Physics 117 Lab 2: Capacitor properties and functions

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1. Beginning Exercises

1.1. Part A

In this laboratory we sought to observe specifically the capacitor in many different ways. To start we measured the capacitance of two $.047\mu F$ capacitors in series and then in parallel using a LCR meter. To measure capacitance using the LCR meter is similar to measuring resistance, the LCR provides its own voltage, so there is no power source, and reads the the output after it travels the circuit, so all you do is place banana plugs with clips and place the clips in the appropriate positions as shown in figure 1. Theoretically the capacitance in series adds inversely and in parallel it adds proportionaly.

$$\frac{1}{C_{tot}} = \frac{1}{C_1} + \frac{1}{C_2} \qquad [1]$$

$$C_{tot} = C_1 + C_2 \qquad [2]$$

Our measurement was consistent with the theoretical value of $.022\mu F$ for the two $.047\mu F$ capacitors in series; and close to accurate with $.089\mu F$ instead of $.094\mu F$ for the two capacitors in parallel.

2. RC Circuit (2-1)

2.1. Part B

The next step required us to create a simple RC circuit, shown in figure 2. The circuit consisted of a 10k Ohm resistor, a $.01\mu F$ capacitor and a 500 Hz square wave as the power source. The reading we got using an oscilloscope is

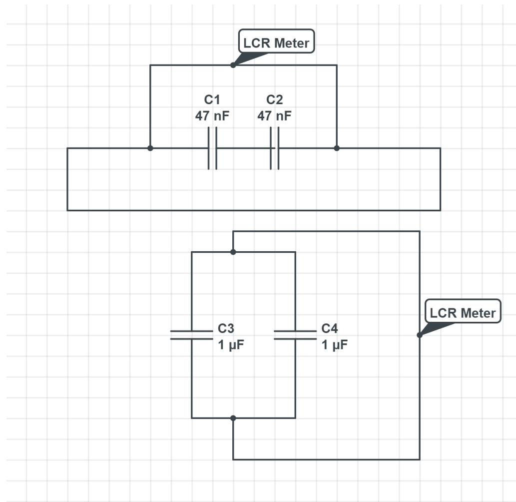

Figure 1: This figure shows the circuit diagram to measure the total capacitance of two capacitors in series and parallel

shown in figure 3. The RC circuit was in the correct time domain as it was in phase with the input voltage and correctly chops the top voltages away as this is effectively a low pass filter. In this part we specifically use DC coupling instead of AC, the reason why is that AC coupling hurts the resulting wave, specifically because it adds an extra capacitor to couple the wave to AC so it messes with our results. We then looked at the rise and fall time first theoretically taking the product of RC in this case $.01\mu F * 10000 Ohm = .1 millisecond$. For our actual measurements using the bars of the oscilloscope we received for the drop time from 100 to 37% to be $137\mu s$ and the rise time from 0 to 63% was approximately 140 μs using the measure menu of the oscilloscope we got a measurement about 234 μs and 244 μs for the rise and fall time respectively. The reason why these values are so inconsistent with the ones we got manually is that it measures from 10% to 90% scaling the measurments differently and covering more than it needs to for the rise time of the graph.

3. Differentiator (2-2)

3.1. Part C

The next part of the experiment had us create a differentiator, basically a high pass filter or the reverse of the last circuit we constructed, which can be

