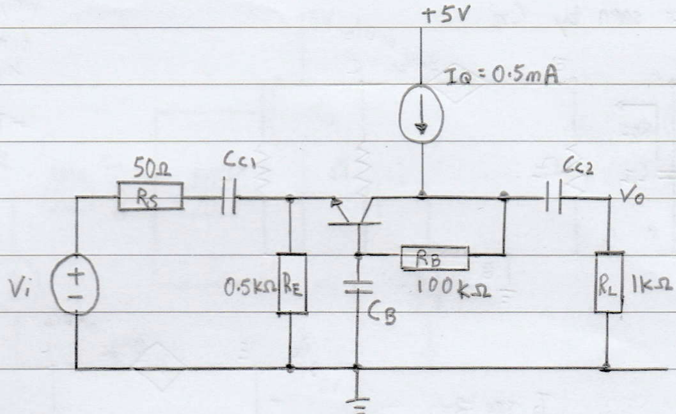
No.: Date:

Esmund Lim

A.E Tutorial 12

1)



$\beta = 100$

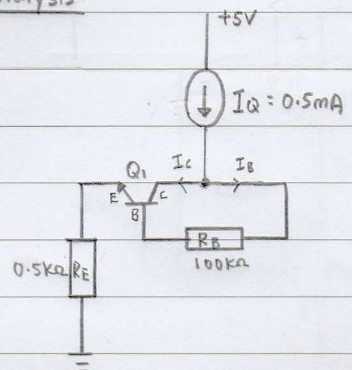
$V_A = \infty$

$C_\mu = 1pF$

$f_T = 285MHz$ (unity gain frequency) GBW (Gain BW product)

Assume $V_T = 25mV$

DC Analysis



$I_Q = I_C + I_B$ — ①

$I_C = \beta I_B$

$I_B = \frac{I_C}{\beta}$ — ②

sub ② into ①

$I_Q = I_C + \frac{I_C}{\beta}$

$0.5mA = I_C + \frac{1}{100} I_C$

$I_C = 0.495049505mA$

$\approx 0.5mA$

$g_m = \frac{I_C}{V_T}$

$= \frac{0.5mA}{25mV}$

$= 0.02S$

$g_m r_\pi = \beta$

$r_\pi = \frac{\beta}{g_m}$

$= \frac{100}{0.02}$

$= 5000\Omega$

$= 5k\Omega$

$r_o = \frac{V_A + V_{CE}}{I_C}$

$= \frac{\infty + V_{CE}}{I_C}$

$= \infty$

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

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

$f_T \div \frac{g_m}{2\pi} = \frac{1}{C_\pi + C_\mu}$

$\frac{f_T 2\pi}{g_m} = \frac{1}{C_\pi + C_\mu}$

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

$C_\pi = \frac{g_m}{f_T 2\pi} - C_\mu$

$= \frac{0.02}{285 \times 10^6 \times 2\pi} - 1 \times 10^{-12}$

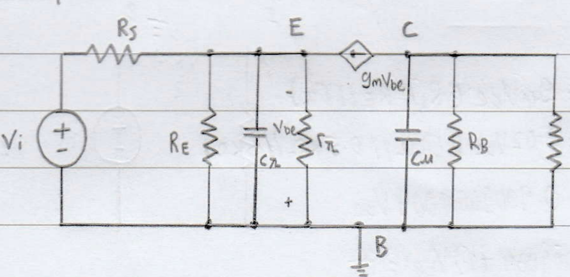
$= 10.16876794 \times 10^{-12} F$

$\approx 10pF$

$\omega_{H-3dB} = \frac{1}{\sum C_i R_i}$

$= \frac{1}{C_\pi R_{\pi 0} + C_\mu R_{\mu 0}}$

AC analysis



* $r_o = \infty$ open-circuit

C_π is always between base and emitter

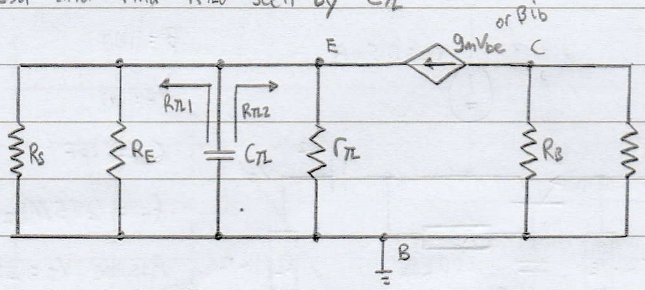
C_μ is always between base and collector

high frequency small signal equivalent circuit by replacing external capacitor C_{C1}, C_B, C_{C2} by short circuit (ideal case)

