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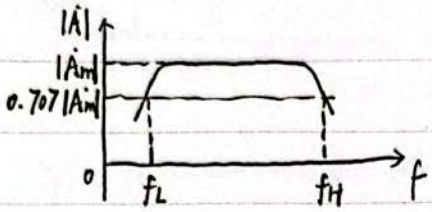
[专题六] 频响

知识点1：波特图

△一些概念：



通频带 $BW = f_H - f_L \approx f_H$

增益带宽积（别死记，字面意思） $GB = |A_M| \times BW$

△绘制相关：

幅度和相位波特图的绘制

因子		幅度		相位	
K	$V_{out} = KV_{in}$	$20\log_{10}K$	放大	0°	不影响相位
$(j\omega)^N$	$V_{out} = (jw)\cdot V_{in}$ ∴ V_o 随 w 线性增加	20N dB/decade		90N°	
$\frac{1}{(j\omega)^N}$	$V_{out} = \frac{1}{jw}\cdot V_{in}$	-20N dB/decade		-90N°	
△ $(\frac{1+j\omega}{z})^N$	$(1+\frac{jw}{z})^N$?	20N dB/decade	★	90N°	①
△ $\frac{1}{(1+j\omega/p)^N}$		-20N dB/decade	★	-90N°	②

构建波特图的方法：

分析常数项和原点处的零极点，随着频率的增加：

每碰到一个零点，幅度的斜率增加20dB/十倍频，相位增加90度（从0.1到10倍频率）

每碰到一个极点，幅度的斜率减小20dB/十倍频，相位减小90度（从0.1到10倍频率）

对应 $\frac{k}{1+\frac{p}{jf}}$

高频

低频 $\frac{k}{1+\frac{jf}{p}}$

[P1-Ex.6] $20\lg|A_M| = 30$ $A_M = 10^{\frac{3}{2}} \approx 32$

$f_L = 10\,Hz$ $f_H = 1\times10^5\,Hz$

∴ $A_V = \frac{-32}{(1+\frac{10}{jf})(1+\frac{jf}{1\times10^5})}$

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[P1 - Ex.7]

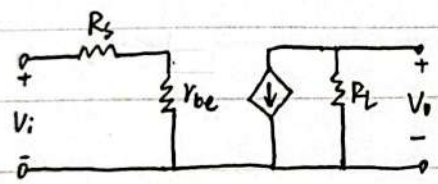
解: $A_v = \frac{\pm 100}{(\frac{1}{10}+\frac{1}{jf})(1+j\cdot\frac{f}{10^4})(1+j\cdot\frac{f}{10^5})} = \frac{\pm 1000}{(1+\frac{10}{jf})(1+\frac{jf}{10^4})(1+\frac{jf}{10^5})}$

$\therefore f_L = 10Hz$, $f_H = 10kHz$

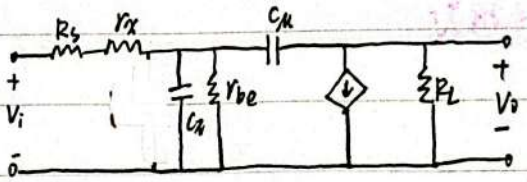
知识点2: 频率响应

[P2 - Ex.1]

解: 先画原小信号:



再加高频参数:



$A_M = \frac{-g_m V_\pi R_L'}{V_\pi} = -g_m R_L'$

③ 再对 C_M 拆环 $C_1 = (1-A)C_M = (1+g_m R_L')C_M$ $C_2 = C_M$

此时 $C_\pi \to C_\pi' = (1+g_m R_L')C_M + C_\pi$.

求上限截止: $\omega_H = \frac{1}{RC}$

$R = R_{in} = (R_s + r_x) // r_{be}$ 而 $g_m = \frac{I_C}{V_T} = \frac{\beta}{r_{be}}$ $\therefore r_{be} = 100 \cdot \frac{26}{1} = 2.6k\Omega$

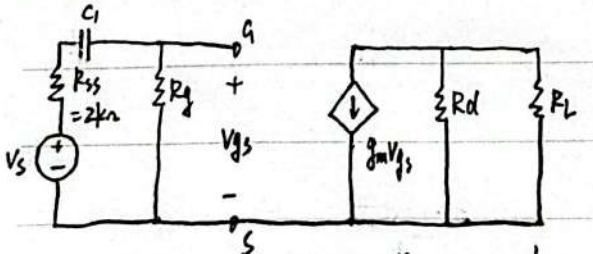
$\Rightarrow R = 1.2k\Omega // 2.6k\Omega = 0.82k\Omega$

$C_\pi' = (1+\frac{1}{26}\times 5000)\times 0.5 + 14.8 = 111.45pF$

$\therefore \omega_H = \frac{1}{0.82\times 10^3 \times 111.45\times 10^{-12}}$ $f_H = \frac{\omega_H}{2\pi} = \sout{2.01\times 10^6 Hz}$ $1.74\times 10^6 Hz = 1.74MHz$

