EE 464
STATIC POWER CONVERSION-I
Spring 2022-2023

Complete Design Report and Test Results

Autobots

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Introduction

This report presents the design decisions for the hardware project. Furthermore, it gives the details computer simulation results and component selection details. In addition, the report presents test results. The design calculations are done mainly on MATLAB and complete MATLAB code is given in Appendix 1.

Topology Selection

The converter needs to be isolated. Therefore, the alternatives are listed below:

- Flyback converter
- Forward converter
- Push-Pull converter

Among these converter topologies, the flyback converter is chosen as an appropriate converter for given requirements. When compared with other topologies, it is easier to increase the output voltage with Flyback due to its input-output voltage relation. Thus, it requires fewer turns ratio with the same duty cycle or, it requires less duty cycle with the same turns ratio. This may decrease the losses on copper or conduction losses of switching devices. Additionally, the Flyback converter requires fewer components than the other converter topologies, so its control is less complex.

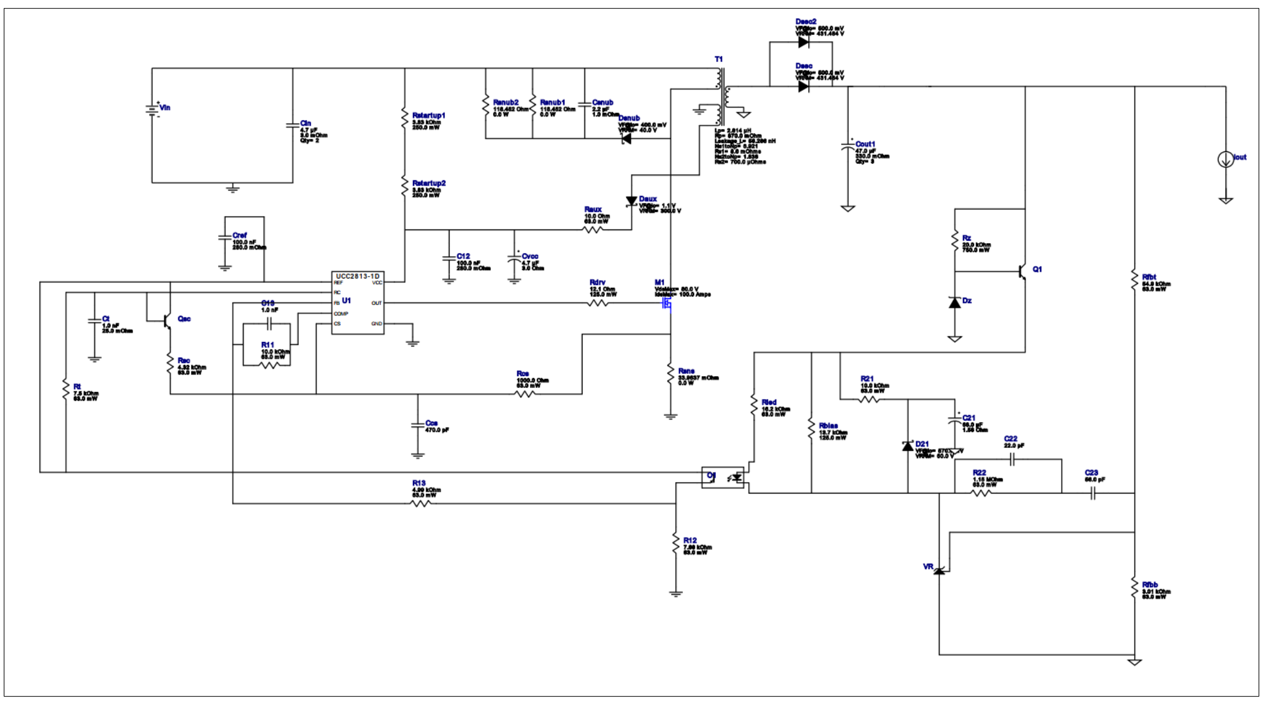


Figure 1: TI Webench design [Appendix 2]

Magnetic Design

a) The duty range of the converter is selected as [0.278 – 0.336] to match the design by the Ti Webench. According to the duty range determination, the turn ratio is calculated via the MATLAB code below.

```
clearvars
syms d turnsRatio
v_o = 48
d_min = 0.278; v_d_minduty = 18;
d_max = 0.366; v_d_maxduty = 12
turnsRatio_minduty = ( (d_min/(1-d_min)) * (v_d_minduty/v_o) )^-1
turnsRatio_maxduty = ( (d_max/(1-d_max)) * (v_d_maxduty/v_o) )^-1
```

According to the code above, the transformer turns ratio (N_s/N_p) is calculated as 6.93.

b)

1. The available cores and coil formers are investigated. Firstly, due to its available stock number is high, PCB5530-FA is selected as the coil former. Therefore, the compatible core 0P45530EC is selected as the transformer core.
2. Using the MATLAB code below, the primary turn number is found 1.14, while the secondary turn number is 7.93. The magnetizing inductance is 8 uH. 1.14 turn makes no sense and increasing the inductance a little bit makes no harm. Therefore, the primary turns are made into 2 turns. The corresponding secondary turns number then becomes 13.89, which is pretty close to 14. Hence, the primary wounded 2 turns while the secondary wound 14 turns.

```
U_o = v_o;
v_t = d_max;
f_sw = 100e3;
i_out = 1;
i_avgSec = i_out/(1-v_t);
xformerCurrRipple = 0.5; % percent
L_sec = (U_o*(1-v_t))/(xformerCurrRipple*i_avgSec*f_sw)
L_pri = L_sec/(turnsRatio_maxduty^2)
% (turnsRatio_maxduty^2)*2.814e-6
```

```
syms priTurns secTurns
AL = 6130e-9 % nH/T^2; minimal

priTurns = double(solve(L_pri == AL*priTurns^2))
secTurns = double(solve(L_sec == AL*secTurns^2))
% make sure core is not saturated
ampTurns = i_out*secTurns
```

3. According to the AWG table, the secondary should be wounded using 2 parallel 24 AWG wires. The primary, on the other hand, 2 parallel 17 AWG wires will be used. The AWG calculation is done by the snippet below.

```
p_o = i_out * v_o
i_in_max = v_o/v_d_maxduty
% Primary selected as 17  AWG
selectedAWGRating_pri = 2.9;
primaryDiameter_mm = 1.15062;
cableAreaPri_mm2 = 1.04;
% Secondary selected as 24  AWG
selectedAWGRating_sec = 0.577;
secondaryDiameter_mm = 0.5;
cableAreaSec_mm2 = 0.327;


primaryRadius_mm = primaryDiameter_mm/2
secondaryRadius_mm = secondaryDiameter_mm/2
num_of_paralles_sec = i_out/selectedAWGRating_sec
num_of_paralles_pri = i_in_max/selectedAWGRating_pri
```

4. According to the code below, the fill factor is 1.75%, which is low but reasonable.

```
windowArea_mm2 = 537;
priTurns = ceil(priTurns(priTurns>0))
secTurns = ceil(secTurns(secTurns>0))
num_of_paralles_pri = ceil(num_of_paralles_pri)
num_of_paralles_sec = ceil(num_of_paralles_sec)


primaryArea_mm2 = priTurns*num_of_paralles_pri*cableAreaPri_mm2
secondaryArea_mm2 = secTurns*num_of_paralles_sec*cableAreaSec_mm2
totalCableArea_mm2 = primaryArea_mm2 + secondaryArea_mm2
fillFactor_perc = 100*totalCableArea_mm2/windowArea_mm2
```

5. Cable resistance calculation is done by the code below:

```
skinDepth_mm = 75/sqrt(f_sw)
innerRadiusPri_mm = primaryRadius_mm - skinDepth_mm
hollowAreaPri_mm2 = pi*innerRadiusPri_mm^2
effectiveAreaPri = cableAreaPri_mm2 - hollowAreaPri_mm2
innerRadiusSec_mm = secondaryRadius_mm - skinDepth_mm
hollowAreaSec_mm2 = pi*innerRadiusSec_mm^2
effectiveAreaSec = cableAreaSec_mm2 -  hollowAreaSec_mm2
% calculate the ratios to convert DC resistance to AC resistance
DC_to_AC_ratio_pri = cableAreaPri_mm2/effectiveAreaPri
```

```
DC_to_AC_ratio_sec = cableAreaSec_mm2/effectiveAreaSec

windingLengthPerTurn_mm = 68.2
ohms_per_meter = 212.872 / 1e3
primaryLength_m = windingLengthPerTurn_mm * priTurns * 1e-3
secondaryLength_m = windingLengthPerTurn_mm * secTurns * 1e-3
primary_DC_resistance_ohm = ohms_per_meter * primaryLength_m /
num_of_paralles_pri
secondary_DC_resistance_ohm = ohms_per_meter * secondaryLength_m /
num_of_paralles_sec
```

According to the results the snippet outputs, the primary AC Resistance is 22.2 mOhm while the secondary AC Resistance is 58.2 mOhm.

6. Copper losses are calculated by the code below:

```
primary_AC_resistance_ohm = primary_DC_resistance_ohm*DC_to_AC_ratio_pri
secondary_AC_resistance_ohm = secondary_DC_resistance_ohm*DC_to_AC_ratio_sec
resistancePri_ohm = vpa(primary_AC_resistance_ohm * u.Ohm)
resistanceSec_ohm = vpa(secondary_AC_resistance_ohm * u.Ohm)
copperLossPri = vpa(unitConvert((i_in_max*u.A)^2 * resistancePri_ohm, u.W))
copperLossSec = vpa(unitConvert((i_out*u.A)^2 * resistanceSec_ohm, u.W))
copperLoss_W = copperLossPri + copperLossSec
```

According to the calculations, the total copper losses are **0.41 W**.

7. Core losses are calculated by the code below:

```
wattLoss_mW_cm3 = 142*u.mW/u.cm^3
volume_mm3 = 52000;
volume_cm3 = vpa(unitConvert(volume_mm3*u.mm^3, u.cm^3))
coreLoss_w = vpa(unitConvert(wattLoss_mW_cm3 * volume_cm3, u.W))
```

Core Loss: 7.38 W

The core loss is way greater than the copper loss. Therefore, the efficiency will suck. However, the other available cores resulted in high leakage inductance experimentally. This core gives the best results in terms of leakage inductance. Therefore, we will proceed with this core, even though its efficiency sucks.

c) The open-loop flyback design is simulated on Simulink as shown in Figure 2. The circuit is simulated at its edges, namely, 12V input voltage and 0.366 duty and 18V input voltage and 0.278

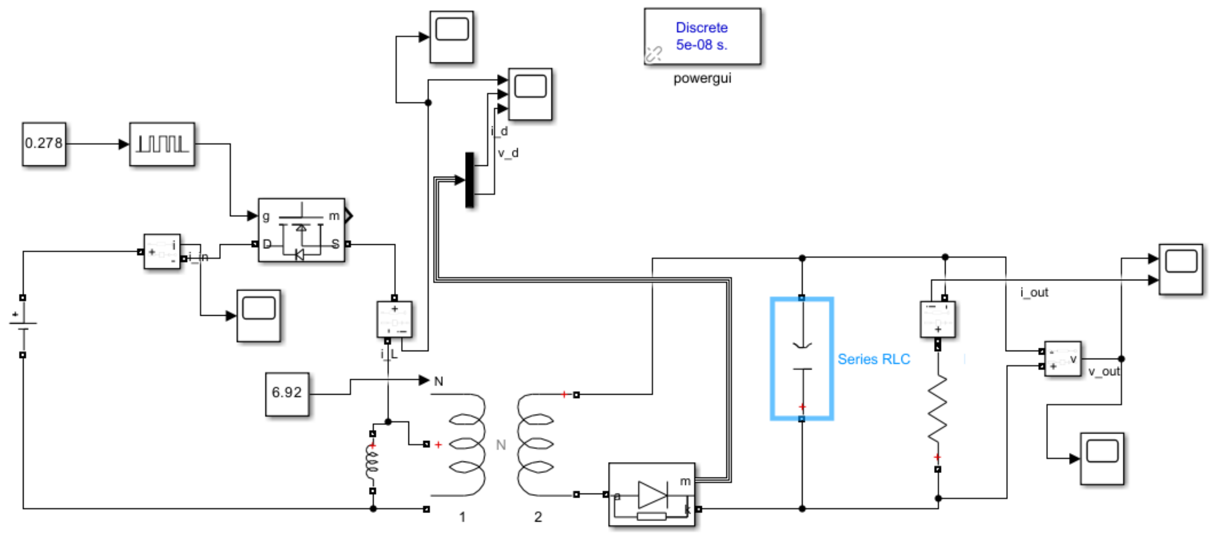


Figure 2: The Flyback converter in Simulink

duty. The simulation results are shown in Figures 3-6 for 0.278 duty and Figures 7-10 for 0.366 duty.

