# 第三章 运算放大器的非线性应用

## —— 3.2 & 3.3 & 3.4

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# 3. 运算放大器的非线性应用

## 本节内容

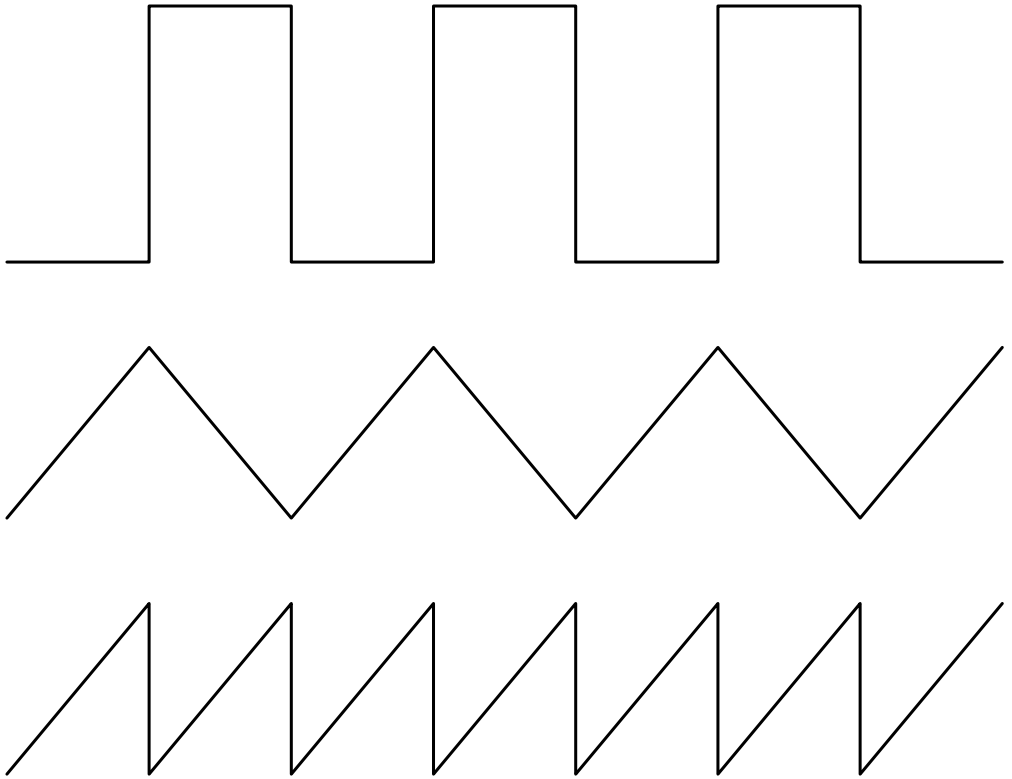
**3.2 非正弦波产生电路**

**3.3 555集成定时器及应用**

**3.4 运放非线性应用实例**

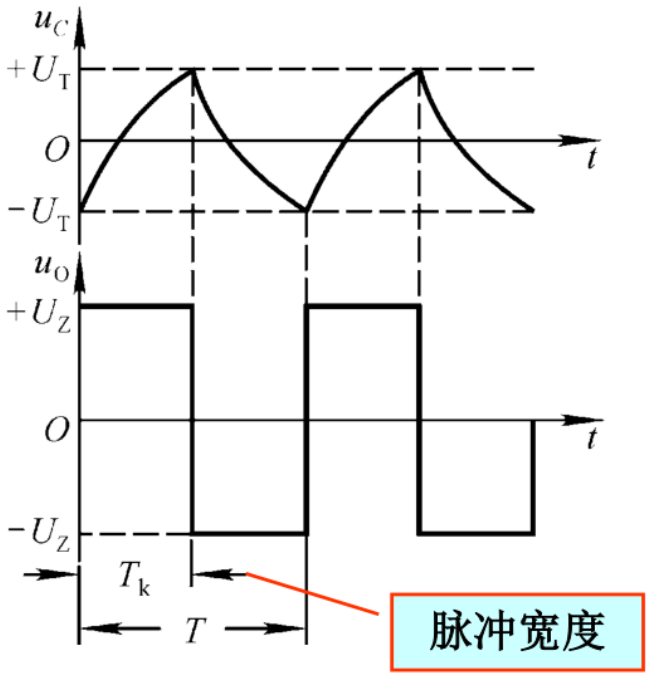
# 3.2 非正弦波产生电路

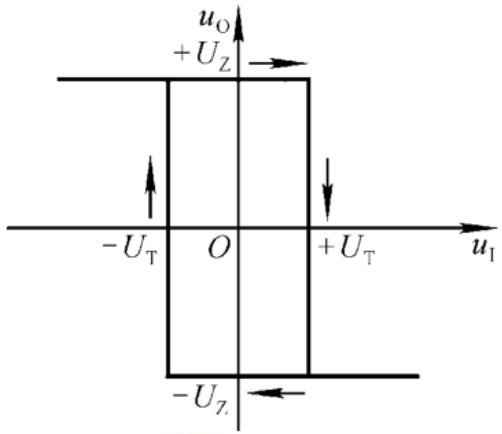
- ✓ **方波：**
- ✓ **三角波：**
- ✓ **锯齿波：**



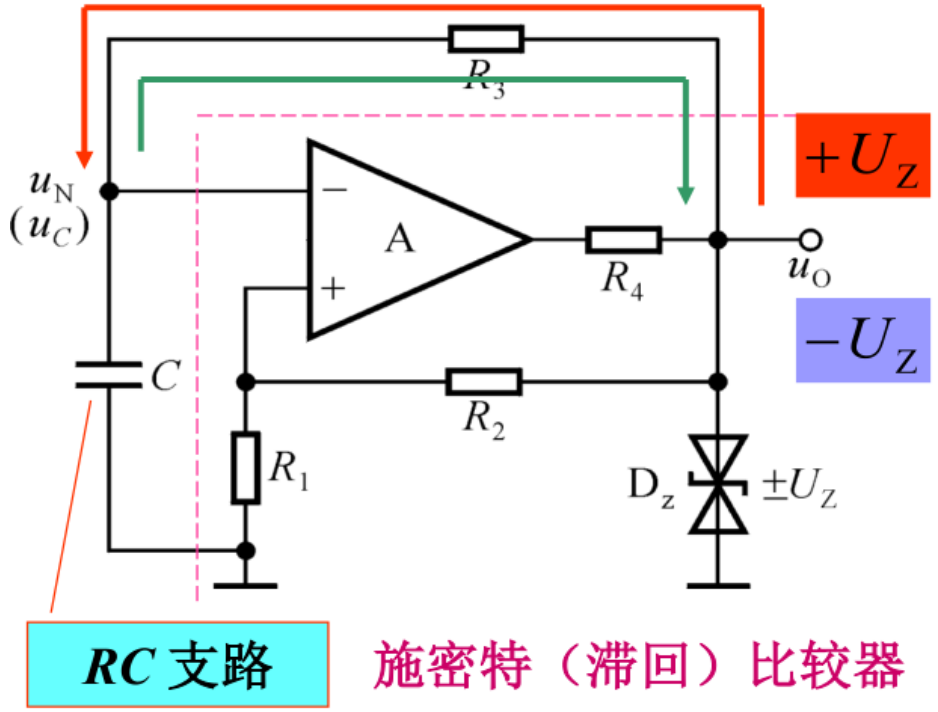
# 3.2.1 矩形波产生电路

- ✓ **振荡器**：产生时钟
- ✓ **正向充电**：$u_o$（$+U_z$）→$R_3$→$C$→地
- ✓ **反向放电**：地→ $C$ → $R_3$ → $u_o$（$-U_z$）




$$\pm U_T = \pm \frac{R_1}{R_1 + R_2} \cdot U_Z$$




***RC* 支路**　　施密特（滞回）比较器

# 3.2.1 矩形波产生电路

✓ **三个要素：**起始值，终了值，时间常数

- 如何手算瞬时电压变化?

