Design and Implementation of a Single-Phase AC-DC Conversion System Including Multiple Outputs

Logan Johnson

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____
Jung-Uk Lim, Ph.D.
Thesis Chair

____
Kyung Kyoon Bae, Ph.D.
Committee Member

____
David Schweitzer, Ph.D.
Assistant Honors Director

____
Date

Abstract

Power conversion between alternating and direct current is a common application of Electrical Engineering in daily life, and most modern technology relies heavily on regulating voltage and current flow. This paper discusses the theoretical underpinnings, design, and assembly of a custom power converter built to convert the standard US outlet power of 120VAC to a 18.5V DC source and a 5V DC source: the goal of this device is to create a charger that can power a laptop and USB port at the same time with a single wall plug. The paper discusses the theoretical background of such a device, along with the practical aspects of its implementation. The design is then reviewed, and possible improvements noted.

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Introduction

Power conversion is a common application of Electrical Engineering concepts in daily life, and most modern technology relies heavily on regulating voltage and current flow. This is typically done by modifying source AC and DC voltages into a more specialized and useful form. For instance, a typical phone charger incorporates a switched-mode power supply to change the standard USA 120V AC outlet power into the 5V DC that is standard for USB-powered devices.

The motivation of this thesis was to build a charger that could power two electronic devices simultaneously with a single charger: namely a laptop computer and a USB outlet for charging a cell phone. This design would minimize the complexity of charging both at the same time, save space, and reduce the number of wall outlets needed to charge the two devices. These changes make these devices easier to charge in daily life, minimizing the equipment needed to do so. A block diagram describing the system is shown in Fig. 1.

The use of a flyback topology as the primary power conversion stage of the device was chosen due to its versatility, ability to step down high input voltages at a variety of duty cycles, and the fact that the topology ensures that the input and output voltages are galvanically isolated from one another. This topology will be expanded upon later in this paper, along with the buck converters used to step the output of the flyback converter down to the voltages used by the laptop and phone outputs.

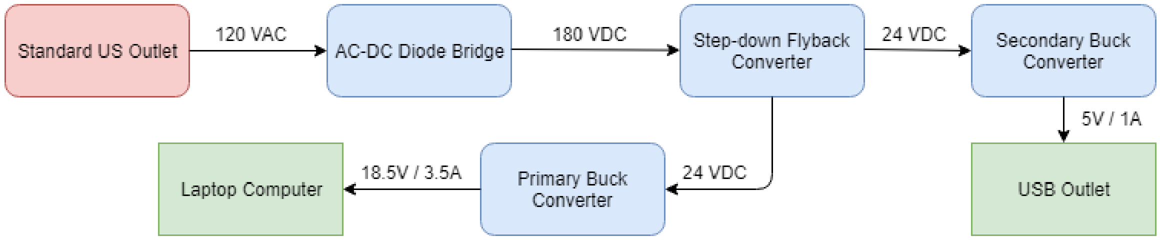

Fig. 1. The block diagram representing the converter architecture.

The coming sections will discuss the theory behind the stages of the converter. They begin with a discussion of the flyback converter, later moving on to the workings of the buck converter topology. Following the theoretical background are sections concerning the requirements of the power conversion system, the design implementation of the system, and the physical fabrication of the device itself. The paper will conclude with the results of testing the device, and analyzing the outcome of those tests.

Flyback Converter Theory

The first stage of the power conversion process for this charger is implemented using a flyback converter. To better illustrate the motivation behind the final design, the theoretical concepts of the circuit are explained below.

Topology

The basic topology of a flyback converter is shown in Fig. 2 [1]. It consists of a DC voltage source and switch on the primary side: in practical applications the switch is typically an N-channel MOSFET transistor, but is modeled as an ideal switch here. On the secondary side is a diode, output capacitor, and output load. Separating the two is a

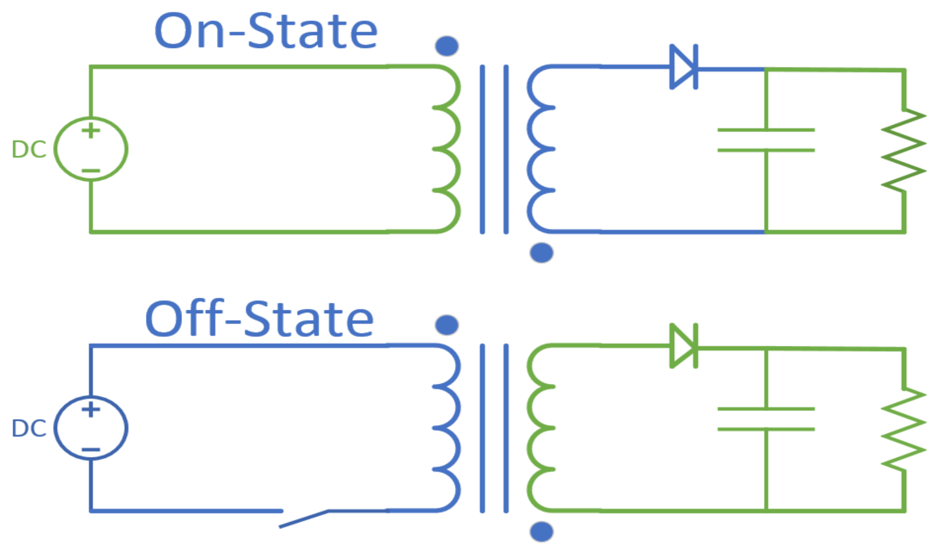

Fig. 2. The two states of flyback converter operation, with zones of current flow in green.

transformer, although that designation is a misnomer: it acts as a coupled inductor rather than a true AC-AC transformer. This topology results in galvanic isolation between the two sides of the converter, which prevents one side from interfering with the other during the operation of the device [2].