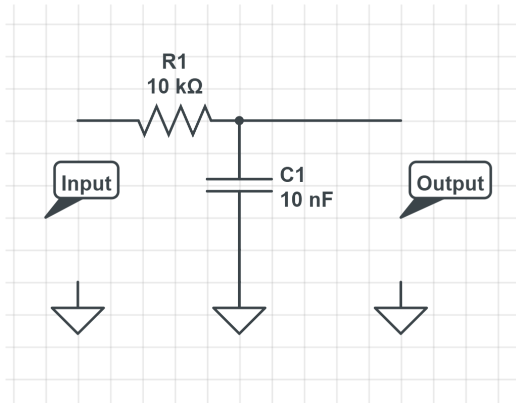

Figure 2: This figure shows the circuit diagram for a simple RC circuit

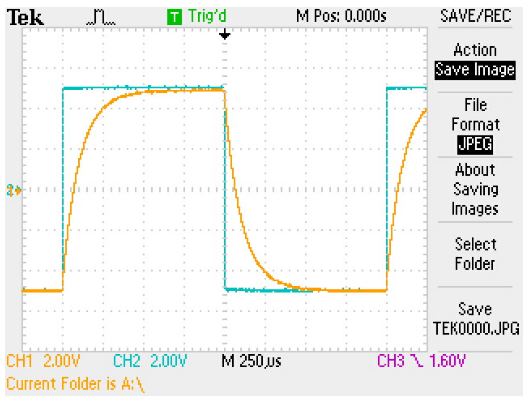

Figure 3: This figure shows the initial measurement of a 500 Hz square wave, showing a consistent RC circuit

seen in figure 4. This circuit though required a 100 picoFarad capacitor a 100 Ohm resistor, and we used a square wave of 100 kHZ because we needed a high frequency. We ran the wave as a square, triangle, and sine, all the waves were out of phase according to what we wanted and displayed signs of being derivatives of the input waves, these can be seen in figures 5,6, and 7. The next step was to measure the input impedance at infinite and 0 frequency. In this case the input impedance can be given by equation 3.

$$Z_{in} = R + \frac{-i}{wC} \qquad [3]$$

This equation shows at frequency 0 the imaginary component of the input impedance expands to infinity as 1 is divided by 0, and for infinite frequency

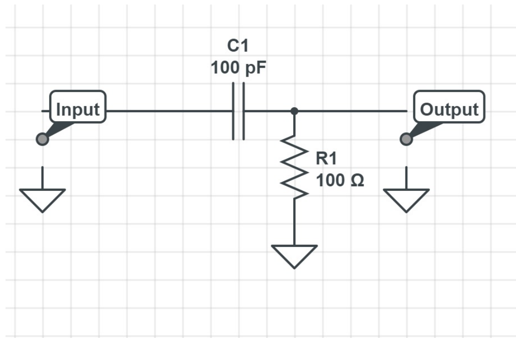

Figure 4: This figure shows the circuit diagram for the differentiator

the impedence becomes just R as the imaginary compoenent becomes 0.

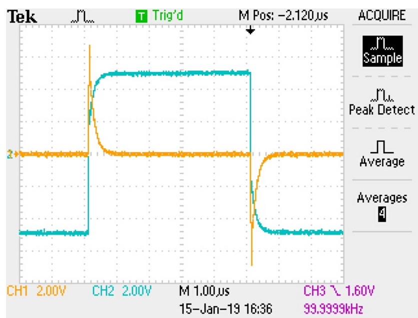

Figure 5: This figure shows how the differtiator acts on a square wave

4. Intergrator (2-3)

4.1. Part D

The next part of the experiment had us return to our original circuit in structure and with the 10k Ohm resistor and .01μF capacitor, but can be seen again in figure 8. Specifically we drove this low pass filter with a high square wave frequency and the result was a similar to a triangle wave, and then we sent a triangle wave and it gave us a sine wave which can be seen in figures 9 and 10. The wave forms we receive are collections of wave forms for the specific parts of the inputted frequency. We were also asked a few questions, like what is the input impedance at DC which means 0 frequency which would be R, and the impedance at infinite frequency which would be infinite, since this is a low pass filter this makes sense. Also because this is a

