Frequency Response

(Part 3)

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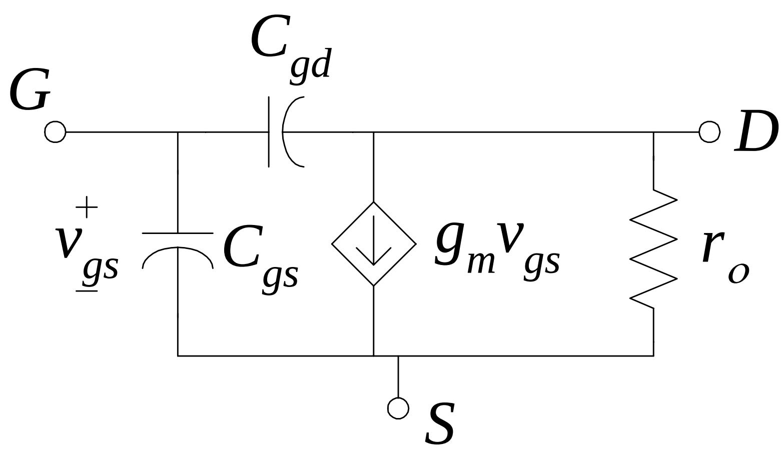
Most of the diagrams of this presentation were taken from the web site of the authors of the books:

A.R. Hambley, *Electronics: A Top-Down Approach to Computer-Aided Circuit Design*. Englewood Cliffs, NJ: Prentice Hall, 2000.

R.C. Jaeger, *Microelectronic Circuit Design*. New York, NY: McGraw-Hill, 1996.

The FET High-Frequency Model



$$g_m = 2K(V_{GS} - V_t)$$

$$r_o = \frac{|V_A|}{I_{DS}}$$

$$V_A = 1/\lambda$$

$C_{iss} = C_{gs} + C_{gd}$ (input capacitance)

$C_{oss} = C_{ds} + C_{gd}$ (output capacitance)

$C_{rss} = C_{gd}$ (reverse capacitance)

The FET Unity-Gain Frequency (f_T)

It is the frequency at which the magnitude of the short-circuit current gain of the Common Source configuration becomes unity

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

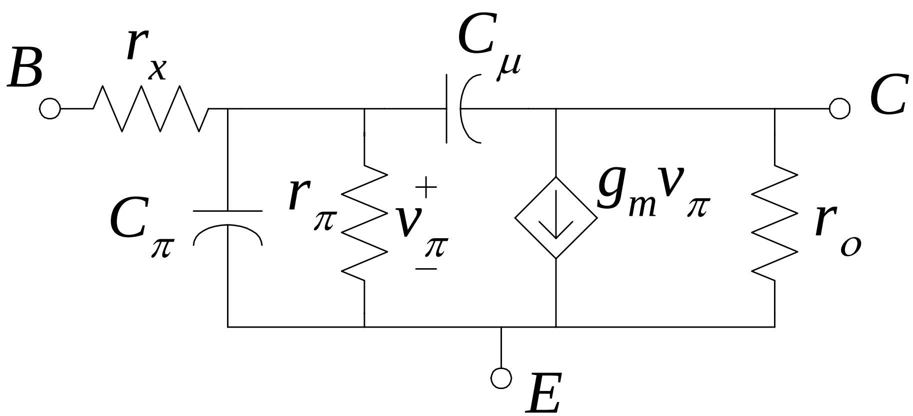
20 MHz $\leq f_T \leq$ 100 MHz for JFETs

