JNOTES

日期: /

半导体的基础知识、

1. 半导体的材料: Si. Ge.

特点 | 光热性
　　 | 掺杂性

T=0K
T=300K

价电子 → 最外层电子
束缚电子 → 共价键电子
自由电子

2. 本征半导体

· 共价键结构

· 本征激发

· 自由电子—空穴对

· 空穴的移动 ——→ 电流

3. 杂质半导体

<1> N型半导体 (negative 负)

掺+5 (磷)

(正离子. 施主杂质)

主要取决于掺杂比例

| 多数载流子: 自由电子
| 少数载流子: 空穴

主要取决于温度

<2> P型半导体 (positive 正)

掺+3 (硼)

(负离子, 受主杂质)

| 多子: 空穴
| 少子: 自由电子

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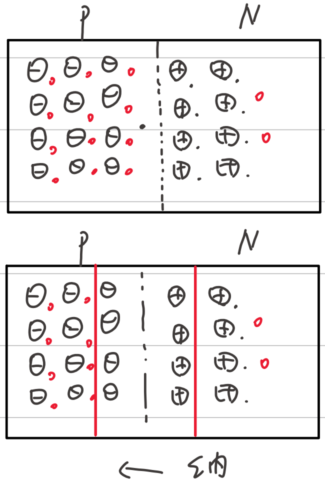
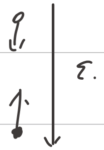
一、PN结的形成



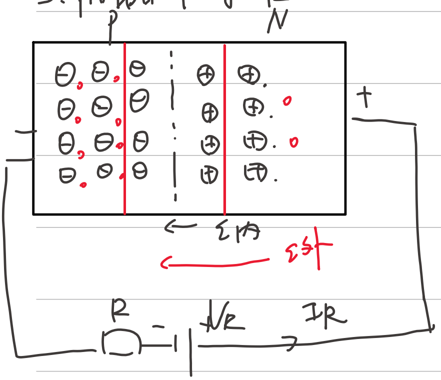
多子 扩散运动 — 浓度差引起的.

少子 漂移运动 — 电场作用下



空间电荷区

二、PN结的单向导电性

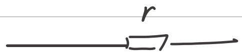


$\frac{U}{I}$ → 大

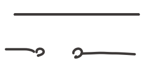
外加电压

① 正向电压（正偏）：P(+) N(-) 低阻

② 反向电压（反偏）. P(-). N(+) 高阻



理想化：



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二、单向导电性

1. 外加正向电压

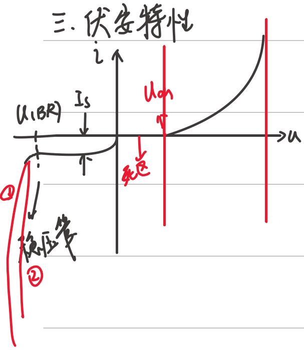
$i = I_s\left(e^{\frac{V}{V_T}} - 1\right)$　　$V_T = \frac{kT}{q}$

$\approx I_s \cdot e^{\frac{V}{V_T}}$　　I_s：反向饱和电流　　k. 玻尔兹曼常数.

2. 外加反向电压

$\underline{V>0}$ → $I = I_s \cdot e^{\frac{V}{V_T}}$

三、伏安特性



1. 正向特性
2. 反向特性 → $I = -I_s$

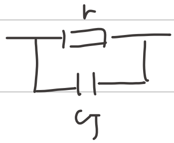
(1) I_s：反向饱和电流

(2) 击穿
- 雪崩 → 掺杂浓度低 ①（需电压高）
- 齐纳 → 掺杂浓度高 ②（需电压低）

- 热击穿（不可逆）
- 电击穿（可逆）.

四、电容效应

1. 势垒电容　2. 扩散电容



$X_c = \frac{1}{wC_j}$　　$2\pi f$

C_j小

$\underline{X_c\text{大}}$

f:高频不能忽视

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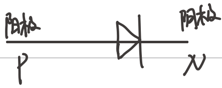
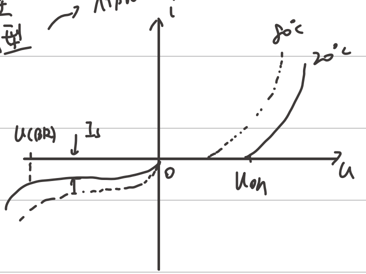
1.2 半导体二极管

一、常见结构 { 点接触型 → 高频、电压电流小
面接触型 → 整流.

二、二极管的伏安特性

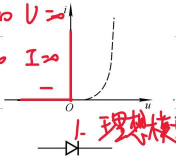




温度升高 → 正向压降↓
反向电流↑

直流模型:
由伏安特性折线化得到的等效电路.

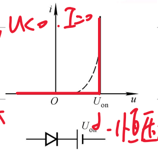
{ I>0 U=0
U<0 I=0



1. 理想模型 ★

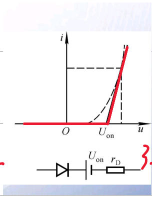
理想二极管.

{ I>0 U=U_D
U<0 I=0



2. 恒压模型

正向导通时端电压为常量



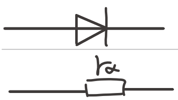
3. 折线模型.

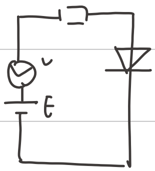
正向导通时端电压与电流是线性

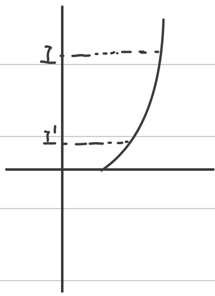
分析: 判断二极管是否导通
先假设二极管是截止的.

4. 小信号模型 (交流模型)

$u < U_{on}$ 截止.
$u \geq U_{on}$ 导通 $\quad i = \frac{u-U_{on}}{r_D}$







$i_D = I_s(e^{u/U_T}-1)$

$i_D = I_s \cdot e^{u/U_T}$

$\frac{di_D}{dV} = \frac{I_s}{V_T} e^{\frac{u}{V_T}} = \frac{I}{V_T}$ $\quad r_D = \frac{dV}{di_D} = \frac{V_T}{I_D}$ — 26mV

三、主要参数：

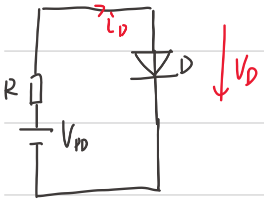
1. I_F
2. V_{BR} - 击穿电压
3. $V_{BR}/2$ 工作电压
4. $I_R(I_S)$ 小
5. V_D T
6. f_M → 结电容容抗↓ 不能忽视

7. 温度系数.

$T\uparrow \to I_R\uparrow$ 正温度系数

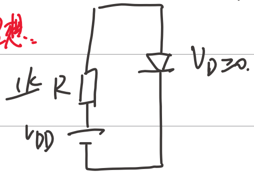
$T\uparrow \to V_D\downarrow$ 负温度系数

二极管电路的分析与计算.

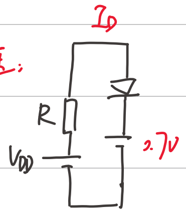


理想：

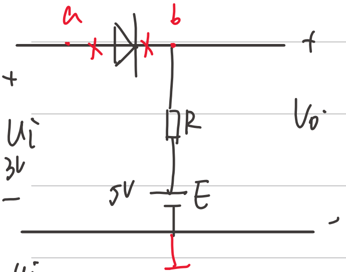
$I_D=\frac{V_{DD}}{R}$



恒压：



$I_D=\frac{V_{DD}-0.7}{R}$



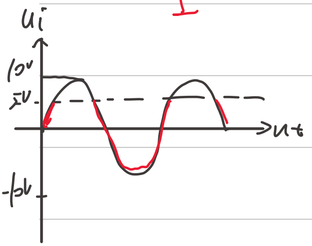
假设二极管是截止的.

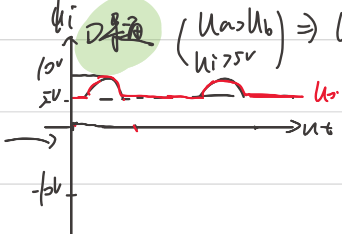
$U_a=U_i$

$U_b=E=5V$

D截止 $\begin{cases}U_a<U_b\\ U_i<5V\end{cases} \Rightarrow U_o=5V$

D导通 $\begin{cases}U_a>U_b\\ U_i>5V\end{cases} \Rightarrow U_o=U_i$





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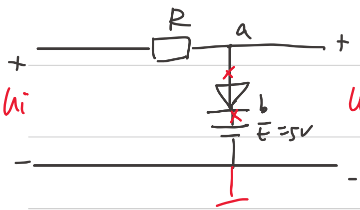
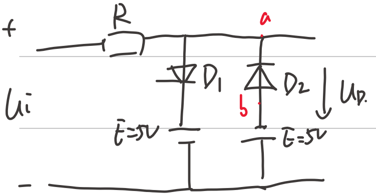


$u_a = u_i$ $u_b = E = 5V$

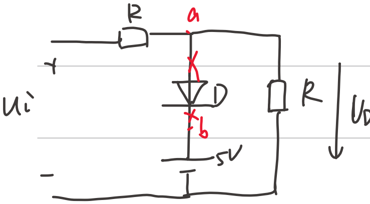
D通: $u_a > u_b$, $u_i > 5V$ $u_o = 5V$

D截止: $u_a < u_b$, $u_i < 5V$ $u_o = u_i$



$u_a = u_i$ $u_b > u_a$ 导通 ⇒ $u_i < -5V$

$u_b = -5V$



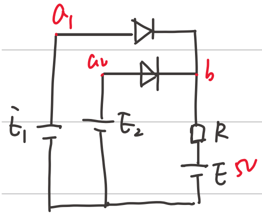
$U_b = 5V$

$U_a = \frac{u_i}{2}$

$u_a > u_b$ ⇒ $u_i > 10V$ 导通. $u_o = 5V$

$u_i < 10V$ 截止 ⇒ $u_o = \frac{1}{2}u_i$

多个二极管: 比较哪个优先导通



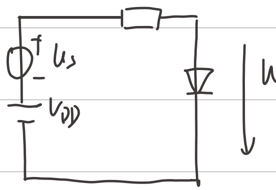
$u_b = E = 5V$

$u_{a1} = E_1$

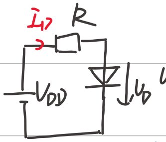
$u_{a2} = E_2$

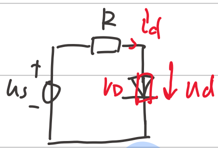
优先导通

交流时相当于电阻



叠加原理 ⇒





$I_D = \frac{V_{DD}-0.7}{R}$ $\xrightarrow{\text{代入}}$ $r_D = \frac{V_T}{I_D} = \frac{26mV}{I_D}$

$V_D = 0.7V$

直流电流

$u_D = V_D$ 直流电压 + u_d 交流电压

$i_D = I_D$ 直流电流 + i_d 交流电流

$i_d = \frac{u_s}{R+r_D}$ $u_d = \frac{r_D}{R+r_D} \cdot u_s$

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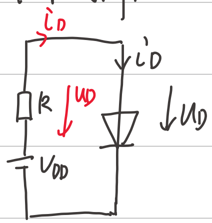
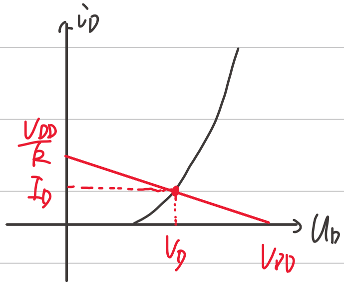
二极管图解法:

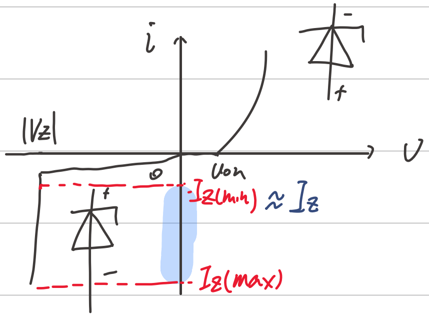




$u_D = \underline{V_{DD} - i_D \cdot R}$ 直线

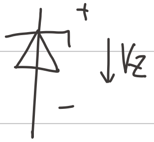
稳压管:

一. 稳压管的伏安特性



二. 稳压管的主要参数

符号.



正向导通. 反向稳压

1. V_Z: 稳定电压
2. $I_{Z(min)}$: 稳定电流 (最小)
3. $I_{Z(max)}$: - - - (最大)
4. $P_Z = U_Z \cdot I_{Z\max}$

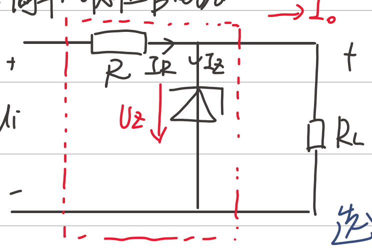
齐纳

5 温度系数: $U_Z < 6V$, 负　　U_Z在6V左右. 受温度影响最小

$U_Z > 6V$, 正

雪崩

三. 简单的稳压管电路



$I_o = \frac{U_Z}{R_L}$　　R_L最大　I_o最小

小　　大

$$\begin{cases} U_Z = U_o \\ I_{Z\max} = (2\sim3)\times I_{o\max} \end{cases}$$

选电阻的最大功耗. $P_R \geq (1.5\sim2) \cdot \frac{(V_{I\max}-V_Z)^2}{R}$

$I_R - I_o = I_Z$

$$\frac{U_{i\max}-U_Z}{R} - I_{o\min} < I_{Z\max}$$

$$\frac{U_{i\min}-U_Z}{R} - I_{o\max} > I_{Z\min}$$

⇒ 可得出 R范围

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判断稳压管能否稳压:

法一: ① 假设稳压管不能稳压(截止).

② R和R_L串联分压

③ 分压 ≥ U_Z 则可以稳压

法二: ① 假设可以稳压

$U_{R_L} = U_Z$　$U_R = U_I - U_Z$

② 计算I_R和I_{R_L}

③ $I_{DZ} \geq I_{min}$ 能稳压

$(I_{DZ} \leq I_{max})$

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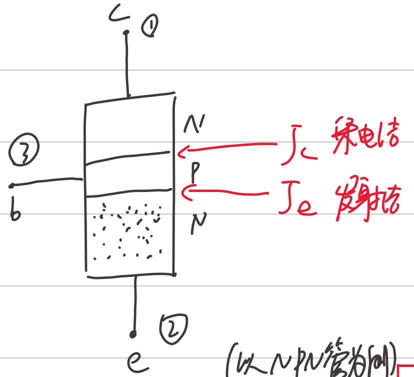
一、三极管的结构

① 集电区 collector：收集载流子
② 发射区 emitter：发射载流子
③ 基区 base：控制载流子

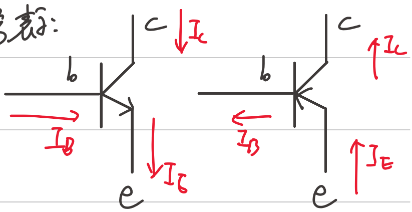
：面积大
：浓度高
：浓度低、面积小

放大的内部条件

放大的外部条件：Je 正向电压（正偏）
Jc 反向电压（反偏）



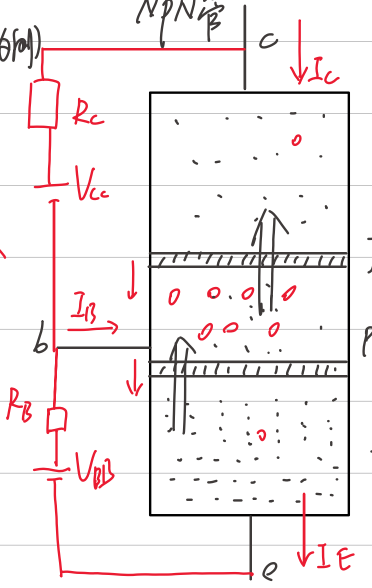
符号表示：



（以NPN管为例）

二、BJT的放大原理：

① ∵ Je正偏，Je电子注入b区
② 电子与空穴复合。b极提供空穴
③ ∵ Jc反偏：b区注入电子漂移到c区



$* \; I_E = I_C + I_B$（I_C 大，I_B 小）

$* \; \beta = \dfrac{I_C}{I_B}$

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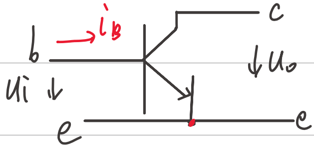
一、三极管的伏安特性

1. 三极管的三种接法：ce. cb. cc

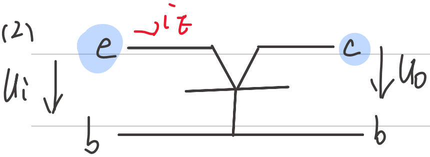
(1)



共射接法：发射极是输入与输出的公共端

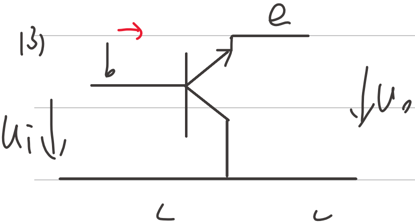
ce

(2)



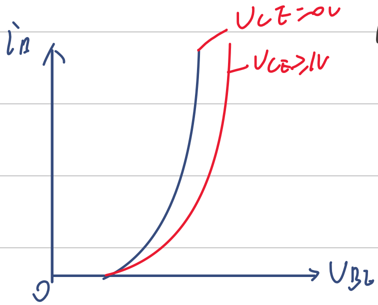
共基接法：cb.

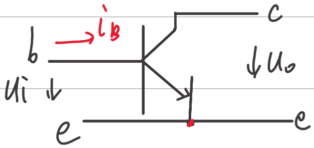
(3)



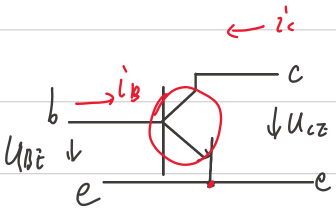
共集接法：cc.

2. ce 输入特性：$i_B = f(u_{BE})$

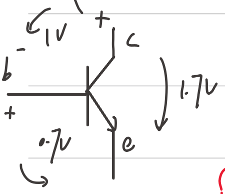


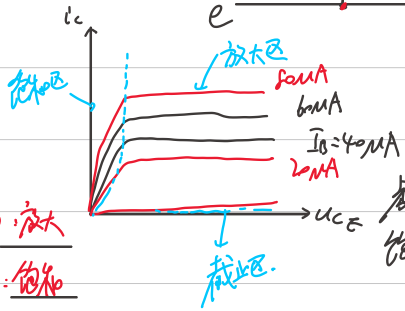


3. ce 输出特性: $i_C = f(u_{CE})$



$\beta = \frac{I_C}{I_B}$





Je 正偏 通 { Jc 反偏: 放大
Jc 正偏: 饱和 }

Je 反偏: 截止

截止区. CE相当于开路

饱和区. CE相当于短路

⇒ 作电子开关

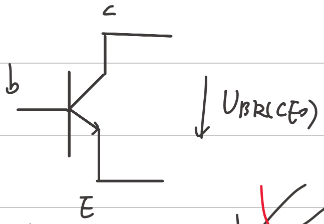
二、三极管的主要参数

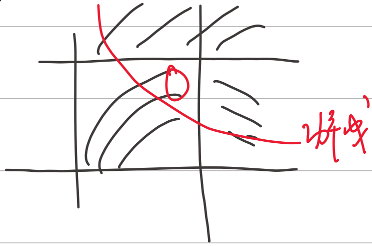
1、电流: I_{CM}

2、功率: $P_{CM} = U \cdot i$

3、电压: $U_{(BR)CEO}$

CEO — open 断开





4. β — 电流放大系数 ce

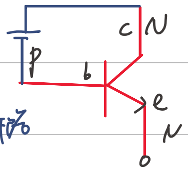
$\bar{\beta} = \frac{I_C}{I_B}$ (直流) $\beta = \frac{\Delta I_C}{\Delta I_B}$ (交流)

温度增大, I_{CEO}↑ β↑

α — 电流 --- cb

$\alpha = \frac{I_C}{I_E} < 1$ (接近于1) $I_E = I_C + I_B$

日期: /

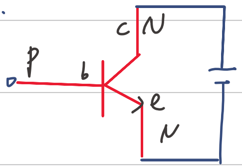


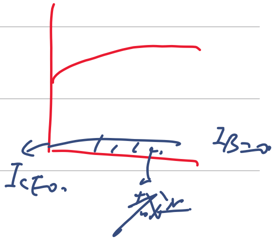
I_R 二极管反向电流.

3. 极间电流

I_{CBO} (T) e开路

I_{CEO} b开路.





$I_{CEO} = (1+\beta)\cdot I_{CBO}$

(T) (T)

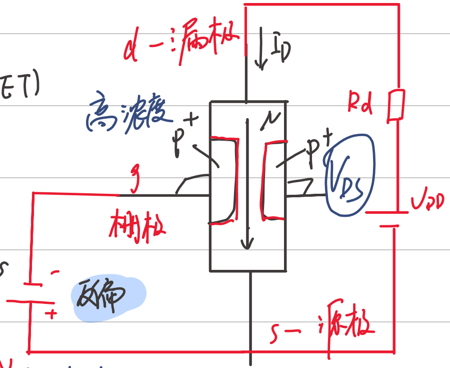
多子控制 → 单极型器件.

↗ 电压控制电流

结型场效应管 (JFET)

一. 结构

二. 工作原理



弥补二极管的不足

输入电阻大

{N沟道
P沟道

1. $V_{DS}=0$时. U_{GS}单独作用

夹断电压V_P

N - 负

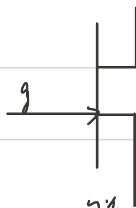
P - 正

2. $V_{GS}=0$时.

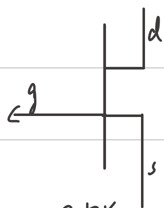
栅源上宽下窄

上面靠拢时的V_{DS} → 预夹断

3. V_{GS}、V_{DS}同时作用.



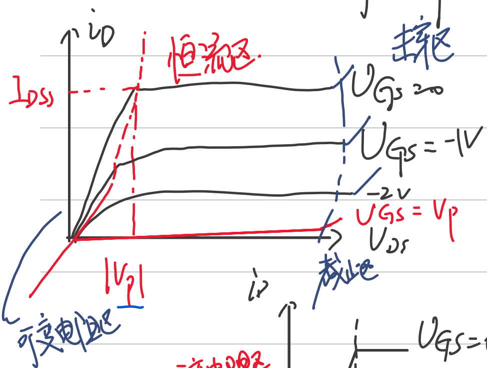
N沟道

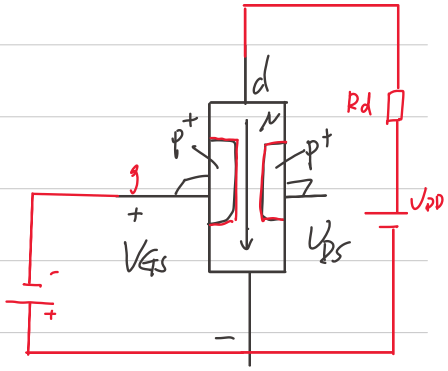


P沟道

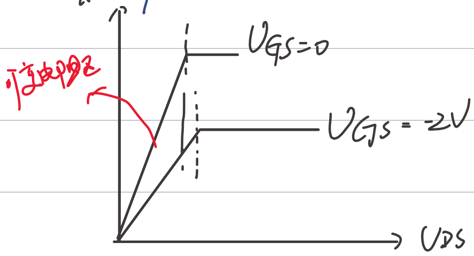
三.特性曲线

1.输出特性曲线 $i_D = f(U_{DS})\big|_{U_{GS}}$



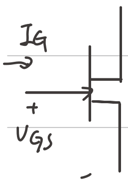


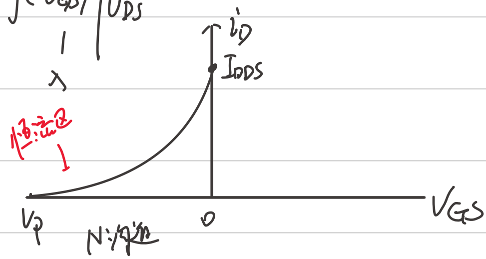
非线性



2.转移特性曲线 $i_D = f(U_{GS})\big|_{U_{DS}}$

出 入





四.主要参数

1. V_p. I_{DSS}

2. 跨导 $g_m = \dfrac{\Delta i_D}{\Delta U_{GS}}$ ← 电压控制电流 mA/V

$\beta = \dfrac{\Delta I_C}{\Delta I_B}$ ← 电流控制电流

日期: /

$$i_D = I_{DSS}\left(1-\frac{V_{GS}}{V_P}\right)^2 \qquad g_m = \frac{di_D}{du_{GS}} = ?\,\Big|_{V_{GS}}$$

$- \; V_P < V_{GS} < 0$

3. I_{DM}, P_{DM},

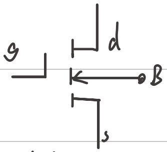
$U_{(BR)DS}$ $U_{(BR)GS}$.

MOSFET

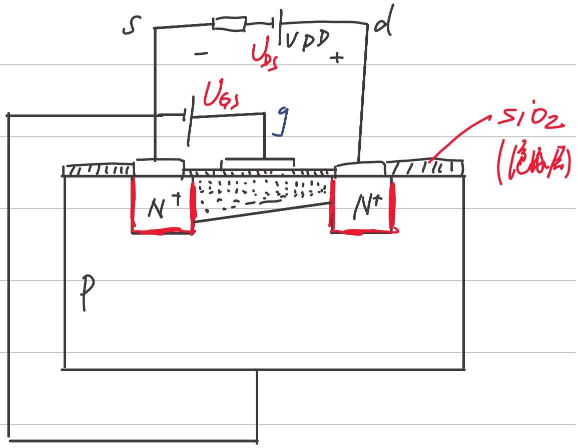
一. N沟道增强型 MOSFET

1. 结构

符号:



N沟道



(虚线为增强型 实线⋯耗尽型)

场效应管 { 耗尽型 ② ← JFET ; 增强型 ✓ ① }

$U_{GS}=0,\ i_D=0$ ①

$U_{GS}=0,\ i_D\neq 0$ ②

2. 工作原理

<1> $U_{DS}=0$, V_{GS}作用

$V_{GS}=0$ $V_{GS}\uparrow$

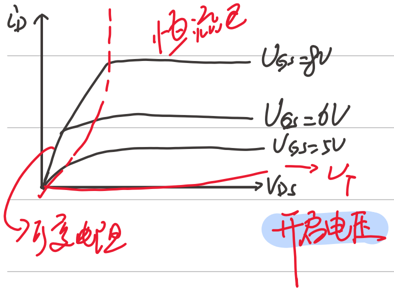
$V_{GS}\geq V_T$ (开启电压)

<2> U_{DS} 同时考虑

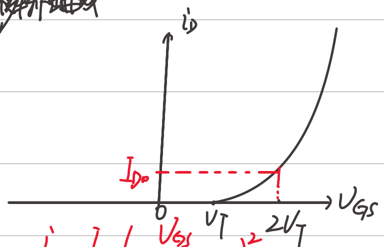
日期: /

3. 特性曲线.

<1> 输出特性曲线



<2> 转移特性曲线

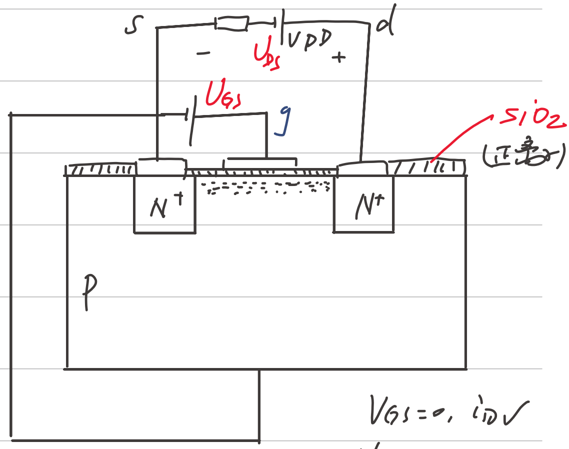


$$i_D = I_{D0}\left(\frac{V_{GS}}{V_T}-1\right)^2$$

$i_D = I_{D0}$ $V_{GS}=2V_T$

二. N沟道耗尽型 MOSFET.

