

dc

Introduction

Conversions 1 meter = 100 cm = 39.37 in., 1 in. = 2.54 cm,
 1 yd = 0.914 m = 3 ft, 1 mile = 5280 ft. °F = 9/5°C + 32, °C =
 5/9(°F - 32), K = 273.15 + °C **Scientific notation** 10¹² =
 tera = T, 10⁹ = giga = G, 10⁶ = mega = M, 10³ = kilo = k, 10⁻³ =
 milli = m, 10⁻⁶ = micro = μ, 10⁻⁹ = nano = n, 10⁻¹² = pico = p
Powers of ten 1/10ⁿ = 10⁻ⁿ, 1/10⁻ⁿ = 10ⁿ, (10ⁿ)(10^m) = 10^{n+m},
 10ⁿ/10^m = 10^{n-m}, (10ⁿ)^m = 10^{nm}

Voltage and Current

Coulomb's law $F = kQ_1Q_2/r^2$, $k = 9 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2$,
 $Q = \text{coulombs (C)}$, $r = \text{meters (m)}$ **Current** $I = Q/t$ (amperes),
 $t = \text{seconds (s)}$, $Q_e = 1.6 \times 10^{-19} \text{ C}$ **Voltage** $V = W/Q$ (volts),
 $W = \text{joules (J)}$

Resistance

Circular wire $R = \rho l/A$ (ohms), $\rho = \text{resistivity}$, $l = \text{feet}$,
 $A_{\text{CM}} = (d_{\text{mils}})^2$, $\rho(\text{Cu}) = 10.37$ **Metric units** $l = \text{cm}$, $A = \text{cm}^2$,
 $\rho(\text{Cu}) = 1.724 \times 10^{-6} \text{ ohm}\cdot\text{cm}$ **Temperature** $(|T| + T_1)/R_1 =$
 $(|T| + T_2)/R_2$, $R_1 = R_{20}[1 + \alpha_{20}(T_1 - 20^\circ\text{C})]$, $\alpha_{20}(\text{Cu}) = 0.00393$
Color code Bands 1-3: 0 = black, 1 = brown, 2 = red, 3 = orange,
 4 = yellow, 5 = green, 6 = blue, 7 = violet, 8 = gray, 9 = white,
 Band 3: 0.1 = gold, 0.01 = silver, Band 4: 5% = gold, 10% = silver,
 20% = no band, Band 5: 1% = brown, 0.1% = red, 0.01% = orange,
 0.001% = yellow **Conductance** $G = 1/R$ siemens (S)

Ohm's Law, Power, and Energy

Ohm's law $I = E/R$, $E = IR$, $R = E/I$ **Power** $P = W/t =$
 $VI = I^2R = V^2/R$ (watts), 1 hp = 746 W
Efficiency $\eta\% = (P_o/P_i) \times 100\%$, $\eta_T = \eta_1 \cdot \eta_2 \cdot \eta_3 \cdots \eta_n$
Energy $W = Pt$, W (kWh) = $[P(\text{W}) \cdot t(\text{h})]/1000$

Series Circuits

$R_T = R_1 + R_2 + R_3 + \cdots + R_N$, $R_T = NR$, $I = E/R_T$, $V = IR$
Kirchoff's voltage law $\sum_C V = 0$, $\sum_C V_{\text{rises}} = \sum_C V_{\text{drops}}$
Voltage divider rule $V_x = R_x E/R_T$

Parallel dc Circuits

$R_T = 1/(1/R_1 + 1/R_2 + 1/R_3 + \cdots + 1/R_N)$, $R_T = R/N$,
 $R_T = R_1R_2/(R_1 + R_2)$, $I = EG_T = E/R_T$
Kirchoff's current law $\sum I_{\text{entering}} = \sum I_{\text{leaving}}$
Current divider rule $I_x = (R_T/R_x)I$, (Two parallel elements):
 $I_1 = R_2I/(R_1 + R_2)$, $I_2 = R_1I/(R_1 + R_2)$

Series-Parallel Circuits

Potentiometer loading $R_L \gg R_T$
Ammeter $R_{\text{shunt}} = R_m I_{CS}/(I_{\text{max}} - I_{CS})$
Voltmeter $R_{\text{series}} = (V_{\text{max}} - V_{VS})/I_{CS}$
Ohmmeter $R_x = (E/I_{CS}) - R_m - \text{zero-adjust}/2$

