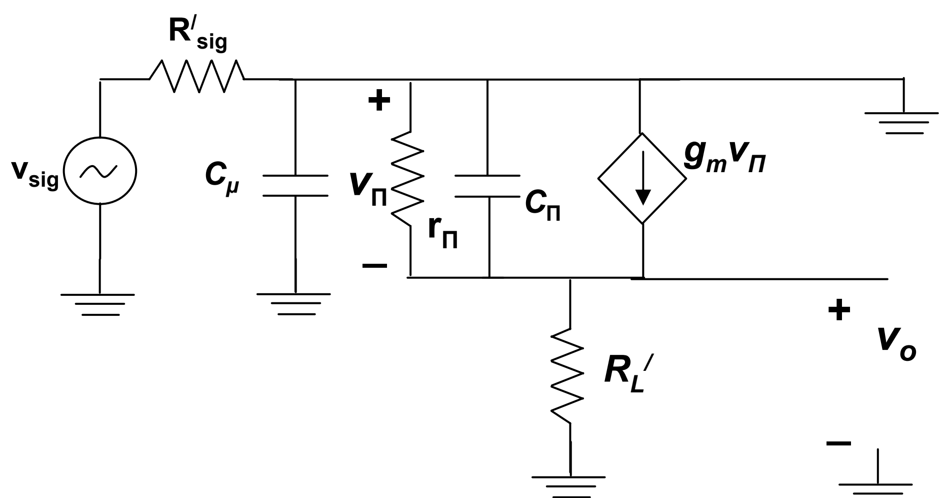


- Simplified circuit!

The Emitter Follower…contd



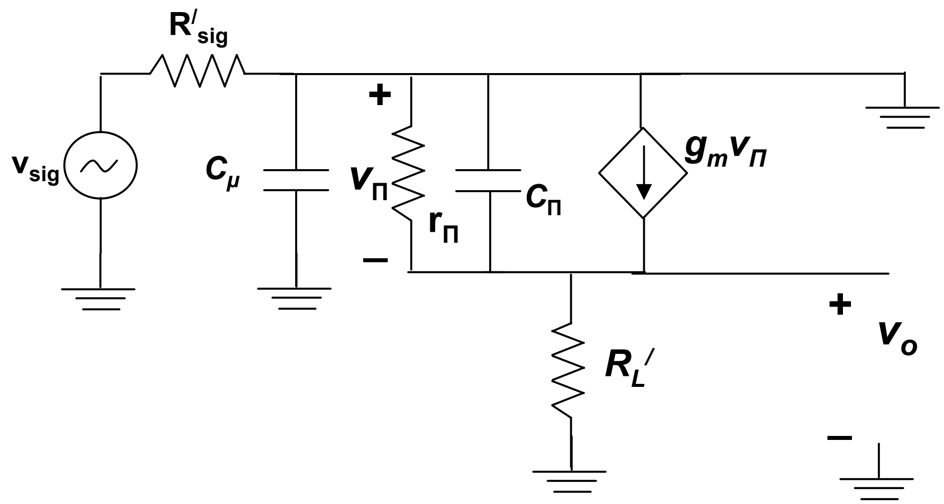
- The simplified circuit is:



- Here R'_{sig} = ? and R'_L = ?
- Simplified circuit!

The Emitter Follower…contd

- The simplified circuit is:



- The resistance seen by C_μ is the parallel equivalent of R'_{sig} and input resistance:

$$R_\mu = R'_{sig} // \left[r_\pi + (\beta+1)R'_L\right]$$

- And resistance seen by C_Π is:

$$R_\pi = \frac{R'_{sig} + R'_L}{1 + \frac{R'_{sig}}{r_\pi} + \frac{R'_L}{r_e}}$$

- The high-frequency is:

$$f_H = \frac{1}{2\pi\left(C_\mu R_\mu + C_\pi R_\pi\right)}$$

- Home Assignment!