100 MHz $\leq f_T \leq$ 2 GHz for MOSFETs

5 GHz $\leq f_T \leq$ 15 GHz for GaAs MESFETs

10 GHz $\leq f_T \leq$ 200 GHz for SiGe MOSFETs

The BJT High-Frequency Hybrid π Model



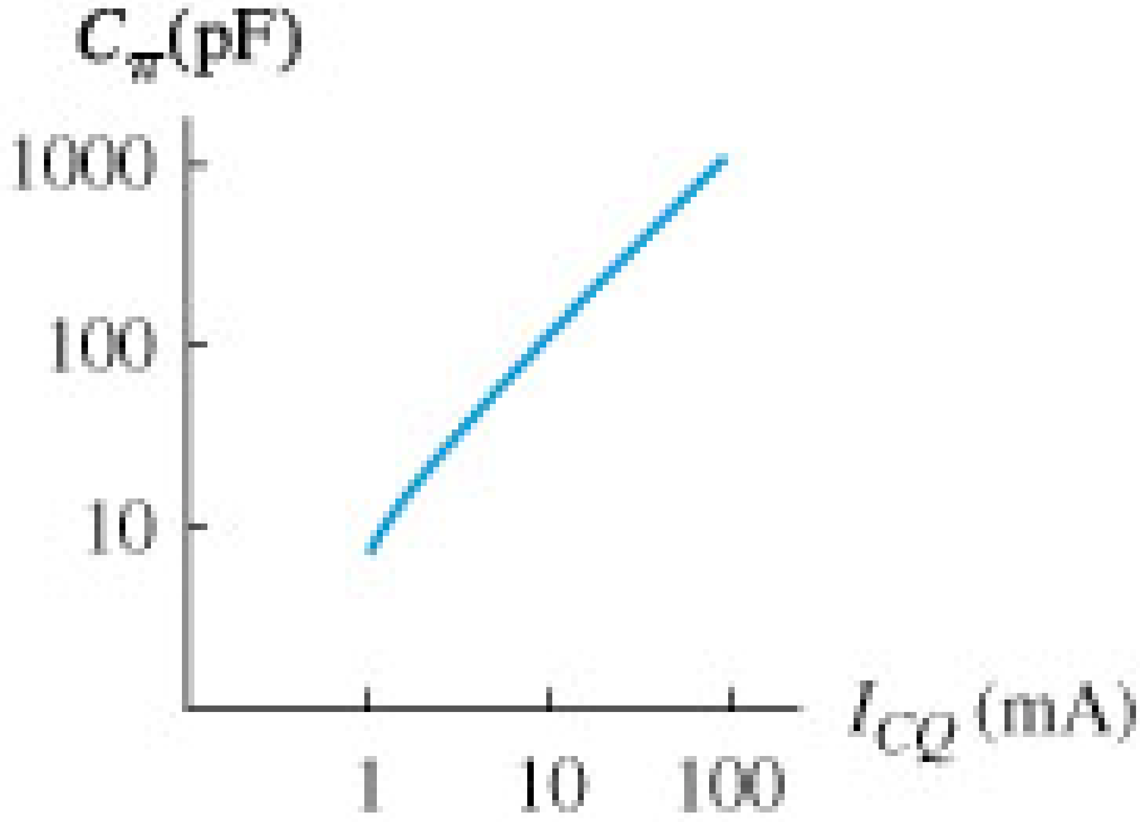
$$g_m = \frac{I_C}{V_T} \qquad r_\pi = \frac{\beta}{g_m} \qquad r_o = \frac{V_A}{I_C}$$

$$r_x = h_{ie} - r_\pi \qquad r_\mu = r_\pi / h_{re}$$

$C_\mu = C_{ob} = C_{cb}$ (Collector-Base capacitance)

