

**MIDDLE EAST TECHNICAL UNIVERSITY**

**DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING**

**EE 464 - Static Power Conversion II - Term Project**

**Social Isolation Inc.**

**Development of a DC-DC Converter for Battery Charging**

**Berkay Uzun - 2263812**

**Ali BELLİ - 2231421**

**Ahmet Halis Sabırlı – 2305225**

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# 1.Project Definition

In electrical cars, inside the vehicle, there are two different electrical systems which are low voltage and high voltage. The use of low voltage is to run the low power and low voltage components of the vehicle such as monitor, audio player or fans of the cooling system. To be able to charge the low voltage battery, there is a need of DC/DC converter between high voltage and low voltage system. The main motivation of the project is to construct an isolated 100W DC/DC converter which steps down the 220-400 V input to the 12 V output.

# 2. Topology Selection

For the topology selection, there is only one main consideration which is the output power level. The selected topology must satisfy the output power and should not be over designed on it. To do that, we have made some research and found the source to decide the topology. From the information given in Table 1, there are 5 options [1].

Table 1- Power ranges of some of isolated DC-DC converter topologies

|  |  |
| --- | --- |
| **TOPOLOGY** | **POWER RANGE HISTORICALLY USED** |
| **Flyback** | <100 W |
| **Forward** | 50W-200W |
| **Active Clamp Forward** | 50W-300W |
| **Push-Pull** | 100W-500W |
| **Half-Bridge** | 100W-500W |
| **Full-Bridge** | >500W |

When we look at the options, the Full-Bridge is not suitable. In addition, we can see that Push-Pull and Half-Bridge may be over design for our application because the lower limit of them is satisfying the maximum power requirement of our system. Therefore, they are not suitable for our application. After that point, there are staying 3 different topologies. Forward and Active Clamp Forward has more component compared to the Flyback converter and the Flyback converters maximum power limitation is satisfying our power level. Because of these reasons, we decided to use the Flyback topology to design the DC-DC converter. In addition to them, Flyback is a widely used topology and there are a lot of sources and controllers for this topology in power electronics field. Therefore, easy implementation of the topology has also made us to choose this topology.

# 3. Controller Selection

For the controller selection, we have only found two different controllers of the Analog Devices for our application. One of them is Forward and the other one is Flyback converter. The main limitation on the controllers is the maximum input voltage. Although, we have checked so many different producers’ controllers, we did not find suitable controllers other than the LT8316 and LT3752-1. The main typical applications of the controllers are given in Fig.-1 and Fig.-2.

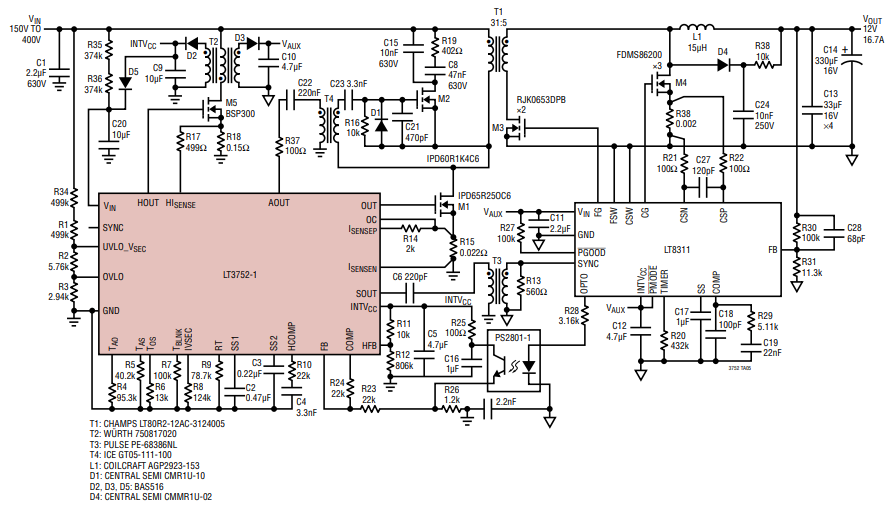


Figure-1 LT3752-1 Typical use

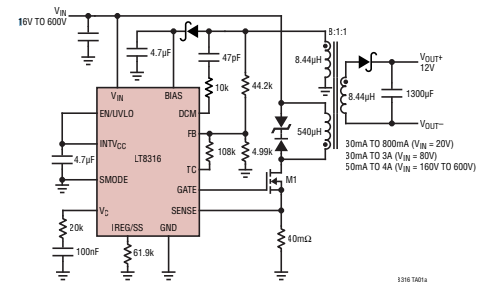


Figure-2 LT8316 Typical use

As the consideration given in the topology selection session, the Forward controller requires more component than the Flyback controller. Therefore, we have chosen the LT8316 DC-DC Flyback controller to develop the converter.

