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UNIVERSITY OF NEW BRUNSWICK

ELECTRICAL AND COMPUTER ENGINEERING

Room D36, Head Hall

LABORATORY / ASSIGNMENT / REPORT
COVER PAGE

Course # : _____ECE2701_____________ Experiment # or Assignment # ___Lab 4___

Date: ___Friday, November 29________ Course Instructor: ____Howard Li____________

Title: _______EE2701 Experiment 4 – Rectifier Circuits__________________
(if applicable)

Group # ____________________________ ___Justen Di Ruscio_________________________
(if applicable) *Name (print)*

__Stephen Cole____________________________
Name (print)

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Name (print)

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Name (print)

Name of Author: ___Justen Di Ruscio & Stephen Cole_______
Name (print)

Signature of Author: ____
Student Name (signature)

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Comments:

________/________ ______________
Grade Initials of Marker

Group # _________________________
(if applicable)

_3624673_____ / __Justen Di Ruscio__________
Student # *Name (print)*

_3553803_____ / __Stephen Cole____________
Student # *Name (print)*

______________ / ___________________________
Student # *Name (print)*

______________ / ___________________________
Student # *Name (print)*

Name of Author: _3624673 & 3553803 __ / __Justen Di Ruscio & Stephen Cole____
Student # **Name (print)**

Contents

Abstract

As most power distribution systems deliver electricity as alternating current, devices which use direct current must be powered through an AC-DC converter [1]. The principle devices in these converters are diodes [2]. Diodes are effectively one-way check valves for electrical current and can be used to rectify AC sources to obtain a better approximation of a DC source. A single diode achieves this by allowing the current to flow in a single direction which chops the negative portion of the sinusoidal voltage [1]. The use of additional diodes allows for a full wave rectifier to be constructed. A full wave rectifier allows the complete sinusoidal voltage to be used similarly to a conventional DC voltage, while only oscillating slightly [1]. In this lab, these properties of half wave and full wave rectifiers are examined, along with the characteristics of filtering using output capacitors.

1 Introduction

In EE2701 Experiment 4 - Rectifier Circuits, the behaviour of of some elementary diode circuits are analyzed and characterized in order to better understand their behaviour and verify the theoretical models referenced [2]. Diodes are an elementary, nonlinear electronic device, that are mainly for converting AC voltage into DC voltage as in an AC line operated power supply [1] [2]. The background needed for this lab is a knowledge of: the characteristics of a diode, sinusoidal AC waveforms, half wave rectifiers and full wave rectifiers. The theory required to complete this experiment includes understanding of the following topics: AC Voltage, characteristics of diodes, the skills to operate oscilliscopes and function generators, and the basics of resistors and capacitors. These concepts are used in the analysis of the constructed circuits depicted in figures 1 and 3.

In this experiment, two rectifiers are analyzed: a half wave rectifier and a full wave rectifier. The tests are carried out by supplying an AC voltage to the rectifiers input and probing the input and output voltages on an oscilloscope, where measurements can be performed. Both rectifiers will have their output voltage recorded and analyzed. Using the above theories and techniques, the output voltages will be compared to an constant DC source. For the half wave rectifier, only the positive portion of the sinusoidal voltage was present in the output, exactly as expected based on [1]. For the full wave rectifier the entire sinusoidal voltage is utilized as the negative portions of the wave were inverted. Additionally, the measured waveforms were very near the theoretical waveforms at the test frequencies. Finally, the measured voltage of the full wave rectifier was significantly better than the output of the basic half wave rectifier, for it better resembled a constant DC source. The measurements performed in this lab follow the theoretical ones, thereby verifying the theoretical models, and increasing our understanding of diodes and their use in rectifying AC voltages, therefore meeting the objective of this lab.

2 Experiment

2.1 Apparatus

2.1.1 Instruments

Rigol DS1000E Oscilliscope This dual-channel oscilloscope was used to measure the input and output signals of the rectifier circuits under test.

Function Generator This device was the source for all signals throughout the experiment. It provided a variable amplitude, variable frequency signal for the sine waves required.

1N914 Diode Block To make simpler connections to the banana connectors, a diode block was used instead of bare diodes. This consisted of a bare 1N914 diode connected to two female banana plugs, all embedded within a small block of wood. Only a single diode block was required [2]. The 1N914 diode is a *small signal fast switching diode*. It exhibits a forward voltage of $\approx 1V$ and has a very fast reverse recovery time of $\approx 4ns$ [3].

