Announcements

- Homework solutions moved to “Pages” section of Canvas
- Homework Scanning – Check Quality
- Experiment 1 posted

Schedule

L12 - Feb. 19 Phasor Analysis Examples LTSpice and MATLAB Phasor Analysis	**L13 - Feb. 21** Phasor Power: Average and RMS *Sections 11.1-11.2*	**L14 - Feb. 23** Phasor Power Complex, Reactive, and Apparent Power Power Factor *Sections 11.3-11.5* Homework 4 Due *Complete Experiment 1 Prelab*
L15 - Feb. 26 Maximum Power Transfer Impedance Matching *Sections 11.3 & 11.6*	**L16 - Feb. 28** Quiz 2: Phasor Circuit Analysis	**L17 - Mar. 1** Homework 5 Due Experiment 1 Due
L18 - Mar. 4	**L19 - Mar. 6** **Midterm Exam 1**	**L20 - Mar. 8** *Complete Experiment 2 Prelab*
Mar. 11 Spring Break	Mar. 13 Spring Break	Mar. 15 Spring Break
L21 - Mar. 18	**L22 - Mar. 20**	**L23 - Mar. 22** Homework 6 Due Experiment 2 Due

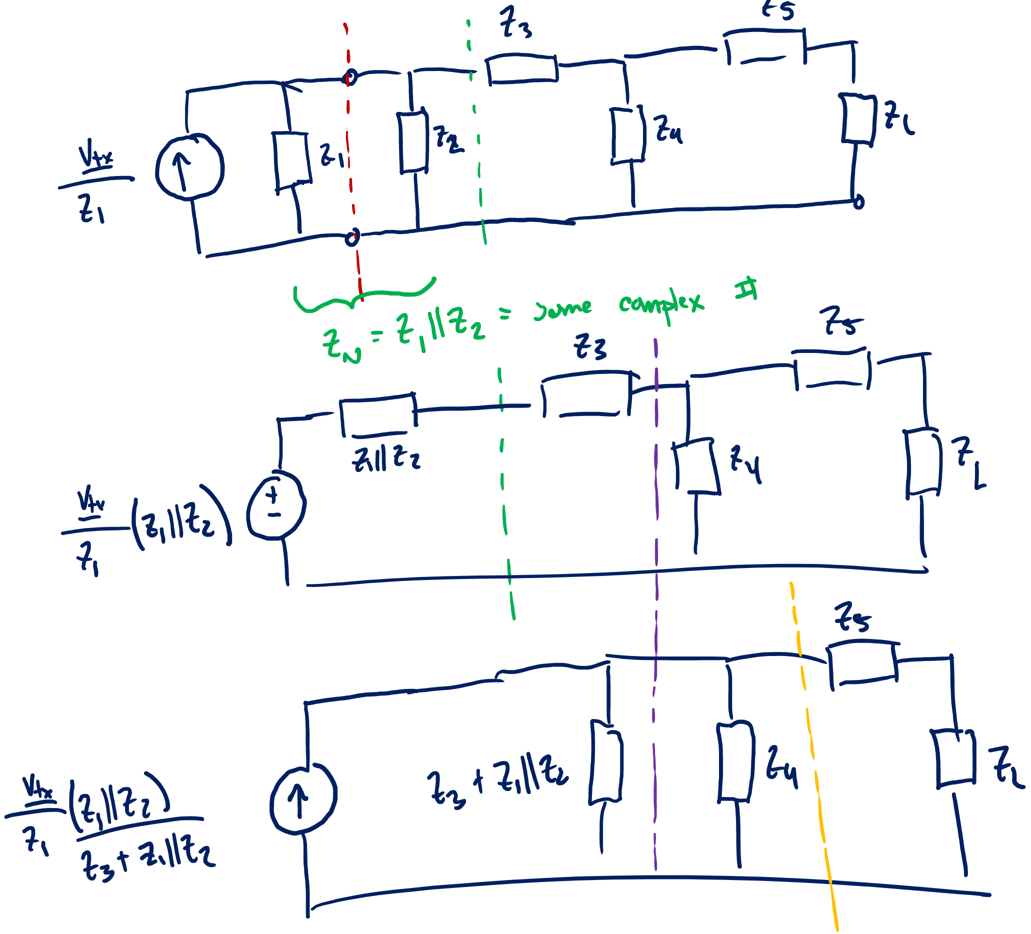