# 4. Transformer Design

In this part of the project, the following steps were done, the Magnetic Core Design, Winding Selection and Finite Element analysis. To do that, at first, we examined the Flyback topology and developed and Excel program to find the proper interval of inductance and turning ratios. There are mainly to considerations to find the intervals, which are the properties of the controller and the requirements of the Flyback topology. Before going into the calculations of the controller, we calculated the topology requirements for these conditions. After that we obtained the controller needs and intervals. By considering the results, we decided on which core we will use. When we finished the core selection, we began to clarify the wiring properties which are depended on the effective window area of the core and current flowing through wirings. After completing the wire and core selection parts, we run a finite element on ANYSY to check whether our transformer going into the saturation or not. By proving the non-saturated behavior of the core during the maximum limits of the operation, we finished the Transformer Design part.

## 4.1. Magnetic Core Selection

Before going through the design, at first, we need to decide how we make design, in other words we need to fix some of the parameters to find the rest of the values. We decided to fix the desired duty cycle, desired current ripple, estimated efficiency, and the switching frequency. The switching frequency and the desired current ripple are fixed by considering the operation of the converter. After the fixing the values, the theoretical calculation of the Flyback topology going through like that,

We need to find some important variables of the circuit to continue the calculations,

The ratio is hard to find a proper turn numbers of the primary and secondary, therefore,

After deciding the turn, we need calculate estimated duty cycle of the system to find the turn number of the primary and secondary windings.

Now, let’s find the maximum turn number of the primary side,

As you can observe, we need the find a core to use the effective core area (Ac) and the saturation flux density (Bsat). Selecting the core is not straight forward issue. We selected it by checking the limitations again and again for different cores. The limitations will be calculated later. We selected one of the cores of TDK, which is ETD 29/16/10. The selected core properties are given in the Table 2.

Table 2- Selected magnetic Mn-Zn ETD shape core

|  |  |
| --- | --- |
| **PROPERTIES** | **VALUES** |
| **Saturation Flux Density(T)** | 0.39 |
| **Effective magnetic cross section(mm2)** | 76 |
| **Window Area (Winding Cross Section) (mm2)** | 97 |
| **Inductance Factor(nH/turn2)** | 383 |
| **Average Length of Turn(mm)** | 52.8 |
| **Effective magnetic path length (mm)** | 70.4 |
| **Relative permeability of core material (Ungapped)** | 1470 |
| **Relative permeability of core material (Gapped)** | 281 |
| **Airgap(mm)** | 0.2 |

We decided to use the primary turn as 25 and secondary as 3. Now, we need to calculate the final, effective, duty cycle,

Now, let’s find the effective inductance values for %100 inductor current ripple,

After finishing the theoretical calculations, now we need the find the limitations of the controller. There are 3 different minimum primary inductance limitation and one maximum primary inductance limitation. Before starting to the calculations, there are some parameters must be given which are used in the following calculations coming from the nature of the controller.

By using the core properties, we can calculate the primary and secondary inductances and check whether we stay in the controller specifications or not and whether we close to theoretical calculations.

The selection of the inductance factor (AL) is not a straightforward issue and we selected it by considering the saturation limit of the selected core. Therefore, we have had to lose some inductance to satisfy the non-saturated operation and to leave the final duty cycle lower than the desired one. As a result, the inductance values are suitable for the controller and the controller will handle rest of the parameters by using the feedback loop inside it.

We checked how much airgap we need to stay in the non-saturated region during the operation,

We have used the equation given below to check whether the core is going through the saturation during the operation or not,

We are satisfying saturation condition, which is the most important one for the application. At that point, we are finishing the core selection part and moving to the winding selection part.

## 4.2. Winding Selection

## 4.3. Finite Element Analysis

# 5. Component Selection

For the component selection part, there are 3 main subtitles, which are the output capacitor selection, controller passive elements selection and the power semiconductor selection for now to complete the simulations. When we begin to develop the PCB schematics and layouts, there will be also connector selection part.

## 5.1 Output Capacitor Selection

The output capacitor should be selected to reduce output voltage ripple while also keeping in view the larger size and price of a larger capacitor. The minimum output capacitor can be calculated using the equation as below:

*where Ilim = Maximum primary current = 100mV/Rsense*

In this equation, we found the minimum output capacitor value. However, we chose 470 capacitor for better filtering and to minimize the EMI effect.

