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Session 19
Frequency Response of Transistor Amplifiers

Electronic Components and Circuits

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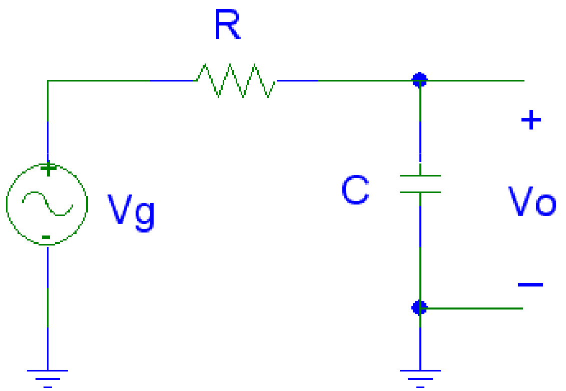
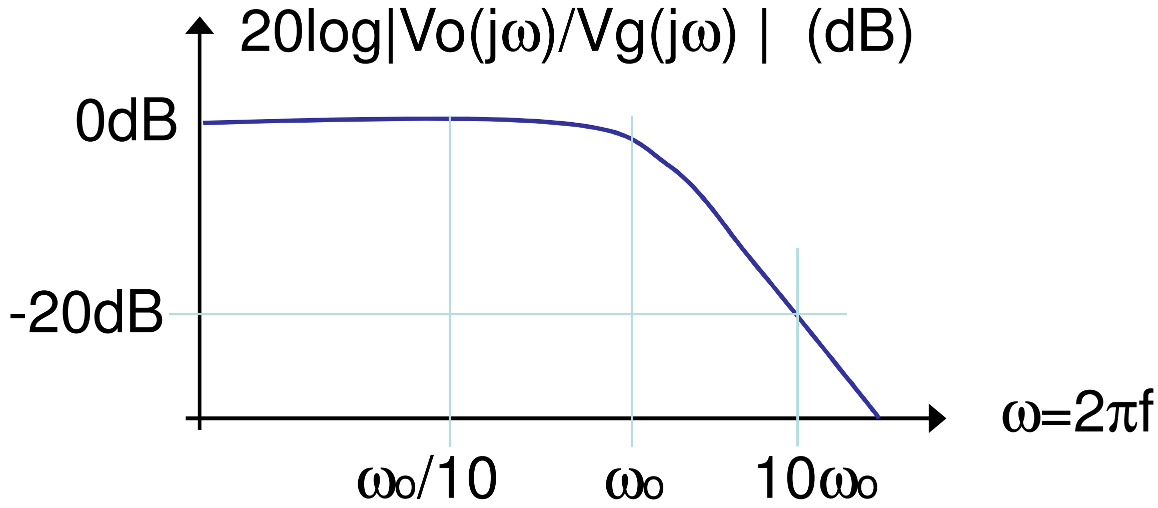
Frequency Response of Transistor Amplifiers

INDEX

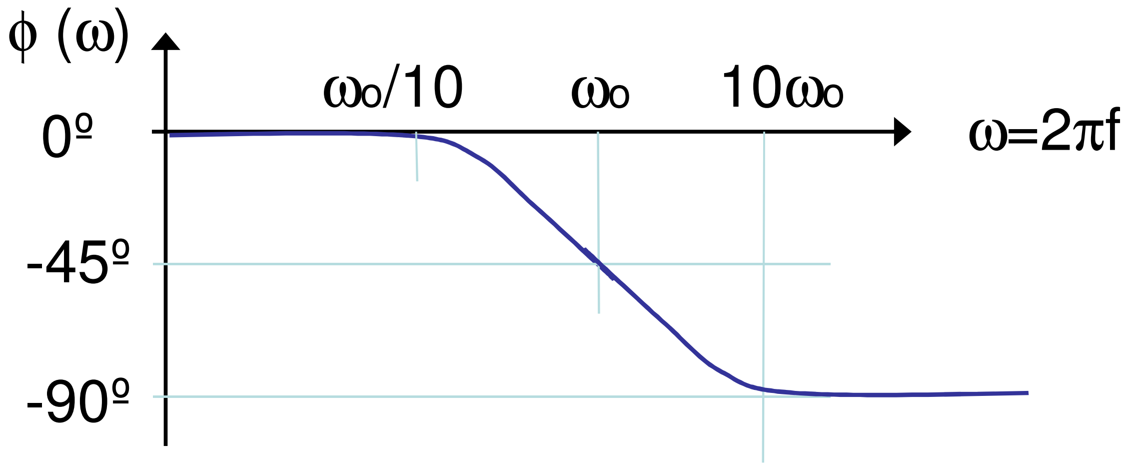
- Fundamentals and tools for frequency response analysis of transistor amplifier circuits.
- BJT and FET small signal high-frequency models.
- High-Frequency response analysis of amplifier circuits. Open-circuit time constants method. Examples.
- Low-Frequency response analysis of amplifier circuits. Short-circuit time constants method. Example.

Fundamentals
Low-pass RC Circuit





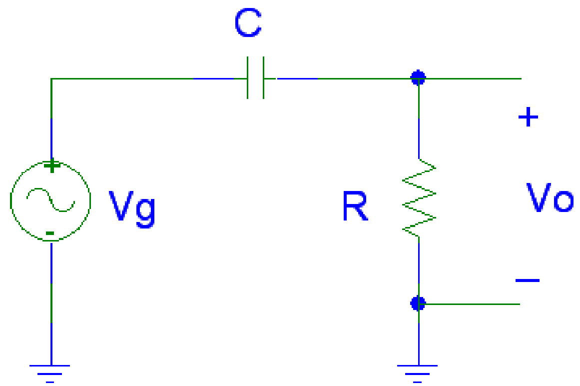
$$T(s)=\frac{V_o}{V_g}=\frac{1}{1+(s/\omega_0)}$$