Experiment 1

- Prelabs: Individual Submissions
- Experiment Report: Group Submission
- Equipment Requirements (per *group*)
  - Purchase from MK108 (VolCard only)
    - ECE 201/202 parts kit ($31.20+)
    - ECE 202 supplement ($9)
  - Analog Discovery Studio

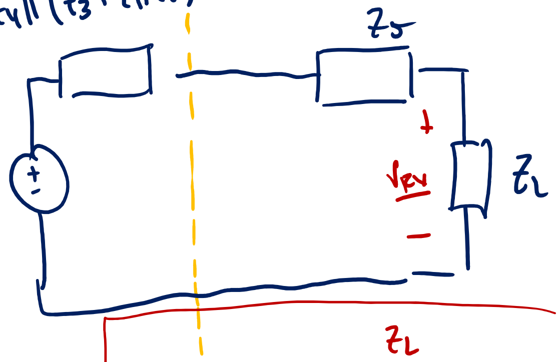
    or
  - Test in MK333

Upcoming In-Class Assignments

- Quiz 2
  - Phasor Circuit Analysis
    - Chapter 10
    - Homeworks 3 & 4
    - Lectures 7-12


Z3
Z5
Z1
Z2
Z4
ZL
Vtx / Z1
ZN = Z1||Z2 = same complex #
Z1||Z2
Vtx / Z1 (Z1||Z2)
Z3 + Z1||Z2
Vtx / Z1 · (Z1||Z2) / (Z3 + Z1||Z2)

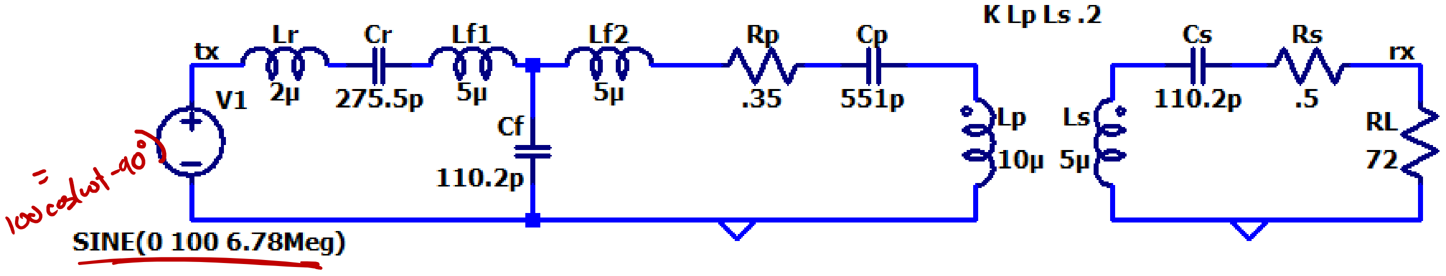
$$Z_{th} = Z_4 \| (Z_3 + Z_1 \| Z_2)$$



$$\underbrace{\frac{V_{tx}}{Z_1} \frac{(Z_1 \| Z_2)}{Z_3 + (Z_1 \| Z_2)} \left[Z_4 \| (Z_3 + Z_1 \| Z_2) \right]}_{V_{th}}$$

$$V_{RX} = V_{th} \frac{Z_L}{Z_L + Z_5 + Z_{th}}$$

Numerical Example



MATLAB Code:

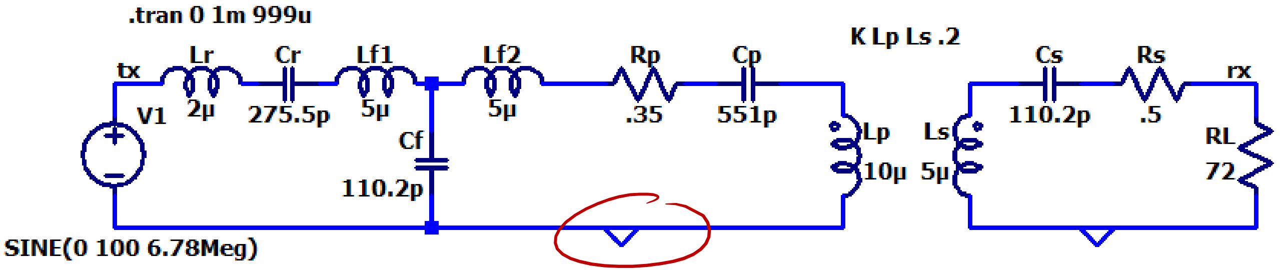
```
f = 6.78e6;          % Sinusoidal frequency [Hz]
w = 2*pi*f;          % Sinusoidal frequency [rad/sec]
VTX = 100*exp(-1i*pi/2); % Transmitter Voltage Phasor

Lr = 2e-6;
Cr = 1/w^2/Lr;

Lf1 = 5e-6;
Lf2 = Lf1;
Cf = 1/w^2/Lf1;

Rp = .35;
Lp = 10e-6;
Cp = 1/w^2/Lp;

k = .2;
M = k*sqrt(Lp*Ls);

Ls = 5e-6;
Cs = 1/w^2/Ls;
Rs = .5;

RL = 72;
```

```
Z1 = 1j*(w*Lr + w*Lf1 - 1/w/Cr);
Z2 = -1j/w/Cf;
Z3 = Rp + 1j*(w*Lf2 - 1/w/Cp) + 1j*w*(Lp-M);
Z4 = 1j*w*M;
Z5 = Rs + 1j*w*(Ls-M) -1j/w/Cs;
ZL = RL;

Za = 1/(1/Z4 + 1/(Z3 + (Z1*Z2/(Z1+Z2)))); % Z4 || (Z3 + Z1||Z2)
Va = VTX/Z1  * (Z1*Z2/(Z1+Z2))  /  (Z3 + (Z1*Z2/(Z1+Z2))) * Za;

VRX = Va*(RL/(RL+Z5+Za))

mag = abs(VRX)
phase = angle(VRX)/pi*180
```

