非线性电子线路

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1.2 （2）

解: $i=5u+u^2-0.5u^2(mA)$ $\quad U_Q=3.5V, u=U_Q+0.8\cos\omega t(V)$

$$I_Q=5U_Q+U_Q^{\,2}-0.5U_Q^{\,3}=8.3mA$$

$$G_Q=\frac{I_Q}{U_Q}=\frac{8.3mA}{3.5V}=2.375mS$$

$$g=\frac{\partial i}{\partial u}\bigg|_{u=U_Q}=5+2u-1.5u^2\bigg|_{u=U_Q}=-6.375ms$$

将 $u=U_Q+0.8COSwt(V)$ 代入 $i=5u+u^2-0.5u^3(mA)$ 并计算得:

$$I_1=4+1.6U_Q-0.192-1.2U_Q^{\,2}=-5.292mA$$

$$G_{m1}=\frac{I_1}{U_1}=-\frac{5.292}{0.8}=-6.615ms$$

1.3 （2）

解: 设 $u = 0.5\cos 2\pi\times 1.5\times 10^5 t + 2\cos 2\pi \times 2\times 10^5 t(V)$

$$w_1 t = 2\pi\times 1.5\times 10^5 t, w_2 t = 2\pi\times 2\times 10^5 t$$

$$u=0.5\cos w_1 t+2\cos w_2 t$$

$$i = 5u + u^2 - 0.5u^3 = 5(0.5\cos\omega_1 t + 2\cos\omega_2 t) +$$

$$(0.5\cos w_1 t+2\cos w_2 t)^2-0.5(0.5\cos w_1 t+2\cos w_2 t)^3$$

计算得直流分量: 2.125ms

$$w_1{:}0.9531mA; w_2{:}608125mA; 2w_1{:}0.125mA; 2W_2{:}2mA;$$

$$w_1\pm w_2{:}1mA; 3w_1{:}-0.015625mA; 3w_2{:}-1mA;$$

$$2w_1\pm w_2{:}-0.09375mA; w_1\pm w_2{:}-0.75mA.$$

1.4 （2）

$$C_j = 20(1+0.25u)^{-0.5}(pF);u \in (1,3)$$

$$C = C_j + 20 = 20\left[1+(1+0.25u)^{-0.5}\right]$$

$$L = 10\mu h$$

$$f = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{10\times10^{-6}\times20\times\left[1+(1+0.25u)^{-0.5}\right]\times10^{-12}}}HZ$$

$$u=1, f=8.17\times10^{6}HZ,$$

$$u=3, f=8.49\times10^{6}HZ.$$

2.1

（1）恒流源: $$I_{C2}=\beta I_{B2},I_{E2}=(1+\beta)I_{B2}$$

$$\beta=\frac{\alpha}{1-\alpha}=\frac{0.98}{0.02}=49$$

$$2(I_{C2}+2I_{B2})+U_{BE}+0.5I_{E2}=6$$

解得: $$I_K=I_{C2}=2.05mA$$

（2）静态时: $$U_{BE}=-U_{CEO}$$

$$I_K=I_{ES}e^{\frac{U_{BE}}{U_r}}=I_{ES}e^{-\frac{U_{CEO}}{U_r}}$$

解得: $$U_{CEO}=-U_r\ln\frac{I_K}{I_{ES}}=-778.85mV$$

2.1

（3）由

$$x = \frac{U_i}{U_r} = 20$$

$$I_{E0} = I_{ES} e^{\frac{U_{BE}}{U_r}} I_0(x) = I_K$$

查表得: $I_0(20) = 0.08978 \times e^{20}$

解得:

$$U_{BE} = U_r [\ln \frac{I_K}{I_{ES}} - \ln I_0(20)] = 321.52mv$$

$$U_{CE} = -U_{BE} = -322mv$$

2. 2

$$x = \frac{U_i}{U_r} = 10$$

（1）由 $\omega = \frac{1}{\sqrt{LC}} = 10^7$ 网络调谐于基波频率

$$Q_T = \omega RC = 50$$

$$G_{m1} = \frac{\alpha I_{E0}}{U_r} \frac{2I_1(x)}{xI_0(x)}$$ 查表得: $$\left. \frac{2I_1(x)}{xI_0(x)} \right|_{x=10} = 0.18972$$

所以: $G_{m1} = 7.3ms$

$$u_o(t) = 10 + G_{m1} U_i R_L \cos \omega t = 10 + 4.74 \cos 10^7 t \quad V$$

$$THD = D(x) / Q_T = 1.27\%$$

2.2

（2）由 $\omega = \frac{1}{\sqrt{LC}} = 3\times 10^7$ 网络调谐于三次谐波频率

$$Q_T = \omega RC = 50$$

$$G_{m3} = \frac{\alpha I_{E0}}{U_r}\frac{2I_3(x)}{xI_0(x)} = \frac{\alpha I_{E0}}{U_i}\frac{2I_3(x)}{I_0(x)}$$

所以:

$$u_o(t) = 10 + G_{m3}U_iR_L\cos\omega t = 10 + 3.12\cos 3\times 10^7 t \quad V$$

$$\left.\frac{n}{n^2-1}\right|_{n\to\frac{n}{3}} = \frac{3n}{n^2-9}$$

$$THD_3 = \frac{1}{Q_T}\sqrt{\sum_{\substack{n=1\\ n\neq 3}}^{\infty}\left[\frac{I_n(x)}{I_3(x)}\frac{3n}{n^2-9}\right]} = 4.2\%$$

2.3

电阻分压式偏置电路:

$$U_{BB} = \frac{R_{B2}}{R_{B1}+R_{B2}}V_{CC} = 3V$$

$$R_B = R_{B1} \parallel R_{B2} = 33.33K\Omega$$

$$U_{\lambda} = U_{BB} - U_{BEQ} = 2.3v$$

$$x_{\lambda} = \frac{U_{\lambda}}{U_r} = 88.5$$

$$I_{EQ} = \frac{U_{\lambda}}{R_E + \dfrac{R_B}{1+\beta}} = 1.07mA$$

$$g_{mQ} = \frac{\alpha I_{EQ}}{U_{\lambda}} = 40.3mS$$

$$x = \frac{U_i}{U_r} = 15$$

查表得: $I_0(15) = 0.1039e^{15} \quad \frac{2I_1(x)}{xI_0(x)}\Big|_{x=15} = 0.12881$

$$G_{m1}(x) = g_{mQ}[1+\frac{\ln I_0(x)}{x_{\lambda}}]\frac{2I_1(x)}{xI_0(x)} = 5.94ms$$

$$u_0(t) = G_{m1}(x)Ru_i = 2.32\cos w_0 t(v) \qquad P = \frac{(\frac{U_0}{\sqrt{2}})^2}{R_L} = 2.69mW$$

2.4

静态时，$x=10$　　对9V电压源进行诺顿等效

$$I_K = 10V/5k\Omega = 2mA \qquad R' = 5k\Omega$$

又
$$\begin{cases} I_{E0} = I_K - \dfrac{U_E}{5k\Omega} \\ I_{E0} = I_{ES}\exp(\frac{U_{EB}}{u_r})I_0(x) \end{cases}$$

解得
$$\begin{cases} U_{EB} = U_E = 570.2mV \\ I_{E0} = 1.886mA \end{cases}$$

所以

$$G_{m1}(x) = g_{mQ}\cdot\frac{2I_1(x)}{xI_0(x)} = \frac{\alpha I_{E0}}{u_r}\cdot\frac{2I_1(x)}{xI_0(x)} = 13.487ms$$

$$u_0(t) = -9v + G_{m1}(x)\cdot R_L\cdot u_i\cos\omega_0 t$$
$$= -9 + 5.26\cos\omega_0 t \qquad V$$

2.5

恒流源偏置差分放大电路:

$$x=\frac{U_i}{U_r}=2 \quad I_K=2mA \qquad \alpha=\frac{\beta}{1+\beta}=\frac{100}{101}$$

输出端RLC谐振回路: $C=\frac{C_1C_2}{C_1+C_2}=20PF$

$$\omega_0=\frac{1}{\sqrt{LC}}=10^8 rad/s \qquad Q_T=\omega_0 RC=10$$

$$u_o'(t)=V_{CC}-\alpha I_K a_1(2)R_L\cos 10^8 t=10-4.02\cos 10^8 t(v)$$

$$u_o(t)=\frac{60}{60+30}(-4.02\cos 10^8 t)=-2.68\cos 10^8 t(v)$$

$$THD=\frac{1}{Q_T}D(x)=0.25\%$$

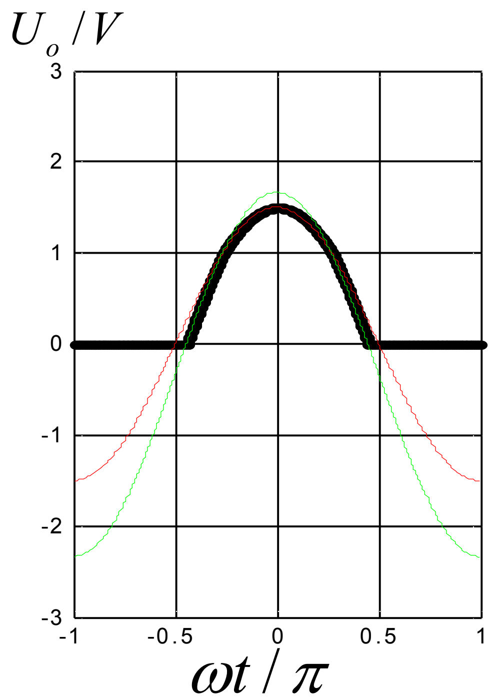
2.7

当 $U_i \le 0.5V$时，VD_1 VD_2截止

$$U_o = 0$$

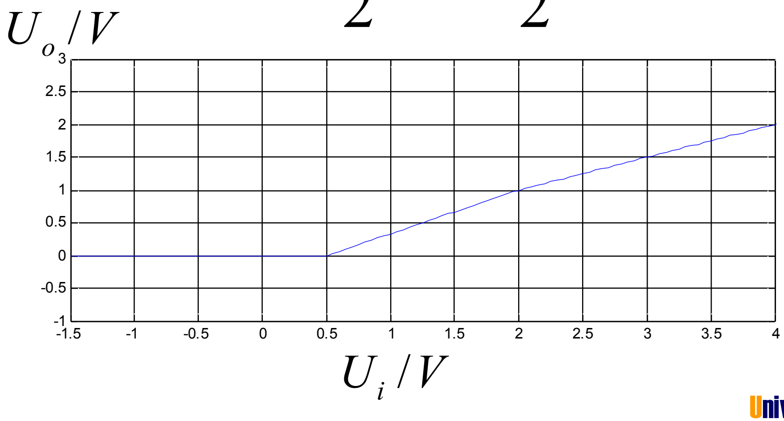
当 $2V \le U_i \le 0.5V$时，VD_1导通 VD_2截止

$$U_o = \frac{2}{3}U_i - \frac{1}{3} = 2\cos\omega t - \frac{1}{3}$$



当 $U_i \ge 2V$时，VD_1 VD_2导通

$$U_o = \frac{1}{2}U_i = \frac{3}{2}\cos\omega t$$



2.8

- 2.8 增强型MOSFET管的转移特性为：

$$i_D = \begin{cases} \beta_n (u_{GS} - 2)^2 & u_{GS} \geq 2V \\ 0 & u_{GS} \leq 2V \end{cases}$$

式中 $\beta_n = 0.8mA/V^2$。求下列情况下等效基波跨导Gm1：

（1） $u_{GS} = U_Q + U_1 \cos \omega t = 3 + \cos \omega t (V);$

（2） $u_{GS} = U_Q + U_1 \cos \omega t = 3 + 2\cos \omega t (V).$

- 解:(1) $u_{GS}=3+\cos\omega t\,(V)\geq 2\,(V)$

此时MOS管工作在完全平方律区

$$\mathrm{i_D}=0.8(3+\cos\omega t-2)^2$$

$$=1.2+1.6\cos\omega t+0.4\cos 2\omega t$$

$$I_{D1}=1.6mA$$

$$G_{m1}=\frac{I_{D1}}{U_1}=\frac{1.6mA}{1V}=1.6mS$$

- (2) $u_{GS} = 3 + 2\cos\omega t\,(V),\ u_{GS\min} = 1V < 2V$

此时MOS管工作在导通角状态。

$$\varphi = \cos^{-1}\frac{U_p - U_Q}{U_1} = \cos^{-1}\frac{2-3}{2} = 120^\circ$$

$$I_P = \frac{I_{DSS}}{U_P^2}U_1^2(1-\cos\varphi)^2$$

$$= \frac{4\beta_n}{2^2}2^2(1-\cos 120^\circ)^2$$

$$= 7.2mA$$

$$I_{D1} = I_P\alpha_1(120^\circ) = 3.457mA$$

$$G_{m1} = \frac{I_{D1}}{U_1} = \frac{3.457}{2} = 1.728mS$$

2.10

- 2.10自生负偏压场效应管放大电路如图E2.8所示。场效应管的参数为：I_{DSS}=6mA，U_P=-4V。又知漏极回路的中心频率$\omega_0 = 10^7 rad/s$，带宽$BW = 5 \times 10^5 rad/s$。若已知漏极电流的均值分量为1.8mA。求：
- (1)回路压降幅度及其总谐波失真THD；
- (2)场效应管的平均功耗和电压增益。

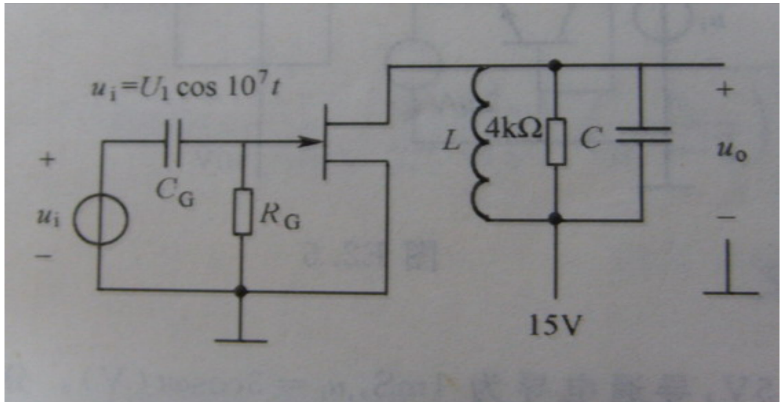


图 E2.8

- 解: $I_{D0} = 1.8mA, \quad Q_T = \dfrac{\omega_0}{BW} = 20$
- (1)

$$u_{GS} = -U_1 + U_1 \cos \omega t$$

$$\varphi = \cos^{-1}\frac{U_P - U_Q}{U_1} = \cos^{-1}\frac{-4-(-U_1)}{U_1}$$

$$= \cos^{-1}(1-\frac{4}{U_1})$$

$$I_P = I_{DSS} = 6mA$$

由$I_{D0} = I_P \alpha_0(\varphi) = 1.8mA$

得到$\alpha_0(\varphi) = 0.3 \Rightarrow \varphi = 110^\circ$

$$I_{D1} = I_P \alpha_1(\varphi) = 2.799mA$$

$$\mathrm{U_o = I_{D1} R = 11.2V}$$

$$\mathrm{U_1 = 2.981V}$$

$$\mathrm{THD} = \frac{1}{\mathrm{Q_T}} D(\varphi) = 1.4\%$$

• (2) $\overline{P} = \frac{1}{2\pi}\int_0^{2\pi} u_{ds} i_D \, d\omega t$

$$= \frac{1}{2\pi}\int_0^{2\pi} (15 - 11.2\cos\omega_0 t)(1.8 + 2.8\cos\omega_0 t)\, d\omega t$$

$$= 11.32 mW$$

其中$\mathrm{u}_{ds} = 15 - 11.2\cos\omega_0 t$

$$Au = \frac{Uo}{Ui} = \frac{11.2}{2.981} = 3.76$$

2.12

- 2.12在如图E2.10所示电路中，场效应管I_{DSS}=10mA，U_P=-4V；C_G=0.1μF,R_G=1MΩ；回路中心频率为f_0，Q_T=20。输入信号 $u_1 = U_1\cos 2\pi f_1 t\,(V), u_2 = U_2\cos 2\pi f_2 t\,(V)$ 计算以下两种情况下的输出电压表达式：

(1) $U_1 = 2V, f_1 = 1.465MHz, U_2 = 0.2V, f_2 = 1MHz, f_0 = 465kHz$；

(2) $U_1 = \frac{8}{3}V, f_1 = 10MHz, U_2 = 0.3V, f_2 = 250kHz, f_0 = f_1$。

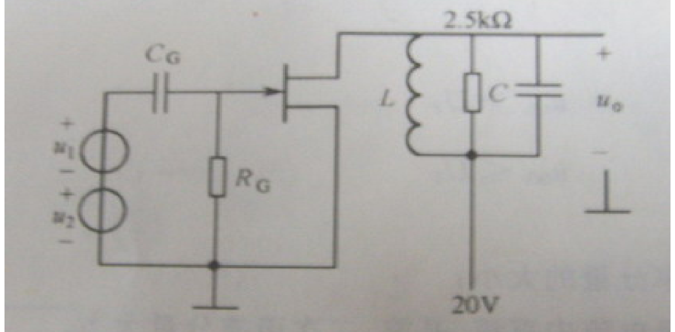


图 E2.10

解:(1) $U_{GS} = -U_1 + U_1\cos\omega_1 t$ $\qquad \varphi = \cos^{-1}\dfrac{-4+2}{2} = 180^\circ$

$$= -2 + 2\cos\omega_1 t$$

$$i_D = I_{DSS}(1 - \frac{u_{GS}}{U_P})^2$$

$$g = \frac{\partial i_D}{\partial u_{GS}}\bigg|_{u_{GS}=-2+2\cos 2\pi f_1 t} = \frac{2I_{DSS}}{U_P}(\frac{u_{GS}}{U_P} - 1)\bigg|_{u_{GS}=-2+2\cos 2\pi f_1 t}$$

$$= \begin{cases} 5(\dfrac{u_{GS}}{4} + 1) & U_P \le u_{GS} \le 0 \\ 0 & u_{GS} < U_P \end{cases}$$

$$g_P = 5mS,\ g_1 = g_P \alpha_1(\varphi) = 2.5mS$$

$$I_{IF} = \frac{1}{2} g_1 U_2 = 0.25mA$$

$$u_o = 20 - I_{IF} R\cos[2\pi(f_2 - f_1)t]$$

$$= 20 - 0.625\cos 2\pi \times 465 \times 10^3 t \ \ (V)$$

- (2) $BW=\dfrac{f_0}{Q_T}=\dfrac{10\times10^6}{20}=500kHz$

u_o包含f_1, f_1+f_2, f_1-f_2

$$U_{GS}=-\frac{8}{3}+\frac{8}{3}\cos\omega_1 t$$

$$\varphi=\cos^{-1}\frac{-4+\frac{8}{3}}{\frac{8}{3}}=120^\circ$$

$$I_{D1}=I_P\alpha_1(\varphi)=10\times\alpha_1(120^\circ)=4.801mA$$

$$g=\frac{\partial i_D}{\partial u_{GS}}\bigg|_{u_{GS}=-U_1+U_1\cos\omega_1 t}=\begin{cases}5(1+\dfrac{u_{GS}}{4}) & U_P\le u_{GS}\le 0\\ 0 & u_{GS}<U_P\end{cases}$$

$$g_1=g_P\alpha_1(\varphi)=5\times\alpha_1(120^\circ)=2.6815mS$$

$$I_{IF}=\frac{1}{2}g_1U_2=0.40225mA$$

$$BW = 500KHz = 2f_2$$

故$f_1 - f_2$，$f_1 + f_2$落在通带的边缘，其对应的幅度为$\frac{1}{\sqrt{2}}$，

相应的相位差分别偏移$\frac{\pi}{4}$和$-\frac{\pi}{4}$。

故

$$u_o = 20 - [I_{D1}R\cos\omega_1 t + \frac{1}{\sqrt{2}}I_{IF}R\cos((\omega_1+\omega_2)t - \frac{\pi}{4}) + \frac{1}{\sqrt{2}}I_{IF}R\cos((\omega_1-\omega_2)t + \frac{\pi}{4})]$$

$$= 20 - 12[1 + 0.11847\cos(2\pi\times 250\times 10^3 t - \frac{\pi}{4})]\cos 2\pi\times 10^7 t \quad (V)$$

2.14

- 2.14在如图E2.12(a)所示电路模型中，耦合电容足够大，VD为指数律二极管，其I_S=2exp(-30)mA，$u_i(t)$为图(b)所示的周期波形。
- (1)画出输出电压波形并注明电平值；
- (2)求输入电压低电平为-520mV时电路的自生负偏压系数ξ。

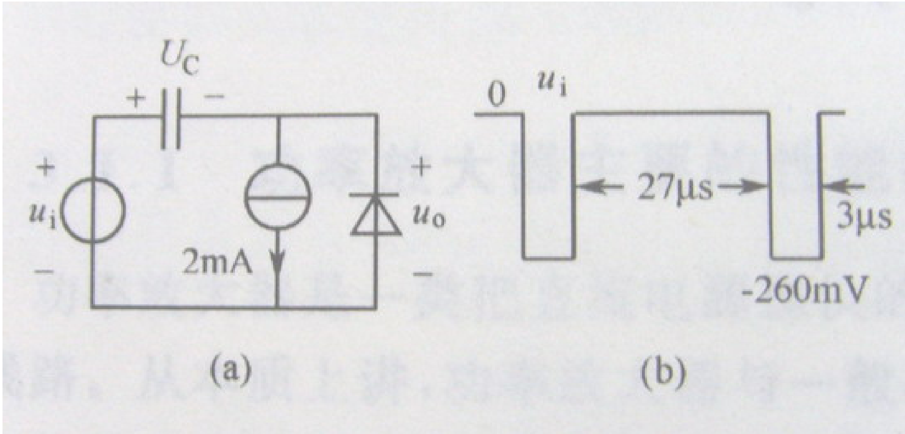


图 E2.12

解:(1)由图有：

$$i_C = 2 - i_D$$

流经耦合电容C的均值电流为0,

即： $\overline{i_C} = 2 - \overline{i_D} = 0 \qquad (*)$

因为 $i_D = I_S e^{\frac{-U_o}{U_r}} = I_S e^{\frac{U_C - U_i}{U_r}}$

$$= I_S e^{\frac{U_C}{U_r}} e^{-\frac{U_i}{U_r}}$$

所以 $\overline{i_D} = I_S e^{\frac{U_C}{U_r}} \overline{e^{-\frac{U_i}{U_r}}}$

$$\overline{e^{-\frac{U_i}{U_r}}} = \frac{1}{30}\int_0^3 e^{-\frac{U_i}{U_r}} dt + \frac{1}{30}\int_3^{30} 1 dt$$

$$= \frac{1}{10} e^{-\frac{U_i}{U_r}} + \frac{9}{10}$$

$$\approx \frac{1}{10} e^{-\frac{U_i}{U_r}} \quad (\text{此处} U_i = -260mV)$$

故： $\overline{i_D} = I_S e^{\frac{U_C}{U_r}} \cdot \frac{1}{10} e^{-\frac{U_i}{U_r}} = \frac{1}{10} e^{\frac{U_C - U_i}{U_r}}$

将$\overline{i_D}$代入(*)式,有:

$$U_C = U_r \ln\frac{20}{I_S} + U_i = 840 - 260$$

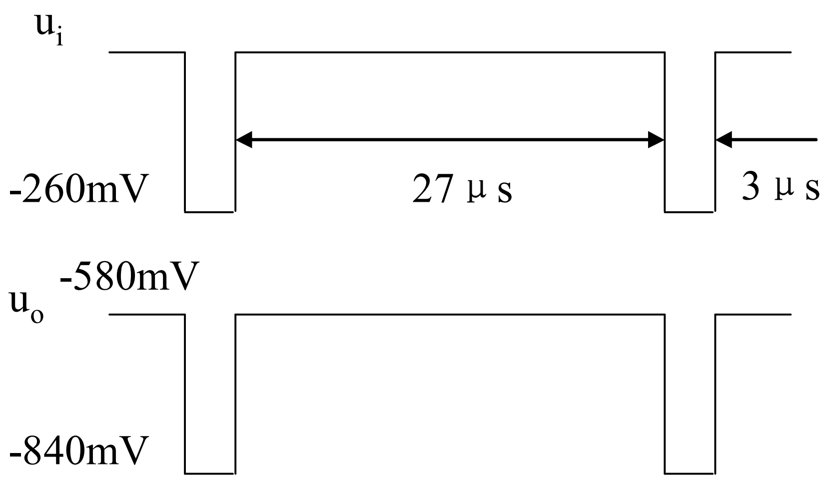
$$= 580mV$$

所以

$$u_o = u_i - u_C$$
$$= u_i - U_C$$
$$= u_i - 580(mV)$$

当$U_i = 0$时,$u_o = -580mV$

当$U_i = -260mV$时,$u_o = -840mV$



(2)同(1)中

$$\overline{i_D} = I_S e^{\frac{U_C}{U_r}} \overline{e^{-\frac{U_i}{U_r}}} = 2mA$$

$$\overline{e^{-\frac{U_i}{U_r}}} = \frac{1}{30}\int_0^3 e^{-\frac{U_i}{U_r}} dt + \frac{1}{30}\int_3^{30} 1 dt$$

$$= \frac{1}{10} e^{-\frac{U_i}{U_r}} + \frac{9}{10}$$

$$\therefore \quad I_S e^{\frac{U_C}{U_r}} \left(\frac{1}{10} e^{-\frac{U_i}{U_r}} + \frac{9}{10}\right) = 2$$

故有 $U_C = -U_r[\ln\frac{I_S}{20} + \ln(e^{-\frac{U_i}{U_r}} + 9)]$

$$\frac{dU_C}{dU_i} = \frac{e^{-\frac{U_i}{U_r}}}{e^{-\frac{U_i}{U_r}} + 9}$$

$$\xi = -\frac{dU_C}{dU_i}\Big|_{U_i = -520mV} = -1$$

(U_C和U_i参考方向相反)

