A red and white logo

Description automatically generatedçizim, taslak, kırpıntı çizim, grafik içeren bir resim

Açıklama otomatik olarak oluşturuldu

**HACETTEPE UNIVERSITY**

**Department of Electrical and Electronics Engineering**

**ELE713: SWITCHING POWER SUPPLIES**

**Final Project Report**

**Project Type:** Two Switch Flyback (36-72V to 12V)

**Student 1:** Elif Topaloğlu - O24142630

**Student 2:** Arda Kasım -

**Table of Contents**

[Introduction 3](#_Toc169132546)

[Project Definition 3](#_Toc169132547)

[Topology Selection 4](#_Toc169132548)

[Validation of Design 5](#_Toc169132549)

[General Design 5](#_Toc169132550)

[Transformer Design 9](#_Toc169132551)

[RCD Snubber Design 14](#_Toc169132552)

[Open-Loop Simulation Results **Hata! Yer işareti tanımlanmamış.**](#_Toc169132553)

[Closed-Loop Simulation Results 14](#_Toc169132554)

[Component Selection 20](#_Toc169132555)

[Transformer Tests 21](#_Toc169132556)

[Final Design 23](#_Toc169132557)

[Demo Day Test Results 25](#_Toc169132558)

[Physical Properties 27](#_Toc169132559)

[Conclusion 29](#_Toc169132560)

## Introduction

The goal of this project is to design and build a "Two Switch Flyback" converter, with its specifications provided later in the report. The report will cover the design procedures done, explain the transformer design for this topology, describe the circuit built based on the simulations, detail the closed-loop control of the design, and present some test results in detail.

## Project Definition

An isolated DC-DC two switch flyback converter is be designed for this hardware project. The specs of the project are:

* **Minimum Input Voltage:**
* **Maximum Input Voltage:**
* **Nominal Input Voltage:**
* **Output Voltage Ripple:**
* **Output Voltage:**
* **Output Nominal Current:**
* **Overload Current:**
* **Line Regulation:**
* **Load Regulation:**
* **Transient Response Peak Deviation:**
* **Transient Response Recovery:**
* **Continuous Output Power:**
* **Efficiency at Full load**:

## Topology Explanation

To start with, the origin of the two swich flyback converter is the standard flyback converter topology. To understand better the two switch topology, one should examine the standard flyback converter topology first. Both topology schematics are given below in Figure 1.

metin, diyagram, çizgi, yazı tipi içeren bir resim

Açıklama otomatik olarak oluşturuldu

Figure 1: Standard Flyback and Two Switch Flyback Topologies

The flyback converter topology is one of the simplest options for designing an isolated DC-DC converter because of its several advantages. For example, it has a straightforward design process as it uses only one active switch. Additionally, it requires fewer components compared to other topologies, making it more cost-effective. This simplicity and cost advantage are significant benefits. The flyback converter is also a good choice for low-power applications, typically under 200W, which is the case for this project.

However, this topology also has some disadvantages. Since it is a single-ended type converter, it operates in only one quadrant of the B-H curve. It charges and discharges the inductors during different switching cycles, requiring a gapped core to increase energy storage capacity. This can result in poor transformer utilization, which is a key drawback. Furthermore, the high ripple currents on the input and output sides due to the low inductance of the gapped core necessitate the use of larger capacitors, which is another disadvantage of this topology. Finally, as for the standard flyback topology return path for the primary current does not exists which forces the snubber design. However, since general flyback snubbers are designed based on the fact that the current in the primary winding dissipated loss on it. Thus, this energy is lost which decreases the efficiency of the design.

For the two-switch flyback converter, all the advantages of the standard topology apply. Moreover, due to the usage of two switches and two diodes, a return path for the primary winding current is created with fairly minimal losses compared to the snubbers which increases the efficiency and makes it possible to use this topology for higher power ratings than the standard topology. Even though the two switch increases the efficiency, it also increases the cost of the project and complicates the design which is the disadvantages of this topology.

