Flyback Converter Design for Phone Chargers

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***Abstract*— Flyback converters are DC-DC converters used commonly in phone chargers. The most important component to design in this converter is the transformer because it provides isolation for safety and steps voltages down to charge low voltage devices. The transformer design depends on the transformer's windings turn ratio and its magnetizing inductance. The other key factor is the switch that allows current through the transformer to create a magnetic field. I use a MOSFET, which requires a trigger to turn it on and off, depending on the duty cycle. A good design will result in a phone charger that is efficient (output power is close to input power). In this lab, I show that as input voltage increases, I get a more efficient converter for charging phones. I also show how simulation circuits can give a great starting point in design, showing what to expect before manufacturing the circuit.**

I. Introduction

FLYBACK converters have many uses in electronics. One important use is a phone charger, a device used daily by billions of people worldwide. Many are designed to approximately output 500mA at 5V. Designing a phone charger for this output is important because if the voltage is too low or too high, the phone will either not charge or may be damaged if it cannot handle high current charging. The objective of the lab is to design a circuit that can get as close as possible to this safe output. The main component I designed in the lab is the transformer.

II. Flyback Design

Flyback converters are important because they serve two functions: they provide safety by isolating the user from the main power line, and they convert high voltages to lower voltages efficiently. To achieve this, a transformer must be implemented. A transformer provides isolation because there are two windings of wire in the coupled inductor, which means that the winding from the primary (the source) is not connected to the winding of the secondary (the load). Current is transmitted through the magnetic field generated.

The flyback converter is not the only stage in a full power adapter. A rectifier is needed to convert AC to the DC voltage the flyback needs. I use a power supply for experimentation purposes. The MOSFET needs a trigger to the gate to allow power throughput to the transformer. For this trigger, I use a waveform generator that outputs a square wave. In the real world, another circuit, which incorporates feedback, is used to make sure the output to the load is always 500mA at 5V given varying loads. See Fig. 1 for the schematic drawing.

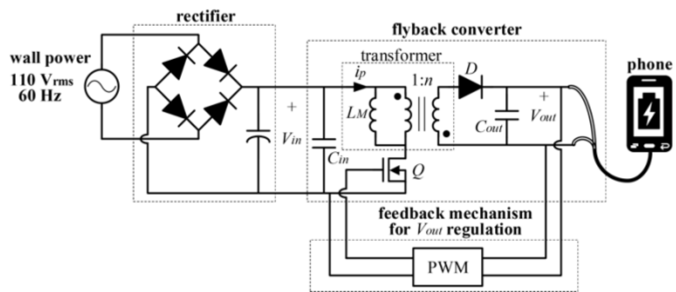


Fig. 1. Circuit schematic of phone charger in three stages. (Source: EE 153 Lab 6 handout).

In the lab, I built the transformer by calculating a turn ratio that optimized for minimal switching losses (a 50% duty cycle). The rest of the components—the capacitors, diodes, MOSFET, and resistor—were pre-selected.

III. Building a Flyback

Before building the circuit, I created an Ltspice simulation circuit to verify that the design worked. See Fig. 2 for the completed circuit. To do this, I first had to calculate the turn ratio, measure magnetizing inductance, and obtain duty cycles for the transformer. I used equation (1) to get the Vout to Vin relationship. Where N is the turns ratio and D is the duty cycle.

$$\frac{V_{out}}{V_{in}} = \frac{N*D}{(1-D)} \tag{1}$$

I picked 25V for Vout and 5V for Vin, which gave me a 25:5 turn ratio for the transformer. This ensures that the turn ratio ideally works for a 20V through 30V input.

To find the magnetizing inductance I used equation (2) to find the reluctance of the transformer core. Then I used equation (3) to solve for inductance, given the turns on the primary:

$$R_c = \frac{l}{u_c A_c} \tag{2}$$

$$L_M = \frac{n_1^2}{R_c} \tag{3}$$

The data sheet of the transformer core B65807J0000R087, gives the values to solve for reluctance R_c to then get the magnetizing inductance which about 300uH given an airgap length of ~100um (one sheet of paper). When making the transformer, I measured a ~220uH magnetizing inductance with a leakage inductance of ~1.87uH.

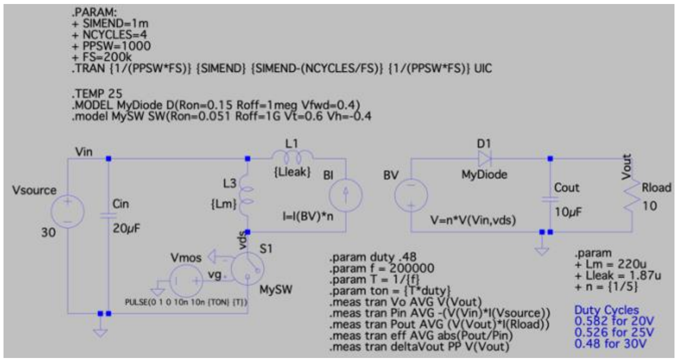


Fig. 2. Ltspice schematic of the flyback converter after inputting computed values for the turn ratio, measured values for magnetizing inductance, and optimized duty cycles.