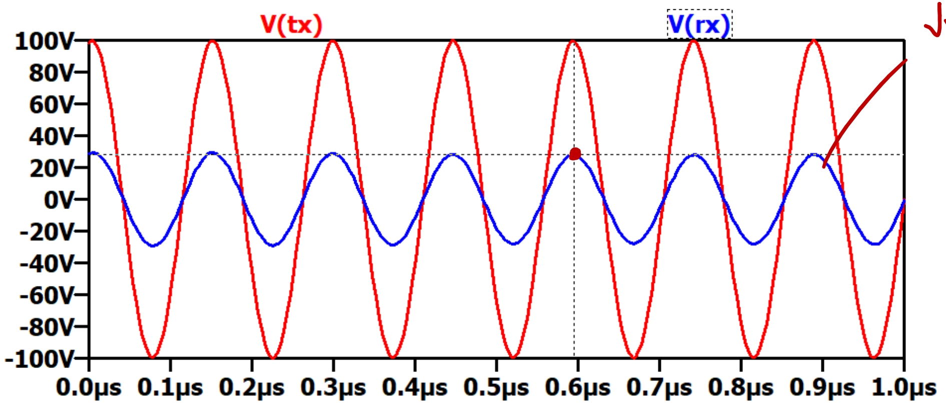
mag =
28.0892

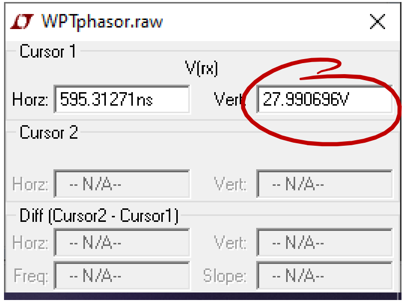
phase =
-90.0000

Circuit Simulation

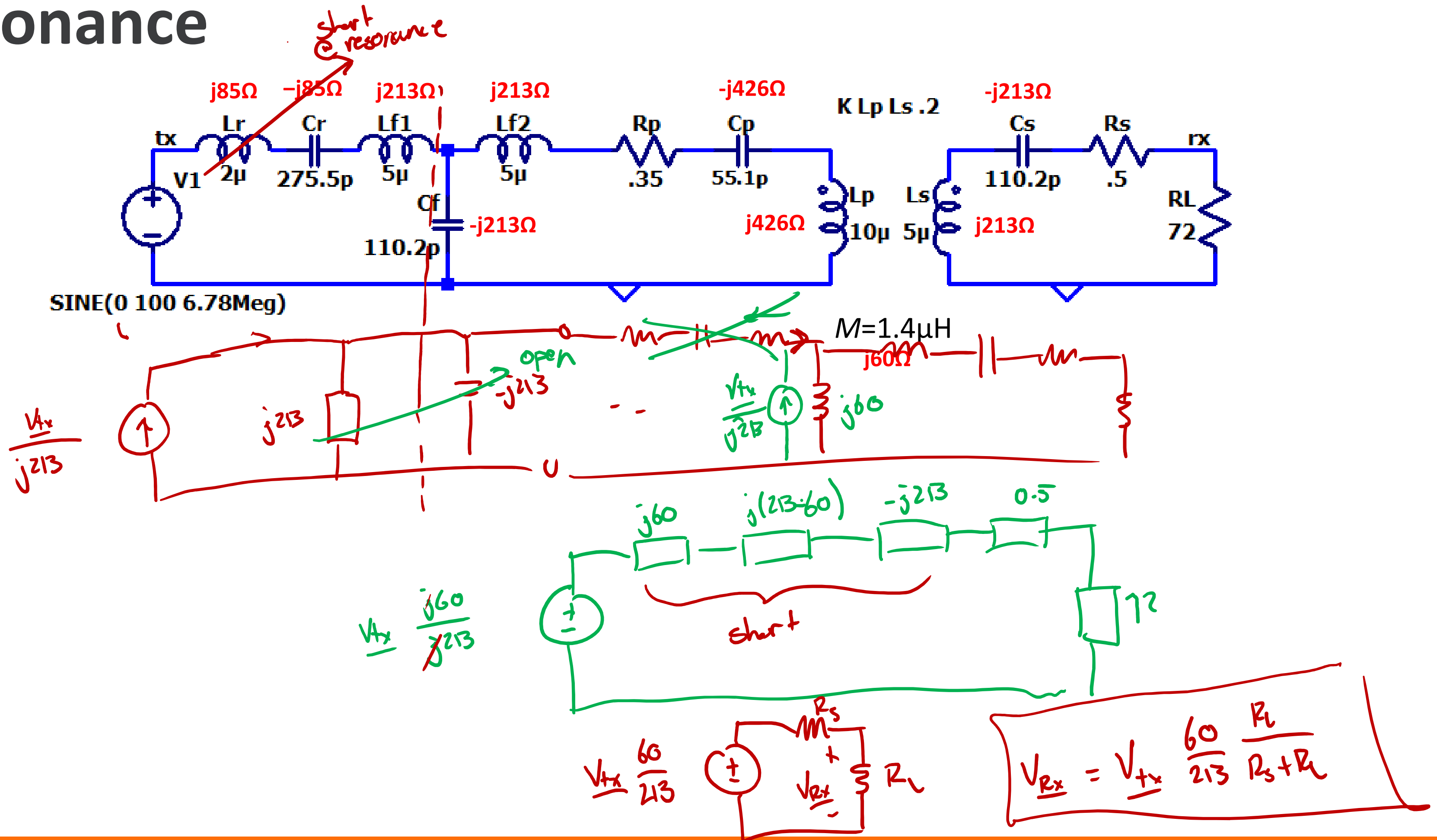


V_{RX} is in-phase w/ V_{tx} @ -90°



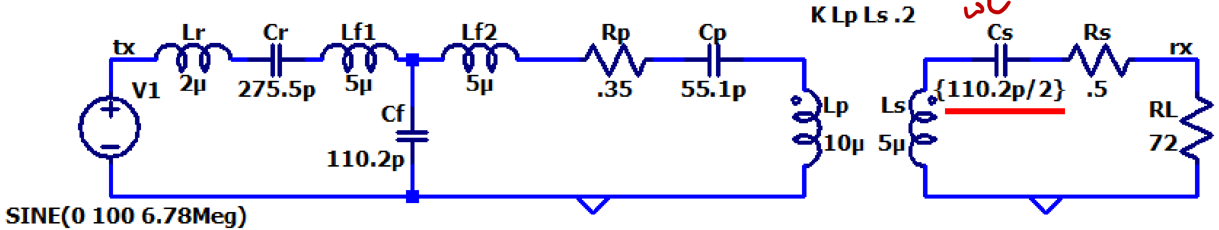


Resonance


j85Ω
−j85Ω
j213Ω
j213Ω
-j426Ω
K Lp Ls .2
-j213Ω
tx
Lr
2µ
Cr
275.5p
Lf1
5µ
Lf2
5µ
Rp
.35
Cp
55.1p
Cs
110.2p
Rs