Add in internal capacitor C_π and C_μ

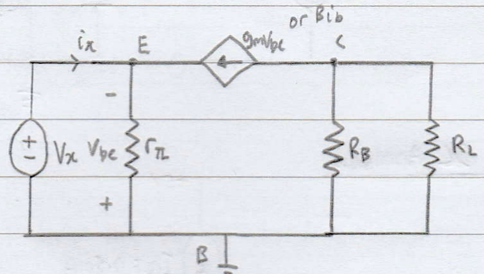
No.: .... Date: ....

Open circuit C_μ and find $R_{\pi o}$ seen by C_π



Why is it called open circuit time constant when you find higher cutoff frequency?

- To see resistance seen by one capacitor without the other capacitor
  ↳ O/C "killed" it



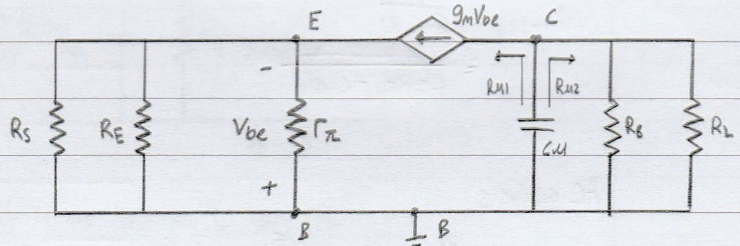
$$R_{\pi 1} = R_S // R_E$$
$$= \frac{50 \times 0.5\times10^3}{50 + 0.5\times10^3}$$
$$= 45.45454545\,\Omega$$

To see $R_{\pi 2}$

$$R_{\pi 2} = \frac{V_x}{i_x}$$
$$= \frac{-V_{be}}{-g_m V_{be}}$$
$$= \frac{1}{g_m}$$
$$= \frac{1}{0.02}$$
$$= 50\,\Omega$$

$$\therefore R_{\pi o} = R_{\pi 1} // R_{\pi 2}$$
$$= \frac{45.45 \times 50}{45.45 + 50}$$
$$= 23.80952381\,\Omega$$
$$\approx 24\,\Omega$$

Open circuit C_π and find $R_{\mu o}$



$$-V_{be} = g_m V_{be}(R_S // R_E // r_\pi)$$
$$= 0.02 V_{be}(50\Omega // 0.5k\Omega // 5k\Omega)$$
$$= 0.9009009009 V_{be}$$
$$(0.9009009009 + 1)V_{be} = 0$$
$$V_{be} = 0$$

Since $V_{be} = 0$

$$R_{\mu 1} = \infty$$
$$R_{\mu 2} = R_B // R_L$$
$$= 100k\Omega // 1k\Omega$$
$$= 990.0990099\,\Omega$$
$$\approx 990\,\Omega$$

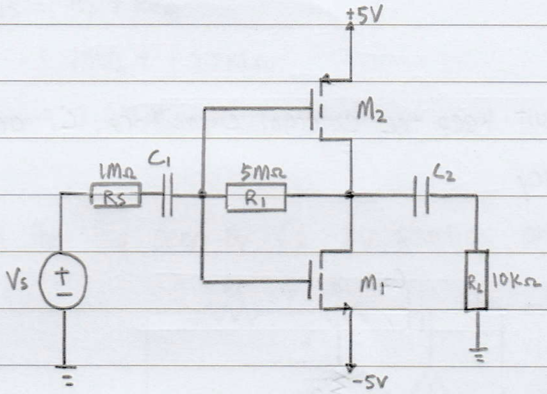
$$R_{\mu o} = R_{\mu 1} // R_{\mu 2}$$
$$= \infty // R_{\mu 2}$$
$$= 990\,\Omega$$

$\therefore$ By OCTC method

$$\omega_{H\,-3dB} = \frac{1}{R_{\mu o}C_\mu + R_{\pi o}C_\pi}$$
$$= \frac{1}{990(1\times10^{-12}) + 24(10\times10^{-12})}$$
$$= 813.0081301 \times 10^6\ \text{rad/s}$$
$$\approx 813\ \text{M rad/s}$$

