NPTEL ONLINE CERTIFICATION COURSES

Course Name: *Analog Electronic Circuits*

Faculty Name: *Dr. Pradip Mandal*

Department : *Electronics and Electrical Communication Engineering*

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Topic:

Frequency response of CE and CS Amplifiers

Flow of Discussion (Bottom-up) – *Building blocks*

- System/ Sub-systems (*for specific application*)
  - Modules (*performing specific tasks*)
    - **Building blocks (** *having specific characteristics* **)**
      - Components (*devices/circuit elements*)
- Week 4:
  - **Frequency response of CE and CS amplifiers,**
  - **High frequency models of BJT and MOSFET, and their usages.**
  - **Limitations of CE/CS amplifiers and hence the need of buffers.**

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CONCEPTS COVERED

Concepts Covered:

- Frequency response of R-C and C-R circuits
- Frequency response of CS amplifier
  - *Circuit analysis*
  - *Numerical example*
- Frequency response of CE amplifier (*with fixed bias*)
  - *Circuit analysis*
  - *Numerical example*
- Frequency response of CE amplifier (*with self bias*)
  - *Circuit analysis*
  - *Numerical example*
- Design guidelines

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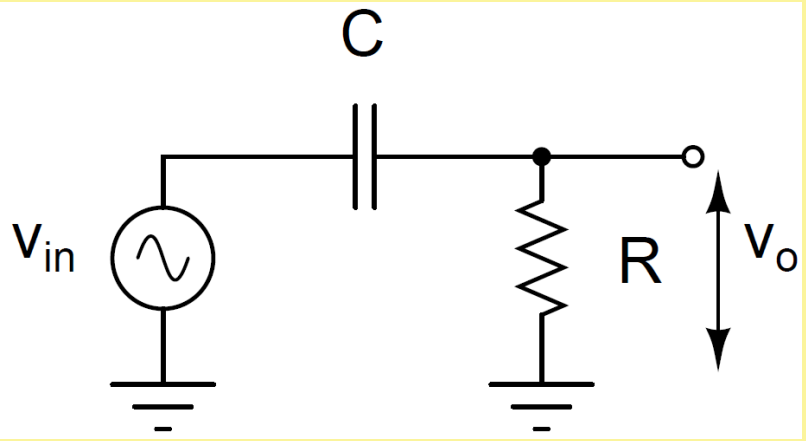
Frequency response of C-R circuit (*recapitulation*)



$$\frac{V_o(s)}{V_{in}(s)} = \frac{sRC}{(1+sRC)}$$

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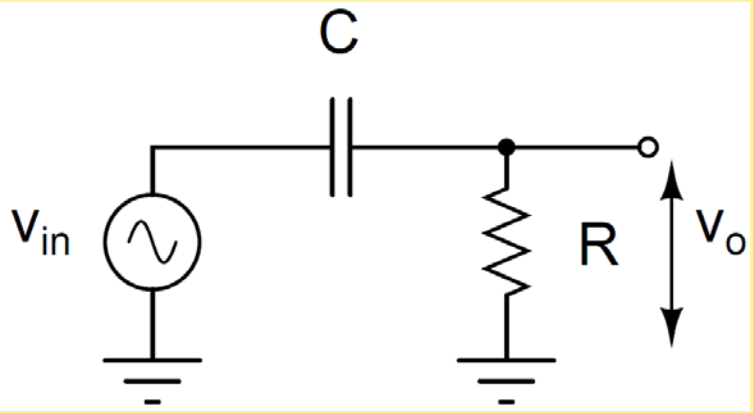
$$\frac{V_o(j\omega)}{V_{in}(j\omega)} = \frac{j\omega RC}{(1+j\omega RC)}$$

- **Analyses in *Laplace Domain* and then in *Fourier Domain***
- ***Gain plot* and *Phase plot* of Transfer function**

Frequency response of C-R circuit (*contd.*)



$$\frac{V_o(j\omega)}{V_{in}(j\omega)} = \frac{j\omega RC}{(1+j\omega RC)}$$

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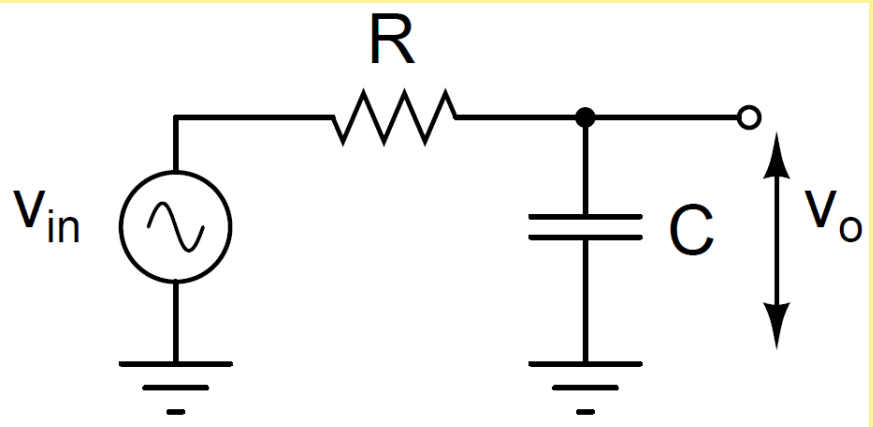
- **Bode' plots:** ***Gain plot and Phase plot***

Frequency response of R-C circuit (*recapitulation*)



$$\frac{V_o(s)}{V_{in}(s)} = \frac{1}{(1+sRC)}$$

$$\frac{V_o(j\omega)}{V_{in}(j\omega)} = \frac{1}{(1+j\omega RC)}$$

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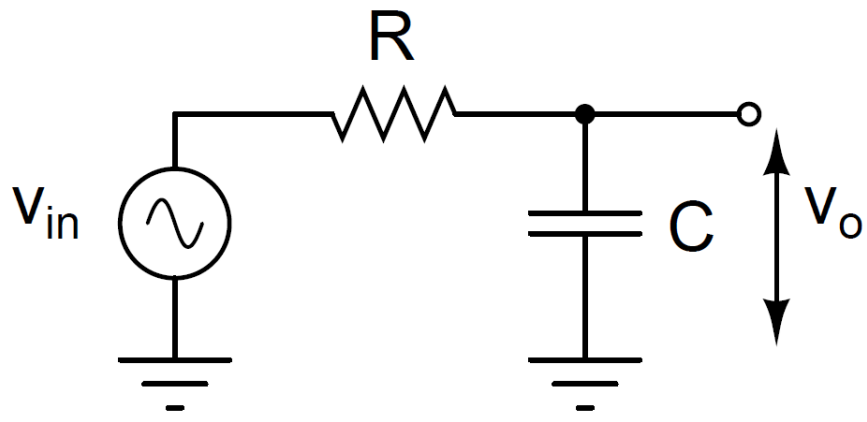
- **Analyses in *Laplace Domain* and then in *Fourier Domain***
- ***Gain plot* and *Phase plot* of Transfer function**

Frequency response of R-C circuit (*contd.*)



$$\frac{V_o(j\omega)}{V_{in}(j\omega)} = \frac{1}{(1 + j\omega RC)}$$

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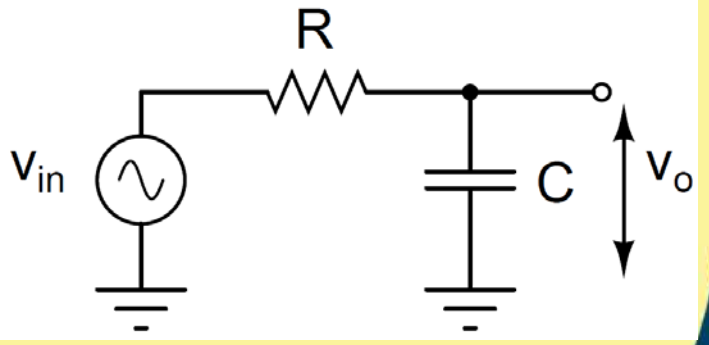
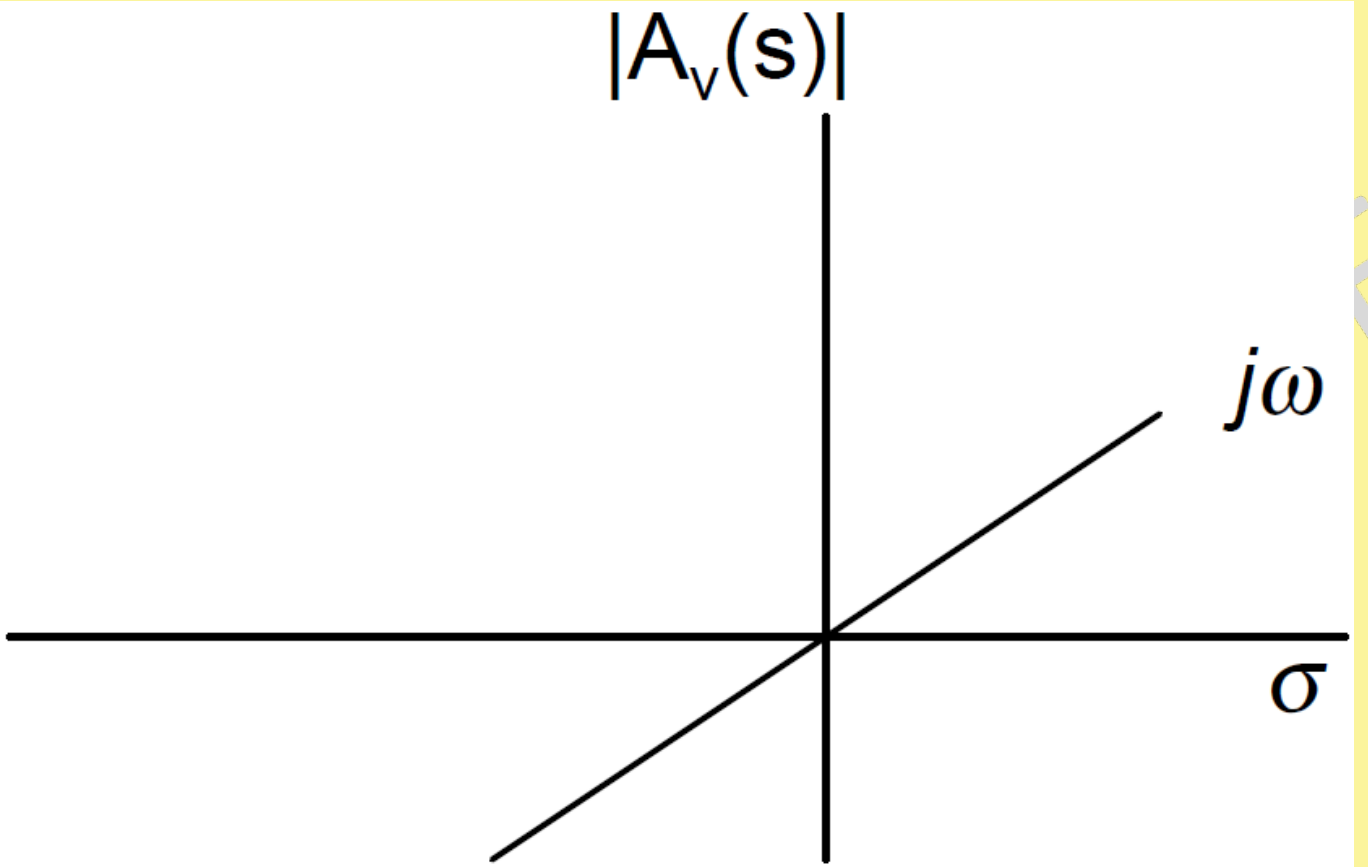
- **Bode' plots:** ***Gain plot and Phase plot***

How pole of Laplace Transfer function and cutoff frequency related !

R-C circuit as an example



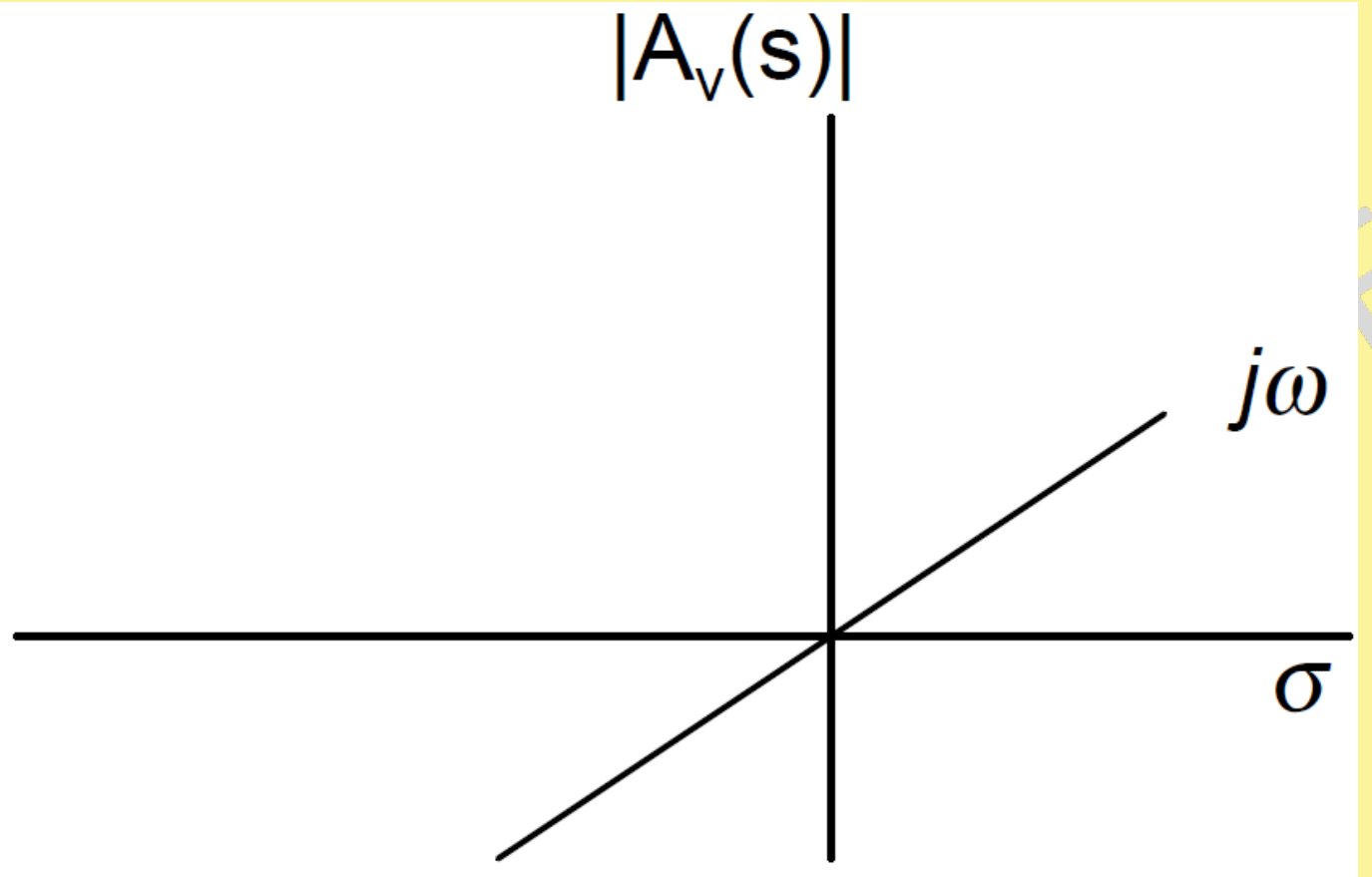


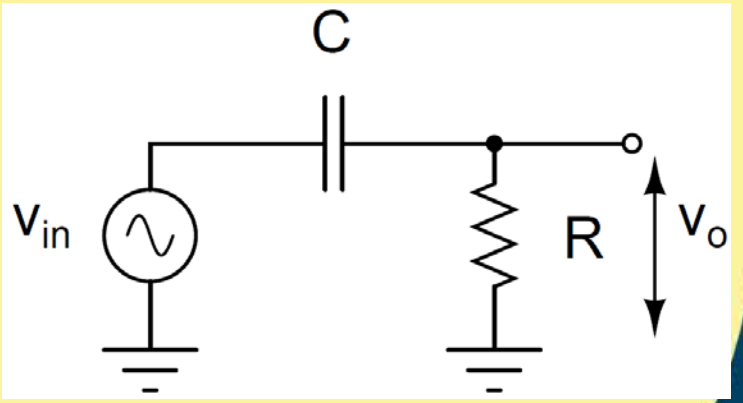
$$\frac{V_o(s)}{V_{in}(s)} = \frac{1}{(1+sRC)}$$

$$\frac{V_o(j\omega)}{V_{in}(j\omega)} = \frac{1}{(1+j\omega RC)}$$

How pole of Laplace Transfer function and cutoff frequency related !