The device has an on-state and an off-state, which depends on whether the primary loop allows the flow of current. When the switch on the primary side is closed, the converter is in the on-state. When the switch is open, the converter is in the off-state.

Switching Cycle Behavior

The proper operation of the flyback converter depends on the position of the primary switch cycling on and off at a frequency that typically ranges from 65kHz to 130kHz [2]. When the switch is closed, current flows into the primary side of the transformer. This results in the transformer storing energy by increasing its magnetic flux as it resists the change in current due to its primary inductance. This will continue until the switch is opened or the transformer core becomes magnetically saturated. While the transformer is storing energy, the output capacitor on the secondary side of the topology is releasing energy to maintain a constant voltage to the load resistance. The diode is reverse-biased, preventing the flow of current through the secondary coil of the transformer [3].

When the primary switch is opened, current stops flowing on the primary side of the converter. The stored energy in the transformer is then released into the secondary side, forward-biasing the diode. This current charges the output capacitor and maintains the output voltage. This process continues until the transformer has used its stored energy, at which point the output capacitance stabilizes the voltage once again.

The two states of the topology work to maintain a constant output voltage, with energy being transferred from the primary side to the secondary side on each cycle.

Output Voltage Regulation

The output voltage of the converter can be adjusted based on a number of factors. The first is in the ratio of primary to secondary turns of wire on the transformer [1]. If there are many primary turns and few secondary turns, the output voltage is lower than the input voltage on the primary side. The opposite holds true as well: a larger number of secondary coils than primary coils results in a voltage increase from the primary side. By adjusting the turns ratio, a general output voltage can be reached.

In addition, the output voltage is regulated by the duty cycle of the MOSFET switch. The longer the switch is closed during each switching cycle, the higher the output voltage [1]. This is regulated by a feedback circuit from the output voltage, dynamically adjusting the output voltage to the proper value [4], [5]. This has the side benefit of allowing the converter to work with slight variations in input voltage [6], as the duty cycle automatically adjusts to maintain the output voltage.

Another key part of the voltage regulation process is the output capacitance. The higher the output capacitance, the lower the output ripple voltage [7]. Ideally the capacitance would be infinite, but in practice it is kept high enough to minimize the ripple voltage to an acceptable level.

One more component of the output regulation is additional filtering after the output capacitor [2]: typically an LC filter is used to dampen high-frequency noise in the voltage output and reduce the ripple voltage.

Protecting the Primary Switch

No real-world component will exactly match the theoretical ideal operation. The transformer in the flyback topology is no exception. It has a primary inductance value which indicates the amount of power it can store. However, approximately 3% [8] of this inductance leaks from the transformer, acting like an inductor in parallel with the transformer connections. This causes problems in the switching cycle, due to the inductor causing voltage spikes across the primary switch.

Inductors resist changes in the flow of current through them. Since the current in the primary side of the circuit stops flowing in the off-state, this sudden drop in current causes a voltage spike across the switching MOSFET. This can result in component damage if not accounted for.

This problem is remedied by introducing a voltage snubber. The RCD snubber seen in Fig. 3 is inactive during the on-state of the converter, allowing current to flow

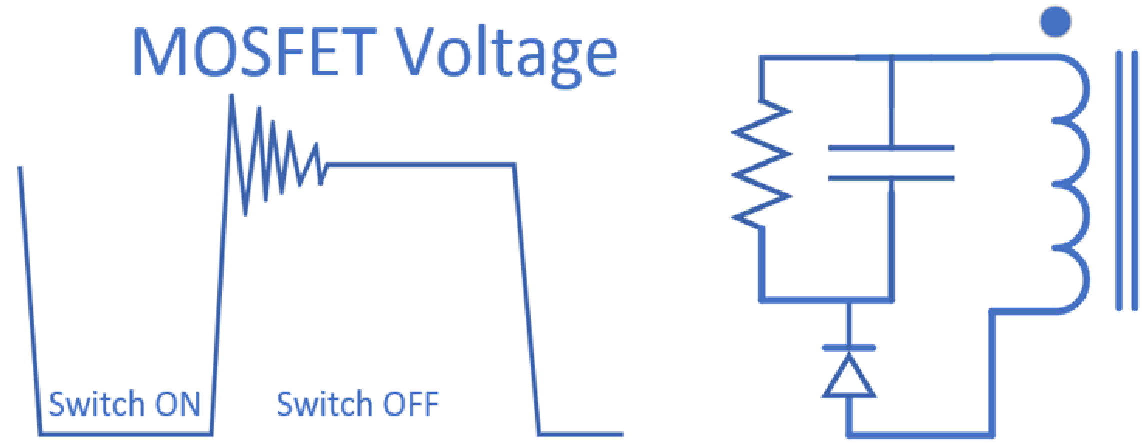

Fig. 3 The effect of parasitic inductance on the V_{DS} value of the primary switch (left) and a typical RCD snubber configuration (right).

into the transformer. When the switch is opened on the primary side, voltage increases on the drain terminal of the switching MOSFET. This voltage forward-biases the diode of the snubber, allowing current to flow to the resistor and capacitor connected in parallel to it. The current is then dissipated in the RC circuit [2]. This reduces the voltage stress on the MOSFET, allowing it to remain operational.