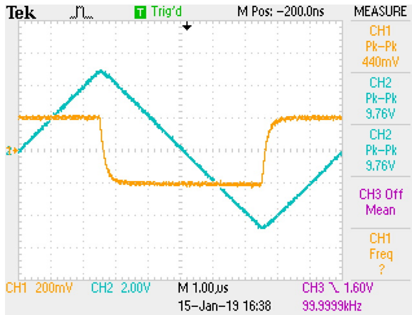

Figure 6: This figure shows how the differtiator acts on a triangle wave

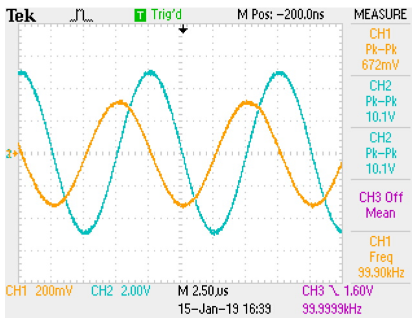

Figure 7: This figure shows how the differtiator acts on a sine wave

low pass filter the phase difference between the input and the output begins to differ only at very high frequencies, othewise the phase is similar. Also we are in the correct timescale because RC in this case is 100μs and occurs at 400Hz rather than a large frequency of 10 kHz.

5. Low Pass Filter (2-4)

5.1. Part E: Preliminaries

Before we continued with the experiment we had to answer 2 questions. First being, why -3dB corresponds to 70.7% of the voltage. The reason why is that the dB ranges are a formulation of power of the circuit from the initial to final point, this means -3dB corresponds to half the power in the circuit and since voltage is related to power by a square the voltage corresponding to dB changes is the square root of the power changes, so .5 power becomes square root of .5, the negative corresponds to power going down.

The next question asked how many dB down corresponds to half the voltage. This question basically wants us to find a point of power that is

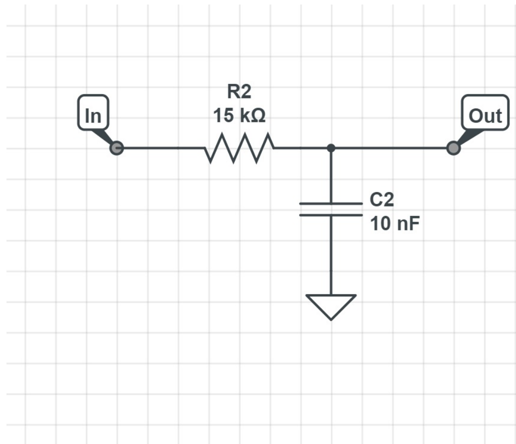

Figure 8: This shows the circuit diagram for a differetiantor same as the first circuit

1/4 from its original since the square root of 1/4 is 1/2 to see how voltage corresponds to the power change, we see how just jumping from -3dB for 1/2 power to -6dB for 1/4 power and how that simply leads to 1/2 voltage from the original.

the equation we use for voltage dB is given in equation 4.

$$dB = 20log\frac{v_{out}}{v_{in}} \qquad [4]$$

5.2. Part F

The next item we had to cover was constructing the low pass filter shown in figure 13. The first thing we are asked is to find the -3dB frequency for this filter,mathematically this can be seen in equation 5.

$$log^{-1}(\frac{dB}{20}) = \frac{v_{out}}{v_{in}} = \frac{\frac{-i}{wc}}{\frac{-i}{wc} + R} \qquad [5]$$

Equation 5 shows that we can send the 20 and use an anti log to get to the point where the only variable left is frequency, since the angular frequency is 2pi times f and the capacitance and resistance is given by the components of the circuit using this to find when dB equals -3 yields 1.061 kHz. Experimentally we found it to be 1.1413 kHz which is in range of the values that we found mathematically.To look at how the low pass filter removes high frequency voltages over time we did a sweep from 100Hz to 10 kHz which