C-R circuit as an example



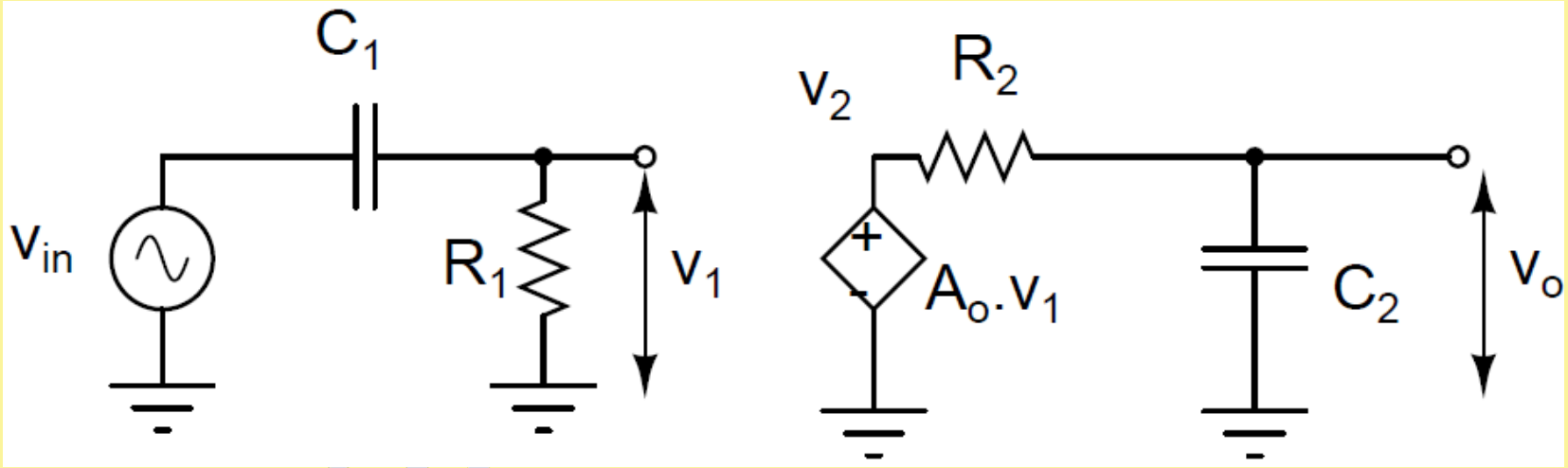


$$\frac{V_o(s)}{V_{in}(s)} = \frac{sRC}{(1+sRC)}$$

$$\frac{V_o(j\omega)}{V_{in}(j\omega)} = \frac{j\omega RC}{(1+j\omega RC)}$$

Frequency response of (C-R)-Amplifier-(R-C) circuit

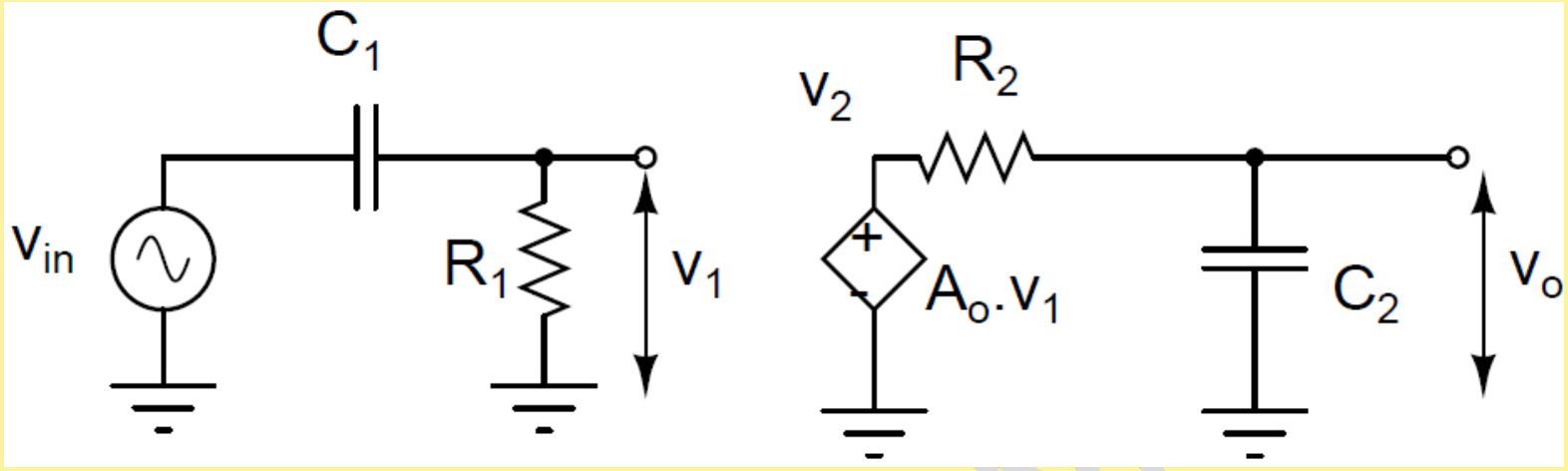
- **Transfer function:**



$$\frac{V_o(s)}{V_{in}(s)} = \frac{V_1(s)}{V_{in}(s)} \times \frac{V_2(s)}{V_1(s)} \times \frac{V_o(s)}{V_2(s)}$$

Frequency response of (C-R)-Amplifier-(R-C) circuit

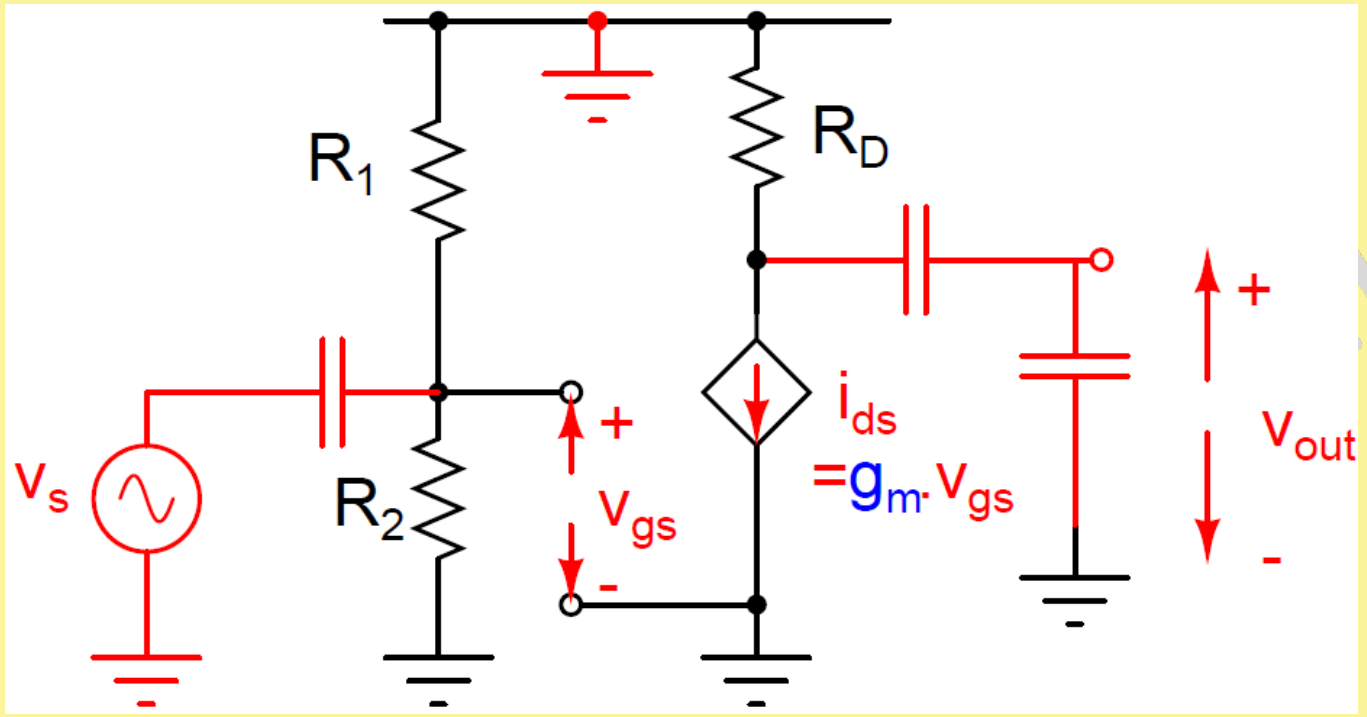
- **Bode plots:**

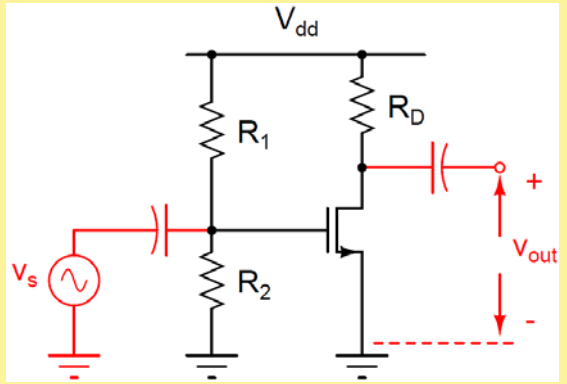


$$\frac{V_o(s)}{V_{in}(s)} = \frac{V_1(s)}{V_{in}(s)} \times \frac{V_2(s)}{V_1(s)} \times \frac{V_o(s)}{V_2(s)}$$

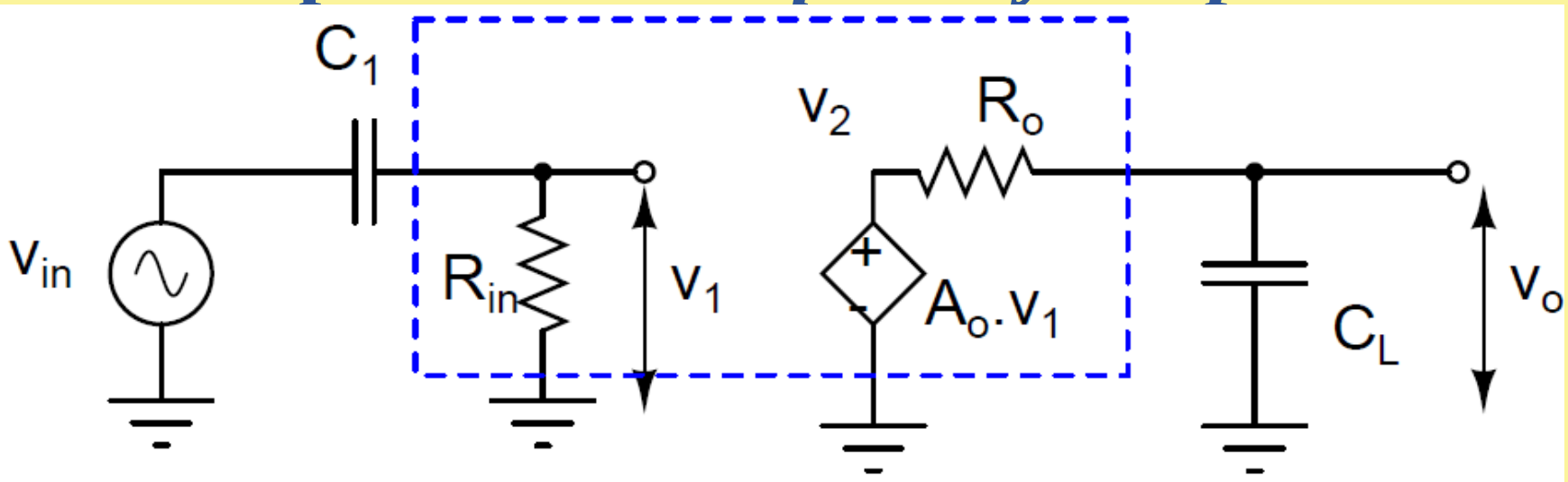
$$= \frac{sR_1C_1A_o}{(1+sR_1C_1).(1+sR_2C_2)}$$

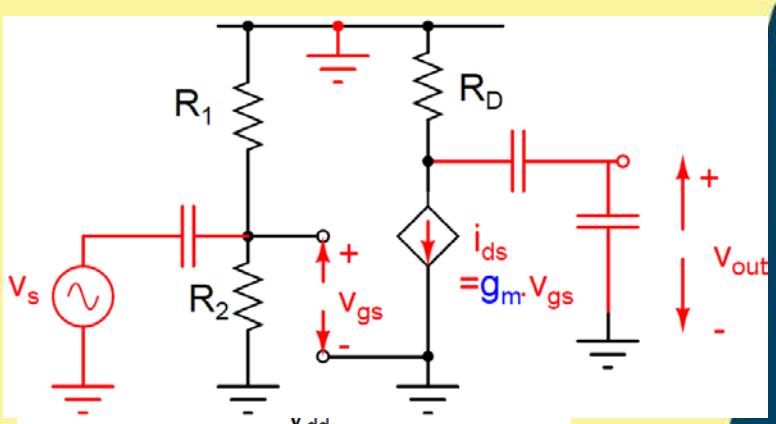
CS amplifier – *Frequency response*

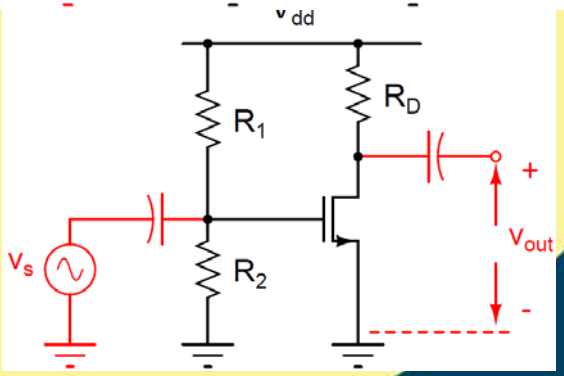




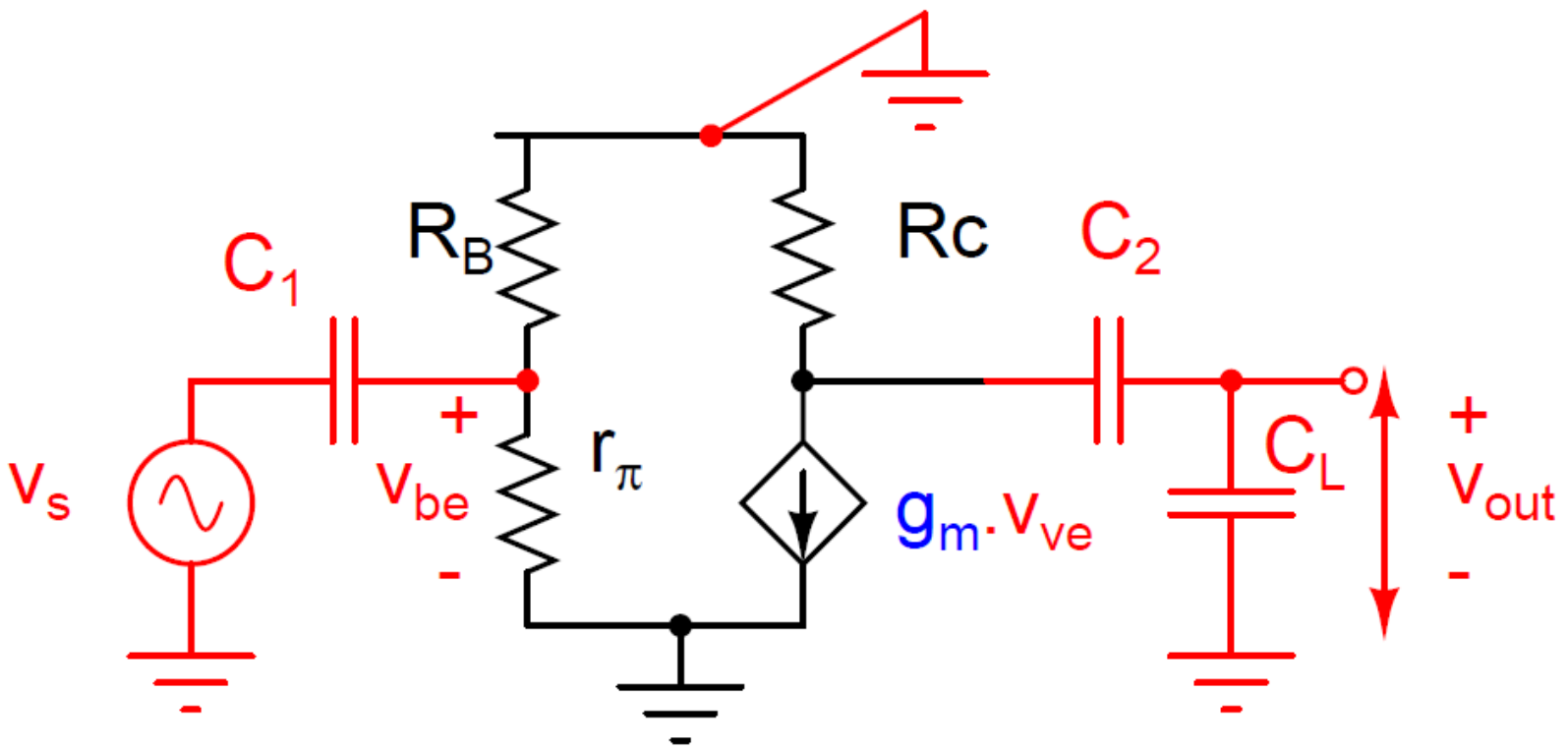
CS amplifier – *Frequency response*

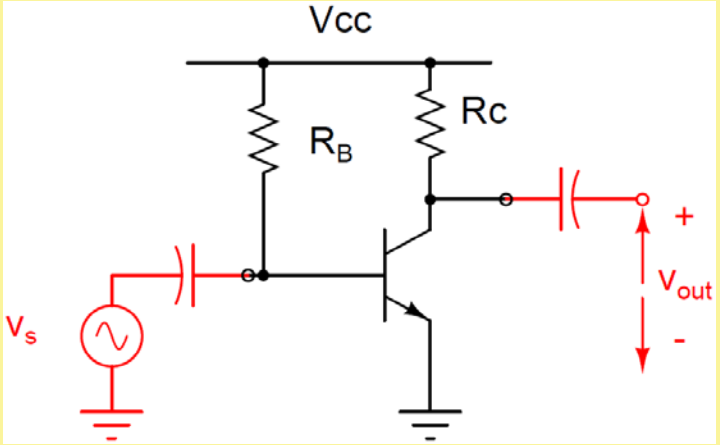




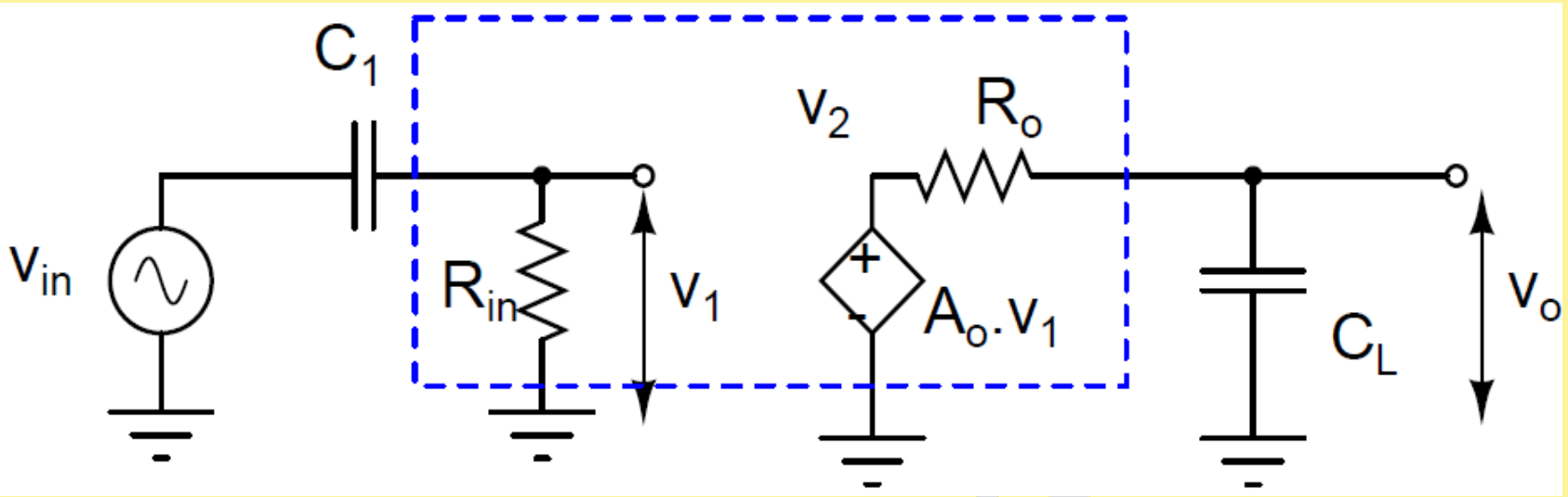


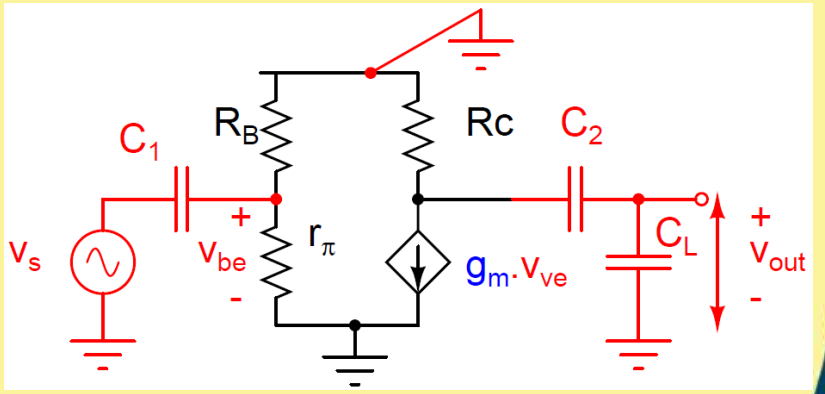
CE amplifier – *Frequency response*





CE amplifier – *Frequency response*





Conclusion

Conclusion:

- Revisited C-R and R-C circuit
- Transfer function and Frequency response
- Relationship between pole in TF and cutoff frequency
- Frequency response of R-C and C-R circuits helps to analyze frequency response of CS/CE amp

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- Pending items:
  - Frequency response of CE amplifier with fixed bias
  - Numerical example
  - Design guidelines

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Thank you

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Topic:

Frequency response of CE and CS Amplifiers (contd.)

CONCEPTS COVERED

Concepts Covered:

- Frequency response of R-C and C-R circuits
- Frequency response of CS amplifier
  - *Circuit analysis*
  - ***Numerical example***
- Frequency response of CE amplifier (***with fixed bias***)
  - *Circuit analysis*
  - ***Numerical example***
- **Frequency response of CE amplifier (*with self bias*)**
  - ***Circuit analysis***
  - ***Numerical example***
- ***Design guidelines***

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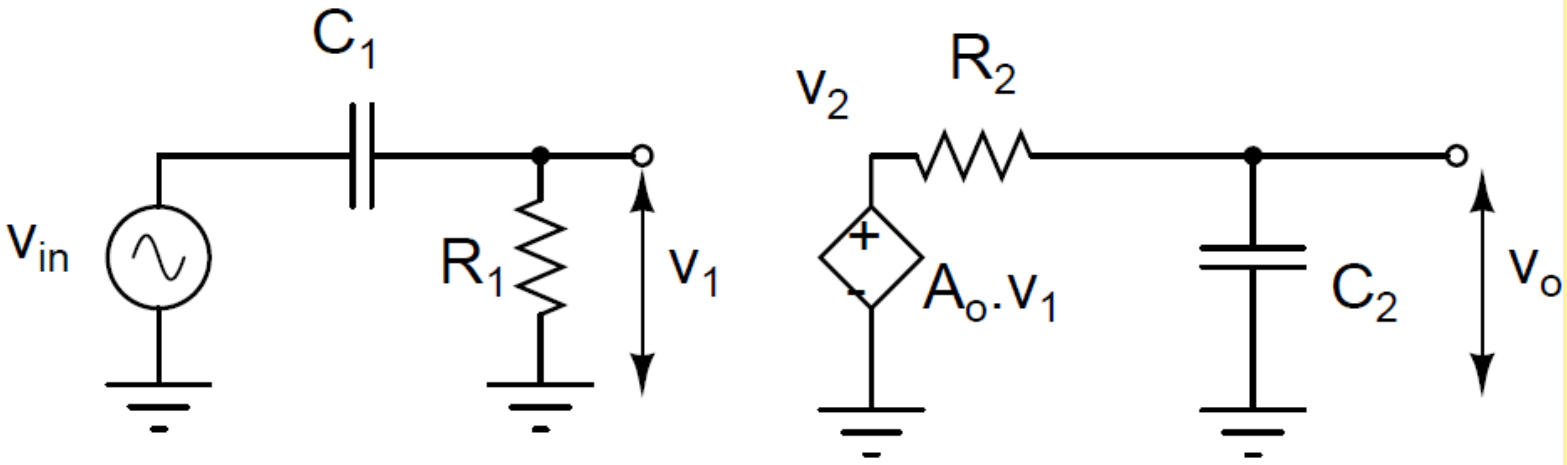
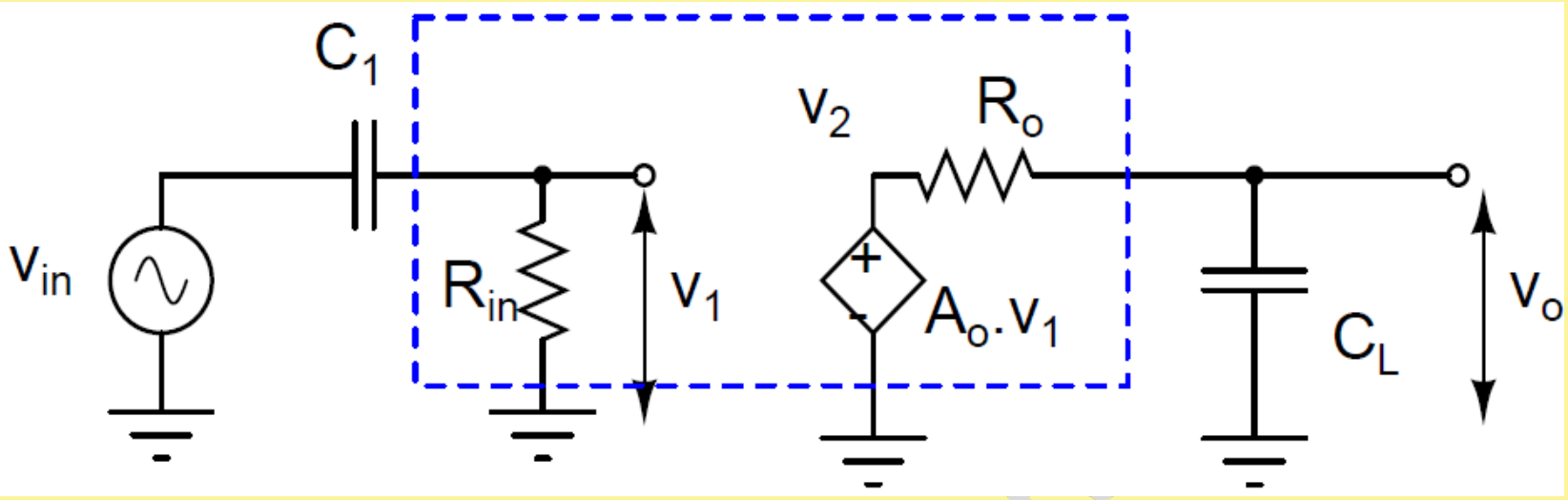
Frequency response of (C-R)-Amplifier-(R-C) circuit

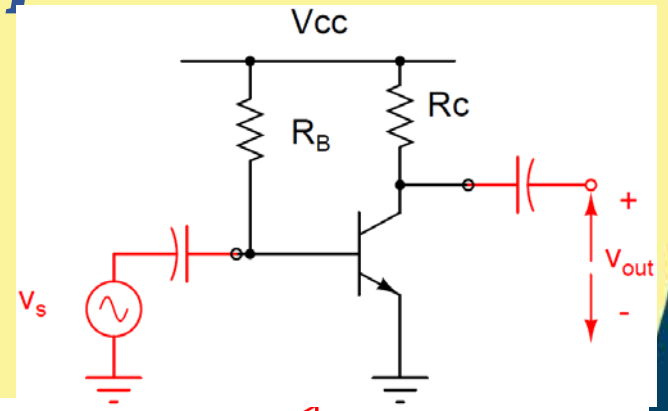
- **Bode plots:**

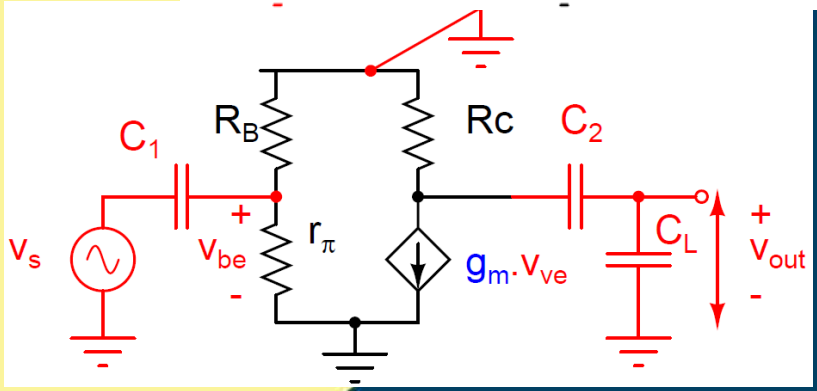


$$\frac{V_o(s)}{V_{in}(s)} = \frac{V_1(s)}{V_{in}(s)} \times \frac{V_2(s)}{V_1(s)} \times \frac{V_o(s)}{V_2(s)} = \frac{sR_1C_1}{(1+sR_1C_1)} \times A_o \times \frac{1}{(1+sR_2C_2)}$$

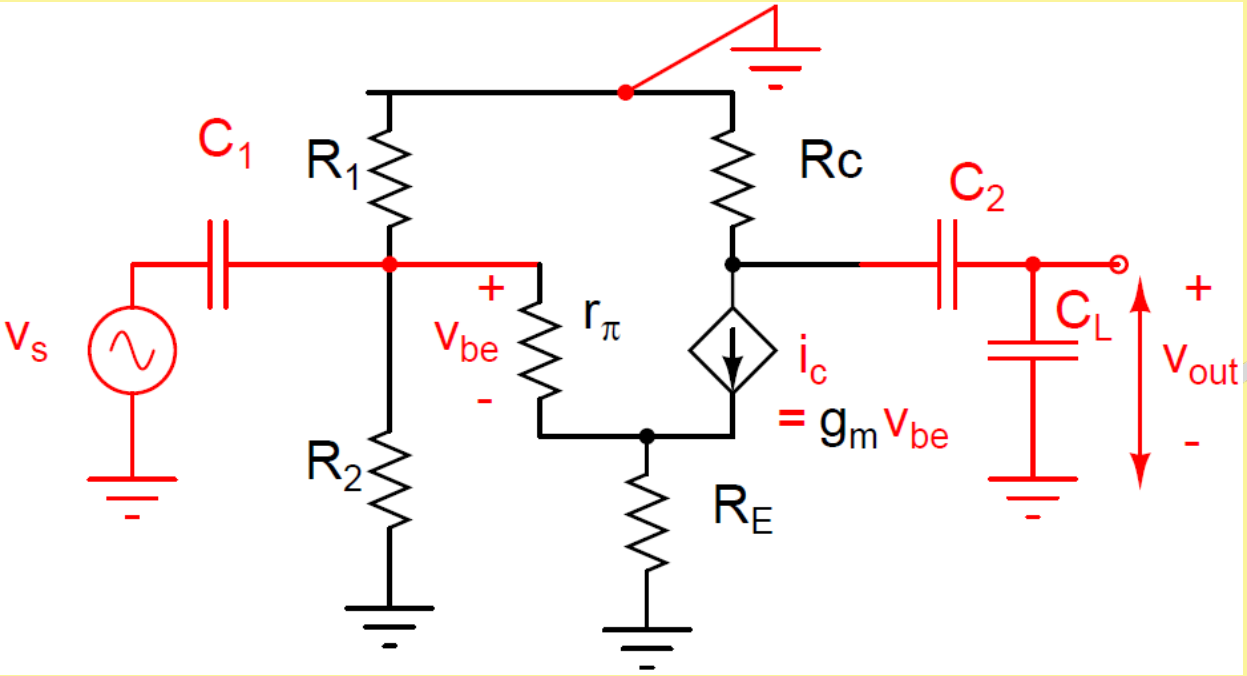
CE amplifier (fixed bias) – *Frequency response*

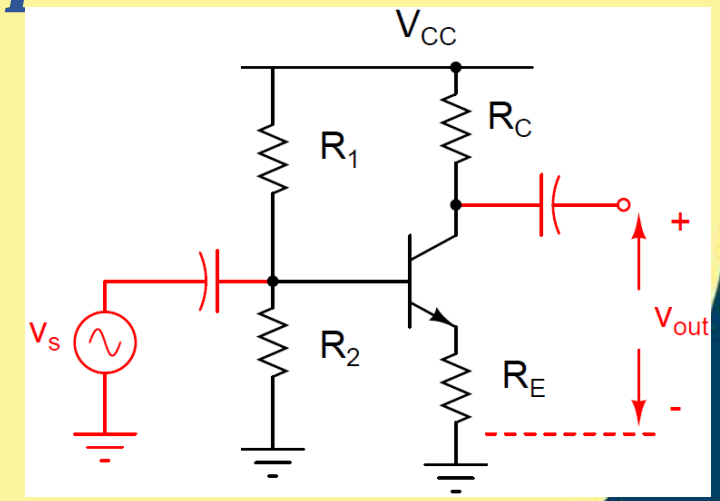






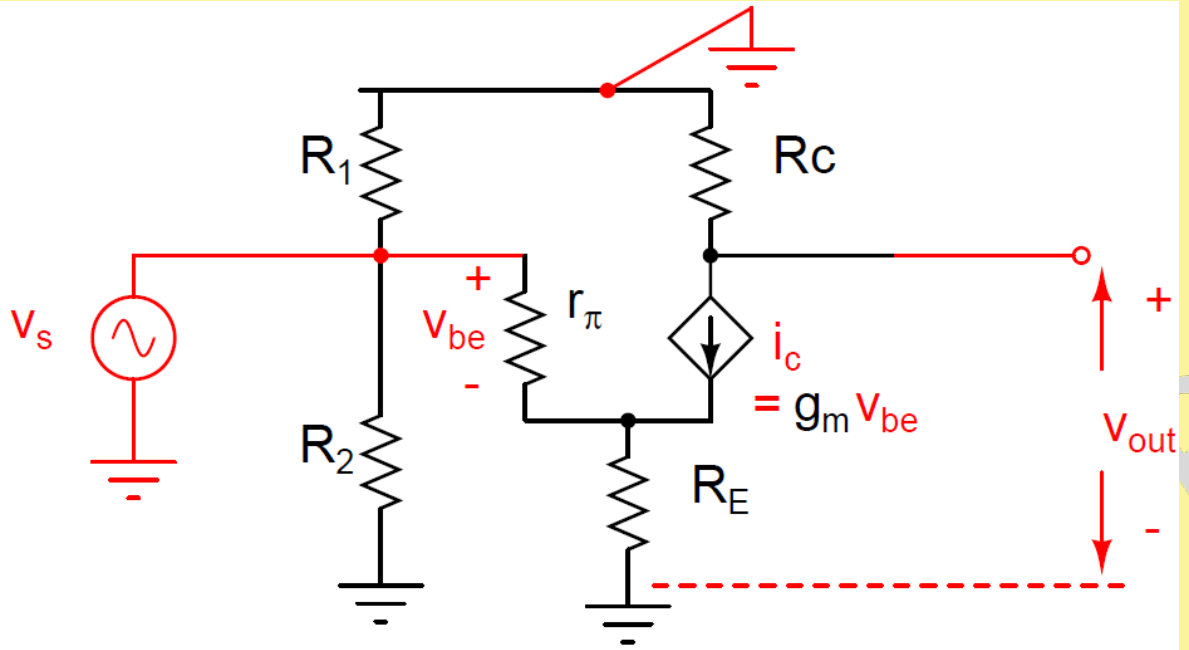
CE amplifier (Self bias) – *Frequency response*

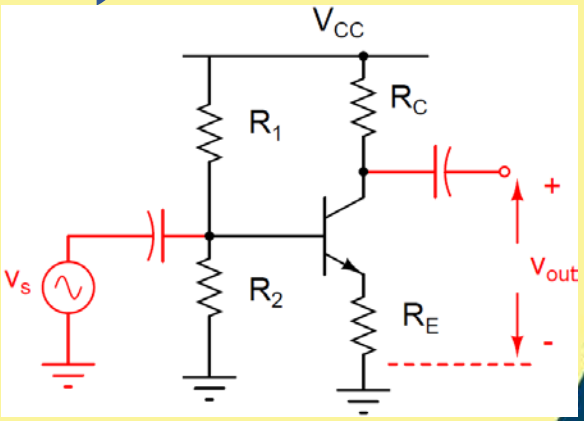




$$\frac{V_{out}(s)}{V_s(s)} = \frac{sR_{in}C_1}{(1+sR_{in}C_1)} \times A_o \times \frac{1}{(1+sR_oC_L)}$$