Bride Rectifier Block Instead of connecting multiple discrete diodes together, a pre-made bridge rectifier was used. This consisted of the bare bridge rectifier package connected to four female banana plugs, all embedded within a small block of wood. A single diode bridge was required for this lab.

Resistor Block For convenience over bare resistor components, a resistor block was used rectifier networks. This consisted of a resistor connected to two female banana plugs, all embedded within a small block of wood. Two $10k\Omega$ blocks were required.

Banana Connectors 9 Banana Connectors were required. Five of these were used to make electrical connections between the components of the rectifier networks, and the remaining four were used to connect the test and supply instruments to the network.

Capacitor Blocks Again, for convenience over bare capacitor components, capacitor blocks were used in the rectifier networks. These consisted of a capacitor connected to two female banana plugs, all embedded within a small block of wood. A single $1\mu F$ capacitor was used in this lab.

These pieces of equipment slightly vary from that listed in the lab manual. Instead of resistor, diode, and capacitor blocks, individual components are listed in the lab manual, which do not contain female banana plugs. In addition, banana connectors were completely omitted from the lab manual. These discrepancies introduced resistances and inductances which the lab procedure did not account for, introducing errors in the results [2].

2.1.2 Rectifier Networks

Depicted below are the two filter networks that are analyzed in this lab. The resistors act as output loads, and the capacitor filters the output voltage to reduce the ripple.

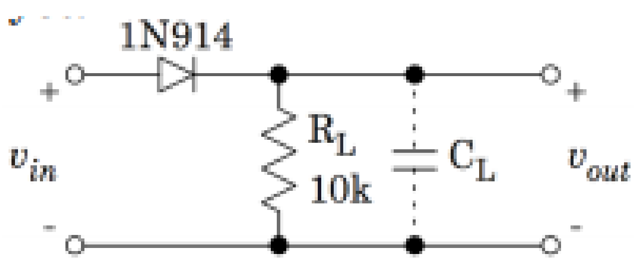

Figure 1: Half-Wave Rectifier Network [2]

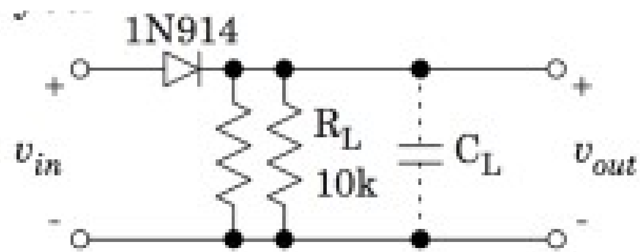

Figure 2: Half-Wave Rectifier Network with Additional Resistor [2]

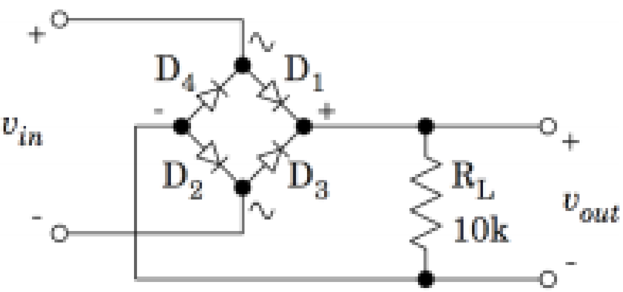

Figure 3: Full-Wave Bridge Rectifier [2]

2.2 Descriptions

2.2.1 Theory

Diodes are the fundamental electical component used to rectify alternating currents (AC) to direct currents (DC). These devices are nonlinear semiconductors that act as single-way check valve [2]. Diodes are represented with the symbol illustrated below.

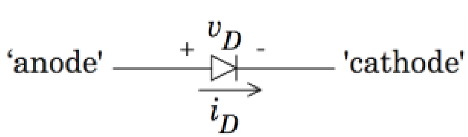

Figure 4: General Purpose Diode Schematic Symbol [2]

Just as is shown in the figure, diodes have two terminals: an anode and a cathode. When the voltage from anode to cathode - called the forward voltage - is above $0.6V - 0.7V$, the diode will begin to conduct [1]. This *forward biases* the diode. Conversly, the diode can be reverse biased, where the voltage from cathode to anode is positive. In this state, the diode will block current flow until the reverse voltage meets the reverse breakdown voltage [1] [2]. A graph of these properties can be seen below.