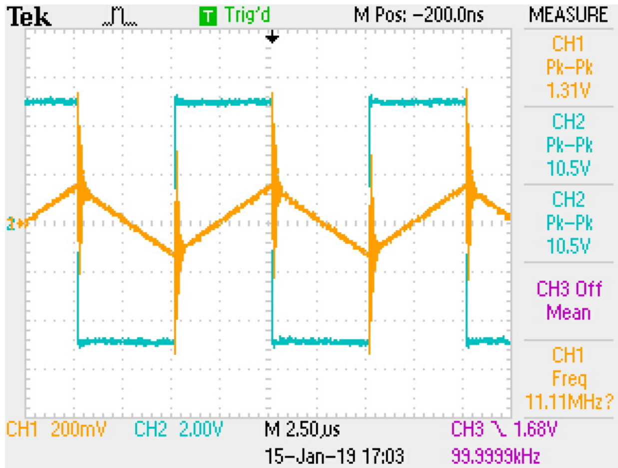

Figure 9: This shows the Integrator acting on a square wave turning it into a triangle wave

can be seen in figure 12 and gives accurate result of what we were looking for.

The last thing we had to account for was how the low pass filter attenuates for frequencies above -3dB specifically at 10 and 20 times -3dB, and frequencies 2,4, and 10 times frequency at -3dB, as well as evaluating the phase shift for frequencies above, below, and at -3dB. For starters the phase shift at -3dB was not large, at values lower than -3dB ie frequencies below -3dB which in this case is a low pass filter will also have phase shifts that are minimal, frequencies well above -3dB are incredibly out of phase nearing -pi/2. The attenuation I will use a table below

dB	Multiplier	Voltage
-3	1	6.72 V
-6	2	4.32 V
-9	3	3.08 V
-12	4	2.48 V
-15	5	1.90 V
-30	10	1.02 V
-48	16	.683 V
-60	20	.544 V

We were asked what the limiting phase shift was, before we do this we had

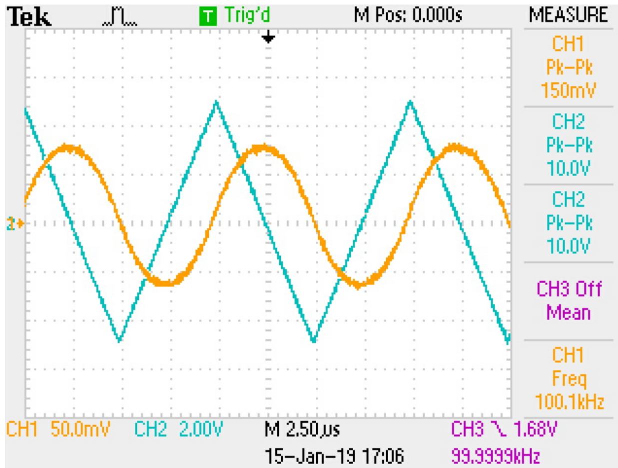

Figure 10: This graph shows a triangle wave intergrated to a Sin wave

to see if the phase made sense which we did in figure 11 in this case at very low frequencies the phase shift was nominal and for very high frequencies the phase shift was Pi/2 as this can also be seen as a Intergrator of Sin waves.

5.3. Part G

The last thing we are asked to do is set up a sweep using this circuit, we have already shown a sweep with this circuit on figure 11, showing how the sweep and frequencies are changing with time. To conduct the sweep we started from 100Hz to 20 kHz, we also gathered the sweep rate and in this case it was 52 milliseconds which lead to an average of 3.8 kHz per millisecond in the sweep.We are also asked to connect a speaker to the sweeping signals and it made a very alien noise.

