第九章　分立元件放大电路

- 9.1 放大概述
- 9.2 放大电路的组成和工作原理
- 9.3 放大电路的分析方法
- 9.4 常用单管放大电路
- 9.5 多极放大和其它*

9.4.1分压偏置放大电路

静态工作点稳定的问题

合理设置静态工作点是保证放大电路正常工作的条件

放大电路的静态工作点常因外界条件的变化而发生变动

温度变化、三极管老化、电源电压波动等

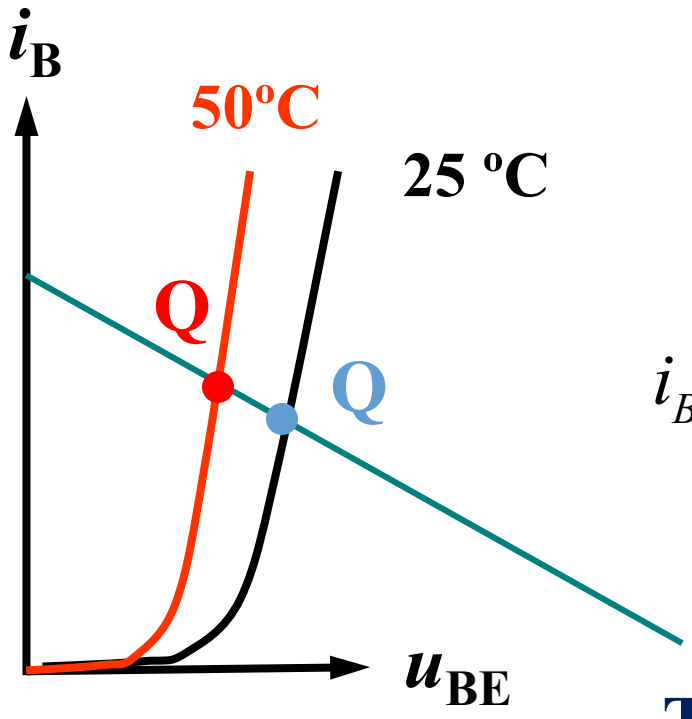
如： 早期冬天生产出的收音机夏天不好用

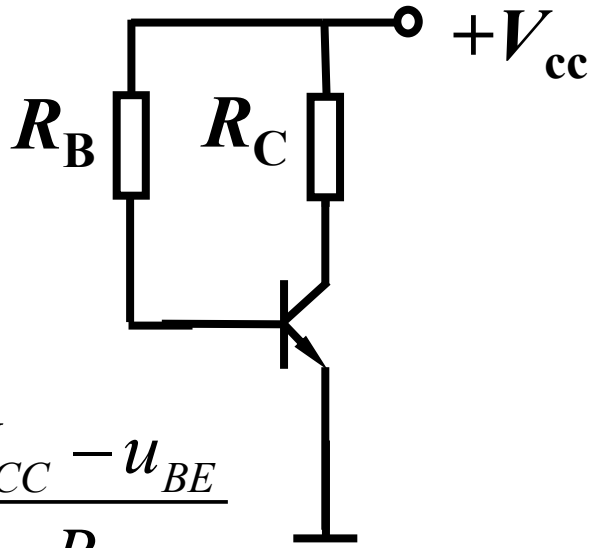
夏天生产出的冬天不好用

?