$V_{GS}=0$, I_D ✓

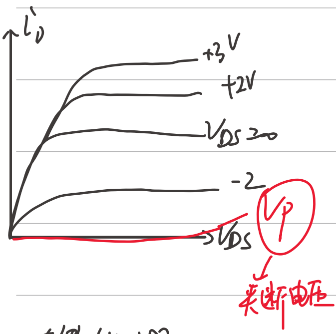


$V_{GS}=0$, i_D ✓

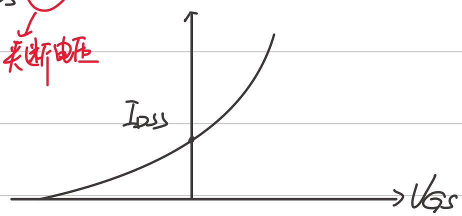
$V_{GS}>0$

$V_{GS}<0$

<1> 输出特性曲线

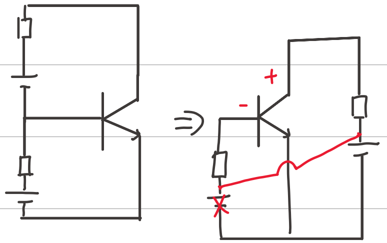


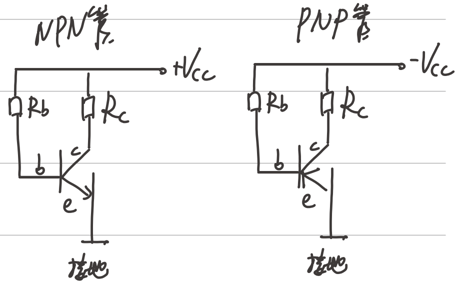
<2> 转移特性曲线

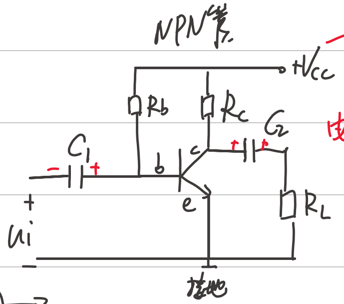


共射放大电路 (CE)

一. 电路组成







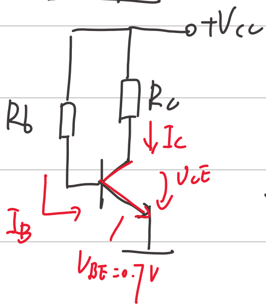
→ 用来保证三极管处于放大状态

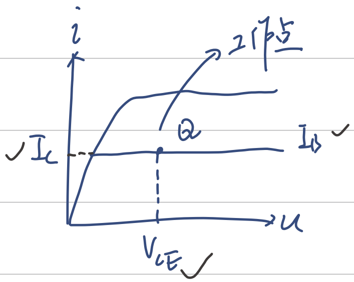
电解电容

$\frac{1}{wC_1} \to 0$　　C1, C2足够大

二. 静态分析:

1. 直流通路





2. 估算法

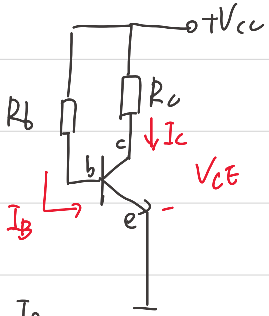
Q点

$$I_B = \frac{V_{CC}-0.7}{R_b}$$

$$I_C = \beta \cdot I_B$$

$$V_{CE} = V_{CC} - R_C \cdot I_C$$

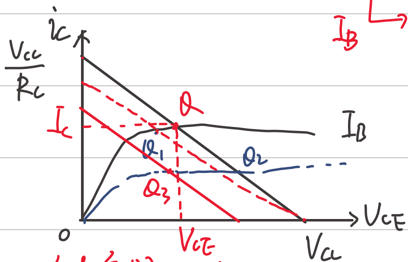
静态工作点的图解分析：



① $I_B = \frac{V_{CC}-0.7}{R_b}$

② $V_{CE} = V_{CC} - I_C R_C$

$\quad x \qquad\qquad y$



$I_C = \frac{1}{R_C} U_{CE} + \frac{V_{CC}}{R_C}$ (直流负载线)(DC)

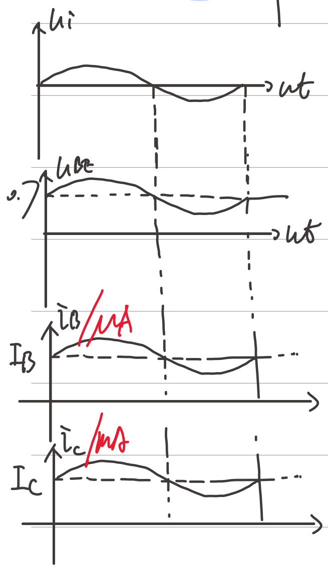
③ 确定Q点

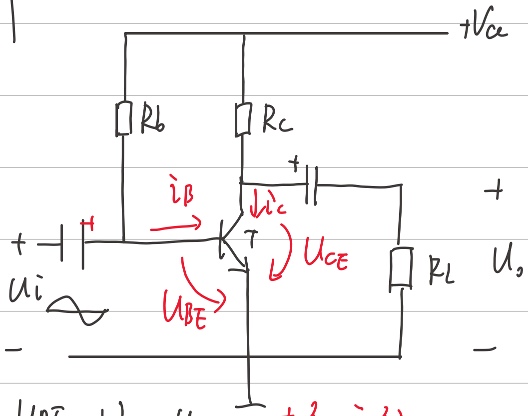
$R_C\uparrow \to Q_1$

$R_b\uparrow \to Q_2$

$V_{CC}\downarrow \to Q_3$

放大电路的动态分析 — 图解法

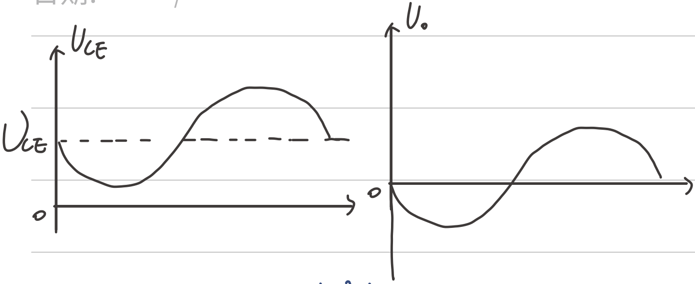




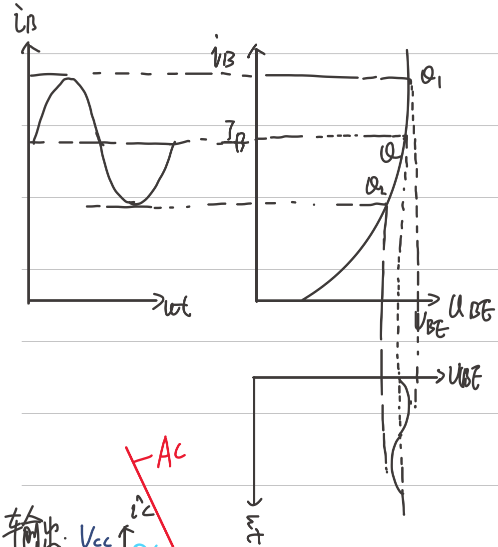
$u_{BE} = \underbrace{U_{BE}}_{0.7V} + \underbrace{u_{be}}_{u_i}$ 直流+交流

日期: /

电容隔直流通交流：

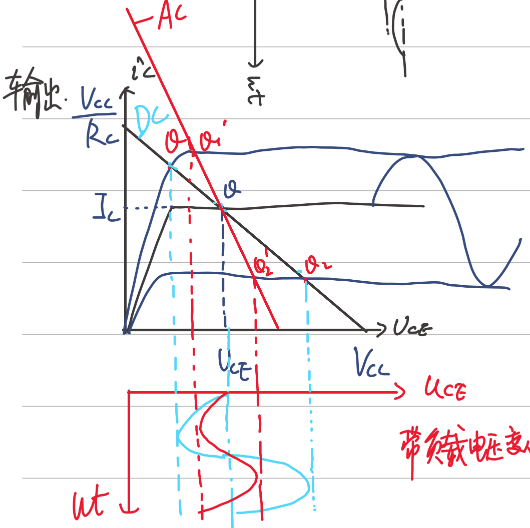


U_i与U_o相比：①反相 ②幅度大（放大）



$Q \to Q_1$

交流

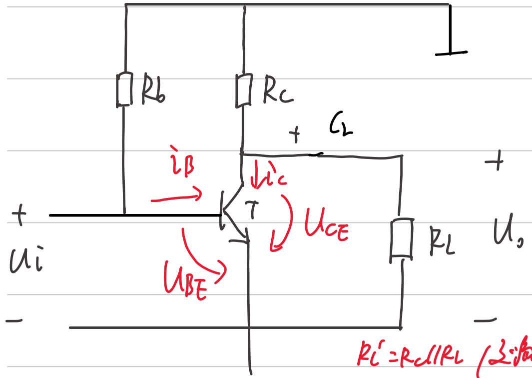


带负载电阻变小

日期:　　/

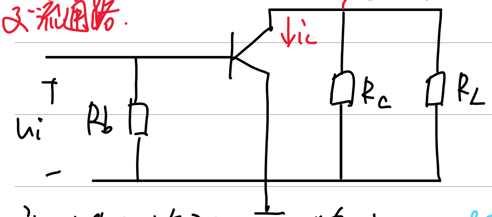
交流负载线(AC)

斜率: $-\frac{1}{R_L'}$

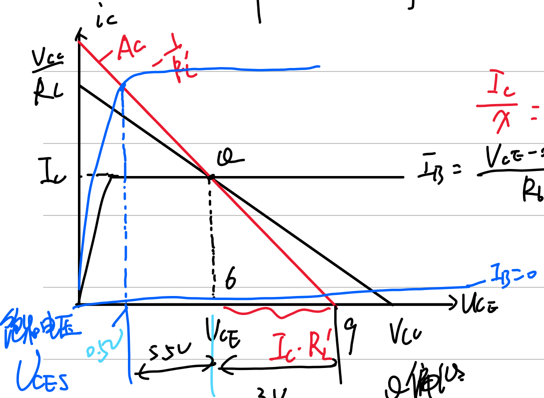


$R_L' = R_c // R_L$ (交流负载)

交流通路.



放大电路的动态分析 — 失真分析. 波形不一样 (以NPN管为例)



$\frac{I_c}{x} = \frac{1}{R_L'} \Rightarrow x = I_c R_L'$

$I_B = \frac{V_{CC}-0.7}{R_b}\downarrow$

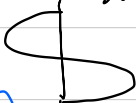
$U_{CES} = 0.5V$

→ 顶部失真 (电压波动)

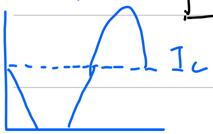
Q偏低 → 碰到截止区失真 → 截止失真

Q偏高 → 碰到饱和区失真 → 饱和失真

① 输入信号过大
② 静态工作点不合适

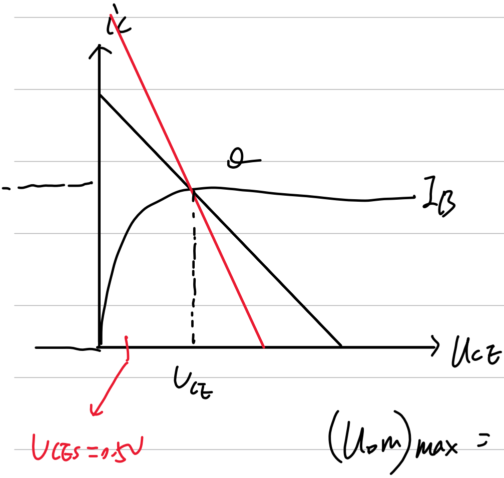


电压波动.



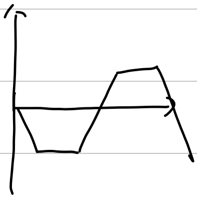
底部失真 (电压波动) → 电流与之相反. PNP管的结论与之相反

日期:　　　/



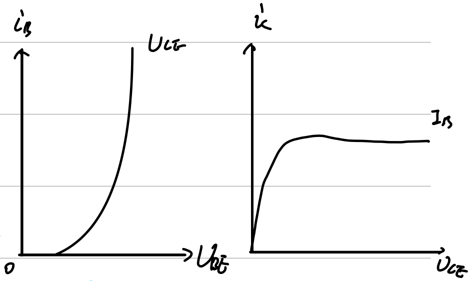
最大不失真输出

$$(U_{om})_{max} = \min\{U_{CE}-U_{CES},\ I_C\cdot R_L'\}$$



由于输入信号过大 → 调小信号(有一端失真消失)

三极管的小信号模型



$$\begin{cases} i_B = f(U_{BE})\big|_{U_{CE}} \\ i_C = f(U_{CE})\big|_{I_B} \end{cases} \Rightarrow \begin{cases} u_{BE} = f_1(i_B, U_{CE}) \\ i_C = f_2(i_B, U_{CE}) \end{cases}$$

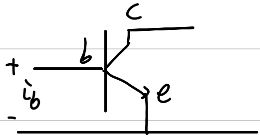
$$\begin{cases} du_{BE} = \dfrac{\partial u_{BE}}{\partial i_B}\Big|_{U_{CE}} \cdot di_B + \dfrac{\partial U_{BE}}{\partial U_{CE}}\Big|_{i_B} \cdot dU_{CE} \\ di_C = \dfrac{\partial i_C}{\partial i_B}\Big|_{U_{CE}} \cdot di_B + \dfrac{\partial i_C}{\partial U_{CE}}\Big|_{i_B} \cdot dU_{CE} \end{cases}$$ （全微分）

$d \to \Delta \to \sim$ （小信号）

$$\begin{cases} u_{be} = r_{be}\, i_b + \mu_r\, u_{ce} \\ i_c = \beta\, i_b + \dfrac{1}{r_{ce}}\, u_{ce} \end{cases}$$

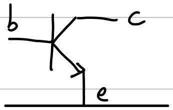
μ_r → 非常小

$\dfrac{1}{r_{ce}}$ → 非常小

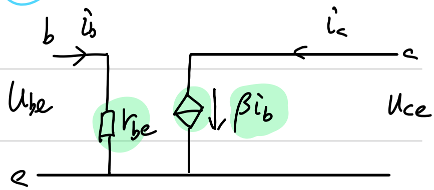


$r_{ce} = \dfrac{\partial U_{CE}}{\partial i_C}$ 大

$$\begin{cases} u_{be} = r_{be}\, i_b \\ i_c = \beta\, i_b \end{cases}$$



交流 ⇒



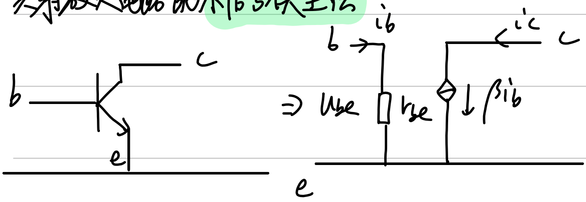
* $r_{be} = r_{bb'} + (1+\beta)\dfrac{26\text{mV}}{I_{E\,\text{mA}}}$ $\quad I_E = I_C$ 静态直流电流

$r_{bb'}$: $100\Omega \sim 300\Omega$

h参数的物理意义

$h_{11e} = r_{be}$ $\quad h_{12e} = \mu_r$ $\quad h_{21e} = \beta$ $\quad h_{22e} = \dfrac{1}{r_{ce}}$

共射放大电路的小信号模型法

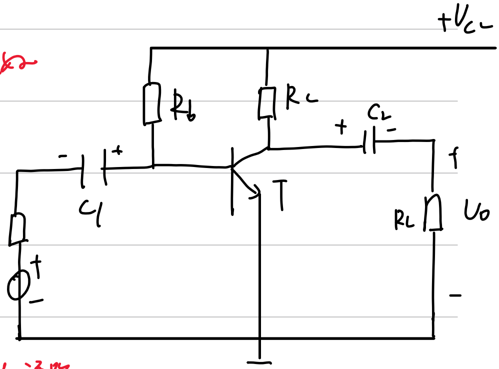


$$r_{be} = r_{bb'} + (1+\beta)\cdot\frac{26mV}{I_E}$$

交流参数:

1. 电压放大倍数 $A_u = \frac{U_o}{U_i}$ 越大越好

$$A_u = \frac{U_o}{U_i} = \frac{-\beta\cdot\cancel{i_b}\cdot R_c'}{\cancel{i_b}\cdot r_{be}} = -\frac{\beta\cdot R_c'}{r_{be}}$$

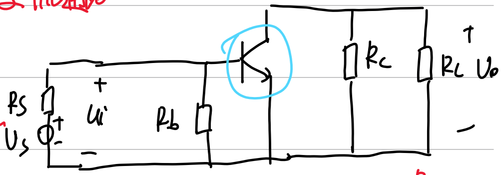


2. 放大电路的输入电阻 R_i 越大越好

$$R_i = \frac{U_i}{I_i} = R_b // r_{be}$$

$\approx r_{be}$

交流通路

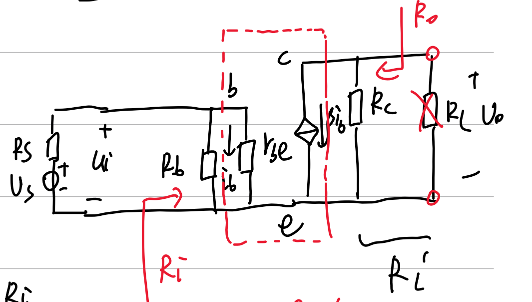


3. 放大电路的输出电阻 R_o 越小越好

(1.去掉负载 R_L. 2. U_s 置零)

$$R_o = \frac{U_o}{I_o}\Big|_{\substack{R_L\to\infty \\ U_s\to 0}}$$

$$R_o = R_c$$



4. 源电压放大倍数

$$A_{us} = \frac{U_o}{U_s} = \frac{U_o}{U_i}\cdot\frac{U_i}{U_s} = A_u\cdot\frac{R_i}{R_s+R_i}$$

即: $A_{us} \overset{\triangle}{=} -\frac{\beta R_L'}{R_s + r_{be}}$

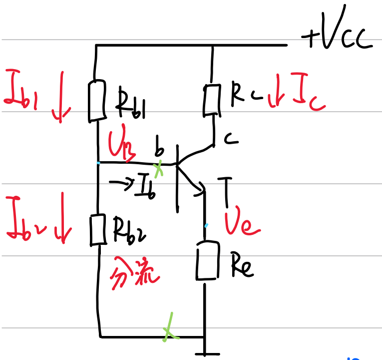
日期: /

射极偏置电路(分压式电路)

一、温度对工作点的影响

$$T\uparrow \longrightarrow \left\{\begin{array}{l} \beta\uparrow \\ I_{CBO}\uparrow \\ U_{BE}\downarrow \end{array}\right\} \Rightarrow I_C\uparrow$$

二. 分压式射极偏置电路



由 $I_C \longrightarrow U_{CE}$
$\quad \longrightarrow I_B$

即 $(1+\beta)R_e \gg R_{b1}//R_{b2}$

R_{b1}、R_{b2} 较小

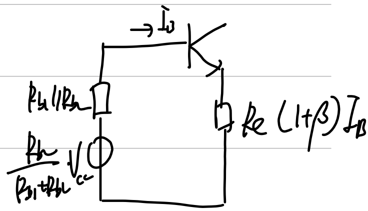
若不满足，则使用戴维南定理

1. 静态分析

若 $I_{b1} \gg I_b$，$I_{b2} \gg I_b \Rightarrow I_{b1} \doteq I_{b2}$

$$U_b = V_{CC}\cdot\frac{R_{b2}}{R_{b1}+R_{b2}}$$

$$U_E = U_B - U_{BE}$$

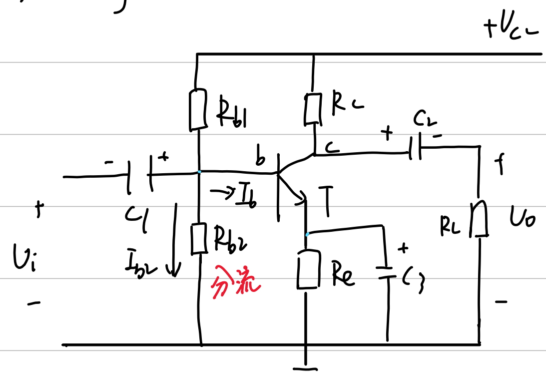


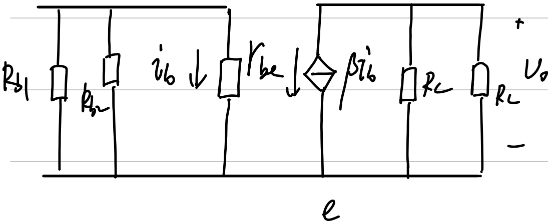
若 $U_B \gg U_{BE}$

$$I_C \doteq I_E = \frac{V_E}{R_e}$$

$$U_{CE} = V_{CC} - I_C(R_C + R_e)$$

2. 动态分析





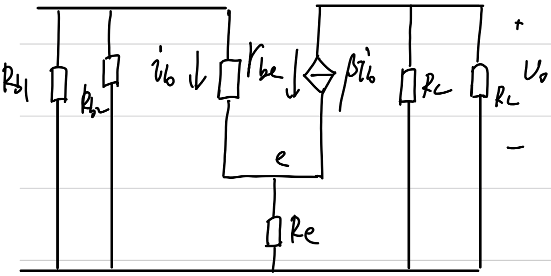
$$A_u = -\frac{\beta R_L'}{r_{be}}$$

$$R_i = R_b // r_{be}$$

$$= (R_{b1}//R_{b2})//r_{be}$$

$$R_o = R_c$$

去掉电容 C_3，交流通路应等效为



$$A_u = \frac{V_o}{V_i}$$

$$= \frac{-\beta i_b \cdot R_L'}{i_b r_{be} + (1+\beta) i_b \cdot R_e}$$

$$= \frac{-\beta \cdot R_L'}{r_{be} + (1+\beta) R_e} \downarrow\downarrow$$

$$R_i = R_{b1}//R_{b2}//[r_{be} + (1+\beta)\cdot R_e] \uparrow$$

$$R_o = R_c$$

日期: /

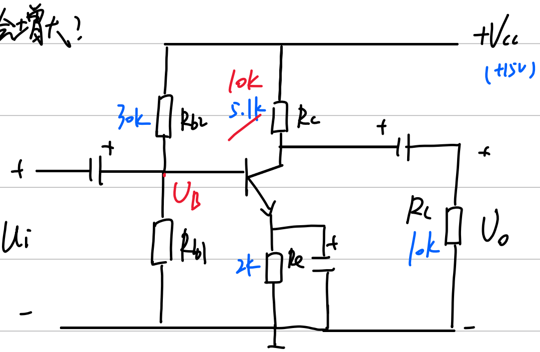
三极管放大电路补充习题(CE电路)

1. $\beta=100$, $U_{BE}=0.7V$. $i_b=12\sin\omega t\ \mu A$

① 为了不至于接近截止. $I_B>I_{bm}+3\mu A$

问 I_C, U_{CE}, $R_{b1}=?$

② R_c 调整到 $10k\Omega$, A_u 是否会增大?



① $I_C=\beta\cdot I_B=100\times(12\mu A+3\mu A)=1.5\ mA$

$U_{CE}=V_{CC}-I_C(R_C+R_e)=15V-10.65V=4.35V$

$U_B=\dfrac{R_{b1}}{R_{b1}+R_{b2}}V_{CC}=U_{BE}+R_e\cdot I_C=3.7V \Rightarrow R_{b1}=9.8k$

② $A_u=-\dfrac{\beta R_L'}{r_{be}}=-\dfrac{\beta(R_c//R_L)}{r_{be}}$ $\quad 5.1k\to 10k$ $\quad |A_u|\uparrow$

要在放大区 Au才有意义

$U_{CE}=V_{CC}-I_C(R_C+R_e)<0$ 不在放大区, 处于饱和状态.

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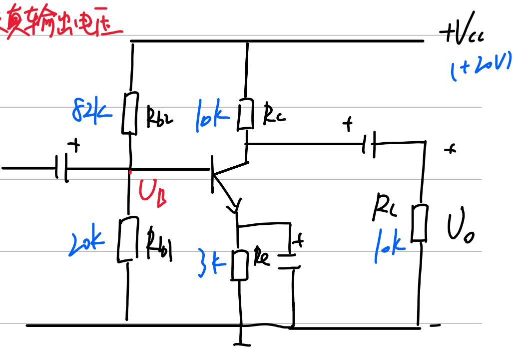
2. $V_{CC}=20V$. $R_{b1}=20k\Omega$, $R_{b2}=82k\Omega$. $R_c=10k\Omega$ $R_e=3k\Omega$.

$R_L=10k\Omega$. $U_{CES}=0.5V$ $\beta=50$

(1) Q点 (2) A_u. (3) $(U_{om})_{max}$ 最大不失真输出电压

(4) 增大输入电压幅值至输出临界不失真

逐渐增大 R_{b2}，则输出会出现什么现象



截止失真（顶部）

减小？ 一开始不会失真，最后饱和失真

(1) $V_B=V_{CC}\cdot\dfrac{R_{b1}}{R_{b1}+R_{b2}}=3.92V$ $\quad U_E=U_B-U_{BE}=3.92V-0.7V=3.22V$

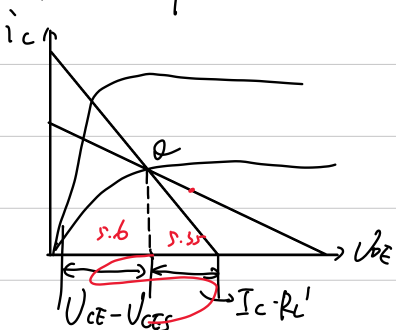
$I_c=I_E=\dfrac{U_E}{R_e}=\dfrac{3.22V}{3k\Omega}=1.07mA$

$U_{CE}=V_{CC}-I_C(R_c+R_e)=6.1V$

(2) $r_{be}=300\Omega+(1+\beta)\cdot\dfrac{26mV}{I_E}=1.54$

$A_u=-\dfrac{\beta\cdot R_L'}{r_{be}}=-\dfrac{\beta\cdot(R_L//R_c)}{r_{be}}=-162$

(3) $(U_{om})_{max}=\min\{I_C R_L',\ U_{CE}-U_{CES}\}=5.35V$



$I_C R_L'=1.07mA\times5k\Omega=5.35V$

$U_{CE}-U_{CES}=6.1V-0.5V=5.6V$

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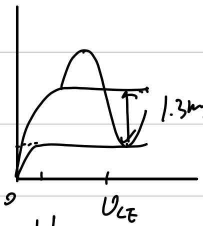
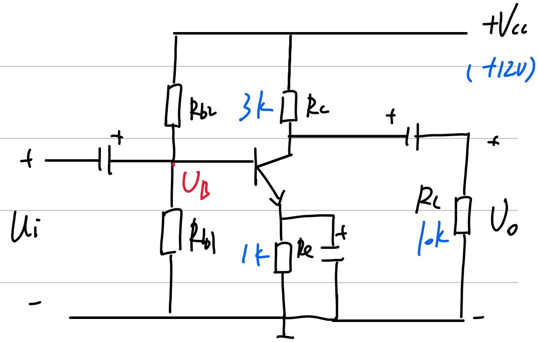
3. $U_{om}=3V$

为了不至于饱和失真. $U_{CE}>0.5V$

为了不至于截止失真. $I_C>0.1mA$ ✓

求 I_C 的范围?





$I_{om}=\frac{U_{om}}{R_L'}=\frac{3V}{2.3k\Omega}=1.3mA$ $R_L'=3k//10k=2.3k\Omega$

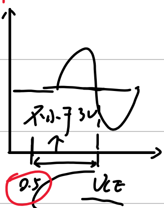
若U_{CC}不知道,代入得出U_{CC}

$U_{CE}=U_{CC}-I_C(R_C+R_e)\geq U_{om}+0.5=3.5V$

$I_C\leq 2.3mA$

$I_C\geq I_{om}+I_C=1.4mA$

$\therefore 1.4mA\leq I_C\leq 2.3mA$



$U_{CE}\geq 3.5V$

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4. 静态时 ($U_i=0$) 电流表的读数 I_{CQ}

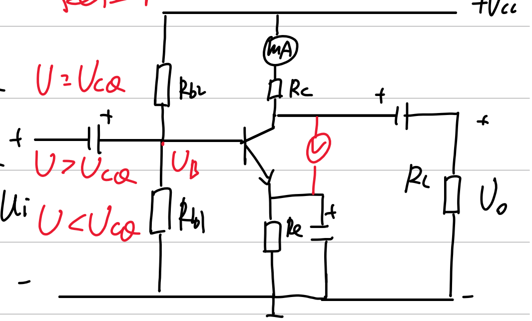
U_i 的频率 1KHz 正弦

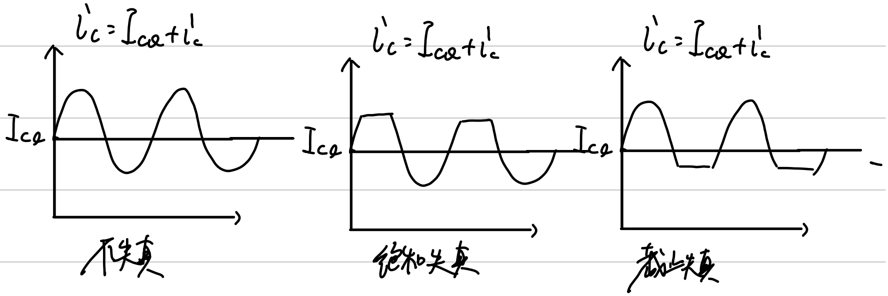
电压波形与电流波形相反.