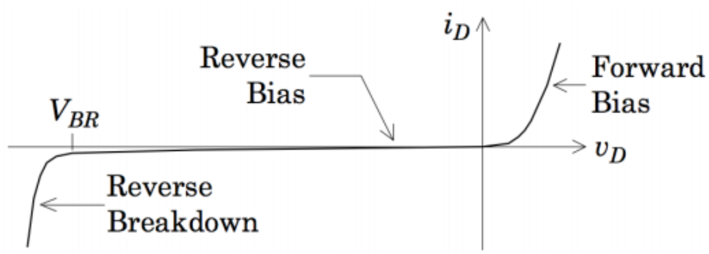

Figure 5: Diode I-V Characteristics [2]

These characteristics are the fundamental principles that allow diodes to convert AC current to DC current; negative currents are either blocked or steered to become positive [4]. However, the resulting positive voltage still oscillates, which is why bypass capacitors are often included on the output rail, to reduce the ripple voltage. The capacitor provides a storage medium which provides current to the load while the input voltage is very low or not present [1]. For further reference, figure 7 shows this arrangement [2].

2.2.2 Procedure

1. After acquiring the listed materials and examining the rectifier components, the rectifier circuit depicted in figure 1 was constructed using the function generator as the AC source, and without the parallel capacitor.

2. Next, the function generator was configured to supply a 12 V_{pp}, 400 Hz sine wave for V_{in}. Using the oscilloscope both V_{in} and V_{out} were observed and captured.

3. After that test was complete, a $1\mu F$ capacitor was added to the output of the half-wave rectifier. Using the oscilloscope, both the V_{in} and V_{out} waveforms were observed and recorded.

4. From here, another $10k\Omega$ resistor was added in parallel across the rectifier output, as shown in figure 2. A printout of the oscilloscpe display

was obtained, containing both input and output voltage waveforms.

5. Finally, the rectifier circuit depicted in figure 3 was constructed using the aforementioned function generator at the same specifications. The output voltage was obtained by individually probing each output line with reference to the AC ground, and taking the difference. This data was retreived from the ocilloscope via a printout.

6. Once the lab was complete, the aparatus was cleaned and powered down.

[2]

2.3 Results and Analysis

The results of this lab were oscilloscope captures that plotted the voltage waveforms of interest. All of these captures are included below.

Half Wave Rectifier Without Capacitor Shown below is the input voltage, v_{in}, shown in blue, and the output voltage, v_{out}, shown in yellow, of the network shown in figure 1. In this test, the filtering capacitor was not included.

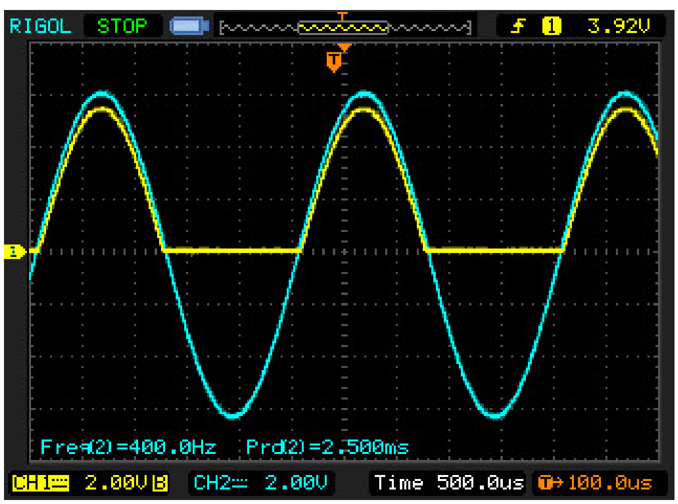

Figure 6: Half Wave Rectifier Capture [2]

The diode prevent current flowing backwards, which allows only the positive going currents to flow through the load. Consequently, v_{out} has a

pulsed waveform. The small decrease in output voltage, as compared to the input voltage, arises from the forward voltage drop of the diode, along with any intrinsic resistive drops along the banana connectors. Theoretically, the output voltage should take the form in equation 2, where the forward voltage drop of the diode is considered.
[1] [4].

$$v_{out} = \begin{cases} v_{in} - v_f & v_{in} \geq v_f \\ 0V & v_{in} < v_f \end{cases} \tag{1}$$

$$v_{out} = \begin{cases} 6V\cos(2513.27t) - v_f & v_{in} \geq v_f \\ 0V & v_{in} < v_f \end{cases} \tag{2}$$

The results for this test, shown in figure 6 follow the mathematical model above. Seeing as the output voltage varies drastically for half of the time and is $0V$ for the other half. Although the output voltage is constant during the regions of no output voltage, a non-zero output voltage is expected. Therefore, this is not a good representation of a constant DC (non-zero) voltage.