No.: Date:

2)

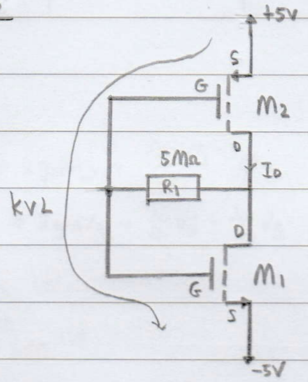


$$\overbrace{\mu_n C_{ox1}\left(\frac{W_1}{L_1}\right)}^{=K_n} = \mu_p C_{ox2}\left(\frac{W_2}{L_2}\right) = 50\mu A/V^2$$

$$|V_{TP}| = V_{TN} = 2V$$

$$\lambda = 0.005\,V^{-1}$$

DC analysis



By KVL

$$-5 + V_{SG2} + V_{GS1} - 5 = 0$$

$$V_{SG2} + V_{GS1} = 10$$

$$V_{GS} = 5V \qquad V_{SG2} = 5V,\ V_{GS1} = 5V$$

$$I_D = \frac{K_n}{2}(V_{GS} - V_{TN})^2$$

$$= \frac{50\mu A}{2}(5-2)^2$$

$$= 225\mu A$$

$$g_{m1} = g_{m2} = g_m$$

$$= \sqrt{2K_n I_D}$$

$$= \sqrt{2(50\mu A)(225\mu A)}$$

$$= 150\times10^{-6}\,S$$

$$r_{o1} = r_{o2} = r_o$$

$$= \frac{1}{\lambda I_D}$$

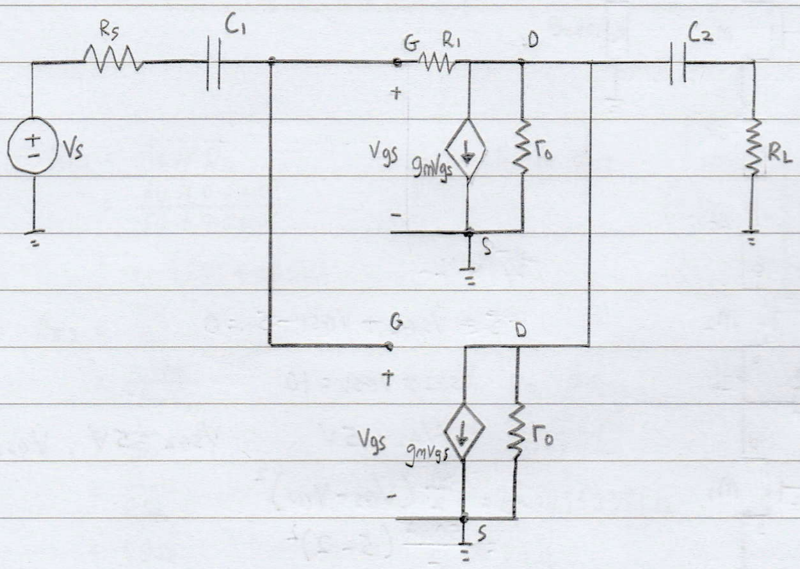
$$= \frac{1}{0.005(225\mu A)}$$

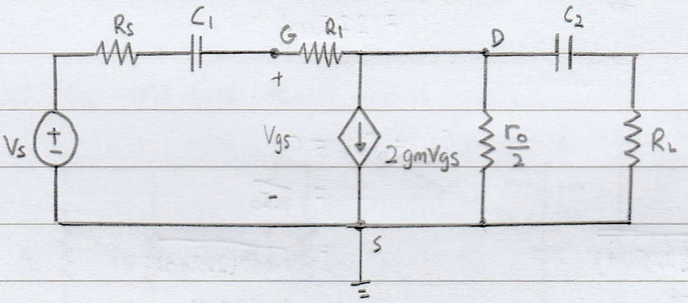
$$= 0.888\,M\Omega$$

No.: Date:

AC Analysis

Low frequency small signal equivalent circuit. keep the external capacitors, C_1 and C_2, that contribute to the lower cut-off frequency

