第五章 基本放大电路

—— 5.5 放大电路的频率特性

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第五章内容

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5.2 放大电路的分析方法

5.3 放大电路的稳定偏置

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5.5 放大电路的频率特性

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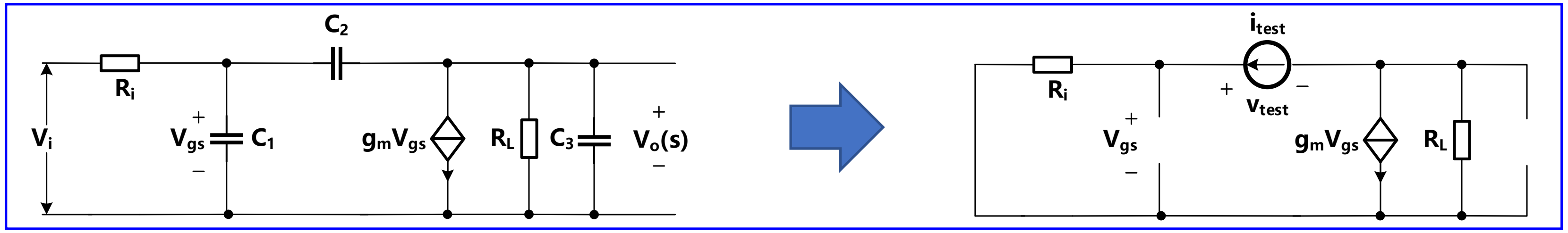
5.5.3 三极管的高频参数——回顾

✓ **开路时间常数法：计算步骤**

- 计算每个电容两端的等效电阻（其他电容开路）
- 每个电容乘以其两端的等效电阻，得到对应时间常数τ_i
- 将每一个τ_i求和，估算上限截止频率ω_H

$$H(s)=\frac{A}{(\tau_1 s+1)(\tau_2 s+1)\dots(\tau_n s+1)}\approx\frac{A}{(\tau_1+\tau_2\dots+\tau_n)s+1}$$

$$\omega_H=\frac{1}{\tau_1+\tau_2\dots+\tau_n}$$



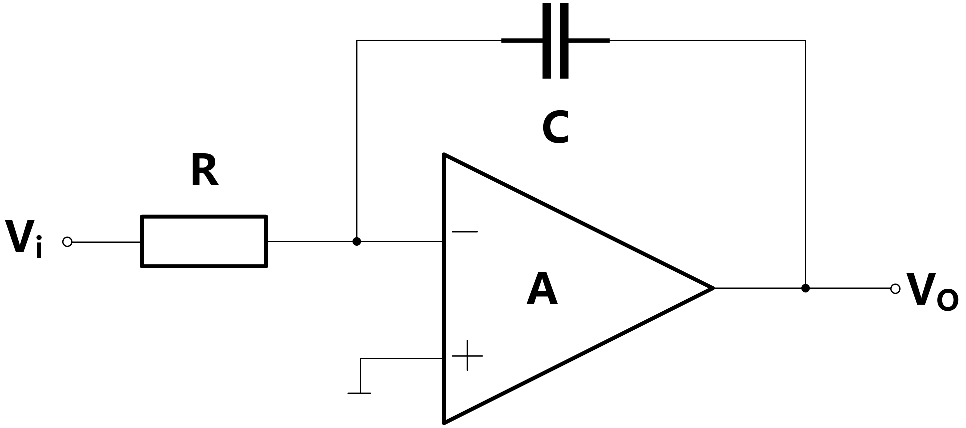
5.5.3 三极管的高频参数——回顾

✓ **密勒效应：**

- 计算积分器的传输函数

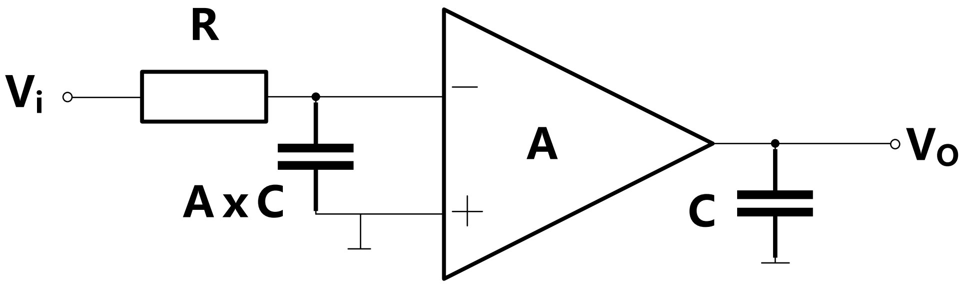
$$\frac{V_i - V_-}{R} \times \frac{1}{sC} = V_o,\quad v_- \times A = -v_o$$

