MIDDLE EAST TECHNICAL UNIVERSITY

Electrical & Electronics Engineering

Summer Practice Report

EE 300

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Company: TÜBİTAK Space Technologies Research Institute

Company Division: Platform Power Systems Group

Location of the Company: METU, Çankaya/ANKARA

Summer Practice Date: 03.07.2017 – 28.07.2017

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1. Description of the Company

1.1. Company Name

TÜBİTAK Space Technologies Research Institute

(TUBİTAK UZAY)

1.2. Company Location

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1.3. General Information about the Company

At the first stage, TUBİTAK Information Technologies and Electronics Research Institute was founded in 1985 in METU Campus for research and development purposes in electronics area. In 1991, the field of study of the company were extended and the support from the government had increased. The institute was named as TÜBİTAK BİLTEN in 1995. In 2001, some Turkish engineers decided to make our own satellite from this company and they received crucial education about satellites and they built up the BİLSAT which is our first own made satellite in Turkey. After this important success, the main study area was determined as Space Technologies. Hence, the name of the company is converted to TÜBİTAK Space Research Institute (TÜBİTAK - Uzay).

TÜBİTAK Space specializes in different areas. The main working area of the company is space technologies and carries out researches in space related areas. The Institute is aiming to be pioneer in space technologies in Turkey. Recently, they gave special interest on satellite design manufacturing and test. They have built first two Turkish made small satellites named RASAT and Göktürk-2. Now, they are working on new two Turkish satellites TURKSAT 6A and İMECE. With the experiences they gain from two first two satellites, they are planning to build these two new enhanced satellites.

1.4. Organization

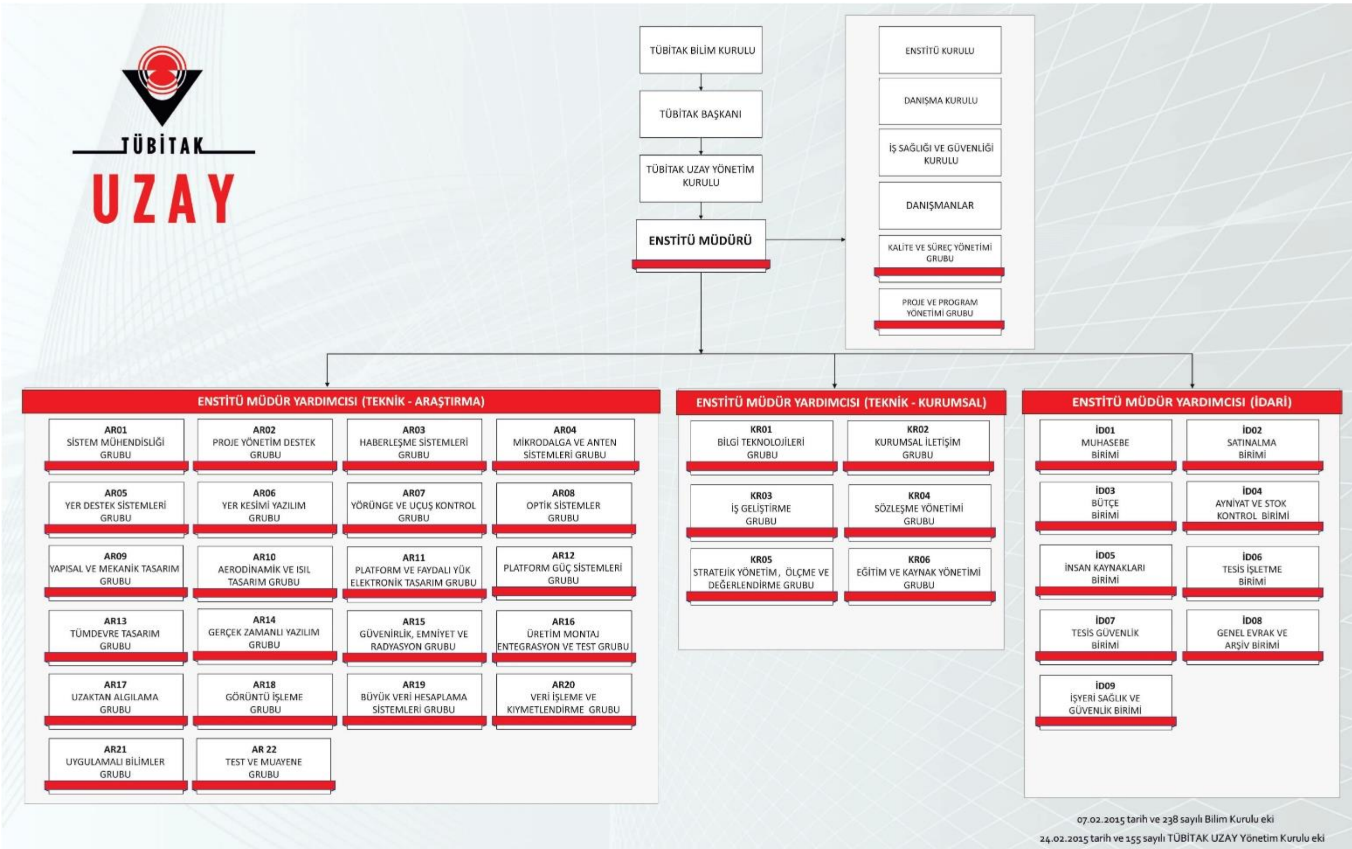

Figure 1: The organization schematic

TÜBİTAK Uzay is a governmental organization. Because of this, Turkish Ministry of Science and Technology is at the top of the organization. There are many subgroups in the company working for different purposes. My subgroup is the Platform Power Systems, which is mainly working on the Power System of satellites. In Figure 1, the organization schematic is illustrated.

1.5. Employees of the Company

The distribution of employees is illustrated in Table 1.

Distributions of	
Electrical & Electronics Engineer	%55
Computer Engineer	%15
Mechanical Engineer	%5
Other Researcher	%6
Technicians	%13
Support Staff	%6
Total	**%100**

Table 1: The distribution of staff

Since the company is mainly based on research & development (R&D), they support the high level of education. Therefore, employees can have their further education while they are working for the company. This results in more qualified R&D. The education level of researchers in TÜBİTAK Uzay is shown in Table 2.

Education Levels of Researchers	
Undergraduate	%27
Graduate	%42
Ph.D.	%14
Other	%17
Total	**%100**

Table 2: The distribution of education levels of employees

2- Introduction

I have done my first summer practice in TÜBİTAK Uzay. My internship is lasted in one month (20 Work Day). Before the summer practice, I was very curious and excited because it is the very first experience I would have had about my job. Therefore, I was very optimistic in entire period of my internship progress. I preferred to perform my internship in TÜBİTAK Uzay as they develop satellites and conduct research about space technologies. It was rare area of interest in Turkey and being a part of this kind of a unique organization is significantly valuable.

I was involved in the Platform Power Systems subgroup regard of my request. Since I would like to know what design engineers actually do, I have understood I have chosen the right group for my internship period. I also was lucky to work with lots of successful engineers who are mainly interested in power electronics. They were very kind while sharing their experiences to me. I mainly interested in power regulators and converters.

First, I worked on designing a Flyback Converter. My main purpose was building up a converter according to defined parameters. During the internship, there were also some instructive trainings for interns, which enabled us to understand basic concepts about satellites and other projects being conducted in the company

In general, during my internship I improved my designing skills in simulation programs, i.e. LTSpice, PSim. Moreover, I learnt the PCB designing programs and their concept, i.e. Altium Designer. The working principles of regulators and converters were my main area of interest, but I also have experienced the fundamentals of EMI filters and Feedback and Control Systems. In this report, the experiences I have had in my internship period are explained in detail.

3- Fundamental Researches

Before going into a project, I was asked to conduct some research basic circuit components and their working principles. Hence, I prepared the document about MOSFET, Op-Amp, Zener Diode and BJT. This helped me to refresh my knowledge on fundamentals of mentioned components. At first, we were planning to build up a Linear Regulator Circuit. Then, we have changed our opinion to create more complex circuitry. Therefore, the document related to MOSFET is used and can be found in Appendix A. The others are excluded.

During the period of preparing these documents, I understand the importance of observing the specifications mentioned in the datasheets. For instance, in a MOSFET datasheet following properties are crucial in engineering design.

- V_{DS} (Drain Source Voltage)
- $R_{DS\,(ON)}$ (The resistance seen while the MOSFET is on)
- I_D (Allowed max. drain current)
- C_{ISS} (Input capacitance)
- C_{OSS} (Output capacitance)

In every each of component used in the design of an engineering application, datasheets are examined carefully in order not to make mistake.

Furthermore, I heard about Switch-Mode Power Supplies (SMPS) while researching and I have realized the importance of SMPS in Power Electronics and especially in DC-DC converters. Unlike a linear power supply, the pass transistor of a switching-mode supply continually switches between low-dissipation, full-on and full-off states, and spends very little time in the high dissipation transitions, which minimizes wasted energy. In ideal cases, a switched-mode power supply dissipates no power.

Voltage regulation is achieved by varying the ratio of on-to-off time. On the other hand, a linear power supply regulates the output voltage by continually dissipating power in the pass transistor. This higher power conversion efficiency is an important advantage of a SMPS. Switched-mode power supplies may also be substantially smaller and lighter than a linear supply due to the smaller transformer size. [1]

4-The Project: Flyback Converter

My project is designing a basic Flyback Converter that is as an AC/DC and DC/DC converter with galvanic isolation, which can be defined as possessing different ground potentials for individual parts of the electrical system, between the input and any outputs [2].

In isolation topologies, main concerns are safety and isolating circuits from each other in applications to make them work properly. The Flyback converter is a buck-boost converter with the inductor split to form a transformer, so that the voltage ratios are multiplied with an additional advantage of isolation [3].

