Electronics Reference

Kaedon Cleland-Host

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Contents

Chapter 1

General Components

Definition 1.0.1. Electric Field force per unit charge or N/C

Definition 1.0.2. Voltage or *Potential* is the change in energy per unit charge brought on by traveling through an electric field or J/C or simply V

Remark. The units N/C is equivalent to V/m

Definition 1.0.3. Power can be derived from units of current and voltage for the following formula where P is power(W), V is voltage(V), and I is current(A).

$$P = VI \tag{1.0.1}$$

Law 1.0.1. Ohms Law models the voltage drop across a purely resistive load with the following formula where V is voltage(V), I is current(A), and R is resistence(Ω).

$$V = IR \tag{1.0.2}$$

Definition 1.0.4. A **Resistor** a device that will produce a voltage drop according to ohms law with a resistance as V/A

Definition 1.0.5. Resistivity($\Omega\,$m) is used to calculate how much resistance we expect from a material use the following formula where R is resistence(Ω), ρ is **Resistivity**($\Omega\,$m), l is length(m), and A is cross sectional area(m^2).

$$R = \rho\frac{l}{A} \tag{1.0.3}$$

Law 1.0.2. Kirchoff's Voltage Law states precisely that the algebraic sum of all voltages around a closed path is zero.

$$\sum V_n = 0 \tag{1.0.4}$$

Law 1.0.3. Kirchoff's Current Law states precisely that the algebraic sum of all currents entering a node is zero.

$$\sum I_n = 0 \tag{1.0.5}$$

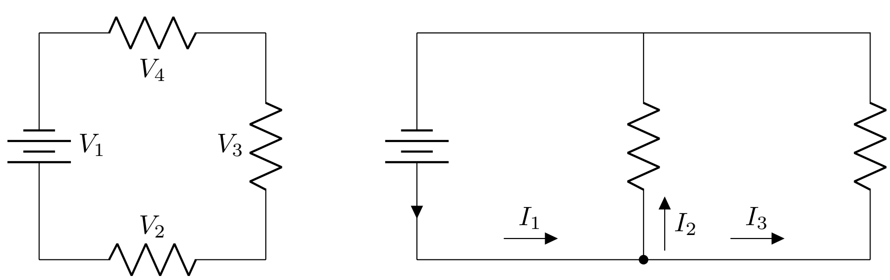
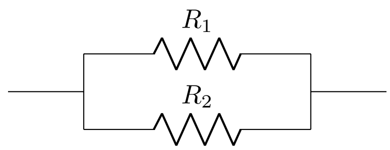


Figure 1.1: Two circuits to demonstrate Krichhoff's Laws

Law 1.0.4. Resistors in Series will simply be the sum of the individual resistance because we are adding the length of the resistors together.

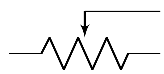
$$R_T = \sum R_i \tag{1.0.6}$$

Law 1.0.5. Resistors in Parallel will decrease the overall resistance as indicated by the definition of resistivity 1.0.5.

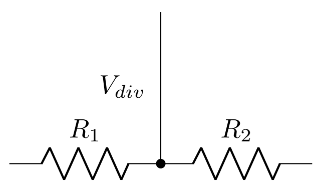


$$\frac{1}{R_T} = \sum \frac{1}{R_i} \tag{1.0.7}$$

Definition 1.0.6. Voltage Divider or **Potentiometer** is a arangement of two resistors with a connection between them. A potentiometer refers to a voltage divider where the resistance ratio between the two resistors can be adjusted.



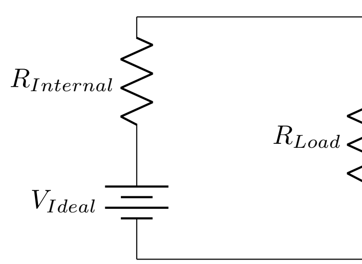
To calculate the voltage we expect at the divider we need to know the voltage across the whole potentiometer V and the ratio between the two resistors $\frac{R_2}{R_1}$.



$$V_{div} = V \frac{R_2}{R_1 + R_2} \tag{1.0.8}$$

Definition 1.0.7. Ideal Battery - a battery that always produces the same potential difference.

Definition 1.0.8. Real Battery - a battery with some internal resistance that reduces the potential difference across the terminals depending on the amount of current.

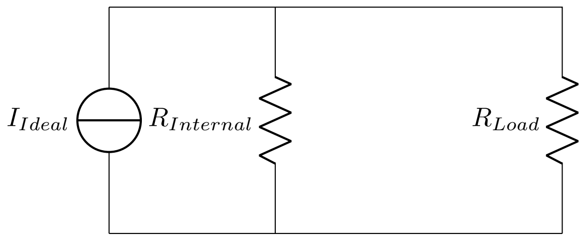


$$V_{Real} = V_{Ideal} - IR_{Internal}$$

$$V_{Real} = V_{Ideal} \frac{R_{Load}}{R_{Internal} + R_{Load}} \tag{1.0.9}$$

Definition 1.0.9. Ideal Current Source - a device that always provides that same current to a load.

Definition 1.0.10. Real Current Source - a current source with an internal resistance connected in parallel that reduces the current produced when the load resistance is high.



