Lab 5: Electronic Oscillator
（振盪器電路）

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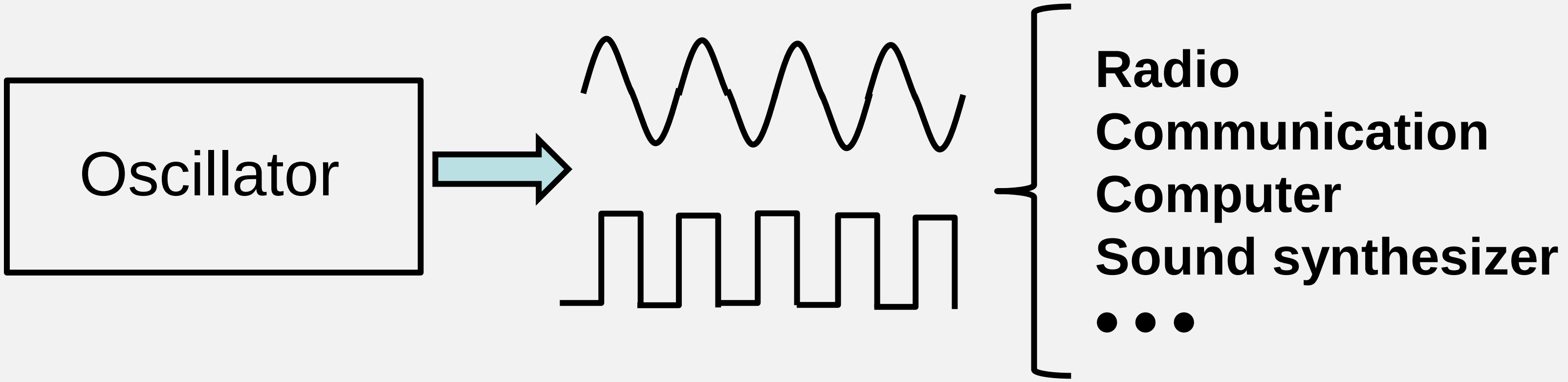
Electronic Oscillator

- An electronic oscillator is a circuit that produces a periodic signal, often a sine wave or a square wave
  - Numerous applications: radio, communication, clock signals for computers, etc
  - 如何能讓振盪器電路插電後便能產生振盪波形?在本次實驗我們將會介紹三種常用的振盪器電路

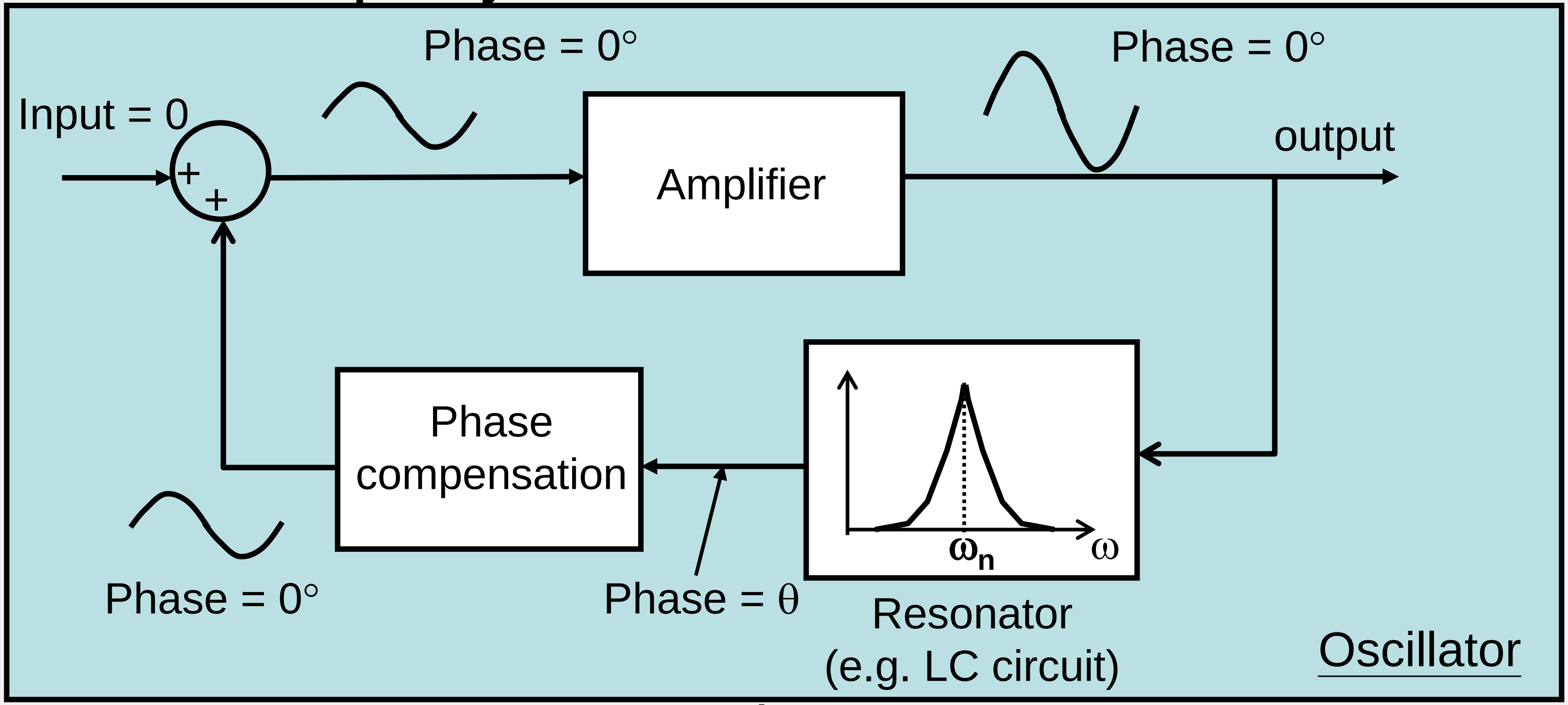


Types of Oscillators

- Feedback oscillators
  - Operated based on feedback（迴授）；we need to properly design the loop gain and phase to produce oscillation
    - » Examples: the Wien-bridge oscillator, the phase-shift oscillator, the twin-tee oscillator, etc
- Relaxation oscillators
    - » Also use feedback; usually use a mechanism to alternately charge and discharge a capacitor through a resistor in order to sustain oscillation
- Triangular, square-wave oscillator using Schmitt trigger
  - An integrator is used in the feedback loop

Type I: Feedback Oscillators

- 經由" 迴授 "，當整個loop有適當的gain以及phase(滿足Barkhausen criterion)，在不需輸入訊號下，電路本身的噪聲(noise)得以被持續放大，形成週期性的振盪訊號
- **Key: need a frequency selective device (i.e. resonator) to define the oscillation frequency**