6. High Pass Filter (2-5)

6.1. Part H

This section required us to create a high-pass filter, using the components of the low pass so $.01\mu F$ and the 15kOhm resistor switch places which can be seen in figure 14. We are then asked to find the -3dB point, in this case it will be around 1.04 KHz. Then we are asked how the circuit treats sine waves, which is nicely, but this specific filter, gets rid of low frequencies, so at frequencies below -3dB the wave starts to become a line. This leads into the limiting phase shift which for high frequencies was 0 and for low frequencies

Figure 11: This shows the phase shift between the sync and output are not out of phase

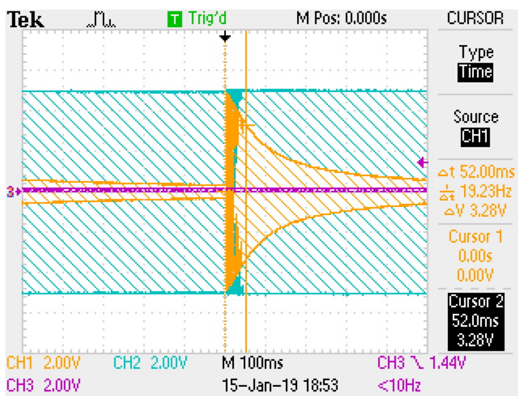

Figure 12: This shows the graph for the sweep from 100Hz to 10KHz on the low pass filter

was -pi/2, you can see starting from lower and going to higher frequencies; in a sweep how the voltages begin to become larger with frequency in figure 15.

7. Transformer

7.1. Part I

Observing the Transformer was our next task, which can be seen in figure 16. The first observation was to see the 1:1 ratio of voltages that was inverted. We were able to successfully do this by running a voltage through one corner and measuring it on a rung on the other corner and then comparing these voltages as seen in figure 17. We then were asked to find the of frequency

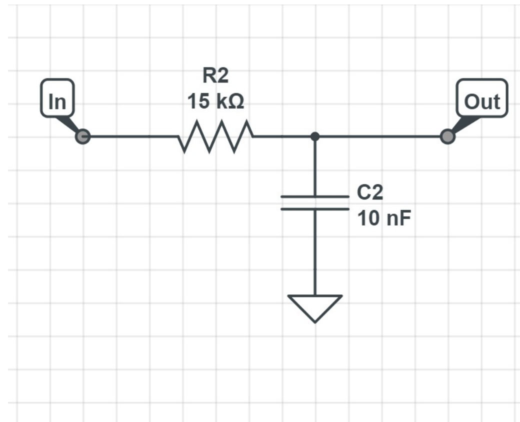

Figure 13: This shows the circuit diagram for the low pass filter

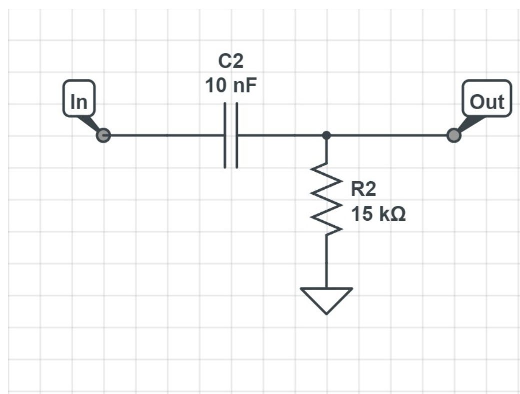

Figure 14: This shows the circuit diagram for the high pass filter

ranges at which the transformer works as expected and for us that was from 0Hz to 5-6 kHz, after that the output loop began to have issues. The last task we were given was to explain why the voltage was flipped and halved when measuring from the center tap, it is simply because when you measure from the center tap you are only measuring half the circuit and thus only looking at half the voltage, this can be seen in figure 18.

