EE 464
STATIC POWER CONVERSION-I
Spring 2022-2023

Homework 2
Complete Simulation Report

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Introduction

This report explains the design decisions for the hardware project. Furthermore, it presents the details of the Magnetic Design of the Isolated Power Supply and the simulation results for the selected topology.

Topology Selection

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

- Flyback converter
- Forward converter
- Push-Pull converter

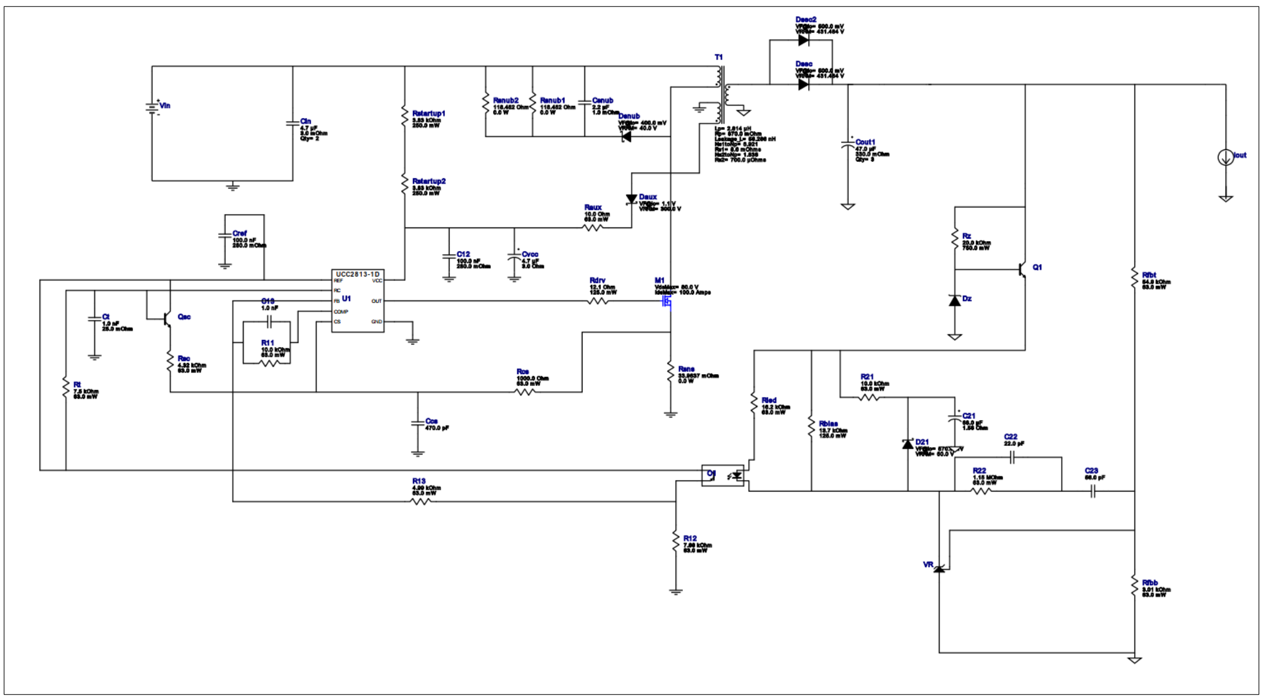


Figure 1: TI Webench design

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. However, after calculations, it is seen that this core is overkill. Afterward, **79440A7 toroidal core is selected** due to its high stock number and wide window area. A wide window area makes the wounding procedure easier.
2. Using the MATLAB code below, the primary turn number is 13, while the secondary turn number is 87. The magnetizing inductance is 8 uH.

```
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 = 51e-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 5 parallel 28 AWG wires. The primary, on the other hand, 18 parallel 28 AWG wires will be used.
4. According to the code below, the fill factor is 12.53%, which is reasonable.

```
windowArea_mm2 = 427;
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)
cableArea_mm2 = 0.080;
primaryArea_mm2 = priTurns*num_of_paralles_pri*cableArea_mm2
secondaryArea_mm2 = secTurns*num_of_paralles_sec*cableArea_mm2
totalCableArea_mm2 = primaryArea_mm2 + secondaryArea_mm2
fillFactor_perc = 100*totalCableArea_mm2/windowArea_mm2
```

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

```
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
```

The DC and AC resistances of the transformer are assumed equal thanks to the skin depth being greater than the radius.

Primary Resistance: 10.5 mOhm

Secondary Resistance: 252 mOhm

6. Copper losses are calculated by the code below:

```
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
DC_to_AC_ratio = 1
primary_AC_resistance_ohm = primary_DC_resistance_ohm*DC_to_AC_ratio
secondary_AC_resistance_ohm = secondary_DC_resistance_ohm*DC_to_AC_ratio
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
```

Total Copper Losses: 0.42 W

7. Core losses are calculated by the code below:

```
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))
```

Core Loss: 1.27 W

The core loss is comparable with the copper loss. Hence, the design is good. No need to iterate more.

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

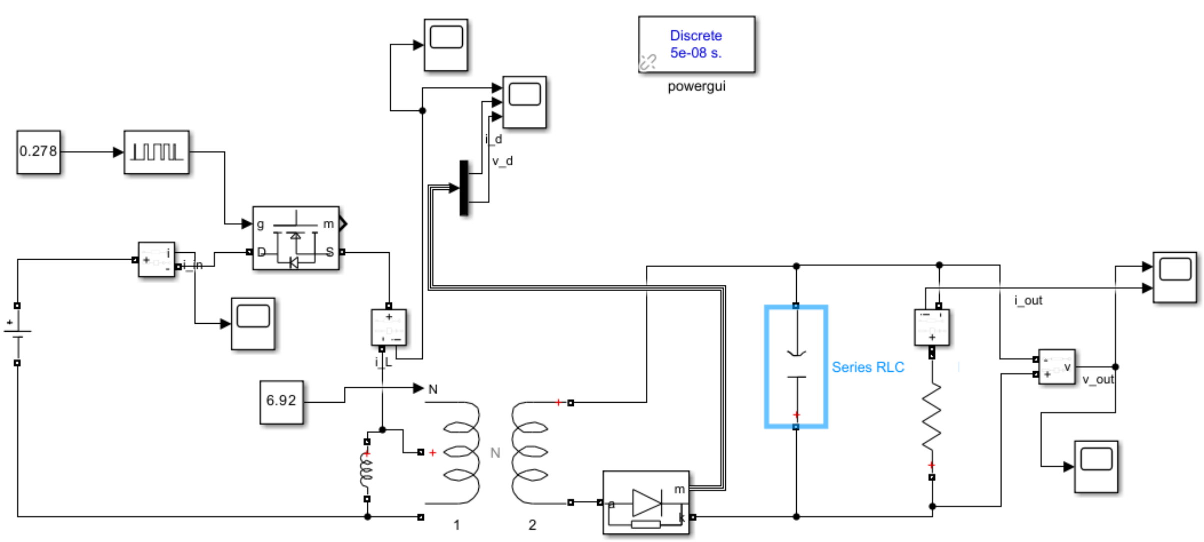


Figure 2: The Flyback converter in Simulink

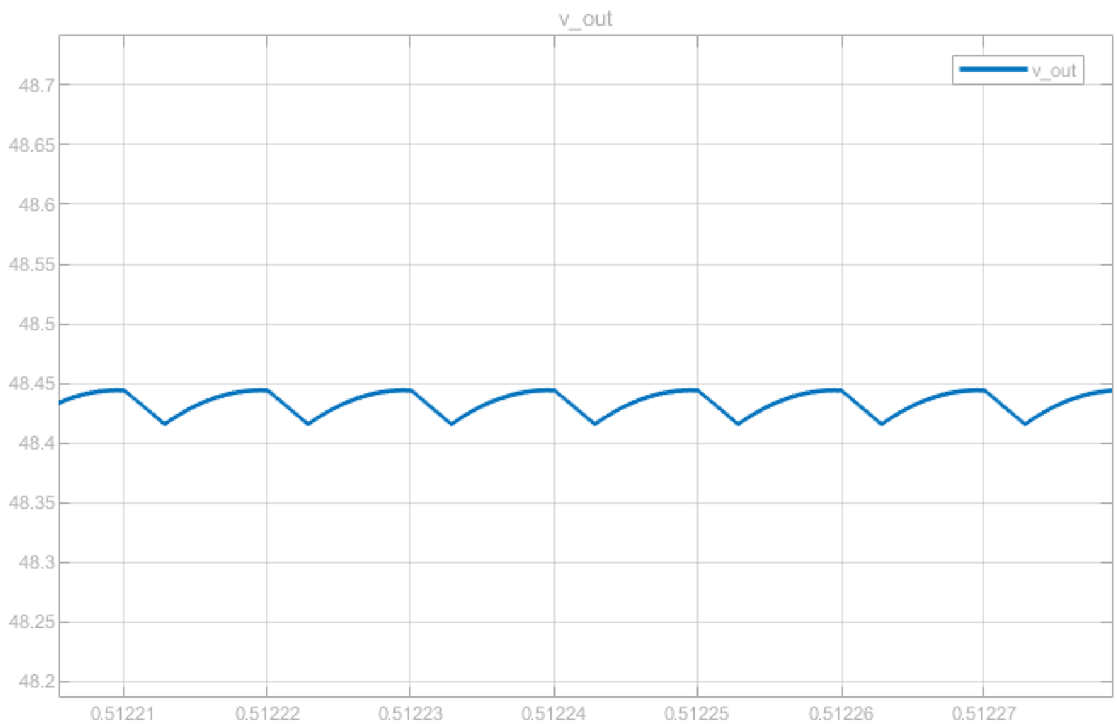