Conduction Modes

Several types of converters have conduction modes, each dealing with a magnetic storage element that is energized and discharged during the switching cycle. This concept is relevant to most switched-mode power supplies. The maintenance or collapse of the magnetic field in the transformer is what determines the conduction mode of the converter. Each mode has benefits and drawbacks which must be balanced when selecting a mode for the converter [9]. In addition, each mode requires a slightly different converter design to operate correctly.

Discontinuous conduction mode. In the discontinuous conduction mode (DCM), the magnetic energy stored in the transformer is allowed to collapse in each switching cycle, meaning that the primary winding current drops to zero in each cycle. This allows for the use of a smaller transformer, since it doesn't need to store enough energy to maintain the magnetic field in each cycle [2]. It also has a lower turn-on and reverse recovery losses than the boundary conduction mode or continuous conduction mode [9]. However, this mode requires a larger output capacitance to reduce the output voltage ripple caused by the variation in the primary current. In addition, the constant energizing and de-energizing of the transformer results in higher core losses than for the other conduction modes [2]. The hardware in this thesis is designed to operate in the discontinuous current mode due to the smaller transformer size required.

Continuous conduction mode. Continuous condition mode (CCM) occurs when the magnetic field of the transformer never collapses, meaning that the transformer is re-energized before its stored energy runs out. This allows for a smaller output capacitor to be used, since lowering the variation in primary-side current has the side effect of lowering ripple voltage [3]. This also serves to reduce peak MOSFET and diode current, as well as lower power loss in the transformer windings due to the constant energizing and de-energizing of the transformer. However, this conduction mode requires a large inductance value for the transformer in order to maintain the magnetic field during each cycle. This can result in large transformer cores that increase the cost and size of the converter [2].

Boundary conduction mode. The boundary conduction mode or critical conduction mode occurs when the energizing portion of the cycle begins as soon as the magnetic field of the transformer is dissipated into the secondary side of the topology. It is the boundary between CCM and DCM operation, and is useful for theoretical calculations that apply to both operation states. However, this mode results in high input-current ripple, greater stresses on the primary switch, and requires a variable operation frequency to be properly implemented [9]. For these reasons this mode is typically not used for power conversion applications.

Buck Converter Theory

The secondary stages of the power conversion process for this charger are implemented with buck converters, which step down a DC input voltage to a lower value efficiently. To better illustrate the motivation behind the final design, the theoretical concepts of the circuit are explained below.

Topology

The topology of the buck converter is simpler than that of the flyback converter: it is composed of a DC voltage source, a switch, a diode, an inductor, an output capacitor, and a load resistance as seen in Fig. 4 [10]. Most of the components have a direct parallel to the flyback converter, like the output capacitor and diode. The primary difference between the two topologies is that the buck converter uses an inductor as a storage element rather than a transformer core. This eliminates the need for a bulky transformer core but prevents the converter from being able to increase the input voltage to a higher value. Removing the transformer core also makes adding additional outputs more difficult than it would be if using a flyback topology: the flyback topology can easily add an output by adding another set of windings [2].

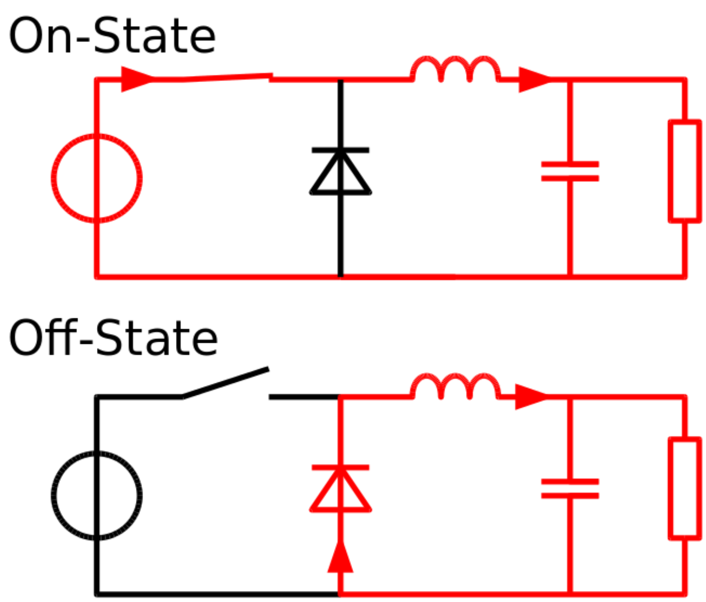

Fig. 4. Operation states of a buck converter with areas of current flow marked in red. Used with permission

Switching Cycle Behavior

While the switch is closed, current flows directly into the inductor. The diode is reverse-biased, preventing the flow of current through it. During this time the inductor stores energy while resisting changes in the current flowing through it. As the current stabilizes, the voltage drop across the inductor decreases, increasing the voltage at the load resistor. Since there will always be at least some voltage drop across the inductor, the voltage supplied to the load will be less than the input voltage [10].

