Electronics Key Equations

Basic Electricity

Ohm's Law	$V = IR$	Work Done	$W = QV$
Charge	$Q = It$		$W = VIt$
Power	$P = IV$	Current	$I = nAve$
	$P = I^2R$	Internal Resistance	$\varepsilon = I(R + r)$
	$P = \frac{V^2}{R}$		$\varepsilon = V + Ir$
Resistors in Series	$R = R_1 + R_2 + \cdots$	Potential Divider	$\frac{V_1}{V_2} = \frac{R_1}{R_2}$
Resistors in Parallel	$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$		$V_{out} = V_{in}\frac{R_2}{R_1 + R_2}$
Resistivity	$R = \frac{\rho L}{A}$		

Waveforms

Sinusoidal Waves	$v = V \sin(\omega t)$	Sinusoidal RMS	$V_{eff} = \sqrt{\frac{1}{T}\int_0^T \frac{v^2}{R} dr}$
	$v = V \cos(\omega t)$		
Angular Frequency	$\omega = \frac{2\pi}{t}$	Piecewise RMS	$V_{rms} = \sqrt{\frac{1}{N}\sum v_n^2}$
Converting between rad/s and rpm	$rad\ s^{-1} = \frac{\pi}{30}(rpm)$	Pulse Width Modulation	$\alpha = \frac{on\ time}{off\ time}$
Phase difference	$v = V \cos(\omega t + \phi)$		$V_{rms} = V_{max}\sqrt{\alpha}$
			$I_{rms} = I_{max}\sqrt{\alpha}$

Capacitors & Capacitance

Capacitance	$C = \frac{Q}{V}$	Capacitors in Series	$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots$
	$C = \frac{\varepsilon_0 A}{d}$	Capacitors in Parallel	$C = C_1 + C_2 + \cdots$
	$C = 4\pi\varepsilon_0 R$	Energy Stored	$W = \frac{1}{2}QV$
Time Constant	$\tau = CR$		$W = \frac{1}{2}\frac{Q^2}{C}$
Q & V when Charging	$x = x_0\left(1 - e^{-\frac{t}{\tau}}\right)$		$W = \frac{1}{2}V^2C$
I when Charging	$I = I_0 e^{-\frac{t}{\tau}}$		
Q, I & V when Discharging	$x = x_0 e^{-\frac{t}{\tau}}$		

Rectification & Smoothing

Maximum DC Voltage $V_{max} = \sqrt{2} \times V_{rms,AC}$

Minimum DC Voltage $V_{min} = V_{max}\left(1 - \frac{T}{\tau}\right)$

$V_{min} = V_{max}\left(1 - \frac{1}{f\tau}\right)$

Ripple Voltage $V_{rpp} = V_{max} - V_{min}$

$V_{rpp} = V_{max}\frac{T}{\tau}$

DC Output Voltage $V_{DC} = V_{max} - \frac{1}{2}V_{rpp}$

Assuming $V_{DC} \approx V_{rpp}$ $V_{rpp} = V_{DC}\frac{T}{\tau}$

$V_{rpp} = V_{DC}\frac{1}{f\tau}$

Note: When a bridge rectifier is used, the rectified frequency is double the AC frequency, and the ripple voltage is half what it would be if a half-bridge rectifier were used.

Resistor Series

E3 1.0, 2.2, 4.7, 10, 22, 47, 100 ...

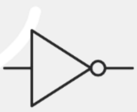
E6 1.0, 1.5, 2.2, 3.3, 4.7, 6.8, 10, 15,22,33,47,68,100 ...

E12 1.0, 1.2, 1.5, 1.8, 2.2, 2.7, 3.3, 3.9, 4.7, 5.6, 6.8. 8.2, 10, 12, 15 ...

Logic Gates

NOT Gate

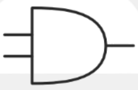
$M = \bar{A}$



A	M
0	1
1	0

AND Gate

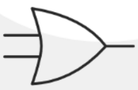
$M = A \cdot B$



A	B	M
0	0	0
1	0	0
0	1	0
1	1	1

OR Gate

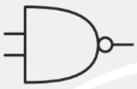
$M = A + B$



A	B	M
0	0	0
1	0	1
0	1	1
1	1	1

NAND Gate

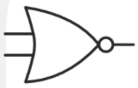
$M = \overline{A \cdot B}$



A	B	M
0	0	1
1	0	1
0	1	1
1	1	0

NOR Gate

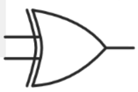
$M = \overline{A + B}$



A	B	M
0	0	1
1	0	0
0	1	0
1	1	0

XOR Gate (exclusive OR)

$M = A \oplus B$



A	B	M
0	0	0
1	0	1
0	1	1
1	1	0

Boolean Identities

$A + B = \overline{(\bar{A} \cdot \bar{B})}$ $\overline{A + B} = (\bar{A} \cdot \bar{B})$ $A + \bar{A} = 1$ $A \cdot \bar{A} = 0$