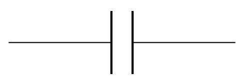
$$I_{Real} = I_{Ideal} - \frac{V}{R_{Internal}}$$

$$I_{Real} = I_{Ideal}\frac{R_{Internal}}{R_{Internal} + R_{Load}} \tag{1.0.10}$$

Definition 1.0.11. A **Capacitor** is a device that accumulates a charge q when a voltage v is applied with a proportionality constant C with units $\mathrm{F(farad)} = \mathrm{C\,V^{-1}} = \mathrm{C^2\,J^{-1}}$

$$q = Cv \tag{1.0.11}$$

$$i = C\frac{dv}{dt} \tag{1.0.12}$$



Remark. The energy stored in a capacitor can derived by integrating power over time:

$$\omega_C = \frac{1}{2}Cv^2 \tag{1.0.13}$$

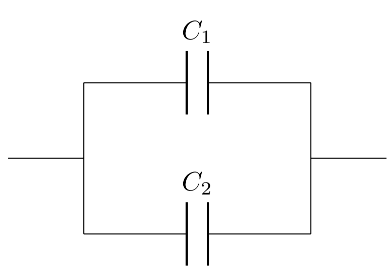
Definition 1.0.12. A **Plate Capacitor** is a capacitor made of two conductive plates with area A separated by distance l.

$$C = \frac{\varepsilon_0 \kappa A}{l}$$

Law 1.0.6. Capacitors in Series will decrease the overall capacitance.

$$\frac{1}{C_T} = \sum \frac{1}{C_i} \tag{1.0.14}$$

Law 1.0.7. Capacitors in Parallel is simply the sum of the individual capacitance.



$$C_T = \sum C_i \tag{1.0.15}$$

Definition 1.0.13. An **Inductor** is a device which accumulates a magnetic flux $\phi = BA$ when a current is applied with a proportionality constant L with units H(henry) $= \mathrm{J\,A^{-2}}$

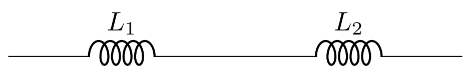
$$\phi = Li \tag{1.0.16}$$

$$v = L\frac{di}{dt} \tag{1.0.17}$$

Remark. The energy stored in an inductor can derived by integrating power over time:

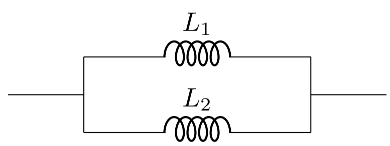
$$\omega_L = \frac{1}{2}Li^2 \tag{1.0.18}$$

Law 1.0.8. Inductors in Series is simply the sum of the individual inductance.



$$L_T = \sum L_i \tag{1.0.19}$$

Law 1.0.9. Inductors in Parallelwill decrease the overall inductance.



$$\frac{1}{L_T} = \sum \frac{1}{L_i} \tag{1.0.20}$$

1.1 RC and RL Circuits

Definition 1.1.1. Charging RC Circuit is a circuit with a resistor, capacitor and voltage source to charge the capacitor. The voltage equation around the loop can be written as

$$V = Ri + \frac{1}{C}\int_0^t i(\sigma)d\sigma$$

$$i(t) = \frac{V}{R}e^{-t/RC}$$

$$v_c(t) = V(1 - e^{-t/RC})$$

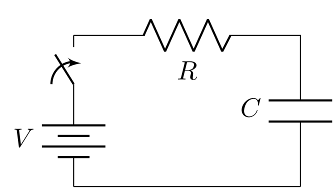


Figure 1.2: a basic RC circuit in the charging arrangement

Definition 1.1.2. Discharging RC Circuit is a circuit with a capacitor and resistor to discharge the capacitor. The current relation during discharge is symmetric to charge so we can rewrite the equations

$$i(t) = \frac{V}{R}(1 - e^{-t/RC})$$

$$v_c(t) = Ve^{-t/RC}$$

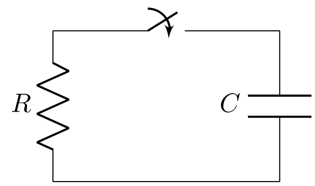


Figure 1.3: a basic RC circuit in the discharging arrangement

Definition 1.1.3. Charging RL Circuit is a circuit with a resistor, inductor and voltage source to charge the inductor. The current equation can be written as

$$i(t) = \frac{V}{R}(1 - e^{-tR/L})$$

$$v_l(t) = Ve^{-tR/L}$$

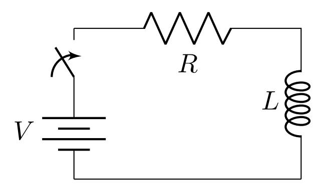


Figure 1.4: a basic RL circuit in the charging arrangement

Definition 1.1.4. Discharging RL Circuit is a circuit with a inductor and resistor to discharge the inductor. The current relation during discharge is symmetric to charging so we can rewrite the equations

$$i(t) = \frac{V}{R}e^{-tR/L}$$

$$v_l(t) = Ve^{-tR/L}$$

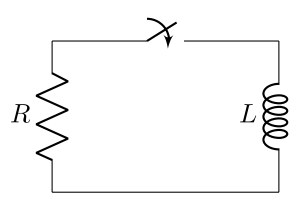


Figure 1.5: a basic RL circuit in the discharging arrangement

Chapter 2

AC Circuits

Definition 2.0.1. An AC Voltage source is a voltages source with a alternating voltage. Typically the voltage changes according to the following function:

$$V(t) = V_p \sin(\omega t)$$

Definition 2.0.2. Effective Voltage or **Root Mean Square Voltage** is the voltage $V_p/\sqrt{2}$ where V_p is the peak sinusoidal voltage. This represents the DC voltage that would produce the same power draw as the AC voltage.