When the switch turns off, the inductor resists the change in current by acting as a current source. This charges the output capacitor and supplies power to the load. The buck converter can operate in continuous conduction mode, discontinuous conduction mode, and boundary conduction mode [10] much like the flyback converter can.

Output Voltage Regulation

The output voltage of a buck converter is much more dependent on the duty cycle of the switch than the corresponding voltage in the flyback converter. This is in part due to the lack of a transformer core that allows the output voltage to be increased or decreased by adjusting the primary to secondary coil turns ratio. In an ideal buck converter operating in CCM, the duty cycle is equal to the output voltage divided by the input voltage. For example, stepping down from an input voltage of 24V to an output voltage of 6V would require a duty cycle of 25%, meaning that the converter would be in the on-state and supplying current to the inductor around 25% of the switching cycle. As the duty cycle increases the output voltage increases toward the input voltage [10].
In addition, the output is stabilized by an output capacitor and often an additional LC filter. These serve to reduce ripple voltage. The higher the output capacitance, the smaller the ripple.

System Requirements

Input and Output Power

The converter must take standard 120 VAC power from a wall outlet and transfer it to two DC outputs. The first output is for a laptop charger, namely an 18.5 V 3.5A supply for an Acer laptop. The second output is a 5V 1A USB port: it is intended to charge a cell phone, but any USB-powered devices should be able to use it without modifications. Each output allows for 10% ripple in the voltage to reduce the need for bulky and expensive output capacitors.

Constraints

The converter should be no more than 50% larger than a standard HP charger. It should also remain cool enough to avoid compromising the 3D-casing that will surround it. The total cost of the unit should be below $100 to ensure the solution is relatively affordable. Lastly, its connectors must match those found in current chargers to ensure the safety of the users and their devices. This entails using a standard NEMA 5-15P three-pronged plug to fit US outlets [11], a USB-A output port, and an EIAJ coaxial power connector to plug into the laptop.

System Implementation

The converter design can be broken into three stages. The first stage filters and rectifies the AC input voltage, then uses a flyback topology to step the voltage down to 24VDC. Stage two uses the flyback converter's output and steps it down to 18.5VDC using a buck converter. Stage three is much like stage two, only that its buck converter steps the voltage down to 5VDC.

Central Flyback Converter

The primary flyback circuit is the most complex stage of the converter. Points of interest are discussed below.

Line filter and AC rectification. The flyback converter is a DC-DC topology, which means that the 120VAC input must first be rectified and filtered is a relatively stable DC voltage: this process is illustrated in Fig. 5. The first component used for this process is an FPP-01 line filter, which removes some of the noise from the voltage input. It also ensures that the actions of the circuit do not interfere with any other voltage sources

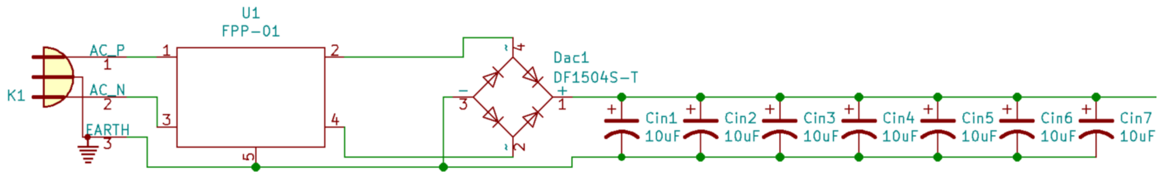

Fig. 5. Line filter and DC rectification implementation.

connected to this one. The second component in the circuit is a DF1504S-T diode bridge [12], which rectifies the input voltage to strictly DC using a full bridge topology. From there the voltage is stabilized using input capacitors. Using an array of capacitors as shown above reduces component size and cost when compared to using a singular capacitor with both high voltage tolerance and high capacitance. The plug represented above is an IEC 320-C14 connector designed to work with a NEMA 5-15P to IEC 320-C13 cord for standard US three-pronged outlets [11].

Transformer selection. The transformer core chosen is a TDK ferrite E-shaped core. It is mounted to the board using a specialized coil former, which allows the primary, secondary, and auxiliary wire turns to connect easily to the rest of the board. It has a primary inductance of 461 μH, which is small enough to keep the circuit running in discontinuous current mode. The windings of the transformer are all wound around the center of the core and insulated from each other and the core, with primary turns wound directly on the core and other coils wound on top of them to maximize magnetic coupling. There are 37 turns of 22-gauge wire for the primary side, 6 turns of 22-gauge wire for the secondary side, and 3 turns of 22-gauge wire [2] to provide power for the circuit dealing with the gate driver and primary MOSFET switch.