Figure 3: Output voltage ripple for 0.278 duty

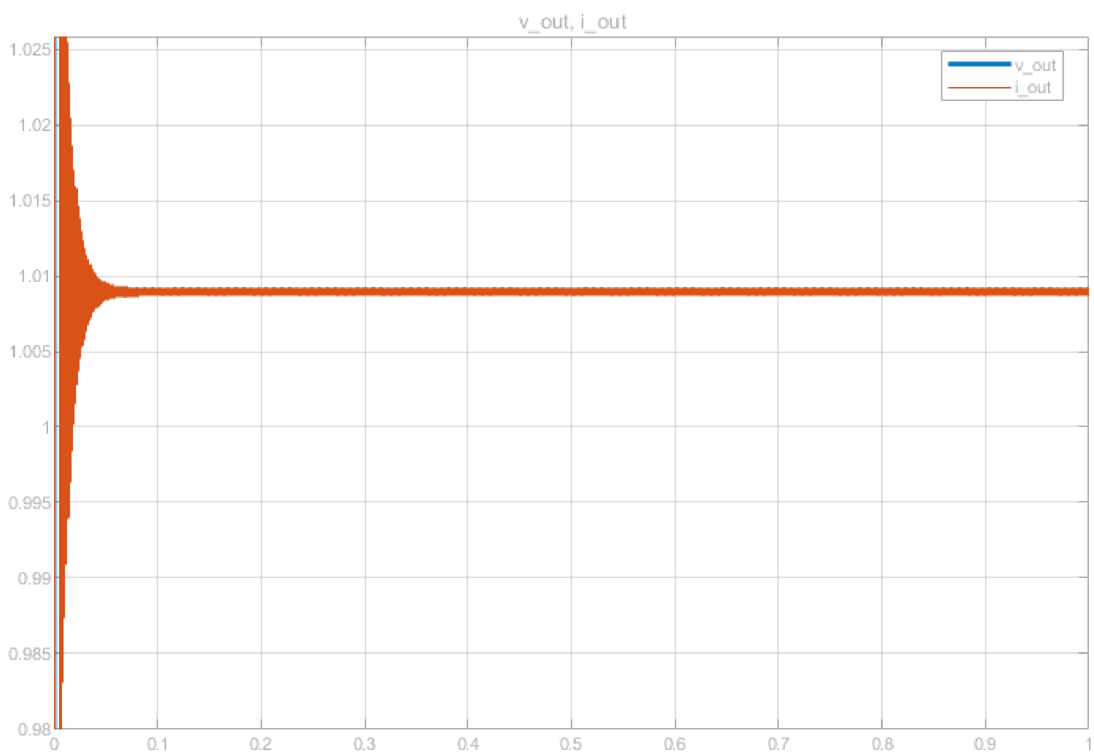


Figure 4: Output current waveform for 0.278 duty

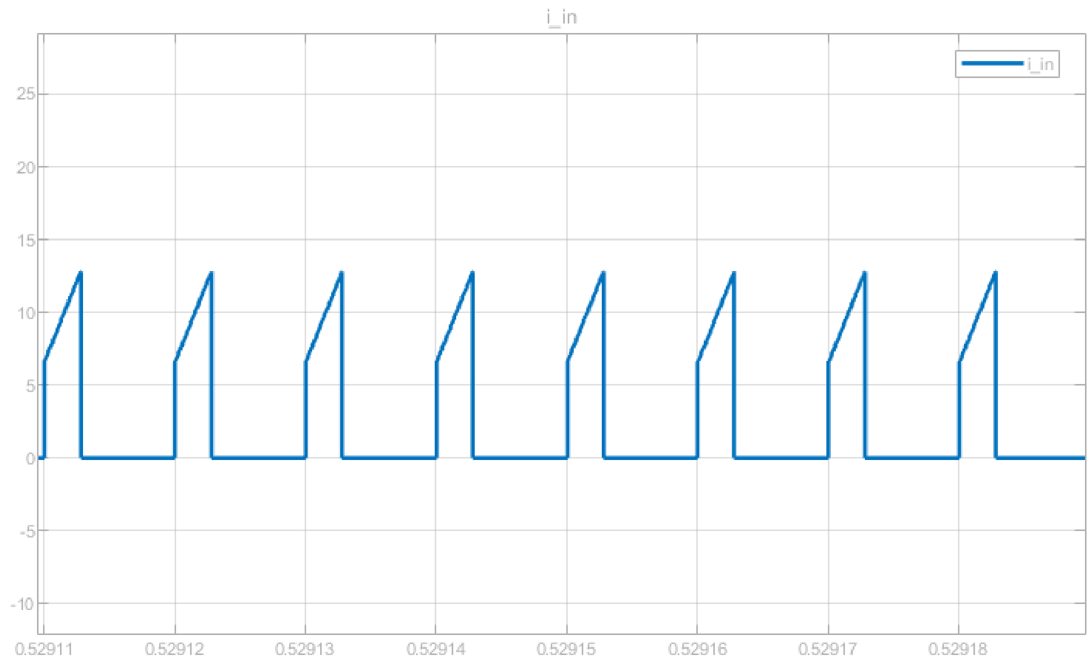


Figure 5: Input current waveform for 0.278 duty

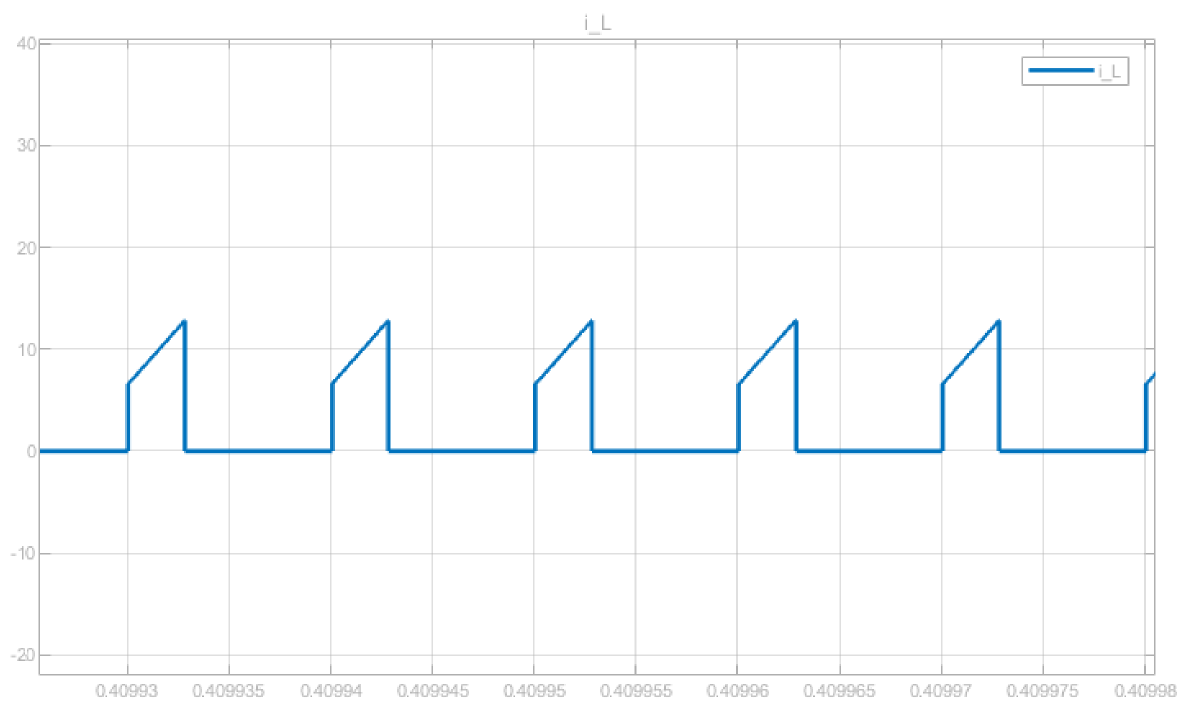


Figure 6: Transformer primary current waveform for 0.278 duty

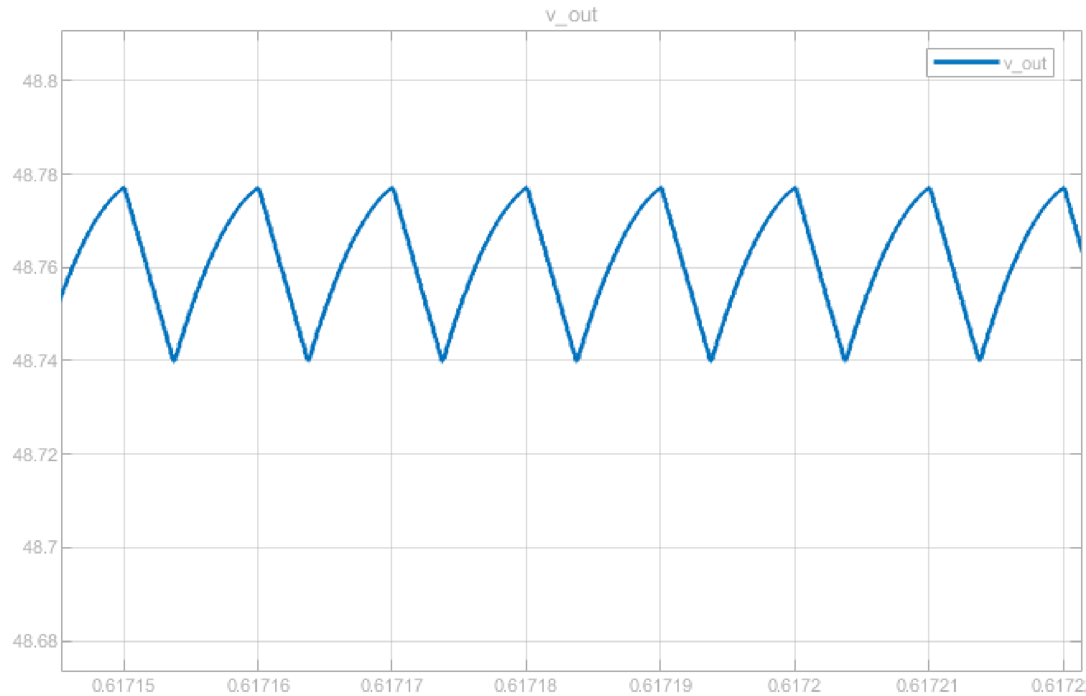