① 输出不失真, 电流表读数 $I = I_{CQ}$ $U=U_{CQ}$

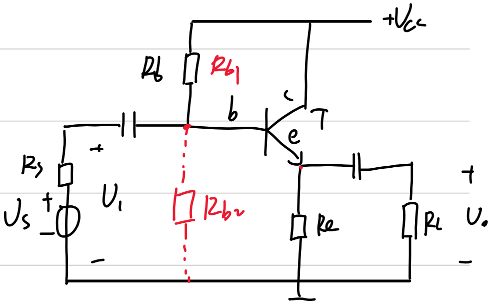
② ---- 饱和失真 ---- $I < I_{CQ}$ $U>U_{CQ}$

③ --- 截止失真 --- $I > I_{CQ}$ $U<U_{CQ}$





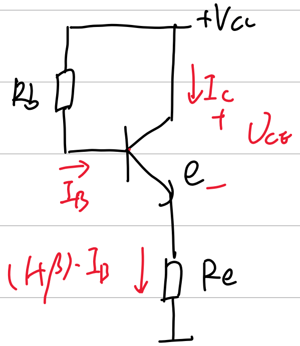
共集电极电路(cc)



一、静态分析,

$$V_{CC} = R_b \cdot I_B + V_{BE} + (1+\beta)\cdot I_B \cdot R_e$$

$$\Rightarrow I_B = \frac{V_{CC}-V_{BE}}{R_b+(1+\beta)\cdot R_e}$$



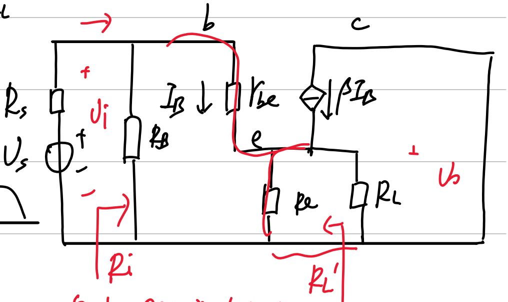
$I_C = \beta I_B$　　$I_C \to I_B$

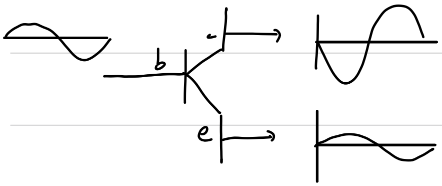
$$V_{CE} = V_{CC} - I_C R_e$$

二、动态分析:

1. $$A_u = \frac{U_o}{U_i} = \frac{(1+\beta)\cdot i_b \cdot R_L'}{i_b \cdot r_{be} + (1+\beta)\cdot i_b \cdot R_L'}$$

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





射极跟随器/输出器

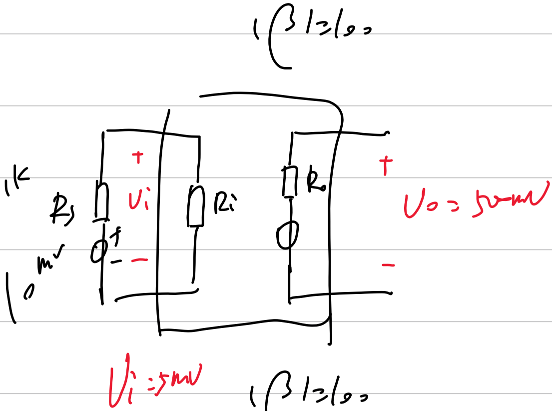
2. $R_i = R_B // (r_{be}+(1+\beta)\cdot R_L')$ 比较大

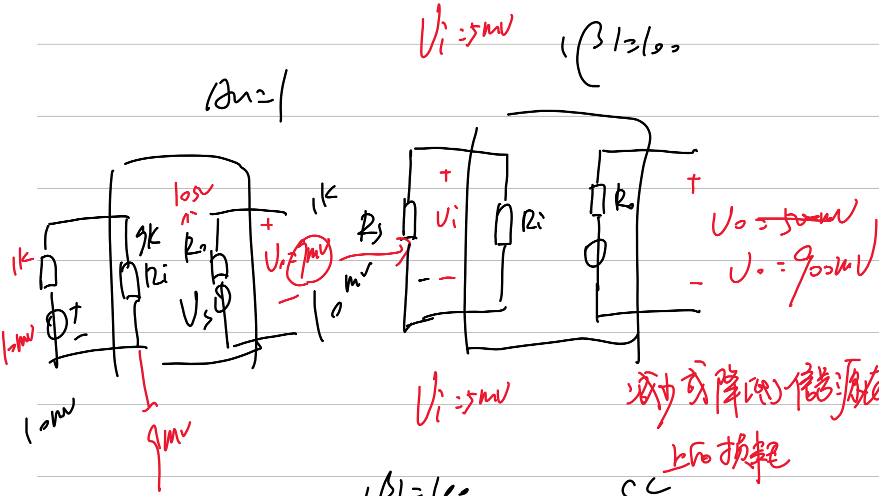
3. $R_o = R_e // \frac{(R_s//R_B)+r_{be}}{1+\beta} \approx \frac{R_s'+r_{be}}{1+\beta}$

k　　非常小 ↓↓ N,

CC电路应用.

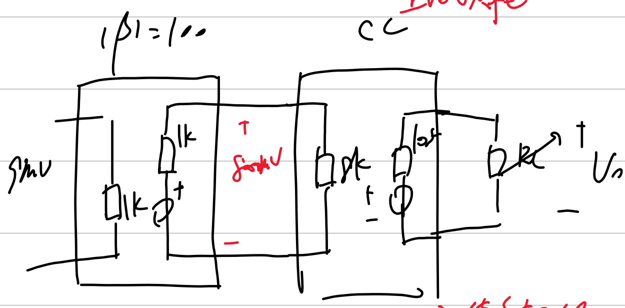
1. 输入级





减小或降低信号源内阻上的损耗

2. 输出级:



3. 中间级

提高带负载能力

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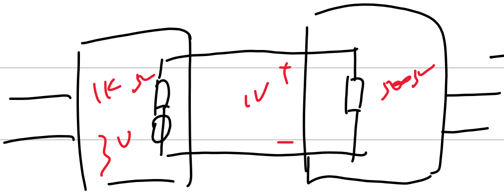
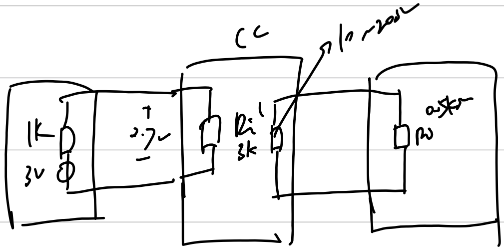


阻抗不匹配



输入电阻大

输出电阻小

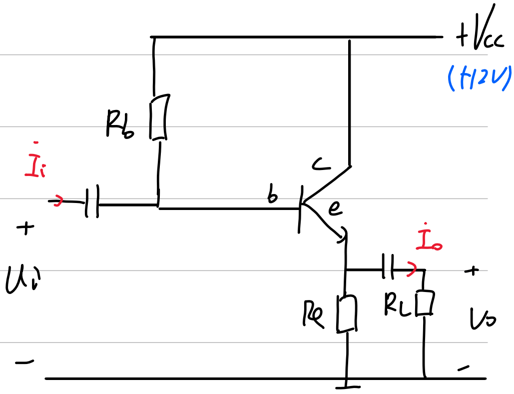
日期:　　/

三极管放大电路补充习题(CC电路)

1. $\beta=100$, $r_{be}=2k\Omega$. $R_b=470k\Omega$. $R_e=3k\Omega$ $R_L=3k\Omega$

①$\dot{A}_u$. R_i　② $\dot{A}_I$　③ $\dot{A}_p$ 功率放大倍数

电流放大倍数



① $\dot{A}_u=+\dfrac{(1+\beta)R_L'}{r_{be}+(1+\beta)\cdot R_L'}=0.987$

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

$=116k\Omega$.

② $\dot{A}_I=\dfrac{\dot{I}_o}{\dot{I}_i}=\dfrac{U_o/R_L}{U_i/R_i}$

$=\dot{A}_u\cdot\dfrac{R_i}{R_L}=39$

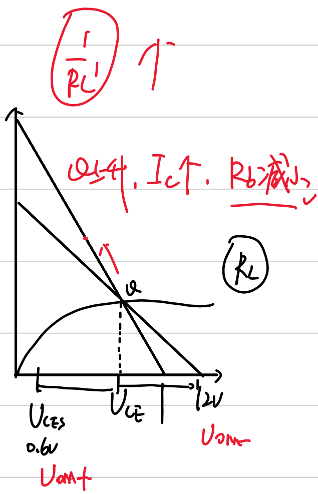
③ $\dot{A}_p=\dot{A}_u\cdot\dot{A}_I=38$

2. $\beta=110$. $U_{BE}=0.7V$ $U_{CES}=0.6V$, $R_e=2k\Omega$

调节R_b使输出电压的正.反跟踪范围相等.

①求R_b. I_c. U_{CE}　②加R_L后. 跟踪范围有何变化!

③为了使正.负跟踪范围仍相等，R_B应如何调整



①. $U_{CE}=\dfrac{U_{CES}+V_{cc}}{2}=6.3V$

$I_c=\dfrac{V_{cc}-U_{CE}}{R_e}=1.9mA$　$I_B=\dfrac{I_e}{1+\beta}$

$V_{cc}=I_B\cdot R_b+U_{BE}+(1+\beta)\cdot I_B\cdot R_e \Rightarrow R_b=327k\Omega$

② 输出正相不变. 输出反相减小

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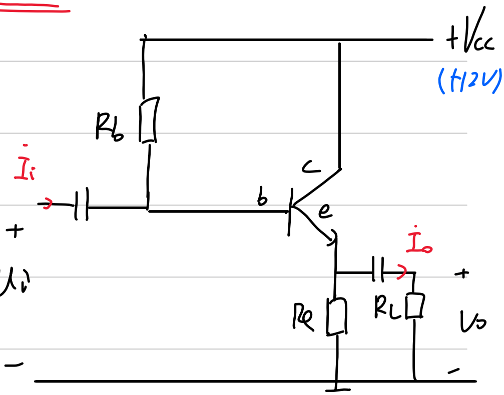
3. $\beta=90$. $U_{BE}=0.7V$. $U_{CES}=0$

①若 $I_c=2mA$. 使得 $U_{om+}=U_{om-}$. 求R_b和R_e

②在上述条件下. 接入R_L. 要求输出电压幅值不小于4V. 求R_{Lmin}

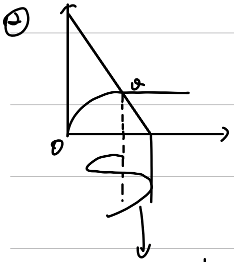


① $U_{CE}=\dfrac{U_{cc}+U_{CES}}{2}=6V$

$U_E=V_{cc}-U_{CE}=6V$ $\quad R_e=\dfrac{U_E}{I_c}=3k\Omega$

$U_B=U_E+U_{BE}=6.7$ $\quad R_b=\dfrac{V_{cc}-U_B}{I_B}=241k\Omega$

②



$R_L'\geq 2k\Omega$

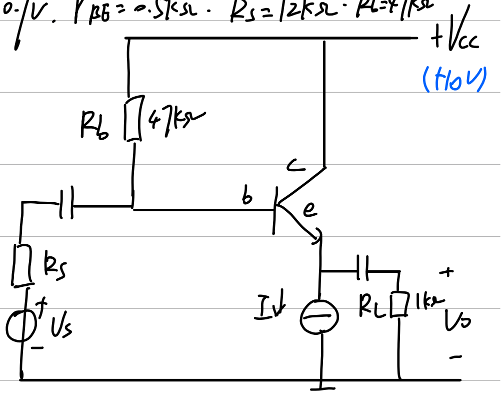
$R_e // R_L \geq 2k\Omega \Rightarrow R_{Lmin}=6k\Omega$

$I_c\cdot R_L'\geq 4V$

4. $I=10mA$. $\beta=90$. $V_{CC}=10V$. $U_{BE}=0.7V$. $r_{BE}=0.5k\Omega$. $R_S=12k\Omega$. $R_L=47k\Omega$

① 求 V_E. ② 求 A_{us}. R_i. R_o

③ 接入 $R_L=1k\Omega$. $U_s=100mV$. 求 $U_o=?$



解: ① $V_E = V_{CC} - \underset{\uparrow \frac{I}{1+\beta}}{I_B} \cdot R_b - U_{BE} = 4.1V$

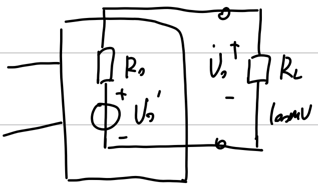
② $\dot{A}_{us} = \dfrac{U_o}{U_s} = A_u \cdot \dfrac{R_i}{R_i+R_s}$

$R_i = R_b // [r_{be}+(1+\beta)\cdot R_e] = R_b = 47k\Omega$

$A_{us} = 1\times\dfrac{47}{47+12} = 0.8$ $R_o = \underset{\downarrow \infty}{R_e} // \dfrac{r_{be}+(R_s//R_b)}{1+\beta} = 111\Omega$

③ 若求得* $A_{us} = \dfrac{U_o}{U_s} = A_u \cdot \dfrac{R_i}{R_i+R_s}$

或用戴维南法:



$U_o' = U_o|_{R_L\to\infty}$

$U_o' = A_{us}\cdot U_s = 0.8\times100 = 80mV$

$\dot{U}_o = U_o' \cdot \dfrac{R_L}{R_o+R_L} = 80mV\times\dfrac{1000}{111+1000} = 72V$

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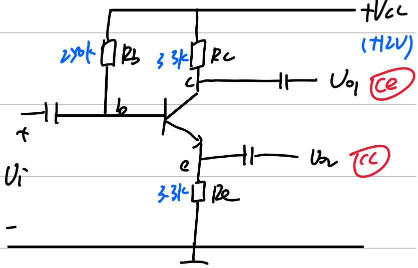
(4)

5. $\beta=120$. $U_{BE}=0.7V$. $V_{CC}=12V$



求: ①Q点 ②画出U_{o1}, U_{o2}的波形

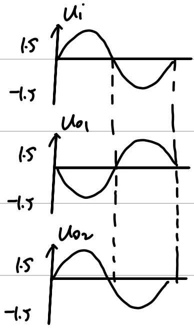
③逐渐增大U_i幅值. U_{o1}, U_{o2}会出现什么失真

U_{o1}—ce—底
U_{o2}—cc—顶 (顶部or底部)

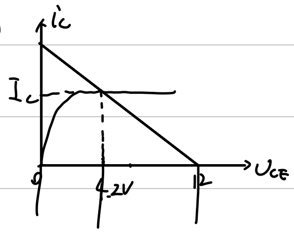
解: ① $I_B=17.4\mu A$ $I_C=\beta\cdot I_B$. $V_{CE}=4.2V$

② $A_{u1}=-\dfrac{\beta\cdot R_C}{r_{be}+(1+\beta)R_e}=-1$

$A_{u2}=\dfrac{(1+\beta)R_e}{r_{be}+(1+\beta)R_e}=+1$



③



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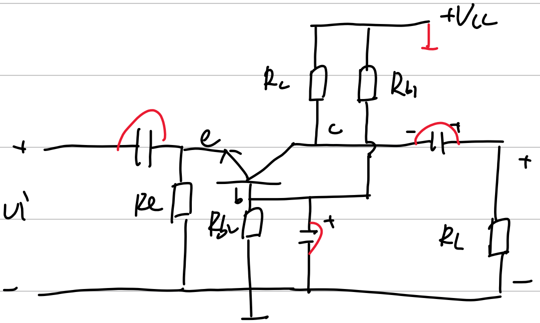
共基极放大电路(cb)



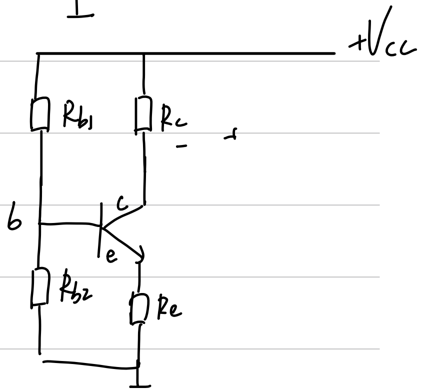
一. 静态分析 (与分压式相似)

$$U_B = \frac{R_{b2}}{R_{b1}+R_{b2}} \cdot V_{CC}$$

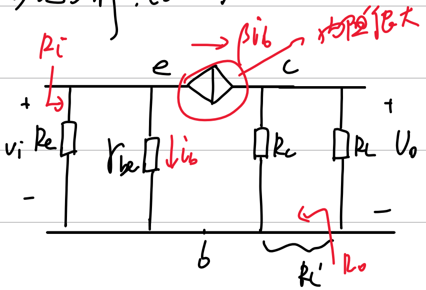
$$U_E = U_B - U_{BE}$$

$$I_C \approx I_E = \frac{U_E}{R_e}$$

$$U_{CE} = V_{CC} - I_C(R_C + R_E)$$



二. 动态分析: (与ce类似)



优点: 高频性能非常好

1. $A_u = \frac{U_o}{U_i} = \frac{\beta i_b \cdot R_L'}{i_b \cdot r_{be}} = + \frac{\beta \cdot R_L'}{r_{be}}$

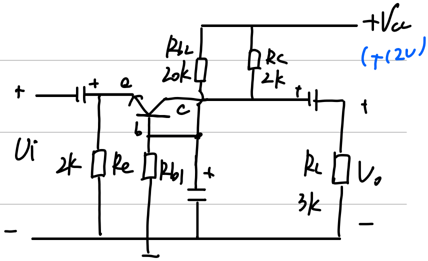
2. $R_i = R_e // \frac{r_{be}}{1+\beta}$ ↓↓ 非常小

3. $R_o = R_c$

日期:　　/

三极管放大电路补充习题（Cb电路）

1. $\beta >> 1$. $U_{BE}=0.6V$. $U_{CES}=0.5V$



<1> 要求 $U_{CE}=4V$, 求 $R_{b1}=?$

<2> 逐渐增大正弦输入电压，输出首先出现什么失真

<3> 在条件1的情况下，最大不失真输出电压有效值是多少

解：<1> $U_B=\frac{R_{b1}}{R_{b1}+R_{b2}}\cdot V_{cc}=U_E+U_{BE}=4.6V$ ⇒ 求得 $R_{b1}=12.4k\Omega$

$I_E=\frac{V_{cc}-U_{CE}}{R_c+R_E}=2mA$　　$I_E\cdot R_e$

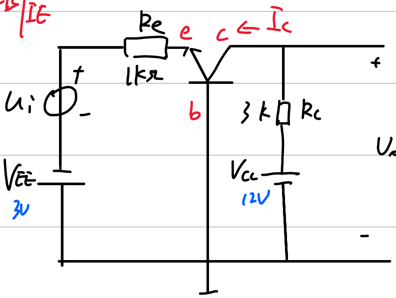
<2> $U_{om+}: I_cR_L'=2mA\cdot 1.2k\Omega=2.4V$ 截止失真（顶部失真）

$U_{om-}=U_{CE}-U_{CES}\approx 4V>2.4V$

AC与DC是同一负载线　无R_L

<3> $U_o=\frac{U_{om}}{\sqrt{2}}=1.7V$

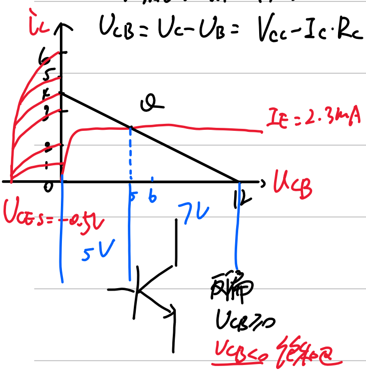
2. $U_{BE}=0.7$. 给出输出特性曲线　$i_c-U_{CB}|_{I_E}$



求：<1> 估算 I_E　<2> 作DC负载线，确定Q，确定 U_{CB}

<3> 随着 U_i 增加，首先会出现什么失真？

$U_{CB}=U_C-U_B=V_{cc}-I_c\cdot R_c=12-3I_c$



<1> $I_E=\frac{-0.7-(-3)}{R_e}=2.3mA$

<2> $U_{CB}=5V$

$K=-\frac{1}{R_L}=-\frac{1}{3}$

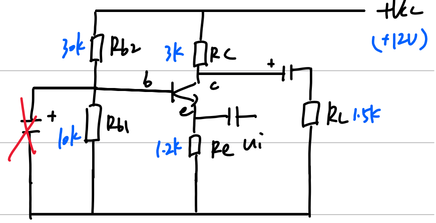
<3> $U_i=5V$ ⇒ 饱和失真

3. $U_{BE}=0.6V$ 特性曲线已知

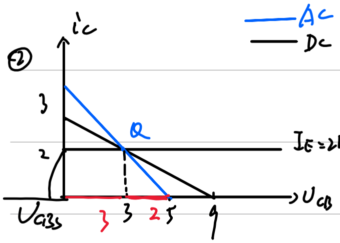
求：① I_E ② 画DC. 确定U_{CB} ③ 画AC. 确定$(U_{om})_{max}$. 判断失真情况

解：① $U_B = \frac{R_{b1}}{R_{b1}+R_{b2}} \cdot V_{cc} = 3V$

$I_E = \frac{V_B - V_{BE}}{R_e} = 2mA$



②



$U_{CB}=3V$

③ $k=-\frac{1}{R_L'}=-1$ $I \cdot R_L' = 2$

$(U_{om})_{max}=2V$ 首先出现截止失真.

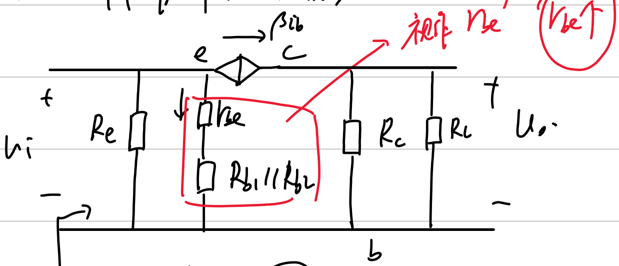
DC. $U_{CB}=U_c-U_B$

$=U_{cc}-I_c R_c-U_B$

$=9-3I_c$

等效电路怎么来？

④ 电容 C_b 断开. $|A_u|$. R_i. R_o 有何变化.



$R_i = R_e // \frac{r_{be}}{1+\beta}$ 变大

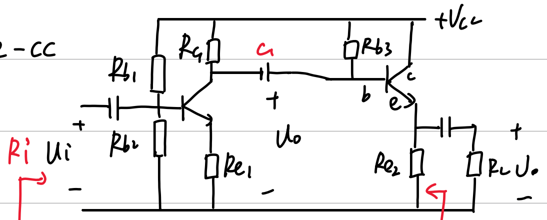
$A_u = +\frac{\beta R_L'}{r_{be}}$ 变小

$R_o = R_c$ 不变

多级放大电路

1. ce-cc

ce-cc



阻容耦合. 两个静态工作点互不影响

有无 C_1 直接耦合: 有良好的低频特性. 易集成

$$A_u = A_{u1}\cdot A_{u2}$$

$$R_i = R_{i1}$$

$$R_o = R_{o2}$$

ce: $A_{u1} = -\dfrac{\beta_1 \cdot R_{L1}'}{r_{be1}+(1+\beta_1)\cdot R_{e1}}$

$$R_{L1}' = R_{c1} // R_L$$

$$= R_{c1} // R_{i2}$$

$$R_{i2} = R_{b3} // [r_{be2} + (1+\beta_2)(R_{e2}//R_L)]$$

cc: $A_{u2} = \dfrac{(1+\beta_2)\cdot R_L'}{r_{be2}+(1+\beta_2)R_L'}$

$$R_L' = R_{e2} // R_L$$

$$R_i = R_{i1} = R_{b1} // R_{b2} // [r_{be1} + (1+\beta_1)\cdot R_{e1}]$$

$$R_o = R_{o2} = R_{e2} // \frac{R_s // R_{b3} + r_{be2}}{1+\beta_2}$$

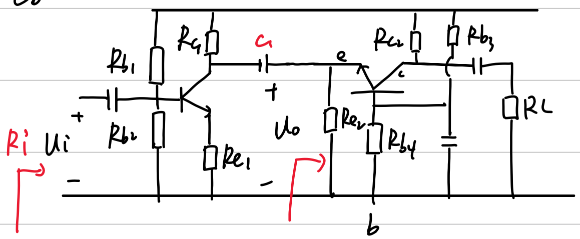
R_s: 信号源内阻.

$R_s = R_{o1}$

$= R_{c1}$

2. ce-cb

ce-cb



$$A_{u1} = -\frac{\beta_1 \cdot R_L'}{r_{be1}+(1+\beta_1)R_{e1}}$$

$$R_L' = R_L // R_{c1} = R_{c1} // R_{i2}.$$

$$R_{i2} = R_{e2} // \frac{r_{be2}}{1+\beta_2}$$

$$A_{u2} = +\frac{\beta_2 \cdot R_L'}{r_{be2}}$$

$$R_L' = R_{c2} // R_L$$

$$A_u = A_{u1} \cdot A_{u2}.$$

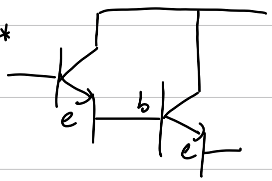
$$R_i = R_{i1} = R_{b1} // R_{b2} // [r_{be} + (1+\beta) \cdot R_{e1}]$$

$$R_o = R_{o2} = R_{c2}$$

3. cc-ce

4. cc-cc *

复合管: b



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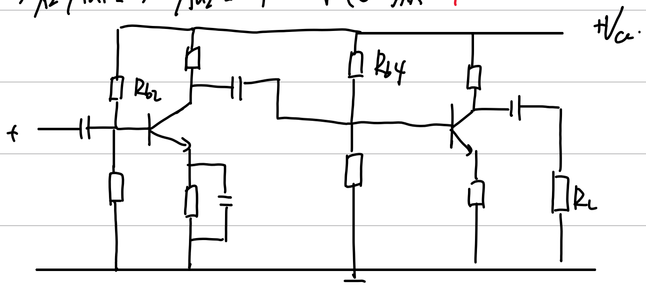
多级放大电路补充习题

1. $I_{C_1}=1mA$. $U_{CE_1}=5V$. $U_{CES}=0.5V$ $R_{L_1}'=1k\Omega$

$I_{C_2}=2mA$. $U_{CE_2}=5.5V$ $U_{CES_2}=0.5V$ $R_{L_2}'=3k\Omega$

<1> 若 $A_{u_1}=-30$. $A_{u_2}=-20$. 求 $(U_{om})_M$ $=5V$

<2> 若 $A_{u_1}=-30$. $A_{u_2}=-4$ 求 $(U_{om})_M$ $=4V$



$U_{om_1}=\min\{\underbrace{U_{CE_1}-U_{CES}}_{4.5V},\ \underbrace{I_{C_1}R_L'}_{1V}\}=1V$

$U_{om_2}=\min\{\underbrace{U_{CE_2}-U_{CES}}_{5V},\ \underbrace{I_{C_2}R_L'}_{6V}\}=5V$

<1> $\frac{5V}{20}<1V$ 第2级引起失真

饱和失真(底部)

<2> $\frac{5V}{4}>1V$ 第1级引起失真

截止失真(顶部)

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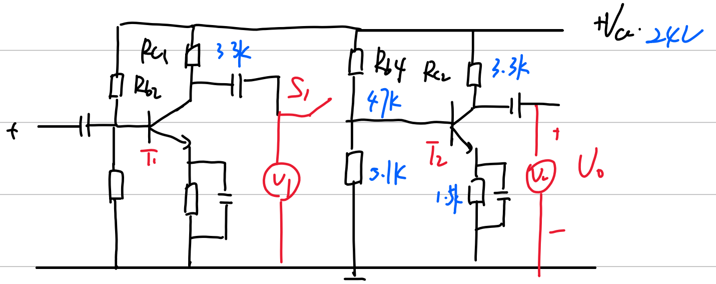
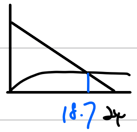
2. $\beta=50$, $r_{bb'}=300\Omega$　S_1断开时 V_1读数为0.05V.

⇒ 问T_2有没有失真、

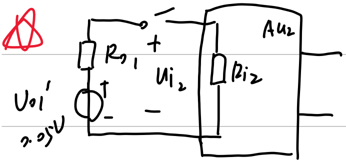
问S_1闭合后, V_2的读数能否用来反映电路的放大能力? 为什么?



$I_{C1}=I_{C2}=1.1mA$　　$U_{CE1}=U_{CE2}=18.7V$　　$r_{be1}=r_{be2}=1.5k$



$(U_{om2})_M = I_{C2}\cdot R_L' \;(\to R_{C2}) = 3.6V$



$R_{i2}=47k//5.1k//1.5k=1.16k$

$R_{o1}=R_{C1}=3.3k$

电压有效值

$|A_{u2}| = \frac{\beta_2 R_{C2}}{r_{be2}} = 110$　　$U_2 = A_{u2}\cdot\frac{R_{i2}}{R_{o1}+R_{i2}}\cdot U_{o1}' = 1.43V$

$(U_2)_m = \sqrt{2}U_2 = 2V < 3.6V$　可以用来反映...

若$V_1=0.1V$ ⇒ $(U_2)_m=4V>3.6V$ 不能反映.—

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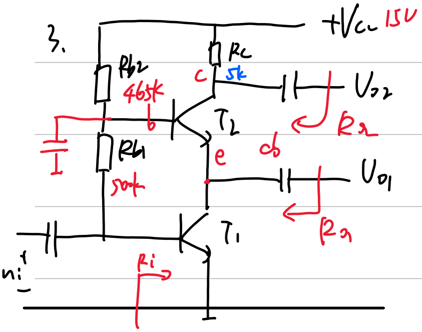
3.



