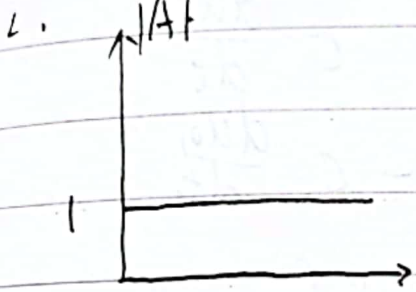
$\Rightarrow R^2 - \frac{1}{\omega_0^2 C^2} = \frac{2R}{\omega_0 C} \Rightarrow \omega_0 = \frac{1+\sqrt{2}}{RC}$

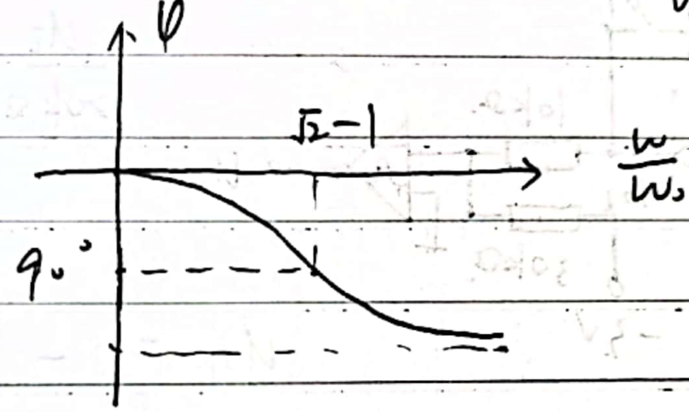
$$\frac{u_o}{u_i} = \frac{R-\frac{1}{sC}}{R+\frac{1}{sC}} = \frac{1-\frac{1}{s}\times\frac{\omega_0}{1+\sqrt{2}}}{1+\frac{1}{s}\times\frac{\omega_0}{1+\sqrt{2}}} = \frac{(1+\sqrt{2})-\frac{\omega_0}{j\omega}}{(1+\sqrt{2})+\frac{\omega_0}{j\omega}}$$

$$= \frac{(1+\sqrt{2})+\frac{\omega_0}{\omega}j}{(1+\sqrt{2})-\frac{\omega_0}{\omega}j} \Rightarrow |A(s)| = 1$$

$$\varphi = \arctan\frac{2RC\omega}{R^2C^2\omega^2-1} = \arctan\frac{2(1+\sqrt{2})\frac{\omega}{\omega_0}}{(1+\sqrt{5})^2\frac{\omega^2}{\omega_0^2}-1}.$$

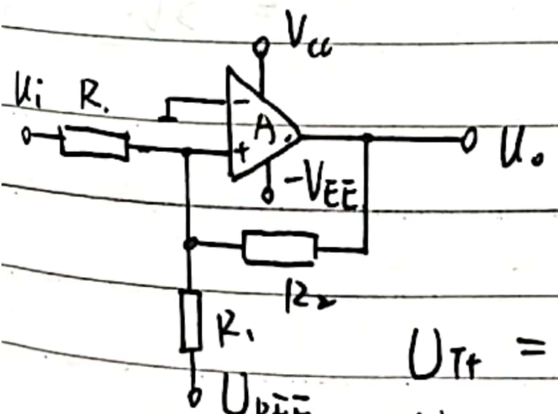
2.