Retrieved from: (Kamil, 2007)

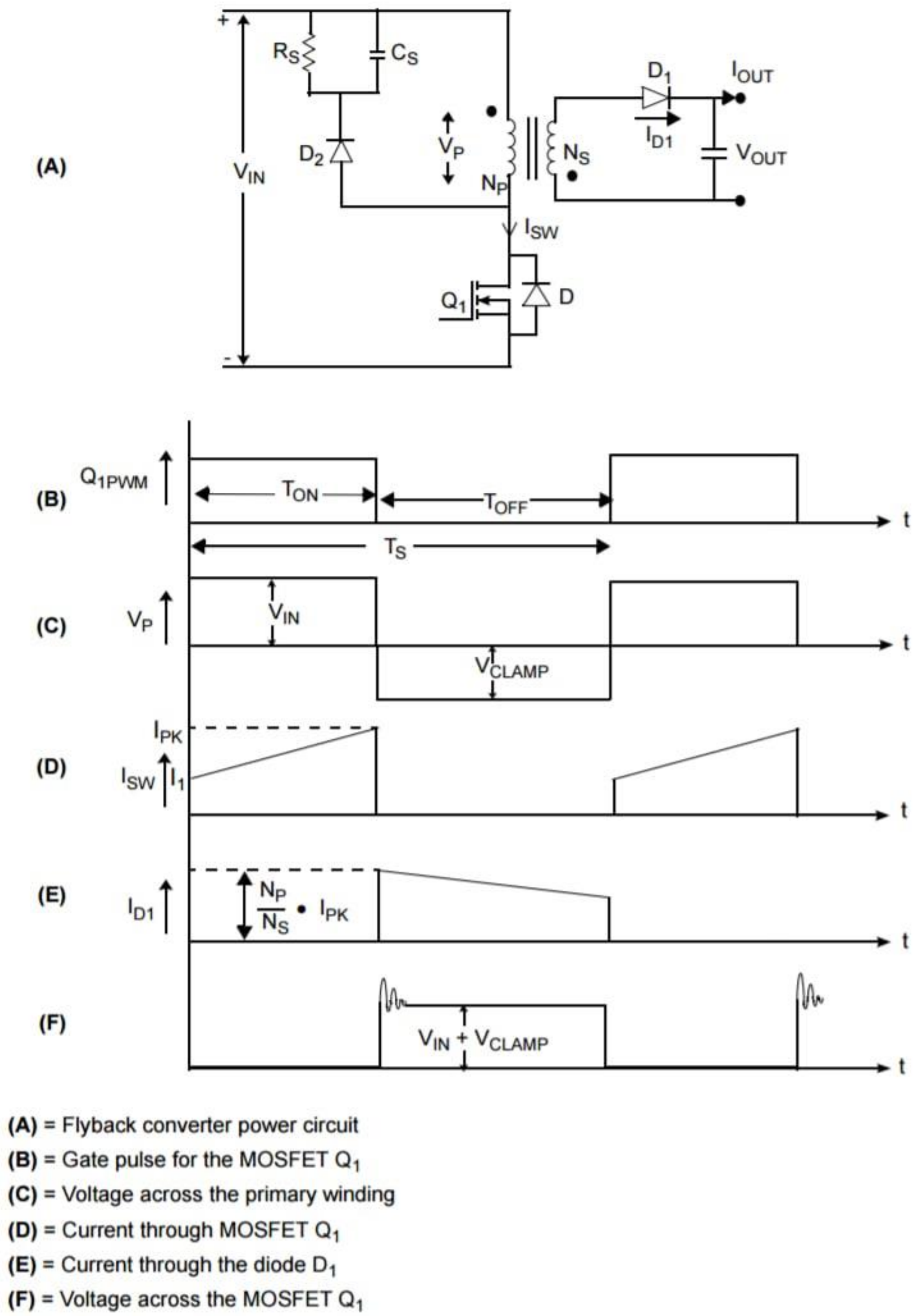

Figure 2: The basic schematic and switching waveforms of Flyback Converter

4.1 The Working Principle of Flyback Converter

The basic switching techniques are not sufficient for the converter purposes as mentioned in SMPS section in this document. Hence, some transistors are used for the switching purposes i.e. BJT, MOSFET. There are two period of actions happening while the converter is working. One with the switch (MOSFET in our case) on and other one with the switch is closed.

4.1.1 The Case while Switch is ON

A Flyback Converter (FBT) is a transformer-isolated converter based on the basic buck boost topology. The basic schematic and switching waveforms are shown in Figure 2. In a Flyback converter, a switch (Q_1) is connected in series with the transformer. The transformer is used to store the energy during the ON period of the switch, and provides isolation between the input voltage source V_{IN} and the output voltage V_{OUT}.

In a steady state of operation, when the switch is ON for a period of T_{ON}, the dot end of the winding becomes positive with respect to the non-dot end. During the T_{ON} period, the diode D_1 becomes reverse-biased and the transformer behaves as an inductor. The value of this inductor is equal to the transformer primary magnetizing inductance L_M, and the stored magnetizing energy from the input voltage source V_{IN}. Therefore, the current in the primary transformer, I_M rises linearly from its initial value I_1 to I_{PK}, as shown in Figure 2 (D). As the diode D_1 becomes reverse-biased, the load current (I_{OUT}) is supplied from the output capacitor (C_O). The output capacitor value should be large enough to supply the load current for the time period T_{ON}, with the maximum specified droop in the output voltage.

4.1.2 The Case while Switch is OFF

At the end of the T_{ON} period, when the switch is turned OFF, the transformer magnetizing current continues to flow in the same direction. The magnetizing current induces negative voltage in the dot end of the transformer winding with respect to non-dot end. The diode D_1 becomes forward-biased and clamps the transformer secondary voltage equal to the output voltage. The energy stored in the primary of the Flyback transformer transfers to secondary through the Flyback action. This stored energy provides energy to the load, and charges the output capacitor. Since the magnetizing current in the transformer cannot change instantaneously at the instant the switch is turned OFF, the primary current transfers to the secondary, and the amplitude of the secondary current will be the product of the primary current and the transformer turns ratio, NP/NS. [4]

4.1.3. The Comparison of Continuous Conduction Mode and Discontinuous Conduction Mode

Flyback converters can operate in Continuous Conduction Mode (CCM), where the inductor current never falls to zero, and in the Discontinuous Conduction Mode (DCM) where the inductor current does fall to zero each cycle once enough energy has been supplied to satisfy the load as shown in Figure 3. If the load is too small, the converter is forced into the DCM, which is a more difficult system to stabilize, and that is why some popular SMPS units found in PCs require a minimum load for correct output regulation. The best efficiency and use of the physical inductor geometry is seen at the boundary of CCM and DCM that is defined as Boundary Conduction Mode (BCM). [5]

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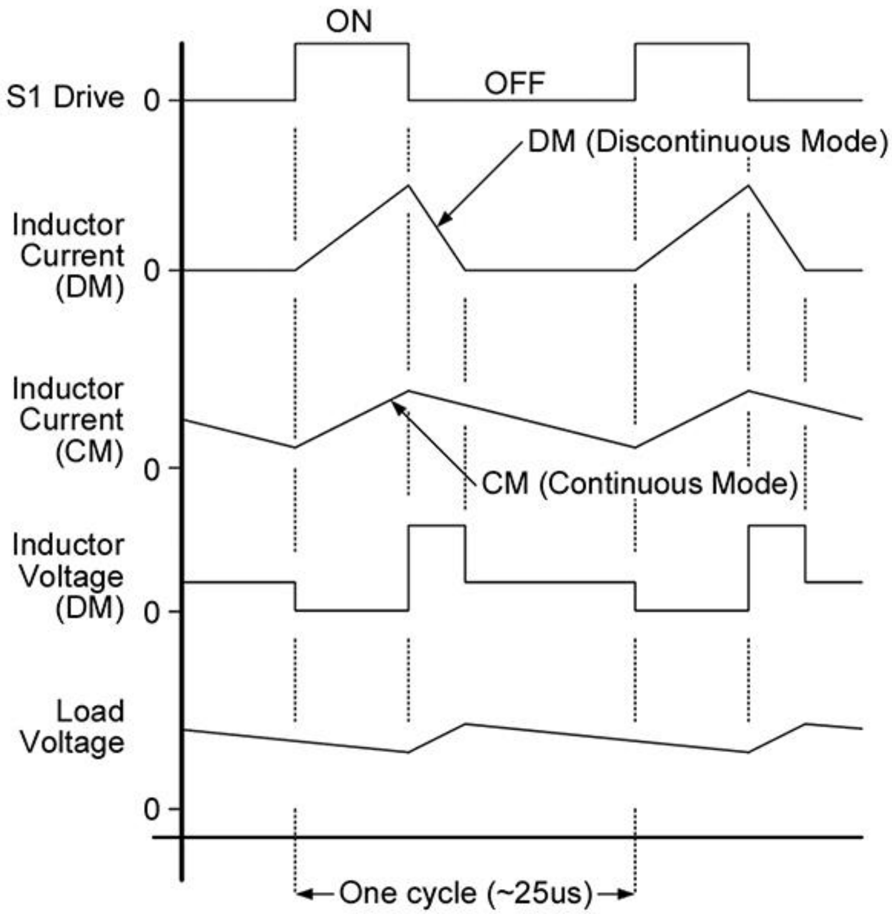


Figure 3: CCM-DCM Comparison

I was asked to design a Flyback Converter, which generally works in CCM. Our goal is to keep the converter work in BCM. When it is not working in BCM, we defined an interval to maintain the sustainability.

V_{OUT}/V_{IN} Relationship

For a Flyback converter, the transfer function can be obtained basically by analyzing the inductor waveforms. To apply this method, we need to use the Inductor Volt-Second Balance Theory. It basically states that the net inductor voltage in a switching period must be zero for steady state operation of an inductor in a DC-DC Converter [6]. As illustrated in Figure 2 (C), we need to consider the primary winding voltage waveform to derivate the transfer function. The total sum of average voltages should be zero i.e. $T_{ON}*V_{LP} + T_{OFF}*V_{LP} = 0$

During the T_{ON} period

$T_{ON}*V_{LP} = V_{IN}*D*T_P$

During the T_{OFF} period

$T_{OFF}*V_{LP} = -N_1/N_2*V_O*(1-D)*T_P$

$V_{IN}*D*T_P \; -N_1/N_2*V_O*(1-D)*T_P = 0$

If we solve these equations for V_O the transfer function of the Flyback Converter is calculated as:

$$V_{\mathrm{out}} = -\frac{N_2}{N_1} \cdot \frac{D}{1-D} \cdot V_{\mathrm{in}} \quad (1)$$

where D is the duty cycle, and N_1 and N_2 are the turns numbers of the primary and secondary windings.

A duty cycle is the fraction of one period in which a signal or system is active. Duty cycle is commonly expressed as a percentage or a ratio. A period is the time it takes for a signal to complete an on-and-off cycle. Pulse-width modulation (PWM), which is a duty cycle type, is used in a variety of electronic situations, such as power delivery and voltage regulation. Therefore, it is very important in Control and Power theories.

4.2. Project Description

Input: 28 V_{DC} Output: $5V_{DC}$, 4A %70 Efficiency

My main goal is to have an output with $5V_{DC}$, 4A when the input is near the 28 V_{DC}. We worked on power issues very much to have an at least %70 efficiency.

4.2.1. How to Choose Components

Generally, Flyback converters work less than 0.5 duty cycle. According to our design, the duty cycle of our converter is assumed as 0.35. Because we need the turn ratio of transformer, I used this assumption for this purpose in the equation (1).

Turns Ratio = 65/196 = 0.33

This information will be used while assuming inductance values for the transformer in equation (2).

$$\frac{N_1}{N_2} = \sqrt{\frac{L_1}{L_2}} \quad (2)$$

The input range should be arranged so that the converter works properly. To regulate 28V we assumed input voltage to be in the range of 18V and 32V. By using the formula (1), the duty cycle range is calculated as

$0.45 < D < 0.32$

The inductance values are calculated according to higher voltage values and lower duty cycles to have more reliable circuit design.

In many applications of Flyback Converters, output average ripple current is assumed as the %10 of output current. Hence,

$I_{Ravg} = 4A*\%10 = 0.4$ A

When the output current waveforms are concerned, it can be easily seen in Figure 3 that it is in the form of triangle. Therefore, the peak of ripple current is 0.8A.

$$\frac{N_P}{N_S} = \frac{I_S}{I_P} \qquad (3)$$

Since we know the turns ratio and the change of the current in the secondary side, we know the change of current in primary side by using the equation (3).

$0.33 = I_P/0.8$
$I_P = 0.264$ A

Inserting these values in to the Ohm's Law for inductor, the primary side inductance value is found as 422µH and the secondary side inductance is calculated as 46µH by using the equation (2).

The ripple voltage at the output is assumed as %1 of output voltage which is 0.05 V. The capacitor is chosen by using Ohm's Law for capacitor. Hence, the output capacitance is calculated as 280µF. However, 330µF capacitor is used for practical purposes and the circuit is not affected considerably by this margin.