Methods of Analysis and Selected Topics (dc)

Source conversions $E = IR_p$, $R_s = R_p$, $I = E/R_s$

Determinants $D = \begin{vmatrix} a_1 & b_1 \\ a_2 & b_2 \end{vmatrix} = a_1b_2 - a_2b_1$

Bridge networks $R_1/R_3 = R_2/R_4$ **Δ-Y conversions** $R' =$
 $R_A + R_B + R_C$, $R_3 = R_A R_B / R'$, $R_2 = R_A R_C / R'$, $R_1 = R_B R_C / R'$, $R_Y = R_{\Delta}/3$
Y-Δ conversions $R' = R_1 R_2 + R_1 R_3 + R_2 R_3$, $R_C = R' / R_3$, $R_B = R' / R_2$,
 $R_A = R' / R_1$, $R_{\Delta} = 3R_Y$

Network Theorems

Superposition Voltage sources (short-circuit equivalent), current
 sources (open-circuit equivalent)
Thévenin's Theorem R_{Th} : (all sources to zero), E_{Th} : (open-circuit
 terminal voltage)
Maximum power transfer theorem $R_L = R_{Th} = R_N$, $P_{\text{max}} =$
 $E_{Th}^2 / 4R_{Th} = I_N^2 R_N / 4$

Capacitors

Capacitance $C = Q/V = \epsilon A/d = 8.85 \times 10^{-12} \epsilon_r A/d$ farads (F),
 $C = \epsilon_r C_o$ **Electric field strength** $\mathcal{E} = V/d = Q/\epsilon A$ (volts/meter)
Transients (charging) $i_C = (E/R)e^{-t/\tau}$, $\tau = RC$, $v_C = E(1 - e^{-t/\tau})$,
 (discharge) $v_C = Ee^{-t/\tau}$, $i_C = (E/R)e^{-t/\tau}$ i_C $i_{C_{\text{av}}} = C(\Delta v_C/\Delta t)$
Series $Q_T = Q_1 = Q_2 = Q_3$, $1/C_T = (1/C_1) + (1/C_2) + (1/C_3) + \cdots +$
 $(1/C_N)$, $C_T = C_1 C_2 / (C_1 + C_2)$ **Parallel** $Q_T = Q_1 + Q_2 + Q_3$,
 $C_T = C_1 + C_2 + C_3$ **Energy** $W_C = (1/2)CV^2$

Inductors

Self-inductance $L = N^2 \mu A/l$ (henries), $L = \mu_r L_o$
Induced voltage $e_{L_{\text{av}}} = L(\Delta i/\Delta t)$ **Transients** (storage) $i_L =$
 $I_m(1 - e^{-t/\tau})$, $I_m = E/R$, $\tau = L/R$, $v_L = Ee^{-t/\tau}$ (decay), $v_L =$
 $[1 + (R_2/R_1)]Ee^{-t/\tau}$, $\tau' = L/(R_1 + R_2)$, $i_L = I_m e^{-t/\tau}$, $I_m = E/R_1$
Series $L_T = L_1 + L_2 + L_3 + \cdots + L_N$ **Parallel** $1/L_T = (1/L_1) +$
 $(1/L_2) + (1/L_3) + \cdots + (1/L_N)$, $L_T = L_1 L_2 / (L_1 + L_2)$
Energy $W_L = 1/2(LI^2)$

Magnetic Circuits

Flux density $B = \Phi/A$ (webers/m²) **Permeability** $\mu = \mu_r \mu_o$
 (Wb/A·m) **Reluctance** $\mathcal{R} = l/\mu A$ (rels) **Ohm's law** $\Phi = \mathcal{F}/\mathcal{R}$
 (webers)
Magnetomotive force $\mathcal{F} = NI$ (ampere-turns) **Magnetizing**
force $H = \mathcal{F}/l = NI/l$ **Ampère's circuital law** $\sum_C \mathcal{F} = 0$
Flux $\sum \Phi_{\text{entering}} = \sum \Phi_{\text{leaving}}$ **Air gap** $H_g = 7.96 \times 10^5 B_g$