2.16

- 2.16在如图E2.14所示电路中，C=100μF，r=50Ω，非线性电阻特性为 $i_o = 3u_o + 2u_o^2 (mA)$ 计算当输入信号为图E2.14(a)所示时，电阻r所消耗的功率。

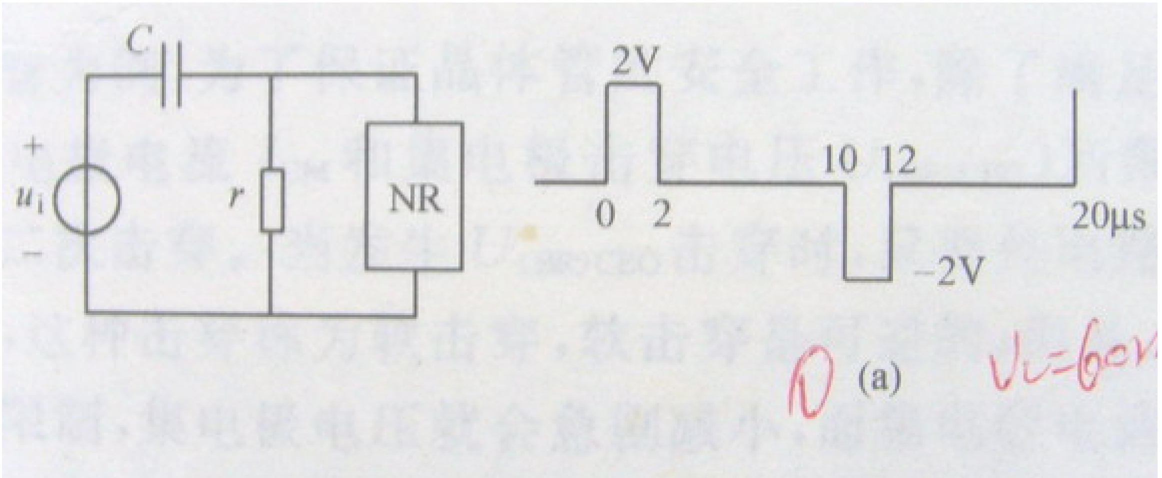


图 E2.14

解：由图有

$$u_o = U_C + u_i$$

稳态时，流经电容C的均值电流为0

即：$\overline{i_C} = \overline{i_r + i_o} = 0$

而 $$\overline{i_r + i_o} = \overline{\frac{u_o}{r} + 3u_o + 2u_o^2}$$

$$= \overline{23u_o + 2u_o^2}$$

$$= 2U_C^2 + 23U_C + (8U_C + 23)\overline{u_i} + 2\overline{u_i^2}$$

$$= 2U_c^2 + 23U_C + 1.6$$

所以 $2U_c^2 + 23U_C + 1.6 = 0$

得到 $\mathrm{U_C} = -0.07\mathrm{V}$

$$\mathrm{P_r} = \frac{1}{20}\int_0^{20} \frac{u_o^2}{r} dt$$

$$= \frac{1}{20}\int_0^{2} [\frac{(u_i - 0.07)^2}{0.05}] dt\Big|_{u_i=2V}$$

$$+ \frac{1}{20}\int_{10}^{12} [\frac{(u_i - 0.07)^2}{0.05}] dt\Big|_{u_i=-2V}$$

$$= 16.1mW$$

2.18

- 2.18求如图E2.16所示电路在不同输入和不同负载条件下回路的有载Q_T及输出电压u_o表达式。
- (1) $i_i(t)=4\cos10^7t(\text{mA})$,负载如图(a)所示，VD为指数律二极管。

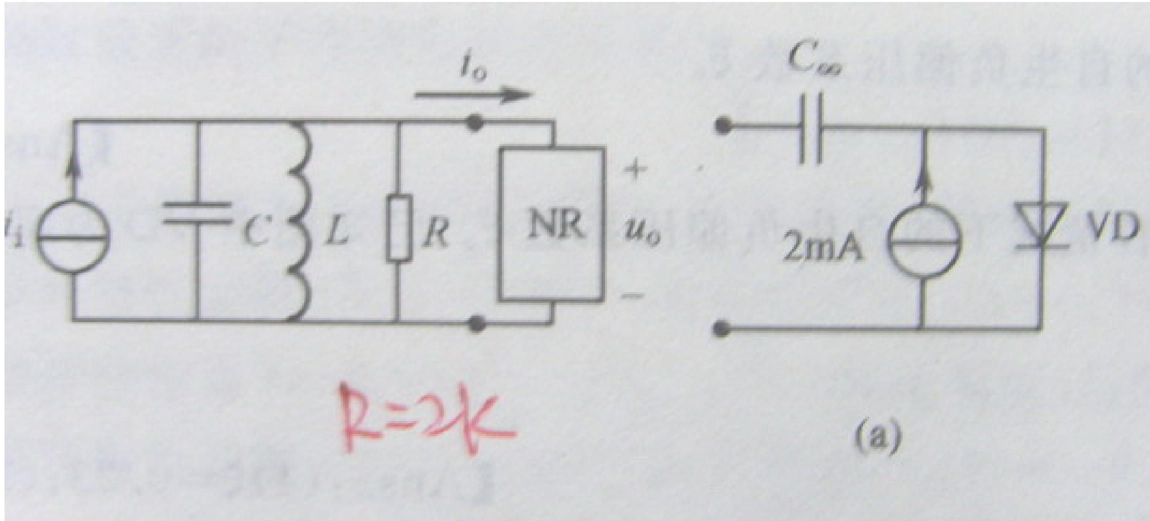


图 E2.16

解：

基波线性负载方程为：

$$I_{o1} = I_{i1} - GU_o = 4 - 0.5U_o \qquad (1)$$

基波非线性负载方程为：

$$I_{o1} = I_{o0}\frac{2I_1(x)}{I_0(x)} = 2mA \times \frac{2I_1(x)}{I_0(x)} \qquad (2)$$

$$x = \frac{U_o}{U_r} \qquad (3)$$

联立上面三个方程有：

$$\frac{I_1(x)}{I_0(x)} = 1 - 0.125U_o = 1 - 0.00325x$$

因为

当$x=12$时，$\dfrac{I_1(x)}{I_0(x)}=0.95736$，$U_o=0.312V$， $1-0.00325x=0.961$

当$x=13$时，$\dfrac{I_1(x)}{I_0(x)}=0.96072$，$U_o=0.338V$， $1-0.00325x=0.95775$

最后求得$x=12.57$，$U_o=0.3286V$，代入(2)式有：$I_{o1}=3.84mA$

故：$u_o(t)=0.3286\cos 10^7 t(V)$

$$G_{NS} = \frac{I_{o1}}{U_o} = \frac{3.84mA}{0.3268V} = 11.75mS$$

$$Q_T = \frac{\omega C}{G + G_{NS}} = Q_0 \frac{G}{G + G_{NS}}$$

$$= 400 \times \frac{G}{G + G_{NS}}$$

$$= 400 \times \frac{0.5}{0.5 + 11.75}$$

$$= 16.33$$

2.18

$$R = 2k\Omega, \quad L = 0.5\mu H, \quad C = 0.02\mu F$$

$$\omega = \frac{1}{\sqrt{LC}} = 10^7 rad/s \qquad Q_0 = \omega CR = 400$$

（1）VD为指数律二极管 $\quad i_i(t) = 4\cos 10^7 t$

假设Q_T足够高 $\quad u_o(t) = U_{o1}\cos\omega t$

流过VD直流分量 $\quad \overline{i_D} = I_K = 2mA$

由指数律： $\quad \dfrac{I_{o1}}{I_K} = \dfrac{2I_1(x)}{I_0(x)} \qquad x = \dfrac{U_{o1}}{26mV}$

基波线性负载方程： $\quad I_{o1} = I_i - \dfrac{U_{o1}}{R}$

$$\begin{cases} U_{o1} = 0.3268V \\ G_{NS} = I_{o1}/U_{o1} = 11.74ms \end{cases} \qquad Q_T = Q_0\frac{G}{G+G_{NS}} = 16.34$$

2.18

（2） $i_i(t)=4\cos 10^7 t$　　开启电压$V_T=3V$

假设Q_T足够高　　$u_o(t)=U_{o1}\cos\omega t$

非线性器件导通角　$\varphi=\arccos\dfrac{3}{U_{o1}}$

基波电流：　$I_{o1}=\dfrac{1}{\pi}\int_{-\varphi}^{\varphi}3mA\cdot\cos\theta d\theta=\dfrac{6}{\pi}\sqrt{1-\dfrac{9}{U_{o1}^2}}mA$

基波线性负载方程：　$I_{o1}=I_i-\dfrac{U_{o1}}{R}$

$$\begin{cases} U_{o1}=3.73V \\ I_{o1}=1.135mA \end{cases}$$

$G_{NR}=I_{o1}/U_{o1}=0.304ms$

$u_o(t)=3.73\cos\omega t\quad V$

$Q_T=Q_0\dfrac{G}{G+G_{NS}}=249$

2.18

（3）$i_i(t)$导通角　$\varphi_i=\pi/4$　Q_T足够高 $u_o(t)=U_{o1}\cos\omega t$

激励电流源$i_i(t)$基波分量

$$I_{i1}=\frac{1}{\pi}\int_{-\varphi_i}^{\varphi_i}2mA\cdot\cos\theta d\theta=\frac{4}{\pi}\sin\varphi_i=0.903mA$$

折线二极管导通角：$\varphi=\arccos{U_T}/{U_{o1}}$

$$I_P=G\left(U_{o1}-U_T\right)\qquad\qquad I_{o1}=\alpha_1(\varphi)I_P$$

基波线性负载方程：$I_{o1}=I_{i1}-\dfrac{U_{o1}}{R}$

$$\begin{cases}U_{o1}=1.152V\\ I_{o1}=0.327mA\end{cases}\qquad \begin{array}{l}\varphi=29.77^o\\ G_{NR}=I_{o1}/U_{o1}=0.284ms\end{array}$$

$$u_o(t)=1.152\cos\omega t\quad V\qquad Q_T=Q_0\frac{G}{G+G_{NS}}=256$$

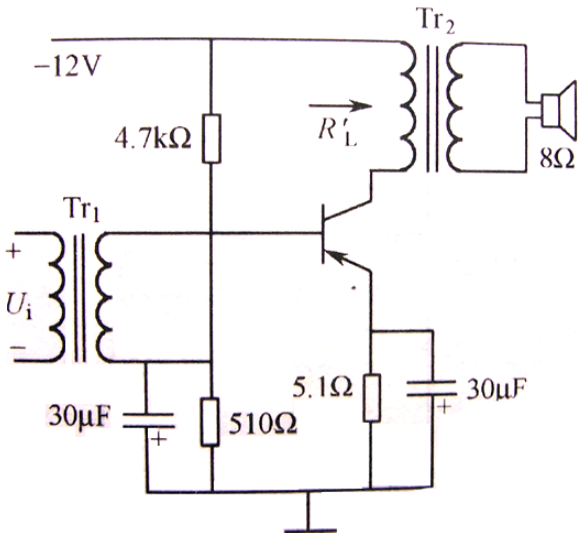
3.1

3.1如图所示的甲类功率放大器电路中，若不计变压器损耗，且晶体管U_{CES}=0，I_{CEO}=0，发射极电阻R_E上滞留压降可以忽略不计，放大器输入信号充分激励。

（1）若输出变压器Tr_2的匝数比n=4，放大器实现最佳匹配。求R_L所获不失真最大功率P_O及相应的放大器效率η_c；

（2）在维持I_{CQ}不变的条件下，不用变压器，直接将扬声器接到集电极，再求不失真最大输出功率P_O和η_c；

（3）在维持I_{CQ}不变的条件下，将变压器外接负载增大到16Ω，求此时的不失真最大输出功率P_O和η_c；



3.1

解： （1）$V_{o\max} = V_{cc} = 12V$

$$R_L' = n^2 R_L = 128\Omega$$

$$I_{CQ} = \frac{V_{CC}}{R_L'} = 93.75mA$$

$$P_{O\max} = \frac{1}{2}\frac{V_{O\max}^2}{R_L'^2} = 562.5mV$$

$$\eta_C = \frac{P_{O\max}}{V_{CC}I_{CQ}} = 50\%$$

（2）$I_{CQ} = 93.75mA \quad R_L = 8\Omega$

$$P_{O\max} = \frac{1}{2}I_{CQ}^2 R_L = 35.16mV$$

$$\eta_C = \frac{P_{O\max}}{V_{CC}I_{CQ}} = 3.125\%$$

（3） $R_L' = n^2 R_L = 256\Omega$

$$P_{O\max} = \frac{1}{2}\frac{V_{CC}^2}{R_L'} = 281.25mV$$

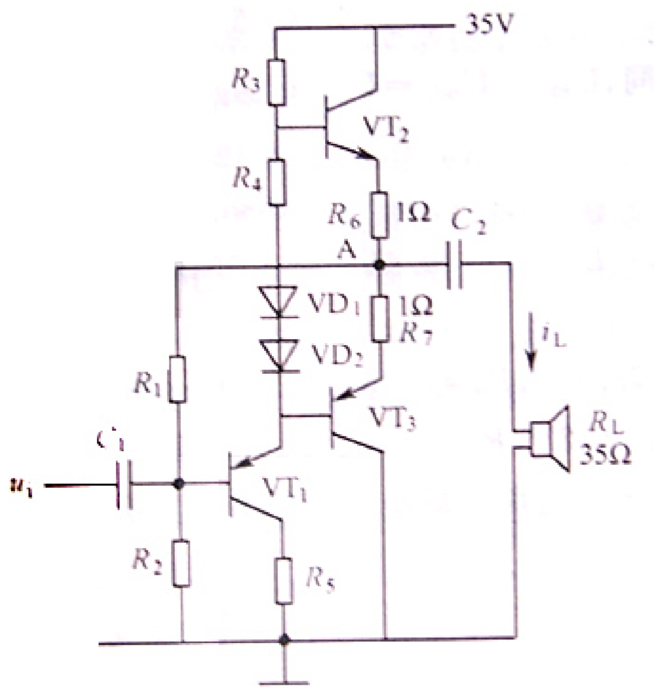
$$\eta_C = \frac{P_{O\max}}{V_{CC}I_{CQ}} = 25\%$$

3.3

如图所示为互补对称功放电路，设在正弦激励的情况下，负载电流幅度为$I_L = 0.45A$，求：

（1）负载获得的功率

（2）电源提供的功率P_{DC}和放大器效率η_C



解： $$I_L = 0.45A$$

$$P_L = \frac{1}{2} I_L{}^2 R_L = 3.54W$$

电源的平均电流为 I_L 的均值分量

$$\bar{I}_C = \frac{I_C}{\pi}$$

$$P_{DC} = \bar{I}_C \bullet \frac{V_{CC}}{2} \bullet 2 = \frac{I_C}{\pi} V_{CC} = 5.01W \qquad \eta_C = \frac{P_L}{P_D} = 70.7\%$$

3.4

如图所示电路中，设输入信号足够大且不考虑晶体管安全

（1）说明图中各二极管和电阻的作用

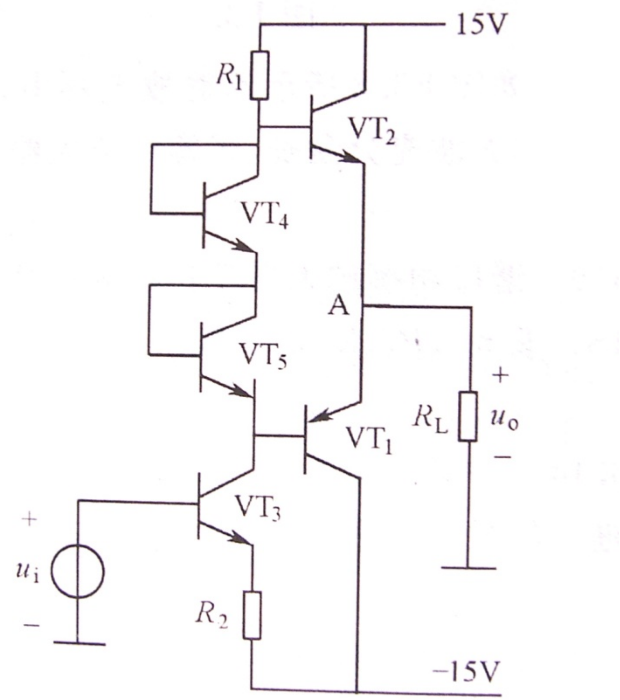
（2）设晶体管饱和压降U_{CES}=0.3V，R_L=8，求负载最大不失真功率

解:VT1、VT2组成互补乙类 推挽电路；

VT3推动级

VT4、VT5两个集电极短接的三极管及二极管；提供偏置减少交越失真

R1 R2 提供偏置

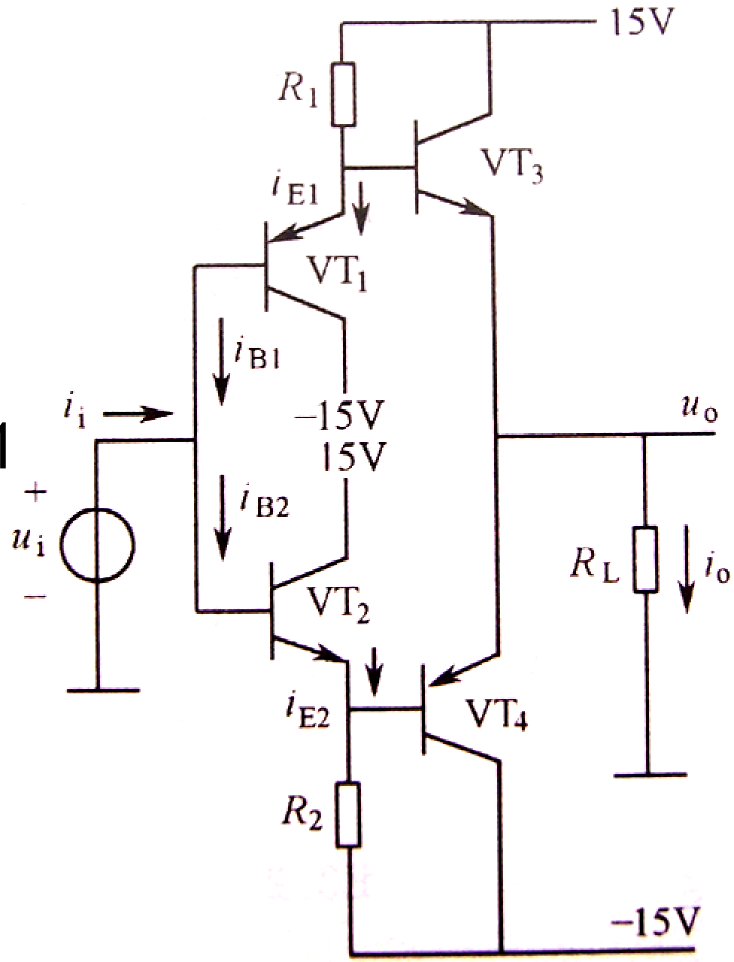


$$U_O = 15 - 0.3 = 14.7V$$

$$P_O = \frac{U_O{}^2}{2R} = 13.51W$$

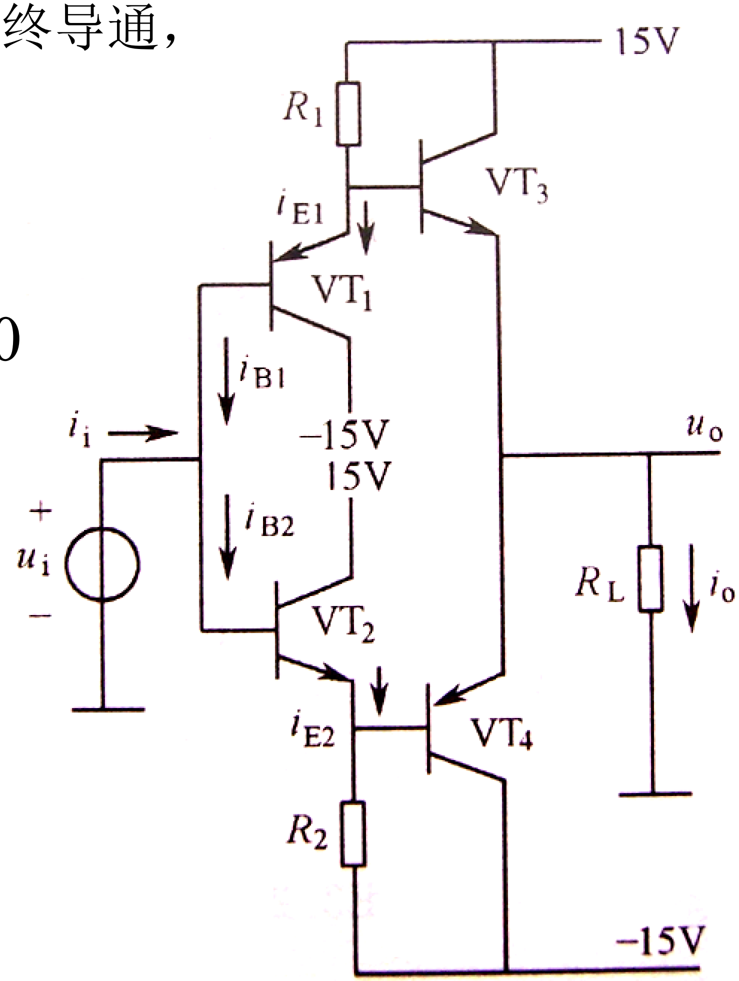
3.5

3.5 如图所示的有输入缓冲级的互补对称乙类放大器，设$R_1=R_2=2k\Omega$，$R_L=100\Omega$，所有晶体管$\beta=60$，$U_{BE}(npn)=U_{EB}(pnp)=0.6V$，计算电流增益。（提示：VT1、VT2、VT3、VT4分别组成射极跟随器。因此有$u_o=u_i$）



3.5

解：由于乙类放大器，故VT1，VT2始终导通，VT3，VT4轮流导通。



当输入信号正半周时，VT3导通，对交流信号有：

$$(1+\beta)i_{b1}+i_{E3}/(1+\beta)+\frac{U_i+0.6}{R_1}=0$$

$$i_i=2i_{b1}$$

$$i_o=i_{E3}=\frac{U_i}{R_L}$$

联立以上方程可以解得：

$$A_i=\frac{i_o}{i_i}=459.38$$

3.9

谐振功率放大器工作在临界状态，已知V_{CC}=30V，$-E_B=U_T$=0.6V，ζ=0.96，临界动态线斜率G_{cr}=0.4S。求η_C，P_o，R_T，P_C的值

$$\because \cos\varphi = \frac{U_T + E_B}{U_b} = 0 \therefore \varphi = 90^o$$

M点横标

$$U_C = \varsigma V_{CC}$$

$$V_{CC} - \frac{V_{CC} - U_C\cos\varphi}{1 + \frac{G_{cr}U_C}{g_m U_b}} = U_C$$

$$\therefore g_m U_b = G_{cr}U_{CC}(1-\varsigma) = 0.48A$$

$$I_{CP} = g_m U_b(1-\cos\varphi) = g_m U_b = 0.48A$$

3.9

$$I_{C0} = I_{CP}\alpha_0(\varphi) \qquad\qquad I_{C1} = I_{CP}\alpha_1(\varphi)$$

$$\eta_C = \frac{P_0}{P_{DC}} = \frac{\frac{1}{2}I_{C1}U_C}{I_{C0}V_{CC}} = \frac{\alpha_1(\varphi)\varsigma}{2\alpha_0(\varphi)} = 75.4\%$$

$$P_0 = \frac{1}{2}I_{C1}U_C = \frac{1}{2}I_{CP}\alpha_1(\varphi)\varsigma V_{CC} = 3.456W$$

$$R_T = \frac{\frac{1}{2}U_C{}^2}{P_0}120\Omega$$

$$P_C = P_{DC} - P_0 = I_{C0}U_{CC} - P_0 = 1.128W$$

3.10

3.10 一谐振功率放大器工作在欠压状态。若已知V_{CC}=12V，R_T=110Ω，P_O=500mW，η_c=68.5%。为了进一步提高效率，在维持V_{CC}，R_T，P_O不变得前提下，将电流的通角φ减小到60^o，并使放大器不工作在饱和区。

（1）这时，η_c转换效率多大?

（2）如何调整放大器，才能使放大器的电流通角减小到60^o?