温度对Q点的影响

温度对U_{BE}的影响





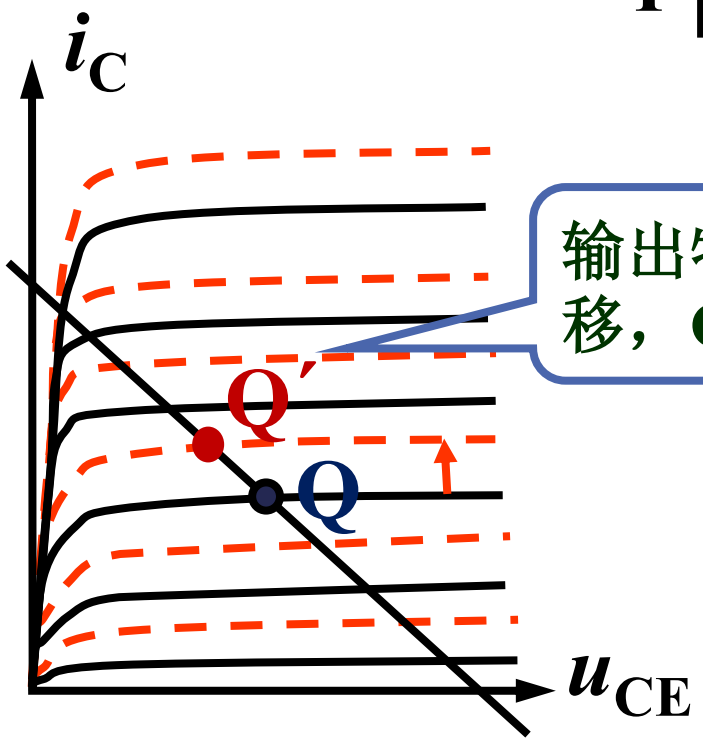
$$i_B = \frac{V_{CC} - u_{BE}}{R_B}$$

T ↑ → I_{BQ} ↑ → I_{CQ} ↑

温度对Q点的影响

温度对β值，I_{CEO}的影响

T↑ ⟶ β、I_{CEO}↑ ⟶ I_C↑



输出特性曲线上移，Q点上移

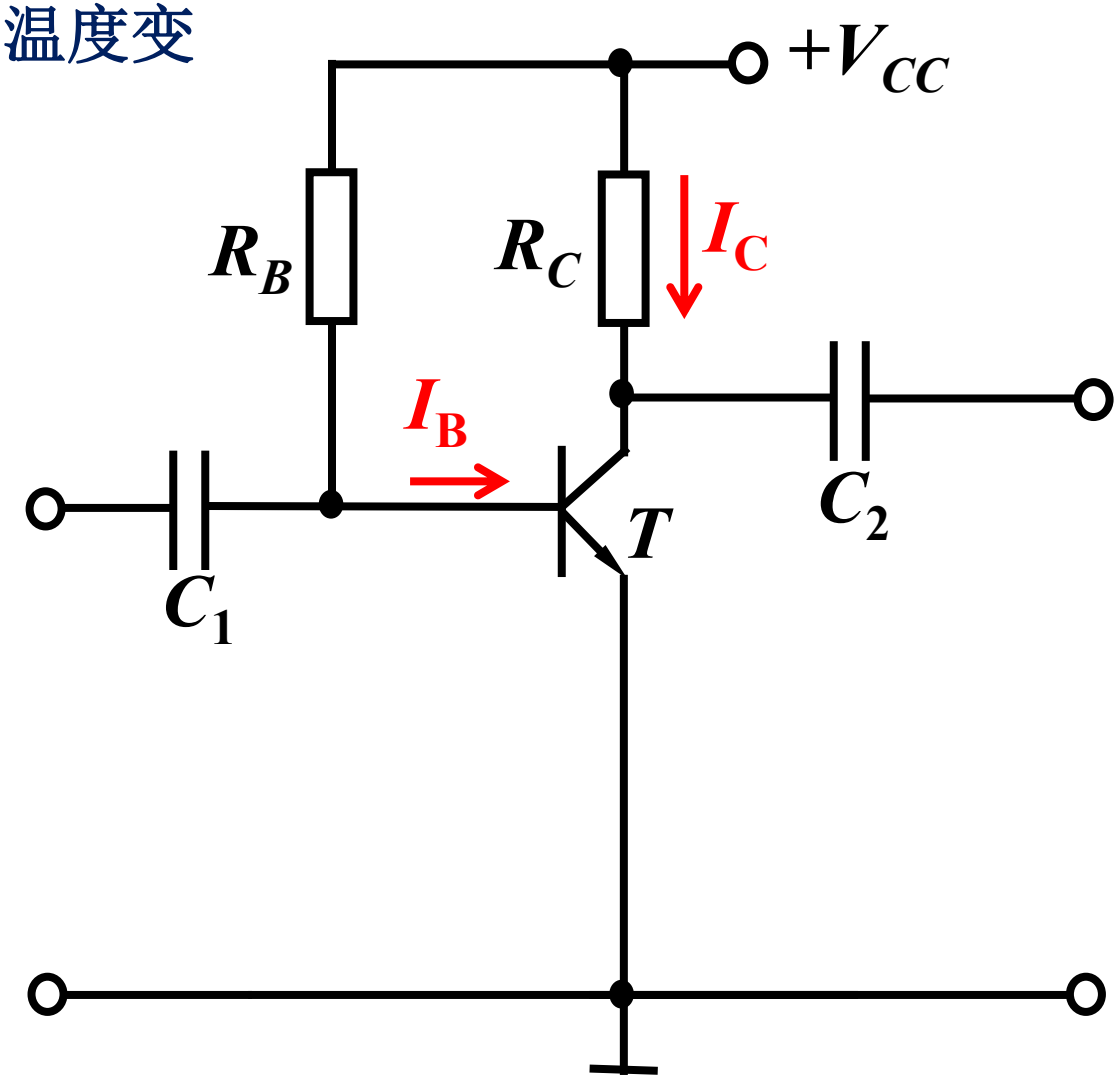
结果：容易使晶体管进入饱和区造成饱和失真

电路改进

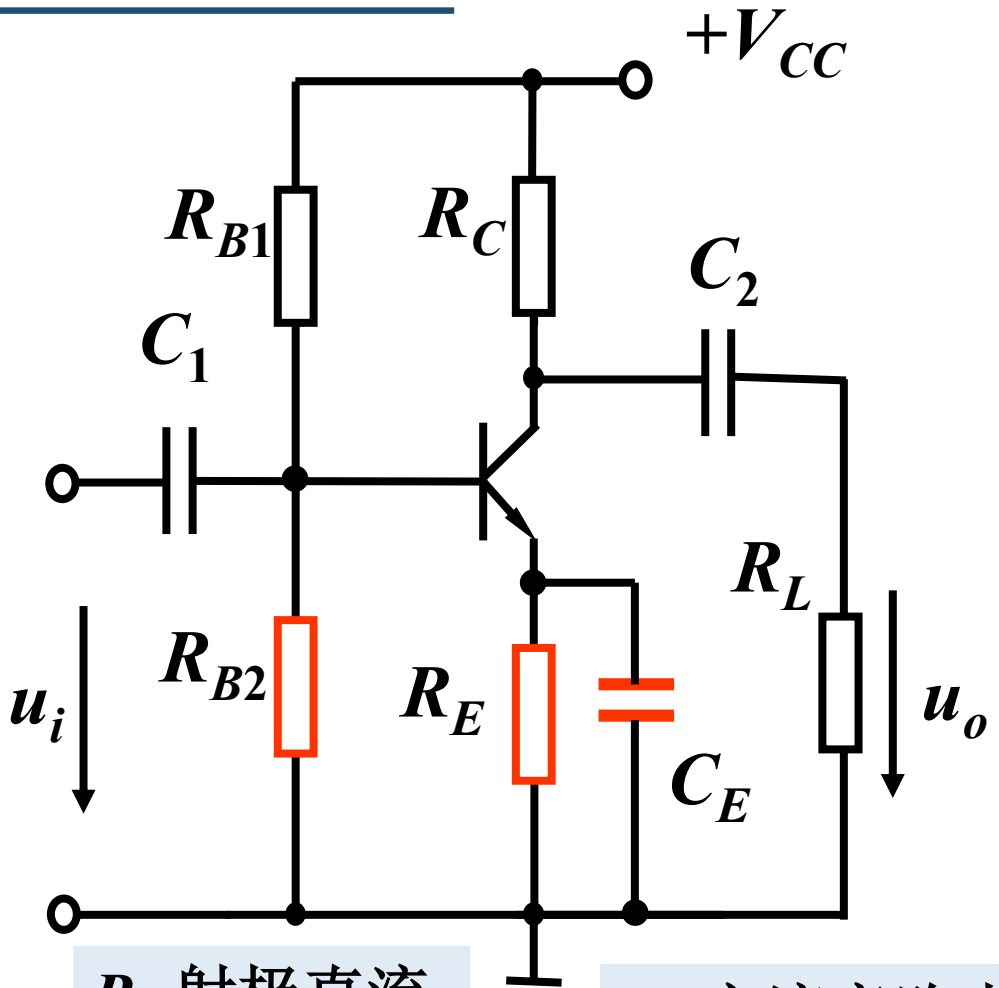
固定偏置电路的Q点随温度变化而变化，不稳定

改进目标：

当温度升高使I_C增加时，能够自动减少I_B，从而抑制Q点的变化，保持Q点基本稳定



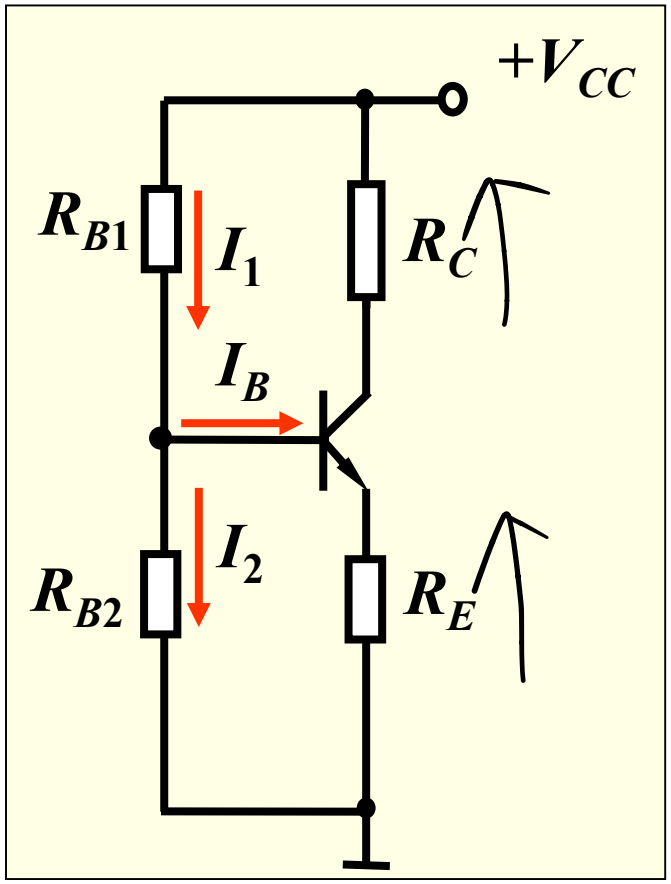
分压式偏置电路



R_E 射极直流负反馈电阻

C_E 交流旁路电容

分压式偏置电路稳定Q点的原因



在 $I_{1,2} >> I_{BQ}$ 的情况下

$$V_B \approx \frac{R_{B2}}{R_{B1}+R_{B2}} U_{CC}$$

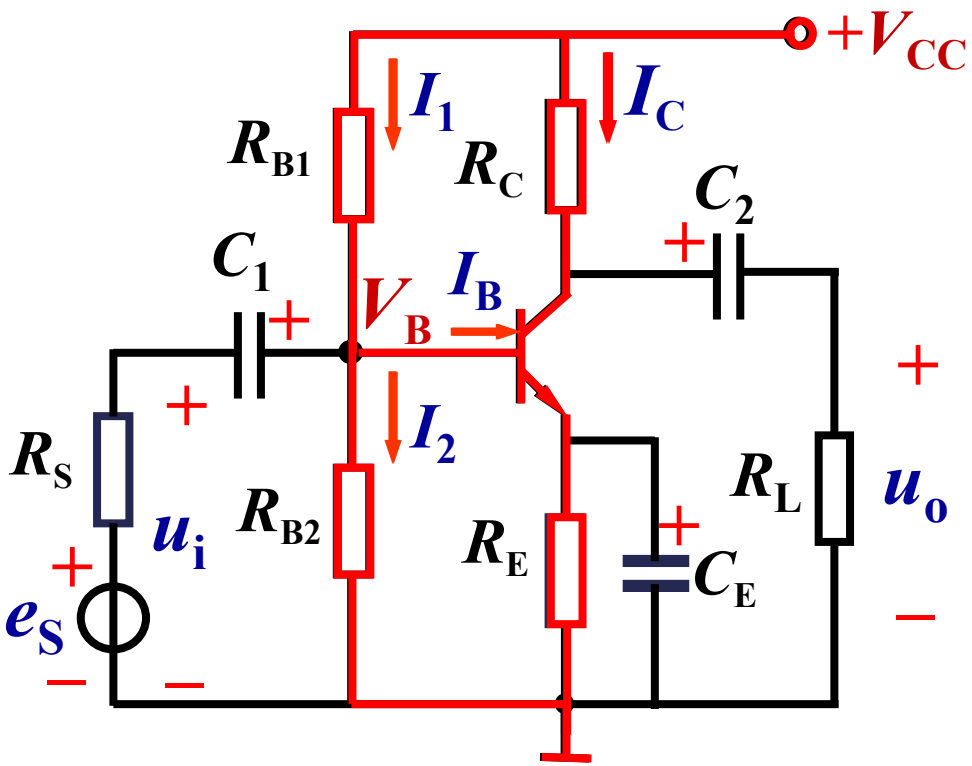
基极电位V_B在温度变化时基本不变

$T \uparrow \rightarrow I_C \uparrow \rightarrow V_E \uparrow \rightarrow U_{BE} \downarrow$

$I_C \downarrow \leftarrow I_B \downarrow \leftarrow$

T 变化时，I_C 基本不变

静态工作点的计算



估算法:

$$V_{\mathrm{B}} \approx \frac{R_{\mathrm{B2}}}{R_{\mathrm{B1}}+R_{\mathrm{B2}}} V_{\mathrm{CC}}$$

$$I_{\mathrm{C}} \approx I_{\mathrm{E}} = \frac{V_{\mathrm{B}}-U_{\mathrm{BE}}}{R_{\mathrm{E}}}$$

$$I_{\mathrm{B}} \approx \frac{I_{\mathrm{C}}}{\beta}$$

$$U_{\mathrm{CE}} = V_{\mathrm{CC}} - I_{\mathrm{C}}R_{\mathrm{C}} - I_{\mathrm{E}}R_{\mathrm{E}}$$
$$= V_{\mathrm{CC}} - I_{\mathrm{C}}(R_{\mathrm{C}}+R_{\mathrm{E}})$$

例：已知$\beta = 50$，$V_{CC} = 12\text{V}$，$R_{B1} = 7.5\text{k}\Omega$，$R_{B2} = 2.5\text{k}\Omega$，$R_C = 2\text{k}\Omega$，$R_E = 1\text{k}\Omega$，试求该电路的静态工作点

解：

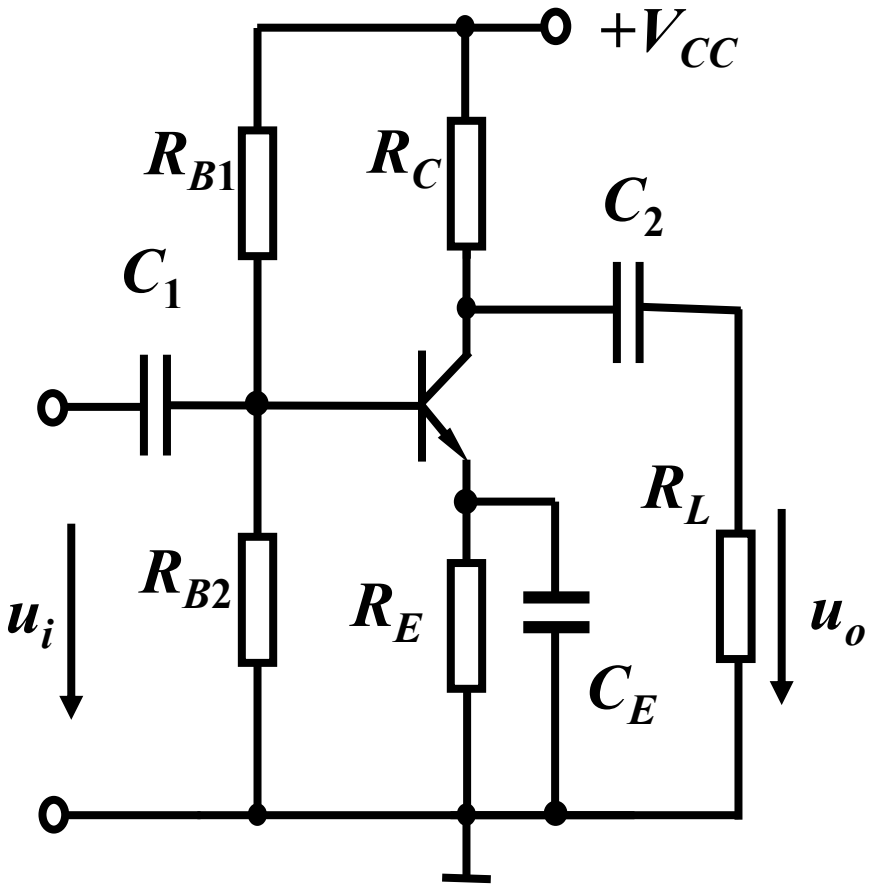
$$V_B \approx \frac{R_{B2}}{R_{B1} + R_{B2}} V_{CC} = 3\text{V}$$