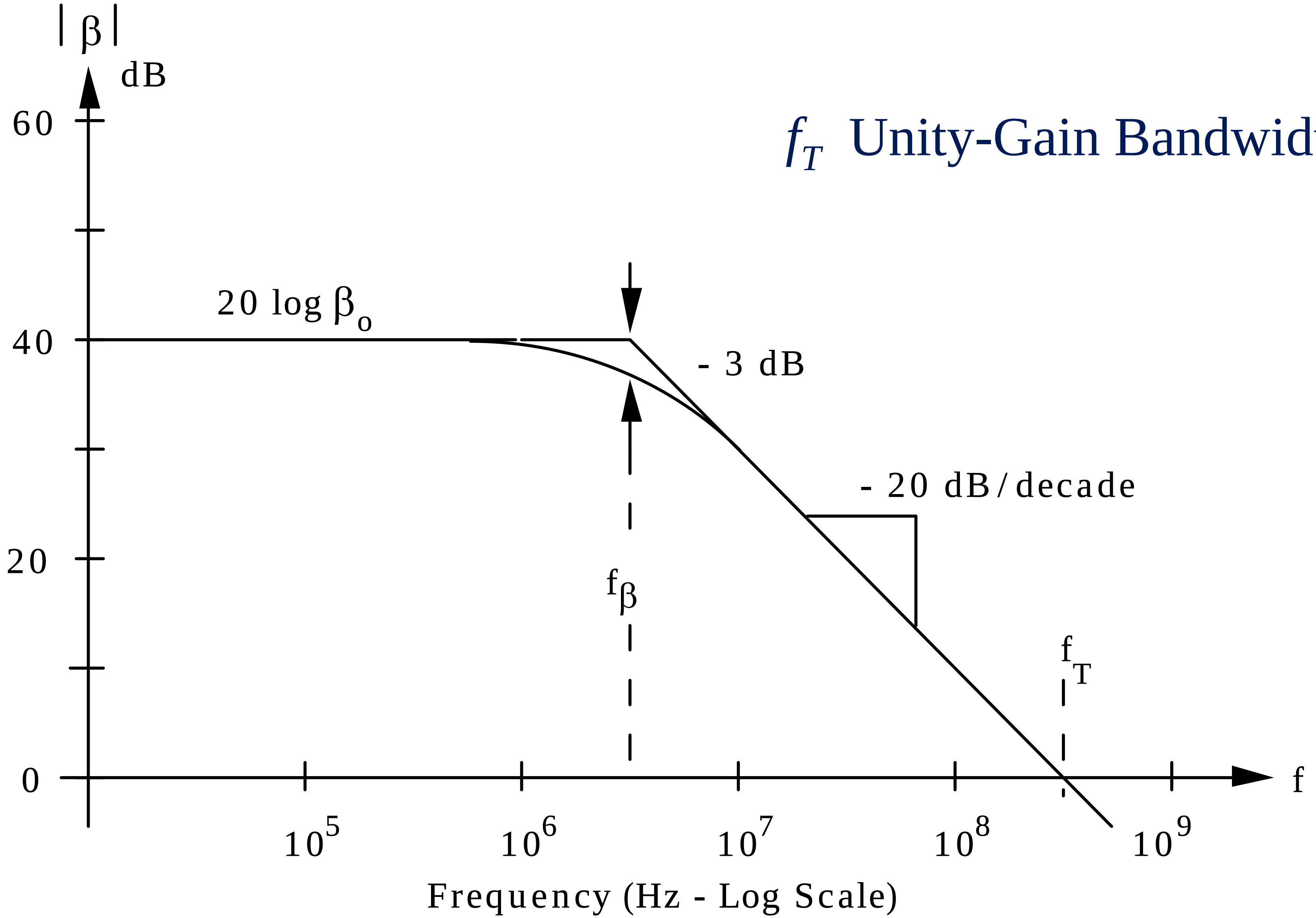
$C_\pi = C_{eb}$ (Base-Emitter capacitance)

Typical Behaviour of C_π



Typical Behaviour of β

f_T Unity-Gain Bandwidth



The BJT Unity-Gain Bandwidth (f_T)

It is the frequency at which the magnitude of the short-circuit current gain of the common emitter configuration becomes unity