第3章 运算放大器的非线性应用

3.3 推导电路的阈值电压和回差的表达式，画出传输特性曲线



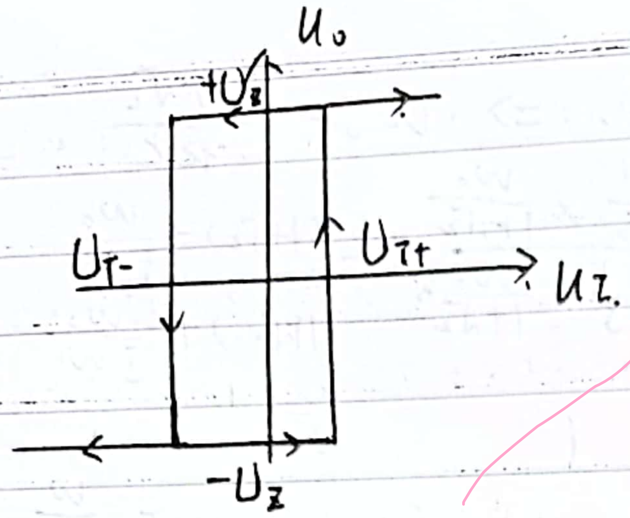
$$u_o = \pm U_Z$$

$$\frac{u_i}{R} + \frac{u_o}{R_2} + \frac{U_{REF}}{R_1} = 0$$

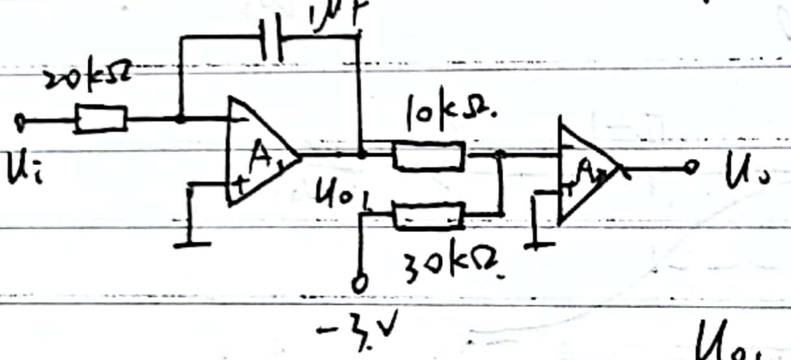
$$u_i = -\left(\frac{R}{R_2}u_o + \frac{R}{R_1}U_{REF}\right)$$

$$U_{T+} = \frac{R}{R_2}V_{EE} - \frac{R}{R_1}U_{REF}$$

$$U_{T-} = -\frac{R}{R_2}V_{CC} - \frac{R}{R_1}U_{REF}$$



3.6 画出 u_{o1} 和 u_o 的波形图，并标出转折点电压值



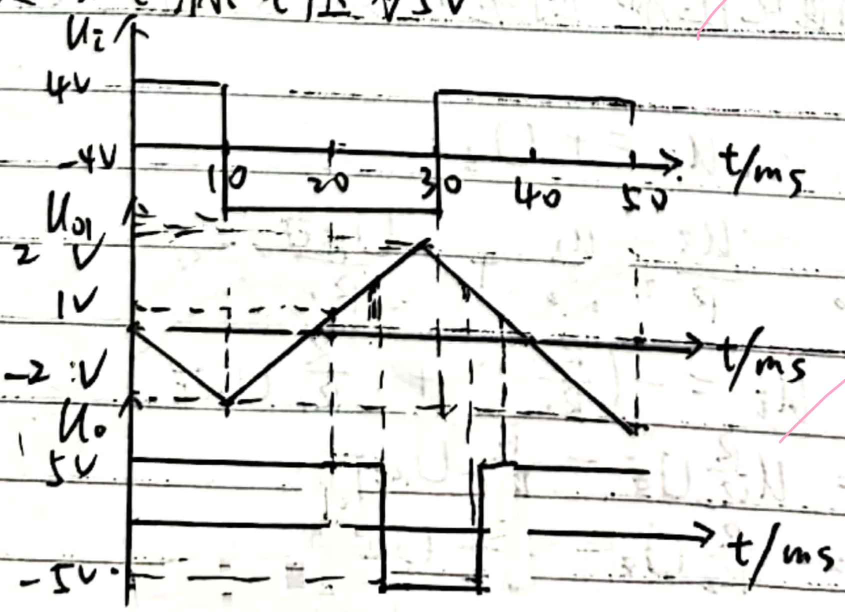
$$\frac{u_i}{20k\Omega} = C\frac{du_c}{dt} = -C\frac{du_{o1}}{dt}$$

$$u_{o1} = -\frac{1}{C}\times\frac{1}{20k}\int u_i\,dt = -\frac{1}{20\times10^3\times10^{-6}}\int u_i\,dt = -50\int u_i\,dt$$