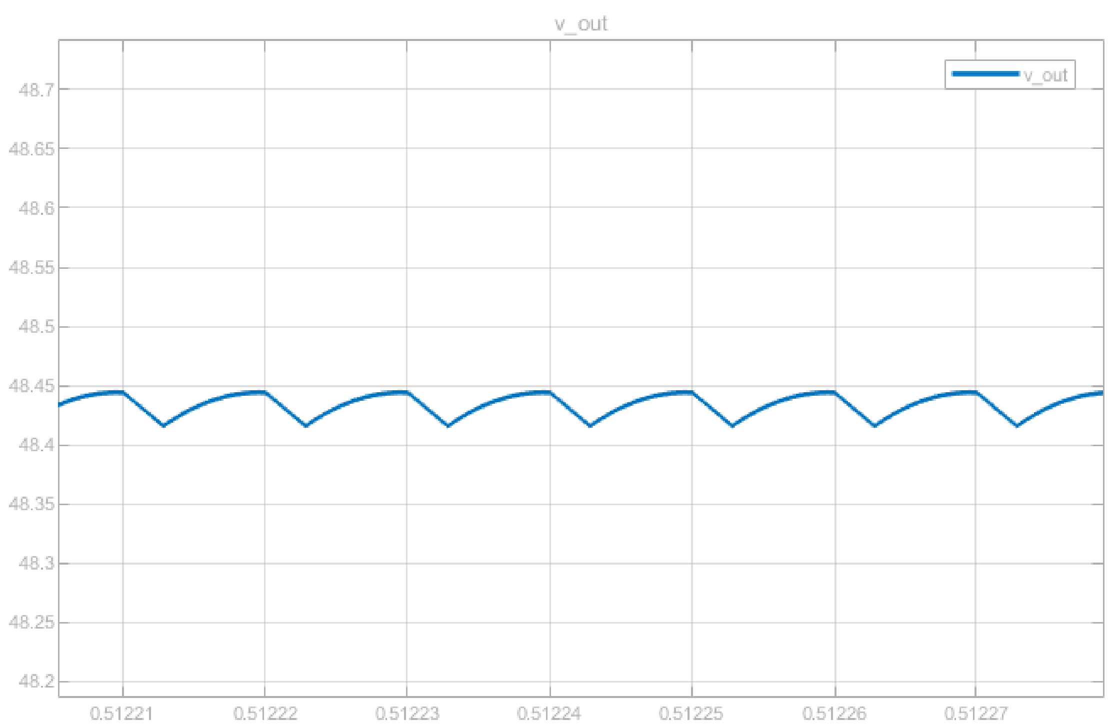


Figure 3: Output voltage ripple for 0.278 duty

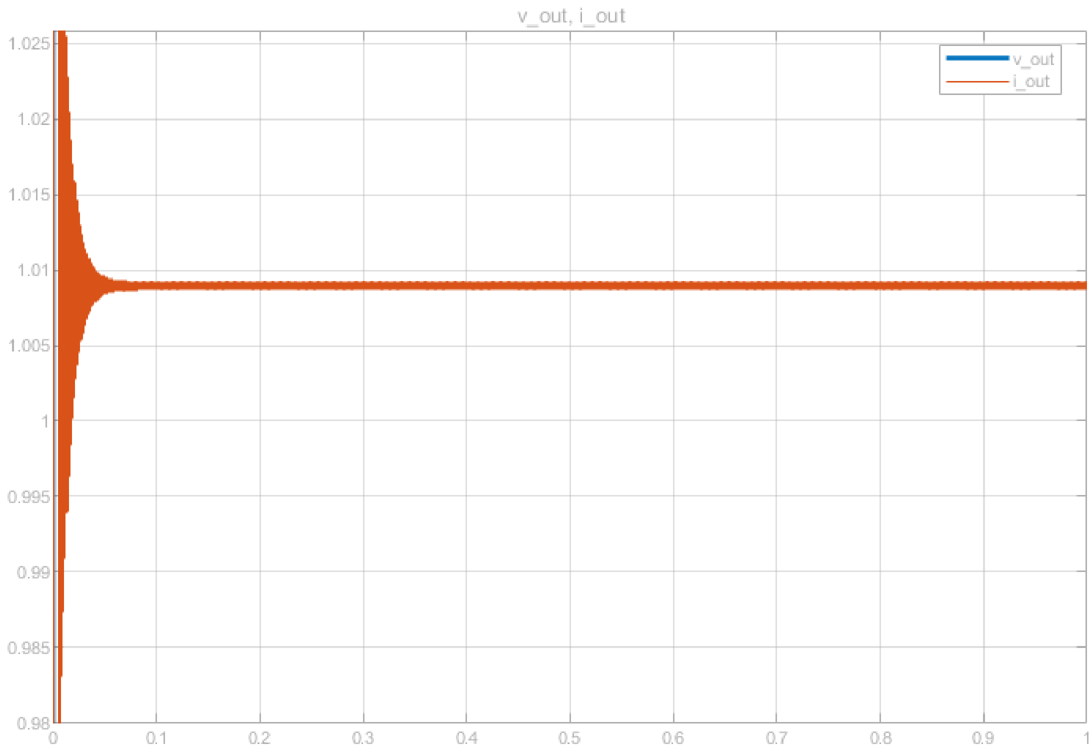


Figure 4: Output current waveform for 0.278 duty

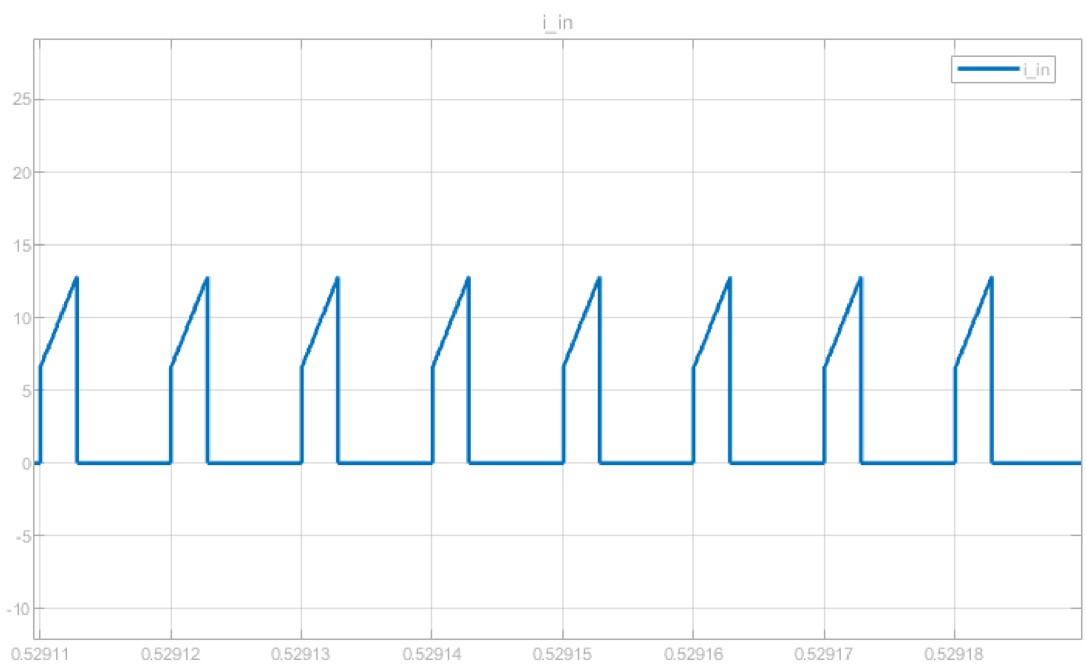


Figure 5: Input current waveform for 0.278 duty

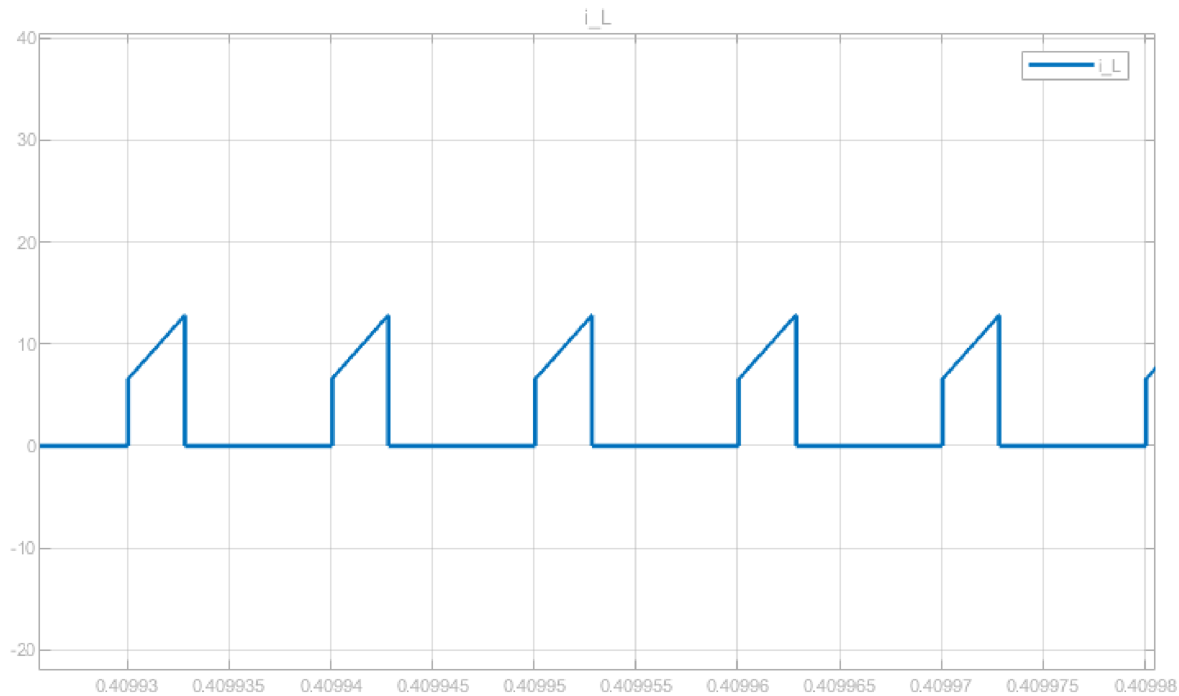


Figure 6: Transformer primary current waveform for 0.278 duty

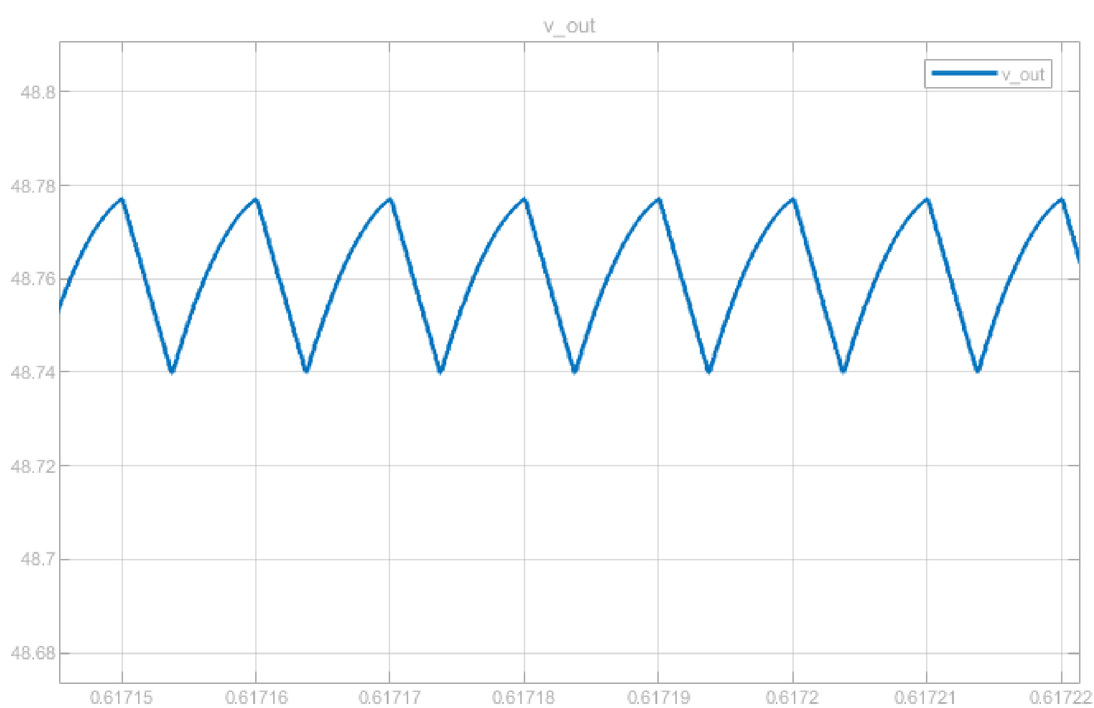


Figure 7: Output voltage ripple for 0.366 duty

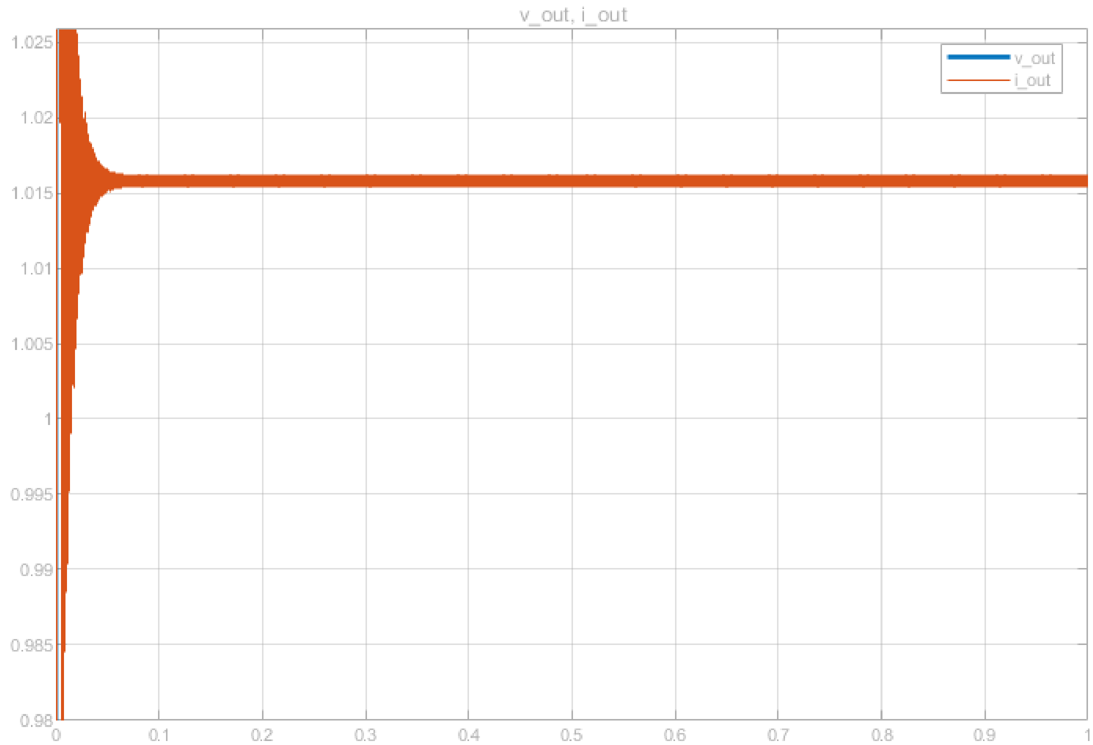


Figure 8: Output current waveform for 0.366 duty

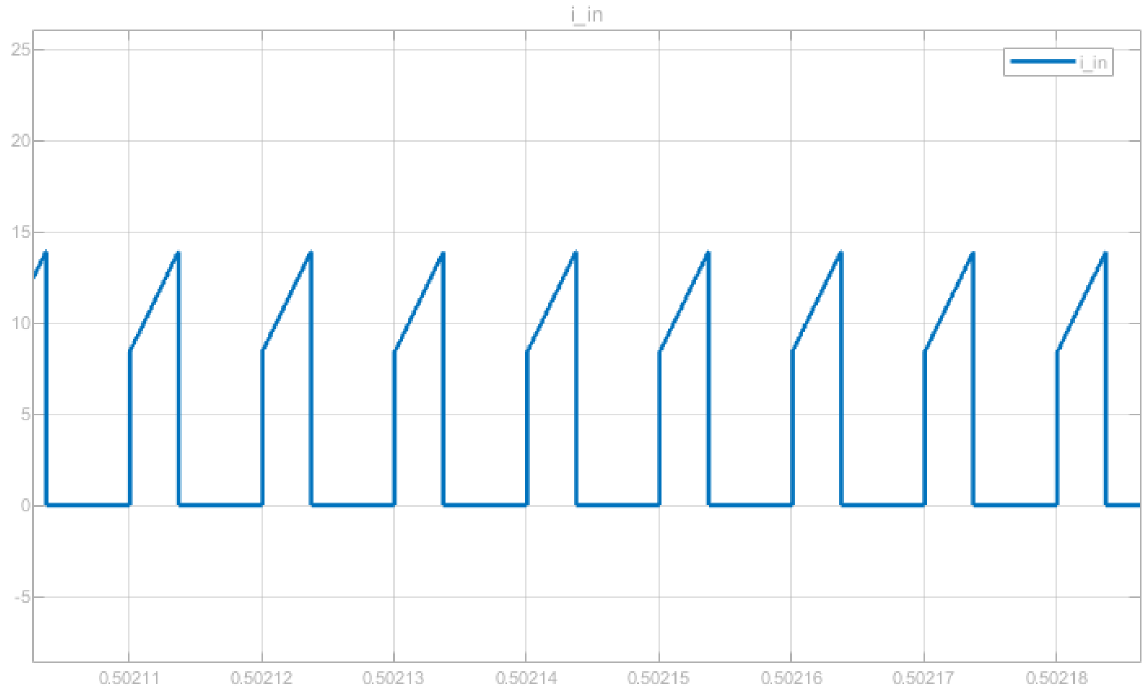


Figure 9: Input current waveform for 0.366 duty

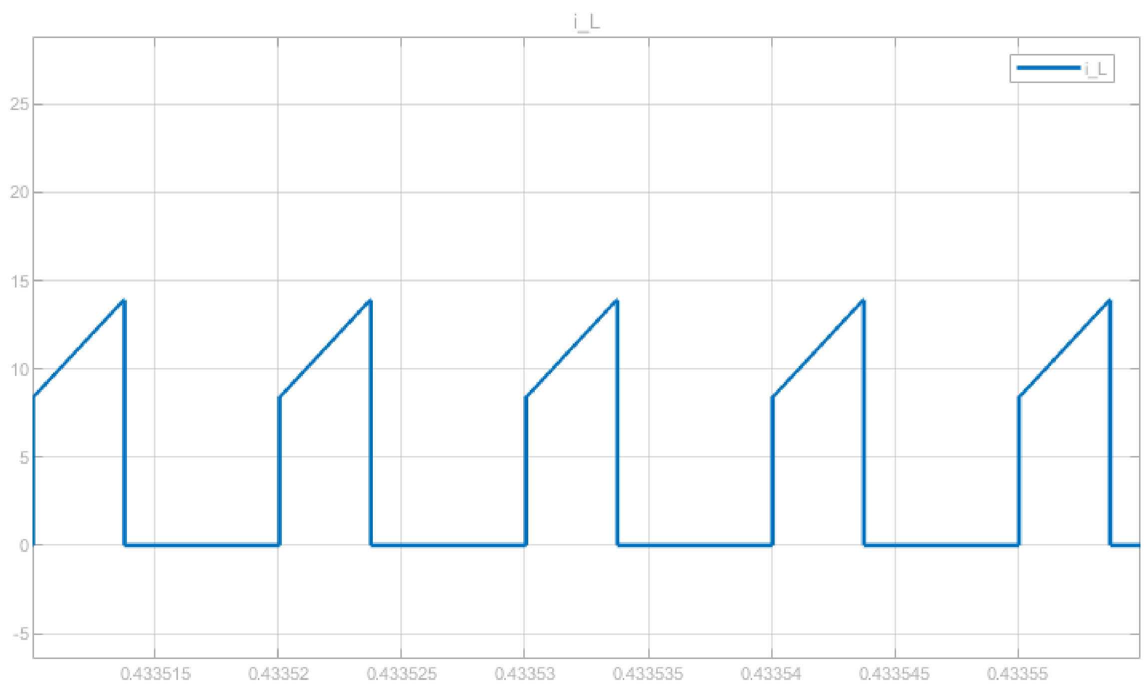


Figure 10: Transformer primary current waveform for 0.366 duty

d) The minimum load current to avoid DCM is calculated with the code below:

```
Lm = 8*10^-6; f_sw = 100*10^3;

% DCM
% for Vs = 12V
Vs = 12; D = 0.366;
deltaI_lm = Vs*D/(Lm*f_sw);
P_min = Vs^2 * D^2 / (2*Lm*f_sw);
I_load_min = P_min / 48

% for Vs = 18V
Vs = 18; D = 0.278;
deltaI_lm = Vs*D/(Lm*f_sw);
P_min = Vs^2 * D^2 / (2*Lm*f_sw);
I_load_min = P_min / 48
```

Minimum load current to operate in CCM when input is 12V = 0.251mA
Minimum load current to operate in CCM when input is 18V = 0.326mA

The maximum current that can flow through the transformer is calculated with the code below:

```
% max I_Lm current occurs when input voltage is 12V and at 100% load
Vs = 12; D = 0.366;
turnsRatio = 6.92; R = 48;
deltaI_lm = Vs*D/(Lm*f_sw);
P_out = Vs^2 * D^2 * turnsRatio^2 / ((1-D)^2 * R);
I_Lm_max = deltaI_lm/2 + P_out/(Vs*D)
```

Current can rise up to the 13.645A while converter is working with 100% load and 12V input voltage.

e)

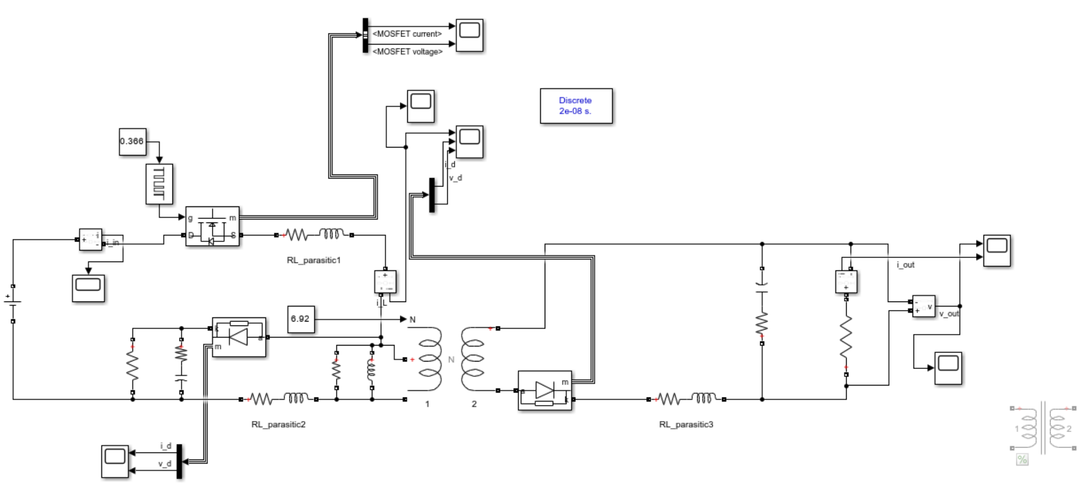


Figure 11: Simulation of the converter with parasitic elements of transformer and switching device.

Figure 12: Voltage and current waveforms of MOSFET with parasitic elements.

In Figure 12, it can be seen that, due to parasitic inductances, there are voltage spikes on MOSFET while switching. Because of leakage inductance, a snubber must be used to discharge the leakage inductance. Snubber design is taken from the recommended design of Webench.

f)

The flyback converter is simulated with parasitic elements and non-ideal switching devices as shown in Figure 13.

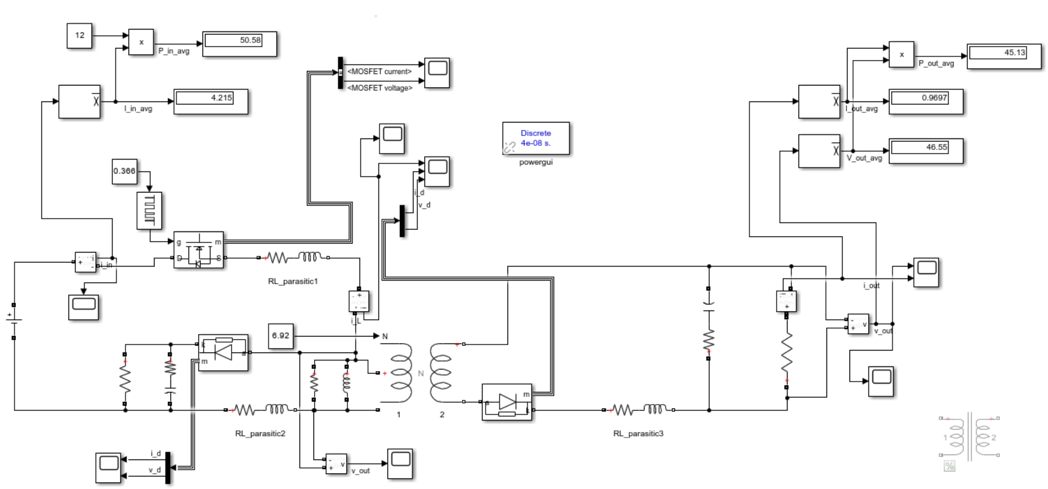


Figure 13: Simulation design for efficiency test.

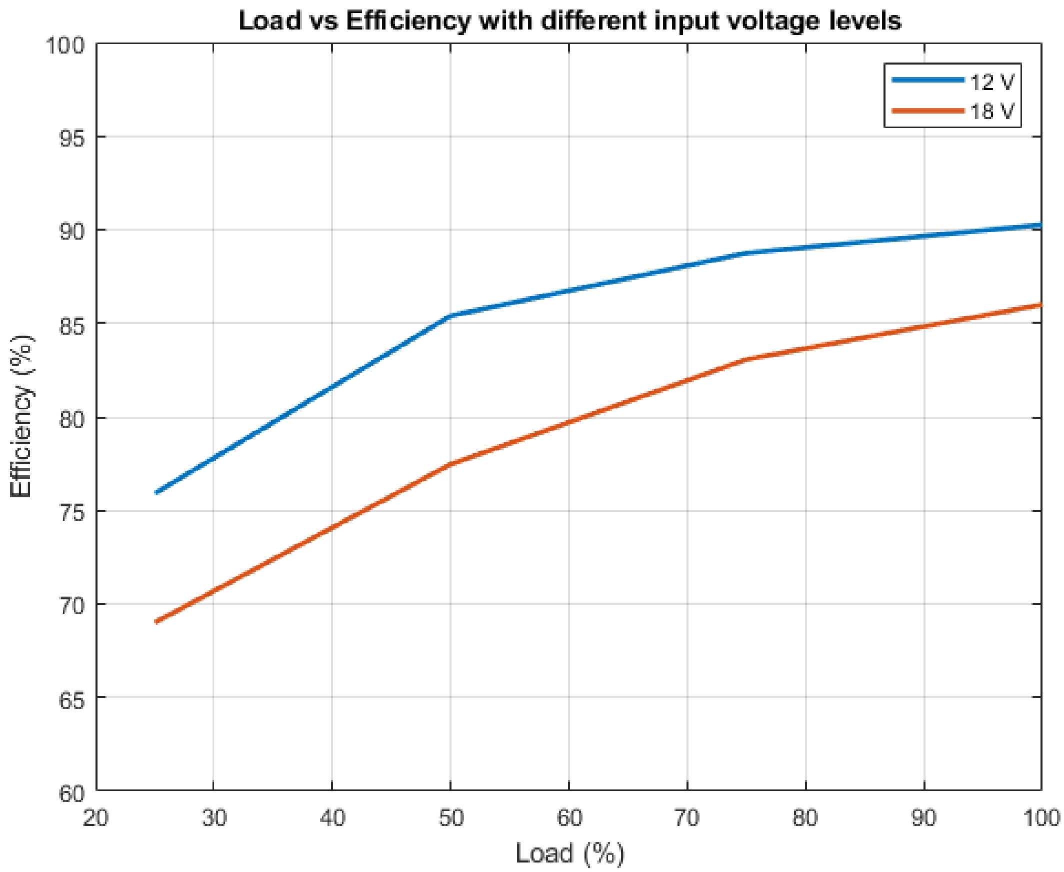


Figure 14: Efficiency vs Load curves for different voltage input levels.