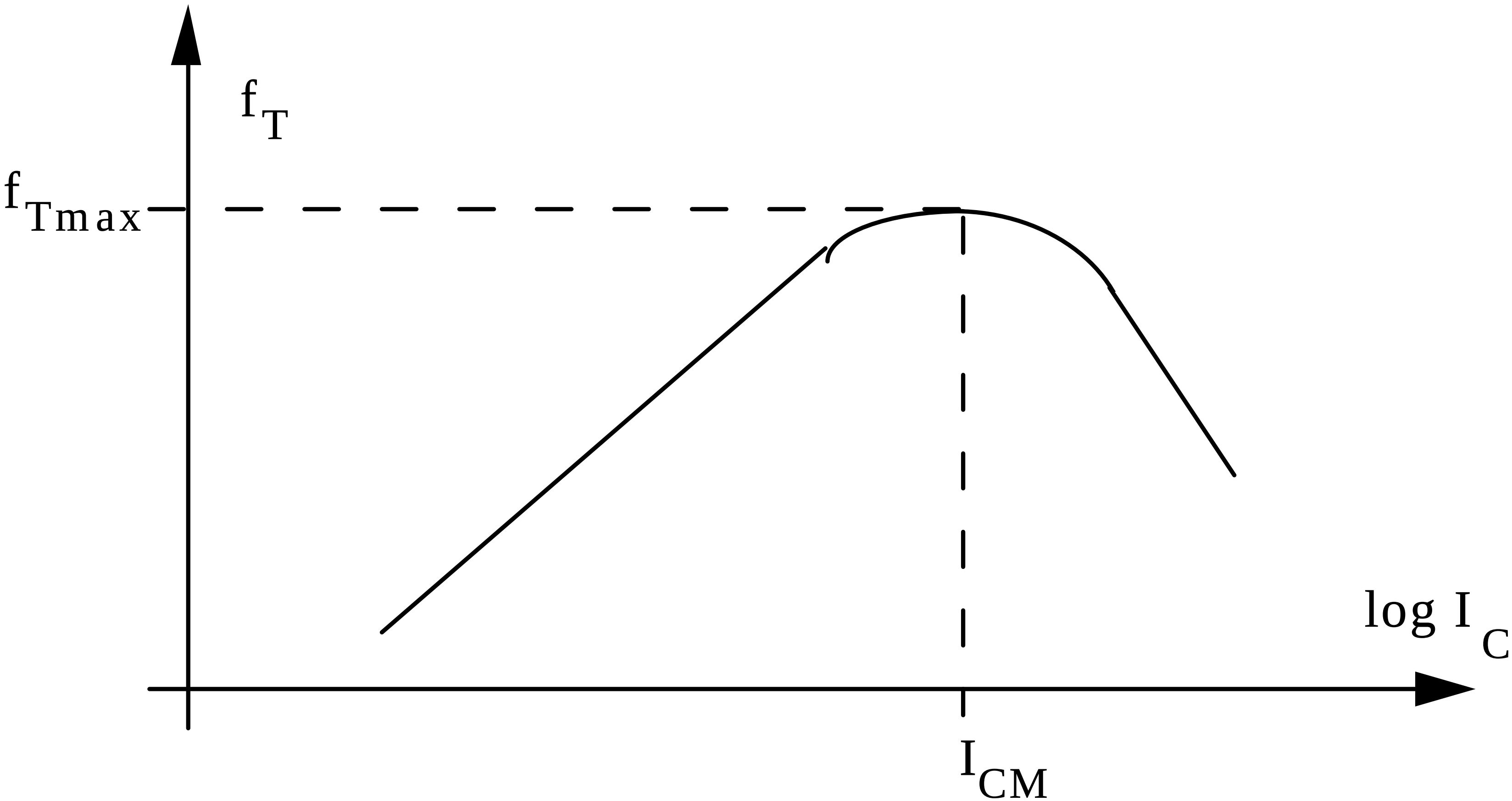
$$f_T = \frac{g_m}{2\pi(C_\pi + C_\mu)}$$

2 MHz $\leq f_T \leq$ 100 MHz for general purpose BJTs

1 GHz $\leq f_T \leq$ 10 GHz for high speed BJTs

1 GHz $\leq f_T \leq$ 50 GHz for HBTs and HEMTs

Typical Behaviour of f_T



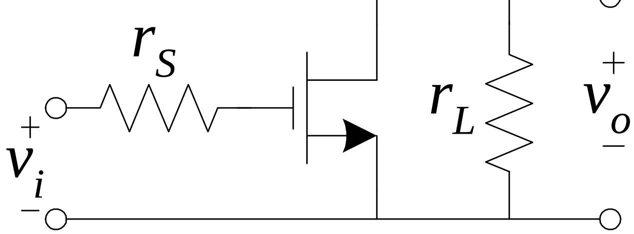
The Open-Circuit Time Constant Method (HF)

