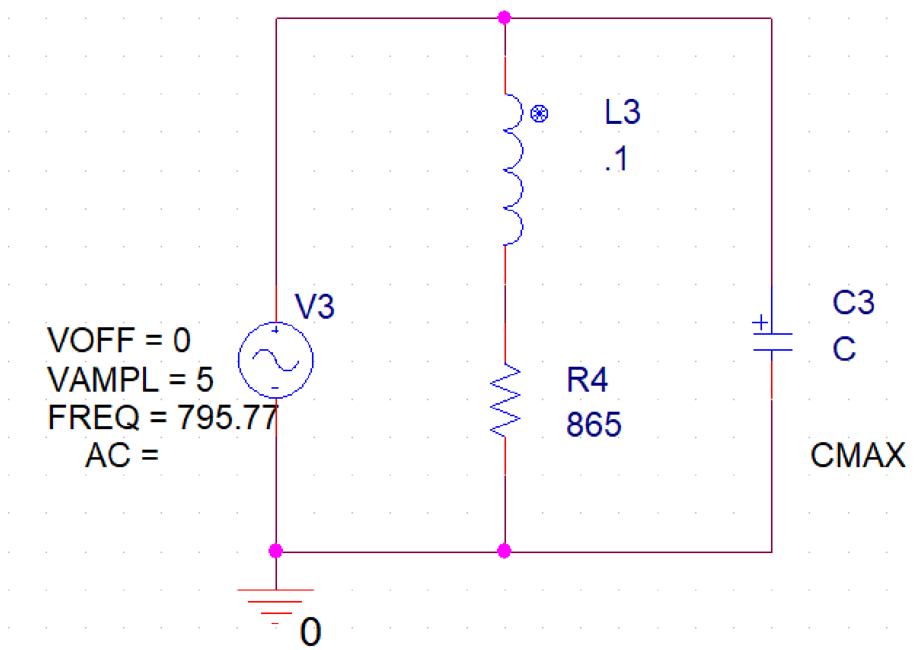
# ECE 2101L Lab #8

# Power Measurements





Kyler Martinez and Daniel Ruiz – Group 2


November 28th, 2020

# Objective

The objective of the lab is to explore complex power measurements and power factor correction can be used to increase the power efficiency of a circuit.

# Materials

The necessary equipment needed for the lab are as follows

1. Breadboard
2. 4 BNC Clip Connectors
3. Clip Leads
4. .01μF, .1μF, 1μF, Capacitors
5. 865Ω and 10Ω Resistors
6. Inductor Box or .1H inductor
7. LCR Meter
8. Digital Multimeter
9. Oscilloscope
10. Function Generator

## Pre-Lab

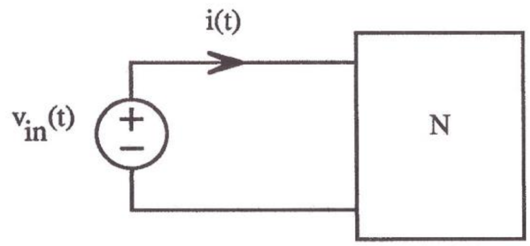
1. What is the rms value of $5 \cos 10^3 t$

1. $V_{rms} = \frac{5}{\sqrt{2}} V \approx 3.536 V$

2. What is the power being delivered to a 1K resistor if the rms voltage across it is 3 volts

2. $P = \frac{V_{rms}^2}{Z_R} = \frac{3^2}{1K} = 9 mW$

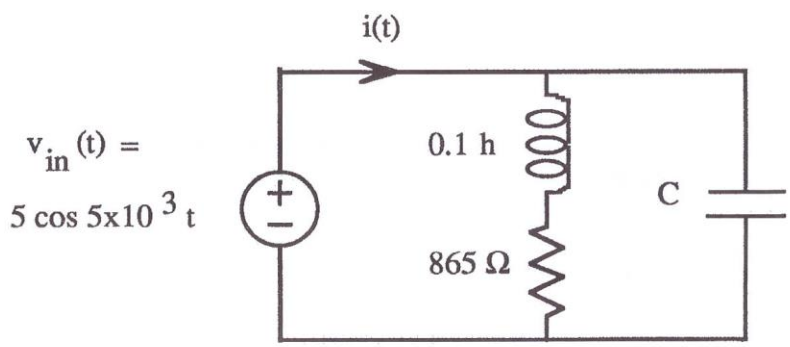
3. Given



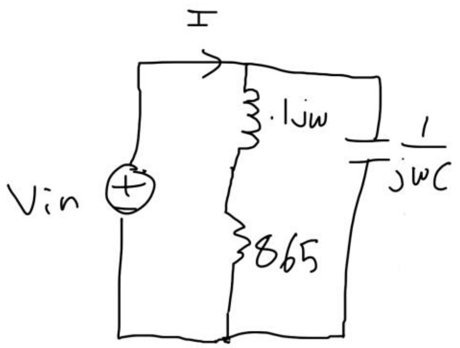

Suppose we are able to modify N so that we don't change the average power being delivered to N but we are able to increase the power factor. What will happen to i(t)

Since $P_{avg} = V_{rms} * I_{rms} * pf$, if we increase the power factor, to keep the same average power then the $I_{rms}$ will decrease which results in the amplitude of the current decreasing. The phase shift of the current will also increase to be in phase with the voltage source.