Half Wave Rectifier with Capacitor Shown below is the input voltage, v_{in}, shown in blue, and the output voltage, v_{out}, shown in yellow, of the network shown in figure 1. In this test, the $1\mu F$ filtering capacitor was included, which supplied current to the $10k\Omega$ load during the input valleys. With an output capacitor present, the output voltage ripple is reduced. This is a result of the capacitor storing energy while the input voltage reaches its peak, and discharging a portion of its energy to the load while the input voltage decreases. During this time, the capacitor supplies current to the load, thereby maintaining an output voltage. With the understanding that the input voltage is a cosine wave, the theoretical output voltage should take the form given in equation 4, where the diode forward voltage is considered [1].

$$v_{out} = \begin{cases} v_{max}e^{-t/RC} - v_f & 0 \leq \theta \leq \frac{3\pi}{2} + \alpha \\ 6V\cos(\omega t) - v_f & \frac{3\pi}{2} + \alpha \leq 2\pi + \alpha \end{cases} \tag{3}$$

$$v_{out} = \begin{cases} v_{max}e^{-100t} - v_f & 0 \leq \theta \leq \frac{3\pi}{2} + \alpha \\ 6V\cos(2513.27t) - v_f & \frac{3\pi}{2} + \alpha \leq 2\pi + \alpha \end{cases} \tag{4}$$

Shown in the above equations, the resistor, capacitor, and angular velocity values, R,C, and ω, dictate the ripple of the output voltage. In this particular test, the output voltage was remotely constant, as shown in figure 7.

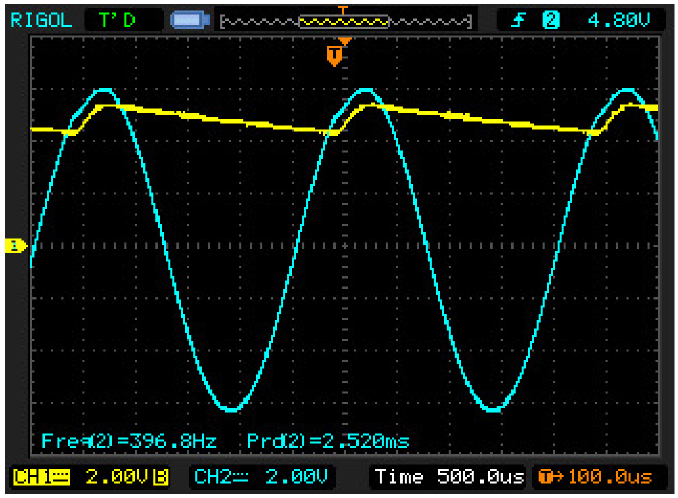

Figure 7: Half Wave Rectifier Capture with Capacitor [2]

It has slight to moderate ripple, and could be adequate for certain loads. Nevertheless, it cannot be considered a constant DC voltage, as it clearly exhibited voltage ripple and followed the theoretical equations precisely.

Half Wave Rectifier with Capacitor and Resistor Shown below is the input voltage, v_{in}, shown in blue, and the output voltage, v_{out}, shown in yellow, of the network shown in figure 2. In this test, the $1\mu F$ filtering capacitor was included, along with an additional $10k\Omega$ load.