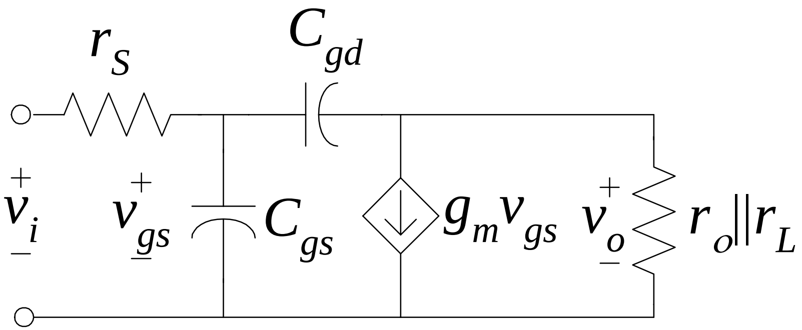
1) Replace the amplifier by its high frequency model
2) Calculate the resistance R_i in parallel with the capacitor C_i, considering all the remaining capacitors as open circuits
3) Repeat step 2) for each capacitor (i = 1, 2, ..., n_H)
4) Calculate ω_H using

$$\omega_H \approx \frac{1}{\sum_{i=1}^{n_H} R_i C_i}$$

High-Frequency Response of FET Amplifiers

Common Source





$$R_{gs} = r_S$$

$$R_{gd} = \frac{v_{gs} - v_o}{v_{gs} / r_S} = r_S (1 - \frac{v_o}{v_{gs}})$$

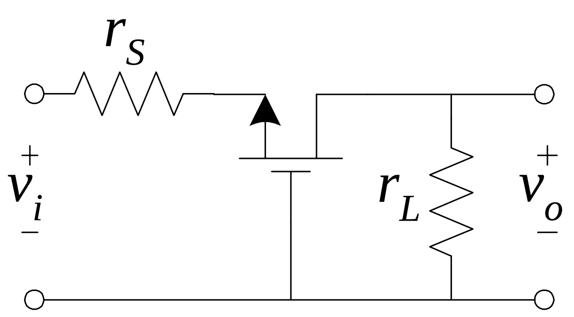
$$v_o = -(\frac{v_{gs}}{r_S} + g_m v_{gs})(r_o \| r_L)$$

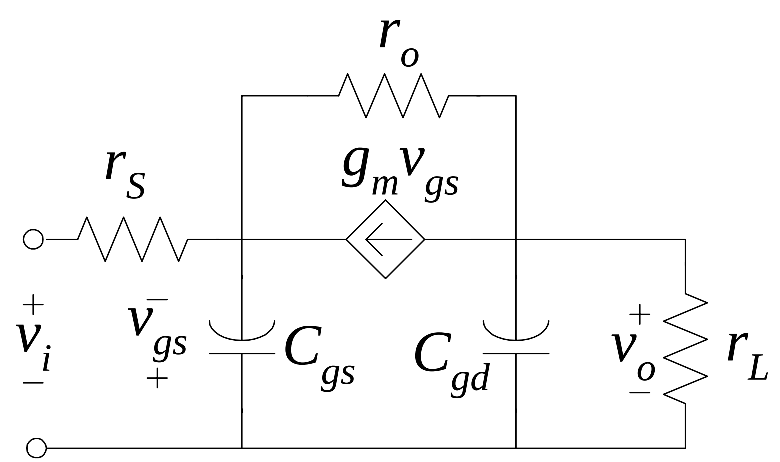
$$R_{gd} = r_S [1 + (r_o \| r_L)(g_m + 1/r_S)]$$

$$\omega_H \approx 1/(R_{gs} C_{gs} + R_{gd} C_{gd})$$

High-Frequency Response of FET Amplifiers

Common Gate





$$R_{gs} = r_S \parallel Z_1 \qquad Z_1 = \frac{-v_{gs}}{v_o / r_L} \qquad v_o = \left[-g_m v_{gs} + \left(\frac{-v_{gs} - v_o}{r_o} \right) \right] r_L$$