Primary switch and gate driver. The practical implementation of a primary switch for the flyback converter, as seen in Fig. 6, is complex. It needs to account for

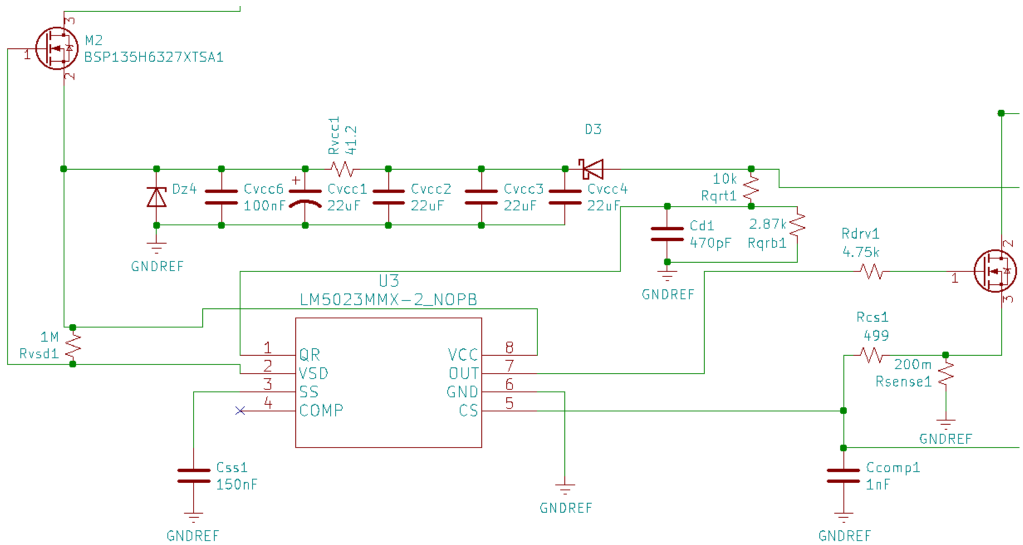

Fig. 6. Implementation of the primary switch and gate driver.

circuit feedback and the lack of a stored power source on startup. This converter uses a LM5023MMX-2 NOPB PWM controller [13] to manage the signals sent to the primary MOSFET switch. The IC is powered by an auxiliary winding while the converter is running, but that winding is unable to supply power when the converter is in an off state. To remedy this, a depletion-mode MOSFET is placed directly after the input voltage is rectified and stabilized to around 180VDC.

This voltage is reduced by a resistor in series with the aforementioned transistor. During startup, the transistor allows current to flow into the VCC pin of the LM5023 chip.

The voltage is stabilized and limited by a pair of output capacitors in parallel with a Zener diode with a breakdown voltage of 14V. This allows the circuit to start without power from the auxiliary windings. When the converter is functioning at a steady frequency with consistent switching cycles, the depletion-mode MOSFET restricts the flow of current to the controller from the rectified DC, allowing the power sourced from the auxiliary winding to operate the integrated circuit.

The central IC is a complex device, and its configuration reveals important details behind the regulation of the converter. Its QR pin monitors the output of the auxiliary windings to ensure that an output overvoltage results in the circuit shutting down to avoid component damage. The VSD pin is connected to the gate of the depletion MOSFET mentioned earlier to disable the startup voltage after the VCC input from the auxiliary winding is stabilized at the correct value. The SS pin sets the soft start ramp, meaning that the converter will slowly increase the duty cycle of its switching in order to properly set up the normal operation of the converter. The COMP pin is a pin that adjusts the duty cycle of the converter based on the output of the feedback circuit: this ensures that the output voltage stays within the targeted range regardless of the input voltage or power draw [6, 13].

The rest of the pins are comparatively simple: VCC refers to the input voltage received from the startup circuit or auxiliary winding, while GND is connected to a ground reference. The OUT pin outputs a current to the gate of the primary switching MOSFET, which allows the controller to allow or restrict the flow of current in the primary loop. The CS pin is a current sense pin that acts as a backup control mechanism and guards against abnormally high currents in the primary side of the circuit. If the current in the primary side exceeds safe levels as determined by an internal current sense comparator, the circuit shuts down to avoid damaging components [13].

The last component of interest is the SPA20N60C3XKSA1 N-Channel MOSFET used to implement the primary switch. This component can withstand a drain to source voltage of 600V and continuous drain current of 20.7A [14], making it ideal for this high-stress application. It accepts a drive voltage that ranges from 10-20V, making it compatible with the LM5023 chip: when supplied a voltage in this range, the resistance between the drain and source of the transistor drops to its $R_{DS(on)}$ value of .19Ω.

The optocoupler in Fig. 7 ensures that the feedback circuit remains isolated from the primary loop. Internally it has a phototransistor and an LED. Current flows through the LED, which causes it to light up and engage the phototransistor [5]. Optocouplers have a specified current transfer ratio (CTR), which refers to how much current the transistor-side draws based on the current through the diode. It is heat-dependent, increasing as the part temperature increases.

Rfbb3 serves as the lower half of the main voltage divider between Rfbt3 and Rfbb3. This divider cuts the output voltage down to the level of the voltage reference, which is typically 2.5 volts for most TL431 chips. Rfbt3 is the other half of the divider. Here they are stabilized by Cfb1 to smooth out the output voltage signal.