5. Now suppose we take our RL circuit and add a parallel capacitor as follows




a. Find the impedance of the RLC load
b. For what value of C will the power factor be 1
c. How does the parallel capacitor affect the average power being delivered to the circuit and dissipated in the resistor
d. How did adding C affect i(t)
e. What would have happened if we had added a larger or smaller capacitor
f Sketch the power factor pf as a function of C




a. $$\frac{1}{Z} = \frac{1}{.1jw+865} + \frac{1}{\frac{1}{jwC}} = \frac{1}{865+.1jw} + jwC$$

$$\frac{1}{Z} = \frac{1+jwC(865+.1jw)}{865+.1jw}$$

$$Z = \frac{865+.1jw}{1+wC(865j-.1w)}$$

$$\boxed{Z(5k) = \frac{865+.1jw}{1+5kC(865j-.1w)}}$$

b. if pf = 1 then Z must have only real parts

$$\frac{1}{Z} = \frac{1}{500j+865} + j5kC = \frac{865-500j}{998225} + j5kC$$

$$\frac{500\cancel{j}}{998225} = \cancel{j}5kC, \quad \boxed{C = 1\times10^{-7}F = .1\mu F}$$

$$C.\ S_{RLC}(C=0) = \frac{\left(\frac{5}{\sqrt{2}}\right)^2}{(865-500j)} = 10.832 + 6.261j \text{ mVA}$$

$$P_{avg} = 10.832\text{mW}$$

$$Z = \frac{998225}{865} \approx 1.154\text{ k}\Omega$$

$$S_{RLC}(C=.1\mu F) = \frac{\left(\frac{5}{\sqrt{2}}\right)^2}{(1.154k)} = 10.832\text{mVA}$$

$$P_{avg} = 10.832\text{ mW}$$

$$I_R(C=0) = \frac{V}{Z} = \frac{5}{865+500j} = .0043 - .0025j\text{ mA}$$

$$I_R(C=0) = 5\angle 30^\circ\text{mA}$$

$$P_R(C=0) = \left(\frac{5}{\sqrt{2}}\right)^2 865 \approx 10.81\text{mW}$$

$$I = \frac{5}{1.154k} = 4.33\text{mA}$$

$$I_R = \frac{1.154k}{865+500j}4.33\text{mA} = 4.33 - 2.51j\text{ mA}$$

$$I_R(C=.1\mu F) = 5.01\angle -30^\circ\text{ mA}$$

$$P_R(C=.1\mu F) \approx \left(\frac{5.01}{\sqrt{2}}\right)^2(865) \approx 10.86\text{ mW}$$

By adding the capacitor, the average power delivered to the system and the power dissipated did not change by a large margin. The change seen in the power dissipated by the resistors is likely the result of rounding errors. However, i(t) changed in the way that the amplitude of the current signal decreased when C was added and was put in phase with the voltage source, however, the current through the resistor stayed relatively the same.

e.

If we increased or decreased the value of C then the impedance will have a phase shift and this will result in the average power staying the same but the current will increase in order to cancel the effect the non-unity power factor causes. If we decrease C, then the current will have a negative phase angle and if we increase C we will have a positive phase angle. If we increased C enough then it will act as a short circuit.

f. $\frac{1}{.1j\omega+865} + j\omega c = \frac{1}{Z}$

$$\frac{865-500j}{998225} + j5kC$$

$$\theta_Z = \tan^{-1}\left(\frac{5kC - 5\times10^{-4}}{\frac{865}{998225}}\right)$$

$$\theta_Z = \tan^{-1}\left(5.77\times10^{6}C - 577\times10^{-3}\right)$$

$$Pf = \cos\left(\tan^{-1}\left(5.77\times10^{6}C - 577\times10^{-3}\right)\right)$$