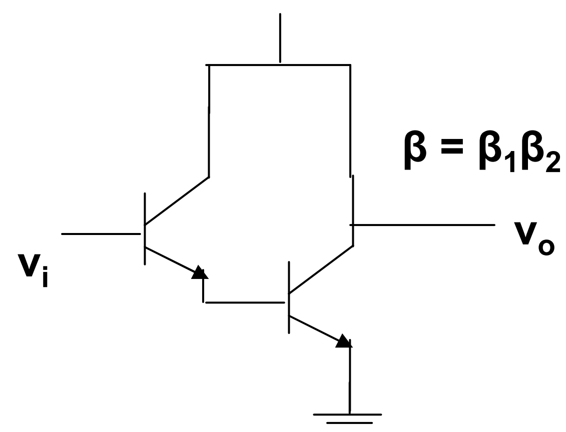
Home Assignment

Ex : 6.35

- **…Some useful transistor pairings!**

Some Useful Transistor Pairings

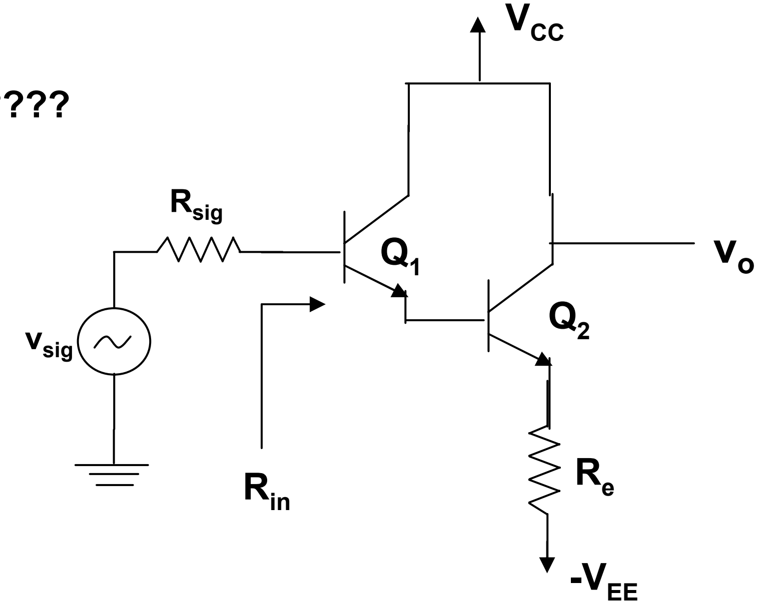
- **Sometimes the transistor pairings are done in such a way that the superior performance is achieved through maximizing the advantages and minimizing the shortcomings of each of the two individual configurations.**
- **In such cases the transistor pair is considered as a compound device and the resulting amplifier is considered as a single stage.**
- **The Darlington Configuration:**



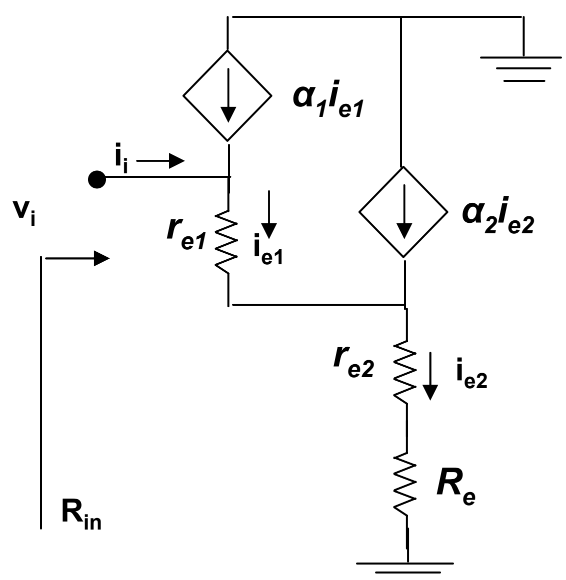
- …contd!

Example : Transistor Pairings

- Consider the circuit shown. If β_1=50, β_2=100, R_E=500 Ω and r_{e1}=r_{e2}=25 Ω determine the value of R_{in}.



- Solution: $R_{in} = (\beta_1 + 1)\{r_{e1} + (\beta_2 + 1)(r_{e2} + R_e)\}$????



- QED!

Single-stage IC Amplifiers : Summary

- IC technology offers the circuit designers a very large number of inexpensive small-area MOS transistors.
- For minimization of chip area, large-valued resistors and capacitors are virtually absent.
- Biasing in integrated circuits utilizes current sources.
  - An accurate and stable reference current is generated and then replicated to provide bias currents for various amplifier stages.
  - The heart of the current-steering circuitry utilized to perform this function is the current-mirror.
- The high-frequency response of IC amplifiers is limited by the transistor internal capacitances, mainly C_{gs} and C_{gd} in the MOSFET and C_{Π} and C_{μ} in the BJT.
- IC amplifiers employ constant-current sources in place of the resistances R_D(R_C) that connects the drain (collector) to the power supply. Reason?
  - These active loads enable the realization of reasonably large voltage gains while using low voltages supplies (as low as 1 V)
- …contd

……contd

- The largest voltage gain available from a CS or a CE amplifier is equal to the intrinsic gain of the transistor: $A_o = g_m r_o$
  - for a BJT, it is 2000 to 4000 V/V.
  - for a MOSFET, it is 20 to 100 V/V.
    - CE amplifier has low input resistance and
    - CS amplifier has an infinite input resistance
- Including a small resistance in the source (emitter) of a CS(CE) amplifier provides the designer with a tool to effect some performance improvements e.g. wider bandwidth in return for gain reduction (a trade-off characteristic of negative feedback).
- Note some of the ICs dissipate as much as100 watts.

- End of the part.

Choose a job you love, and you will not have to work a day in your life.

(Confucius)