Part 1: Analog Circuits

Principles

Ohm's Law:

$$V = IR \qquad P = VI = I^2R = \frac{V^2}{R}$$

Resistors and Capacitors: Parallel vs. Series:

$$R_{\text{series}} = R_1 + R_2 \qquad R_1||R_2 = \left(\frac{1}{R_1} + \frac{1}{R_2}\right)^{-1}$$

$$C_1||C_2 = C_1 + C_2 \qquad C_{\text{series}} = \left(\frac{1}{C_1} + \frac{1}{C_2}\right)^{-1}$$

Capacitors and RC Charging/Discharging:

$$C = \frac{Q}{V} \qquad C = \frac{\epsilon_r \epsilon_0 A}{D}$$

$$\textit{Permittivity of Free Space: } \epsilon_0 = 8.854 \times 10^{-12} F/m$$

$$\textit{Energy stored: } E_C = \frac{1}{2}CV^2$$

$$\textit{Charging: } V_C = V_{in}\left(1 - e^{-t/\tau}\right)$$

$$\textit{Discharging: } V_C = V_0 e^{-t/\tau}$$

Voltage and Current Dividers:

$$V_2 = V_1 \frac{Z_2}{Z_1 + Z_2} \qquad I_{R_1} = I_T \frac{R_2}{R_1 + R_2}$$

Methods & Tools

Thevenin Equivalence

R_{th}: Remove load, short voltage sources, and open current sources. Find resistance which the load sees.

V_{th}: Remove load and find open-circuit voltage.

Norton Equivalence

$$R_{nor} = R_{th} \qquad V_{th} = I_{nor}R_{nor}$$

Fourier Transforms

$$\textit{Continuous Domain: } V(\omega) = \int_{-\infty}^{\infty} v(t) e^{-j\omega t} dt$$

$$v(t) = a_0 + \sum_{i=1}^{\infty} [a_i \cos(\omega_i t) + b_i \sin(\omega_i t)]$$

$$a_i = \frac{2}{T}\int_0^T v(t)\cos(\omega_i t) dt \qquad b_i = \frac{2}{T}\int_0^T v(t)\sin(\omega_i t) dt$$

Common component Fourier-Domain Impedances:

$$Z_R(\omega) = R \qquad Z_C(\omega) = \frac{1}{j\omega C} \qquad Z_L = j\omega L$$

- Capacitor: Voltage lags current by 90°
- Inductor: Voltage leads current by 90°

Power

Transformers

Faraday's Law: $V = -N\frac{\mathrm{d}}{\mathrm{d}t}[B \cdot A]$

$$\Rightarrow V_s = \frac{N_s}{N_p}V_p \qquad I_s = \frac{N_p}{N_s}I_p$$

Zener Diodes

Dynamic resistance: $\frac{\Delta V}{\Delta I} = R_{DYN}$

Linear Regulators (LM317)

$$V_{out} = 1.25\left(1 + \frac{R_2}{R_1}\right)$$

AC/DC Converters: Linear

Main components:

- Transformer adjusts AC voltage
- Diode bridge rectifies the signal
- Capacitor smooths DC
- Linear regulator gives final cleaned output

AC/DC Converters: Switching

Main components:

- Diode bridge rectifies 60 Hz AC voltage
- Capacitor smooths DC
- Switch (controlled by feedback loop) adjusts voltage with PWM and switches at a much higher frequency
- Transformer acts on this new higher frequency AC
- Cleaned by another capcitor and linear regulator

Main advantages: higher switching frequency → smaller transformer (Faraday's Law); more efficient.

DC/DC Converters

- Buck Converter: Step Down
- Boost Converter: Step Up
- Buck/Boost: Inverting, Step Up or Down

Main takeaways:

- Very efficient — no intentionally dissipative components
- Switching devices → the output will always have some noise

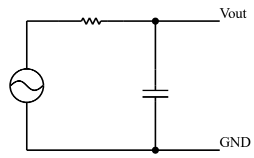
Filters

Cutoff frequency ω_0 is defined such that:

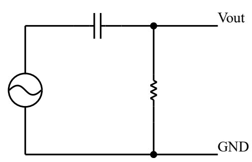
$$\omega_0 = \frac{1}{RC} \qquad \rightarrow \qquad |H(\omega_0)| = \frac{1}{\sqrt{2}}$$

