XMUT204 Electronic Design
Design Project 1: 5 V Regulated Power Supply

Due Date: Friday, 18 April 2024, 19:59 (online submission to XMUT204 website at VUW)

For marking, you must submit a group report (max of 3 students) and a video presentation clearly showing your names and IDs. See the requirements of report and video at the end of this document.

A. CIRCUIT DESIGN

A.1. Design Requirements

You work in a team of 3 (three) students and must design, construct and test a power supply circuit for a regulated 5 V DC output based on the 230 V AC main input. The input voltage from the main is to step down by a 12 V 500 mA transformer. The AC output from the transformer should first be rectified by a full-wave diode bridge rectifier using 1N4007 diodes. The DC output of the bridge rectifier should be further regulated to a stable 5V supply by means of a three-terminal L7805 regulator and should be able to provide at least 500 mA. You will also have to use further components (mainly capacitors) to stabilise the output of the supply.

A.2. Preliminary Work

You should do a basic circuit design research before you attempt the design project. Read your class notes as well as the material in your textbook on power supplies (approximately pp. 53 – 115) and study the data sheets (supplied in wiki website of VUW) for the 1N4007 diodes as well as the L7805 regulator. Use these data sheets together with your class notes and textbook and ensure that you can answer the following questions in order to be able to do design the basic circuit:

a. What is the peak inverse voltage that the diode can handle?
b. What is the maximum forward current that the diode can handle?
c. What is the input voltage range for the regulator?
d. What is the maximum output current that the regulator can supply?
e. Design a (500 mA) transformer circuit for stepping down the voltage from the 230 V AC main supply to 12 V AC.
f. Design a basic circuit for a diode bridge rectifier and sketch the anticipated input and output waveforms as well as the relative magnitudes of the waveforms.
g. Sketch a circuit implementing L7805 voltage regulator.
h. Combine the above three circuits as well as any additional components needed in order to produce a basic circuit for your power supply.

A.3. Note Keeping

It is essential that you keep detailed notes of your circuits and test results as you will need these to complete your report. Make sure that you sketch all circuits, take down all measurements (including units!) and note your conclusions in your lab notebook as you progress with your design.

A.4. Design of Power Supply Circuit

This section outlines brief designs of components used in the power supply circuit e.g. transformer, diode rectifier, and voltage regulator.

A4.1. Characteristics of Transformer

The input voltage is supplied by a transformer that steps down the 230 V input of the mains to produce what is specified as a 12 V 500 mA (6 VA) output.

The output should contain a fuse that will limit current draw to 500 mA. You might need also to consider adding a capacitor for signal waveform filtering.

Explain the concepts of V_{DC}, V_{RMS} and V_{P-P} for the power supply application.

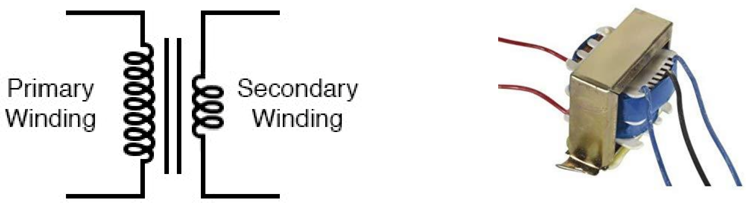

Figure 1: Transformer

A4.2. Characteristics of a Diode Rectifier

There are a number of diode rectifier circuits that are available for you to choose from for this project: half-wave rectifier, CT based full-wave rectifier and bridge full-wave rectifier. It is suggested that you consider the bridge full-wave rectifier due to its efficiency for the diode rectifier part of the power supply.

What are the efficiency and ripple factors of these diode rectifiers?

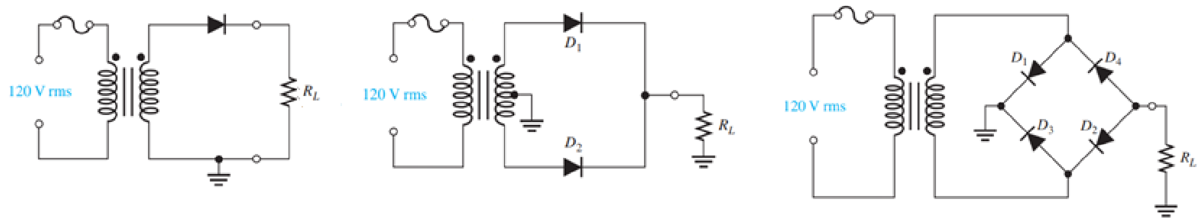

Figure 2: Diode rectifier circuits

A4.3. Characteristics of a Voltage Regulator

The use of an integrated circuit voltage regulator should lead to a much more stable output voltage than can be achieved using a Zener diode. For this project, consider to use LM7805 integrated circuit as the voltage regulator part of the power supply.