Example. **Resistor in AC Circuit** Bellow is a AC Circuit with a resistor. The current is determined by the following function

$$i(t) = \frac{V_p}{R} \sin \omega t$$

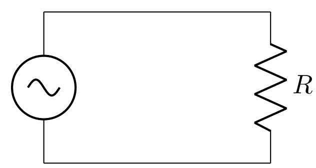


Figure 2.1: a basic AC circuit connected to a resistive load

Definition 2.0.3. Effective Current or **Root Mean Square Current** is the current $I_p/\sqrt{2}$ where I_p is the peak sinusoidal current. This represents the DC current that would produce the same power draw as the AC current.

Example. **Capacitor in AC Circuit** Bellow is a AC Circuit with a capacitor. The current is determined by the following function

$$i(t) = -\omega C V_p \sin \omega t$$

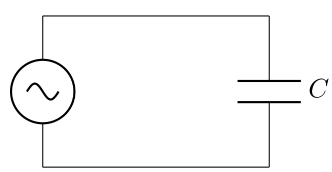


Figure 2.2: a basic AC circuit connected to a capacitive load

Definition 2.0.4. A Phasor Signal is a complex number that we use to represent the output of a wavelike function.

$$Re^{i\theta} = R\cos(\theta) + Ri\sin(\theta)$$

Law 2.0.1. To convert froma phasor signal to the observed signal the following formula applies where $x(t)$ si the observed signal and c is the complex phasor signal.

$$x(t) = Real(c \cdot e^{i\omega t})$$

Law 2.0.2. Generalized Ohm's Law is the complex version of ohm's law that includes complex impedance.

$$\tilde{V} = \tilde{I}\tilde{Z}$$

$$\tilde{Z} = R + iX$$

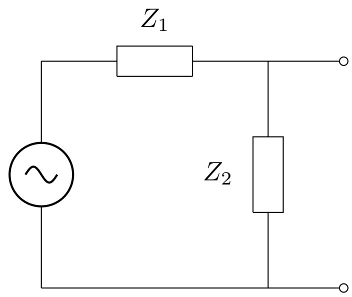
Where R is circuit resistance and X is circuit reactance.

Example. **Impotence of basic components**:

- **Resistor** $\tilde{Z} = \frac{\tilde{V}}{\tilde{I}} = R$
- **Capacitor** $\tilde{Z} = \frac{\tilde{V}}{\tilde{I}} = \frac{1}{i\omega C}$
- **Inductor** $\tilde{Z} = \frac{\tilde{V}}{\tilde{I}} = i\omega L$

Law 2.0.3. Generalized Voltage Divider is the complex version of the voltage divider formula that includes complex impedance.

$$\tilde{V_{out}} = \tilde{V_{in}} \frac{\tilde{Z}_2}{\tilde{Z}_1 + \tilde{Z}_2}$$



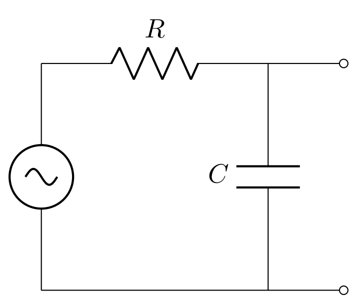
2.1 AC Filters

Definition 2.1.1. A **Low Pass Filter** is a circuit that allows low frequency signals through, but blocks out higher frequency signals.

$$\tilde{V_{out}} = \tilde{V_{in}} \frac{1}{1 + i\omega RC}$$

$$V_{out} = V_{in} \frac{1}{\sqrt{1 + (\omega RC)^2}}$$

$$\phi = \tan(-\omega RC)$$

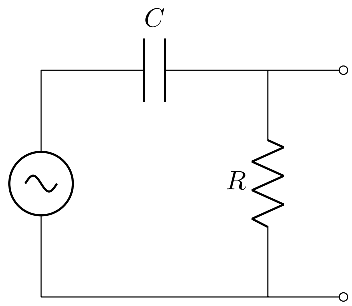


Definition 2.1.2. A **High Pass Filter** is a circuit that allows high frequency signals through, but blocks out lower frequency signals.

$$\tilde{V_{out}} = \tilde{V_{in}}\frac{1}{1-\frac{i}{\omega RC}}$$

$$V_{out} = V_{in}\frac{1}{\sqrt{1+(\frac{1}{\omega RC})^2}}$$

$$\phi = \tan(\frac{1}{\omega RC})$$



Definition 2.1.3. The **Breakpoint Frequency** is the frequency of a filter that produces an inflection point on the frequency response of that circuit. For simple low and high pass filters it can be represented as the following:

$$\omega_c = \frac{1}{RC}$$

$$f_c = \frac{1}{2\pi RC}$$

Definition 2.1.4. A **Decibel** scale is used to measure a ratio that can represent very large and very small values.