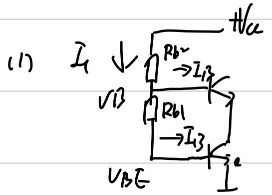
$\beta = 100.\ U_{BE} = 0.7V\ .\ r_{bb_1} = 300\Omega$

求: ① $Q_1 . Q_2$

② $A_{u_1} = \frac{U_{o1}}{U_i}\ .\ A_{u_2} = \frac{U_{o2}}{U_i}$

③ 求 $R_i .\ R_{o1} .\ R_{o2}$

(1)



$I_1 = 2I_B = \frac{V_{cc} - V_B}{R_{b2}}$

$V_B = U_{BE} + I_B \cdot R_{b1}$

$I_B = \frac{V_{cc} - U_{BE}}{2R_{b2} + R_{b1}} = 0.01mA$

$I_{c1} = I_{c2} = \beta \cdot I_B = 1mA$

$U_{CE_1} = I_B \cdot R_{b1} = 5V$ (都加一个 U_{BE})

cb的 R_i

(2) ce: $A_{u_1} = -\beta_1 \cdot \frac{R_L'}{r_{be_1}} = -\beta \frac{\frac{r_{be_2}}{1+\beta_2}}{r_{be_1}} = -1$

$A_u = \frac{U_{o2}}{U_{i2}} = \frac{U_{o1}}{U_{i2}} \cdot \frac{U_{o2}}{U_{o1}} = A_{u_1} \cdot \frac{\beta_2 R_c}{r_{be_2}} = -172$

cb放大倍数

$R_i = R_{b1} // r_{be_1} = 2.7k$　　$r_{be} = 300 + (1+\beta) \cdot \frac{26}{I_D} = 2.9k$

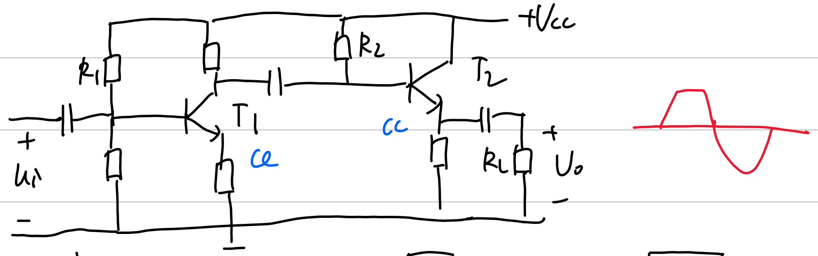
$R_{o1} = \frac{r_{be_2}}{1+\beta_2} = 29\Omega$　　$R_{o2} = R_c = 5k$

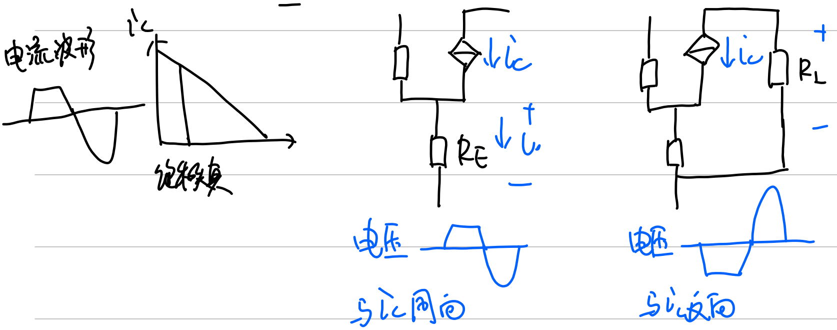
把cb看成一个 $R_c = R_{i2} = \frac{r_{be_2}}{1+\beta_2}$

4. U_o出现顶部失真

<1> 若是第一级引起的，则第一级出现（截止）失真

- - - 二 - - = - - - （饱和）失真



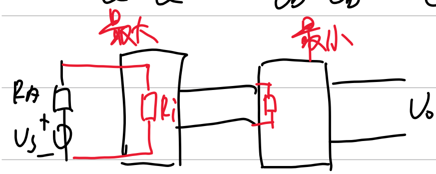


<2> 如何调整 R_1（或R_2）使失真消除？

若是T_1截止失真，（Q偏低→上调，I_B变大，U_B↑，R_1↓）若是T_2饱和失真 ⇒ R_2↑

5. ①判断ce和cb组合的源电压放大倍数的大小，需要考虑输入电阻

ce-ce　　cb-cb　　ce-cb　　cb-ce



R_i↑　U_i↑

$R_i = \frac{r_{be}}{1+\beta}$

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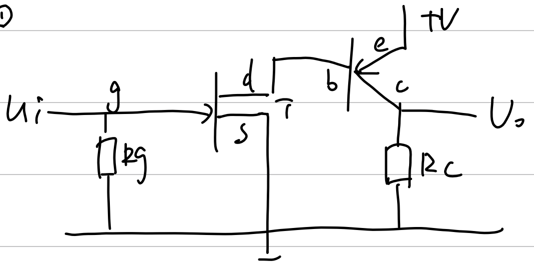
② 判断ce和cc组合的输入电阻和输出电阻的大小

	ce−ce	cc−cc	ce−cc	cc−ce
	小	大	小	中
R_i	小	大	小	中
R_o	大	小	大	中

6. 判断电路的组态 计算 A_u、R_i、R_o (r_{be}、β、g_m 均已知)

①



ce. cc. cb

cs. cd. ×

cs − ce 电路. $A_u = A_{u_1} \cdot A_{u_2}$

$R_i = R_{i_1} = R_g$

$A_{u_1} = -g_m \cdot R_L$

$R_o = R_{o_2} = R_c$

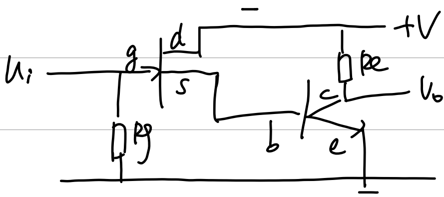
↳ $R_{i_2} = r_{be}$

$A_{u_2} = -\dfrac{\beta \cdot R_c}{r_{be}}$ $A_u = A_{u_1} \cdot A_{u_2} = g_m \cdot \beta \cdot R_c$

$R_L' = R_{i_2} = r_{be}$

② cd − ce 电路:

$A_{u_1} = +\dfrac{g_m \cdot R_L'}{1+g_m R_L'}$ ✓



$A_{u_2} = -\dfrac{\beta \cdot R_c}{r_{be}}$

$A_u = A_{u_1} \cdot A_{u_2}$

$= -\dfrac{\beta \cdot g_m \cdot R_c}{1+g_m \cdot r_{be}}$

$R_i = R_{i_1} = R_g$

$R_o = R_{o_2} = R_c$

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③ CS-CC

$$A_{u_1} = -g_m \cdot R_L' = -g_m \cdot \underbrace{R_d // [r_{be} + (1+\beta) \cdot R_e}_{R_d // R_{i_2}}$$

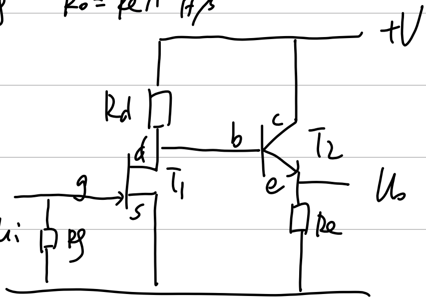
$R_{i_2} = r_{be} + (1+\beta) \cdot R_e$

$$A_{u_2} = \frac{(1+\beta) \cdot R_e}{r_{be} + (1+\beta) \cdot R_e} \qquad A_u = A_{u_1} \cdot A_{u_2}$$

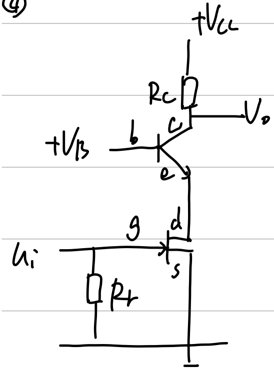
信号源内阻

$$R_i = R_{i_1} = R_g \qquad R_o = R_e // \frac{r_{be} + R_{s_2}}{1+\beta}$$

$R_{s_2} = R_{o_1} = R_d$



④



CS-cb 电路.

$$A_{u_1} = -g_m \cdot R_{L_1}' \qquad R_{i_2} = \frac{r_{be}}{1+\beta}$$

$$= \frac{-g_m \cdot r_{be}}{1+\beta}$$

$$A_{u_2} = + \frac{\beta \cdot R_c}{r_{be}}$$

$$A_u = A_{u_1} \cdot A_{u_2} \doteq -g_m \cdot R_c$$

$$R_i = R_g \qquad R_o = R_c$$

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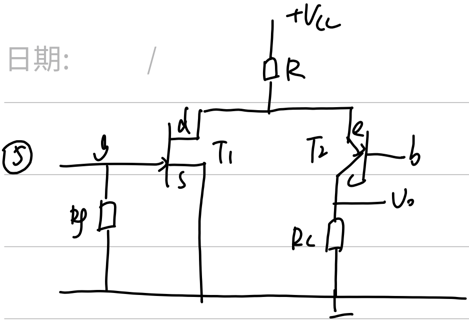
⑤



cs-cb电路

$A_{u_1} = -g_m R_{L}'$　　$R_{L_1}' = R // R_{i_2}$

$= R // \frac{r_{be}}{1+\beta}$

$A_{u_2} = +\frac{\beta \cdot R_C}{r_{be}}$

$A_u = A_{u_1} \cdot A_{u_2}$　　$R_i = R_g$

$R_o = R_C$

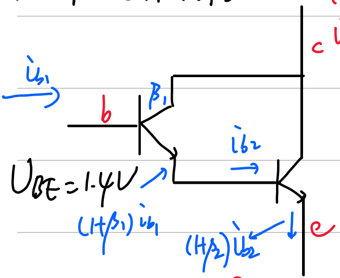
复合管(达林顿管)

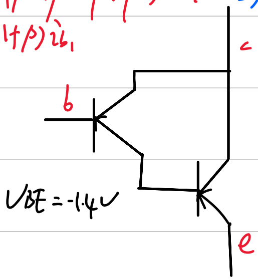
$i_e = (1+\beta_1+\beta_2+\beta_1 \cdot \beta_2) \cdot i_{b_1}$

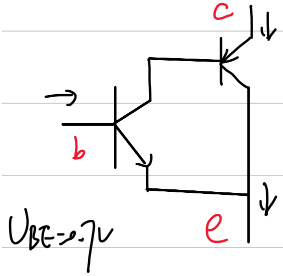
$i_e = (1+\beta) i_{b_1}$

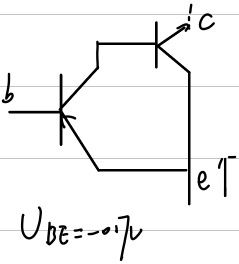
$\Rightarrow^{*} \beta = \beta_1 + \beta_2 + \beta_1 \cdot \beta_2$

$\approx \beta_1 \cdot \beta_2$ (β很大)



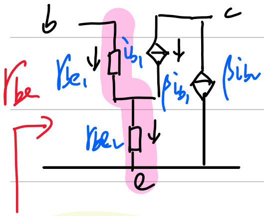






不同类型管子复合可

以减小温度所带来的影响



两个同类型

$r_{be} = r_{be_1} + (1+\beta) \cdot r_{be_2}$

两个不同类型: $r_{be} = r_{be_1}$

同类型相当于有2个PN结

不同 - - 1个PN结

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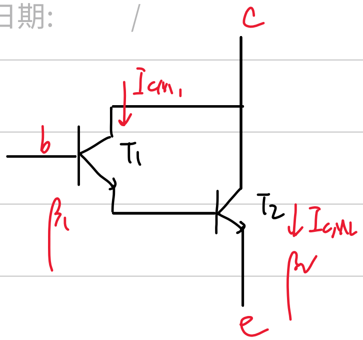


β. I_{CM}. P_{CM} $U_{(BR)CEO}$.

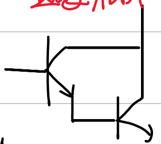
击穿电压

相近的两个管子：$\beta_1 \cdot \beta_2$. I_{CM_2}. P_{CM_2} $\min\{U_{BR_1}, U_{BR_2}\}$

相差较大的两个管子：

	β	I_{CM}	P_{CM}	$U_{(BR)CEO}$
T_1	60	0.2A	0.5W	80V
T_2	80	15A	50W	100V
复合管	4800	15A	40W	80V → 直接取小

直接相乘



$0.2\times80=16A$　　$16A>15A$　　$80\times0.2=40W$　　$40W<50W$

$\min\{I_{CM_2}, I_{CM_1}\cdot\beta_2\}$　　$\min\{P_{CM_2}, P_{CM_1}\cdot\beta_2\}$

$\parallel$

I_{CM}

① $I_G=0$ ② I_D 公式

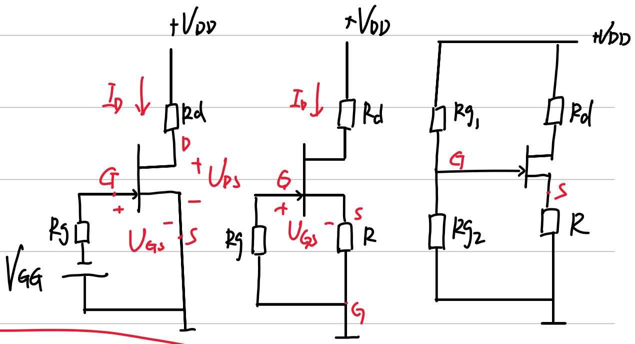
FET放大电路

共源放大电路(CS)

一、直流偏置电路

1. 固定偏置电路
2. 自偏压电路 → 适用于耗尽型
3. 分压式电路

输入回无电流



二、工作点的计算

1. 估算
2. 图解法

固定偏置电路:

$$\begin{cases} V_{GS} = -V_{GG} \\ I_D = I_{DSS}\left(1-\frac{V_{GS}}{V_P}\right)^2 \end{cases}$$

I_{DSS}:最大饱和电流　V_P:夹断电压

代入 → $U_{DS} = U_{DD} - I_D R_d$

增强型: $I_D = I_{DSS}\left(\frac{V_{GS}}{V_P}-1\right)^2$

自偏压电路:

$$\begin{cases} V_{GS} = -I_D \cdot R \\ I_D = I_{DSS}\left(1-\frac{V_{GS}}{V_P}\right)^2 \end{cases}$$

解得 I_D 和 V_{GS}

$U_{DS} = U_{DD} - I_D(R_d+R)$

分压式电路:

$U_G = V_{GG} \cdot \frac{R_{g2}}{R_{g1}+R_{g2}}$

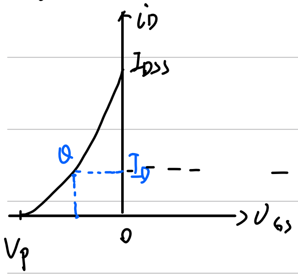
$U_S = I_D \cdot R$

$$\begin{cases} U_{GS} = U_G - U_S \\ I_D = I_{DSS}\left(1-\frac{U_{GS}}{U_P}\right)^2 \end{cases}$$

$U_{DS} = U_{DD} - I_D(R_d+R)$

图1.

转移特性曲线



输出特性曲线:

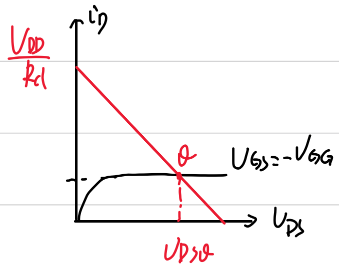
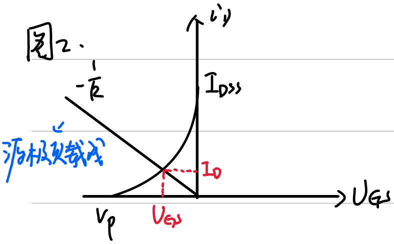


图2.



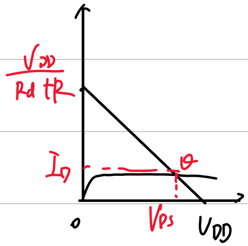
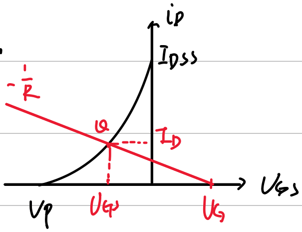
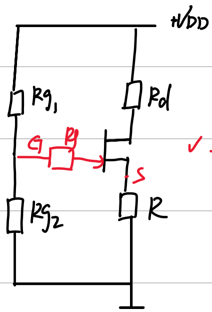


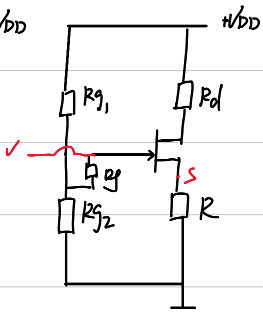
图3.



$$U_{GS} = U_G - U_S = U_G - I_D R$$



对Q点无影响

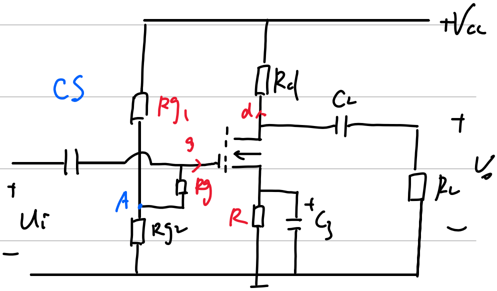


对Q点无影响

日期: /

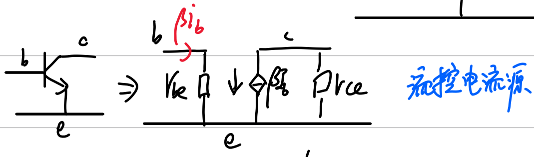
g: 栅极 s: 源极 d: 漏极

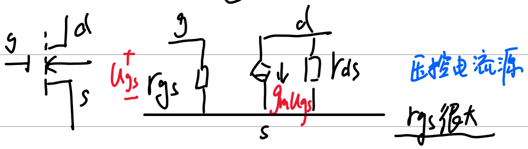
共源放大电路的小信号模型

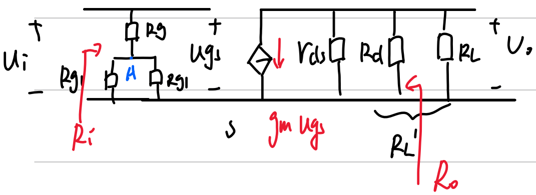


一. FET的交流小信号模型

二. CS放大电路的交流小信号模型







三. 动态参数计算

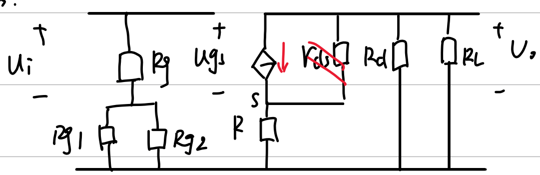
1. $\dot{A}_u = \frac{U_o}{U_i} = -\frac{R_L'\cdot g_m\cdot U_{gs}}{U_{gs}} = -g_m\cdot R_L'$

2. $R_i = R_g + (R_{g1}//R_{g2})$

3. $R_o = R_d // r_{ds} \approx R_d$

$\dot{A}_u = \frac{U_o}{U_i} = \frac{-g_m\cdot U_{gs}\cdot R_L'}{U_{gs}+g_m U_{gs}\cdot R} = \frac{-g_m\cdot R_L'}{1+g_m R}$

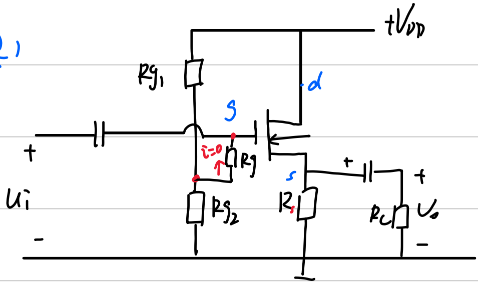
若去掉Cs:



(作为输出电阻不够理想)

共漏放大电路 (cd)

一、电路结构



二、静态分析

$$V_G = \frac{R_{g2}}{R_{g1}+R_{g2}} V_{DD}$$

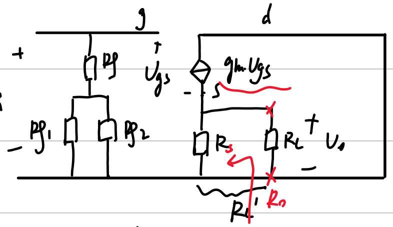
$$U_S = I_D R$$

$$\begin{cases} U_{GS} = V_G - V_S \\ I_D = I_{DSS}\left(1-\frac{V_{GS}}{V_P}\right)^2 \end{cases}$$ (解方程)

$$V_{DS} = V_{DD} - I_D \cdot R$$

三、动态分析

1. 等效电路



2. $\dot{A}_u = \frac{\dot{U}_o}{\dot{U}_i} = \frac{R_L' \cdot g_m \cdot U_{gs}}{U_{gs} + R_L' \cdot g_m \cdot U_{gs}} = +\frac{g_m \cdot R_L'}{1 + g_m \cdot R_L'} < 1$

3. $R_i = R_g + (R_{g1} // R_{g2})$

4. $R_o = R_s // \frac{1}{g_m}$

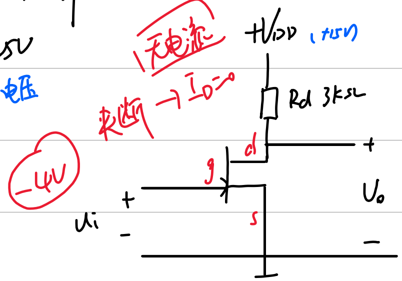
日期:　　　/

场效应管两种问题

1. $U_{GS(off)}=-4V$. $|U_{(BR)GD}|=25V$ 击穿电压

U_i: 0 ~ -4V 之间变化.

求 V_{DD} 最大值?



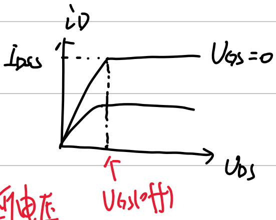
$U_{GD}=U_{GS}-U_{DS}=U_i-V_{DD}$

$25=\underset{-4}{U_i}-V_{DD}$ 　$V_{DD}=21V$.

2. 当 V_{DD}↑时, Rd 两端电压↑

当 $V_{DD}>12V$ 后 Rd 两端电压固定为12V

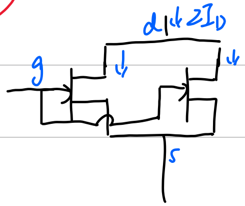
试求 I_{DSS} 和 $U_{GS(off)}$



饱和 $I_{DSS}=\frac{V_{DD}}{R_d}=\frac{12V}{3k\Omega}=4mA$ 　夹断电压

$U_{GD}=U_{GS}-U_{DS}=0-(V_{DD}-I_{DSS}\cdot R_d)=-3V$ 　$U_{GS(off)}=-3V$

3.

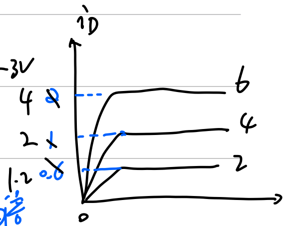


两个场效应管并联.

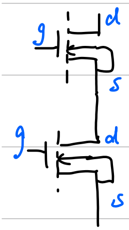
$U_{GS(off)}$ 不变

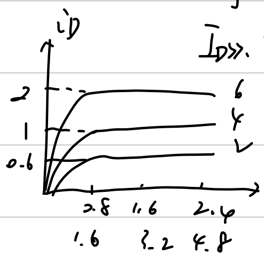
I_{DSS}↑. g_m↑ 如何变化

原来的两倍



两个场效应管串联



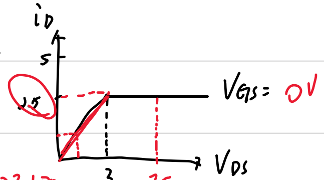


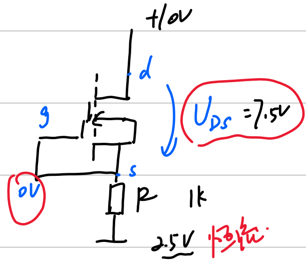
I_{DSS}. g_m 不变.

$U_{GS(off)}$ 变为原来两倍

日期: /

4.





① R=1kΩ 工作在恒流区　　假设工作在恒流区

② R=10kΩ 工作在可变电阻区　　$10V\cdot\frac{10}{10+1.2}=$

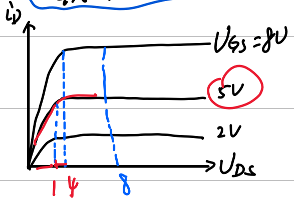
5. 增强型N沟道

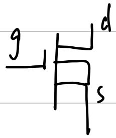
$V_{GS(th)}=4V$ ✓

$V_{GS}=V_{GS(off)}=V_{GS}-V_{DS}=4V$

状态	1	2	3	4
U_{GS}/V	2	5	8	8
U_{DS}/V	10	3	3	8
工作区	截止	恒流	可变电阻区	恒流

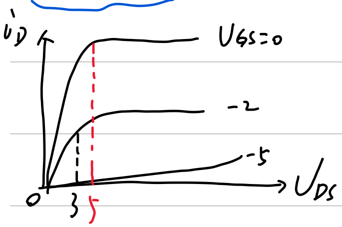
首先要大于开启电压
⇒ 否则截止





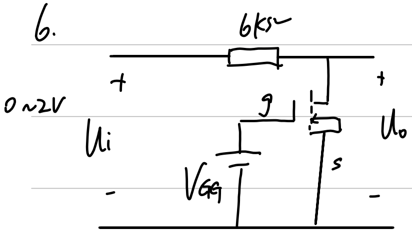
N沟道. 结型

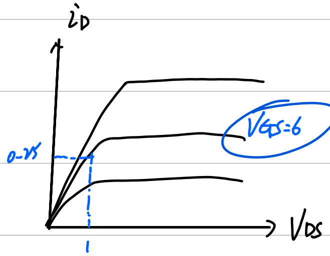
$V_{GS(off)}=-5V$



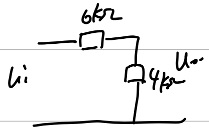
状态	1	2	3	4
U_{GS}/V	0	-2	-2	-6
U_{DS}/V	4	4	2	10
工作区	可变电阻区	恒流	可变电阻区	截止

6.





$\frac{u_o}{u_i}=0.4$　　问 $V_{GG}=?$ 1



看成两个电阻分压

满足可变电阻区的曲线

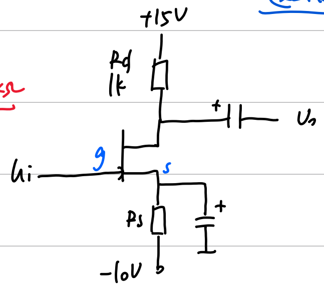
选出曲线

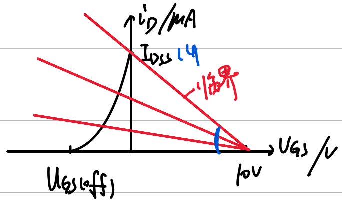
7. $I_{DSS}=4mA$　　$U_{GS(off)}=-2V$.

问：R_s的值是否有限制？　$R_s>2.5k\Omega$

若有限制，R_s的合理范围是多少

$$i_D=I_{DSS}\left(1-\frac{V_{GS}}{V_{GS(off)}}\right)^2$$





$V_{GS}+I_DR_s=10V$

$I_D=-\frac{1}{R_s}V_{GS}+\frac{10}{R_s}$

$-2<U_{GS}<0$

$-\frac{1}{R_s}=-\frac{4}{10}$　　∴ $R_s=2.5k\Omega$

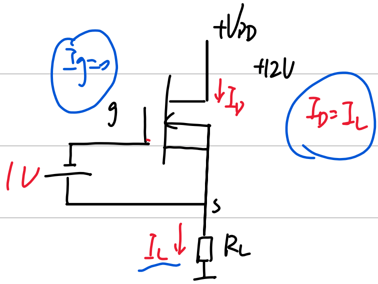
R_s大 斜率小

日期: /

8. $I_{DSS}=4mA$ $V_{GS(off)}=-2V$.

① $I_L=?$

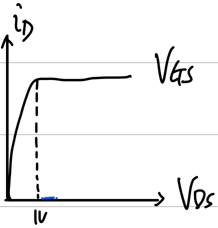
② R_L在什么范围 I_L恒定 恒流区



① $I_D=I_{DSS}\left(1-\frac{V_{GS}}{V_{GS(off)}}\right)^2$ 已知 $V_{GS}=-1V$

$=4\times0.5^2=1mA$

②

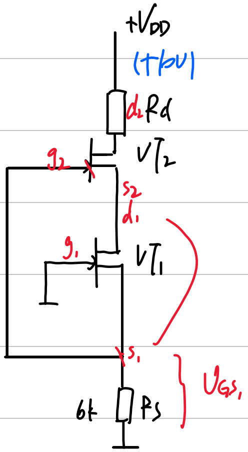


$V_{DS}>V_{GS}-V_{GS(off)}$ $V_{DS}>-1-(-2)=1V$

$V_{DD}=V_{DS}+I_L\cdot R_L$ (I_L = 1mA) $R_L\le 11k\Omega$.

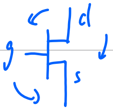
9. $V_{GS(off)}=-2V$

$I_{DSS}=4mA$



$U_{DG1}=U_{DG2}=1.5|U_{GS(off)}|$

求Rs. Rd



$i_{D1}=i_{D2}\Rightarrow U_{GS1}=U_{GS2}$

$i_D=i_{DSS}\left(1-\frac{V_{GS}}{V_{GS(off)}}\right)^2$

$U_{DS}=V_{DG}+V_{GS1}$.