LM7805 is a type of linear voltage regulator which is simple to design and construct and it provides a reasonable voltage regulation outcome.

By consulting the datasheet of this voltage regulator, determine its ranges of input and output voltage and current and also its main features.

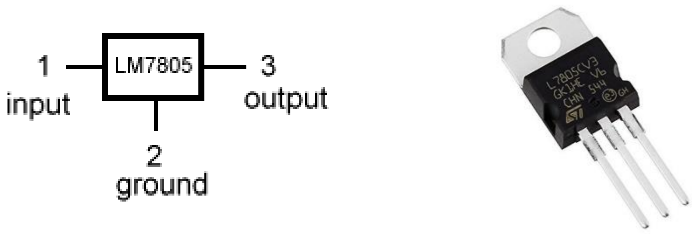

Figure 3: LM7805 voltage regulator

A5. The Complete Power Supply

A complete 5 V power supply is constructed from your transformer, rectifier and regulator sections. Check that it should meet the design requirements of Section A1.

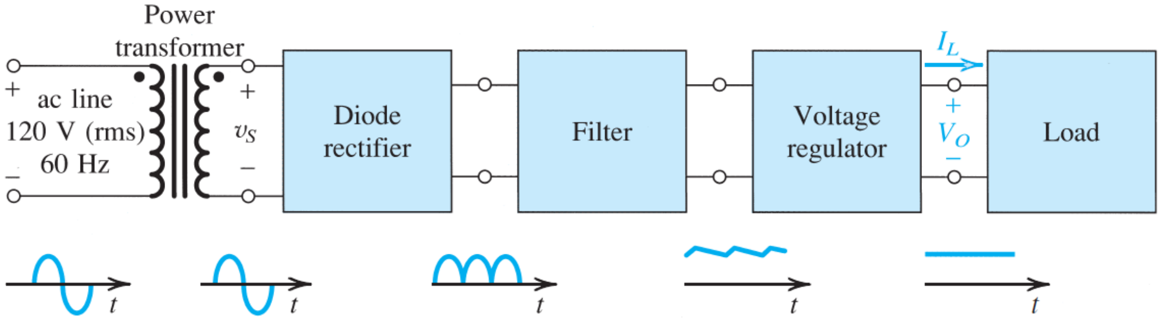

Figure 4: Block diagram of the power supply circuit

B. SIMULATION AND TESTING OF YOUR CIRCUIT

In this particular section, you will simulate and test the components that make up the power supply circuit in simulation software. This will consist of the following tasks:

B.1. Simulation in ECAD Software

In the normal design procedure, we would normally first prototype our circuit in simulation software and construct the circuit in the breadboard (and or stripboard) and ensure that it is working as intended before we proceed with producing a PCB.

However, for this design exercise, the circuit design was provided to you and we skipped the construction of the circuit in the breadboard step.

We will proceed with prototyping of our circuit in the simulation software and investigate the role of some selected components.

B.1.1. Transformer

As the input voltage is supplied by a transformer that steps down the 230 V input of the mains to produce what is specified as a 12 V, 500 mA (6 VA) output, we will first characterise this output.

Start by measuring the output voltage of the transformer. What voltage do you obtain?

Now, choose a sensible load resistor (remember a resistor has a power rating, typically 0.25 watt for a small resistor) and measure the output waveform of the transformer. How does this compare to your previous measurement?

Have a look also at the data sheets of the diodes and the voltage regulator. What is the power dissipation of these components? What is the maximum current that our supply will be able to deliver? What will be a sensible value for a load resistor to test the supply?