$$I_{CQ} \approx I_{EQ} = \frac{V_B - U_{BE}}{R_E}$$

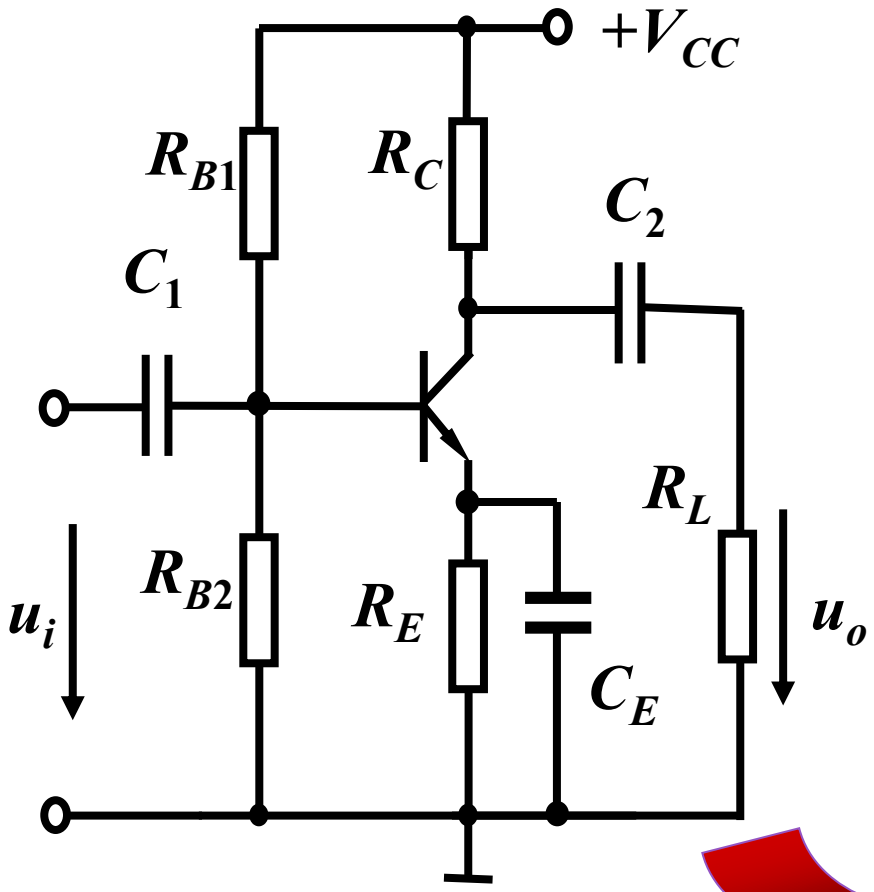
$$\approx 2.3\text{mA}$$

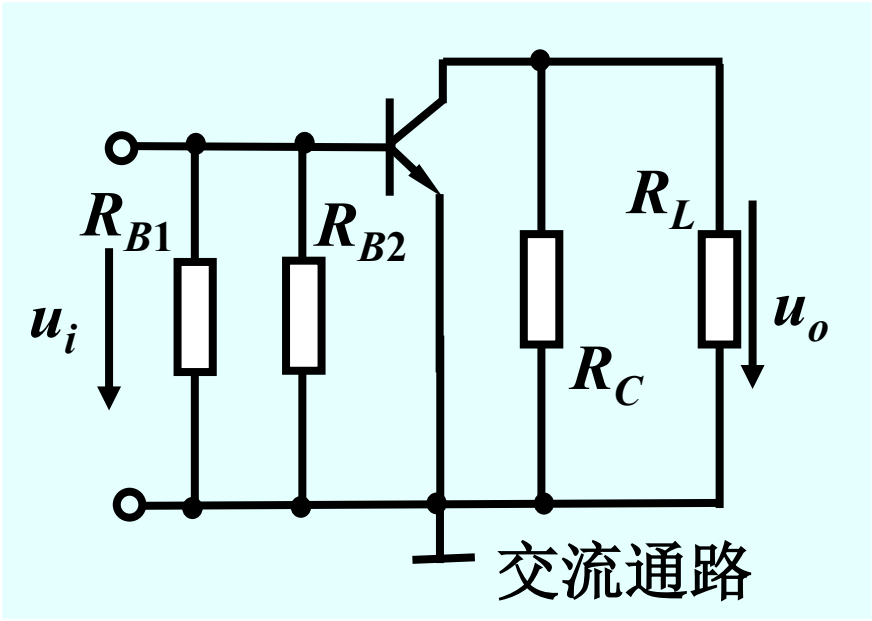
$$U_{CEQ} \approx V_{CC} - I_{CQ}(R_C + R_E)$$