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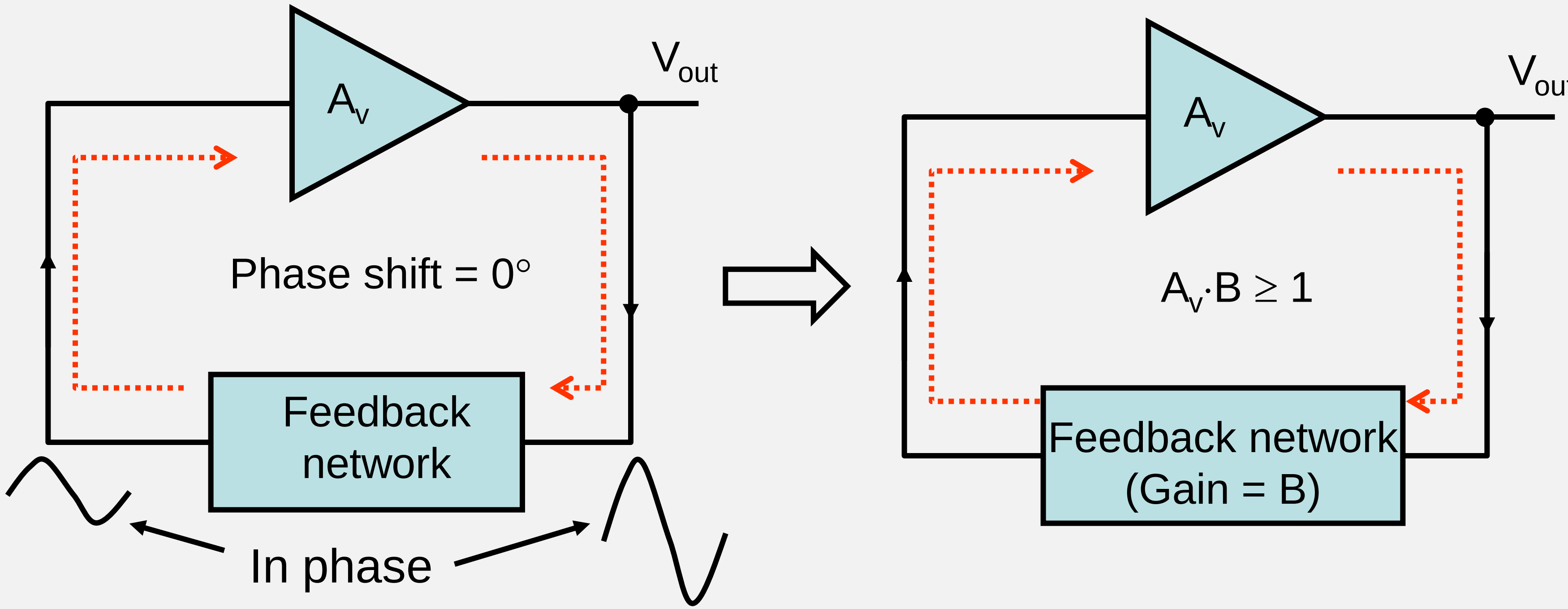
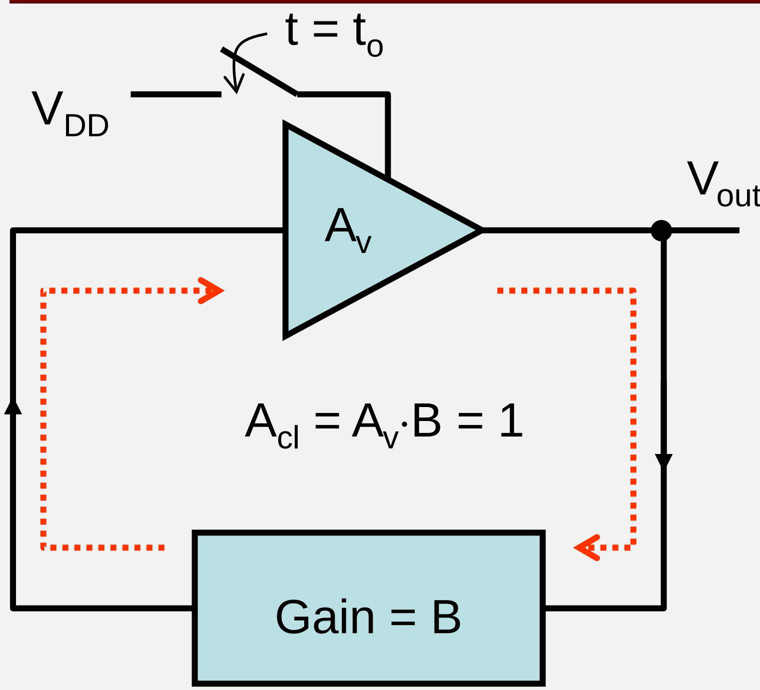
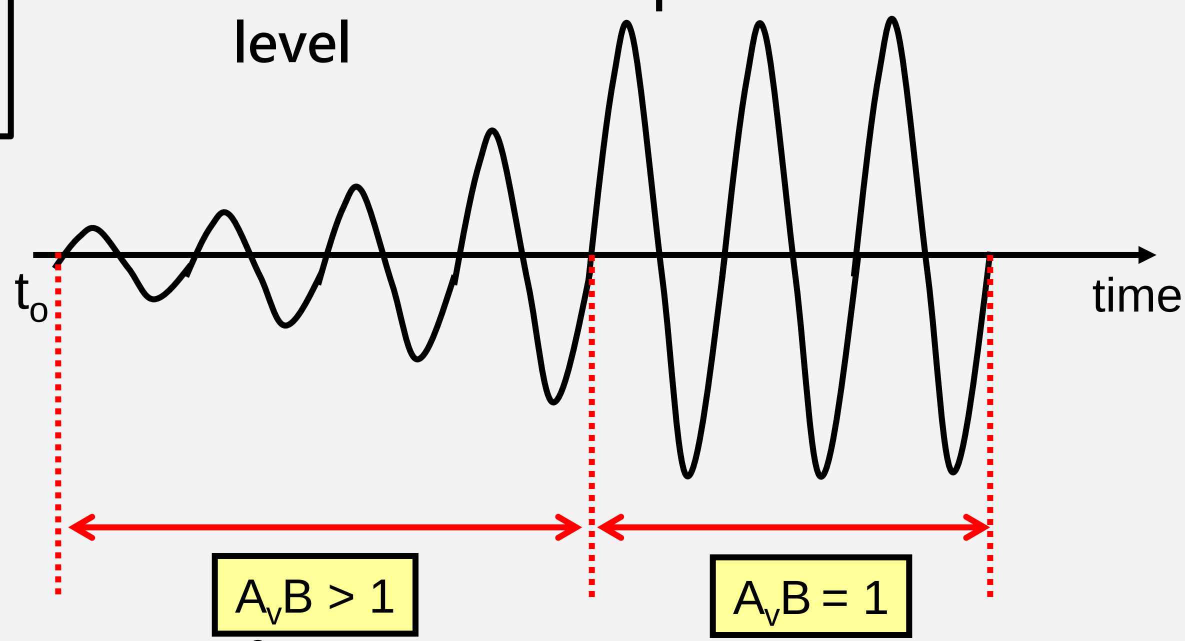
- Conditions (Barkhausen criterion) for producing oscillations（重要!）:
  - The phase shift around the feedback loop must be 0° (or 360°)
  - The loop gain (voltage gain) around the feedback loop must be at least 1



Start-Up Conditions（起振條件）

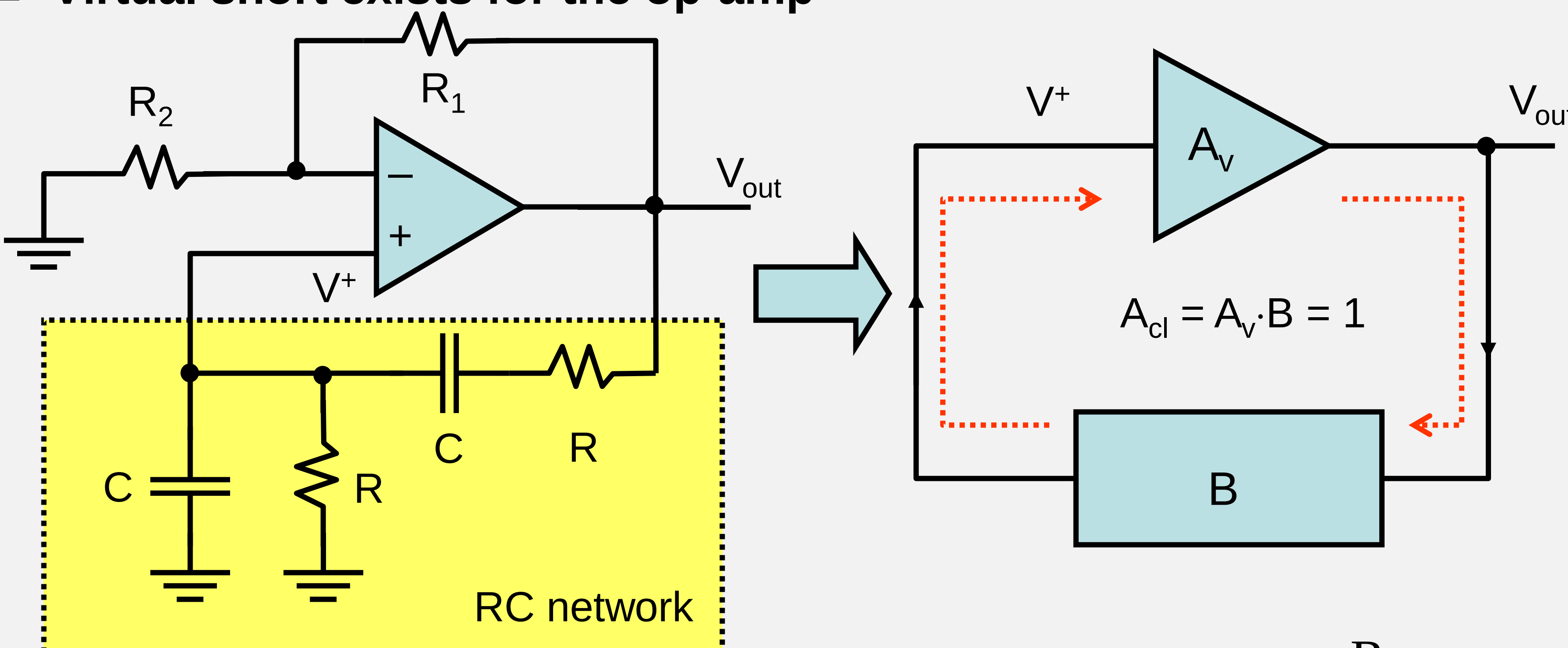


- Oscillation can be produced by electronics noise or initial transient during power-on
- Operation: initial gain can be greater than one to build up the waveform, then decreases to one to maintain the amplitude at the same level