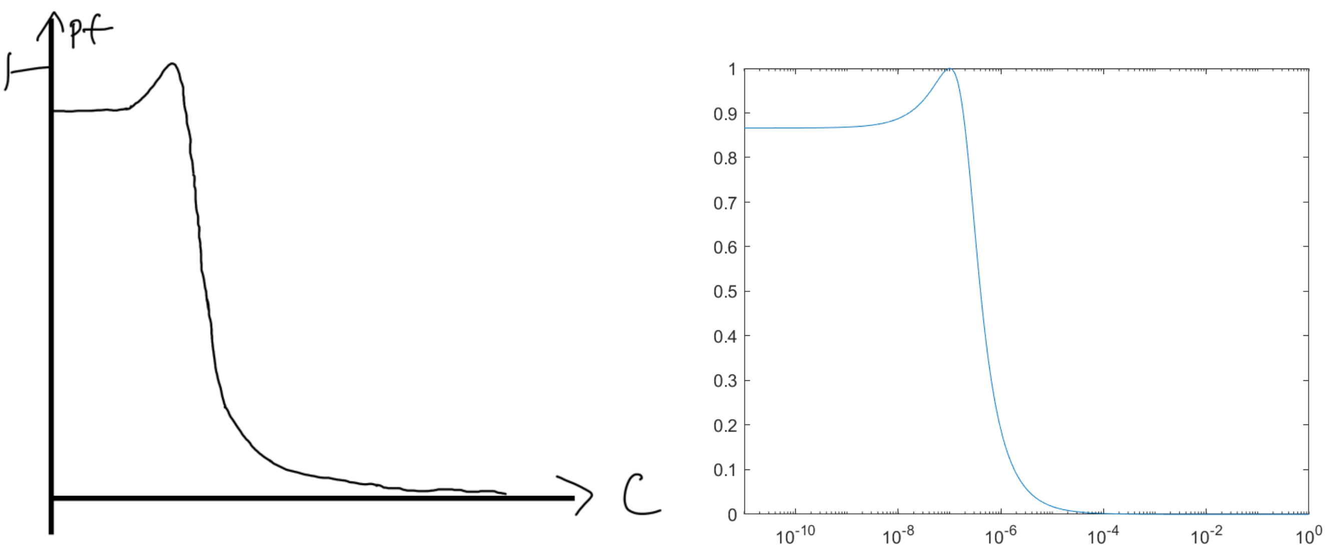



*Figure 1: Sketch of power factor as a function of C & MATLAB Plot*

The power factor would represent a low pass filter for capacitance since power factor reaches a max in between 0F and infinite capacitance and we established that the power factor is at a finite value at C= 0F and by the general behavior of capacitors in the phasor domain, we know the power factor will decrease to 0 as C become infinitely large.

# Procedure

For the lab we found our power measurements by constructing the circuit in figure 2 and finding the voltage across the 10Ω resistor for each capacitor used. We then constructed the circuit in figure 3 then found the voltage across the 865Ω resistor for each capacitor used. After gathering this data, we then were able to find the power factor and other pertinent measurements.

