Extra Study Guide

Common Engineering Exponential Factors

T (Tera)	10^{12}	E12	p (pico)	10^{-12}	E-12
G (Giga)	10^{9}	E9	n (nano)	10^{-9}	E-9
M (Mega)	10^{6}	E6	u (micro)	10^{-6}	E-6
k (Kilo)	10^{3}	E3	m (milli)	10^{-3}	E-3

Exponential Numbers

- 146,730,000 = 146.73 x 10^{6} = 146.73E6 = 1.4673 x 10^{8} = 1.4673E8
- 146,730,000 Hz = 146.73 x 10^{6} Hz = 146.73 MHz
- 0.000,022 = 22 x 10^{-6} = 22E-6
- 0.000,022 F = 22 x 10^{-6} F = 22 μF
- 2,000,000,000,000 B = 2 x 10^{12} B = 2E12 B = 2 TB

Impedance, Resistance, Reactance

- Impedance (Z) is the opposition to the flow of current in an AC circuit
- Resistance (R) is the opposition to the flow of current in a DC circuit
- Reactance (X) is the opposition to the flow of AC current in Inductors and Capacitors
- All have units Ohms (Ω)
- Impedance is a complex number Z = (R, jX)

Admittance, Conductance, Susceptance

- Admittance (Y) is the ability to allow the flow of current in an AC circuit
- Conductance (G) is the ability to allow the flow of current in a DC circuit
- Susceptance (B) is the ability to allow the flow of AC current in Inductors and Capacitors
- These are all inverse units of Impedance, Resistance, and Reactance
  Y = 1/Z, G = 1/R, B = 1/X
- All have units Siemens, informally mhos or upside-down Ohms symbol
- Admittance is a complex number Y = (G, jB)

Reactance

Inductive Reactance
$X_L = j2\pi fL$
Inductive Reactance is Positive Reactance

Capacitive Reactance
$$X_C = \frac{1}{j2\pi fC} = \frac{1}{j2\pi fC} \times \frac{j}{j} = \frac{j}{j^2 2\pi fC} = \frac{-j}{2\pi fC}$$
Capacitive Reactance is Negative Reactance

Complex Numbers

i = j = SQRT(-1) = $\sqrt{-1}$ $\quad$ $j^2 = j * j = -1$

Complex Number: C = (X + jY) = (X, jY) [Cartesian Coordinates]

$C_1 + C_2 = (X_1, jY_1) + (X_2, jY_2) = (X_1 + X_2, j(Y_1 + Y_2))$
$C_1 * C_2 = (X_1, jY_1) * (X_2, jY_2)$
$C_1 * C_2 = (X_1 * X_2 - Y_1 * Y_2, j(X_1 * Y_2 + X_2 * Y_1))$

The Complex Conjugate of a Complex number has the opposite Sign for the Imaginary Part
Conjugate of C = (X, jY) is C^*= (X, -jY)

C x C^* produces a Real Number $X^2 + Y^2$
The Imaginary cross product parts cancel each other out.
Dividing by a Complex number is the same as Multiplying by its Complex Conjugate and Dividing by a Real Number

$$\frac{1}{C} = \frac{1}{C} \times \frac{C^*}{C^*} = \frac{1 \times C^*}{C \times C^*} = \frac{C^*}{X^2 + Y^2}$$

Example: Converting between Susceptance and Reactance

$$jX = \frac{1}{jB} = \frac{1}{jB} \times \frac{j}{j} = \frac{-j}{B}$$

Converting between Susceptance and Reactance causes the sign of the value to change in addition to the inverse of the magnitude.

Complex Number: C = (R, ΘA)   [Polar Coordinates]

Cartesian to Polar

$$R = \sqrt{X^2 + Y^2} \qquad A = \tan^{-1}\left(\frac{Y}{X}\right)$$

Polar to Cartesian

$$X = R\cos(A) \qquad Y = R\sin(A)$$

To multiply or divide in Polar Coordinates:
Multiply: Multiply R's, Add A's
Divide: Divide R's, Subtract A's

$$C_1 \times C_2 = (R_1, \Theta A_1) \times (R_2, \Theta A_2) = (R_1 \times R_2, \Theta(A_1 + A_2))$$

$$\frac{C_1}{C_2} = \frac{(R_1, \Theta A_1)}{(R_2, \Theta A_2)} = \left(\frac{R_1}{R_2}, \Theta(A_1 - A_2)\right)$$

Decibels

$$dB = 10 \times \log_{10}\left(\frac{P_{out}}{P_{in}}\right)$$

3 dB (-3 dB) is a doubling (halving) of the power.
10 dB per Decade. Each order of magnitude (power of 10) is 10 dB.
Increase of magnitude is positive dB, decrease of magnitude is negative dB.
$\log_{10}(10) = 1 \qquad \log_{10}(0.1) = -1 \qquad \log_{10}(2) = 0.301$

Decibel formula also used in noise floor calculations, but using the ratio of frequency bandwidth.