$V_{DG1}=V_{DS1}-V_{GS1}=-2V_{GS2}\Rightarrow V_{GS2}=-1.5V$ (V_{DS1} = $-V_{GS2}$)

$R_s=-\frac{V_{GS1}}{I_{D1}}=6k\Omega$

$V_{DD}=R_d\cdot I_D+V_{DG}+I_D R_s$

$\Rightarrow R_d=22k$

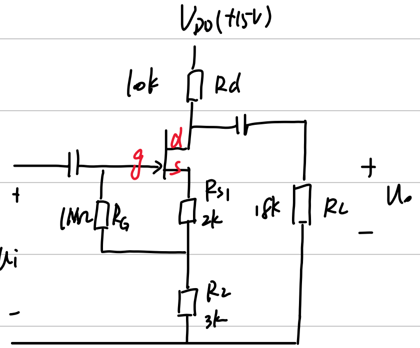
日期:　　　/

10. $g_m = 2mS$　$r_{ds} \to \infty$

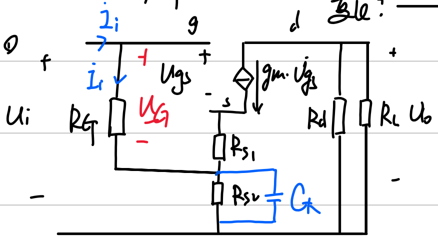
① 画等效电路

② 求 $\dot{A}_u$、R_i、R_o

③ 若在 R_{s2} 两端并联一个大电容，参数如何变化？



解 ①



相当于 $R_{s2}=0$

$\dot{A}_u \uparrow$　$R_i \downarrow$　$R_o = R_d$ 不变

$$\dot{A}_u = \frac{\dot{U}_o}{\dot{U}_i} = \frac{-g_m U_{gs} (R_d // R_L)}{U_{gs} + g_m U_{gs}(R_{s1}+R_{s2})} \uparrow$$

$$\dot{I}_i = \frac{U_{gs} + g_m U_{gs} \cdot R_{s1}}{R_G}$$

$$R_i = \frac{\dot{U}_i}{\dot{I}_i} = \frac{1+g_m(R_{s1}+R_{s2})}{1+g_m \cdot R_{s1}} R_G$$

用定义做

$= 22.2M\Omega$

$R_o = R_d$

(与 R_G 是存在比例关系)

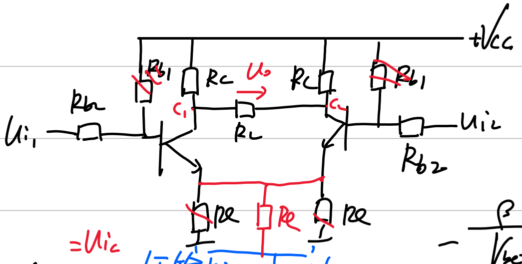
日期:　　/

零点漂移的抑制(差分式结构)

温漂

一、基本电路

对称



二、信号输入的形式

① 共模输入　$u_{i1}=u_{i2}$ $=u_{ic}$　(无输出)　⊥ → Rb1可不要

② 差模输入　$u_{i1}=-u_{i2}$ $=u_{id}$　(有输出)

$$-\frac{\beta\cdot R_L'}{r_{be}+(1+\beta)\cdot \cancel{r_e}}$$ — 共模的 差模的

⇓

$U_{CE}\downarrow$ → 趋于饱和

③ 任意输入　$u_{i1}=8mV$　$8=5+3$　差模

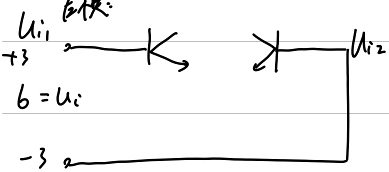
(比较)　$u_{i2}=2mV$　$8=5-3$　共模

①、②的叠加

$u_{i1}=u_{ic}+\frac{u_{id}}{2}$

$u_{i2}=u_{ic}-\frac{u_{id}}{2}$

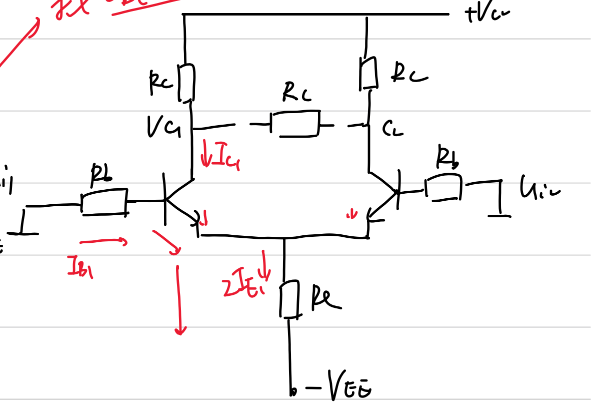
差模:



共模:

日期: /

找 U_{BE} 的通路



基本差分放大电路

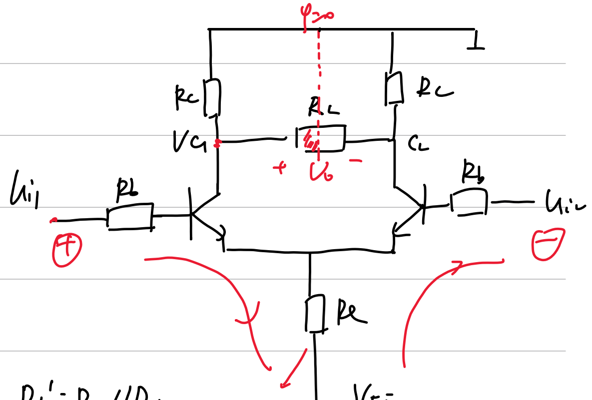
一. 静态分析

$$I_{B1}R_b + 0.7 + 2(1+\beta) I_{B}\cdot R_e = V_{EE}$$

$$I_{B1} = \frac{V_{EE} - 0.7}{R_b + (1+\beta)2R_e}$$

$$I_{C1} = \beta \cdot I_{B1}$$

$$V_{C1} = V_{CC} - I_{C1}\cdot R_C$$

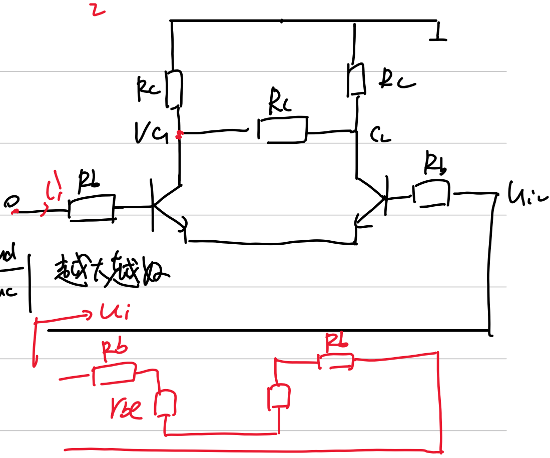


二. 动态分析

1. 差模电压放大倍数 A_{ud}

$$A_{ud} = \frac{U_o}{U_{id}} = \frac{U_o}{U_{i1} - U_{i2}} = \frac{2V_{C1}}{2U_{i1}} = \frac{V_{C1}}{U_{i1}} = -\frac{\beta \cdot R_L'}{R_b + r_{be}}$$

$$R_L' = R_C // \frac{R_L}{2}$$



2. 共模电压放大倍数 A_{uc}

$$A_{uc} = \frac{U_o}{U_{ic}} = \frac{U_{C1} - U_{C2}}{U_{ic}} = 0$$

3. 共模抑制比 $K_{CMR} = \left| \frac{A_{ud}}{A_{uc}} \right|$ 越大越好

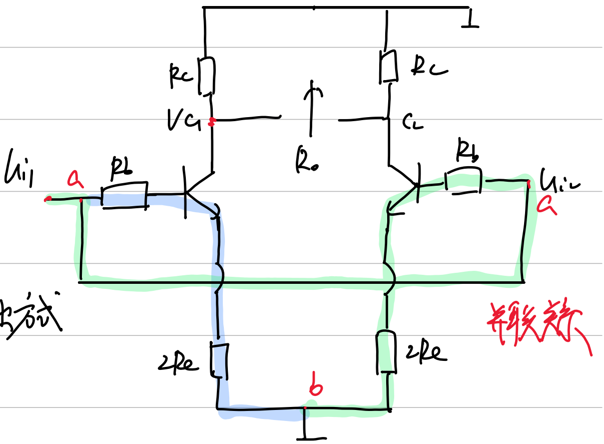
4. 差模输入电阻 $R_{id} = 2(R_b + r_{be})$

与 R_e 无关

日期:　　/

5. 共模输入电阻　$R_{ic} = \frac{1}{2}[R_b + r_{be} + (1+\beta)\cdot 2R_e]$

6. 输出电阻　$R_o = 2R_c$



差分放大电路的输入/输出方式

一、双端输入/双端输出

二、单端输入/双端输出

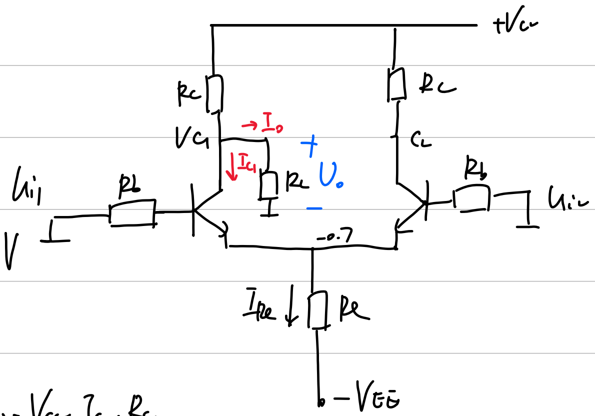
$u_i = \frac{u_i}{2} + \frac{u_i}{2}$　　差模和共模的叠加

$0 = \frac{u_i}{2} - \frac{u_i}{2}$

三、双端输入/单端输出

四、单端输入/单端输出

单出情况分析：



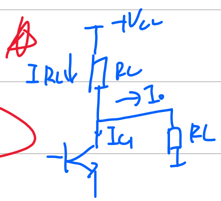
1. 静态分析.

$I_{Re} = \frac{V_{EE}-0.7}{R_e}$　　　$V_{C2} = V_{CC} - I_{C2}\cdot R_c$

$I_{C1} = I_{C2} = \frac{1}{2} I_{Re}$　　　$I_{Rc} = I_{C1} + I_o$

$$\frac{V_{CC}-V_{C1}}{R_c} = I_{C1} + \frac{V_{C1}}{R_L}$$

结论　⇒ 解出 V_{C1}



2.动态分析: 一正负

① $A_{ud单}=\frac{\pm U_o}{U_{id}}=\frac{U_{c1}}{u_{i1}-u_{i2}}=\frac{U_{c1}}{2U_{i1}}=\frac{1}{2}\cdot\frac{\beta\cdot R_L'}{r_{be}+R_b}$　($R_L'=R_C//R_L$)

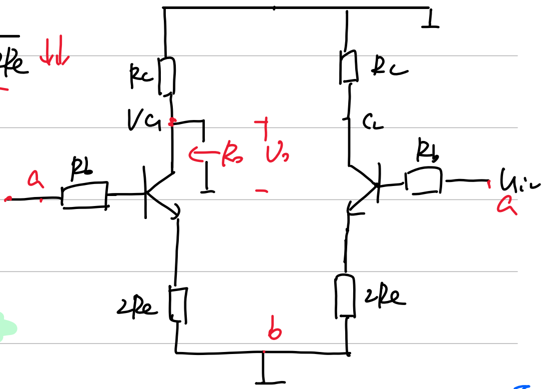
② $A_{uc单}=-\frac{\beta\cdot R_L'}{r_{be}+R_b+(1+\beta)\cdot 2R_e}$ ↓↓

③ 共模抑制比

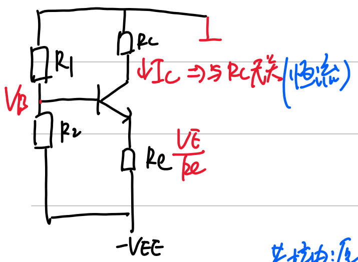
$K_{CMR}=\left|\frac{A_{ud}}{A_{uc}}\right|$

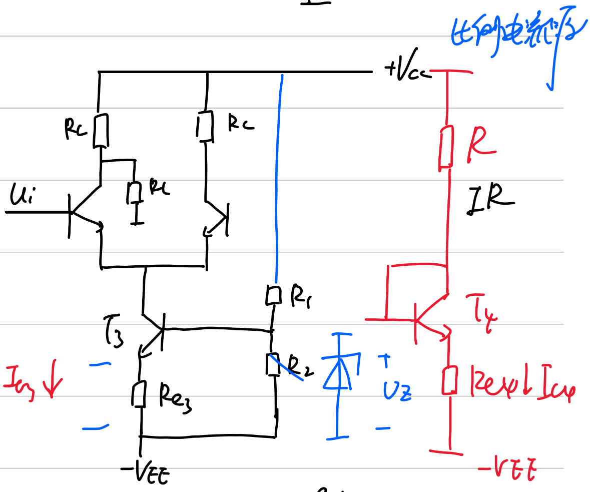
④ 输入电阻 同双出

⑤ 输出电阻 $R_{o单}$　　$R_{o单}=R_c$



带恒流源的差分放大电路





$U_{R2}=\frac{R_2}{R_1+R_2}(V_{EE}+V_{CC})$ 若接电源

$U_{Re3}=U_{R2}-0.7$　　$I_{C1}=I_{C2}=\frac{1}{2}I_{Re3}$

$I_{Re3}=\frac{U_{Re3}}{R_{e3}}$

$r_o=r_{e3}\left(1+\frac{\beta\cdot R_{e3}}{R_{e3}+r_{be}+(R_1//R_2)}\right)$ 很大

$I_R=\frac{V_{CC}+V_{EE}-0.7}{R+R_{e4}}$

$\frac{I_{C3}}{I_{C4}}=\frac{R_{e4}}{R_{e3}}$

FET差分放大电路

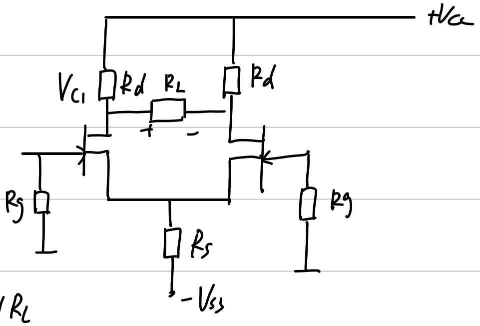
$A_{ud} = \pm g_m \cdot R_L'$

↳ $R_L' = R_d // \frac{1}{2}R_L$

$A_{uc} = 0$

$A_{ud单} = \pm \frac{1}{2} \cdot g_m \cdot R_L'$

↳ $R_L' = R_d // R_L$



$$A_{uc} = -\frac{g_m \cdot R_L'}{1 + g_m \cdot 2R_s}$$

动态范围较小 $V_T = 26mV$

$R_i = R_g$

CS

优点：输入电阻比较大

$R_o = 2R_d$ (双出)

$= R_d$ (单出)

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1. 恒流源差分放大电路.

（A: 增大 . B: 减小 . C. 不变或基本不变）

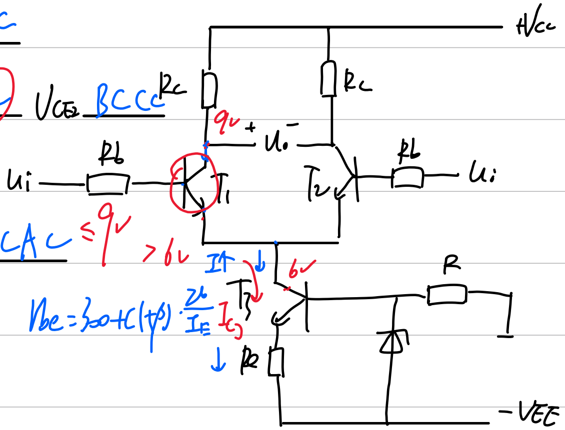
<1> 电源电压减小 <2> R_b 减小 <3> R_c 增大 <4> R_L 增大

静态电流 I_{C1} <u>CACC</u>

静态电压 U_{CE1} <u>BBBC</u> U_{CE2} <u>BCCC</u>

A_{ud} <u>CAAB</u>

R_{id} <u>CBCA</u> R_o <u>CCAC</u>



$$\frac{\beta \cdot R_L}{r_{be}}$$

$$r_{be} = 300 + (1+\beta)\cdot\frac{26}{I_E}$$

2. 判断题

<1> 差模输入时, I_{C3} 恒定. 而共模输入时 I_{C3} 会随信号而改变（ X ）

<2> 双端输入时. I_{C3} 恒定. 而单端输入时. I_{C3} 不再恒定（ X ）

<3> 对于差模输入, T_3 没有负反馈作用. 而共模输入. T_3 有负反馈作用（ ✓ ）

$$A_{ud} = \pm\frac{1}{2}\frac{\beta \cdot R_L}{R_b + r_{be}}$$

$$A_{uc} = -\frac{\beta \cdot R_L}{R_b + r_{be} + (1+\beta)\cdot 2R_e}$$ → 负反馈

<4> 该电路允许的负向最大共模输入电压受 T_3 饱和限制（ ✓ ）

<5> . . . . - - 正向 、 . . . T_1, T_2 （ ✓ ）

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7.

差分放大电路的补充习题 双入单出

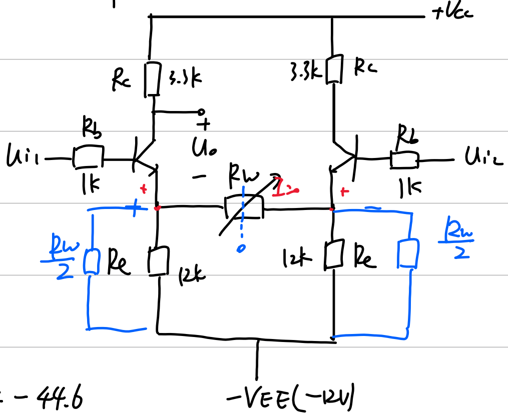
1. 已知 $\beta=100$, $r_{be}=2.7k$

$U_{i1}=2.03V$ $U_{i2}=2.05V$

① $R_w=0$ 时，$U_o=?$

② $R_w=470\Omega$ $U_o=?$

$R_{id}=?$ $R_{ic}=?$



解：① $A_{ud单}=-\frac{1}{2}\frac{\beta R_c}{R_b+r_{be}}=-44.6$

$A_{uc}=-\frac{\beta R_c}{R_b+r_{be}+(1+\beta)\cdot R_e}=-0.27$

$U_o=A_{ud单}\cdot U_{id}+A_{uc}\cdot U_{ic}=0.34V$

差值 $U_{i1}-U_{i2}=-0.02$ 均值：2.04

共模时，Rw上无电流

差模时，Rw上有电流

② $A_{ud}=-\frac{1}{2}\frac{\beta R_c}{R_b+r_{be}+(1+\beta)\cdot(R_e//\frac{R_w}{2})}=-6.1$

$A_{uc}=-0.27$（同上）

$U_o=A_{ud单}\cdot U_{id}+A_{uc}\cdot U_{ic}=-0.43V$

总结：Rw对静态、共模不起作用

只仅对差模有影响。

$R_{id}=2[R_b+r_{be}+(1+\beta)\cdot(R_e//\frac{R_w}{2})]$

$R_{ic}=\frac{1}{2}(R_b+r_{be}+(1+\beta)\cdot R_e)$

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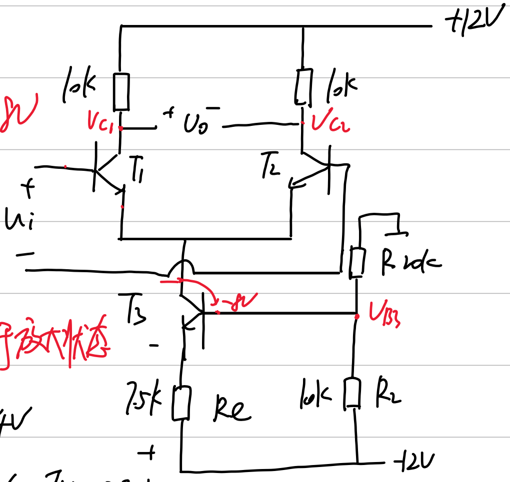
2 $V_{BE}=0.7V$

① 求静态 V_{C1}、V_{C2}、V_{B3}. $=9.8V$ $=-8V$

②求电路允许的输入最大共模电压范围?

⇒ 保证 T_1/T_2 都处于放大状态



解: ① $V_{R_2}=\frac{R_2}{R_1+R_2}\cdot V_{EE}=4V$

$V_{Re}=V_{R_2}-U_{BE}=4V-0.7V=3.3V$

$I_{Re}=\frac{3.3V}{7.5}=0.44A=I_{C3}$

$I_{C1}=I_{C2}=\frac{1}{2}I_{C3}=0.22A$

$U_{C1}=V_{C2}=12-10k\cdot0.02=9.8V$ $U_{B3}=-8V$

② 保证 T_1/T_2 处于放大状态 $u_{imax}<V_{C1}=9.8V$

- - - T_3 - - - - - $V_{C3}>V_{B3}=-8V$

$u_{imin}-0.7V>-8V$

$u_i>-7.3V$ u_i 范围即为 $-7.3V\sim9.8V$

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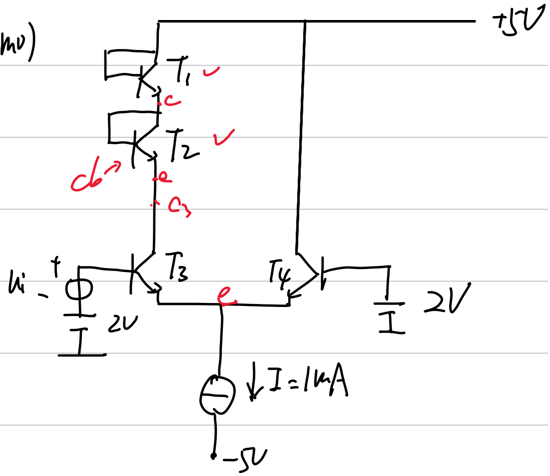
3. β非常大. $U_i = 10\sin\omega t\,(mV)$

画出 U_E. U_{C_3} 的交流波形



① $U_e = \frac{1}{2}U_i = 5\sin\omega t\,(mV)$

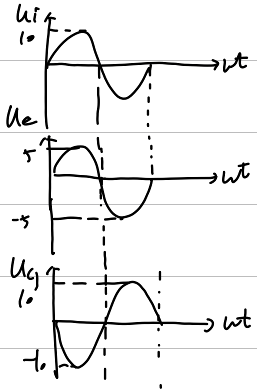
② $U_{C_3} = A_{ud单} \cdot U_i$

$A_{ud单} = -\frac{1}{2}\frac{\beta \cdot R_C}{r_{be}}$

$= -\frac{1}{2} \cdot \frac{\beta}{r_{be}} \cdot \frac{r_{be}}{1+\beta} \times 2$

$= -1$

$\underline{U_{C_3} = -U_i}$



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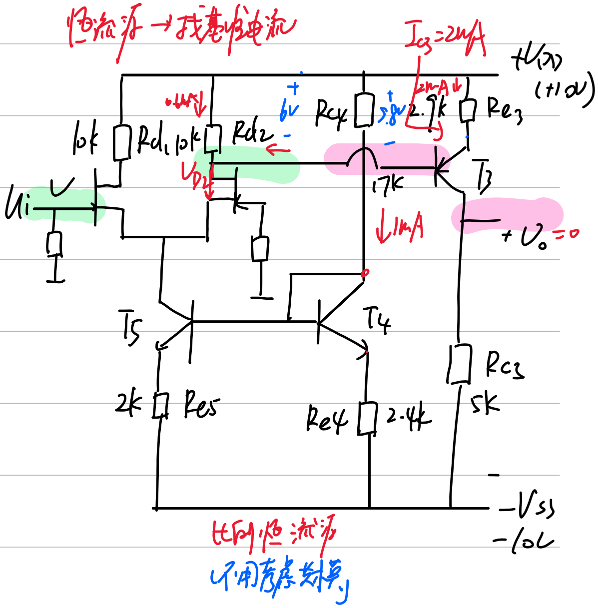
4. $g_m = 2mA/V$

$\beta = 100.\ r_{bb'} = 300\Omega$

$V_{BE} = 0.6V.\ V_{BE_3} = -0.2$

求各管的静态电流 I_{C5} 及 U_{D2}, U_6

② 总的放大倍数 $A_u = \frac{U_o}{U_i}$



解: ① $I_{C4} = \frac{10+10-0.6}{R_{C4}+R_{e4}} = 1mA$

$R_{e5} I_{C5} = R_{e4} I_{C4}$

$I_{C5} = 1.2mA$

$I_{D1} = I_{D2} = \frac{1}{2} I_{C5} = 0.6mA$

② $A_u = \frac{U_o}{U_i}$

$A_{u1} = +\frac{1}{2} \cdot g_m \cdot R_L' = 10$

$R_L' = R_d // R_{i2}$

$R_{i2(ce)} = r_{be3} + (1+\beta_2) R_{e3}$

$A_{u2} = -\frac{\beta \cdot R_{e3}}{r_{be3} + (1+\beta_3) \cdot R_{e3}}$

$A_u = A_{u1} \cdot A_{u2}$

③ $R_i = R_g$ (场效应管)

④ $R_o = R_{C3}$

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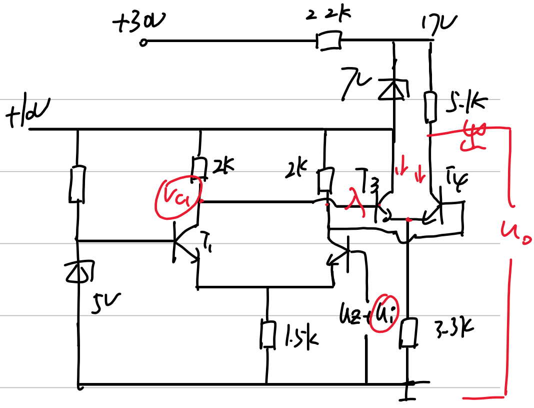

5. $\beta=50$, $r_{be1}=r_{be2}=1.23k$

$r_{be3}=r_{be4}=1.65k$

① 求Q点

② A_{ud} ③ R_{id}, R_o

解: ① $I_{C1}=I_{C2}=\frac{1}{2}I_e=\frac{1}{2}\cdot\frac{5-0.7}{1.5k}=1.43mA$　　$V_{C3}=10V$　　$V_{C4}=7+10-5.1\times0.98$

$=12V$

$V_{C1}=V_{CC}-I_C\cdot R_C=10-1.43\times2=7.14V$

$V_{E34}=7.14-0.7=6.44V$

$I_{C3}=I_{C4}=\frac{1}{2}\cdot\frac{6.44V}{3.3}=0.98mA$

② $A_{ud1}=\frac{u_{c1}}{u_i}=\frac{\beta\cdot(R_{c1}//\frac{1}{2}R_{i2})}{r_{be1}}=\frac{\beta(R_{c1}//\frac{1}{2}\cdot 2r_{be})}{r_{be1}}=36.7$

$A_{ud2单}=\frac{1}{2}\cdot\frac{\beta\cdot R_{c4}}{r_{be3}}=77.27$

$A_{ud}=A_{ud1}\cdot A_{ud2单}=2840$

③ $R_{id}=2r_{be1}=2.46k$　　$R_o=R_{c4}=5.1k$

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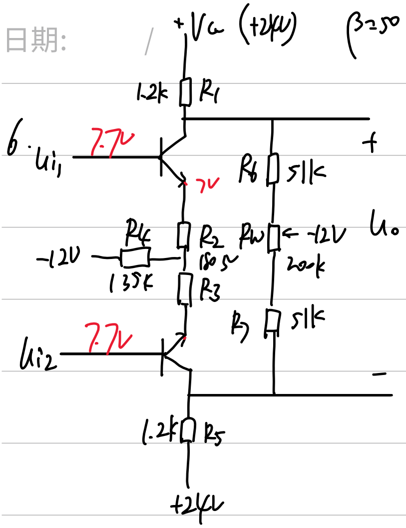

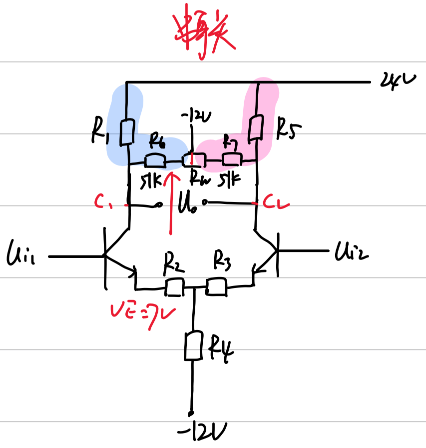

求: ① Q点 ② A_{ud} ③ R_{id}, R_o

① $I_{C1}=I_{C2}=\dfrac{12+7}{R_2+2R_4}=6.6mA$

$U_{C1}=U_{C2}=24-I_{C1}\cdot R_{C1}=24-6.6\times 1.2=16.08V$

$U_{CE}=U_{C1}-U_E=9V$

② $A_{ud}=-\dfrac{\beta\cdot(R_1//(R_6+\frac{1}{2}R_w))}{r_{be}+(1+\beta)\cdot R_2}$

$=-6.2$

$r_{be}=300+(1+\beta)\cdot\dfrac{26mV}{6.6mA}=0.5k$

③ $R_{id}=2[r_{be}+(1+\beta)\cdot R_2]$

$R_o=[R_1//(R_6+\frac{1}{2}R_w)]+[R_5//(R_7+\frac{1}{2}R_w)]$

$\approx R_1+R_5\approx 2.4k$

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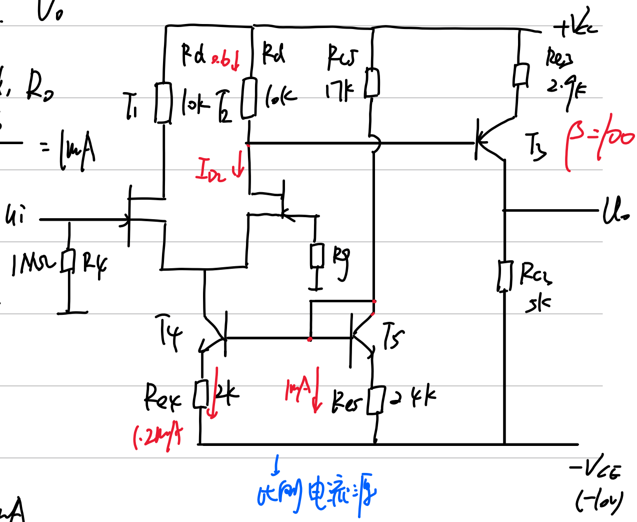
7. 已知 $g_m = 2mA/V$. $\beta = 100$ $r_{bb'} = 300\Omega$

$U_{BE1,2} = 0.6$　　$U_{BE3} = -0.2V$

求: ① I_{D1}. I_{B1}, I_{C3}. V_o

② A_{ud}　　③ R_{id}, R_o



解: ① $I_{C5} = \dfrac{0-(-10)-0.6}{R_{C5}+R_{e5}} = 1mA$

$I_{C4} = 1.2mA$

$I_{D1} = I_{D2} = \frac{1}{2} I_{C4} = 0.6mA$

$U_{D1} = V_{D2} = V_{CC} - I_{D1} \cdot R_d$

$= 4V$

$I_{C3} = I_{e3} = \dfrac{6-0.2}{R_{e3}} = 2mA$

$U_o = -6 + 5k \cdot 2mA = 0$

② $A_{ud} = A_{u1} \cdot A_{u2} = 10 \times (-1.7) = -17$

$A_{ud1} = \frac{1}{2} \cdot g_m \cdot R_L' = \frac{1}{2} \times 2 \times 10k = 10$

半

R_L': $R_d // R_{i2}$

$\hookrightarrow [r_{be3} + (1+\beta) \cdot R_{e3}]$

$A_{u2} = -\dfrac{\beta \cdot R_{c3}}{r_{be}+(1+\beta) R_e}$

$\approx \dfrac{-R_{c3}}{R_e} = -\dfrac{5}{2.9} = -1.7$

③ $R_i = R_g = 1M\Omega$

$R_o = R_{c3} = 5k$

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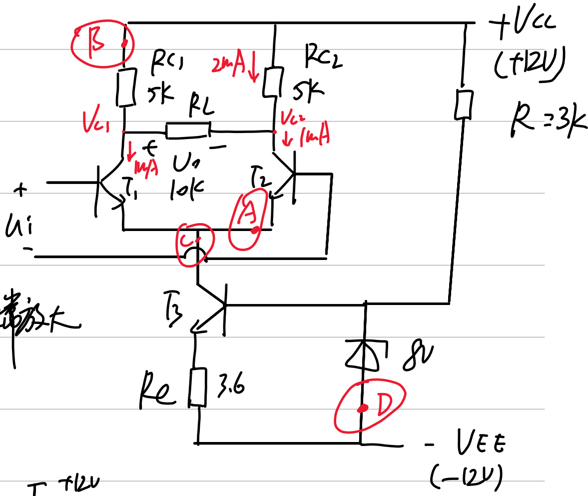
8. $\beta=50$.　$U_{BE}=0.7V$

在A.B.C.D四处分别开路时

判断T_1, T_2, T_3的工作状态

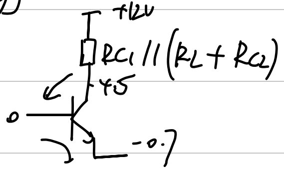


① A断开：T_2截止，T_1与T_3正常放大

$$I_{C1}=I_3=\frac{8-0.7}{3.6k}=2mA$$

$$V_{C1}=12V-I_{C1}\cdot[R_{C1}//(R_L+R_{C2})]$$

$=4.5V$ (放大)



② B断开

$I_{C3}=2mA$　　$I_{C1}=I_{C2}=\frac{1}{2}I_{C3}=1mA$

$V_{C2}=V_{CC}-2mA\cdot 5k=2V$　　T_2放大

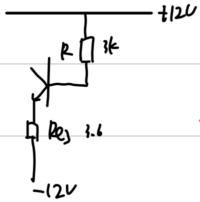
$V_{C1}=V_{C2}-1mA\cdot 10k=-8V$　　T_1饱和

T_3放大

③ C断开　$I_{C3}=0$,　$I_{C1}=I_{C2}=0$

T_1, T_2, T_3截止.