.5
rx
V1
Cf
-j213Ω
110.2p
j426Ω
Lp
10µ
Ls
5µ
j213Ω
RL
72
SINE(0 100 6.78Meg)
M=1.4µH

Numerical Example 2

$$\frac{-j}{\omega C} = -j426 = (-j213)\,2$$



MATLAB Result:

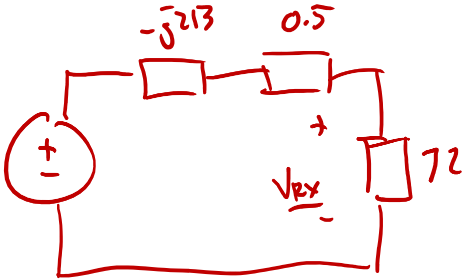
mag =

9.06

phase =

-18.7973

$$V_{tx}\,\frac{60}{213}$$



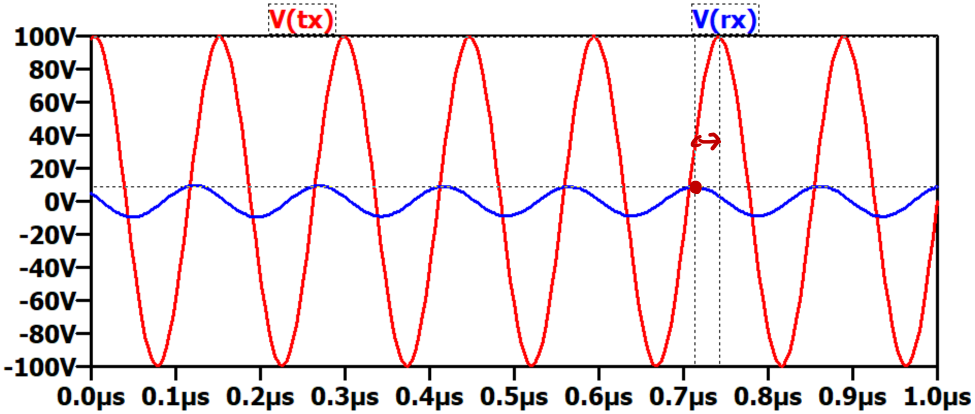
$$V_{RV} = V_{tx}\,\frac{60}{213}\,\frac{72}{72 + 0.5 - j213}$$