Ropto1 is used to limit current running through the optocoupler to acceptable ranges for the component.

Lastly the TL431 serves as a reference voltage to compare the divided output voltage with [9]. The internal reference is 2.5 volts, which is a little like the breakdown voltage for a Zener diode. If the voltage to the reference pin exceeds 2.5V, the TL431 allows the flow of current. This flow of current sends a signal through the optocoupler to

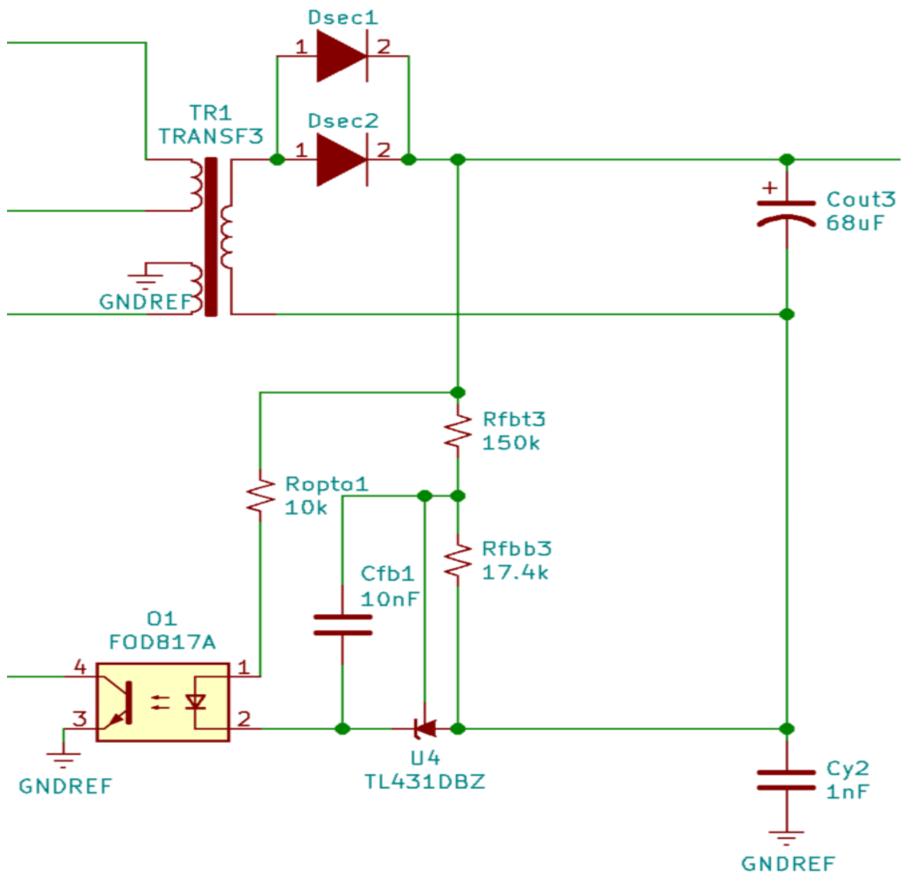

Fig. 7. Implementation of the output voltage feedback circuit.

the COMP pin of the LM5023 chip, communicating that the output voltage is too high and needs to be lowered by adjusting the duty cycle.

Primary Output

The primary output of the circuit is pictured in Fig. 8, and draws from the 24V output of the flyback converter and steps it down to an 18.5V 3.5A power supply. Owing to the lack of a transformer and need for galvanic isolation of the feedback loop, this part of the circuit is relatively simple.

Buck converter implementation. The main component of this output is the LM73605RNPR regulator [15] designed by Texas Instruments to handle an output current of up to 5A with adjustable output voltages. The input voltage from the output of

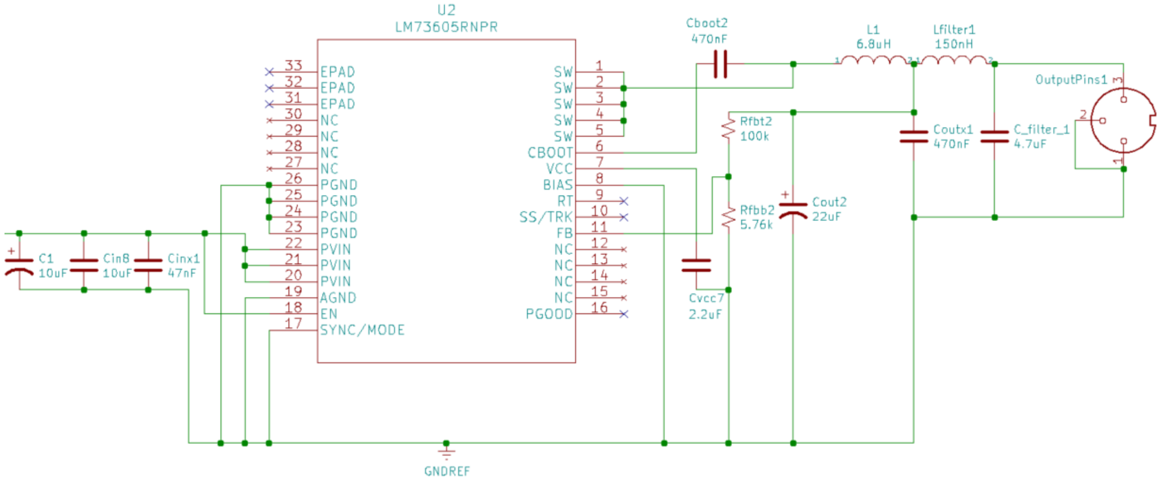

Fig. 8. Implementation of the 18.5V output.