A_o, R_{in} and R_o of core CE amplifier (Self bias)

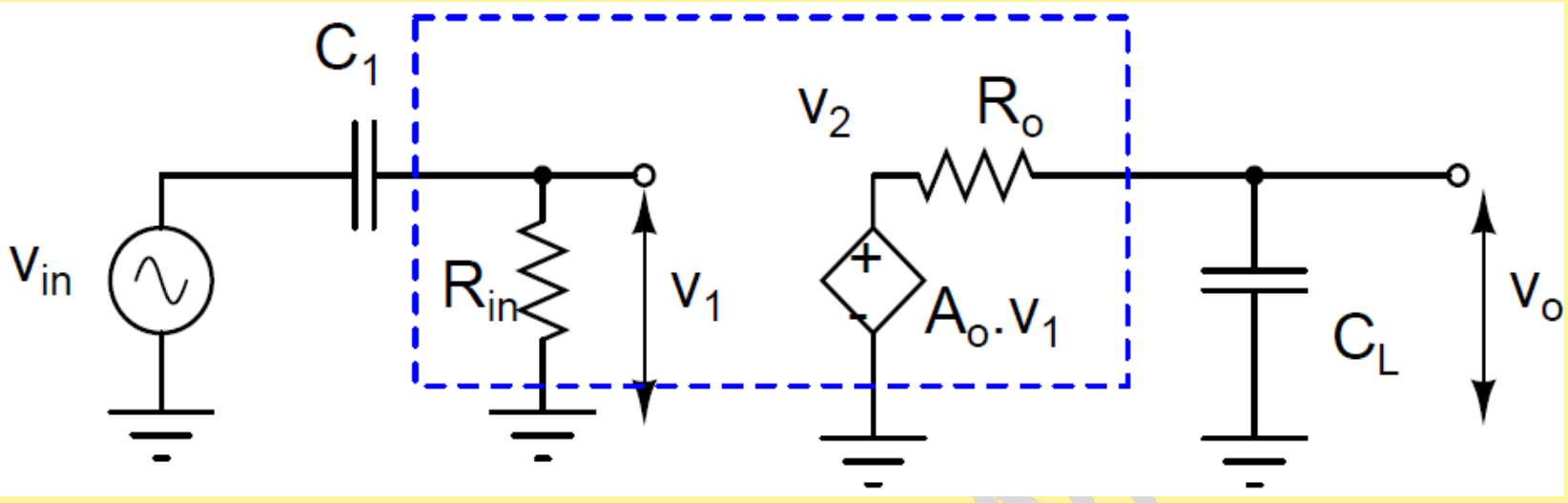


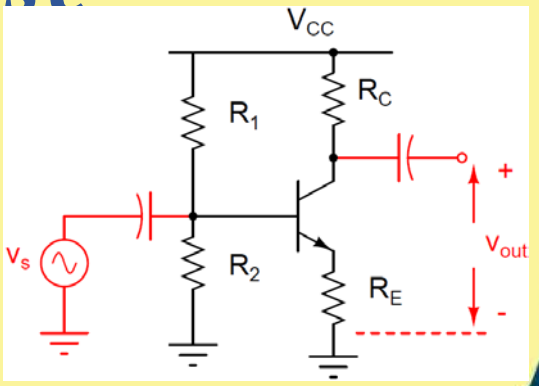


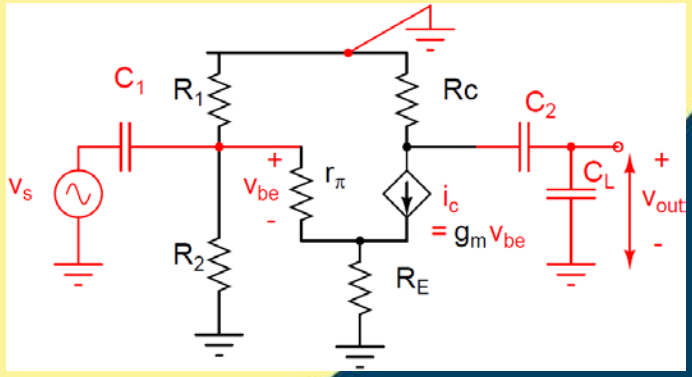
$$A_o = \frac{-g_m R_C}{(1 + g_m R_E)}$$

$$R_{in} = R_1 || R_1 || (r_\pi + R_E(1 + \beta))$$

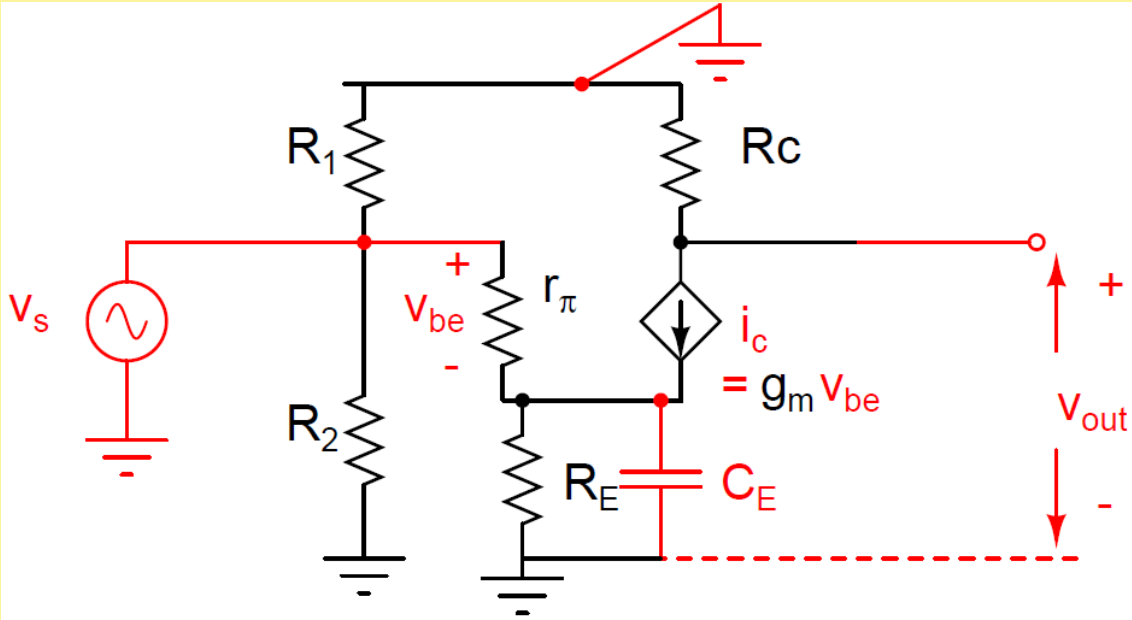
CE amplifier (self bias) – *Frequency response*

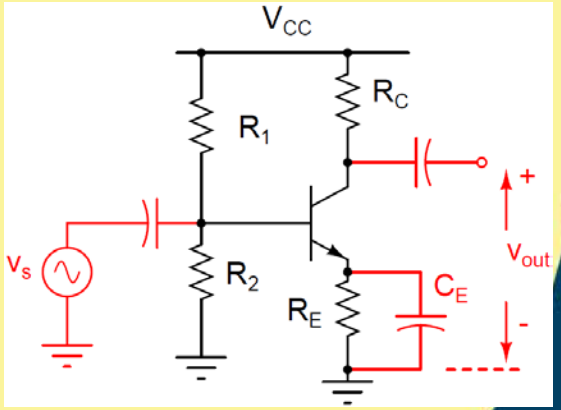






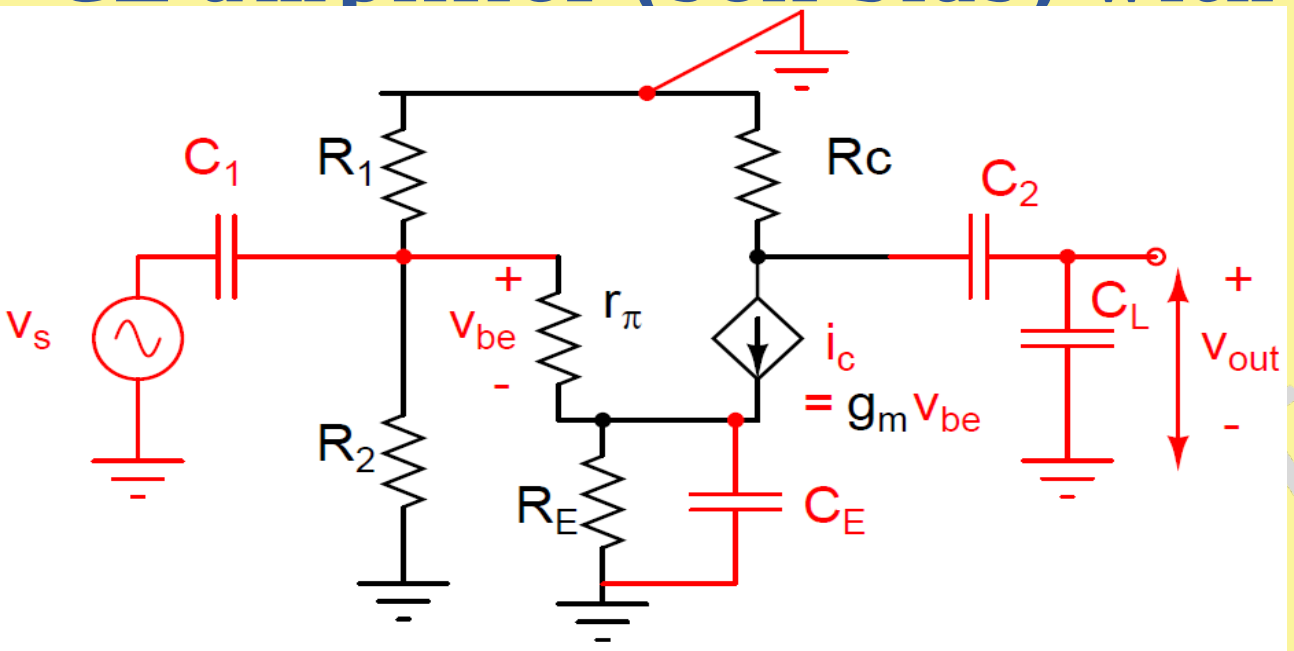
A_o, R_{in} and R_o of core CE amplifier (Self bias) with C_E

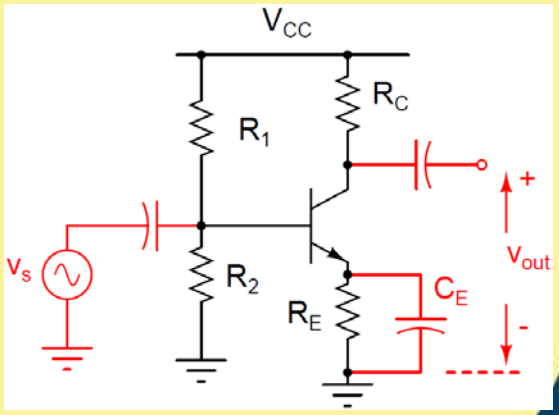




$$A_o = \frac{-g_m R_C}{(1+g_m R_E)} \times \frac{(1+sR_E C_E)}{\left(1+\frac{sR_E C_E}{(1+g_m R_E)}\right)}$$

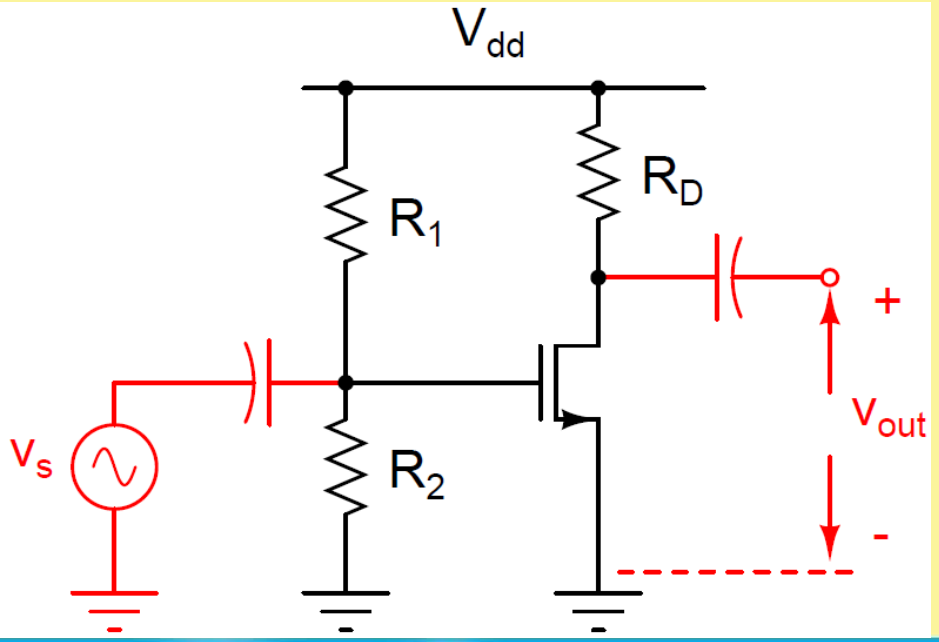
CE amplifier (self bias) with C_E – *Frequency response*





Numerical Example of CS amplifier

- **Given: (K.W/L) = 1mA/V^2; Vth = 1V, Vdd = 12V, R1 = 9kΩ, R2 = 3k Ω , RD = 3 k Ω => *Find small signal parameter, Av, Rin and Ro***
- **$C_1 = C_2 = 10$ µF; $C_L = 100$ pF . *Find Lower and upper cutoff frequencies***



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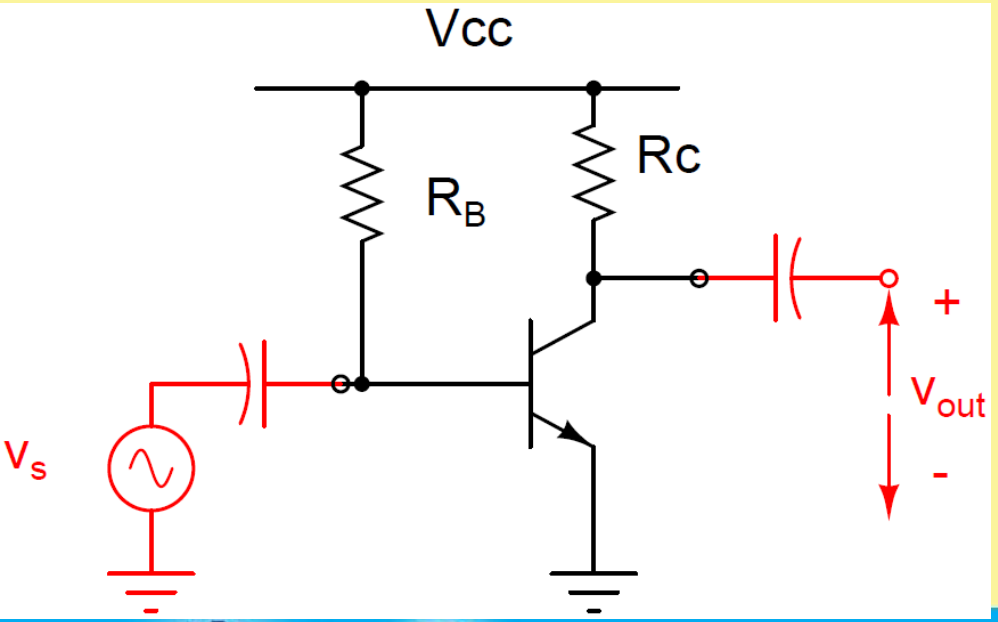
Numerical Example: CE amplifier –Fixed-bias

- $V_{CC} = 12V$; $\beta = 100$; $V_{BE(on)} \approx 0.6V$; $R_B = 570k\Omega$; $R_C = 3.3k\Omega$.