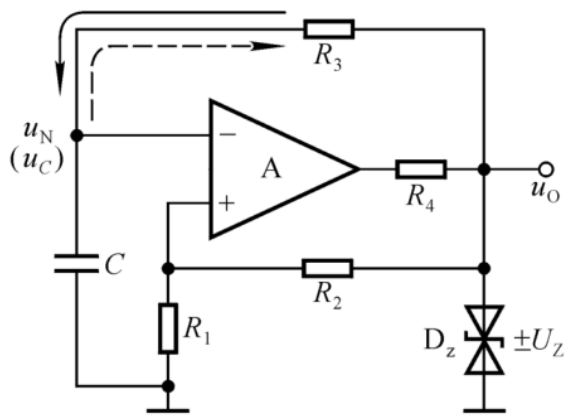
$$u_C(0_+) = -U_T, \quad u_C(\infty) = +U_Z, \quad \tau = R_T C_T$$

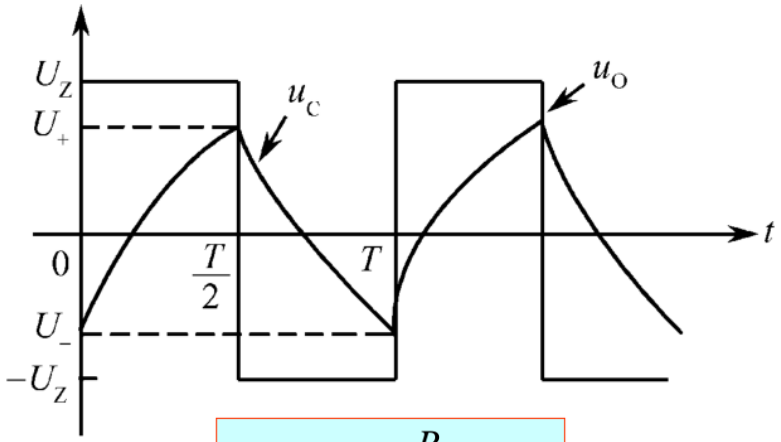
$$u_C(t) = u_C(\infty) + \left[u_C(0_+) - u_C(\infty)\right] e^{-t/\tau}$$