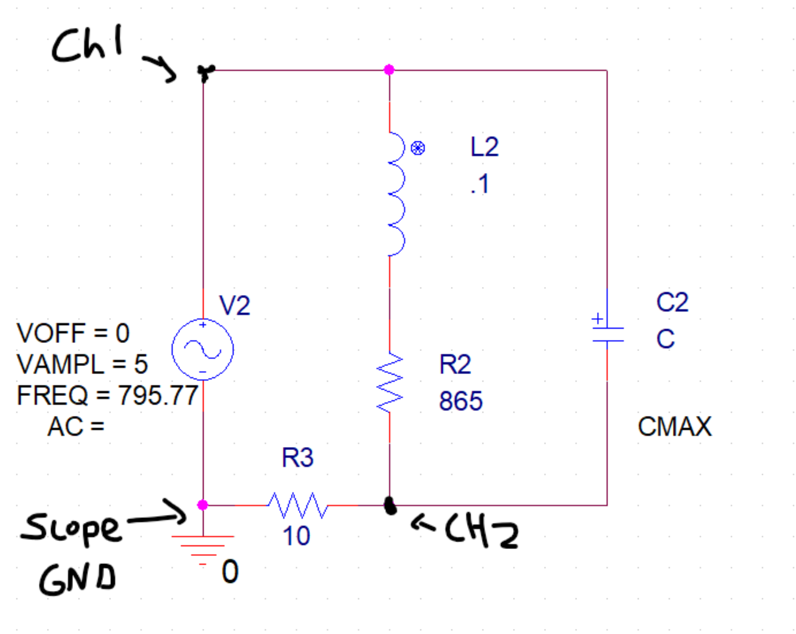



*Figure 2: Circuit Designed To Find Power Delivered To RLC Load*

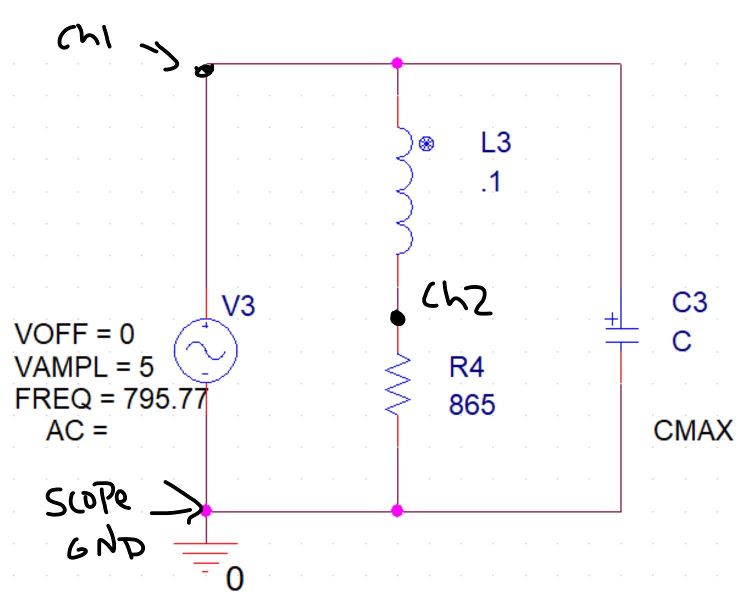



*Figure 3: Circuit Designed To Find Power Dissipated By 865Ω Resistor*

# Results

## When C = .01µF

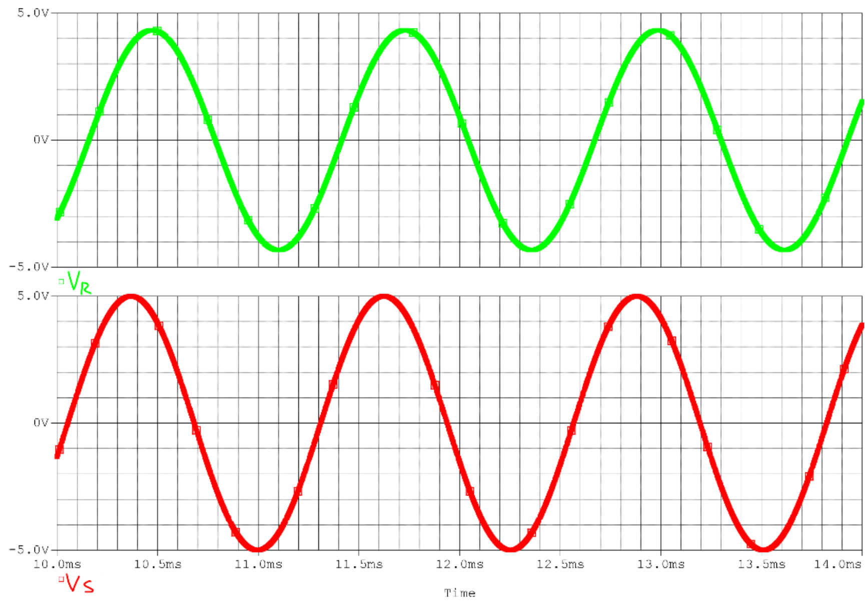



*Figure 4: PSPICE Output of $V_S$, $V_R$ , when C = .01µF*

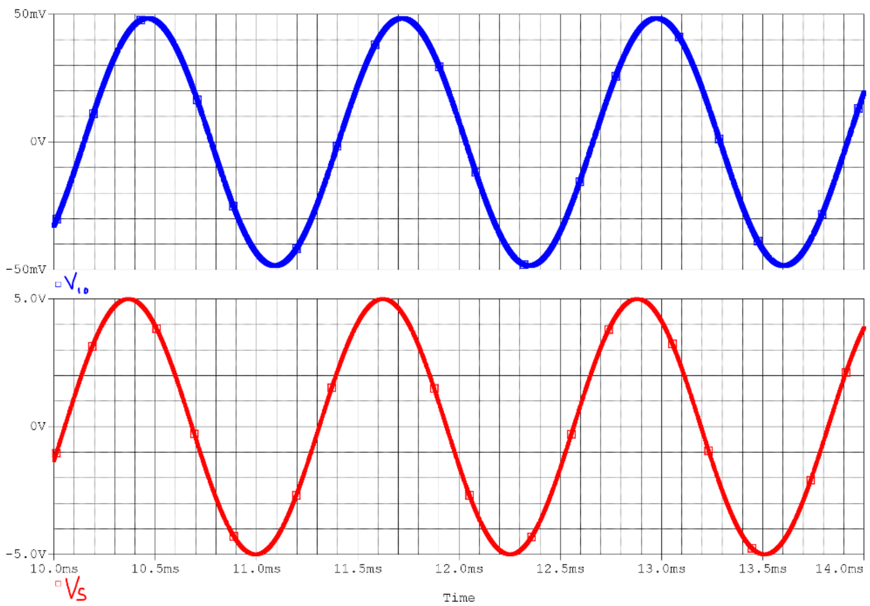



*Figure 5: PSPICE Output of $V_S$, $V_{R=10\Omega}$ , when C = .01µF*

| Measurement | Value |
|---|---|
| XatNthY(V(V2:+),0,2) | 10.68148m |
| XatNthY(V(R3:2),0,2) | 10.77654m |
| Max_XRange(V(V3:+),10m,14m) | 5.00000 |
| Max_XRange(V(R4:1),10m,14m) | 4.32885 |
| MAX_XRANGE(V(R3:2),10m,14m) | 48.42131m |
| 1/ Period_XRange(V(V3:+),10m,14m) | 795.77000 |
