ELECTRONIC CIRCUITS
FUNDAMENTALS AND APPLICATIONS

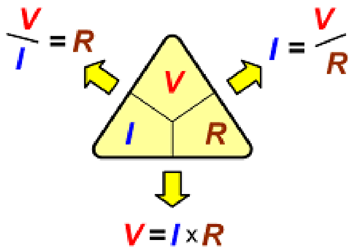
USEFUL FORMULAE

Electrical symbols and units

Quantity	*Symbol*	*Unit*	*Abbreviated units*
Angle	ϕ	radian or degree	Rad or °
Capacitance	C	Farad	F
Charge	Q	Coulomb	C
Conductance	G	Siemen	S
Current	I	Ampere	A
Energy	J	Joule	J
Flux	Φ	Weber	Wb
Flux density	B	Tesla	T
Frequency	f	Hertz	Hz
Impedance	Z	Ohm	Ω
Inductance	L	Henry	H
Power	P	Watt	W
Reactance	X	Ohm	Ω
Resistance	R	Ohm	Ω
Time	t	second	s
Voltage	V	Volt	V

Charge, current and voltage

$Q = I \times t$

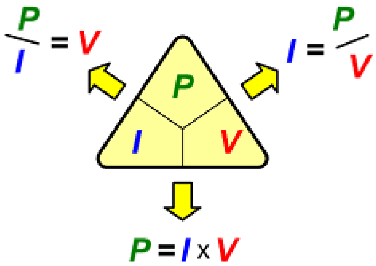


Ohm's Law

$V = I \times R$ and $I = V / R$ and $R = V / I$

Similarly if *resistance* is replaced by *reactance* or *impedance*:

$V = I \times X$ and $I = V / X$ and $X = V / I$
$V = I \times Z$ and $I = V / Z$ and $Z = V / I$



Power and energy

$P = I \times V$ and $P = V^2 / R$ and $P = I^2 R$
$J = P \times t$ and since $P = I \times V$ so $J = I\,V\,t$

Resistors in series

$R_T = R_1 + R_2 + R_3$

Resistors in parallel

$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$ but where there are *only two* resistors $R_T = \frac{R_1 \times R_2}{R_1 + R_2}$

Capacitance

$C = \frac{\varepsilon A}{d}$ where ε is the *permittivity* of the dielectric and $\varepsilon = \varepsilon_0 \varepsilon_r$

Capacitance, charge and voltage

$Q = C V$

Inductance

$L = n^2 \frac{\mu A}{l}$ where μ is the *permeability* of the magnetic medium and $\mu = \mu_0 \mu_r$

Energy stored in a capacitor

$J = ½ C V^2$

Energy stored in an inductor

$J = ½ L I^2$

Inductors in series

$L_T = L_1 + L_2 + L_3$

Inductors in parallel

$\frac{1}{L_T} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3}$ but where there are *only* two inductors $L_T = \frac{L_1 \times L_2}{L_1 + L_2}$

Capacitors in series

$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$ but where there are *only* two capacitors $C_T = \frac{C_1 \times C_2}{C_1 + C_2}$

Capacitors in parallel

$C_T = C_1 + C_2 + C_3$

Induced e.m.f. in an inductor

$e = -L\frac{di}{dt}$ where $\frac{di}{dt}$ is the *rate of change of current with time*

Current in a capacitor

$i = C\frac{dv}{dt}$ where $\frac{dv}{dt}$ is the *rate of change of voltage with time*

Sine wave voltage

$v = V_{max}\sin(\omega t)$ or $v = V_{max}\sin(2\pi f t)$ because $\omega = 2\pi f$

$f = 1/T$ where T is the periodic time

For a *sine wave*, to convert:
RMS to **peak** multiply by **1.414**
Peak to **RMS** multiply by **0.707**
Peak to **average** multiply by **0.636**
Peak to **peak-peak** multiply by **2**

Capacitive reactance

$$X_C = \frac{V_C}{I_C} = \frac{1}{2\pi fC}$$

Inductive reactance

$$X_L = \frac{V_L}{I_L} = 2\pi fL$$

Resistance and reactance in series

$Z = \sqrt{(R^2 + X^2)}$ and $\phi = \arctan\left(\frac{X}{R}\right)$

Resonance

$X_L = X_C$ thus $\omega L = \frac{1}{\omega C}$ or $2\pi f_o L = \frac{1}{2\pi f_o C}$

$$f_o = \frac{1}{2\pi\sqrt{LC}}$$

$Q = \frac{\omega L}{R}$ Bandwidth $= \frac{f_o}{Q}$

Power factor

Power factor = True power/Apparent power = Watts / Volt-amperes = W / VA

True power = $V \times (I \times \cos\phi) = V I \cos\phi$ Power factor = $\cos\phi = R / Z$

Reactive power = $V \times (I \times \sin\phi) = V I \sin\phi$

Bipolar junction transistors (BJT)

Transistor junction current equation $I_E = I_B + I_C$

Large signal (or d.c.) common emitter current gain $h_{FE} = \frac{I_C}{I_B}$

Small signal (or a.c.) common emitter current gain $h_{fe} = \frac{\Delta I_C}{\Delta I_B}$ (Δ is a small change)

Collector power dissipation $P_C = I_C \times V_{CE}$

Total power dissipation $P_T = P_C + P_B = (I_C \times V_{CE}) + (I_B \times V_{BE})$

$P_T \approx I_C \times V_{CE}$ when h_{FE} is large

Junction gate field effect transistors (JFET)