$$u_C(\frac{T}{2}) = +U_T = \frac{R_1}{R_1 + R_2} \cdot U_Z$$

$$T = 2R_T C_T \cdot \ln(1 + \frac{2R_1}{R_2})$$

$$f = \frac{1}{T}$$



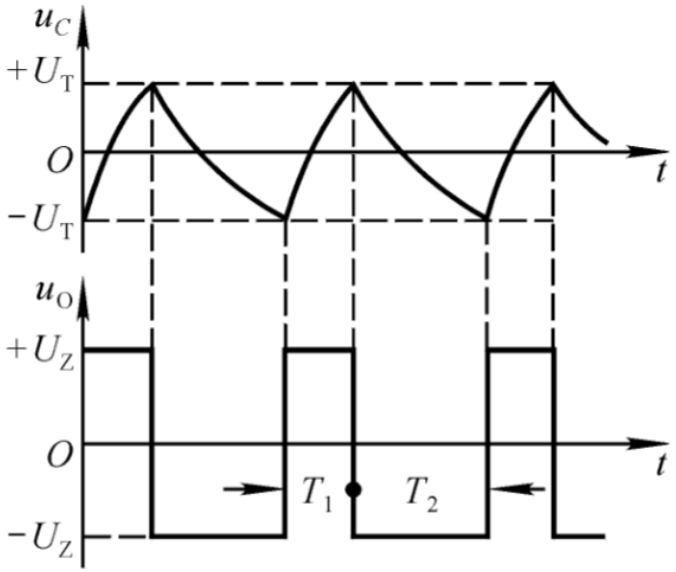




$$\pm U_T = \pm \frac{R_1}{R_1 + R_2} \cdot U_Z$$

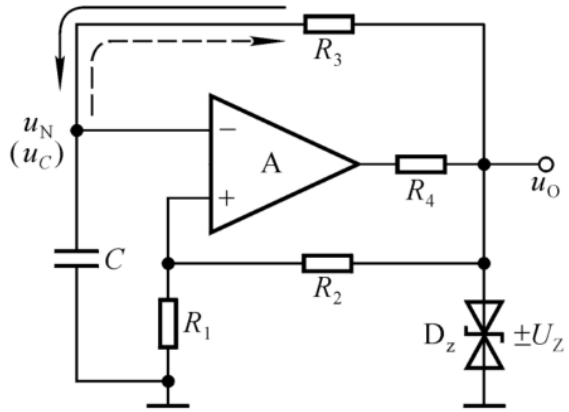
# 3.2.1 矩形波产生电路

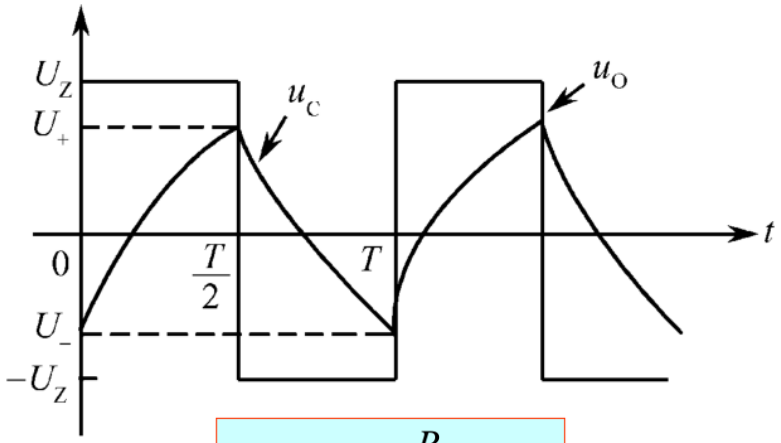
✓ **占空比可调：**

- 什么是**占空比？**怎么调？




$$占空比\delta=\frac{T_1}{(T_1+T_2)}$$



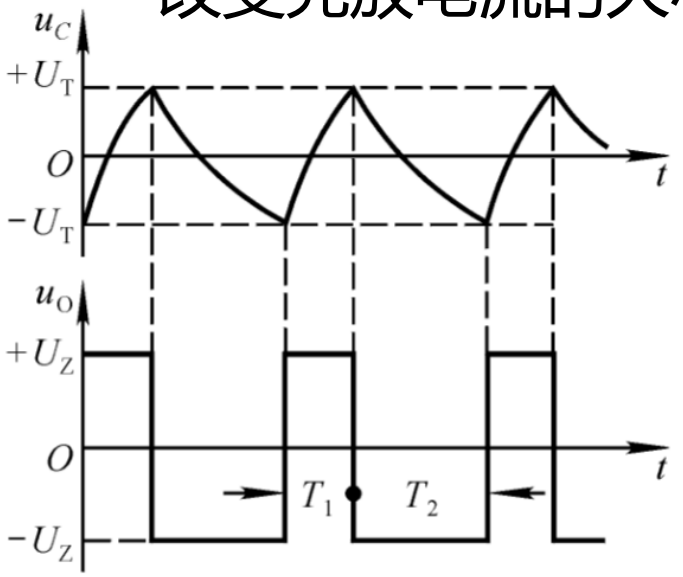

$$\pm U_T=\pm\frac{R_1}{R_1+R_2}\cdot U_Z$$

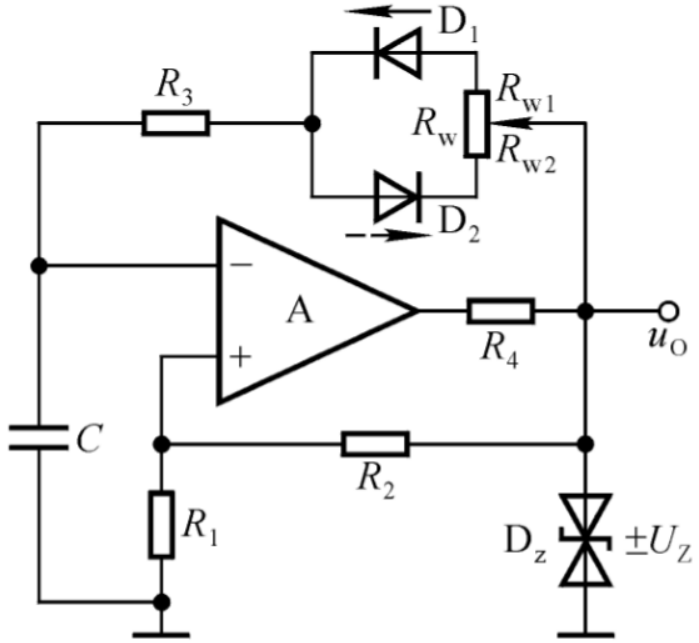
# 3.2.1 矩形波产生电路

✓ **占空比可调：**

- 什么是**占空比？**怎么调？

  - 改变充放电流的大小



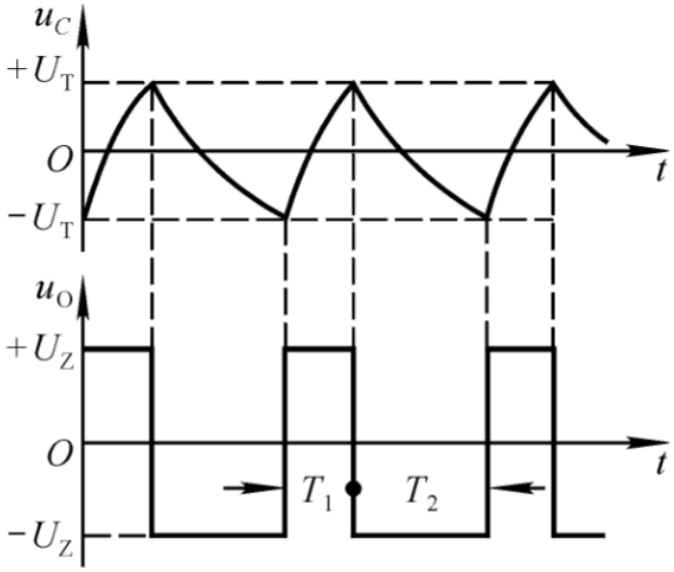



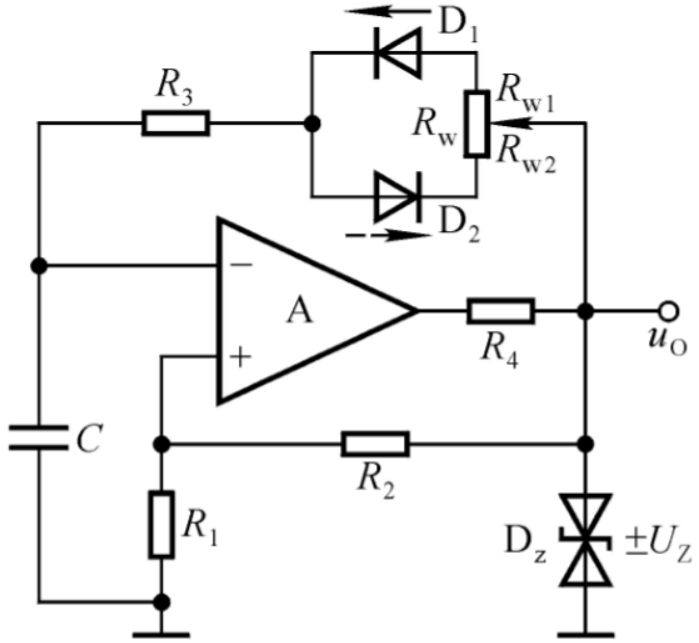