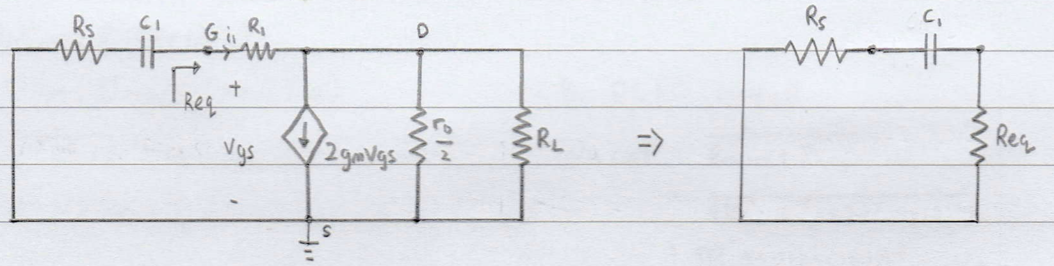




$$\omega_{L-3dB} = \sum_i \frac{1}{C_i R_{is}}$$ → short circuit

$$= \frac{1}{C_1R_{1s} + C_2R_{2s}}$$

Find R_{1s} seen by C_1 by shorting other capacitor



$$R_{eq} = \frac{V_{gs}}{i_1}$$

By KCL

$$\frac{V_g - V_d}{R_1} = 2g_m V_{gs} + \frac{V_d}{r_o/2} + \frac{V_d}{R_L}$$

$V_{gs} = V_g - V_s$

$= V_g - 0$

$= V_g$

$$\frac{V_g - V_d}{R_1} = 2g_m V_g + \frac{V_d}{r_o/2} + \frac{V_d}{R_L}$$

$$\frac{1}{R_1}V_g - \frac{1}{R_1}V_d = 2g_m V_g + \frac{1}{r_o/2}V_d + \frac{1}{R_L}V_d$$

$$\left(\frac{1}{R_1} - 2g_m\right)V_g = \left(\frac{2}{r_o} + \frac{1}{R_L} + \frac{1}{R_1}\right)V_d$$

$$\left[\frac{1}{5\times10^6} - 2(150u)\right]V_g = \left(\frac{2}{0.888M} + \frac{1}{10k\Omega} + \frac{1}{5m}\right)V_d$$

$$-299.8\times10^{-6}\,V_g = 1.024522523\times10^{-4}\,V_d$$

$$V_d = -2.926241183\,V_g$$

$$R_{eq} = \frac{V_g}{(V_g - V_d)/R_1}$$

$$= \frac{V_g}{(V_g - (-2.926)V_g)/5M}$$

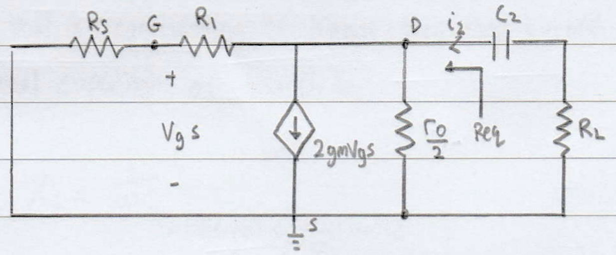
$$= 1.273482643\times10^6\,\Omega$$

$$\approx 1.273M\Omega$$

No.: .... Date: ....

$$R_{1S} = R_S + R_{eq}$$
$$= 1M\Omega + 1.27M\Omega$$
$$= 2.27M\Omega$$

Find the R_{2S} seen by C_2 by shorting other capacitor



By KCL

$$i_2 = \frac{V_d}{r_o/2} + 2g_mV_{gs} + \frac{V_d - V_g}{R_1}$$
$$= \frac{2}{r_o}V_d + 2g_mV_g + \frac{1}{R_1}V_d - \frac{1}{R_1}V_g$$

$$V_g = \frac{R_S}{R_S + R_1}V_d$$
$$= \frac{1M\Omega}{1M\Omega + 5M\Omega}V_d$$
$$= \frac{1}{6}V_d$$

$$V_d = 6V_g$$

$$R_{eq} = \frac{V_d}{i_2}$$
$$= \frac{V_d}{\frac{2}{r_o}V_d + 2g_mV_g + \frac{1}{R_1}V_d + \frac{1}{R_1}V_g}$$
$$= \frac{6\cancel{V_g}}{\frac{2}{0.888m}(6\cancel{V_g}) + 2(150\times10^{-6})\cancel{V_g} + \frac{1}{5\times10^6}(6\cancel{V_g}) + \frac{1}{5\times10^6}\cancel{V_g}}$$
$$= 19.0528502\times10^3\Omega$$
$$\approx 19.05k\Omega$$