Example I: The Wien-Bridge Oscillator

- 分析：電阻與電容要如何設計才能起振？另外，振盪頻率是多少？
- **Need to satisfy Barkhausen criterion**
- **Virtual short exists for the op-amp**



What are A_v and B?

$$A_v = 1 + \frac{R_1}{R_2}$$

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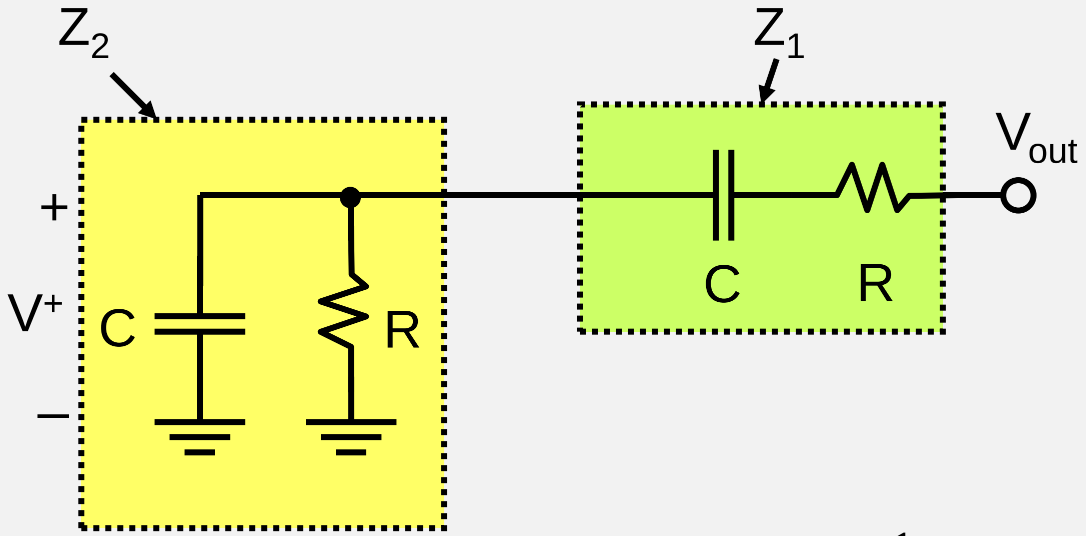

$$\frac{V^{+}(s)}{V_{out}(s)} = \frac{Z_2}{Z_1 + Z_2} = \frac{R \,||\, \frac{1}{sC}}{\left(R + \frac{1}{sC}\right) + R \,||\, \frac{1}{sC}}$$

$$= \frac{sRC}{R^2C^2s^2 + 3RCs + 1}$$

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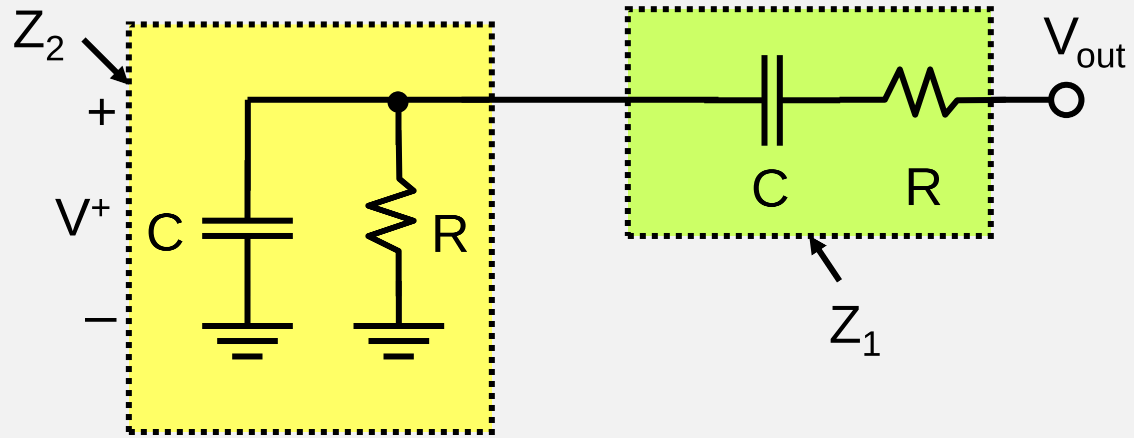


Replacing s = jω: $\frac{V^+(j\omega)}{V_{out}(j\omega)} = \frac{j\omega RC}{(1-\omega^2R^2C^2) + j\omega 3RC}$

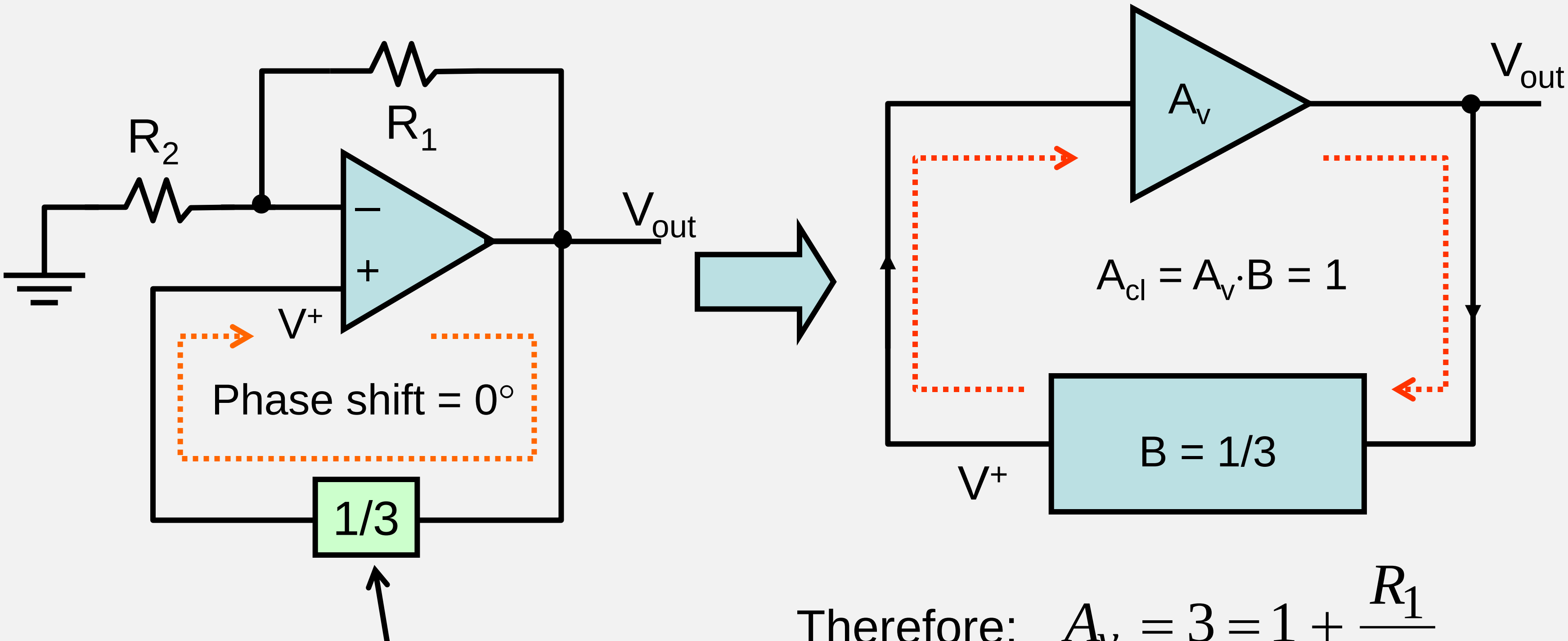
For now (believe me), the phase shift between V^+ and V_{out} must be zero才能產生振盪（因為Av是一個單純的gain，相角為零）, therefore:

$$1-\omega^2R^2C^2 = 0 \Rightarrow \omega = \frac{1}{RC}\ \text{rad}/sec \ \therefore \frac{V^+(j\omega)}{V_{out}(j\omega)} = \frac{j\omega\cdot RC}{j\omega\cdot 3RC} = \frac{1}{3}$$

resonant frequency

Cont'd: 起振條件 -- Determine the Ratio of R_1/R_2

- The resonant frequency in Hertz: $f_r = 1/(2\pi RC)$



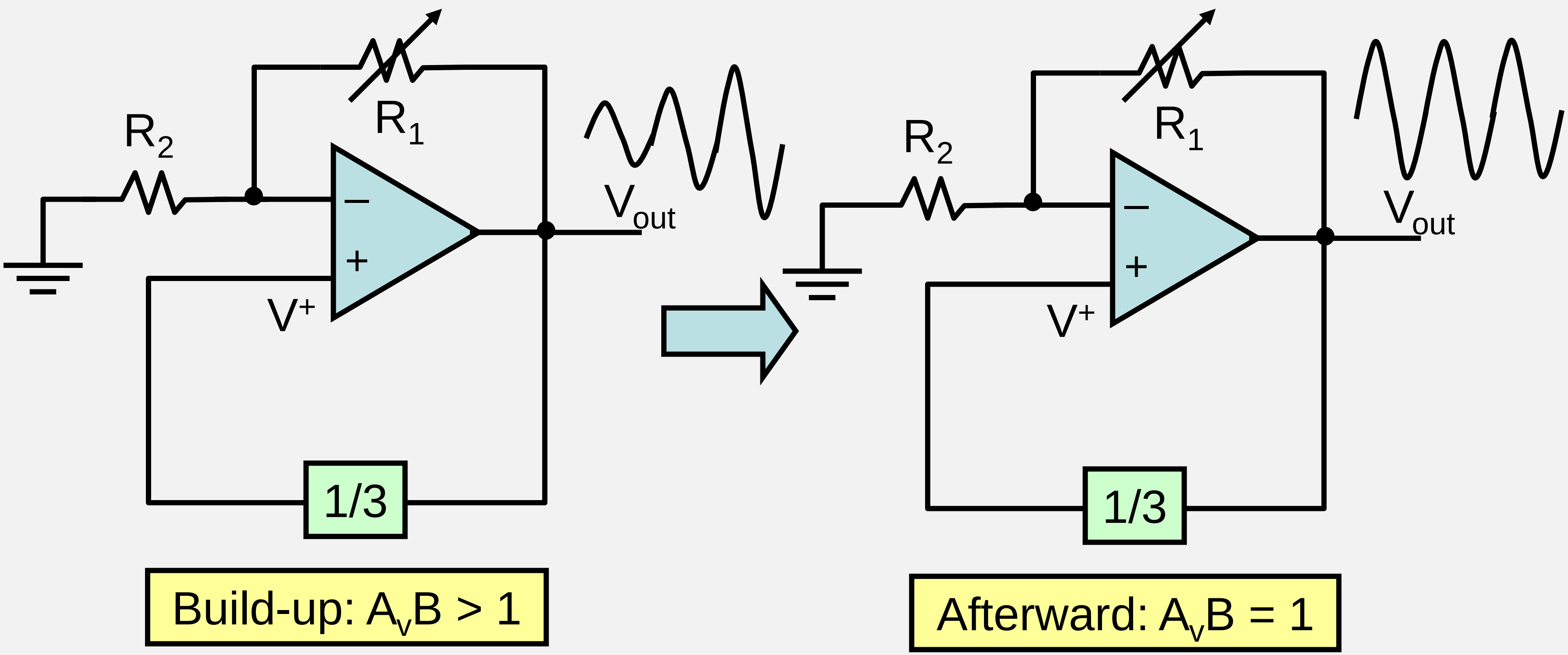
At resonance

Therefore: $A_v = 3 = 1 + \dfrac{R_1}{R_2}$

$$\therefore R_1 = 2R_2$$

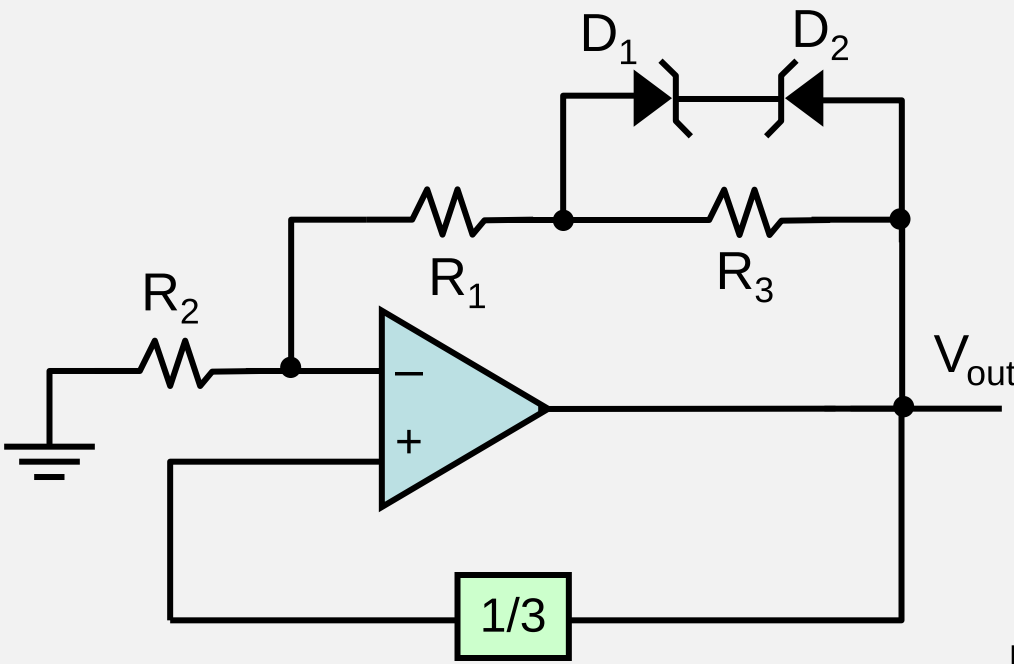
Start-Up of Oscillations: Implementation

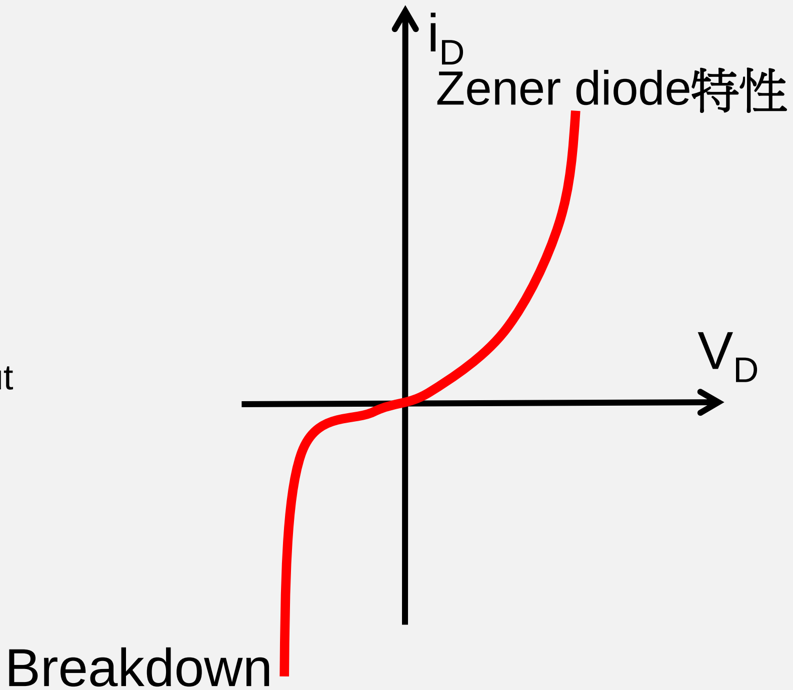
- It is desired to have a loop gain $A_v \cdot B > 1$ to start up the oscillation, then reduce the loop gain to one to sustain the oscillation
  - 如何製作一個可以調整增益的電阻？