Xxxxxxxxx ESR xxxxxxxx MATERIAL

## 5.2 Controller Passive Elements Selection

### 5.2.1 Snubber Resistance Selection

The proposed design solution for the RC snubber is to power up at low voltage to prevent overvoltage stress, calculate the duration of the ringing on the MOSFET's drain when the power switch turns off without the snubber, and then apply capacitance CSnubber until the ringing period is 1.5 to 2 times longer. To find the snubber resistance, we first need to find leakage inductance. The leakage inductance depends on the coupling coefficient. Coupling coefficients of k=99 percent are typical, and they are determined by the transformer's structure and materials.

Now, we can find the snubber resistance with equation below. The capacitor value here is taken from the datasheet of the mosfet we have chose.

Xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

### 5.2.2 Feedback Resistances Selection

The isolated output voltage is controlled by the LT8316 using a special sampling scheme. The scheme experiences repeatable delays and error sources due to its sampling design, which would influence the output voltage and cause a reevaluation of the resistor values. So, the controller needs feedback resistors to regulate this situation. According to the datasheet, in order to determine the values of these resistors, we need to assign a value to one of them and find the other with the equation below.

Xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

### 5.2.3 RIREG/SS Selection

This resistor is used to regulate the output current. We can find the resistance value we need to use with the equation given below:

According to the above equation, we found the required resistance value of 68.9 k. However, while analyzing the simulation, we made changes on the values. Through trial and error, we found this resistance to be 61.9 kΩ

xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

### 5.2.4 Sense Resistor Selection

We need a sense resistor to be able to set the maximum current. In the datasheet of the controller we chose, the formula for Rsense is shown as below:

## 5.3 Semiconductor Selection

### 5.3.1 Snubber Diodes Selection

**Fast recovery**: According to the application note, breakdown voltage of this diode must be greater than the drain pin voltage of the MOSFET.

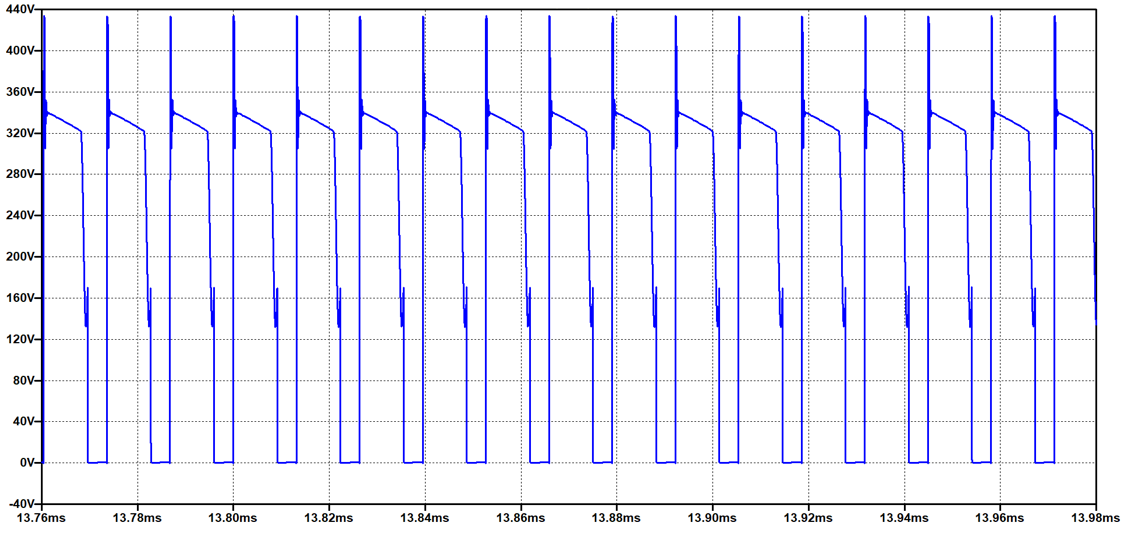
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**Zener:** Zener voltage must be largest possible value withing given limitations. And it is recommended to use around 500 mV Zener diode in the snubber. According to the controller's datasheet, we can calculate the maximum voltage capacity of the Zener diode with the following equation:

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

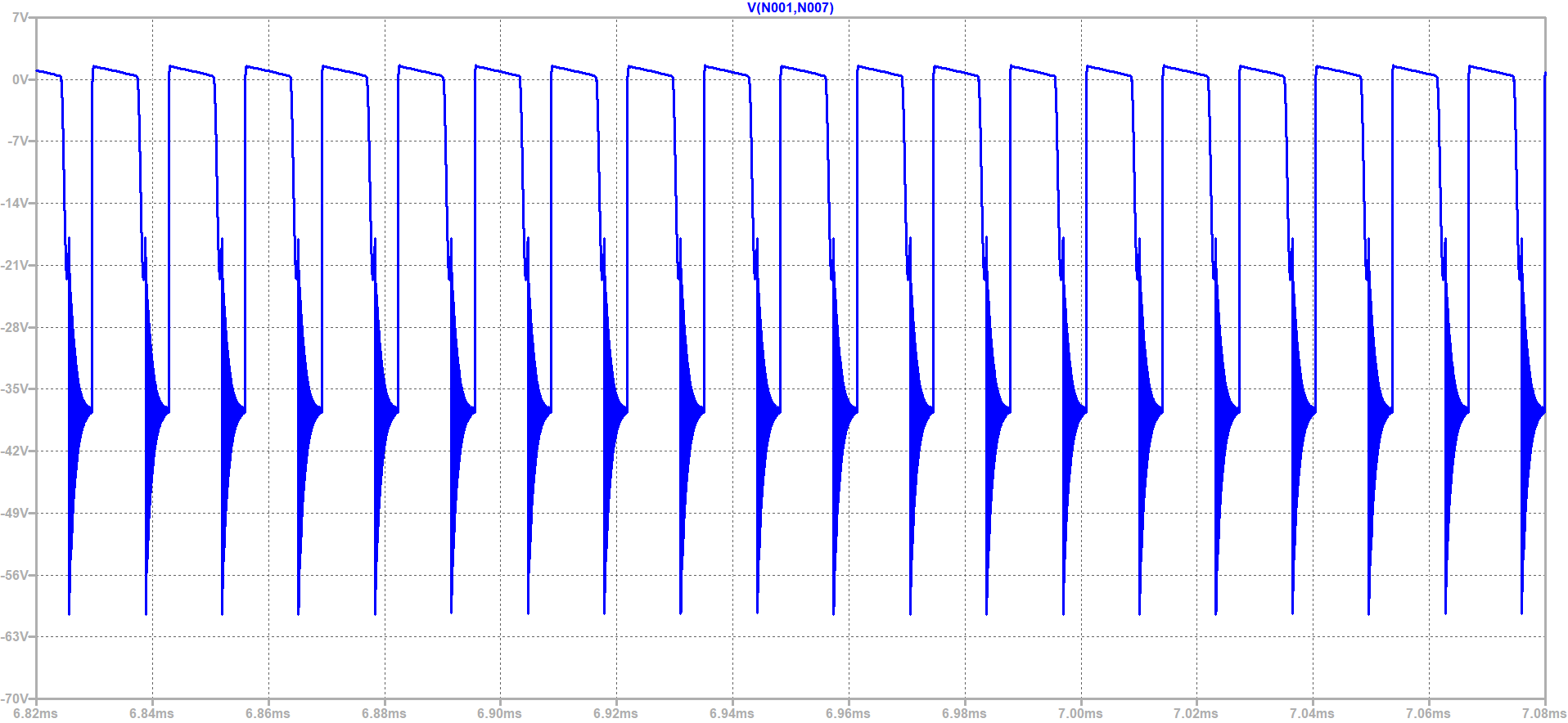
### 5.3.2 MOSFET Selection

As can be seen from the simulation result in Figures X and X, the maximum voltage around 450V and current value around X A on the MOSFET. While choosing the MOSFET, we made a choice considering these values.