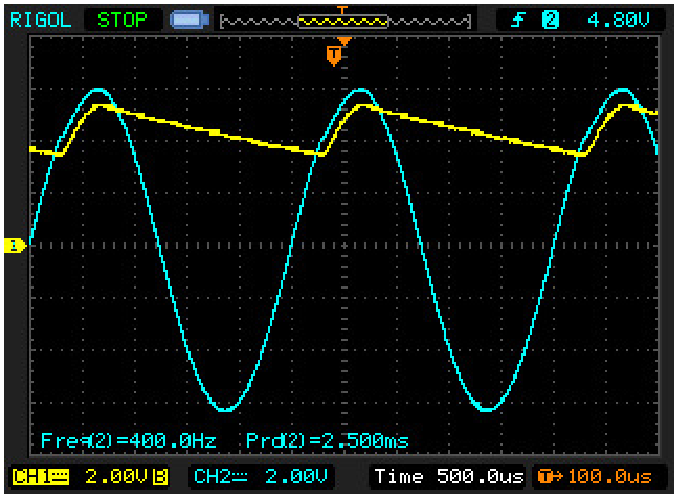

Figure 8: Half Wave Rectifier Capture with Capacitor and Resistor [2]

The output capacitor in this circuit has the same function as that for the above network - it supplies energy to the load during periods of low input voltage to maintain a steadier output voltage. As such, the output voltage in this test also follows equation 4. As can be seen from figure 8, the output voltage corresponds to the mathematical equations. Both the equations and the output waveform illustrate that adding another $10k\Omega$ resistor in parallel increases the voltage ripple. This is due to the fact that when resistors are in parallel, their equivalent resistance is lower than either of the individual values. As such, the load draws more current from the source and discharges the capacitor to a greater degree [1]. The output voltage in this case had slight to moderate ripple, and could be adequate for certain loads. Nevertheless, it cannot be considered a constant DC voltage, as it clearly exhibited voltage ripple and followed the theoretical equations precisely.

Full Wave Bridge Rectifier Shown below is the output voltage, v_{out}, shown in purple, of the network shown in figure 3.

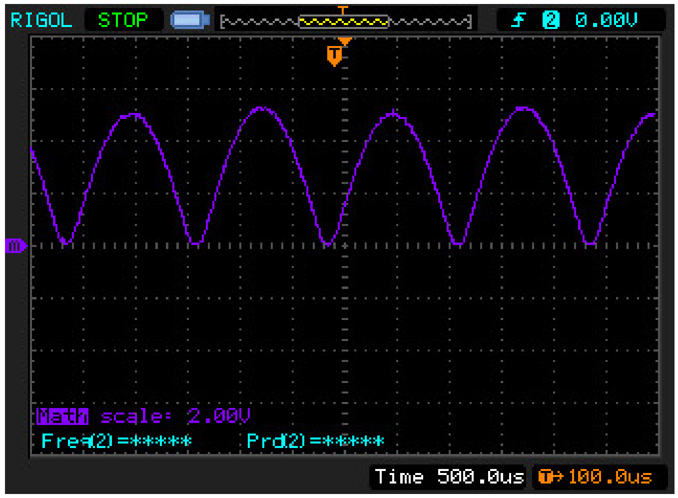

Figure 9: Full Wave Bridge Rectifier [2]

Unlike the simple half-wave rectifier in figure 1, which simply prevented the negative going current from flowing, the bridge rectifier in figure 3 redirects both polarities of input current to positive going output current [1]. Consequently, the output experiences less time without voltage present and the average output voltage is higher [4]. Theoretically, the output voltage of the bridge rectifier can be mathematically modelled with equation 6, with the bridge rectifier forward voltage drop considered [1].

$$v_{out} = \begin{cases} 0V & -v_f < v_{in} < v_f \\ |v_{in}| - v_f & otherwise \end{cases} \tag{5}$$

$$v_{out} = \begin{cases} 0V & -v_f < v_{in} < v_f \\ |6V\cos(2513.27t)| - v_f & otherwise \end{cases} \tag{6}$$

As illustrated in figure 9, the experiment results follow the mathematical model very closely, with the exception of slower transitions between regions. Seeing as the output voltage in this experiment is positive for a greater period of time and supplies the load for a greater period of time than the circuit in figure 1, the output voltage depicted in figure 9 is a better representation of a constant DC voltage than that of figure 6. For reference, a constant DC positive voltage is never zero and always supplies the load [1]. Even subjectively, this plot resembles a positive, constant DC voltage better than the plot resulting from a half-wave rectifier.
In a practical sense, the full-wave output voltage would have less ripple with

a given output capacitance than that of the half-wave rectifier. This is a result of the period between output peaks being shorter, causing the capacitor to discharge less [1].