Find Operating point, small signal parameters and voltage gain

- $C_1 = C_2 = 10\ \mu F$; $C_L = 100\ pF$. *Find Lower and upper cutoff frequencies*



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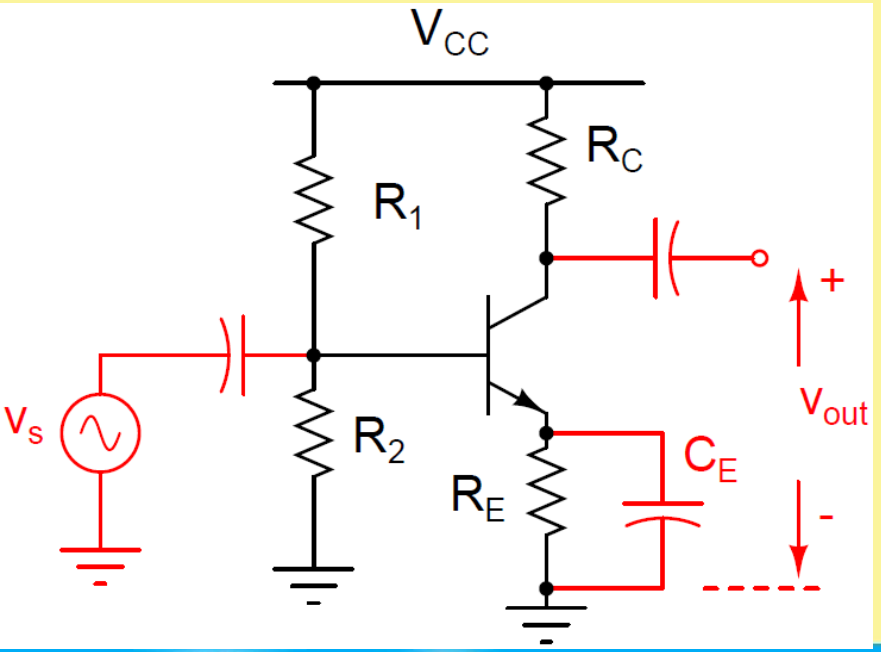
Numerical Example: CE amplifier –Self-bias

- V_{CC} = 12V; β = 200; $V_{BE(on)} \approx$ 0.6V; R_1 = 9.9kΩ; R_2 = 3.3kΩ; R_C= 2.7 kΩ; R_E= 1.2 kΩ . *Find Operating point, small signal parameters and voltage gain*
- $C_1 = C_2$ = 10 µF; C_E = 100 µF ; C_L = 100 pF . *Find Lower and upper cutoff frequencies*



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Conclusion

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- Transfer function and Frequency response
- Relationship between pole in TF and cutoff frequency
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- Frequency response of CE amplifier with fixed bias
- Numerical example
- Design guidelines

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Faculty Name: *Dr. Pradip Mandal*

Department : *Electronics and Electrical Communication Engineering*

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Topic:

Frequency response of CE / CS Amplifiers considering high frequency models of BJT and MOSFET

Flow of Discussion (Bottom-up) – *Building blocks*

- System/ Sub-systems (*for specific application*)
  - Modules (*performing specific tasks*)
    - **Building blocks (** *having specific characteristics* **)**
      - Components (*devices/circuit elements*)
- **Week 4**:
  - **Frequency response of CE and CS amplifiers,**
  - **High frequency models of BJT and MOSFET, and their usages.**
  - **Limitations of CE/CS amplifiers and hence the need of buffers.**

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CONCEPTS COVERED

Concepts Covered:

- Impact of high frequency models of transistors on Frequency response of CE and CS amplifiers
- Use of Miller's theorem
- Frequency response of R-C-R||C circuit
- *Numerical examples*
  - *CE amp. with fixed-bias*
  - *CS amp*
  - *CE amp with self bias*

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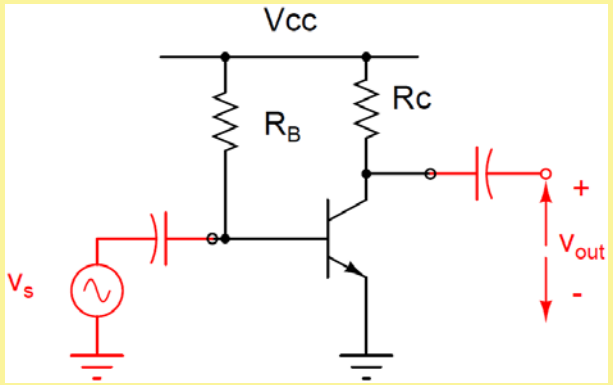
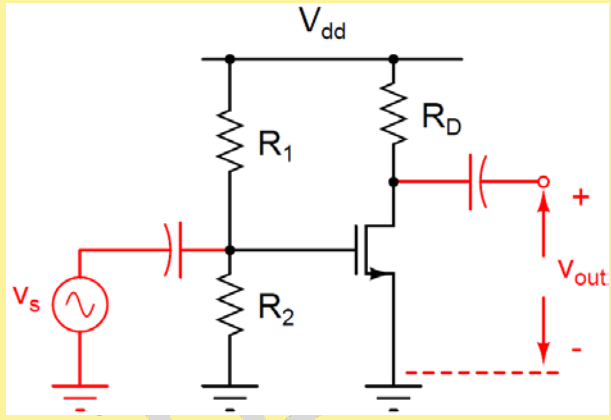
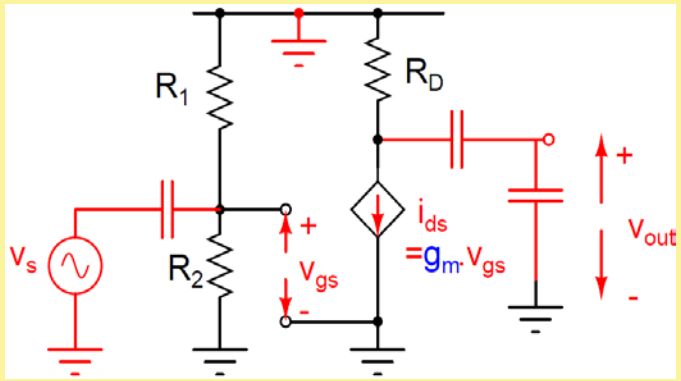
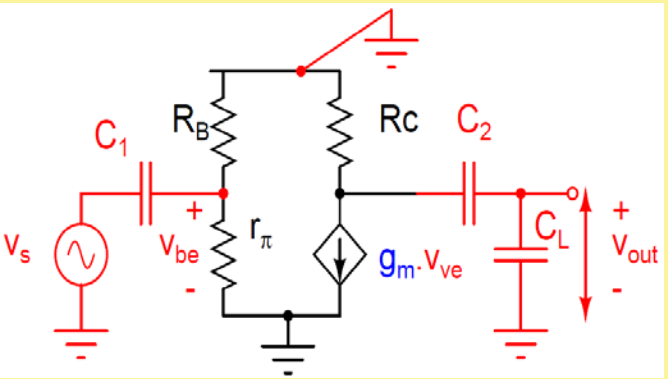
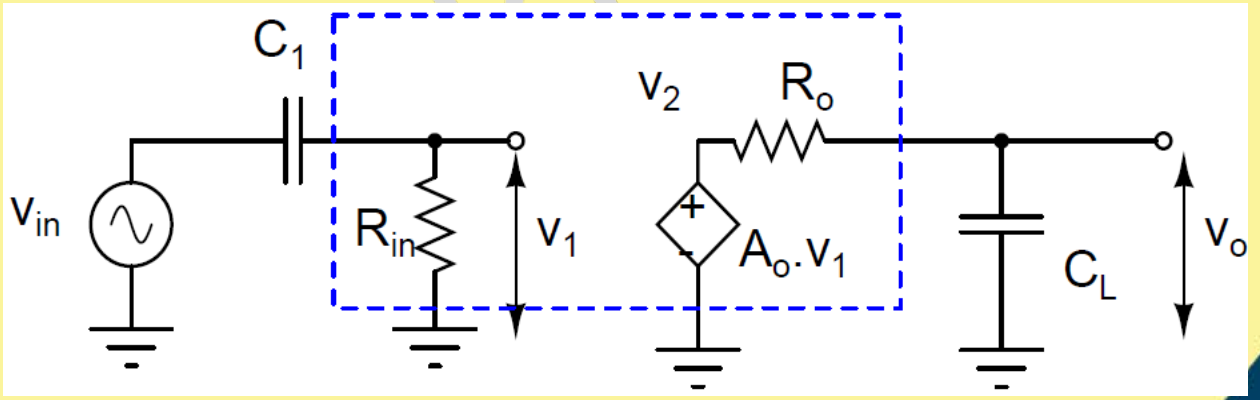
Frequency response of CE and CS amplifier (*recapitulation*)





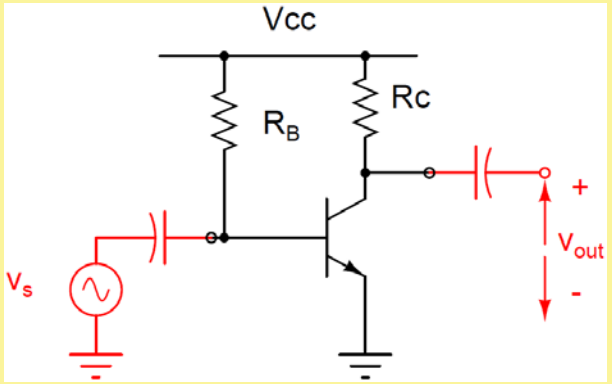


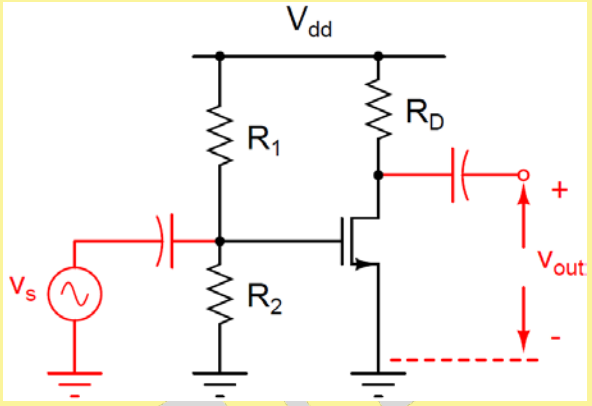


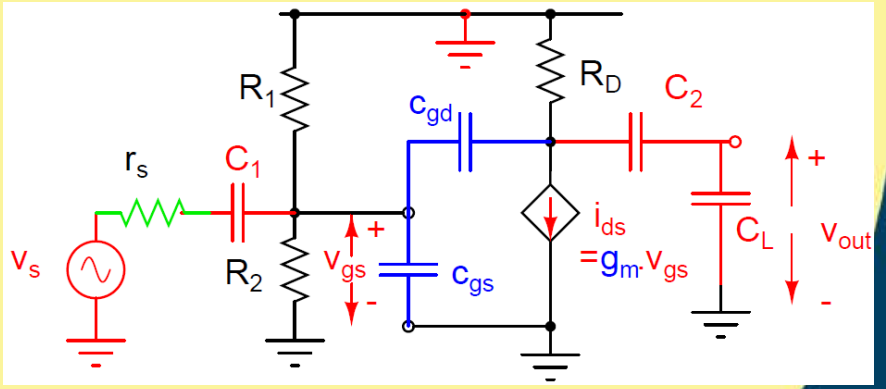


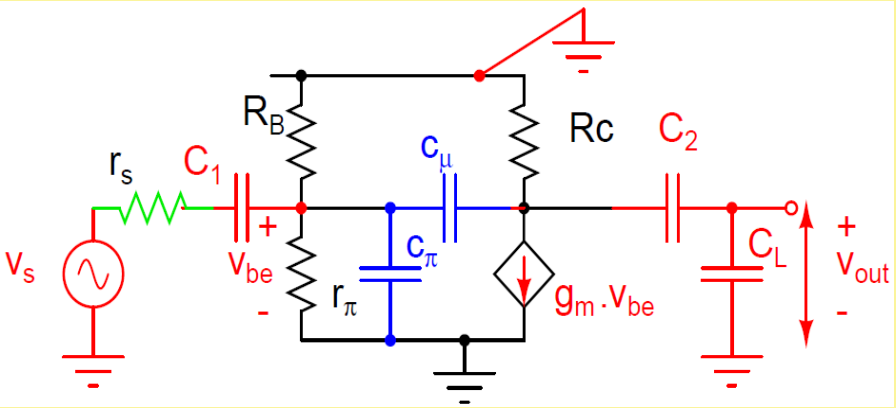
Frequency response of CE and CS amplifier

(considering high frequency models of transistors)



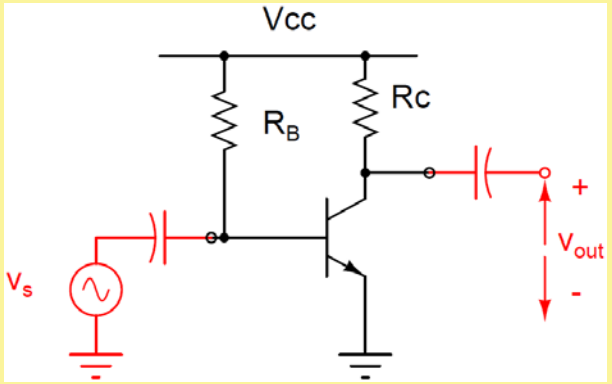


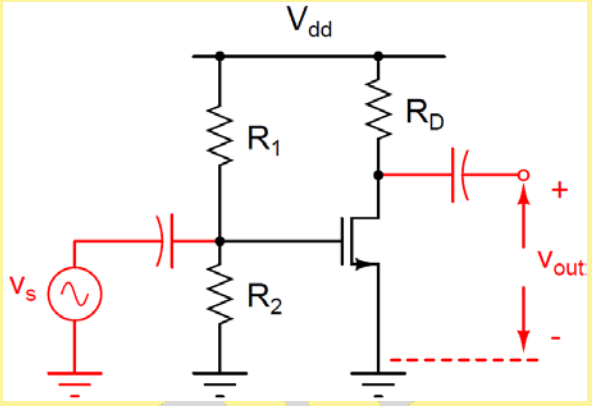


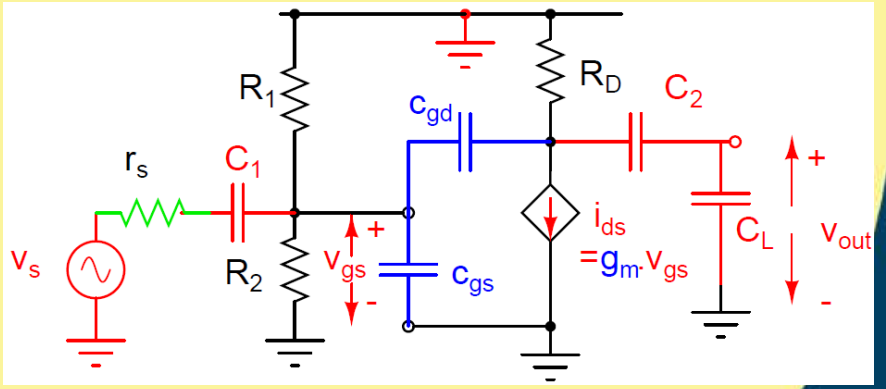


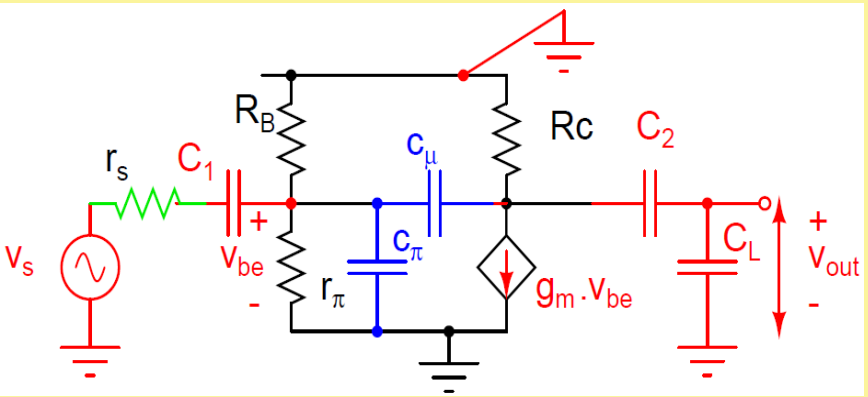
- **Cπ/ Cgs at input port and**
- **Cμ /Cgd between input and output terminals**
- **Presence of source resistance rs**

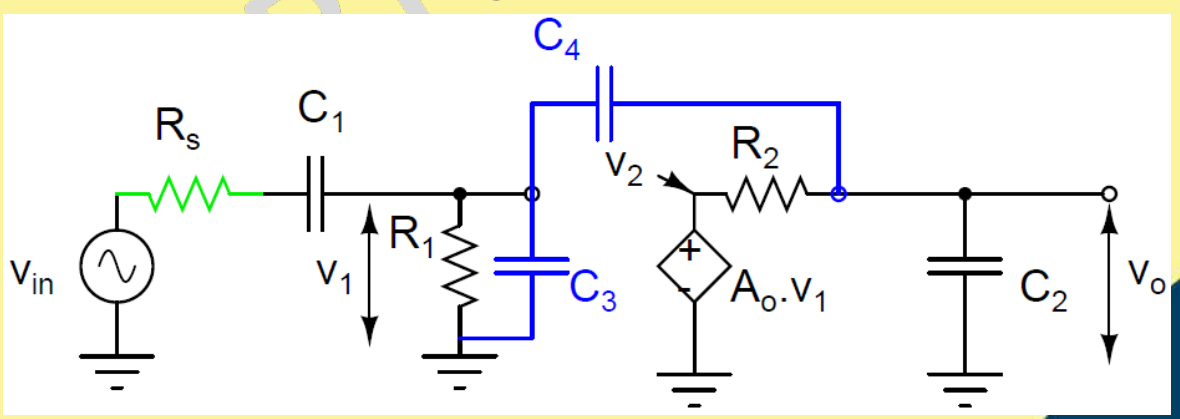
Frequency response of CE / CS amplifier
considering high frequency models of transistors (contd.)