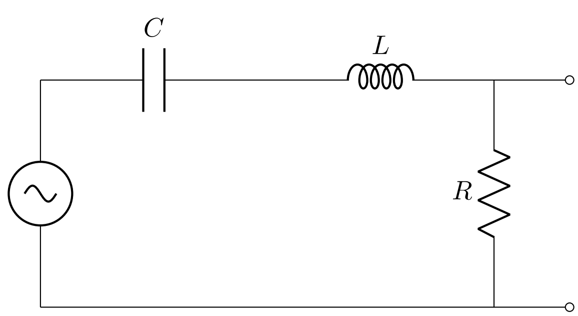
$$\text{Decibal} = 20\log_{10}(|\frac{V_{out}}{V_{in}}|) = 10\log_{10}(|\frac{P_{out}}{P_{in}}|)$$

Definition 2.1.5. A **Band Pass Filter** is a circuit that only allows mid range frequency signals through, but blocks out lower and higher frequency signals.

$$\tilde{V_{out}} = \tilde{V_{in}}\frac{1}{1-\frac{i}{\omega RC}+i\omega L}$$

$$V_{out} = V_{in}\frac{1}{\sqrt{1+(\omega\frac{L}{R}-\frac{1}{\omega RC})^2}}$$

$$\phi = \tan(\frac{1}{\omega RC}-\omega\frac{L}{R})$$



Definition 2.1.6. The **Resonance Frequency** is the frequency of resonance or max output for a band pass filter.

$$\omega_0 = \frac{1}{\sqrt{RL}}$$

$$f_0 = \frac{1}{2\pi\sqrt{RL}}$$

Definition 2.1.7. The **Band Width** is the difference between the two cutoff frequencies for a band pass filter.

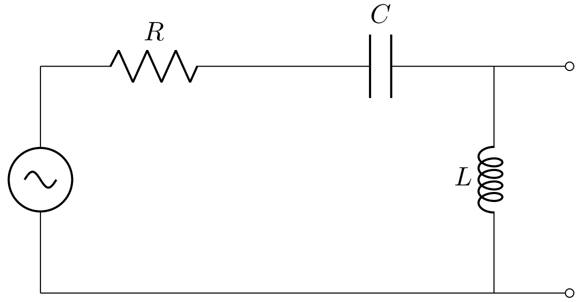
$$\omega_{c1} - \omega_{c2} = \frac{R}{L}$$

$$f_{c1} - f_{c2} = \frac{R}{2\pi L}$$

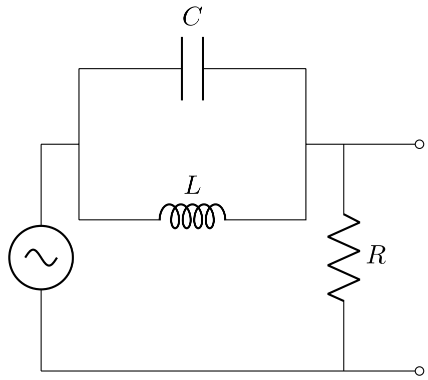
Definition 2.1.8. The **Quality Factor** is a measure of the sharpness of the resonance peak of a band pass filter.

$$Q = \frac{f_0}{f_{c1} - f_{c2}} = \frac{\omega_0}{\omega_{c1} - \omega_{c2}}$$

Example. **Resonant High Pass Filter**:



Example. **Notch Filter**:

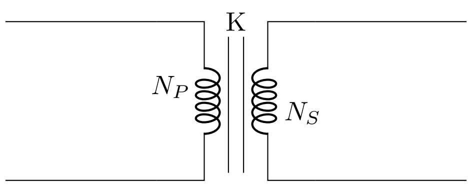


2.2 Transformers

Definition 2.2.1. A **Transformer** is a primary and secondary connected by a ferromagnetic core such that the primary coil induces voltage in the secondary.

$$\frac{V_S}{V_P} = \frac{V_S}{V_P}$$

$$\frac{I_S}{I_P} = \frac{V_P}{V_S}$$



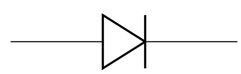
Chapter 3

Silicon-based Components

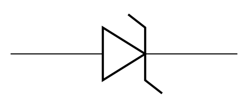
Definition 3.0.1. N-type silicon is silicon doped with an element like Phosphorous which produces free electrons in the material.

Definition 3.0.2. P-type silicon is silicon doped with an element like Boron which produces electron holes in the material.

Definition 3.0.3. A **Diode(PN Junction)** is a device that has a very low resistance for current in one direction but a very high resistance for current in the other direction.



Definition 3.0.4. A **Zener Diode** is a diode with extremely high doping that operates like a standard diode in the forward direction, but in a situation of very high (4-500V) reverse potential the diode very quickly becomes conducting without damage.