Table 1: Simulation result of efficiency values for different input voltage and load conditions.

Load (%)	Efficiency (%)	
	12V	18V
25	75.9	69
50	85.39	77.46
75	88.74	83.06
100	90.25	85.99

Table 2: Calculated efficiency values without snubber losses.

Load (%)	Efficiency (%)	
	12V	18V
25	87.7	87.89
50	92.78	93.03
75	94.3	94.62
100	94.94	95.33

The efficiency of the flyback converter decreases with less load since core loss and snubber losses become dominant. Also, when the input voltage increases, the losses on the switching device increase quadratically; thus, the converter becomes less efficient with a higher input voltage. Lastly, how inefficient is snubber can be seen by comparing two results.

Component Selection

Switching Device

Peak switching current and voltage can be calculated equations below:

```
V_sw = Vs + 1/turnsRatio*48
I_sw = 1./(1-duty).*turnsRatio.*I_out_avg + 1/turnsRatio.*
      (1-duty)./2./L_pri./f_sw*48
```

Switching voltages are calculated as 18.94V and 24.94V, respectively with 12V and 18V input voltage, and the maximum switching current is calculated as 13.65A. However, due to leakage inductances and parasitic elements, there are voltage spikes while switching. Thus, also it can be seen in Webench design, a Mosfet with 80V rated voltage and 100A rated current is selected [1]. For less rated voltages it is easy and cheap to find high current rated Mosfets, which also results in fewer losses on Mosfet due to less Rds value.

Secondary Diode:

```
V_d_max = Vs*turnsRatio + 48
I_d_max = I_sw./turnsRatio
```

By using the above equations, the maximum voltage on the diode is found as 131.04V and 172.56V, respectively, with 12V and 18V input voltage, and the maximum current is calculated as 1.976A. The voltage rating of the diode should be selected higher because the effect of voltage spikes increases with the turns ratio at the secondary side. Thus, the diode is selected with a 600V rated voltage, and 3A rated current with a forward voltage drop of 1.0V [2].

Output Capacitor:

The maximum allowed voltage ripple at the output is 3%.

```
C_min = duty/f_sw/R/ripple
```

The minimum capacitance value of the output capacitor is found as 2.54µF with the equation above. However, the output voltage is 48V, and to be safe rated voltage of the capacitor should be higher. A high voltage-rated capacitor is found as an aluminum capacitor which has high ESR values compared with other types. Found capacitors in the market have high voltage ratings, so they also have high ESR values. Because ESR values become dominant on output ripple, a capacitor with high capacitances is selected. The selected capacitor has 47µF capacitance and 2Ω ESR. The effect of ESR can be calculated equation below:

```
V_ESR = ESR * I_out_avg
```

The ripple due to ESR can be around 2V when a single capacitor is used. Thus, four of the selected capacitors [3] must be connected in parallel.

Controller IC:

UCC2813DTR-1 is selected which is appropriate for Webench's design. It is a current-mode PWM controller that can drive the gate of the Mosfet with respect to sensed current and output voltage [4].

Transformer:

The detailed calculation of the transformer's turn ratio, cable parameters, core, magnetizing inductance, etc. is given in the magnetic design section.

Experimental results of transformer on first try:

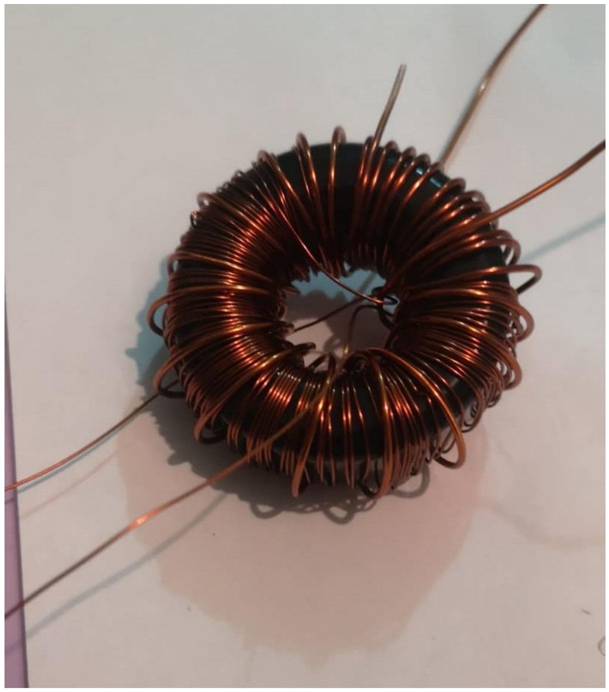


Figure 15: Wound transformer for initial experiments.

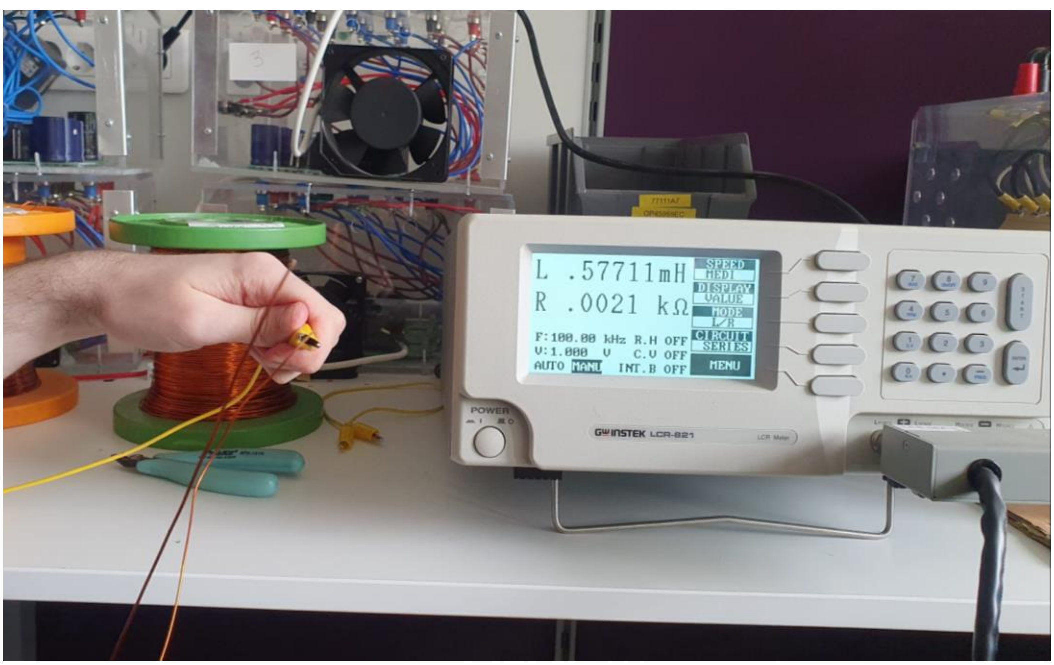


Figure 16: Primary is open circuited to measure leakage + magnetizing inductance at secondary.

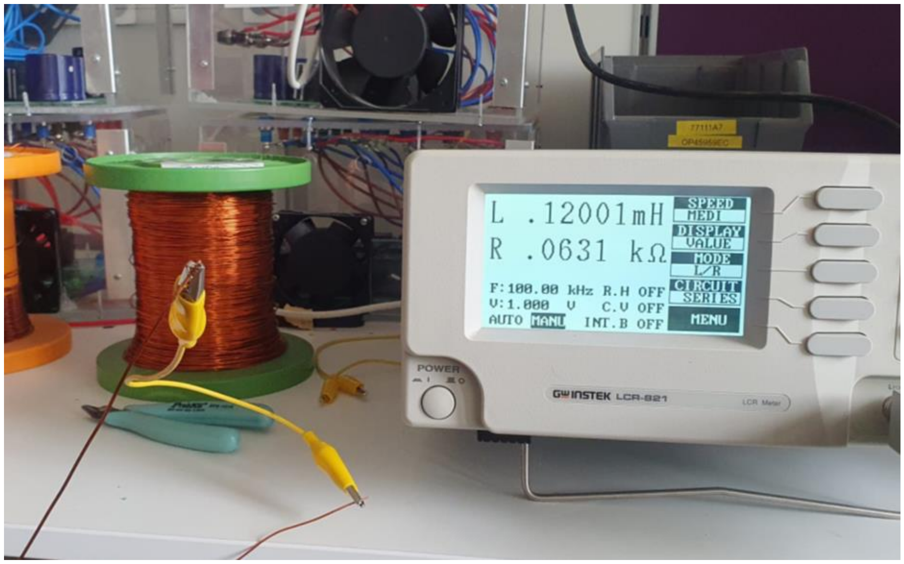


Figure 17: Primary is short circuited to measure leakge inductance at secondary.

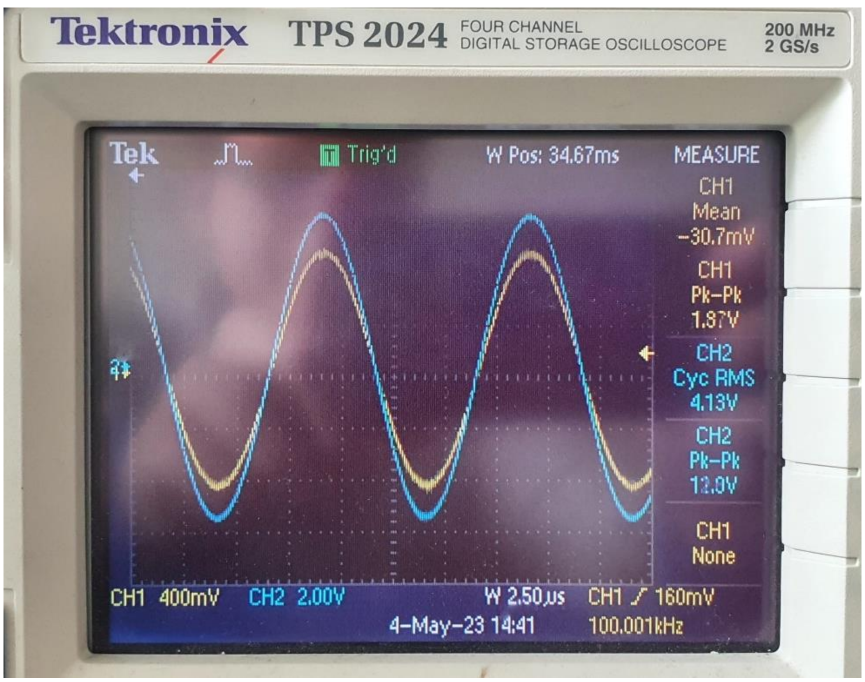


Figure 18: Input and output voltage ratio to observe turns ratio.

The leakage inductance at the secondary is measured as 120µH and by subtracting this value from the total inductance measured as 577µH, magnetizing inductance is measured as 457µH. Also, the turns ratio, which is the ratio of output and input voltage, is measured as 6. It can be seen that the leakage inductance is too high than the expected values. This may be caused by the toroid core because winding around a toroid core is difficult and results in high leakage which can be seen also Figure 15.

Some additional plots are given on Page 4 of Appendix – 2.

Experimental results of transformer on last try:

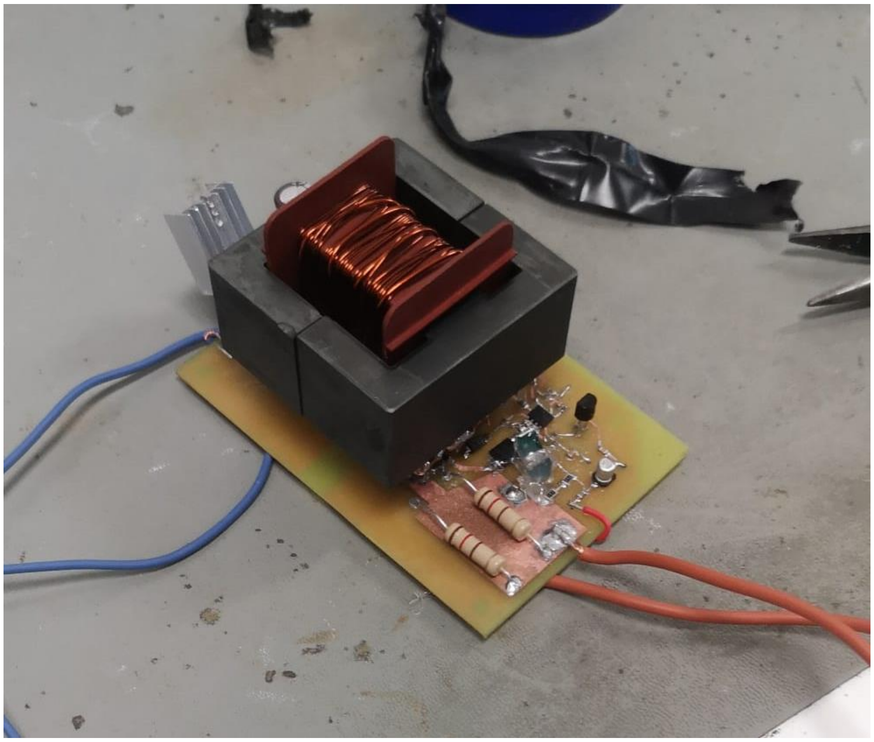


Figure 19: The PCB with last transformer soldered

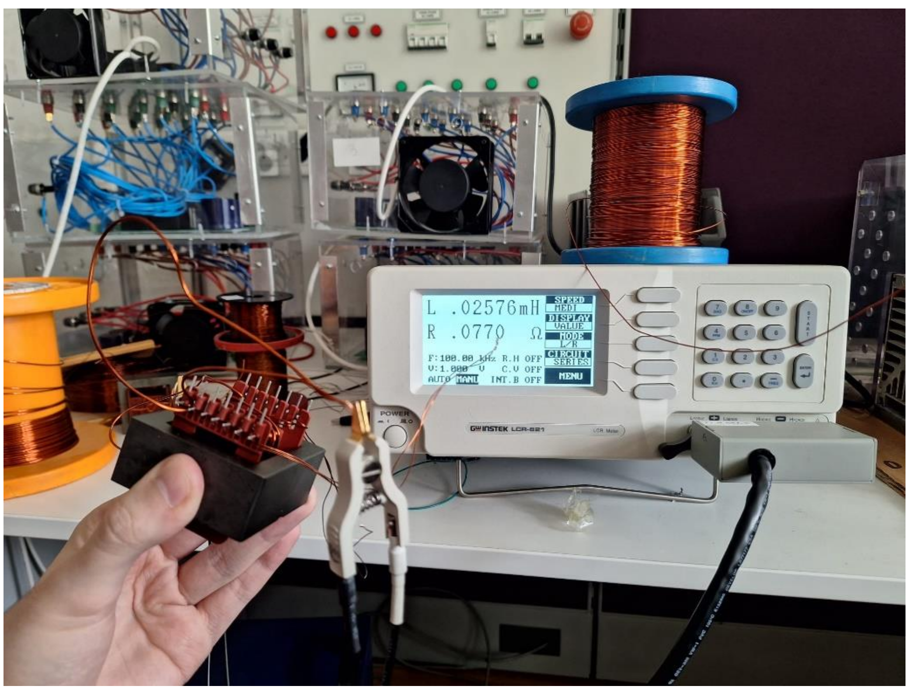


Figure 20: Secondary is open circuited to measure leakage + magnetizing inductance at primary

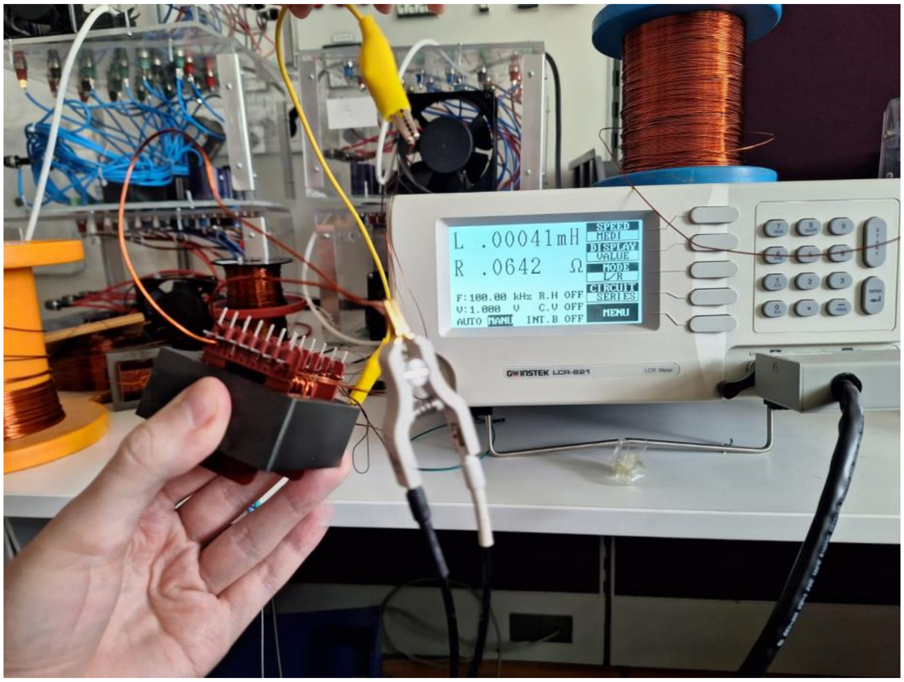


Figure 21: Secondary is short circuited to measure leakge inductance at primary

The leakage inductance at the secondary is measured as 41 nH and by subtracting this value from the total inductance measured as 25.7µH, magnetizing inductance is measured as 25.7µH. In addition, leakage is calculated as 0.2 %. Considering the primary inductance should greater than 8 µH according to the calc.mlx, this transformer should work.

PCB Design

Most of the our components are SMD packets. Therefore, we need to design a PCB in order four our circuit to work. Moreover, we aimed PCB bonus.

The 2D view of the designed PCB is shown in Figure 22. In Figure 22, the red layer is front layer while the blue layer is the back layer. The 3D view of the PCB is shown in Figure 23.