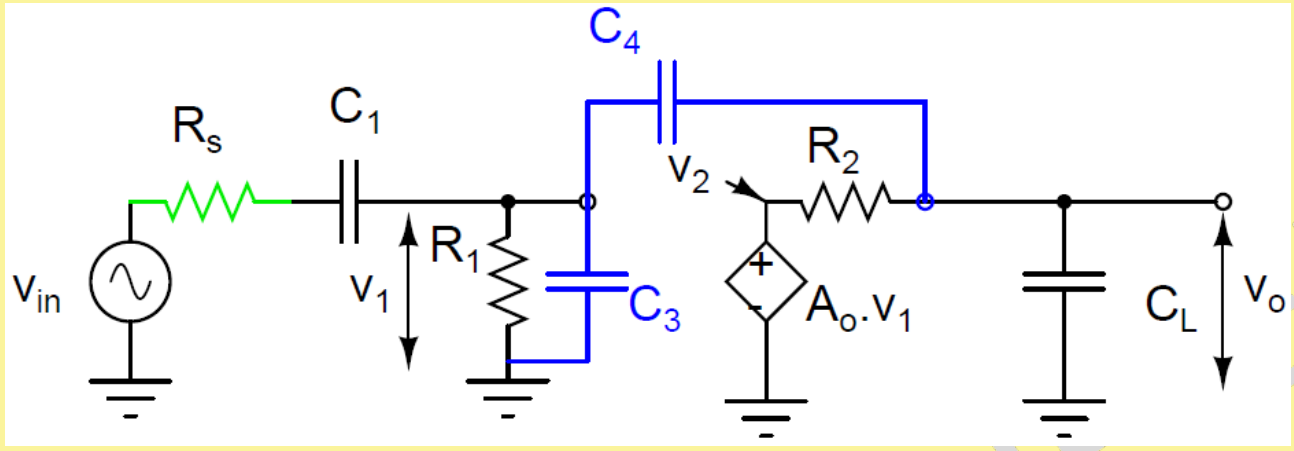






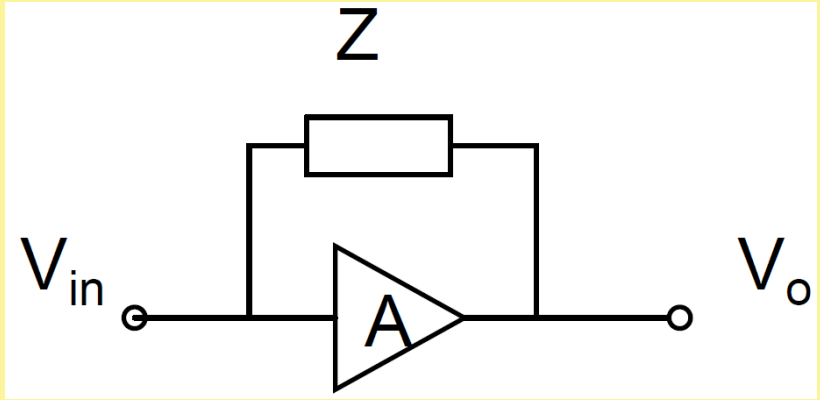
Frequency response of CE / CS amplifier

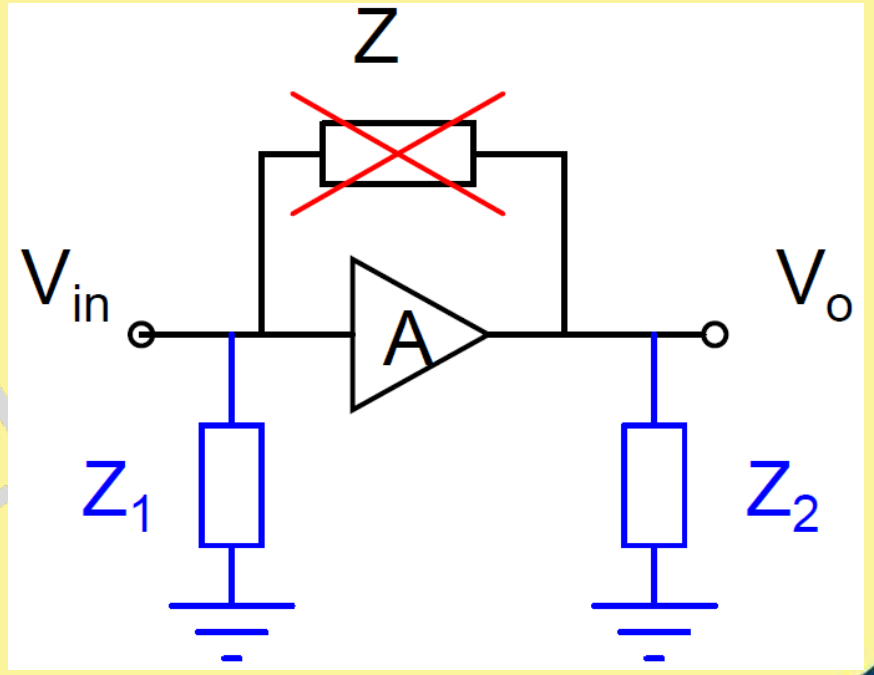
considering high frequency models of transistors (contd..)



- **Effect of C3 (Cπ/ Cgs) and Rs: Additional R-C effect at the input port**
- **Effect of C4 (Cμ /Cgd) connecting input and output terminals**
  - **Millers theorem**

Miller's Theorem:





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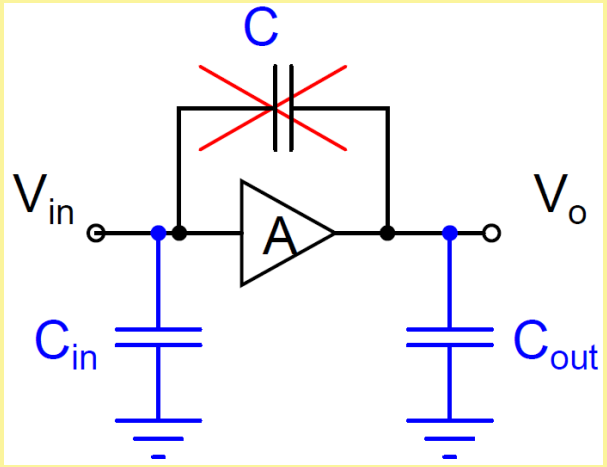
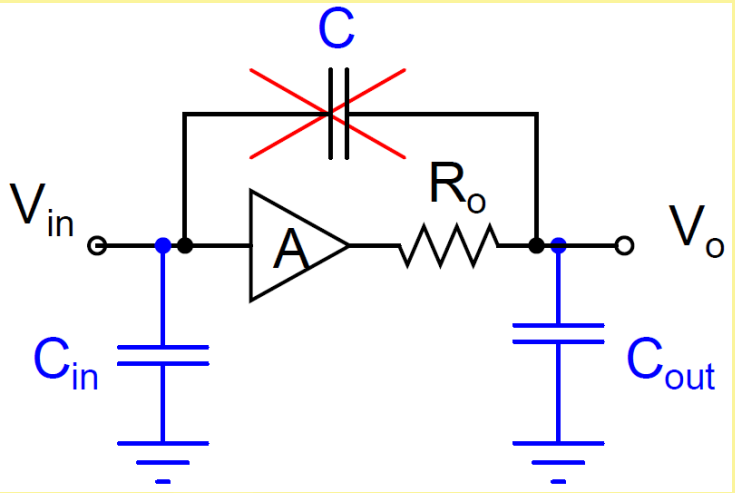
Miller's Theorem (contd.) :





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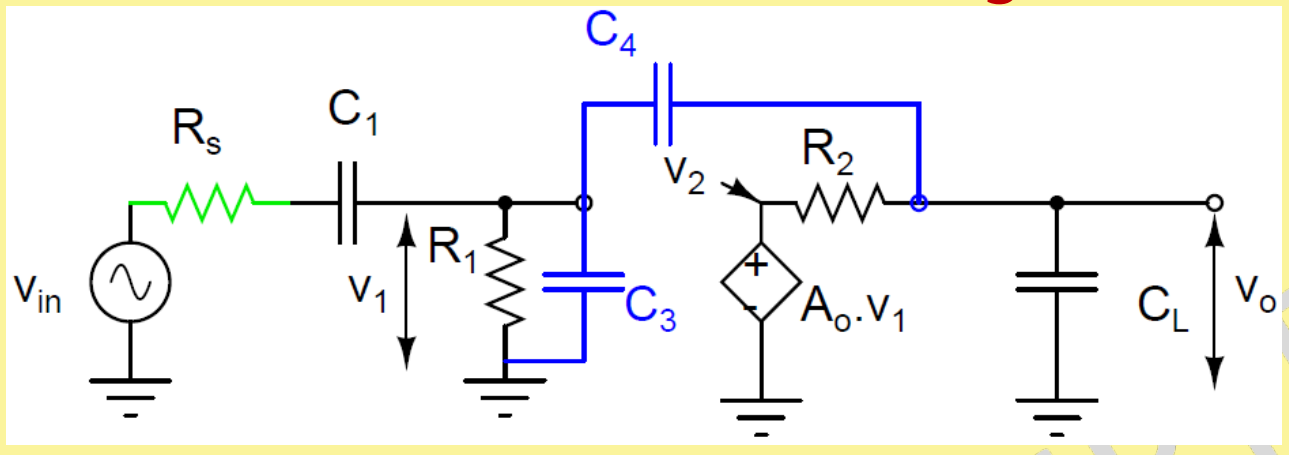
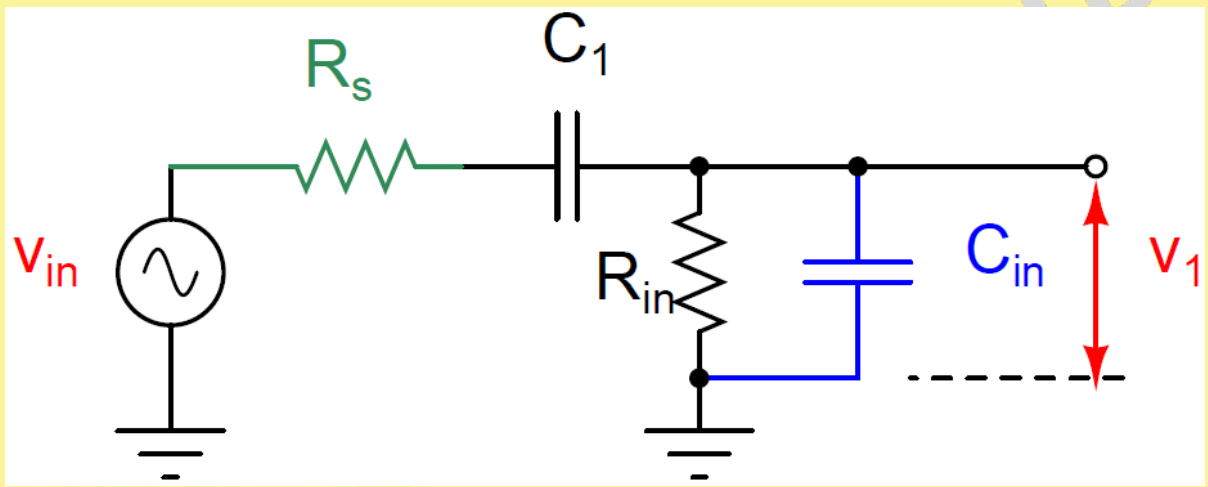
Effective input/output capacitances of CE / CS amplifiers

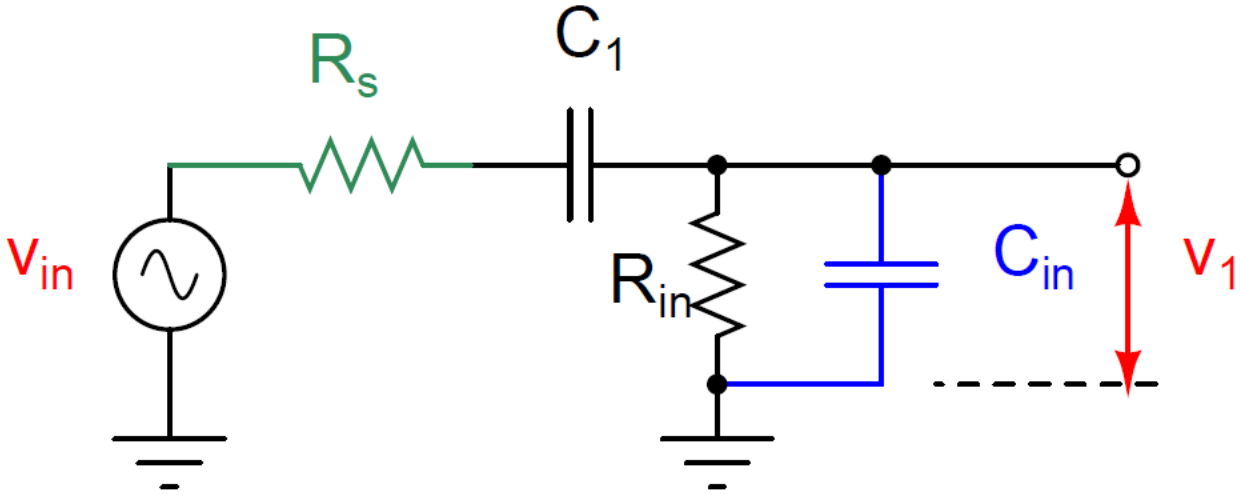
using Miller's theorem





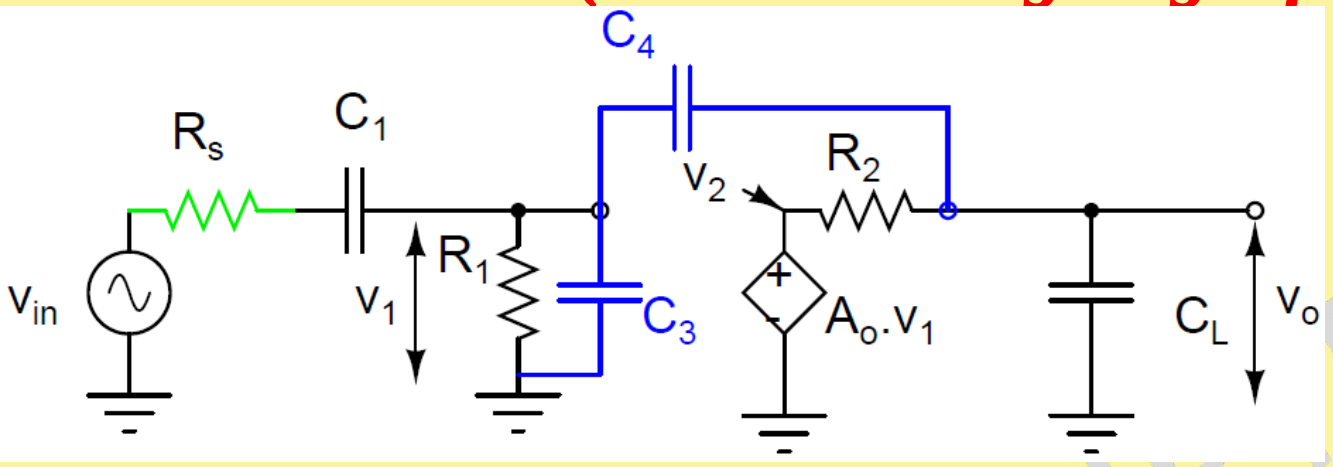
- **C4 (C_μ /Cgd) can be "converted" into input port cap and output port cap**

Frequency response of R-C-R||C circuit



Frequency response of generalized equivalent ckt of CE / CS amps

(considering high frequency models)



- **Find the expressions of lower- and upper-cutoff frequencies**

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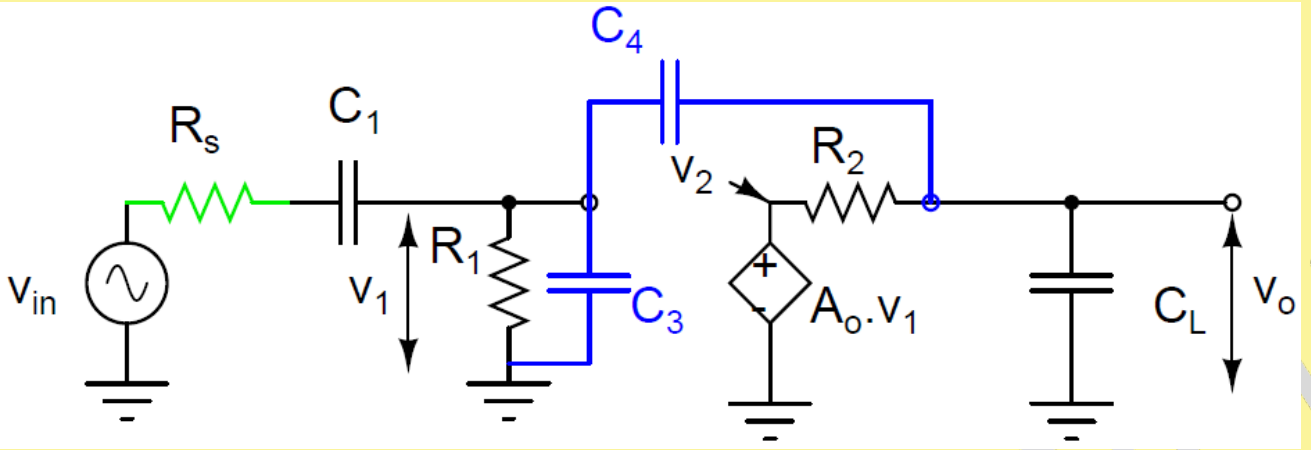
Numerical example:

Frequency response of equivalent circuit of CE / CS amplifier



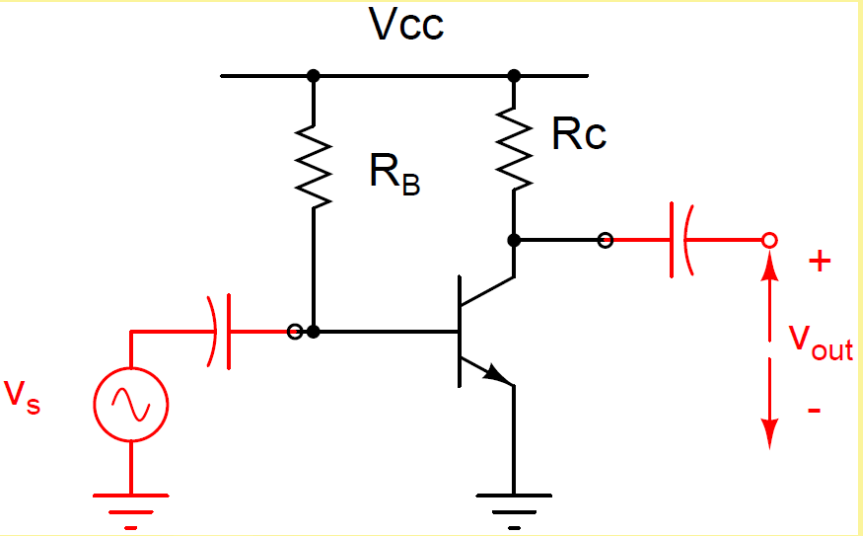
- R1 = 1.3kΩ, R2 = 3.3 kΩ, Rs = 650Ω
- C_L = 100pF, C1 = 10μF, C3 = 10pF C_4 = 5pF
- Av = -240
- **Find the frequency response of the circuit.**
  - **Mid-frequency gain**
  - **lower-cutoff frequency and**
  - **upper-cutoff frequencies**

Numerical Example: CE amplifier –Fixed-bias

- $V_{CC} = 12V$; $\beta = 100$; $V_{BE(on)} \approx 0.6V$; $R_B = 570k\Omega$; $R_C = 3.3k\Omega$,

Find Operating point, small signal parameters and voltage gain

- $C_1 = C_2 = 10\ \mu F$; $C_L = 100\ pF$; $R_S = 650\Omega$
- ***Find Lower and upper cutoff frequencies considering $C\pi = 10\ pF$ and $C\mu = 5\ pF$***