B.1.2. Bridge Rectifier

Design your four-diode bridge (no capacitors) in the simulation software and add a sensible load resistor and measure the output waveform. Does this look at expected? Analyse this output waveform by measuring both the peak-to-peak output voltage, $V_{O(p\text{-}p)}$, as well as the average voltage, V_{DC}. The % ripple can then be calculated as (also see sketch below):

$$\%\ \text{ripple} = \frac{V_O(p-p)}{V_{DC}} \times 100\%$$

Now, add the following electrolytic capacitors (polarity!) over the output and in each case measure the % ripple again: 1 µF, 10 µF, 100 µF, 1000 µF. What are your conclusions from these measurements?

For the case of the 1µF capacitor, replace the fixed load resistor with a variable resistor of approximately 1 kΩ and vary the load resistance while you again measure the ripple for each value of load resistance. Set values of approximately 1 kΩ, 500 Ω, 250 Ω, 100 Ω, 10 Ω and in each case measure the ripple in the output. What are your conclusions from these measurements?

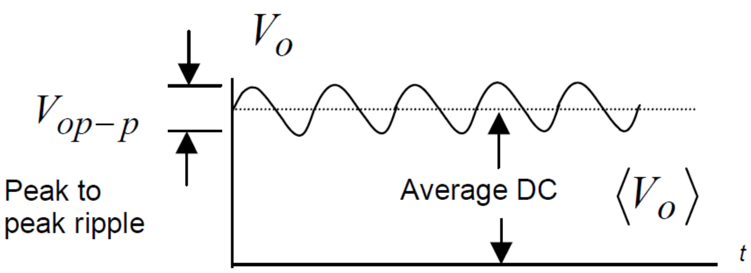

Figure 5: Ripple peak-to-peak voltage waveform

B.1.3. LM7805 Regulator

In the simulation software, set up a LM7805 regulator circuit and use capacitor values as indicated by the data sheet on the input and output side of the regulator.

Vary the input voltage from 4 V to 15 V in steps of 1 V and for each input measure the output of the regulator. What can you conclude regarding the requirements on the input voltage?

Look at the data you have collected for V_{in} = 8 V to 15 V plot V_{out} vs V_{in}. This ratio $\Delta V_{out}/\Delta V_{in}$ is called the *line regulation* and defines the ability of the regulator to maintain a constant output voltage despite changes in the input voltage. Determine this ratio from your graph and compare to the value quoted in the data sheet.

The *load regulation* of a regulator is defined as the ability of the regulator to maintain a constant voltage output despite changes in the load. Again, use the 1 kΩ variable resistor and set approximate values of 1 kΩ, 500 Ω, 200Ω and 100Ω for the load resistance. In each case measure V_{out} and I_{out}. Plot and determine the load regulation from the ratio $\Delta V_{out}/\Delta I_{out}$ and compare to the value quoted in the data sheet.

Set your load resistance to 1 kΩ again and determine the efficiency of your regulator by measuring the power on the input side (current and voltage) as well as the power on the output side. Now, calculate the efficiency (η) as:

$$\eta = \frac{P_{out}}{P_{in}} \times 100\%$$

Perform this efficiency measurement for number of input voltages, e.g. 8 V, 10 V, 12 V, and 15 V. Calculate the efficiency in each case and plot efficiency vs input voltage. What does this indicate about the efficiency of a linear voltage regulator?

Note on power dissipation in a linear regulator:

As you have seen above, linear regulators are very inefficient i.e. only a small portion of the input electrical energy is actually available at the output. The “missing” energy is dissipated by the device in the form of heat. This mean that these regulators heat up quickly and in practice is meant to be provided with a heat sink in cases where it needs to dissipate significant heat. To keep things simple in this design, we will need to limit the power so that we should not require a heatsink.

B.2. Testing of the Power Supply

When simulation of the parts is completed, you can test your power supply by connecting a load to it and measuring the voltage over the load. Is this actually 5 V? Do you observe any ripple on this load? Ensure that you stay well within the limits of the load resistor you have chosen in the previous sections.

Assume that your power supply is not working (assume zero volts at the output) and think carefully how you will test your circuit. Identify a number of logical test points and predict what voltage/ waveform you should measure at these test points. Go through your circuit (even if it is working correctly!), and measure at these test point. Compare your measured voltages to those you predicted.

Now, connect a variable load to your power supply. Also, measure the load current as well as the input current from the transformer. Vary the load resistance over a range of values and measure the output voltage as well as the output and input currents.