解：（1）

$$\eta_c = \frac{1}{2}\frac{\alpha_1(\varphi)}{\alpha_0(\varphi)}\frac{U_c}{V_{CC}}$$

V_{CC} R_T P_O不变，得U_c I_c不变

$$P_O = \frac{1}{2}\frac{U_c^2}{R_T} = 500mW \qquad U_c = 10.49V$$

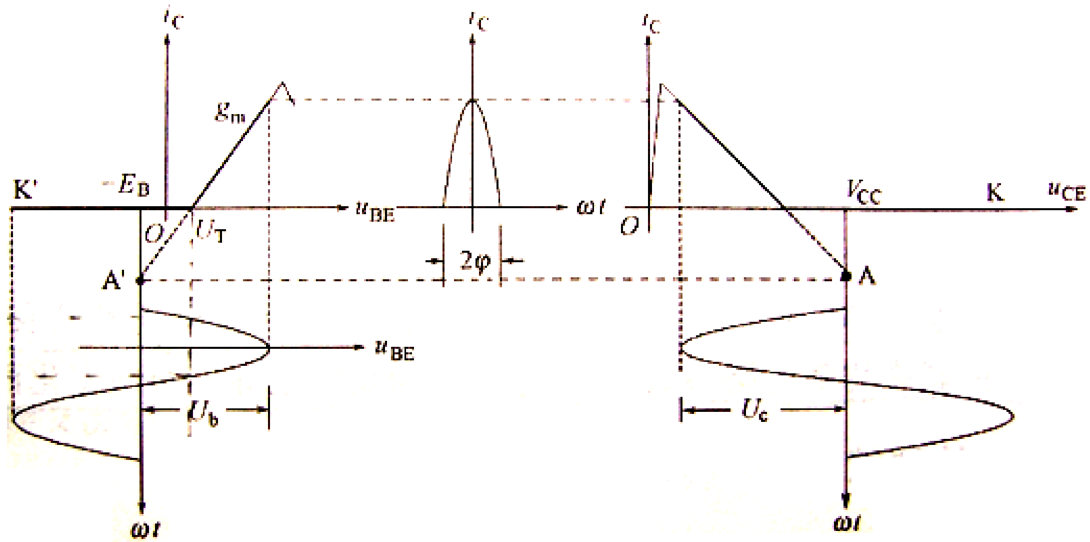
$$\eta_c' = \frac{1}{2}\frac{\alpha_1(60^o)}{\alpha_0(60^o)}\frac{U_c}{V_{CC}} = 78.4\%$$

3.10

（2） $$\varphi = \arccos\frac{E_B + V_T}{U_b}$$ E_B增大或U_b减小？

如果U_b减小，则 $$I_{CP} = g_m U_b (1-\cos\varphi)$$

$$I_c = I_{CP}\alpha_1(\varphi)$$ 减小，与题设矛盾



(a) 欠压状态波形

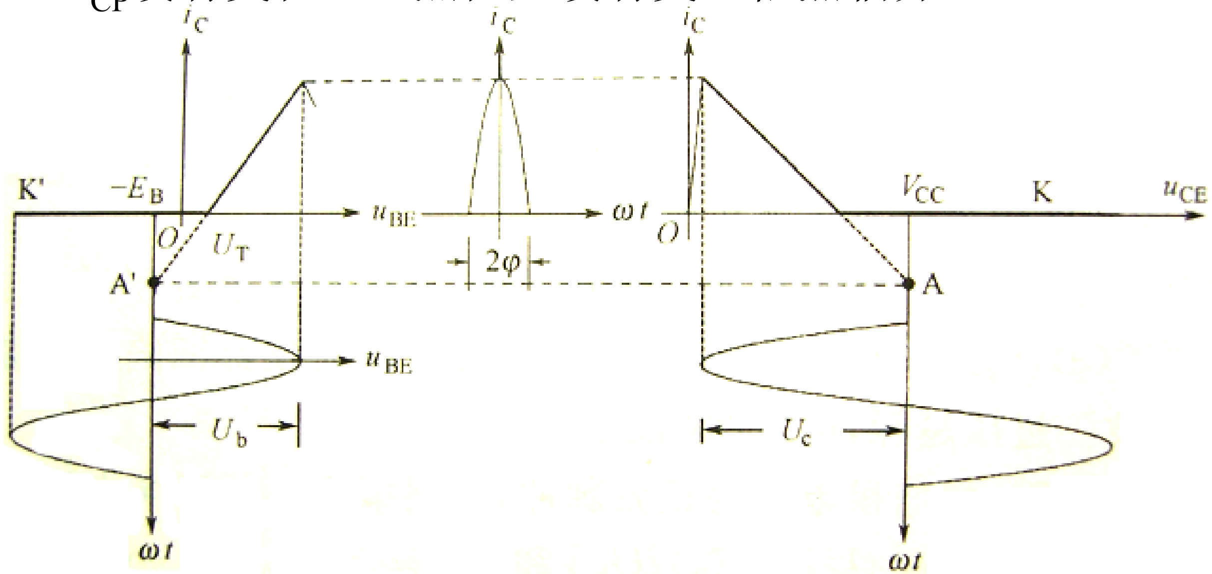
3.11

3.11 谐振功率放大器原来工作在临界状态，且 $\varphi=70°$，$P_o=3W$，$\eta_C=60\%$。后来发现其性能发生变化，发现 P_o减小，而 η_C却增加到 68%，但 V_{CC}、U_c、u_{BEmax} 却保持不变。试问此时放大器工作在什么状态？P_o和 φ 值各为多大？并分析性能变化的原因。 【Ans.：$\varphi=26.9°$，$P_o=1.3375W$】

解：放大器依然工作在临界状态：

A 放大器正常工作，晶体管没有损坏，饱和区特性没有改变，又U_{BEMAX}没有改变，故知放大器依然临界

B U_c没有变化，I_{CP}没有变化，M点位置没有变，依然临界。



(b) 临界状态波形

3.11

由放大器效率公式：

$$\eta_c = \frac{1}{2}\frac{\alpha_1(\varphi)}{\alpha_0(\varphi)}\frac{U_c}{V_{CC}} \qquad \frac{\eta_c'}{\eta_c} = \frac{\dfrac{\alpha_1(\varphi')}{\alpha_0(\varphi')}}{\dfrac{\alpha_1(\varphi)}{\alpha_0(\varphi)}} = \frac{\dfrac{\alpha_1(\varphi')}{\alpha_0(\varphi')}}{\dfrac{\alpha_1(70^o)}{\alpha_0(70^o)}} = \frac{\dfrac{\alpha_1(\varphi')}{\alpha_0(\varphi')}}{1.7258} = \frac{68\%}{60\%}$$

$$\frac{\alpha_1(\varphi')}{\alpha_0(\varphi')} = 1.9559 \qquad \varphi' = 26.89^o$$

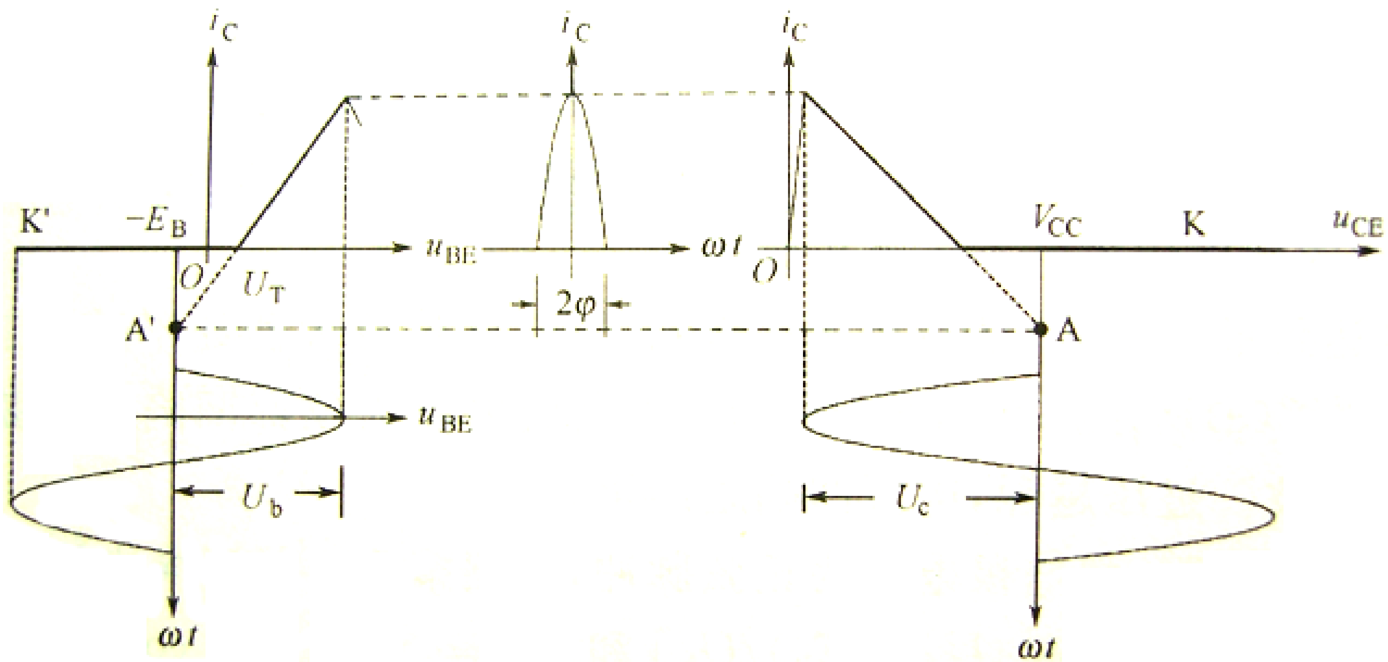
输出的交流功率：

$$P_o = \frac{1}{2} I_{C1} U_c = \frac{1}{2} U_c I_{CP} \alpha_1(\varphi)$$

$$\frac{P_o'}{P_o} = \frac{\alpha_1(\varphi')}{\alpha_1(\varphi)} = \frac{\alpha_1(26.89^o)}{\alpha_1(70^o)} = \frac{0.1940}{0.4356} \qquad P_o' = 1.3375W$$

3.11

性能变化的原因：$P_o = \dfrac{1}{2}\dfrac{U_c^2}{R_T}$ 减小，故R_T增大

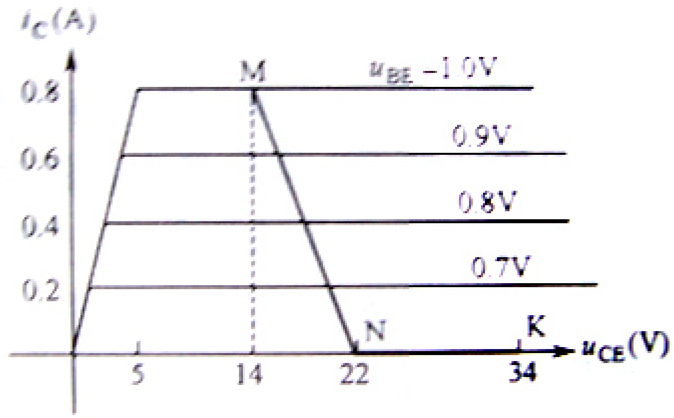


(b) 临界状态波形

3.12

(1) 放大器工作在欠压状态

(2) 由图知:



$$U_C = \frac{34-14}{2} = 10V$$

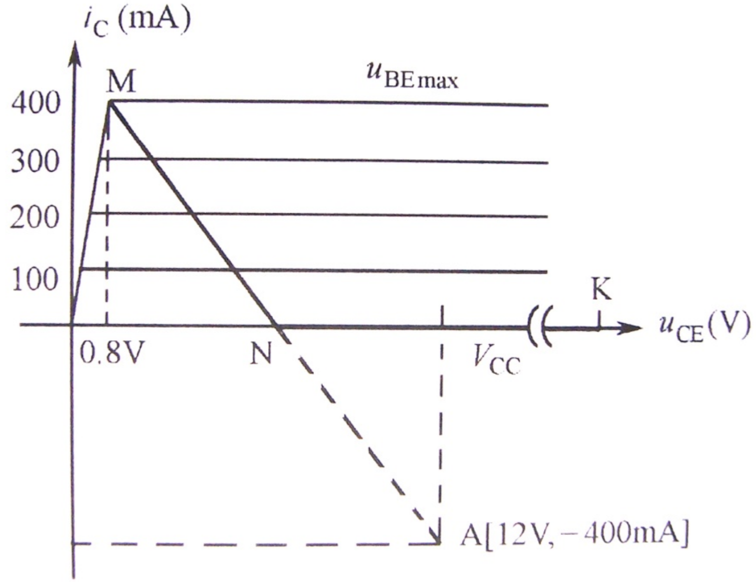
$$V_{CC} = 14 + \frac{34-14}{2} = 24V \qquad G_{cr} = \frac{0.8A}{5V} = 0.16S$$

$$\because -g_m \frac{U_b}{U_c} = -0.1 \therefore g_m U_b = 0.1 U_c = 1V$$

$$\because I_{CP} = 0.8A \quad \therefore \cos\varphi = 1 - \frac{I_{CP}}{g_m U_b} = 0.2 \quad \varphi = 78.46^0$$

3.13

假设谐振功放的输出特性如图中的折线MNK所示，试根据动态特性计算功放的输出功率和转换效率



解：由图知 ：

$$U_c = V_{CC} - 0.8 = 12 - 0.8 = 11.2V$$

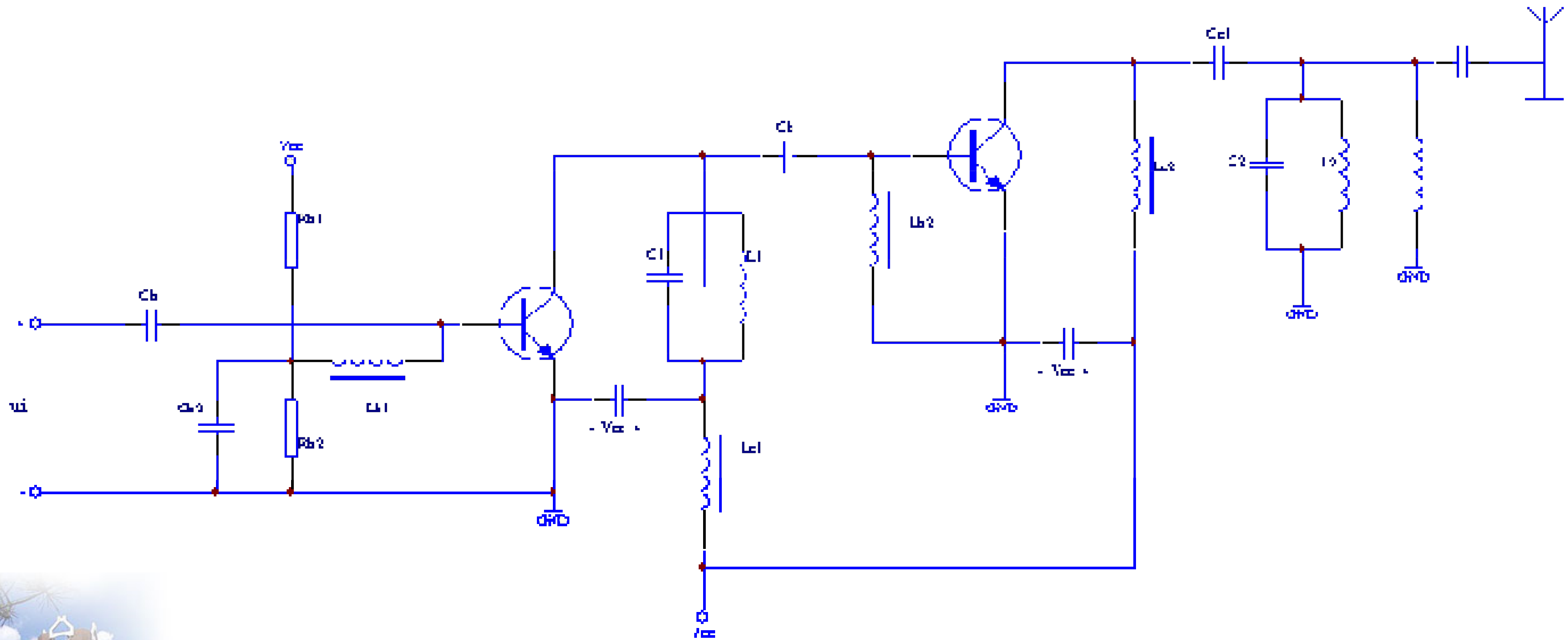
$$\cos\varphi = 1 - \frac{I_{CP}}{g_m U_b} = 1 - \frac{0.4}{0.8} = 0.5$$

$$\varphi = 60^0$$

$$I_{C1} = I_{CP}\alpha_1(\varphi) = 0.1564A$$

$$P_0 = \frac{1}{2} I_{C1} U_c = 875.84mW \qquad \eta_C = \frac{1}{2}\frac{\alpha_1(\varphi)}{\alpha_0(\varphi)}\varsigma = 83.7\%$$

3.14

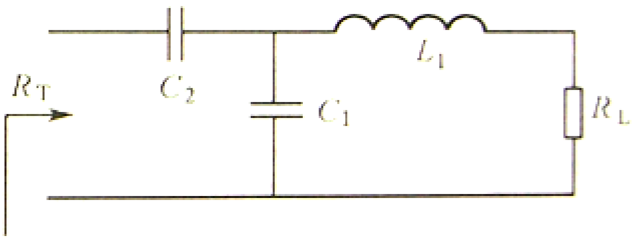


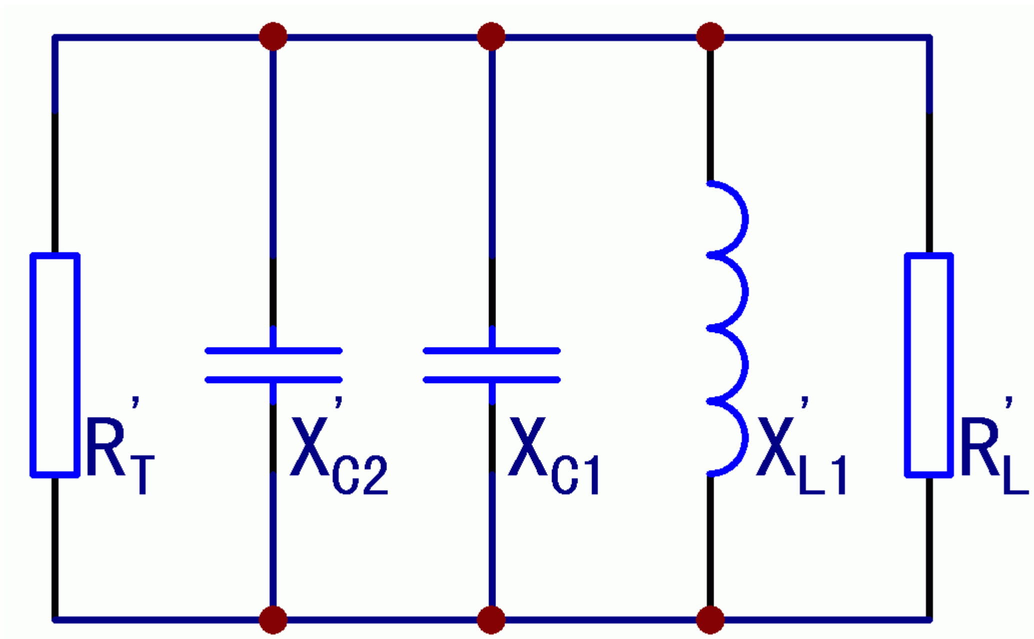
3.16

3.16 已知如图 E3.12 所示的 T 型匹配网络中，负载电阻为 R_L，放大器要求的阻抗为 R_T。

(1) 设 $Q_{e1}=X_{L1}/R_L$，且满足 $Q_{e1}^2>R_T/R_L-1$，试推导阻抗变换公式；

(2) 若给定 $R_L=100\Omega$，$Q_{e1}=4$，$f=50\text{MHz}$，$R_T=250\Omega$，确定 C_1、C_2、L_1 的值。





3.16

解：（1）由串并联转换：

$$Q_{e1}=\left|X_{L1}\right|/R_L \qquad Q_{e2}=\left|X_{C2}\right|/R_T$$

$$X_{L1}'=\left(1+\frac{1}{Q_{e1}}\right)X_{L1} \qquad X_{C2}'=\left(1+\frac{1}{Q_{e2}}\right)X_{C2}$$

$$R_L'=\left(1+Q_{e1}^2\right)R_L \qquad R_T'=\left(1+Q_{e2}^2\right)R_T$$

匹配条件： $R_T'=R_L'$ $\qquad Q_{e2}=\sqrt{\frac{R_L}{R_T}\left(1+Q_{e1}^2\right)-1}$

谐振条件： $$1/X_{L1}'+1/X_{C1}+1/X_{C2}'=0$$

故： $X_{C1}=\frac{1}{j\omega C_1}=-\left(\frac{1}{X_{L1}'}+\frac{1}{X_{C2}'}\right)^{-1}$ $\qquad \omega^2L_1'\left(C_1+C_2'\right)=1$

3.16

（2）将数据代入（1）中计算：

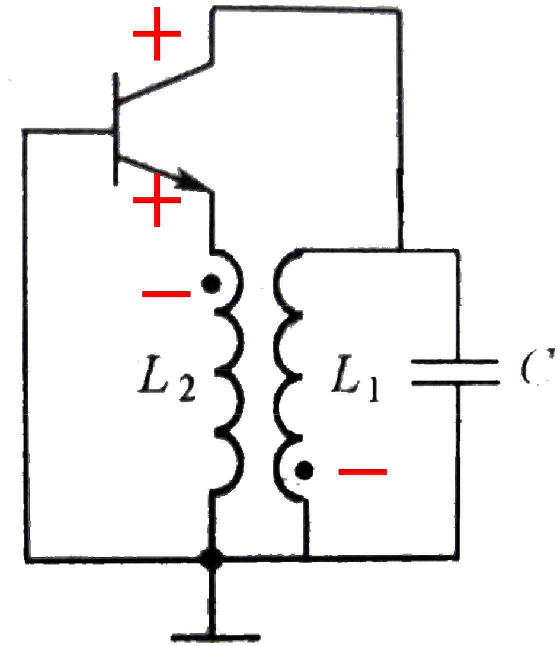
$$R_T' = R_L' = \left(1 + Q_{e1}^2\right)R_L = 1700\Omega$$

$$\left|X_{L1}\right| = R_L Q_{e1} = 400\Omega \qquad L_1 = 1.27\mu H$$

$$Q_{e2} = \sqrt{\frac{R_L}{R_T}\left(1 + Q_{e1}^2\right) - 1} = 2.408 \qquad C_2 = 5.29pF$$

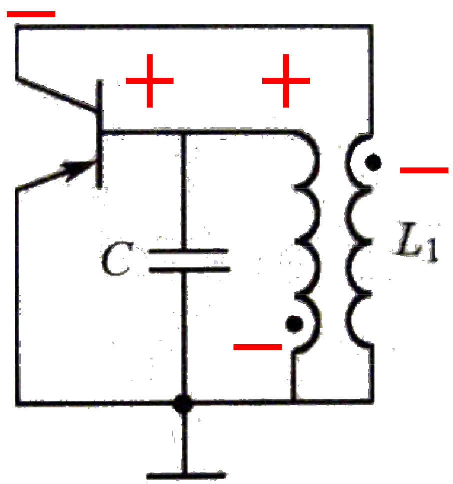
$$C_1 = 2.98pF$$

4.1(a)



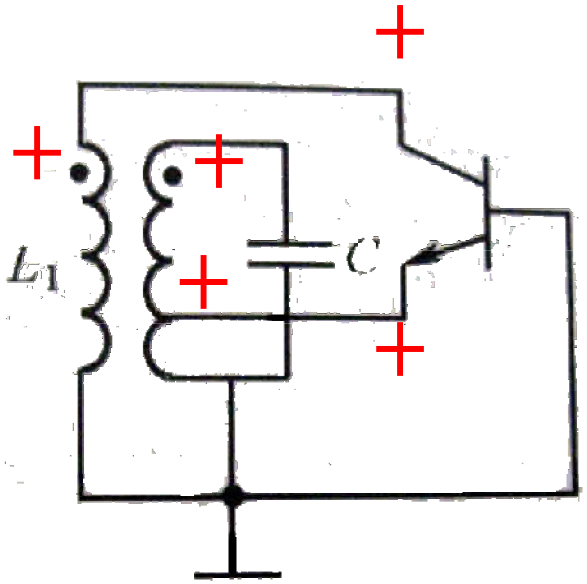
不符合起振相位条件

4.1(b)



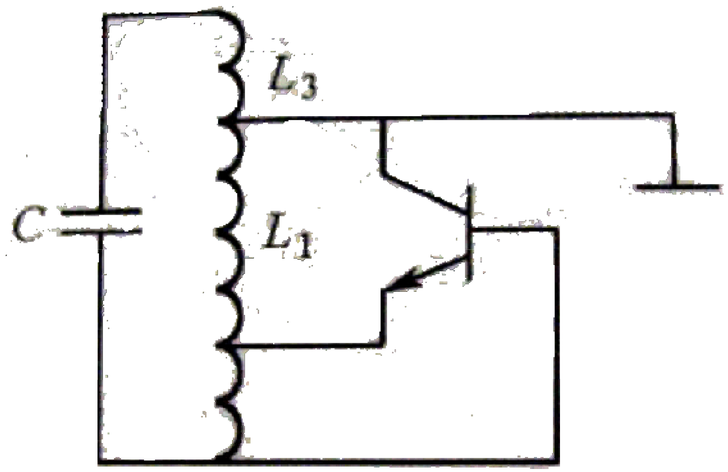
符合起振相位条件

4.1(c)



符合起振相位条件

4.1(d)

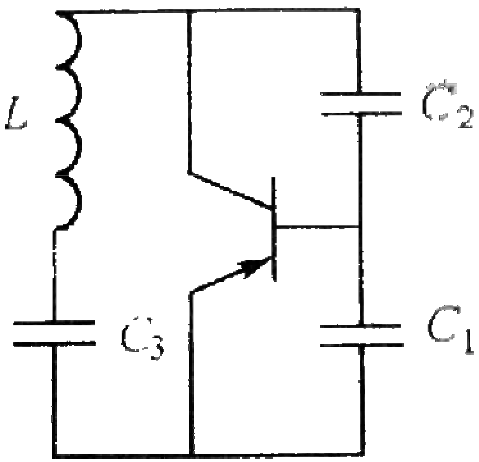


当L3、C串联的阻抗

呈容性时

符合起振相位条件

4.1(e)

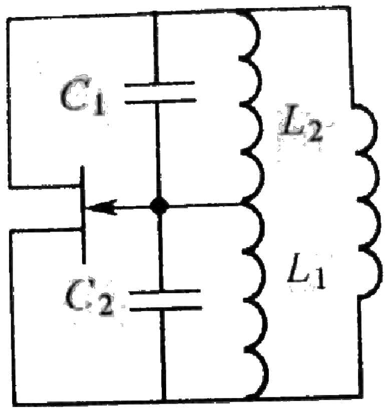


不符合起振相位条件

4.1(f)