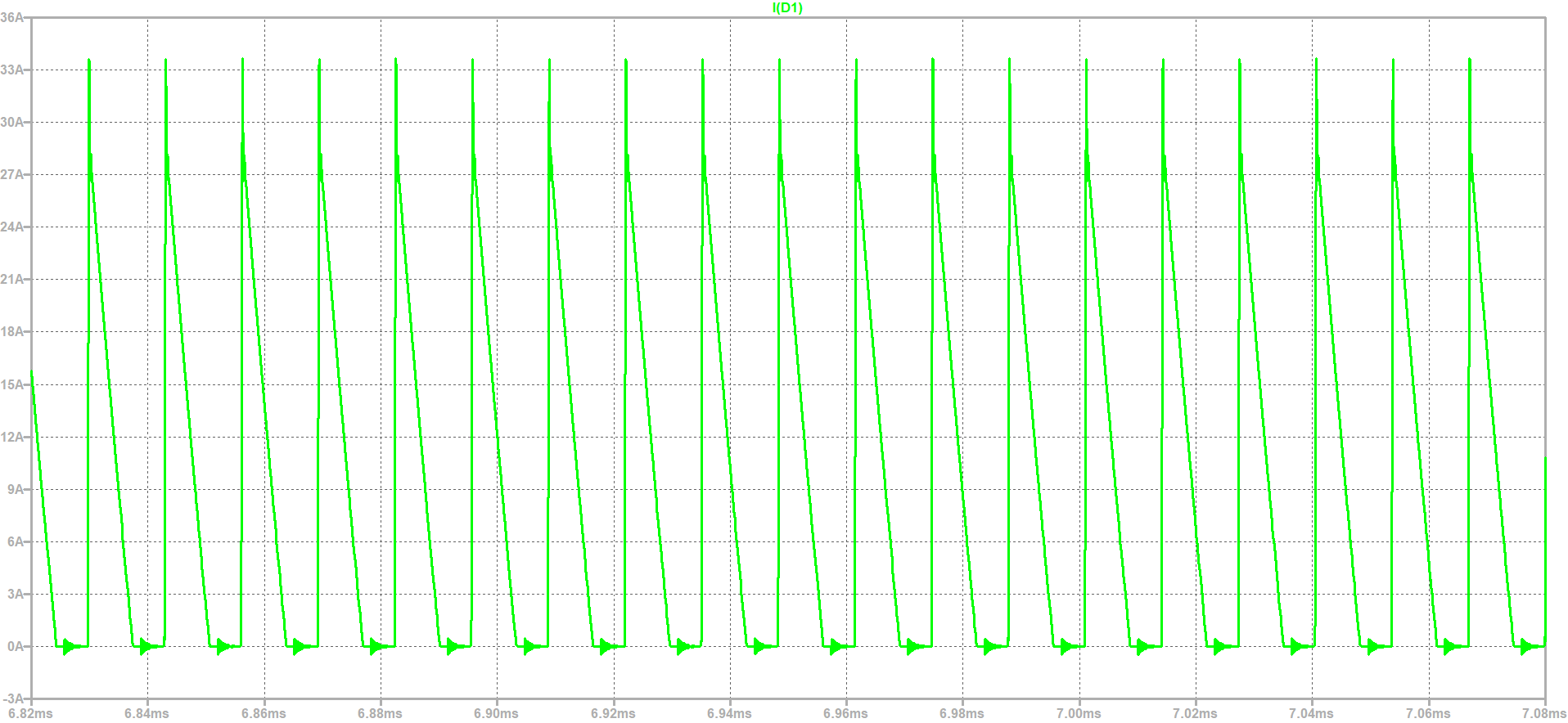


### 5.3.3 Output Diode Selection

The Figures below, namely Figure X and Figure X, show the reverse voltage of the diode and the peak forward current. According to these graphs, the reverse voltage on the diode is around 65. The current flowing on it is approximately 35 A. We should choose the output diode by considering these criteria.