The MOSFET is chosen according to the voltage on the drain source of MOSFET. The MOSFET chosen should be durable to at least 130 V, as demonstrated in Figure 4 & Figure 5, and $R_{DS(ON)}$ should be small to reduce power consumption on MOSFET.

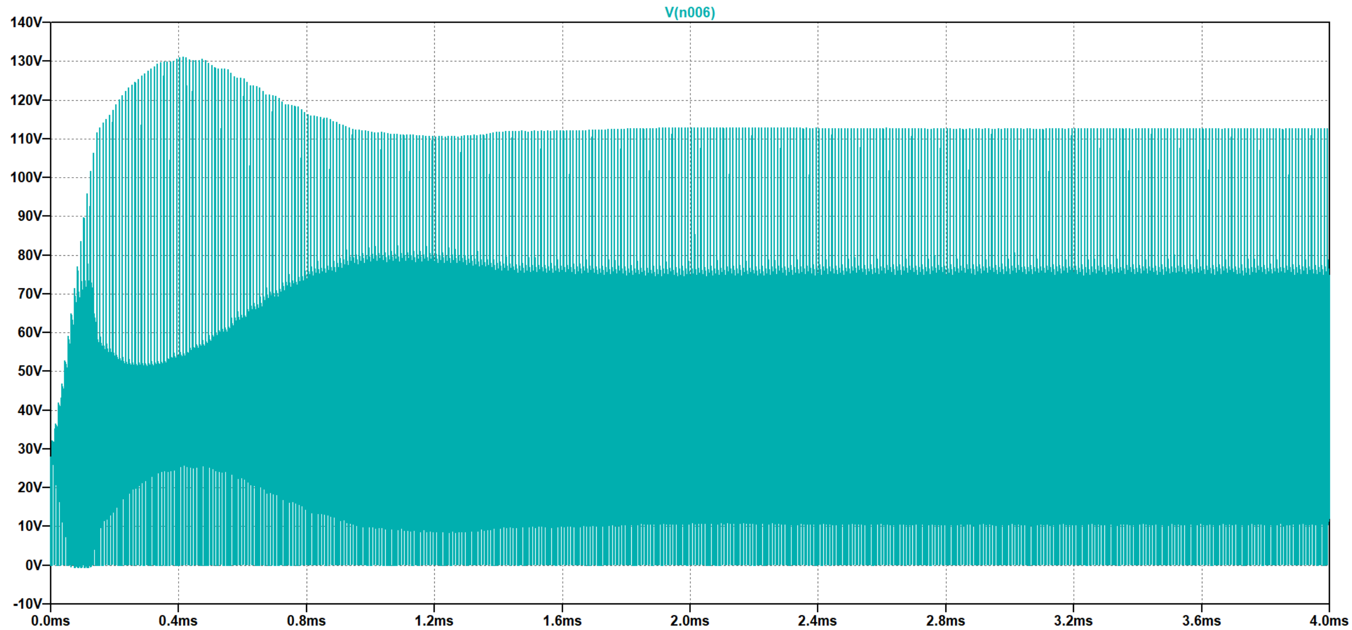


Figure 4: The voltage on the drain source of the MOSFET

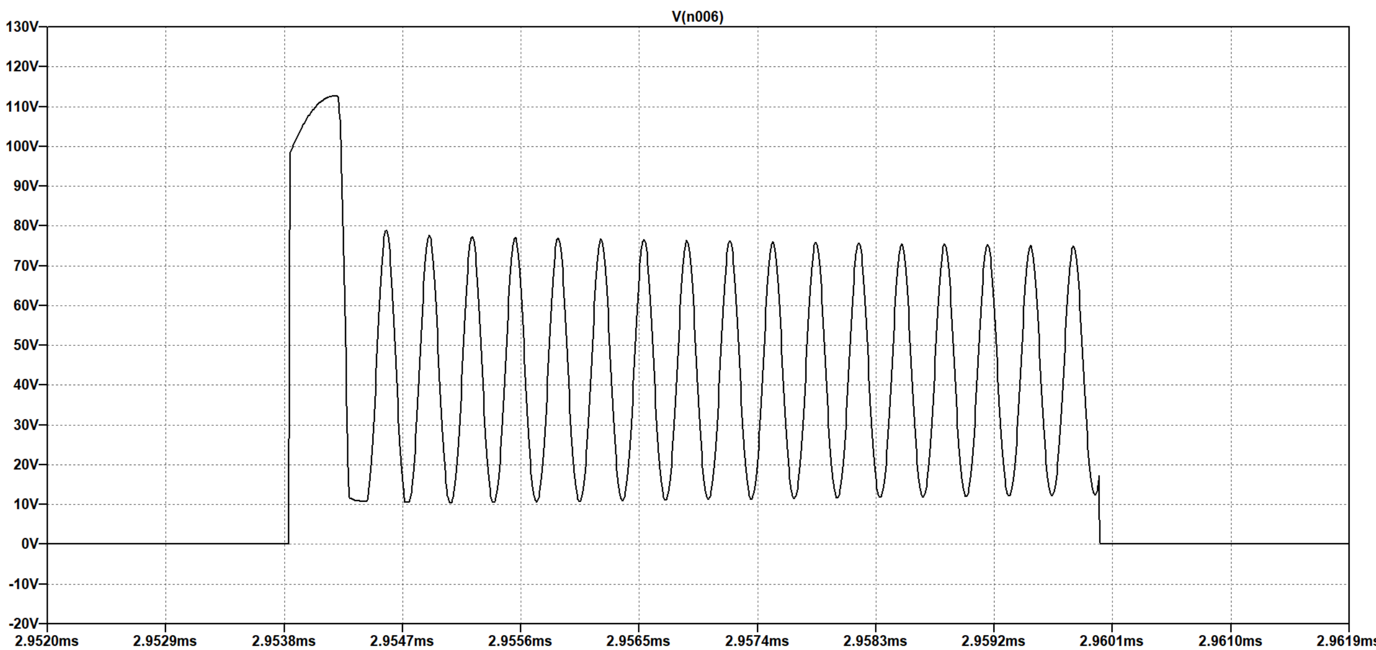


Figure 5: The voltage on the drain source of the MOSFET zoomed in

4.2.2. The Design and Simulation Process

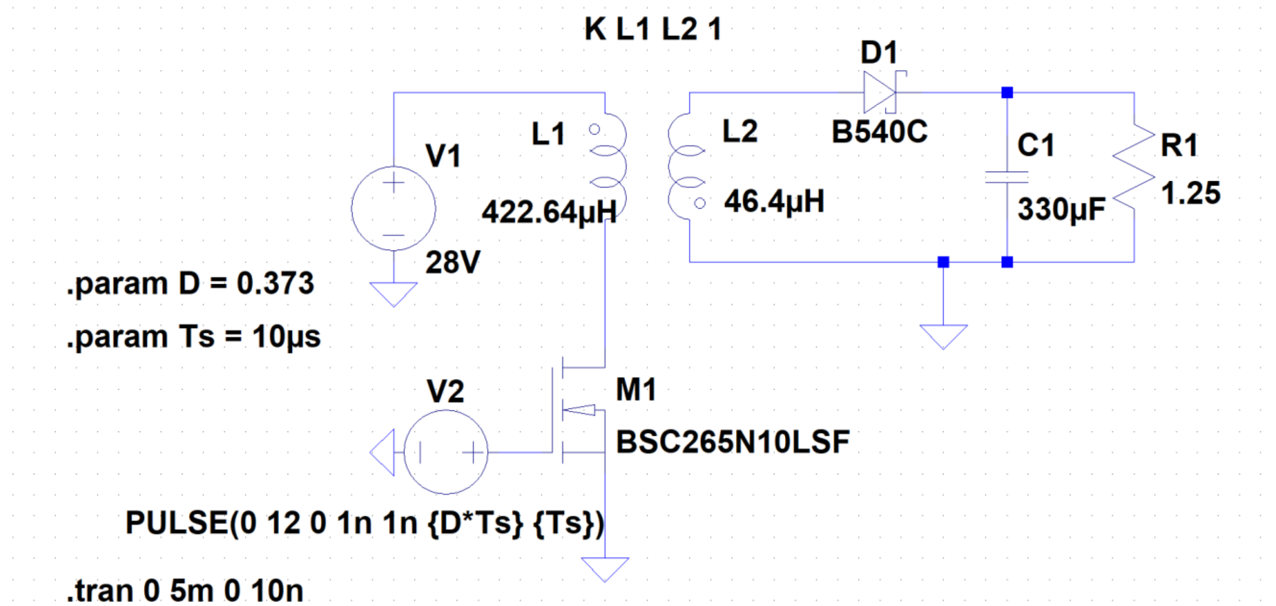


Figure 6: The first draft of the Flyback converter circuit

In the first attempt, the leakage current of the transformer is ignored to have a basic draft of the circuit as shown in Figure 6. Duty cycle is arranged ideally according to the load regulation to be consistent since there is no feedback circuit to arrange duty cycle.

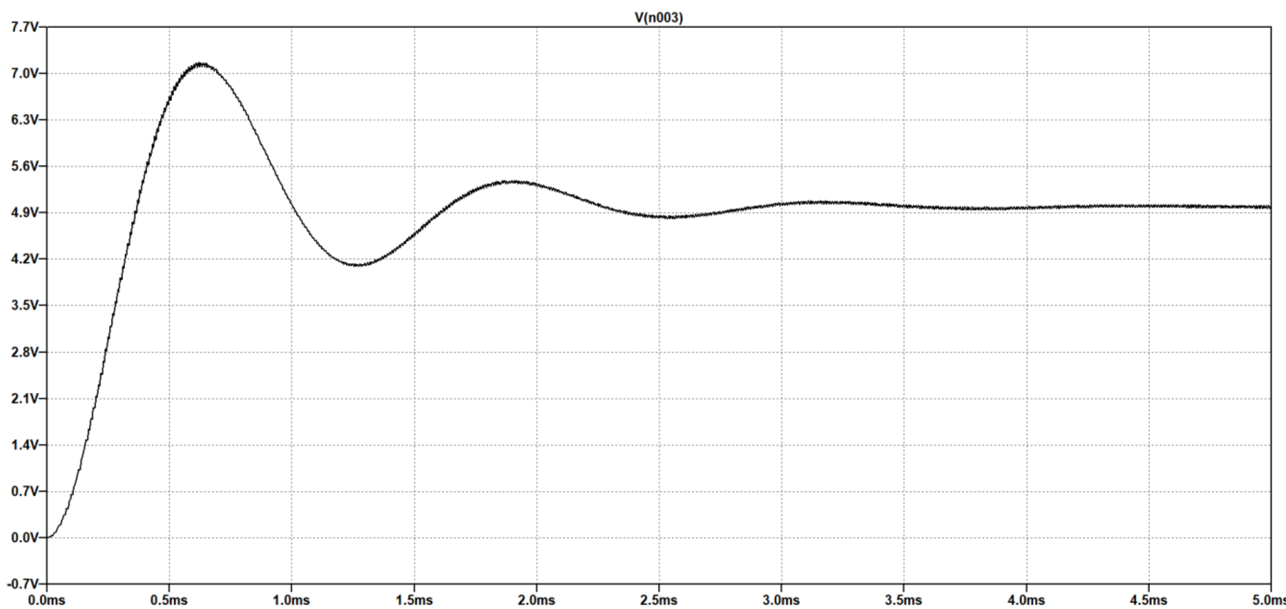


Figure 7: The output waveform of 1st draft circuit

The output waveform of the first draft was successful as shown in Figure 7. Then, real world applications are considered and the leakage inductor is added to the circuit with some enhancements.