| (XatNthY(V(V2:+),0,2)-XatNthY(V(R3:2),0,2))*360/Period_XRange(V(V2:+),10m,14m) | -27.23324 |

*Figure 6: PSPICE Measurements When C = .01µF*

<u>When C = .1µF</u>

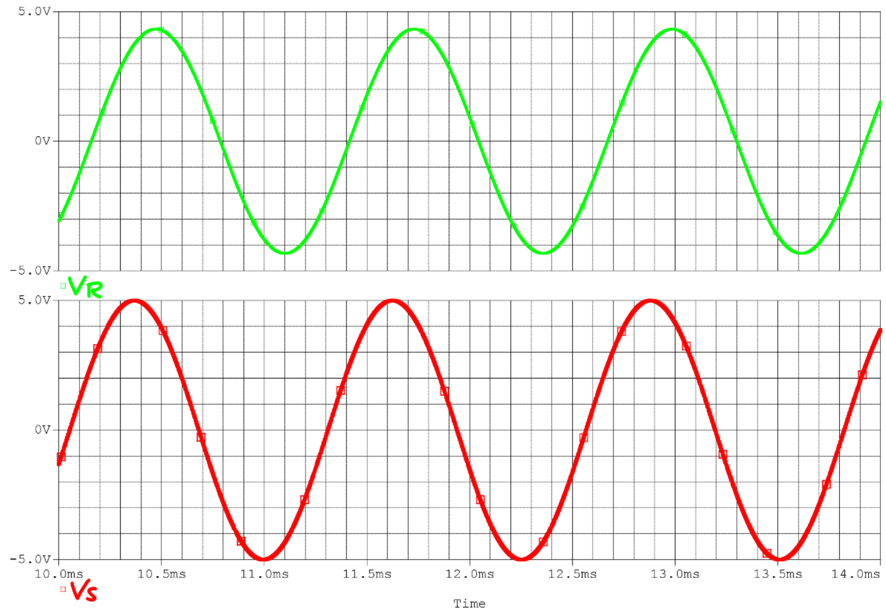



*Figure 7: PSPICE Output of $V_S$, $V_R$ , when C = .1µF*

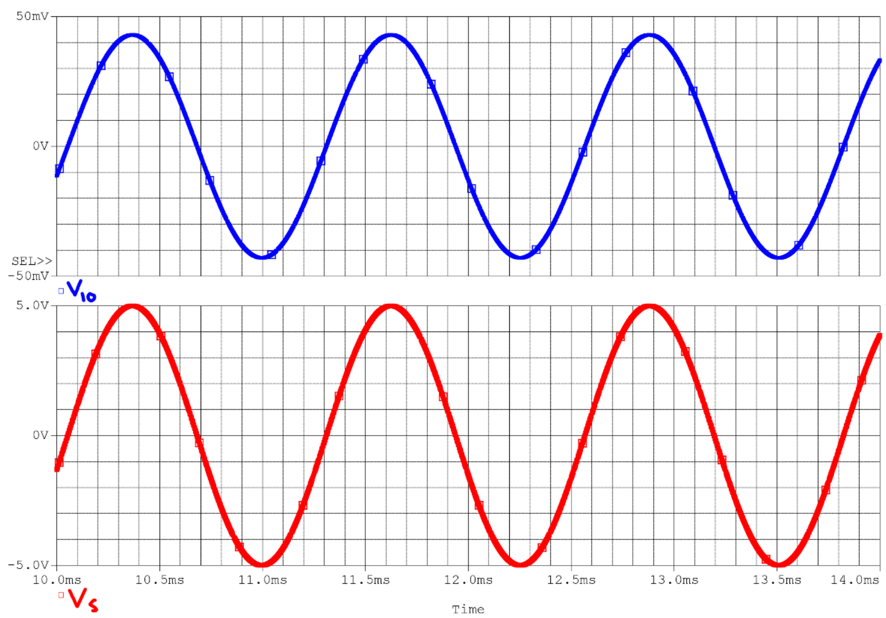



*Figure 8: PSPICE Output of $V_S$, $V_{R=10\Omega}$ , when C = .1µF*

| Measurement | Value |
|---|---|
| XatNthY(V(V2:+),0,2) | 10.68148m |
| XatNthY(V(R3:2),0,2) | 10.68168m |
| Max_XRange(V(V3:+),10m,14m) | 5.00000 |
| Max_XRange(V(R4:1),10m,14m) | 4.32885 |
| MAX_XRANGE(V(R3:2),10m,14m) | 42.95483m |
| 1/ Period_XRange(V(V3:+),10m,14m) | 795.77000 |
| (XatNthY(V(V2:+),0,2)-XatNthY(V(R3:2),0,2))*360/Period_XRange(V(V2:+),10m,14m) | -58.37768m |