Definition 3.0.5. Half Bridge Rectifier is a diode that converts alternating current into directed current with changing magnitude. A capacitor is often included across the output leads to smooth out the output. The two following equation model the output voltage and ripple voltage of a full bridge rectifier.

$$V_{out} = V_s - (D_v)$$

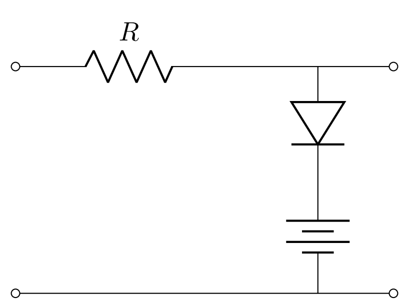
$$\Delta V = \frac{V_o ut}{f R_L C}$$

Definition 3.0.6. Full Bridge Rectifier is a system of diodes that converts alternating current into directed current with changing magnitude. A capacitor is often included across the output leads to smooth out the output. The two following equation model the output voltage and ripple voltage of a full bridge rectifier.

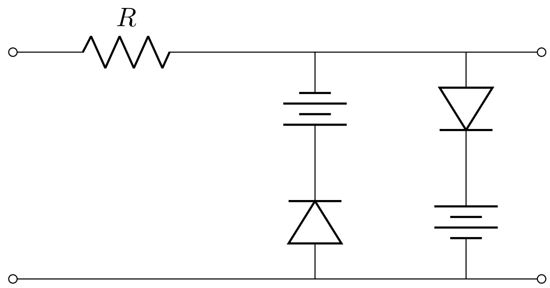
$$V_{out} = V_s - 2(D_v)$$

$$\Delta V = \frac{V_o ut}{2 f R_L C}$$

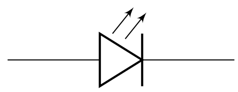
Definition 3.0.7. Half Bridge Diode Clamp - limits the positive voltage using a battery and a diode. The voltage cannot rise higher than the voltage of the battery plus the activation voltage of the diode.



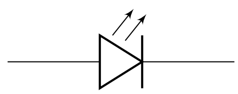
Definition 3.0.8. Full Bridge Diode Clamp - limits the positive and negative voltage using batteries and diodes. The voltage cannot rise higher or lower than the voltage of the battery plus the activation voltage of the diode.



Definition 3.0.9. A **Photo-diode** is a component made by a pin-junction that works like a normal diode unless it is exposed to light. When exposed to light it allows current in the reverse direction.

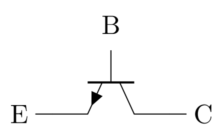


Definition 3.0.10. A **Light emitting diode** is a diode made with a direct bandgap semiconductor that converts some of the energy used in it's voltage drop to produce light.



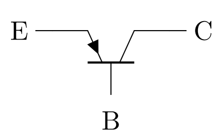
Definition 3.0.11. A **NPN Transistor** is an active component with three contacts on n-type, p-type, and n-type semiconductors. α represents the ratio between the collector current and the current through the emitter. β represents the ratio between the collector current and the base current. β is usually large which allows a very small current to create a very large current through the collector.

$$I_E = I_B + I_C$$
$$\beta = \frac{\alpha}{1-\alpha}$$
$$I_C = \alpha I_E$$
$$I_C = \beta I_B$$



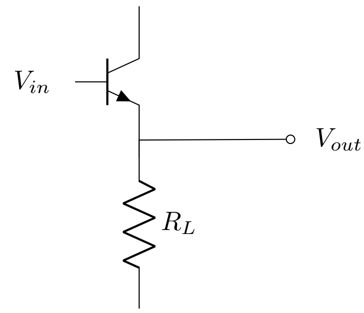
Definition 3.0.12. A **PNP Transistor** is an active component with three contacts on p-type, n-type, and p-type semiconductors. A PNP is identical to the NPN transistor but the current flows in the opposite direction.

$$I_E = I_B + I_C$$
$$\beta = \frac{\alpha}{1-\alpha}$$
$$I_C = \alpha I_E$$
$$I_C = \beta I_B$$



Example. **Emitter-follower circuit** is a circuit that uses a transistor to apply the same voltage as the the base to a load at the emitter but at a much higher current.

$$V_{out} = V_{in} - 0.6$$



Example. **Common Emitter Amplifier circuit** is a circuit that uses a transistor to an resistor network to amplify a voltage.

$$V_{out} = V_{cc} - R_c I_c$$

$$V_B = V_E + 0.6$$

$$I_E = I_B + I_C$$

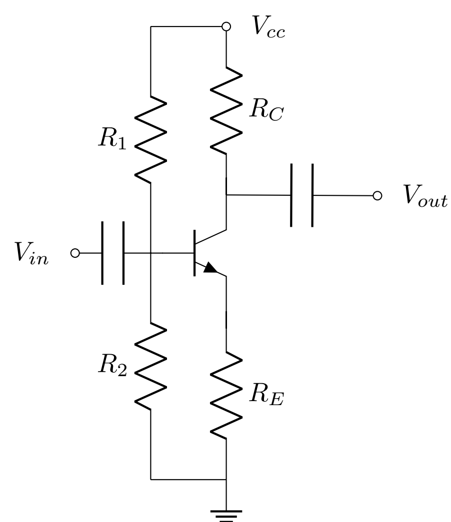
$$\frac{\Delta V_{out}}{\Delta V_{in}} = -\frac{R_C}{R_E}$$

