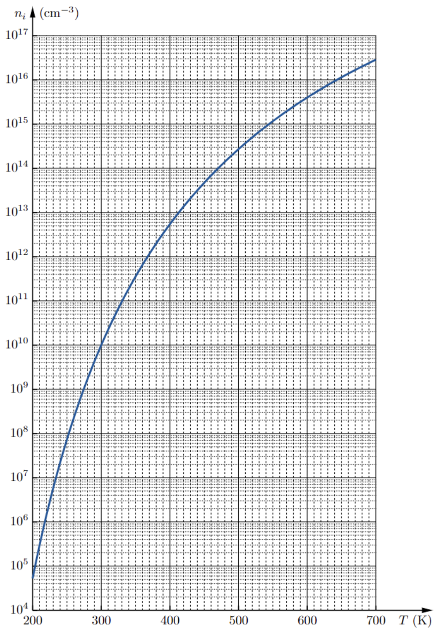
# Equations

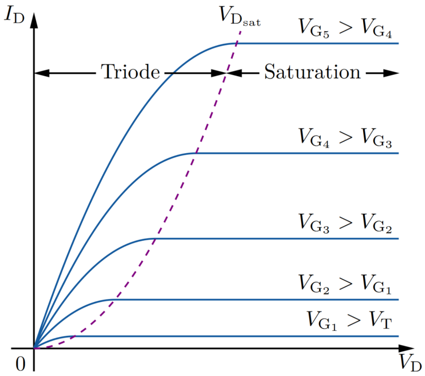
1. Constants:
$$\epsilon_0 = 8.85 * 10^{-14}\frac{F}{cm}$$
$$k = 1.386 * 10^{-23}$$
2. $P = \frac{dW}{dt} = IV$
3. $I = \frac{dq}{dt}$
4. $V = \frac{W}{q}$
5. $R = \frac{\rho L}{A}$
6. Ohm's Law: $V = IR$
7. Coulomb's Law: $\vec{F} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2}\hat{r}$
8. Kirchhoff's Loop Law: $\sum V_i = 0$ (around a closed loop)
9. Kirchhoff's Current Law: $\sum I_i = 0$ (going into a node)
10. Conductance: $G = \frac{1}{R}$
11. Equivalent resistance: $R_{eq} = \frac{V_{test}}{I_{test}}$
12. Series capacitance: $\frac{1}{C_{total}} = \frac{1}{C_1} + \frac{1}{C_2} + \ldots$
13. Parallel capacitance: $C_{total} = C_1 + C_2 + \ldots$
14. Series inductor: $L_{total} = L_1 + L_2 + \ldots$
15. Parallel inductor: $\frac{1}{L_{total}} = \frac{1}{L_1} + \frac{1}{L_1} + \ldots$
16. $I_{cap} = C\frac{dV}{dt}$
17. $V_{ind} = L\frac{dI}{dt}$
18. Energy stored in capacitor: $\frac{1}{2}CV^2$
19. Energy stored in inductor: $\frac{1}{2}LI^2$
20. Voltage in RC circuit:
$$v_c(\infty) + (v_c(t_0) - v_c(\infty))\, e^{(\frac{-1}{RC})(t-t_0)}$$
21. Current in RL circuit:
$$I_L(\infty) + (I_L(t_0) - I_L(\infty))\, e^{(\frac{-R}{L})(t-t_0)}$$
22. Impedance of a capacitor: $\frac{-j}{\omega C}$
23. Impedance of an inductor: $j\omega L$
24. Equivalent impedance for impedances in series:
$$Z_{eq} = \sum_i^n Z_i$$
25. Equivalent impedance for impedances in parallel:
$$\frac{1}{Z_{eq}} = \sum_i^n \frac{1}{Z_i}$$
26. RMS value of signal: $S_{rms} = \sqrt{\frac{1}{T}\int_{t_0}^{t_0+T} s^2(t)dt}$
27. Maximum power extracted in DC circuits: $\frac{Vth^2}{4R_{th}}$
28. Maximum power extracted in AC circuits: $\frac{|\tilde{V}_{th}|^2}{8R_{th}}$
29. Average power: $P_{avg} = \frac{V_m I_m}{2}\cos(\theta_v - \theta_i)$
30. Reactive power: $V_{ar} = Im(\frac{1}{2}\tilde{V}\tilde{I}^*)$
31. Apparent power: $P_{app} = \frac{|V_{rms}|^2}{|z|}$
32. Coupling coefficient in coupled circuit: $k = \frac{L_{12}}{\sqrt{L_1 L_2}}$
33. Voltage in magnetically coupled coils:
$$v_1(t) = L_1\frac{di_1(t)}{dt} + L_{12}\frac{di_2(t)}{dt}$$
$$v_2(t) = L_1\frac{di_2(t)}{dt} + L_{12}\frac{di_1(t)}{dt}$$
34. Voltage in ideal transformer:
$$\frac{v_2(t)}{v_1(t)} = \frac{N_2}{N_1}$$
$$\frac{i_2(t)}{i_1(t)} = -\frac{N_1}{N_2}$$
35. Terminated transformer circuit equations:
$$\tilde{V}_1 = \frac{\tilde{V}_2}{n}$$
$$\tilde{I}_{out} = \frac{\tilde{I}_{in}}{n}$$
$$\tilde{V}_{in} = Z_{in}\tilde{I}_{in} + \tilde{V}_1$$
$$\tilde{V}_2 = Z_{out}\tilde{I}_{out}$$
$$\tilde{V}_2 = Z_{out}\frac{\tilde{I}_{in}}{n}$$
$$\frac{\tilde{V}_{in}}{\tilde{I}_{in}} = Z_{in} + \frac{Z_{out}}{n^2}$$
36. Energy stored in magnetically coupled circuit:
$$E = \frac{1}{2}L_1 i_1^2 + \frac{1}{2}L_2 i_2^2 + L_{12}i_1 i_2$$
37. Equilibrium in pn junction: $pn = n_i^2$
38. Current in pn junction:
$$J_N = q\mu_n n E_x + qD_n\frac{dn}{dx}$$
$$J_P = -qD_p\frac{dp}{dx} + q\mu_p p E_x$$
39. Width of depletion region:
$$W = \left[\frac{2\epsilon_r\epsilon_0}{q}\left(\frac{N_A + N_D}{N_A N_D}\right)V_{bi}\right]^{1/2}$$
40. Built-in potential: $V_{bi} = \frac{kT}{q}\ln\left(\frac{N_A N_D}{n_i^2}\right)$