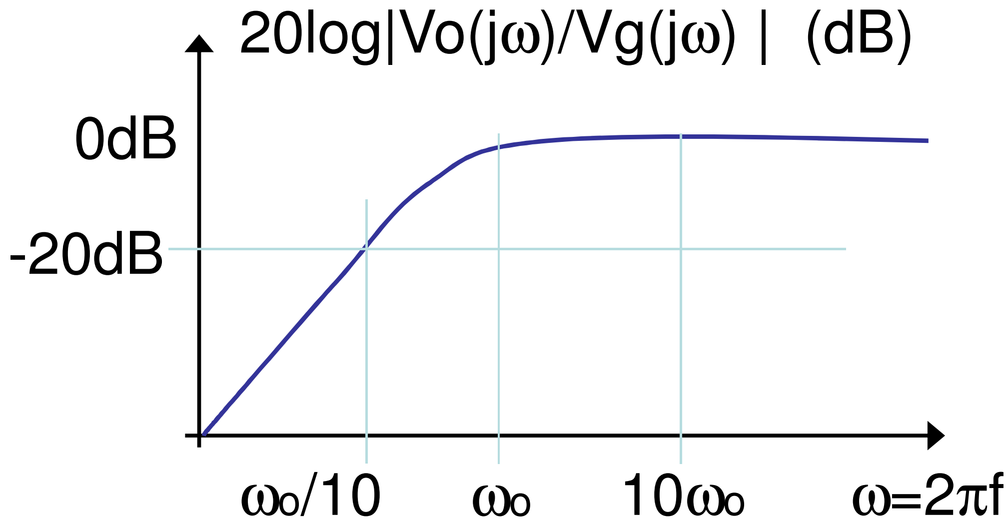


$$|T(j\omega)|=\frac{1}{\sqrt{1+(\omega/\omega_0)^2}}$$

$$\phi(\omega)=-\tan^{-1}(\omega/\omega_0)$$

Fundamentals
High-pass RC Circuit

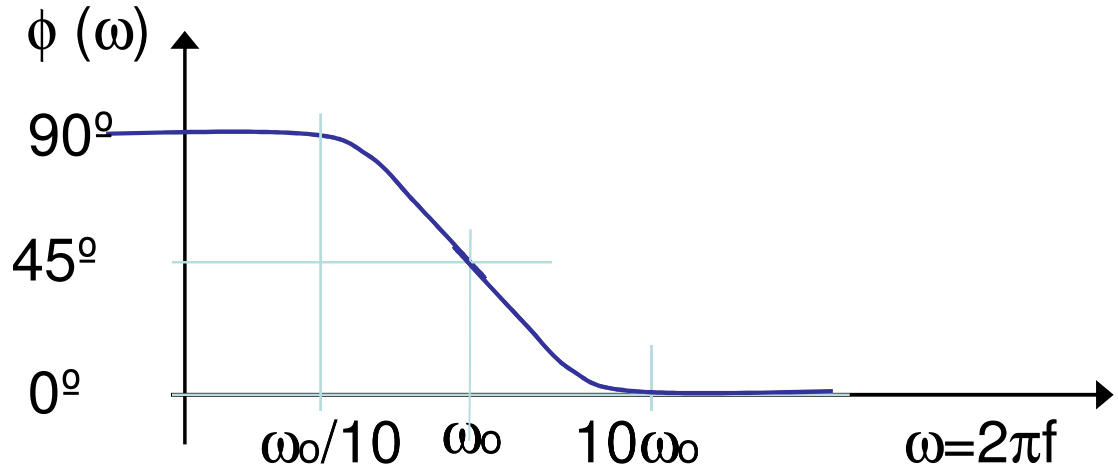




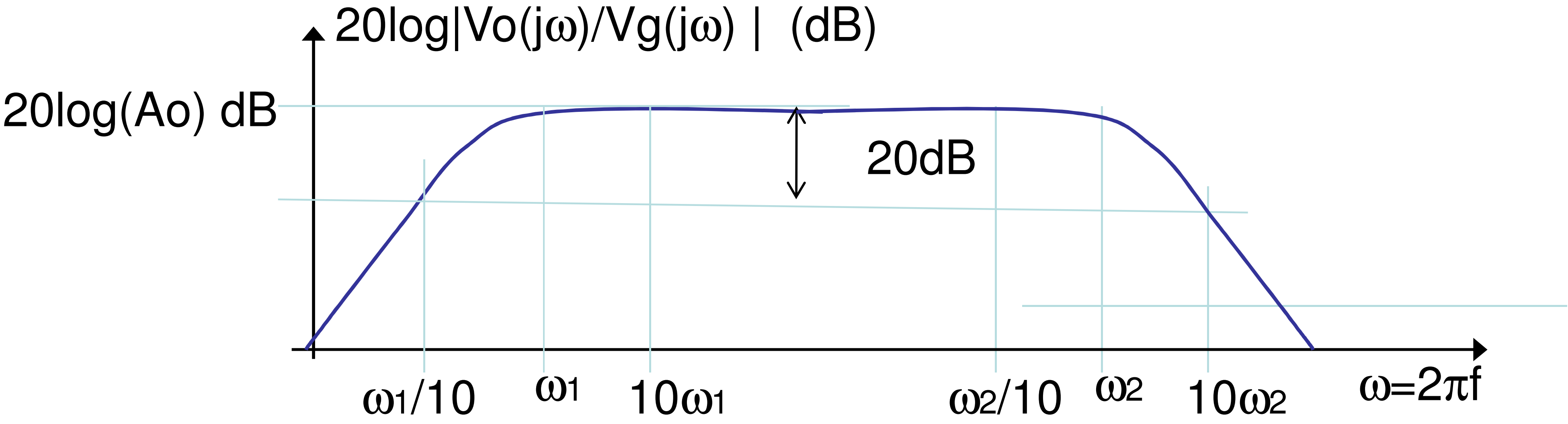
$$T(s) = \frac{V_o}{V_g} = \frac{s}{s+\omega_0}$$