$$V_{cc} - (R_C + R_E)I_C - V_{CE} = 0$$

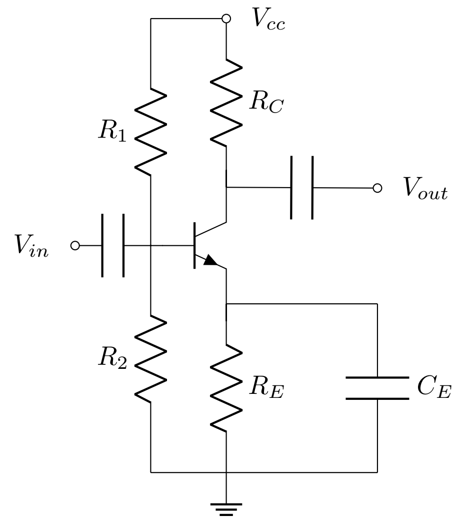
$$\bar{V_B} = (\frac{R_2}{R_1 + R_2})V_{cc}$$

$$\bar{V_C} = \frac{1}{2}V_{cc}$$

$$\frac{V_{cc}}{R_1 + R_2} = \frac{R_C}{R_E}\frac{I_C}{\beta}$$

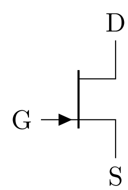


Example. **Emitter Bypass**



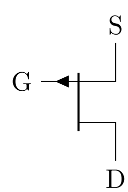
Definition 3.0.13. N-Channel Field Effect Transistor is a n-type channel with a p-type gate. The voltage on the gate determines the resistance of the channel.

$$\frac{\Delta I_D}{\Delta V_{GS}} = g_m$$



Definition 3.0.14. P-Channel Field Effect Transistor is a p-type channel with a n-type gate. The voltage on the gate determines the resistance of the channel.

$$\frac{\Delta I_D}{\Delta V_{GS}} = g_m$$



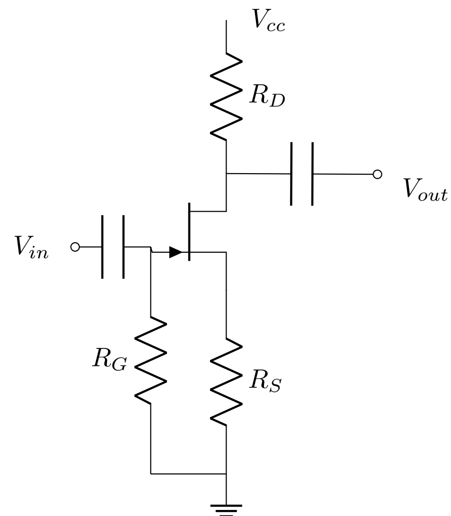
Example. **Common Source JFET Amplifier** is a circuit that uses a JFET to amplify an AC signal.

$$\bar{V_G} - \bar{V_S} = -R_S \bar{I_D}$$

$$\bar{V_S} = R_S \bar{I_D}$$

$$R_S = \frac{-(\bar{V_G} - \bar{V_S})}{\bar{I_D}}$$

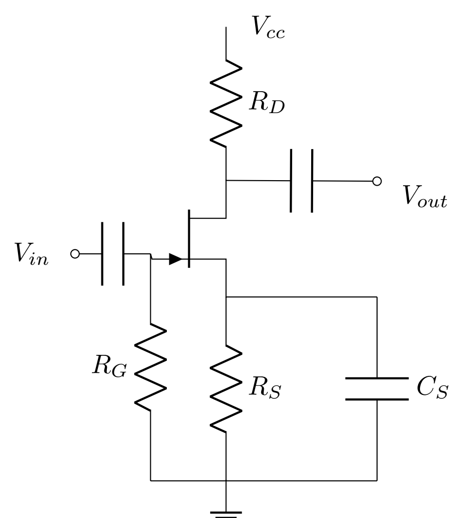
$$\frac{\Delta V_{out}}{\Delta V_{in}} = \frac{-R_D(\frac{\Delta I_D}{\Delta V_{GS}})}{1 + R_S(\frac{\Delta I_D}{\Delta V_{GS}})} = \frac{-R_D(g_m)}{1 + R_S(g_m)}$$



Example. **Common Source JFET Amplifier Source Bypass** is a circuit that uses a JFET to amplify an AC signal. The capacitor increases the gain for high frequencies.

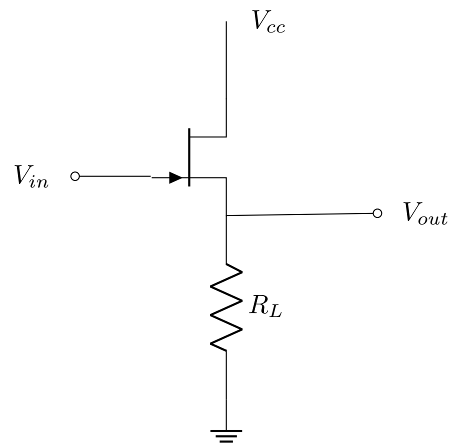
$$\frac{1}{\omega C_s} = \frac{R_S}{10}$$

$$\frac{\Delta V_{out}}{\Delta V_{in}} = -R_D g_m$$



Example. **FET follower** is a circuit that uses a JFET to following an AC input voltage. The output voltage follows the input if $R_L g_m >> 1$

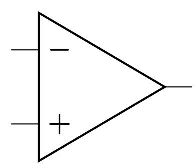
$$\Delta V_{out} = R_L g_m(\Delta V_{in} - \Delta v_{out})$$



3.1 Operational Amplifiers

Definition 3.1.1. Ideal Operational Amplifier is an amplifier with ∞ input impedance, 0 output impedance, and a gain(A) of ∞.