41. Intrinsic carrier density at given temperature:




42. Current through a non-ideal diode: $I = I_0(e^{qV_A/kT} - 1)$

43. $I_D - V_D$ characteristic graph:



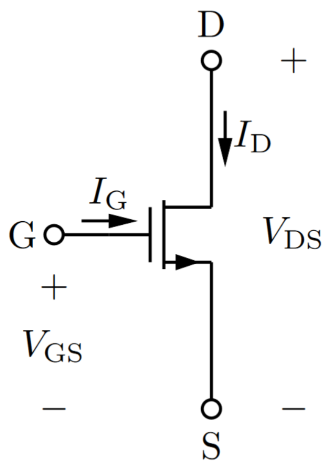

44. Transistor equations:

$$
\begin{aligned}
V_{DS} &= V_D - V_S \\
V_{GS} &= V_G - V_S \\
I_D &= \mu_n C_{ox}\left(\frac{W}{L}\right)\left[(V_{GS} - V_T)V_{DS} - \frac{1}{2}V_{DS}^2\right] \\
&= k\left[(V_{GS} - V_T)V_{DS} - \frac{1}{2}V_{DS}^2\right], V_{DS} \le V_{GS} - V_T, V_D \le V_G - V_T \\
I_D &= \mu_n C_{ox}\left(\frac{W}{L}\right)\left[\frac{1}{2}(V_{GS} - V_T)^2\right] \\
&= k\left[\frac{1}{2}(V_{GS} - V_T)^2\right], V_{DS} \ge V_{GS} - V_T, V_D \ge V_G - V_T
\end{aligned}
$$

45. Condition for CSA distortion less than 10%: $V_G < 0.2(V_G - V_T)$

46. Gain of a CSA: $A = -R_D k(V_G - V_T) = -g_m R_D$

47. Schematic of a MOSFET:




To find Thevenin voltage and Norton current:

($R_{eq}$) Turn off all independent sources (dependent sources remain unchanged) and calculate the resulting resistance at the desired port. Notice that you may have to apply the i-v test if resistors cannot be combined through series and parallel connections, or if the circuit includes dependent sources.

($V_{th}$) Leave the desired port open-circuited (i.e. no load connected) and find the voltage across it.

($I_N$) Short-circuit the desired port (i.e. connect a short circuit across the port) and find the current through it.