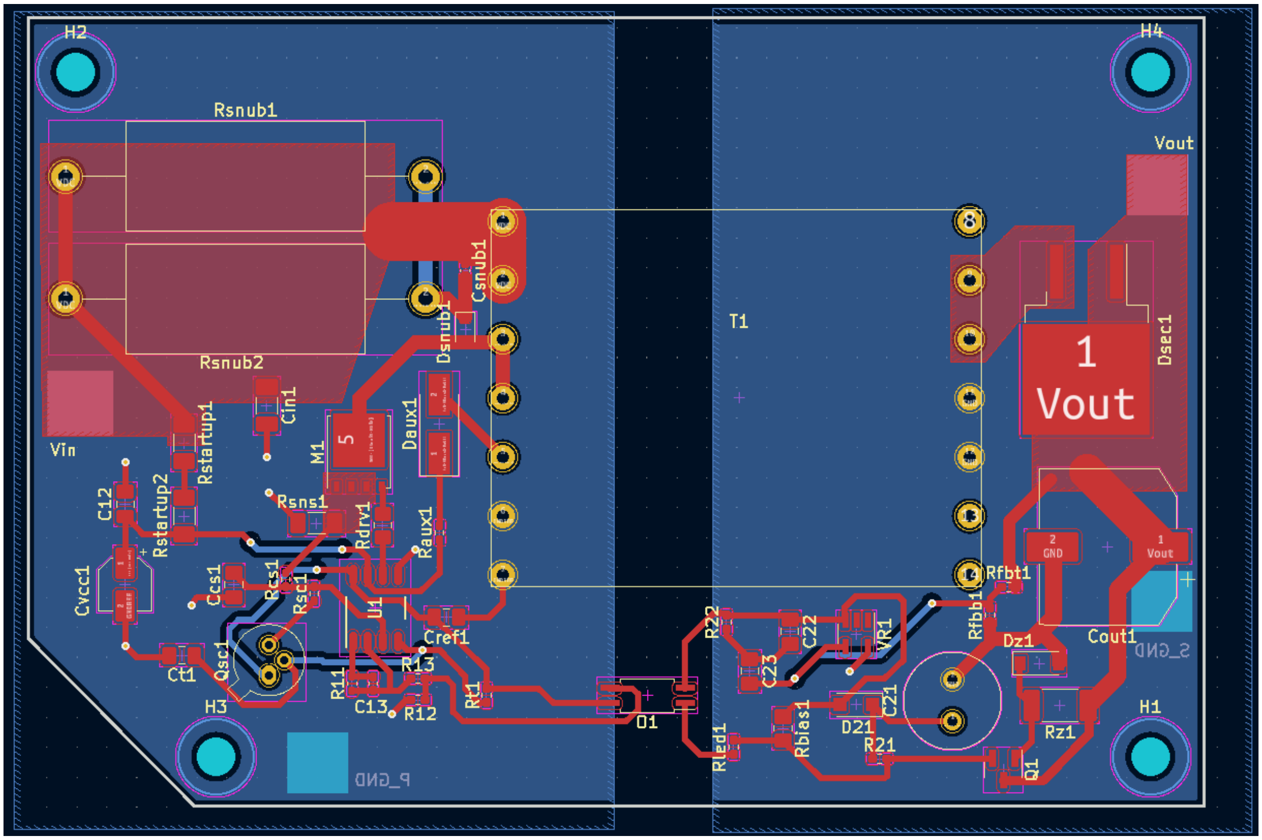


Figure 22: The PCB design in 2D view

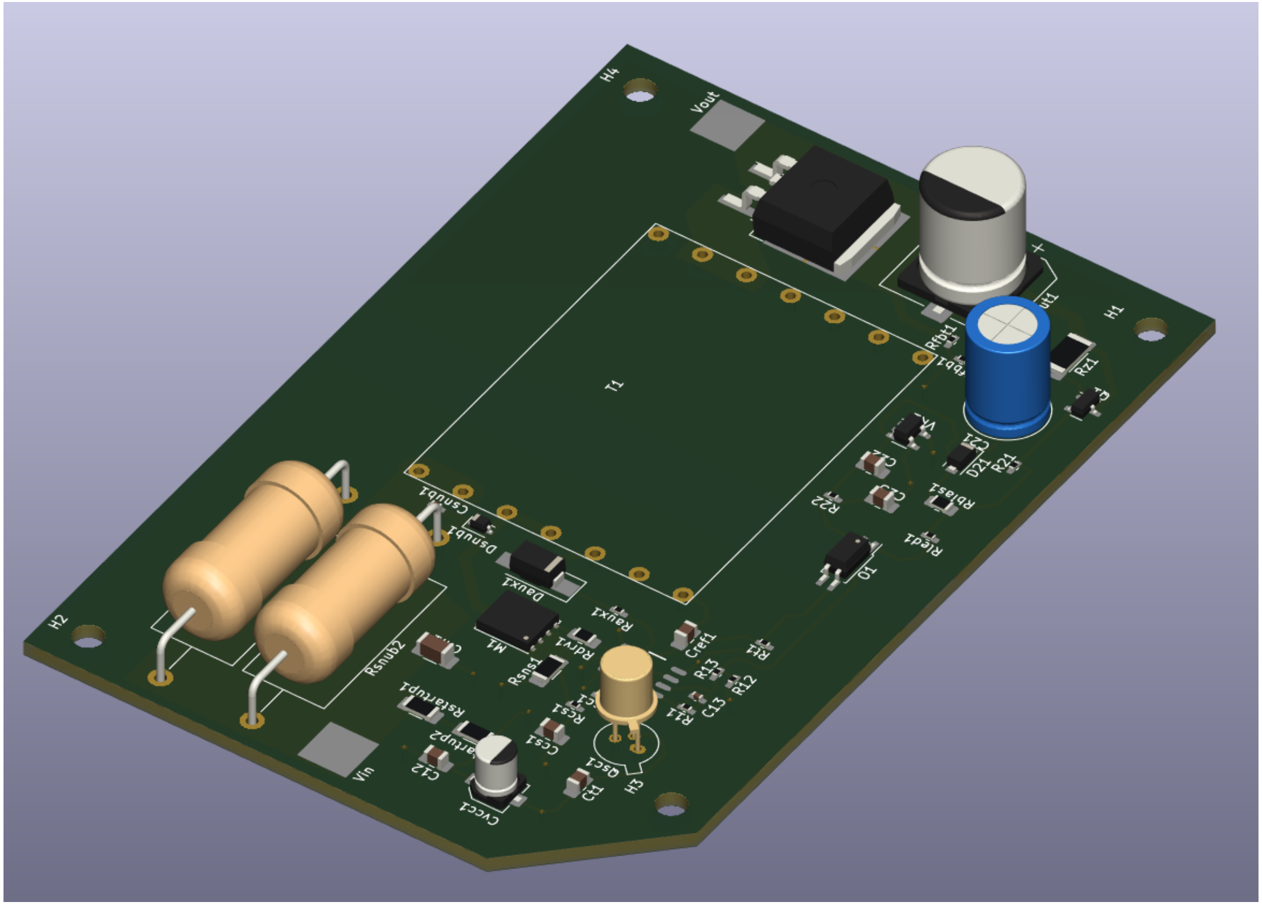


Figure 23: The PCB design in 3D view

We aimed industrial design bonus, so the box in Figure 24 is designed.

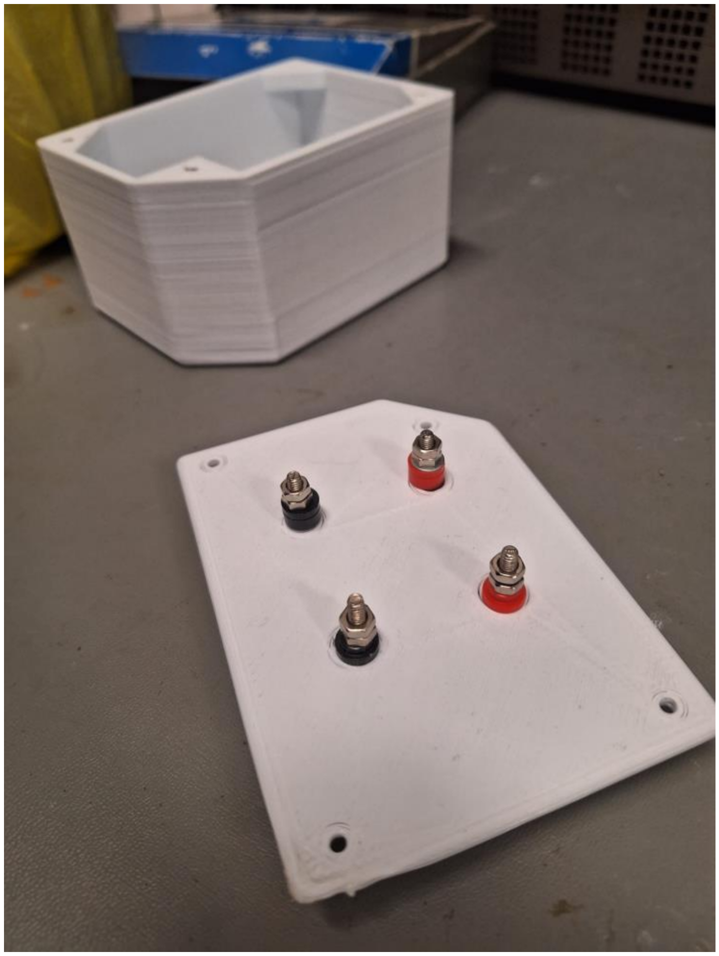


Figure 24: The box for the PCB

Tests

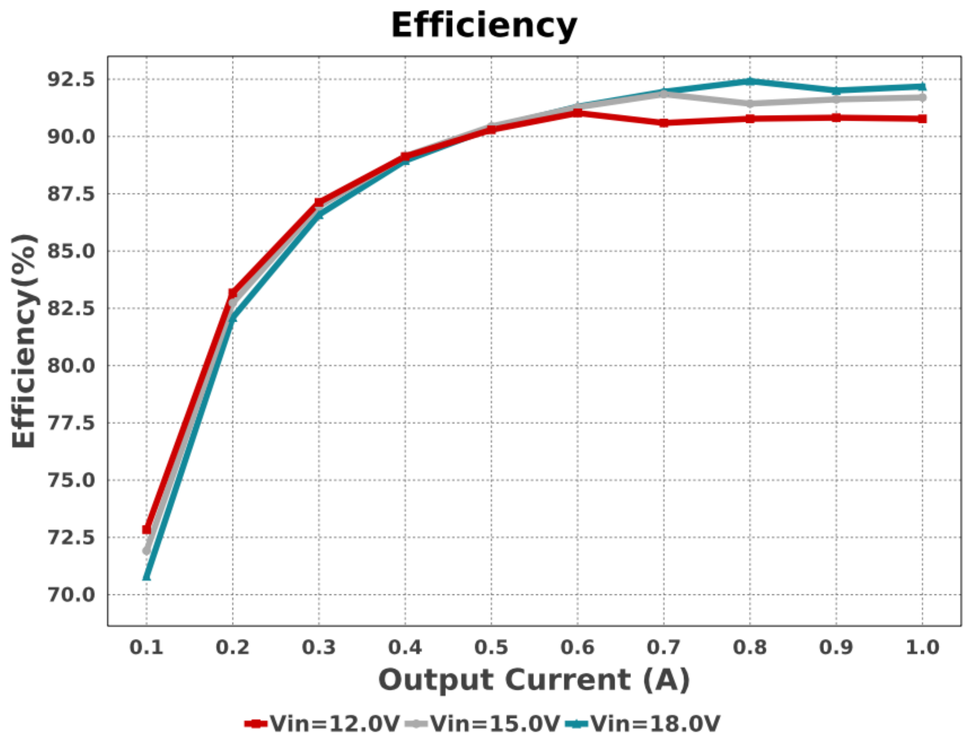


Figure 25: Closed-loop simulation efficiency result.

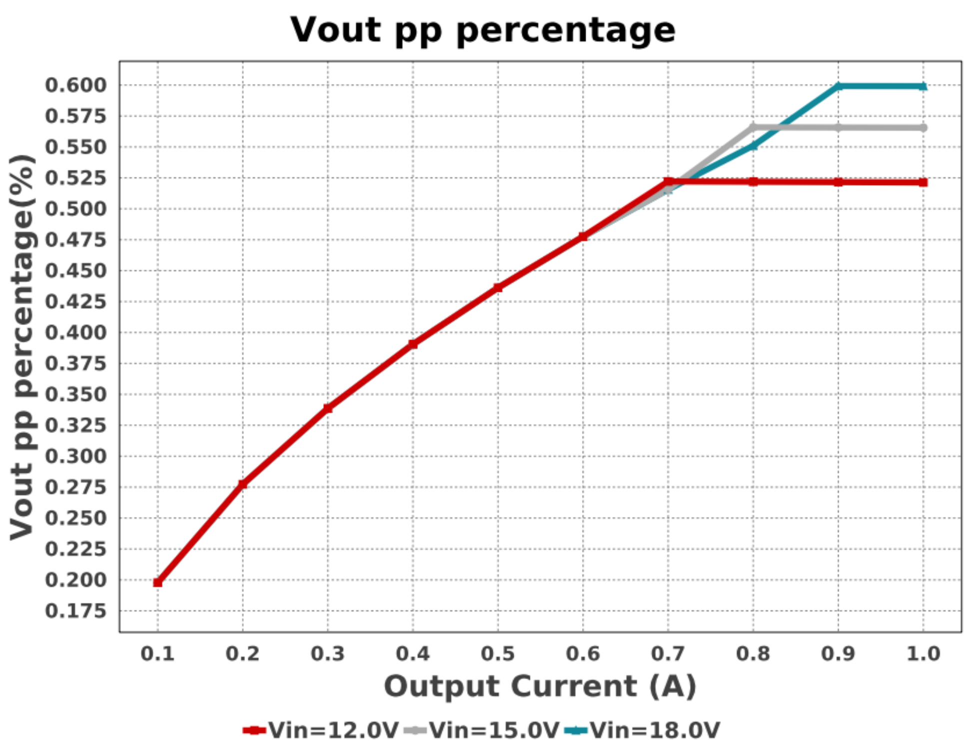


Figure 26: Closed-loop simulation output voltage ripple percentages.

The closed-loop simulations are operated in WEBench app, and Figure 25 and Figure 26 is obtained. It can be seen that the maximum voltage rippe occurs when the input voltage is 18V. The efficiency seems to be around at 90%; however, in the practical design, chosen core has higher core losses than the expected. Thus, the efficiency would probably be lower at the experiment, if the design was working.

Experimental Demo

Because the clearance on the PCB was not enough, the arcing between the lines observed. Although we tried to isolate the arcing points with silicon, other points started to arc. Due to time limitation, we were unable to design and fabricate a new PCB.

Conclusion

In conclusion, this report has effectively demonstrated the design process, computer simulations, and component selection for the flyback converter project. Through meticulous analysis and optimization, the design decisions were made with the primary goal of maximizing efficiency and reliability. Moreover, preliminary experimental results have shown promising outcomes, with measured magnetizing inductance and leakage inductance falling within acceptable ranges. The transformer, capacitor, and semiconductor components were carefully chosen to complement the overall design and meet performance requirements. In additon, the PCB and enclosure box designed for the target bonuses.

However, unfortunately, the design did not work. Even though the design is not working; however, we gained lots of useful experience. For example, we understood that the supply chain is a key factor in a hardware design job. Furthermore, we learned that some extra time needs to be allotted for bug fixes while planning the time schedule of a project.

References

[1] Ozdisan, "STB100N10F7 - MOSFET DIS.80A 100V N-CH TO263(D2PAK) SMT," [Online]. Available: https://ozdisan.com/guc-yari-iletkenleri/mosfetler/discrete-mosfetler/STB100N10F7/585449. [Accessed 05 05 2023].

[2] Ozdisan, "STTH3R06S - DIODE U.FAST Single 3A 600V SMT DO214AB (SMC)," [Online]. Available: https://ozdisan.com/guc-yari-iletkenleri/diyotlar-modul-diyotlar-ve-dogrultucular/genel-amacli-diyotlar/STTH3R06S/497200. [Accessed 05 05 2023].

[3] Ozdisan, "PKLH-400V470MJ200 - CAP.EL.47UF 400V 16X20 7.5MM 105C L.ESR 5000H," [Online]. Available: https://ozdisan.com/pasif-komponentler/kondansatorler/aluminyum-kondansatorler/PKLH-400V470MJ200/487365. [Accessed 05 05 2023].

[4] Digikey, "UCC2813DTR-1," [Online]. Available: https://www.digikey.com/en/products/detail/texas-instruments/UCC2813DTR-1/1911585. [Accessed 05 05 2023].

Appendix – 1 [calc.mlx]

```
clearvars
u = symunit;

2/1.24*8.614
```

```
ans = 13.8935
```

```
syms d turnsRatio
format shortEng
% format short
v_o = 48
```

```
v_o =
    48.0000e+000
```

```
d_min = 0.278; v_d_minduty = 18;
d_max = 0.366; v_d_maxduty = 12
```

```
v_d_maxduty =
    12.0000e+000
```

```
turnsRatio_minduty = ( (d_min/(1-d_min)) * (v_d_minduty/v_o) )^-1
```

```
turnsRatio_minduty =
     6.9257e+000
```

```
turnsRatio_maxduty = ( (d_max/(1-d_max)) * (v_d_maxduty/v_o) )^-1
```

```
turnsRatio_maxduty =
     6.9290e+000
```

```
U_o = v_o;
v_t = d_max;
f_sw = 100e3;
i_out = 1;
i_avgSec = i_out/(1-v_t);
xformerCurrRipple = 0.5; % percent
L_sec = (U_o*(1-v_t))/(xformerCurrRipple*i_avgSec*f_sw)
```

```
L_sec =
   385.8778e-006
```

```
L_pri = L_sec/(turnsRatio_maxduty^2)
```

```
L_pri =
     8.0374e-006
```

```
% (turnsRatio_maxduty^2)*2.814e-6
```

```
syms priTurns secTurns
% the last core is 0P45530EC
% % now switched to E42/21/20-3C94 E core
AL = 6130e-9 % nH/T^2; minimal
```

```
AL =
     6.1300e-006
```

```
priTurns = double(solve(L_pri == AL*priTurns^2))
```

```
priTurns = 2×1
    -1.1451e+000
     1.1451e+000
```

```
secTurns = double(solve(L_sec == AL*secTurns^2))
```

```
secTurns = 2×1
    -7.9340e+000
     7.9340e+000
```

```
% make sure core is not saturated
ampTurns = i_out*secTurns
```

```
ampTurns = 2×1
    -7.9340e+000
     7.9340e+000
```

AWG selection

```
p_o = i_out * v_o
```

```
p_o =
    48.0000e+000
```

```
i_in_max = v_o/v_d_maxduty
```

```
i_in_max =
     4.0000e+000
```

```
% Primary selected as 17  AWG
selectedAWGRating_pri = 2.9;
primaryDiameter_mm = 1.15062;
cableAreaPri_mm2 = 1.04;
% Secondary selected as 24  AWG
selectedAWGRating_sec = 0.577;
secondaryDiameter_mm = 0.5;
cableAreaSec_mm2 = 0.327;

primaryRadius_mm = primaryDiameter_mm/2
```

```
primaryRadius_mm =
   575.3100e-003
```

```
secondaryRadius_mm = secondaryDiameter_mm/2
```

```
secondaryRadius_mm =
   250.0000e-003
```

```
num_of_paralles_sec = i_out/selectedAWGRating_sec
```

```
num_of_paralles_sec =
     1.7331e+000
```

```
num_of_paralles_pri = i_in_max/selectedAWGRating_pri
```

```
num_of_paralles_pri =
     1.3793e+000
```

Skin Depth Calculation

```
skinDepth_mm = 75/sqrt(f_sw)
```

```
skinDepth_mm =
   237.1708e-003
```

```

innerRadiusPri_mm = primaryRadius_mm - skinDepth_mm
```

```
innerRadiusPri_mm =
   338.1392e-003
```

```
hollowAreaPri_mm2 = pi*innerRadiusPri_mm^2
```

```
hollowAreaPri_mm2 =
   359.2037e-003
```

```
effectiveAreaPri = cableAreaPri_mm2 - hollowAreaPri_mm2
```

```
effectiveAreaPri =
   680.7963e-003
```

```

innerRadiusSec_mm = secondaryRadius_mm - skinDepth_mm
```

```
innerRadiusSec_mm =
    12.8292e-003
```

```
hollowAreaSec_mm2 = pi*innerRadiusSec_mm^2
```

```
hollowAreaSec_mm2 =
   517.0676e-006
```

```
effectiveAreaSec = cableAreaSec_mm2 -  hollowAreaSec_mm2
```

```
effectiveAreaSec =
   326.4829e-003
```

```

% calculate the ratios to convert DC resistance to AC resistance
DC_to_AC_ratio_pri = cableAreaPri_mm2/effectiveAreaPri
```

```
DC_to_AC_ratio_pri =
    1.5276e+000
```

```
DC_to_AC_ratio_sec = cableAreaSec_mm2/effectiveAreaSec
```

```
DC_to_AC_ratio_sec =
    1.0016e+000
```