## Validation of Design

### General Design

For this project, a two-switch flyback converter is designed. This section will explain the general design for the overall project part by part. First of all, as the project requires strict line and load regulations, in order to stabilize the input voltage and decrease the voltage fluctuations an input filer is designed. Theis filter also supplies energy during the transients. Thus, variety of capacitors in different materials are connected in parallel to form the input filter such as film and ceramic capacitors. Ceramic capacitors are effective due to low ESR and ESL values to supress the high frequency noises. Film capacitors are often used with ceramic capacitors to handle noises in a slightly lower range. The schematic for the input filter side is presented in Figure X.

metin, diyagram, çizgi, yazı tipi içeren bir resim

Açıklama otomatik olarak oluşturuldu

Figure: input filter schematic

In addition to the filter, a thermistor is used for the circuit to start slowly when the input is supplied. Thermistor initially has a high resistance which limits the current and while the current flows, temperature of it increases and the resistance decreases approximately near zero. Also, a fuse is connected to the input to protect the circuit in overload conditions. The fuse is selected as 6 A which is slightly higher than the maximum input current.

Since the input voltage is between 36V and 72V, one should obtain smaller DC voltage values in order to feed the controllers, drivers, etc. Thus, a buck converter to step down the input voltage is designed. For this purpose, LM5576 is used. The schematic for this design is presented below in Figure X.

metin, diyagram, çizgi, ekran görüntüsü içeren bir resim

Açıklama otomatik olarak oluşturuldu

Figure: 36-72 to 12V Buck Converter IC Design

For this IC, one can use the TI Workbench tool by defining input and output requirements for the design. To feed the other IC in the design, 12V is required and sufficient; therefore, corresponding elements in the schematic is selected to obtain this voltage at the output using the Workbench.

Even though 12V is obtained for various ICs, an isolated 12V is also needed. The reason is that the topology has two switches as high side and low side. To drive the high side switch, 12v is also supplied to the high side switch. However, the source leg of the high side switch is not grounded which complicates the drive of this MOSFET. Thus, there is a need for isolated 12V which is obtained by the Recom R1S-1212 converter. This component does not require much design and can create an isolated 12V using the 12V generated by buck converter explained above. For filtering purposes, it only has two capacitors in the input. Schematic for this component is given below.

metin, el yazısı, diyagram, yazı tipi içeren bir resim

Açıklama otomatik olarak oluşturuldu

Figure: İsolated 12V Recom schematic

After the isolated 12V generation, two channel gate driver from Infineon 2EDB8259F is designed. Two channel is preferred rather than using two different gate drivers in order to have a compact and smaller design. Design is done using the datasheet of the driver itself and it has fairly simple design. As the two switches are working synchronously, same PWM is supplied to the driver. At the output of it, high and low side switches are driven. For the high side switch, isolated 12V sully and isolated ground generated by the Recom is used. Finally, an RC filter is connected to the metin, diyagram, yazı tipi, ekran görüntüsü içeren bir resim

Açıklama otomatik olarak oluşturuldusupply input of the IC for proper working. Schematic for the gate driver is given in figure below.

Figure: Two channel gate driver schematic

As a closed-loop control is needed for the project, a controller needs to be used to ensure that the voltage at the output is 12V continuously. For this reason, an analog controller will be utilized to generate the PWM signal supplied to the gate driver. As the controller, UC3845 is selected since it has detailed application notes available and it is widely used and sufficient for this project. Design for the controller is done using its own application note. Typical application part of the application note explains all the calculations for this design. The schematic for the controller is given Figure X.