3 Discussion

Overall, the results of the experiment followed the theoretical expectations depicted in the above equations and theory. The oscilloscope captures of the input and output voltage waveforms shown in the above figures represent the experimental results, which only varied from the expected by signal noise and the rate at which the signal transitioned from one region to the other. These errors are mostly attributed to systematic errors in the experiment. The most signifiant of these errors include:

- The accuracy and precision of the oscilloscope. As our results were exclusively represented by the oscilloscope, its ability to accurately represent the input voltage directly affects the results [2]. To improve this issue, a higher quality oscilloscope, one with greater accuracy, precision, and noise floor, could be used. With this, the signal noise would be reduced and the actual voltage waveforms would be better represented [1].

- The intrinsic inductance and resistances of the banana connectors and the connections between them. These caused the experimental waveforms to have slower transitions than the theoretical expectation as the intrinsic diode capacitance was charged slower. In addition, the line inductance caused signal distortion, as time is required for the current through an inductor to change [1]. Either accounting for these or reducing the lead length in the circuit would improve this error by altering the model or minimizing the effects of the unaccounted for parasitics. Figure 7 shows the results of this error, as the peaks of the input voltage sine wave dips when the diode enters conduction, and current is drawn from the source. As the output voltage directly depends on the input voltage, this directly affected the results [2].

- Function generator signal output impedance and accuracy. The function generator was assumed to produce a perfect sine wave to feed the rectifier networks with. However, as can be seen from the peaks of the input voltage plot in figure 7, when the diode goes into conduction, the input voltage sags, which directly affects the output voltage waveform. This can be attributed to the intrinsic inductance and resistances of the connections (mentioned above), and the output impedance of the voltage source. In this experiment, these two sources of error cannot be isolated, as both are contributors. Nevertheless, no source is perfect, and using a higher quality voltage source, or one with a lower output impedance, would help to reduce this sage.

- Reverse recovery time of diode. Time is required for the diode to switch from reverse biased to forward biased, this value is the reverse recovery time of the diode [3]. Therefore, the output voltage cannot instantaneously change, even if there were no circuit parasitics (discussed below). This value is clearly stated in the devices datasheet, [3], and could have been accounted for in the theoretical model, or at least mentioned. Nevertheless, this diode is a fast switching diode, so the reverse recovery time was effectively minimized [3].

4 Conclusion

In this lab, the behaviour of multiple simple diode circuits was analyzed. With a particular interest on rectifier circuits, both half-wave rectifiers using a single diode, and full-wave rectifiers using a bridge rectifier was analyzed [2]. Half-wave rectifiers prevent negative going current, completely chopping the negative input voltage waveform. As a result, half wave rectifiers exhibit regions of no output current and voltage. On the other hand, full-wave rectifiers redirect all polarities of input current to positive output current. This produces a more constant, positive DC output voltage and allows for more effective filtering [1]. With the half-wave rectifier, the affect of adding an output filter capacitor and additional load resistor in parallel was characterized. A parallel capacitor stores energy from the input voltage peaks and supplies load current while the input voltage low or non-existent. This produces a more steady output voltage. Lowering the load resistance with an additional resistor increased the load current, thereby discharging the capacitor to a greater degree and increasing the output voltage ripple. This behaviour was clear in the experiment results and followed the mathematical expectations precisely. Deviations from the theoretical waveforms are a consequence of systematic errors in the experiment, such as intrinsic lead impedance and resistance, diode capacitance, and oscilloscope accuracy [1] [3]. Nevertheless, the properties of the diode circuits were effectively investigated, thereby accomplishing the lab objective [2].

5 Summay of Roles

Justen G. Di Ruscio

1. Experiment
2. Discussion
3. Conclusion
4. Bibliography

Stephen W.W. Cole

1. Abstract
2. Introduction
3. Procedure

References

[1] H. Li, "Ece2701 lectures," October 2019.

[2] I. Veach, *ECE2701 Experiement 4 - Rectifier Circuits*, December 2009.

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[4] "Single phase rectification," 2019.

[5] H. Li, "Lab marking scheme," Winter 2008. EE3312.