8. Filter Application I: Garbage Detector (2-6)

8.1. Part J

Another transformer circuit to show the usefulness of transformers had to be done. This circuit can be seen in figure 19. The first thing we had to

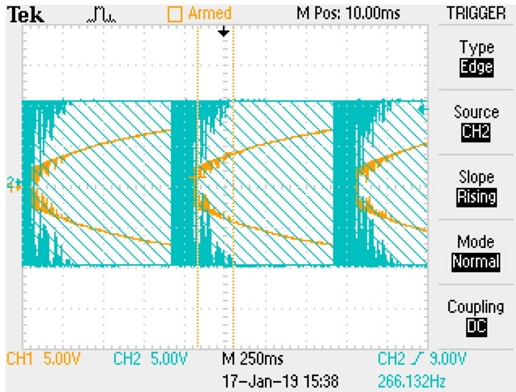

Figure 15: This shows the sweep from low to high frequencies on the high pass filter

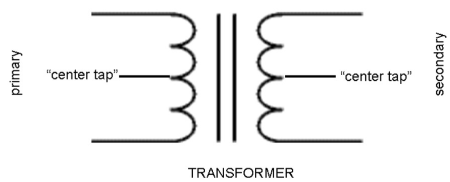

Figure 16: This shows the circuit diagram a Transformer

do was look at the output at junction A, which produces a regular sine wave seen in figure 20. To see the garbage collection begin we look at figure 21 which incidentally is at point B on the circuit, which is after it passes through the high pass filter. We are then asked what the filters attenuation at 60Hz we use equation 4 again and this time we use $V_{out} = 2.16V corresponding to 9V AC transformer and V_{in} = 31.4 corresponding to the 120V we start with.$

9. Blocking Capacitor (2-8)

9.1. Part K

Before we finish with the last section we had to answer a few questions. First we had to ask why do electrolytic capacitors have a polarity, the reason has to do with its structure, its made with metals forming an electrolyte forming an oxide type battery polarizing it, but the reason why its useful is that it allows for much more capacitance than a non polarized capacitor. The polarity of the capacitor was positive along the long wire and negative along

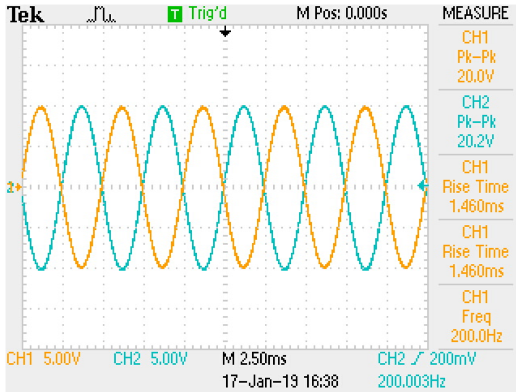

Figure 17: This shows the 1:1 voltage but flipped for transformer

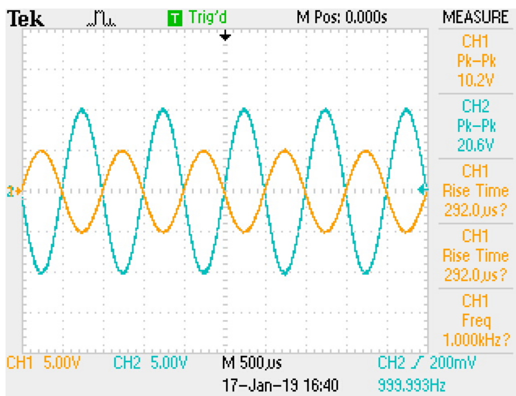

Figure 18: This shows the transformer from the center tap

the small wire. We also used the LCR to measure the exact capacitance of a $4.7\mu F$ capacitor we got $5.22\mu F$.

9.2. Part L

This part had us construct the circuit in figure 22 which shows a blocking capacitor and a capacitor with two resistors in parallel of it afterwards. When we observe just part A of the circuit not connected, the AC signal carries a 5 volts along side it since the resistor does not diminish the voltage from the DC, the result is given in figure 23. After that we are asked to find apply the part B to this circuit and measure at the other end. This got rid of our DC offset as the Part B effectively acts as a High Pass filter and DC has 0 frequency. We are last asked to find the low frequency limit of the