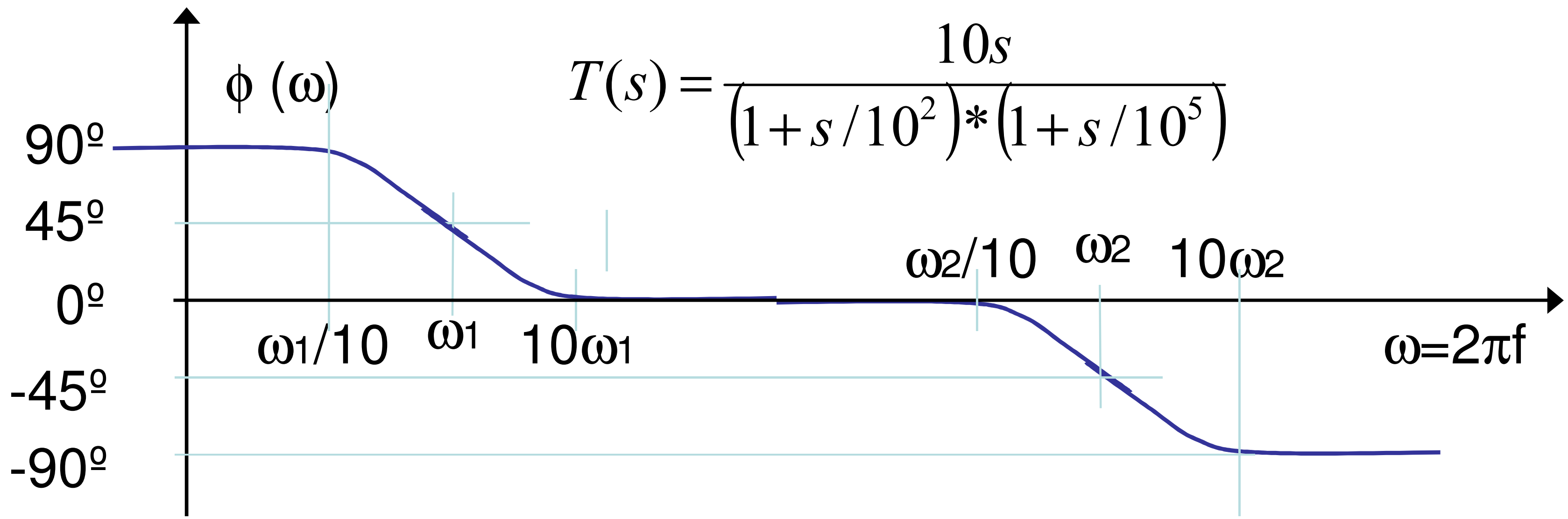
$$|T(j\omega)| = \frac{1}{\sqrt{1+(\omega_0/\omega)^2}}$$

$$\phi(\omega) = \tan^{-1}(\omega_0/\omega)$$



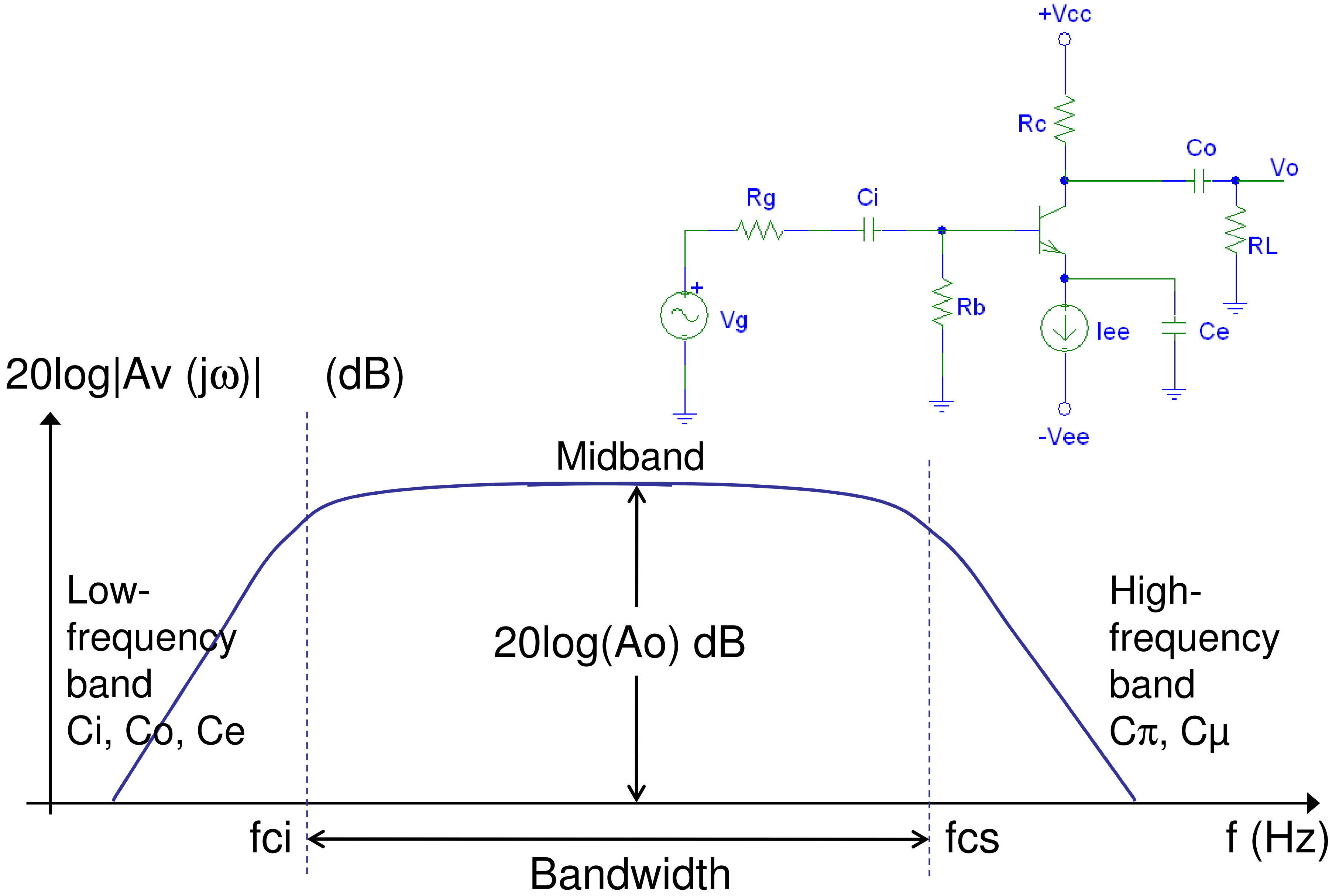
Fundamentals
Bode Plot (Amplitude and Phase)