*Figure 9: PSPICE Measurements When C = .1µF*

# When C = 1μF

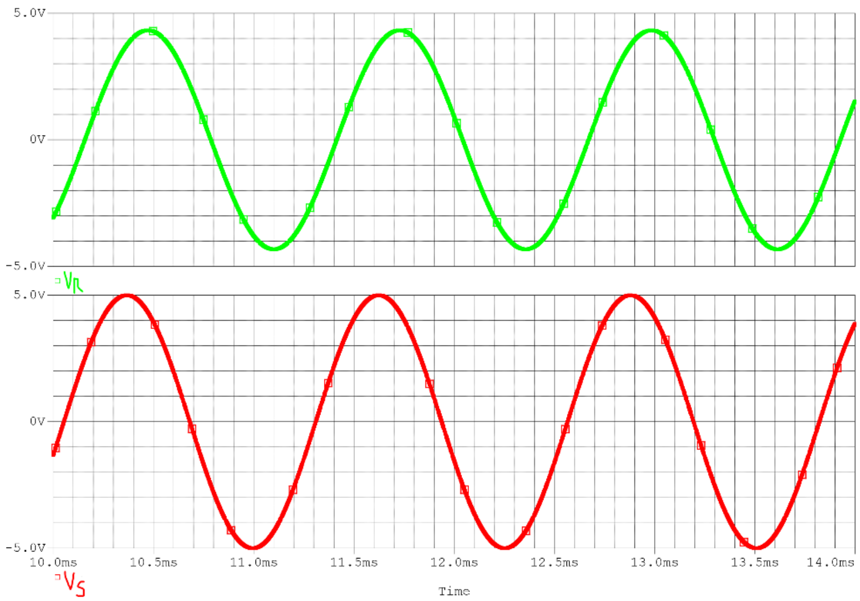



*Figure 10: PSPICE Output of $V_S$, $V_R$, when C = 1μF*

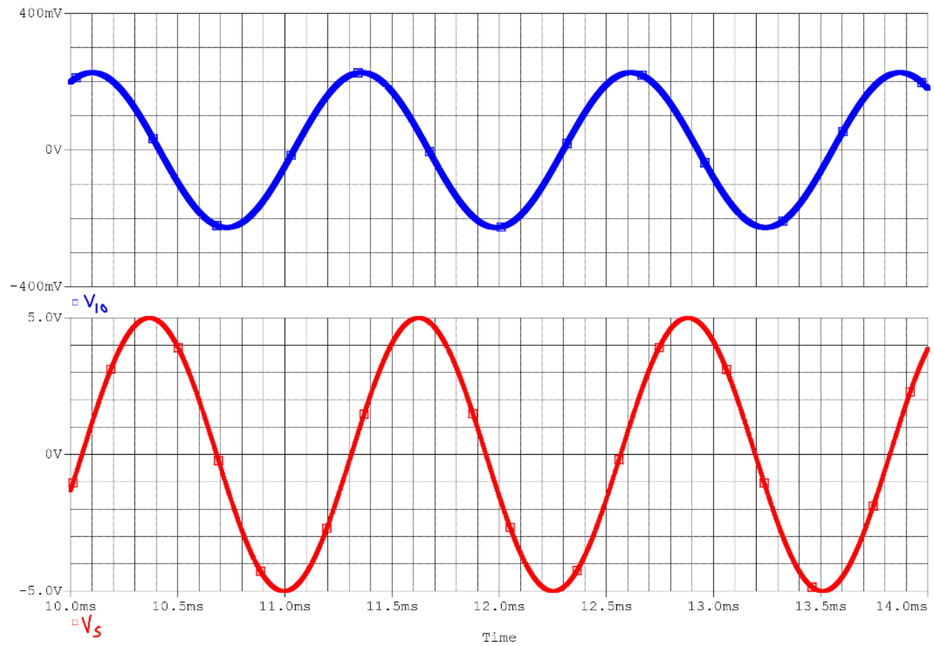



*Figure 11: PSPICE Output of $V_S$, $V_{R=10\Omega}$, when C = 1μF*

| Measurement | Value |
|---|---|
| XatNthY(V(V2:+),0,2) | 10.68148m |
| XatNthY(V(R3:2),0,1) | 10.41429m |
| Max_XRange(V(V3:+),10m,14m) | 5.00000 |
| Max_XRange(V(R4:1),10m,14m) | 4.32885 |
| MAX_XRANGE(V(R3:2),10m,14m) | 226.89493m |
| 1/ Period_XRange(V(V3:+),10m,14m) | 795.77000 |
| (XatNthY(V(V2:+),0,2)-XatNthY(V(R3:2),0,1))*360/Period_XRange(V(V2:+),10m,14m) | 76.54416 |