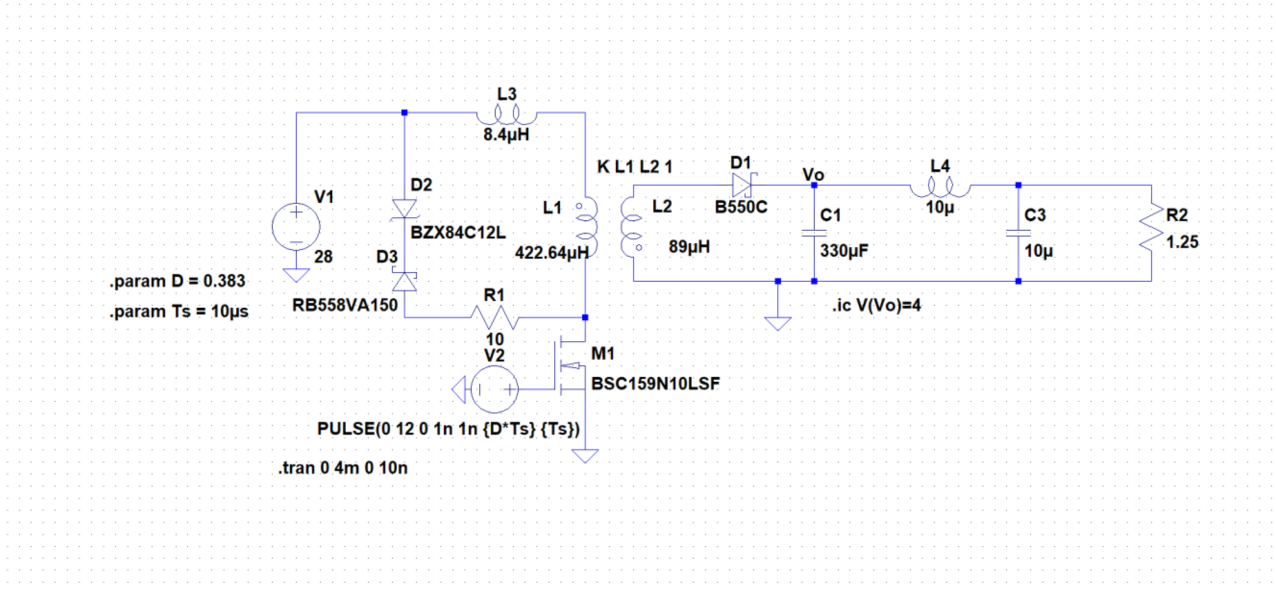


Figure 8: The second draft of the Flyback converter circuit with zener snubber and LC filter

In the second attempt, a zener snubber circuit and an LC filter is added due to some reasons as shown in Figure 8 (L3 represents the leakage inductor in the transformer). The purpose of zener snubber circuit is to consume the leakage current on the resistor R1 and keep the voltage difference in an arranged interval (For further info about zener diode see Appendix B). Otherwise, this leakage current may cause some problems on MOSFET's drain voltage and thus to the MOSFET. The zener diodes are chosen according to their forward voltage durability.

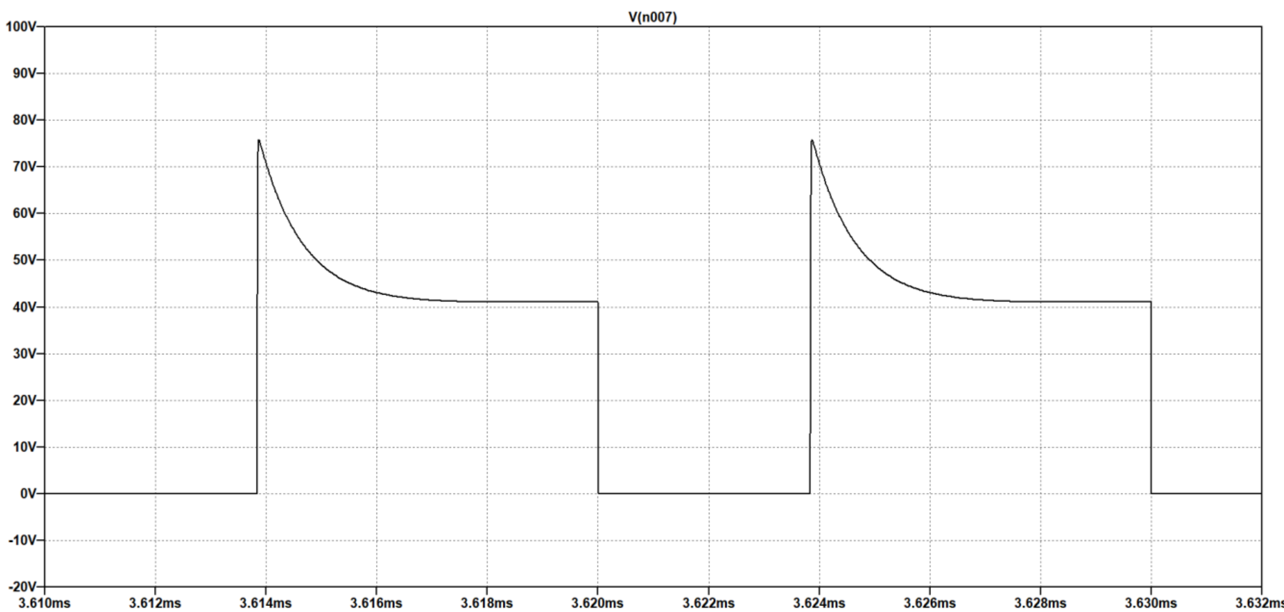


Figure 9: The waveform of voltage on the MOSFET (V_{DS})

In Figure 9, drain-source voltage across the MOSFET is illustrated. With the zener snubber circuit, we have reached more stabilized MOSFET switching operation. Also, our MOSFET's V_{DS} durability does not need to be too much which helps us to use more basic MOSFET. This decreases the cost of the project and we have safer converter.

Moreover, the usage of LC filter is the decrease the swing in the output waveforms, can be seen in Figure 10 and Figure 11, since we do not want it to happen for the sake of consistency.

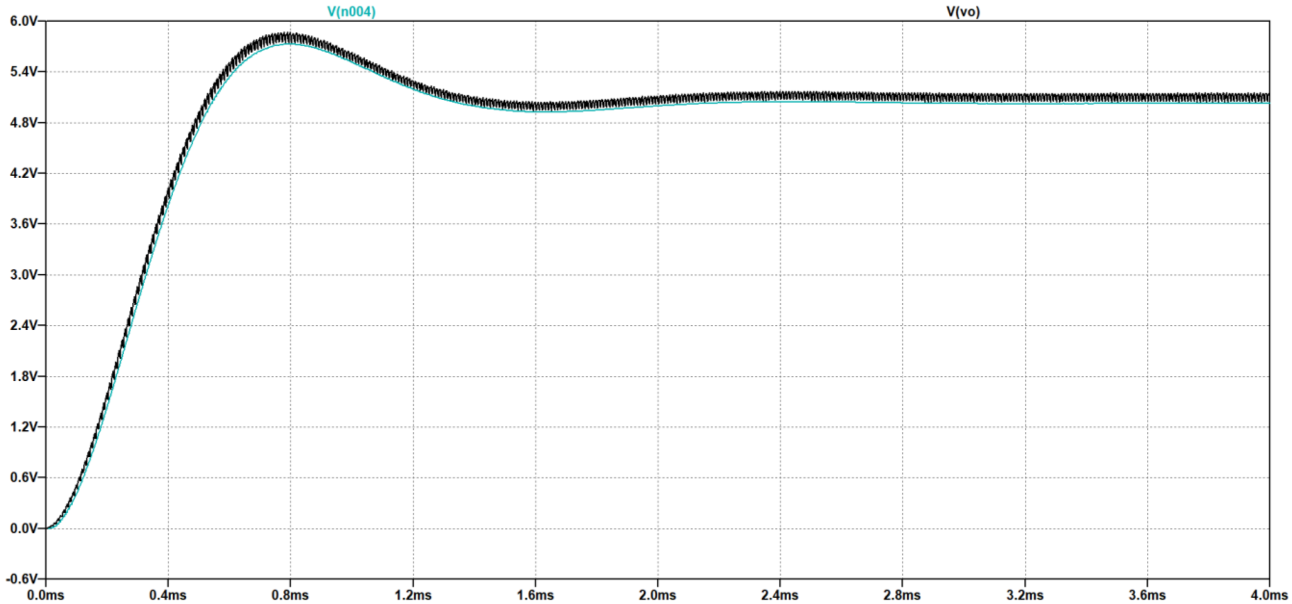


Figure 10: The output waveforms with and without LC filter.

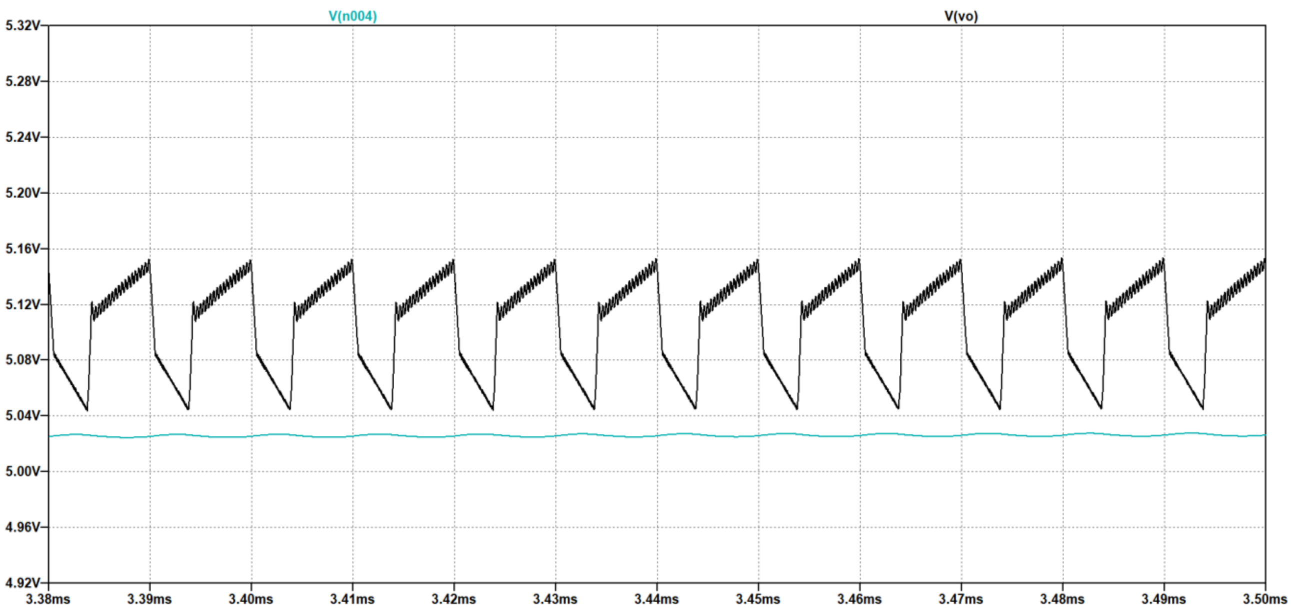


Figure 11: The output waveforms zoomed in with and without LC filter.