$$\Rightarrow \frac{V_o}{V_i} = -\frac{A}{1+sCR\times A}$$



- 运用密勒效应计算

$$\frac{V_o}{V_i} = -\frac{A}{1+sCR\times A}$$



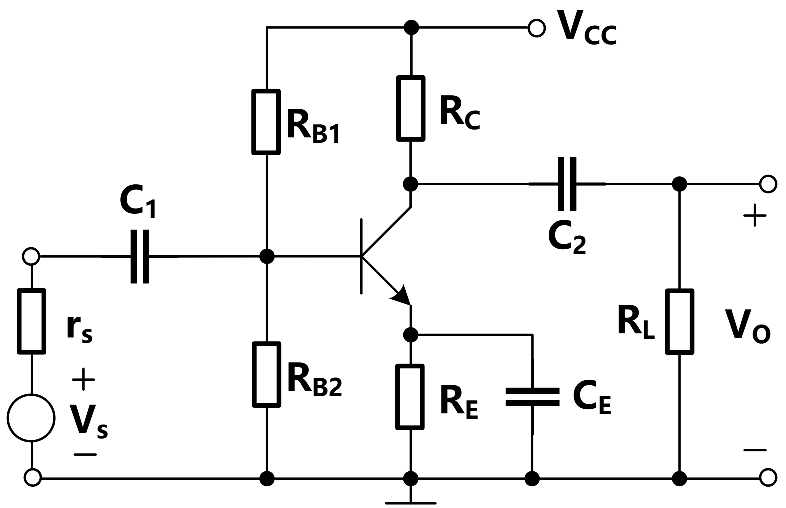
5.5.4 共射放大电路的频率特性

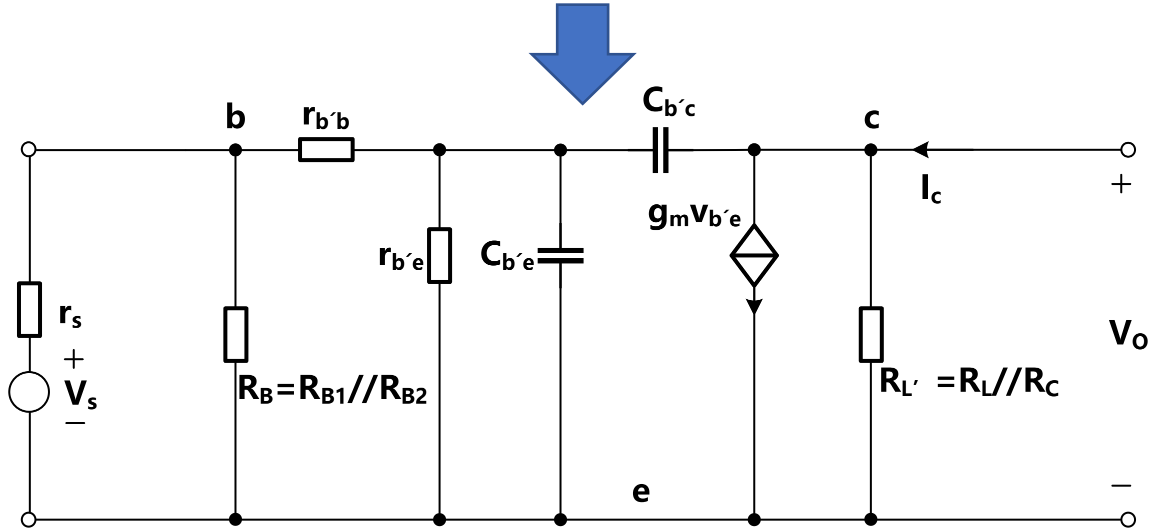
✓ **几点结论：**

- 耦合电容、旁路电容决定高通，下限截止频率主要由低频时间常数中较小的一个决定

- 三极管的结电容和分布电容决定高频响应，上限截止频率由高频时间常数中较大的一个决定

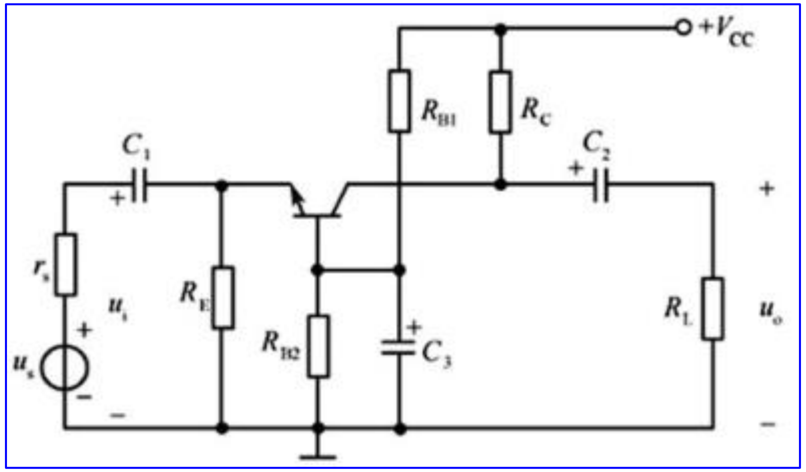
- 通过密勒效应可知，若放大倍数增加，C_M也增加，上限截止频率就下降，通频带变窄。增益和带宽是一对矛盾，增益带宽积是放大器一项重要指标。