There are some key elements in the controller design worth to mention. Firstly, there is one resistor called RT and one capacitor called CT. These are used in order to set the switching frequency of the controller. In this project, switching frequency is selected as 100 kHz as it is seen to be efficient and proper during the simulation phases. Moreover, compensator design can be done by setting both capacitors and inductors connected between the COMP and FB pins of the controller and between the optocoupler and the output. Detailed design for the compensator can be found in the datasheet of UC3845.

diyagram, metin, plan içeren bir resim

Açıklama otomatik olarak oluşturuldu

Another important part of the controller is the output voltage division part. This is the main section where the output voltage is tried to set to 12V as required in the project specifications. Moreover, TL431 is used as voltage reference and a Zener diode to set the voltage across itself to 10V is used where both are placed to properly arrange output reference. An optocoupler is used in order to sustain the isolation between the input and the output side. As the optocoupler, TCMT1103 is used which has the current transfer ratio between 100 and 200%. Other side of the optocoupler arranges the current flows to ISENSE pin. Other capacitors are connected as it is suggested in the design notes. At the end, PWM is generated by the controller.

After these designs, main part of the project, which is the two switch flyback controller part is designed. MOSFETs and diodes are selected due the maximum rms currents after the simulations are done. Series resistors are connected to gate to limit the current and oscillations and also pull up resistors are connected in parallel to help discharging. İn addition to the switching side, transformer should be design since it is almost impossible to find a transformer suitable for the ratings of the project. Thus, the transformer is design and the details about the design will be explained in the following section. The schematic for the two-switch part is given in Figure X. Finally, some additional capacitors are connected in different types like the input filter for proper filtering of the ripple.

metin, diyagram, ekran görüntüsü, çizgi içeren bir resim

Açıklama otomatik olarak oluşturuldu

Figure: Two-switch flyback schematic

### Transformer Design

The design procedure of the transformer for the two-switch flyback converter does not differ than the standard flyback converter. Thus, the calculations are done for a standard flyback converter.

To start with the magnetic design of the topology, duty cycle should be arranged to calculate the corresponding turns ratio. In flyback converters, duty cycle can obtain values between zero and one. However, for the two switch converters, duty cycle should not be more than 0.5. Thus, maximum duty cycle is set as 0.5. When the maximum duty cycle is selected, maximum turns ratio can be calculated using the following formula below. The important point in this calculation is that output voltage is taken as 13V to consider the voltage drop across the output diode and to stay within the predefined duty cycle limits. For ease of manufacturing and simplicity, turns ratio is selected as 2. For the selected turns ratio, duty cycle for both input voltages is calculated below.

Table: Turns Ratio Selection and Duty Cycle Limits

|  |  |
| --- | --- |
| Turns Ratio (N1/N2) | 2 |
| Duty Cycle Range | 0 to 0.5 |
| Maximum Duty Cycle | 0.419 |
| Minimum Duty Cycle | 0.265 |

At this point, a target efficiency should be selected in order to move on to further calculation. Target efficiency is selected as 85% which is the limit for this project.

After determining the efficiency target, input power can be calculated:

Knowing the limits of the duty cycles, the average current flowing on the magnetizing inductance during on period when the input voltage is 36V can be calculated as below.

Now, another design decision should be given which is the value for current ripple on the magnetizing inductance. High current ripple increases the losses on the transformer; however, decreasing the ripple increases the transformer size and cost significantly. Therefore, for a sweet spot, it is selected as 4A.

Then:

As the minimum primary inductor voltage, the switching frequency, the duty cycle at the minimum voltage and current ripple are known, the inductance of the primary inductor can be easily calculated using the inductor equation:

Considering the on period, the same equation can be converted to the equation below.

At this point, the core material is decided using the area product method. Fill factor is selected as 0.3 to easy manufacturing, current density is selected as , and peak flux density is selected as 0.3 T in order not to saturate the core.

In order to increase the energy storage capacity for the flyback converter, the core should have an airgap. As we have an E core already suitable for the calculations, it is selected as the core for this project. The core is selected as “B66363G0500X187” which is an N87 type ETD39 ferrite core from TDK Electronics and has area product approximately as 9422 which suits well. It has a built-in 0.5mm airgap so that when two of them are used, a total of 1mm airgap will be obtained. Some information from the datasheet is give below:

To find the number of turns in the primary side:

The turn number is required as an integer for manufacturability, the turn number selection is made as:

As the turns ratio is selected as 2, the secondary side will have number of turns.