④ D断开



$$I_{B3}=\frac{12+12-0.3}{3+(1+50)\times 3.6}$$

$=$

$I_{C3}=\beta\cdot I_{B3}=6.37mA$

假设T_3是放大的

$V_{CE1}=V_{CE2}=V_{CC}-I_{C1}\cdot R_{C1}+0.7$

<0

∴T_3是饱和的.　$I_{C3}=3mA$　$I_{C1}=I_{C2}=1.5mA$. 最后得出T_1, T_2放大

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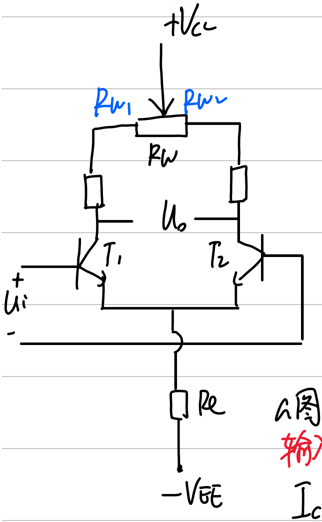
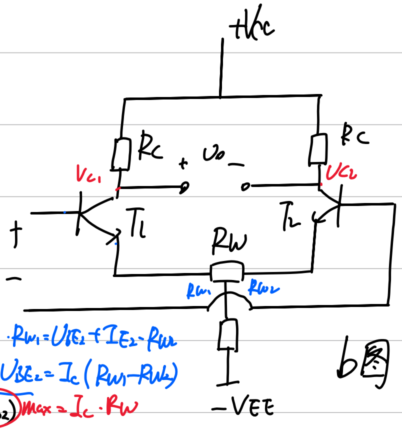
9, 已知 A_{ud} 相同, R_W 相同

证明: 发射极调零的调节范围是集电极…的 A_{ud} 倍



a图



b图

$U_{BE1}+I_{E1}\cdot R_{W1}=U_{BE2}+I_{E2}\cdot R_{W2}$

$\Rightarrow U_{BE1}-U_{BE2}=I_C(R_{W1}-R_{W2})$

输入 $(V_{B1}-V_{B2})_{max}=I_C\cdot R_W$

$$I_{C1}(R_{C1}+R_{W1})=I_{C2}\cdot(R_C+R_{W2})$$

调节范围: $|\Delta U_{C1}|=I_{C1}\cdot R_W$

$|\Delta U_{C2}|=I_{C2}\cdot R_W$

输出

$|\Delta U_{C1}|=|\Delta U_{C2}|=I_C\cdot R_W\cdot A_{ud}$

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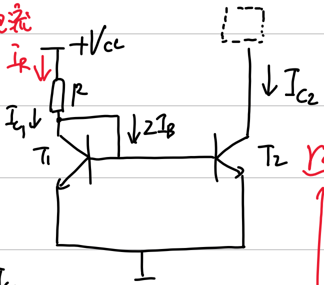
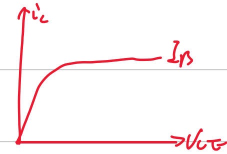
电流源

一、镜像电流源





两管对称

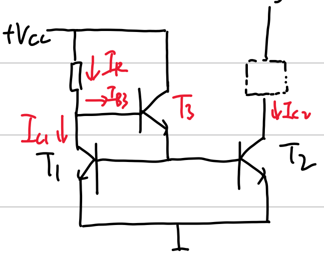
$$I_R = \frac{V_{CC}-0.7}{R}$$

$$I_R = I_{C1} + 2I_B = I_{C1} + 2\cdot\frac{I_{C1}}{\beta}$$

$$= I_{C1}\left(1+\frac{2}{\beta}\right) = I_{C2}\left(1+\frac{2}{\beta}\right) \qquad \frac{2}{\beta}\to 0$$

$$I_R \doteq I_{C2}$$

二、高精密镜像电流源



$$I_R = \frac{V_{CC}-0.7-0.7}{R}$$

$$I_R = I_{C1} + I_{B3} = I_{C1} + \frac{I_{E3}}{1+\beta_3}$$

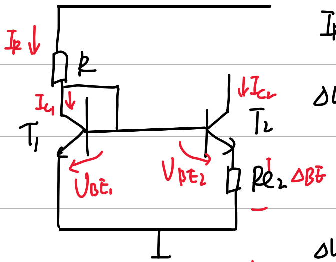
$$= I_{C1} + \frac{2I_{C1}}{(1+\beta_3)\beta_1}$$

$$= I_{C1}\left(1+\frac{2}{(1+\beta_3)\cdot\beta_1}\right) \to I_{C1}$$

$2I_B \to \frac{I_{C1}}{\beta_1}$

$\frac{2}{(1+\beta_3)\cdot\beta_1}$ 很小

三、微电流源



$$I_R = \frac{V_{CC}-0.7}{R}$$

$$\Delta U_{BE} = U_{BE1} - U_{BE2}$$

$$I_C = I_s\left(e^{\frac{u}{V_T}}-1\right) \approx I_s\cdot e^{\frac{u}{V_T}}$$

$$U_{BE} = V_T \ln\frac{I_C}{I_s}$$

$$\Delta U_{BE} = V_T\ln\frac{I_{C1}}{I_s} - V_T\ln\frac{I_{C2}}{I_s} = \boxed{V_T\ln\frac{I_{C1}}{I_{C2}} = I_{C2}\cdot R_{e2}}$$

$$r_{o2} = r_{ce2}\left(1+\frac{\beta_2 R_{e2}}{r_{ce2}+R_{e2}}\right)$$

R_{e2}已知，I_{C2}可求

如需要$I_{C2}=1mA$，问R_{e2}取多少？

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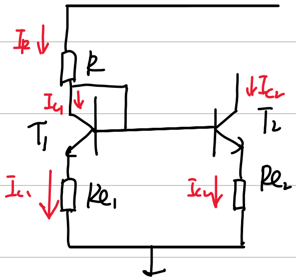
四. 比例电流源

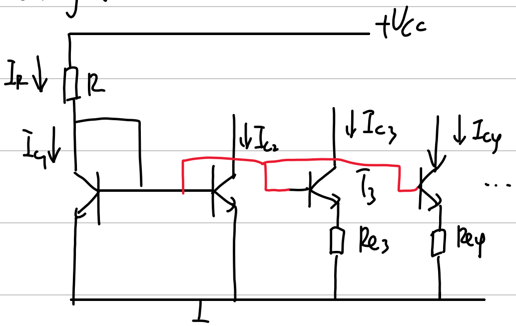


$I_{c1}Re_1 = I_{c2}Re_2$

$$\frac{I_{c1}}{I_{c2}} = \frac{Re_2}{Re_1}$$

$$I_R = \frac{V_{cc}-0.7}{R+Re_1}$$

五. 多路电流源



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反馈的基本概念与分类

一、反馈的定义

将电路的输出电量、电流、电压的一部分或全部通过反馈网络，按照一定的方法送回到回路当中，从而影响输入、输出电量、电流、电压的过程

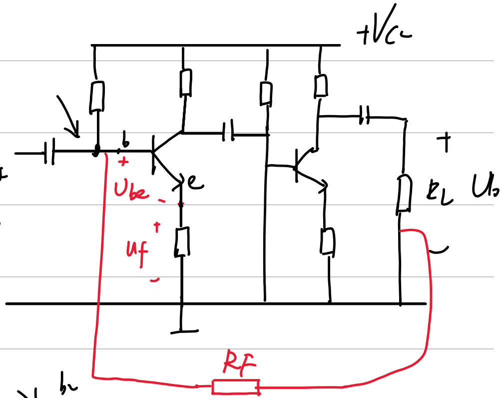
二、分类

对地短路反馈是否消失

(组合)

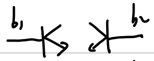
- 电压反馈 ✓
- 电流反馈 ✓

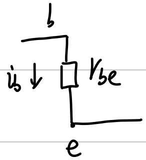
(反馈是否取自于输出端)

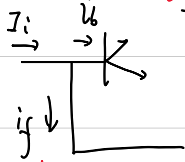


- 串联 → 不同点
- 并联 → 同点

$U_i = U_{be} + U_f$

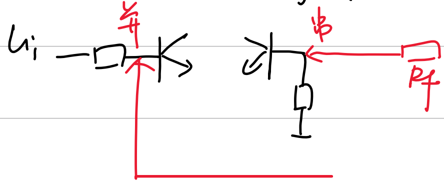




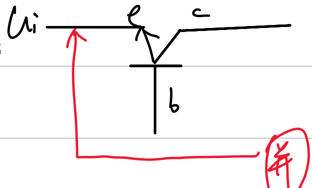


$I_i = i_b + i_f$

总:

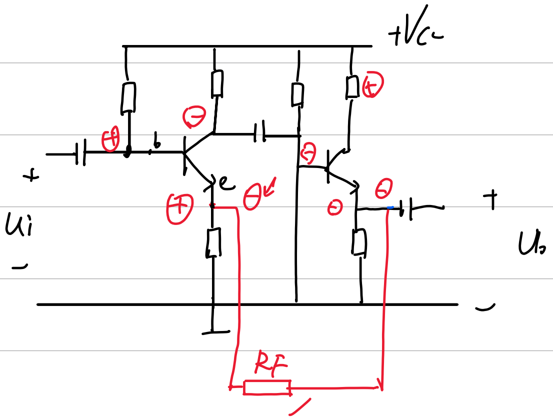


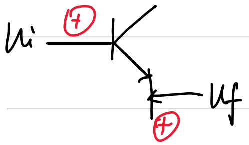
Cb:



正 → ↑
负 → ↓

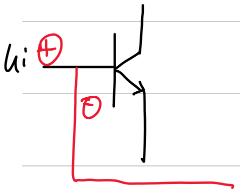
(瞬时极性法)





串同负
(串反正)

电压.串联.正负馈



并反负
(并同正)

直流反馈 (影响Q点)
交流反馈 ✓

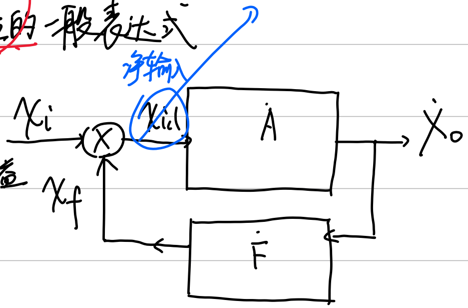
深度负反馈的实质：忽略净输入量

反馈放大电路增益的一般表达式

$\dot{X}_i - \dot{X}_f = \dot{X}_{id}$

$\dot{A} = \frac{\dot{X}_o}{\dot{X}_{id}}$ → 开环增益

$\dot{F} = \frac{\dot{X}_f}{\dot{X}_o}$



$\dot{A}_f = \frac{\dot{X}_o}{\dot{X}_i}$ → 闭环增益

$= \frac{\dot{X}_o / X_{id}}{(\dot{X}_f + \dot{X}_{id}) / X_{id}} = \frac{\dot{A}}{1+\dot{A}\cdot\dot{F}}$ 一般表达式

$\frac{X_f}{X_{id}} = \frac{X_f}{X_o}\cdot\frac{X_o}{X_{id}} = \dot{A}\cdot\dot{F}$

$|1+\dot{A}\dot{F}|$ —反馈深度

$AF >> 1$

$\frac{A}{1+AF}$　$1+AF \to 1$　⇒ $\frac{1}{F}$

① $|1+\dot{A}\cdot\dot{F}| > 1$　$|\dot{A}_f| < |\dot{A}|$　(负反馈)

$|1+\dot{A}\dot{F}| >> 1$　$A_f \approx \frac{1}{F}$　深度负反馈✓

② $|1+\dot{A}\dot{F}| < 1$　$|\dot{A}_f| > |\dot{A}|$　(正反馈)

$|1+\dot{A}\dot{F}| = 0$　$\dot{A}_f = \frac{X_o}{X_i} \to \infty$

X_o →有限值

X_i ‖ 0

没有输入的情况下也有输出

(自激振荡)

A.F.Af — 广义

四种组合

$\dot{A} = \frac{X_o}{X_{id}}$ → $\begin{cases} u_o \text{ — 电压反馈} \\ i_o \text{ — 电流反馈} \end{cases}$

↘ $\begin{cases} u_{id} \text{ — 串联反馈} \\ i_{id} \text{ — 并联反馈} \end{cases}$

$A_u = \frac{u_o}{u_{id}}$ ✓　$A_R = \frac{u_o}{i_{id}}$

$A_G = \frac{i_o}{u_{id}}$　$A_i = \frac{i_o}{i_{id}}$ ✓

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负反馈对放大电路性能的影响

一、提高增益的稳定性

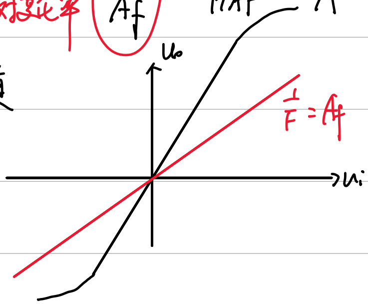
$$\dot{A}_f = \frac{\dot{A}}{1+\dot{A}\dot{F}}$$

当 $|1+\dot{A}\dot{F}| \gg 1$ 时，$A_f \approx \frac{1}{F}$

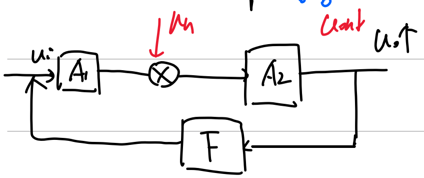
$$\frac{dA_f}{dA} = \frac{1+AF-A\cdot F}{(1+AF)^2} = \frac{1}{(1+AF)^2} = \frac{1}{1+AF}\cdot\underbrace{\frac{A}{1+AF}}_{A_f}\cdot\frac{1}{A}$$

相对变化率 $\frac{dA_f}{A_f} = \frac{1}{1+AF}\cdot\frac{dA}{A}$

二、减小非线性失真



三、提高信噪比（抑制环内噪声）



$$U_o = \frac{A_1A_2}{1+A_1A_2F}U_i + \frac{A_2}{1+A_2\cdot A_1F}U_n$$

增益带宽积为常数

$$f_{Hf} = (1+AF)f_H$$

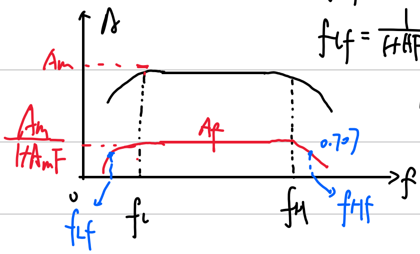
$$f_{Lf} = \frac{1}{1+AF}f_L$$

$$BW_f = f_{Hf} - f_{Lf} \approx f_{Hf} = (1+AF)\cdot f_H = (1+AF)\cdot BW$$

四、展宽频带

$$BW = f_H - f_L$$

$$A_f = \frac{A}{1+AF}$$



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五. 对放大电路的输入电阻的影响

1. 串联负反馈: $R_{if}=(1+AF)R_i$ 变大

并联负反馈: $R_{if}=\frac{1}{1+AF}R_i$ 变小

$A_f=\frac{X_o}{X_i}$

u_o

X_o — i_o

压 u_o稳定

流 i_o稳定

六. 对放大电路的输出电阻的影响

1. 电压负反馈 ⟶ 恒压 ⟶ 内阻小　$R_{of}=\frac{1}{1+AF}\cdot R_o$ (*)

2. 电流负反馈 ⟶ 恒流 ⟶ 内阻大　$R_{of}=(1+AF)\cdot R_o$ (*)

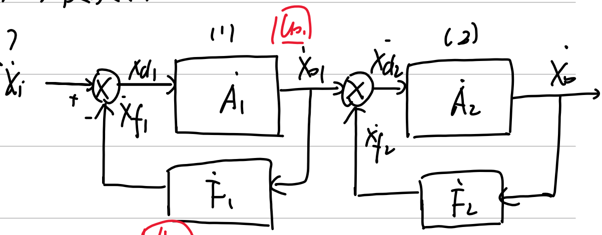
$A=-\frac{\beta\cdot(R_C\|R_L)}{r_{be}}$ 不可以代入(*)式

不带负载

$A_o=A|_{R_L\to\infty}$

负反馈放大电路的补充习题(1)

1. 为取得满意的反馈效果，反馈(1)、反馈(2)应分别采用何种负反馈？



X_i { 理想电压源 内阻小⇒串联
理想电流源 内阻大⇒并联

A1		A2
电压	串联	电压
电流	并联	
电压	串联	
电流	并联	电流
压	串	电压
流	并	
压	串	电流
流	并	

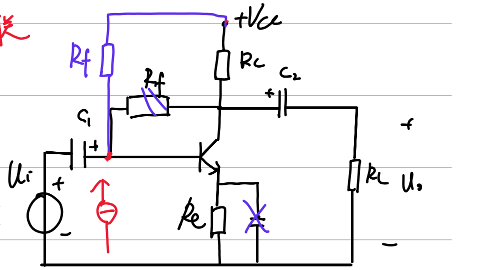
X_o { 稳定输出电压
稳定输出电流

(有反馈和无反馈区别要明显)

总结 电压—串联
电流—并联

2. <1> 有无交流反馈 { 若有，判别类型
若无。

<2> 若要实现电流串联负反馈如何修改电路？



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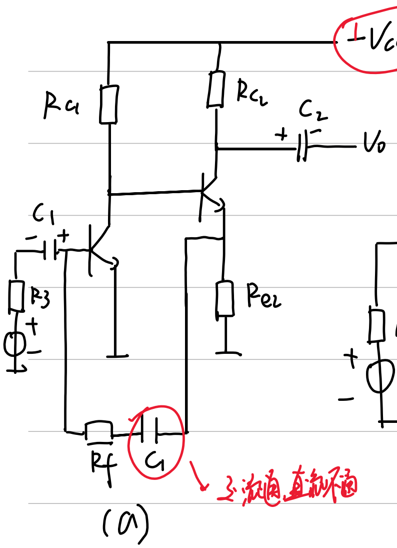
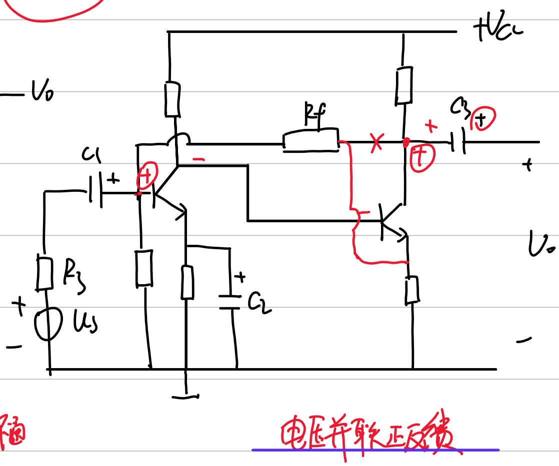
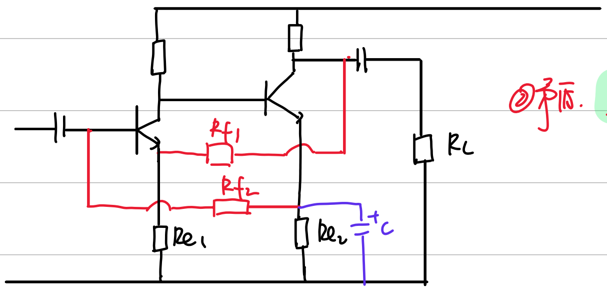
3.① (a)(b) 两图能否放大?　② 改进后 希望 Q稳定. Ri低







②引入. 输入电阻

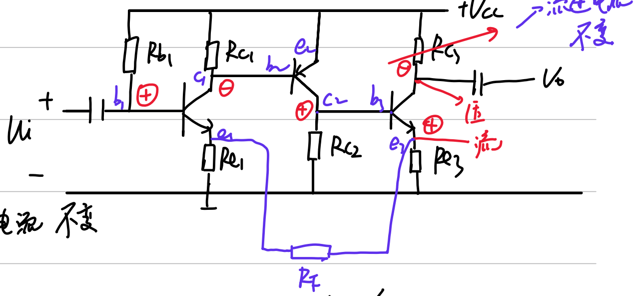
4.① 类型:　f_1 → 交.直　f_1: 电压串联负反馈

f_2 → 交.直　f_2: 电流并联负反馈

②这两种反馈合理吗? 如何修改?

5. 接一个电阻,构成负反馈

1. 级间反馈 { 整体 ✓ / 局部 }



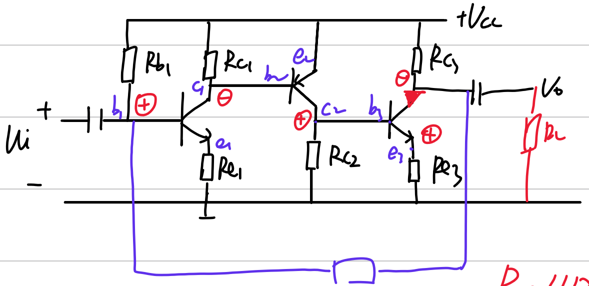
电流串联负反馈

要求: ① Rc3阻值改变时,流过其上的电流不变

$e_3 - e_1$

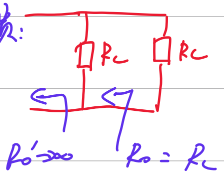
② 接负载RL后,电压波动不大

$c_3 - b_1$



Rc//RL

电流负反馈:



RL' 流过电流基本不变

不是RL

日期: /

负反馈放大电路的估算

1. 电压串联负反馈

$$A_f = \frac{A}{1+AF} \approx \frac{1}{F}$$

$$A_u = \frac{U_o}{U_{id}} \qquad F_u = \frac{U_f}{U_o}$$

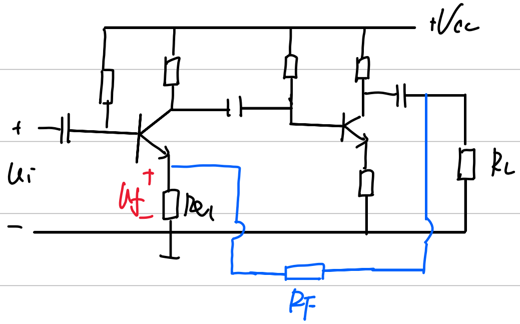
$$A_{fu} = \frac{U_o}{U_i} \qquad A_{fu} = \frac{1}{F_u}$$

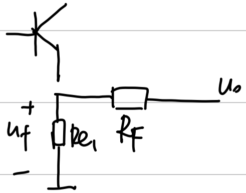
$$F_u = \frac{U_f}{U_o} = \frac{R_{e1}}{R_{e1}+R_F}$$

$$A_{fu} = \frac{1}{F_u} = 1 + \frac{R_F}{R_e}$$

串 → $R_{if} = (1+AF)\cdot R \to \infty$

压 → $R_{of} \to 0$





压 u_o
流 i_o
串 u_i, u_f. u_d
并 i_i, i_f. i_d

2. 电流串联负反馈

$$A_G = \frac{i_o}{U_{id}} \qquad F_R = \frac{U_f}{i_o}$$

$$A_{Gf} = \frac{i_o}{U_i} = \frac{1}{F_R}$$

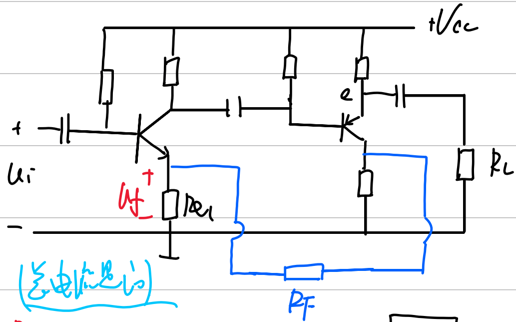
$$i_1 = -\frac{R_{c2}}{R_F+R_{e1}+R_{c2}} i_o$$ (总电流是 i_o)

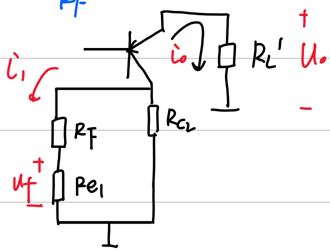
$$U_f = i_1 \cdot R_{e1} = -\frac{R_{e1}\cdot R_{c2}}{R_F+R_{e1}+R_{c2}} \cdot i_o$$

$$F_R = -\frac{R_{e1}\cdot R_{c2}}{R_F+R_{e1}+R_{c2}}$$

$$A_{uf} = \frac{U_o}{U_i} = \frac{i_o R_L'}{U_i} = A_{Gf}\cdot R_L'$$

A_{Gf} $R_{if} \to \infty$



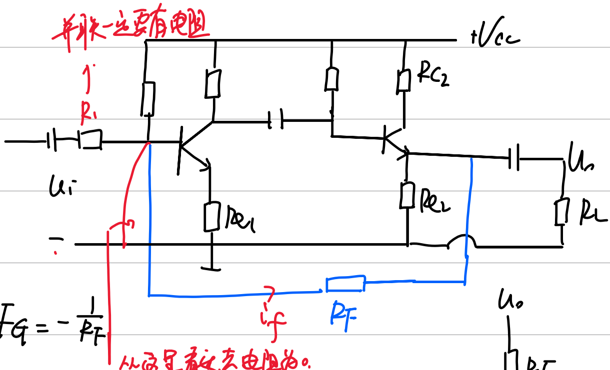


3. 电压并联负反馈

$$A = \frac{u_o}{i_{id}}$$

$$F_G = \frac{i_f}{u_o}$$

$$A_{rf} = \frac{u_o}{i_i} = \frac{1}{F_G}$$



$$u_o = -i_f \cdot R_F \qquad F_G = -\frac{1}{R_F}$$

$$\therefore A_{rf} = -R_F$$

$$A_{uf} = \frac{u_o}{u_i} = \frac{u_o}{i_i \cdot R_i} = -\frac{R_F}{R_1}$$

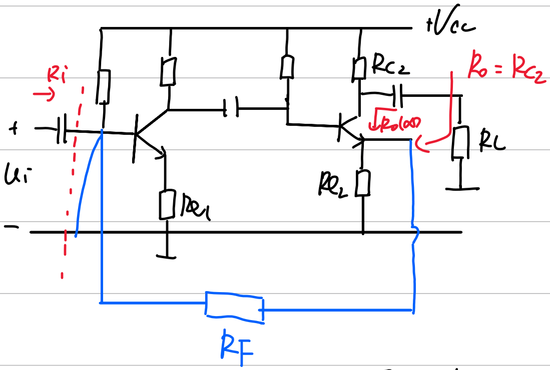
A_{rf} $\quad R_1$

4. 电流并联负反馈

$$A_i = \frac{i_o}{i_{id}}$$

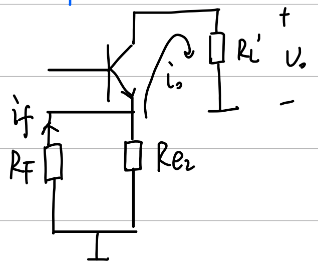
$$F_I = \frac{i_f}{i_o}$$

$$A_{If} = \frac{i_o}{i_i} = \frac{1}{F_I}$$



$$i_f = \frac{R_{e2}}{R_F + R_{e2}} i_o$$

$$F_I = \frac{i_f}{i_o} = \frac{R_{e2}}{R_F + R_{e2}}$$



$$A_{If} = 1 + \frac{R_F}{R_{e2}}$$

A_{If}

$$A_u = \frac{u_o}{u_i} = \frac{i_o \cdot R_L'}{i_i \cdot R_i} = A_{If} \cdot \frac{R_L'}{R_1}$$