Figure 7: Output voltage ripple for 0.366 duty

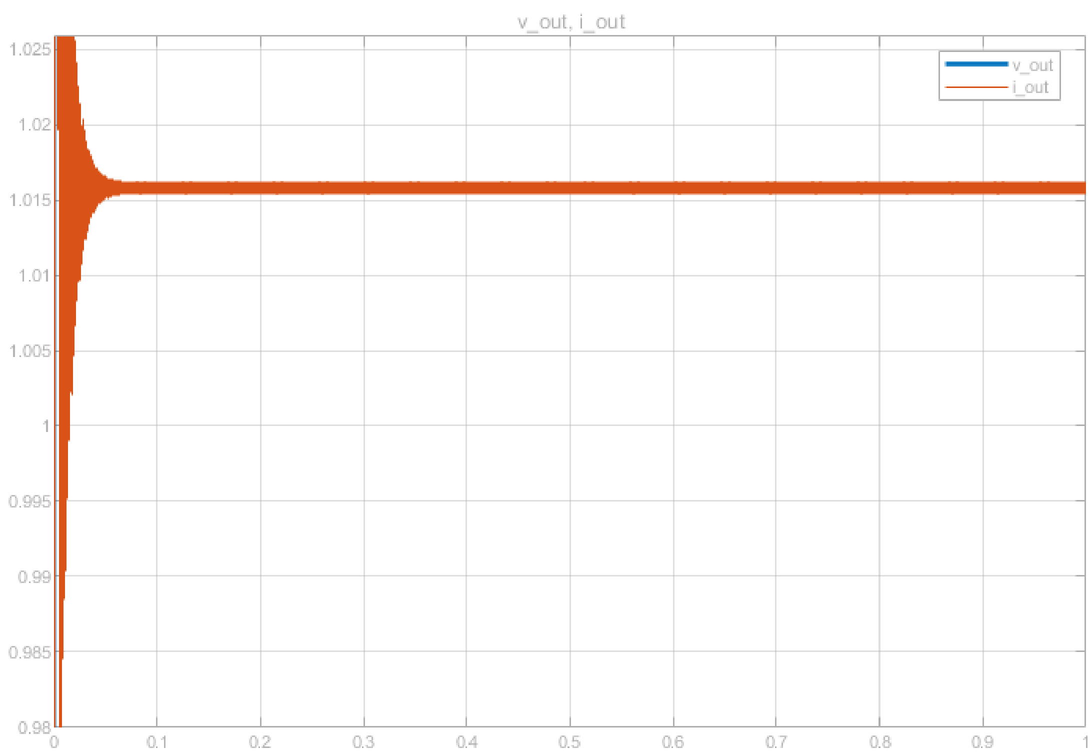


Figure 8: Output current waveform for 0.366 duty

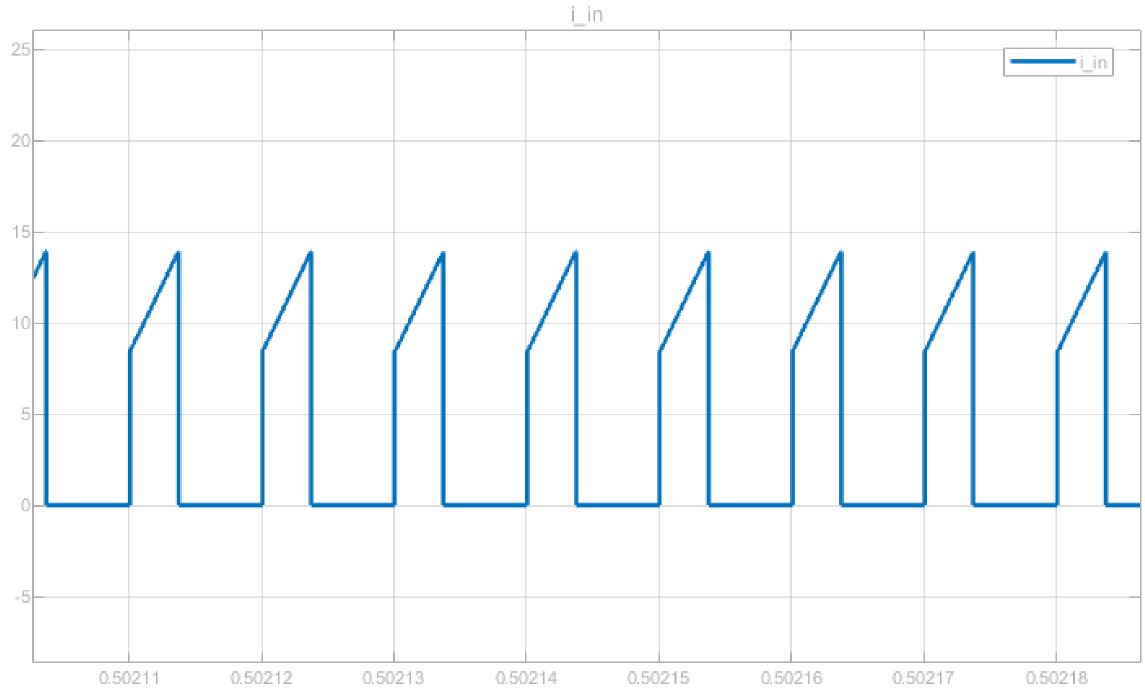


Figure 9: Input current waveform for 0.366 duty

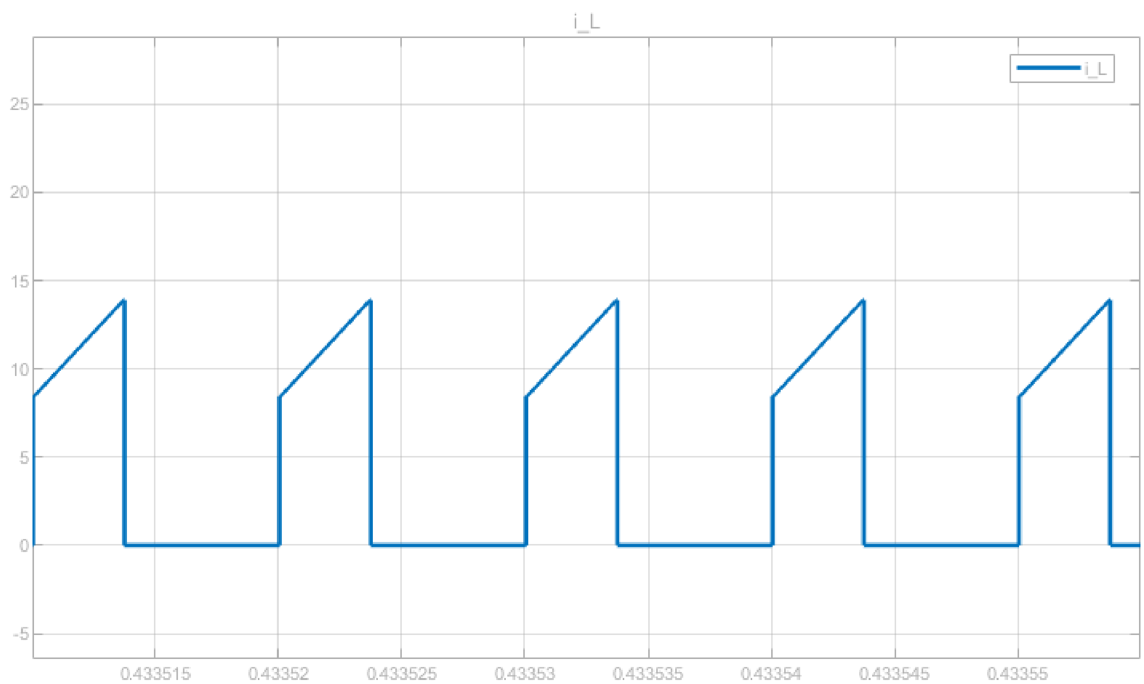


Figure 10: Transformer primary current waveform for 0.366 duty

Complete Simulations

Conclusion

Appendix – 1 [calc.mlx]