$$= 5.1\text{V}$$

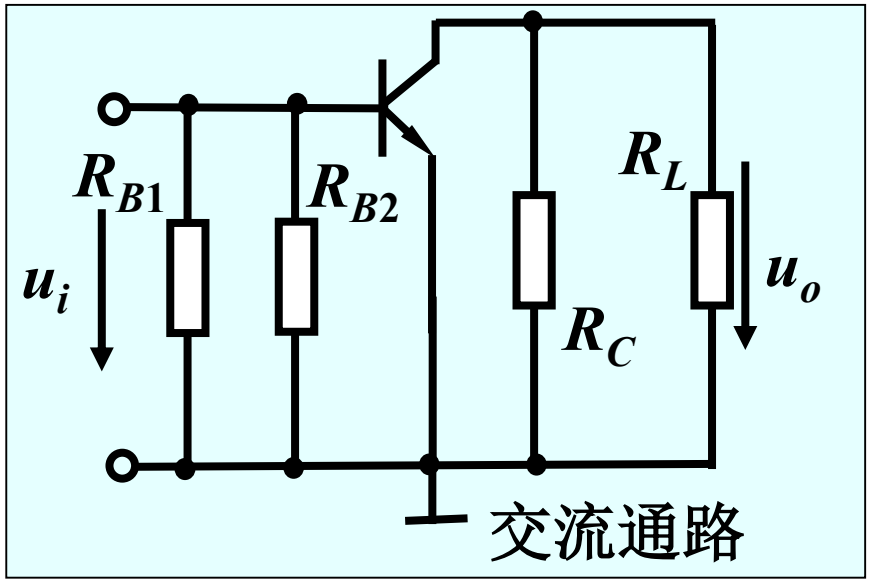


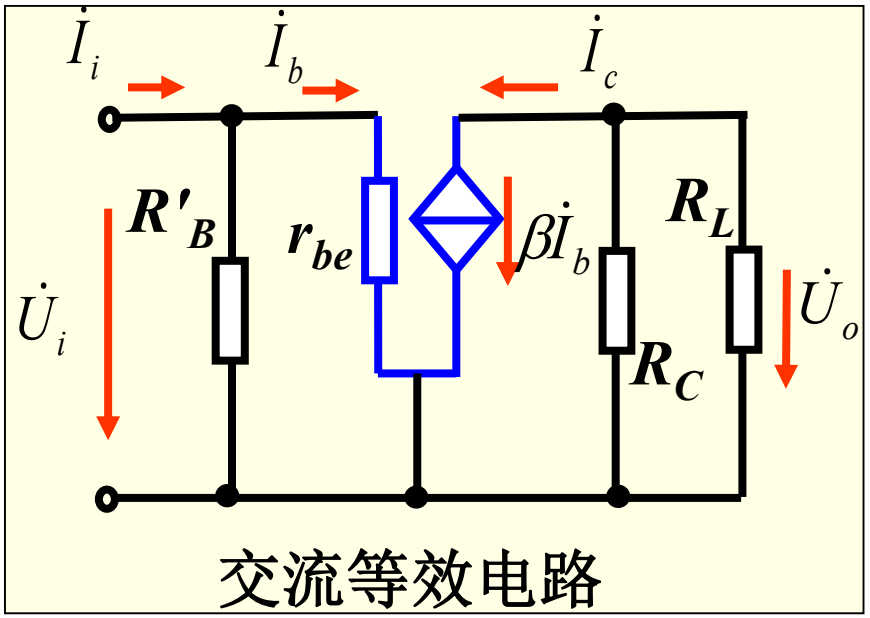
动态分析





动态分析





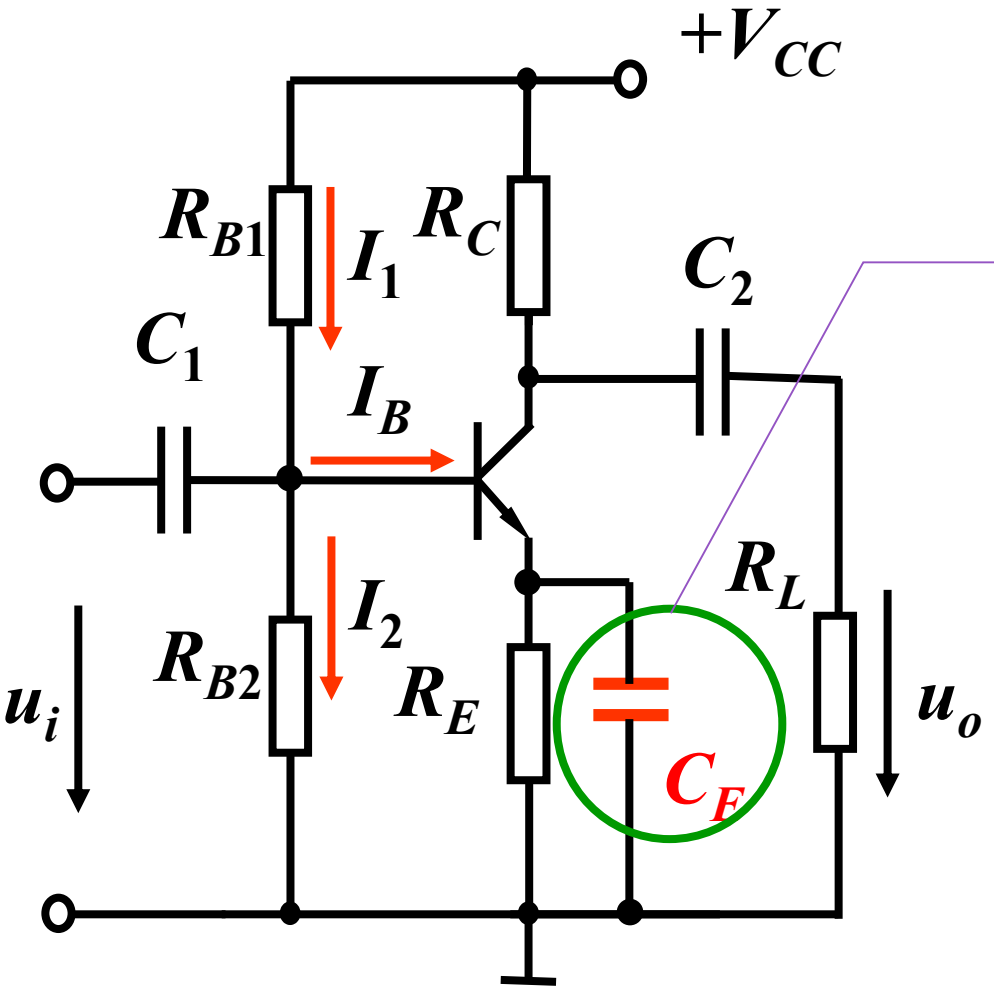
$$A_u = -\beta \frac{R'_L}{r_{be}}$$

$$R_i = R'_B // r_{be} \approx r_{be}$$

$$R_O = R_C$$

思考及讨论

问题1：如果去掉C_E，放大倍数如何变化？

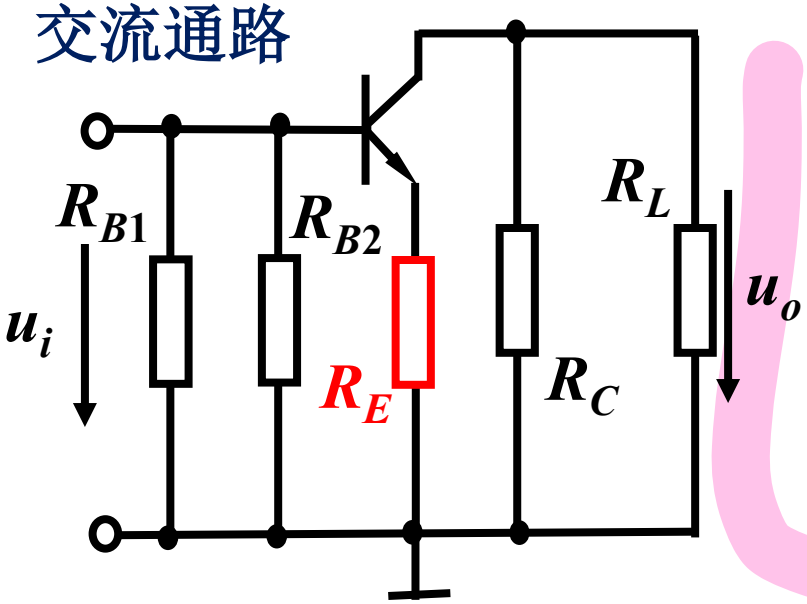


C_E的作用？

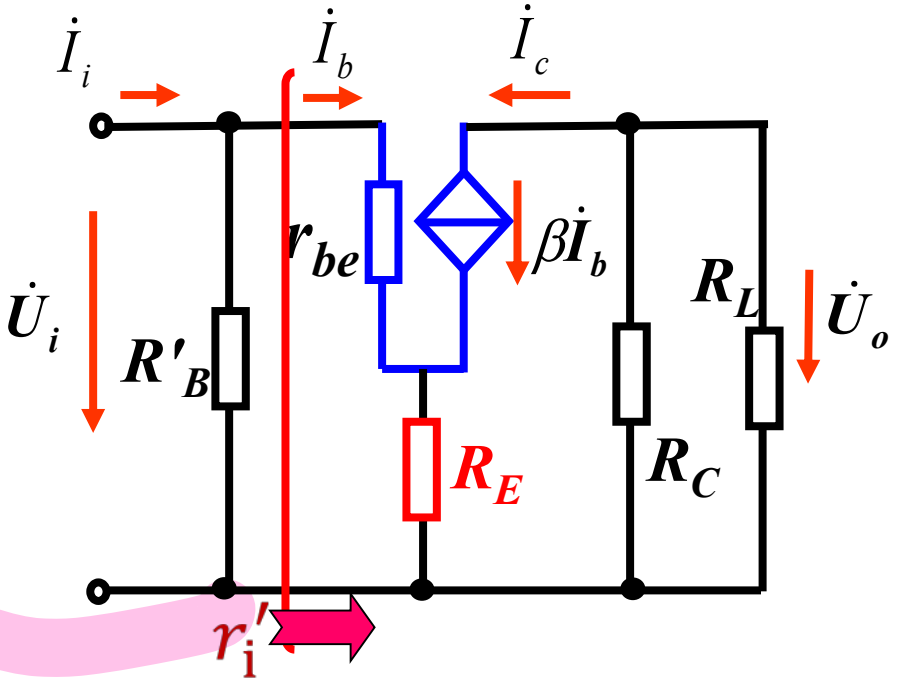
交流通路中，它可将R_E短路，使R_E对交流信号不起作用，放大倍数不受影响。

去掉 C_E 后

交流通路