5.5.4 共射放大电路的频率特性

✓ **共基极放大电路：**

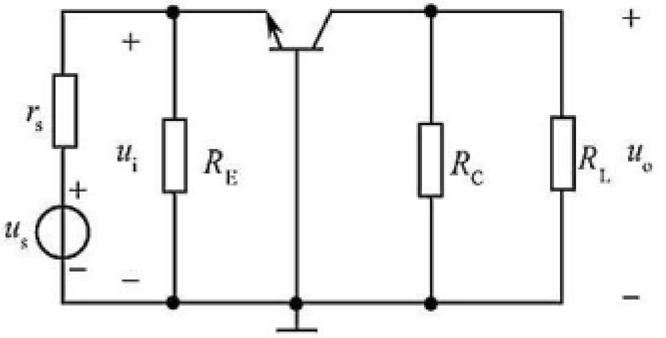


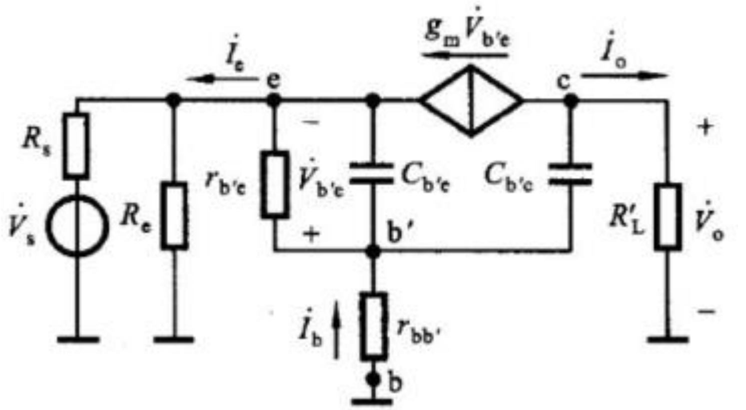
$$r_e = \frac{r_{b'e}}{1+\beta}$$

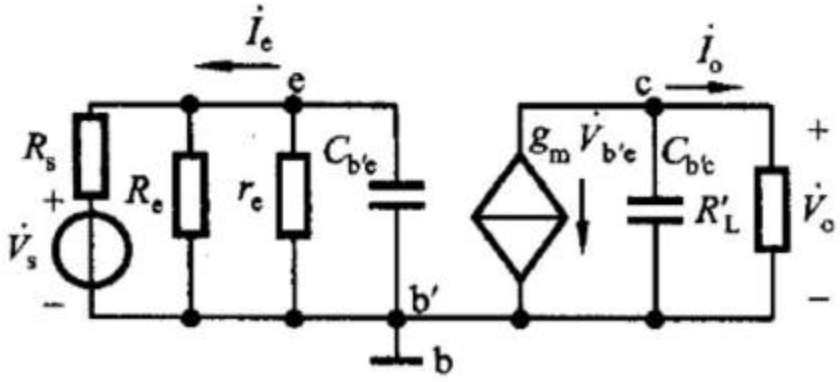
$$f_{H2} = \frac{1}{2\pi R_L' C_{b'c}}$$

$$f_{H1} = \frac{1}{2\pi\left(R_s \parallel R_e \parallel r_e\right) C_{b'e}}$$

$$\begin{aligned}\frac{\dot{U}_o}{\dot{U}_s} &= g_m\left[R_L' \parallel \left(1/j\omega C_{b'c}\right)\right]\frac{R_e \parallel r_e \parallel \left(1/j\omega C_{b'e}\right)}{R_s + R_e \parallel r_e \parallel \left(1/j\omega C_{b'e}\right)} \\ &= g_m R_L' \frac{R_e \parallel r_e}{R_s + R_e \parallel r_e}\cdot\frac{1}{1+jf\cdot 2\pi R_L' C_{b'c}}\cdot\frac{1}{1+jf\cdot 2\pi\left(R_s \parallel R_e \parallel r_e\right)C_{b'e}}\end{aligned}$$







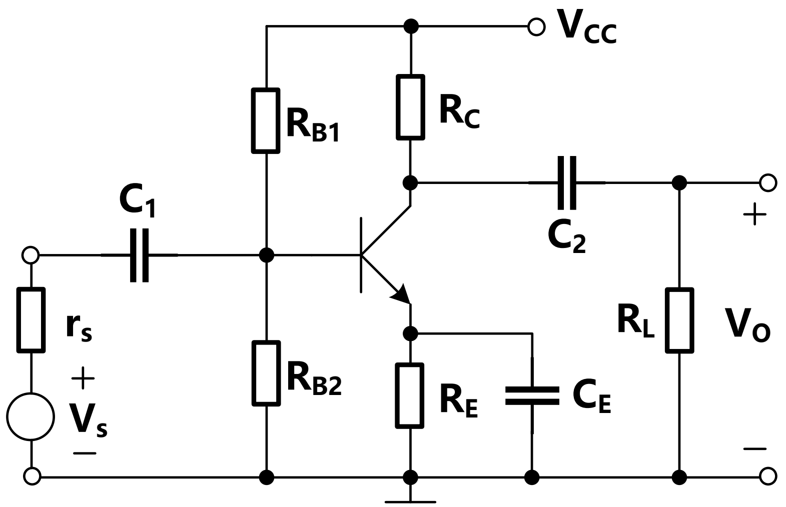
5.5.4 共射放大电路的频率特性

✓ **共射极与共基极放大电路的频率响应对比：**

- **共射极：**

$$f_H=\frac{1}{2\pi\left[r_{b'e}\parallel\left(r_{bb'}+R_b\parallel R_s\right)\right]\left[C_{b'e}+\left(1+g_mR_L'\right)C_{b'C}\right]}$$

$$\approx\frac{1}{2\pi\left[r_{b'e}\parallel\left(r_{bb'}+R_s\right)\right]g_mR_L'C_{b'C}}$$