the flyback converter is stabilized using some input capacitors and fed to the PVIN pins to power the device. The acceptable input voltage in this circuit ranges from 21.6V to 26.4V, allowing for smaller input capacitance that reduces the circuit cost and size. The EN pin is tied to the input voltage to help the buck converter adjust the variability in the input voltage. The PGND, AGND, and SYNC/MODE pins are all connected directly to a ground reference: the former two are power ground and analog ground references, while tying the latter to ground disables the unneeded synchronization input and mode setting pin.

The SW pins send out the unfiltered voltage output, reduced to appropriate levels. This output connects to the Cboot capacitor and CBOOT pin: this is a bootstrap circuit that ensures that the switching components inside the LM73605 chip are supplied with a high enough voltage to operate correctly when the circuit starts up [15]. The VCC pin refers to the output of the internal control circuitry of the IC, which is stabilized by a 2.2μF capacitor. Since the output voltage is greater than 18V, the BIAS pin is tied to ground: otherwise it would be tied to the output voltage to increase the converter efficiency. Lastly the FB pin is connected to a voltage divider near the circuit output. This works a little like the TL431 reference mentioned earlier: when the voltage to this pin exceeds the 1V reference voltage of the chip, the duty cycle of the converter is lowered to decrease the output voltage. The rest of the pins of the IC are not used in this application and remain unconnected.

Voltage stabilization. While the primary switch and diode of the buck converter are implemented with the internal circuity of the LM73605RNPR regulator [15], the inductor used to store power during switching cycles is a discrete 6.8μH component. It is followed by some output capacitors to stabilize the voltage output, as well as another LC filter to reduce high frequency noise in the output voltage. From there the output voltage is sent to set of output pins which will be soldered to a cord with the appropriate connector for the laptop output.

Secondary Output

Owing to the smaller output power required for the 5V 1A supply, the implementation is both slightly smaller and simpler than the primary output. The primary difference between the two topologies is the output connector and the switching controller used.

Buck converter implementation. This buck converter is implemented using an LMR23615DRRT regulator as seen in Fig. 9 [15], which is a smaller and lower power IC than that LM73605RNPR chip in the previous buck converter. Its pin outputs share many similarities with the earlier chip. The input voltage flows to the VIN pins, PGND and AGND are connected to a ground reference to set the power and analog grounds for the

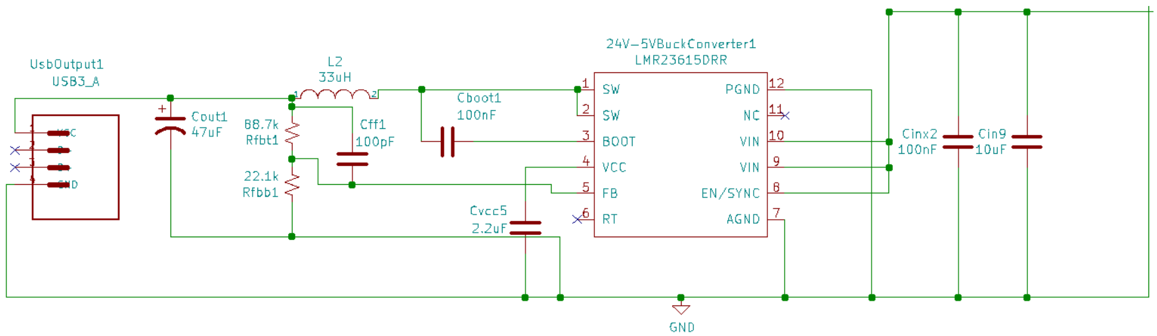

Fig. 9. Secondary 5V output implementation.

device. The EN/SYNC pin is configured differently than the previous converter: here it is enabled by tying it to the input voltage. When the input voltage exceeds 1.6V, the voltage on the pin starts the regulator. The converter outputs the reduced voltage through the SW pins, and the BOOT, VCC, and FB pins act like they do in the previous buck converter configuration [14].

Voltage stabilization. The voltage stabilization of this converter is simpler than the previous 18.5V output due to the reduced power of the converter stage. It lacks the LC filtering seen on output of the previous stages, instead only using a 47µF capacitor coupled with an unpolarized 100pF capacitor that reduces noise to the feedback pin. Part of the reason for this is the increased size of the power inductor used in the topology: its 33µH inductance value allows the converter to run in continuous current mode if the output draws at least .2A of current. This helps to reduce the output ripple voltage [10].

The USB output is enabled by running the output voltage to the VBUS pin of the connector and the ground reference to the GND pin. Since no data needs to be processed from the port, the remaining pins of the USB output are left unconnected.