日期: /

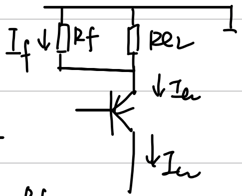
负反馈放大电路补充习题(2)

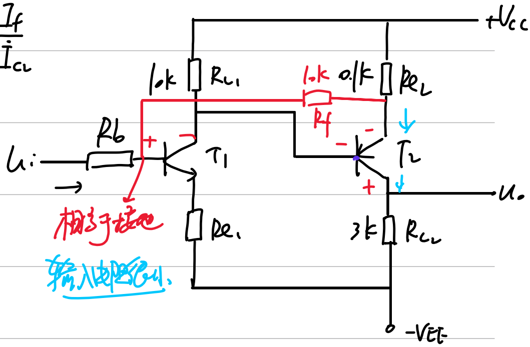
1. <1> 为使 $R_i = R_b$（交流），同时还要稳定Q点（直流），应引入什么反馈？　交、直流反馈（电流并联负反馈）

在图中标出。（$R_f = 10k\Omega$）

<2> 在深度负反馈条件下，$A_{uuf} = \frac{U_o}{U_i} = 60$，$R_b = ?$

$$A_f = \frac{1}{F} \qquad F_I = \frac{I_f}{I_o} = \frac{\dot{I}_f}{I_{c2}}$$





$$F_I = \frac{R_{e2}}{R_f + R_{e2}}$$

$$A_{If} = \frac{1}{F_I} = 1 + \frac{R_f}{R_{e2}} = \frac{I_{c2}}{I_i}$$

$$A_{uf} = \frac{U_o}{U_i} = \frac{I_{c2} \cdot R_{c2}}{I_i \cdot R_b} = \left(1 + \frac{R_f}{R_{e2}}\right) \cdot \frac{R_{c2}}{R_b} = 60$$

$$\Rightarrow R_b = 5k\Omega$$

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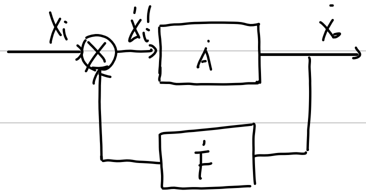
负反馈放大电路的稳定性



一、自激振荡及稳定工作的条件

$\dot A\dot F=-1$ $\quad \begin{cases} |\dot A\dot F|=1 \\ \varphi_a+\varphi_f=-180^\circ \end{cases}$

$A_f=\dfrac{\dot A}{1+\dot A\dot F}$

$|1+\dot A\dot F|$: 反馈深度 $\quad$ <1 正反馈

$|1+AF|=0$ 时 $A_f=\dfrac{A}{1+AF}\to\infty$

$=\dfrac{X_o}{X_i}$ ← 有限值, X_i ← 0

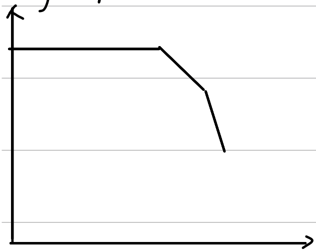
无输入却有输出

(自激振荡)

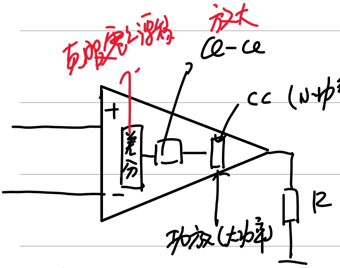
稳定的条件:

$\begin{cases} |\dot A\dot F|=1 \\ \varphi_a+\varphi_f<-180^\circ \end{cases}$ or $\begin{cases} |AF|<1 \\ \varphi_a+\varphi_f=180^\circ \end{cases}$

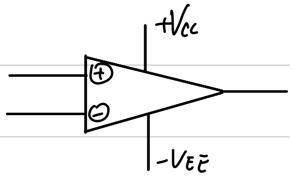
$20\lg|\dot A\dot F|/dB$

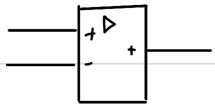


集成运算放大电路



符号:



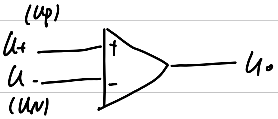


理想运放

① $A_{ud}\to\infty$ ② $A_{uc}\to 0$ ③ $R_i\to\infty$ ④ $R_o\to 0$

⑤ 温漂→0

二个结论:



① $u_+=u_-$ ($u_P=u_N$) (只有负反馈才能起作用)

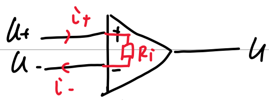
虚假短路(虚短)

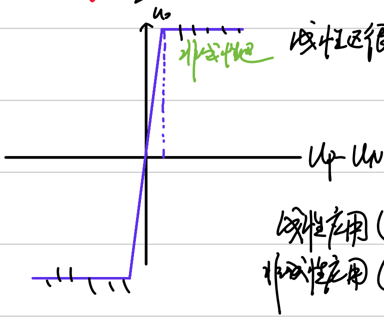
$u_o=A_u(u_+-u_-)$ → 有限值, ∞, 0

② $R_i\to\infty$

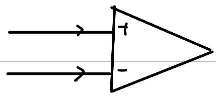
$i_+=i_-=0$

虚假断路(虚断)





线性区很小



失调 电流 / 电压 (差分电路若不对称)

偏置 电流

线性应用(负反馈)

非线性应用(正反馈、无反馈)

运算放大电路的线性应用

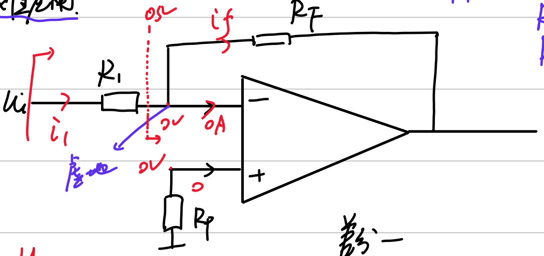
一、比例电路

1. 反相比例

电压并联负反馈

$R_i = R_1$

$R_o \to 0$

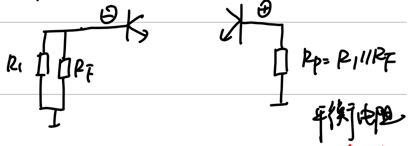


$i_1 = i_f$

$$\frac{U_i - 0}{R_1} = \frac{0 - U_o}{R_F}$$

$$U_o = -\frac{R_F}{R_1} U_i$$

$U_+ = U_-$　虚短

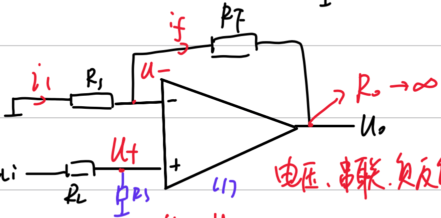


$R_p = R_1 // R_F$

平衡电阻

(保持对称性)

2. 同相比例



电压、串联、负反馈

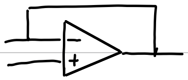
$U_+ = U_i$　　$i_1 = i_f$　　$\frac{0 - U_+}{R_1} = \frac{U_+ - U_o}{R_F}$

$$\Rightarrow U_o = \left(1 + \frac{R_F}{R_1}\right) U_+$$

$U_o = U_i$

$1 + \frac{R_F}{R_1} = 1$　$\begin{cases} ① \ R_F = 0 \\ ② \ R_1 = \infty \end{cases}$

跟随器:



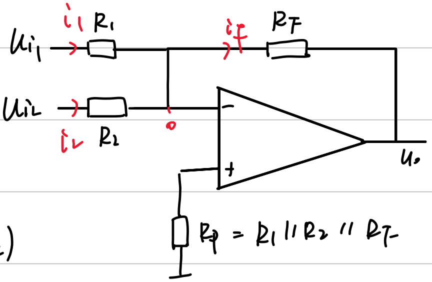
放大倍数为1

注: 在上图(1)中. $U_+ = U_i$　若再接一个电阻R_3, $U_+ \neq U_i$　$R_i = R_2 + (R_3 // \infty) = R_2 + R_3$

不接R_3: $R_i = \infty$

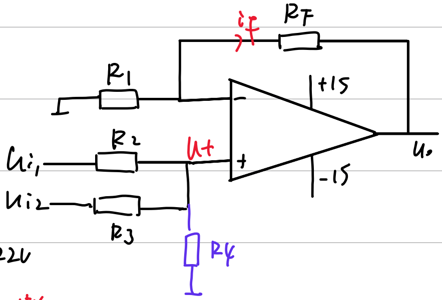
二、加法电路

1. 反相加法:



$$U_o = -\left(\frac{R_F}{R_1}U_{i1} + \frac{R_F}{R_2}U_{i2}\right)$$

2. 同相加法:



$$U_o = \left(1+\frac{R_F}{R_1}\right)\cdot U_+$$

$$U_+ = \frac{R_3}{R_2+R_3}U_{i1} + \frac{R_2}{R_2+R_3}U_{i2}$$

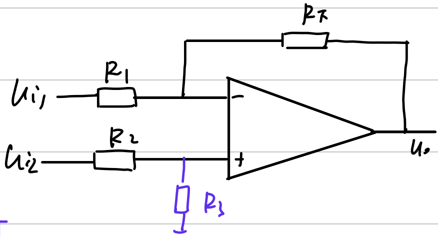
(叠加原理)

$$U_o = 2U_1 + 3U_2 + 4U_3 = 22V$$

$\downarrow$ 2V　$\downarrow$ 2V　$\downarrow$ 3V　✗ 15V

(不能超过电源电压)

三 减法电路



叠加原理

$$U_o = -\frac{R_F}{R_1}U_{i1} + \left(1+\frac{R_F}{R_1}\right)U_{i2}$$

若有了电阻　$U_+ = \frac{R_3}{R_2+R_3}U_{i2}$ 代入

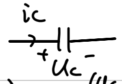
$$= -\frac{R_F}{R_1}U_{i1} + \frac{R_F}{R_1}\left(1+\cancel{\frac{R_1}{R_F}}\right)\frac{1}{\left(1+\cancel{\frac{R_2}{R_3}}\right)}\cdot U_{i2}$$

假 $\frac{R_1}{R_F} = \frac{R_2}{R_3} \Rightarrow U_o = \frac{R_F}{R_1}(U_{i2} - U_{i1})$ (标准减法器)

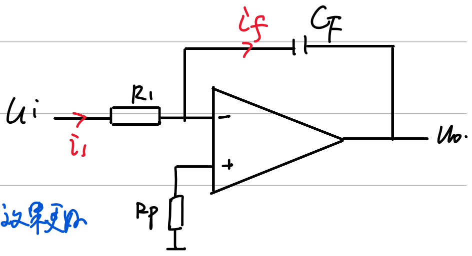
$\Downarrow$

又要满足平衡电阻. 最后是 $\begin{cases} R_1 = R_2 \\ R_F = R_3 \end{cases}$

日期: /



$$i_c = C\frac{dU_c}{dt}$$



四 积分运算

$i_1 = i_f$

$R_1 \cdot C_F$: 积分时间常数

大一点 → 积分效果更好

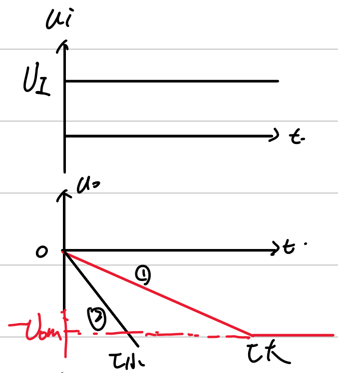
$$\frac{u_i - 0}{R_1} = C_F \cdot \frac{dU_c}{dt} = -C_F \cdot \frac{dU_o}{dt}$$

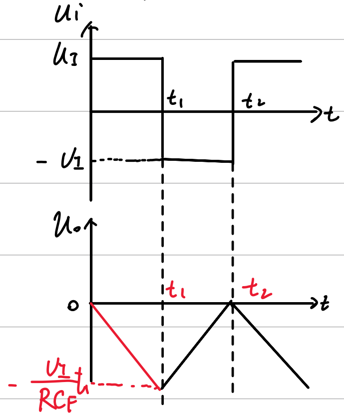
$$\frac{dU_o}{dt} = -\frac{1}{R_1C_F}U_i$$

$$U_o = -\frac{1}{R_1 \cdot C_F}\int U_i dt + K$$ 常数

① $U_i = U_I$ $U_o = -\frac{U_I t}{R_1C_F} + K$

② U_i — 方波 $U_o \to$ 三角波





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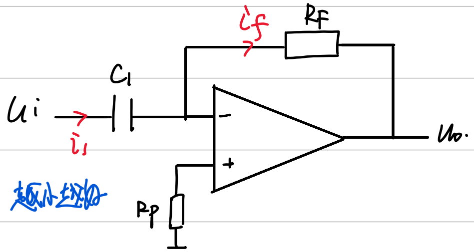
五.微分运算



$i_1 = i_f$

$$C_1 \frac{du_i}{dt} = \frac{0-u_o}{R_F}$$

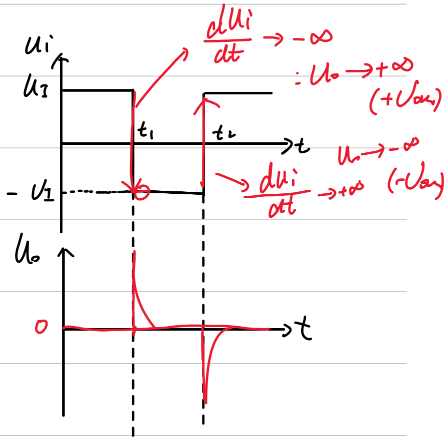
微分时间常数: $\tau = R_F \cdot C_1$ 越小越好

$$\therefore u_o = -R_F C_1 \cdot \frac{du_i}{dt}$$

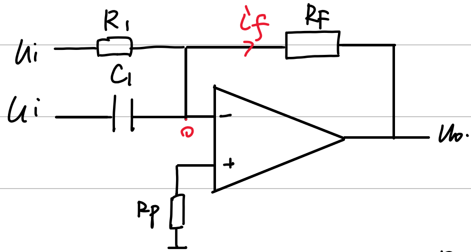
① u_I 常数. $u_o = 0$

② u_I 是方波

③ u_i 是三角波　u_o 是方波

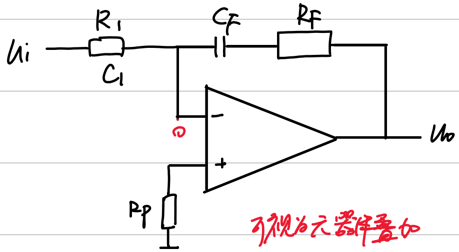


六.其他运算



$$u_o = -\frac{R_F}{R_1} u_i - R_F C_1 \frac{du_i}{dt}$$

PD



可视为元器件叠加

$$u_o = -\frac{R_F}{R_1} u_i - \frac{1}{R_1 C_F} \int u_i dt$$

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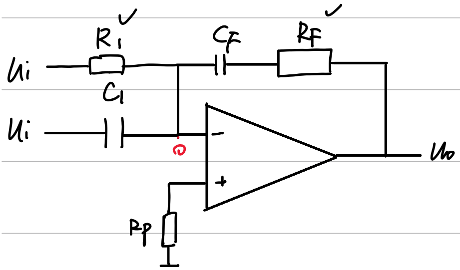


比例　　电阻之比 (电容反比).

$$U_o = -\left(\frac{R_F}{R_1}U_i + \frac{C_1}{C_F}U_i\right) - \frac{1}{R_1C_F}\int U_i dt - R_F C_1 \frac{dU_i}{dt}$$

积分　　微分

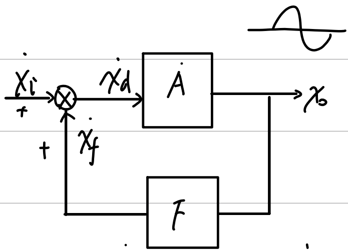
PID

输入2个　反馈2个 ⇒ 排列组合4个.

日期: /

正弦波振荡电路的振荡条件

1. 维持振荡的条件



$\dot A\dot F=+1$

$$\begin{cases} |\dot A\dot F|=1 & \text{幅值条件} \\ \varphi_a+\varphi_f=2n\pi & \text{相位条件} \end{cases}$$

$\dot A\dot F=1$

$$\frac{\dot X_o}{\dot X_d}\cdot\frac{\dot X_f}{\dot X_o}=\frac{\dot X_f}{\dot X_d}=1$$

$$\dot A_f=\frac{\dot A}{1+\dot A\dot F}$$

$1+\dot A\dot F=0$

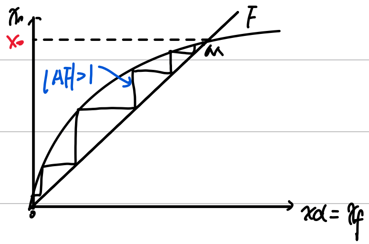
$\dot A\dot F=-1$ 自激

$$\dot A_f=\frac{\dot A}{1-\dot A\dot F}$$

$\dot A\dot F=1$

2. 振荡的建立(起振) 干扰、噪音

起振条件: $|\dot A\dot F|>1$



3. 振荡电路的组成部分

· 放大器 A

· 正反馈网络 $\dot F_+$

· 选频网络 *

· 稳幅环节

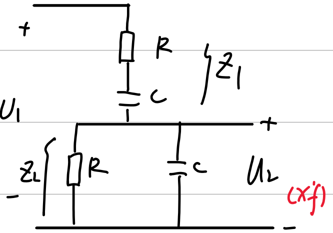
L.C

RC ——

LC ——

RC正弦波振荡电路

1. RC串并联选频网络



$$Z_1 = R + \frac{1}{j\omega C}$$

$$\frac{1}{Z_2} = \frac{1}{R} + j\omega C$$

$$\frac{\dot U_2}{\dot U_1} = \dot F$$

$$\dot F = \frac{\dot U_2}{\dot U_1} = \frac{Z_2}{Z_1+Z_2} = \frac{1}{\frac{Z_1}{Z_2}+1}$$

$$= \frac{1}{(R+\frac{1}{j\omega C})(\frac{1}{R}+j\omega C)+1} = \frac{1}{3+j\omega RC+\frac{1}{j\omega RC}}$$

$$= \frac{1}{3+j(\omega RC-\frac{1}{\omega RC})}$$

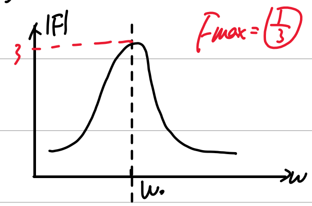
$$\omega_0 = \frac{1}{RC}$$

$$= \frac{1}{3+j(\frac{\omega}{\omega_0}-\frac{\omega_0}{\omega})}$$

$$|\dot F| = \frac{1}{\sqrt{3^2+(\frac{\omega}{\omega_0}-\frac{\omega_0}{\omega})^2}} \qquad \varphi_f = -\arctan\frac{\frac{\omega}{\omega_0}-\frac{\omega_0}{\omega}}{3}$$

$f = f_0 = \frac{1}{2\pi RC}$ $(\omega = \omega_0)$

$\dot F_{max} = \frac{1}{3}$ $\quad \varphi_f = 0°$

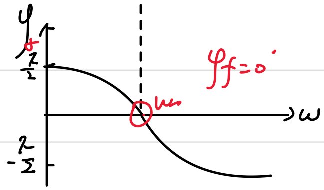


$\dot F_{max} = \frac{1}{3}$

$A \geq 3$

$$\begin{cases} |\dot A\dot F| \geq 1 \quad (\dot F \to \frac{1}{3}) \\ \varphi_a + \varphi_f = 2n\pi \quad (\varphi_f \to 0°) \end{cases}$$

同相



$\varphi_f = 0°$

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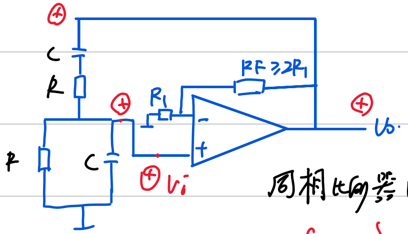
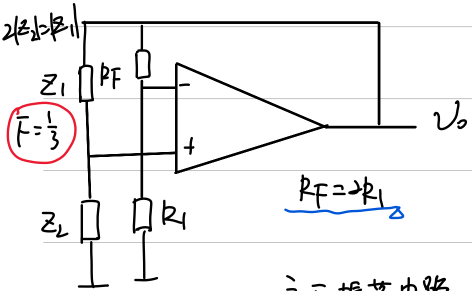
2. RC桥式振荡电路.

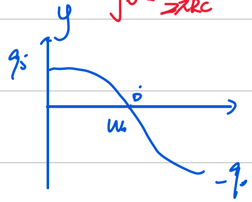


同相比例器 $1+\frac{R_F}{R_1} \geq 3$.

$f_0 = \frac{1}{2\pi RC}$



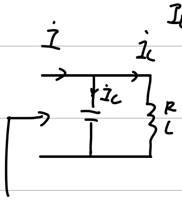
$R_F = 2R_1$



文氏振荡电路

$Q = \frac{\omega_0 L}{R} = \frac{\frac{1}{\omega_0 C}}{R}$ Q个 选择性好

$I_L \approx I_C = Q \cdot I$



$\omega L >> R$

LC正弦波振荡电路.

1. LC并联选频网络.

$$Z = \frac{1}{j\omega C} // (R+j\omega L)$$

$$= \frac{(\cancel{R}+j\omega L)\cdot\frac{1}{j\omega C}}{(R+j\omega L)+\frac{1}{j\omega C}}$$

$$\approx \frac{\frac{L}{C}}{R+j(\omega L-\frac{1}{\omega C})}$$

令 $\omega L - \frac{1}{\omega C} = 0 \Rightarrow \omega = \omega_0 = \frac{1}{\sqrt{LC}}$

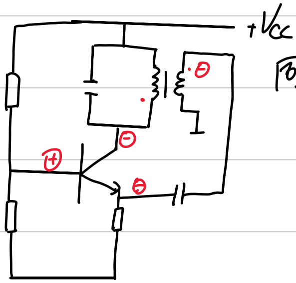
$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

$Z_0 = \frac{L}{RC}$ 纯电阻. $\varphi = 0°$

max.

日期: /

2. 变压器反馈式振荡电路.



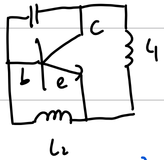
同名端

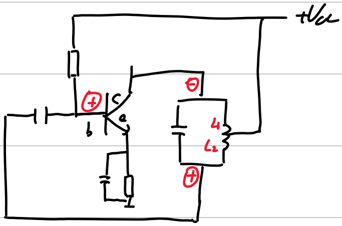
3. 三点式 — $f_0=\frac{1}{2\pi\sqrt{LC}}$

<1> 电感三点式…

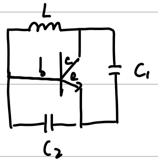
<2> 电容三点式…

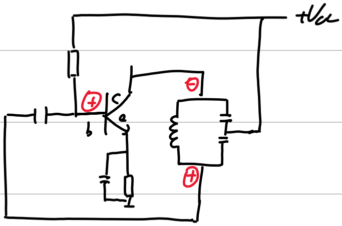
电感:





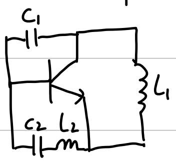
$L=L_1+L_2+2M$ (互感)





$C=C_1//C_2$
$=\frac{C_1C_2}{C_1+C_2}$

若简化后如图所示，问能否振荡.



L

若并联: $\omega L_2<\frac{1}{\omega C_2}$ → 呈感性

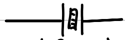
$\omega L_2>\frac{1}{\omega C_2}$ ⇒ 呈感性

条件振荡: 当 $\omega>\frac{1}{\sqrt{L_2C_2}}$ ✓

石英晶体振荡电路 → 纯电阻/电感

$f_0 = \frac{1}{2\pi RC}$　　$f_0 = \frac{1}{2\pi\sqrt{LC}}$

1. 压电效应



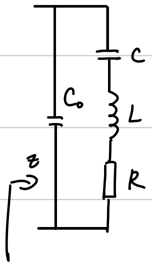
电场 → 变形　　机械力 → 电场

交变电压 → 机械振动 → 电场

固有频率 — 压电谐振

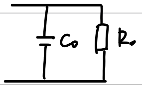
2. 等效模型

$R + j(\omega L - \frac{1}{\omega C})$

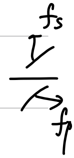


串联谐振　Z最小　$\omega L - \frac{1}{\omega C} = 0$

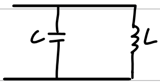
$f_s = \frac{1}{2\pi\sqrt{LC}}$

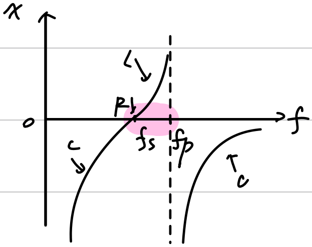


$Z = \square + j\square \rightarrow$



$\frac{1}{\omega_0 C_0} \gg R$　　其右边呈感性:



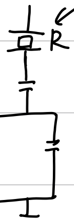


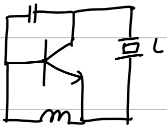
$f_p = f_s\sqrt{1 + \frac{C}{C_0}}$

$(C \ll C_0)$ 几乎 $f_p = f_s$

3. 振荡电路

f_0





感性

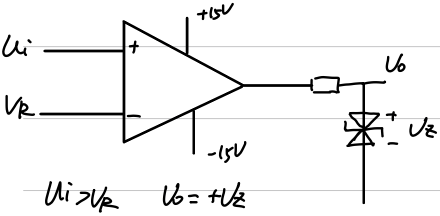
$f_s \sim f_p$

日期: /

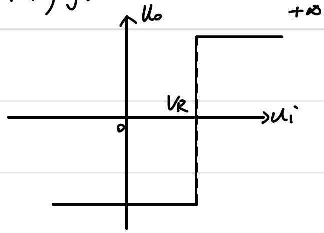
电压比较器:

一 单门限比较器

正端与负端比大小

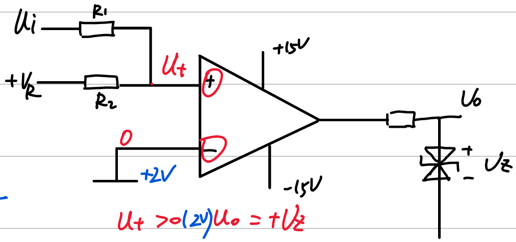


电压传输特性曲线



$U_i > V_R \quad U_o = +U_Z$

$U_i < V_R \quad U_o = -U_Z$



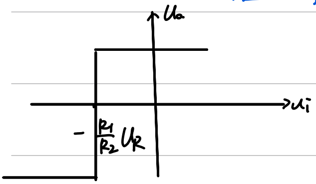
$U_+ = \frac{R_2}{R_1+R_2}U_i + \frac{R_1}{R_1+R_2}U_R = 0\ (2V)$

$U_{th} = U_i = -\frac{R_1}{R_2}U_R$

$\boxed{U_i = ?}$ 计算

$U_+ > 0\ (2V)\ U_o = +U_Z$

$U_+ < 0\ (2V)\ U_o = -U_Z$



日期: /

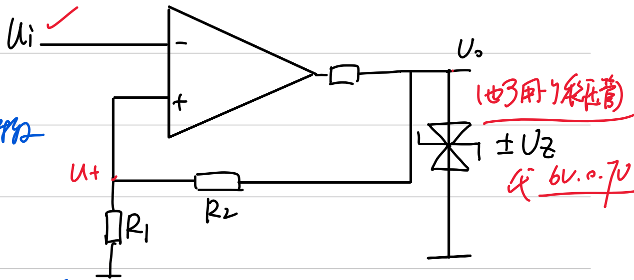
二、双门限比较器

$U_+ = \frac{R_1}{R_1+R_2}(\pm U_Z)$

$U_{T+} = +\frac{R_1}{R_1+R_2}U_Z$ +2V

$U_{T-} = -\frac{R_1}{R_1+R_2}U_Z$ -2V

对称

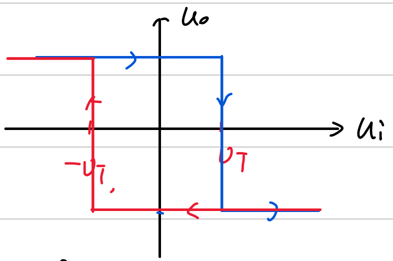


由小变大，在上限门槛翻

由大变小，在下限门槛翻.

(若接 +UR) → $u_i = \frac{R_1}{R_1+R_2}U_o + \frac{R_2}{R_1+R_2}U_R$.