Implementation of the Adjustable Gain Using Zener Diodes

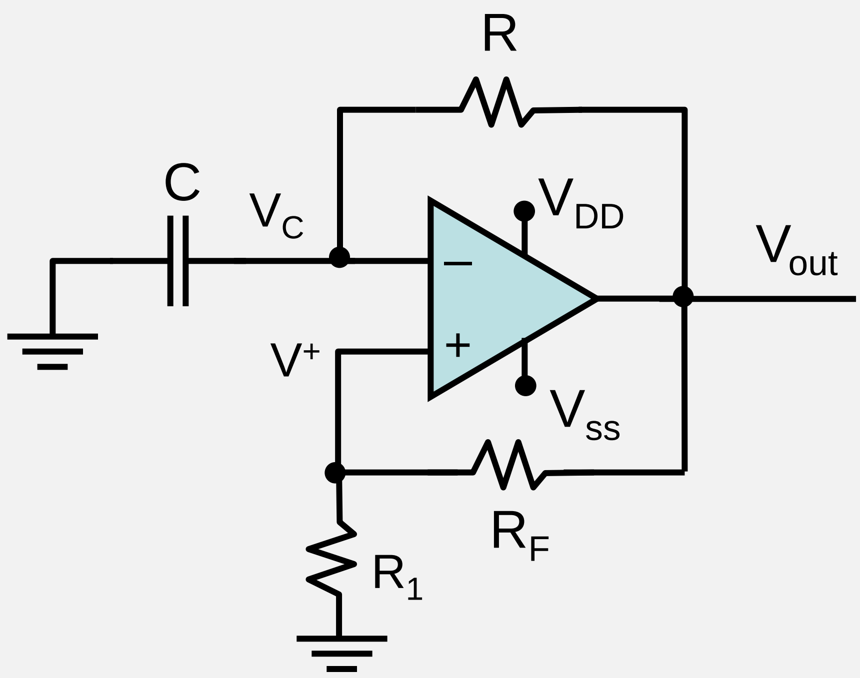
- 想想看：back-to-back connected zener diodes的作用
  1. 當還沒起振時（back-to-back連接zener diodes電阻值較大）
  2. 當已經產生較大的振盪訊號V_{out}之後（back-to-back連接zener diodes電阻值較小，短路）





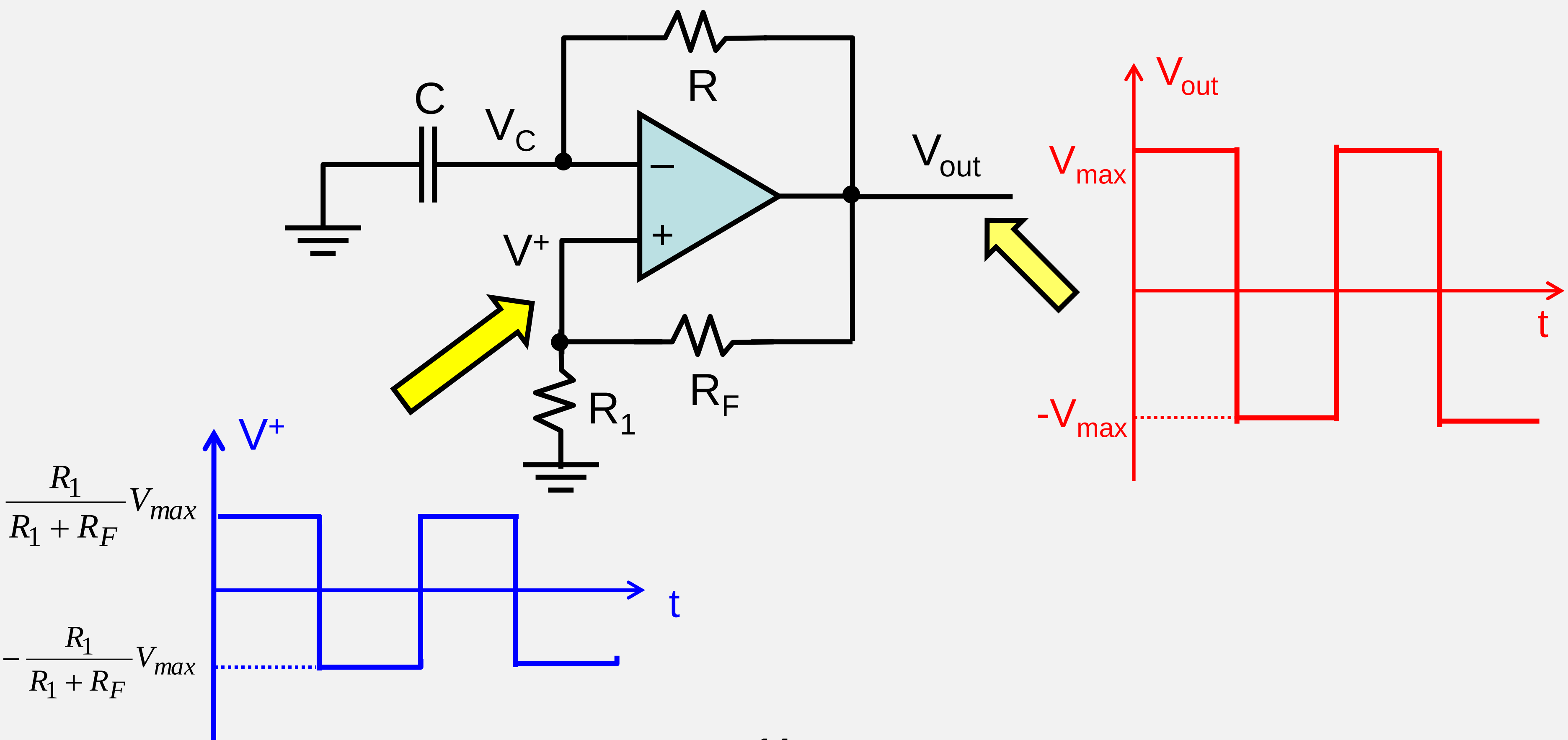
Type II: Relaxation Oscillator

- Note： the op-amp here works like a comparator（比較器）, no virtual short exists between V^+ and V_C ; the output is a square wave
  1. When $V^+ > V_C$: V_{out} is close to V_{DD}
  2. When $V^+ < V_C$: V_{out} is close to V_{ss}



Analysis

- Waveform of V^+: R_F and R_1 determine the value of V^+, which sets the level to compare with V_C