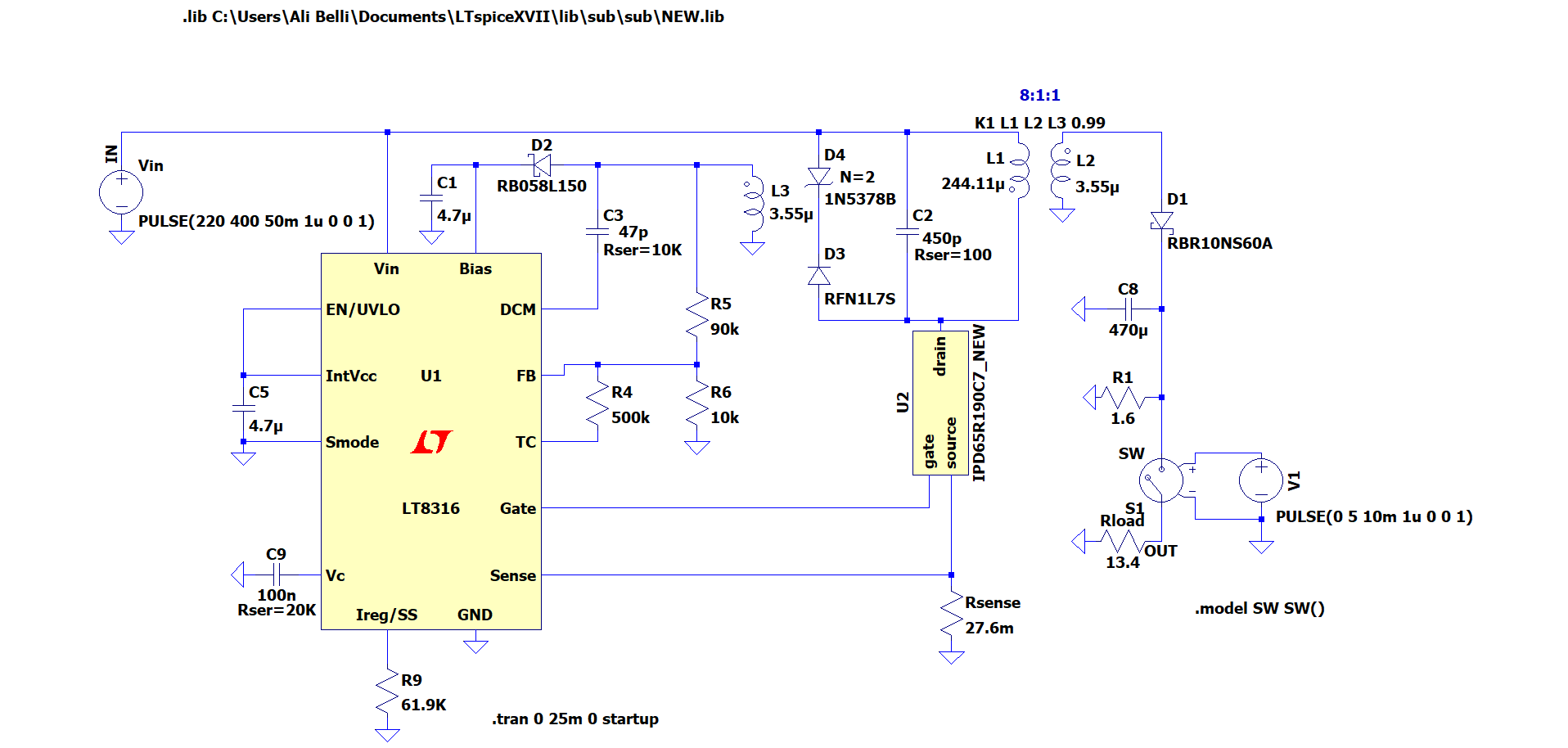
Output diode voltage



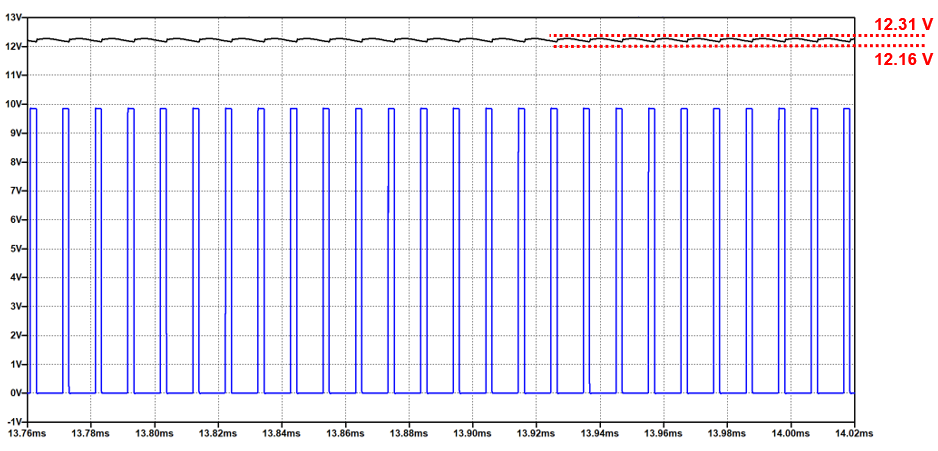
Output diode current.