```
clearvars
u = symunit;
```

```
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
AL = 51e-9 % nH/T^2; minimal
```

```
AL =
    51.0000e-009
```

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

```
priTurns = 2×1
   -12.5537e+000
    12.5537e+000
```

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

```
secTurns = 2×1
   -86.9841e+000
    86.9841e+000
```

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

```
ampTurns = 2×1
   -86.9841e+000
    86.9841e+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
```

```
selectedAWGRating = 0.226;
num_of_paralles_sec = i_out/selectedAWGRating
```

```
num_of_paralles_sec =
     4.4248e+000
```

```
num_of_paralles_pri = i_in_max/selectedAWGRating
```

```
num_of_paralles_pri =
    17.6991e+000
```

Fill Factor Calculation

```
windowArea_mm2 = 427;
priTurns = ceil(priTurns(priTurns>0))
```

```
priTurns =
    13.0000e+000
```

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

```
secTurns =
    87.0000e+000
```

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

```
num_of_paralles_pri =
    18.0000e+000
```

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

```
num_of_paralles_sec =
     5.0000e+000
```

```


cableArea_mm2 = 0.080;


primaryArea_mm2 = priTurns*num_of_paralles_pri*cableArea_mm2
```

```
primaryArea_mm2 =
    18.7200e+000
```

```
secondaryArea_mm2 = secTurns*num_of_paralles_sec*cableArea_mm2
```

```
secondaryArea_mm2 =
    34.8000e+000
```

```
totalCableArea_mm2 = primaryArea_mm2 + secondaryArea_mm2
```

```
totalCableArea_mm2 =
    53.5200e+000
```

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

```
fillFactor_perc =
    12.5340e+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 =
   886.6000e-003
```

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

```
secondaryLength_m =
     5.9334e+000
```

```
primary_DC_resistance_ohm = ohms_per_meter * primaryLength_m / num_of_paralles_pri
```

```
primary_DC_resistance_ohm =
    10.4851e-003
```

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

```
secondary_DC_resistance_ohm =
   252.6109e-003
```

Copper Loss Calculation

```
diameter_mm = vpa(0.32004*u.mm)
```

diameter_mm = $0.32004\ \mathrm{mm}$

```
radius_mm = diameter_mm/2
```

radius_mm = $0.16002\ \mathrm{mm}$

```
skinDepth_cm = vpa(7.5/sqrt(f_sw)*u.cm)
```

skinDepth_cm = $0.023717082451262844989991701583245\ \mathrm{cm}$

```
skinDepth_mm = unitConvert(skinDepth_cm, u.mm)
```

skinDepth_mm = $0.23717082451262844989991701583245\ \mathrm{mm}$

```
% skin depth is greater than radius.
% Therefore, AC reistance equals DC resistance
DC_to_AC_ratio = 1
```

```
DC_to_AC_ratio =
     1.0000e+000
```

```
primary_AC_resistance_ohm = primary_DC_resistance_ohm*DC_to_AC_ratio
```

```
primary_AC_resistance_ohm =
    10.4851e-003
```

```
secondary_AC_resistance_ohm = secondary_DC_resistance_ohm*DC_to_AC_ratio
```

```
secondary_AC_resistance_ohm =
   252.6109e-003
```

```

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

resistancePri_ohm = $0.010485128622222223207516300647058\ \Omega$

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

resistanceSec_ohm = $0.25261094496000002784796834021108\ \Omega$

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

```
copperLossPri = 0.16776205795555557132026081035292 W
```

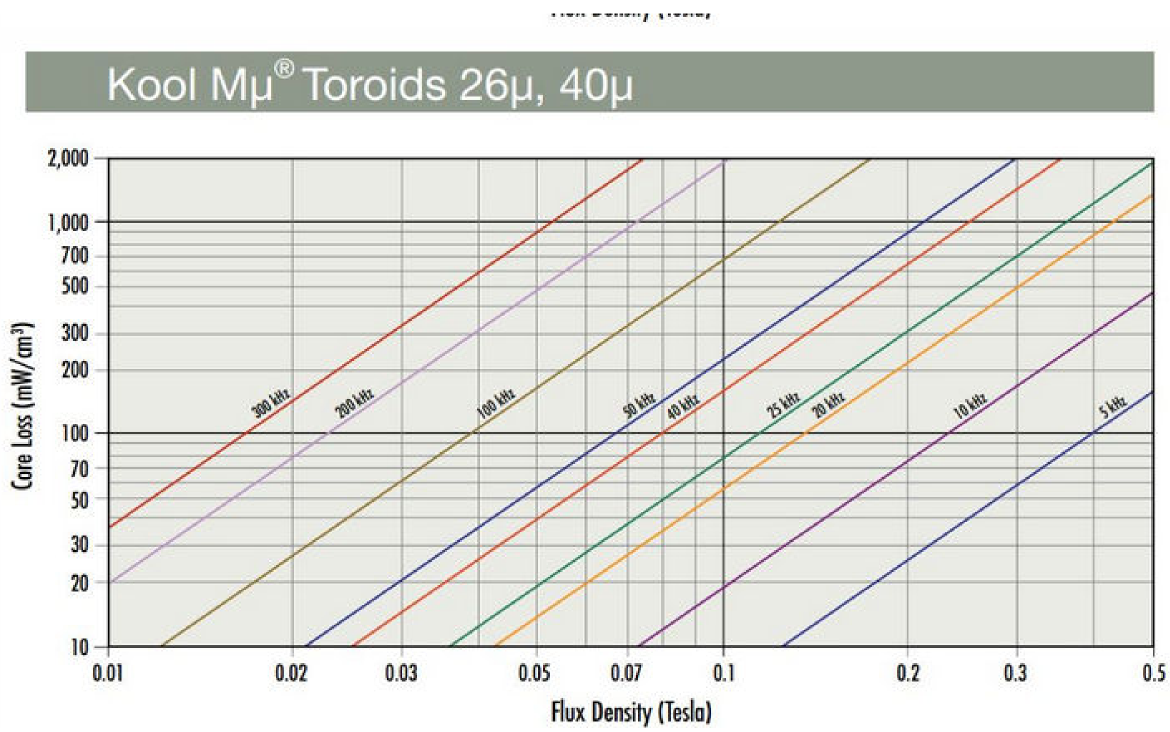
```
copperLossSec = vpa(unitConvert((i_out*u.A)^2 * resistanceSec_ohm, u.W))
```

```
copperLossSec = 0.25261094496000002784796834021108 W
```

```
copperLoss_W = copperLossPri + copperLossSec
```

```
copperLoss_W = 0.42037300291555559916822915056 4 W
```