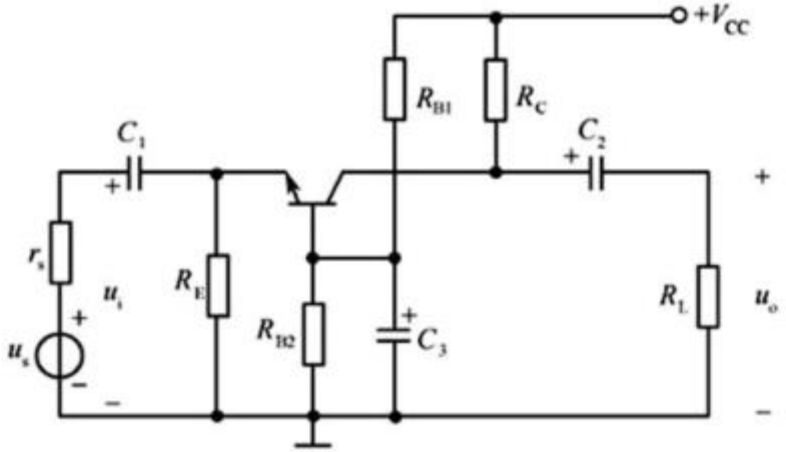


- **共基极：**

$$f_{H2}=\frac{1}{2\pi R_L'C_{b'c}}$$

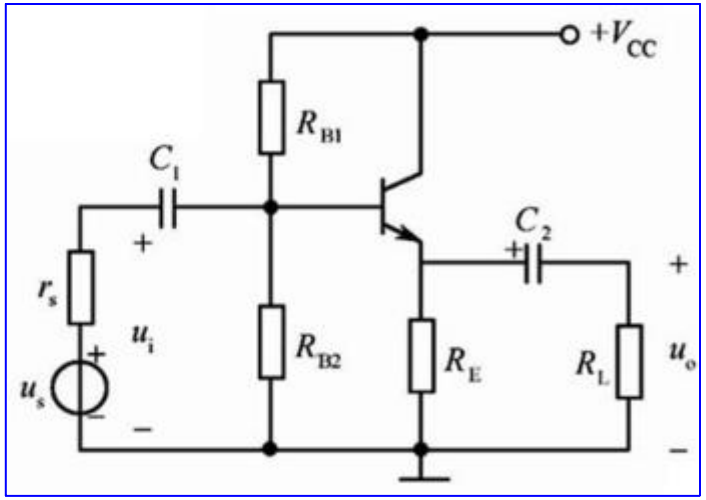
$$f_{H1}=\frac{1}{2\pi\left(R_s\parallel R_e\parallel r_e\right)C_{b'e}}\approx\frac{1}{2\pi R_sC_{b'e}}$$