Fill Factor Calculation

```
windowArea_mm2 = 537;
priTurns = ceil(priTurns(priTurns>0))
```

```
priTurns =
    2.0000e+000
```

```
secTurns = ceil(secTurns(secTurns>0))
```

```
secTurns =
    8.0000e+000
```

```
num_of_paralles_pri = ceil(num_of_paralles_pri)
```

```
num_of_paralles_pri =
    2.0000e+000
```

```
num_of_paralles_sec = ceil(num_of_paralles_sec)
```

```
num_of_paralles_sec =
    2.0000e+000
```

```


primaryArea_mm2 = priTurns*num_of_paralles_pri*cableAreaPri_mm2
```

```
primaryArea_mm2 =
    4.1600e+000
```

```
secondaryArea_mm2 = secTurns*num_of_paralles_sec*cableAreaSec_mm2
```

```
secondaryArea_mm2 =
    5.2320e+000
```

```
totalCableArea_mm2 = primaryArea_mm2 + secondaryArea_mm2
```

```
totalCableArea_mm2 =
    9.3920e+000
```

```
fillFactor_perc = 100*totalCableArea_mm2/windowArea_mm2
```

```
fillFactor_perc =
    1.7490e+000
```

Cable Resistance Calculation

```
windingLengthPerTurn_mm = 68.2
```

```
windingLengthPerTurn_mm =
    68.2000e+000
```

```
ohms_per_meter = 212.872 / 1e3
```

```
ohms_per_meter =
   212.8720e-003
```

```
primaryLength_m = windingLengthPerTurn_mm * priTurns * 1e-3
```

```
primaryLength_m =
   136.4000e-003
```

```
secondaryLength_m = windingLengthPerTurn_mm * secTurns * 1e-3
```

```
secondaryLength_m =
   545.6000e-003
```

```

primary_DC_resistance_ohm = ohms_per_meter * primaryLength_m / num_of_paralles_pri
```

```
primary_DC_resistance_ohm =
    14.5179e-003
```

```
secondary_DC_resistance_ohm = ohms_per_meter * secondaryLength_m /
num_of_paralles_sec
```

```
secondary_DC_resistance_ohm =
    58.0715e-003
```

Copper Loss Calculation

```
% diameter_mm = vpa(0.32004*u.mm)
% radius_mm = diameter_mm/2
% skinDepth_cm = vpa(7.5/sqrt(f_sw)*u.cm)
% skinDepth_mm = unitConvert(skinDepth_cm, u.mm)
% % skin depth is greater than radius.
% % Therefore, AC reistance equals DC resistance
primary_AC_resistance_ohm = primary_DC_resistance_ohm*DC_to_AC_ratio_pri
```

```
primary_AC_resistance_ohm =
    22.1778e-003
```

```
secondary_AC_resistance_ohm = secondary_DC_resistance_ohm*DC_to_AC_ratio_sec
```

```
secondary_AC_resistance_ohm =
    58.1635e-003
```

```

resistancePri_ohm = vpa(primary_AC_resistance_ohm * u.Ohm)
```

resistancePri_ohm = $0.022177832240272008640369350018773\ \Omega$

```
resistanceSec_ohm = vpa(secondary_AC_resistance_ohm * u.Ohm)
```

resistanceSec_ohm = $0.058163452362757488145472706264627\ \Omega$

```
copperLossPri = vpa(unitConvert((i_in_max*u.A)^2 * resistancePri_ohm, u.W))
```

copperLossPri = $0.35484531584435213824590960030037\ \mathrm{W}$

```
copperLossSec = vpa(unitConvert((i_out*u.A)^2 * resistanceSec_ohm, u.W))
```

copperLossSec = $0.058163452362757488145472706264627\ \mathrm{W}$

```

copperLoss_W = copperLossPri + copperLossSec
```

copperLoss_W = $0.41300876820710962639138230656499\ \mathrm{W}$

Core Loss Calculation

```
% permeability = 26;
% mu_zero = 1.25663706212e-6;
% pathLength_m = 107e-3;
% fluxDensity_Tesla = mu_zero * permeability * ampTurns / pathLength_m
% % using graph above, 0.03 Tesla @ 100 kHz corresponds to
% wattLoss_mW_cm3 = 60*u.mW/u.cm^3
% volume_mm3 = 21300;
% volume_cm3 = vpa(unitConvert(volume_mm3*u.mm^3, u.cm^3))
% coreLoss_w = vpa(unitConvert(wattLoss_mW_cm3 * volume_cm3, u.W))
wattLoss_mW_cm3 = 142*u.mW/u.cm^3
```

wattLoss_mW_cm3 =

$$142\ \frac{\mathrm{mW}}{\mathrm{cm}^3}$$

```
volume_mm3 = 52000;
volume_cm3 = vpa(unitConvert(volume_mm3*u.mm^3, u.cm^3))
```

volume_cm3 = $52.0\ \mathrm{cm}^3$

```
coreLoss_w = vpa(unitConvert(wattLoss_mW_cm3 * volume_cm3, u.W))
```

coreLoss_w = $7.384\ \mathrm{W}$

```
magnetizingResistance = v_d_minduty^2/p_o
```

```
magnetizingResistance =
     6.7500e+000
```

```
Lm = 8*10^-6; f_sw = 100*10^3;

% DCM
```

```
% for Vs = 12V
Vs = 12; D = 0.366;
deltaI_lm = Vs*D/(Lm*f_sw);
P_min = Vs^2 * D^2 / (2*Lm*f_sw);
I_load_min = P_min / 48
```

```
I_load_min =
   251.1675e-003
```

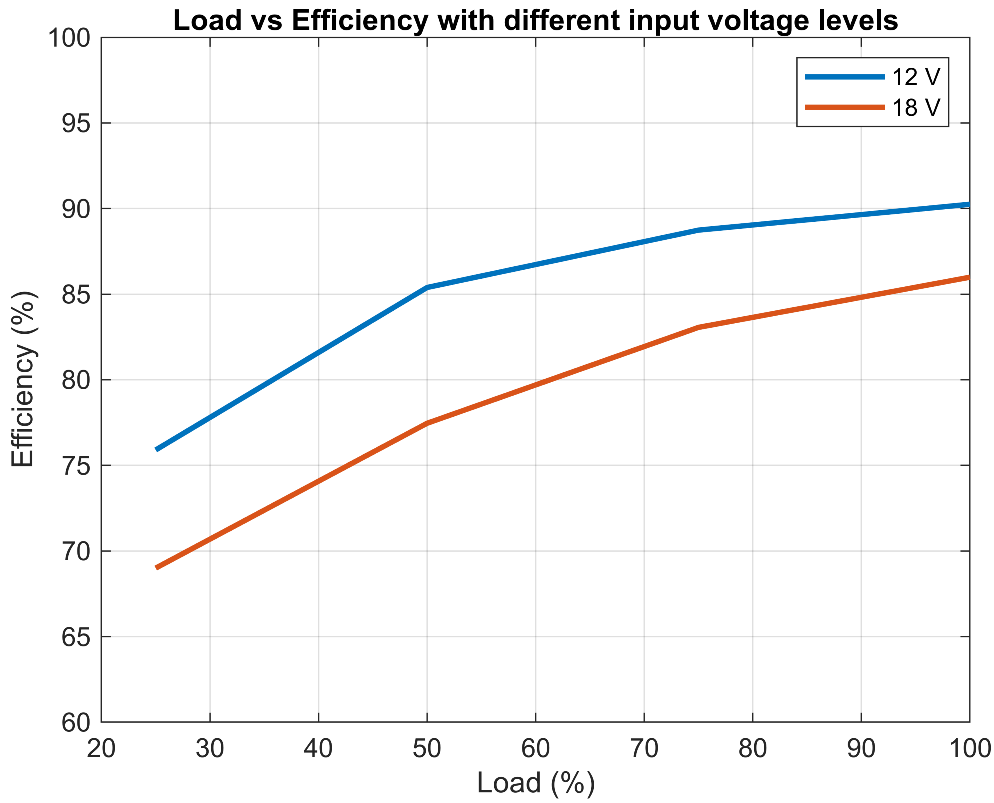
```
% for Vs = 18V
Vs = 18; D = 0.278;
deltaI_lm = Vs*D/(Lm*f_sw);
P_min = Vs^2 * D^2 / (2*Lm*f_sw);
I_load_min = P_min / 48
```

```
I_load_min =
   326.0419e-003
```

```
% max I_Lm current occurs when input voltage is 12V and at 100% load
Vs = 12; D = 0.366;
turnsRatio = 6.92; R = 48;
deltaI_lm = Vs*D/(Lm*f_sw);
P_out = Vs^2 * D^2 * turnsRatio^2 / ((1-D)^2 * R);
I_Lm_max = deltaI_lm/2 + P_out/(Vs*D)
```

```
I_Lm_max =
    13.6457e+000
```

```
% efficiency plot
plot([25 50 75 100], [75.9 85.39 88.74 90.25], 'LineWidth', 2);
hold on
plot([25 50 75 100], [69 77.46 83.06 85.99], 'LineWidth', 2);
grid on
legend("12 V", "18 V");
xlabel("Load (%)");
ylabel("Efficiency (%)")
title("Load vs Efficiency with different input voltage levels");
ylim([60 100])
```




```
% loss calculations
P_out = [12 24 36 48];  Vs = [12; 18];   Vf = 0.5; Rds_on = 3.6*10^-3; Q =
22.6*10^-9;
I_in_avg = P_out./Vs;    I_out_avg = P_out./48;
P_c = 1.278;

P_mosfet_conduction = I_in_avg.^2*Rds_on;    P_mosfet_switching =
19*I_in_avg*Q*f_sw;
P_diode_conduction = I_out_avg*Vf;
P_copper = I_in_avg.^2*primary_AC_resistance_ohm +
I_out_avg.^2*secondary_AC_resistance_ohm;

P_total_loss = P_c + P_mosfet_conduction + P_mosfet_switching + P_diode_conduction
+ P_copper;
efficiency = 100-P_total_loss./P_out*100
```

```
efficiency = 2×4
    87.7054e+000    92.7853e+000    94.3152e+000    94.9576e+000
    87.9440e+000    93.1432e+000    94.7925e+000    95.5542e+000
```

```
% component selections
% mosfet
duty = [d_min; d_max]
```

```
duty = 2×1
   278.0000e-003
   366.0000e-003
```

```
V_sw = Vs + 1/turnsRatio*48
```

```
V_sw = 2×1
    18.9364e+000
    24.9364e+000
```

```
I_sw = 1./(1-duty).*turnsRatio.*I_out_avg + 1/turnsRatio.*(1-duty)./2./L_pri./
f_sw*48
```

```
I_sw = 2×4
     5.5116e+000     7.9078e+000    10.3039e+000    12.7000e+000
     5.4645e+000     8.1932e+000    10.9219e+000    13.6506e+000
```

```
% diode
V_d_max = Vs*turnsRatio + 48
```

```
V_d_max = 2×1
   131.0400e+000
   172.5600e+000
```

```
I_d_max = I_sw./turnsRatio
```

```
I_d_max = 2×4
   796.4784e-003     1.1427e+000     1.4890e+000     1.8353e+000
   789.6655e-003     1.1840e+000     1.5783e+000     1.9726e+000
```

```
% output voltage ripple
R = 48; ripple = 0.03; ESR = 2
```

```
ESR =
     2.0000e+000
```

```
C_min = duty/f_sw/R/ripple
```

```
C_min = 2×1
     1.9306e-006
     2.5417e-006
```

```
V_ESR = ESR * I_out_avg
```

```
V_ESR = 1×4
   500.0000e-003     1.0000e+000     1.5000e+000     2.0000e+000
```

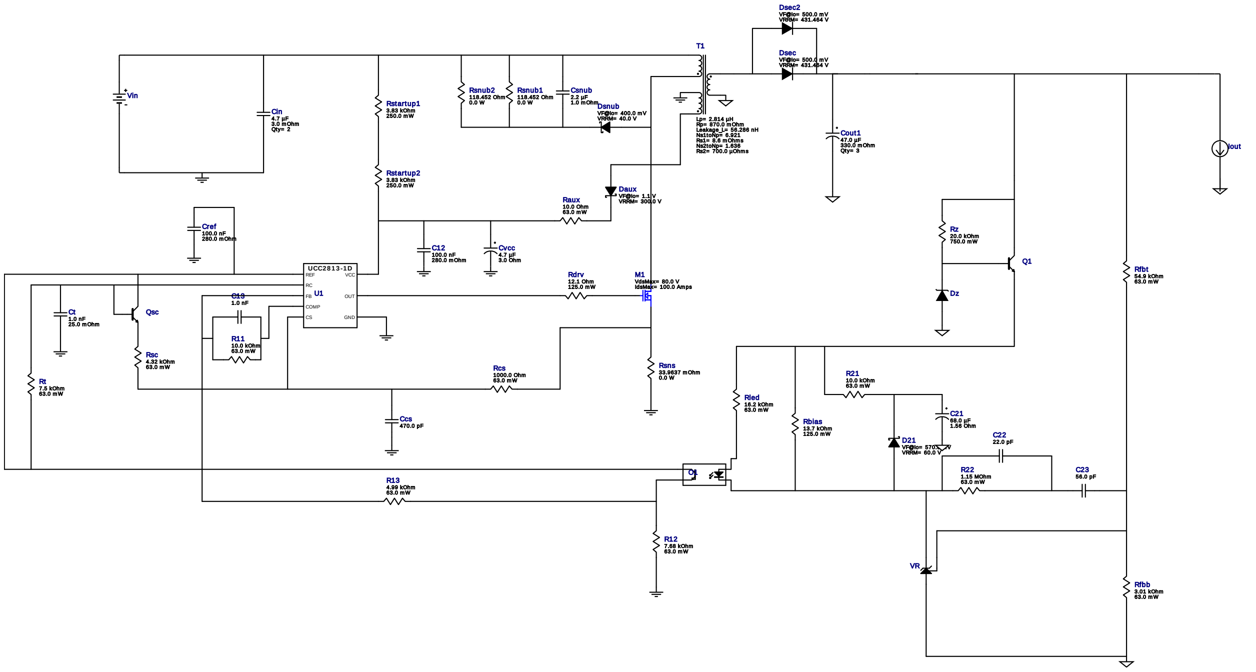
Appendix – 2 [TI Webench Design]

VinMin = 12.0V
VinMax = 18.0V
Vout = 48.0V
Iout = 1.0A

Device = UCC2813DTR-1
Topology = Flyback
Created = 2023-04-30 12:30:51.274
BOM Cost = NA
BOM Count = 48
Total Pd = 4.88W

WEBENCH ® Design Report

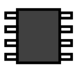
Design : 4 UCC2813DTR-1
UCC2813DTR-1 12V-18V to 48.00V @ 1A



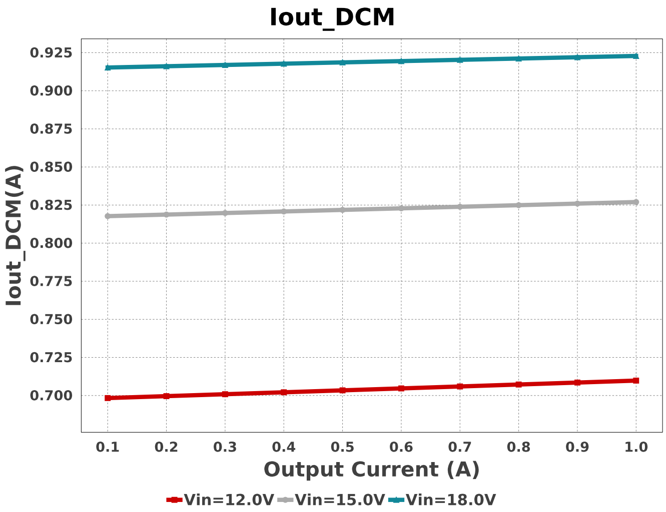
Electrical BOM

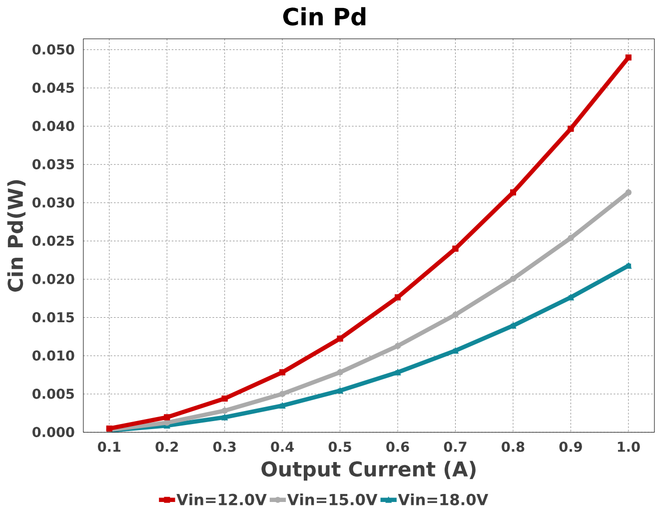
Name	Manufacturer	Part Number	Properties	Qty	Price	Footprint
C12	AVX	08053C104KAT2A Series= X7R	Cap= 100.0 nF ESR= 280.0 mOhm VDC= 25.0 V IRMS= 0.0 A	1	$0.01	0805 7 mm²
C13	MuRata	GRM1555C1H102JA01J Series= C0G/NP0	Cap= 1.0 nF VDC= 50.0 V IRMS= 0.0 A	1	$0.01	0402 3 mm²
C21	Chemi-Con	ELXZ630ELL680MH12D Series= LXZ	Cap= 68.0 uF ESR= 1.5601 Ohm VDC= 63.0 V IRMS= 405.0 mA	1	$0.17	Chemi-Con_800x1200 100 mm²
C22	Samsung Electro-Mechanics	CL21C220JBANNNC Series= C0G/NP0	Cap= 22.0 pF VDC= 50.0 V IRMS= 0.0 A	1	$0.01	0805 7 mm²
C23	Yageo	CC0805JRNPO9BN560 Series= C0G/NP0	Cap= 56.0 pF VDC= 50.0 V IRMS= 0.0 A	1	$0.01	0805 7 mm²
Ccs	Samsung Electro-Mechanics	CL21C471JBANNNC Series= C0G/NP0	Cap= 470.0 pF VDC= 50.0 V IRMS= 0.0 A	1	$0.01	0805 7 mm²
Cin	MuRata	GRM31CR71H475KA12L Series= X7R	Cap= 4.7 uF ESR= 3.0 mOhm VDC= 50.0 V IRMS= 4.98 A	2	$0.10	1206 11 mm²