Core Loss Calculation




```
permeability = 26;
mu_zero = 1.25663706212e-6;
pathLength_m = 107e-3;
fluxDensity_Tesla = mu_zero * permeability * ampTurns / pathLength_m
```

```
fluxDensity_Tesla = 2×1
   -26.5607e-003
    26.5607e-003
```

```
% using graph above, 0.03 Tesla @ 100 kHz corresponds to
wattLoss_mW_cm3 = 60*u.mW/u.cm^3
```

```
wattLoss_mW_cm3 =
```

$$60 \frac{\mathrm{mW}}{\mathrm{cm}^3}$$

```
volume_mm3 = 21300;
volume_cm3 = vpa(unitConvert(volume_mm3*u.mm^3, u.cm^3))
```

volume_cm3 = $21.3\ \mathrm{cm}^3$

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

coreLoss_w = $1.278\ \mathrm{W}$

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

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

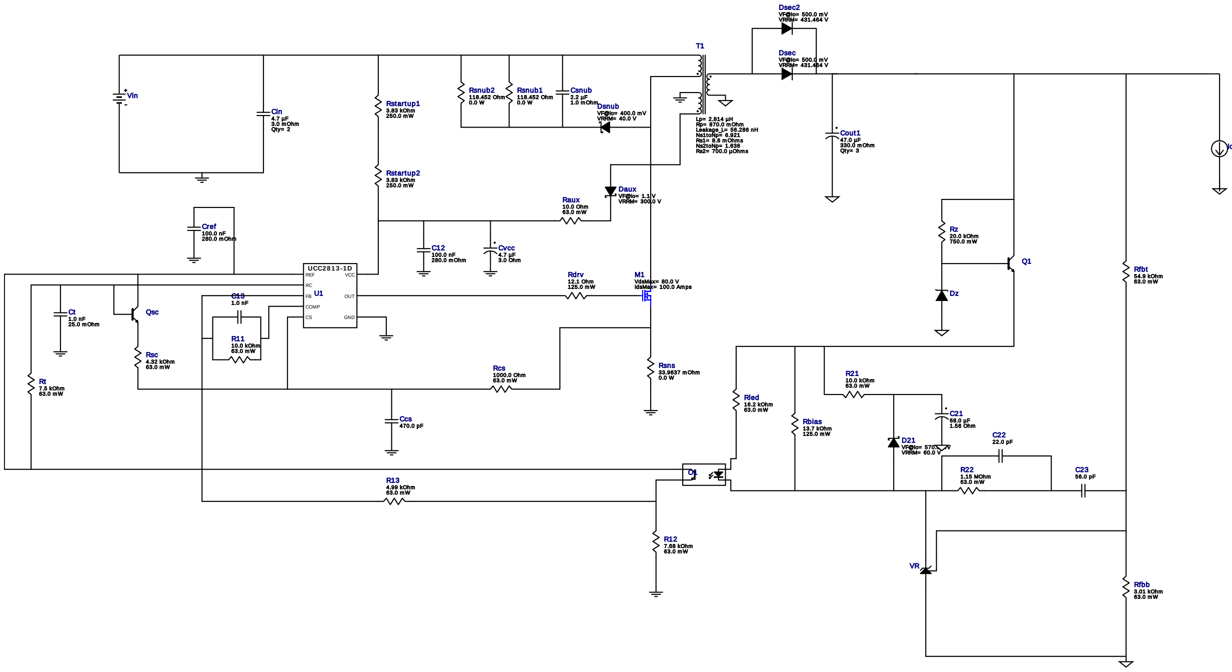
Appendix – 2 [TI Webench Design]

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

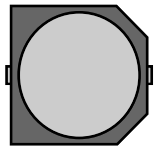
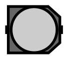
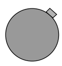
WEBENCH ® Design Report

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



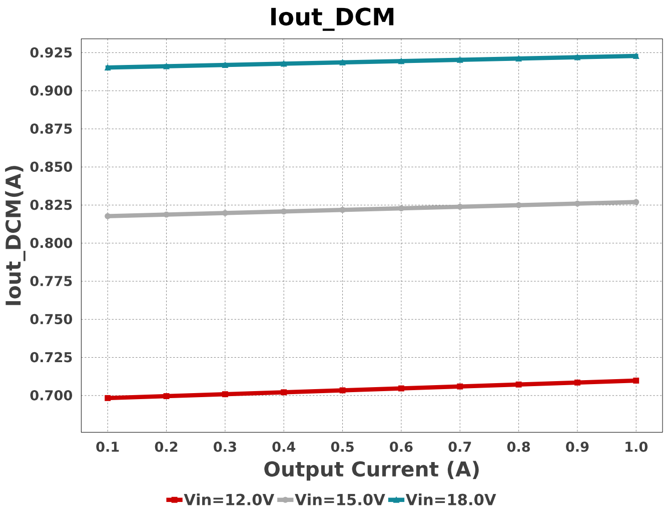
Electrical BOM

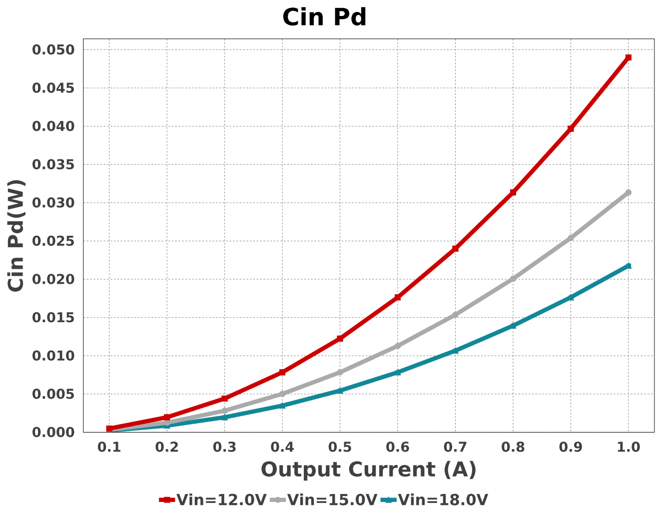
Name	Manufacturer	Part Number	Properties	Qty	Price	Footprint
C12	AVX	08053C104KAT2A Series= X7R	Cap= 100.0 nF ESR= 280.0 mOhm VDC= 25.0 V IRMS= 0.0 A	1	$0.01	0805 7 mm²
C13	MuRata	GRM1555C1H102JA01J Series= C0G/NP0	Cap= 1.0 nF VDC= 50.0 V IRMS= 0.0 A	1	$0.01	0402 3 mm²
C21	Chemi-Con	ELXZ630ELL680MH12D 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