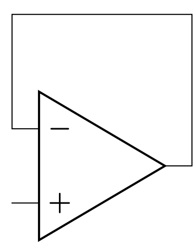
$$V_{out} = A(V_+ - V_-)$$



Example. **Operational Amplifier Follower**

$$V_+ = V_-$$

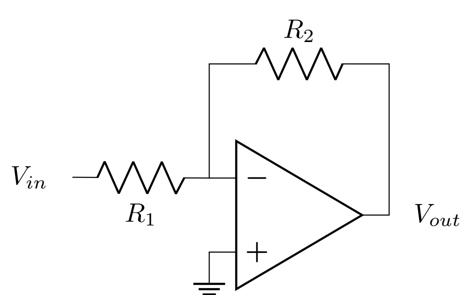
$$\frac{V_out}{V_in} = 1$$



Example. **Inverting Operational Amplifier**

$$V_+ = V_- = 0$$

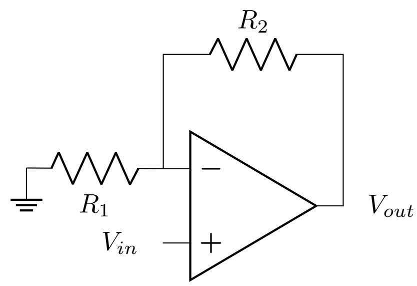
$$\frac{V_out}{V_in} = -\frac{R_2}{R_1}$$



Example. **Non-inverting Operational Amplifier**

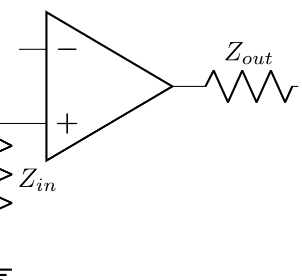
$$V_+ = V_- = V_{in}$$

$$\frac{V_out}{V_in} = \frac{R_2}{R_1}$$



Definition 3.1.2. Real Operational Amplifier is an amplifier with large input impedance, small output impedance, and a large gain(A).

$$V_{out} = A(V_+ - V_-)$$

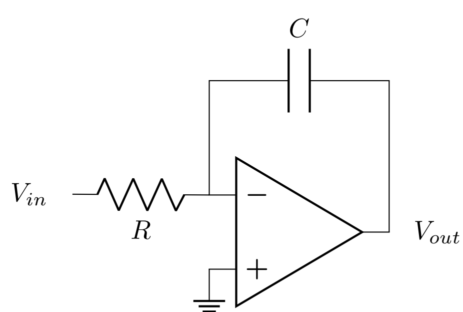


Definition 3.1.3. Slew rate represents how fast the output of an op-amp can respond to changes in the input voltage.

$$\frac{dV_{out}}{dt} = 110\,\mathrm{V\,s^{-1}}$$

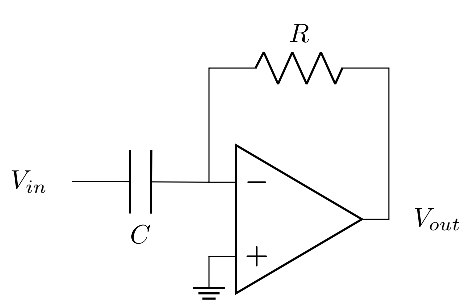
Example. **Integrator**

$$V_{out} = \frac{-1}{RC}\int V_{in} dt$$



Example. **Differentiator**

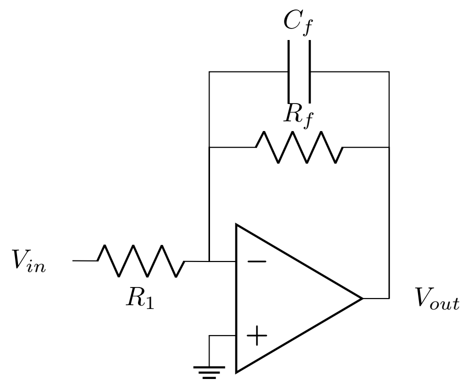
$$V_{out} = -CR\frac{dV_{in}}{dt}$$



Example. **Low-pass Filter**

$$\frac{\tilde{V_out}}{\tilde{V_in}} = -\tilde{Z}_f R_1 = -\frac{\frac{R_f}{R_1}}{1 + i\omega C_f R_f}$$

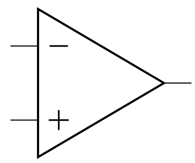
$$\omega_{bp} = \frac{1}{R_f C_f}$$



Chapter 4

Digital Circuits

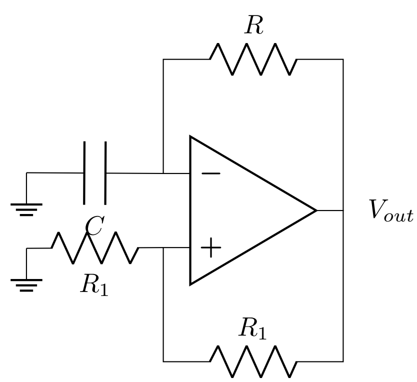
Definition 4.0.1. Comparator - if V_+ is greater than V_- then the output is V_{CC} otherwise it is $-V_{CC}$.