$\log_{10}$ and 10^x are inverse functions. $\log_{10}(10^x) = x$

Real and Apparent Power

Apparent Power (Complex)	Power (Real)
$P_A = V * A$ (Any Phase)	$P = I * E$ (In Phase, Phase = 0)
$P_A = A^2 * Z$ (Z is Complex)	$P = I^2 * R$ (R is Real)
$P_A = V^2 / Z$ (Z is Complex)	$P = E^2 / R$ (R is Real)
	$P = P_A * PF = P_A * COS(\theta)$

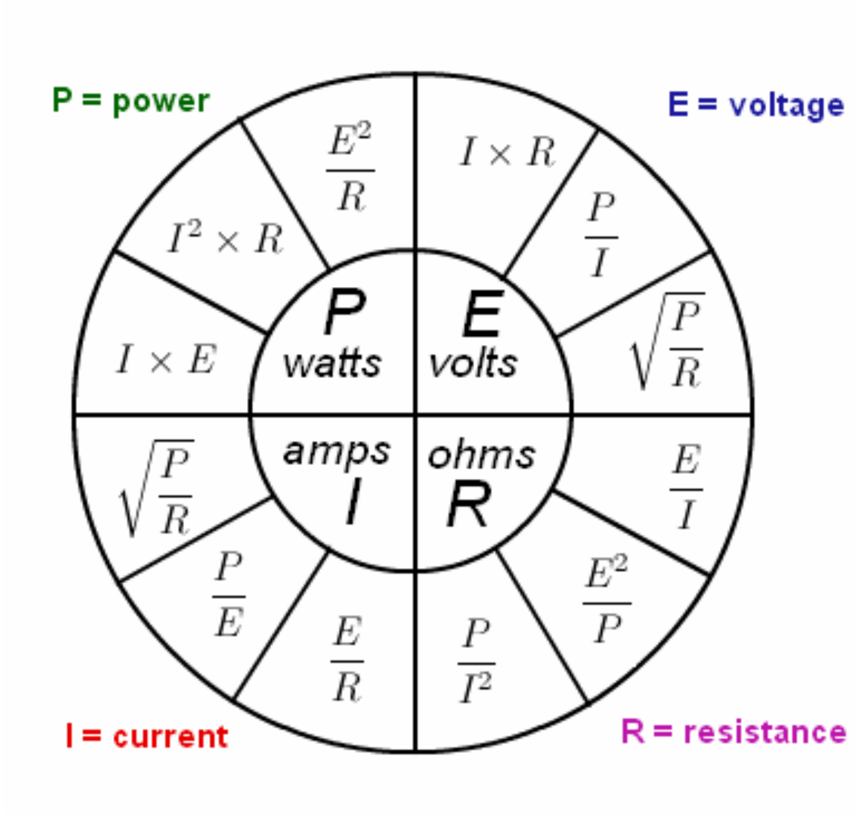
Voltage / Current, Lead / Lag

Capacitor:
- Voltage Lags Current by 90
- Negative Reactance
- Capacitors store Energy in the Electric Field

Inductor:
- Voltage Leads Current by 90
- Positive Reactance
- Inductors store Energy in the Magnetic Field

ELI the ICE man
- Voltage (E) before [leads] Current (I) in an Inductor (L)
- Current (I) before [leads] Voltage (E) in a Capacitor (C)

Ohms Law: $E = IR$, $I = E/R$, $R = E/I$
Power Equation: $P = IE$, $I = P/E$, $E = P/I$
Variables can be substituted between these equations to create more complex equations. Given 2 values from P, I, E, or R calculate 1 of the other 2 variables.



Wavelength/Frequency

Speed of Light c = 299,792,458 meters/second
This is exact because the length of a meter is defined by the speed of light.
Approximate speed of light is 300,000,000 meters/second
Close enough for government work, and the FCC

Frequency (MHz) = 300 / Wavelength (meters)

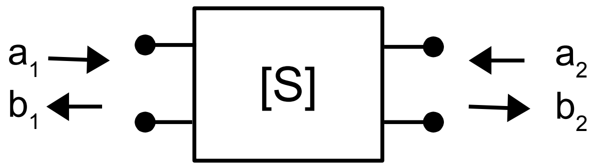
Wavelength (meters) = 300 / Frequency (MHz)

This is why frequency ranges always have a 3

MF (medium frequency): 300 – 3000 kHz	Part 97.3(b)(5)
HF (high frequency): 3 – 30 MHz	Part 97.3(b)(2)
VHF (very high frequency): 30 – 300 MHz	Part 97.3(b)(10)
UHF (ultra-high frequency): 300 – 3000 MHz	Part 97.3(b)(9)
SHF (super-high frequency): 3 – 30 GHz	Part 97.3(b)(8)
EHF (extremely high frequency): 30 – 300 GHz	Part 97.3(b)(1)

S-Parameters (or Scattering Parameters)

A matrix representation of a linear electrical network (circuit) expressed by the incident (input) and reflected power at a port. Any number of ports may be specified, but a 2-port network is most common. A length of coax may be modeled using 2-port S-parameters.