当L1、C2并联阻抗

呈感性

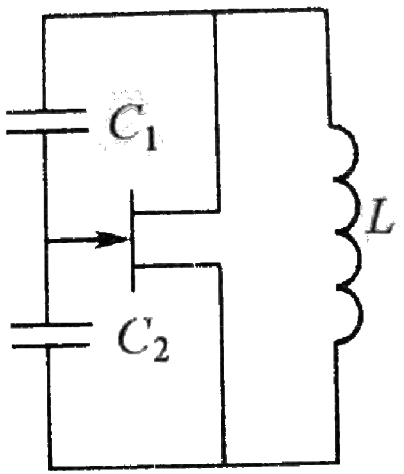


且L2、C1并联阻抗

呈容性时

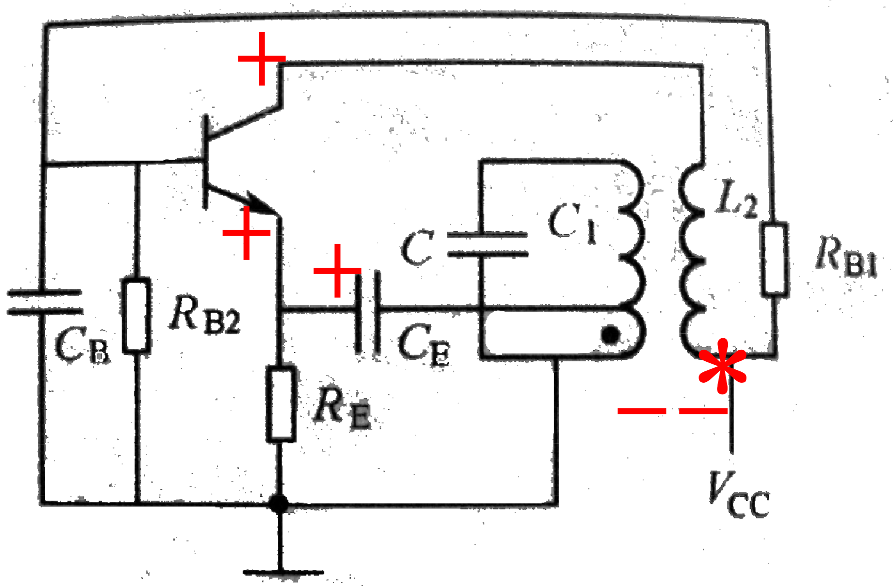
符合起振相位条件

4.1(g)

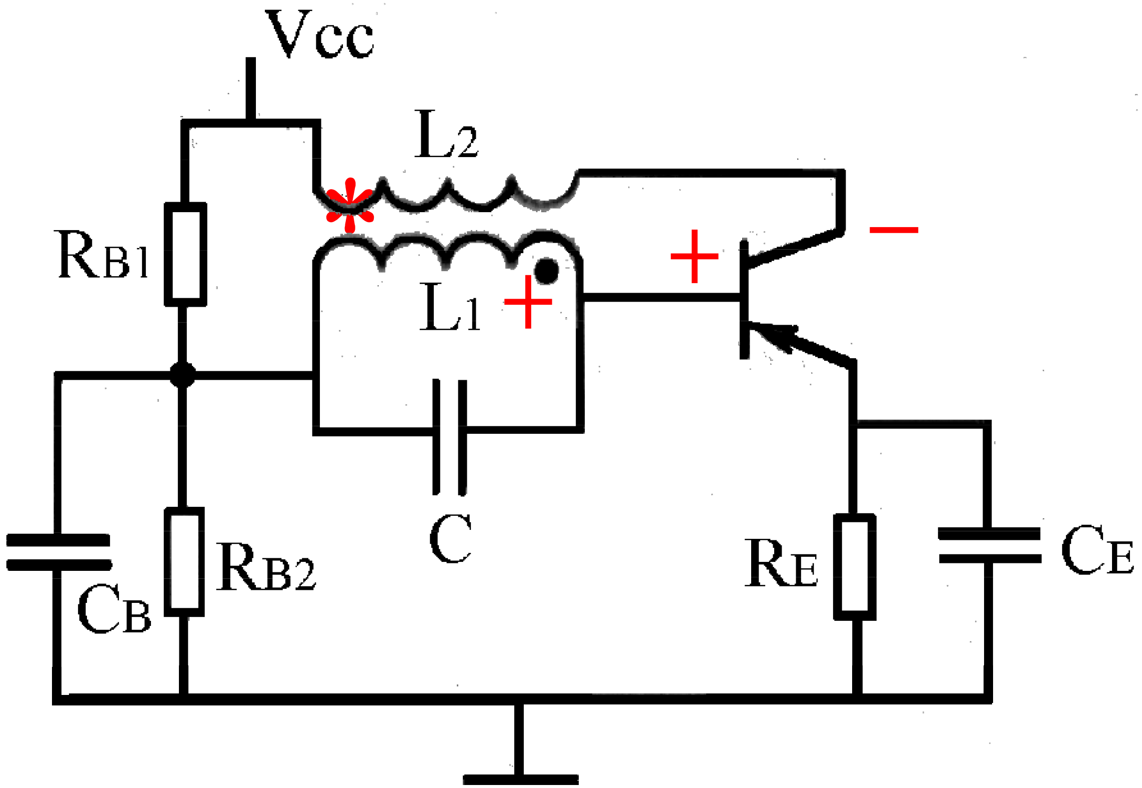


不符合起振相位条件

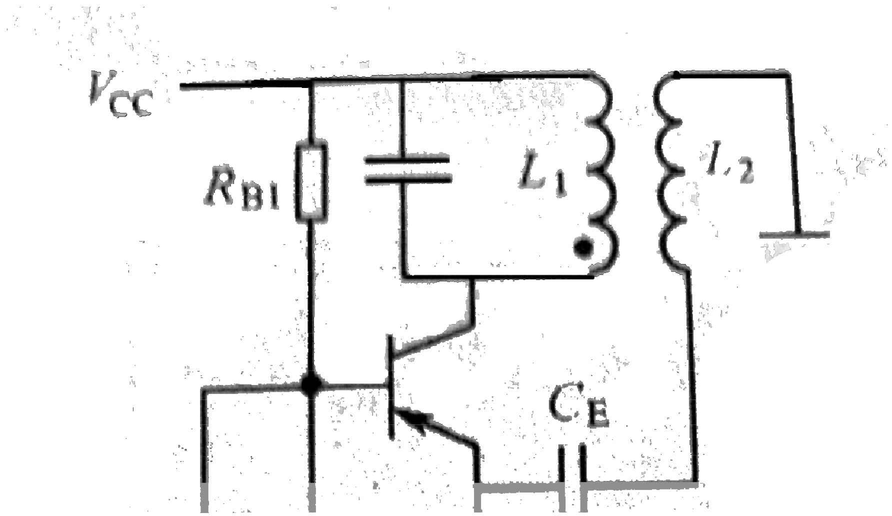
4.2(a)



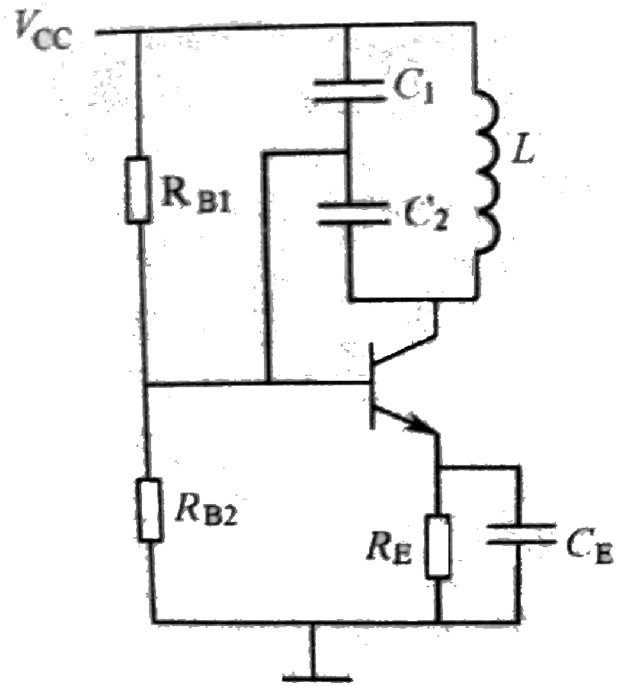
4.2(b)



4.2(c)

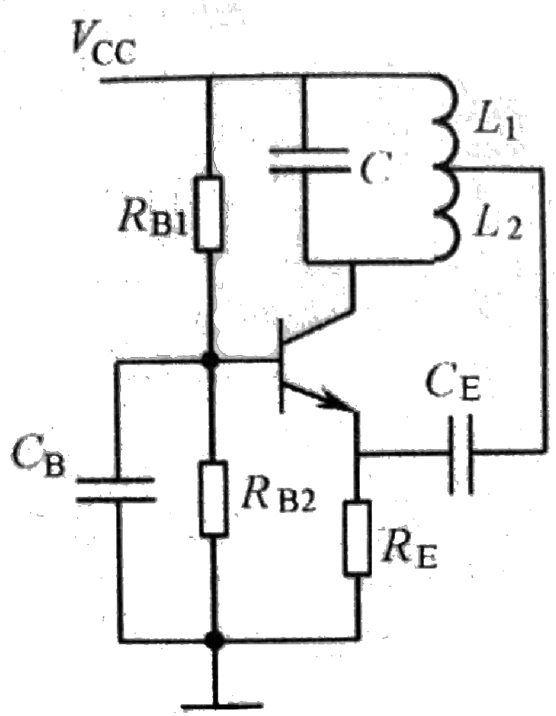


4.3(a)



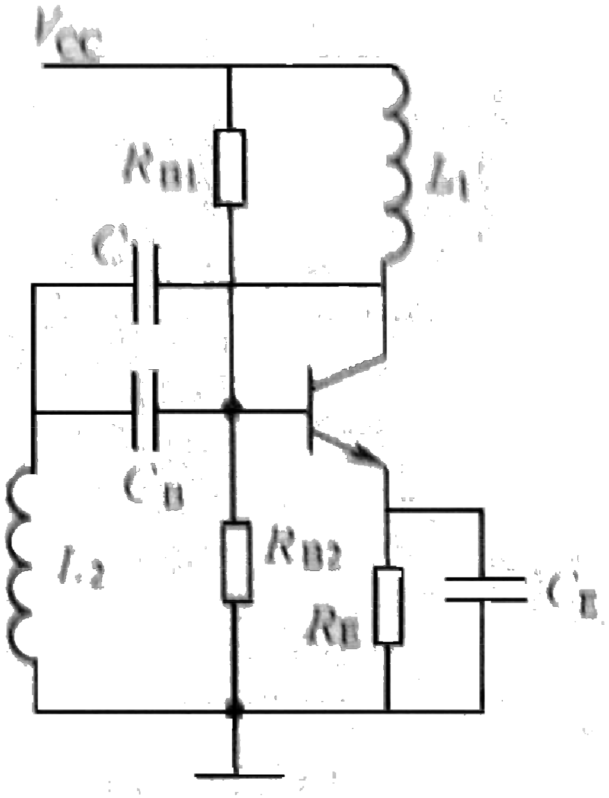
不能起振

4.3(b)



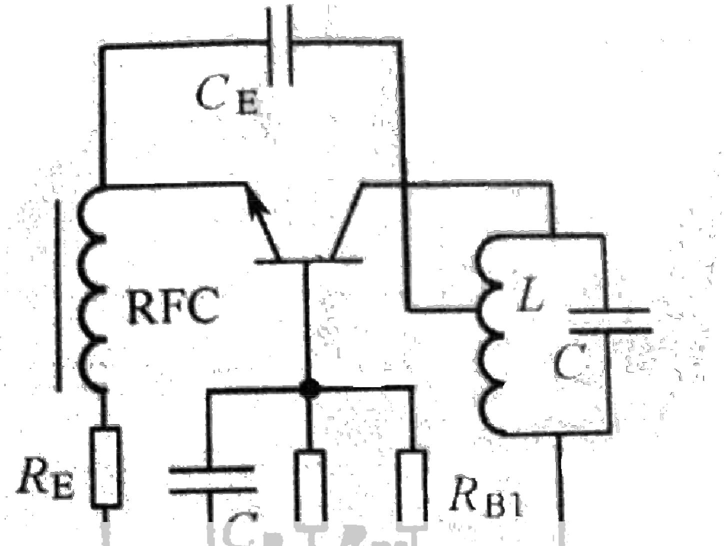
能够起振

4.3(c)



能够起振

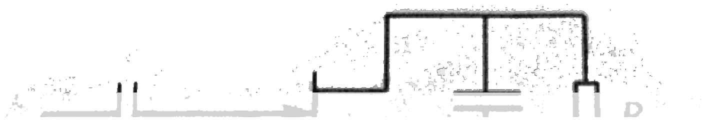
4.3(d)



4.4(a)

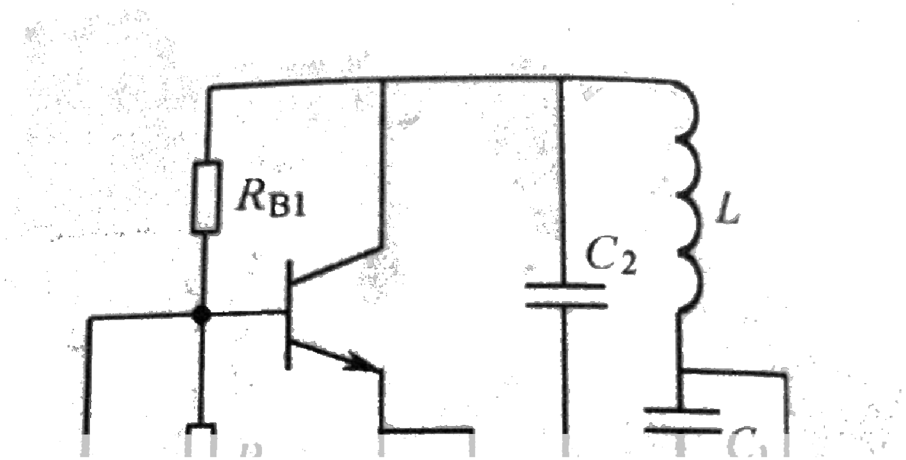
4.4(a)改正后

4.4(b)

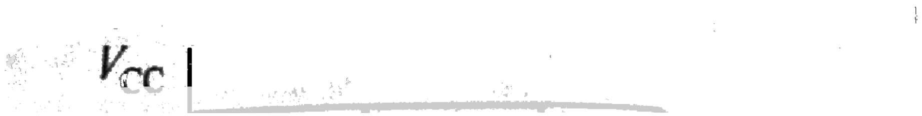


4.4(b)改正后

4.4(c)

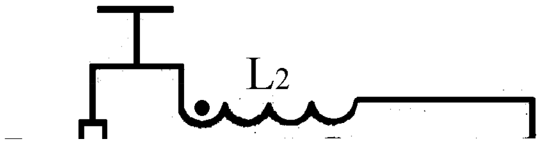


4.4(c)改正后



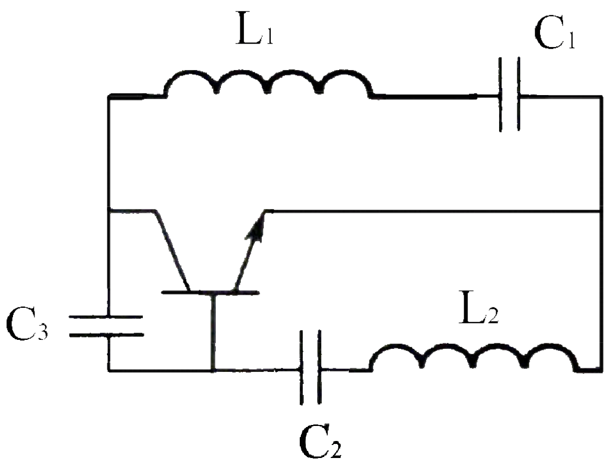
4.5

- 4.5按下列要求，画出实际的振荡器电路。
- (1)基极调谐、集电极耦合的变压器耦合振荡器，采用PNP三极管，正电源工作，发射极交流接地。

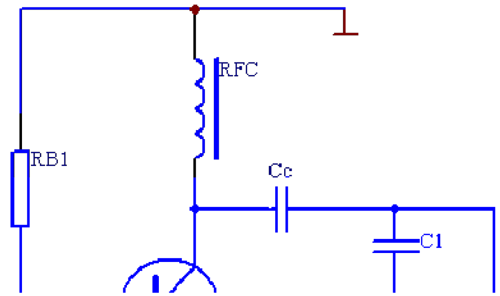


4.5

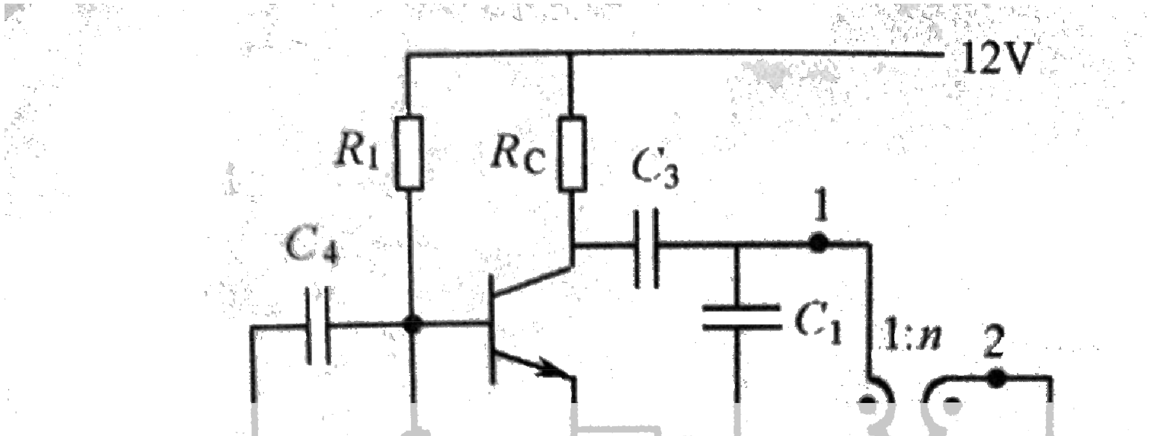
- (2)负电源工作，基极交流接地，交流等效电路如图所示



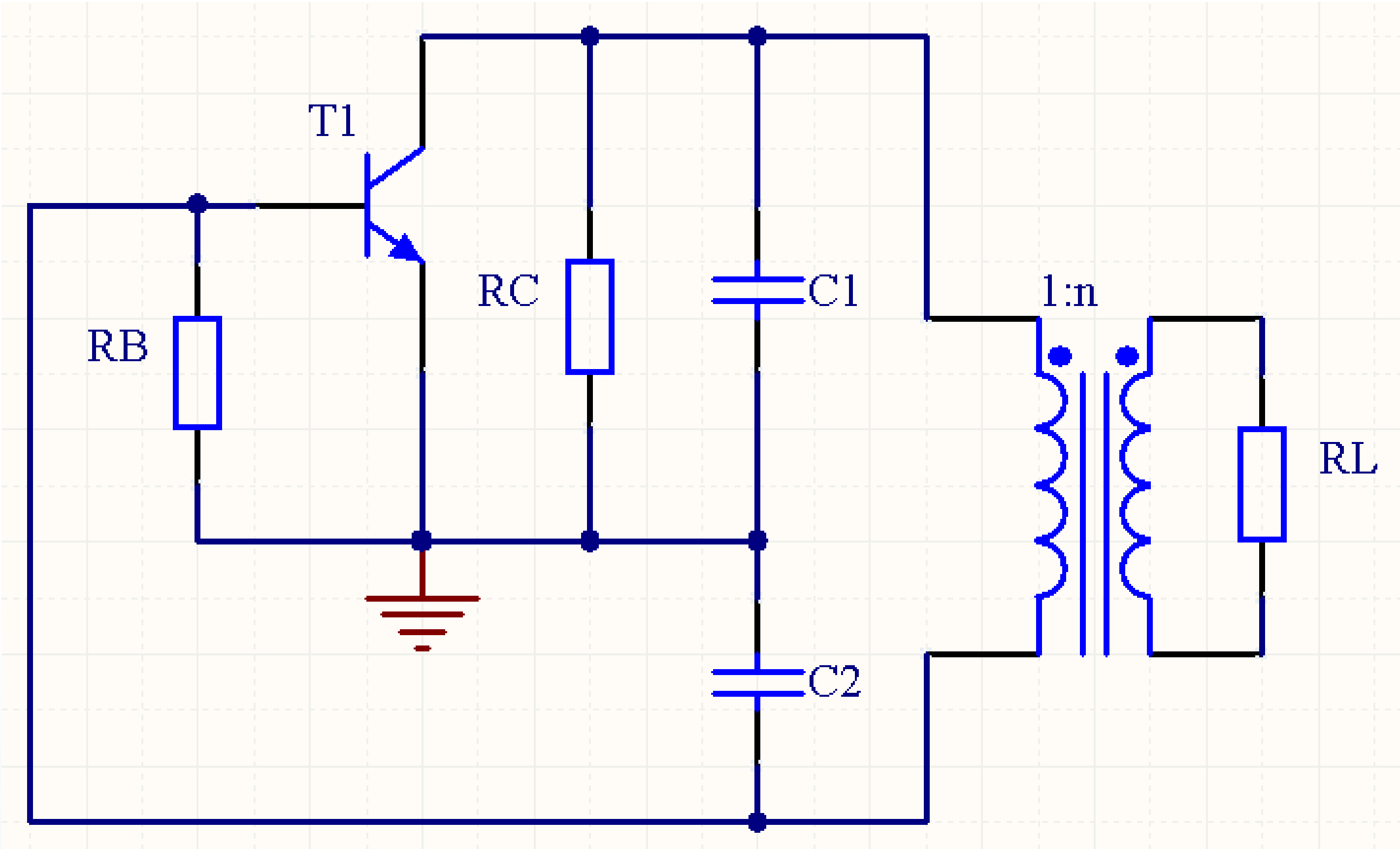
4.5



4.6



4.6(1)



4.6(2)

ω_0不变，则应有C不变：

$$\mathrm{C}=\frac{\mathrm{C}_1'\mathrm{C}_2'}{\mathrm{C}_1'+\mathrm{C}_2'}=\frac{\mathrm{C}_1\mathrm{C}_2}{\mathrm{C}_1+\mathrm{C}_2}=414\,pF \qquad (1)$$

$F'=2F$,即：

$$\frac{\mathrm{C}_1'}{\mathrm{C}_2'}=2\frac{\mathrm{C}_1}{\mathrm{C}_2}=0.464 \qquad (2)$$

由(1)(2)式得:

$$\mathrm{C}_1'=606\,pF$$

$$\mathrm{C}_2'=1307\,pF$$

4.6(3) (4) (6) (7)

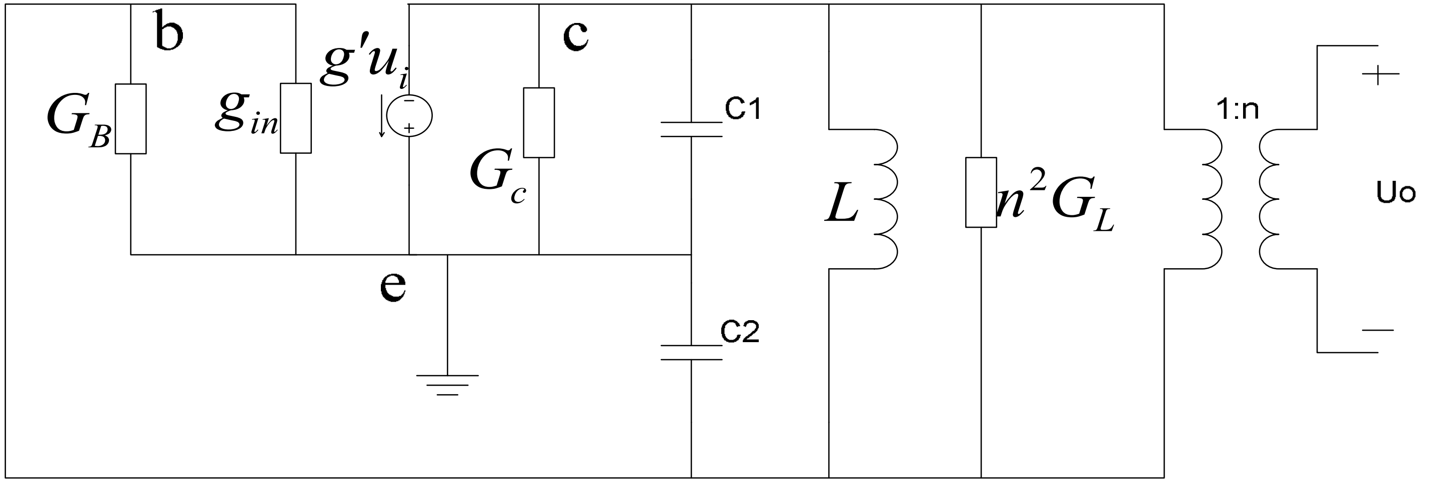
- (3) 导线不可以，会将C1交流短路

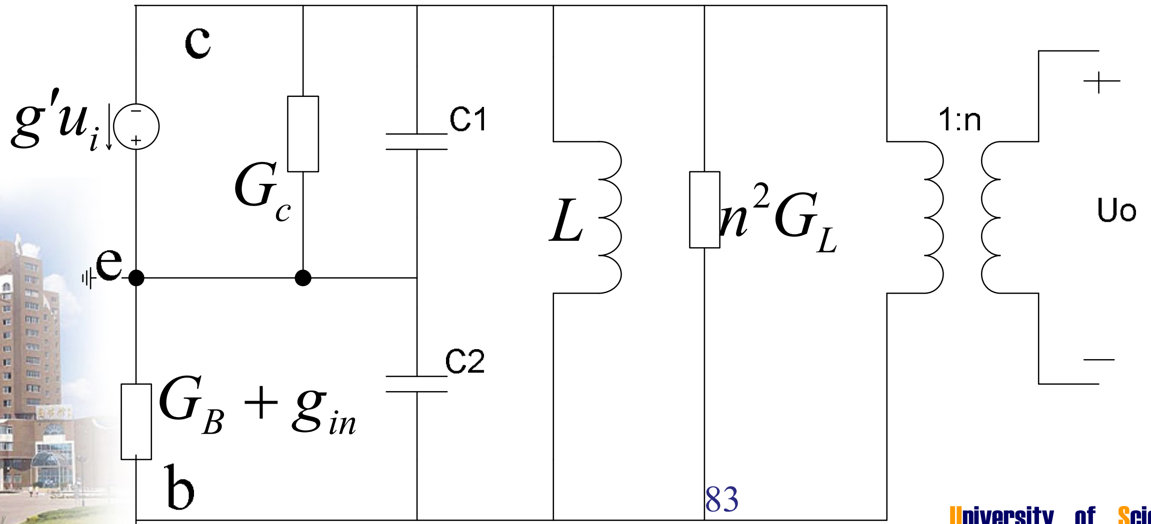
  高频扼流圈可以，起到隔交流通直流的作用
- (4) 只能去掉一个，起到对反馈回路隔直流的作用
- (6) 2端测量比较合理，频率计探头具有接入电容，在1端会影响电路谐振频率
- (7) $U_{BE}<U_{BEO}$

