Topology in Circuit Analysis

- Many different circuits actually operate the same
- Can reduce a circuit to a "graph"
- Graph only shows the branches, not the devices
- Two Circuits are said to have the same topology
  When the graphs can be made the same

**Figure 5.1** (a) A circuit; (b) its graph.

**Figure 5.3** A circuit that is topologically the same as the circuit shown in Fig. 5.1(a).
Example Inverting Op Amplifier

For an inverting op am with

\[ R_s = 1 \, K\Omega \quad R_f = 10 \, K\Omega \]

\[ V_{CC} = +15 \, V \quad V_{EE} = -15 \, V \]

What is the output for a 0.5 V input

The voltage gain is:

\[ A_v = \frac{V_o}{V_s} = -\frac{R_f}{R_s} = -\frac{10000}{1000} = -10 \]

Thus the output is:

\[ V_o = A_v V_s = -10 \times 0.5 = -5 \, V \]
Analog and Digital

• Electronics divided into Analog and Digital
• Analog devices: have a continuous range of values
• All real world signals are Analog
• Analog devices: examples
  • Amplifiers: increase/decrease signals
  • Sensors: measure some variable
    • eg: light intensity, temperature, air flow
  • Transducers: cover one energy to another form
    • eg: light to electrical or electrical to heat

Analog advantages:
• Easy representation of real world measurements
• Wide range of values
• Can be very fast reacting circuits

Analog disadvantages:
• Circuits very tricky to build linear
  • Eg. difficult to keep gain constant in amplifiers
• Thus analog reproduction is inaccurate
  • Very sensitive to noise/interference
    • Eg Amplification often injects noise in signal
• These combine: thus analog reproduction is inaccurate
Digital Signals

- Digital: signal can only have discrete values
- Simplest (commonest) Binary
- Binary: only two values: 0 (off or low) or 1 (on or high)
- Almost all digital devices binary at heart
- Effectively all computers digital these days

**Digital advantages:**
- Very accurate if enough digits
- Noise insensitive, because only discrete values
- Error free coping
- Circuits easy to build

**Digital disadvantages:**
- Does not reflect continuous real world variables
- Must convert from analog to digital to for computer measurement
- Must convert from digital to analog for many applications
Ideal Operational Amplifier (EC 5)

- Amplification: increase of a signal by a constant factor
- eg. voltage amplification

\[ A_F = \frac{V_{out}}{V_{in}} \]

- Amplification is also called the gain G
- Ideal amplifier = ideal voltage controlled voltage source
- An ideal amplifier does not affect the input signal
Ideal Operational Amplifiers

- "Operational Amplifier":
- An approximation to ideal amplifier
- Shorten to "op amp" for common usage
- Originally used in Analog computers during 1940-50's
- "Operational Amplifier" from original function:
  - Performance of "mathematical operations"
- Current devices are Integrated Circuits:
  - Full amplifier circuit made at once in a single package
- Most common of these called 741 series
- In course treat as a black box:
  - Ignore internal operation: only look at outside behaviour

![Operational Amplifier Diagram]
741 Op Amp

Figure 2.39 Microphotograph of an integrated circuit that makes use of several diffused resistor patterns. A 4 kΩ resistor is indicated by the arrow. (Courtesy Signetics Corp.)
Ideal Operational Amplifiers

- Op amps act as an ideal amplifier
- But only over limited input range
- Have two signal inputs: $v_p$ and $v_n$ (note often $v_+$ and $v_-$)
- Signal is applied between them (differential input)
- Voltage powering device limits operation:
  - Positive powering voltage $V_{CC}$
  - Negative powering voltage $V_{EE}$
- Note often, but not always $V_{EE} = -V_{CC}$
- Text only discusses that condition
- Symbol simple triangle (power input often omitted)
Ideal Operational Amplifiers Behaviour

- Ideal op amp has infinite input resistance
- Thus draws no current from input signal
- Has 3 areas of operation which affect the output $v_o$

**Linear Region**
- Output linearly related to input
  \[ v_o = A_0(v_p - v_n) \quad \text{for} \quad V_{EE} < A_0(v_p - v_n) \lor V_{CC} > A_0(v_p - v_n) \]

**Positive Saturation**
- Output saturated at positive power $V_{CC}$
  \[ v_o = V_{CC} \quad \text{for} \quad A_0(v_p - v_n) > V_{CC} \]

**Negative Saturation**
- Output saturated at negative power $V_{EE}$
  \[ v_o = V_{EE} \quad \text{for} \quad A_0(v_p - v_n) < V_{EE} \]

- Note: output can be both positive and negative
- Typical gain numbers $A_0 = 200,000$
- Ideal op amp, assume gain nearly infinite
- Thus negligible voltage across input
- In course only consider the linear region

![Diagram showing the three regions of operation for an ideal operational amplifier: linear, positive saturation, and negative saturation.](image-url)
Feedback and Op Amplifiers

- Adding resistors to op amp can control the gain
- Gain controlled by **Feedback**: Feeding output back into input
- **Negative Feedback**: output subtracts input signal
- **Positive Feedback**: output adds to input signal
- Note positive feedback generally less stable
- Need to create balance point between output value and op amp
- SP = summing point, where output and input signals sum
- Different op amp circuits use different feedbacks

![Op Amp Circuit Diagram](image-url)
Inverting Op Amplifier

- Adding resistors to op amp can control the gain
- Gain controlled by "Feedback":
- Feeding input back into output
- This circuit gives negative gain:
- Called Inverting op amp

- SP = summing point, where output and input signals sum
Inverting Op Amplifier

- Place a feedback resistor $R_f$ from op amp output to positive input
- The $R_s$ between the setpoint and input $V_s = V_{in}$
- Allows current to flows from input and output to SP
- This circuit gives negative gain:
- Increases signal but makes it negative
- Called Inverting op amp
Inverting Op Amplifier

- Putting the input into $v_n$ gives negative gain
- Output becomes the opposite polarity to input
\[ V_{sp} = 0 \quad I_s = 0 \]

- Thus SP = a virtual ground
- In practice has small voltage offset
\[ V_s = V_i = V_{in} \]
\[ I_s = I_i = \frac{V_{in}}{R_s} = I_{in} \]
Inverting Op Amplifier Gain equations

- Virtual ground requires $V_f$ to reverse relative to $V_{in} = V_s$

$$I_s = I_f = \frac{V_s}{R_s} = \frac{V_{out}}{R_f}$$

$$V_{out} = V_f = I_f R_f = -V_s \frac{R_f}{R_s}$$

- The amplification (or gain) is:

$$A_v = \frac{V_o}{V_s} = -\frac{R_f}{R_s}$$