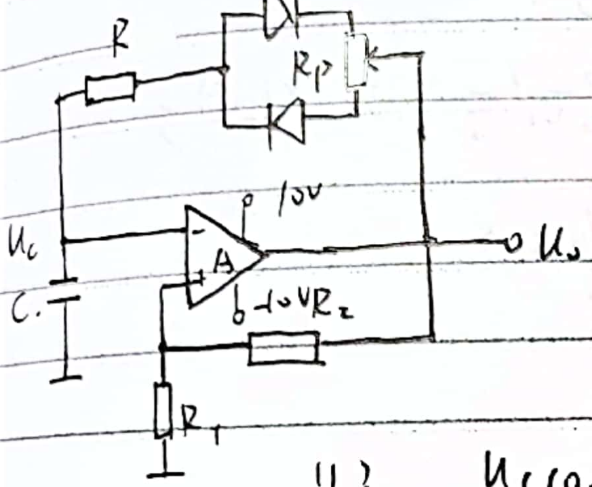
$$\frac{u_{o1}}{10k} = \frac{3}{30k} \Rightarrow U_T = 1V$$

运放电源电压为5V

$$u_{o1}(10) = -50\int_0^{10} 4\,dt = 2V$$



3.7 $R=10k\Omega$，$R_1=12k\Omega$，$R_2=15k\Omega$，电位器 $R_p=100k\Omega$，$C=0.01\mu F$（忽略二极管导通电阻）



(1) 电位器在中间，输出电压 u_o 和电容电压 u_c 的波形，并计算 u_o 的振荡频率 f_o

(2) 调至上端和下端，电容充电时间 T_1、放电时间 T_2、输出波形的振荡频率 f 及占空比各为多少？

(1) $u_c(0_+) = -U_T \qquad u(\infty)=U_Z$

$u_c(t)=u_c(\infty)+[u_c(0_+)-u_c(\infty)]e^{-\frac{t}{\tau}} \qquad \tau=C(R+\frac{1}{2}R_p)$

$= U_Z+(-U_T-U_Z)\,e^{-\frac{t}{\tau}}$

$U_Z=10V \qquad U_T=\frac{R_1}{R_1+R_2}U_Z=\frac{12}{12+15}\times 10=\frac{40}{9}V$

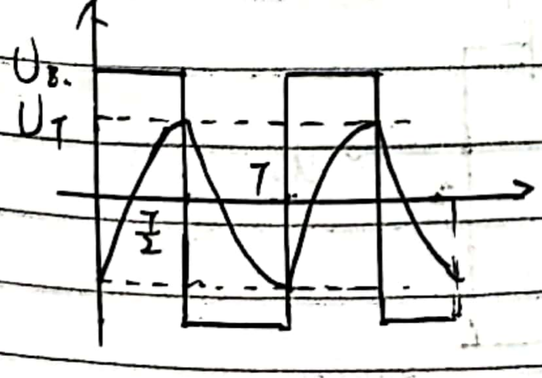
$\tau=0.01\times10^{-6}\times(10+50)\times10^{3}=6\times10^{-4}$

$u_c(\frac{T}{2})=U_T=\frac{40}{9}V$

$10-(\frac{40}{9}+10)\times e^{-\frac{t}{6\times10^{-4}}}=\frac{40}{9}$

$\frac{130}{9}e^{-\frac{t}{6\times10^{-4}}}=\frac{50}{9}$

$\Rightarrow t=5.73\times10^{-4}s \qquad T=1.15\,ms \quad f_o=872.1Hz$



(2) 1° 调至最上端.