Fabrication

Component Sourcing

The components of this circuit were all sourced from Digikey. The integrated circuits of the design were purchased from Texas Instruments, and the miscellaneous discrete components were purchased without any constraints on the manufacturing. Simulation using Webench was used to verify that the components selected would withstand the stress placed upon them in the design. Each component was ordered with a duplicate to allow for mistakes in assembly. The total cost of the converter itself is approximately $50, though that would be greatly reduced when purchasing components in bulk. As such, the budget goal of this converter has been reached.

The printed circuit board will be manufactured by JLPCB, a Chinese PCB manufacturing company known for their fast turn-around time and consistent quality. It has been routed and is being shipped to the US for its assembly here.

Schematic Creation

The schematic for the circuit was created using the free software KiCAD. This was selected owing to its substantial library of existing schematic symbols and footprints, which helped to streamline the PCB creation process. Most of the symbols used in the circuit diagram were pulled directly from the existing libraries, while some new symbols like the switching controllers were either created manually using the KiCAD symbol editor or downloaded from the Ultra Librarian symbol library accessible through Digikey. The stages were all designed on a single sheet for simplicity, and connections were checked against the datasheets for each component.

PCB Layout

The PCB layout of this circuit started with creating footprints that corresponded to each schematic symbol used in the circuit. Many were simple standard package sizes for resistors and capacitors, while other also had library references. When possible, component footprints were downloaded from Ultra Librarian to ensure proper pad spacing. The remainder of the component footprints were created based on datasheet specifications.

The final PCB design seen in Fig. 10 was a matter of arranging the components in a way that conserved space and minimized electromagnetic interference [2] by separating the transformer and the switching regulators.

Component Installation

Component installation on the final circuit board was done by soldering each individual component to the pads laid out on the circuit board. Flux was used to ensure that the components bonded strongly to the board, and smaller components were shifted into place using tweezers. Care was used when soldering the more delicate components to prevent heat damage from the iron to the part. The transformer core was wound by hand as described earlier using magnet wire, stripping the ends to ensure a strong electrical connection. The core was then soldered into place, completing the board’s physical implementation.

Fig. 10. The physical implementation of the power converter.

Testing

Test Results

The first part of testing attempted to verify the operation of the buck converters by providing a 24V source to the input of both stages. This was to ensure that the output converters were functional when provided the expected output of the primary flyback converter. A second test was planned based on the completion of the first: it was to verify the operation of the flyback circuit and the converter as a whole by simply plugging in the device, connecting the outputs to load resistances, and verifying that the output voltage and currents are within their expected values.

The final component of testing was to be executed upon the successful completion of the previous two, which connects the 18.5V output to the laptop it was designed for and the 5V output to a USB charging station via a USB to Micro USB cord. If both devices indicated they were charging normally, the converter would be considered fully functional.

However, this testing proved to be impossible as a short circuit was found between the input voltage of the two buck converters and the copper fill that served as a ground reference for the output voltages. This was apparent from watching the current spike to the maximum level allowed by the external power supply coupled with a major voltage decrease due to the limiting of the output current. This also showed itself from some observed sparking after the voltage source was connected. As a result, the outputs of the converter could not be tested when provided the correct input voltage.

Due to the above problem, it was deemed that connecting the device to a wall outlet would result in a massive current spike on the secondary side of the transformer. This was a major safety concern that halted further testing. Consequently, none of the outputs could be verified. The converter is not currently functional.

Possible Error Sources

The first possible error source was evident in the short circuit of the secondary side of the flyback. It appears that somewhere between the output of the secondary-side diodes and the buck converter there was a connection to the ground plane, which caused the short. This may have occurred due to a misplaced trace, damage to the PCB during the soldering process, or an unintentional solder bridge on an integrated circuit. Another possible cause may have been due to the tolerances used for trace width: there may have been a point at which two adjacent traces accidentally connected due to their proximity.

Additional errors in the build process almost certainly exist, but they cannot be currently verified due to this electrical short.

Suggestions for future improvements

The converter described in the paper above has many points to improve upon. The design would have been improved by creating the circuit on a breadboard prior to building a PCB. This would have allowed for the correction of topology errors and unexpected problems before a PCB was manufactured, allowing for a more iterative testing format. Doing so would have allowed this project to confirm the functioning of each stage of the converter separately.

The design of this converter was in part influenced by its ease of manufacturing, with all components being mounted on the same side of the PCB. A future design improvement would be to reduce the space required by the circuit by mounting parts on both the top and bottom of the board. This could be further optimized using a planar transformer to reduce the overall height of the board if components like the line filter and input voltage connector were adjusted accordingly.

In addition, a future implementation of the board should use as much automation to complete the soldering process as possible to minimize the chance of human error causing a failure in the circuit. Failing that, an approach that used solder paste and a heat gun to form electrical connections would be more effective at mounting small components than the traditional hand soldering used on this project.

Conclusion

This thesis examined the creation of a custom 70W AC-DC converter with both an 18.5V and 5V output built to be compatible with typical 120VAC US outlets. The theory of such a device was discussed and later transferred into a practical design. This design was then fabricated and tested. While the final circuit had some errors in implementation, it nonetheless acts as an example of the engineering design process. Future development of the design would increase its reliability, efficiency, and reduce the size of the converter after its current problems are addressed.

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