$$占空比\delta=\frac{T_1}{(T_1+T_2)}$$

# 3.2.1 矩形波产生电路

✓ **频率可调：**

- 怎么调？



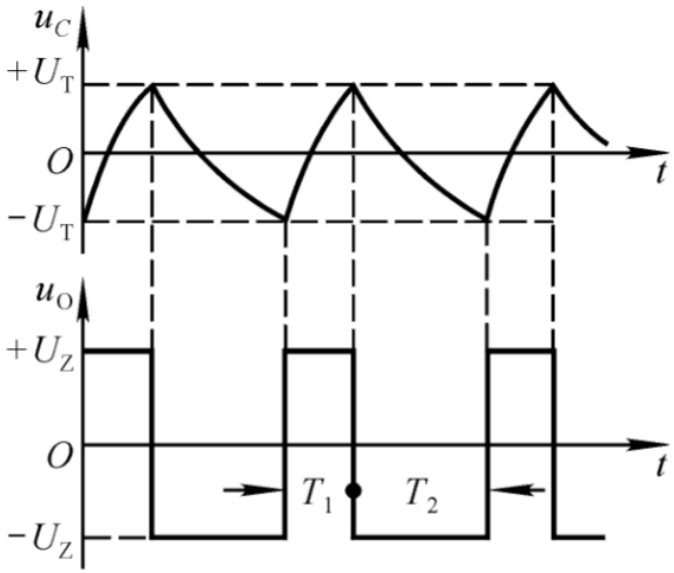




$$占空比\delta = \frac{T_1}{(T_1 + T_2)}$$

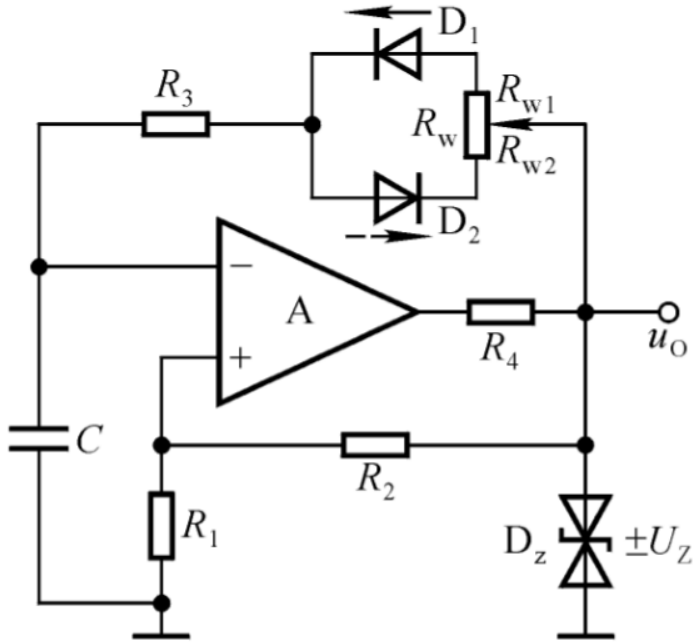
# 3.2.1 矩形波产生电路

✓ **频率可调：**

- 怎么调？



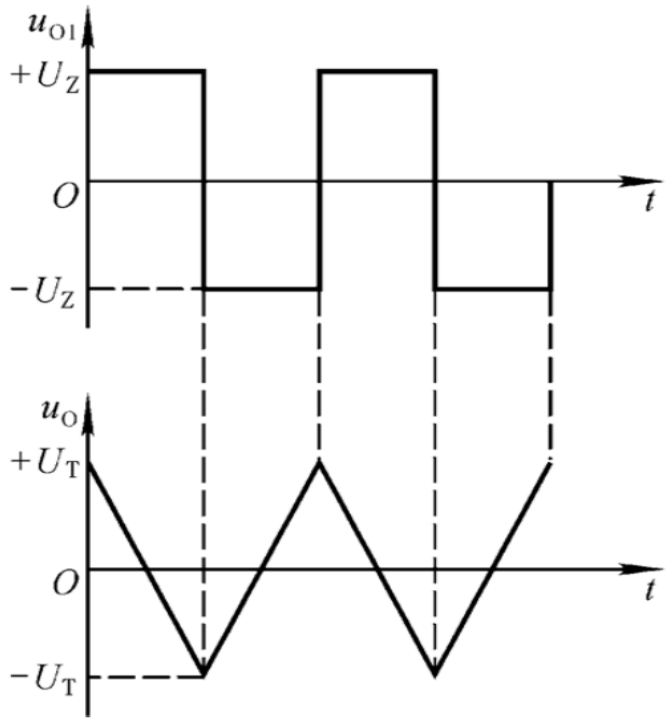

$$占空比\delta=\frac{T_1}{(T_1+T_2)}$$



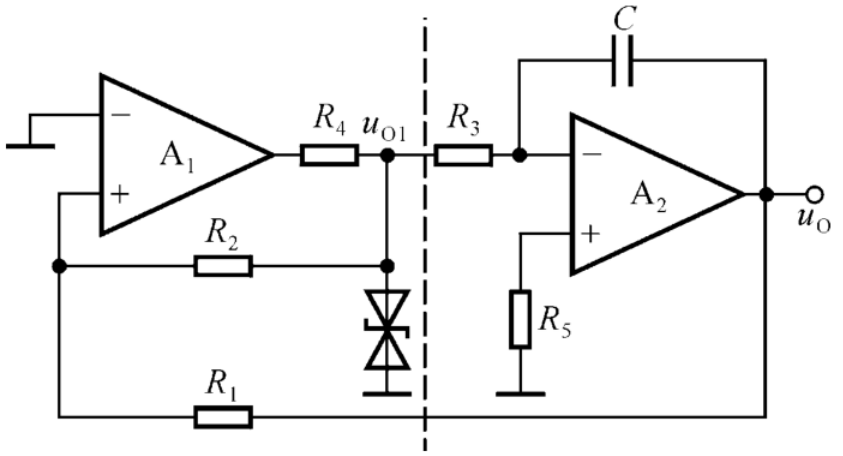
# 3.2.2 三角波产生电路

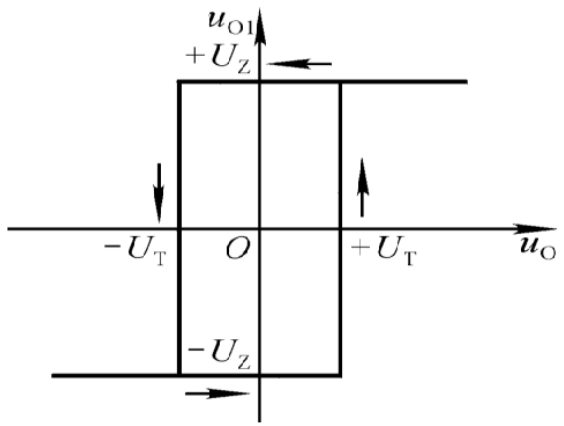
✓ **三角波产生条件：**

- 固定电流对C充放电（积分器）
- 比较阈值以及反馈回路（比较器）



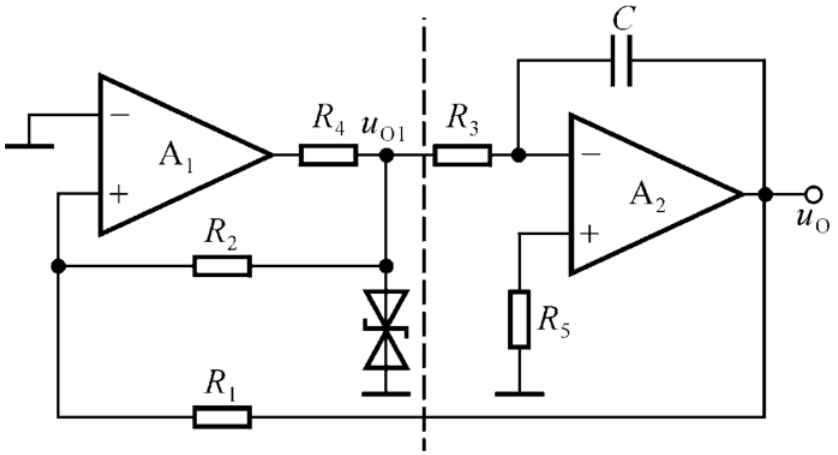

滞回比较器　　积分器

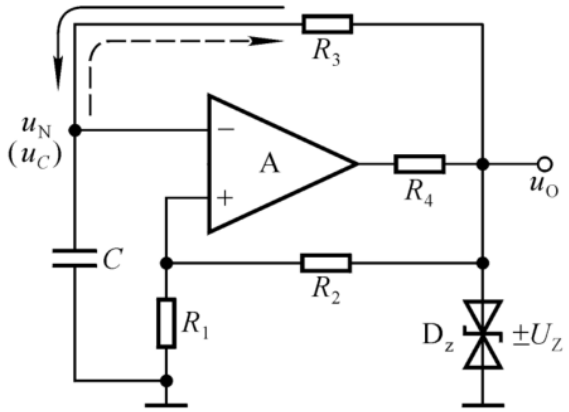


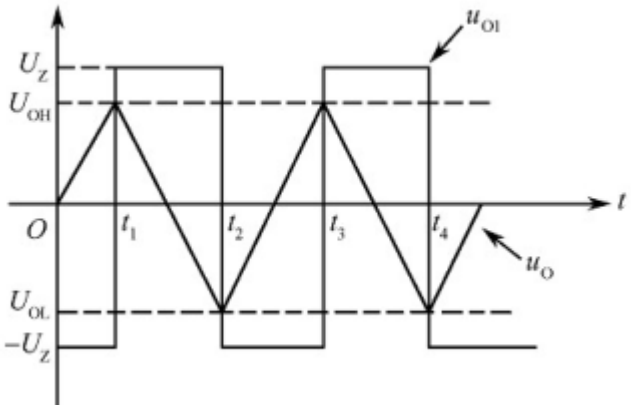



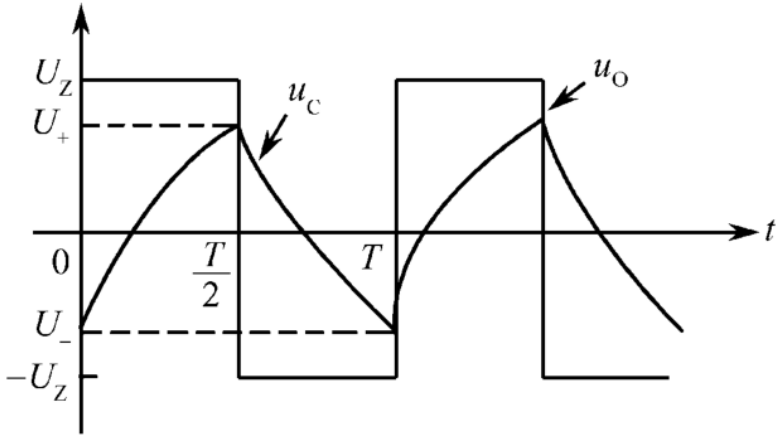