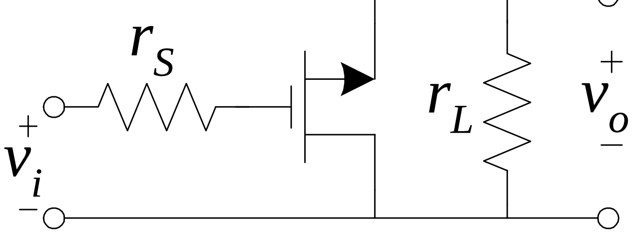
$$Z_1 = \frac{r_L (1 + r_L / r_o)}{g_m r_L + r_L / r_o} \qquad \text{if } r_o >> r_L \text{ then } Z_1 \approx \frac{1}{g_m}$$

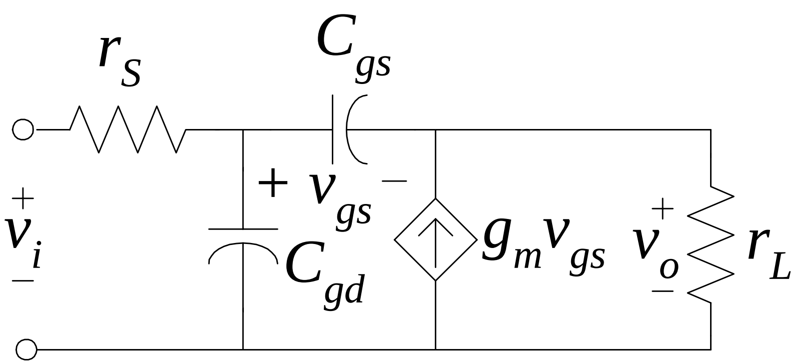
To calculate R_{gd}, assume $r_o >> r_S$, then $v_{gs} = 0$: $\quad R_{gd} = r_o \parallel r_L$

$$\omega_H \approx 1/(R_{gs} C_{gs} + R_{gd} C_{gd})$$

High-Frequency Response of FET Amplifiers

Common Drain





$$R_{gd} = r_S \qquad R_{gs} = \frac{v_{gs}}{g_m v_{gs} - v_o / r_L} \qquad \frac{v_{gs} + v_o}{r_S} = g_m v_{gs} - \frac{v_o}{r_L}$$

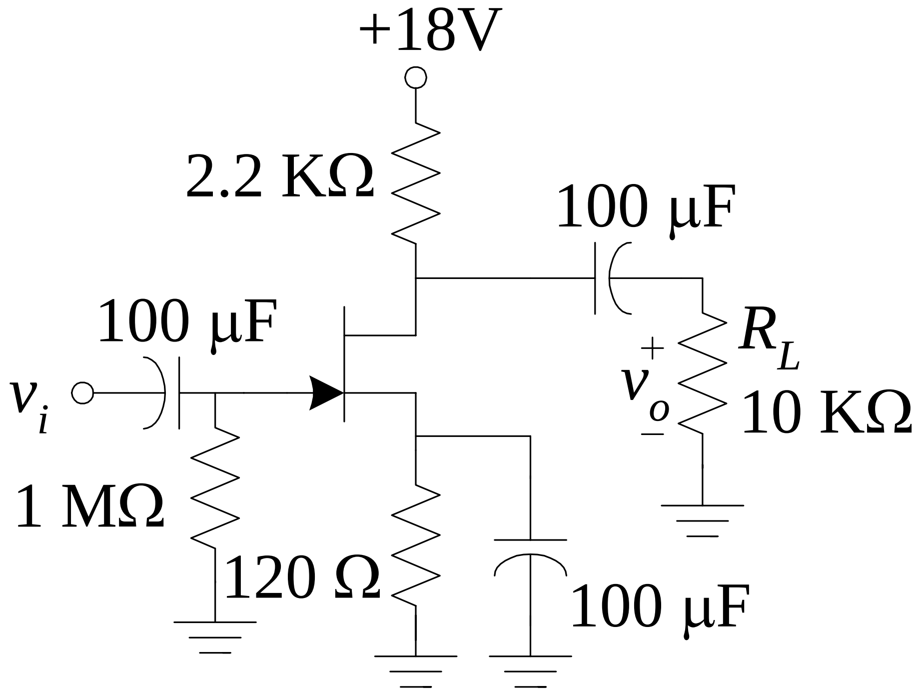
$$v_o = \frac{v_{gs}(g_m r_S - 1)}{1 + r_S / r_L} \approx \frac{-v_{gs}}{1 + r_S / r_L}$$