However, it is realized that the zener snubber circuit is consuming too much energy and it decreases the efficiency to the %60's. Furthermore, we have understood that zener snubber circuits are suitable for circuits works with low voltages and currents. Hence, I have found another snubber circuit design for this purpose.

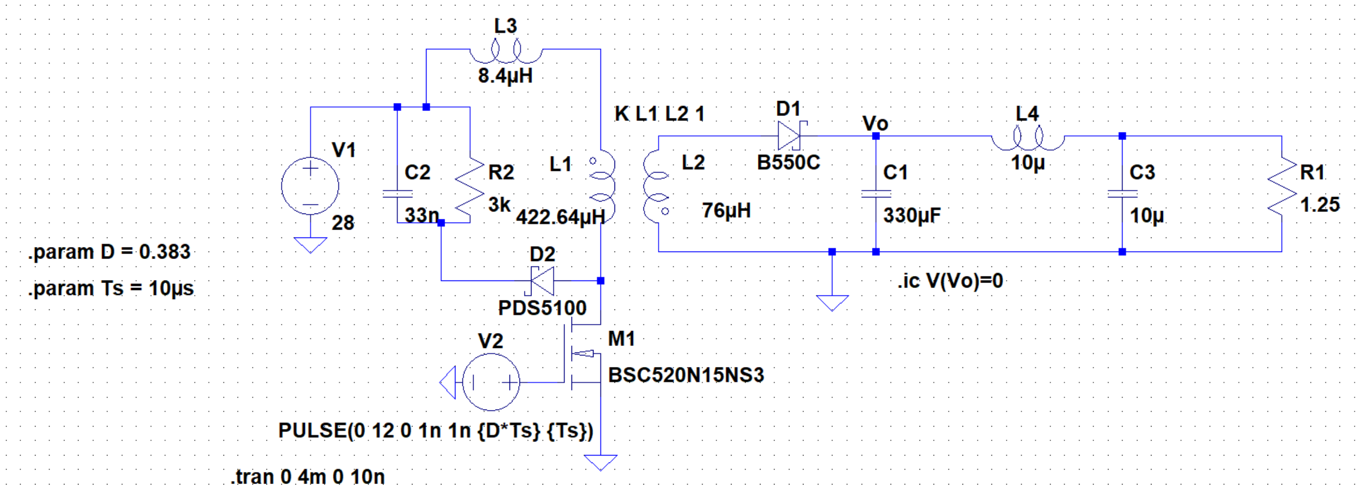


Figure 12: The third draft of the Flyback converter circuit with RC snubber and LC filter

The values for RC snubber is assumed at first. Then, resistor and capacitor values are arranged so that the power consumption is decreased as much as it could by keeping the time constant (T= RC) to fixed value.

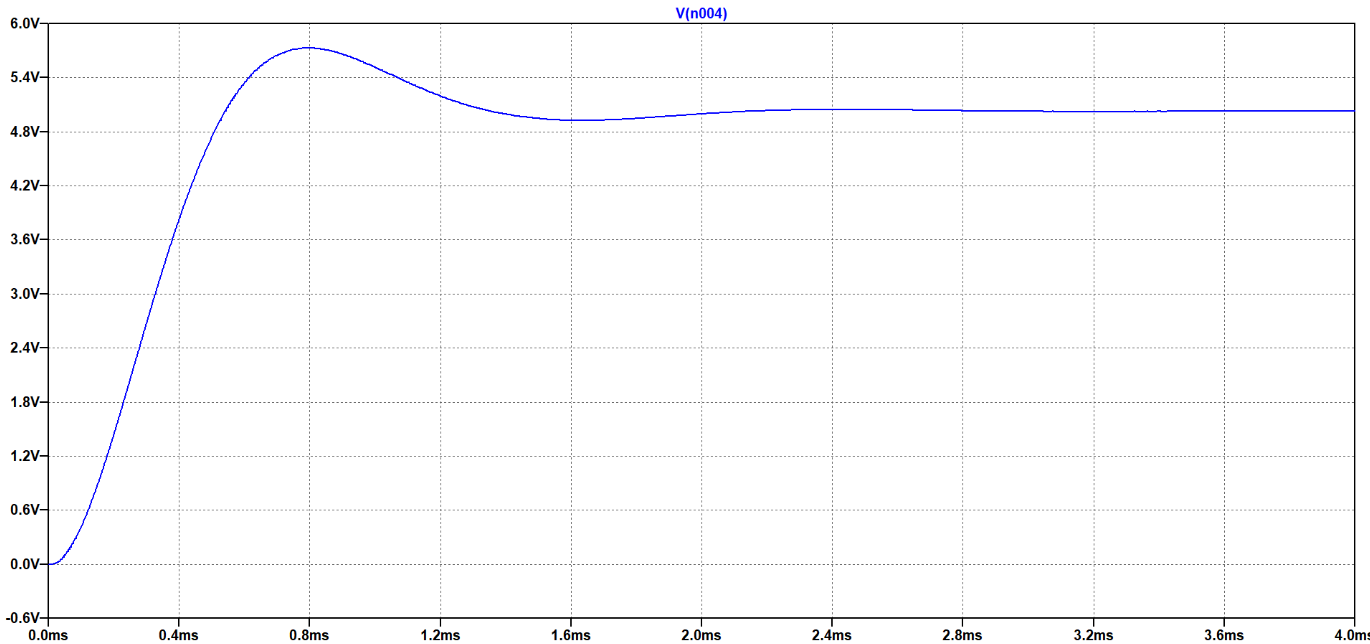


Figure 13: The output waveform of the finalized circuit

Finally, we have reached a consistent and efficient circuit and the output waveform is illustrated in Figure 13.

While researching, I have found an important feature that can be used in SMPS topologies as Valley Switching operation mode. There are two main advantages of Valley Switching, in other words Quasi Resonant[7].

Lower Turn-on Loss: Since it turns on at the valley the turn on losses due to the discharging of CD is significantly reduced. This makes QR Flyback efficiency higher especially high line/lighter loads.

Less Conducted EMI: Due to the ripple voltage appearing across the bulk capacitor, the switching frequency is modulated of QR Flyback is modulated at twice the mains frequency. This causes the spectrum to be spread over the wide frequency band than a single frequency values.

Therefore, I have considered the switching point as much as to be close to the lowest value in order to reduce the switching power losses and increasing the efficiency as illustrated in Figure 14.

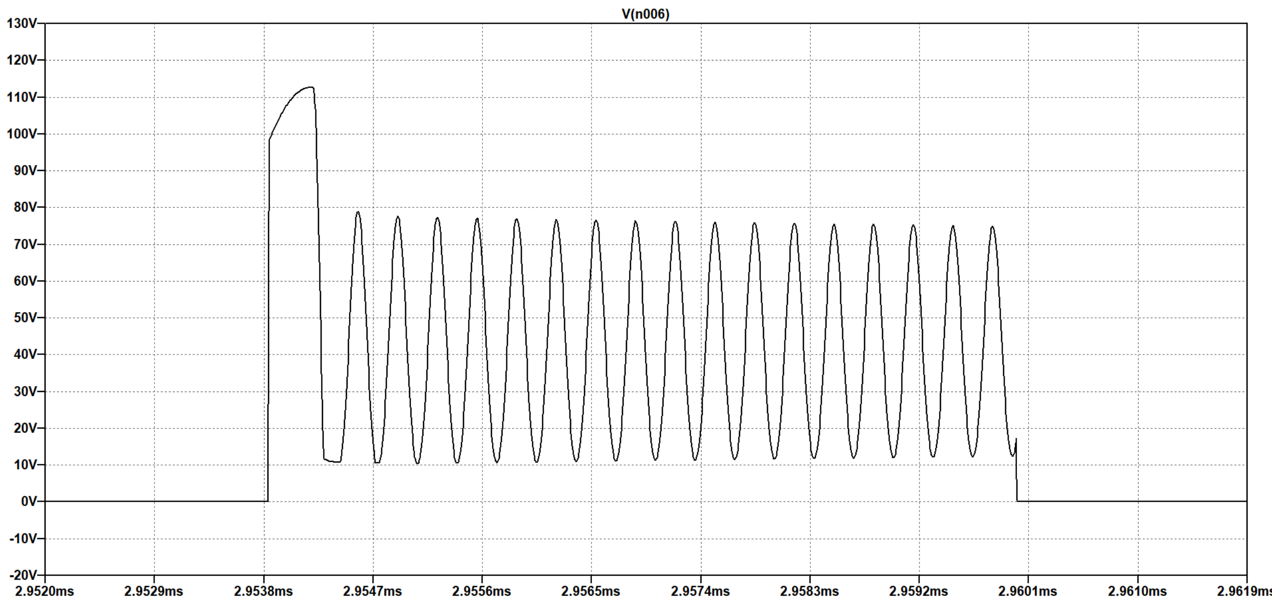


Figure 14: The demonstration of Valley Switching

Unfortunately, there was no suitable time for me to add a Feedback Controller Circuit to control the circuit without giving a fixed duty cycle. The design process was finished at this point.

4.3. Power Calculations

4.3.1. Fundamental Concepts of Loss Model

There are three major energy losses of the Flyback converter namely in the output diode rectifier, the conduction losses in the power MOSFET and loss due to leakage inductance of the coupled inductor (Flyback transformer) and switching losses of the main switch of the converter. On the other hand, gate charge and reverse recovery losses of the body diode of MOSFET may be included of the converter circuit based on these losses, simple mathematical expressions have been deduced by the fundamental equations with some assumptions.

4.3.2. Switching Losses

In order to work out the switching losses, considering the overlapping section as a triangle of small time (Δt) width shown below, the average power dissipated by the MOSFET at turn off is simple triangle area.
Worst case takes place when the drain to source voltage, Vds(t) instantly rises up at the switch opening. Hence, a snubber implemented to slow the voltage rise, the idealized can happen with more complimentary loss accounts.

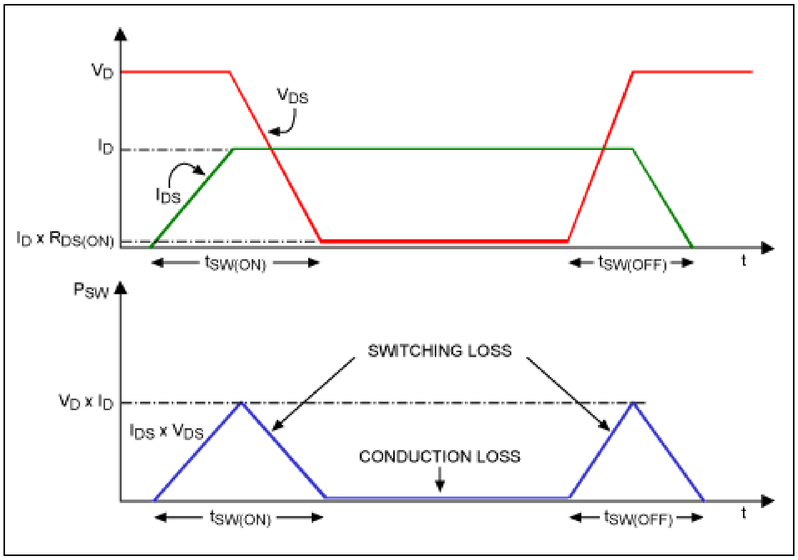


Figure 15: Switching losses occur as a MOSFET transitions between its on and off states.

If the total sum of the areas of triangle as shown in Figure 15 calculated, we can figure out the switching loss.