  电路振荡以后BE结处于大电流状态，压降有所降低——晶体管工作特性

  若相等说明电路没有起振

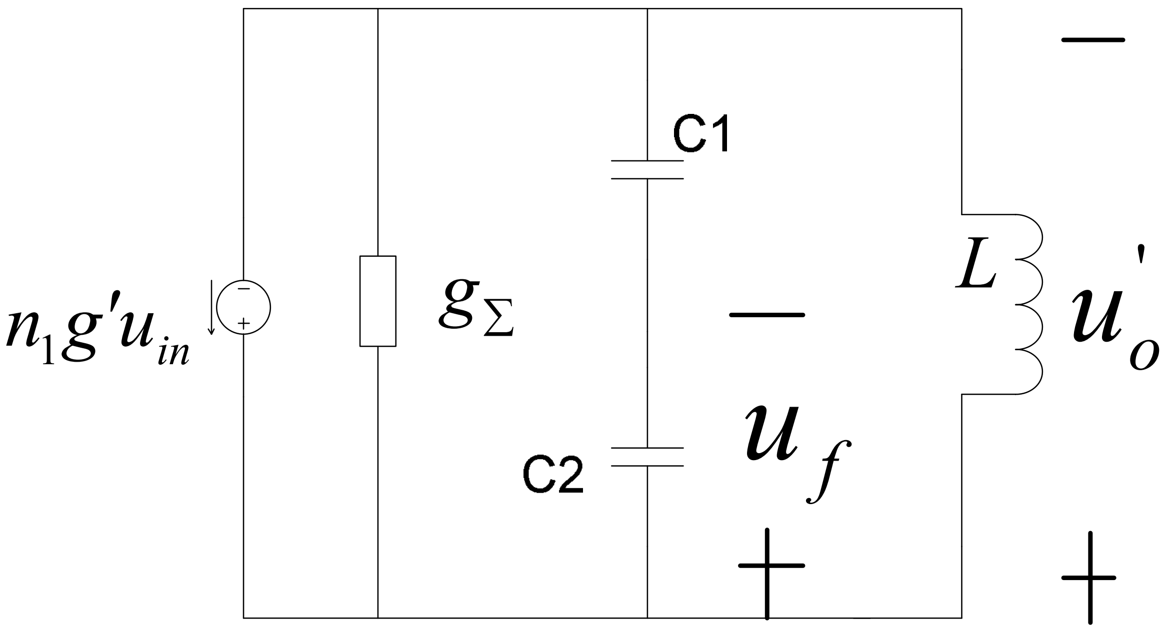
4.6(5)





$$n_1 = \frac{C_2}{C_1 + C_2}$$

$$n_2 = \frac{C_1}{C_1 + C_2}$$



$$g_\Sigma = n^2 G_L + n_1^2 G_C + n_2^2 (G_B + g_{in})$$

$$u_o' = n_1 g' u_{in} / g_\Sigma$$

反馈系数 $F = \dfrac{C_1}{C_1 + C_2} = n_2 \qquad u_f = u_o' F = n_1 g' u_{in} n_2 / g_\Sigma$

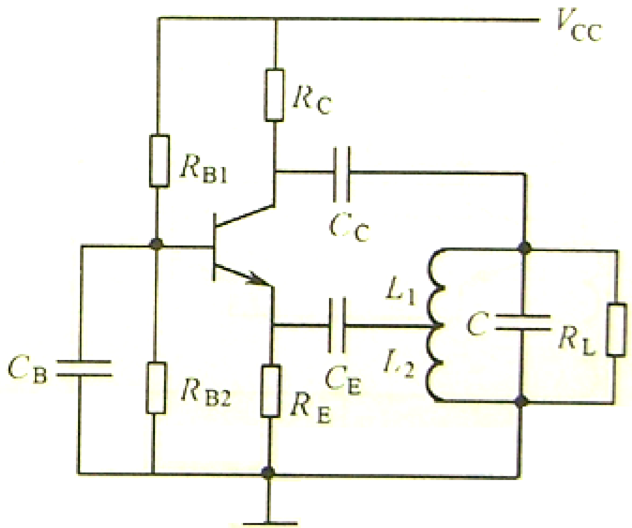
$\therefore T = \dfrac{u_f}{u_{in}} = \dfrac{n_1 n_2 g'}{g_\Sigma} > 1 \qquad$ 求得 $R_E < 377\Omega$

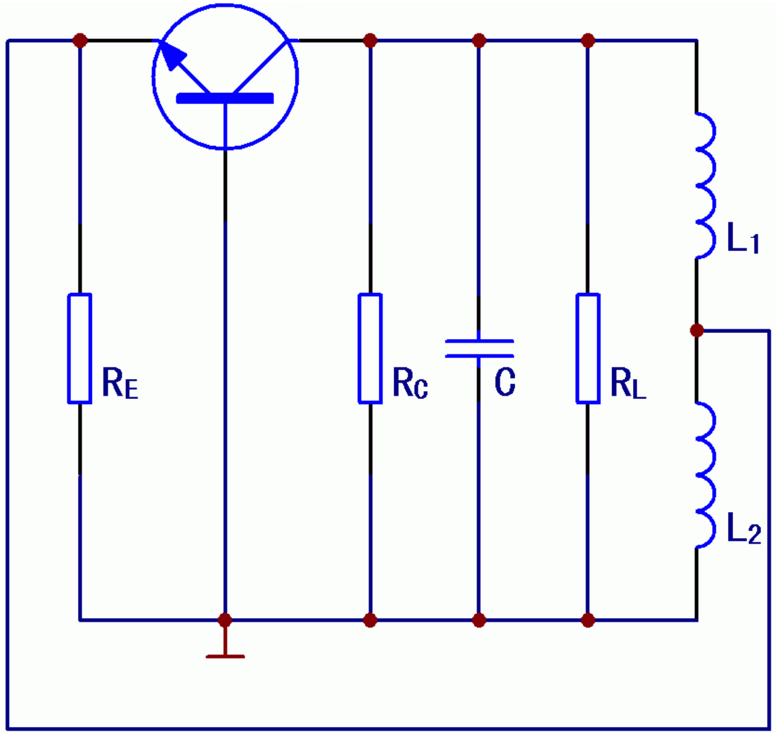
4.10

4.10　图 E4.10 所示的电路中，给定：晶体管 $\alpha=0.98$，$V_{CC}=6\text{V}$，C_E，C_B，C_C 均为 $0.01\mu\text{F}$。其他电路元件为：$C=510\text{pF}$，$R_L=1\text{k}\Omega$，$R_{B1}=8.1\text{k}\Omega$，$R_{B2}=5\text{k}\Omega$，$R_E=1\text{k}\Omega$，$L_1=100\mu\text{H}$，$L_2=20\mu\text{H}$，且其 Q_0 值均为 100，$=2\text{k}\Omega$。

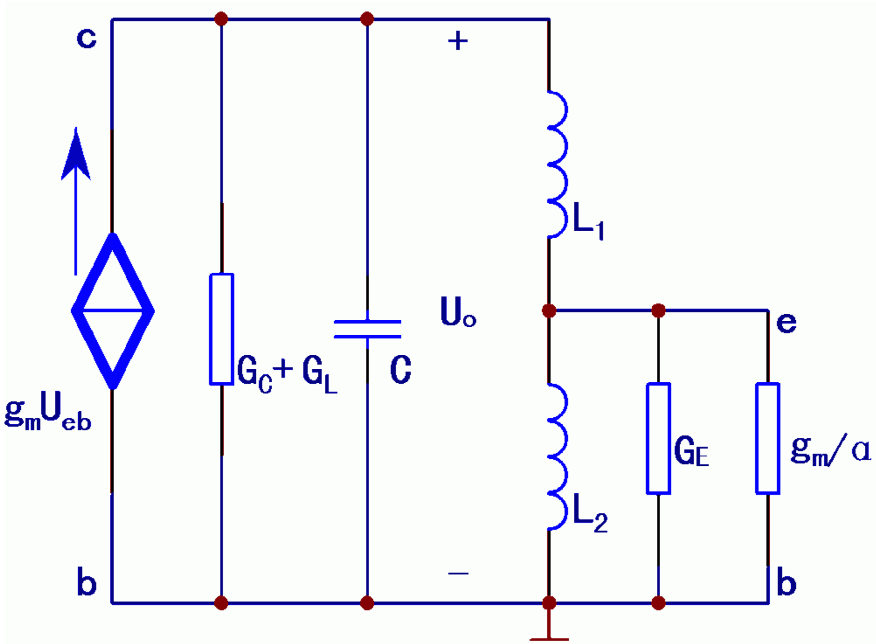
（1）试推导起振幅度条件。　【Ans.：$g_m>11.05\text{mA}$】

（2）计算负载 R_L 上正弦电压的频率和幅度。　【Ans.：$U_{R_L}=1.602\text{V}$，$f_{osc}=643.35\text{kHz}$】





4.10



$$n=\frac{L_2}{L}\qquad L=L_1+L_2$$

$$g_\Sigma=G_C+G_L+n^2\left(G_E+g_m/\alpha\right)$$

$$AF=\frac{ng_m}{g_\Sigma}\geq 1$$

$$g_m\geq g_{m\min}=11.044ms$$

电阻分压式：

$$g_{mQ}=\frac{\alpha I_{EQ}}{U_r}=\frac{\alpha\left(V_{BB}-U_{BEQ}\right)}{U_r\left[R_E+\left(1-\alpha\right)R_B\right]}=56.457ms$$

教材P13页

4.10

谐振频率：

$$f_{OSC} = \frac{1}{2\pi\sqrt{(L_1 + L_2)C}} = 643.35kHz$$

振荡稳定时：

$$G_{m1}(x) = g_{m\min}$$

$$\frac{G_{m1}(x)}{g_{mQ}} = \frac{g_{m\min}}{g_{mQ}} = \frac{11.044ms}{56.457ms} = 0.1965$$

$$x = 11.223 = \frac{U_f}{U_r} = \frac{nU_o}{26mV}$$

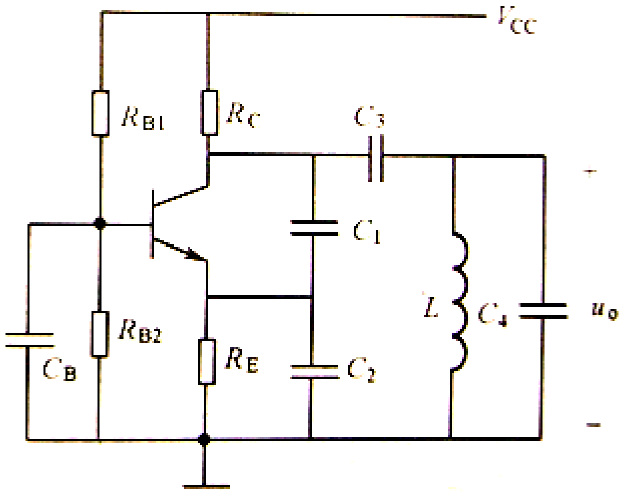
$$U_o = 1.75V$$

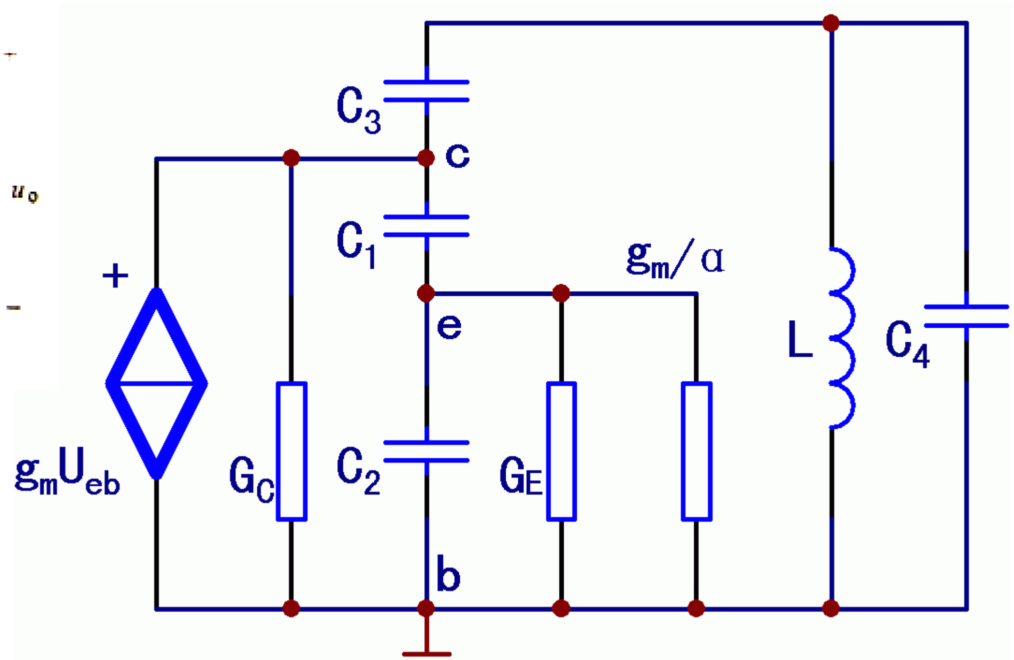
4.12

4.12 设图 E4.12 所示的 Siller 电路中，晶体管 $\alpha=0.97$，$V_{CC}=12\text{V}$，$L=0.8\mu\text{H}$；$R_{B1}=39\text{k}\Omega$，$R_{B2}=3.6\text{k}\Omega$，$R_C=1.5\text{k}\Omega$，$R_E=1\text{k}\Omega$，$C_1=100\text{pF}$，$C_2=200\text{pF}$，$C_3=6.8\text{pF}$，$C_4=2.2\text{pF}$。

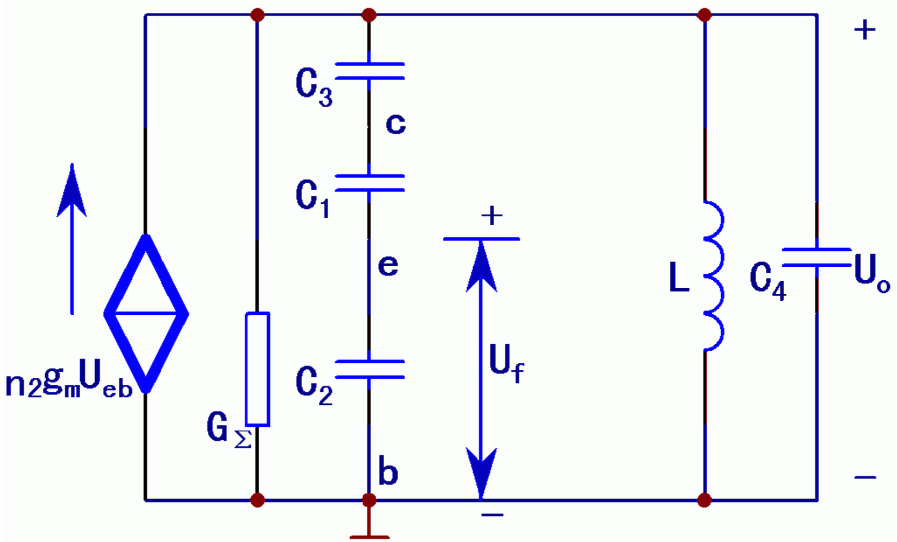
(1) 求输出电压的频率、幅度和 THD。 【Ans.：$f_{osc}=61.5\text{MHz}$，$U_o=7.44\text{V}$，THD=0.2%】

(2) 若电源电压增大 5%，求输出电压的相对变化量 $\Delta U_o/U_o$。 【Ans.：28.5%】





4.12



$$n_1 = \frac{C_1}{C_1 + C_2} = 0.333$$

$$n_2 = \frac{C_3}{C_3 + C_{12}} = \frac{6.8}{6.8 + 66.67} = 0.9255$$

$$g_\Sigma = n_2^2\left[G_C + n_1^2\left(G_E + g_m/\alpha\right)\right]$$

$$U_o = n_2 g_m U_{eb}/g_\Sigma \qquad A = \frac{U_o}{U_{eb}} = \frac{n_2 g_m}{g_\Sigma}$$

$$F = \frac{U_f}{U_o} = \frac{C_{123}}{C_2} = \frac{6.17}{200} = 0.031$$

$$AF \geq 1 \qquad g_m \geq g_{m\,\min} = 3.556ms$$

4.12

电阻分压式：
$$g_{mQ}=\frac{\alpha I_{EQ}}{U_r}=\frac{\alpha\left(V_{BB}-U_{BEQ}\right)}{U_r\left[R_E+(1-\alpha)R_B\right]}=10.66ms$$

$$\frac{G_{m1}(x)}{g_{mQ}}=\frac{g_{m\min}}{g_{mQ}}=\frac{3.556ms}{10.66ms}=0.334 \qquad x=8.85$$

输出电压：
$$U_o=\frac{xU_r}{F}=7.67V$$

谐振频率：
$$f_{OSC}=\frac{1}{2\pi\sqrt{L\left(C_{123}+C_4\right)}}=61.5MHz$$

$$Q_o=\frac{\omega_{osc}\left(C_{123}+C_4\right)}{g_\Sigma}=275 \qquad THD=\frac{1}{Q_o}D(x)=0.2\%$$

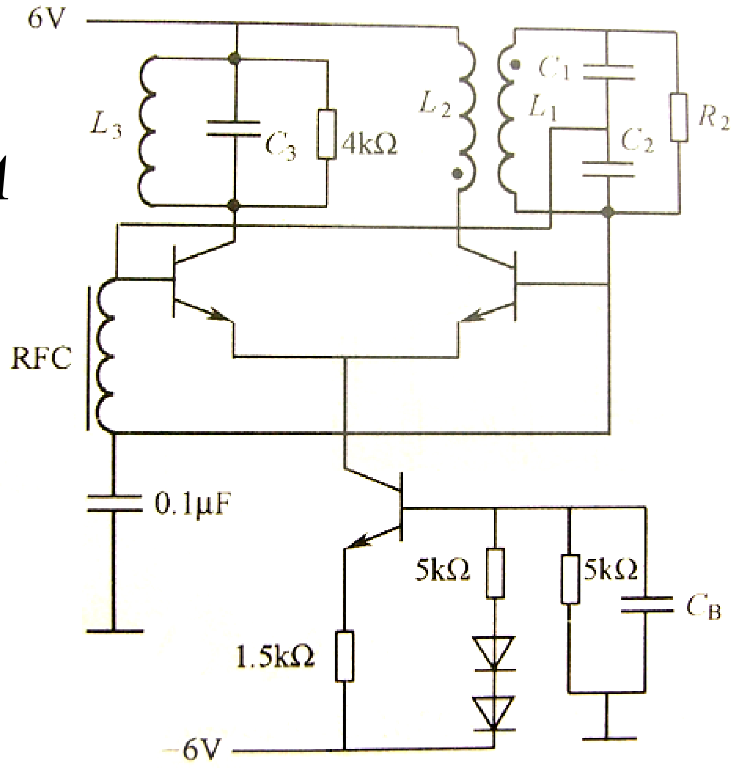
4.13

4.13 一实际差分放大器振荡器如图 E4.13 所示，已知：$\omega_0=6\times10^6$ rad/s；$C_2=9C_1$，$L_2=M=24\mu H$，$L_1=120\mu H$，L_3C_3 回路亦调谐于 6×10^6 rad/s，各晶体管的 β 值足够大。

(1) 求差分放大器的偏置恒流源 I_K 的大小。

(2) 选择 R_2，使左管差动输入电压幅度为 104mV。

(3) 在(2)的基础上，求输出电压幅度 U_o 及其 THD。



解：（1） $U_B=-2.3V \qquad I_K=2mA$

（2） $U_i=104mV=U_{C2}$

$$x=\frac{U_i}{U_r}=4$$

$$\frac{U_{R2}}{U_i}=\frac{1/C_{12}}{1/C_2}=\frac{C_2}{C_{12}}=10$$

$$U_{R2}=1.04V$$

4.13

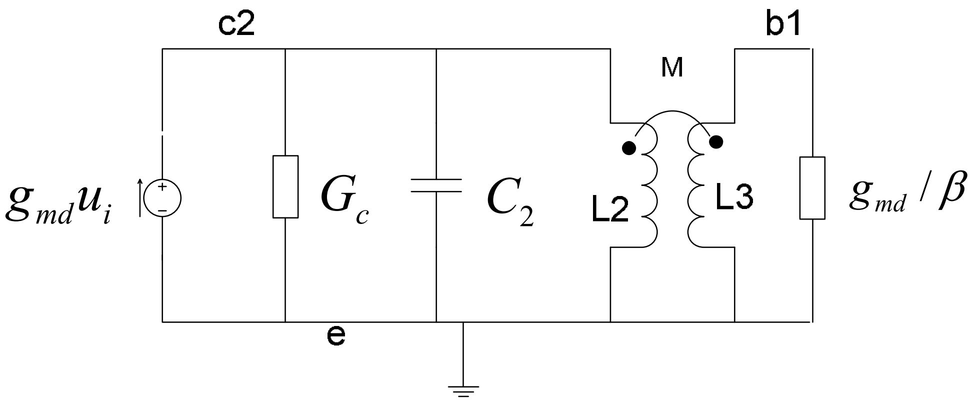
$$I_{C1}=I_K\alpha_1\left(x\right)=1.118mA \qquad R_2=\frac{U_{R2}}{\frac{M}{L_1}\cdot I_{C1}}=4.65k\Omega$$

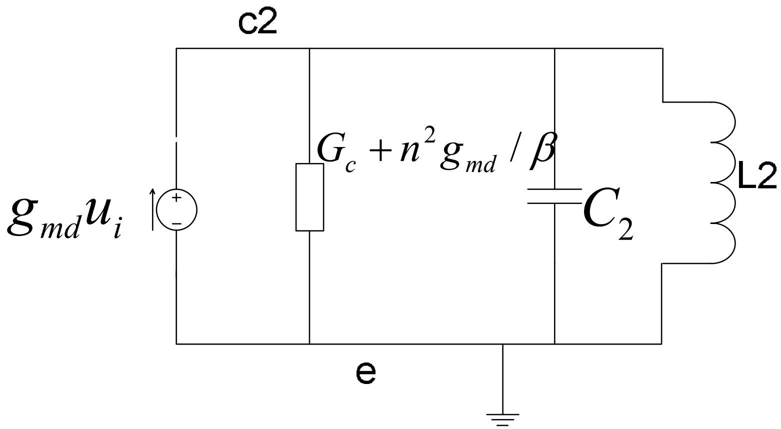
（3）　$$U_o=I_{C1}R=4.47V$$

$$Q=\frac{R_2}{\omega_o L_1}=6.5$$

$$THD=\frac{1}{Q}D\left(x\right)=0.98\%$$

4.14(差分对右侧)





$$n=\frac{M}{L_2}\qquad \text{起振条件}:\frac{ng_{md}}{g_\Sigma}\geq 1\qquad g_{md}\geq g_{md\min}$$

$$\frac{g_{md1}(x)}{g_{mdQ}}\rightarrow\frac{g_{md\min}}{g_{mdQ}}=\frac{1.204ms}{9.423ms}=0.1278\qquad x=19.871$$

4.14(差分对左侧)

$$f_o = \frac{1}{2\pi\sqrt{L_2C_2}} = 7.958MHz = 3f_{osc}$$

LC谐振回路提取振荡信号的三次谐波

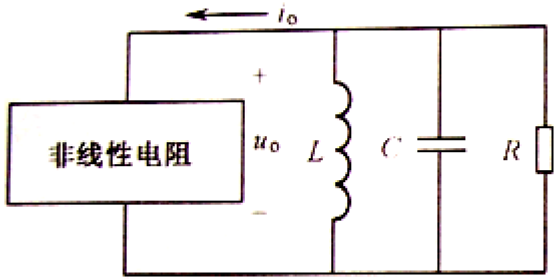
输出电压为：$u_o = \alpha a_3(x)R_L = 0.203$ v

4.15

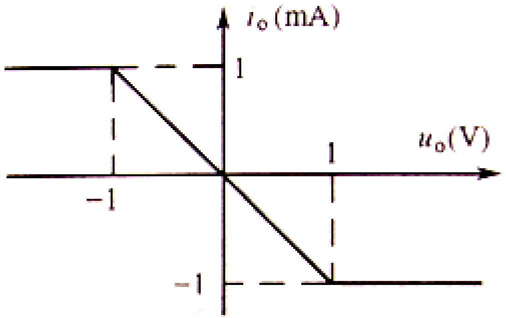
4.15　如图 E4.15(a)所示的电路模型中，已知：$L=10\mu H$，$C=1nF$，$R=2k\Omega$。计算下列两种情况下，非线性电阻消耗的平均功率。

(1) 非线性电阻特性如图 E4.15(b)所示。　【Ans.：$-2.116mW$】

(2) 非线性电阻特性为 $i=-6u+2u^2+u^3$。　【Ans.：$-1.833mW$】



(a)



(b)