In Appendices A-C, the simulated voltage outputs give a ripple that is within the specification of ±5% of 5V. The best peak-to-peak ripple I got was about 0.2175V meaning a ~3.5% ripple when Vin is 30V.

Once the transformer parameters were calculated and verified in Ltspice, I constructed the circuit. In the lab, I used the same components I used in the simulation. The transformer primary has 25 turns, and the secondary has 5 turns. Both windings are using 30AWG wire to make efficient use of the core window, which minimizes power losses. There is also an airgap of 100um to avoid saturation. See Fig. 3 for the built circuit.

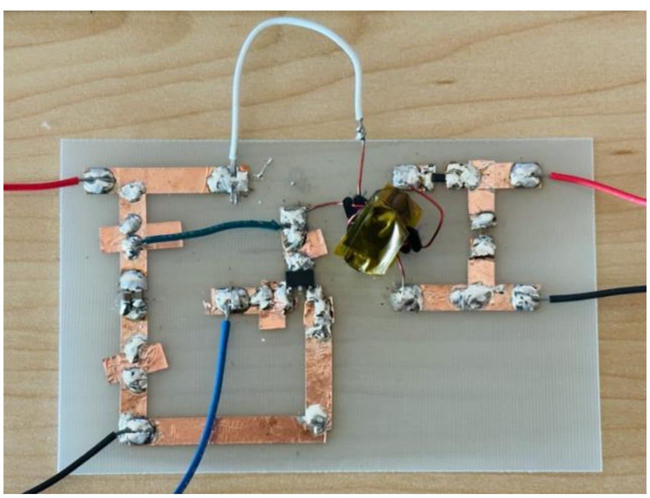


Fig. 3. Flyback circuit built using copper tape.

IV. Results of the Experiment

Once the circuit was built, I inputted 20V-30V using a power supply. I created a square wave with a waveform generator at 200kHz by varying the duty cycles to the spice simulation values to achieve a ±5% of 5V at around 500mA. To measure the needed values, like voltage out and current out, I used an oscilloscope to view the waveforms outputted.

Shown in Appendix A, the experiment voltage averages 4.878V with a duty cycle of 0.582. The voltage in the experiment was lower than the 5V simulation. The output current averages 474mA meaning the converter outputs 2.31W of power with an input of 2.6W. My flyback converter at 20V had an efficiency of 88.85%.

Shown in Appendix B, the experiment voltage averages 4.923V with a duty cycle of 0.526 The voltage in the experiment was lower than the 5V simulation. The output current averages 472mA meaning the converter outputs 2.33W of power with an input of 2.75W. My flyback converter at 25V had an efficiency of 84.85%.

Shown in Appendix C, the experiment voltage averages 5.001V with a duty cycle of 0.48. The voltage in the experiment was equal to the 5V simulation. The output current averages 474mA, meaning the converter outputs 2.39W of power with an input of 2.7W. My flyback converter at 30V had an efficiency of 88.46%.

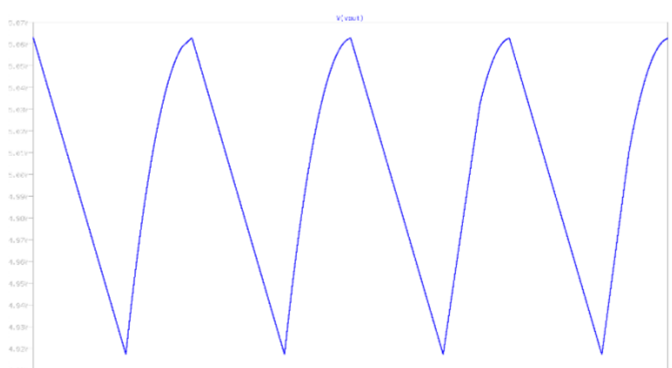
The measurements showed that the higher voltage inputs result in lowering the duty cycle, which, in turn, lowers the power consumption of the circuit. As voltage increases, my flyback converter is more efficient and ripple is minimized.

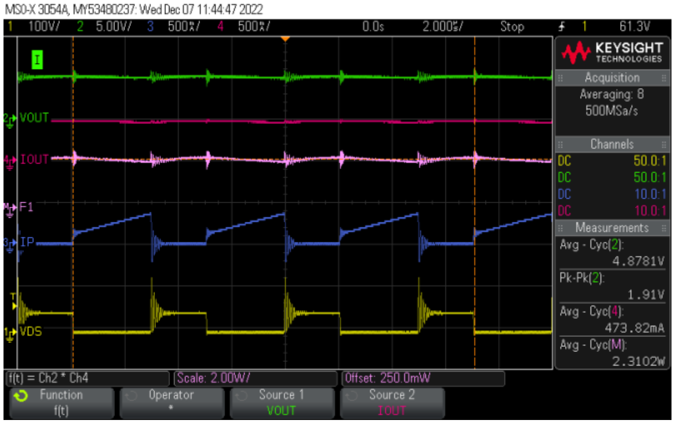
V. Conclusion

In this lab, I showed that as input voltage increases and duty cycle decreases, I get a more efficient converter for charging phones. I also showed how simulation circuits can provide a good starting point in design, demonstrating what to expect before manufacturing the circuit. After simulating and testing my flyback converter design, I realized that to create an actual phone charger another circuit is needed to create a square wave that triggers the MOSFET at a duty cycle to maintain the ±5% of 5V at 500mA. The turn ratio may also be adjusted to allow for lower duty cycles to further increase efficiency as higher voltages from wall outlets are used.