充电 $\tau_1 = C(R_2+R_p) = 1.1\times10^{-3}$

放电 $\tau_1' = CR_2 = 10^{-4}$

由 ∴ 得: $\frac{t}{\tau} = \ln\frac{13}{5}$ $t_1 = 1.05\times10^{-3}$ s $t_1' = 9.56\times10^{-5}$ s

$T = t_1 + t_1' = 1.146\times10^{-3}$ s $= 1.146$ ms

$f = 872.94$ Hz

占空比 $\frac{t_1}{t_1+t_1'} = 91.62\%$

2° 调至最下端.

充电 $\tau_2 = CR_2 = 10^{-4}$

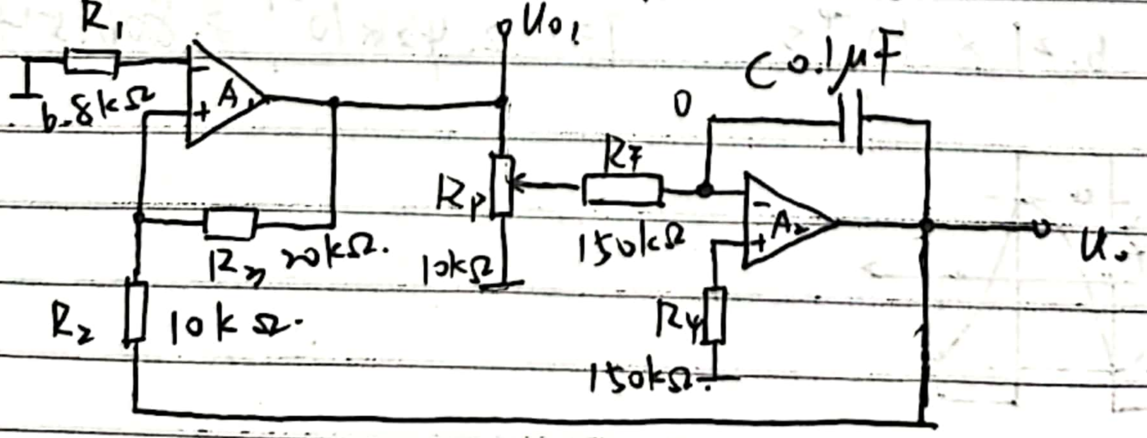
放电 $\tau_2' = C(R_2+R_p) = 1.1\times10^{-3}$

$t_2 = 9.56\times10^{-5}$ s $t_2' = 1.05\times10^{-3}$ s

$T = 1.146$ ms $f = 872.94$ Hz

占空比 $\frac{t_2}{t_2+t_2'} = 8.345\%$

3.8. 画出 u_{o1}、u_o 的波形 → ic.



1) 电路的最高振荡频率

2) 方波和三角波的峰峰值

1) $i_C = C\frac{du_C}{dt} = -C\frac{du_o}{dt} = \frac{u_{o1}}{R_f+kR_p}$

$\frac{u_{o1}}{R_3}+\frac{u_o}{R_2}=0 \Rightarrow \cancel{u_{o1}=-2u_o}$

以此题为例，问：如何判断一个运放工作在线性区还是线性区

以下命题：1.一般有负反馈就工作在线性区

2. 大部分正反馈 or 开环 在非线性区

正确 & 错误？

将错就错 把 A_1 当线性区算 ……果？

结论基本正确，有些负反馈也会变成正反馈（这种在后面会学，先不管）。为什么按照线性区计算也能得出结果？首先线性区的计算方法一般就是虚短虚断（正负一直相等）。而用作比较器的是比较正负端，正负相等时就是翻转点（只有这一瞬间），所以用这个直接算也是对的，但是本质上完全不是一回事。

u_{o1} 变化离散　u_o 变化连续

$$\frac{u_{+1}-u_{o1}}{R_3}+\frac{u_{+1}-u_o}{R_2}=0 \Rightarrow \left(\frac{1}{R_3}+\frac{1}{R_2}\right)u_{+1} = \frac{u_{o1}}{R_3}+\frac{u_o}{R_2}$$

