$f = 1/T$
$\omega = 2\pi f$
Voltage divider:
$V_{r1} = v_i \frac{R1}{R1+R2}$

**Voltage and Current gain in decibels**:
$A_{\text{v-dB}} = 20\log_{10}(A_{\text{V/V}})$
$A_{\text{i-dB}} = 20\log_{10}(A_{\text{A/A}})$
**Power gain in decibels**:
$A_{\text{p-dB}} = 10\log_{10}(A_{\text{W/W}})$
The power gain in decibels is the average of the voltage and amperage gain in decibels.

**Amplifier Models**:
$v_o = A_{v_o} v_i \frac{R_L}{R_L+R_o}$
$A_v = A_{v_o}\frac{R_L}{R_L+R_o}$
Consider the voltage divider at the output for the load. There may also be one at the source getting into the input of the amplifier.

**Amplifier Types**:
**Voltage**: $A_{v_o} \equiv \frac{v_o}{v_i}$
Wants: $R_i \to \infty$ and $R_o \to 0$
**Current**: $A_{i_s} \equiv \frac{i_o}{i_s}$
Wants: $R_i \to 0$ and $R_o \to \infty$
**Transconductance**: $G_m \equiv \frac{i_o}{v_i}$
Wants: $R_i \to \infty$ and $R_o \to \infty$
**Transresistance**: $R_m \equiv \frac{v_o}{i_s}$
Wants: $R_i \to 0$ and $R_o \to 0$

**Frequency Response of Amplifier**
STC (single time constant) networks:
$\tau =$ L / R or $\tau =$ CR
Low-pass filter with RC, voltage output is across the capacitor because it appears short at high frequencies.
High-pass filter with RC, voltage output is across the resistor.
This is opposite for inductors.

**Semiconductors**
Intrinsic means not doped. Group IV elements make good semiconductors because they have 4 valence electrons.
At low temps, covalent bonds remain more intact and don't conduct electricity. Higher temps means more free electrons means more current.
**Recombination** $n_i$ is number of free holes and electrons in a unit volume.
$n_i = BT^{3/2}e^{-E_g/2kT}$
$B$ is material dependent parameter ($7.3\times10^{15}\text{cm}^{-3}\text{K}^{-3/2}$ for Si)
$E_g$ is band gap energy, in Si it's 1.12 eV.
$k$ is Boltzmann's Constant ($8.62\times10^{-5}$eV/K)

**Doped semiconductors**
**N-type**: Dope the semiconductor with a Group V element. Those have an extra electron, so now there are extra free electrons making it N-type.
If $N_D \gg n_i$ then $n_n \approx N_D$
$n_n p_n = n_i^2$
$p_n = \frac{n_i^2}{N_D}$
**P-type**: Dope the semiconductor with a Group III element, more holes.
If $N_D \gg n_i$ then $n_n \approx N_D$
$p_p n_p = n_i^2$
$n_p = \frac{n_i^2}{N_A}$

**Drift Current**
Hole velocity $v_{p-drift} = \mu_p E \frac{cm}{s}$
$\mu_p = 480\frac{cm^2}{s}$
Electron velocity $v_{n-drift} = -\mu_n E\frac{cm}{s}$
$\mu_n = 1350\frac{cm^2}{s}$
Hole current: $I_p = Aqpv_{p-drift}$
$I_p = Aqp\mu_p E$
$J_p = \frac{I_p}{A} = qp\mu_p E$
$p$ is hole concentration
Electron current: $I_n = -Aqnv_{n-drift}$
$I_n = -Aqn\mu_n E$
$J_n = \frac{I_n}{A} = qp\mu_n E$
$n$ is electron concentration $q$ is magnitude of charge: $1.609\times10^{-19}$
**Drift current density**:
$J = J_p + J_n$

**Diffusion Current**:
$J_p = -qD_p\frac{dp(x)}{dx}\frac{A}{cm^2}$
$J_n = qD_n\frac{dn(x)}{dx}\frac{A}{cm^2}$
$\frac{D_n}{\mu_n} = \frac{D_p}{\mu_p} = V_T$
$V_T$ is the thermal voltage. $V_T = 25.9$mV

**Junction Built-in Voltage**:
$V_0 = V_T\ln\left(\frac{N_A N_D}{n_i^2}\right)$
Usually, $V_0$ is between 0.6 and 0.9 V.
**Magnitude of Charge**:
$|Q_+| = qAx_nN_D$
$|Q_-| = qAx_pN_A$
$A$ is cross sectional area.

**Width of depletion layer**:
$W = x_n + x_p = \sqrt{\frac{2\varepsilon_s}{q}\left(\frac{1}{N_A}+\frac{1}{N_D}\right)V_0}$
$x_n = W\frac{N_A}{N_A+N_D}$
$x_p = W\frac{N_D}{N_A+N_D}$
$Q_J = A\sqrt{2\varepsilon_s q\left(\frac{N_AN_D}{N_A+N_D}\right)V_0}$
**With reverse voltage** $V_R$:
$Q_J = A\sqrt{2\varepsilon_s q\left(\frac{N_AN_D}{N_A+N_D}\right)(V_0+V_R)}$
Capacitance can be found by:
$C_j = \frac{dQ_J}{dV_R}\Big|_{V_R=V_Q}$
$C_j = \frac{\alpha}{2\sqrt{V_0+V_R}}$
Where $\alpha$ is shown by
$\alpha = A\sqrt{2\varepsilon_s q\frac{N_AN_D}{N_A+N_D}}$

**Diffusion Capacitance**:
$Q_p = Aq[p_n(x_n) - p_{n0}]L_p$
$Q_p = \frac{L_p^2}{D_p}I_p$
$\tau_p = \frac{L_p^2}{D_p}$
$Q = \tau_T I$
$C_d = \frac{dQ}{dV}$
$C_d = \frac{\tau_T}{V_T}I$
Where $I$ is the forward bias current, it is really small when the diode is reverse biased.

**Depletion Capacitance**:
$C_{j0} = A\sqrt{\left(\frac{\varepsilon_s q}{2}\right)\left(\frac{N_AN_D}{N_A+N_D}\right)\frac{1}{V_0}}$
$C_j = \frac{C_{j0}}{\left(1+\frac{V_R}{V_0}\right)^m}$
$m$ is between 1/3 and 1/2

**Saturation Current**:
$I_s = Aqn_i^2\left(\frac{D_p}{L_pN_D}+\frac{D_n}{L_nN_A}\right)$
$I = I_s\left(e^{V/V_T}-1\right)$
**Forward Current**:
$I = I_p + I_n$
$I_p = Aqn_i^2\frac{D_p}{L_pN_D}(e^{V/V_T}-1)$
$I_n = Aqn_i^2\frac{D_n}{L_nN_A}(e^{V/V_T}-1)$
**Diodes**:
$V_T = \frac{kT}{q} = 25.9$mV
**Iterative Solution**:
Guess $V_1$ and $I_1$
$I_2 = \frac{V_{DD}-V_1}{R}$
$V_2 = V_1 + V_T\ln\left(\frac{I_2}{I_1}\right)$
Now use $V_2$ and $I_2$ as the new inputs for another iteration.
Constant drop: $V_D = 0.7$ V.
**Small Signal**:
$r_d = \frac{V_T}{I_D}$
**Zener Regions**:
$V_Z = V_{Z0} + r_zI_Z$
**Rectifiers**:
Ripple voltage:
$V_r = \frac{V_p}{fCR} = \frac{I_L}{fC}$