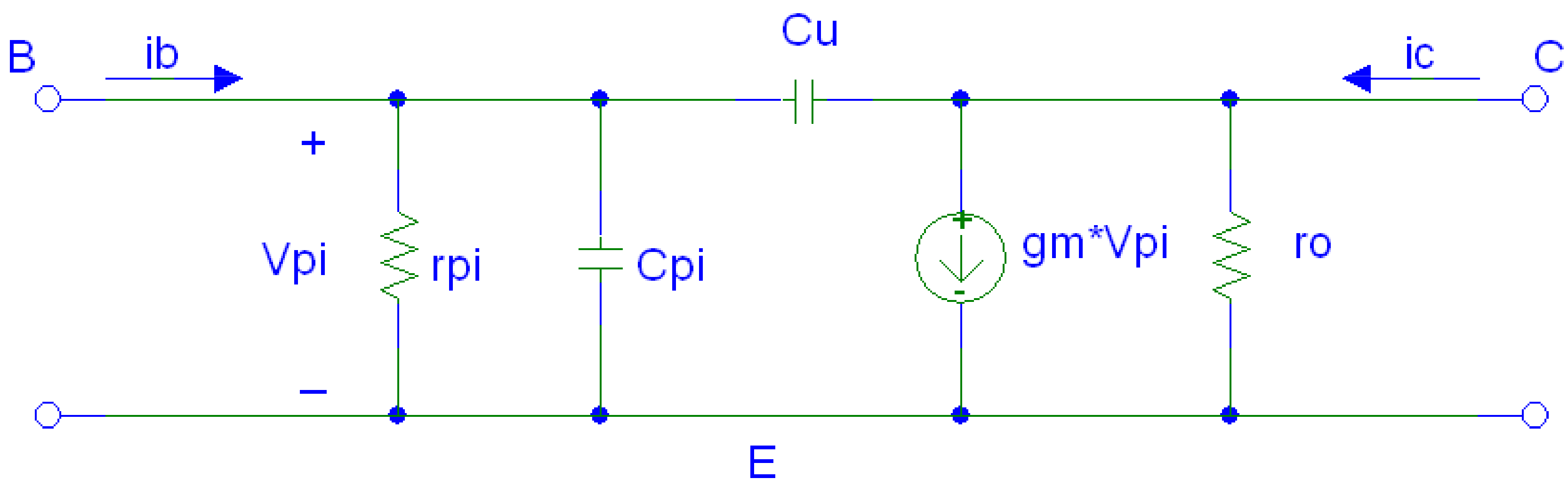


$$T(s) = \frac{10s}{\left(1 + s/10^2\right) * \left(1 + s/10^5\right)}$$

Fundamentals: The three Frequency Bands



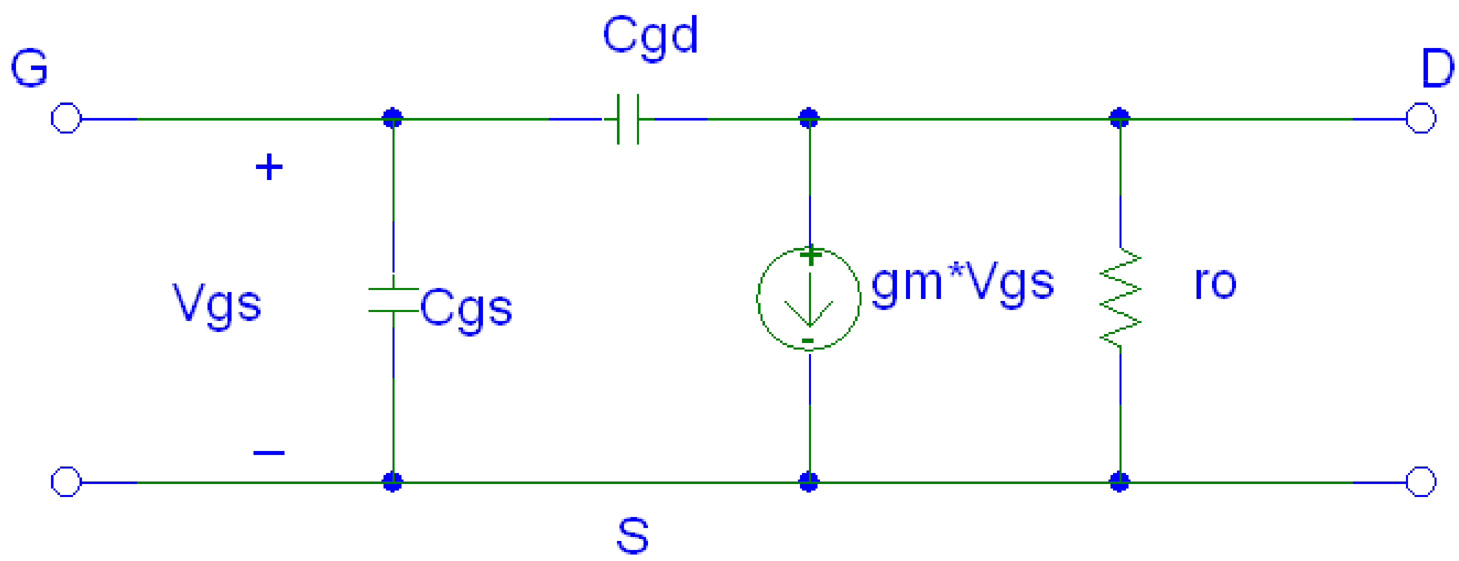
BJT high-frequency small-signal model



Unity-gain bandwidth

$$f_T = \frac{g_m}{2\pi(C_\pi + C_\mu)}$$

FET high-frequency small-signal model



Unity-gain bandwidth

$$f_T = \frac{g_m}{2\pi(C_{gs} + C_{gd})}$$

High-frequency response analysis of amplifier circuits.

- High frequency response of transistor amplifier circuits is fixed by the internal capacitances of the devices and the associated time constants.
- In general, we will assume that the high-frequency response is fixed by a DOMINANT POLE. This way, the high-frequency analysis is reduced to the calculation of such dominant pole.
- The dominant pole frequency calculation will be performed using the Open-circuit time constants method.

Open-circuit time constants method.

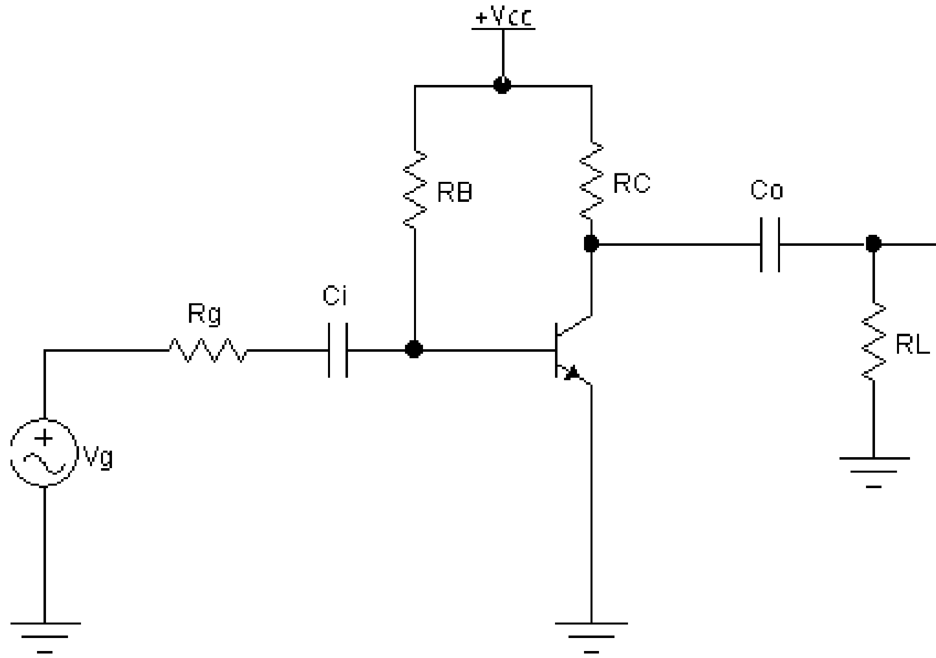
$$f_{cs}(3dB) = \frac{1}{2\pi}\frac{1}{\sum_i R_i^0 C_i}$$