$$R_{gs} = \frac{1}{g_m + 1/(r_L + r_S)} = \frac{r_L + r_S}{1 + g_m(r_L + r_S)}$$

$$\omega_H \approx 1/(R_{gs}C_{gs} + R_{gd}C_{gd})$$

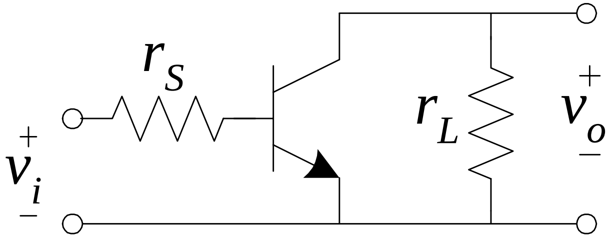
Example

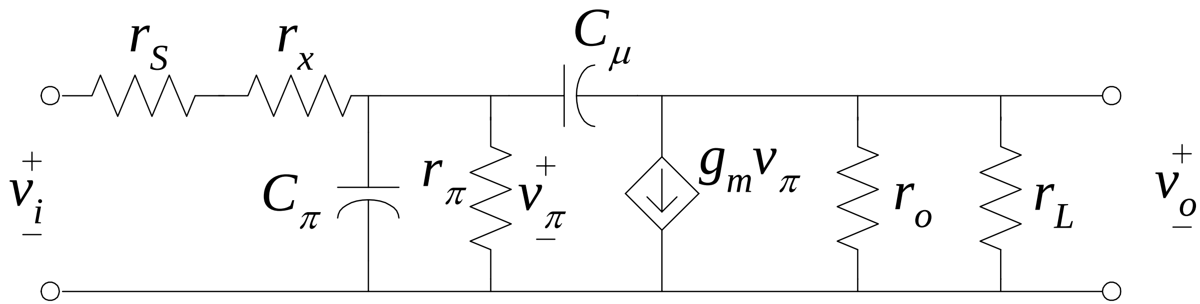
Calculate the cutoff high-frequency for the following JFET amplifier (assume $V_P = -3$ V, $I_{DSS} = 7$ mA, $\lambda = 10^{-2}$ V^{-1}, $C_{gd} = 1$pF, $C_{gs} = 3$ pF)



High-Frequency Response of BJT Amplifiers

Common Emitter





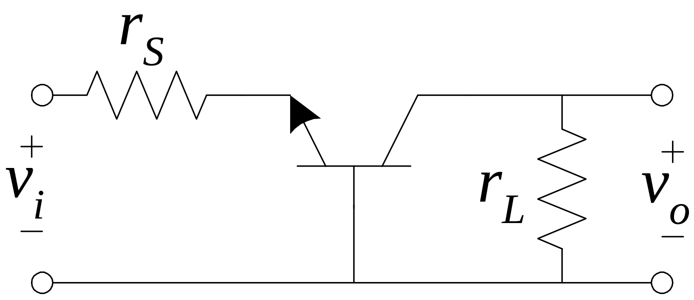
$$R_\pi = (r_S + r_x) \parallel r_\pi \qquad R_\mu = \frac{v_\pi - v_o}{v_\pi / R_\pi} = R_\pi \left(1 - \frac{v_o}{v_\pi}\right)$$

$$v_o = -\left(\frac{v_\pi}{R_\pi} + g_m v_\pi\right)(r_o \parallel r_L) \qquad R_\mu = R_\pi [1 + (r_o \parallel r_L)(g_m + 1/R_\pi)]$$