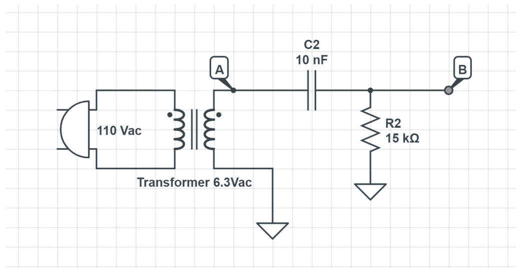

Figure 19: This shows the circuit diagram for the garbage collecting circuit

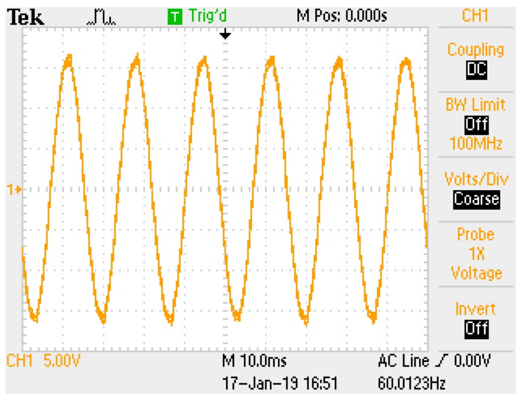

Figure 20: This shows the Sine wave at junction A for garbage collector transformer circuit

whole circuit which occurred around 100Hz and then completely decouples at around 50Hz.

9.3. Part M

The last part of our experiment was to measure a 20V supply through an electrolytic capacitor the correct way which yielded a result of .0009 miliAmps and then do it the wrong way and watch the capacitor blow up which we did as well.

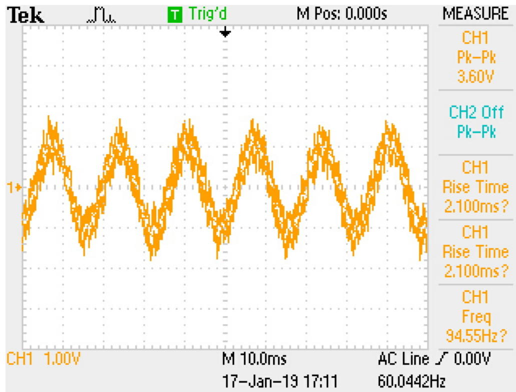

Figure 21: This graph shows the Sine wave at Junction B for Garbage collecting transformer circuit

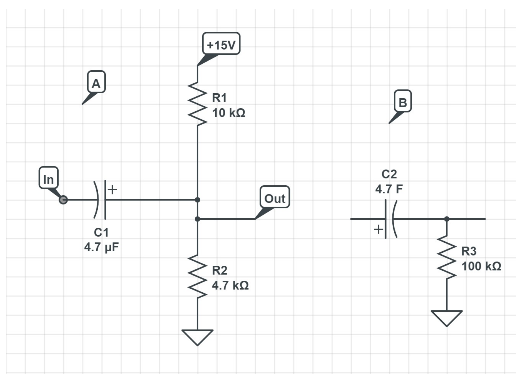

Figure 22: This shows the polarized capacitor circuit with blocking capacitor

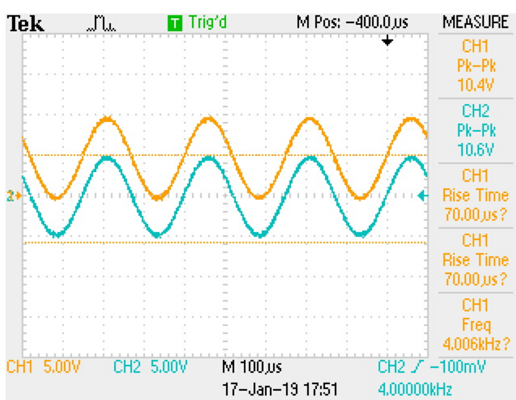

Figure 23: This shows the AC current with DC pumping it up in the electrolytic capacitor