Greek Alphabet

Letter	Capital	Lowercase	Letter	Capital	Lowercase
Alpha	A	α	Nu	Ν	ν
Beta	B	β	Xi	Ξ	ξ
Gamma	Γ	γ	Omicron	Ο	ο
Delta	Δ	δ	Pi	Π	π
Epsilon	Ε	ε	Rho	Ρ	ρ
Zeta	Z	ζ	Sigma	Σ	σ
Eta	H	η	Tau	Τ	τ
Theta	Θ	θ	Upsilon	Υ	υ
Iota	I	ι	Phi	Φ	φ
Kappa	K	κ	Chi	Χ	χ
Lambda	Λ	λ	Psi	Ψ	ψ
Mu	M	μ	Omega	Ω	ω

Prefixes

Multiplication Factors	SI Prefix	SI Symbol
1 000 000 000 000 000 000 = 10 ¹⁸	exa	E
1 000 000 000 000 000 = 10 ¹⁵	peta	P
1 000 000 000 000 = 10 ¹²	tera	T
1 000 000 000 = 10 ⁹	giga	G
1 000 000 = 10 ⁶	mega	M
1 000 = 10 ³	kilo	k
0.001 = 10 ⁻³	milli	m
0.000 001 = 10 ⁻⁶	micro	μ
0.000 000 001 = 10 ⁻⁹	nano	n
0.000 000 000 001 = 10 ⁻¹²	pico	p
0.000 000 000 000 001 = 10 ⁻¹⁵	femto	f
0.000 000 000 000 000 001 = 10 ⁻¹⁸	atto	a

ac

Sinusoidal Alternating Waveforms

Sine wave $v = V_m \sin \alpha$, $\alpha = \omega t = 2\pi ft$, $f = 1/T$, 1 radian = 57.3°, radians = $(\pi/180^\circ) \times (\text{degrees})$, degrees = $(180^\circ/\pi) \times (\text{radians})$

Identities $\sin(\omega t + 90^\circ) = \cos \omega t$, $\sin \omega t = \cos[\omega t - (\pi/2)]$, $\sin(-\alpha) = -\sin \alpha$, $\cos(-\alpha) = \cos \alpha$ **Average value** $G =$

algebraic sum of areas/length of curve

Effective (rms) value $I_{rms} = 0.707I_m$, $I_m = \sqrt{2}I_{rms}$,

$I_{rms} = \sqrt{\text{area } [i(t)]^2/T}$

The Basic Elements and Phasors

R: $I_m = V_m/R$, in phase **L:** $X_L = \omega L$, v_L leads i_L by 90°
C: $X_C = 1/\omega C$, i_C leads v_C by 90° **Power** $P = (V_m I_m / 2) \cos \theta =$
 $V_{rms} I_{rms} \cos \theta$ **R:** $P = V_{rms} I_{rms} = I_{rms}^2 R = V_{rms}^2 / R$ **Power**
factor $F_p = \cos \theta = P / V_{rms} I_{rms}$ **Rectangular form** $C = A + jB$
Polar form $C = C \angle \theta$ **Conversions** $C = \sqrt{A^2 + B^2}$, $\theta =$
 $\tan^{-1}(B/A)$, $A = C \cos \theta$, $B = C \sin \theta$ **Operations** $j = \sqrt{-1}$,
 $j^2 = -1$, $1/j = -j$, $C_1 \pm C_2 = (\pm A_1 \pm A_2) + j(\pm B_1 \pm B_2)$,
 $C_1 \cdot C_2 = C_1 C_2 \angle (\theta_1 + \theta_2)$, $C_1 / C_2 = (C_1 / C_2) \angle (\theta_1 - \theta_2)$

Series and Parallel ac Circuits

Elements $R \angle 0^\circ$, $X_L \angle 90^\circ$, $X_C \angle -90^\circ$
Series $Z_T = Z_1 + Z_2 + Z_3 + \dots + Z_N$, $I_s = E/Z_T$, $F_p = R/Z_T$
Voltage divider rule $V_x = Z_x E / Z_T$ **Parallel** $Y_T = Y_1 + Y_2 +$
 $Y_3 + \dots + Y_N$, $Z_T = Z_1 Z_2 / (Z_1 + Z_2)$, $G \angle 0^\circ$, $B_L \angle -90^\circ$,
 $B_C \angle 90^\circ$, $F_p = \cos \theta_T = G / Y_T$ **Current divider rule** $I_1 =$
 $Z_2 I_T / (Z_1 + Z_2)$, $I_2 = Z_1 I_T / (Z_1 + Z_2)$ **Equivalent circuits** $R_s =$
 $R_p X_p^2 / (X_p^2 + R_p^2)$, $X_s = R_p X_p / (X_p^2 + R_p^2)$, $R_p = (R_s^2 + X_s^2) / R_s$,
 $X_p = (R_s^2 + X_s^2) / X_s$

Series-Parallel ac Networks:

Employ block impedances and obtain general solution for reduced network. Then substitute numerical values. General approach similar to that for dc networks.