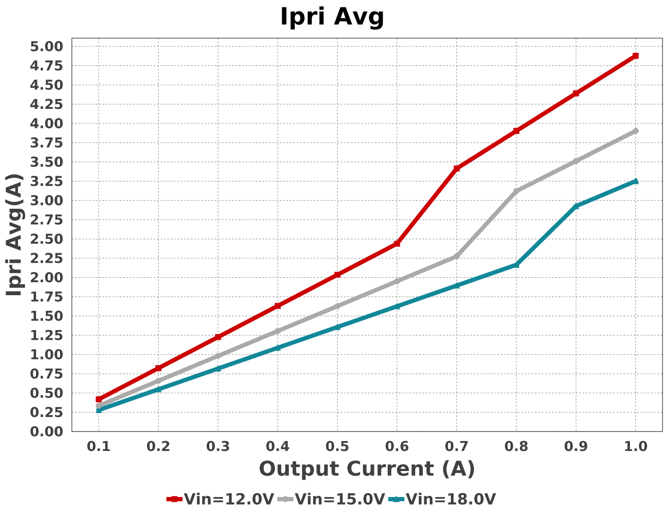
Name	Manufacturer	Part Number	Properties	Qty	Price	Footprint
Cout1	Chemi-Con	EMVY101ATR470MKE0S Series= MVY	Cap= 47.0 uF ESR= 330.0 mOhm VDC= 100.0 V IRMS= 450.0 mA	3	$0.40	CAPSMT_62_KE0 225 mm^2
Cref	AVX	08053C104KAT2A Series= X7R	Cap= 100.0 nF ESR= 280.0 mOhm VDC= 25.0 V IRMS= 0.0 A	1	$0.01	0805 7 mm^2
Csnub	TDK	C1005X5R1V225K050BC Series= X5R	Cap= 2.2 uF ESR= 1.0 mOhm VDC= 35.0 V IRMS= 0.0 A	1	$0.06	0402_065 3 mm^2
Ct	Kemet	C0805C102J5GACTU Series= C0G/NP0	Cap= 1.0 nF ESR= 25.0 mOhm VDC= 50.0 V IRMS= 1.71 A	1	$0.02	0805 7 mm^2
Cvcc	Chemi-Con	EMVY350ADA4R7MD55G Series= MVY	Cap= 4.7 uF ESR= 3.0 Ohm VDC= 35.0 V IRMS= 60.0 mA	1	$0.10	CAPSMT_62_D55 28 mm^2
D21	Nexperia	PMEG6010CEH,115	VF@Io= 570.0 mV VRRM= 60.0 V	1	$0.04	SOD-123F 12 mm^2
Daux	SMC Diode Solutions	ST1300ATR	VF@Io= 1.1 V VRRM= 300.0 V	1	$0.12	SMA 37 mm^2
Dsec	CUSTOM	CUSTOM	VF@Io= 500.0 mV VRRM= 431.464 V	1	NA	CUSTOM 0 mm^2
Dsec2	CUSTOM	CUSTOM	VF@Io= 500.0 mV VRRM= 431.464 V	1	NA	CUSTOM 0 mm^2
Dsnub	Diodes Inc.	ZLLS400TA	VF@Io= 400.0 mV VRRM= 40.0 V	1	$0.16	SOD-323 9 mm^2
Dz	Diodes Inc.	MMSZ5250B-7-F	Zener	1	$0.04	SOD-123 13 mm^2
M1	Texas Instruments	CSD19502Q5B	VdsMax= 80.0 V IdsMax= 100.0 Amps	1	$0.81	DQK0006C 9 mm^2
O1	Vishay-Semiconductor	TCMT1107	Optocoupler	1	$0.19	SOP-4 44 mm^2
Q1	ON Semiconductor	BC846BLT1G	Bipolar Transistor	1	$0.03	SOT-23 14 mm^2
Qsc	STMicroelectronics	2N2222A	Bipolar Transistor	1	$1.19	TO-18 57 mm^2
R11	Vishay-Dale	CRCW040210K0FKED Series= CRCW..e3	Res= 10.0 kOhm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm^2
R12	Vishay-Dale	CRCW04027K68FKED Series= CRCW..e3	Res= 7.68 kOhm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm^2
R13	Vishay-Dale	CRCW04024K99FKED Series= CRCW..e3	Res= 4.99 kOhm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm^2
R21	Vishay-Dale	CRCW040210K0FKED Series= CRCW..e3	Res= 10.0 kOhm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm^2
R22	Vishay-Dale	CRCW04021M15FKED Series= CRCW..e3	Res= 1.15 MOhm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm^2

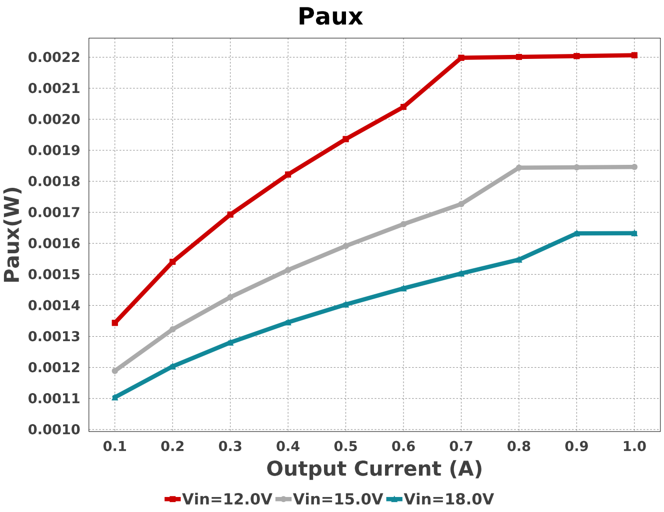
Name	Manufacturer	Part Number	Properties	Qty	Price	Footprint
Raux	Vishay-Dale	CRCW040210R0FKED Series= CRCW..e3	Res= 10.0 Ohm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm^2
Rbias	Vishay-Dale	CRCW080513K7FKEA Series= CRCW..e3	Res= 13.7 kOhm Power= 125.0 mW Tolerance= 1.0%	1	$0.01	0805 7 mm^2
Rcs	Vishay-Dale	CRCW04021K00FKED Series= CRCW..e3	Res= 1000.0 Ohm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm^2
Rdrv	Vishay-Dale	CRCW080512R1FKEA Series= CRCW..e3	Res= 12.1 Ohm Power= 125.0 mW Tolerance= 1.0%	1	$0.01	0805 7 mm^2
Rfbb	Vishay-Dale	CRCW04023K01FKED Series= CRCW..e3	Res= 3.01 kOhm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm^2
Rfbt	Vishay-Dale	CRCW040254K9FKED Series= CRCW..e3	Res= 54.9 kOhm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm^2
Rled	Vishay-Dale	CRCW040216K2FKED Series= CRCW..e3	Res= 16.2 kOhm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm^2
Rsc	Vishay-Dale	CRCW04024K32FKED Series= CRCW..e3	Res= 4.32 kOhm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm^2
Rsns	CUSTOM	CUSTOM Series= ?	Res= 33.9637 mOhm Power= 0.0 W Tolerance= 0.0%	1	NA	CUSTOM 0 mm^2
Rsnub1	CUSTOM	CUSTOM Series= ?	Res= 118.452 Ohm Power= 0.0 W Tolerance= 0.0%	1	NA	CUSTOM 0 mm^2
Rsnub2	CUSTOM	CUSTOM Series= ?	Res= 118.452 Ohm Power= 0.0 W Tolerance= 0.0%	1	NA	CUSTOM 0 mm^2
Rstartup1	Yageo	RC1206FR-073K83L Series= ?	Res= 3.83 kOhm Power= 250.0 mW Tolerance= 1.0%	1	$0.01	1206 11 mm^2
Rstartup2	Yageo	RC1206FR-073K83L Series= ?	Res= 3.83 kOhm Power= 250.0 mW Tolerance= 1.0%	1	$0.01	1206 11 mm^2
Rt	Vishay-Dale	CRCW04027K50FKED Series= CRCW..e3	Res= 7.5 kOhm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm^2
Rz	Vishay-Dale	CRCW201020K0FKEF Series= CRCW..e3	Res= 20.0 kOhm Power= 750.0 mW Tolerance= 1.0%	1	$0.04	2010 32 mm^2
T1	CUSTOM	CUSTOM	Lp= 2.814 µH Rp= 870.0 mOhm Leakage_L= 56.286 nH Ns1toNp= 6.921 Rs1= 8.6 mOhms Ns2toNp= 1.636 Rs2= 700.0 µOhms	1	NA	CUSTOM 0 mm^2
U1	Texas Instruments	UCC2813DTR-1	Switcher	1	$0.69	 D0008A 57 mm^2

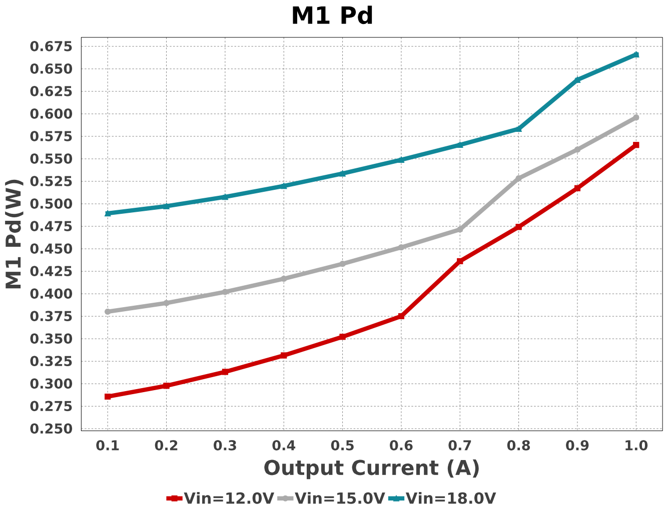
Name	Manufacturer	Part Number	Properties	Qty	Price	Footprint
VR	Texas Instruments	TL431IDBVR	Voltage References	1	$0.09	R-PDSO-G3 16 mm²