# 3.2.2 三角波产生电路

✓ **定性分析：**跟矩形波充放电的区别在哪？



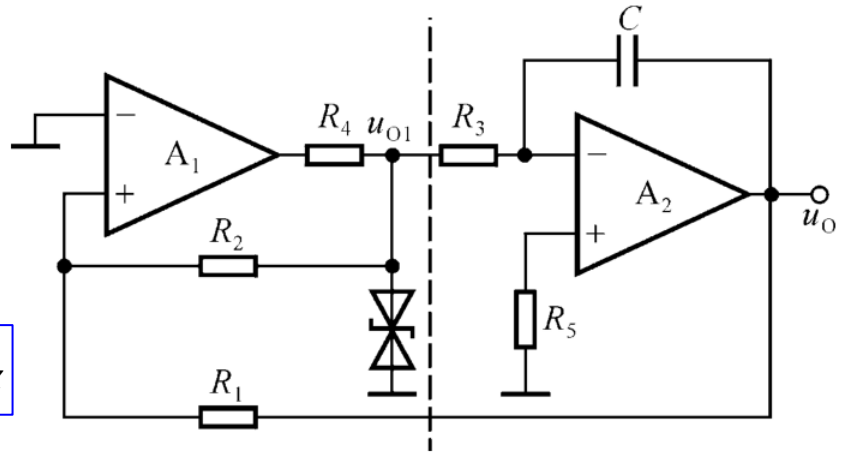



# 3.2.2 三角波产生电路

✓ **定量分析：**

滞回比较器　　积分器




- 线性叠加：

$$u_{+1}=\frac{R_1}{R_1+R_2}u_{o1}+\frac{R_2}{R_1+R_2}u_o$$

$$\Rightarrow \begin{matrix} u_{+1}=u_{-1}=0 \\ u_{o1}=\pm U_Z=0 \end{matrix} \Rightarrow U_{OH}=\frac{R_1}{R_2}U_Z,\quad U_{OL}=-\frac{R_1}{R_2}U_Z$$

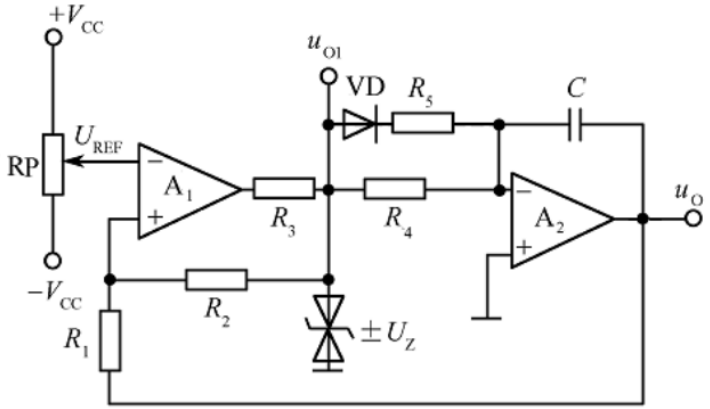
- 周期：$u_{+1}$=0上下翻转

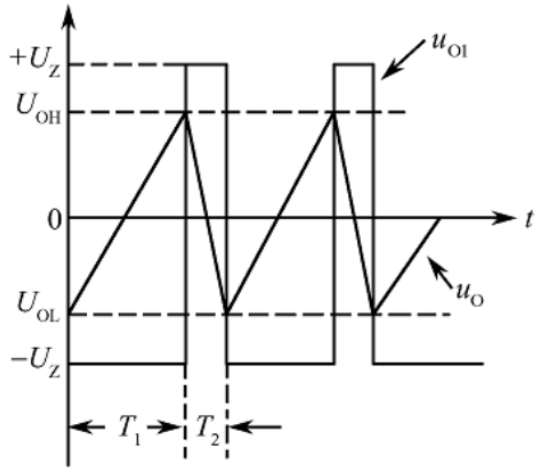
$$\Rightarrow U_{OH}=-\frac{1}{R_3C}\int_0^{t_1}(-U_Z)dt+0 \Rightarrow t_1=\frac{R_1R_3C}{R_2}$$

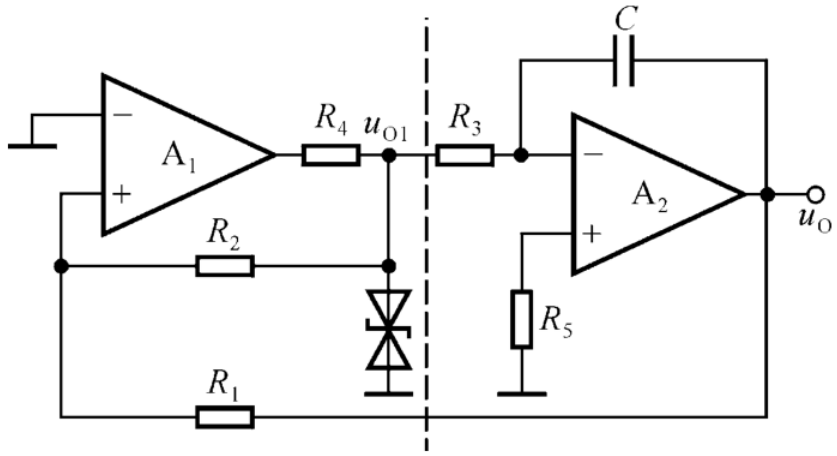
$$\Rightarrow T=4t_1=4\frac{R_1R_3C}{R_2} \Rightarrow f=\frac{1}{T}=\frac{R_2}{4R_1R_3C}$$