等效电路



$$\dot{U}_i = \dot{I}_b r_{be} + (1+\beta)\dot{I}_b R_E$$

$$\dot{U}_o = -\beta \dot{I}_b R'_L$$

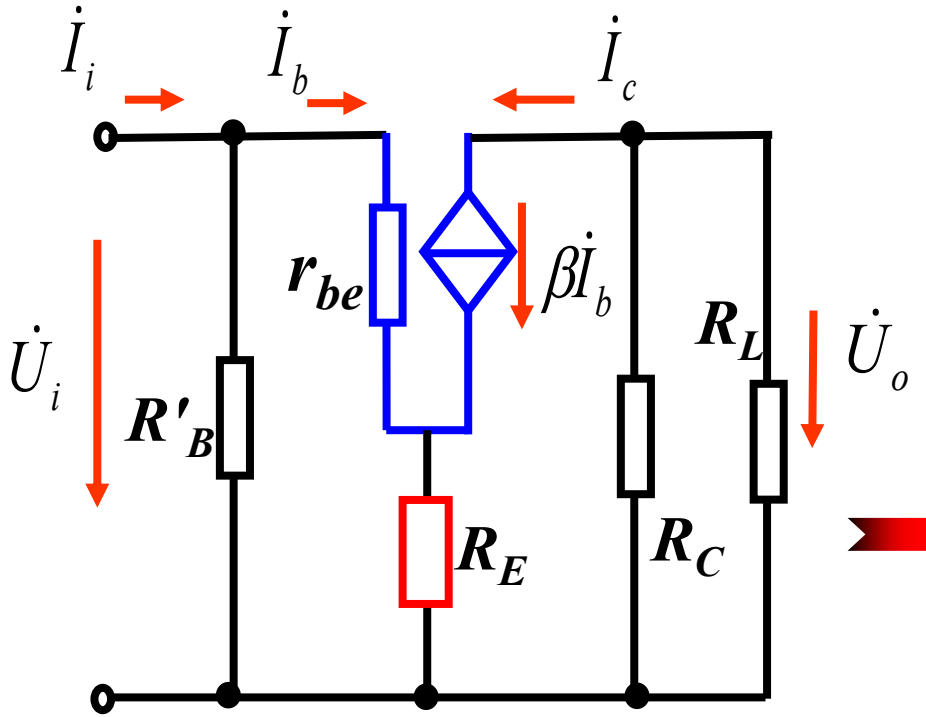
$$A_u = -\frac{\beta R'_L}{r_{be} + (1+\beta)R_E}$$

$$R_i = R'_B // r'_i$$

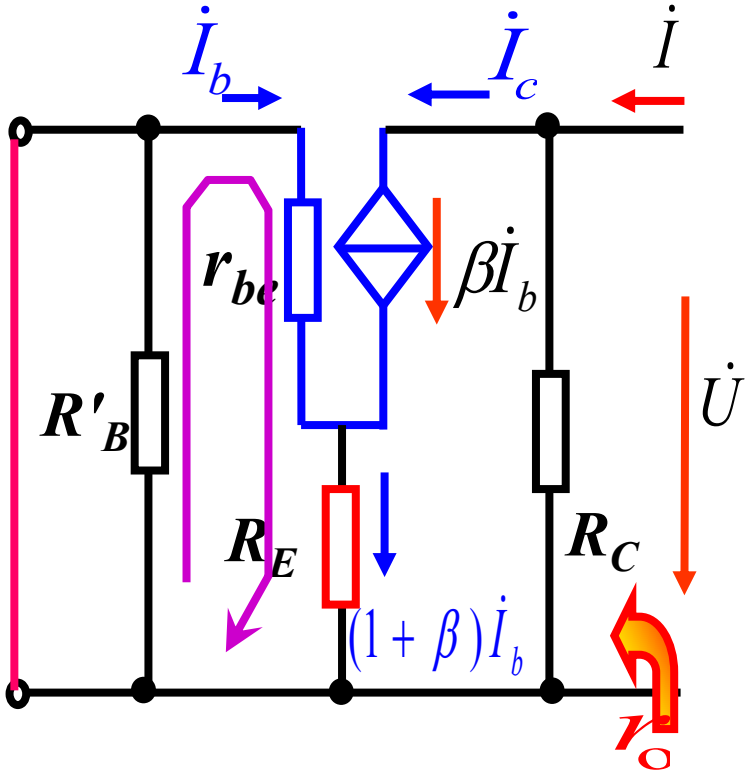
$$R_i = R'_B // (r_{be} + (1+\beta)R_E$$

放大倍数下降，输入电阻增大

输出电阻Ro



用加压求流法求解



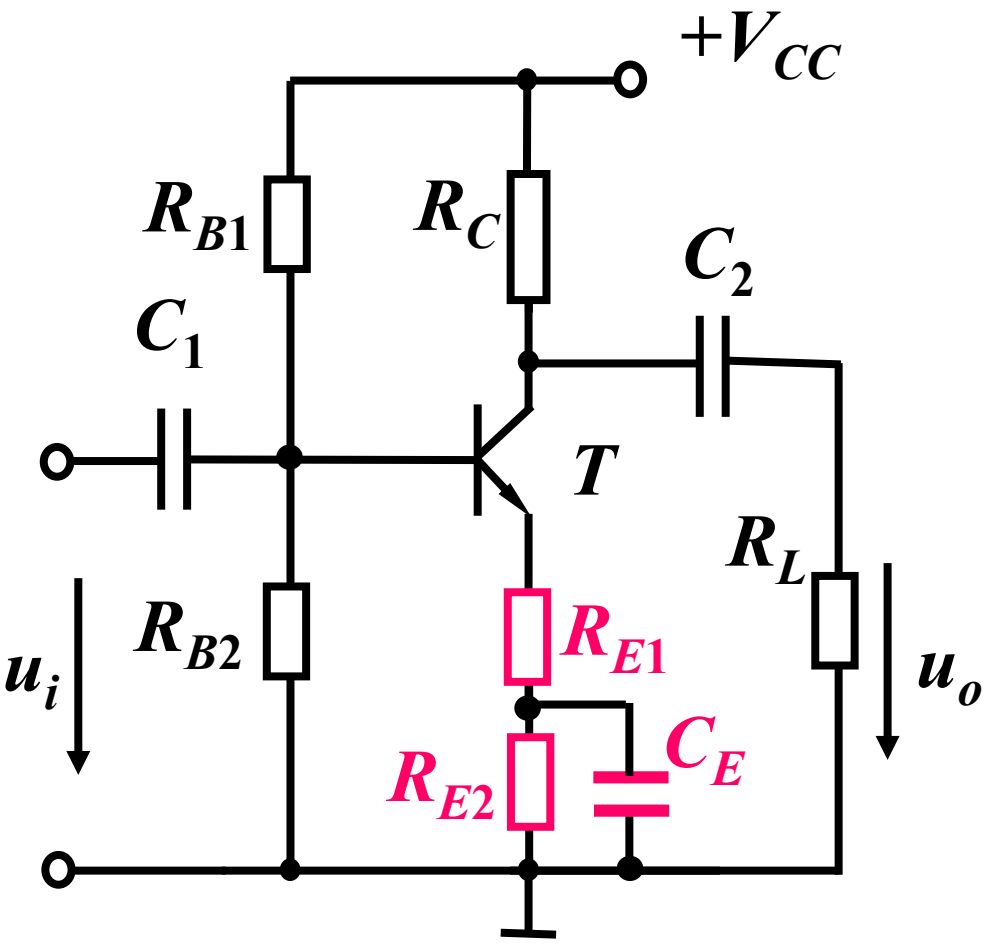
$$\dot{I}_b r_{be} + (1+\beta)\dot{I}_b R_E = 0$$