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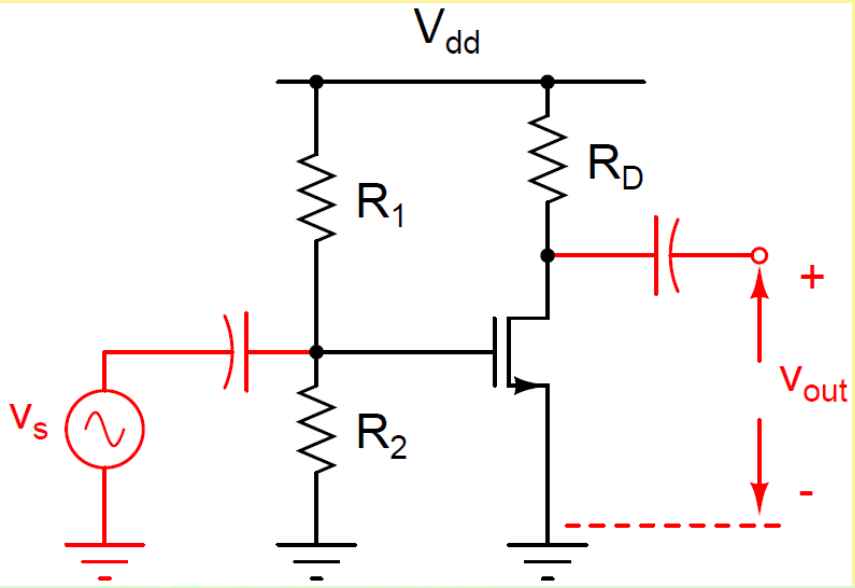
Numerical Exercise (CS amplifier)

- **Given:** (K.W/L) = 1mA/V^2; Vth = 1V, Vdd = 12V, R1 = 9kΩ, R2 = 3k Ω , R_D = 3 k Ω
- *Find small signal parameter, Av, Rin and Ro*
- $C_1 = C_2 = 10\ \mu F$; $C_L = 100$ pF, Rs = 750 Ω.
- *Find Lower and upper cutoff frequencies considering Cgs = 10 pF and Cgd = 5 pF*



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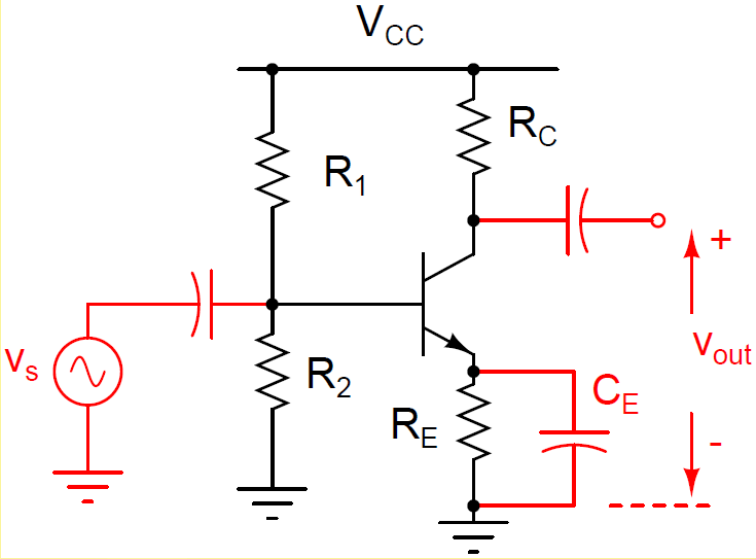
Numerical Exercise: CE amplifier –Self-bias

- V_{CC} = 12V; β = 200; $V_{BE(on)} \approx$ 0.6V; R_1 = 9.9kΩ; R_2 = 3.3kΩ; R_C= 2.7 kΩ; R_E= 1.2 kΩ
- *Find Operating point, small signal parameters and voltage gain*
- $C_1 = C_2$ = 10 µF; C_E = 100 µF ; C_L = 100 pF, **R_s = 650Ω**
- *Find Lower and upper cutoff frequencies considering $C\pi$ = 10 pF and $C\mu$= 5 pF*



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Conclusion

Conclusion:

- Frequency response of CE and CS amplifier considering high frequency model of transistors particularly with Rs
  - Lower cutoff frequency
  - Upper cutoff frequency
  - Mid-frequency gain
- Equivalent circuit of CE and CS has been analyzed Using
  - Miller's theorem and
  - Frequency response of R-C-R||C circuit
- *Numerical examples* considering high frequency models
  - *CE with fixed bias and self bias*
  - *CS*

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Thank you

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Course Name: *Analog Electronic Circuits*

Faculty Name: *Dr. Pradip Mandal*

Department : *Electronics and Electrical Communication Engineering*

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Topic:

Limitation of CE and CS Amplifiers in cascading

Flow of Discussion (Bottom-up) – *Building blocks*

- **System/ Sub-systems (***for specific application***)**
  - **Modules (** *performing specific tasks***)**
    - **Building blocks (** *having specific characteristics* **)**
      - **Components (** ***devices/circuit elements*** **)**
- **Week 4:**
  - **Frequency response of CE and CS amplifiers,**
  - **High frequency models of BJT and MOSFET, and their usages.**
  - **Limitations of CE/CS amplifiers (in cascading) and hence the need of other configurations (buffers).**

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CONCEPTS COVERED

Concepts Covered:

- Frequency response of cascaded amplifiers
  - CE-CE
  - CS-CS
- Cascaded amplifiers with buffer
  - CE-buffer-CE
  - CS-buffer-CS
- Necessary features of a buffer for cascading

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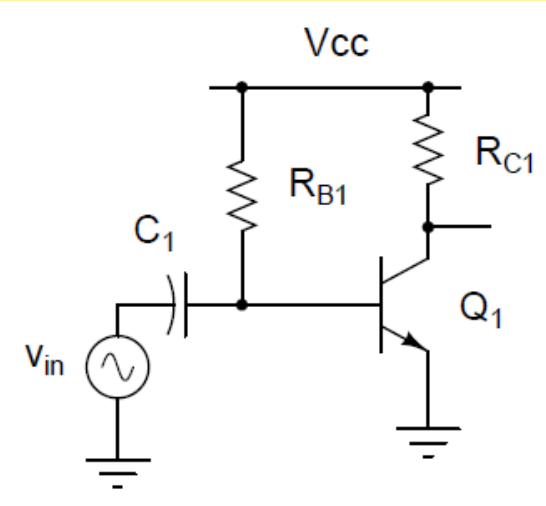
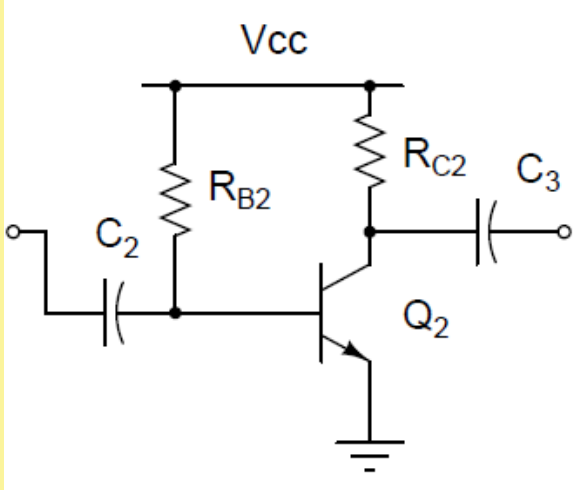
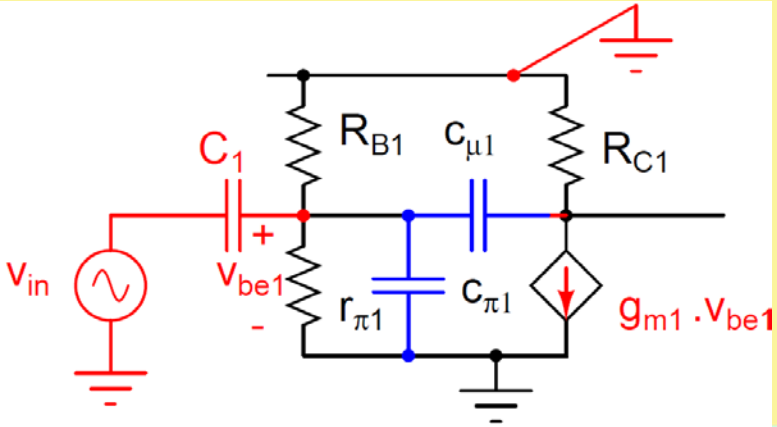
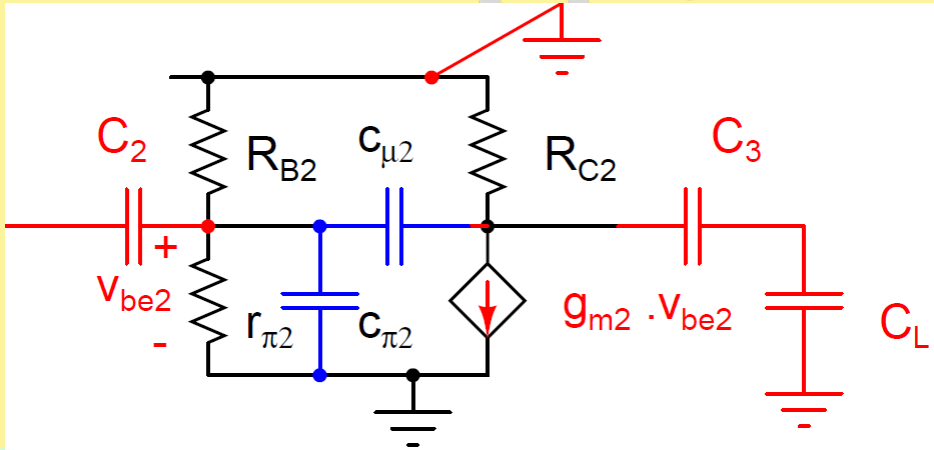
Frequency response of cascaded CE-CE amplifier

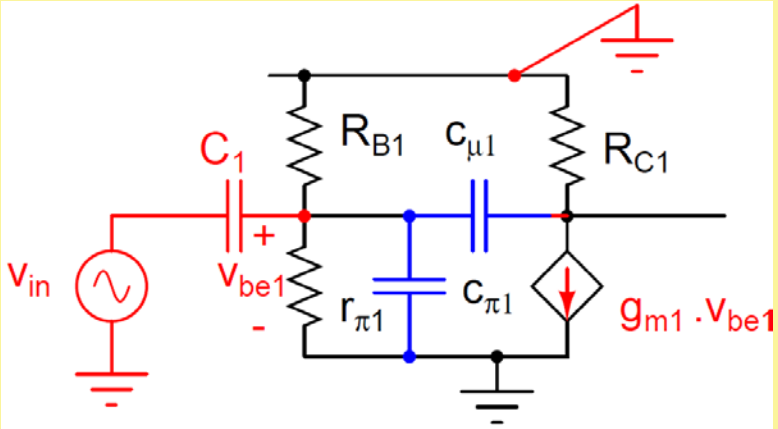


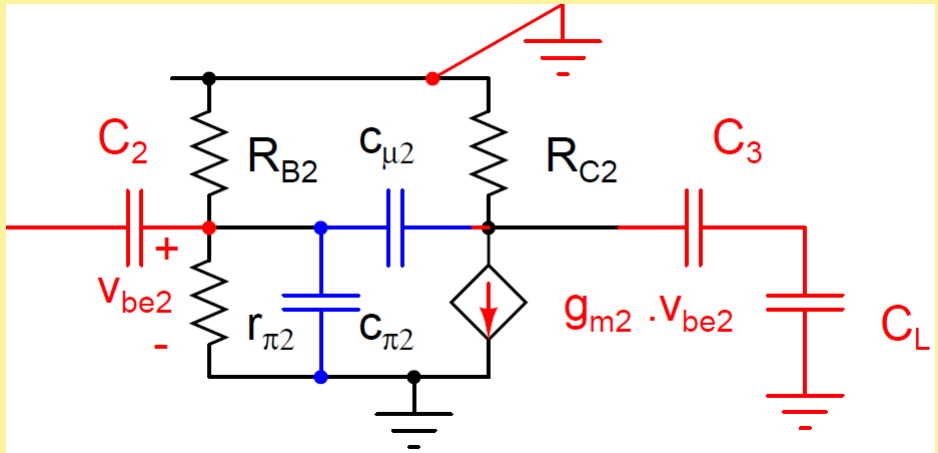


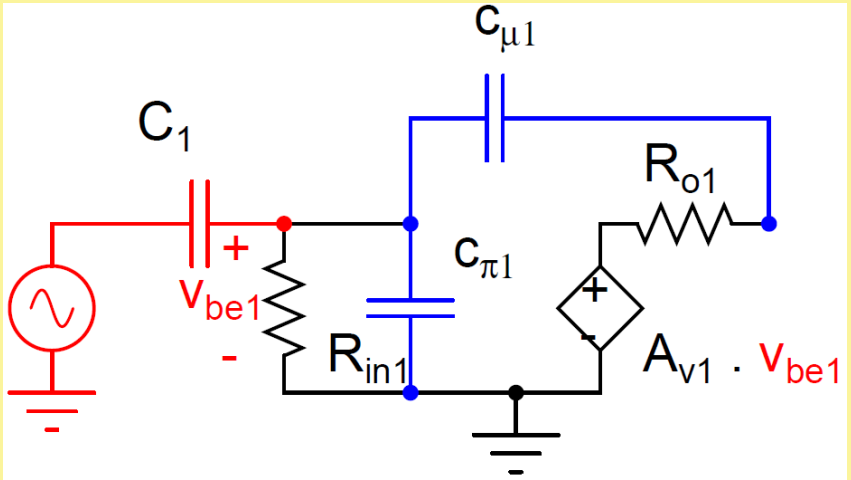


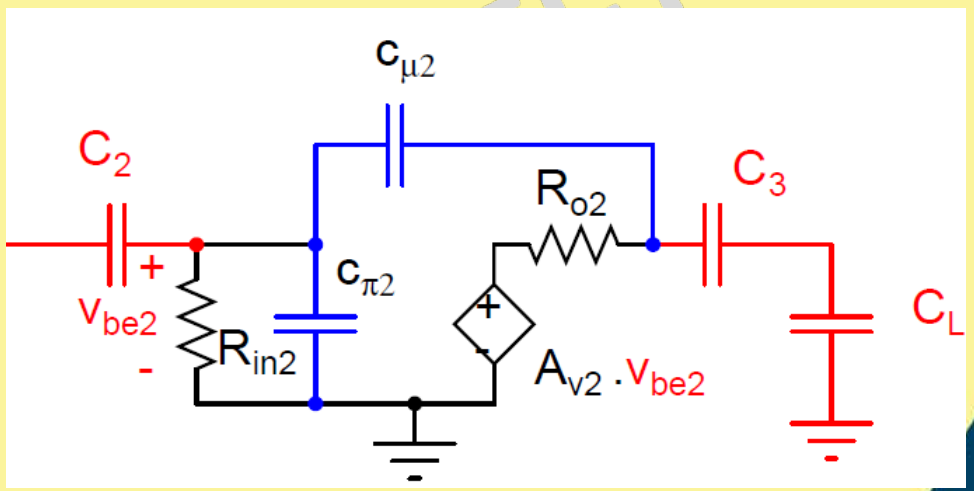


Frequency response of cascaded CE-CE amplifier (*contd.*)

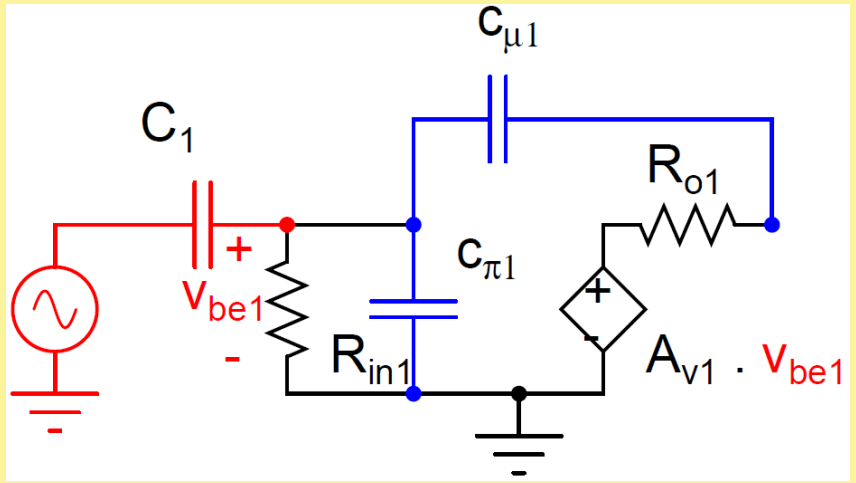


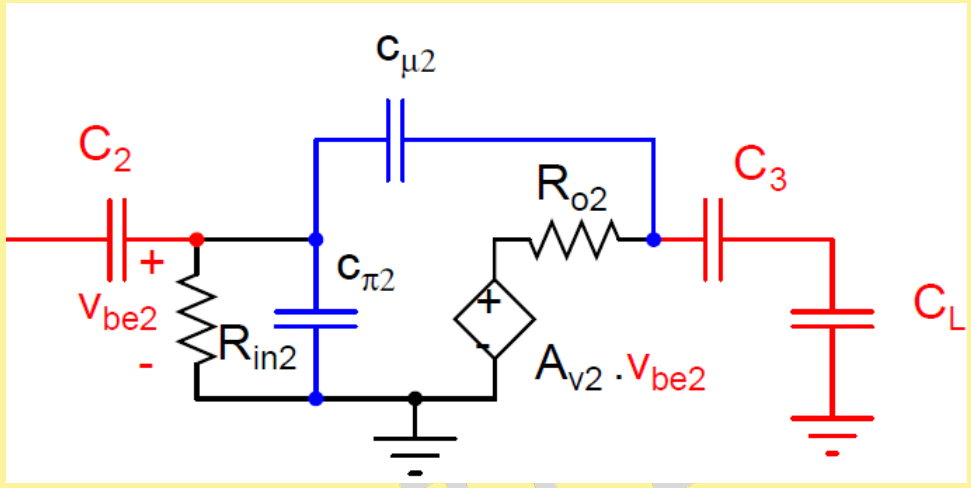






Frequency response of cascaded CE-CE amplifier (*contd.*)