Passive

Low-Pass Filter:

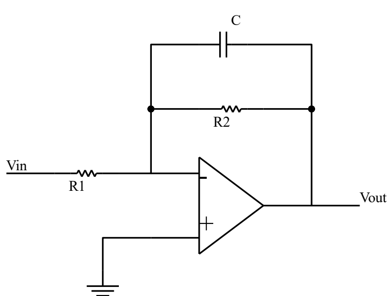


High-Pass Filter:

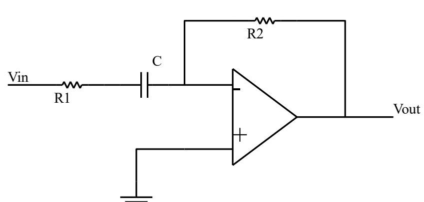


Active (Inverting Topologies)

Low-Pass Filter:



High-Pass Filter:

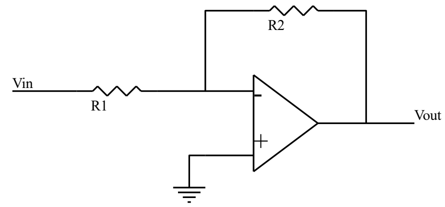


Amplifier Circuits

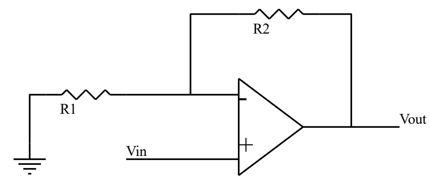
Golden Rules:

- **Golden Rule 1:** $I_{in} \rightarrow 0$
- **Golden Rule 2:** $V_A = V_B$

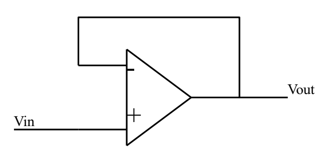
$$\textit{Inverting Amplifier: } H(\omega) = \frac{-R_2}{R_1}$$



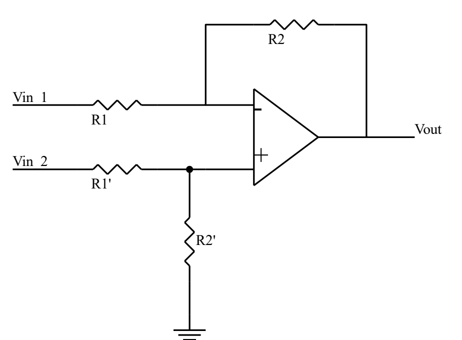
$$\textit{Non-inverting Amplifier: } H(\omega) = 1 + \frac{R_2}{R_1}$$



$$\textit{Buffer (Voltage Follower): } V_{out} = V_{in}$$



$$\textit{Difference Amplifier: } V_{out} = (V_2 - V_1)\frac{R_2}{R_1}$$



Part 2: Digital and Communications

Key topics:

- Binary. octal, and hexadecimal number systems
- ADCs quantize signal amplitude and sample in discrete time

Types of ADCs (increasing speed, decreasing precision):

1. Integrating
2. Sigma Delta
3. Successive Approximation
4. Subranging
5. Flash

Aliasing equation:

$$f_{\text{signal}} = |f_0 \pm N f_s|$$

where f_{signal} is the true signal frequency, f_0 is the apparent (measured) frequency, and f_s is the sampling frequency.

Serial Communications

Types of directional transmission:

- Simplex: data flows in one direction
- Half duplex: data can flow in either direction, but only in one direction at a time
- Full duplex: data flows in both directions simultaneously

RS-232 Data Frame:

1. Start bit (0)
2. Data bits, starting with LSB
3. Parity bit (optional)
4. Stop bit(s)

Serial Port Parameter Shorthand:

$$\overbrace{9600}^{\text{buad rate}} - \overbrace{8}^{\text{data bits}} - \overbrace{\text{E}}^{\text{parity}} - \overbrace{1}^{\text{stop bits}}$$