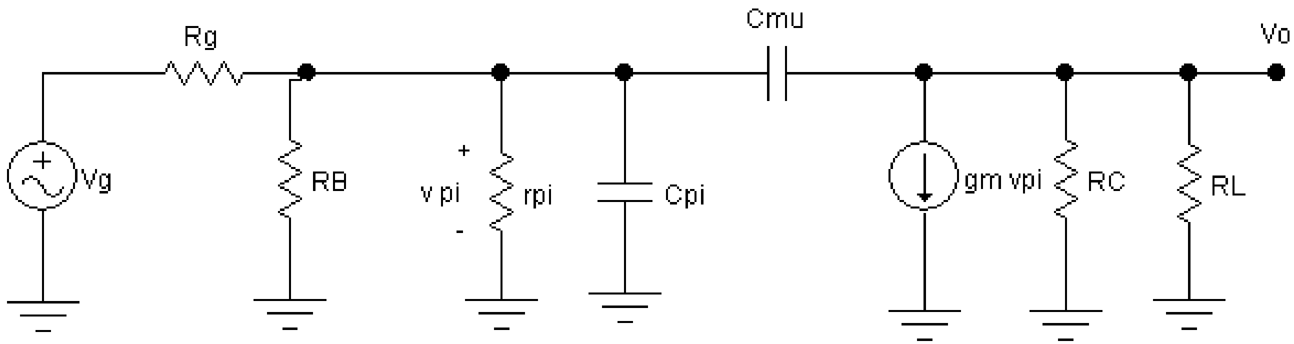
Where:

C_i are all the capacitances that influence in the high-frequency response: active devices internal capacitances, or small capacitors (with low-pass characteristics), introduced in the circuit to control the high-frequency response.

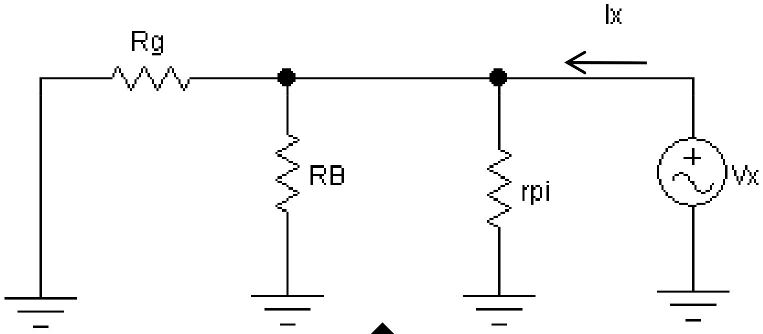
R^0_i is the resistance seen by each of the capacitors when we reduce all other capacitances to zero (Open circuit)

Open-circuit time constants method. Example (I)



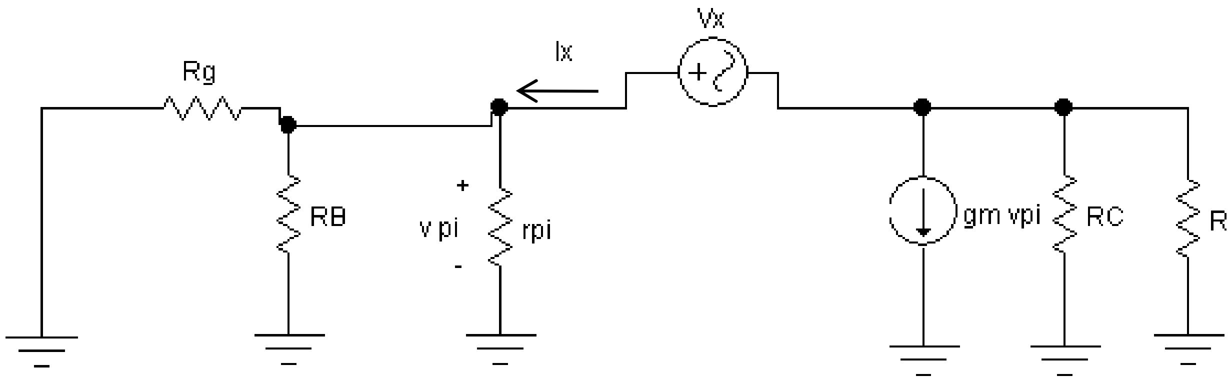


Open-circuit time constants method. Example (II)



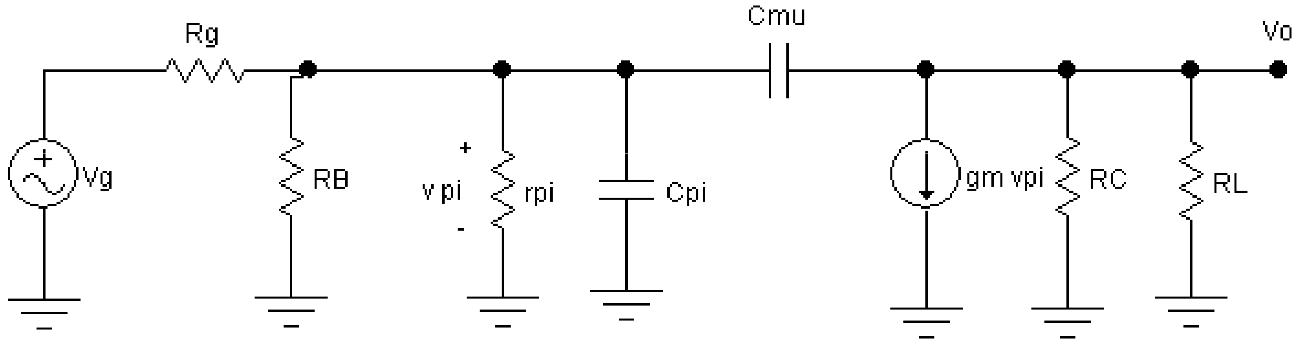
$$R_\mu^0 = R_B \,//\, r_\pi \,//\, R_g (1 + g_m R_C \,//\, R_L) + R_C \,//\, R_L$$