Large signal (or d.c.) common source forward transfer conductance $g_{FS} = \frac{I_D}{V_{GS}}$

Small signal (or a.c.) common source forward transfer conductance $g_{fs} = \frac{\Delta I_D}{\Delta V_{GS}}$

Total power dissipation $P_T = I_D \times V_{DS}$

Power supplies

Output resistance $R_{out} = \frac{\Delta V_{out}}{\Delta I_{out}}$

Regulation = $\left(\frac{\Delta V_{out}}{\Delta V_{in}}\right) \times 100\%$

Amplifiers

Voltage gain $A_v = \frac{V_{out}}{V_{in}}$ Current gain $A_i = \frac{I_{out}}{I_{in}}$ Power gain $A_p = \frac{P_{out}}{P_{in}} = A_i \times A_v$

Gain with negative feedback $G = \frac{A_v}{1 + \beta A_v}$ (when β is large, $G \approx \frac{1}{\beta}$)

Generalised small signal hybrid (*h*-) parameters

Input resistance $h_{\text{i}} = \dfrac{\Delta V_{\text{in}}}{\Delta I_{\text{in}}}$ Reverse transfer voltage ratio $h_{\text{r}} = \dfrac{\Delta V_{\text{in}}}{\Delta V_{\text{out}}}$

Forward current transfer ratio $h_{\text{f}} = \dfrac{\Delta I_{\text{out}}}{\Delta I_{\text{in}}}$ Output conductance $h_{\text{o}} = \dfrac{\Delta I_{\text{out}}}{\Delta V_{\text{out}}}$

Common emitter small signal *h*-parameters

Input resistance $h_{\text{ie}} = \dfrac{\Delta V_{\text{be}}}{\Delta I_{\text{b}}}$ Reverse transfer voltage ratio $h_{\text{re}} = \dfrac{\Delta V_{\text{be}}}{\Delta V_{\text{ce}}}$

Forward current transfer ratio $h_{\text{fe}} = \dfrac{\Delta I_{\text{c}}}{\Delta I_{\text{b}}}$ Output conductance $h_{\text{oe}} = \dfrac{\Delta I_{\text{c}}}{\Delta V_{\text{ce}}}$

Common emitter amplifier voltage gain $A_{\text{v}} \approx \dfrac{h_{\text{fe}} R_{\text{L}}}{h_{\text{ie}}}$

Operational amplifiers

Voltage gain $A_{\text{v}} = \dfrac{V_{\text{out}}}{V_{\text{in}}}$ or $A_{\text{v}} = 20\log_{10}\left(\dfrac{V_{\text{out}}}{V_{\text{in}}}\right)\text{dB}$

Slew rate $= \dfrac{\Delta V_{\text{be}}}{\Delta t}$ Inverting amplifier voltage gain $A_{\text{v}} = \dfrac{V_{\text{out}}}{V_{\text{in}}} = \dfrac{R_{\text{F}}}{R_{\text{IN}}}$

Lower cut-off frequency of an inverting amplifier $f_1 = \dfrac{1}{2\pi C_{\text{IN}} R_{\text{IN}}} = \dfrac{0.159}{C_{\text{IN}} R_{\text{IN}}}$

Upper cut-off frequency of an inverting amplifier $f_2 = \dfrac{1}{2\pi C_{\text{F}} R_{\text{F}}} = \dfrac{0.159}{C_{\text{F}} R_{\text{F}}}$

Bandwidth $f_2 - f_1 = \left(\dfrac{1}{2\pi C_{\text{F}} R_{\text{F}}}\right) - \left(\dfrac{1}{2\pi C_{\text{IN}} R_{\text{IN}}}\right) = 0.159\left(\dfrac{1}{C_{\text{F}} R_{\text{F}}} - \dfrac{1}{C_{\text{IN}} R_{\text{IN}}}\right)$

Oscillators

Gain with positive feedback $G = \dfrac{A_v}{1-\beta A_v}$ (when $\beta A_V \to 1$, $G \to \infty$)

Ladder network oscillator (with three CR sections) $f = \dfrac{1}{2\pi\sqrt{6}CR}$

Wien bridge oscillator (with $C=C_1=C_2=$ and $R=R_1=R_2$) $f = \dfrac{1}{2\pi CR}$

Gain with negative feedback $G = \dfrac{A_v}{1+\beta A_v}$ (when β is large, $G \approx \dfrac{1}{\beta}$)

Astable multivibrator (with $C=C_1=C_2=$ and $R=R_1=R_2$) $T = 1.4\ CR$

Timers

Monostable mode $T = 1.1\ CR$

Astable mode $t_{on} = 0.693C(R_1+R_2)$ $t_{off} = 0.693CR_2$ $T = t_{on}+t_{off} = 0.693C(R_1+2R_2)$

Pulse repetition frequency $p.r.f. = \dfrac{1.44}{C(R_1+2R_2)}$

Mark to space ratio $= \dfrac{t_{on}}{t_{off}} = \dfrac{R_1+R_2}{R_2}$

Duty cycle $= \dfrac{t_{on}}{t_{on}+t_{off}} = \dfrac{R_1+R_2}{R_1+2R_2} \times 100\%$

Transformers

Flux equation $\phi = \phi_{max}\sin(2\pi ft)$

Primary voltage $V_p = 4.44 fN_p\phi_{max}$ Secondary voltage $V_s = 4.44 fN_s\phi_{max}$

Voltage and turns ratio $\dfrac{V_p}{V_s} = \dfrac{N_p}{N_s}$ Turns per volt $= \dfrac{N_p}{V_p} = \dfrac{N_s}{V_s}$