4.15

解：（1）　　$u_o = U_o \cos\omega t$

非线性电阻特性特性曲线：　$i_o = f(u_o)$

$$I_{o1} = \frac{2}{\pi}\int_0^{\pi} f(U_o\cos\theta)\cdot\cos\theta d\theta \qquad \varphi = \arccos\left(\frac{1}{U_o}\right)$$

$$I_{o1} = -\frac{1}{\pi}\sin\varphi + \frac{U_o\varphi}{\pi} - \frac{1}{2}U_o$$

$$G_{n1} = -\frac{1}{\pi U_o}\sqrt{1-\frac{1}{U_o^2}} + \frac{1}{\pi}\arccos\frac{1}{U_o} - \frac{1}{2}$$

振荡平衡条件：　$G_{n1} = -G = -\frac{1}{R} = -0.5ms$

4.15

解得：　　$$U_o = 2.9093V$$

$$P_o = \frac{1}{2}U_o^2 G_{n1} = -2.116mW$$

（2）：同（1）理

$$G_{n1} = -6 + \frac{3}{4}U_o^2 = -0.5ms$$

$$U_o = 2.708V$$

$$P_o = -1.833mW$$

思考的一个问题：

非线性电阻的特性方程：　$i = f(u)$

电压激励：　$u_o = U_Q + U_o \cos \omega t$　　求：G_{n1}

方法一：　$i_o = f(u_o) = f(U_Q + U_o \cos \omega t)$

$$= I_o + I_{o1} \cos \omega t + I_{o2} \cos 2\omega t + \cdots$$

$$G_{n1} = \frac{I_{o1}}{U_o}$$

方法二：　$g(t) = \left.\frac{\partial f}{\partial u}\right|_{u = U_Q + U_o \cos \omega t}$

$$= g_0 + g_1 \cos \omega t + g_2 \cos 2\omega t + \cdots$$

$$G_{n1} = g_1 \,?$$

方法二应该这样计算：

$$g(t) = g_0 + g_1 \cos \omega t + g_2 \cos 2\omega t + \cdots$$

$$i_o = \left(g_0 + g_1 \cos \omega t + g_2 \cos 2\omega t + \cdots\right) \cdot \left(U_Q + U_o \cos \omega t\right)$$

再解4.15（1）：

$$g(t) = -\frac{2}{\pi}\left(\frac{\varphi}{2} + \sin\varphi \cos \omega t + \frac{\sin 2\varphi}{2} \cos 2\omega t + \cdots\right)$$

$$G_{n1} = \frac{I_{o1}}{U_o} = -\frac{2}{\pi}\left(\frac{\varphi}{2} + \frac{\sin 2\varphi}{4}\right) \qquad U_o = 2.924V$$

$$P_o = -2.137mW$$

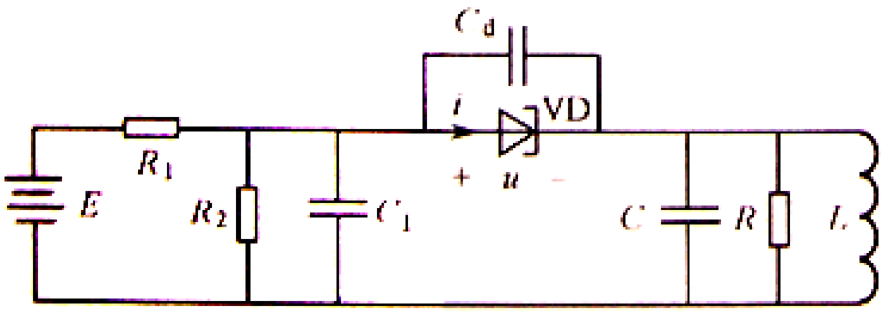
4.16

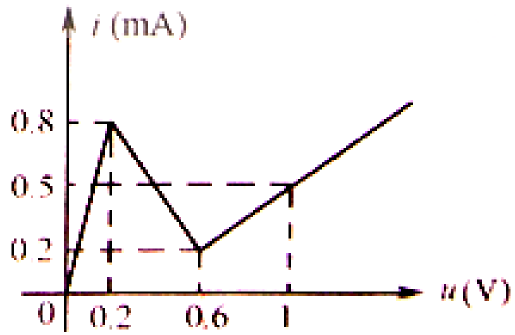
4.16　一压控负阻振荡器如图 E4.16(a)所示，并设负阻特性如图 E4.16(b)所示。已知：负阻支架电容 $C_d=5\text{pF}$，其他参数为：$E=3\text{V}$，$C_1=0.01\mu\text{F}$，$C=25\text{pF}$，$L=0.36\mu\text{H}$，$R=5\text{k}\Omega$。

(1) 画出直流等效电路，选择 R_1、R_2 以保证正确的工作点。

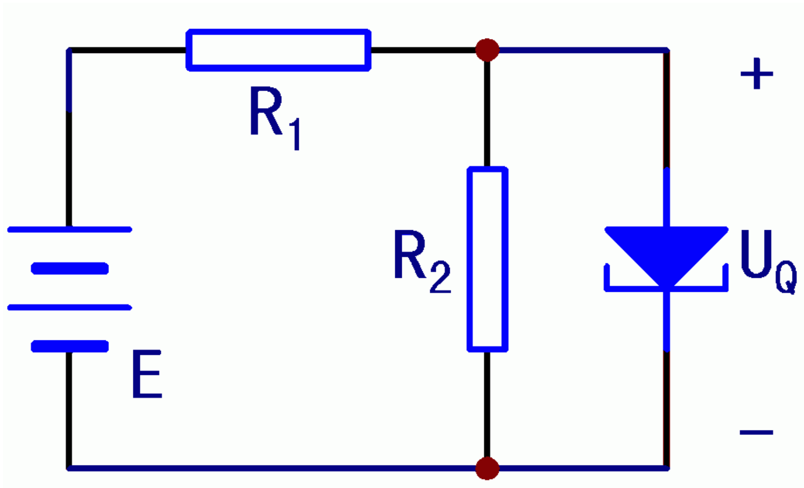
(2) 画出交流等效电路，计算振荡频率和回路压降幅度。

【Ans.：R_1 取 2.3kΩ，R_2 取 0.64kΩ 时，$f_{osc}=48.43\text{MHz}$，$U=0.396\text{V}$】　Iz，$U=0.396\text{V}$】





4.16



解：（1）直流负载线方程

$$E - U_Q = R_1\left(\frac{U_Q}{R_2} + I_Q\right)$$

工作在负阻区：

$0.2V < U_Q < 0.6V$　取：$U_Q = 0.4V$

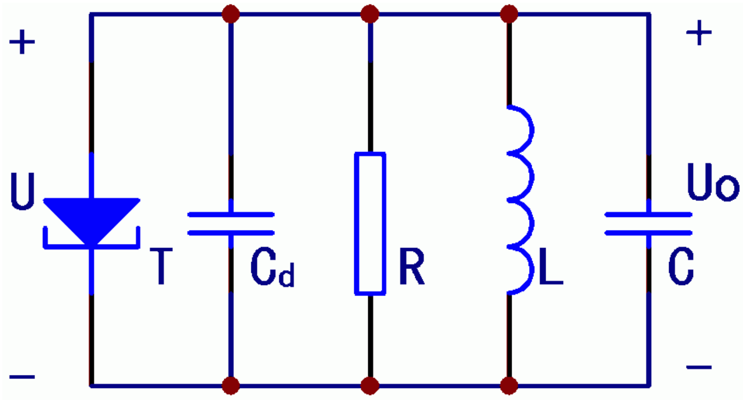
保证直流负载线与负阻特性只有一个交点：$\dfrac{R_1 + R_2}{R_1 R_2} > 1.5$

取：$\dfrac{R_1 + R_2}{R_1 R_2} = 2$　可解得：

$$R_1 = 2.31k\Omega$$

$$R_2 = 0.638k\Omega$$

4.16



（2）振荡频率：

$$f_{OSC}=\frac{1}{2\pi\sqrt{L\left(C_d+C\right)}}=48.45MHz$$

平衡条件： $$G_{n1}=-G=-\frac{1}{R}=0.2ms$$

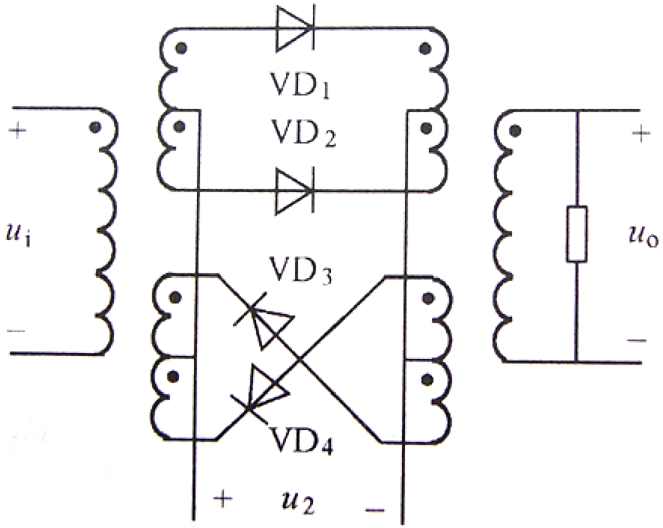
5.3

5.3　图 E5.3 所示为分裂式二极管准模拟乘法器电路，设 u_1 为低频信号 $u_1(t)=A\cos\Omega t$。

(1) 若 4 个二极管均为导通电压为零，导通电导为 g 的折线器件，且 $u_2(\omega_2 t)$ 的幅度远大于 A，试推导输出电压的表达式。　【Ans：$u_o=\dfrac{2gR_L(K^+-K^-)}{2gR_L+1}u_1$】

(2) 若 VD_1、VD_2 的导通电压为零，导通电导为 g_1，而 VD_3、VD_4 的导通电压为零，导通电导为 g_2，其他条件不变，试推导输出电压的表达式。

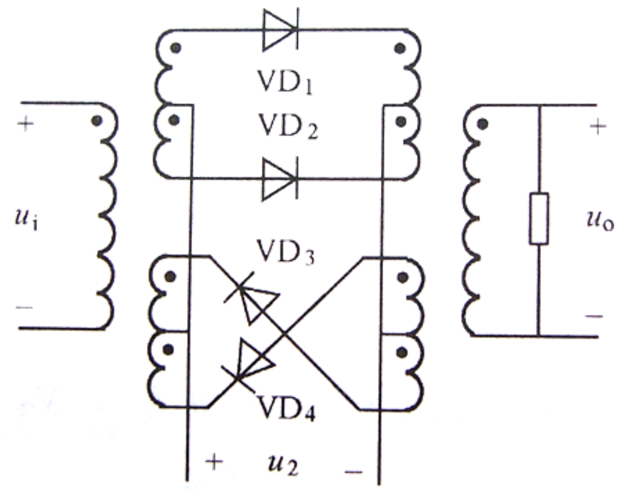
(3) 若条件仍为(1)中所述，但 $u_1(t)$ 和 $u_2(t)$ 的位置对调，再求输出电压的表达式。



5.3

解：(1)高频大幅度的信号 $u_2(\omega_2 t)$ 判为开关控制信号

①当u_2的正半周



$$u_{D1} = u_1 + u_2 - u_o^+$$

$$u_{D2} = -u_1 + u_2 + u_o^+$$

$$i_1 = g u_{D1}$$

$$i_2 = g u_{D2}$$

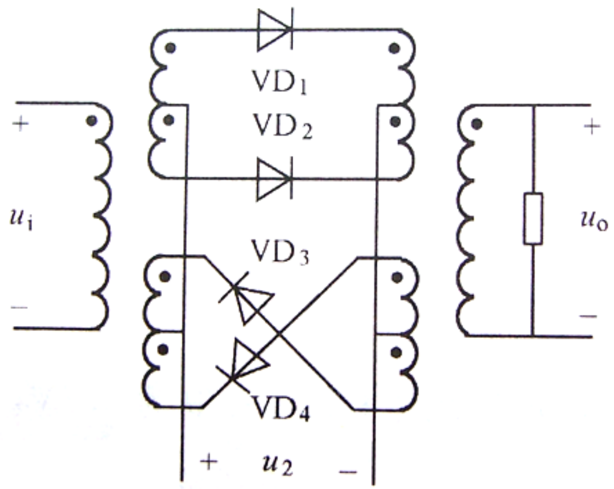
$$u_o^+ = (i_1 - i_2) R_L = g \cdot 2 (u_1 - u_o^+) R_L$$

$$u_o^+ = \frac{2gR_L u_1}{2gR_L + 1}$$

5.3

②当u_2的负半周

$$u_o^- = -\frac{2gR_L u_1}{2gR_L + 1}$$



综上：

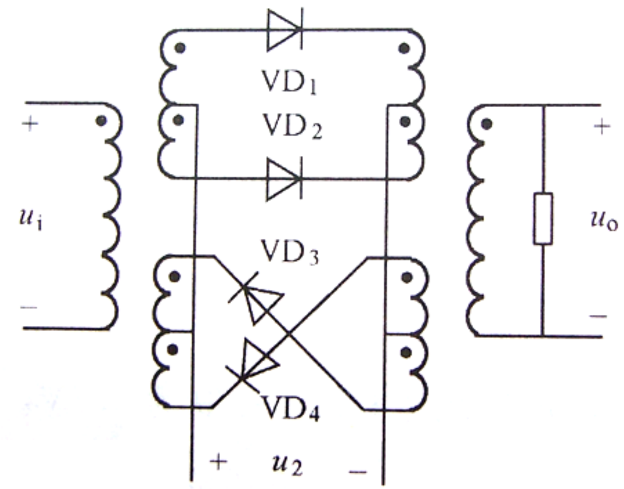
$$u_o = u_o^+ K^+ + u_o^- K^-$$

$$u_o = \frac{2gR_L\left(K^+ - K^-\right)}{2gR_L + 1} u_1$$

5.3

(2) 同(1)

$$u_o^+ = \frac{2g_1R_Lu_1}{2g_1R_L+1}$$



$$u_o^- = -\frac{2g_2R_Lu_1}{2g_2R_L+1}$$

综上：

$$u_o = u_o^+K^+ + u_o^-K^-$$

$$u_o = 2R_Lu_1\left(\frac{g_1K^+}{2g_1R_L+1} + \frac{g_2K^+}{2g_2R_L+1}\right)$$

5.3

(3)开关控制信号u_2

u_2正半周：

$$u_{D1} = u_1 + u_2 - u_o^+$$

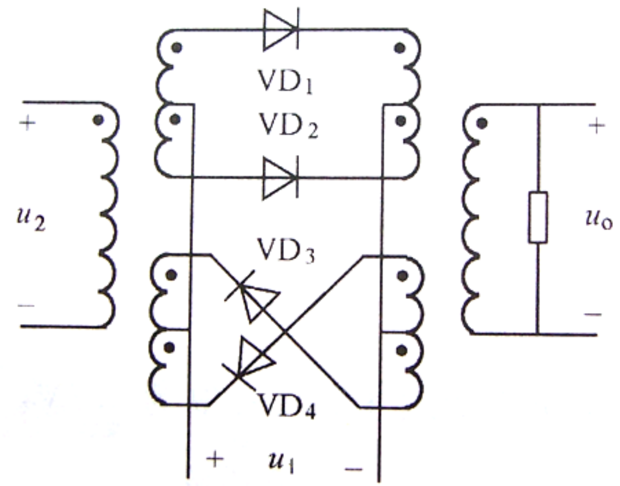
$$u_{D4} = -u_1 + u_2 + u_o^+$$

$$i_1 = g u_{D1}$$

$$i_4 = g u_{D4}$$

$$u_o^+ = (i_1 - i_4) R_L = g \cdot 2 (u_1 - u_o^+) R_L$$

$$u_o^+ = \frac{2gR_L u_1}{2gR_L + 1} \qquad u_o = u_o^+ K^+ = \frac{2gR_L u_1}{2gR_L + 1} K^+$$

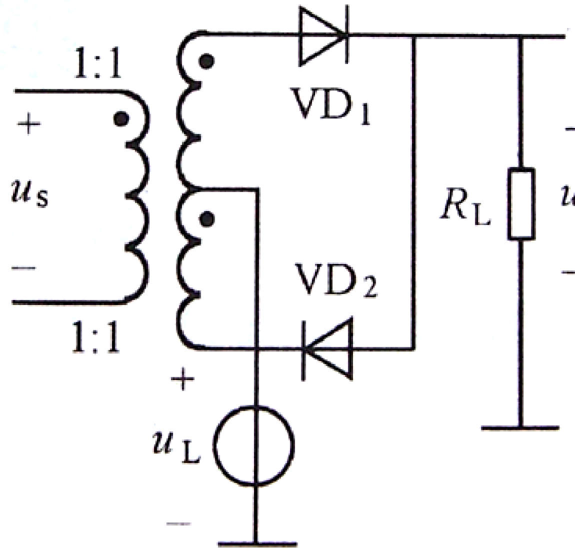


5.5 (c)

5.5 试分别求出如图所示电路输出电压的表达式。设所有二极管特性均为从原点出发、斜率为g_D的直线。且 $U_L >> U_S \quad R_L >> 1/g_D$

(c)解：u_L为开关信号

①当u_L正半周，VD1导通，VD2截止



$$u_{D1} = u_L + u_S - u_o^+$$

$$i_1 = g_D u_{D1}$$

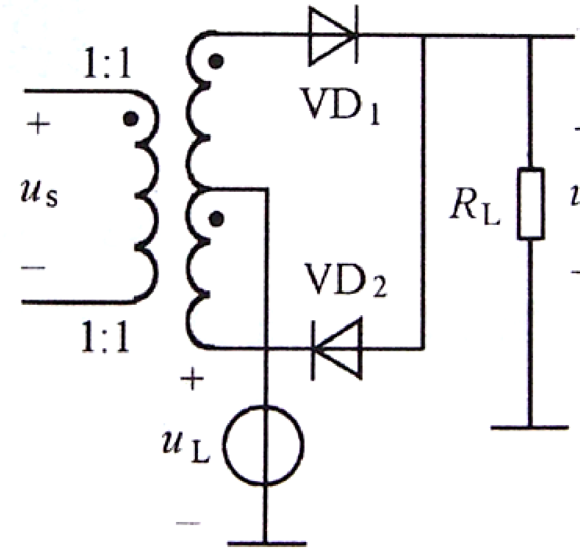
$$u_o^+ = i_1 \cdot R_L = g_D R_L \left(u_L + u_S - u_o^+\right)$$

$$u_o^+ = \frac{g_D R_L}{1 + g_D R_L}\left(u_S + u_L\right)$$

5.5 (c)

②当u_L负半周，VD1截止，VD2导通，同理：

$$u_o^- = \frac{g_D R_L}{1+g_D R_L}\left(u_L - u_S\right)$$



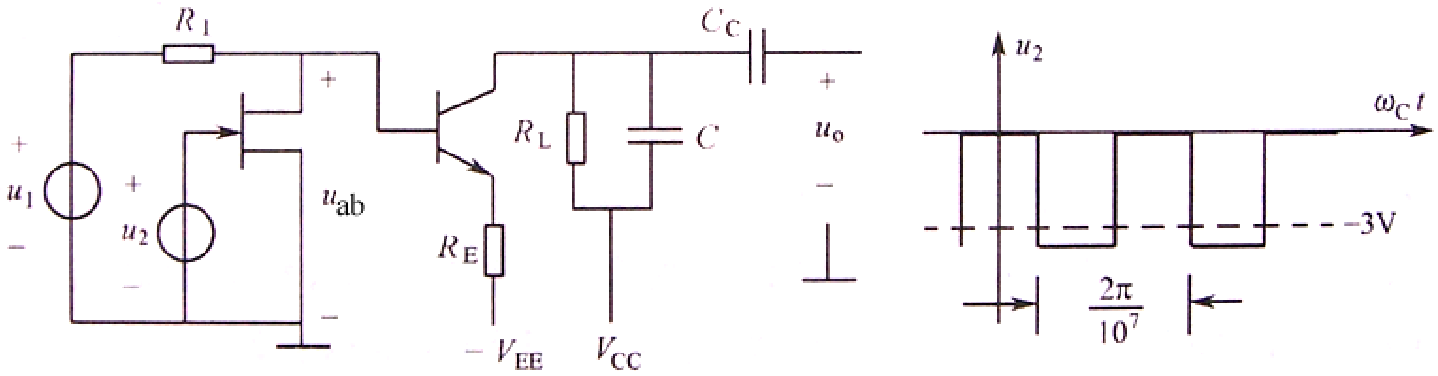
综上：

$$u_o = u_o^+ K^+ + u_o^- K^-$$

$$u_o = \frac{g_D R_L}{g_D R_L + 1}\left[u_S\left(K^+ - K^-\right) + u_L\right]$$

5.6

5.6　设图 E5.6 所示电路中，场效应管的 $I_{DSS}=10\text{mA}$，$U_P=-2\text{V}$；$R_1=R_E=5\text{k}\Omega$，$R_L=4\text{k}\Omega$，$C=0.25\mu\text{F}$，$V_{CC}=V_{EE}=5\text{V}$；$u_1(t)=1.2\cos10^3t\cos10^7t$，$u_2(t)$为图 E5.6(b)所示方波。设晶体管 β 足够大，试求输出电压的表达式及纹波大小（纹波可近似定义为一次高频电压幅度与低频电压幅度之比）。



(a)　　　　　　(b)

5.6

解：场效应管开关准模拟乘法器

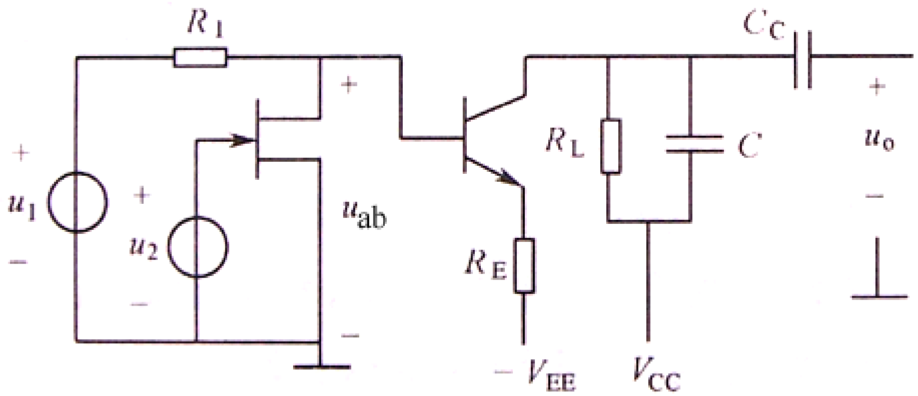
$$u_{ab}=u_1K^-(\omega_2 t)=1.2\cos10^3t\cos10^7t\left(\frac{1}{2}-\frac{2}{\pi}\cos10^7t+\cdots\right)$$

晶体管β足够大，α=1

$$i_C=i_E=\frac{u_{ab}+V_{EE}-0.7V}{R_E}=\frac{u_1K^-(\omega_2 t)+4.3V}{5k\Omega}$$

对于输出端$R_L C$网络：

$$\omega_c=\frac{1}{R_L C}=10^3 rad/s$$



5.6

10^3分量：　　$I_{C1} = 1.2V \times \frac{-2}{\pi} \times \frac{1}{2} \times \frac{1}{5k\Omega}$

$$u_o = -I_{C1} \cdot \dot{Z} \cdot \cos 10^3 t$$

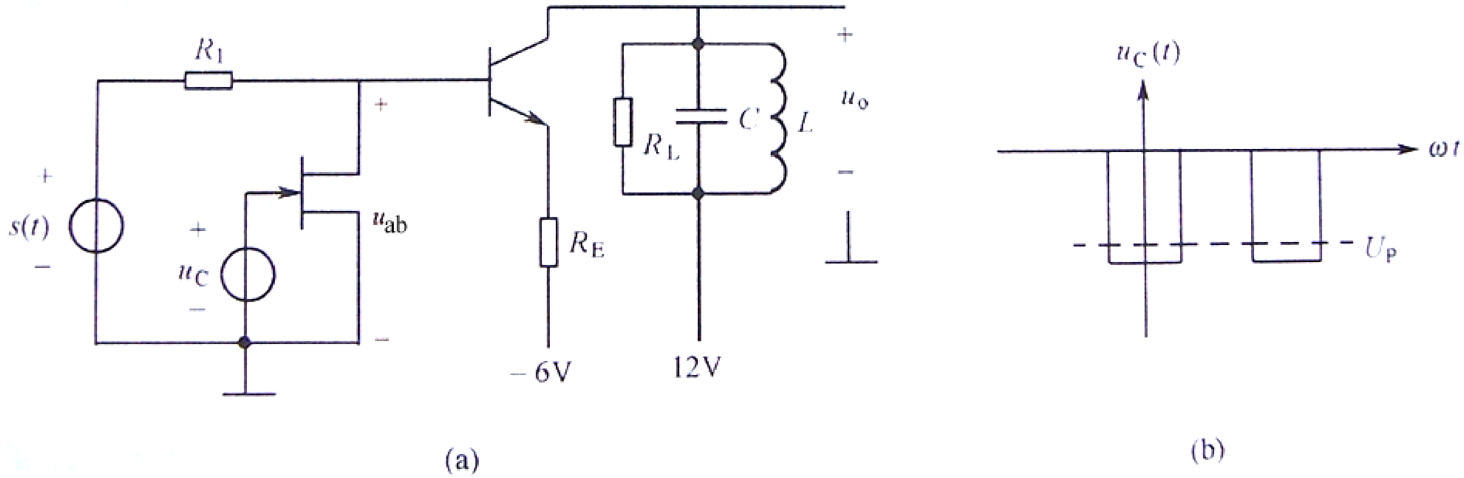
$$= -I_{C1} \cdot \frac{1}{\sqrt{2}} R_L \cdot \cos\left(10^3 t - \frac{\pi}{4}\right) = 0.216\cos\left(10^3 t - \frac{\pi}{4}\right)$$

$$\gamma = \frac{U_{abHigh}}{U_{abLow}} \frac{R_L / \sqrt{1+10^8}}{R_L / \sqrt{2}}$$

$$= \frac{1.2V \times \frac{1}{2} \times \frac{1}{2} \times \frac{1}{5}}{1.2V \times \frac{2}{\pi} \times \frac{1}{2} \times \frac{1}{5}} \frac{R_L / \sqrt{1+10^8}}{R_L / \sqrt{2}} = 0.01\%$$