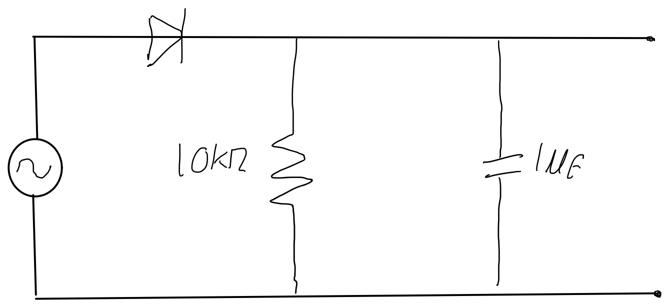
6 Appendicies

6.1 Prelabs - Stephen, Justen

Prelab 4

Friday, November 22, 2019 1:21 PM

Half wave rectifier with a smoothing Capacitor, find the expression of Vout for both the RC charging phase and discharging phase.



$$V_{out}(t) = V_m e^{-t/RC}, \quad 0 \le \theta \; 3\pi/2 + \alpha$$

$$= 6v \, e^{\frac{-t}{10k \cdot 1\mu F}}$$

$$= 6v \, e^{-100t}$$

$$V_{out}(t) = V_m \cos(\omega t), \quad 3\pi/2 \le \theta \le 2\pi$$

$$= 6v\cos(2513.3t) \qquad \omega = 2\pi(400Hz) = 2513.3t$$

finding Average

$$V_{out,avg} = \frac{1}{2\pi}\int_0^{2\pi} V_{out}(t)\, d\omega t$$

$$= \frac{V_{max}}{2\pi}\left(\int_0^{3\pi/2} V_{max} e^{-\frac{100\omega t}{\omega}} d\omega t + \int_{3\pi/2}^{2\pi} \cos(\omega t) d\omega t\right.$$

$$= \frac{V_{max}}{2\pi}\left(\frac{-\omega}{100}\left(e^{\frac{(3\pi/2+\alpha)}{\omega}} - 1\right) + \sin(2\pi) - \sin(3\pi/2 + \alpha)\right)$$

$$= \frac{3}{\pi}\left(\frac{-\omega}{100}\left(e^{\frac{3\pi/2+\alpha}{\omega}} - 1\right) - \sin(3\pi/2 + \alpha)\right)$$

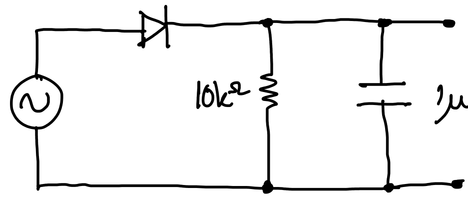
Even though the output is always positive it is not an ideal DC source as it oscillates and is therefore not constant.

Pre-Lab 4

Friday, November 22, 2019 10:52 AM

a) lab manual has been read

b)



$V_{pp} = 12V \rightsquigarrow V_m = 6V$

$\omega = 2\pi(400Hz) \simeq 2513.27$

$$V_{out}(t) = V_m e^{-t/RC} \quad , \quad 0 \leq \Theta \leq 3\pi/2 + \alpha$$
$$= 6V\ e^{-t/(10k\Omega\, 1\mu F)}$$
$$= 6V\ e^{-100t}$$

$$V_{out}(t) = V_m \cos(\omega t) \quad , \quad 3\pi/2 + \alpha \leq \Theta \leq 2\pi + \alpha$$
$$= 6V \cos(2513.27t)$$

$$V_{out,ave} = \frac{1}{2\pi}\int_0^{2\pi} V_{out}(t)\, d\omega t$$

$$= \frac{1}{2\pi}\left(\int_0^{3\pi/2+\alpha} V_{max}\, e^{-100t}\, d\omega t + \int_{\frac{3\pi}{2}+\alpha}^{2\pi} V_{max}\cos(\omega t)\, d\omega t \right)$$

$$= \frac{V_{max}}{2\pi}\left(\int_0^{3\pi/2+\alpha} e^{-\frac{\omega 100 t}{\omega}}\, d\omega t + \int_{\frac{3\pi}{2}+\alpha}^{2\pi} \cos(\omega t)\, d\omega t \right)$$

$$= \frac{V_{max}}{2\pi}\left(-\frac{\omega}{100}\left[e^{\frac{(\frac{3\pi}{2}+\alpha)100}{\omega}} - 1 \right] + \cancelto{0}{\sin(2\pi)} - \sin\left(\frac{3\pi}{2}+\alpha\right) \right)$$

$$= 3/\pi \left(\frac{\omega}{100}\left[1 - e^{\frac{150\pi + 100\alpha}{\omega}} \right] - \sin\left(\frac{3\pi}{2}+\alpha\right) \right)$$

The output, although it's always positive, still oscillates. As a result, it is <u>not</u> a 'good' DC voltage.