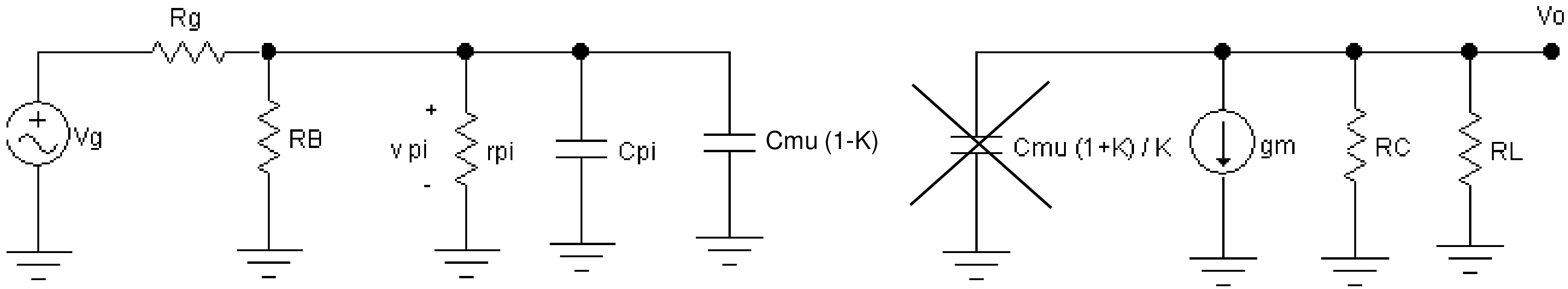
$$R_\pi^0 = R_B \,//\, r_\pi \,//\, R_g$$



$$f_{cs} = \frac{1}{2\pi \, C_\pi \left(r_\pi // R_B // R_g \right) + C_\mu \left(R_B // r_\pi // R_g (1 + g_m R_C // R_L) + \left(R_C // R_L \right) \right)}$$

Miller's Theorem. Example (I)





$$K = -gm\,R_C \,//\, R_L$$

Miller's Theorem. Example (II)
Miller's Theorem vs Dominant Pole Calculation

$$f_{csM} = \frac{1}{2\pi}\frac{1}{\left(r_\pi // R_B // R_g\right)\left[C_\pi + C_\mu\left(1 + g_m R_C // R_L\right)\right]}$$

$$f_{cs} = \frac{1}{2\pi}\frac{1}{C_\pi\left(r_\pi // R_B // R_g\right) + C_\mu\left(R_B // r_\pi // R_g\left(1 + g_m R_C // R_L\right) + R_C // R_L\right)}$$

Low-frequency response analysis of amplifier circuits.

- Low-frequency response of transistor circuits is fixed by the coupling and bypass capacitors and the associated time constants.
- In general, we will assume that the low-frequency response is fixed by a DOMINANT POLE. This way, the low-frequency analysis is reduced to the calculation of such dominant pole.
- The dominant pole frequency calculation will be performed using the Short-circuit time constants method.

Short-circuit time constants method.

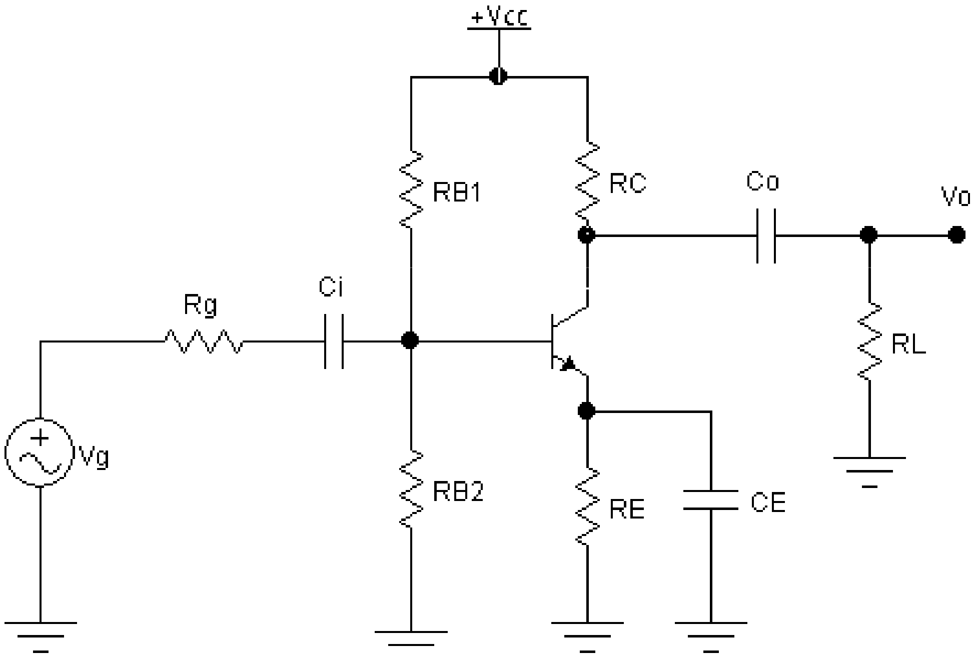
$$f_{ci}(3dB) = \frac{1}{2\pi}\sum_i \frac{1}{R_i^{\infty} C_i}$$