[P2 - Ex.4]

先画原先的小信号:



$A_m = -\frac{g_m V_{gs}(R_d // R_L)}{V_{gs}} \cdot \frac{R_G}{R_G + R_{ss}} = -12.38$

低频下: $\omega_L = \frac{1}{RC}$, $R\uparrow$, $\omega\downarrow$

$R_1 = R_{ss} + R_G = 1002k\Omega$ $R_2 = R_D + R_L = 13.3k\Omega$

$R_3 = \frac{1}{g_m} // R_S = 166.6\Omega$ $\because C_1 = C_2 = C_S$ $\therefore C_S$ 决定 f_L

$f_L = \frac{\omega_L}{2\pi} = \frac{1}{2\pi R_S C_S} = 95.5Hz$

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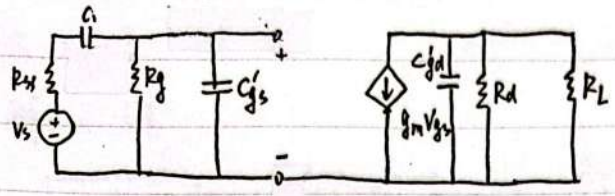
再画高频小信号:



$C_{gs}' = C_{gs} + (1-A_M)\cdot C_{gd} = 5pF + 13.38\times 5pF = 71.9pF$

RC↑ W↓ $\quad R_{ss}//R_g = 1.996k\Omega \quad R_d//R_L = 2.481k\Omega$

$\therefore f_H = \frac{1}{2\pi R_H C_H} = \frac{1}{2\pi\times 1.996\times10^{3}\times 71.9\times10^{-12}} = \underline{1.1MHz}$

[Ex.6] 解:

$A_M = \frac{-g_m V_{gs} R_L'}{V_{gs}} = -12.5$

$C_{gs}' = C_{gs} + (1-A_M)C_{gd} = 87.5fF \quad \tau_{gs}' = 875ps.$

~~$\therefore f_{H1} = \frac{1}{2\pi R_{sig} C_{gs}'} = \frac{1}{2\pi\cdot 10\times10^{3}\times 87.5\times10^{-15}} = 1.82\times10^{8}Hz = 182MHz$~~ X

$C_{gd}' = C_L + C_{gd} = 30fF \quad \therefore \tau_{gd}' = 300ps$

~~$f_{H2} = \frac{1}{2\pi R_L' C_{gd}'} = \frac{1}{2\pi\cdot 10\times10^{3}\times 30\times10^{-15}} = 5.30\times10^{8}Hz$~~ X

好玩环环相扣! $\sum_i R_i C_i = 1175ps$

$f_H = \frac{1}{2\pi\tau_H} = \frac{1}{2\pi\cdot 1175\times10^{-12}} = 135.5MHz$

[Ex.8] 解:

(1) 等效, $V_B' = \frac{R_2}{R_1+R_2}\cdot V_{CC} = 3.21V \quad R_B = R_1//R_2 = 9.673k\Omega$

$\therefore V_B' = I_B R_B + 0.7 + I_E R_E$

$I_B = \frac{V_B' - 0.7}{R_B + (1+\beta)R_E} \qquad I_E = (1+\beta)\cdot\frac{V_B'-0.7}{R_B+(1+\beta)R_E} = 1.94mA$ ✓

(2) $g_m = \frac{I_C}{V_T} = \frac{\beta}{r_{be}} \Rightarrow r_{be} = \frac{\beta V_T}{I_C} = \frac{100\times 25mV}{1.92mA} = \underline{1.3k\Omega}$ ✓

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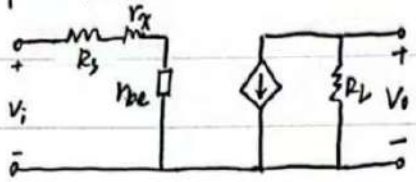
知识点2：频率响应放大电路

[P2-Ex.1]

解：小信号：



静态 $g_m = \frac{I_c}{V_T} = \frac{\beta}{r_{be}}$

$\therefore r_{be} = 2.6k\Omega$

$A_M = \frac{-\beta R_L}{\beta(r_{be}+R_s)} = -100 \times \frac{5}{1.2} = -66.79$

$C_x' = C_x + (1+A_M)C_M = 14.8pF + 66.79 \times 0.5pF = 97.695pF$

$Req_1 = r_{be} // (r_x + R_s) = 0.82k\Omega$

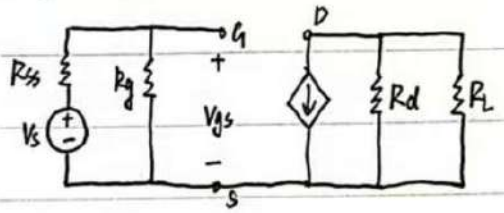
$2.6k\Omega \quad 1.2k\Omega$

$\therefore \tau_1 = Req_1 \cdot C_x' = 8.011 \times 10^{-8} s$ ✓

$C_M = 0.5pF \quad Req_2 = R_L = 5k\Omega \quad \therefore \tau_2 = 2.5 \times 10^{-9} s$