$T_{MOS} = T_{d(on)} + T_r + T_{d(off)} + T_f$
T_{MOS} = 10nS+ 24nS + 20nS + 4nS = 58nS (Given in the Datasheet)

$P_{SW(MOSFET)} = ½ * V_D * I_D * (t_{SW(ON)} + t_{SW(OFF)}) * F_s$
$P_{SW(MOSFET)}$ = ½ * 44.5 * 2.7A * 58nS * 100KHz =0.348W

4.3.3. Snubber Loss

In order Flyback Converter to work, we need to have a snubber circuit which is composed of a diode, a capacitor and a resistor. As the leakage inductor of transformer stores energy inside, we need to discharge it by using snubber circuit. Therefore, this power dissipation is equal to the power dissipated on the snubber resistance of the circuit.

Leakage inductance is generally taken as %2 of the primary inductance of transformer.
$R_S = 3kΩ$
I_{RS} = 25.2 mA (Found from simulation)
$P_{snub} = I_{RS}^2 * R_S = 25.2mA^2 * 3kΩ = 1.9$ W

4.3.4. Conduction Losses

When the MOSFET is switched on, it has a resistance value called $R_{ds(on)}$. According to MOSFET datasheet used in this converter design,
$R_{ds(on)} = 26.5\ m\Omega$
Based on the simulation results, average current flowing through the MOSFET while it is switched on.

$I_{MOSFET(ON)} = 2.7A$
Therefore, the total power dissipated is calculated as,

$P_{COND} = (D*T) * I^2 * R_{ds(on)} * Fs$ (Note that Fs Cancels T out)
$P_{COND} = 0.35*2.7A^2*26.5\ m\Omega = 0.06\ W$

4.3.5. Output Diode Rectifier

We have power dissipation on the diode in the rectifier part of the secondary side of the circuit. The power dissipation is calculated as

$Pdiode = V_{Fmax}*I_{Frms}*(1-D)$
$V_{Fmax} = 0.55\ V$
$I_{Frms} = 6.27A$
$Pdiode = 0.55V*6.4A*0.65 = 2.28\ W$

In the total sum, there is 4.6 W loss in the system and the power of the supply is 27.89 W as shown in Figure 16. Hence, the total efficiency is

23.29/27.89 = %83.5

Therefore, the desired efficiency is provided.

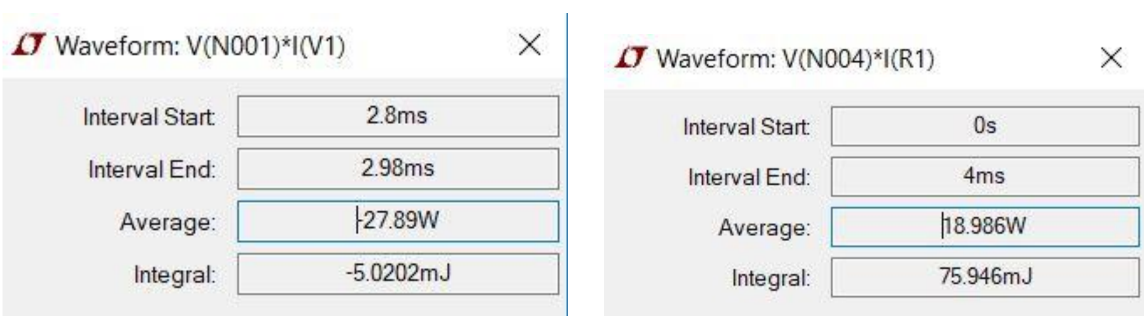


Figure 16: The average value of power supplied

4.4. PCB Drawing

In the last week of my internship period, I have started to learn the Altium Designer program, which is used to create PCB's in real world applications. At first, my responsible engineer has made an introduction about PCB's, how they work, what should be considered while creating a PCB and the basics of Altium Designer program.

Before going in to PCB drawing, I have decided on the components which are used in real life applications by making suitable researches based on our project. In table 3, the manufacturer and type of the components which are used in the project are illustrated.

Component	Manufacturer	Type & Model
33 nF SM Ceramic Capacitor	VISHAY	VJ0805
10 µF SM Tantalum Capacitor	VISHAY	293D106
330µF SM Tantalum Capacitor	VISHAY	293D106
SM Schottky Barrier Rectifier	DIODES INC.	B550C
10µH Shielded High Power Inductor	BOURNS	SRR1208
OptiMOS Power Mosfet	INFINEON	BSC520N15NS3
3kΩ Wirewound Resistors	VISHAY	WSC6927
High Voltage Schottky Barrier Rectifier	DIODES INC.	PDS5100
Transformer Core	FERROXCUBE	RM12/I

Table 3: The list of components used in PCB drawings

Moreover, I have benefit from the online documents and video tutorials. Then, I started to draw my schematic in the program as shown in Figure 17. In this part, I have learned to create schematic library if there is no schematic of the component in the program. For instance, there was no schematic for the selected MOSFET and I created a box with 8 pins since there are 8 pins of the MOSFET as indicated in the datasheet of MOSFET.

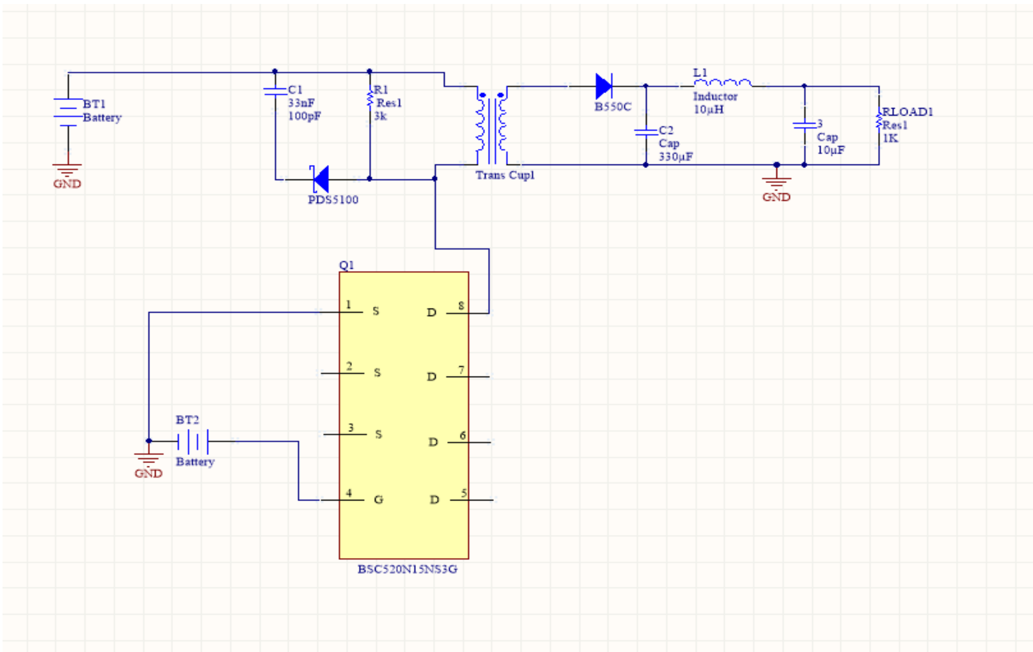
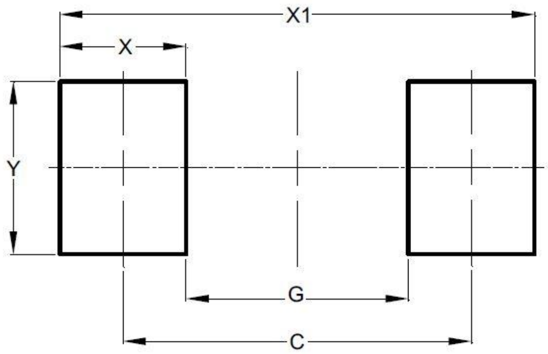


Figure 17: Schematic of the circuit in Altium Designer

Then, I have started to draw each component by checking the real values of their shapes as indicated in datasheet of each component. We work generally on Surface Mounted components. For example, the real world information of shape of the PAD's of diode in the RC snubber circuit is demonstrated in Figure 18 and the drawing is illustrated in Figure 19.



Dimensions	Value (in mm)
C	6.90
G	4.40
X	2.50
X1	9.40
Y	3.30

Figure 18: The PAD's and the distance information of diode in the RC snubber

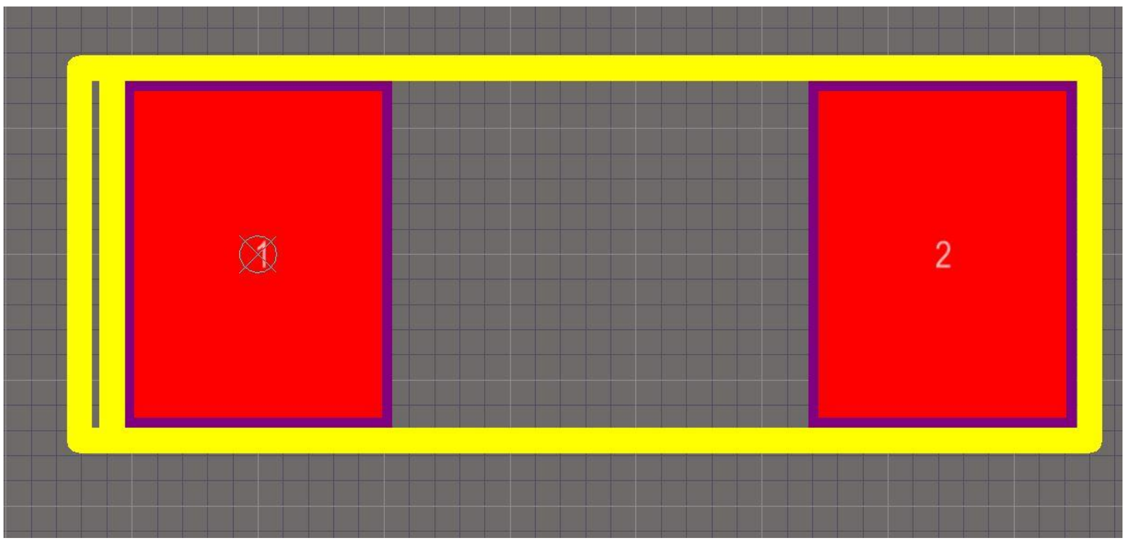


Figure 19: The Altium Designer drawing of the diode according to datasheet

While drawing the paths between the components, I have considered the width of the paths based on the value of current they carry. Also, I tried to avoid sharp turns at the corner since it may cause current to jump to unwilling path. Furthermore, I tried to keep the board as small as possible for efficiency.

Finally, I added two polygons which are referring as ground on the board to have a reference point. These two polygons should not be connected to each other since there should be isolation between the two parts of the circuit as mentioned in the very first paragraph of the project. There seems an error in Figure 20 but it is done on purpose as mentioned.

I did not attempt to draw the 3D models of each component since there was not enough time for this. The final version of my PCB is demonstrated in Figure 20 and Figure 21 with 3D model.