Appendix A

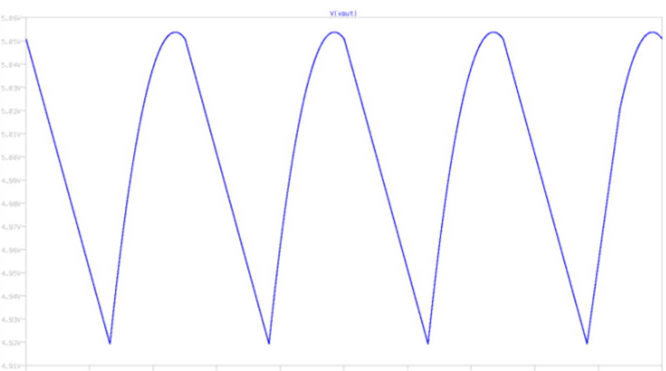
The waveforms here show the voltage across the load in both simulation and the experiment with an input of 20V. The simulation plot is from LTSpice and shows voltage out. The image below is experimental data that shows voltage out in green, voltage across the drain and source of the MOSFET in yellow, current across the primary in blue, current out in red, and power out in pink.

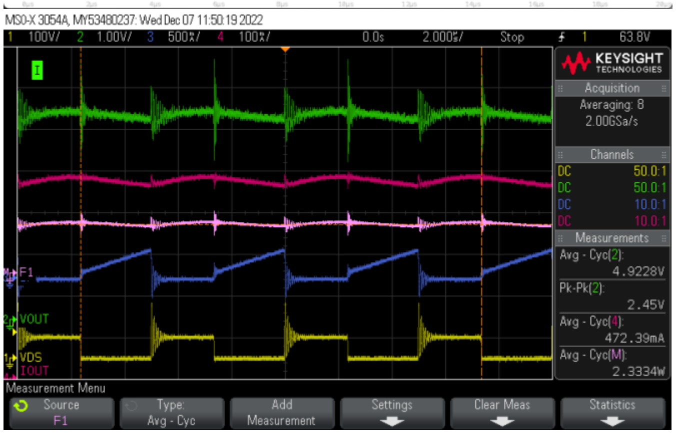




APPENDIX B

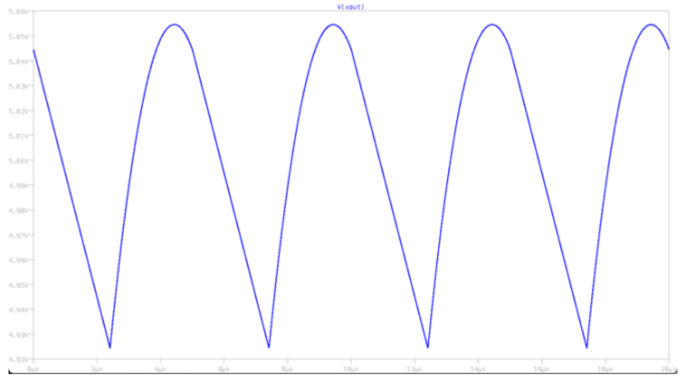
The waveforms here show the voltage across the load in both simulation and the experiment with an input of 20V. The simulation plot is from LTSpice and shows voltage out. The image below is experimental data that shows voltage out in green, voltage across the drain and source of the MOSFET in yellow, current across the primary in blue, current out in red, and power out in pink.

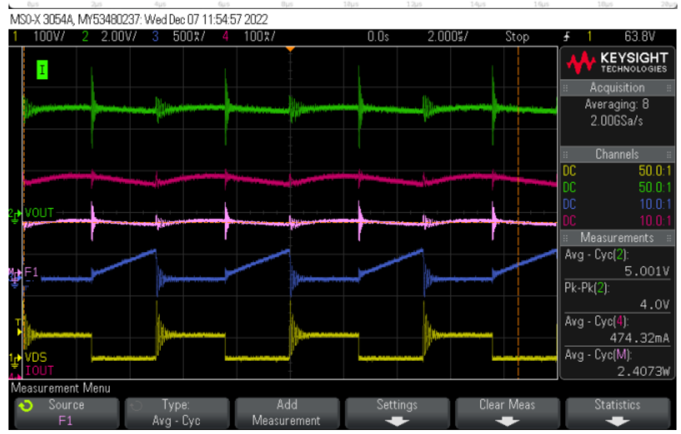




APPENDIX C

The waveforms here show the voltage across the load in both simulation and the experiment with an input of 20V. The simulation plot is from LTSpice and shows voltage out. The image below is experimental data that shows voltage out in green, voltage across the drain and source of the MOSFET in yellow, current across the primary in blue, current out in red, and power out in pink.





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