CE/CS Amplifier Response at High Frequencies

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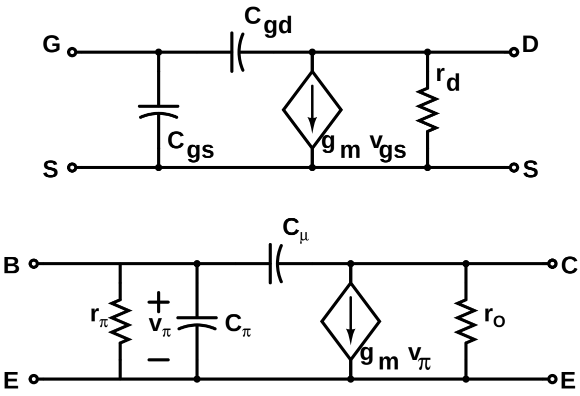
Outline

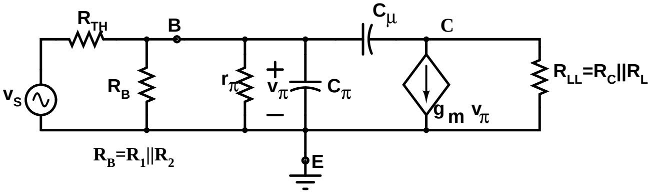
High Frequency Models



small-signal incremental model

PARASITIC CAPS LIMIT GAIN AT HIGH FREQS.

CE High Frequency Model



Open-circuit time constant method

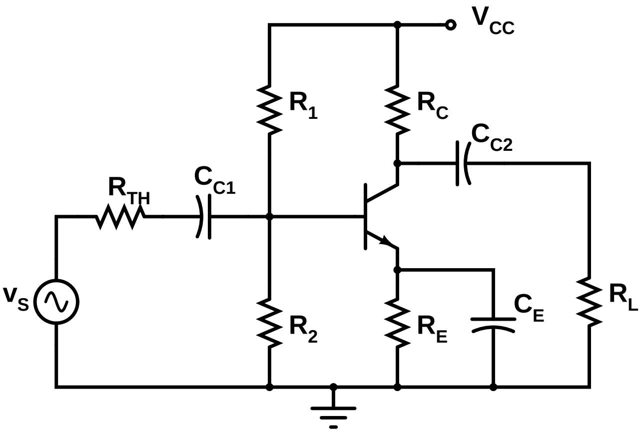
1. Replace all coupling and bypass caps by shorts
2. Select one parasitic cap; call it C_{H1}
3. Replace all other parasitic caps by open circuits
4. Find resistance seen by C_{H1}; call it R_{H1}
5. High frequency pole associated with C_{H1} is

$$\omega_{H1} = \frac{1}{C_{H1} R_{H1}}$$

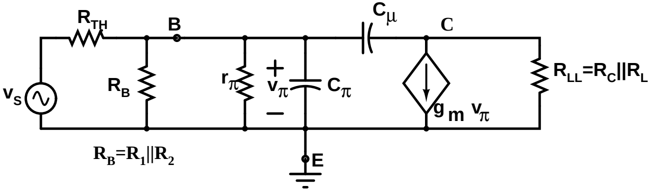
6. Repeat above steps for each parasitic cap
7. Find equivalent high frequency cutoff

$$\omega_H = \frac{1}{\sum_{i=1}^{n} \frac{1}{\omega_{Hi}}}$$

Single-stage amplifier



Single-stage amplifier

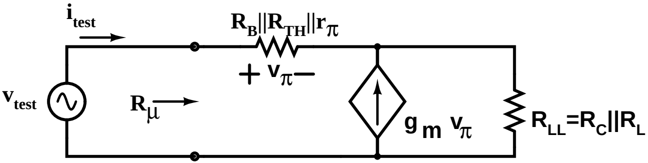


Resistance

Seen by C_π:

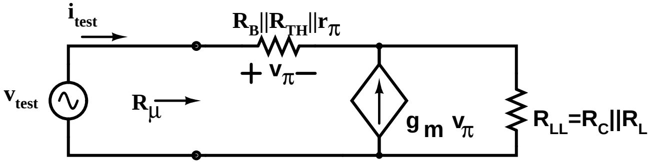
$$R_\pi = r_\pi \mid\mid R_B \mid\mid R_{TH}$$