Then, magnetic flux density () inside the core can be calculated as below:

Considering the information given in the datasheet of N87 materials by TDK Electronics, the found value is far away from the saturation of the core, which is given approximately as .

Since the current density and the current is known, area required for the cable can be calculated. The area value is multiplied with a safety factor by considering the isolation of the cable. Fill factor is calculated again using the found values and seen that the core is manufacturable.

For the copper losses, resistance of the windings should be calculated. Mean length per turn value can be found from the datasheet of the core. Thus, DC resistances can be calculated as follows:

The total copper loss can be calculated as:

As stated before, the core material is N87. Reading the datasheet of the “N87 SIFERRIT Material”, the core loss values for some frequency and Tesla values can be found. In the datasheet, the core loss for at is given approximately as . The datasheet of the core states that the volume of a core is . Then:

The total loss of the transformer can be estimated as:

The design does not require new iterations as the values are in acceptable limits.

### 

### Closed-Loop Simulation Results

For a real-world application, a closed-loop system should be designed so that the system can respond to changes in the input and regulate a better output even if the output load changes also.

It was stated that the bonus for using an analog IC is aimed so that a closed-loop design using an analog IC is generated. For the design, the “WEBENCH Power Designer” tool from the Texas Instruments. From many options generated, the one that uses UC3845 Analog IC is selected as the mentioned IC can be found easily in Turkey, and it fits the design considerations. A critical point is that the series of ICs “UC384x” are very similar in terms of properties. The only difference of UC3845 is that the maximum duty cycle it can generate at its output pin is . As mentioned before, the maximum duty cycle for the application is less than , so that the other ICs of the same family can be used, according to the stocks that are present in Turkey.. Another advantage of the circuit is that by changing some of the feedback resistances, the output voltage can be regulated easily, if there is a need for that. Also, the feedback loop can be updated.

The reference design obtained from the tool can be seen in Figure 13.

A diagram of a machine

Description automatically generatedThen, the design is generated in LTSpice for simulations. During the generation of the circuit, the startup resistors and the auxiliary winding are not included, as we will be powering up the UC3845 with an LM2596 directly from the input. It is tested that the LM2506 can work in the input voltage range of 20-40V, and it can supply the required voltage and current to UC3845.

Figure 1. Reference Design of the Flyback Converter with a UC3845 IC

The schematic of the circuit can be seen in Figure 14.

Figure 2. Closed-Loop Circuit Schematic using an UC3845 IC

The simulation consists of the isolated output voltage feedback loop, the RCD clamp, the RC snubber for the switch, output LC filter, and leakage inductances to be able to generate a circuit as close as possible to a real-life application.

The isolated feedback is obtained using an optocoupler. The feedback is generated with a 10V zener diode. The feedback signal generated is sent back to the UC3845 IC.

The RCD clamp is used to decrease the voltage stress on the switching MOSFET. Also, an RC snubber is placed in parallel with the secondary side diode.

The output LC filter helps the circuit to obtain an output which has less ripple on it.

The circuit will be operated both in inputs of 20V and 40V, and the results will be presented.

First, the input voltage is set to .

Figure 3. Output Current and Voltage Measurements of the Closed-Loop Circuit for Vin = 20V

Figure 15 represents the output current and voltage of the flyback converter. The response reaches a steady state approximately at 6 milliseconds. It can be seen that the responses include very low ripple at the steady state. The average output current at the steady state is measured as 5.065A and the average output voltage at the steady state is measured as 12.157V. The maximum and minimum values that the output voltage oscillate between are 12.164V and 12.150V respectively. This results in an output voltage regulation of 0.11%. It can be said that the result is in a safe margin as in a real-life application, many non-idealities will be disturbing the circuit, and the results may differ from an ideal scenario. The average input power is 80.695W while the average output power is 61.579W which results in an efficiency of 0.763.