Example. **Timer Circuit**

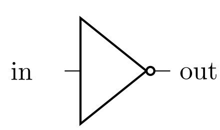
$$V_{out} = A(V_+ - V_-)$$

However V_{out} is limited by $+V_{CC}$ and $-V_{CC}$. So V_{out} is always either $+V_{CC}$ or $-V_{CC}$. The capacitor will charge until it reaches half of the output voltage and then it will start discharging until it reaches half the output voltage and the cycle continuous.



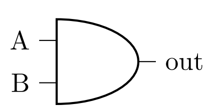
Definition 4.0.2. Inverter Takes a logical input and returns the opposite. It is constructed using a npn bipolar junction transistor.

$$\text{out} = \overline{\text{in}}$$



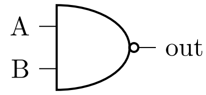
Definition 4.0.3. AND Gate Takes two logical input and returns true if and only if both inputs are true. It is constructed using two npn bipolar junction transistor in series.

$$\text{out} = A \cdot B$$



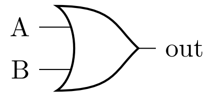
Definition 4.0.4. NAND Gate (Not AND) Takes two logical input and returns false only if and only if both inputs are true. It is constructed using two npn bipolar junction transistor in series.

$$\text{out} = \overline{A \cdot B}$$



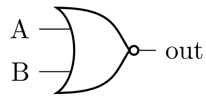
Definition 4.0.5. OR Gate Takes two logical input and returns true if and only if any of the inputs are true. It is constructed using two npn bipolar junction transistor in parallel.

$$\text{out} = A + B$$



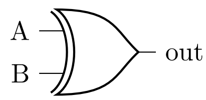
Definition 4.0.6. NOR Gate (Not OR) Takes two logical input and returns false if and only if any of the inputs are true. It is constructed using two npn bipolar junction transistor in parallel.

$$\text{out} = \overline{A + B}$$



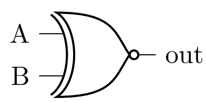
Definition 4.0.7. XOR Gate (eXclusive OR) Takes two logical input and returns true if and only if exactly one of the two inputs is true. It is constructed using bipolar junction transistors.

$$\text{out} = (A + B) \cdot (\overline{A} + \overline{B})$$



Definition 4.0.8. XNOR Gate (eXclusive NOR) Takes two logical input and returns false if and only if exactly one of the two inputs is true. It is constructed using bipolar junction transistors.

$$\text{out} = (A \cdot B) + (\overline{A} \cdot \overline{B})$$



Theorem 4.0.1. Commutative Property of Boolean Algebra

$$A \cdot B = B \cdot A$$

$$A + B = B + A$$

Theorem 4.0.2. Associative Property of Boolean Algebra

$$(A \cdot B) \cdot C = A \cdot (B \cdot C)$$

$$(A + B) + C = A + (B + C)$$

Theorem 4.0.3. Distributive Property of Boolean Algebra

$$A \cdot (B + C) = A \cdot B + A \cdot C$$

$$A + (B \cdot C) = (A + B) \cdot (A + C)$$

Theorem 4.0.4. Absorption Theorem

$$A \cdot (A + B) = A$$

$$A + (A \cdot B) = A$$

Theorem 4.0.5. Demorgan's Theorems

$$\overline{A \cdot B} = \overline{A} + \overline{B}$$

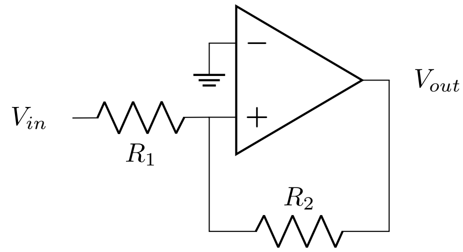
$$\overline{A + B} = \overline{A} \cdot \overline{B}$$

Definition 4.0.9. Schmitt Trigger - is a component of a gate that reduces noise in the undefined section of a gates output(in between 1 and 0). As long as the noise is within the range $[\frac{R_1}{R_2}(-V_{cc}), \frac{R_1}{R_2}(+V_{cc})]$.

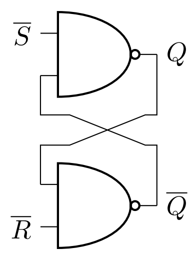
$$V_+ = \frac{V_{out}R_1 + V_{in}R_2}{R_1 + R_2}$$

$$V_{in} < \frac{R_1}{R_2}(-V_{cc}) \Rightarrow V_{out} = -V_{cc}$$

$$V_{in} > \frac{R_1}{R_2}(+V_{cc}) \Rightarrow V_{out} = +V_{cc}$$



Definition 4.0.10. RS flip-flop is a circuit of gates that can store a bit of information.



Definition 4.0.11. Data flip-flop is a circuit of gates that can store a bit of information with a ciruit to allow for a single input that reads according to a clock cycle. If the clock input is 0 then the state of the flip flop cannot be changed.