$$\omega_H \approx 1/(R_\pi C_\pi + R_\mu C_\mu)$$

High-Frequency Response of BJT Amplifiers

Common Base

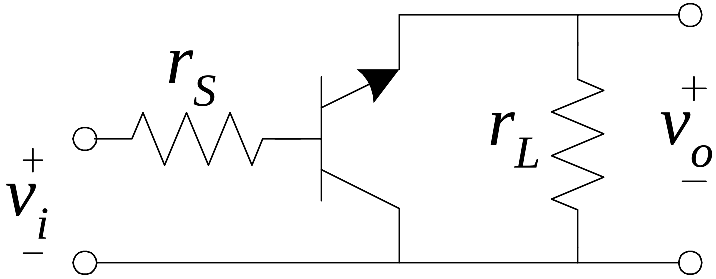


It can be shown that

$$R_\pi = r_\pi \parallel \frac{r_x + r_S}{1 + g_m r_S} \qquad R_\mu = r_L \parallel (r_o + r_x \parallel r_S) \approx r_L$$

$$\omega_H \approx 1/(R_\pi C_\pi + R_\mu C_\mu)$$

Common Collector



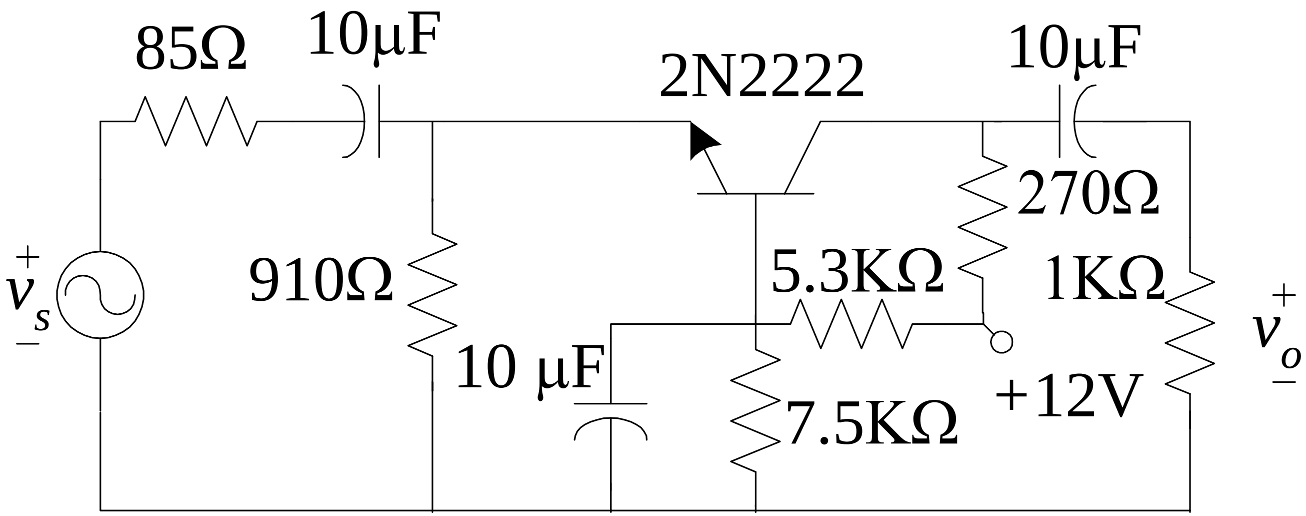
It can be shown that

$$R_\pi = r_\pi \,\|\, \frac{r_x + r_S + (r_L \,\|\, r_o)}{1 + g_m(r_L \,\|\, r_o)} \qquad R_\mu = r_\pi \,\|\, \frac{r_L + r_S + r_x}{1 + g_m(r_L + r_S + r_x)}$$

$$\omega_H \approx 1/(R_\pi C_\pi + R_\mu C_\mu)$$

Example

Calculate the cutoff high-frequency for the following BJT amplifier



Assignment

Solve problems 7.41, 7.47, 7.54, 7.56, 7.67 and 7.68 from the textbook