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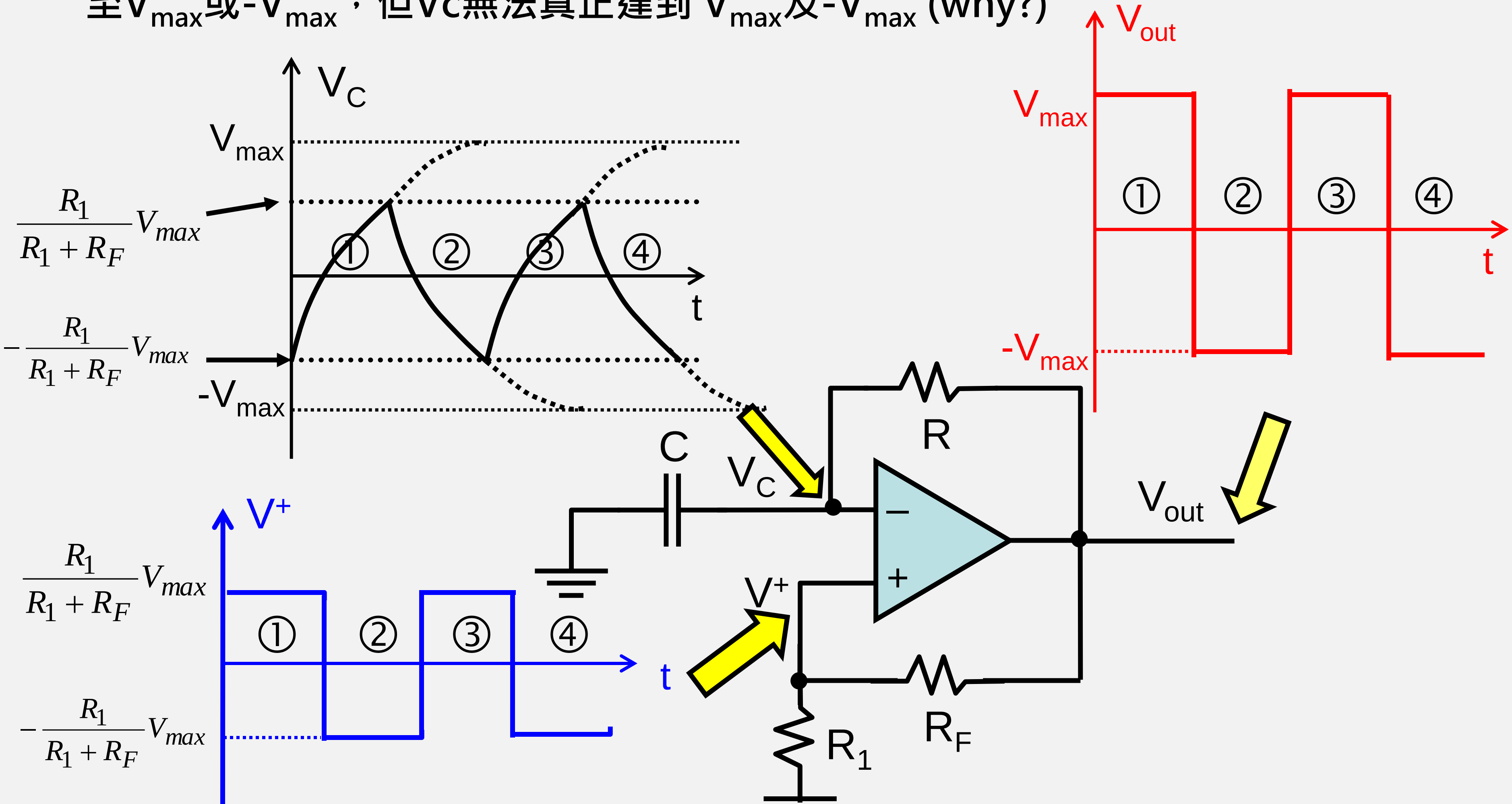
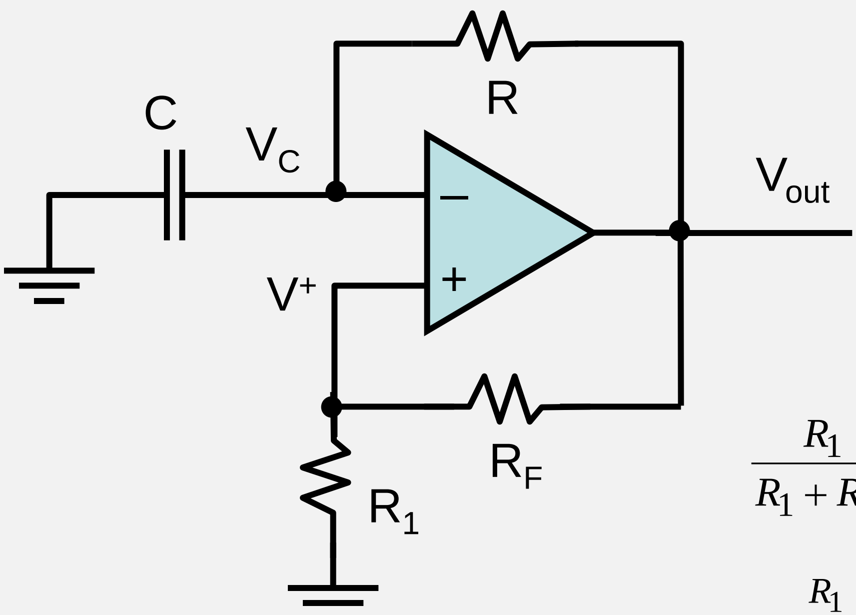
- 當V_{out}是V_{max}或$-V_{max}$ 時，會沿著RC路徑(time constant τ = RC)對C充電及放電至V_{max}或$-V_{max}$ ，但Vc無法真正達到 V_{max}及$-V_{max}$ (why?)

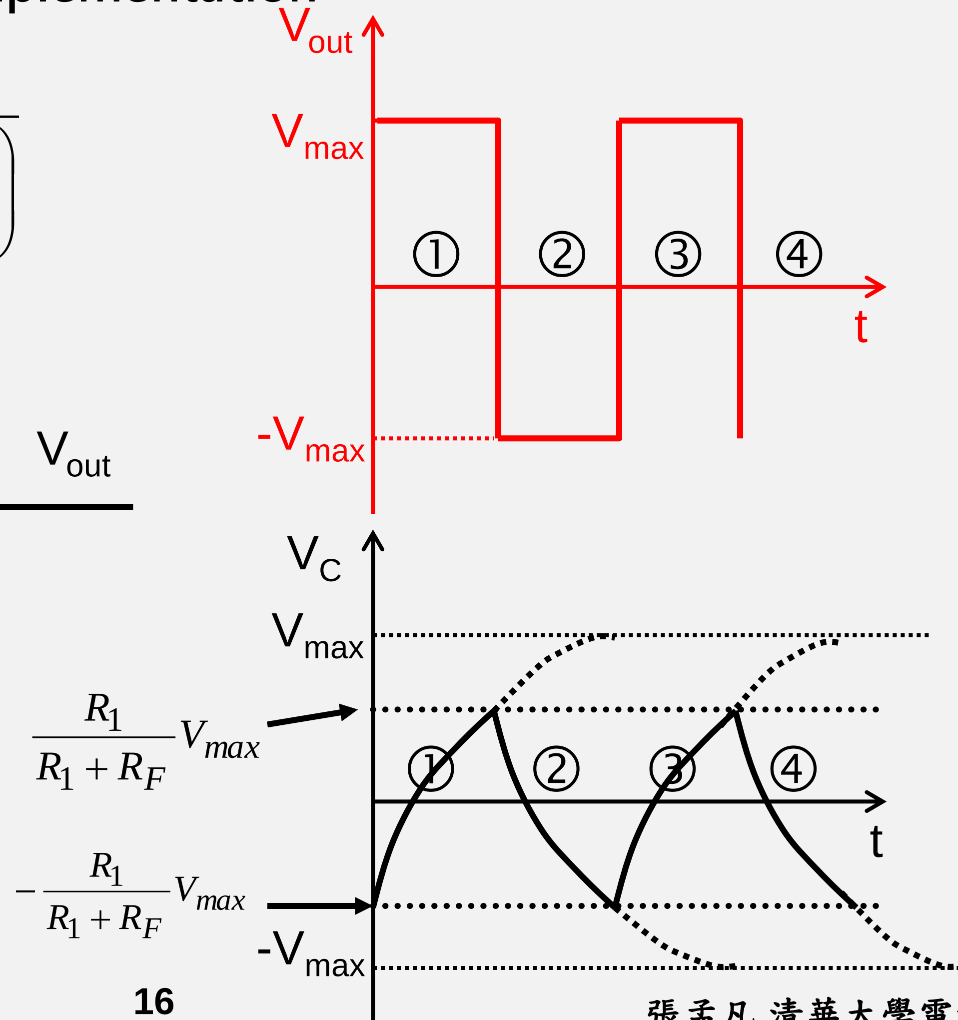


Oscillation Frequency

- Please analyze the frequency based on the waveforms, and show the result to a TA before your implementation

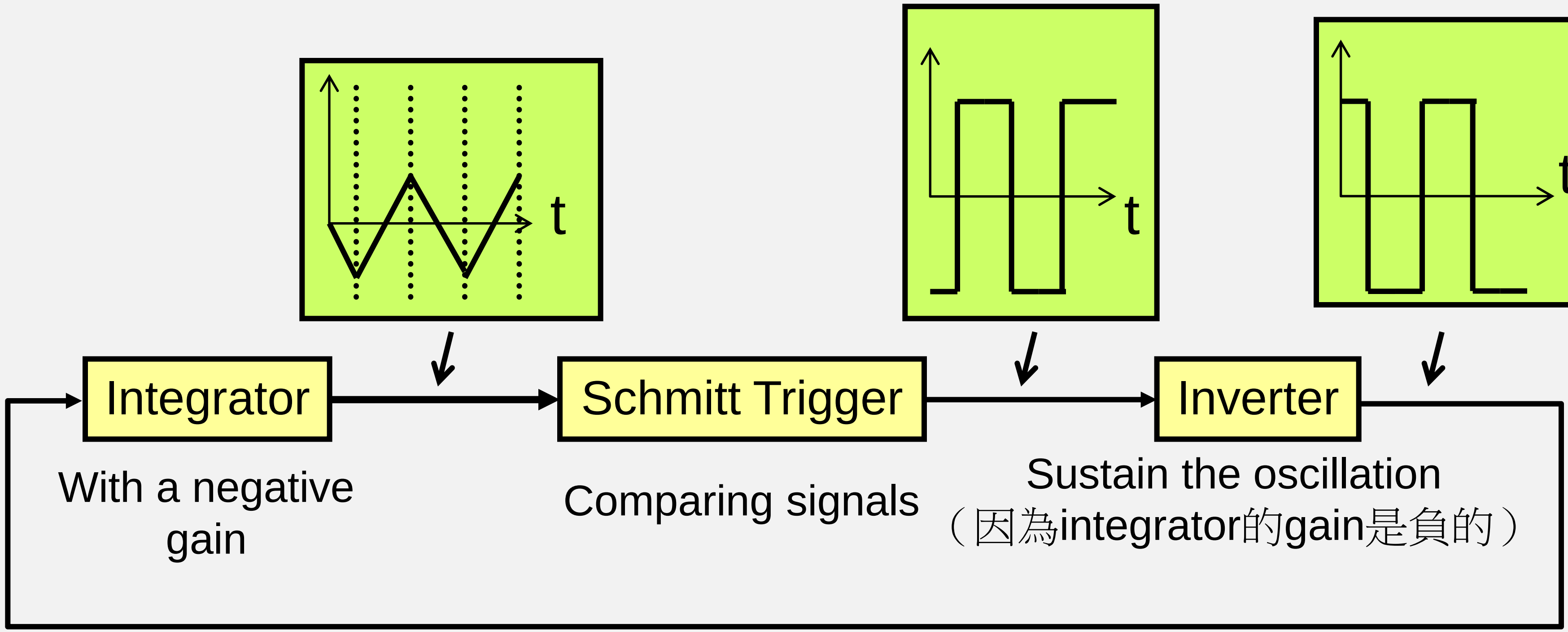
$$f_0 = \frac{1}{T} = \frac{1}{2RC \cdot \ln\left(1 + 2\frac{R_1}{R_F}\right)}$$





