ECEN 214 Reference Sheet Last Updated: November 2, 2016 © Josh Wright

Latex Symbols: http://oeis.org/wiki/List_of_LaTeX_mathematical_symbols

Metric Prefixes:

peta	P	10^{15}	1 000 000 000 000 000
tera	T	10^{12}	1 000 000 000 000
giga	G	10^{9}	1 000 000 000
mega	M	10^{6}	1 000 000
kilo	k	10^{3}	1 000
hecto	h	10^{2}	100
deca	da	10^{1}	10
one		10^{0}	1
deci	d	10^{-1}	0.1
centi	c	10^{-2}	0.01
milli	m	10^{-3}	0.001
micro	μ	10^{-6}	0.000 001
nano	n	10^{-9}	0.000 000 001
pico	p	10^{-12}	0.000 000 000 001
femto	f	10^{-15}	0.000 000 000 000 001

Ohm's Law: $V = IR, \quad I = \frac{V}{R}, \quad R = \frac{V}{I}$

Power: $P = IV = I^2R = \frac{V^2}{R}$

Energy:

- $W = \int_0^t P(s)ds$
- Unit: Watts, $W = \frac{J}{s} = \frac{V^2}{\Omega} = VA = A^2\Omega$

KCL: Kirchoff's Current Law:

- All currents out of (or into) a point sum to 0
- be careful with signs with this!

KVL: Kirchoff's Voltage Law:

- The sum of voltages around a fixed loop is 0
- be careful with signs with this one too!

Exam 1 stuff:

Source Transformation:

- When you have a current source with a resistor in parallel to its load or a voltage source with a resistor in series to it's load, you can use Ohm's Law to transform it into the opposite source type.
- The resistor value stays constant, the source type and value changes

Nodal Analysis:

- use KCL to sum all currents at each node to 0
- when in doubt, use more nodes
- remember to have a ground node for reference
- convention is to count current out of the node as positive
  - current sources pointing into the node are counted negative

Superposition:

- evaluate the circuit many times, killing all but one source each time
- sum the results to get the final result (be careful with signs)
- superposition only applies for linear circuits
  - which nearly all are. Notable exception: stuff with diodes

Mesh:(current loop method)

- use KVL to sum all the voltages in each loop to 0
- convention is to loop clockwise
- when you hit a voltage terminal, use the sign of that terminal; e.g. hit negative terminal of V_x means append "$-V_x$" to equation. (does not matter if V_s is source or component)
- When you hit a resistor, use $V = IR$ to find voltage drop

Thevenin: Independent Only:

- always remove the load resistor (if present) first
- find V_{th} by assuming AB is an open circuit
- find R_{th}:
  - first deactivate all sources in the circuit
  - then determine the equivalent resistance from A to B

Thevenin: Dependent and Independent:

- Note: you can't kill independent sources
- find V_{th} the same way
- find R_{th}:
  - kill all independent sources
  - put a 1Amp independent current source across AB
  - find voltage across new independent source
  - use $R_{th} = \frac{V}{I} = \frac{V}{1\text{Amp}}$

Thevenin: Dependent Only:

- can't find V_{th} regular way, so use 1Amp source method
- This means you will get $R_{th} = \frac{V_{th}}{1\text{Amp}}$

Norton Equivalent:

- just use Ohm's Law on the Thevenin Equivalent

Exam 2 stuff:

Ideal Op Amp:

- The output tries to do whatever is necessary to make the difference between the input voltages zero.
- Zero current in/out from the input pin
- For a real op amp, the output voltage is limited to $\pm V_{CC}$
  - Saturated when $|V_{out}| = V_{CC}$

Op Amp - Inverting:

- $V_o \to R_f \to -$input
  $-$input $\to R_s \to V_s$
  $+$input $\to$ ground
- R_f: feedback resistor
  R_s: source resistor
- $V_o = -\frac{R_f}{R_s} V_s$
- linear region: $\left|\frac{R_f}{R_s}\right| \leq \left|\frac{V_{CC}}{V_s}\right|$

Op Amp - Summing:

- Adds voltages
- Similar to inverting op amp except that each input is wired as $V_x \to R_x \to -$input. (Only one R_f, but one $R_s = R_x$ for each input)
- $V_o = -\left(\frac{R_f}{R_a} V_a + \frac{R_f}{R_b} V_b + \dots\right)$
- If $R_f = R_a = R_b \dots$ then $V_o = -(V_a + V_b + \dots)$

Op Amp - Non-inverting:

- $+$input$\to R_s \to V_g \to$ground
  $-$input$\to R_s \to$ground
  (two different resistors each with value R_s)
  same R_f feedback resistor as inverting amp
  R_f and R_s form an unloaded voltage divider across $-$input
- $V_o = \frac{R_s+R_f}{R_s} V_g$
- Linear region: $\frac{R_s+R_f}{R_s} < \left|\frac{V_{CC}}{V_g}\right|$

Op Amp - Difference:

- regular feedback resistor R_b
  R_a: from V_a to $-$input
  R_c: from V_b to $+$input
  R_d: from $+$input to ground
- $V_o = \frac{R_d(R_a+R_b)}{R_a(R_c+R_d)} V_b - \frac{R_b}{R_a} V_a$
- if $\frac{R_a}{R_b} = \frac{R_c}{R_d}$ then $V_o = \frac{R_b}{R_a}(V_b - V_a)$

Op Amp - Integrator:

- Circuit: just like inverting op-amp except with a capacitor instead of the feedback resistor (R_f)
- The only resistor is R_s, between the source and the $-$input of the op amp
- $V_o = -\frac{1}{R_s C} \int V_{in} dt$
- can be used to turn square wave into sawtooth wave

Op Amp - Differentiator:

- Circuit: just like inverting op-amp except with a capacitor instead of the input resistor (R_s)
- $V_o = -R_f C \frac{dV_{in}}{dt}$
- Can be used to turn sawtooth wave into square wave

Inductors:

- Series and parallel is the same as resistors
- Voltage: $V_L(t) = -L\frac{di_L(t)}{dt}$
  Energy: $W(t) = \frac{1}{2} L * i(t)^2$
- $\tau = \frac{L}{R}$
- RL Charging: $i(t) = i_f + (i_o - i_f)e^{-tR/L}$
- RL Discharging: $i(t) = i_o e^{-tR/L}$

Capacitors:

- Series and parallel is the opposite as resistors
- Current: $I_c(t) = C\frac{dV_C(t)}{dt}$
  Energy: $W(t) = \frac{1}{2} C * V_C(t)^2$
- $\tau = RC$
  V_f =final voltage
  V_o =initial voltage
- RC Charging: $V(t) = V_f + (V_o - V_f)e^{-t/(RC)}$
- RC Discharging: $V(t) = V_o e^{-t/(RC)}$

Exam 3 stuff:

RLC Circuits - Parallel:

- $s_{1,2} = \frac{1}{2/RC} \pm \sqrt{\left(\frac{1}{2RC}\right)^2 - \frac{1}{LC}}$
  $s_{1,2} = -\alpha \pm \sqrt{\alpha^2 - \omega_0^2}$
- $\alpha = \frac{1}{2RC}$
- resonant frequency: $\omega_0 = \frac{1}{\sqrt{LC}}$
- damping:
  - $\omega_0 < \alpha$: over damped
    * $V(t) = A_1 e^{s_1 t} + A_2 e^{s_2 t}$
  - $\omega_0 = \alpha$: critically damped
    * $V(t) = B_1 t e^{\alpha t} + B_2 e^{\alpha t}$
  - $\omega_0 > \alpha$: under damped
    * $V(t) = B_1 t e^{\alpha t}\cos(\omega_0 t) + B_2 e^{\alpha t}\sin(\omega_0 t)$
- $\omega_d = \sqrt{\omega_0^2 - \alpha^2}$ damped frequency (only relevant for under damped)

Impedance:

- $V = IZ$
- $Z_R = R$
  - $\phi_R = 0°$
- $Z_L = j\omega L$
  - Current lags 90° behind voltage
  - $\phi_L = -90°$
- $Z_C = \frac{1}{j\omega C}$
  - Current leads voltage by 90°
  - $\phi_C = 90°$

Reactance:

- $X_L = \frac{V_L}{I_L} = \omega L = 2\pi f L$
- $X_C = -\frac{1}{\omega C} = -\frac{1}{2\pi f C}$

Complex Power:

- $S = P + jQ = \frac{(V_{RMS})^2}{Z^*}$
  - $\bar{Z}$ is complex conjugate of Z
- $P = \frac{V_m I_m}{2}\cos(\theta_v - \theta_i)$
- $Q = \frac{V_m I_m}{2}\sin(\theta_v - \theta_i)$
- $S = V\bar{I}^*$
  - * also means conjugate

Maximum Power Transfer:

- unrestricted: $Z_L = \bar{Z}_{Th}$
- restricted: $|Z_L| = |\bar{Z}_{Th}|$