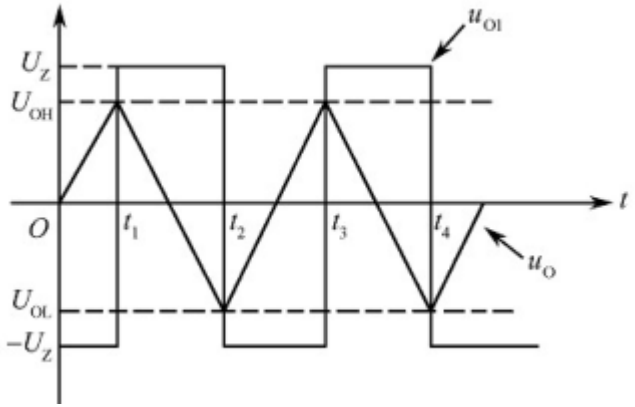
# 3.2.3 锯齿波产生电路

✓ **定性分析**：跟三角波的区别在哪？



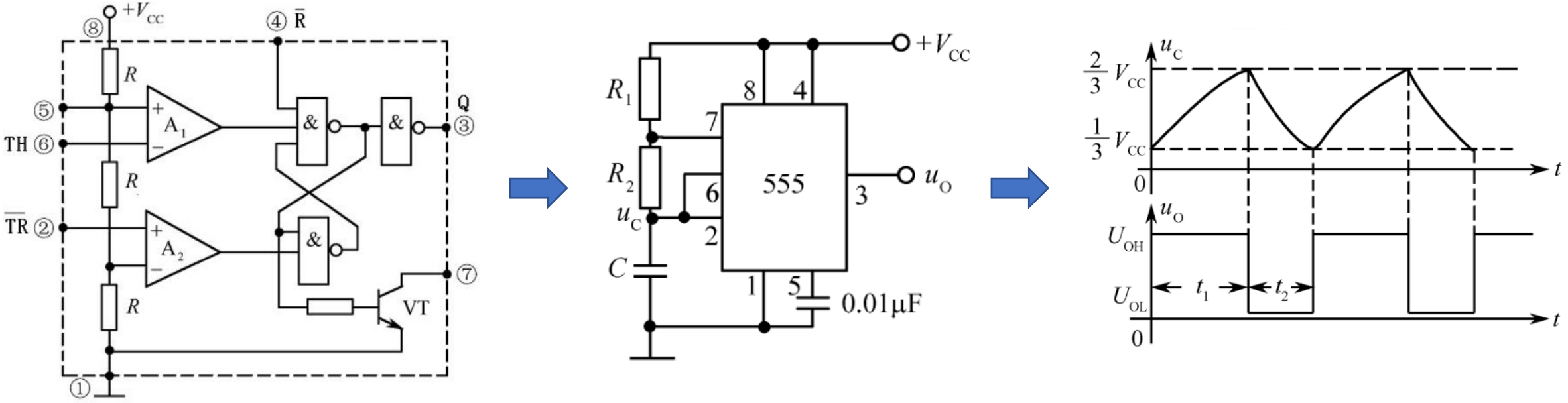



# 3.3 555集成定时器

✓ **电路组成：**

- 分压器，比较器，RS触发器，开集（漏）输出，



# 3.3.1 555集成定时器产生矩形波

✓ **定量分析：**

- 充电

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

$u_c(\infty) = V_{cc}$，$\tau_1 = (R_1 + R_2)C$

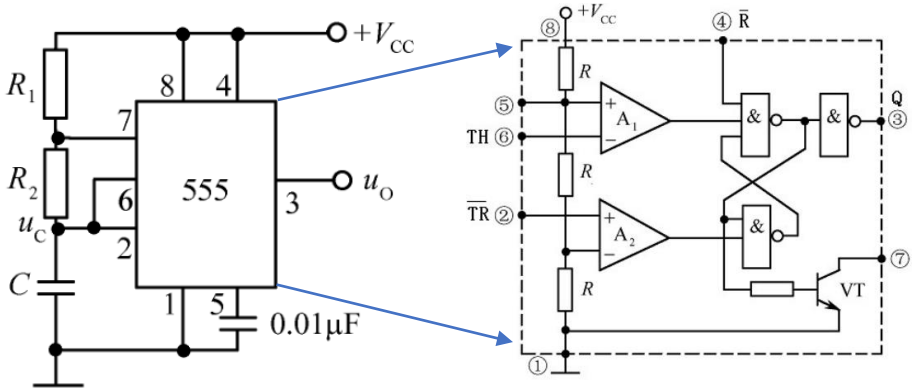
$u_c(t) = u_c(\infty) + [u_c(0_+) - u_c(\infty)]e^{-\frac{t}{\tau}}$

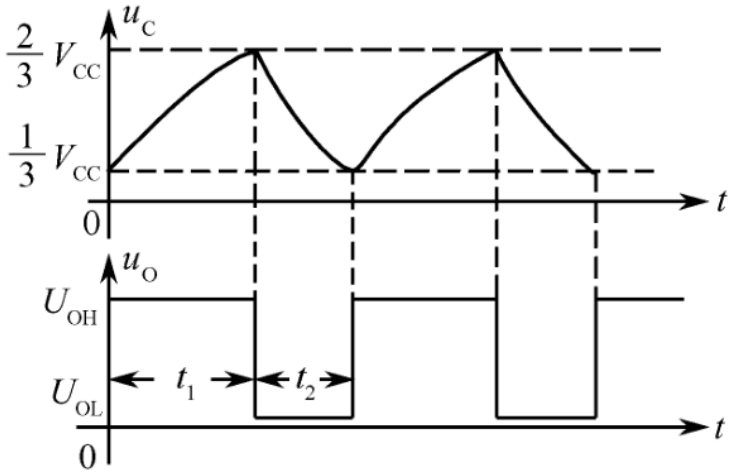
$t_1 = 0.69(R_1 + R_2)C$

- 放电

$u_c(0_+) = \frac{2}{3}V_{cc}$，$u_c(t_2) = \frac{1}{3}V_{cc}$

$u_c(\infty) = 0$，$\tau_2 = R_2C$ ➡ $t_2 = 0.69R_2C$



# 3.3.1 555集成定时器产生矩形波

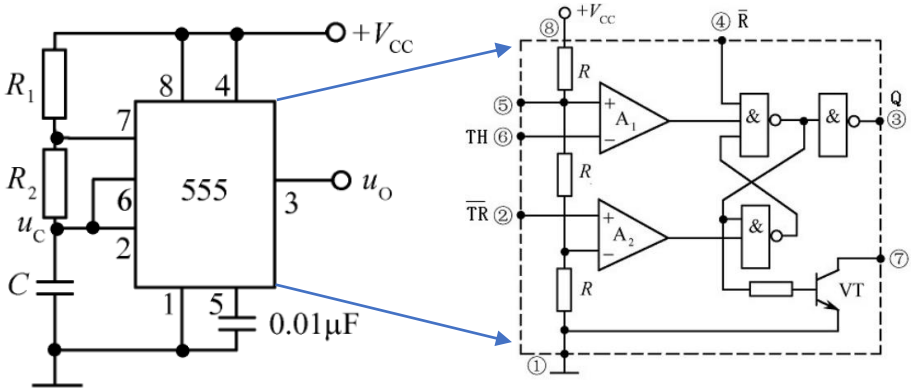
✓ **定量分析：**

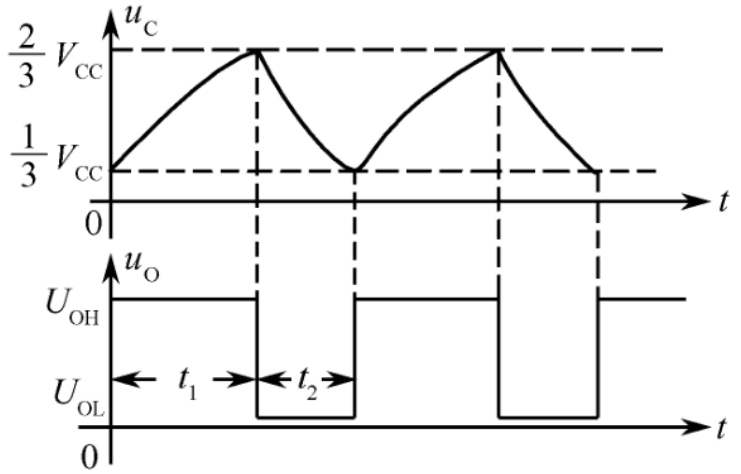
- 充电：$t_1 = 0.69(\mathrm{R_1} + \mathrm{R_2})\mathrm{C}$