B.3. PCB Design

Design the PCB of the power supply circuit in the PCB layout software based on your design. Apply the best practice principles for PCB layout design to ensure that you meet the specified design requirements of the project.

B.4. Design Report

You must also hand in a typed report as will be detailed in Part C as follows.

C. THE DESIGN REPORT

You must now hand in a short design report that describes your design, simulation and testing. This report should be typed and be no more than 2000 words in length (excluding Appendix). Put all diagrams and graphs as the appendices. It should also contain the necessary circuit diagrams and other figures needed for illustration and communication of your design.

C.1. Introduction

The introduction should cover the following aspects:

a. Describe the building blocks (different stages) needed for a power supply.
b. Give a short introduction to diodes and how they can be used for voltage rectification.
c. Describe the design options and trade-offs for the voltage regulator stage.
d. Describe the design requirements that had to be met.

C.2. Design Description

This section should include:

a. A description of your design and explanation how the design and the components selected would meet the requirements and trade-offs as presented in the Introduction.
b. A presentation of your circuit diagram and PCB layout and any comments on these as appropriate.

C.3. Simulation and Testing

Describe the simulation and testing of your circuit. Ensure that you clearly present all the data from tests required from Part B of the document. Your testing must clearly show the operation and characteristics of your power supply.

C.4. Discussion and Conclusions

Your discussion should include the following aspects:

a. Any particular problems that you encountered during the design/simulation/testing and how they were solved.
b. Critically evaluate your design and state any way in which it can be improved or how you would do it differently next time.
c. Discuss what were the aspects of the project that you most enjoyed and that you think provided the most benefit. Were there part(s) that you least enjoyed or found difficult?

C5. Additional Questions

1. In our current design, we start with an AC supply which is first stepped down by a transformer to ~ 12 V and then rectified and regulated to 5 V. However, what will happen if we start with a DC voltage > 5 V and use this as the input to our power supply? Will the same circuit still be able to regulate this down to 5 V? What will be the requirements on this DC input voltage for successful regulation? Do we need to make any changes to the circuit?

2. The role of a capacitor in reducing ripple in the output from the rectifier stage could clearly be seen from the Part B of the design. However, we have used four capacitors in our final design – discuss the role of these different capacitors.

3. You are using a piezoelectric energy harvester as part of a remote sensor network. This harvester generates an AC voltage of maximum value 1 V_{p-p} when it is subjected to environmental vibrations. This voltage must then be rectified in order to charge a battery or capacitor that can then be used to power the sensors and network electronics.

   a. Discuss how appropriate your current design (diode bridge) will be for use with this vibration harvester. What problems may be encountered?
   b. Can you come up with a better circuit design for this task? It may help to do some reading on small signal rectifiers.

D. Presentation and Demo

Prepare a 10 minutes video for the project presentation and demo of your prototype. Talk about all aspects in your design project from the beginning until the end of the project. Use the following guideline for preparing the video and submit this video together with your project report.

No	Section	Duration	Description
1	Your team	0.5 minute	Introduce yourself and roles that you play in the team.
2	Project	0.5 minute	Introduce the design project (i.e. what it is, how is it done and how long the project take place).
3	Design	2 minutes	Describe your design of power supply.
4	Simulation	2 minutes	Describe the things that you do in the simulation and the results of your simulation.

5	Testing	2 minutes	Describe the testing processes that you do and their results.
6	PCB	2 minutes	Describe your PCB design processes and show the result of your PCB design.
7	Conclusion	1 minute	Describe the problems/difficulties that you have in the project and their solutions, evaluation of your design and what you have learnt from the project.

MARKING OF THE DESIGN PROJECT 1

No	**Section**	**Total**	**Description**
A	Design	10	Design processes, choices and rationales.
B	Simulation	10	Simulation processes and simulation results
C	Testing	10	Testing processes, testing results and troubleshooting.
D	PCB Layout	10	PCB design, construction process and PCB layout.
E	Discussion	10	Discuss the project (e.g. problems and solutions, evaluation of the design and what to improve, and enjoyable and difficult parts of the project).
F	Additional Questions	10	Answers to additional questions.
G	Project Report	20	Quality and coverage of your project report.
H	Presentation & Demo	20	Quality and coverage of your project presentation and demo of your working prototype.
	Total	**100**	