6.6

6.6　图 E6.3(a)所示场效应管开关调幅电路中，场效应管参数：$I_{DSS}=4\text{mA}$，$U_P=-4\text{V}$，晶体管 $\beta=50$。$R_1=1\text{k}\Omega$，$R_E=3\text{k}\Omega$，$R_L=500\Omega$，$L=1\mu\text{H}$，$C=10\text{nF}$。基带信号为 $s(t)=3\cos 10^5 t+\cos(2\times 10^5 t)(\text{V})$，载波重复角频率为 $\omega_C=10^7\,\text{rad/s}$，波形如图 E6.3(b)所示。求输出电压表达式。



6.6

解：场效应管开关准模拟乘法器

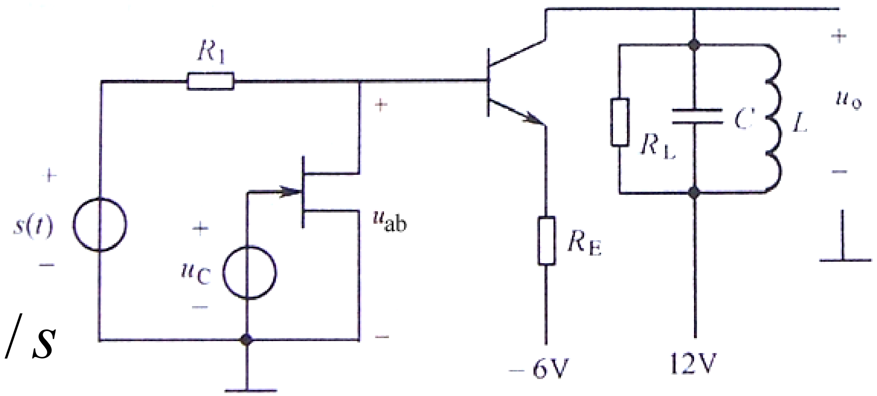
$$u_{ab}=u_1K^-(\omega_C t)=\left(3\cos 10^5 t+\cos 2\times 10^5 t\right)\cdot\left(\frac{1}{2}-\frac{2}{\pi}\cos 10^7 t+\cdots\right)$$

$$i_C=\alpha i_E=\frac{50}{51}\cdot\frac{u_{ab}+6V-0.7V}{R_E}=\frac{50}{51}\cdot\frac{u_1K^-(\omega_2 t)+5.3V}{3k\Omega}$$

RLC选频网络：

$$\omega_o=\frac{1}{\sqrt{LC}}=10^7 rad/s$$

$$\alpha=\frac{1}{2}BW=\frac{1}{2RC}=10^5 rad/s$$



6.6

对于 $\cos 10^5 t \cdot \cos 10^7 t$ 频率成分 $I_{C1} = 3V \cdot \left(-\frac{2}{\pi}\right) \times \frac{50}{51} \cdot \frac{1}{3k\Omega}$

对于 $\cos 2\times 10^5 t \cdot \cos 10^7 t$ 频率成分 $I_{C2} = 1V \cdot \left(-\frac{2}{\pi}\right) \times \frac{50}{51} \cdot \frac{1}{3k\Omega}$

RLC选频网络： $H(j\omega) = \dfrac{R_L}{1 + j\dfrac{\omega - \omega_o}{\alpha}}$

$\cos 2\times 10^5 t \cdot \cos 10^7 t$ 频率成分的相移

$$\arctan(-2) = -63.4^o$$

6.6

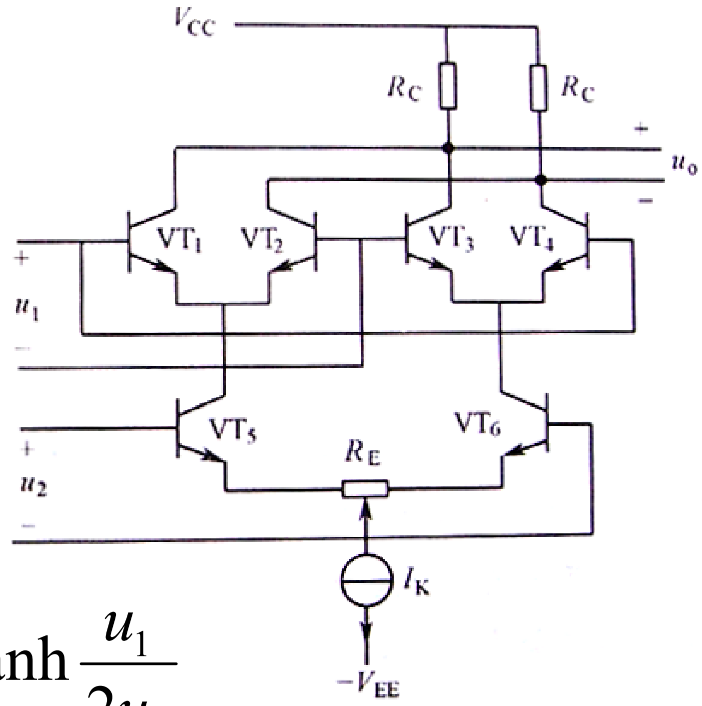
综合以上分析：

$$u_o = 12 - I_{C1}\frac{R_L}{\sqrt{2}}\cos\left(10^5 t - 45^o\right)\cos 10^7 t$$
$$- I_{C2}\frac{R_L}{\sqrt{5}}\cos\left(2\times 10^5 t - 63.4^o\right)\cos 10^7 t$$

$$u_o = 12 + \left[0.221\cos\left(10^5 t - 45^o\right) + 0.0465\cos\left(2\times 10^5 t - 63.4^o\right)\right]\cos 10^7 t$$

6.10

6.10 如图所示的双平衡差分电路中，设所有晶体管均为指数律的。试推导输出电压表达式。若欲用此电路产生DSB信号，u_1、u_2中哪个信号应该为载波？为什么？



解：VT5 VT6组成负反馈的差分放大器：

$$i_{C5} - i_{C6} = i_{E5} - i_{E6} = 2\frac{u_2}{R_E}$$

VT1 VT2组成的差分放大器：

$$i_{C1} - i_{C2} = 2\frac{i_{C5}}{2}\tanh\frac{u_1}{2u_r} = i_{C5}\cdot\tanh\frac{u_1}{2u_r}$$

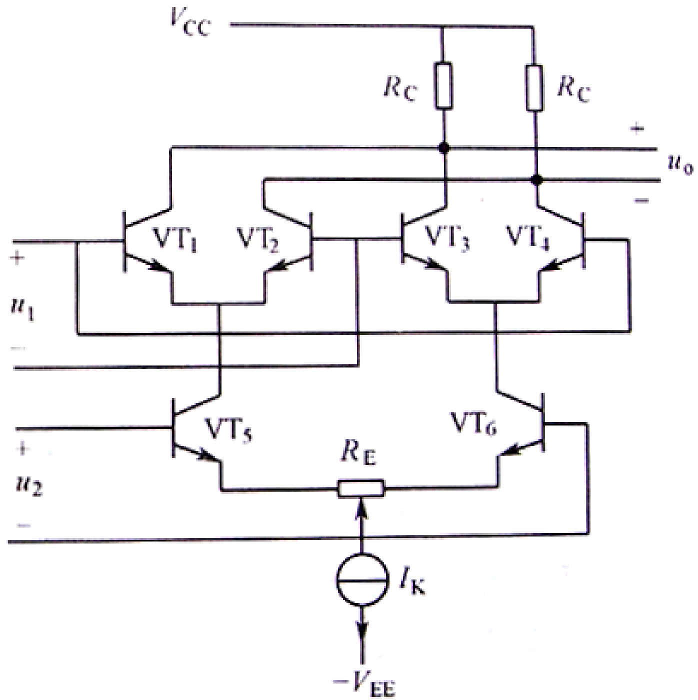
VT4 VT3组成的差分放大器：

$$i_{C4} - i_{C3} = 2\frac{i_{C6}}{2}\tanh\frac{u_1}{2u_r} = i_{C6}\cdot\tanh\frac{u_1}{2u_r}$$

6.10

输出电压：

$$u_o=\left[V_{CC}-R_C\left(i_{C1}+i_{C3}\right)\right]-\left[V_{CC}-R_C\left(i_{C2}+i_{C4}\right)\right]=R_C\left(i_{C2}+i_{C4}-i_{C1}-i_{C3}\right)$$



$$u_o=-R_C\left(i_{C5}-i_{C6}\right)\cdot\tanh\frac{u_1}{2u_r}$$

$$u_o=-\frac{2R_C}{R_E}u_2\tanh\frac{u_1}{2u_r}$$

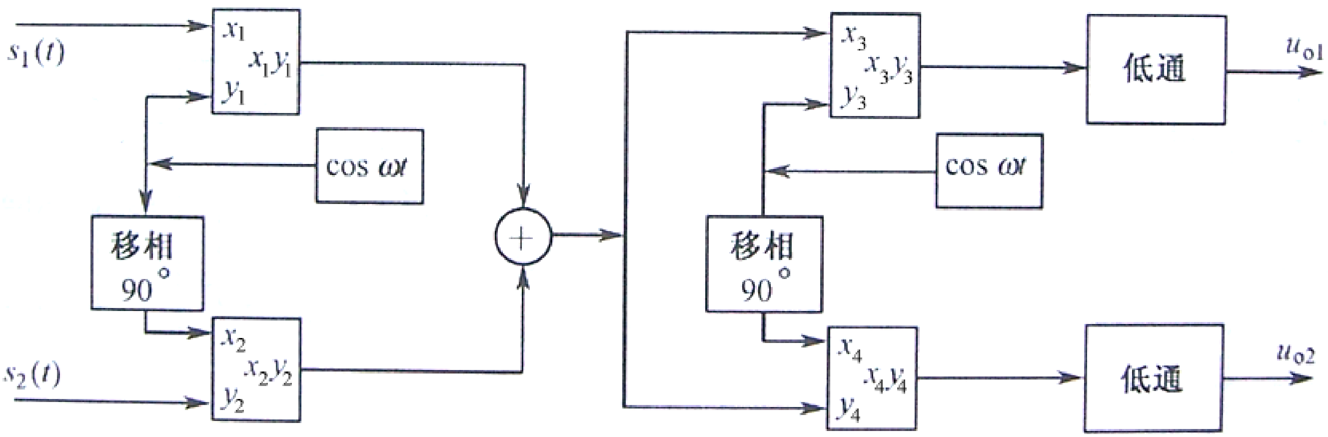
u_1为载波，u_2为调制信号

6.13

6.13 证明如图所示的正交复用系统，可以实现用2Ωmax的带宽传送两路带宽为Ωmax的不同的基带信号。

解：由图 $x_1 y_1 = s_1(t)\cos\omega t$ $\qquad x_2 y_2 = s_2(t)\sin\omega t$

$$x_1 y_1 - x_2 y_2 = s_1(t)\cos\omega t - s_2(t)\sin\omega t$$



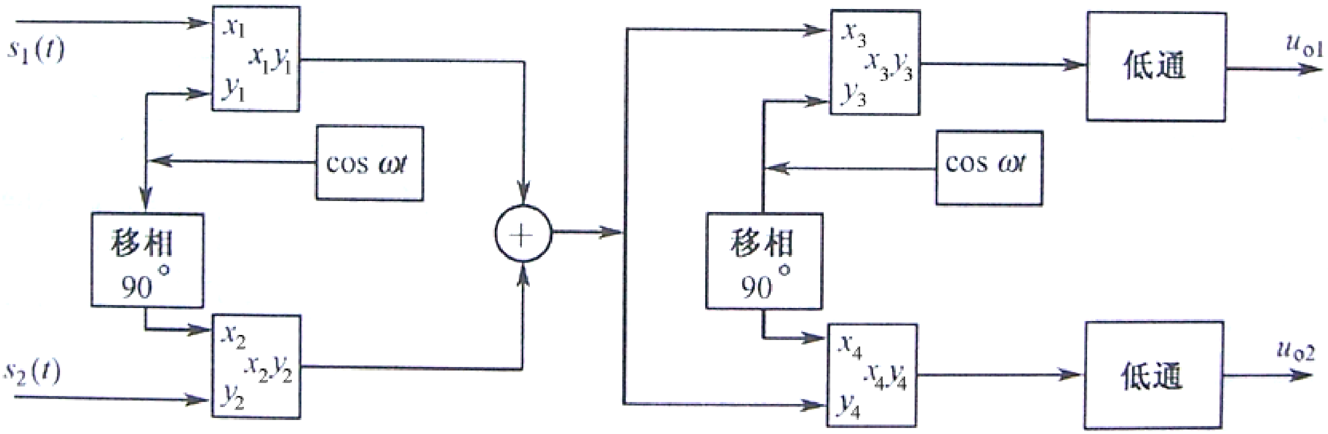
6.13

在接受方： $x_1y_1 - x_2y_2 = s_1(t)\cos\omega t - s_2(t)\sin\omega t$

$$x_3y_3 = s_1(t)\cos^2\omega t - s_2(t)\sin\omega t\cos\omega t = \frac{1}{2}s_1(t) + \frac{1}{2}\left[s_1(t)\cos 2\omega t - s_2(t)\sin 2\omega t\right]$$

$$x_4y_4 = s_1(t)\sin\omega t\cos\omega t - s_2(t)\sin^2\omega t = \frac{1}{2}s_2(t) + \frac{1}{2}\left[s_1(t)\sin 2\omega t + s_2(t)\cos 2\omega t\right]$$

分别通过低通滤波器： $u_{o1} \propto s_1(t)$ $u_{o2} \propto s_2(t)$ 得证！



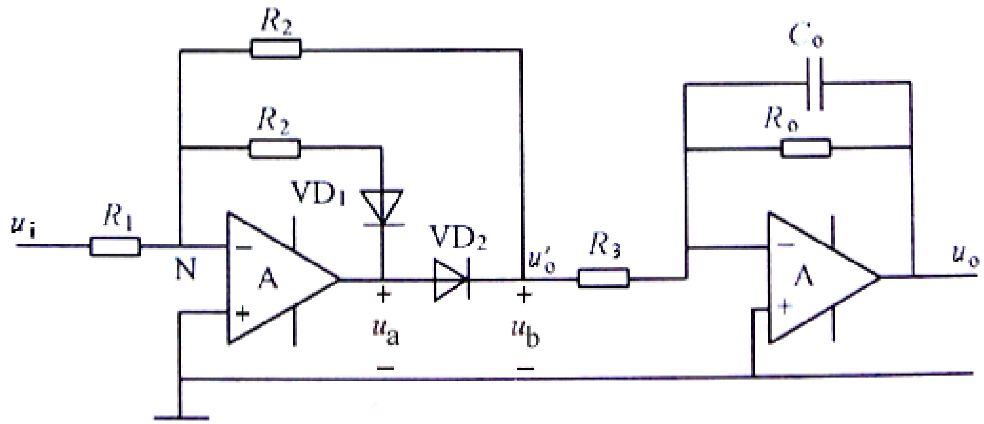
6.14

6.14　对图 E6.10 所示的均值包络检波器，给定：$R_1=R_2=1\text{k}\Omega$，$R_3=50\text{k}\Omega$，$R_o=500\text{k}\Omega$，$C_o=200\text{pF}$。运算放大器开环增益 $A=2000$，$u_i(t)=(1+0.5\cos10^4t)\cos10^8t$ (V)。

(1)求输出电压表达式；　【Ans.：$u_o=-3.18[1+0.354\cos(10^4t-\pi/4)]$(V)】

(2)若 A 改成 1000，VD_1、VD_2 改成导通电压 0.4V、正向导通电阻 200Ω 的折线化二极管，再求输出电压表达式。

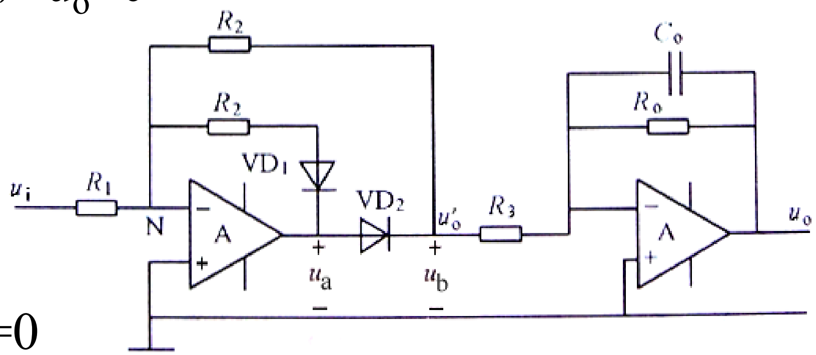
【Ans.：$u_o=-3.16[1+0.356\cos(10^4t-\pi/4)]$(V)】



6.14

解：u_i处于正半周，VD1导通，VD2截止，u_o=0

u_i处于负半周，VD2导通，VD1截止



$$-u_i=\frac{U_T}{1+A}+i\left(R_1+\frac{R_2+R_D}{1+A}\right)$$

1) 其中对于理想二极管，U_T=0，R_D=0

$$-u_i=i\left(R_1+\frac{R_2}{1+2000}\right)\approx iR_1$$

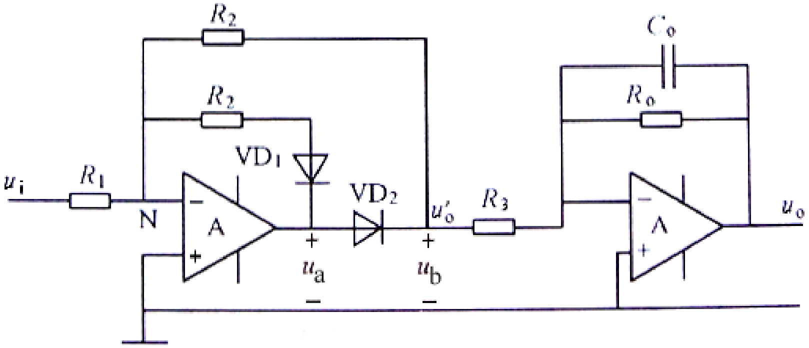
$$u_o^{'}=u_bK^{-}(\omega_Ct)=\left[u_i-\frac{u_i}{R_1}(R_1+R_2)\right]K^{-}(\omega_Ct)=-\frac{R_2}{R_1}u_iK^{-}(\omega_Ct)$$

$$u_o^{'}=-u_iK^{-}(\omega_Ct)=-(1+0.5\cos 10^4 t)\cos 10^8 t\cdot\left(\frac{1}{2}-\frac{2}{\pi}\cos 10^8 t+\cdots\right)$$

6.14

第二级RoCo组成低通滤波器

$$Z(j\omega)=\frac{R_o}{1+j\omega R_o C_o}$$



截止频率： $\omega_C=\frac{1}{R_o C_o}=10^4 rad/s$

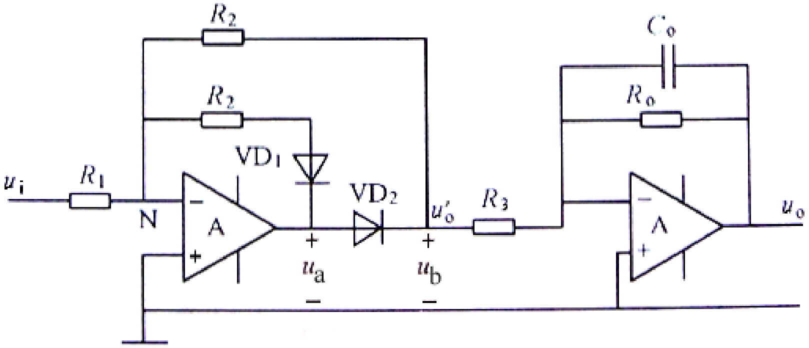
第二级输出：

$$u_o=-\frac{\dot{Z}}{R_3}u_o^{'}=-\frac{R_o}{R_3}\cdot\left[1+\frac{0.5}{\sqrt{2}}\cos\left(10^4 t-\frac{\pi}{4}\right)\right]\times\left(-\frac{2}{\pi}\right)\times\left(-\frac{1}{2}\right)$$

$$u_o=-3.18\left[1+0.354\cos\left(10^4 t-\frac{\pi}{4}\right)\right]$$

6.14

2) 非理想二级管



$$-u_i = \frac{U_T}{1+A} + i\left(R_1 + \frac{R_2 + R_D}{1+A}\right)$$

$$-u_i = 0.0004V + i \cdot 1.0012k\Omega$$

$$u_o^{'} = u_b K^{-}(\omega_C t)$$

$$= \left[u_i + \frac{-u_i - 0.0004V}{1.0012k\Omega}(R_1 + R_2)\right] K^{-}(\omega_C t)$$

同理，通过第二级： $u_o^{'} = -0.9976 \cdot u_i \cdot K^{-}(\omega_C t) - 0.000799 K^{-}(\omega_C t)$

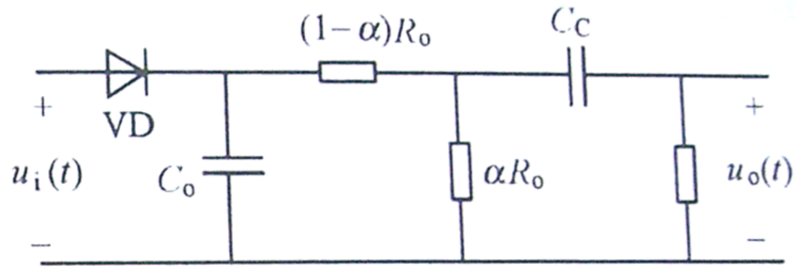
$$u_o = -0.9976 \times 3.18 \cdot \left[1 + 0.354\cos\left(10^4 t - \frac{\pi}{4}\right)\right] - 0.000799 \times \frac{1}{2}$$

$$u_o = -3.17\left[1 + 0.354\cos\left(10^4 t - \frac{\pi}{4}\right)\right]$$

6.16

6.16 如图 E6.12 电路中，VD 为理想二极管，$C_o=1000\mathrm{pF}$，$C_C=10\mu\mathrm{F}$，$R_o=5\mathrm{k}\Omega$，$\alpha=0.4$，$R_1=2\mathrm{k}\Omega$。若 $u_i(t)=2(1+0.8\cos10^5 t)\cos10^8 t$ (V)，此检波器工作时会产生失随失真吗？若不失真，写出输出电压的表达式；若会失真，应如何改变 α 值可避免失随失真？

【Ans.：会失真。要不失真，减小 α 至 $\alpha=0.2387$ 时，$u_o=0.24\cos(10^5 t-24.5^\circ)$ (V)】



解：放电时间常数

$$\tau=\left[\alpha R_o//R_1+(1-\alpha)R_o\right]C_o=kR_oC_o$$

交流负载与直流负载比：

$$k=\left[\alpha R_o//R_1+(1-\alpha)R_o\right]/R_o=\frac{2\alpha}{5\alpha+2}+1-\alpha$$

当 α=0.4时，k=0.8

$$k-m\sqrt{1+(\Omega_{\max}\tau)^2}=0.8-0.8\sqrt{1+0.16}=0.8-0.862<0$$

会发生失随失真

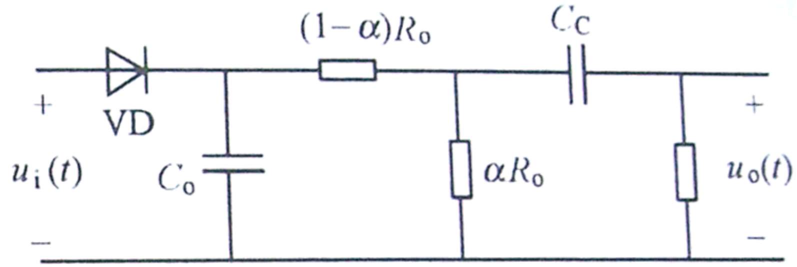
6.16

改变α以满足要求： $k - m\sqrt{1+\left(\Omega_{\max}\tau\right)^2} \geq 0$

得到关于k的方程：

$$k - 0.8\sqrt{1+\left(0.5k\right)^2} \geq 0$$

$$k = \frac{2\alpha}{5\alpha+2} + 1 - \alpha \geq 0.87287$$



关于α的方程：

$$5\alpha^2 - 0.63565\alpha - 0.25426 \leq 0$$

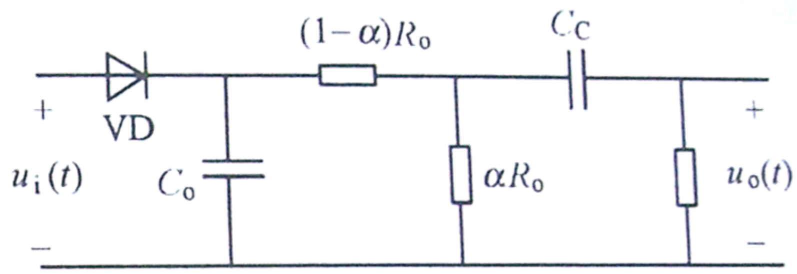
$$0 \leq \alpha \leq 0.2978$$

6.16

当α=0.2978时，等效的交流阻抗： $R_o^{'}=\alpha R_o // R_1+(1-\alpha)R_o=4.3645k\Omega$

$$Z(j\omega)=\frac{R_o^{'}}{1+j\omega R_o^{'}C_o}=\frac{R_o^{'}}{1+j\dfrac{\omega}{\omega_C}}$$

截止频率：



$$\omega_C=\frac{1}{R_oC_o}=2.25\times10^5\,rad/s$$

$$\varphi=-\arctan\frac{\omega}{\omega_C}=-\arctan\frac{1}{2.25}=-24^o$$

输出电压： $u_o=2\times0.8\cdot s(t)\cdot\dot{Z}\cdot\dfrac{\alpha R_o // R_1}{R_o^{'}}$

$$u_o=2\times0.8\cos(10^5t-24^o)\cdot\frac{1}{\sqrt{1+2.25^{-2}}}\cdot\frac{\alpha R_o // R_1}{R_o^{'}}$$