$$\rightarrow \dot{I}_b = 0 \rightarrow \dot{I}_c = 0 \rightarrow R_O = R_C$$

输出电阻不变

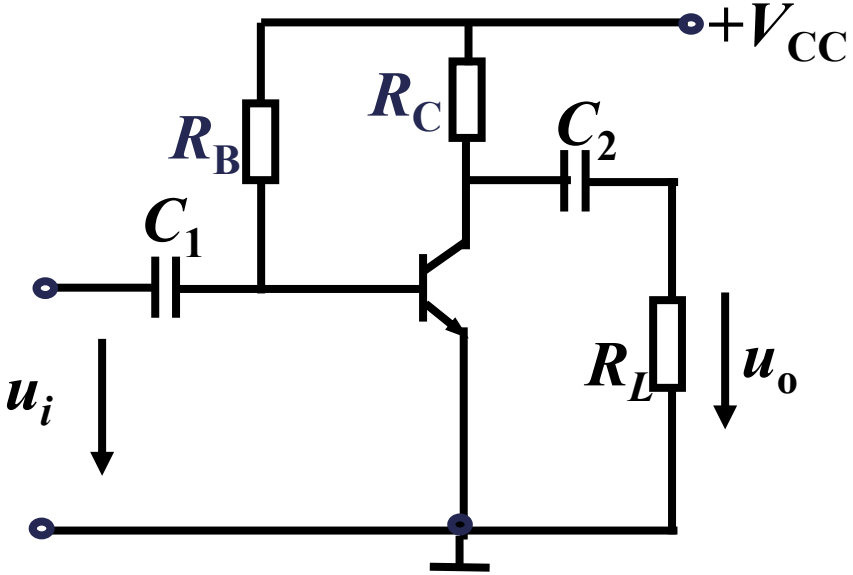
思考及讨论

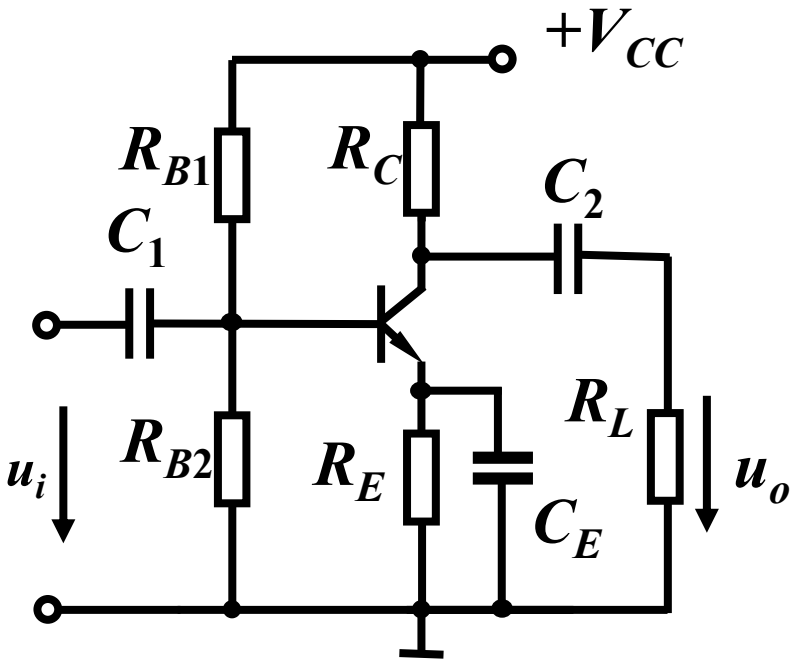
问题2：如果电路如下图所示，如何分析？



思考及讨论

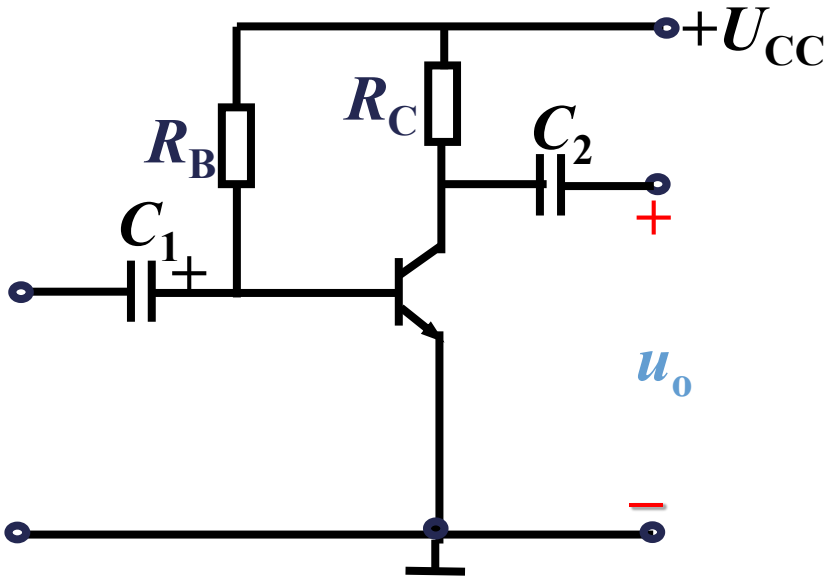
问题3：比较下面电路， β 增大时， Au是否会成比例增大？





$$A_u = -\beta \frac{R'_L}{r_{be}}$$

固定偏置放大电路



$$r_{be} = 200(\Omega) + (1+\beta)\frac{26(\mathrm{mV})}{I_E(\mathrm{mA})}$$

$$= 200(\Omega) + \frac{26(\mathrm{mV})}{I_B(\mathrm{mA})}$$

$$I_{BQ} \approx \frac{V_{CC}}{R_B}$$

I_{BQ}不变！

$$A_u = -\beta\frac{R'_L}{r_{be}}$$

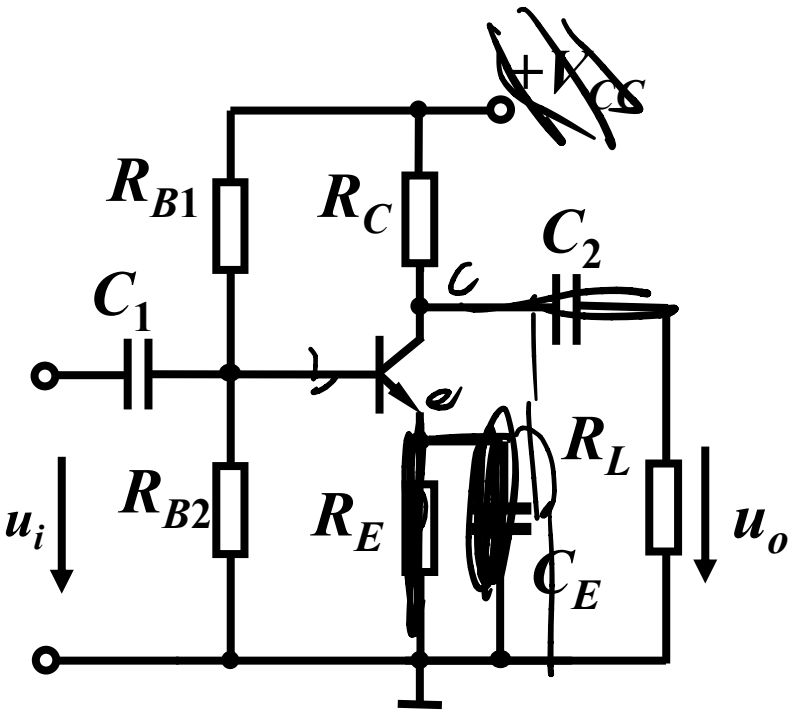
β增大Au大致按相应比例增大!

分压偏置放大电路

$$r_{be} = 200(\Omega) + (1+\beta)\frac{26(\mathrm{mV})}{I_E(\mathrm{mA})}$$

$$I_C \approx I_E = \frac{V_B - U_{BE}}{R_E}$$

I_E一定!

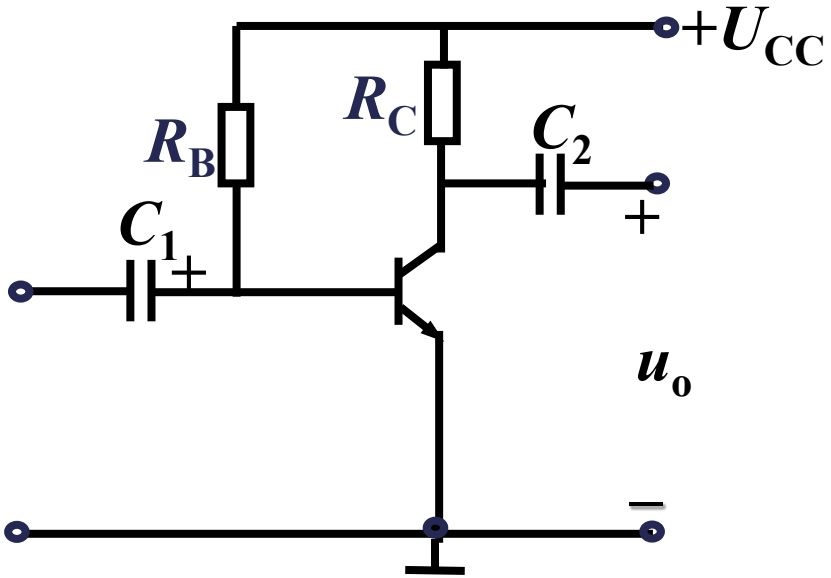


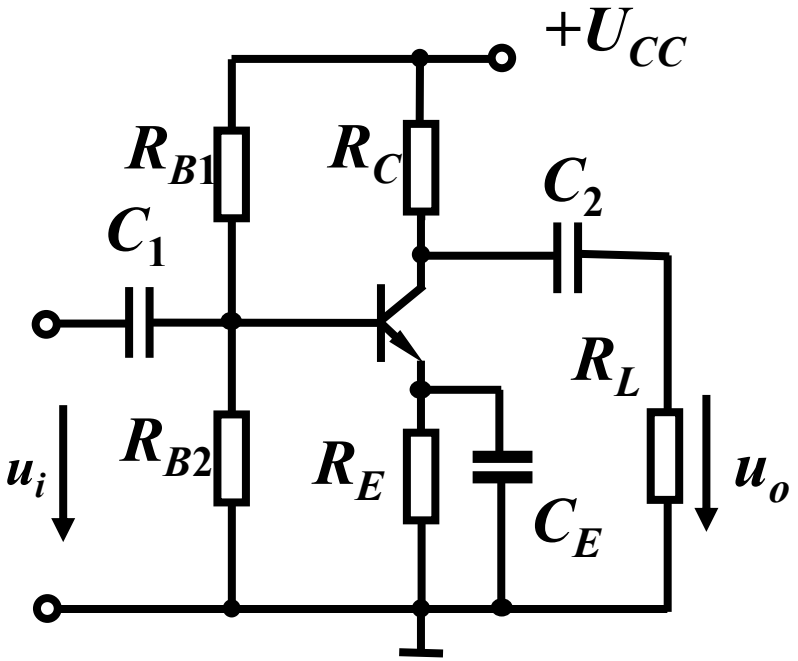
β增大 $\rightarrow r_{be}$ 增大

$$A_u = -\beta\frac{R'_L}{r_{be}}$$

当β足够大时，A_u几乎与β无关!