$$u_{+1} = \frac{R_2}{R_2+R_3}u_{o1}+\frac{R_3}{R_3+R_2}u_o = \frac{1}{3}u_{o1}+\frac{2}{3}u_o$$

$$u_{o1} = \pm U_Z \Rightarrow U_{OH} = \frac{1}{2}U_Z \quad U_{OL} = -\frac{1}{2}U_Z$$

$$\frac{u_{o1}}{\left(\frac{kR_p}{R_f//(1-k)R_p}+1\right)} = -C\frac{du_o}{dt}$$ （注意并联）

$$\frac{u_{o1}}{\frac{1}{1-k}R_f+kR_p} = -C\frac{du_o}{dt}$$

$$U_{OH} = -\frac{1}{C}\times\frac{1}{\frac{1}{1-k}R_f+kR_p}\int_0^{t_1}(-U_Z)\,dt$$

$$\frac{1}{2}U_z = \frac{1}{C} \times \frac{1}{\frac{1}{1-k}R_F + kR_P} \times U_z t_1$$

$$t_1 = \frac{C}{2} \times \left(\frac{1}{1-k}R_F + kR_P \right)$$

$$T = 2C\left(\frac{1}{1-k} \times 150 + k \times 10\right) \times 10^3$$

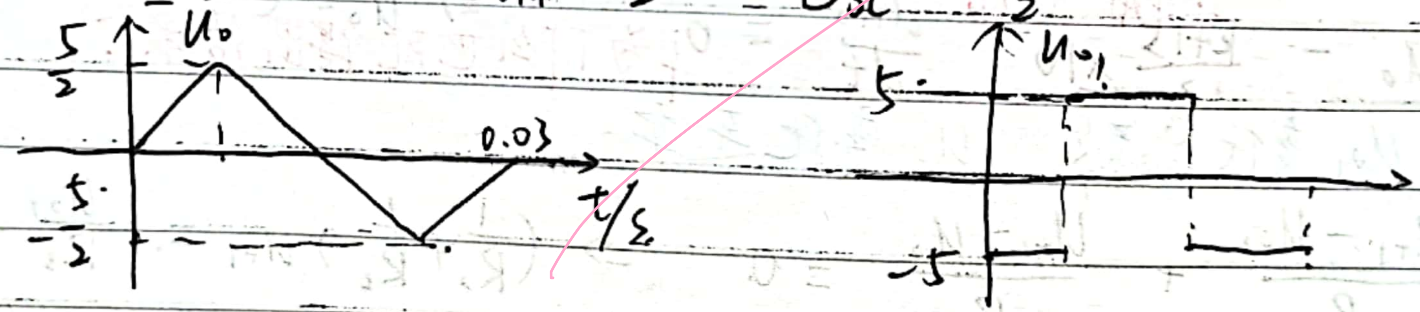
$$= 2C \times \left(\frac{15}{1-k} + k\right) \times 10^4$$

当 $k=0$ 时 T 最小 f 最大

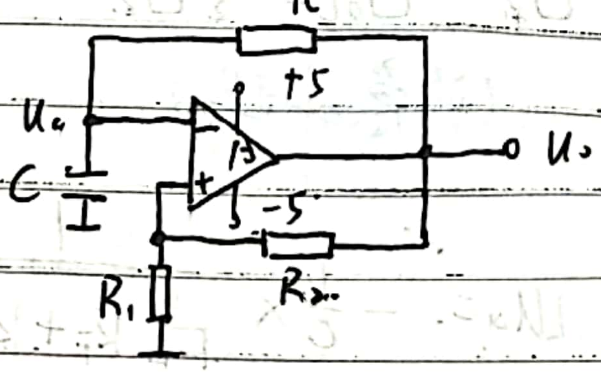
$$T = 3\times10^5 \times 0.1 \times 10^{-6} = 0.03\,s$$