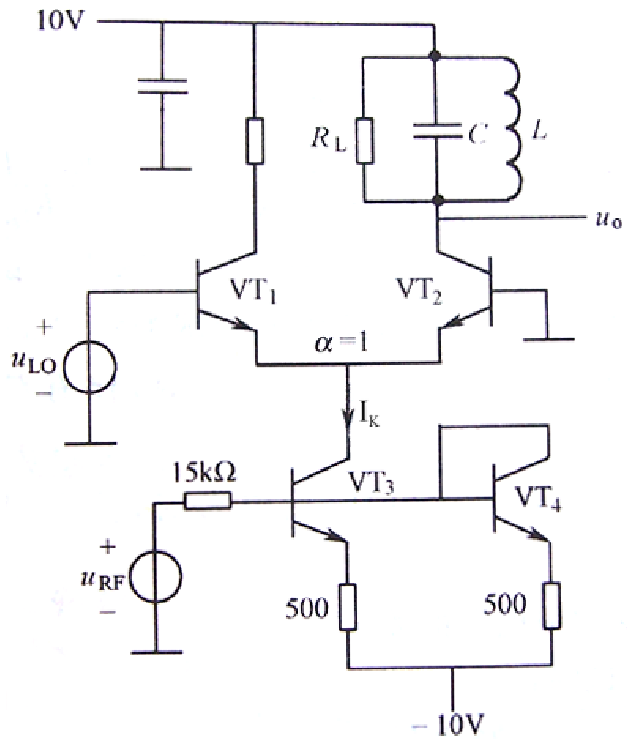
$$u_o=0.286\cos(10^5t-24^o)$$

7.10

7.10 设 $u_{RF}=6(1+\cos10^6t)\cos8\times10^7t$ （V），求下列两种情况下差分混频器的输出电压表达式：

（1）$u_{LO}=26\cos10^8t$（mv）

（2）$u_{LO}=2.6\cos10^8t$ （V）



解：差分对为受控“恒流源”偏置

$$I_K=\frac{u_{RF}+10V-0.7V}{15k\Omega+500\Omega}=\frac{u_{RF}+9.3V}{15.5k\Omega}$$

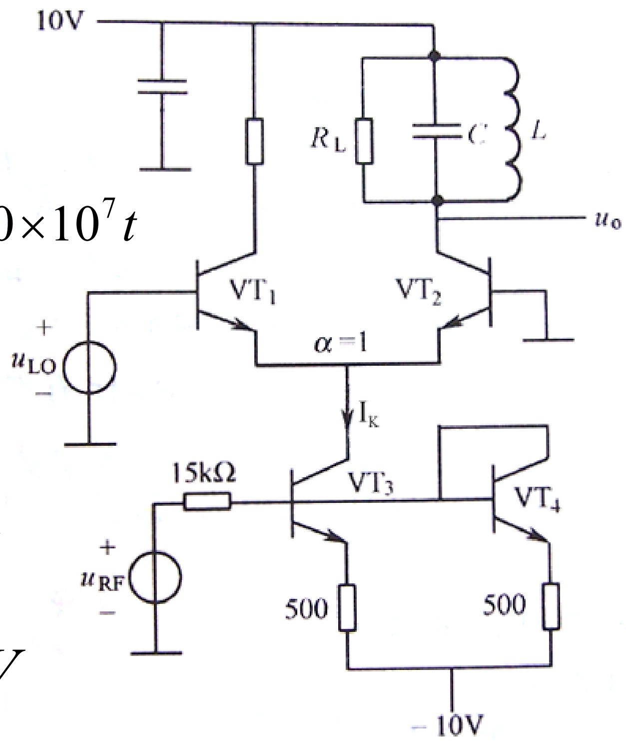
RLC选频网络：

$$\omega_o=\frac{1}{\sqrt{LC}}=2\times10^7rad/s$$

$$\alpha=\frac{1}{2}BW=\frac{1}{2R_LC}=10^6rad/s$$

7.10

（1） $u_{LO} = 26\cos 10^8 t$ （mv）　　　　$x = \dfrac{U_{LO}}{U_r} = 1$



$$I_{C1} = I_K \alpha_1(x)\cos 10^8 t$$

$$= \alpha_1(x)\frac{6\left(1+0.8\cos 10^6 t\right)\cos 8\times 10^7 t + 9.3V}{15.5k\Omega}\cdot\cos 10\times 10^7 t$$

$$u_o = 10 + I_{C1}\cdot\dot{Z}$$

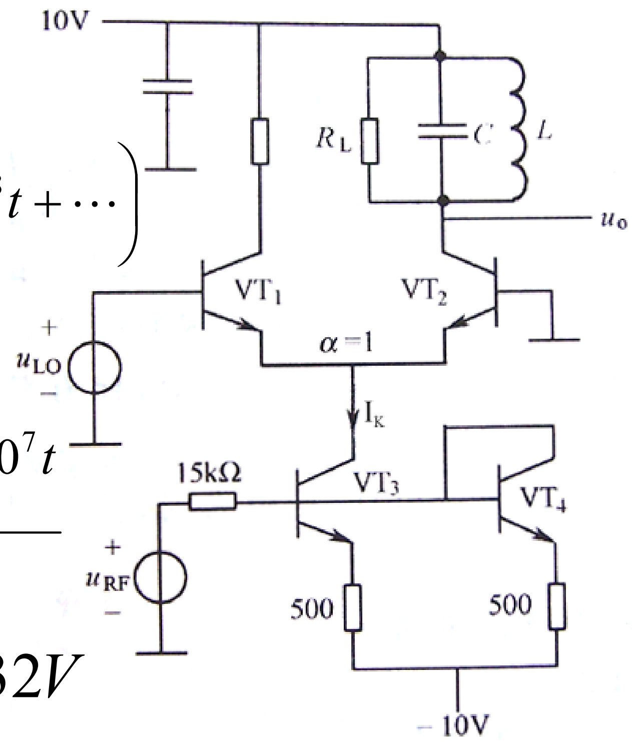
$$u_o = 10 + \frac{1}{2}\alpha_1(x)R_L\frac{6\left[1+\dfrac{0.8}{\sqrt{2}}\cos\left(10^6 t - \dfrac{\pi}{4}\right)\right]\cos 2\times 10^7 t}{15.5k\Omega}$$

其中： $\dfrac{1}{2}\alpha_1(x)R_L\dfrac{6}{15.5k\Omega} = 0.456V$

$$u_o = 10 + 0.456\left[1 + 0.5657\cos\left(10^6 t - \frac{\pi}{4}\right)\right]\cos 2\times 10^7 t$$

7.10

（2）$u_{LO}=2.6\cos 10^8 t$（v）差分对表现出动态限幅特性，电流开关特性:



$$i_C=I_K K^-\left(10^8 t\right)$$

$$=\frac{6\left(1+0.8\cos 10^6 t\right)\cos 8\times 10^7 t+9.3V}{15.5k\Omega}\cdot\left(\frac{1}{2}-\frac{2}{\pi}\cos 10^8 t+\cdots\right)$$

$$u_o=10-i_C\cdot\dot{Z}$$

$$u_o=10-\frac{1}{2}\left(-\frac{2}{\pi}\right)\cdot R_L\frac{6\left[1+\frac{0.8}{\sqrt{2}}\cos\left(10^6 t-\frac{\pi}{4}\right)\right]\cos 2\times 10^7 t}{15.5k\Omega}$$

其中：$\frac{1}{2}\left(-\frac{2}{\pi}\right)R_L\frac{6}{15.5k\Omega}=-1.232V$

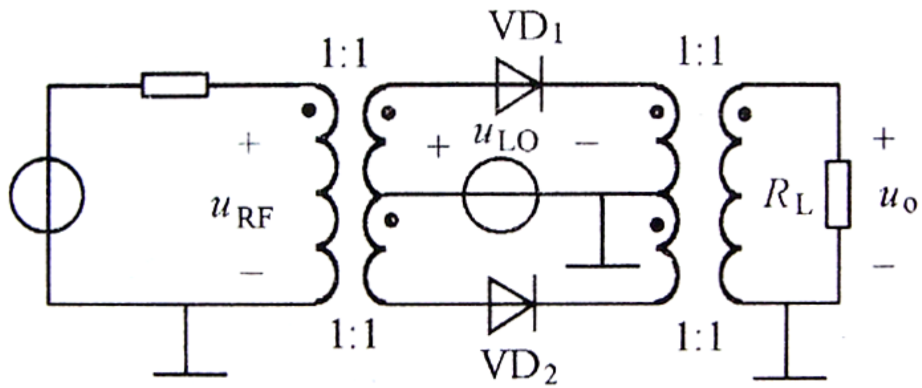
$$u_o=10+1.232\left[1+0.5657\cos\left(10^6 t-\frac{\pi}{4}\right)\right]\cos 2\times 10^7 t$$

7.14

7. 14 求如图示电路的混频损耗L_C。设所有的二极管均为理想二极管，且其通断受控于$u_{LO}(t)$

解：二极管无源混频器

当u_{LO}的正半周：



$$u_{D1} = u_{RF} + u_{LO} - u_o^+$$

$$u_{D2} = -u_{RF} + u_{LO} + u_o^+$$

$$i_2 = g u_{D2} \qquad i_1 = g u_{D1}$$

$$u_o^+ = (i_1 - i_2) R_L = g \cdot 2(u_{RF} - u_o^+) R_L \qquad u_o^+ = \frac{2gR_L u_{RF}}{2gR_L + 1}$$

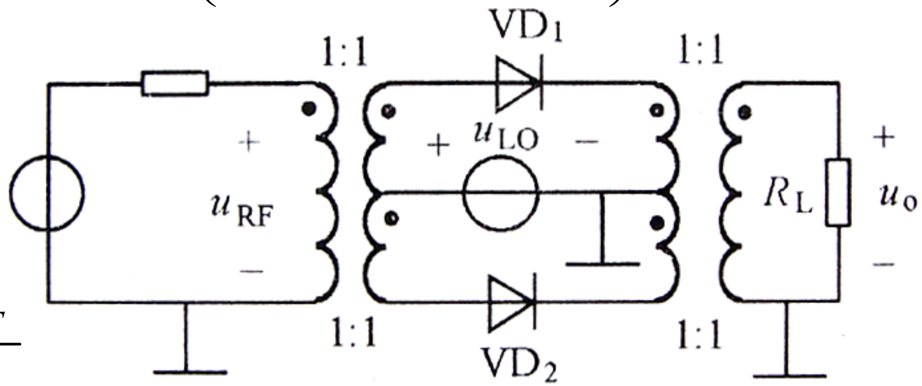
依题意，理想二极管 $g \to \infty$ $\qquad u_o^+ = u_{RF}$

7.14

当u$_2$的负半周，两个二极管同时截止，故：

$$u_o = u_{RF} K^{+}(\omega_{LO} t) = U_{RF}\cos\omega_{RF} t\cdot\left(\frac{1}{2}+\frac{2}{\pi}\cos\omega_{LO} t+\cdots\right)$$

混频的中频分量：



$$U_{IF} = \frac{1}{2}U_{RF}\cdot\frac{2}{\pi} = \frac{1}{\pi}U_{RF}$$

中频输出功率： $P_{IF} = \dfrac{U_{IF}^2}{2R_L}$

射频输入功率： $P_{RF} = \dfrac{U_{RF}^2}{2R_{in,RF}}$

正半周： $R_{in,RF} = R_L$

负半周： $R_{in,RF} = \infty$

$$P_{RF} = \frac{1}{2}\cdot\frac{U_{RF}^2}{2R_L}$$

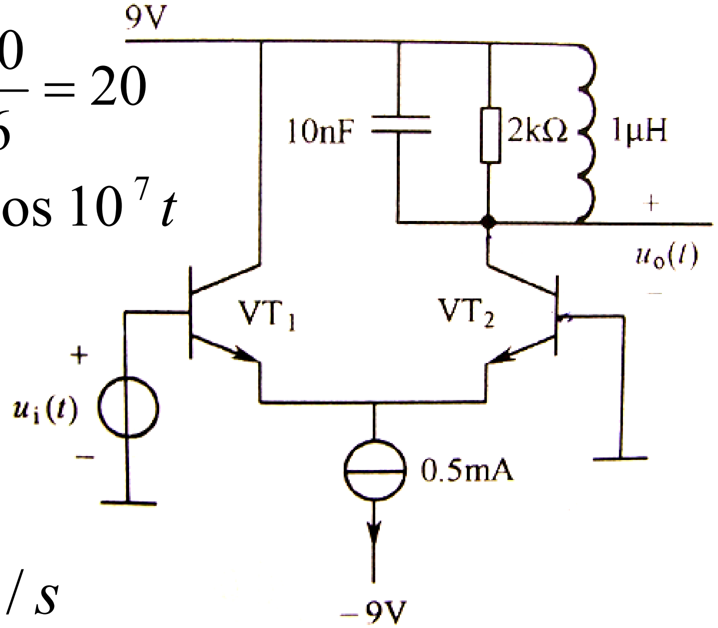
$$L_C = \frac{P_{RF}}{P_{IF}} = \frac{\pi^2}{2} = 6.93dB$$

8.9

8.9 在图所示电路中，设VT1、VT2的 $\alpha=1$。

(1) 若$u_i=0.52\left(1+0.5\cos 2.5\times10^4 t\right)\cos10^7 t$(v)，求输出电压及调幅指数

(2) 若$u_i=0.5\cos\left(10^7 t+\Delta\omega\int_0^t \cos10^4\tau d\tau\right)$(V)，求保证寄生调幅度1%，最大频偏的最大允许值。



解：(1) 差分对为恒流源偏置 $x=\dfrac{U_i}{U_r}=\dfrac{520}{26}=20$

$$i_{C1}=I_K\alpha_1(x)\left(1+0.5\cos 2.5\times10^4 t\right)\cos10^7 t$$

RLC选频网络：

$$\omega_o=\frac{1}{\sqrt{LC}}=10^7 rad/s$$

$$\alpha=\frac{1}{2}BW=\frac{1}{2RC}=2.5\times10^4 rad/s$$

8.9

$$i_{C1} = I_K \alpha_1(x)\left(1 + 0.5\cos 2.5\times 10^4 t\right)\cos 10^7 t$$

输出电压：

$$u_o = 9 + i_{C1} \cdot \dot{Z}$$

$$u_o = 9 + I_K \alpha_1(x) \cdot R \cdot \left[1 + \frac{0.5}{\sqrt{2}}\cos\left(2.5\times 10^4 t - \frac{\pi}{4}\right)\right]\cos 10^7 t$$

$$u_o = 9 + 0.634\left[1 + 0.354\cos\left(2.5\times 10^4 t - \frac{\pi}{4}\right)\right]\cos 10^7 t$$

8.9

(2)：宽带调频信号通过RLC网络，不同频率表现的阻抗不同，产生寄生调幅效应，调幅度：

$$\frac{m_{\max} - m_{\min}}{m_{\max} + m_{\min}} \le 1\%$$

m_{max}正比于中心频率表现的阻抗
m_{min}正比于最大频偏表现的阻抗

$$Z(j\omega) = \frac{R}{1 + j\dfrac{\omega - \omega_o}{\alpha}}$$

$$\frac{R - \dfrac{R}{\sqrt{1 + \left(\dfrac{\Delta\omega}{\alpha}\right)^2}}}{R + \dfrac{R}{\sqrt{1 + \left(\dfrac{\Delta\omega}{\alpha}\right)^2}}} \le 1\%$$

$$\Delta\omega \le 0.505 \times 10^4 \, rad/s$$

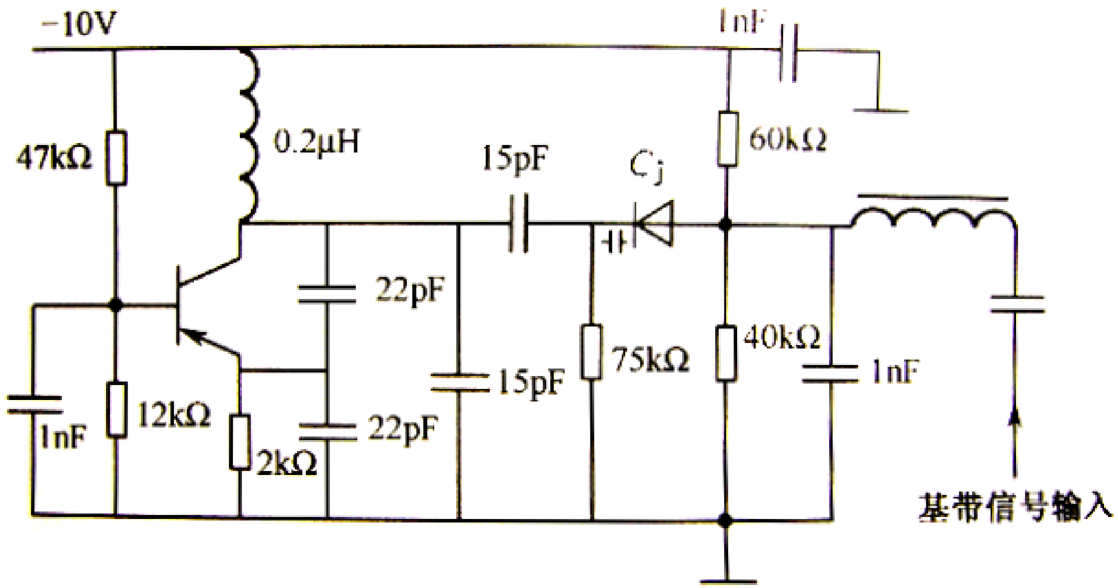
8.11

8.11假定如图所示的变容管直接调频电路中，变容管的特性为

$$C_j = 540(1+2u)^{-1.5}\ pF$$

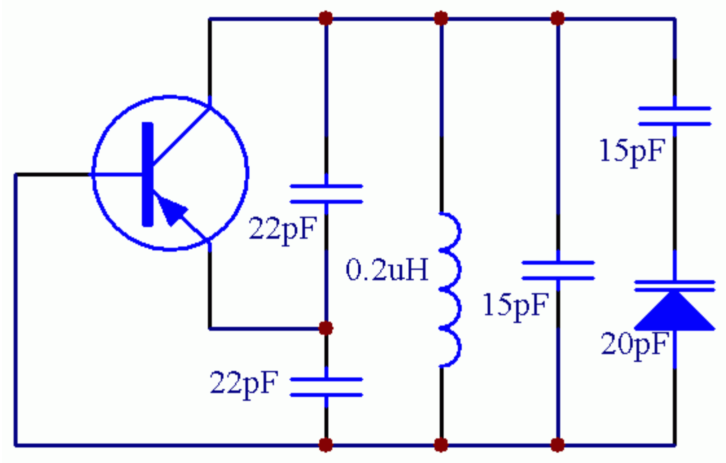
基带信号为： $135\cos 10^4 t(mV)$

其他参数见图。计算产生的调频波的中心频率f_o、最大频偏、调频指数m_f、信号带宽BW_{CR}



8.11

解：Cj的直流偏置：

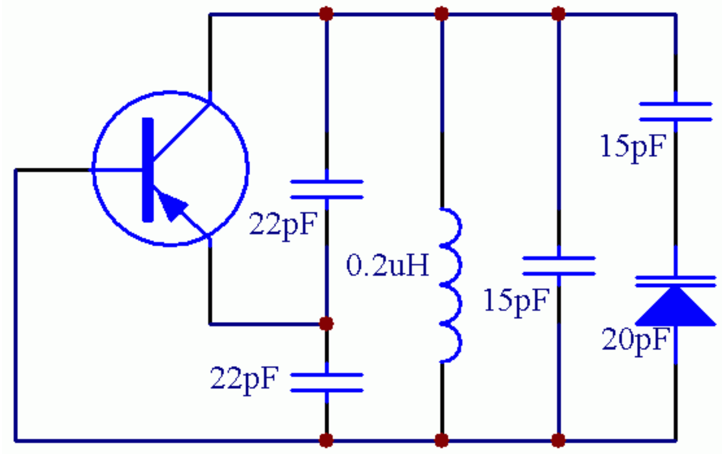


$$U_Q = 10V \times \frac{40}{60+40} = 4V$$

$$C_{jQ} = C_{j0}\left(1 + \frac{U_Q}{U_\Phi}\right)^{-1.5} = 20pF$$

$$C_\Sigma = 34.57pF \qquad f_o = \left(2\pi\sqrt{LC_\Sigma}\right)^{-1} = 60.56MHz$$

8.11



$$C_{open} = 9.51pF$$

$$A = \frac{C_{jQ}}{C_{jQ} + C_{open}} = 0.678$$

$$C_{close} = 15pF$$

$$B = \frac{C_{jQ}}{C_{jQ} + C_{close}} = 0.571$$

$$M = \frac{U_{\Omega}}{U_{Q} + U_{\Phi}} = 0.03 \qquad D_1 = \frac{1}{2} M\gamma(A - B) = 0.00241$$

$$m_f = \Delta\omega / \Omega_{\max} = 91.66 \qquad \Delta f = f_o D_1 = 145.97kHz$$

$$BW_{CR} = 2(m_f + 1)\Omega_{\max} / 2\pi = 295.10kHz$$

8.16

8.16 如图所示为简化的相位鉴频器，设传递函数

$$H(j\omega)=\frac{\dot{U}_2}{\dot{U}_1}=\exp\left\{j\left[\frac{\pi}{2}-\arctan\left(\frac{\omega-\omega_o}{\alpha}\right)\right]\right\}$$

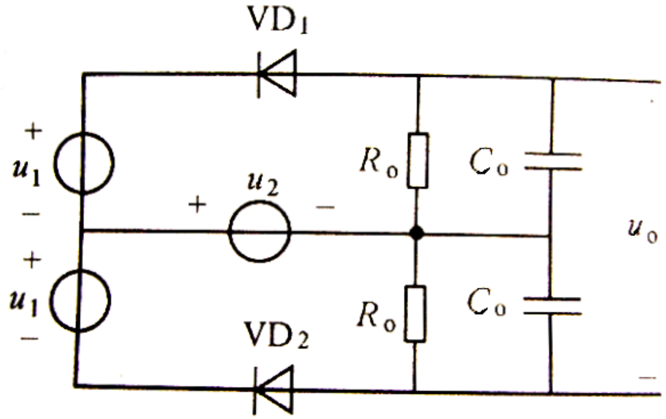
(1) 写出VD1，VD2上高频电压的表达式；
(2) 用矢量图法讨论鉴频特性的形状；
(3) 若 $\omega=\omega_o+\Delta\omega s(t)$，$\Delta\omega<<\alpha$ 求输出电压表达式。

解：

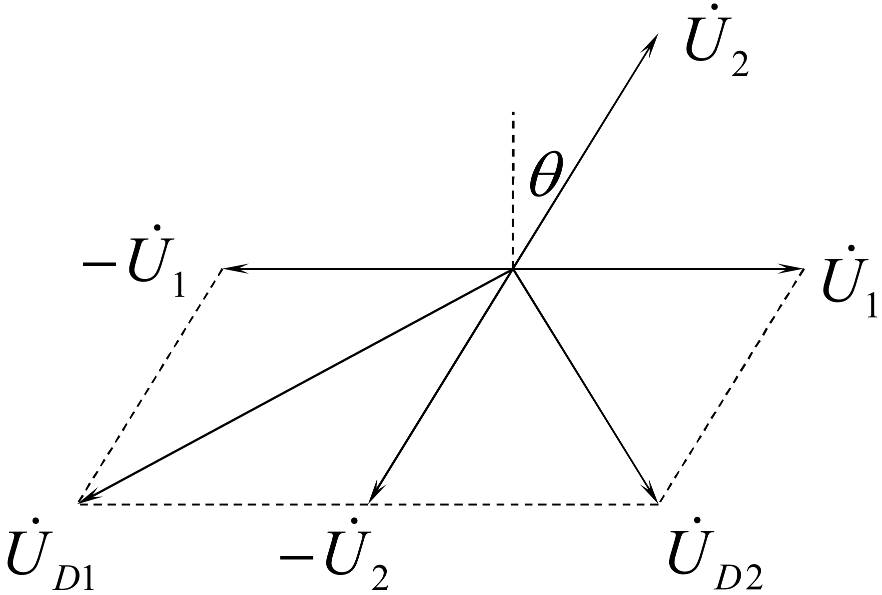
$$\dot{U}_{D1}=-\dot{U}_1-\dot{U}_2$$

$$\dot{U}_{D2}=\dot{U}_1-\dot{U}_2$$

$$\theta=\arctan\frac{\omega-\omega_o}{\alpha}$$



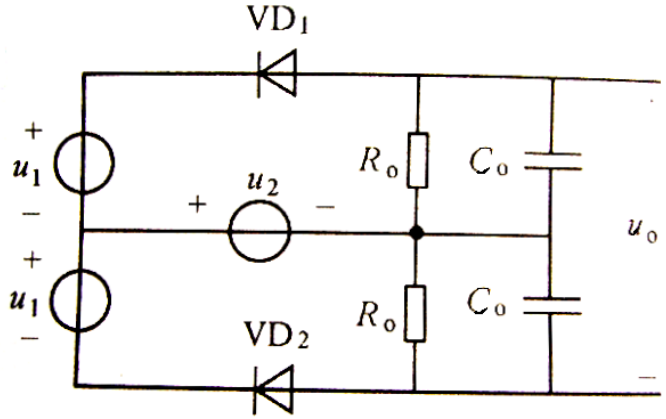
8.16



$$U_{D1} = \sqrt{2}U\sqrt{1-\sin\theta}$$

$$U_{D1} = \sqrt{2}U\sqrt{1+\sin\theta}$$

$$u_o(t) = U_{D2} - U_{D1}$$
$$= \sqrt{2}U\left(\sqrt{1+\sin\theta} - \sqrt{1-\sin\theta}\right)$$



$$u_o(t) = -2\sqrt{2}U\sin\left(\frac{1}{2}\arctan\frac{\omega-\omega_o}{\alpha}\right)$$

$$\omega = \omega_o + \Delta\omega s(t) \qquad \Delta\omega << \alpha$$

$$u_o(t) = -\sqrt{2}U\frac{\Delta\omega}{\alpha}s(t)$$