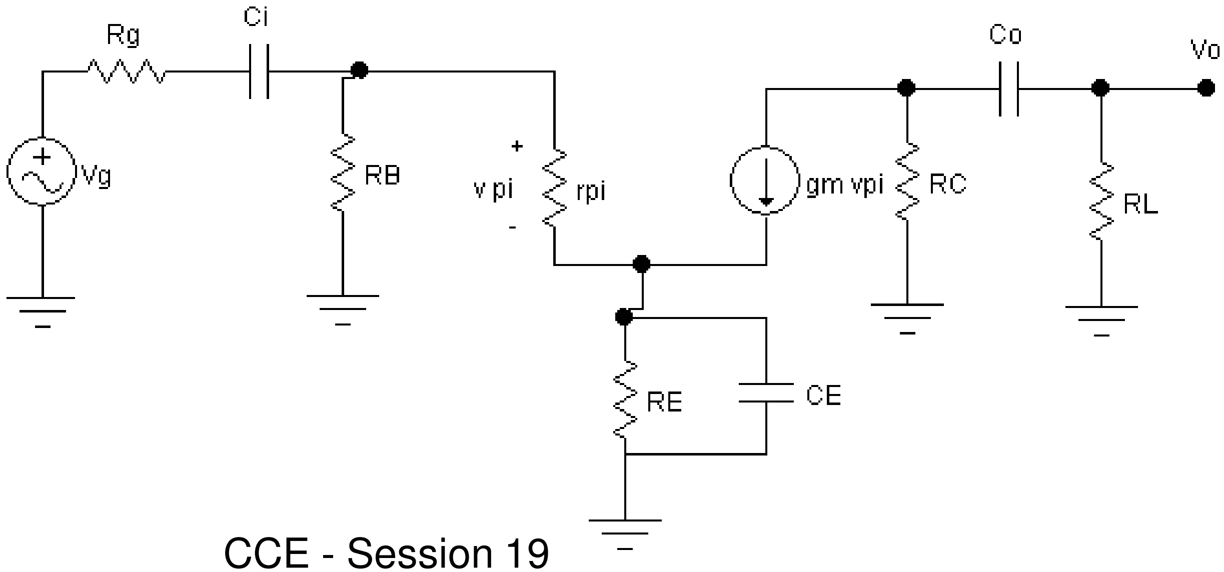
Where:

C_i are all the coupling and bypass capacitors of the circuit.

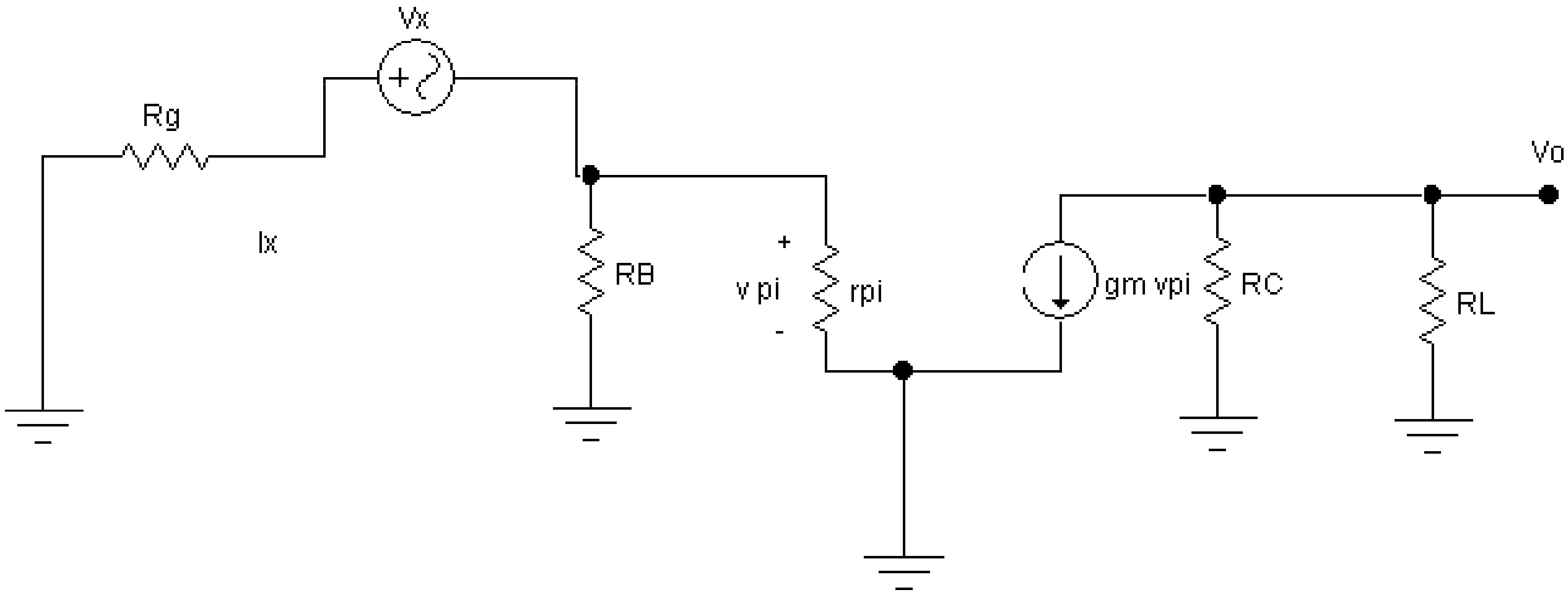
R^{∞}_i is the resistance seen by each of the capacitors when we assume all other capacitances are infinity (Short circuit)

Short-circuit time constants method. EXAMPLE (I)



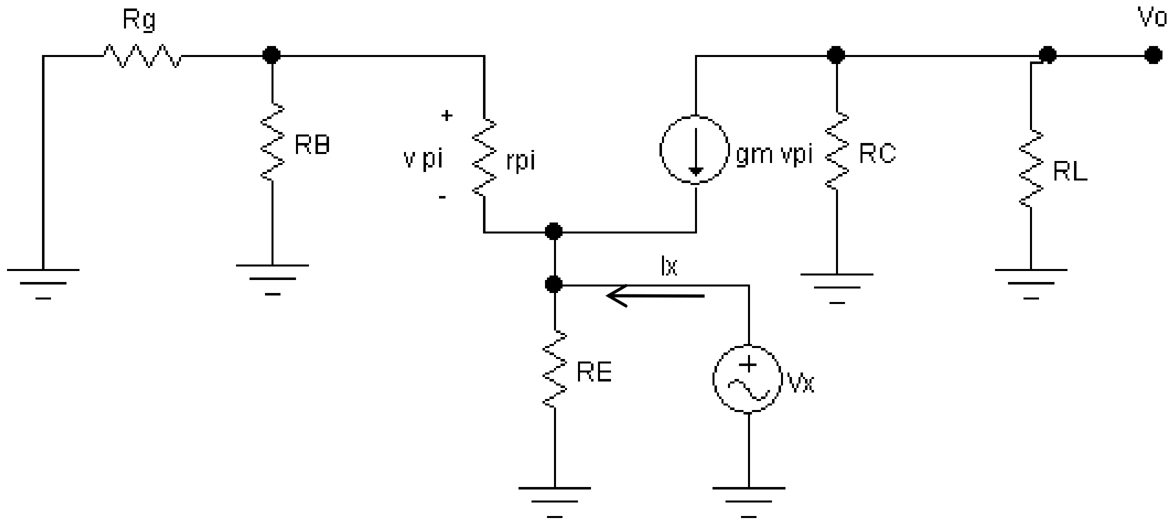


Short-circuit time constants method. EXAMPLE (II)



