Reference sheet: PS203

$$
\begin{aligned}
V &= I \times R \\
R_{series} &= R_1 + R_2 + R_3 + \cdots \\
\frac{1}{R_{parallel}} &= \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots \\
C_{parallel} &= C_1 + C_2 + C_3 + \cdots \\
\text{Power} \quad P &= V \times I = I^2 \times R = \frac{V^2}{R} \text{ watts} \\
\text{Power ratio} &= 10 \log\left(\frac{P_{out}}{P_{in}}\right) = 20 \log\left(\frac{V_{out}}{V_{in}}\right)
\end{aligned}
$$

$$
\begin{aligned}
\omega &= 2\pi f \\
T &= \frac{1}{f} \\
V &= V_0 \sin(2\pi f t + \phi) \\
I &= I_0 \sin(2\pi f t + \phi) \\
V_{Amplitude} &= 1.4 \times V_{RMS} \\
V_{Peak-to-Peak} &= 2 \times V_{Amplitude} \\
\text{Air core} \quad L(\text{nH}) &= \frac{N^2 d^2}{0.46d + 1.02b} \\
\text{Ferrite core} \quad L(\text{nH}) &= N^2 A_L \\
Z_R &= R \quad \text{for resistance} \\
Z_C &= \frac{1}{j\omega C} \quad \text{for capacitor} \\
Z_L &= j\omega L \quad \text{for inductor} \\
V &= ZI \\
&= |Z|\, e^{j\phi} I \\
\text{or} \quad V_0 e^{j\omega t} &= |Z|\, I_0 e^{j(\omega t + \phi)} \\
Z &= R + jX
\end{aligned}
$$

where R is the resistance, X is the reactance.
Generalized potential divider:

$$\frac{V_{out}}{V_{in}} = \frac{Z_2}{Z_1 + Z_2} = |A|\, e^{j\phi}$$

Then $|A| =$ attenuation and $\phi =$ phase shift

$$|c| = |a + jb| = \sqrt{a^2 + b^2} \qquad \tan\phi = \frac{b}{a}$$

$$\left|\frac{1}{c}\right| = \left|\frac{1}{a + jb}\right| = \frac{1}{\sqrt{a^2 + b^2}} \qquad \tan\phi = \frac{-b}{a}$$

$$f_{corner} = \frac{1}{2\pi CR} \quad \text{or} \quad \frac{R}{2\pi L}$$

Thévenin's theorem $R_{out} = \frac{V_{out\ open\ circuit}}{I_{out\ short\ circuit}}$

Principle of superposition: Replace voltage sources by short circuits and current sources by open circuits.

Semiconductor equation:

$$n \times p = n_i^2 = \text{constant for constant } T$$

Current through a pn diode junction is:

$$
\begin{aligned}
I &= I_0\left(\exp\left(\frac{eV}{kT}\right) - 1\right) \\
&\approx I_0 \exp\left(\frac{V}{25\text{ mV}}\right) \\
\frac{kT}{e} &= 25\text{ mV}
\end{aligned}
$$

Voltage across diode is:

$$V = V_k + I \times R_B$$

where $V_k = 0.7$ V for Si, 0.3V for Ge.

$$R_{dyn} = \frac{dV}{dI} = \frac{25\text{ mV}}{I}$$

Ripple voltage of rectified and smoothed AC is:

$$\frac{I_{out}}{2 \times f \times C}$$

Zener diode conducts in reverse bias when the voltage is greater than the Zener voltage for the diode.

For a bipolar transistor:

$$
\begin{aligned}
I_C &= \beta \times I_B \\
I_C &\approx I_E \\
V_{BE} &\approx 0.7\text{V}
\end{aligned}
$$

Basic equation for transistor bias circuits is:

Voltage supply = Sum of individual voltage drops

Common emitter amplifier amplification:

$$
\begin{aligned}
A_V &= -\frac{I_E}{25\text{ mV}} \times R_C \\
R_{in} &= \beta \times \frac{25\text{mV}}{I_E}
\end{aligned}
$$

A JFET is specified by:

$$
\begin{aligned}
V_{GS(off)} &= \text{Gate to source cutoff Voltage} \\
I_{DSS} &= \text{Drain saturation current} \\
g_m &= \frac{dI_D}{dV_{GS}} = \text{Mutual conductance} \\
I_D &= I_{DSS}\left(1 - \frac{V_{GS}}{V_{GS(off)}}\right)^2
\end{aligned}
$$

An enhancement mode MOSFET is specified by:

$$I_D = k(V_{GS} - V_{GS(th)})^2$$

For a JFET common source amplifier select:

- $R_S = \left|\frac{V_{GS(off)}}{I_{DSS}}\right|$
- Then $V_{GS} \approx 0.4 \times V_{GS(off)}$
- and $I_D \approx 0.4 \times I_{DSS}$
- $A_V = -g_m \times R_D$

$$g_m = \frac{dI_D}{dV_{GS}} = -2\frac{I_{DSS}}{V_{GS(off)}}\left(1 - \frac{V_{GS}}{V_{GS(off)}}\right)$$

For op-amps used in linear region:

- **Rule 1.** The voltage difference between the inverting and noninverting inputs is approximately zero.
- **Rule 2.** No current flows into the input terminals of the op-amp.
- The gain of an inverting amplifier is:

$$A_V = -\frac{R_f}{R_{in}}$$

- The gain of a noninverting amplifier is:

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

- $A_V = \frac{1}{\beta} = \frac{1}{\text{Feedback fraction}}$
- The output from an inverting adder is:

$$V_{out} = -R_f\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + \ldots\right)$$

- Output of current to voltage converter is:

$$V_{out} = -I \times R_f$$

- A bridge is in balance when:

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$

- For a differential amplifier:

$$V_{out} = \frac{R_2}{R_1} \times (V_2 - V_1)$$

- For a differentiator:

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

- For an integrator:

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

If a component characteristic is $I = f(V)$ then:

- Putting the component in place of the input resistor of an inverting amplifier gives the forward function:
$$V_{out} = -R \times f(V_{in})$$
- Putting the component in place of the feedback resistor of an inverting amplifier gives the inverse function:
$$V_{out} = -f^{-1}\left(\frac{V_{in}}{R}\right)$$

Frequency response of a 741 op-amp:

- Has a corner at 10 Hz and 100 dB.
- Open loop gain decreases by 20 dB per decade above 10 Hz

Noise in bandwidth B has units of:

$$\text{Volts per } \sqrt{\text{Hz}} \quad \text{or} \quad \text{Amps per } \sqrt{\text{Hz}}$$

- Thermal noise from a resistor, R, at temperature T within a bandwidth B is:
$$V_{noise} = \sqrt{4kTRB}$$
- The shot noise is:
$$I_{noise} = \sqrt{2eIB}$$
- Flicker noise spectrum varies as
$$\frac{1}{f} = \frac{1}{\text{Frequency}}$$

For a 555 Timer IC:

$$T_1 = 0.7(R_A + R_B)C \quad \text{and} \quad T_2 = 0.7R_BC$$

Sinusoidal voltage waveforms are obtained by using an amplifier with:

- Positive feedback,
- Loop gain of 1
- Frequency selective feedback network.

An R–$2R$ ladder gives an output:

$$V_{out} = -R_f\frac{V_{ref}}{4R}\left(S_0 + \frac{S_1}{2} + \frac{S_2}{4} + \frac{S_3}{8} + \ldots\right)$$