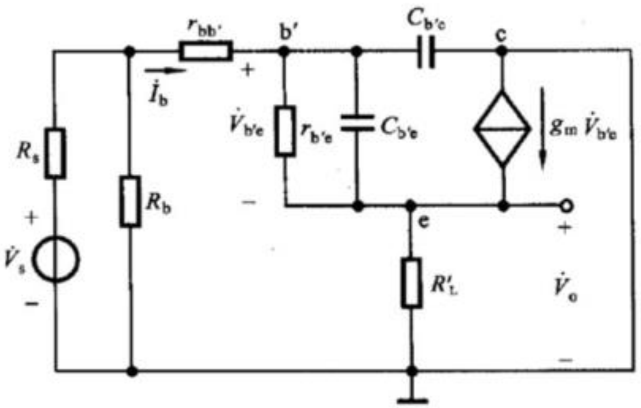
密勒效应对
输入输出阻抗
增益
带宽的影响

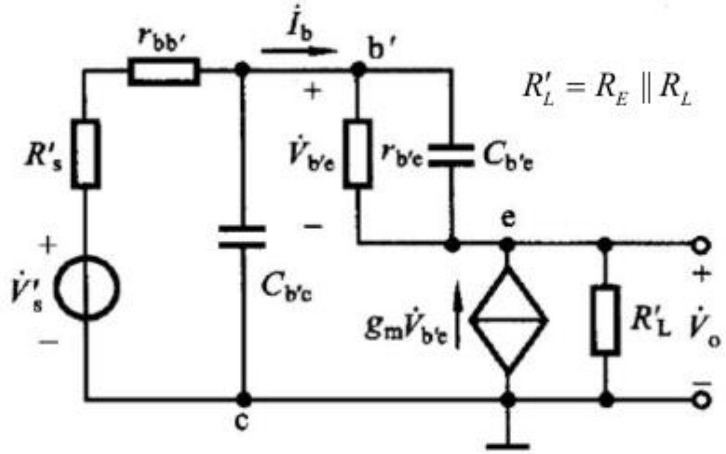


5.5.4 共射放大电路的频率特性

✓ **共集电极放大电路的频率响应：**







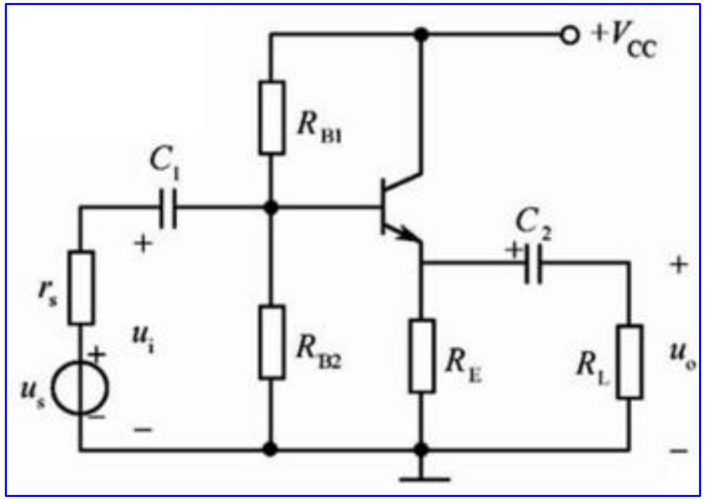
$$V_o = (g_m V_{b'e} + I_b) R_{L'} = \left(g_m V_{b'e} + \frac{V_{b'e}}{r_{b'e}} \right) R_{L'}$$

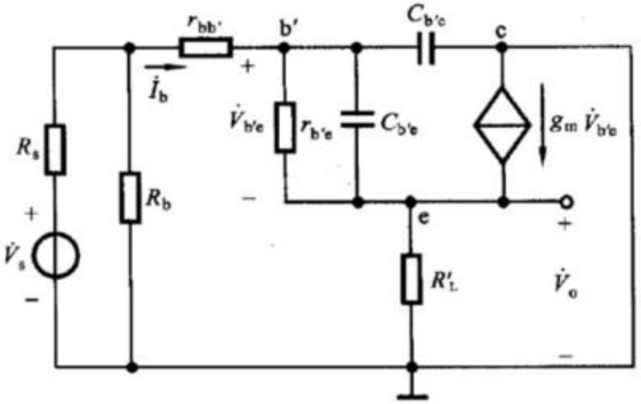
$$V_{b'e} = V_{b'} - V_o\,, \quad g_m = \beta / r_{b'e}$$

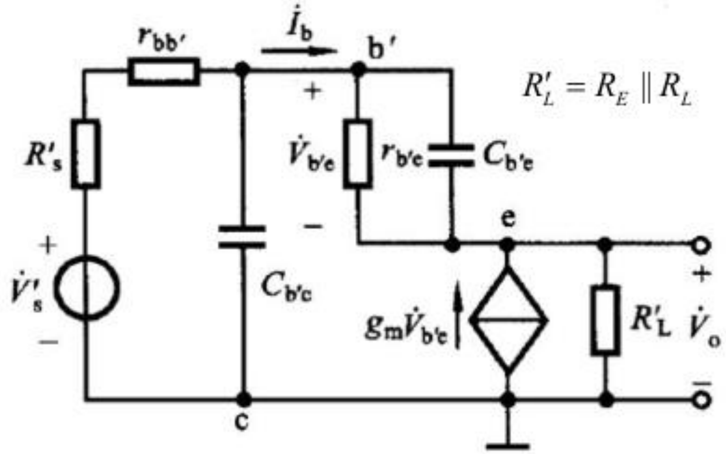
$$A = \frac{V_o}{V_{b'}} = \frac{(1+\beta)R_{L'}}{r_{b'e} + (1+\beta)R_{L'}} \approx \frac{g_m R_{L'}}{1 + g_m R_{L'}}$$