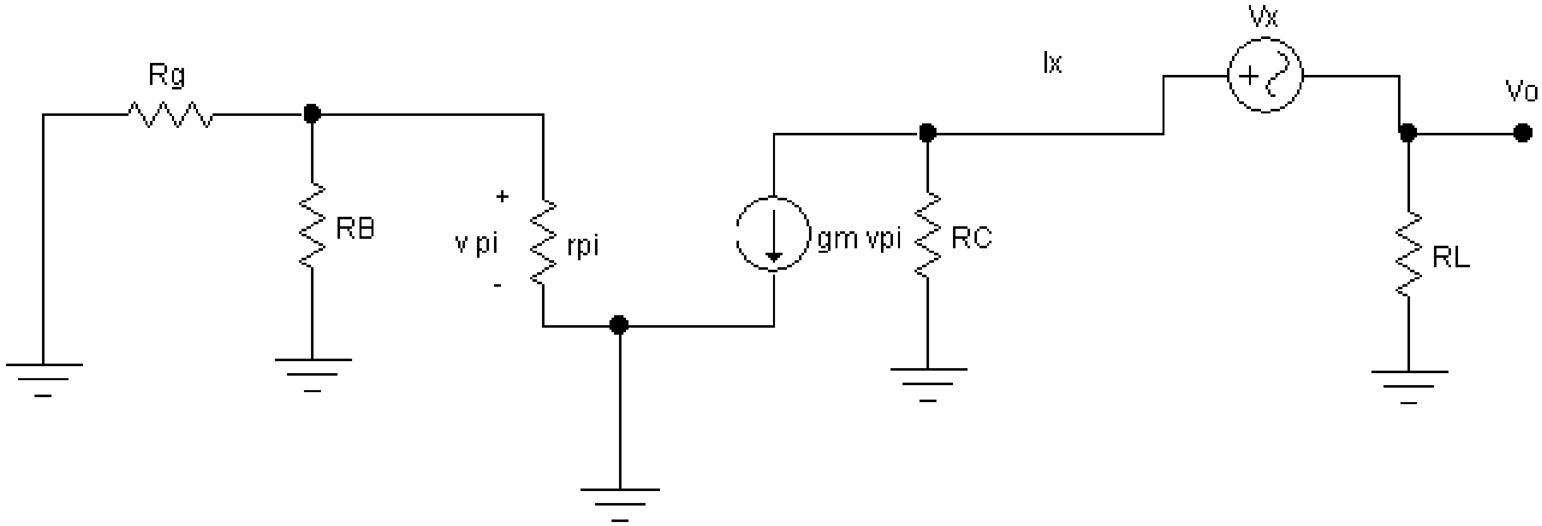
$$R_{Ci}^{\infty} = R_g + R_B \,//\, r_\pi$$

Short-circuit time constants method. EXAMPLE (III)



$$R_E^{\infty} = R_E \,//\, \frac{r_\pi + (R_g \,//\, R_B)}{1+\beta_0}$$

Short-circuit time constants method. EXAMPLE (IV)

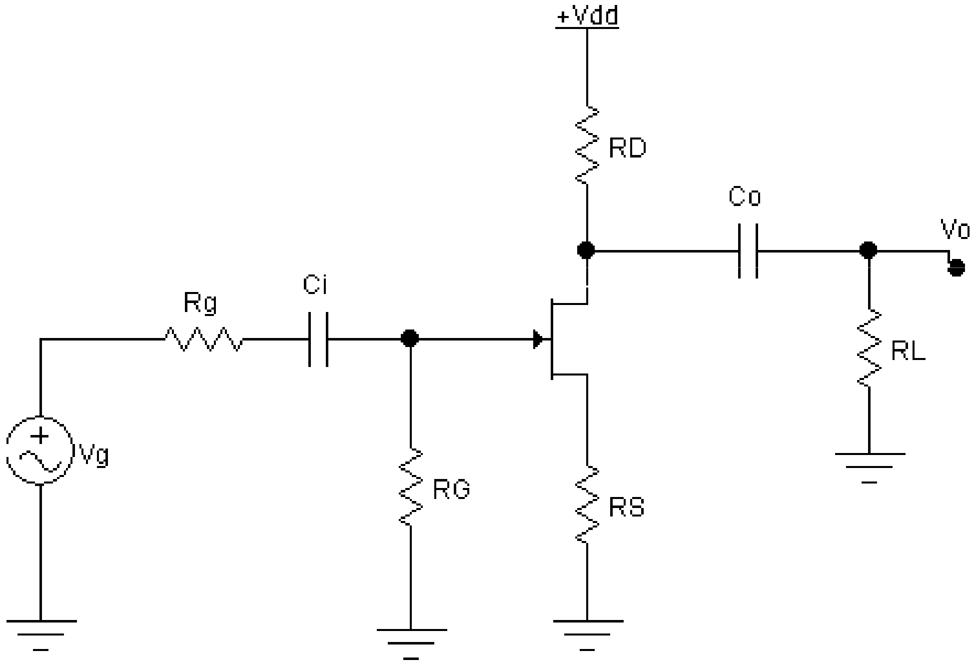


$$R_{Co}^{\infty} = R_C + R_L$$

Short-circuit time constants method. EXAMPLE (V)

$$f_{ci} = \frac{1}{2\pi}\left[\frac{1}{C_i(R_g + R_B // r_\pi)} + \frac{1}{C_E\left(R_E // \frac{r_\pi + (R_g // R_B)}{1+\beta_0}\right)} + \frac{1}{C_o(R_C + R_L)}\right]$$

Proposed Exercise



+Vdd = 15 V

R_S = 560Ω	R_D = 5,6 KΩ	C_i = 10 µF
R_G = 1 MΩ	R_L=10 KΩ	C_0=10 µF
R_g = 50 Ω		

Transistor:

I_{DSS}= 10 mA	V_P = -2 V	C_{gd}=0.36 pF
		C_{gs}=1 pF

$I_D = I_{DSS} \cdot (1-V_{GS}/V_P)^2$