*Figure 12: PSPICE Measurements When C = 1μF*

## Table With All Data

| | C = .01µF | C = .1µF | C = 1µF |
|---|---|---|---|
| $\|V_R\|$ [V] | 4.32885 | 4.32885 | 4.32885 |
| $\|V_S\|$ [V] | 5 | 5 | 5 |
| $\|V_{10\Omega}\|$ [mV] | 48.421 | 42.95 | 226.895 |
| $\|I_S\|$ [mA] | 4.8421 | 4.295 | 22.6895 |
| $\angle V_{10\Omega}$ | $-27.23^0$ | $-58.4m^0$ | $76.54^0$ |
| $\angle I_{10\Omega}$ | $-27.23^0$ | $-58.4m^0$ | $76.54^0$ |
| $\angle Z_{RLC}$ | $27.23^0$ | $58.4m^0$ | $-76.54^0$ |
| $P_R$ [mW] | 10.832 | 10.832 | 10.832 |
| $P_{RLC}$ [mW] | 10.763 | 10.738 | 13.2034 |
| Pf | 0.8892 | 1.0000 | .2328 |

## Power Factor Plot With Lab Data

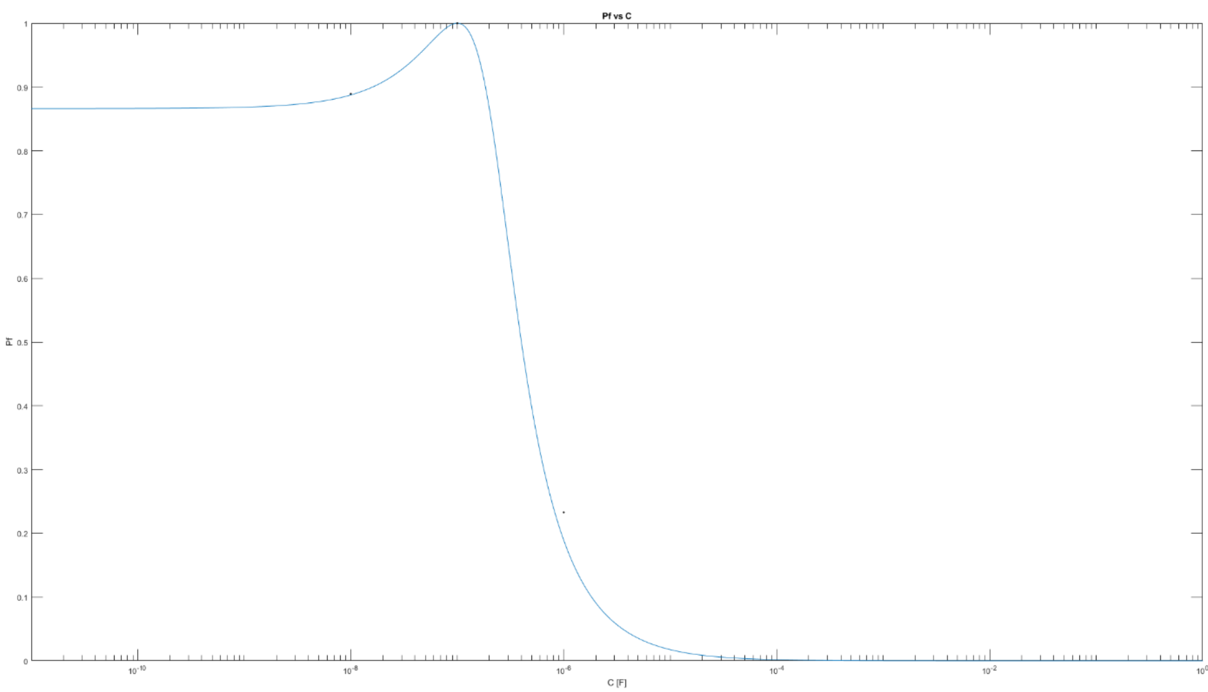



*Figure 13: MATLAB Plot of Power Factor vs Capacitance*

## General Analysis

When we increased C after C = .1µF, we can see the magnitude of the current from the voltage source increase and the power factor decreased. When we decreased C, the magnitude of the current from the voltage source increased and the power factor decreased, but not buy the same margin as the increasing the capacitance. We also noticed that when C = 1µF, our answers were off by a significant margin and this is due to us using the 10Ω resistor to measure the current, and the effects of adding the component to the circuit we not detectable until this point. The value of our capacitance did not generally influence the average power delivered to thew circuit and dissipated, with the sole exception stated previously.