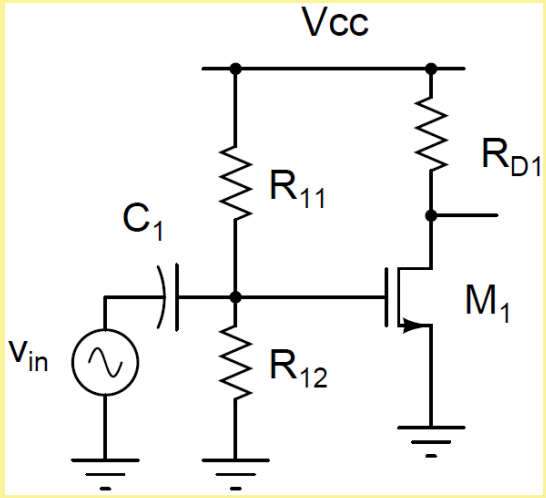


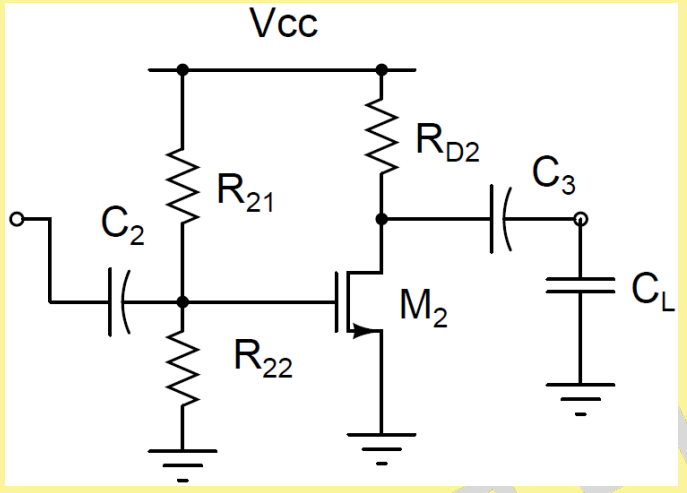


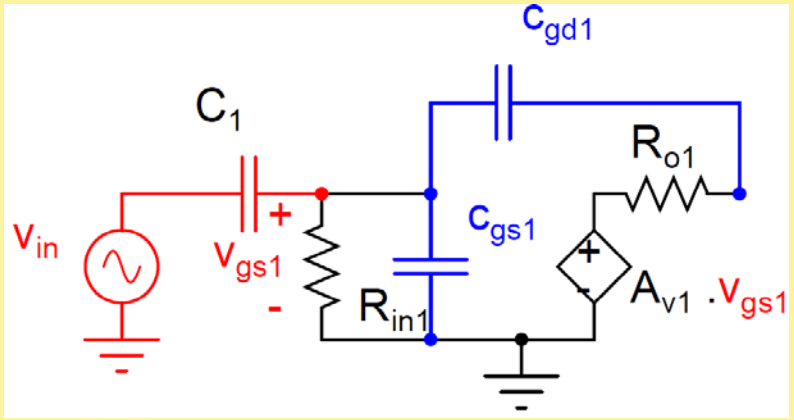
- **Overall voltage gain:**

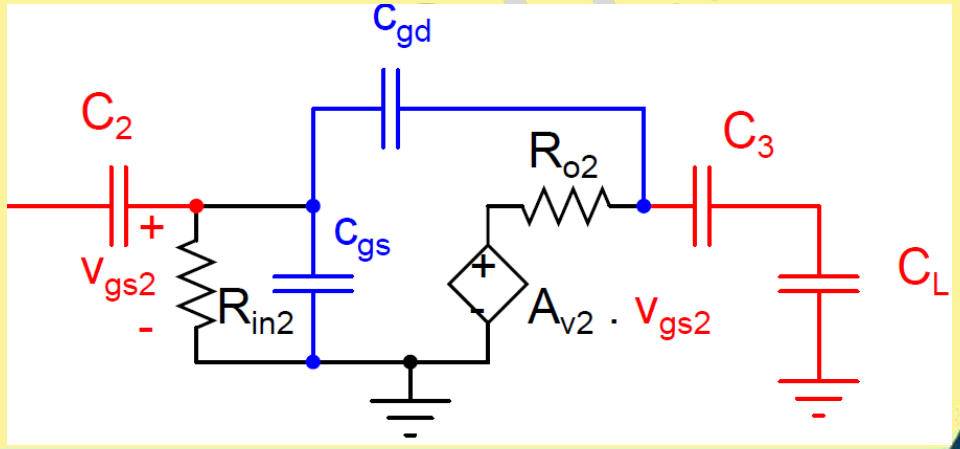
- **Upper cutoff frequency:**

Frequency response of cascaded CS-CS amplifier

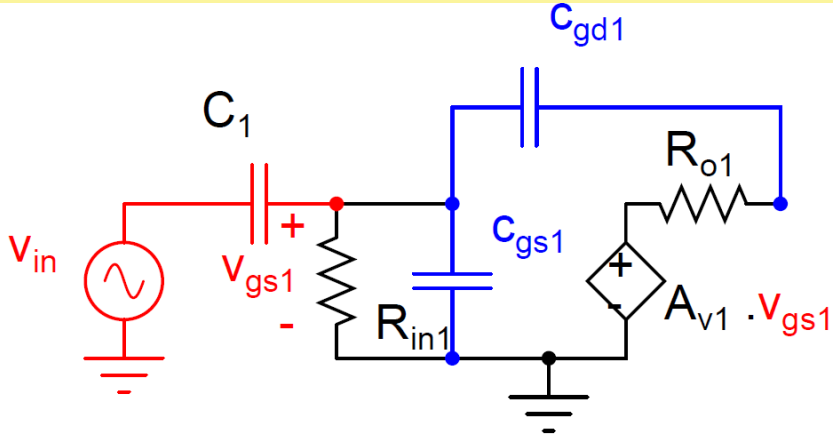


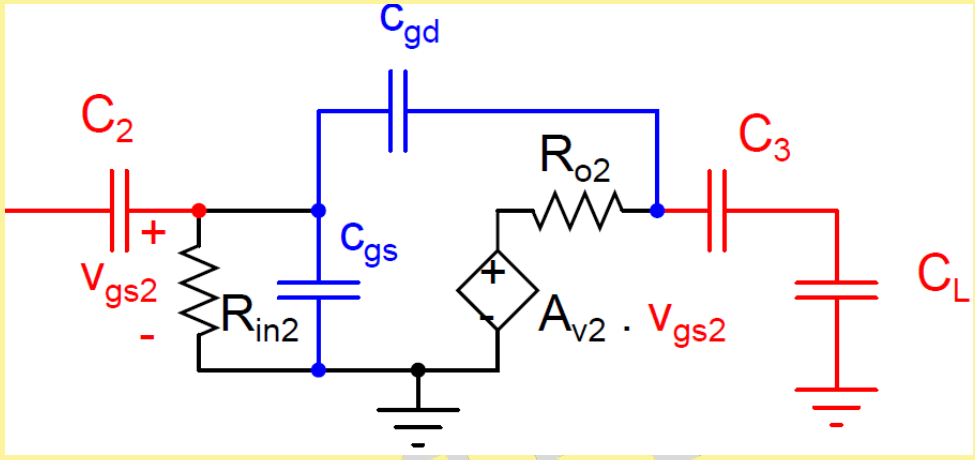






Frequency response of cascaded CS-CS amplifier (*contd.*)

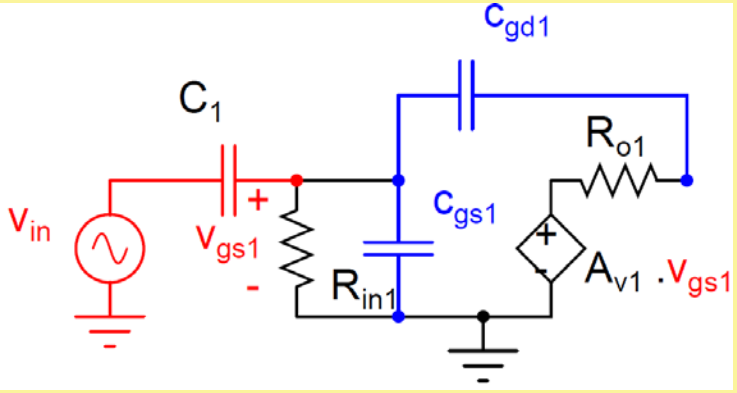


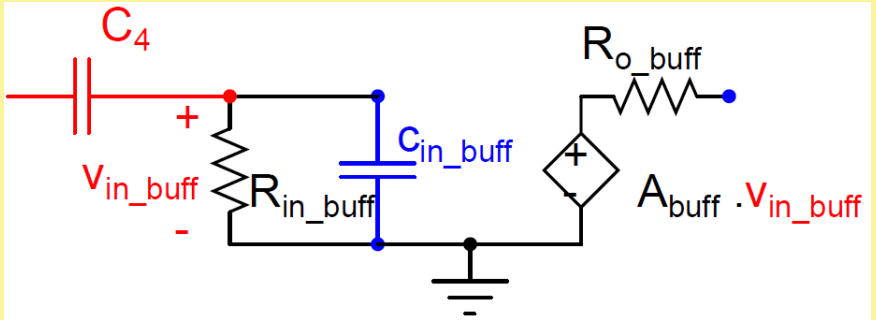


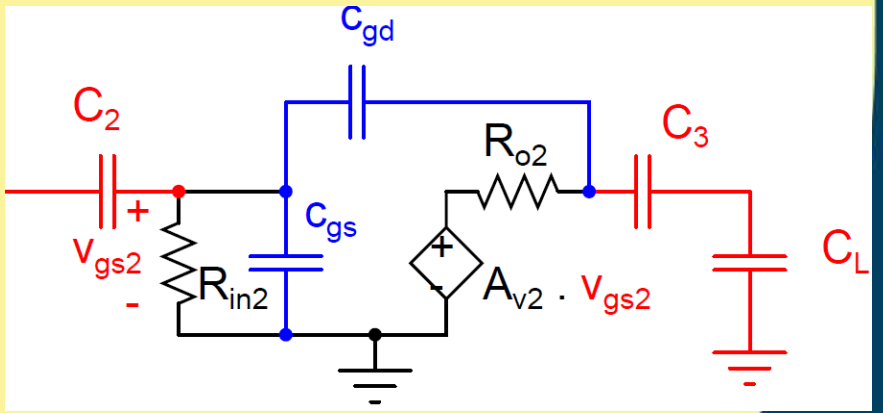
- **Overall voltage gain:**

- **Upper cutoff frequency:**

Frequency response of cascaded CS-buffer-CS amplifier







- **Overall voltage gain:**

- **Upper cutoff frequency:**

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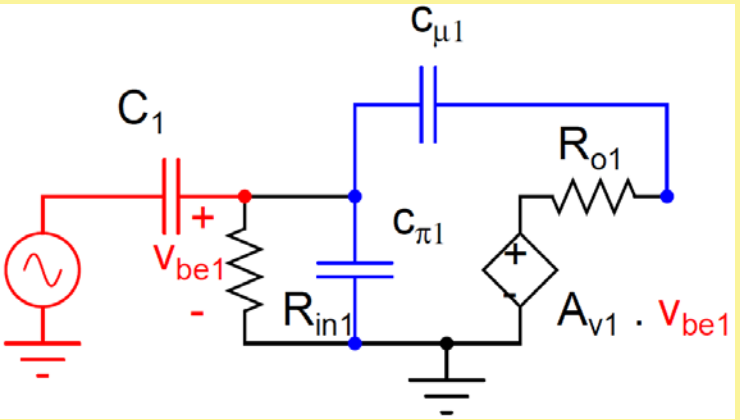
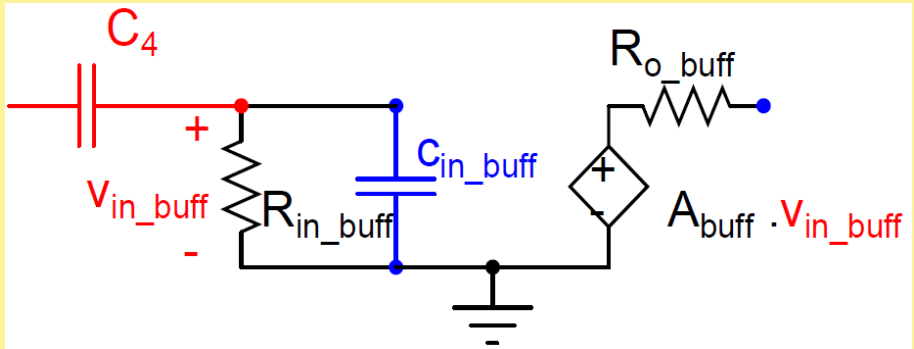
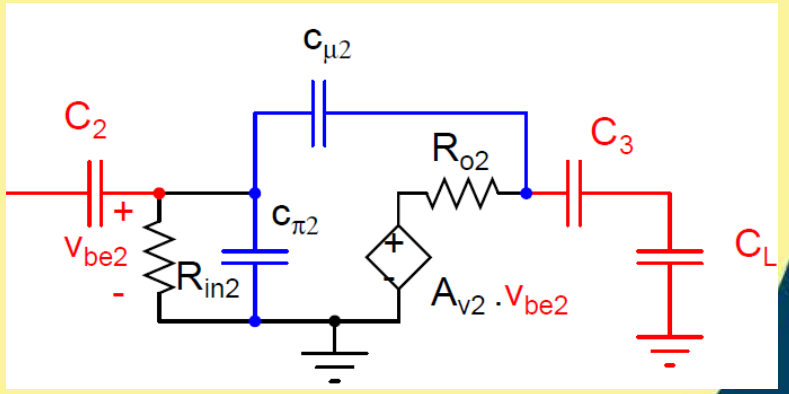
Frequency response of cascaded CE-buffer-CE amplifier







- **Overall voltage gain:**

- **Upper cutoff frequency:**

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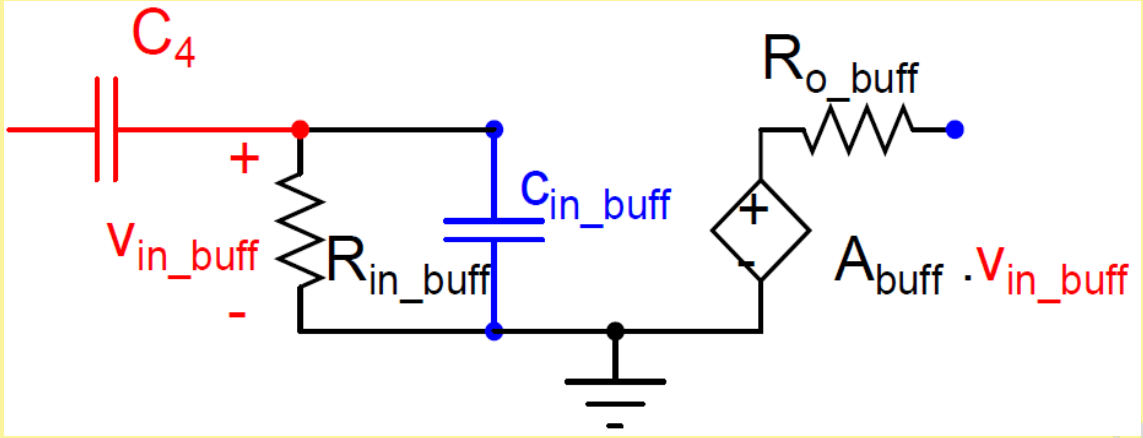
Necessary features of a Buffer (Voltage mode)



- **Output resistance:**
- **Input resistance:**
- **Input capacitance:**
- **Voltage gain:**
- ***Leading to Common collector and Common drain***

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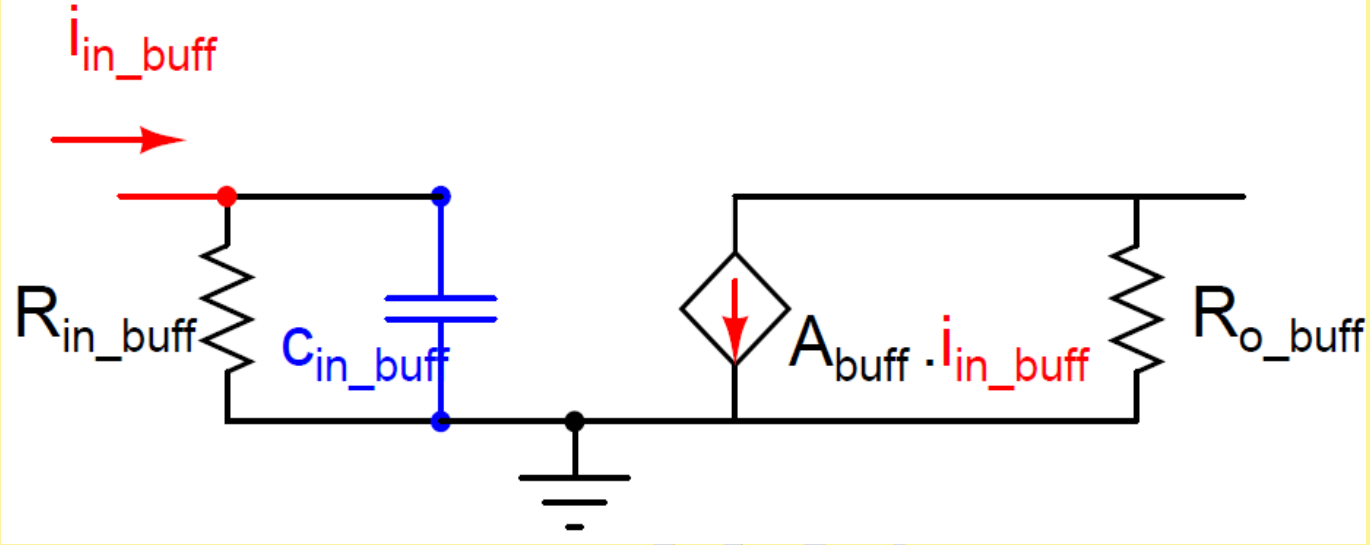
Necessary features of a Current mode Buffer



- **Output resistance:**
- **Input resistance:**
- **Current gain:**

- ***Leading to Common base and Common gate***

Conclusion

Conclusion:

- Frequency response of cascaded amplifiers is affected
- Cascaded amplifiers with buffer has improved frequency response
- Necessary features of a buffer for effective cascading

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Thank you

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