DC Generator

Induced emf	$E = K_e\omega$
Generator Power	$V_a I = T_i\omega - R_a I^2$
Mechanical Torque	$T_i = K_e I$
	$T_i = T - T_f$

DC Motor

Induced emf	$E = K_e\omega$
Generator Power	$V_a I = T_0\omega + R_a I^2$
Mechanical Torque	$T_0 = K_e I$
	$T_0 = T + T_f$

Magnetic Fields & Induction

Magnetic Flux	$\phi = BA\cos\theta$
Flux Linkage	$N\phi = BAN\cos\theta$
Lorentz Force	$F = BIL\sin\theta$
	$F = BQv$
Faraday's Law	$E = N\frac{d\phi}{dt}$
	$E = \frac{d}{dt}(BAN\cos\theta)$

Electromagnetism

Magnetomotive Force	$mmf = NI$
Reluctance	$S = \frac{mmf}{\phi}$
	$S = \frac{L}{\mu_r\mu_0 A}$
Reluctance in Series	$S_{total} = S_1 + S_2 + \cdots$
Reluctance in Parallel	$\frac{1}{S_{total}} = \frac{1}{S_1} + \frac{1}{S_2} + \cdots$
Flux	$\phi = Ni\frac{\mu_r\mu_0 A}{L}$
Flux Density	$B = Ni\frac{\mu_r\mu_0}{L}$
	$B = \frac{NI}{SA}$
Energy	$energy = N^2I^2A\frac{\mu_r\mu_0}{2L}$
	$energy = \frac{1}{2}\frac{N^2I^2}{S}$
	$energy = \frac{1}{2}\phi^2 S$
Force	$F = \frac{AB^2}{2\mu_0}$

Electrical & Magnetic Quantities

Electrical Quantity	Units	Magnetic Equivalent	Units
emf	V	mmf	$A.turns$
Current, I	A	Flux, ϕ	Wb
Resistance, R	Ω	Reluctance, S	$A.turns\,Wb^{-1}$
Resistivity, ρ		1 / Permeability	

Encoders

Rotary Resolution	$resolution = \frac{range}{2^M}$
Linear Resolution	$resolution = \frac{range}{2^M - 1}$
Absolute Uncertainty	$\Delta = \pm r\,esolution$

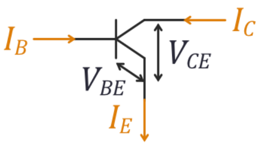
Strain Gauges

Change in Resistance	$\frac{dR}{R} = G\frac{dl}{l} = G\varepsilon$
	$\ln\frac{R_1}{R_2} = G\ln\frac{l_1}{l_2}$

Load Cells

Output Voltage (when $G\varepsilon$ is small)	$V_{out} = \frac{1}{4}V_{in}G\varepsilon$

Bipolar Junction Transistors (BJTs)



$V_{BE} \approx 0.6V$

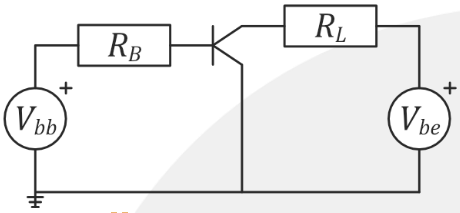
$I_E = I_B + I_C$

$I_C = h_{fe} I_B$

$P_{trans} = I_C V_{CE}$

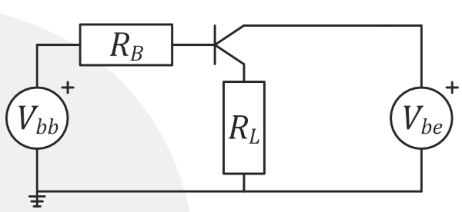
Cut-off state	$I_B = 0$
Active state	$0 < I_B < I_{C,max}$
Saturated state	$I_B > I_{C,max}$

The Common Emitter Ideal current source



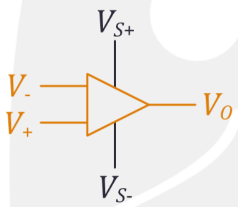
$$I_L = h_{fc} \frac{V_{bb}}{R_B}$$

The Common Collector Ideal voltage source



$$V_L = \frac{V_{bb} - V_{be}}{1 + \frac{1}{h_{fe}} \frac{R_B}{R_L}} \approx V_{bb} - 0.6$$

Operational Amplifiers (Op-Amps)



V_- inverting input

V_+ non-inverting input

V_O output

V_{S-} negative supply

V_{S+} positive supply

Amplification	$V_O = A(V_+ - V_-)$
Output bounds	$V_{S-} \leq V_O \leq V_{S+}$