Triangular, Square-Wave Oscillator

- Can be used to make a function generator
- Three important parts:
  - Integrator： 將方波積分、使成為三角波
  - Schmitt trigger：將三角波與參考電壓比較後，形成方波輸出
  - Inverter (將正訊號變負、負變正)。在整個電路的角色是維持振盪



Integrator with a Negative Gain

- The integrator is:

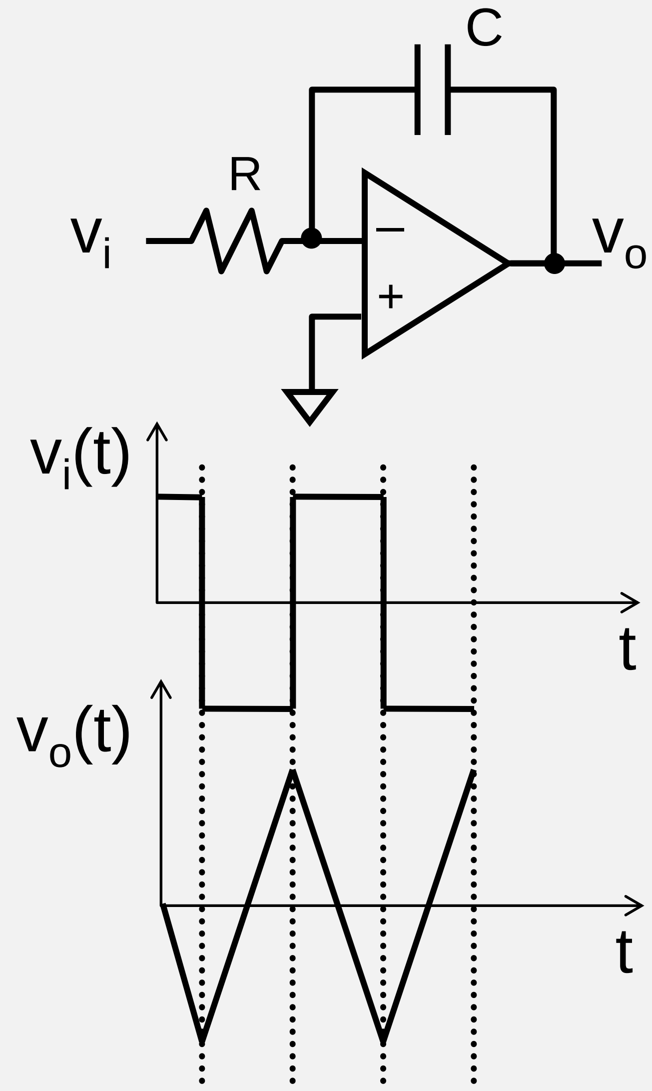
$$\frac{v_o(s)}{v_i(s)} = -\frac{1}{sRC}$$

Assume v_i is constant:

$$\Rightarrow \mathrm{v_o(t)} = \int_0^t -\frac{1}{\mathrm{RC}} \mathrm{v_i dt}$$

$$= \underbrace{-\frac{1}{RC} v_i}_{Slope} \cdot t$$

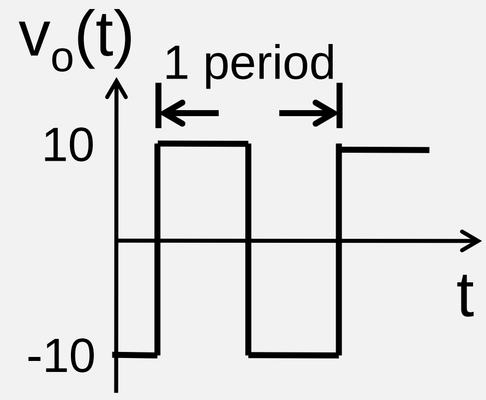
- Given a square waveform, an integrator produces a triangular waveform

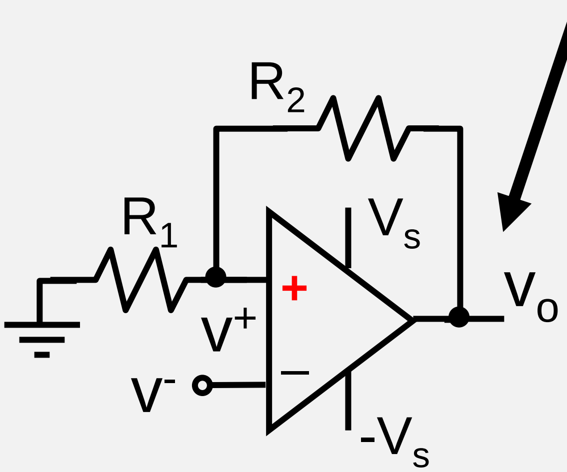


Schmitt Trigger

- 注意: V_o的訊號是拉回到op-amp的正端（不會有virtual short），產生參考電壓V^+，來與輸入訊號V^-比較
- V_o is either HIGH or LOW，with values close to V_s或$-V_s$
- Example: assume $R_1 = R_2$, $V_s = 10$ V. Then

$$v_o \cong \pm 10\,\mathrm{V},\; v^+ = \frac{R_1}{R_1 + R_2} v_o = \pm 5\,\mathrm{V}$$