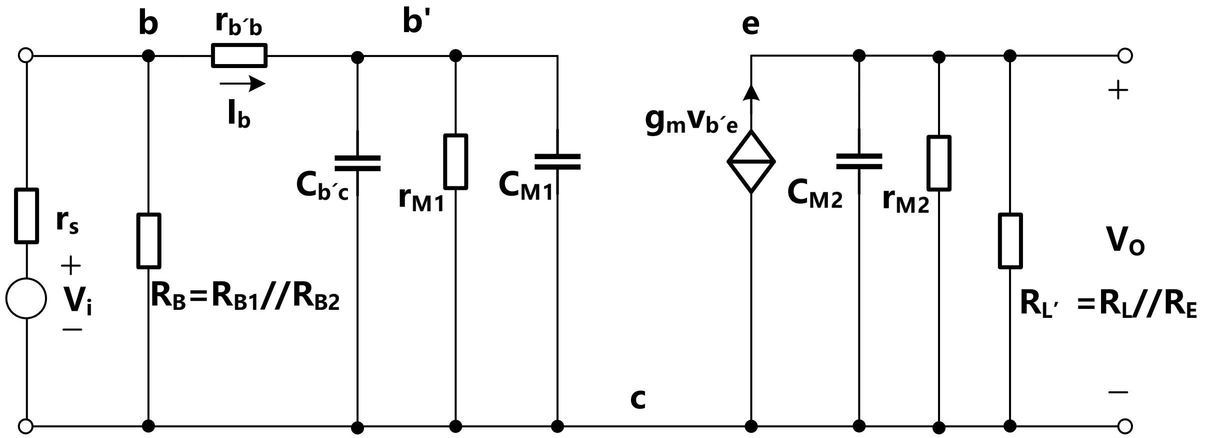
5.5.4 共射放大电路的频率特性

✓ **共集电极放大电路的频率响应：**









$$C_{M1} = \left(1 - \frac{g_m R_{L'}}{1 + g_m R_{L'}}\right) C_{b'e} = \frac{1}{1 + g_m R_{L'}} C_{b'e}$$

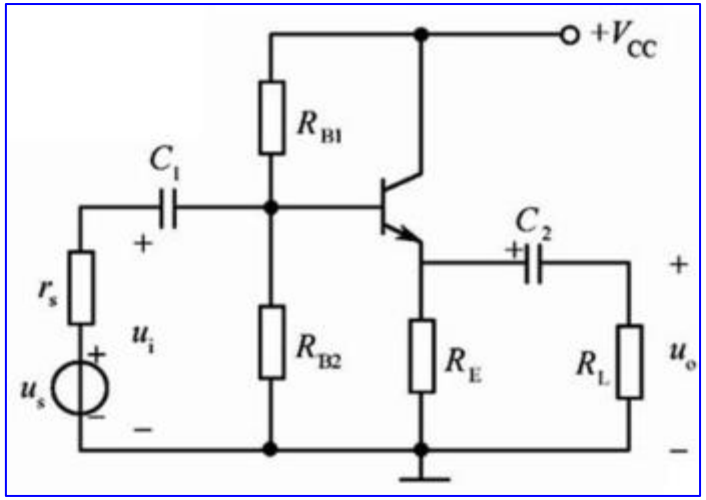
$$C_{M2} = \left(1 - \frac{1 + g_m R_{L'}}{g_m R_{L'}}\right) C_{b'e} = -\frac{1}{g_m R_{L'}} C_{b'e}$$

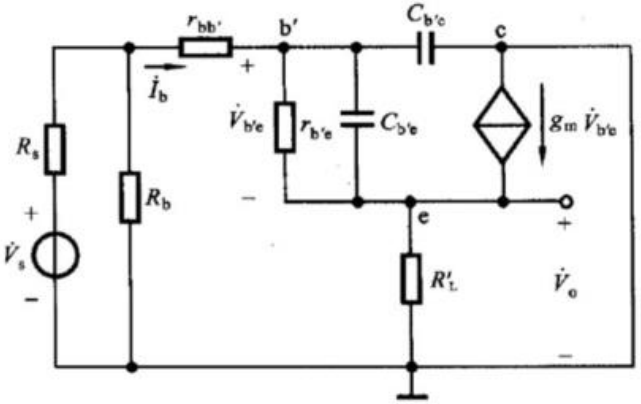
负阻，零点

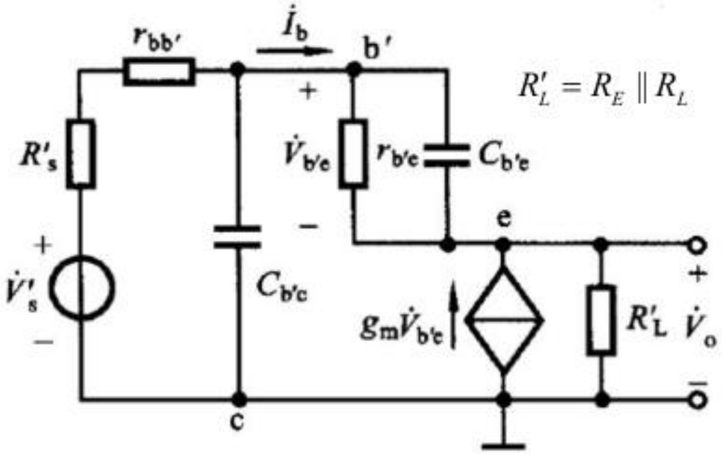
$$r_{M1} = \frac{1}{1 - \frac{g_m R_{L'}}{1 + g_m R_{L'}}} r_{b'e} = (1 + g_m R_{L'}) r_{b'e}, \quad r_{M2} = -g_m R_{L'} r_{b'e}$$