结论





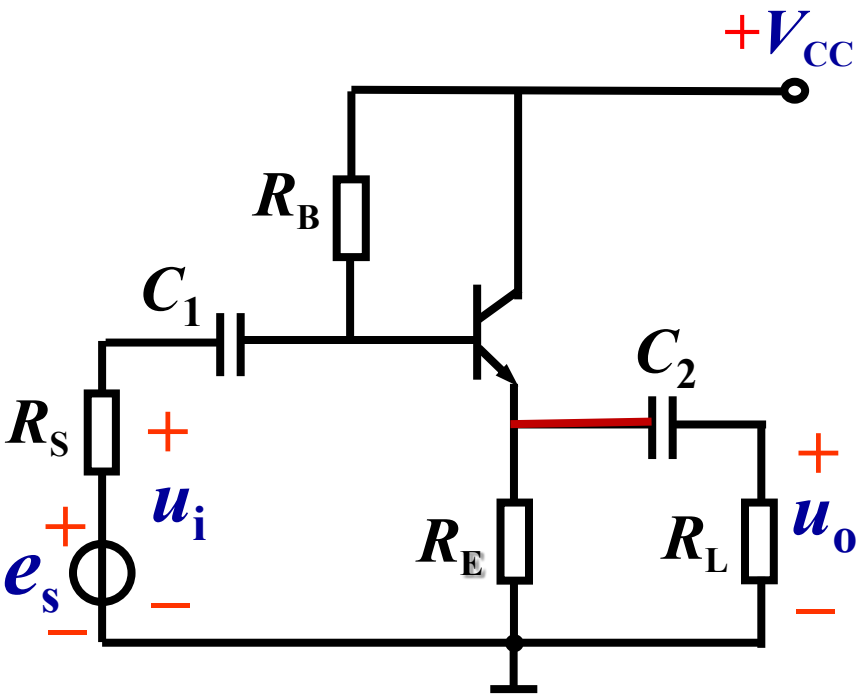
β增大A_u大致按相应比例增大

$$A_u = -\beta \frac{R'_L}{r_{be}}$$

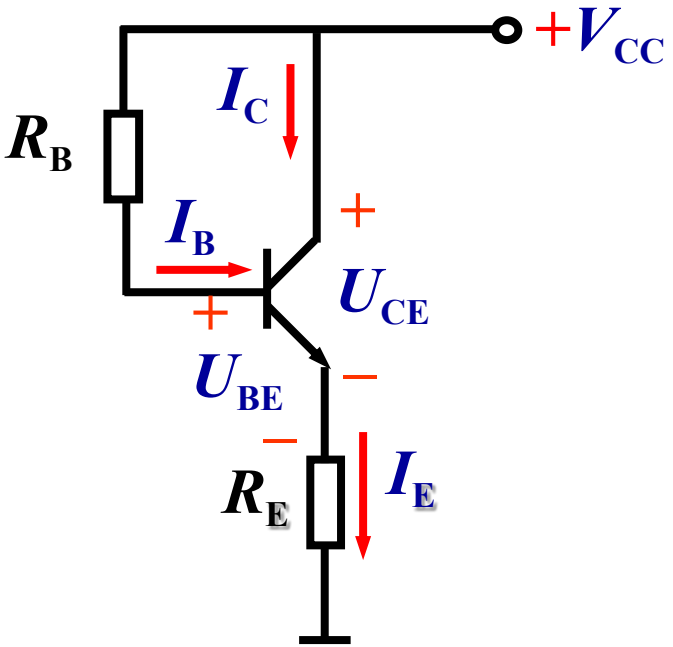
当β足够大时，A_u几乎与β无关

分压偏置放大电路稳定性更好！

9.4.2 射极输出器



直流通路



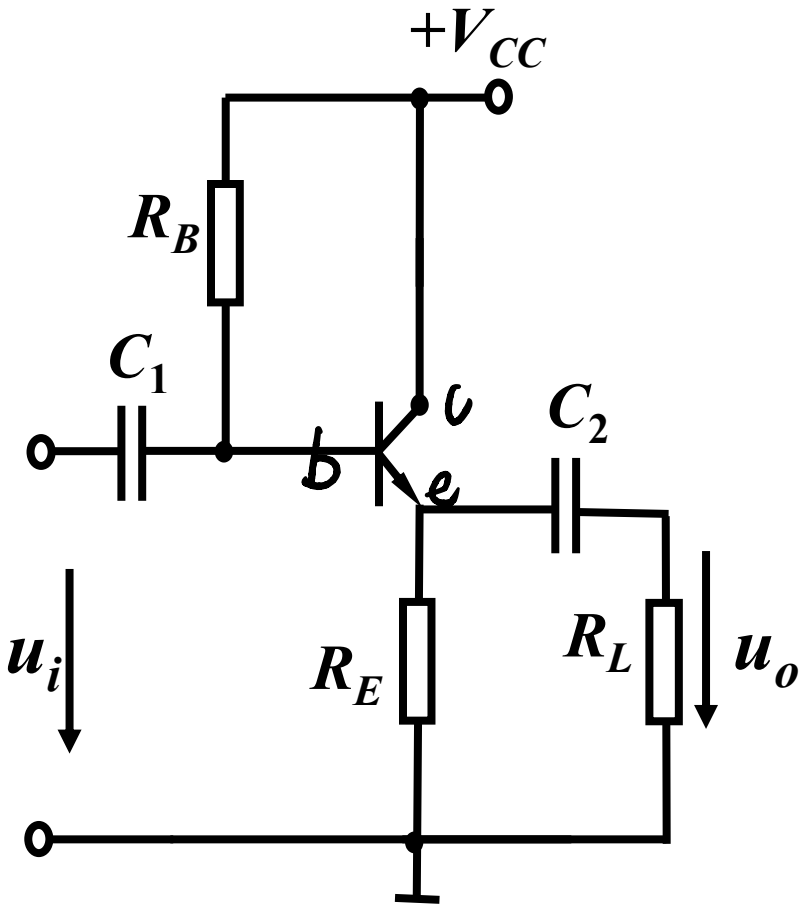
一、静态分析

$$I_{BQ} = \frac{V_{CC} - U_{BE}}{R_B + (1+\beta)R_E}$$

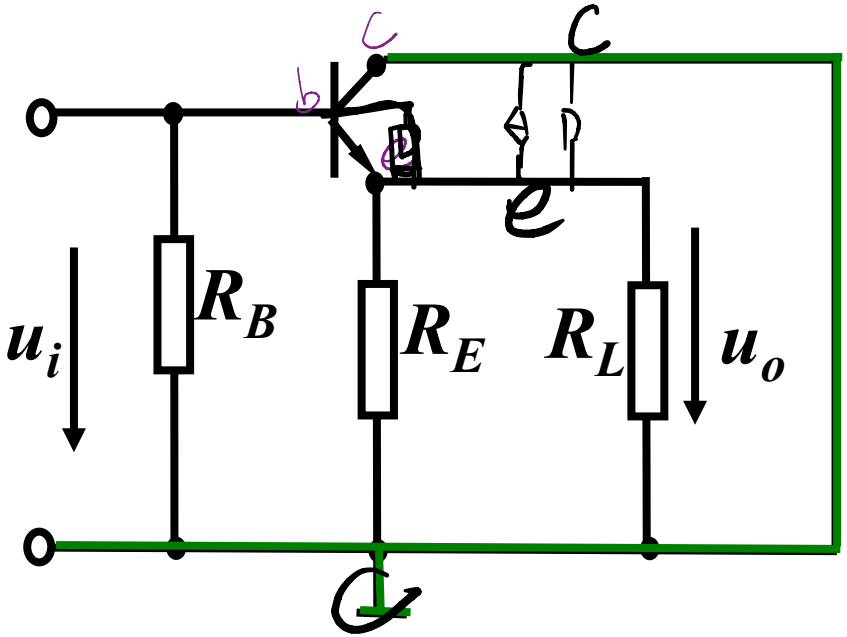
$$I_{EQ} = (1+\beta)I_{BQ}$$

$$U_{CEQ} = V_{CC} - I_{EQ}R_E$$

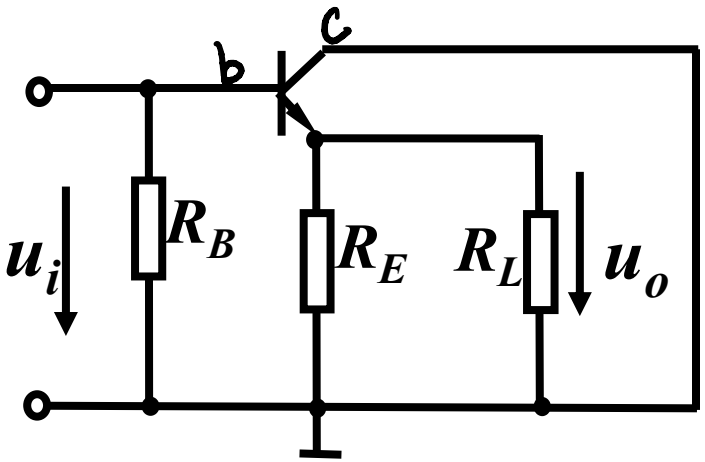
二、动态分析



交流通路

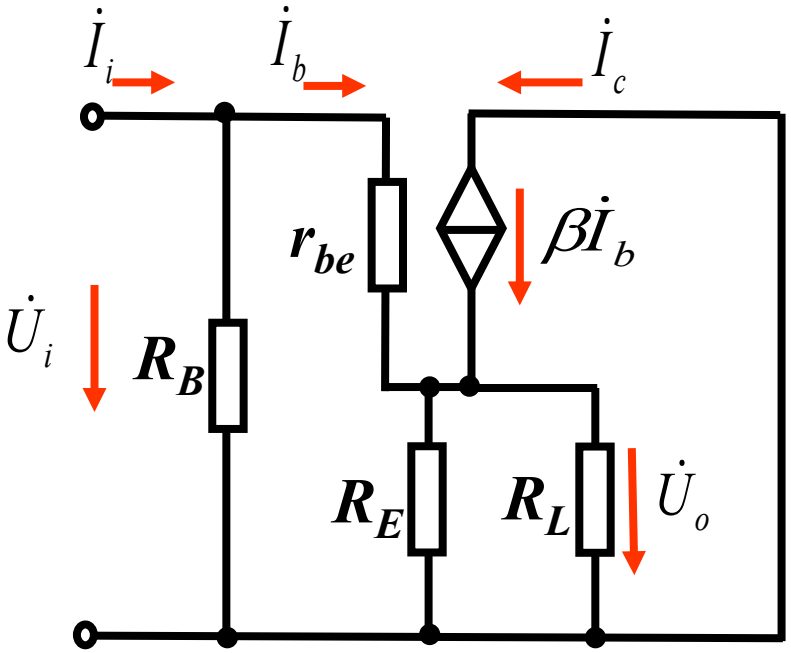


共集放大电路

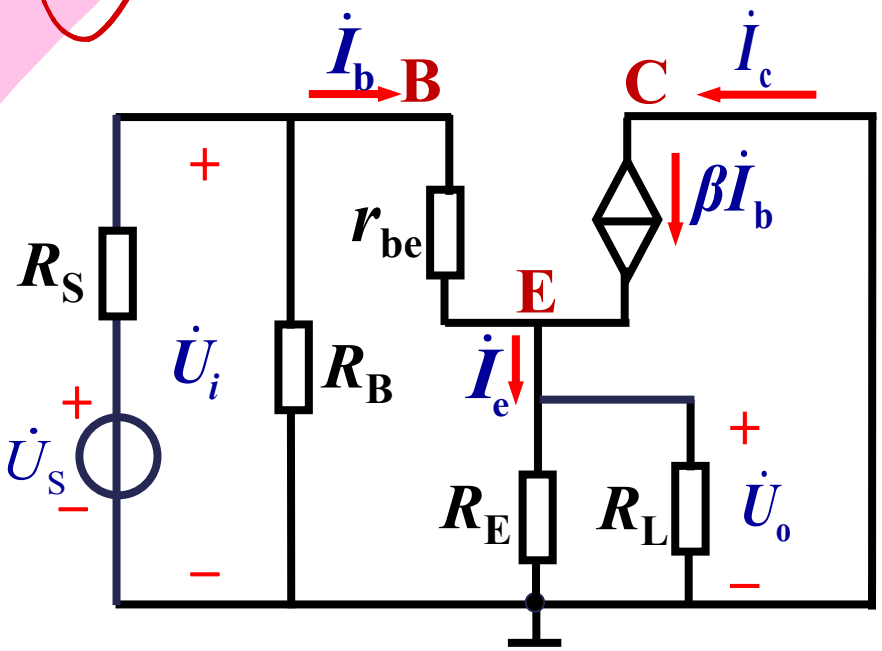

c
b
u_i
R_B
R_E
R_L
u_o

交流通路

交流等效电路


$\dot{I}_i$
$\dot{I}_b$
$\dot{I}_c$
r_{be}
$\beta\dot{I}_b$
$\dot{U}_i$
R_B
R_E
R_L
$\dot{U}_o$

电压放大倍数



电压跟随器

射级输出器输出输入同相

输出电压跟随输入电压

$$R'_L = R_E // R_L$$

$$\dot{U}_o = \dot{I}_e R'_L$$

$$= (1+\beta)\ \dot{I}_b R'_L$$

$$\dot{U}_i = \dot{I}_b r_{be} + \dot{I}_e R'_L$$

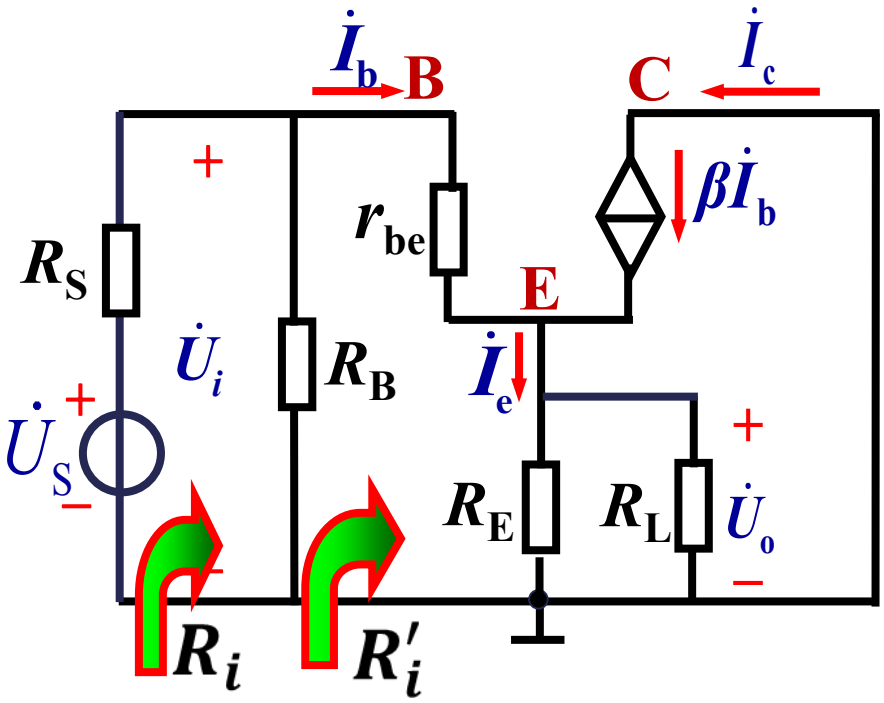
$$= \dot{I}_b r_{be} + (1+\beta)\dot{I}_b R'_L$$

$$A_u = \frac{(1+\beta)\dot{I}_b R'_L}{\dot{I}_b r_{be} + (1+\beta)\dot{I}_b R'_L}$$

$$= \frac{(1+\beta)\ R'_L}{r_{be} + (1+\beta)R'_L} \approx 1$$

虽没有电压放大能力， 但具有电流放大能力

输入电阻R_i



$$R_i = R_B // R_i'$$

$$R_i' = \frac{\dot{U}_i}{\dot{I}_i} = \frac{\dot{I}_b r_{be} + \dot{I}_e R_L'}{\dot{I}_b}$$