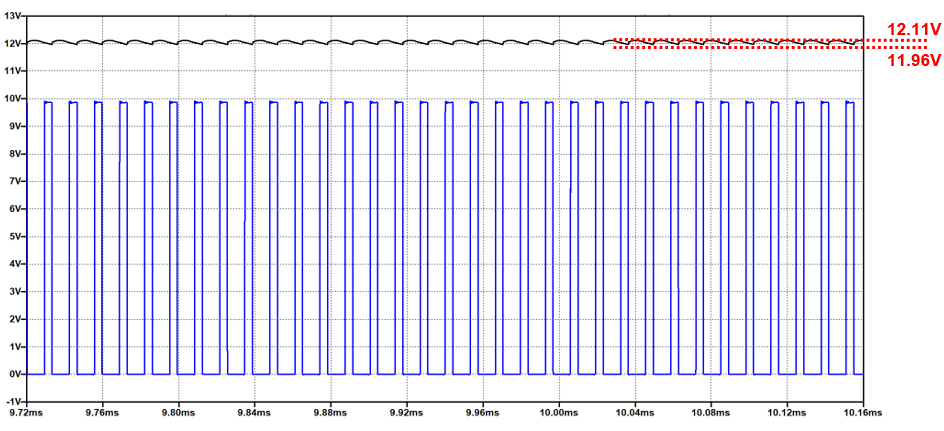
# 6. LTspice Simulation Results

We divided LTspice simulation results into three subtitles, which are Steady-State Full-Load Responses, Load Regulation and Line Regulation. To do that, we constructed all the circuit on the LTspice by reducing the ideality of the circuit by adding some of the real-time application parameters such as Leakage inductances and series resistance of the primary and secondary side of the transformer. The overall simulation model is given in the Fig.-x.