Methods of Analysis and Selected Topics (ac)

Source conversions $E = IZ_p$, $Z_s = Z_p$, $I = E/Z_s$ **Bridge networks** $Z_1/Z_3 = Z_2/Z_4$ Δ -Y, Y- Δ conversions See dc coverage, replacing R by Z.

Network Theorems

Review dc content on other side.

Thévenin's theorem (dependent sources) $E_{oc} = E_{Th}$, $Z_{Th} = E_{oc}/I_{sc}$, $Z_{Th} = E_g/I_g$ **Norton's theorem** (dependent sources) $I_{sc} = I_N$, $Z_N = E_{oc}/I_{sc}$, $Z_N = E_g/I_g$ **Maximum power transfer theorem** $Z_L = Z_{Th}$, $\theta_L = -\theta_{Th}$, $P_{max} = E_{Th}^2 / 4R_{Th}$

Power (ac)

R: $P = VI = V_m I_m / 2 = I^2 R = V^2 / R$ **Apparent power** $S = VI$,
 $P = S \cos \theta$, $F_p = \cos \theta = P/S$ **Reactive power** $Q = VI \sin \theta$
L: $Q_L = VI = I^2 X_L = V^2 / X_L$, **C:** $Q_C = VI = I^2 X_C = V^2 / X_C$,
 $S_T = \sqrt{P_T^2 + Q_T^2}$, $F_p = P_T / S_T$

Resonance

Series $X_L = X_C$, $f_s = 1/(2\pi\sqrt{LC})$, $Z_{T_s} = R$, $Q_L = X_L/R$, $Q_s = X_C/R =$
 $(1/R)\sqrt{L/C}$, $V_{L_s} = Q_s E$, $V_{C_s} = Q_s E$, $P_{HPPF} = (1/2)P_{max}$, $f_1 =$
 $(1/2\pi)[-R/2L + (1/2)\sqrt{(R/L)^2 + 4/LC}]$, f_2 (use $+R/2L$), $BW = f_2 - f_1 =$
 $R/2\pi L = f_s/Q_s$ **Parallel** $X_{L_p} = X_C$, $X_{L_p} = (R^2 + X_L^2)/X_L$,
 $f_p = [1/(2\pi\sqrt{LC})]\sqrt{1 - (R^2/CIL)}$, $Z_{T_p} = R_s \parallel R_p$, $R_p = (R^2 + X_L^2)/R_L$,
 $Q_p = (R_s \parallel R_p)X_{L_p}$, $BW = f_2 - f_1 = f_p/Q_p$ $Q \geq 10$: $Z_{T_p} \approx R_s \parallel Q^2 R_L$,
 $X_{L_p} \approx X_L$, $X_L = X_C$, $f_p \approx 1/(2\pi\sqrt{LC})$, $Q_p = Q_L$, $I_L = I_C \approx QI_T$,
 $BW = f_p/Q_p = R_L/2\pi L$

Decibels, Filters, and Bode Plots

Logarithms $N = b^x$, $x = \log_b N$, $\log_e x = 2.3 \log_{10} x$, $\log_{10} ab =$
 $\log_{10} a + \log_{10} b$, $\log_{10} a/b = \log_{10} a - \log_{10} b$, $\log_{10} a^n = n \log_{10} a$,
 $\text{dB} = 10 \log_{10} P_2/P_1$, $\text{dB}_v = 20 \log_{10} V_2/V_1$

R-C filters (high-pass) $f_c = 1/(2\pi RC)$, $V_o/V_i = R/\sqrt{R^2 + X_C^2}$
 $\angle \tan^{-1}(X_C/R)$ (low-pass) $f_c = 1/(2\pi RC)$, $V_o/V_i = X_C/\sqrt{R^2 + X_C^2}$
 $\angle -\tan^{-1} \frac{R}{X_C}$