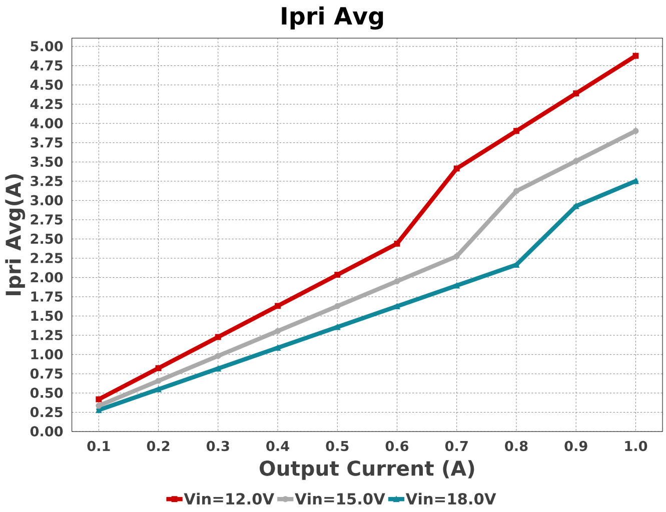
Name	Manufacturer	Part Number	Properties	Qty	Price	Footprint
Cout1	Chemi-Con	EMVY101ATR470MKE0S Series= MVY	Cap= 47.0 uF ESR= 330.0 mOhm VDC= 100.0 V IRMS= 450.0 mA	3	$0.40	 CAPSMT_62_KE0 225 mm^2
Cref	AVX	08053C104KAT2A Series= X7R	Cap= 100.0 nF ESR= 280.0 mOhm VDC= 25.0 V IRMS= 0.0 A	1	$0.01	0805 7 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

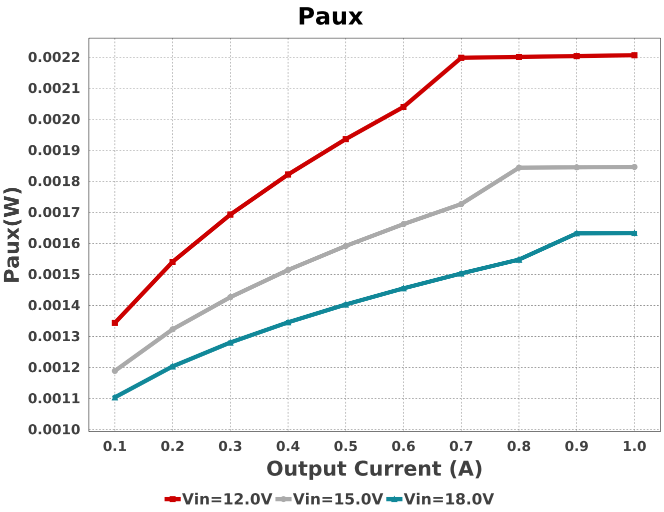
Name	Manufacturer	Part Number	Properties	Qty	Price	Footprint
Raux	Vishay-Dale	CRCW040210R0FKED Series= CRCW..e3	Res= 10.0 Ohm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm^2
Rbias	Vishay-Dale	CRCW080513K7FKEA Series= CRCW..e3	Res= 13.7 kOhm Power= 125.0 mW Tolerance= 1.0%	1	$0.01	0805 7 mm^2
Rcs	Vishay-Dale	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

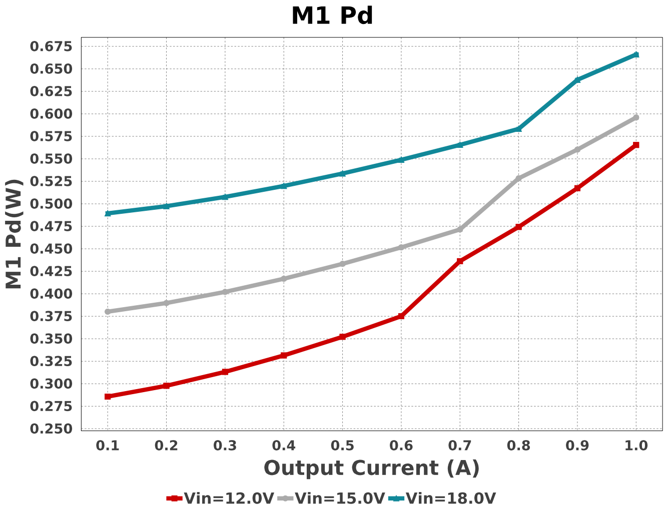
Name	Manufacturer	Part Number	Properties	Qty	Price	Footprint
VR	Texas Instruments	TL431IDBVR	Voltage References	1	$0.09	R-PDSO-G3 16 mm²