Seen by C_μ:



R_μ

Resistance seen by C_μ



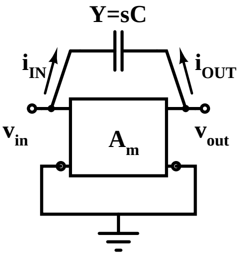
$$v_\pi = i_{test}(R_B \parallel R_{TH} \parallel r_\pi)$$

R_μ

Applying KVL on the external loop yields

$$
\begin{aligned}
v_{test} &= v_\pi + (i_{test} + g_m v_\pi) R_{LL} \\
&= i_{test}(R_B \mid\mid R_{TH} \mid\mid r_\pi) \\
&\quad +(1 + g_m(R_B \mid\mid R_{TH} \mid\mid r_\pi)) i_{test} R_{LL} \\
R_\mu &= \frac{v_{test}}{i_{test}} \\
&= R_B \mid\mid R_{TH} \mid\mid r_\pi + R_{LL} \\
&\quad + g_m(R_B \mid\mid R_{TH} \mid\mid r_\pi) R_{LL}
\end{aligned}
$$

Miller Theorem



Assume that $A_m = \frac{v_{OUT}}{v_{IN}}$ is negative and is independent of $Y = sC$.
Use

$$v_{OUT} = A_m v_{IN}$$

$$v_{IN} = v_{OUT}/A_m$$

Miller Theorem

Input:

$$\begin{aligned} i_{IN} &= Y(v_{IN} - v_{OUT}) \\ &= sC(1 - A_m)v_{IN} = sC_{IN}v_{IN} \end{aligned}$$

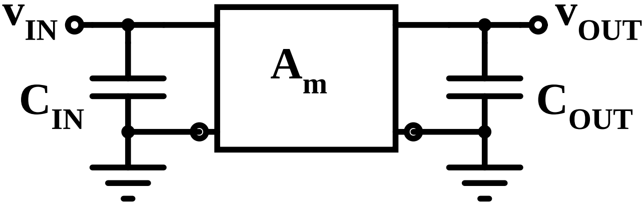
i.e. from the input C looks like a bigger capacitor $C(1 - A_m)$.

Output:

$$\begin{aligned} i_{OUT} &= Y(v_{OUT} - v_{IN}) \\ &= sC(1 - \frac{1}{A_m})v_{OUT} = sC_{OUT}v_{OUT} \end{aligned}$$

i.e. from the output C looks like a capacitor $C(1 - \frac{1}{A_m}) \approx C$.

Miller Theorem



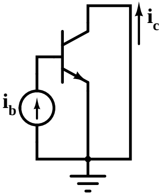
Miller Theorem

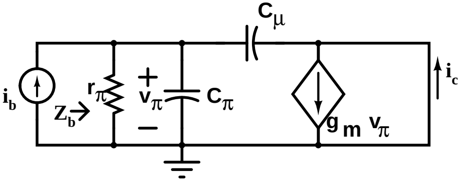
To apply Miller's Theorem, make sure that

- A_m is negative
- A_m is real, i.e. load is resistive

Unity-gain frequency: f_t

f_t: frequency at which the transistor's $\beta = 1$.





Unity-gain frequency: f_t

$$i_c = g_m v_\pi - v_\pi s C_\mu$$

$$v_\pi = i_b \times Z_b$$

$$\begin{aligned} Z_b &= r_\pi \,||\, \frac{1}{sC_\pi} \,||\, \frac{1}{sC_\mu} \\ &= \frac{1}{\frac{1}{r_\pi} + sC_\pi + sC_\mu} \\ &= \frac{r_\pi}{1 + s r_\pi (C_\pi + C_\mu)} \end{aligned}$$

Unity-gain frequency: f_t

$$\beta(s) = \frac{i_c}{i_b}$$
$$= \frac{g_m r_\pi - s r_\pi C_\mu}{1 + s r_\pi (C_\pi + C_\mu)}$$
$$\approx \frac{\beta_0}{1 + s r_\pi (C_\pi + C_\mu)}$$