Figure 4. Vds Measurements on the MOSFET for Vin = 20V

The maximum voltage measured on the MOSFET is 53.2V at the steady state. During startup, the voltage on the MOSFET increases to 117V for an instance.

Figure 5. Ids Measurements on the MOSFET for Vin = 20V

The current on the MOSFET increases to 12.28A from 9.012A during the ON period. During startup, the current on the MOSFET increases to 52.8A for an instance. These maximum values of current and voltage on the MOSFET are considered when the components are chosen.

Figure 6. Voltage on the Output Diode for Vin = 20V

The output diode should be able to stand a reverse voltage of 90V. The ringing on it does not induce a power loss as no current passes through it.

Figure 7. Forward Current on the Output Diode for Vin = 20V

The current on the output diode decreases to 6.81A from 10.39A during a cycle. These maximum values of current and voltage on the output diode are considered when the components are chosen.

Then, the input voltage is set to 40V.

Figure 8. Output Current and Voltage Measurements of the Closed-Loop Circuit for Vin = 40V

Figure 20 represents the output current and voltage of the flyback converter. The response reaches a steady state approximately at 6 milliseconds. It can be seen that the responses include very low ripple at the steady state. The average output current at the steady state is measured as 5.185A and the average output voltage at the steady state is measured as 12.444V. The maximum and minimum values that the output voltage oscillate between are 12.45V and 12.438V respectively. This results in an output voltage regulation of 0.10%. It can be said that the result is in a safe margin as in a real-life application, many non-idealities will be disturbing the circuit, and the results may differ from an ideal scenario. The average input power is 90.603W while the average output power is 64.511W which results in an efficiency of 0.712.

Figure 9. Vds Measurements on the MOSFET for Vin = 40V

The maximum voltage measured on the MOSFET is 69.5V at the steady state. During startup, the voltage on the MOSFET increases to 124V for an instance.

Figure 10. Ids Measurements on the MOSFET for Vin = 40V

The current on the MOSFET increases to 11.95A from 7.637A during the ON period. During startup, the current on the MOSFET increases to 87.5A for an instance. These maximum values of current and voltage on the MOSFET are considered when the components are chosen. Also, the peak one-cycle ratings are considered.

Figure 11. Voltage on the Output Diode for Vin = 40V

The output diode should be able to stand a reverse voltage of 100V. The ringing on it does not induce a power loss as no current passes through it.

Figure 12. Forward Current on the Output Diode for Vin = 40V

The current on the output diode decreases to 4.76A from 9.41A during a cycle. These maximum values of current and voltage on the output diode are considered when the components are chosen.

Overall, it can be seen that the design can be implemented with a proper choice of the components of the circuit.

### Test Results

## Conclusion

This report focuses on the design, implementation, and testing phases of the isolated two switch DC-DC converter project. The research and simulation stages provided a broad understanding of the overall design and helped identify and address both potential and existing issues logically. Even though the analytical calculations and the verification of the project using the simulation tools pointed out a perfectly working design. Implementation of the circuit showed us a different phase of this project.

After the hardware part is done, it is seen that the output voltage ripple is approximately 1.3V which is very high compared to expected during the simulation phases. The ripple in the output voltage seems to stem from the controller as the ripple has a frequency which is not equal to switching frequency. Thus, the ripple also creates an annoying sound due to subharmonic ripples seen in the waveform. Even though the design can be able to regulate the output voltage at all input voltages and different loads, it fails to meet the output voltage ripple requirements. Since the simulation does not show that ripple exists, it is hard to identify the reason of this in such a short time limit. Thus, the design fails to meet the voltage ripple requirement.

Apart from the negative sides of the project, implementation phase is still the most educational and challenging part of the project, involved connecting different modules to create a fully functional design. This step presented unexpected challenges, allowing usto gain valuable experience and better understand the differences between simulation and real-world applications.