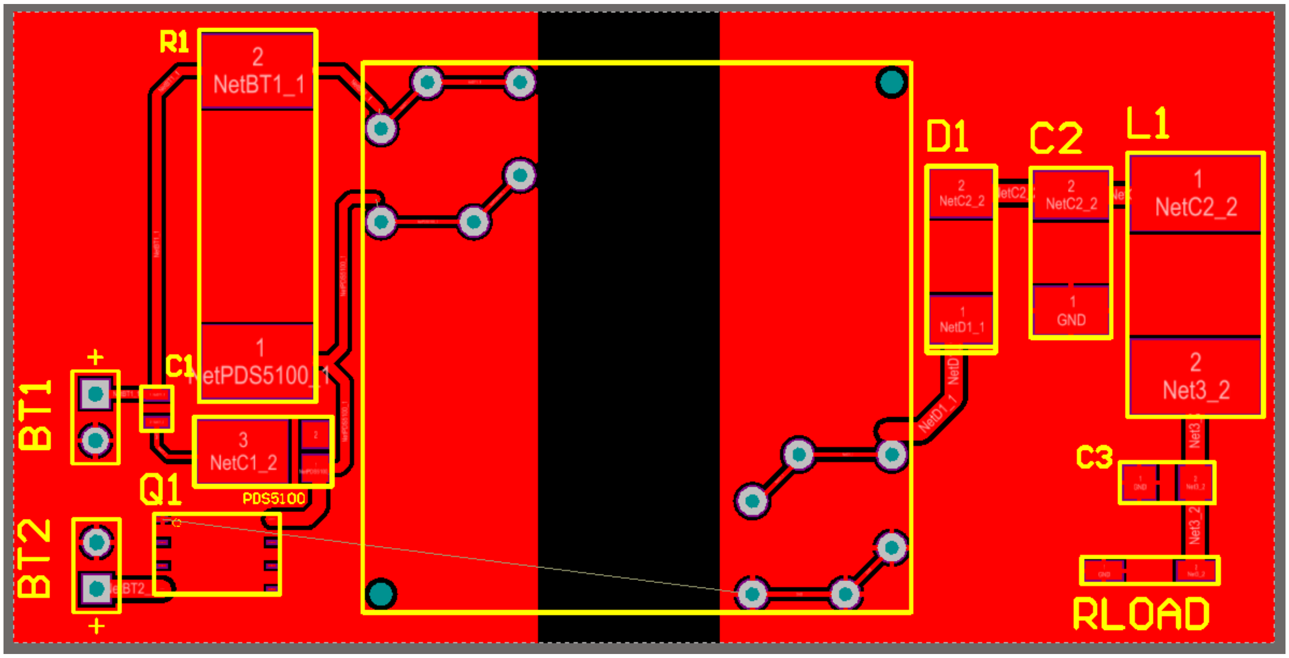


Figure 20: The final version of PCB in 2D

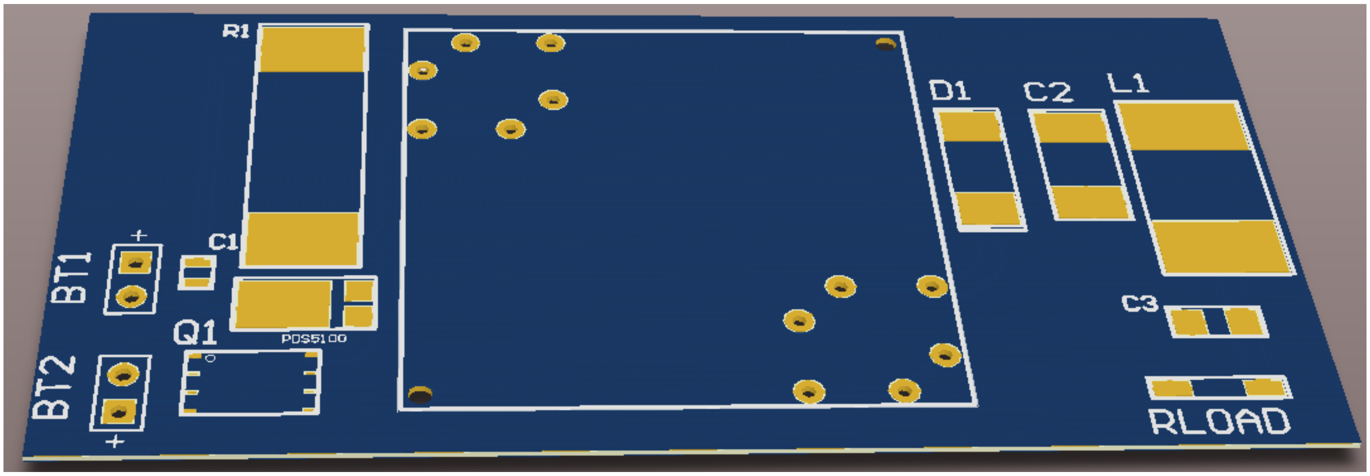


Figure 21: The final version of PCB in 3D

We were planning to create this board in real world. However, there was not enough time and the company's production conditions were not suitable for this. Hence, my project and internship process is finished at this point.

5. Clean Rooms & Ground Station

All interns have had the experience to see clean rooms of TÜBİTAK Uzay. An authorized engineer presented us those rooms and explained how they use these room for different purposes. All satellites were built there, part by part. Actually, there were also engineering models and electronic components and devices which are still used. In general, before any update to real satellite, engineers are trying all the equipment used in the real application in here. To illustrate, there were some devices that are used to make test before satellites were launched. Vacuum test and vibration test were also made on the satellites to simulate space conditions to prevent any possible failure. We were not allowed to take picture of these rooms for safety concerns.

Furthermore, all interns have had chance to see ground station where the control of the satellites are done. The authorized engineer explained us how they control the satellites here and what purposes of the satellites are used for. For instance, they are used in how much damage caused in a forest fire by taking pictures before and after the fire. The real pictures which are taken with our own made satellites can be reached every Turkish Republic citizen by accessing the URL

https://gezgin.gov.tr

6-Conclusion

In my summer practice, I have been a part of TÜBİTAK Uzay for four weeks and it was great opportunity for me to see how things going on work life and what engineers do in real world. This was my first experience as an engineer and there were plenty of thing happening around for me to observe. I understand the point that I need many practical approaches to learn in order to be a good engineer.

During my internship, I have learnt how to design a SMPS topology converter, especially Flyback Converter, which are the main area of interest of Power Electronics subdivision. I worked on this converter with my supervisor engineers. First, I tried to model the circuit part by part by making some calculations. Then, I formed the circuit in LTSpice to simulate and to analyze the problems and whether it works properly or not. Finally, I have learnt how to use Altium Designer to create PCB's and applied it to my circuit. It was a great feeling to be a part of something real and a group of engineers.

All in all, this internship was very valuable experience for me. I have observed and learnt a lot about what engineers do in real life. Also, I observed several fields of electrical and electronics engineering. I believe this experience would help me when it comes to choose a field of expertise at 4^{th} year. Finally, I think TÜBİTAK Uzay is one of the places that a 2^{nd} year student should perform a summer practice since I have learnt many things from my supervisor engineers. There was a great atmosphere and I was thankful to them to provide me this opportunity.

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Appendices
Appendix A

Metal Oxide Semiconductor Field Effect Transistor (MOSFET)

The **metal–oxide–semiconductor field-effect transistor** (**MOSFET**) is a type of field-effect transistor (FET). It has an insulated gate; whose voltage determines the conductivity of the device. This ability to change conductivity with the amount of applied voltage can be used for amplifying or switching electronic signals.
It is a four terminals device. The drain and source terminals are connected to the heavily doped regions. The gate terminal is connected top on the oxide layer and the substrate or body terminal is connected to the intrinsic semiconductor.

Retrieved from: https://www.electrical4u.com/mosfet-working-principle-of-p-channel-n-channel-mosfet/

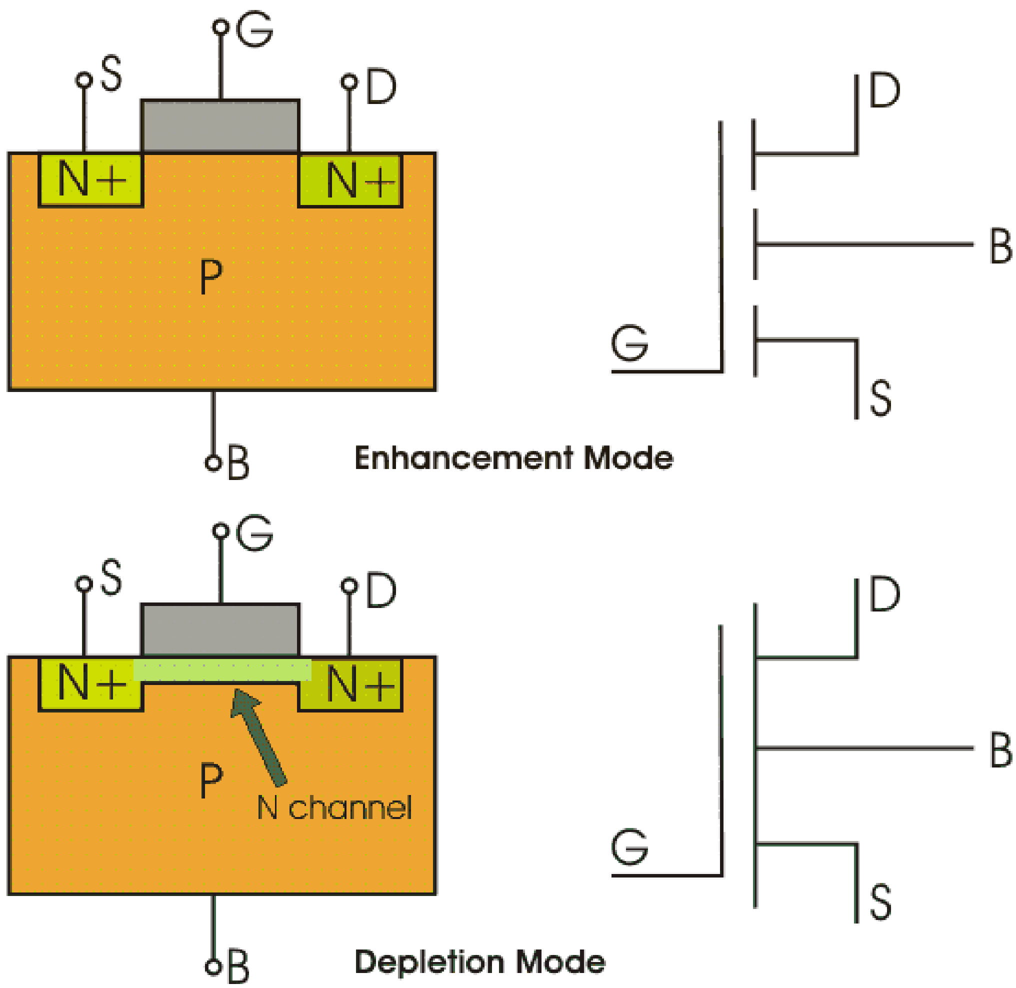

Figure 22: The diagram of N-channel enhancement and depletion MOSFET

The semiconductor surface at below the oxide layer and between the drain and source terminal can be inverted from p-type to n-type by applying a positive or negative gate voltages respectively and the controlling of source to gate voltage is responsible for the conduction of current between source and the drain. Hence, we can make use of MOSFET's as we wish with these properties.