Midband $\beta \equiv \beta_0 = g_m r_\pi$
β has a pole at

$$\omega_\beta = \frac{1}{r_\pi (C_\pi + C_\mu)}$$

Unity-gain frequency: f_t

f_t: f at which $\mid \beta(s) \mid = 1$

$$\beta_0^2 = 1 + \frac{\omega_t^2}{\omega_\beta^2}$$

$$\omega_t = \omega_\beta \sqrt{\beta_0^2 - 1} \approx \beta_0 \omega_\beta$$

Data sheet often specifies f_t and C_μ; C_π can then be found from above equations.

Example

A common-source amplifier is constructed with a $10\mu F$ bypass capacitor in parallel with a $1k\Omega$ resistor, both connected to the FET's source terminal. The equivalent resistance "seen" by the bypass capacitor is 100Ω. At high frequencies there is a single pole located at $1MHz$. If the amplifier's midband gain is $80dB$, find an expression for the amplifer's gain as a function of the complex frequency s, valid for low-, mid- and high-frequencies.

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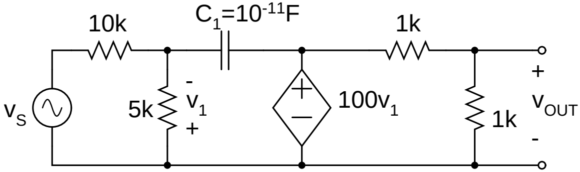
ANSWER:

$$A_v(s) = -10^4 \frac{s + 10^2}{s + 10^3} \frac{1}{{}^{s}\!/_{2\pi \times 10^6} + 1}$$

Example

For the circuit shown below, find (i) the pole frequency applying Miller's theorem; (ii) the pole frequency using the open-circuit time constant method; and (iii) an expression for the voltage gain $A_v(s) = \frac{v_{OUT}}{v_S}$ as a function of complex frequency s, valid for mid- and high-frequencies.



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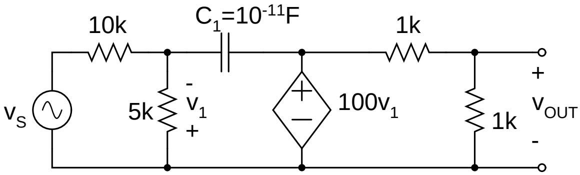

ANSWER: (i) $297krps$; (ii) $297krps$ (iii) $A_v(s) = -16.7\frac{1}{s/297krps+1}$

Prob. 6.110

A CS amplifier is specified to have $g_m = 5mA/V$, $r_o = 40k\Omega$, $C_{gs} = 2pF$, $C_{gd} = 0.1pF$, $C_L = 1pF$, $R_{sig} = 20k\Omega$, and $R_L = 40k\Omega$. (a) Find the low-frequency gain A_M and use open-circuit time constants to estimate the 3-dB frequency f_H. Hence determine the gain-bandwidth product. (b) If a 500Ω resistance is connected in the source lead, find the new values of $|A_M|$, f_H, and the gain-bandwidth product. Assume $g_{mb} = 1mA/V$.

Prob. 6.110

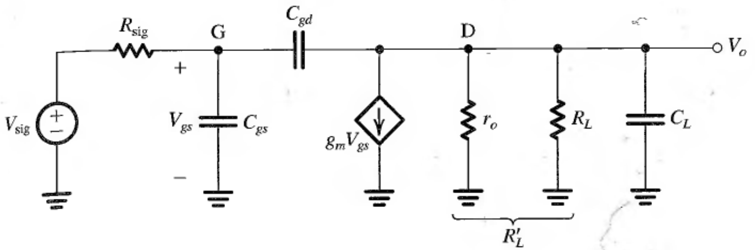

FIGURE 6.20 High-frequency equivalent-circuit model of the common-source amplifier. For the common-emitter amplifier, the values of V_{sig} and R_{sig} are modified to include the effects of r_π and r_x; C_{gs} is replaced by C_π, V_{gs} by V_π, and C_{gd} by C_μ.