Operational Amplifiers

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February 8, 2023

- Frequency
  - Terminology: ω_0 is the fundamental frequency, T is the period, $n\omega_0$ are harmonics of ω_0 or harmonic frequencies of $f(t)$

$$a_0 = \frac{1}{T}\int_{t_0}^{t_0+T} f(t)\,dt \quad \text{(This is the average of the signal over a period)}$$

$$a_n = \frac{2}{T}\int_{t_0}^{t_0+T} f(t)\cos(n\omega_0 t)\,dt \quad \text{(This is how much the signal ``looks'' like a cos at } k\omega_0\text{)}$$

$$b_n = \frac{2}{T}\int_{t_0}^{t_0+T} f(t)\sin(n\omega_0 t)\,dt \quad \text{(This is how much the signal ``looks'' like a sin at } k\omega_0\text{)}$$

- Amplifiers
  - Denoted as a triangle pointed in direction of current in circuit diagrams
  - A signal is usually represented as current (i) or voltage (v)
  - The purpose of amplifier is to increase the magnitude of incoming signal for meaningful use
  - For example, a loud-speaker increases the amount of sound waves to make it audible to a public gathering
  - You can increase or decrease the brightness of your computer screen by controlling the amount of amplification of the LED display
  - The input signal can be (v or i) and the output signal can also be amplified version of (v or i).
  - This gives us 4 combinations:
    1. A Voltage Amplifier amplifies voltage Input (v) to provide a voltage output (Av).

2. A Current Amplifier amplifies current Input (i) to provide a current output (Ai).
3. A Transconductance Amplifier amplifies voltage Input (v) to provide a current output (Ai).
4. A Transresistance Amplifier amplifies current Input (i) to provide a voltage output (Av).

   * A is called the gain of the amplifier.
   * A can be dimensionless or can have the dimension of resistance or conductance.

- Operational Amplifiers
  - Built out of diodes and transistors
  - A complex circuit, but we will not study its internal details
  - It has a very simplified terminal characteristics.
  - Equivalent model is essentially a circuit with dependent source.
  - Op-Amps are very common place in electronics systems.
  - We are only interested in OP-Amp terminal characteristics and not its internal circuitry.
- In 1968, Fairchild made a popular Op-Amp which was an 8-pin micro-chip
  - Out of 8 terminals, terminals NC and two offset terminals will not be discussed in this class
  - Essentially, our Op-Amp will be a 5-terminal device
  - Two input terminals:
    * The $+ve$ terminal is called the non-inverting input
    * The $-ve$ terminal is called the inverting input
  - One output terminal
  - Two power supplies, a $+ve$ voltage and a $-ve$ voltage
- The Op-Amp Operating Region
  - The input voltage to the Op-Amp is $v_i = (v_p - v_n)$
  - The output voltage of the Op-Amp is $Av_i = A(v_p - v_n)$
  - The Op-Amp output has two regions: linear and saturation, as defined below

$$v_0 = \begin{cases} -V_{CC} & A(v_p - v_n) < -V_{CC}, \\ A(v_p - v_n) & -V_{CC} \leq A(v_p - v_n) \leq +V_{CC}, \\ +V_{CC} & A(v_p - v_n) > +V_{CC} \end{cases}$$

- Op-Amp Gain
  - In practical applications, Op-Amps are rarely used in an open-loop configuration
  - It is almost always used in a feedback configuration
  - Feedback is when output is connected back to an input using circuit components
  - When it is connected to the negative terminal, it is called negative feedback, and for the positive terminal, it is called positive feedback

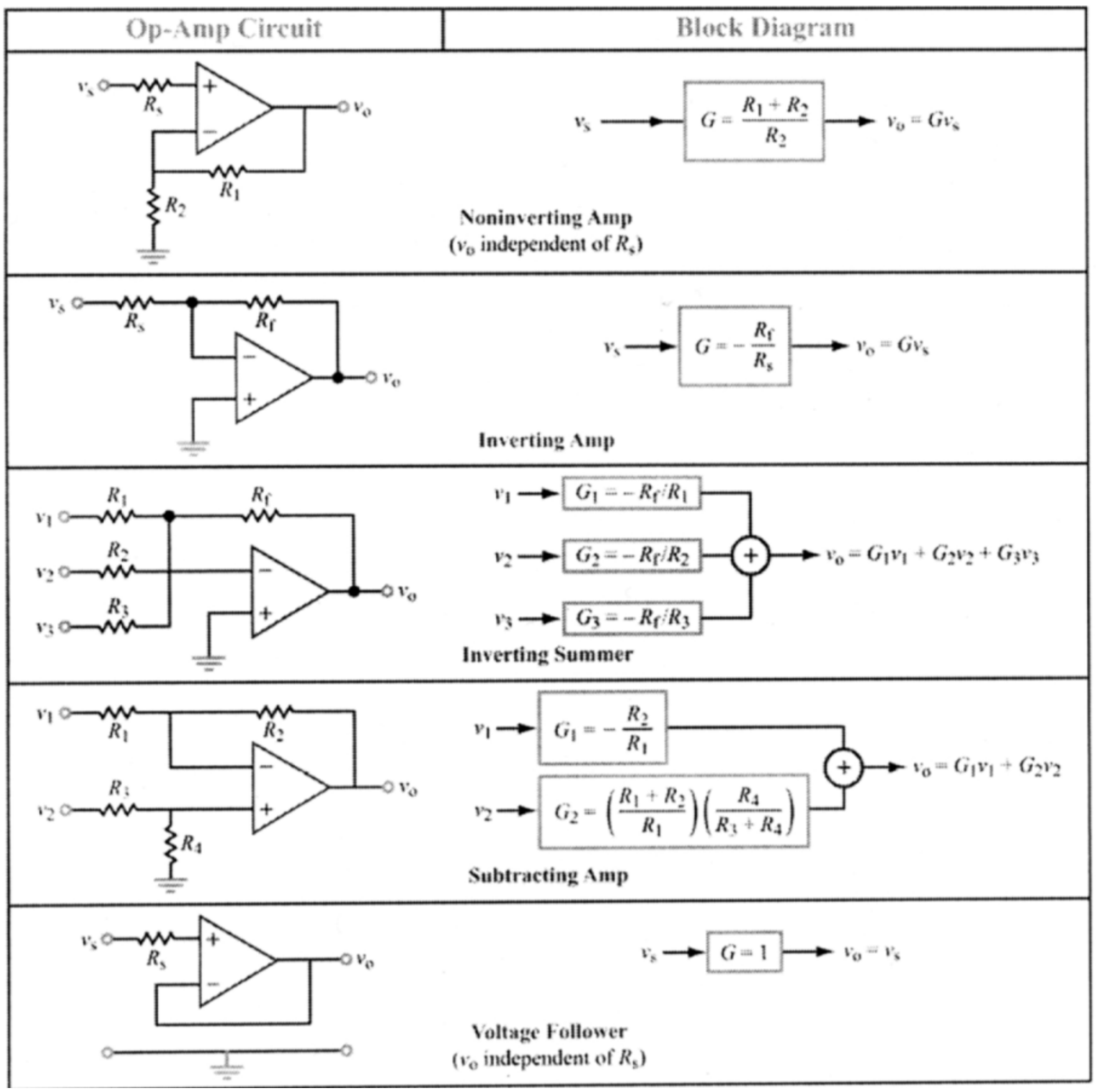

Figure 1: OpAmp Shortcuts