Combinatorial Logic

DeMorgan's Law:

$$\overline{AB} = \overline{A} + \overline{B} \qquad \overline{A+B} = \overline{A}\ \overline{B}$$

AND OR NAND NOR NOT XOR

Sequential Logic

Half-adder:

Full-adder:

SR Latch (NAND):

$\bar{S}$	$\bar{R}$	Q	$\bar{Q}$	Condition
0	0	1	1	Race
0	1	1	0	Set
1	0	0	1	Reset
1	1	Q	$\bar{Q}$	Hold

D Latch:

D	Q	$\bar{Q}$	Mode
0	0	1	Reset
1	1	0	Set

JK Flip-Flop:

J	K	Q	$\bar{Q}$	Condition
0	0	Q	$\bar{Q}$	Hold
0	1	0	0	Reset
1	0	0	0	Set
1	1	$\bar{Q}$	Q	Toggle

Wireless Communications

Frequency mixing:

- Euler Identity: $\cos(\omega_0 t) = \frac{1}{2}\left(e^{j\omega_0 t} + e^{-j\omega_0 t}\right)$
- Multiply two sine waves $\rightarrow f = f_1 \pm f_2$ (half amplitude)
- Add two sine waves $\rightarrow$ both frequencies are present
- Basic AM: $S(t) = B[1 + M \cdot x(t)]\cos(2\pi f_c t)$
- Diode mixers can do mediocre AM by rectifying the sum of the signals
- Basic FM: $S(t) = B\cos\left[2\pi f_c t + \frac{f_\delta}{f_m}\cos(2\pi f_m t)\right]$
- FM Bandwidth (Carson's Rule): $BW \approx 2(f_\Delta + f_m)$

Antennas

Transmission and Reception

Antenna gain:

$$G = 4\pi\eta\frac{A_{\text{phys}}}{\lambda^2} = 4\pi\frac{A_e}{\lambda^2} = \eta\left(\frac{\pi D}{\lambda}\right)^2 \qquad \lambda = \frac{c}{f}$$

(Approximate) antenna beamwidth (half-power):

$$G\theta^2 \approx 4\pi\eta\left(\frac{180}{\pi}\right)^2 \approx \eta 41,253 \text{ deg}^2$$

Transmitter Irradiance:

$$I(R) = \frac{P_t L_t G_t}{4\pi R^2} = \frac{\text{EIRP}}{4\pi R^2}[\text{W/m}^2]$$

Received power (Friis equation):

$$P_r = I(R)\cdot A_e \qquad \rightarrow \qquad P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi R)^2}$$

Alternate form — Space Loss:

$$L_s = \left(\frac{\lambda}{4\pi R}\right)^2 \qquad \rightarrow \qquad P_r = P_t G_t L_t G_r L_s$$

Noise

$$T_{ant} = \eta T_{ext} + (1-\eta)T_{phys}$$

Noise Factor (F, linear) and Noise Figure (NF, dB):

$$F = 1 + \frac{T_{Rx}}{T_0} \qquad NF = 10\log_{10}(F)$$

Total System Noise:

$$T_{sys} = T_{ant} + \frac{T_{cable}}{L} + \frac{T_{Rx}}{L}$$

Noise Power Density (N_O, [W/Hz]) and Noise Power (N, [W]):

$$N_O = kT_{sys} \qquad N = KT_{sys}B$$

$$P_{signal} = \frac{P_t L_t G_t G_r L_{atm}\lambda^2}{(4\pi R)^2} = \text{EIRP}\cdot G_r L_{atm} L_s$$

$$\text{SNR} = \frac{P_{signal}}{N_O B} = \frac{C}{N_O}\frac{1}{R}$$

$$\text{Factor of Merit} = \text{FOM} = \frac{G_r}{T_{sys}}$$

$$\text{SNR} = \frac{1}{k}\cdot\text{EIRP}\cdot\text{FOM}\cdot(L_{atm}L_s)\cdot\frac{1}{R}$$

Digital $\rightarrow$ SNR$=\frac{E_b}{N_O}$:

$$\text{SNR}_{min} = \frac{C}{N_O}[dB] - 10\log_{10}(R) + RDM$$

Link margin = actual SNR - minimum SNR

Carter Mak
ASEN 3300
Final Exam
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