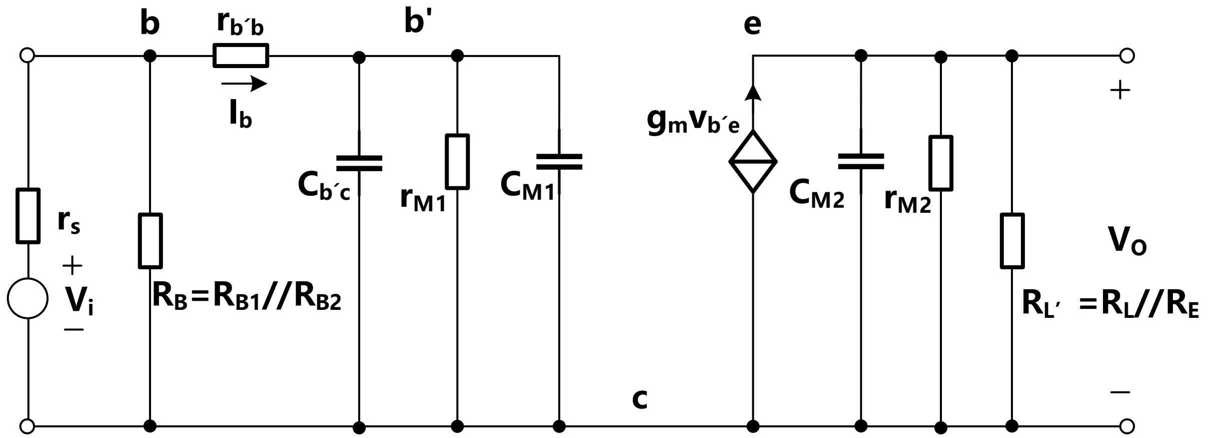
5.5.4 共射放大电路的频率特性

✓ 共集电极放大电路的频率响应：









$$A = \frac{R_B // [r_{be} + (1+\beta)R_{L'}]}{R_S + R_B // [r_{be} + (1+\beta)R_{L'}]} \cdot \frac{(1+\beta)R_{L'}}{r_{b'e} + (1+\beta)R_{L'}}$$

$$f_H = \frac{1}{2\pi[R_S // R_B // (1+g_m R_{L'})r_{b'e}](C_{b'c} + \frac{1}{1+g_m R_{L'}} C_{b'e})}$$

5.5.4 共射放大电路的频率特性

✓ **共射极与共基极放大电路的带宽对比：**

- 共射极：

$$f_H=\frac{1}{2\pi\left[r_{b'e}\parallel\left(r_{bb'}+R_b\parallel R_s\right)\right]\left[C_{b'e}+\left(1+g_mR_L'\right)C_{b'C}\right]}\approx\frac{1}{2\pi\left[r_{b'e}\parallel\left(r_{bb'}+R_s\right)\right]g_mR_L'C_{b'C}}$$

- 共基极：

$$f_{H2}=\frac{1}{2\pi R_L'C_{b'c}}\qquad f_{H1}=\frac{1}{2\pi\left(R_s\parallel R_e\parallel r_e\right)C_{b'e}}\approx\frac{1}{2\pi R_sC_{b'e}}$$

- 共集电极：

共基极>共集电极>共发射极

$$f_H=\frac{1}{2\pi[R_S\,//\,R_B\,//\,(1+g_mR_{L'})r_{b'e}](C_{b'c}+\frac{1}{1+g_mR_{L'}}C_{b'e})}$$

5.5.4 共射放大电路的频率特性

✓ **共射极与共基极放大电路的增益对比：**

- 共射极：

$$A = -g_m R_{L'} \cdot \frac{r_{b'e}}{r_{b'b} + r_{b'e}} \cdot \frac{R_B \,//\, (r_{b'b} + r_{b'e})}{r_s + R_B \,//\, (r_{b'b} + r_{b'e})}$$

- 共基极：

$$A = g_m R_{L'} \cdot \frac{R_e \,//\, r_e}{r_s + R_e \,//\, r_e}$$

共基极>共集电极>共发射极

- 共集电极：

$$A = \frac{R_B//[r_{be}+(1+\beta)R_{L'}]}{R_S+R_B//[r_{be}+(1+\beta)R_{L'}]} \cdot \frac{(1+\beta)R_{L'}}{r_{b'e}+(1+\beta)R_{L'}} \approx \frac{R_B//[r_{be}+(1+\beta)R_{L'}]}{R_S+R_B//[r_{be}+(1+\beta)R_{L'}]} \cdot \frac{g_m R_{L'}}{1+g_m R_{L'}}$$