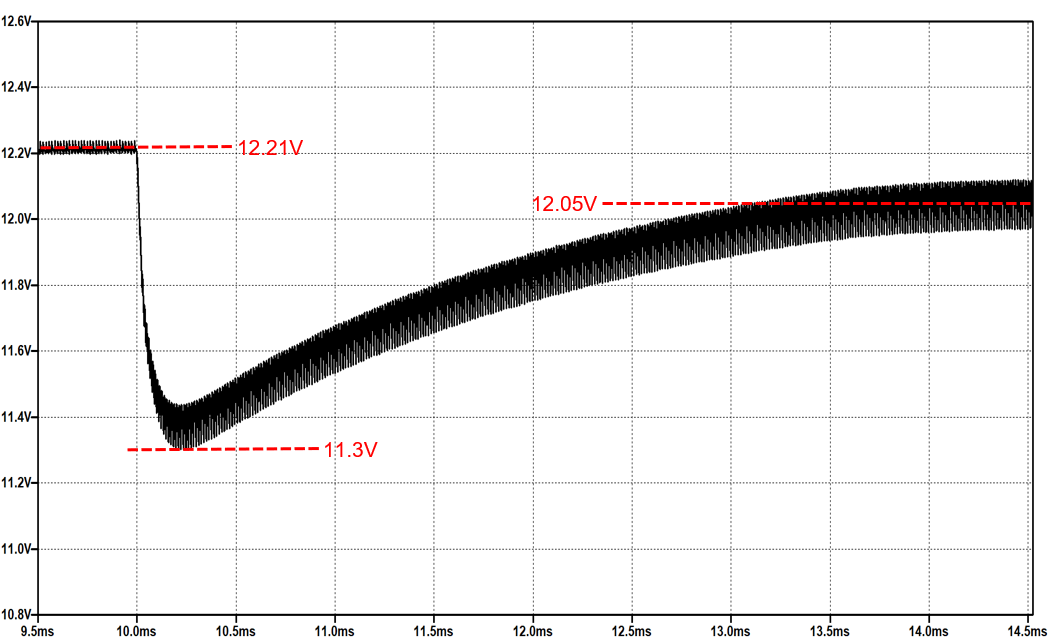


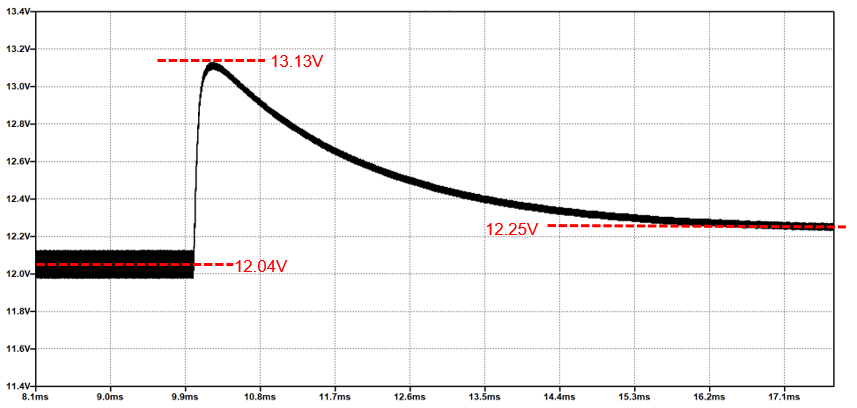
## 6.1 Steady-State Full-Load Responses



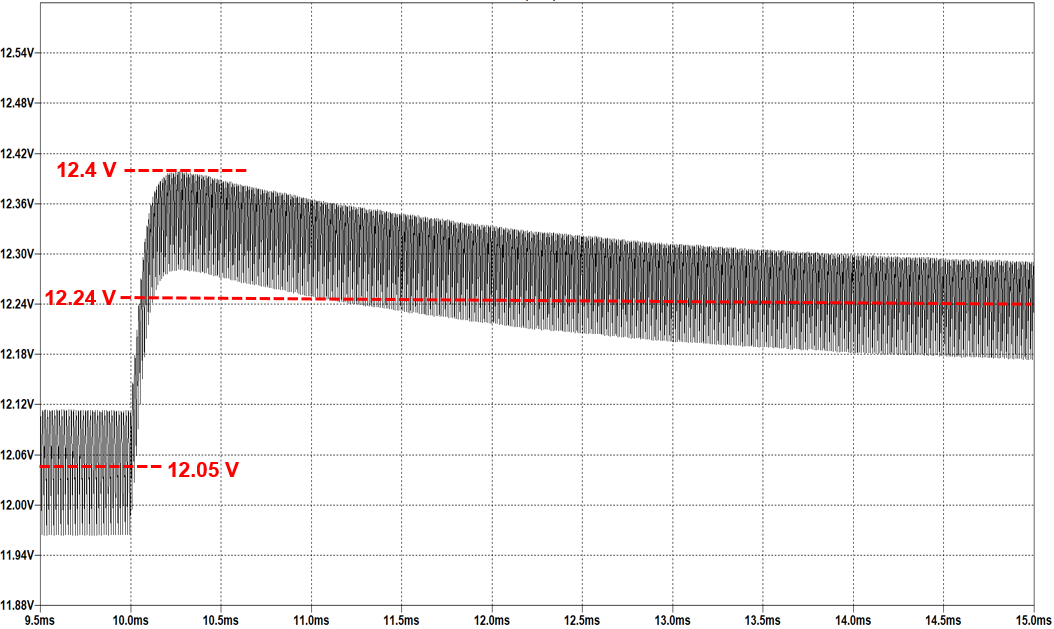


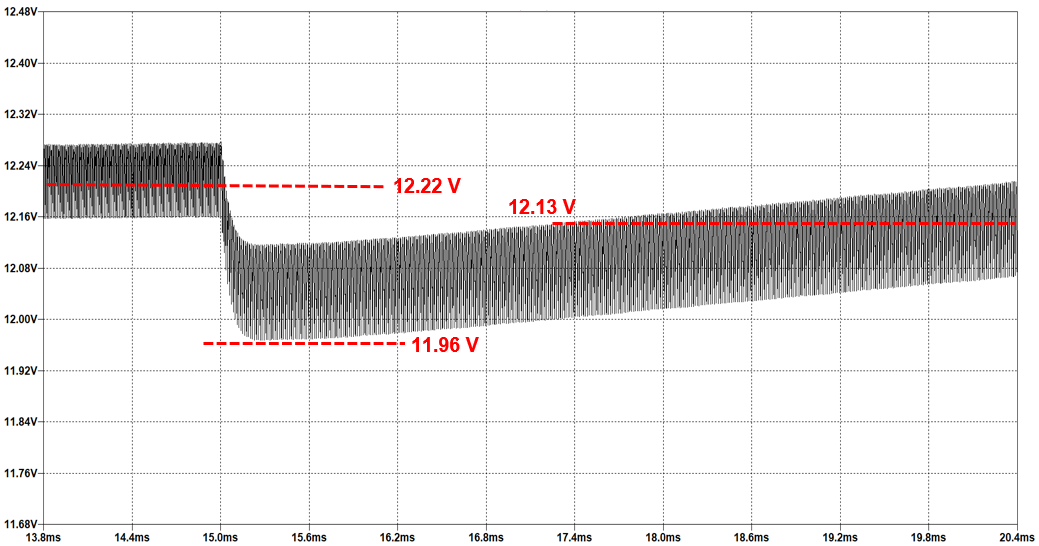
## 6.2 Load Regulation





## 6.3 Line Regulation





# 7. Conclusion

# 8. References

1. Topology Key to Power Density in Isolated DC-DC Converters. (n.d.). Retrieved April 27, 2021, from <https://www.powerelectronics.com/technologies/dc-dc-converters/article/21854364/topology-key-to-power-density-in-isolated-dcdc-converters>