Octave 2 : 1, 6 dB/octave **Decade** 10 : 1, 20 dB/decade

Transformers

Mutual inductance $M = k\sqrt{L_p L_s}$ **Iron-core** $E_p = 4.44fN_p\Phi_m$,
 $E_s = 4.44fN_s\Phi_m$, $E_p/E_s = N_p/N_s$, $a = N_p/N_s$, $I_p/I_s = N_s/N_p$,
 $Z_p = a^2 Z_L$, $E_p I_p = E_s I_s$, $P_i = P_o$ (ideal)
Air-core $Z_i = Z_p + [\omega M]^2 / (Z_s + Z_L)$

Polyphase Systems

Y-Y system $I_{\phi s} = I_L = I_{\phi L}$, $V_{\phi} = E_{\phi}$, $E_L = \sqrt{3} V_{\phi}$ **Y- Δ system**
 $V_{\phi} = E_L$, $I_L = \sqrt{3} I_{\phi}$ **Δ - Δ system** $V_{\phi} = E_L = E_{\phi}$, $I_L = \sqrt{3} I_{\phi}$
 Δ -Y system $E_L = \sqrt{3} V_{\phi}$, $I_{\phi} = I_L$, $E_L = E_{\phi}$ **Power** $P_T = 3P_{\phi}$,
 $Q_T = 3Q_{\phi}$, $S_T = 3S_{\phi} = \sqrt{3} E_L I_L$, $F_p = P_T / S_T$

Pulse Waveforms and the R-C Response

% tilt = $[(V_1 - V_2)/V] \times 100\%$ with $V = (V_1 + V_2)/2$

Pulse repetition frequency (prf) = 1/T

Duty cycle = $(t_p/T) \times 100\%$

$V_{av} = (\text{duty cycle})(\text{peak value}) + (1 - \text{duty cycle}) \times (V_b)$

R-C circuits $v_C = V_i + (V_f - V_i)(1 - e^{-t/RC})$

Compensated attenuator $R_p C_p = R_s C_s$

Nonsinusoidal Circuits

Fourier series $f(\alpha) = A_0 + A_1 \sin \omega t + A_2 \sin 2\omega t + \dots +$

$A_n \sin n\omega t + B_1 \cos \omega t + B_2 \cos 2\omega t + \dots + B_n \cos n\omega t$

Even function $f(\alpha) = f(-\alpha)$, no B_n terms **Odd function** $f(\alpha) =$

$-f(-\alpha)$, no A_n terms, no odd harmonics if $f(t) = f[(T/2) + t]$, no even

harmonics if $f(t) = -f[(T/2) + t]$

Effective (rms) value $V_{(rms)} =$

$\sqrt{V_0^2 + (V_1^2 + \dots + V_n^2 + V_{m1}^2 + \dots + V_{mn}^2)/2}$

Power $P_T = V_0 I_0 + V_1 I_1 \cos \theta + \dots + V_n I_n \cos \theta_n = I_{rms}^2 R = V_{rms}^2 / R$

Standard Resistor Values

Ohms (Ω)					Kilohms (k Ω)		Megohms (M Ω)	
0.10	1.0	10	100	1000	10	100	1.0	10.0
0.11	1.1	11	110	1100	11	110	1.1	11.0
0.12	1.2	12	120	1200	12	120	1.2	12.0
0.13	1.3	13	130	1300	13	130	1.3	13.0
0.15	1.5	15	150	1500	15	150	1.5	15.0
0.16	1.6	16	160	1600	16	160	1.6	16.0
0.18	1.8	18	180	1800	18	180	1.8	18.0
0.20	2.0	20	200	2000	20	200	2.0	20.0
0.22	2.2	22	220	2200	22	220	2.2	22.0
0.24	2.4	24	240	2400	24	240	2.4	
0.27	2.7	27	270	2700	27	270	2.7	
0.30	3.0	30	300	3000	30	300	3.0	
0.33	3.3	33	330	3300	33	330	3.3	
0.36	3.6	36	360	3600	36	360	3.6	
0.39	3.9	39	390	3900	39	390	3.9	
0.43	4.3	43	430	4300	43	430	4.3	
0.47	4.7	47	470	4700	47	470	4.7	
0.51	5.1	51	510	5100	51	510	5.1	
0.56	5.6	56	560	5600	56	560	5.6	
0.62	6.2	62	620	6200	62	620	6.2	
0.68	6.8	68	680	6800	68	680	6.8	
0.75	7.5	75	750	7500	75	750	7.5	
0.82	8.2	82	820	8200	82	820	8.2	
0.91	9.1	91	910	9100	91	910	9.1	