Electrical Engineering Essentials

A quick reference guide for fundamental concepts, formulas, and components in electrical engineering. This cheat sheet covers circuit analysis, electromagnetics, digital logic, and power systems.

Circuit Analysis Fundamentals

Basic Circuit Elements

Resistor (R)	Opposition to current flow. Measured in Ohms (Ω). Ohm's Law: `V = IR`
Capacitor (C)	Stores electrical energy. Measured in Farads (F). `I = C(dV/dt)`
Inductor (L)	Stores energy in a magnetic field. Measured in Henries (H). `V = L(dI/dt)`
Voltage Source (V)	Provides a constant voltage. Ideal voltage source has zero internal resistance.
Current Source (I)	Provides a constant current. Ideal current source has infinite internal resistance.

Circuit Laws

Kirchhoff's Current Law (KCL)	The algebraic sum of currents entering a node is zero. `∑ I = 0`
Kirchhoff's Voltage Law (KVL)	The algebraic sum of voltages around a closed loop is zero. `∑ V = 0`
Ohm's Law	Relates voltage, current, and resistance: `V = IR`
Power (P)	Rate at which energy is transferred. `P = VI = I^2R = V^2/R`
Series Resistors	Equivalent resistance: `R_eq = R_1 + R_2 + ... + R_n`
Parallel Resistors	Equivalent resistance: `1/R_eq = 1/R_1 + 1/R_2 + ... + 1/R_n`

Circuit Analysis Techniques

Nodal Analysis: Solve for node voltages using KCL. Choose a reference node (ground).

Mesh Analysis: Solve for loop currents using KVL. Suitable for planar circuits.

Superposition Theorem: Find the response due to each independent source acting alone, then sum the individual responses. Only applicable for linear circuits.

Thevenin's Theorem: Replace a complex circuit with a voltage source (`V_th`) in series with a resistor (`R_th`).

Norton's Theorem: Replace a complex circuit with a current source (`I_n`) in parallel with a resistor (`R_n`). `R_n = R_th`

Electromagnetics

Fundamental Constants

Permittivity of Free Space (ε_0)	$\varepsilon_0 \approx 8.854 \times 10^{-12}$ F/m
Permeability of Free Space (μ_0)	$\mu_0 = 4\pi \times 10^{-7}$ H/m
Speed of Light (c)	$c \approx 3 \times 10^{8}$ m/s

Electrostatics

Electric Field (E)	Force per unit charge. `E = F/q` (N/C or V/m)
Electric Potential (V)	Potential energy per unit charge. `V = U/q` (Volts)
Coulomb's Law	Force between two point charges: `F = k * (q₁q₂) / r²`, where `k = 1 / (4πε₀)`
Capacitance (C)	Charge stored per unit voltage: `C = Q/V` (Farads)

Magnetostatics

Magnetic Field (B)	Measured in Tesla (T) or Webers per square meter (Wb/m²)
Magnetic Force (F)	On a moving charge: `F = q(v x B)`
Ampère's Law	Relates magnetic field to current: `∮ B · dl = μ₀I_enc`
Inductance (L)	Ability of a conductor to store energy in a magnetic field: `L = Φ/I` (Henries)

Electromagnetic Waves

Maxwell's Equations (Differential Form):

`∇ · D = ρ`

`∇ · B = 0`

`∇ × E = -∂B/∂t`

`∇ × H = J + ∂D/∂t`

Poynting Vector (S): Represents the power flow of an electromagnetic wave. `S = E x H` (W/m²)

Wave Impedance (η): Ratio of electric field to magnetic field in a medium. `η = √(μ/ε)`

Digital Logic

Basic Logic Gates

AND Gate	Output is 1 only if all inputs are 1.
OR Gate	Output is 1 if at least one input is 1.
NOT Gate	Inverts the input. If input is 1, output is 0, and vice versa.
NAND Gate	NOT + AND. Output is 0 only if all inputs are 1.
NOR Gate	NOT + OR. Output is 1 only if all inputs are 0.
XOR Gate	Exclusive OR. Output is 1 if inputs are different.

Boolean Algebra

Basic Theorems:

A + 0 = A

A + 1 = 1

A · 0 = 0

A · 1 = A

A + A = A

A · A = A

Commutative Laws:

A + B = B + A

A · B = B · A

Associative Laws:

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

(A · B) · C = A · (B · C)

Distributive Laws:

A · (B + C) = A · B + A · C

A + (B · C) = (A + B) · (A + C)

DeMorgan's Theorems:

(A + B)' = A' · B'

(A · B)' = A' + B'

Combinational Logic Circuits

Multiplexers (MUX): Select one of several input signals and forward it to the output.

Demultiplexers (DEMUX): Direct a single input signal to one of several outputs.

Encoders: Convert a set of inputs into a binary code.

Decoders: Convert a binary code into a set of outputs.

Adders: Perform binary addition (Half Adder, Full Adder).

Sequential Logic Circuits

Flip-Flops: Basic memory elements (SR, D, JK, T).

Registers: Groups of flip-flops used to store binary information.

Counters: Sequential circuits that count pulses (Asynchronous, Synchronous).

Power Systems

AC Power Fundamentals

RMS Voltage (Vrms)	Root Mean Square voltage. `Vrms = Vpeak / √2` (for sinusoidal waveforms)
RMS Current (Irms)	Root Mean Square current. `Irms = Ipeak / √2` (for sinusoidal waveforms)
Apparent Power (S)	`S = VI*` (VA)
Real Power (P)	`P = VI cos(θ)` (Watts)
Reactive Power (Q)	`Q = VI sin(θ)` (VARs)
Power Factor (PF)	`PF = cos(θ) = P / |S|`

Transformers

Turns Ratio (a): `a = Np / Ns = Vp / Vs = Is / Ip`
Np, Ns: Number of turns in primary and secondary windings.
Vp, Vs: Voltage in primary and secondary windings.
Ip, Is: Current in primary and secondary windings.

Ideal Transformer Equation: `Vp * Ip = Vs * Is`

Three-Phase Power

Line Voltage (V_L)	Voltage between two lines in a three-phase system.
Phase Voltage (V_ph)	Voltage across a single phase.
Line Current (I_L)	Current flowing through a line in a three-phase system.
Phase Current (I_ph)	Current flowing through a single phase.
Y-Connection	`V_L = √3 * V_ph`, `I_L = I_ph`
Delta-Connection	`V_L = V_ph`, `I_L = √3 * I_ph`
Three-Phase Power (P)	`P = √3 * V_L * I_L * cos(θ)`

Power System Protection

Fuses: Overcurrent protection. Melt and interrupt the circuit.

Circuit Breakers: Overcurrent protection. Can be reset after tripping.

Relays: Detect abnormal conditions and initiate protective actions.

Grounding: Provides a low-impedance path for fault currents.