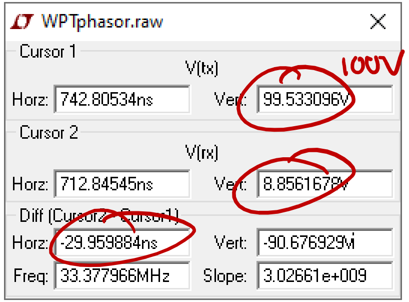
Circuit Simulation 2

phases in rad — phases in degrees

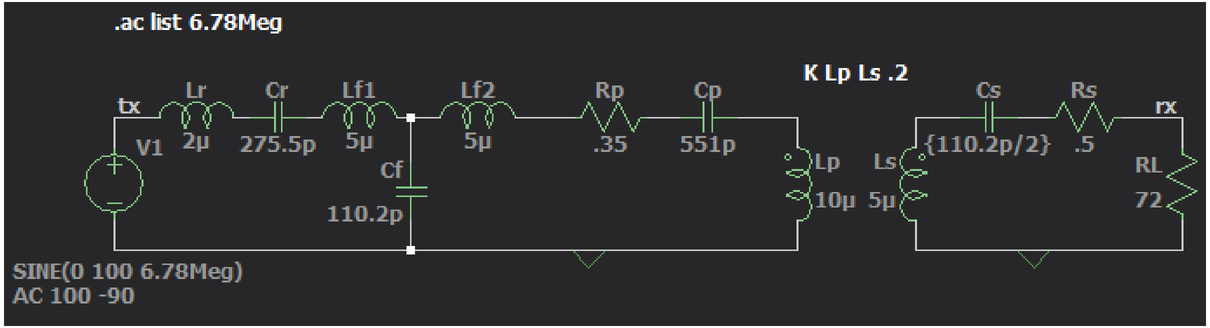
$$\frac{t_{max,rx} - t_{max,rx}}{T} = \frac{\varphi_{rx} - \varphi_{tx}}{2\pi} = \frac{\theta_{rx} - \theta_{tx}}{360^{\circ}}$$

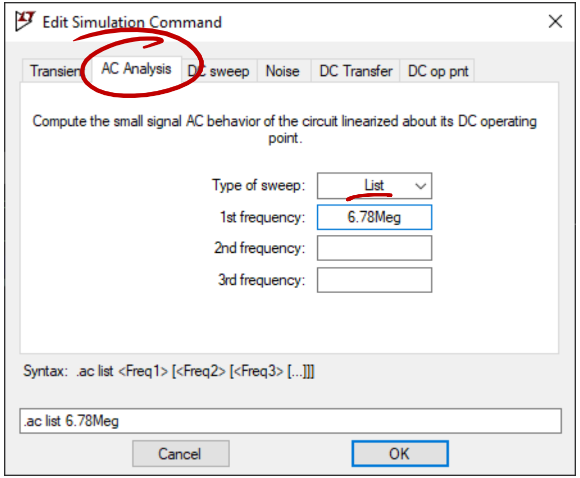
$$T = \text{period} = \frac{1}{6.78\,\text{MHz}}$$

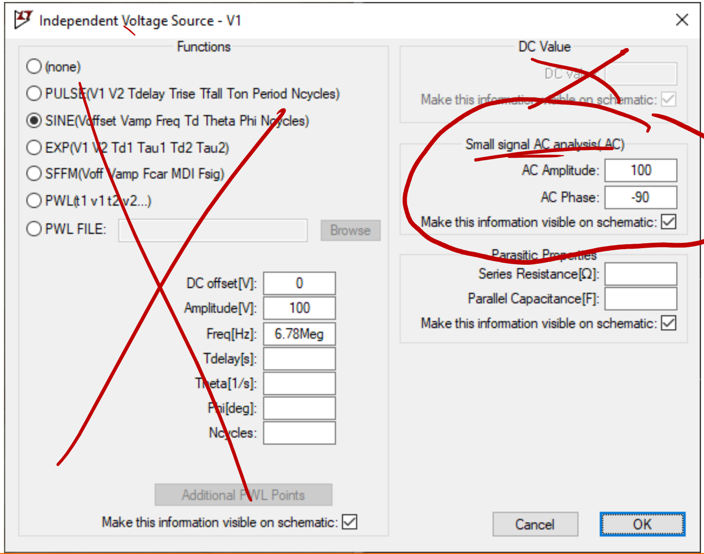




AC Analysis


.ac list 6.78Meg
K Lp Ls .2
tx
V1
Lr
2µ
Cr
275.5p
Lf1
5µ
Cf
110.2p
Lf2
5µ
Rp
.35
Cp
551p
Lp
10µ
Ls
5µ
Cs
{110.2p/2}
Rs
.5
rx
RL
72
SINE(0 100 6.78Meg)
AC 100 -90