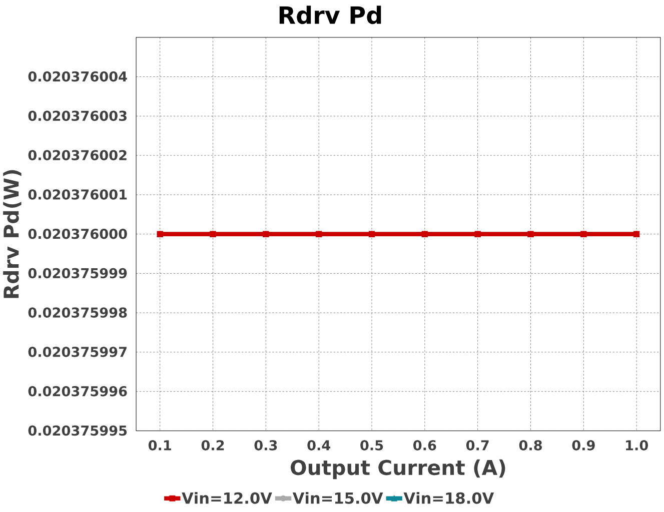


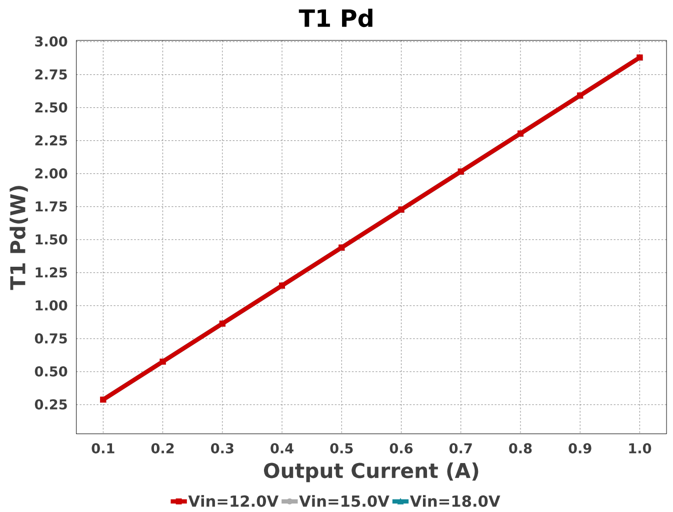


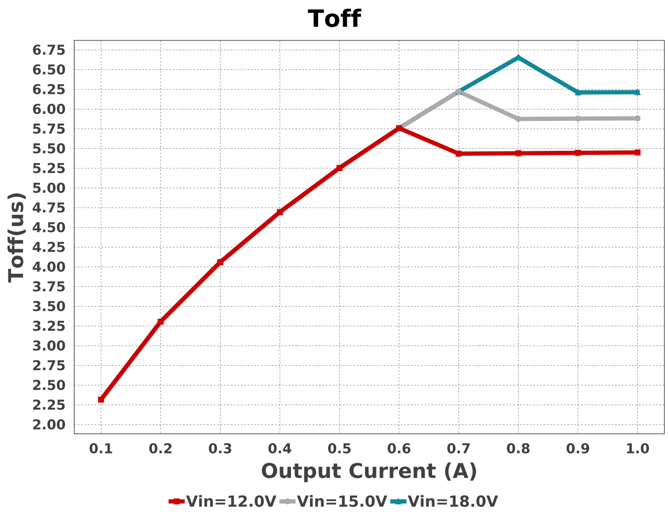


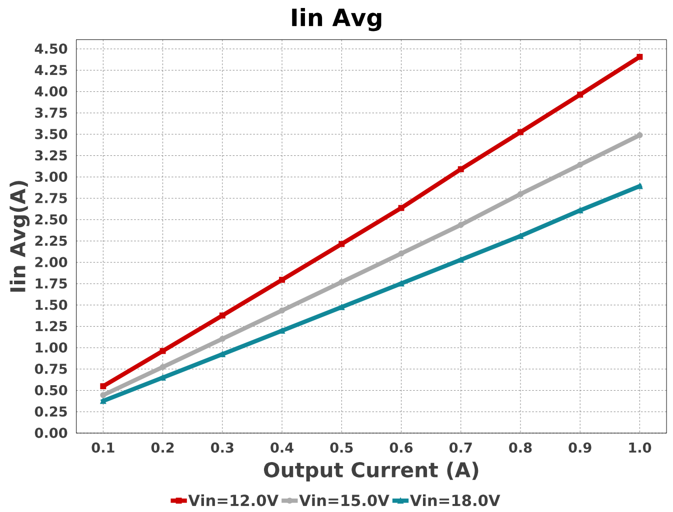


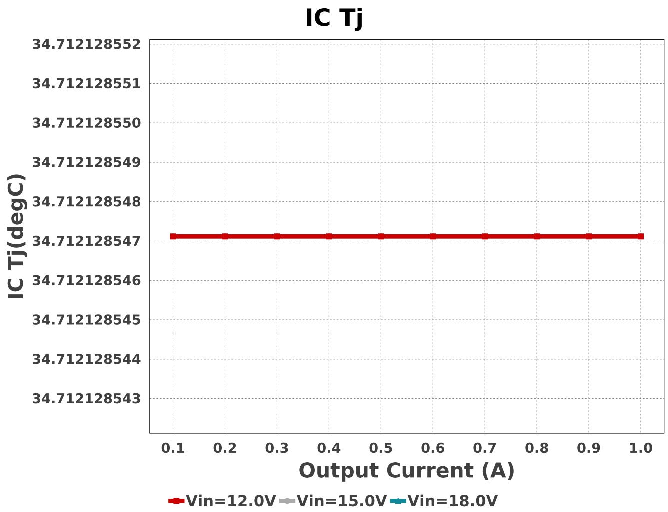


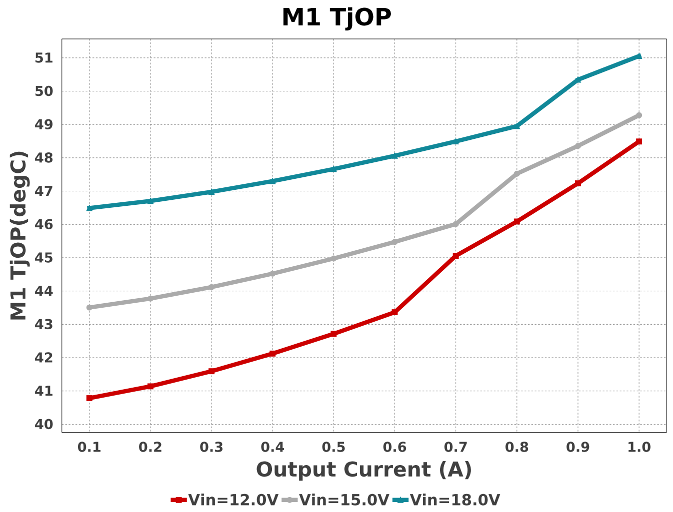


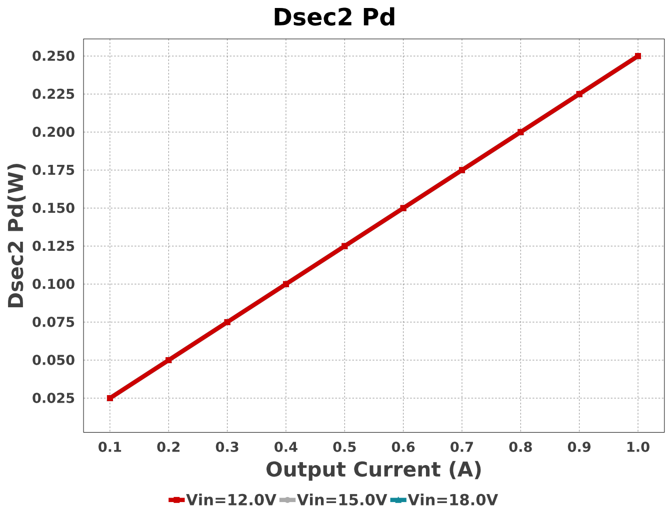

T1 Pd
T1 Pd(W)
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V


Toff
Toff(us)
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V

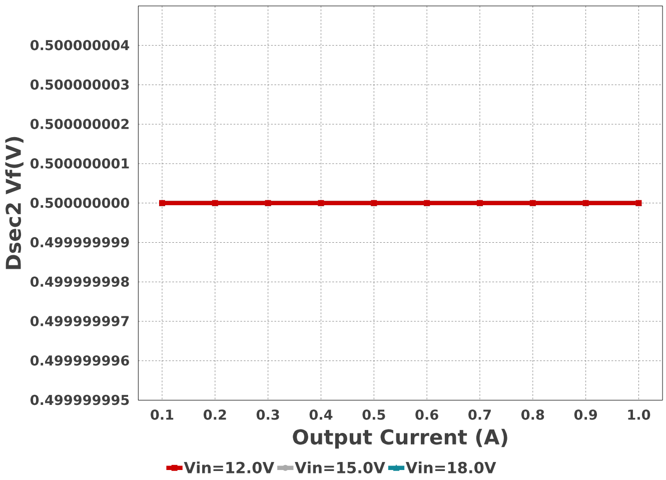

Iin Avg
Iin Avg(A)
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V


IC Tj
IC Tj(degC)
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V

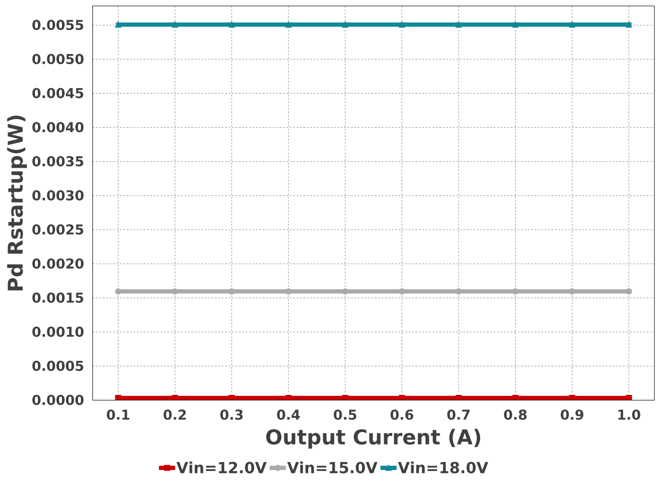

M1 TjOP
M1 TjOP(degC)
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V


Dsec2 Pd
Dsec2 Pd(W)
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V

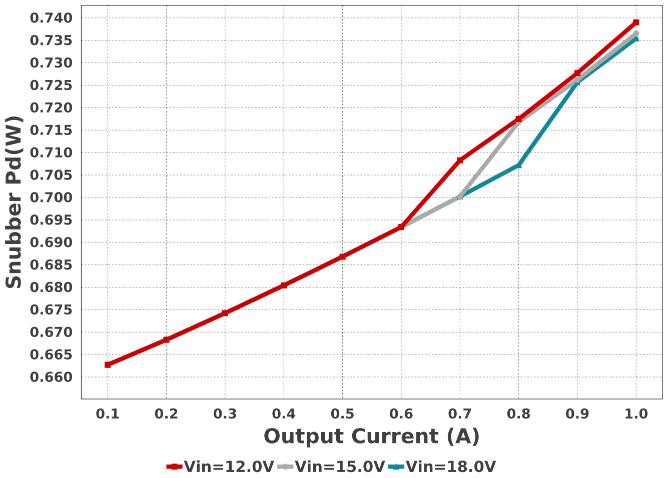
Dsec2 Vf



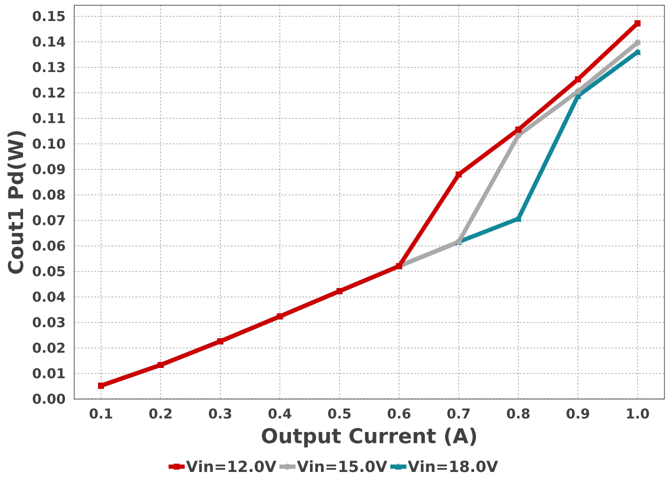
Pd Rstartup



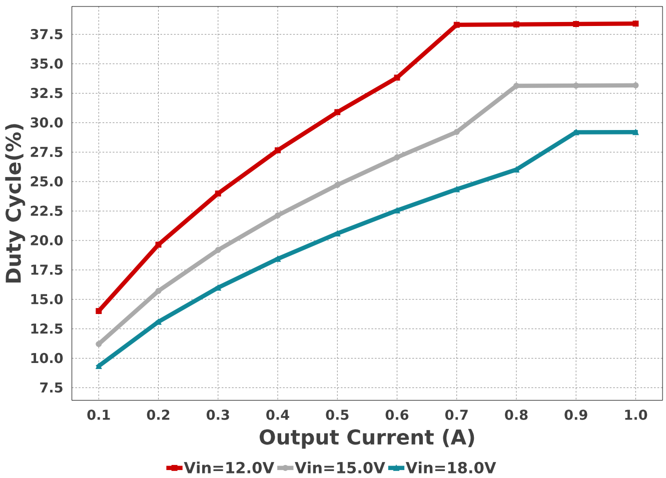
Snubber Pd



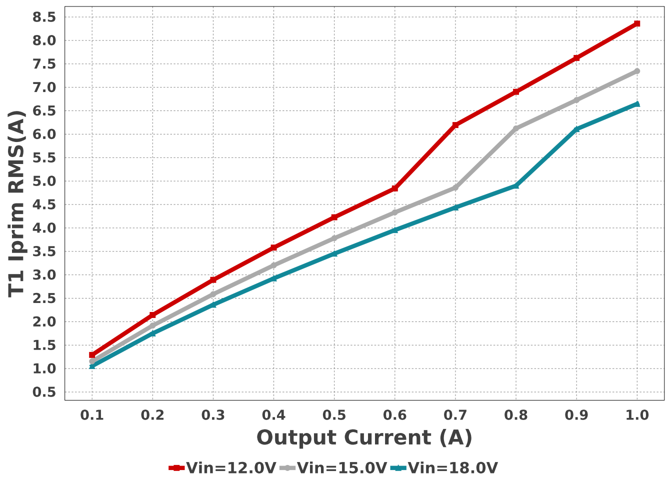
Cout1 Pd

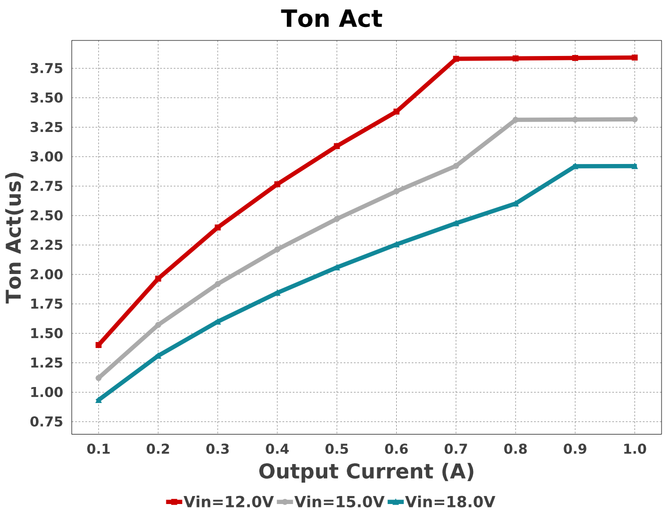


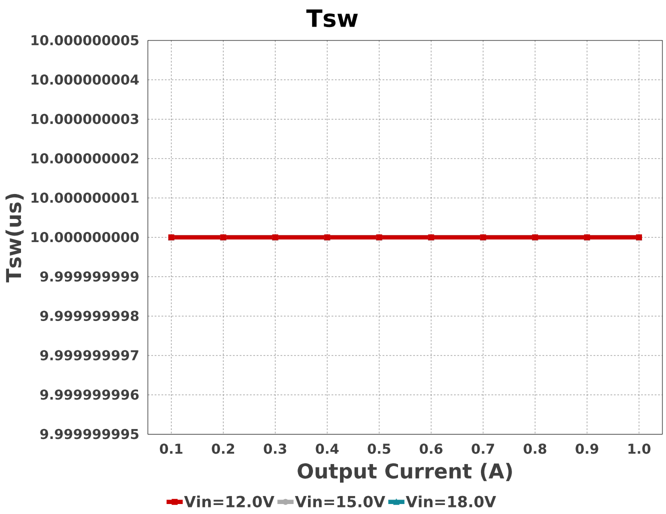
Duty Cycle

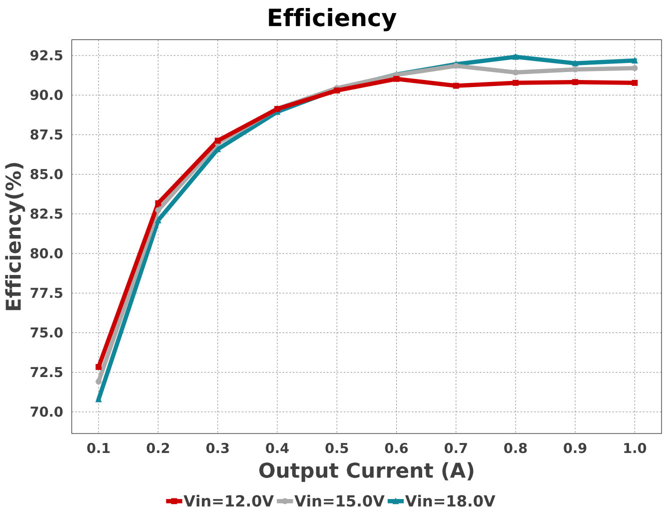


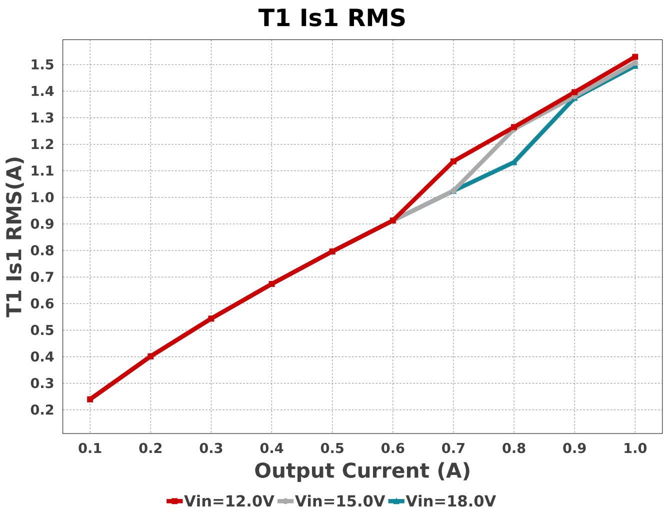
T1 Iprim RMS

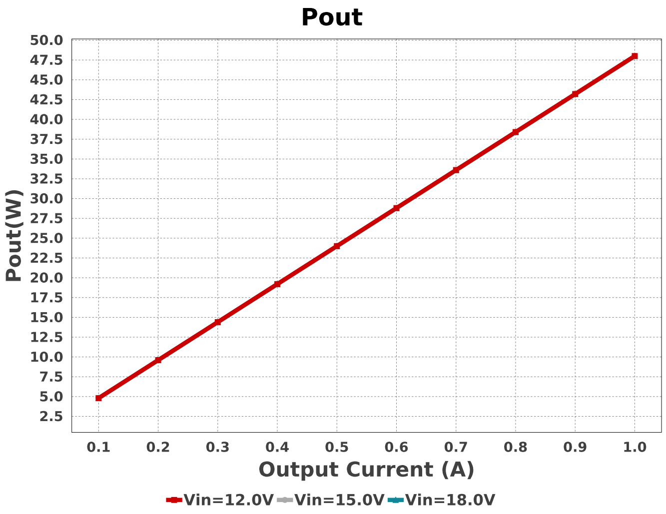


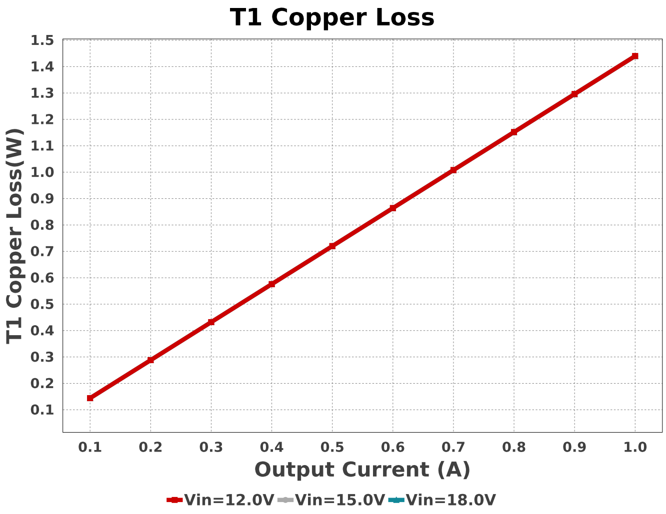

Ton Act
Ton Act(us)
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V


Tsw
Tsw(us)
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V

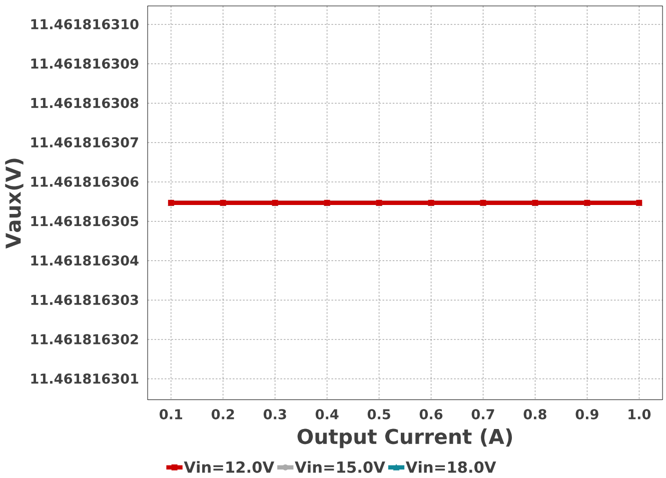

Efficiency
Efficiency(%)
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V


T1 Is1 RMS
T1 Is1 RMS(A)
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V

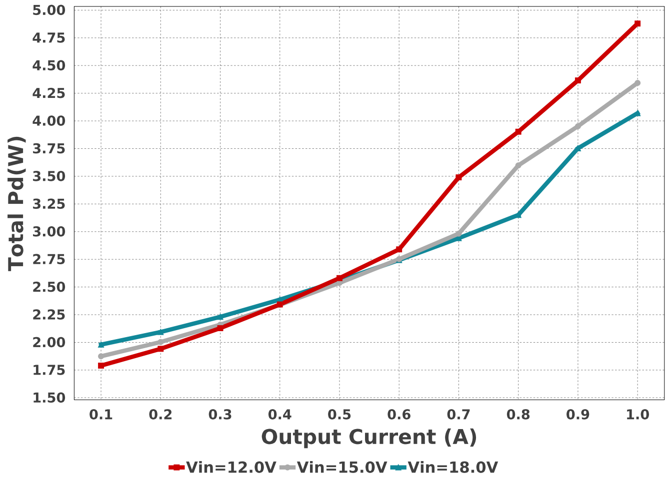

Pout
Pout(W)
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V


T1 Copper Loss
T1 Copper Loss(W)
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V