$\therefore f_H = \frac{1}{2\pi\tau_1} = 1.99 \times 10^6 Hz \approx 2MHz$

[P2-Ex.4] 解：先画小信号：



$A = -g_m(R_d // R_L) = \frac{V_o}{V_i} \qquad A_m = \frac{V_o}{V_i} \cdot \frac{V_i}{V_s} = \frac{R_g}{R_g + R_{ss}} \cdot (-g_m) \cdot (R_d // R_L) \approx -g_m \cdot R_d // R_L = -12.4$

低频下：

计算 $\tau_1 = C_1 R_1 \qquad R_1 = R_{ss} + R_g = 1002k\Omega$

$\tau_2 = C_2 R_2 \qquad R_2 = R_d + R_L = 13.3k\Omega$

$\tau_3 = C_3 R_3 \qquad R_3 = R_s // (\frac{1}{g_m} + R_g // R_{ss})$

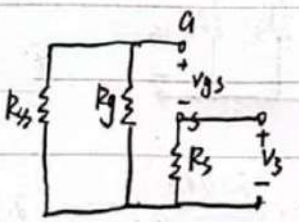
200Ω

$= 1k\Omega // 2.2k\Omega = 687.5\Omega \; 166.7\Omega$

95.4

$\therefore f_L = \frac{1}{2\pi\tau_3} = \frac{1}{2\pi \times 687.5 \times 10 \times 10^{-6}} = 23.15Hz$

166.7



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高频下，$C'_{gs} = C_{gs} + (1-A)C_{gd} = 72pF$　　$R'_{gs} = R_g // R_s = 2k\Omega$

$C'_{gd} = C_{gd} = 5pF$　　$R'_{gd} = R_d // R_L = 2.48k\Omega$

$\therefore f_H \frac{1}{2\pi RC} = \frac{1}{2\pi \times 72\times10^{-12}\times 2\times10^{3}} = 1.1MHz$

Ex.6. 解：

$$A = \frac{-g_m V_{gs} R'_L}{V_{gs}} = -g_m R'_L = -12.5$$

$\therefore C'_{gs} = C_{gs} + (1+g_m R'_L)C_{gd} = 87.5fF$

$R'_{gs} = R'_{sig} = 10k\Omega$

$\tau_1 = C'_{gs} R'_{gs} = 875ps$

$C'_{gd} = C_{gd} // C_L = 30fF$

$R'_{gd} = R'_L = 10k\Omega$

$\therefore \tau_2 = C'_{gd} R_{gd} = 300ps$

$\therefore \tau = \tau_1 + \tau_2 = 1175ps$

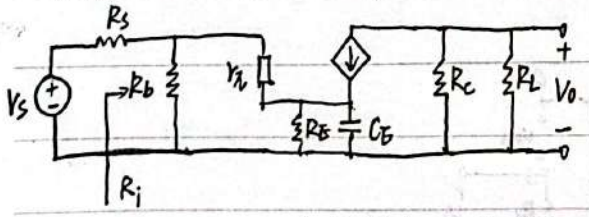
$\therefore f_H = \frac{1}{2\pi RC} = 135.5MHz$

[Ex.8]

(1) $I_E = 1.94mA$

(2) $r_\pi = 1.3k\Omega$

小信号：$R_b = R_1 // R_2 = 9.04k\Omega$



$R_i = R_b // r_\pi = 1.15k\Omega$

$R_o = R_c = 2.2k\Omega$

$$\frac{V_o}{V_s} = \frac{V_o}{V_i}\cdot\frac{V_i}{V_s} = \frac{-\beta(R_c // R_L)}{r_\pi}\cdot\frac{R_b // r_\pi}{R_s + R_b // r_\pi} = -8.33\ V/V$$

(3) $R'_E = R_E // \left(\frac{r_\pi + R_b // R_s}{1+\beta}\right)$　　$R_b // R_s = 4.91k\Omega$　　$\frac{r_\pi + R_b // R_s}{1+\beta} = 0.061k\Omega = 61.5\Omega$

不加 $R'_E = 58.5\Omega \Rightarrow f_L = \frac{1}{2\pi R'_E C_E} = 2712.1Hz$

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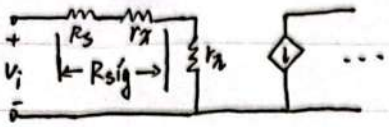
<易错点整理>

1. 高频等效完之后：



但：计算阻值时，R'sig 仍处于网络中，所以要算进去

此时 Am 不计算 Rsig 的部分，考虑放大器本身的增益！

2. $f=\frac{1}{2\pi RC}=\frac{1}{2\pi\tau}$

低频，选 f 最高，τ 最小的

高频，选 f 最低，τ 最大的

若 τ 差距不大，要计算 $\sum R_iC_i$！