Edit Simulation Command
Transient
AC Analysis
DC sweep
Noise
DC Transfer
DC op pnt
Compute the small signal AC behavior of the circuit linearized about its DC operating point.
Type of sweep:
List
1st frequency:
6.78Meg
2nd frequency:
3rd frequency:
Syntax: .ac list <Freq1> [<Freq2> [<Freq3> [...]]]
.ac list 6.78Meg
Cancel
OK

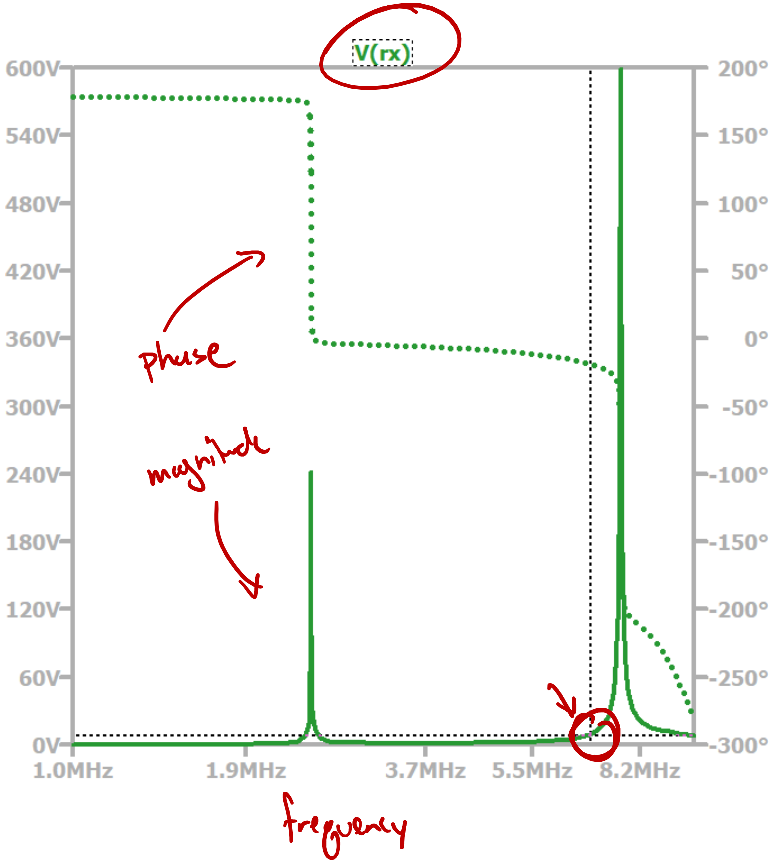

Independent Voltage Source - V1
Functions
(none)
PULSE(V1 V2 Tdelay Trise Tfall Ton Period Ncycles)
SINE(Voffset Vamp Freq Td Theta Phi Ncycles)
EXP(V1 V2 Td1 Tau1 Td2 Tau2)
SFFM(Voff Vamp Fcar MDI Fsig)
PWL(t1 v1 t2 v2...)
PWL FILE:
Browse
DC offset[V]:
0
Amplitude[V]:
100
Freq[Hz]:
6.78Meg
Tdelay[s]:
Theta[1/s]:
Phi[deg]:
Ncycles:
Additional PWL Points
Make this information visible on schematic:
DC Value
DC value:
Make this information visible on schematic:
Small signal AC analysis(.AC)
AC Amplitude:
100
AC Phase:
-90
Make this information visible on schematic:
Parasitic Properties
Series Resistance[Ω]:
Parallel Capacitance[F]:
Make this information visible on schematic:
Cancel
OK