# Problems

1. Compare your calculated and measured power factors and average powers.

The power dissipated by the resistor was 10.832mW which has a 0% difference when compared to the power delivered to the load, the resistor we are measuring is the only component that can dissipate the power. However, when we compare it to the theoretical power dissipated by the resistor, we found there is an approximate .03% difference from the average of the theoretical dissipated power. We suspect the percent error is the result of round off errors, however the difference is still incredibly low since we used a simulation.

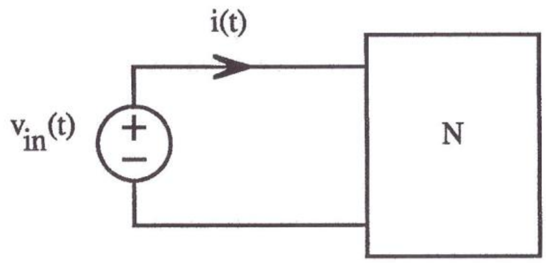
The average power delivered to the load is typically .75% from the theoretical power, the final power was excluded to be addressed separately. This is percent difference is due to the additional 10Ω resistor used to find the current which affects the overall impedance but is not as impactful until the capacitance becomes a high enough value. There is a large difference of 21.89% between the powered delivered to the load and the theoretical calculations. However, if we do our theoretical calculations and include the 10Ω resistor in the calculations for impedance, we find the power delivered to be 13.2mW which is what we found in the lab. If we wanted to reduce this effect, we would need to have used a smaller resistance, however this will prove to be increasingly difficult in a physical lab.

2. Why do power companies start jumping up and down when power factors get low?

Power companies prefer having power factors near 1, or a pf angle around $0^0$ so that they can deliver the same average power to a load with a smaller amplitude for the current, since if the power factor deviates from unity, then it may become more expensive for a power company to supply the necessary power and either increase the prices for customers or reduce the available power resources.

3.

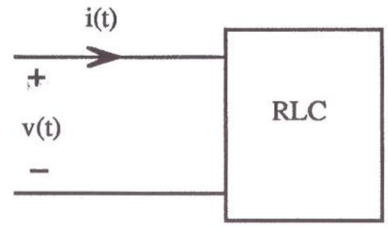
3. Given




Can the magnitude of i(t) increase without a corresponding increase in the power being delivered to N. How can this happen

The magnitude of i(t) can be increased if we decrease the power factor of the load N and this can be accomplished by adding inductors and capacitors to the load N to change the power factor, the quantity and capacitance and inductance values depend on the circuit configuration but if you add a capacitor in parallel and increase the capacitance value enough, the current will eventually increase.

4.




Suppose we get out our trusty true RMS digital multimeter and measure $V_{RMS} = 10$ volts and $I_{RMS} = 2$ ma. Could we then calculate the average power being delivered to N. Why

You generally cannot calculate the average power being delivered to N since the average power delivered to a load is equal to $I_{RMS}$ * $V_{RMS}$ * pf, however we do not know the power factor with the information that we collected so far. We could calculate the average power with the measurements collected if we knew the power factor was equal to one however, without this information, we cannot calculate the average power delivered to N.

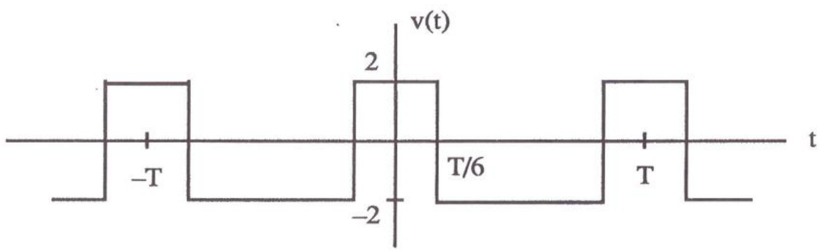
5.

5. Suppose the voltage across a 1K resistor is a triangular wave with an rms value of 4 volts. What is the power being delivered to the resistor

If the $V_{RMS}$ is equal to 4V then the power delivered to a 1K resistor would be 16mW.

6.

Given a 1K resistor with a voltage across it as given by




How much power is being dissipated

$$V_{rms} = \sqrt{\frac{1}{T}\int_0^T v(t)^2 dt} = 2\text{V}$$

$$P = \frac{Vrms^2}{R} = 4\text{mW}$$