The incident and reflected power can be specified as

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

If Port 1 is the input and Port 2 is the output, then the input power is a_1, and the output power is b_2. The calculated value of b_2 is

$$b_2 = S_{21} \times a_1 + S_{22} \times a_2$$

S_{21} is the forward power transfer coefficient. (Possible exam question)

Reflected power at the input is

$$b_1 = S_{11} \times a_1 + S_{12} \times a_2$$

S_{11} is the return loss or SWR (Possible exam question)

For more information on various equations for 2 Port models, see
https://en.wikipedia.org/wiki/Two-port_network

Time Constants

1 Time Constant (1τ) is the amount of time it takes to charge a capacitor in an RC circuit to 63.2% of the applied voltage, or to discharge a capacitor in an RC circuit to 36.8% of its initial voltage.

τ = RC where R is resistance (in ohms) and C is capacitance (in farads).

$$V(t) = V_0 e^{-t/\tau} = V_0 e^{-t/RC}$$

Trigonometry

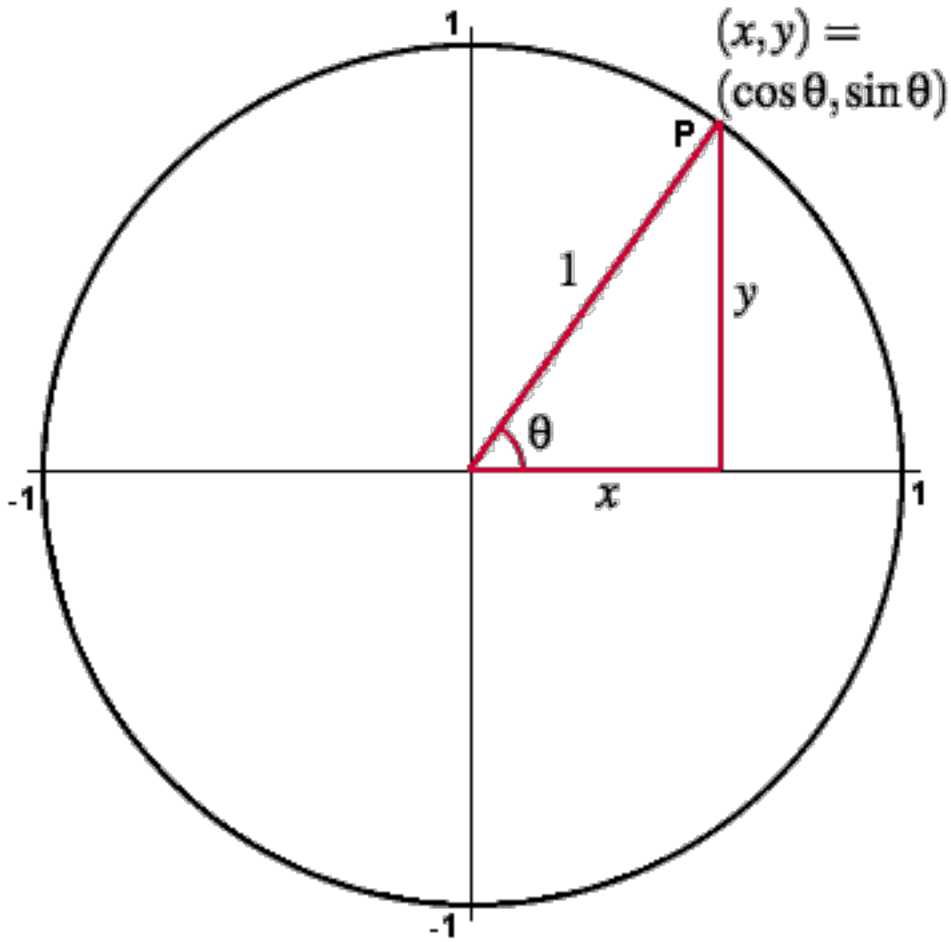
Sine and Cosine are defined as the sides of a right triangle inside a unit circle (circle with a radius of 1), where the hypotenuse is a line from the origin (center) of the circle to a point on the circle. (See below)

Sine (sin) is the y value, Cosine (cos) is the x value.
Both Sine and Cosine have values between -1 and +1.

If the angle θ is swept from 0 to 360° (2π) a plot of y versus θ is a Sine Wave, and a plot of x versus θ is a Cosine Wave. Sine and Cosine waves are offset by 90° $\left(\frac{\pi}{2}\right)$.

Tangent, $\tan(\theta) = \frac{y}{x} = \frac{\sin(\theta)}{\cos(\theta)}$
Cotangent, $\cot(\theta) = \frac{x}{y} = \frac{1}{\tan(\theta)} = \frac{\cos(\theta)}{\sin(\theta)}$
Tangent and Cotangent have values between $-\infty$ to $+\infty$, because the denominator may be 0. For tangent this occurs at angles of 90° and 270°. For cotangent this occurs at angles 0° and 180°.

When performing trig functions on your calculator, be sure you have set the calculator to the correct mode. Degrees for 0° to 360°. Radians (RAD) for 0 to 2π. sin(360) gives completely different answers between Degrees and Radian modes.



$(x, y) =$
$(\cos\theta, \sin\theta)$
P
1
y
θ
x
1
-1
1
-1