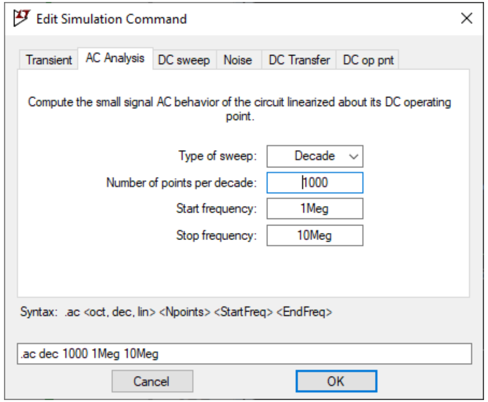
AC Simulation Results (Single Point)

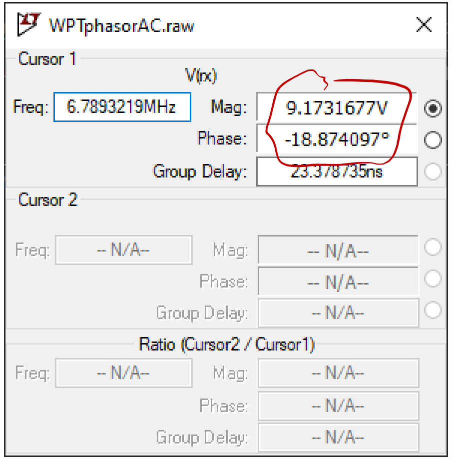
* C:\Users\dcostine\Dropbox\Courses\UTK Courses\ECE 202\In Class Examples\WPTExample-Phasors\WPT...

```
       --- AC Analysis ---

frequency:     6.78e+006      Hz
V(tx):         mag:        100 phase:          -90°       voltage
V(n001):       mag:    174.844 phase:     -90.3419°       voltage
V(n002):       mag:    99.9949 phase:     -90.0005°       voltage
V(n003):       mag:    287.109 phase:     -90.5205°       voltage
V(n004):       mag:     187.14 phase:      -90.798°       voltage
V(n006):       mag:    207.132 phase:     -90.6756°       voltage
V(n007):       mag:    54.3051 phase:      -99.138°       voltage
V(n005):       mag:    187.137 phase:     -90.7477°       voltage
V(n008):       mag:    9.11047 phase:     -18.7958°       voltage
V(rx):         mag:    9.04764 phase:     -18.7958°       voltage
I(Cs):         mag:   0.125662 phase:     -18.7958°       device_current
I(Cp):         mag:   0.469369 phase:      179.999°       device_current
I(Cf):         mag:    1.34784 phase:       179.48°       device_current
I(Cr):         mag:   0.878499 phase:      179.202°       device_current
I(Ls):         mag:   0.125662 phase:     -18.7958°       device_current
I(Lp):         mag:   0.469369 phase: -0.000865793°       device_current
I(Lf2):        mag:   0.469369 phase:      179.999°       device_current
I(Lf1):        mag:   0.878499 phase:    -0.798129°       device_current
I(Lr):         mag:   0.878499 phase:    -0.798129°       device_current
I(Rp):         mag:   0.469369 phase: -0.000865793°       device_current
I(Rl):         mag:   0.125662 phase:      161.204°       device_current
I(Rs):         mag:   0.125662 phase:      161.204°       device_current
I(V1):         mag:   0.878499 phase:      179.202°       device_current
```

Frequency Sweep







Form of the solution

$$\sum_{i=0}^{N} b_i \frac{d^i}{dt^i} v_o(t) = \sum_{i=0}^{M} a_i \frac{d^i}{dt^i} v_i(t)$$

In phaser domain $\frac{d}{dt} \rightarrow (j\omega)$

$$\sum_{i=0}^{N} b_i (j\omega)^i \underline{V_o} = \sum_{i=0}^{M} a_i (j\omega)^i \underline{V_1}$$

$$\underline{V_o} = \underline{V_1} \left(\frac{\sum_{i=0}^{M} a_i (j\omega)^i}{\sum_{i=0}^{N} b_i (j\omega)^i} \right)$$

$\uparrow$

$H(\omega)$