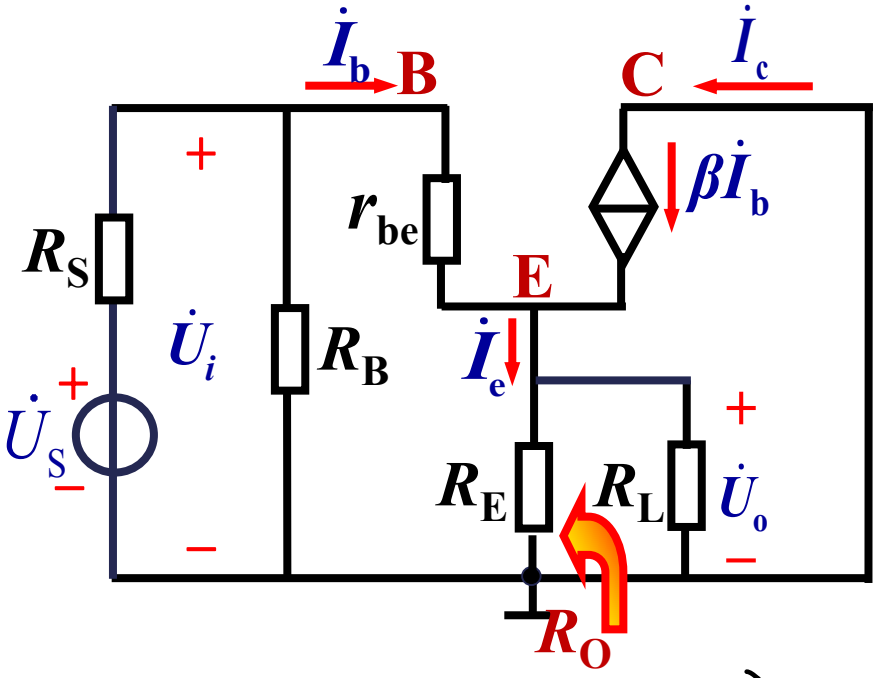
$$= r_{be} + (1+\beta)R_L'$$

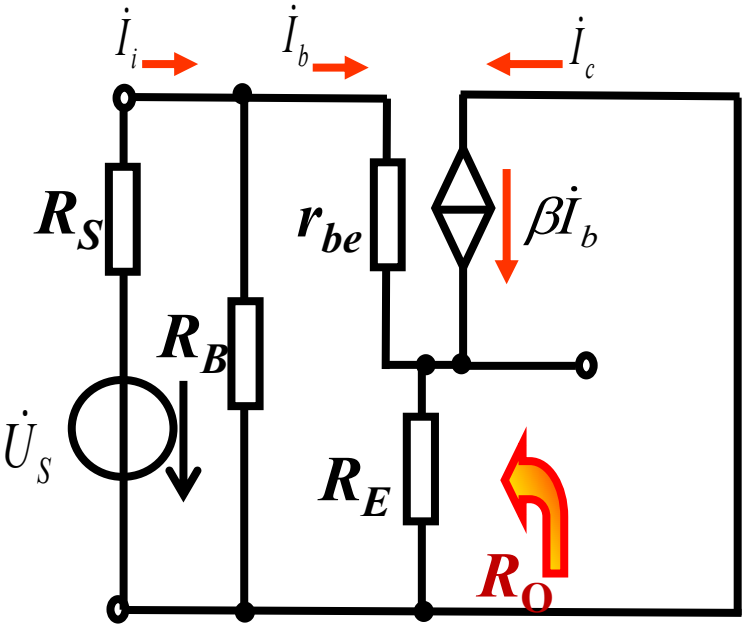
$$R_L' = R_E // R_L$$

射极输出器r_i较大，与负载有关

$$R_i = R_B // [\, r_{be} + (1+\beta)R_L' \,]$$

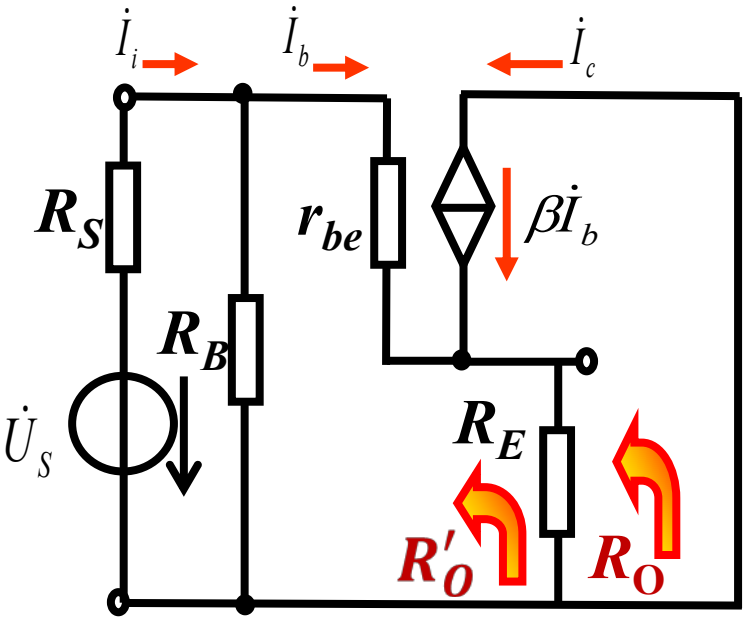
输出电阻R_O



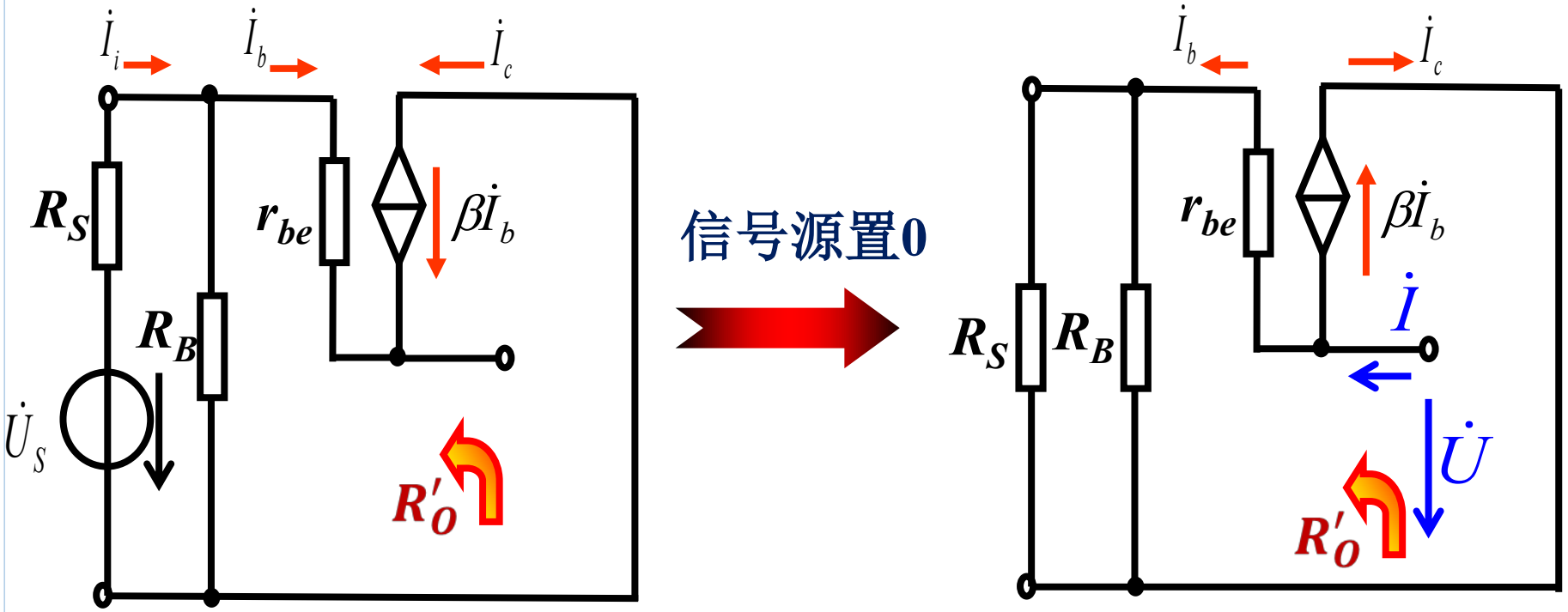


$$R_O = R_E // \left(\frac{(R_S // R_B) + r_{be}}{1+\beta} \right)$$

$$R_O = R'_O // R_E$$



用加压求流法求R'_o


$\dot{I}_i$
$\dot{I}_b$
$\dot{I}_c$
R_S
r_{be}
$\beta\dot{I}_b$
R_B
$\dot{U}_S$
R'_O
信号源置0
$\dot{I}_b$
$\dot{I}_c$
r_{be}
$\beta\dot{I}_b$
R_S
R_B
$\dot{I}$
$\dot{U}$
R'_O

输出电阻R_O

$$\dot{I} = \dot{I}_b + \dot{I}_c = (1+\beta)\dot{I}_b$$

$$\dot{U} = \dot{I}_b(r_{be} + R_s^{'})$$

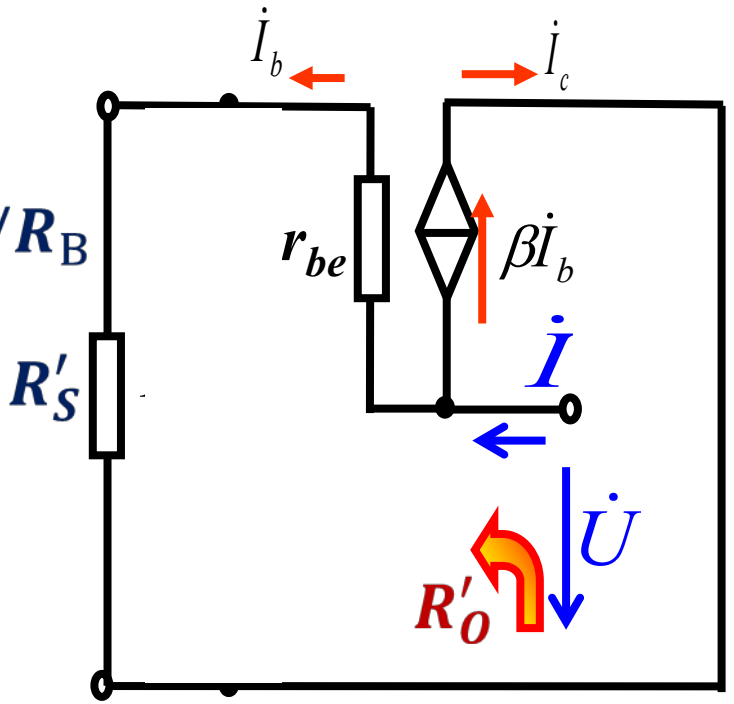
$$R'_O = \frac{\dot{U}}{\dot{I}} = \frac{r_{be} + R'_S}{1+\beta}$$

$$R_O = R'_O // R_E = \frac{r_{be}+R'_S}{1+\beta} // R_E$$

一般 $R_E >> \dfrac{r_{be} + R'_s}{1+\beta}$

$$R_O \approx \frac{r_{be} + R'_S}{1+\beta}$$

$R'_S = R_S // R_B$



举例：如某放大电路β=40,r_{be}=0.8kΩ，R_S=50Ω,R_B=120kΩ

$$r_o \approx \frac{800+50}{40}\Omega = 21.3\Omega$$

射极输出器输出电阻小

射级输出器的特点和应用

$$A_u = \frac{(1+\beta)R'_L}{r_{be}+(1+\beta)R'_L}$$

小于1，约等于1，输出与输入同相

具有电流放大能力，可用于功率的放大

$$R_i = R_B // [r_{be} + (1+\beta)R'_L]$$

输入电阻高

常被用在多级放大电路的第一级，减轻信号源负担

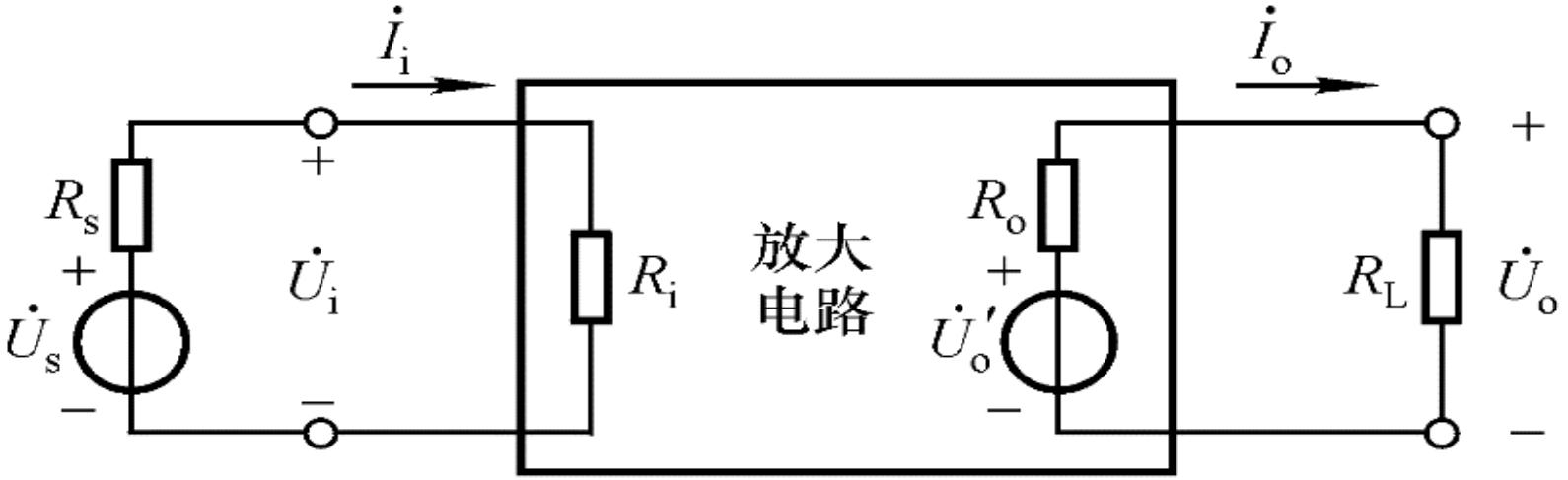
$$R_O \approx \frac{r_{be} + R'_S}{1+\beta}$$

输出电阻低

常被用在多级放大电路的末级，提高带负载能力

常用在放大电路的两级之间，起到阻抗匹配作用，称为缓冲级或中间隔离级

输入输出电阻对放大电路性能的影响



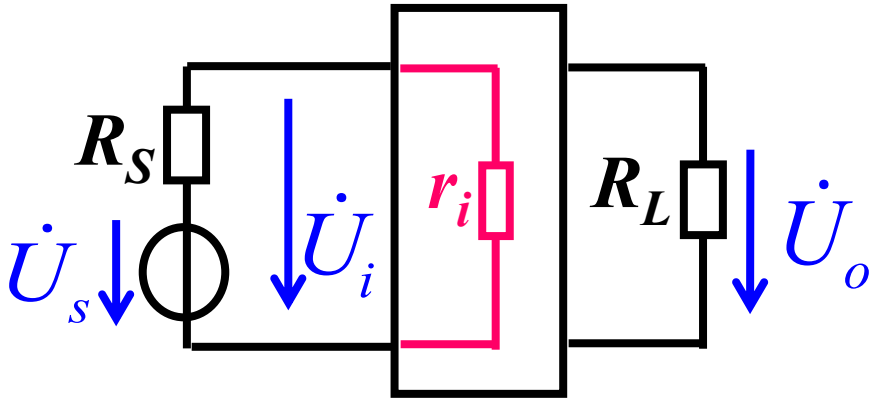
$$\dot{U}_i = \frac{R_i}{R_i + R_S}\dot{U}_s$$

输入电阻大有利于放大电路从信号源取电压

$$\dot{U}_O = \frac{R_L}{R_L + R_O}\cdot\dot{U}_O'$$

输出电阻小有利于负载上得到尽可能高的输出电压

放大电路对信号源的放大倍数 A_{us}



$$A_u = \frac{\dot{U}_o}{\dot{U}_i}$$

$$A_{us} = \frac{\dot{U}_o}{\dot{U}_s}$$

A_u 和 A_{us} 的关系如何?

$$A_{us} = \frac{\dot{U}_o}{\dot{U}_s} = \frac{\dot{U}_o}{\dot{U}_i}\frac{\dot{U}_i}{\dot{U}_s}$$

$$\dot{U}_i = \frac{R_i}{R_S + R_i}\dot{U}_S$$

$$A_{us} = \frac{R_i}{R_S + R_i} A_u$$

本节作业:

P224

9.11 分压偏置放大电路

9.12 射极输出器