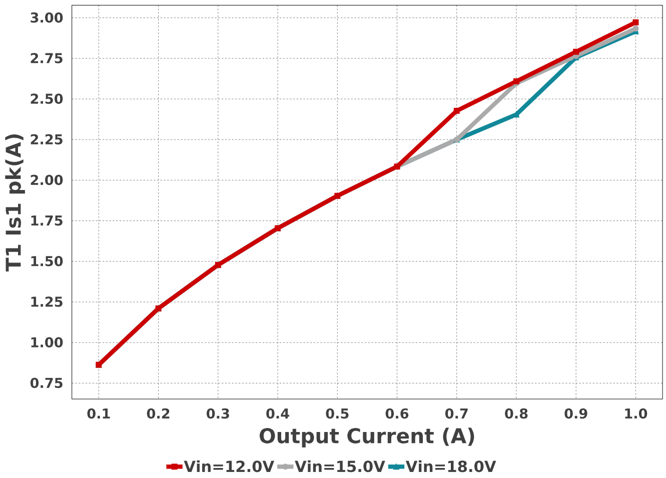
Vaux



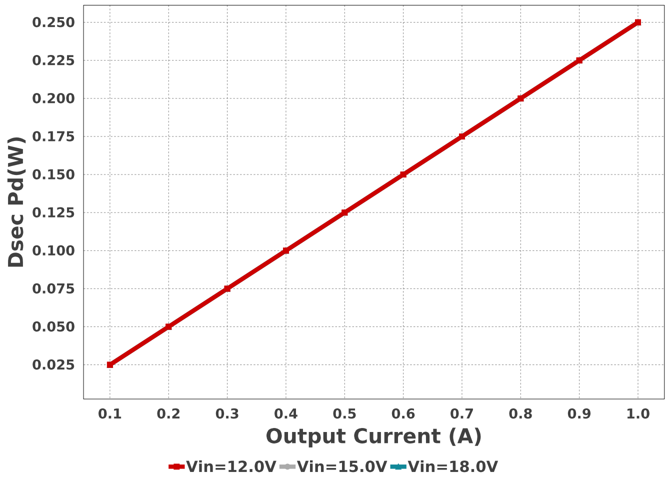
Total Pd



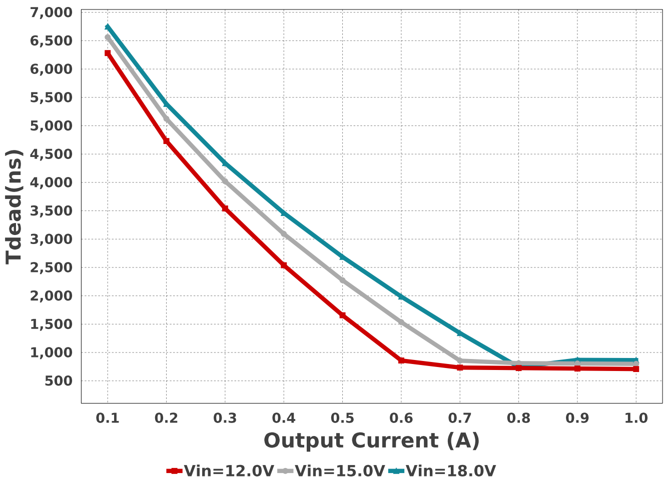
T1 Is1 pk



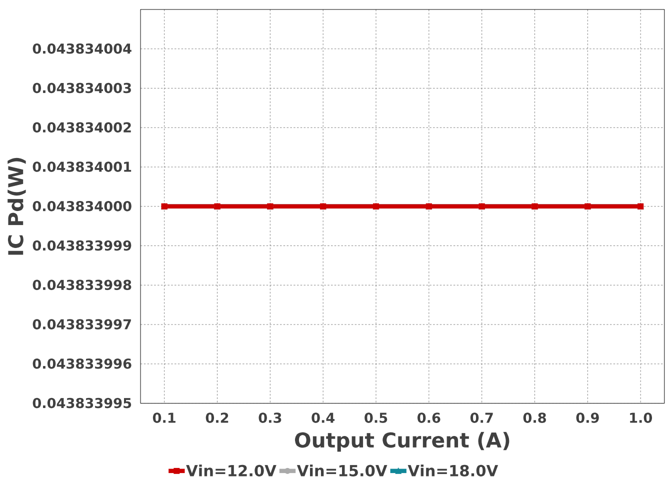
Dsec Pd



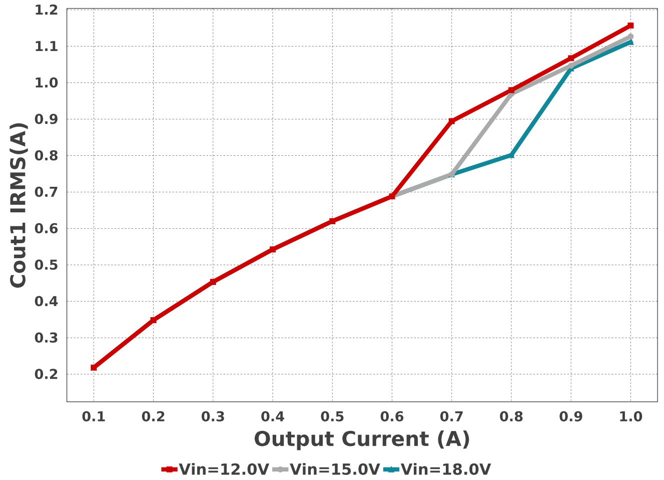
Tdead



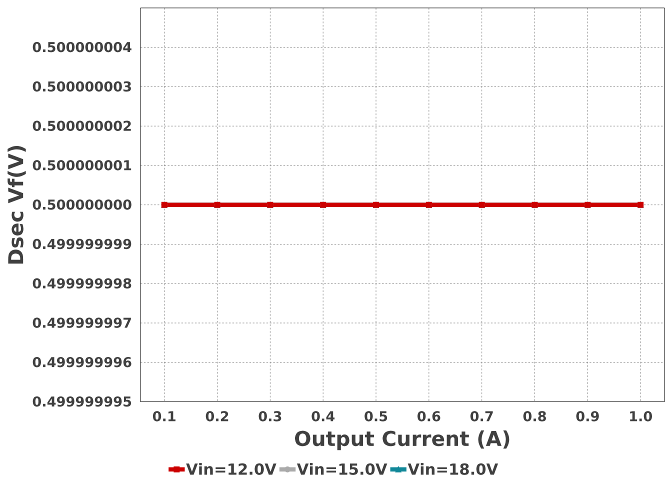
IC Pd



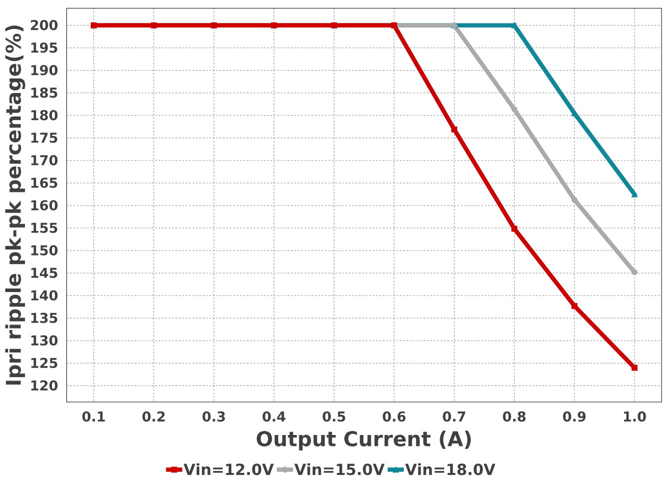
Cout1 IRMS



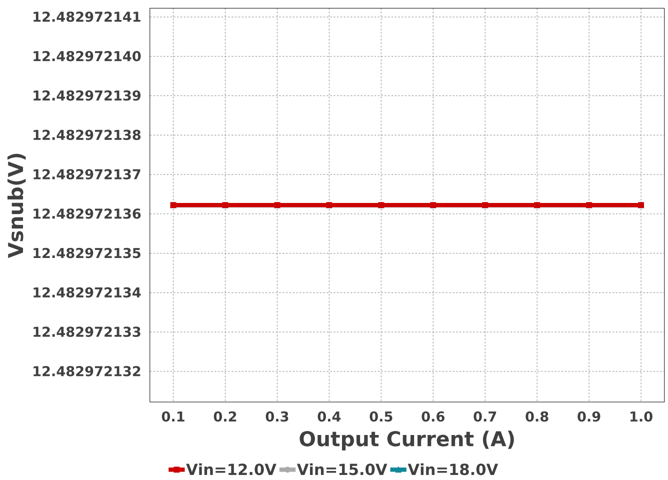
Dsec Vf



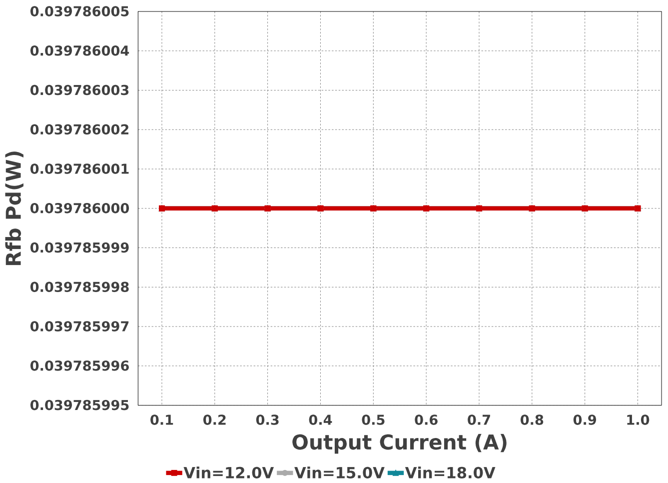
Ipri ripple pk-pk percentage



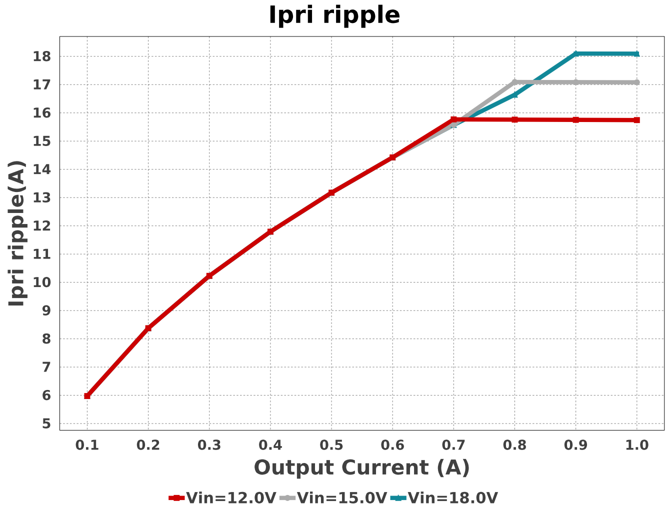
Vsnub

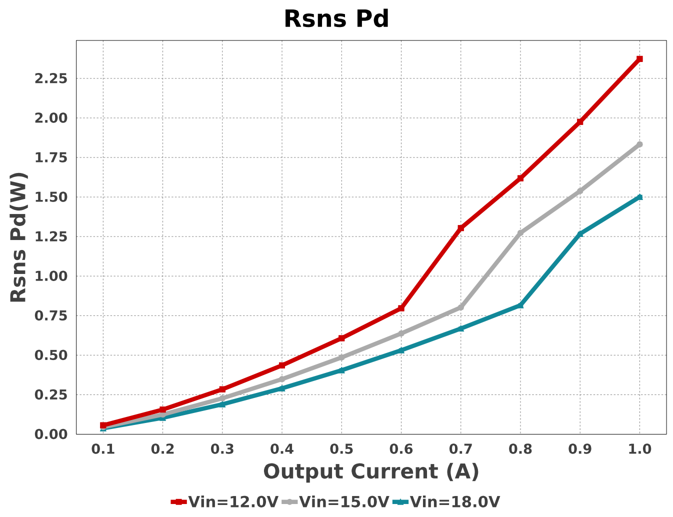


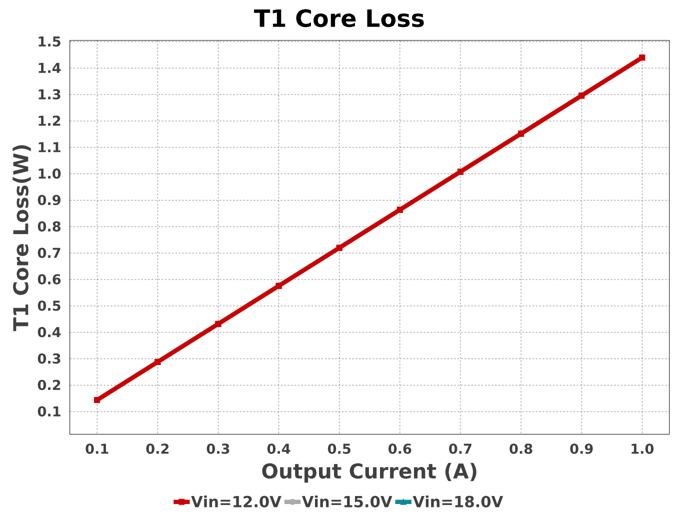
Rfb Pd

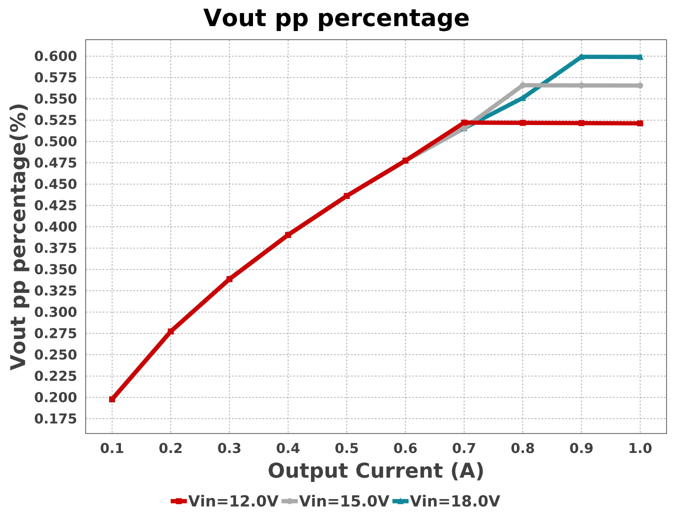


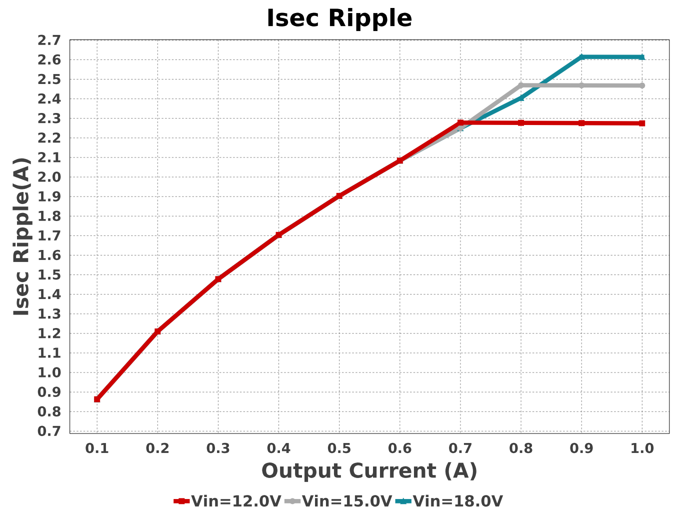
Ipri ripple

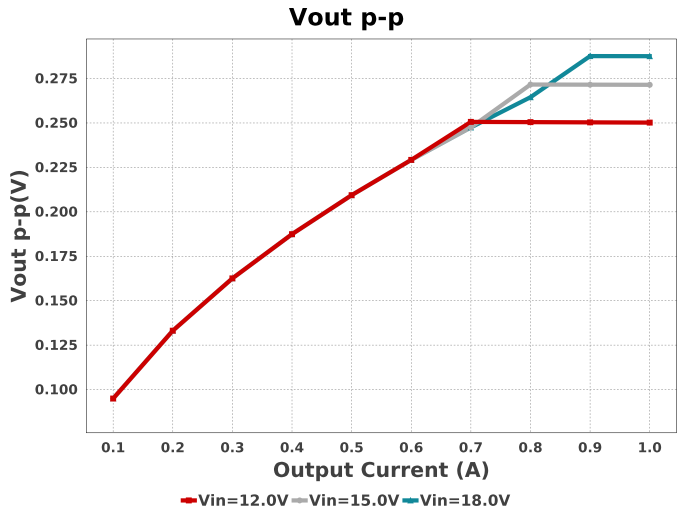


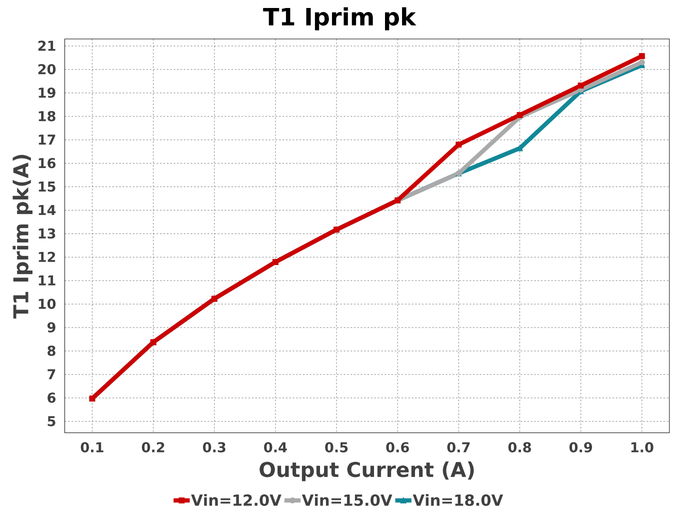












Operating Values

#	Name	Value	Category	Description
1.	Cin Pd	48.98 mW	Capacitor	Input capacitor power dissipation
2.	Cout1 IRMS	1.157 A	Capacitor	Output capacitor1 RMS ripple current
3.	Cout1 Pd	147.24 mW	Capacitor	Output capacitor1 power dissipation
4.	Daux trr	35.0 ns	Diode	Auxiliary Diode Reverse Recovery Time
5.	Dsec Pd	250.0 mW	Diode	Secondary Diode Power Dissipation
6.	Dsec Vf	500.0 mV	Diode	Effective Forward Voltage Drop at the Operating Current
7.	Dsec trr	0.0 ns	Diode	Output Diode Reverse Recovery Time
8.	Dsec2 Pd	250.0 mW	Diode	Secondary Diode Power Dissipation
9.	Dsec2 Vf	500.0 mV	Diode	Effective Forward Voltage Drop at the Operating Current
10.	Dsnub trr	3.0 ns	Diode	Snubber Diode Reverse Recovery Time
11.	IC Pd	43.834 mW	IC	IC power dissipation

#	Name	Value	Category	Description
12.	IC Tj	34.712 degC	IC	IC junction temperature
13.	ICThetaJA	107.5 degC/W	IC	IC junction-to-ambient thermal resistance
14.	Iin Avg	4.407 A	IC	Average input current
15.	M1 Pd	565.4 mW	Mosfet	M1 MOSFET total power dissipation
16.	M1 TjOP	62.239 degC	Mosfet	M1 MOSFET junction temperature
17.	Cin Pd	48.98 mW	Power	Input capacitor power dissipation
18.	Cout1 Pd	147.24 mW	Power	Output capacitor1 power dissipation
19.	Dsec Pd	250.0 mW	Power	Secondary Diode Power Dissipation
20.	Dsec2 Pd	250.0 mW	Power	Secondary Diode Power Dissipation
21.	IC Pd	43.834 mW	Power	IC power dissipation
22.	M1 Pd	565.4 mW	Power	M1 MOSFET total power dissipation
23.	Paux	2.206 mW	Power	Power Dissipation in Raux and Daux
24.	Pd Rstartup	32.037 µW	Power	Power Dissipation in Rstartup1 and Rstartup2
25.	Rdrv Pd	20.376 mW	Power	Power Dissipation in Gate Drive Resistor
26.	Rfb Pd	39.786 mW	Power	Rfb Power Dissipation
27.	Rsns Pd	2.373 W	Power	Current Limit Sense Resistor Power Dissipation
28.	Snubber Pd	739.01 mW	Power	Snubber Power Dissipation
29.	T1 Copper Loss	1.44 W	Power	Transformer Copper Loss Power Dissipation
30.	T1 Core Loss	1.44 W	Power	Transformer Core Loss Power Dissipation
31.	T1 Pd	2.88 W	Power	Estimated Losses in Transformer
32.	Total Pd	4.879 W	Power	Total Power Dissipation
33.	Pd Rstartup	32.037 µW	Resistor	Power Dissipation in Rstartup1 and Rstartup2
34.	Rdrv Pd	20.376 mW	Resistor	Power Dissipation in Gate Drive Resistor
35.	Rfb Pd	39.786 mW	Resistor	Rfb Power Dissipation
36.	Rsns Pd	2.373 W	Resistor	Current Limit Sense Resistor Power Dissipation
37.	BOM Count	48	System Information	Total Design BOM count
38.	Duty Cycle	38.414 %	System Information	Duty cycle
39.	Efficiency	90.773 %	System Information	Steady state efficiency
40.	FootPrint	1.272 k mm^2	System Information	Total Foot Print Area of BOM components
41.	Frequency	100.0 kHz	System Information	Switching frequency
42.	Iout	1.0 A	System Information	Iout operating point
43.	Iout_DCM	709.799 mA	System Information	Approximate Current below which DCM mode of operation will begin
44.	Mode	CCM	System Information	Conduction Mode
45.	Pout	48.0 W	System Information	Total output power
46.	Tdead	708.095 ns	System Information	Approximate Dead Time of the Regulator
47.	Toff	5.451 us	System Information	Approximate Converter Off Time
48.	Ton Act	3.841 us	System Information	Approximate Converter On Time
49.	Total BOM	NA	System Information	Total BOM Cost
50.	Tsw	10.0 us	System Information	Switching Time Period
51.	Vin	12.0 V	System Information	Vin operating point
52.	Vout	48.0 V	System Information	Operational Output Voltage
53.	Vout Actual	48.002 V	System Information	Vout Actual calculated based on selected voltage divider resistors
54.	Vout Tolerance	2.242 %	System Information	Vout Tolerance based on IC Tolerance (no load) and voltage divider resistors if applicable
55.	Vout p-p	250.208 mV	System Information	Peak-to-peak output ripple voltage
56.	Vout pp percentage	521.267 m%	System Information	Output Voltage ripple percentage
57.	Vsnub	12.483 V	System Information	Voltage Across the Snubber
58.	Ipri Avg	4.878 A	Transformer	Average Current in Primary Winding over the complete Switching Period
59.	Ipri ripple	15.744 A	Transformer	Ripple Current in the Primary Winding
60.	Ipri ripple pk-pk percentage	123.979 %	Transformer	Primary Current pk-pk ripple percentage(of Ipri avg during ton only)
61.	Isec Ripple	2.275 A	Transformer	Ripple Current in the Secondary Winding
62.	Paux	2.206 mW	Transformer	Power Dissipation in Raux and Daux
63.	T1 Copper Loss	1.44 W	Transformer	Transformer Copper Loss Power Dissipation
64.	T1 Core Loss	1.44 W	Transformer	Transformer Core Loss Power Dissipation

#	Name	Value	Category	Description
65.	T1 Iprim RMS	8.359 A	Transformer	Transformer Primary RMS Current
66.	T1 Iprim pk	20.57 A	Transformer	Transformer Primary Peak Current
67.	T1 Is1 RMS	1.529 A	Transformer	Transformer Secondary1 RMS Current
68.	T1 Is1 pk	2.972 A	Transformer	Transformer Secondary1 Peak Current
69.	T1 Pd	2.88 W	Transformer	Estimated Losses in Transformer
70.	Vaux	11.462 V	Transformer	Auxiliary Voltage

Design Inputs

Name	Value	Description
Iout	1.0	Maximum Output Current
VinMax	18.0	Maximum input voltage
VinMin	12.0	Minimum input voltage
VinTyp	15.0	Typical input voltage
Vout	48.0	Output Voltage
base_pn	UCC2813-1	Base Product Number
source	DC	Input Source Type
Ta	30.0	Ambient temperature

WEBENCH® Assembly

Component Testing

Some published data on components in datasheets such as Capacitor ESR and Inductor DC resistance is based on conservative values that will guarantee that the components always exceed the specification. For design purposes it is usually better to work with typical values. Since this data is not always available it is a good practice to measure the Capacitance and ESR values of Cin and Cout, and the inductance and DC resistance of L1 before assembly of the board. Any large discrepancies in values should be electrically simulated in WEBENCH to check for instabilities and thermally simulated in WebTHERM to make sure critical temperatures are not exceeded.

Soldering Component to Board

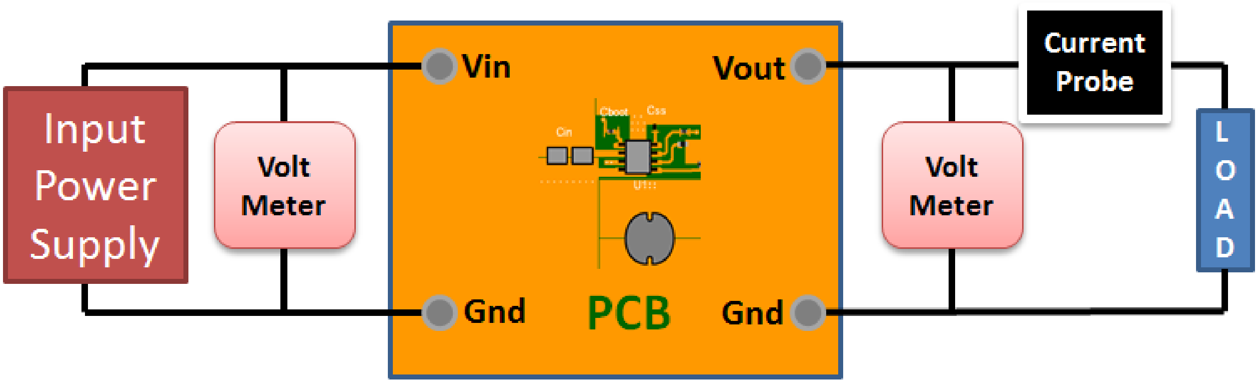
If board assembly is done in house it is best to tack down one terminal of a component on the board then solder the other terminal. For surface mount parts with large tabs, such as the DPAK, the tab on the back of the package should be pre-tinned with solder, then tacked into place by one of the pins. To solder the tab town to the board place the iron down on the board while resting against the tab, heating both surfaces simultaneously. Apply light pressure to the top of the plastic case until the solder flows around the part and the part is flush with the PCB. If the solder is not flowing around the board you may need a higher wattage iron (generally 25W to 30W is enough).

Initial Startup of Circuit

It is best to initially power up the board by setting the input supply voltage to the lowest operating input voltage 12.0V and set the input supply's current limit to zero. With the input supply off connect up the input supply to Vin and GND. Connect a digital volt meter and a load if needed to set the minimum Iout of the design from Vout and GND. Turn on the input supply and slowly turn up the current limit on the input supply. If the voltage starts to rise on the input supply continue increasing the input supply current limit while watching the output voltage. If the current increases on the input supply, but the voltage remains near zero, then there may be a short or a component misplaced on the board. Power down the board and visually inspect for solder bridges and recheck the diode and capacitor polarities. Once the power supply circuit is operational then more extensive testing may include full load testing, transient load and line tests to compare with simulation results.

Load Testing

The setup is the same as the initial startup, except that an additional digital voltmeter is connected between Vin and GND, a load is connected between Vout and GND and a current meter is connected in series between Vout and the load. The load must be able to handle at least rated output power + 50% (7.5 watts for this design). Ideally the load is supplied in the form of a variable load test unit. It can also be done in the form of suitably large power resistors. When using an oscilloscope to measure waveforms on the prototype board, the ground leads of the oscilloscope probes should be as short as possible and the area of the loop formed by the ground lead should be kept to a minimum. This will help reduce ground lead inductance and eliminate EMI noise that is not actually present in the circuit.



Design Assistance

1. Master key : 5A3AA0AEA993C20F55934295563702ED[v1]

2. **UCC2813-1** Product Folder : http://www.ti.com/product/UCC2813%2D1 : contains the data sheet and other resources.

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