Applications of MOSFET's

Retrieved from: http://www.electronics-tutorials.ws/transistor/tran_7.html

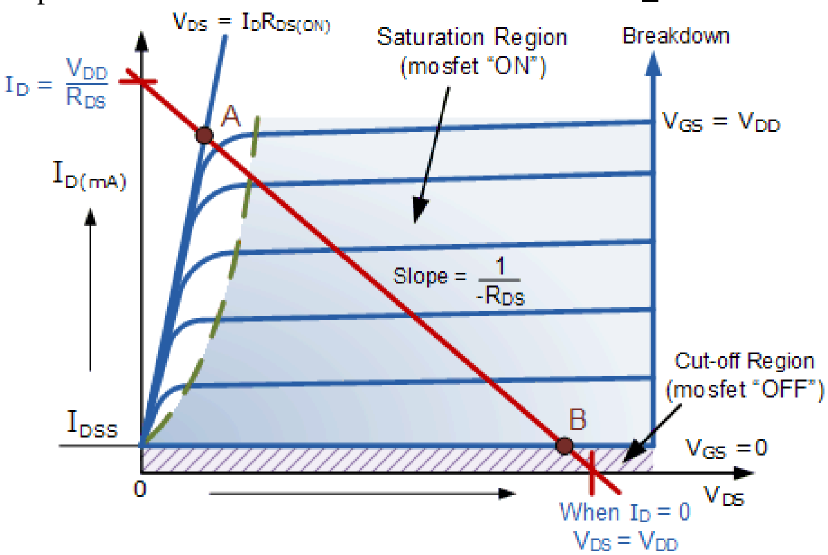

Figure 23: I_D – V_{DS} characteristics of MOSFET

Switch

A direct consequence of MOSFET working leads to their usage as a switch. A n-channel MOSFET can act as a switching circuit when it operates in cut-off and saturation regions.

Amplifiers

Enhancement n-channel MOSFETs are in their OFF state when no gate-to-source voltage is applied. However, when biased with a suitable positive voltage, it starts to conduct allowing the flow of drain current through it. This current is seen to increase in magnitude as the bias voltage increases which in turn leads to the increase in output voltage. Thus the MOSFETs serve as amplifiers. MOSFET amplifiers are used in radio-frequency applications and in sound systems.

Linear Voltage Regulators

Depletion type MOSFETs in source-follower configuration are used in linear voltage regulator circuits as pass transistors. Here the source voltage, V_L follows the gate voltage, V_G minus the gate-to-source voltage, V_{GS}. Further V_{GS} increases with an increase in the drain current, I_D. Thus if the gate voltage is fixed, then the source voltage will reduce as the load current, I_L increases

Switch Mode Power Supply

Series transistor regulator circuit are used in switching operations in power electronics. However, it has same disadvantages such as poor efficiency, wasted power and heat generation.

Retrieved from: http://www.electronics-tutorials.ws/power/switch-mode-power-supply.html

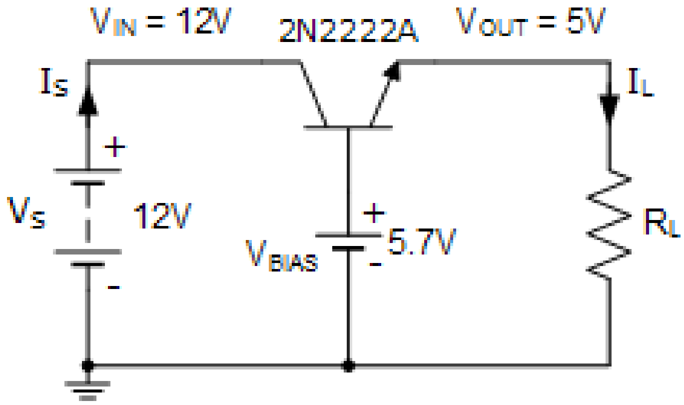

Figure 24: Series transistor regulator circuit

Therefore, Switch Mode Power Supplies (SMPS) are used rather than classical series transistor regulator circuit since **they** cut power consumption, reduce heat dissipation, as well as size and weight.
There are two types of SMPS.

The Buck Switch Mode Power Supply

It is used in Buck Switching Regulator for step-down the voltage across the circuit by arranging duty cycles, which is a DC-to-DC converter and one of the simplest and most popular type of switching regulator.

Retrieved from: http://www.electronics-tutorials.ws/power/switch-mode-power-supply.html

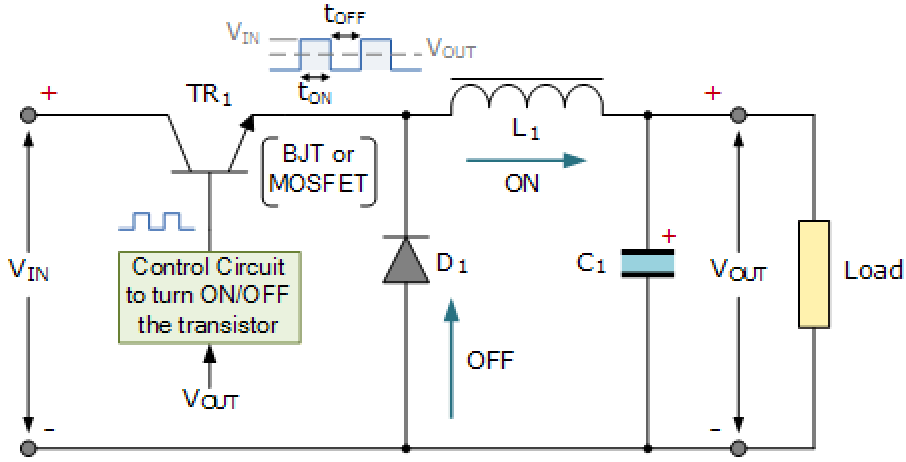

Figure 25: The Buck Switching Regulator

The Boost Switch Mode Power Supply

It is used in Boost Switching Regulator for step-up the voltage across the circuit by arranging duty cycles. The boost converters are commonly used in capacitive circuit applications such as battery chargers, photo-flashes, strobe flashes, etc. because the capacitor supplies all of the load current while the switch is closed.

Retrieved from: http://www.electronics-tutorials.ws/power/switch-mode-power-supply.html

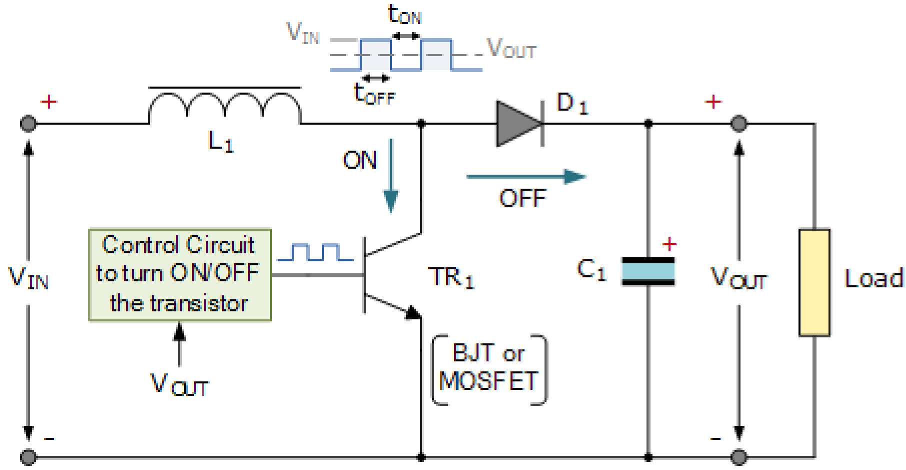

Figure 26: The Boost Switching Regulator

Appendix B

Zener Diode

A Zener diode is a silicon semiconductor device that permits current to flow in either a forward or reverse direction. The diode consists of a special, heavily doped p-n junction, designed to conduct in the reverse direction when a certain specified voltage is reached.

Retrieved from: https://www.electrical4u.com/what-is-zener-diode/

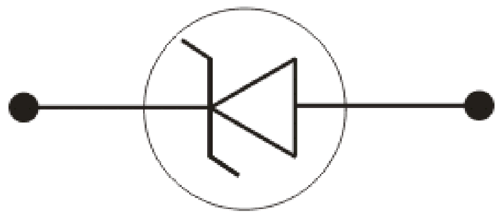

Figure 27: The Schematic representation of Zener Diode

Retrieved from: http://www.electronics-tutorials.ws

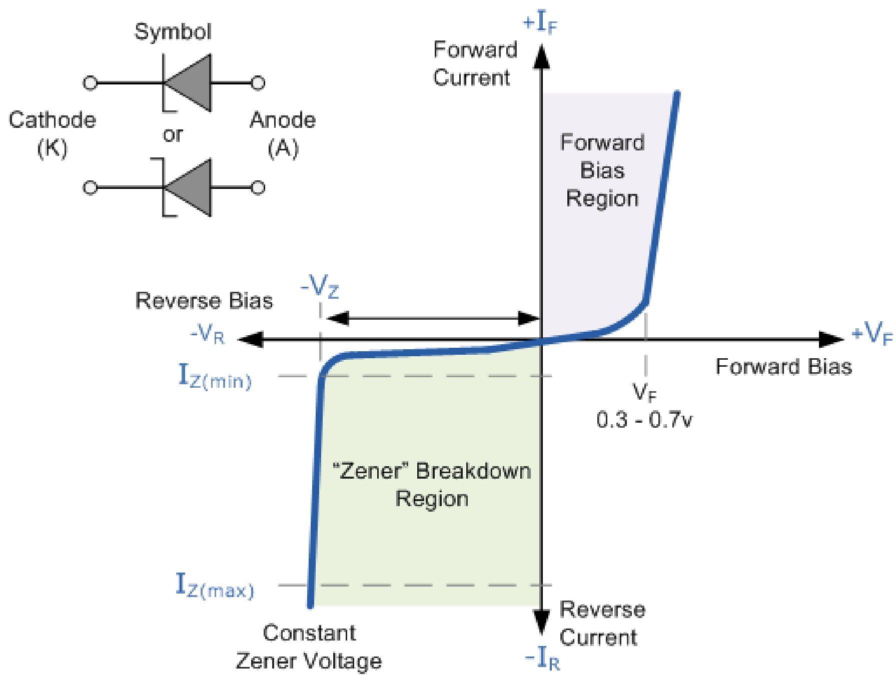

Figure 28: The I-V characteristics of a Zener Diode

A voltage regulator circuit can be designed using a zener diode to maintain a constant DC output voltage across the load in spite of variations in the input voltage or changes in the load current. The zener voltage regulator consists of a current limiting resistor R_S connected in series with the input voltage V_S with the zener diode connected in parallel with the load R_L in this reverse biased condition.

The stabilized output voltage is always selected to be the same as the breakdown voltage V_Z of the diode.

Design of a Voltage Regulator with Zener Diode

When selecting the zener diode, be sure that its maximum power rating is not exceeded.

I_{max} Maximum current for Zener diode

$$I_{max} = \frac{Power}{Zener\ voltage}$$

Calculating voltage and current

V_Z Zener Diode standard voltage
V_{in} Input voltage(it is known)
V_s Voltage across series resistance
V_L Voltage across the load resistance
I_S Current passing through the series resistance
I_Z Current passing through the Zener diode
I_L Current passing through the load resistance

The total current drawn from the source is the same as that through the series resistor

$$I_S = \frac{V_S}{R_S}$$

The current through the load resistor is

$$I_L = \frac{V_L}{R_L}$$

and the zener diode current is

$$I_Z = I_S - I_L$$

If the voltage source is greater than Vz

$$V_s = V_{in} - V_L \quad \text{and} \quad V_L = V_Z$$

If the voltage source is less than Vz

$$V_s = \frac{R_S * V_{in}}{(R_S + R_L)} \quad \text{and} \quad V_L = \frac{R_L * V_{in}}{(R_S + R_L)}$$