- 放电：$t_2 = 0.69\mathrm{R_2C}$

- 周期：$\mathrm{T} = \mathrm{t_1} + t_2 = 0.69(\mathrm{R_1} + 2\mathrm{R_2})\mathrm{C}$

- 占空比：$\mathrm{Duty\ Cycle} = \dfrac{\mathrm{t_1}}{\mathrm{t_1} + \mathrm{t_2}} = \dfrac{\mathrm{R_1} + \mathrm{R_2}}{\mathrm{R_1} + 2\mathrm{R_2}}$

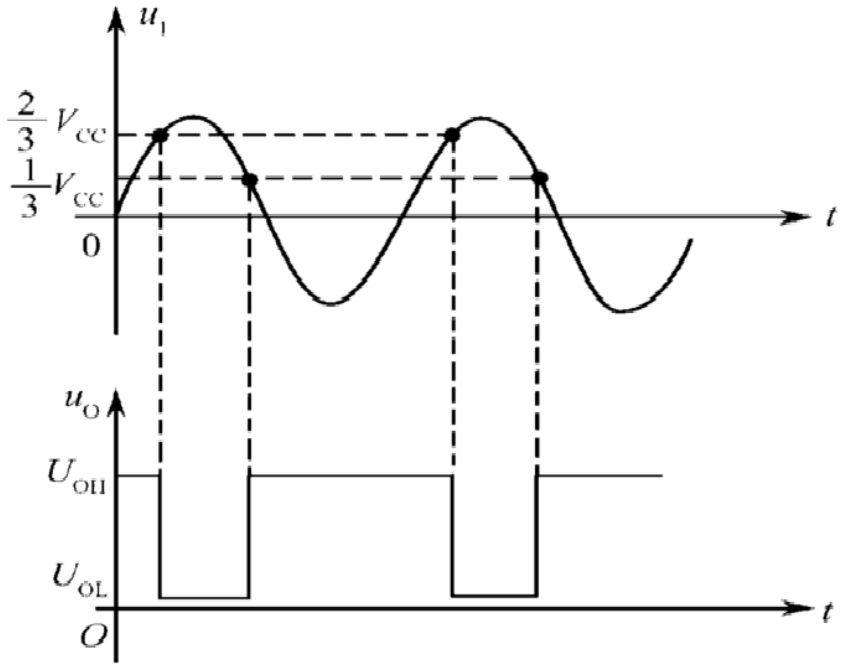


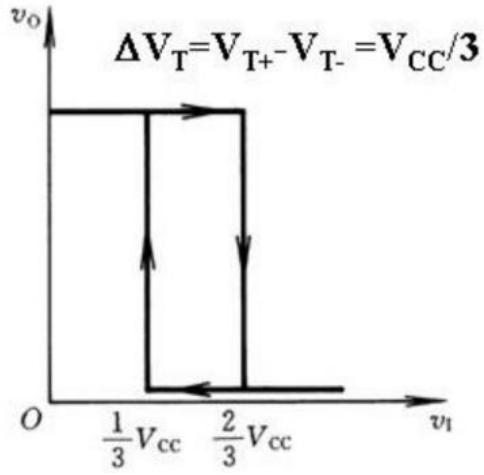



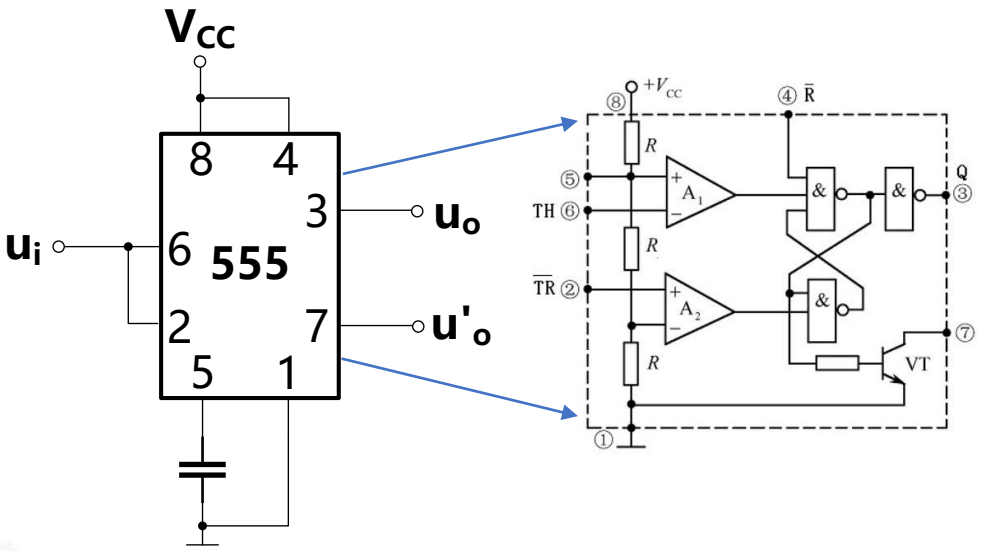
# 3.3.2 555集成定时器构成比较器

✓ **定量分析：**

- $u_i$从低到超过$2/3V_{CC}$, RS触发器由高到低
- $u_i$从高到低于$1/3V_{CC}$, RS触发器由低到高



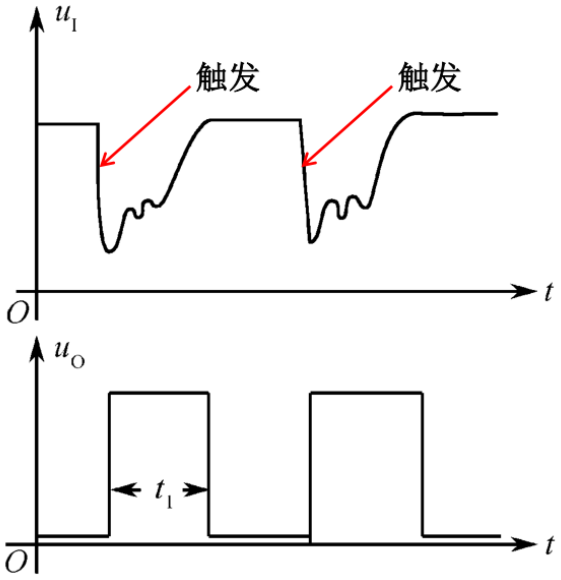




| 输入 | | | | | 输出 | |
|---|---|---|---|---|---|---|
| $\overline{R}$ | $\overline{TR}$-2 | $\overline{S}$ | TH -6 | $\overline{R}$ | VT | Q |
| 0 | X | X | X | X | 导通 | 0 |
| 1 | $< V_{cc}/3$ | 0 | $< 2V_{cc}/3$ | 1 | 截止 | 1 |
| 1 | $> V_{cc}/3$ | 1 | $> 2V_{cc}/3$ | 0 | 导通 | 0 |
| 1 | $> V_{cc}/3$ | 1 | $< 2V_{cc}/3$ | 1 | 不变 | 不变 |