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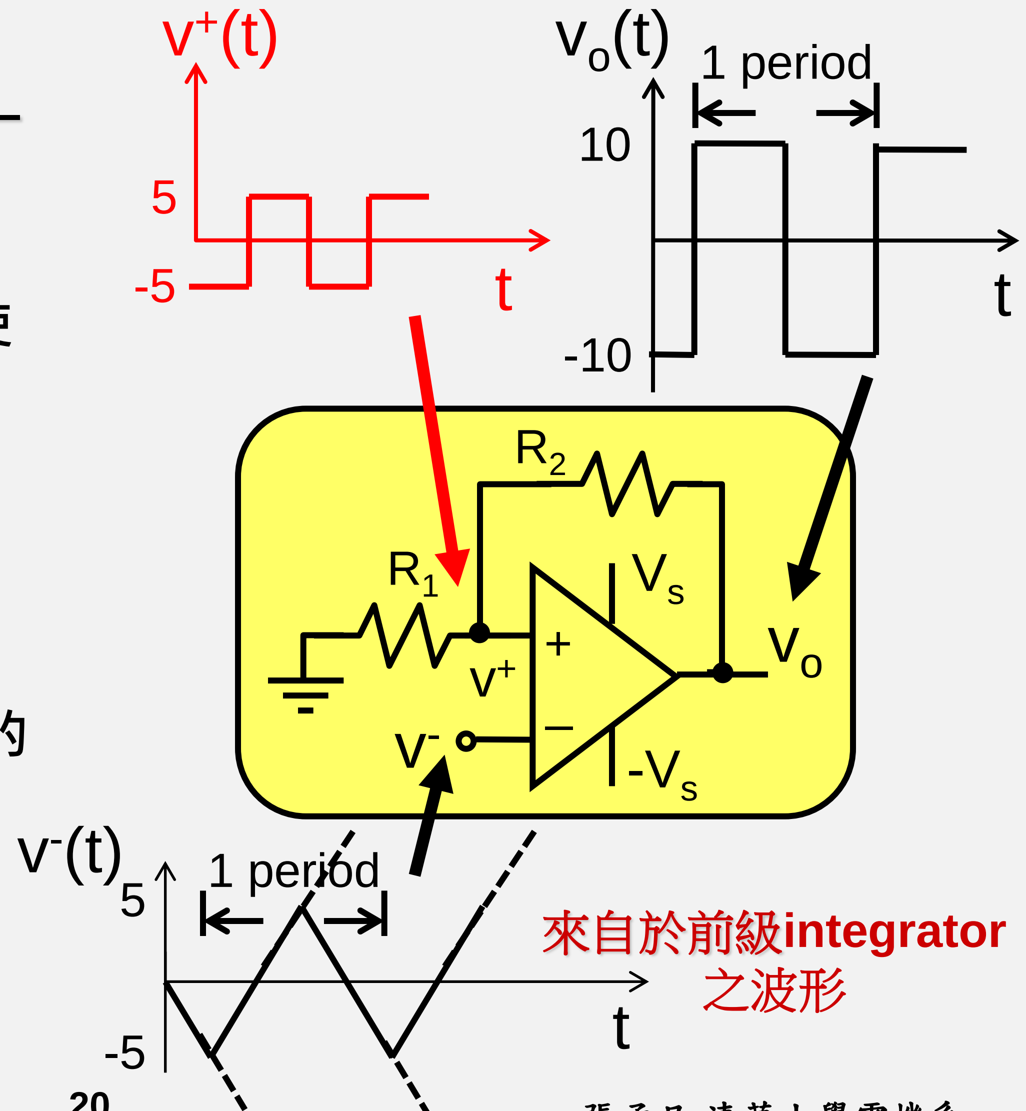
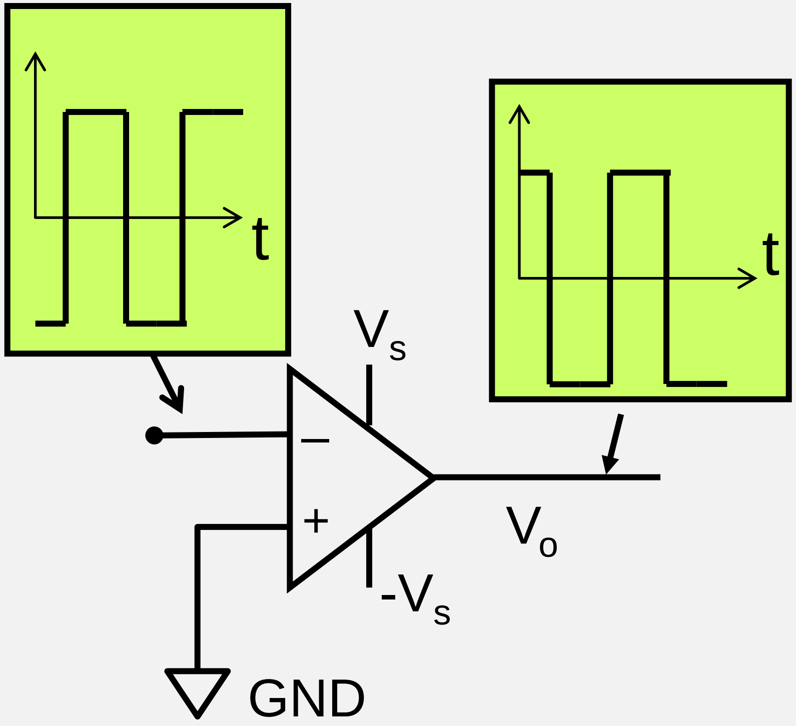
- 輸入端（v^-）的輸入是 triangular wave，來自於前一級的integrator
- 積分器原本持續積分（如虛線所示），經與v+比較後，會使v_o變號（例如由LOW變HIGH）；v_o的訊號再經inverter變號後（下一張），會使得積分器往相反方向積分
- Schmitt trigger的輸出及v+的波形皆是方波(Here $R_1=R_2$)
- 設計重點：方波的週期與v-的斜率、R_1/R_2 ratio皆有關

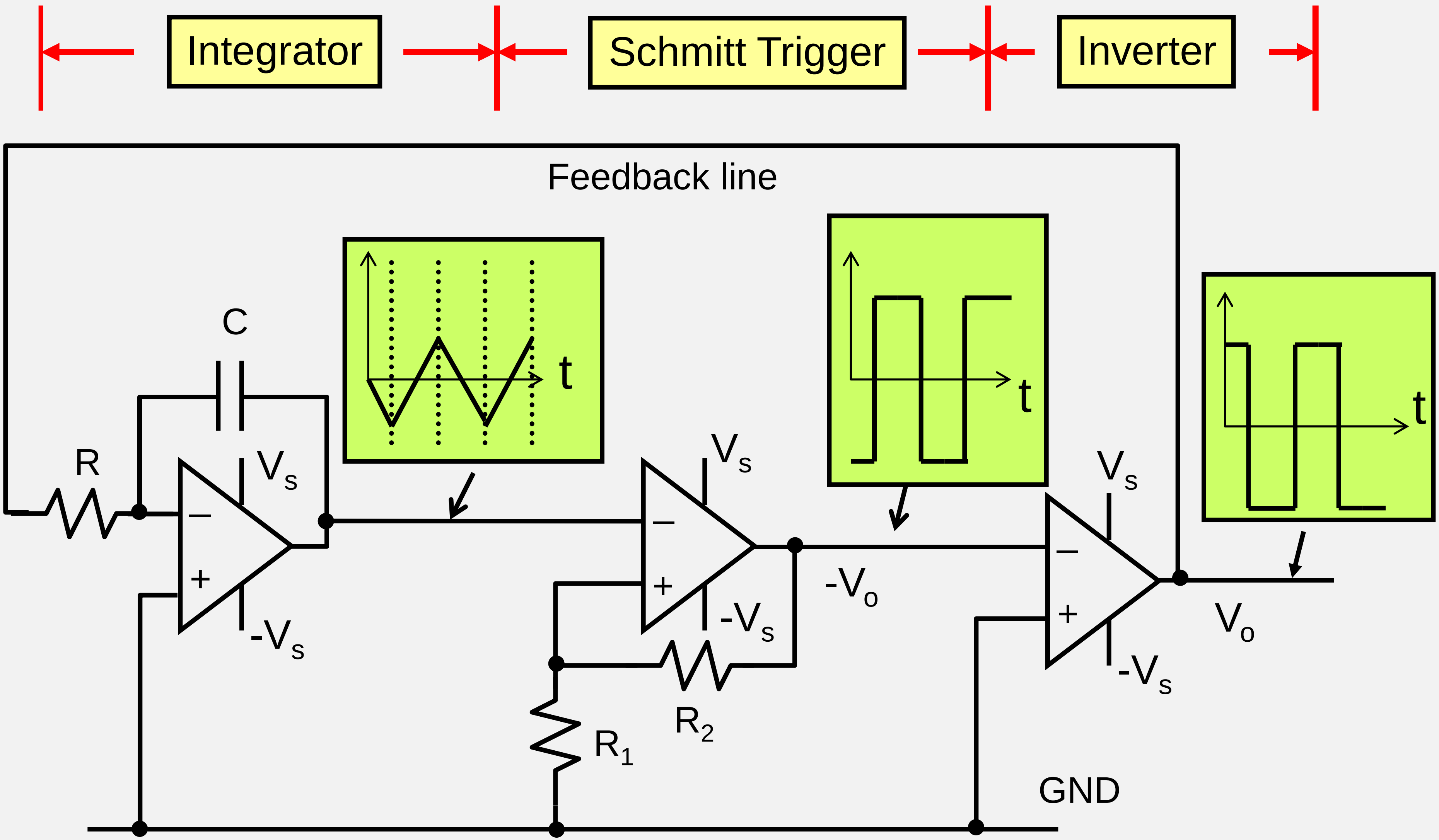


Inverter

- Here, the op-amp is used as a comparator to compare input waveform with 0 V (GND)
- Oscillation can not be sustained without the inverter



Complete Schematic



The LM348 Chip

- You will use it to implement oscillators
- FOUR op amps are included in one chip
- Power supply = ±18 V
- Caution: Try not to touch the metal pins of the chip in order to avoid damage due to electrostatic charges