$$f = \frac{1}{T} = 33.3\,Hz$$

$u_{o1} = \pm 5$ $U_{OH} = \frac{5}{2}$ $U_{OL} = -\frac{5}{2}$



3.9 要求方波频率为1kHz，确定电路中电阻电容参数



$u_c(0_+) = -U_T \quad u_c(\infty) = 5V = U_{cc} \quad \tau = RC$

$$U_T = \frac{R_1}{R_1+R_2} U_{cc}$$

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

$$= 5 + [-\frac{R_1}{R_1+R_2} \times 5 - 5] e^{-\frac{t}{\tau}}$$

$$u_c(\frac{T}{2}) = 5 - [\frac{5R_1}{R_1+R_2} + 5] e^{-\frac{T}{2\tau}} = \frac{5 \times R_1}{R_1+R_2}$$

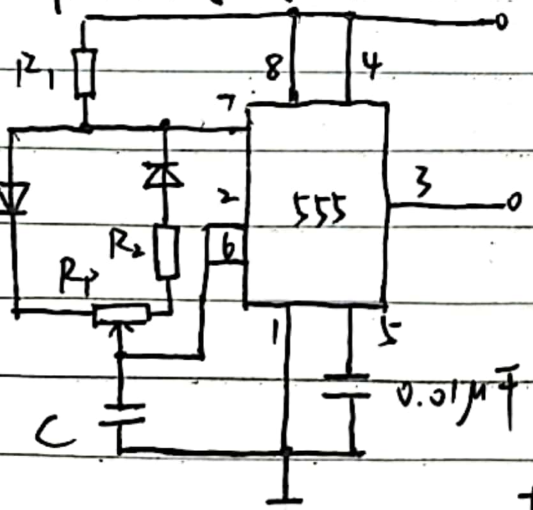
$$\frac{5(2R_1+R_2)}{R_1+R_2} e^{-\frac{T}{2\tau}} = \frac{5R_2}{R_1+R_2} \Rightarrow e^{\frac{T}{2\tau}} = 1 + \frac{2R_1}{R_2}$$

$$T = 2RC\ln(1+2\frac{R_1}{R_2}) = \frac{1}{f} = 10^{-3}$$

∴只需满足 $2RC\ln(1+2\frac{R_1}{R_2}) = 10^{-3}$ 即可。

给出具体参数

3.12. 如图为占空比可调的矩形波产生电路，设二极管正向导通电阻为零，试分析其波形占空比取决于哪些参数？若要求占空比为50%，则这些参数应如何选择？写出输出波形的周期表达式



占空比取决于 R_1、R_2、R_p

充：$u_c(0_+) = \frac{1}{3}V_{cc} \quad u_c(t_1) = \frac{2}{3}V_{cc}$

$u_c(\infty) = V_{cc} \quad \tau_1 = (R_1 + kR_p)C$

$$u_c(t) = V_{cc} + [\frac{1}{3}V_{cc} - V_{cc}] e^{-\frac{t}{\tau_1}}$$

$$= V_{cc} - \frac{2}{3}V_{cc} e^{-\frac{t}{\tau_1}}$$

$$u_c(t_1) = V_{cc}[1 - \frac{2}{3}e^{-\frac{t_1}{\tau_1}}] = \frac{2}{3}V_{cc}$$

$$t_1 = \tau_1 \ln 2$$

放. $\tau_2 = [(1-k)R_p + R_2]C \quad u_c(0_+) = \frac{2}{3}V_{cc}$

$$u_c(t_0) = \frac{1}{3}V_{cc} \qquad u_c(\infty) = 0$$

$$u_c(t_2) = \frac{2}{3}V_{cc}\, e^{-\frac{t}{\tau_2}} = \frac{1}{3}V_{cc}$$

$$t_2 = \tau_2 \ln 2$$

$\tau_1 = \tau_2$ 时 占空比为50%

$\Rightarrow (2k-1)R_p + R_1 - R_2 = 0$

周期 $T = t_1 + t_2 = (\tau_1 + \tau_2)\ln 2$

$$= (R_1 + R_2 + R_p)C\ln 2$$