# 3.3.3 555集成定时器构成单稳态触发器

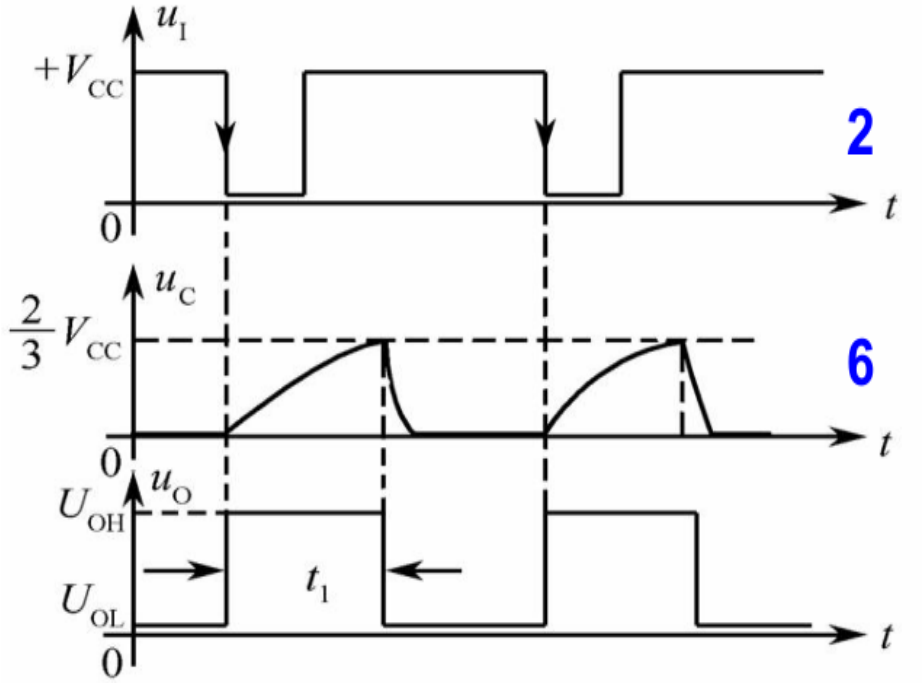
✓ **定性分析：**

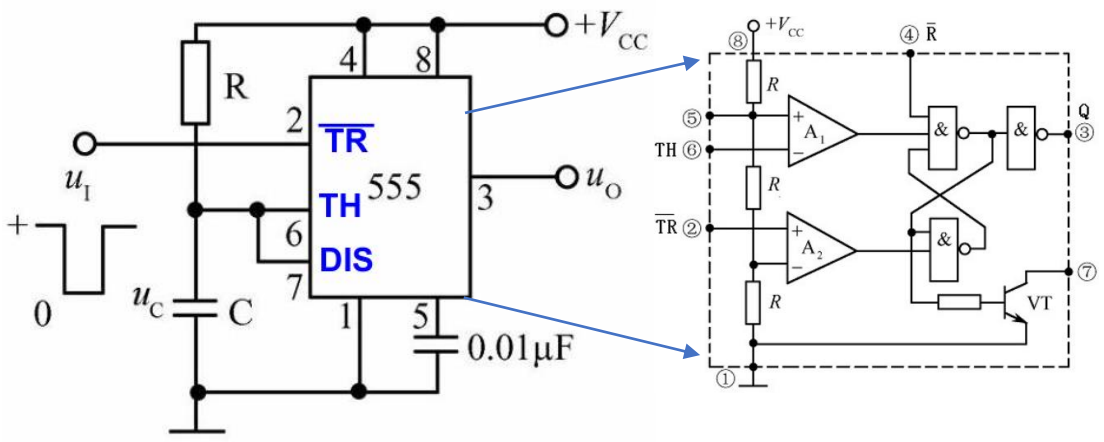
- 只有稳态电平，另一个电平是暂态，暂态电平只维持一段时间
- 需要输入信号触发
- 用途：定时，延时，波形整形



# 3.3.3 555集成定时器构成单稳态触发器

✓ **定性分析：**




$$u_C(t) = u_C(\infty) + [u_C(0_+) - u_C(\infty)]e^{-t/\tau}$$

$$u_C(0_+) = 0, u_C(\infty) = V_{CC}, u_C(t_1) = \frac{2}{3}V_{CC}$$

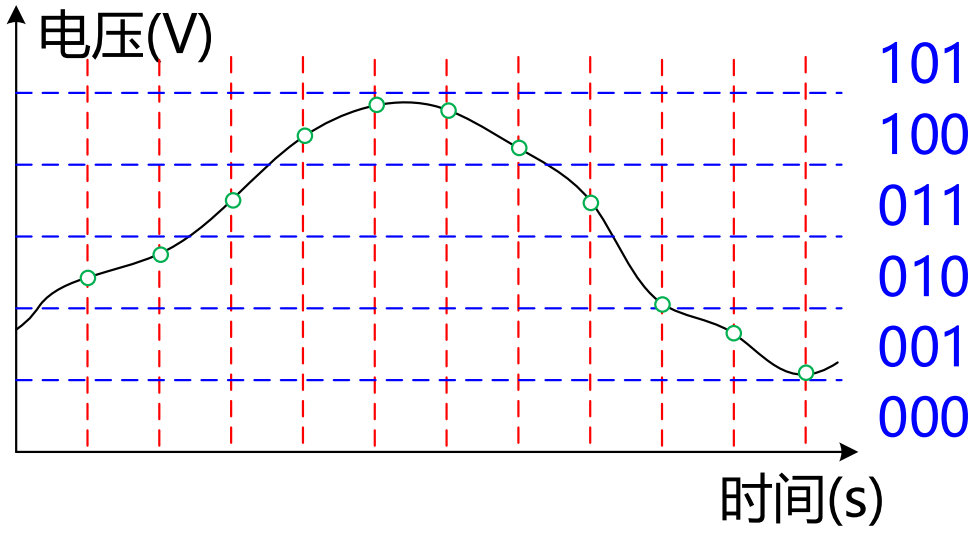
$$t_1 = RC \cdot \ln 3 \approx 1.1RC$$

| 输入 | | | | | 输出 | |
|---|---|---|---|---|---|---|
| $\overline{R}$ | $\overline{TR}$–2 | $\overline{S}$ | TH -6 | $\overline{R}$ | VT | Q |
| 0 | X | X | X | X | 导通 | 0 |
| 1 | $< V_{cc}/3$ | 0 | $< 2V_{cc}/3$ | 1 | 截止 | 1 |
| 1 | $> V_{cc}/3$ | 1 | $> 2V_{cc}/3$ | 0 | 导通 | 0 |
| 1 | $> V_{cc}/3$ | 1 | $< 2V_{cc}/3$ | 1 | 不变 | 不变 |

# 3.4 运放非线性应用实例

✓ **电池电压显示：**

- 获取输入信号
- 进行模数转换




输入信号

模数转换