$$R_{2S} = R_L + R_{eq}$$
$$= 10k\Omega + 19.05k\Omega$$
$$= 29.05k\Omega$$

By SCTC method

$$\omega_{L-3dB} = \sum_i \frac{1}{C_iR_{iS}}$$
$$= \frac{1}{C_1R_{1S}} + \frac{1}{C_2R_{2S}}$$
$$= \frac{1}{1\times10^{-6}\times2.27\times10^6} + \frac{1}{1\times10^{-6}\times29.05k\Omega}$$
$$= 34.86393655\ rad/s$$
$$\approx 34.9\ rad/s$$

No.: Date:

Concept for this tutorial

① need to know which capacitor contribute to higher frequency cutoff and which capacitor contributed to lower frequency cutoff

→ Capacitor that is contributing to higher frequency cutoff is very small capacitance which is the internal capacitor of transistor

$$X_C = \frac{1}{\omega C}$$

→ internal capacitance

$\underbrace{C_\mu, C_\pi}$ value of internal capacitance very small

↳ no matter what frequency ω you have $X_C \approx$ large (o/c)

if we are interested in very high ω

$$\text{eg } \frac{1}{\underbrace{(1\times10^{-12})}_{C}\underbrace{(1\times10^{12})}_{\omega}} = 1\Omega$$

↳ $\underbrace{\text{very small resistance}}$ cannot ignore this resistance

*

C_π	C_μ
B to E	B to C
G to S	G to D

$$\omega_{H-3dB} = \frac{1}{\sum_i C_i R_i} = \frac{1}{C_\pi R_{\pi o} + C_\mu R_{\mu o}}$$

→ Capacitor that is contributing to lower frequency cut-off is very large capacitance which is the external capacitor of transistor

$$X_C = \frac{1}{\omega C} \quad (C \to \infty)$$

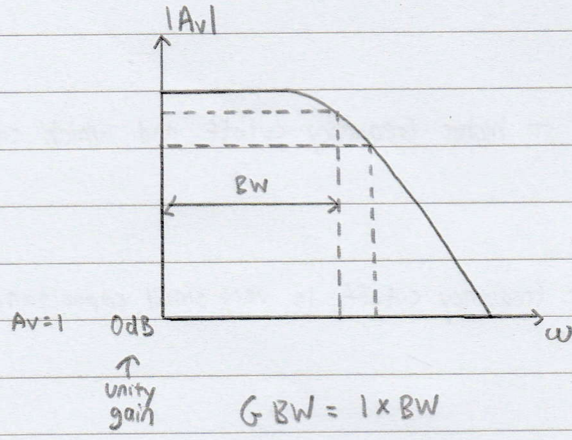
$= 0$ no matter what ω input

$$X_C = \frac{1}{\omega C} \quad (\to \text{finite})$$

if ω get lower, it contribute to lower cut-off frequency

$$\omega_{L-3dB} = \sum_i \frac{1}{C_i R_i}$$

No.: Date:



A_v

GBW

Bandwidth

lower gain = larger bandwidth

If gain = 1

$20\log(1) = 0dB$

$GBW = 1 \times BW$

$f_T \rightarrow$ if you have a transistor that can have this f_T for building amplifier, that is the limit of your frequency operation, because you can't build an amplifier which have a gain lesser than 1

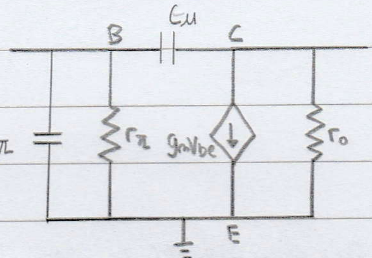
$\rightarrow$ how high the frequency can operate this

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

gain is affected g_m

larger g_m = larger gain
as gain get larger
bw get smaller

gain equation
* g_m always at numerator



ideally if the frequency is very low

$C_\pi , C_\mu = 0/C$

but when frequency is very high

X_C become small enough that some frequency can pass by C_π, C_μ without being amplify by $g_m V_{be}$