5.5.5 场效应三极管高频小信号模型

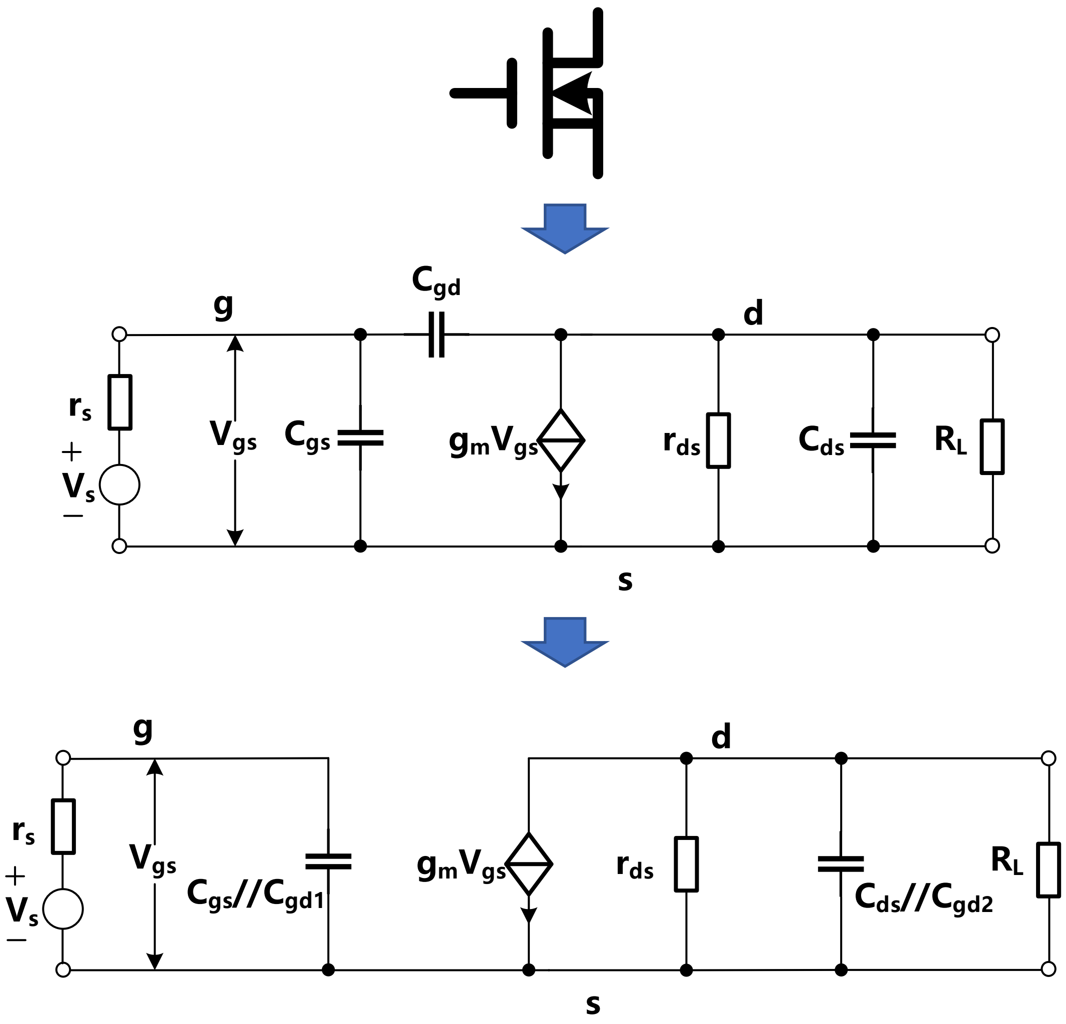
✓ **MOSFET的上限截止频率：**

$$f_{H1} \approx \frac{1}{2\pi r_s(C_{gs}+C_{gd1})}$$

$$f_{H2} \approx \frac{1}{2\pi R_L(C_{ds}+C_{gd2})}$$

✓ **MOSFET的增益（共源放大）：**

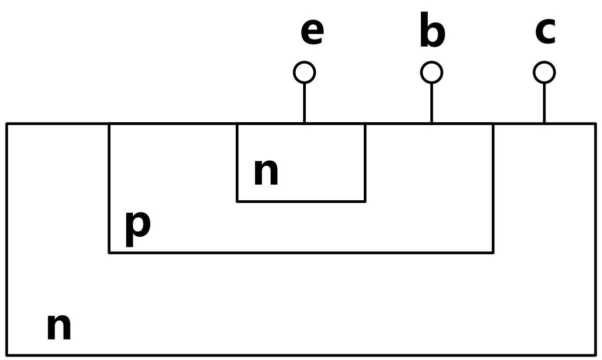
$$A \approx -g_m R_L$$

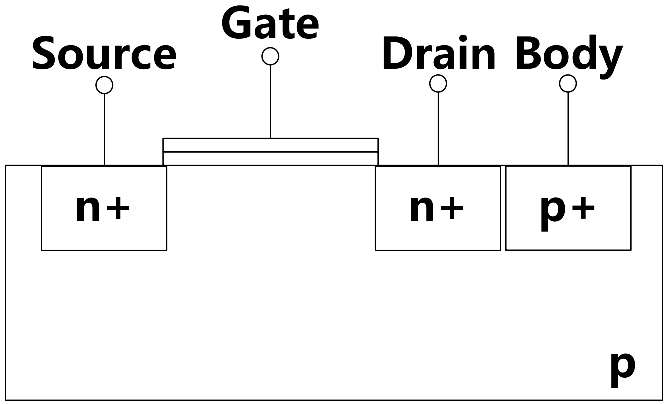


5.5.5 场效应三极管高频小信号模型

✓ **MOSFET共源放大与BJT共发射极放大：**

- **增益：** 约为 $A \approx -g_m R_L$
- **带宽：** r_g与$r_{b'b}$，C_{gs}，C_{gd}与$C_{b'e}$、$C_{b'c}$
- **电压电流关系：** MOSFET平方律器件，BJT指数律器件





5.5.5 场效应三极管高频小信号模型

✓ **NMOSFET与BJT版图对比：**