代入 $\pm U_Z$



两门槛 $\begin{cases} U_{T+} \\ U_{T-} \end{cases}$ 宽度(回差)不变

$U_o = f(u_i)$ 由Ui波形推Uo波形

正跳变:

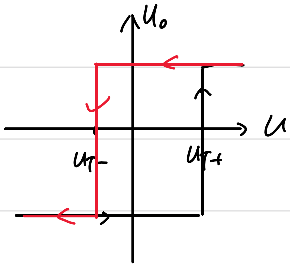
(替换 U_R与U_i)

U_P $\cancel{U_+} = \frac{R_1}{R_1+R_2}U_o + \frac{R_2}{R_1+R_2}U_i$ ⇒ $u_i = U_{T+}$, U_{T-}

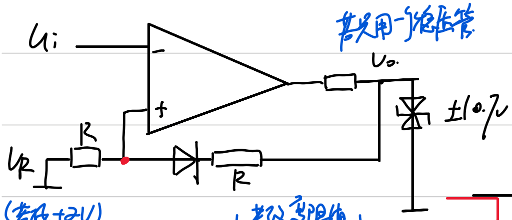
$\pm U_Z$

令 $U_+ = V_R$

负跳变:



电压比较器



(若改+2V)　　(若改变阻值)

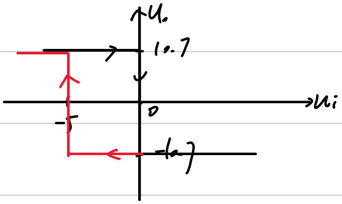
重新计算U_T

$U_o = +10.7V$　D截止.

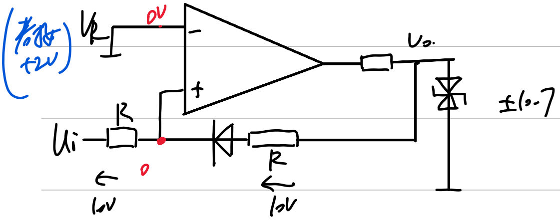
$U_{T+} = 0V$

$U_o = -10.7V$　D导通

$U_{T-} = -5V$



若将二极管反向. 将V_R与U_i交换位置

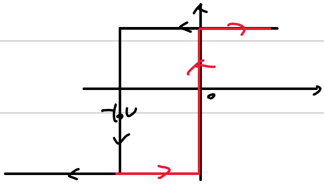


$U_o = -10.7V$.　D截止

$U_{T+} = 0V$

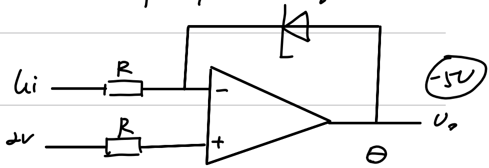
$U_o = +10.7V$.　D导通.

$U_{T-} = -10V$



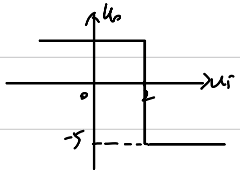
电压比较器

$V_D=0.7V$. $V_Z=7V$

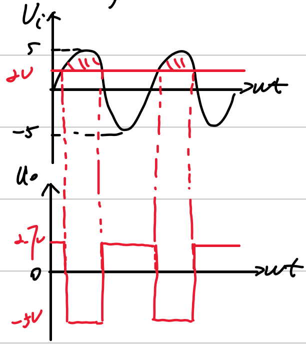


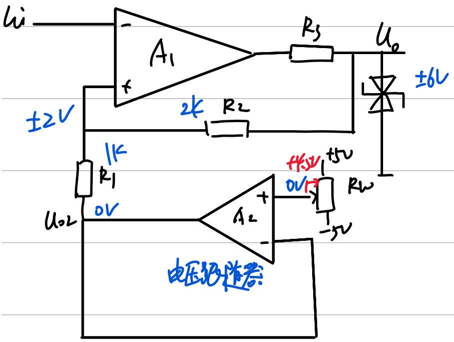
$u_i>2V$ u_o是负的 稳压管稳压 $u_o=-5V$

$u_i<2V$. u_o是正的 稳压管导通 $u_o=+0.7V$



若给出输入电压波形. $u_i=5\sin\omega t(V)$





① 滑动端在中点时. 画出 $u_o=f(u_i)$

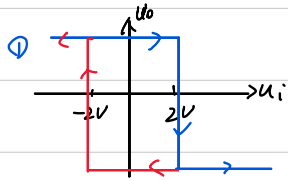
② 若要将电压传输特性向右平移3V.
问滑动端调至多少V!

② $u_+=\frac{R_1}{R_1+R_2}u_o+\frac{R_2}{R_1+R_2}u_{o2}$

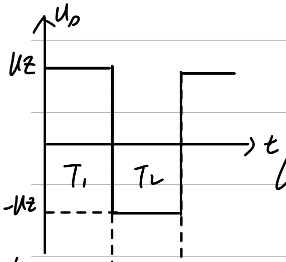
$\frac{R_2}{R_1+R_2}u_{o2}=3V$

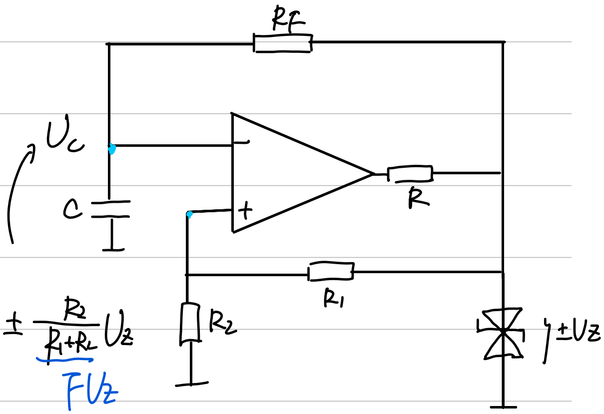
$u_{o2}=+4.5V$.

①

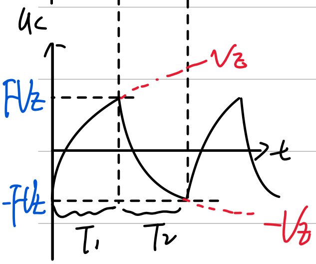


方波产生电路





$$U_{th} = \pm \underbrace{\frac{R_2}{R_1+R_2}}_{} U_Z = FV_Z$$



$$U_c(t) = U_c(\infty) + [U_c(0^+) - U_c(\infty)] \cdot e^{-\frac{t}{\tau}}$$

$$u_c(t) = V_Z + [-FV_Z - V_Z] \cdot e^{-\frac{t}{R_F C}}$$

令 $t = T_1$. $U_c(t) = FV_Z$ 代入 $T_1 = R_F C \ln\frac{1+F}{1-F}$

$$U_c(t) = -V_Z + [FV_Z + V_Z] \cdot e^{-\frac{t}{R_F C}}$$

终了值 $U_c(+\infty) = +V_Z$

$U_c(+\infty) = -V_Z$

令 $t = T_2$. $U_c(t) = -FV_Z$ 代入 $T_2 = R_F \cdot C \ln\frac{1+F}{1-F}$

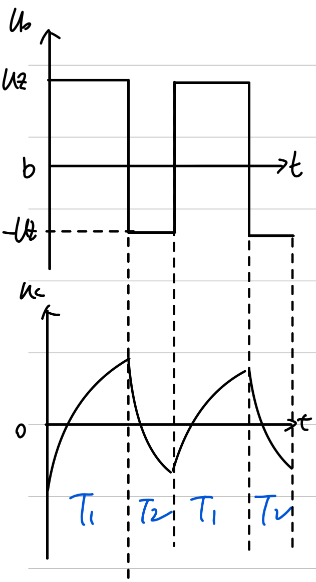
$T_1 = T_2$ ∴ 周期为 $T = 2T_1 = 2R_F C \ln\frac{1+F}{1-F}$ 方波

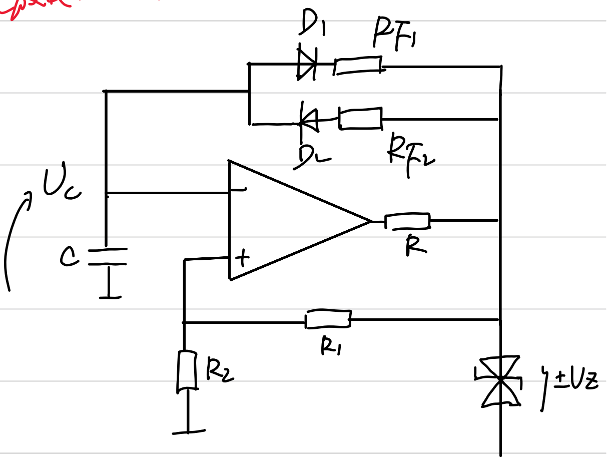
频率为 $f = \frac{1}{T}$

日期: /

(控制电容的充放电时间)

矩形波发生电路:



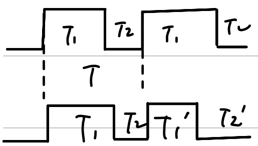


$$T_1 = R_{F_1} C \ln \frac{1+F}{1-F}$$

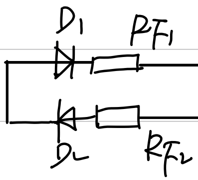
$$T_2 = R_{F_2} C \ln \frac{1+F}{1-F}$$

$$T = T_1 + T_2 = (R_{F1} + R_{F2}) \cdot C \ln \frac{1+F}{1-F}$$

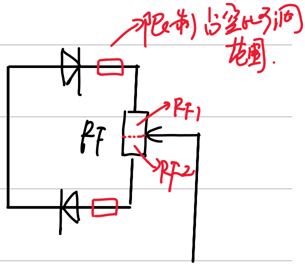
占空比: $\frac{T_1}{T} \times 100\%$



若要占空比可调:



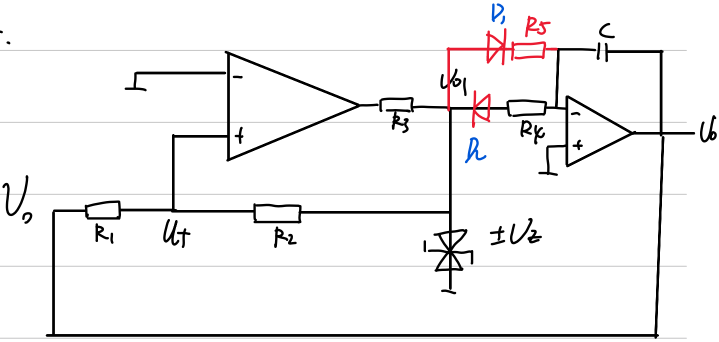
改成



日期: /

当 U_{o1} 为负时. D_2通, 此时. $\tau = R_4 \cdot C$

三角波产生电路.

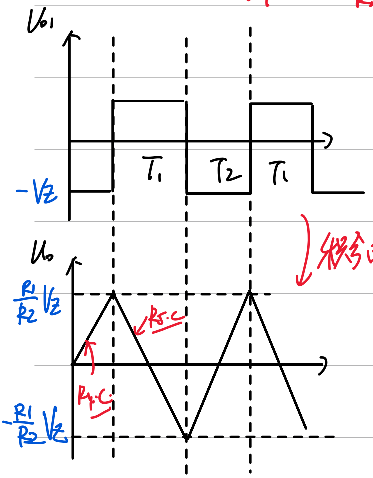


$$U_+ = \frac{R_1}{R_1+R_2} U_{o1} + \frac{R_2}{R_1+R_2} U_o = 0$$

$$U_o = -\frac{R_1}{R_2} U_{o1} \begin{cases} +U_Z \\ -U_Z \end{cases}$$

$$U_{T+} = +\frac{R_1}{R_2} V_Z$$

$$U_{T-} = -\frac{R_1}{R_2} V_Z$$



积分电路

充放电电流为常数.

$$U_o = -\frac{1}{R_4 C}\int U_{o1}\,dt + K$$ 初始值

$$= -\frac{1}{R_4 C}\int V_Z\,dt + \frac{R_1}{R_2} V_Z$$

$$-\frac{R_1}{R_2} V_Z = \frac{-V_Z}{R_4 C} \cdot T_1 + \frac{R_1}{R_2} V_Z$$

$$T_1 = \frac{2R_1 R_4 C}{R_2} = T_2$$

$$T = T_1 + T_2 = \frac{4R_1R_4C}{R_2}$$

锯齿波: $T_1 \ll T_2$ 　　 $T_2 \gg T_1$

可省去 D_1 　 $R_4 \ll R_5$ 　　 $R_4 \gg R_5$ 　 可省去 D_2

(大电阻串联二极管可省略)

三角波幅度可调: 在 U_{o1} 处加一个电位器

日期:　　/

条件: $R_1 >> R_2$

压控振荡电路

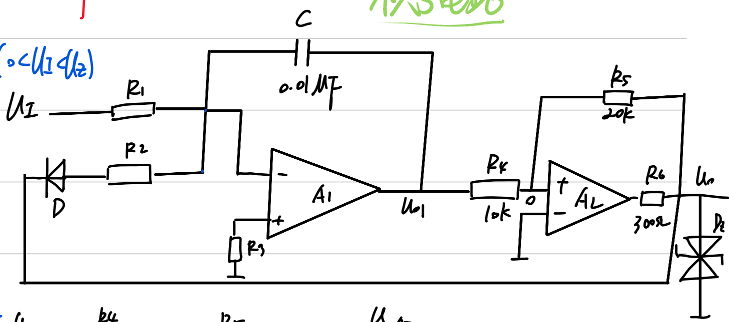
$(0<U_I<U_Z)$

理想运放:

$U_{om}=\pm 12V.\ U_D=0.$

$f_0=kU_I$

积分电路



<1> $U_o=+U_Z$　D截止

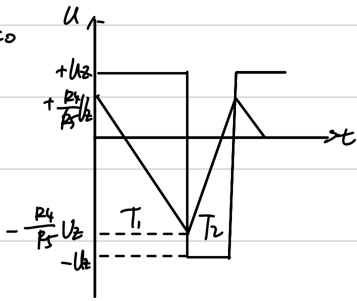
$u_+ = \frac{R_4}{R_4+R_5}U_o + \frac{R_5}{R_4+R_5}u_{o1}=0$

$u_{o1}=-\frac{1}{R_1C}U_I t+\frac{R_4}{R_5}U_Z$

$u_{o1}=-\frac{R_4}{R_5}U_Z$

$-\frac{R_4}{R_5}U_Z=-\frac{1}{R_1C}U_I T_1+\frac{R_4}{R_5}U_Z$

$\therefore T_1=\frac{2R_1R_4C}{R_5}\cdot\frac{U_Z}{U_I}$



$R_1>>R_2$

$\Rightarrow T_1>>T_2$

<2> $U_o=-U_Z$　D导通

$u_{o1}=-\frac{1}{C}\left[\cancel{\frac{U_I}{R_1}}+\frac{-U_Z}{R_2}\right]t-\frac{R_4}{R_5}U_Z \approx \frac{U_Z}{R_2C}t-\frac{R_4}{R_5}U_Z$

令 $t=T_2$

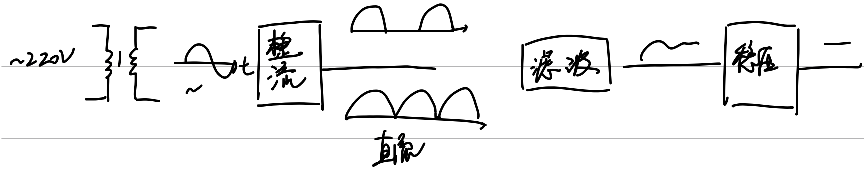
$+\frac{R_4}{R_5}U_Z=\frac{U_Z}{R_2C}T_2-\frac{R_4}{R_5}U_Z$　　$\therefore T_2=\frac{2R_2R_4C}{R_5}$

$\therefore T=T_1+T_2\approx T_1$　　$f=\frac{1}{T}\approx\frac{1}{T_1}=\frac{R_5}{2R_1C\cdot R_4\cdot U_Z}U_I$

$f_0=200U_I$

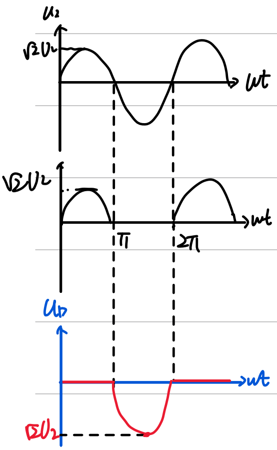
当 $U_I=0\sim10V$, $f_0=0\sim2kHz$

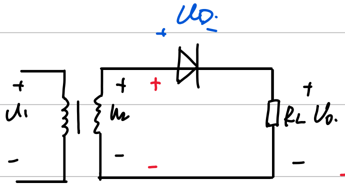
日期: /



整流电路

1.单相半波整流电路





正半周: $u_o = u_2$

负半周: $u_o = 0$

$u_2 = \sqrt{2}U_2 \sin\omega t$

$$U_o = \frac{1}{2\pi}\int_0^{\pi}\sqrt{2}U_2 \sin\omega t\, d\omega t = \frac{\sqrt{2}}{2\pi}U_2 \cdot 2 = \frac{\sqrt{2}}{\pi}U_2 = 0.45U_2$$ 输出电压

$$I_o = \frac{U_o}{R_L}$$

$$I_D = I_o$$

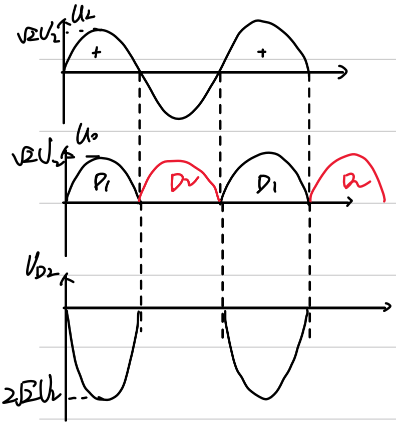
$$U_{DRM} = \sqrt{2}U_2$$

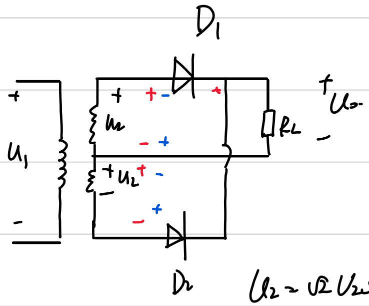
反向最大电压

$u_o = 0.45U_2$

$I_o = \frac{U_o}{R_L}$

2. 单相全波整流





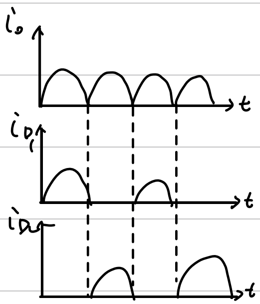
$u_2 = \sqrt{2}U_2 \sin\omega t \, d\omega t$

正半周，D_1导通，D_2截止

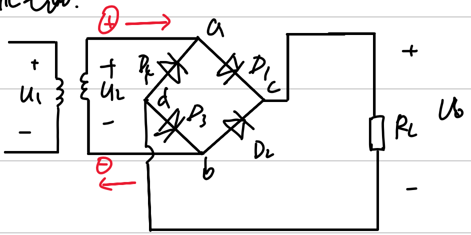
负半周．D_1截止．D_2导通

$$\begin{cases} U_o = 0.9U_2 \\ I_o = \dfrac{U_o}{R_L} \end{cases}$$

$$\begin{cases} I_D = \dfrac{1}{2} I_o \\ U_{DRM} = 2\sqrt{2}U_2 \end{cases}$$



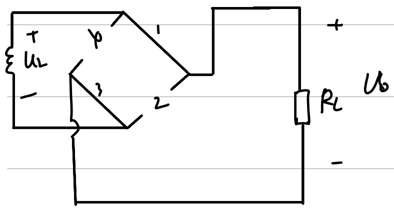
3. 单相桥式整流电路



$u_2 = \sqrt{2}U_2 \sin\omega t$

正半周：D_1、D_3导通．

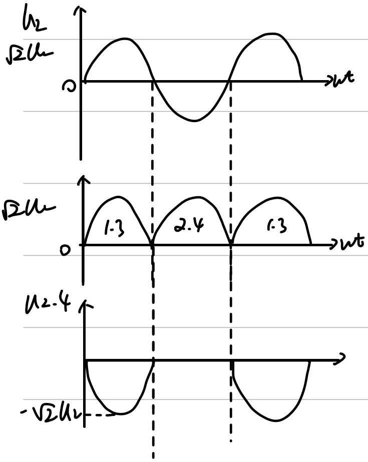
D_2．D_4截止



1.3是串联．2.4并联

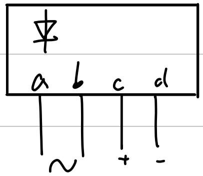
（导通的都是串联的．截止的都是并联的）

日期:　　　/

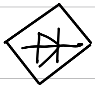


$$\begin{cases} U_0 = 0.9U_2 \\ I_0 = \dfrac{U_0}{R_0} \end{cases} \qquad \begin{cases} I_D = \dfrac{1}{2}I_0 \\ U_{DRM} = \sqrt{2}U_2 \end{cases}$$

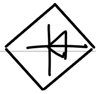
桥堆



符号:



输出正电压

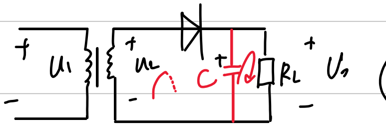


输出负电压

滤波电路

1.电容滤波(适合于小负载)

$R_L\to\infty$ $U_o=\sqrt{2}U_2$

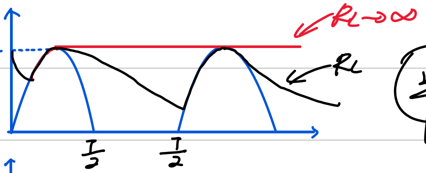


$\tau=R_LC$ → 大 电解电容

$u_2=\sqrt{2}U_2\sin\omega t$

半波. 接入R_L $U_o=U_2$

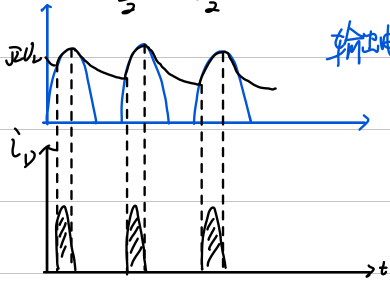
(条件. $R_L\cdot C\geq(3\sim5)\frac{T}{2}$)



半波

全波 桥式 $U_o=(1.1\sim1.2)U_2$

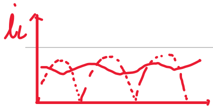
$U_o=1.2U_2$ ✓



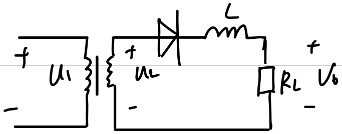
输出电压高. T↓

2.电感滤波

$$\begin{cases}U_o=0.45U_2\\U_o=0.9U_2\end{cases}$$

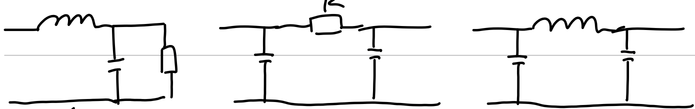


波形较平稳



$u_2=\sqrt{2}U_2\sin\omega t$

3.其他滤波:



倒L　　RC π型　　LC π型

R_L断开 → $1.414U_2$ ($\sqrt{2}U_2$)

半波无C → $0.45U_2$

半波有C → U_2

全波无C → $0.9U_2$

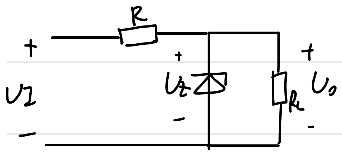
全波有C → $1.2U_2$

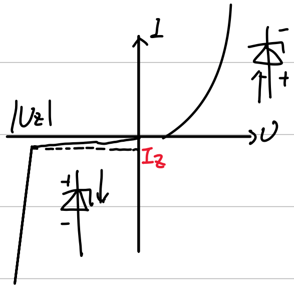
* 求C　$f=50Hz$

条件. $R_LC\geq(3\sim5)\cdot\frac{T}{2}$　$T=20ms$

日期:　　　/

稳压管稳压电路

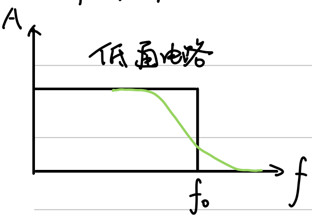




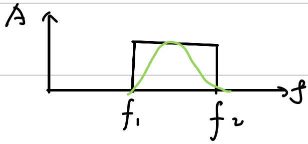
日期: /

一阶有源滤波电路

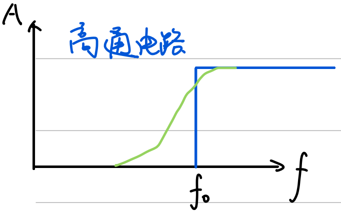
低通电路



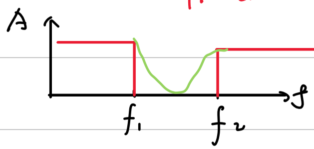
带通电路



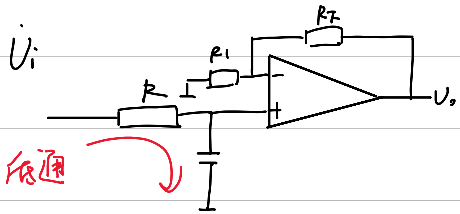
高通电路



带阻电路



1. 低通有源滤波电路:



$$\frac{\dot U_o}{\dot U_+} = 1+\frac{R_f}{R_1} = A_{uf}$$

$$\frac{\dot U_+}{\dot U_i} = \frac{\frac{1}{j\omega C}}{R+\frac{1}{j\omega C}} = \frac{1}{1+j\omega RC}$$

$A_0 \longrightarrow$ 通带电压放大倍数

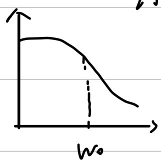
令 $\omega_0 = \frac{1}{RC}$

$$A(s) = \frac{U_o(s)}{U_i(s)} = \frac{U_o(s)}{U_+(s)} \cdot \frac{U_+(s)}{U_i(s)}$$

$$\dot A = \frac{A_0}{1+j\frac{\omega}{\omega_0}}$$

$$A(s) = \frac{A_0}{1+sRC}$$

传递函数.



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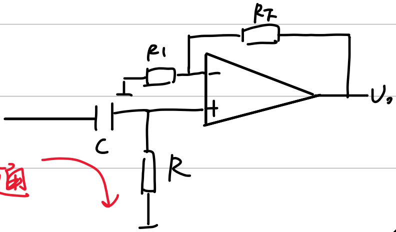
2. 高通有源滤波器



高通

$$\frac{\dot U_o}{\dot U_+} = 1+\frac{R_f}{R_1} = A_{uF}$$

$$\frac{\dot U_+}{\dot U_i} = \frac{R}{R+\frac{1}{j\omega C}} = \frac{j\omega RC}{1+j\omega RC}$$

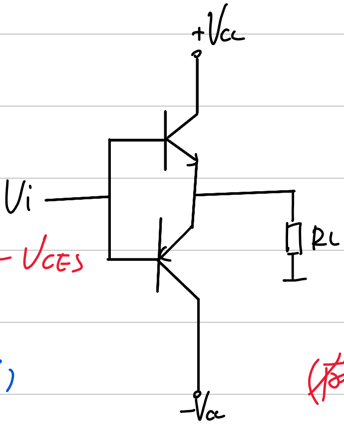
令 $\frac{1}{\omega_0} = RC$ $= \frac{\frac{\omega}{\omega_0}}{1+j\frac{\omega}{\omega_0}}$

$$A(s) = \frac{A_0 \cdot j\frac{\omega}{\omega_0}}{1+j\frac{\omega}{\omega_0}}$$

功率放大电路.

<1> P_o. P_{Vcc}. η P_T

<2> 功率管的选择



双电源互补

$U_{om} = V_{CC} - U_{CES}$ 代入

$$P_o = \frac{1}{2}\frac{U_{om}^2}{R_L}$$

$$P_{V_{CC}} = \frac{U_{om}V_{CC}}{\pi R_L}$$ (一个电源)

乙类 (存在交越失真)

若是两个电源

$$P_{V_{CC}} = \frac{2U_{om}\cdot V_{CC}}{\pi R_L}$$

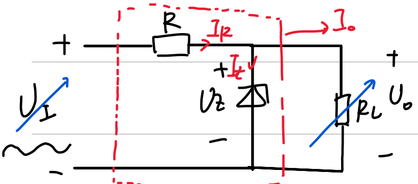
$$\eta = \frac{P_{V_{CC}}}{P_o} = \frac{\pi}{4}\frac{U_{om}}{V_{CC}}$$

$P_T = P_{V_{CC}} - P_o$ 两个管的损耗

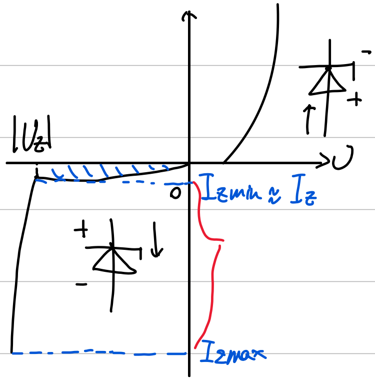
$P_{T1} = \frac{1}{2}P_T$ 一个——

日期:　　/

稳压管稳压电路:



$0.9U_I \sim 1.1U_I$



$I_o = \frac{U_o}{R_L}$　　$R_L: 1k \sim 6k$.

$$I_Z = I_R - I_o$$

$$P_{Zmax} = U_Z \cdot I_{Zmax}.$$

$$\begin{cases} I_{Zmax} > \frac{U_{imax} - U_Z}{R} - I_{omin} \\ I_{Zmin} < \frac{U_{imin} - U_Z}{R} - I_{omax} \end{cases}$$

$$\begin{cases} I_{Zmax} = (2\sim3) \cdot I_{omax} \\ U_Z = U_o \end{cases}$$

$R = 2k\Omega$.　　$P_R \geq (2\sim3)\frac{(U_{imax} - U_Z)^2}{R}$

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