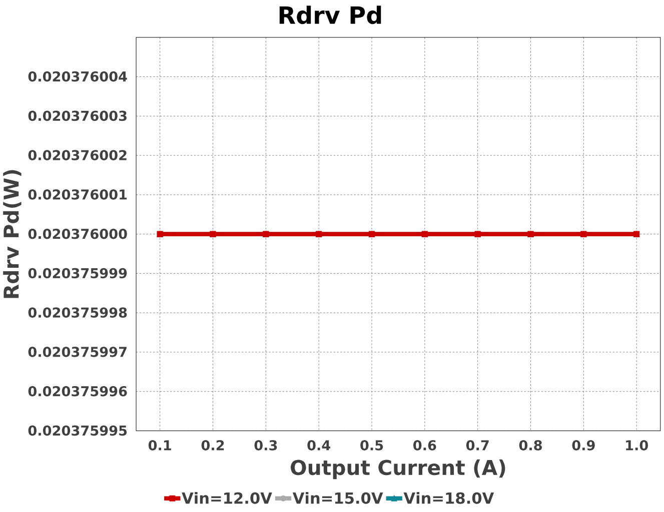


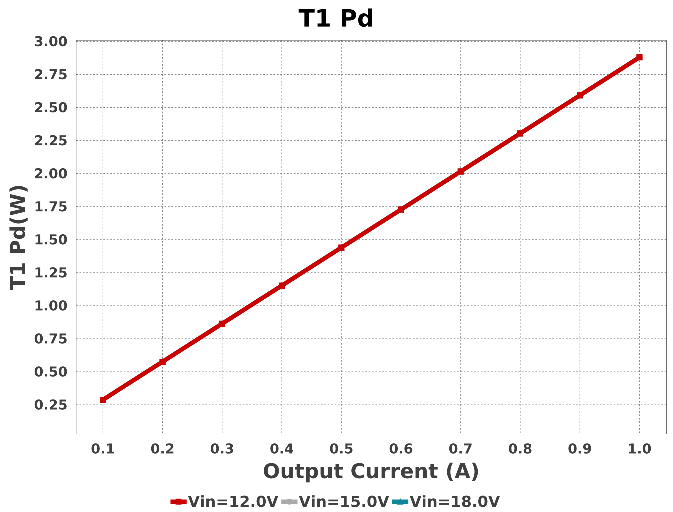


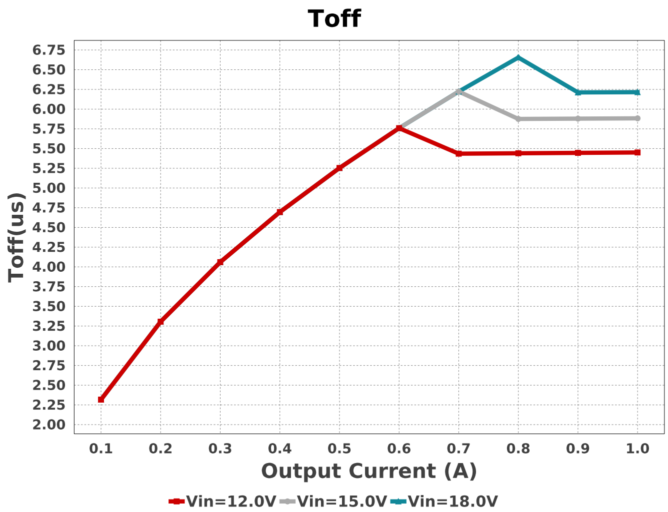


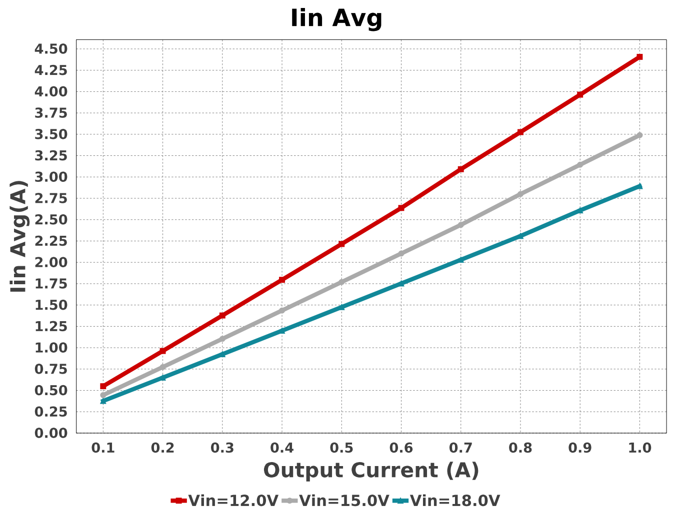


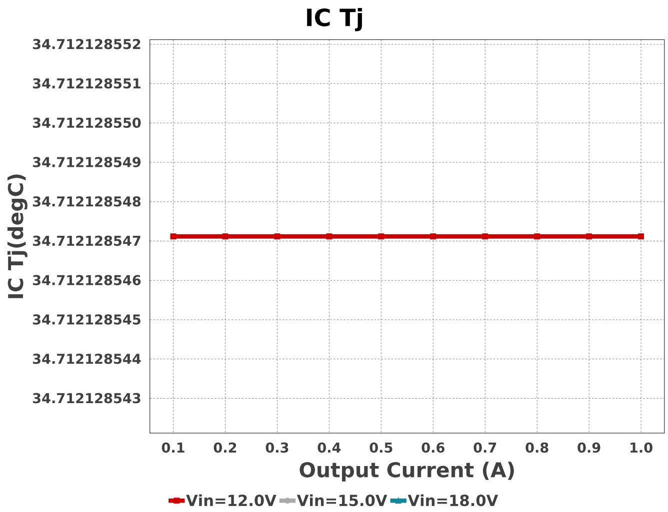


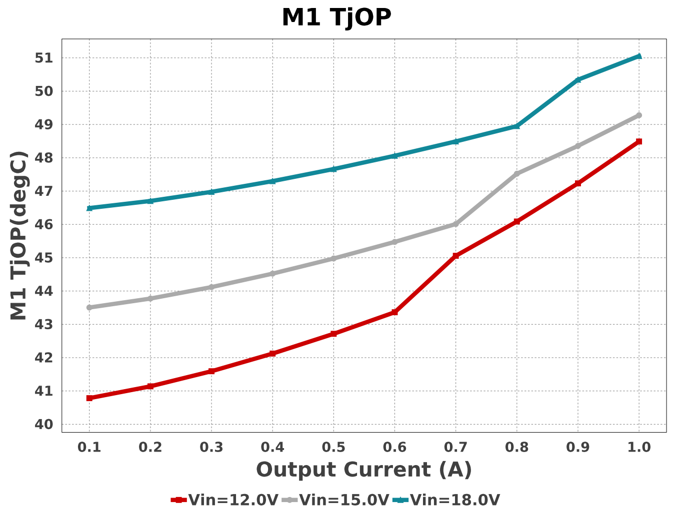


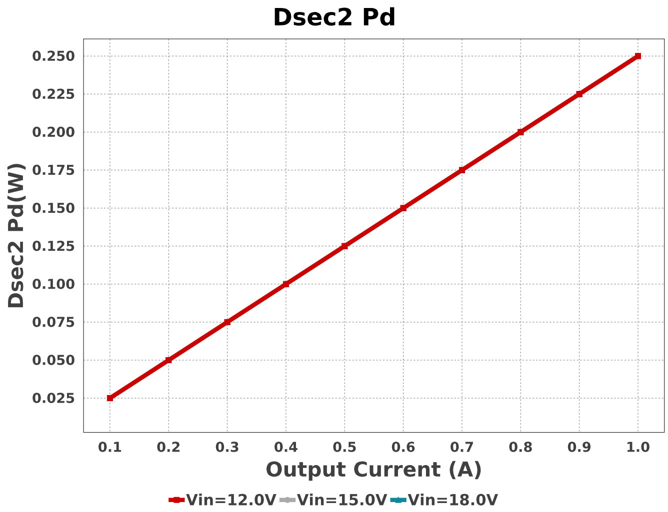

T1 Pd
T1 Pd(W)
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V

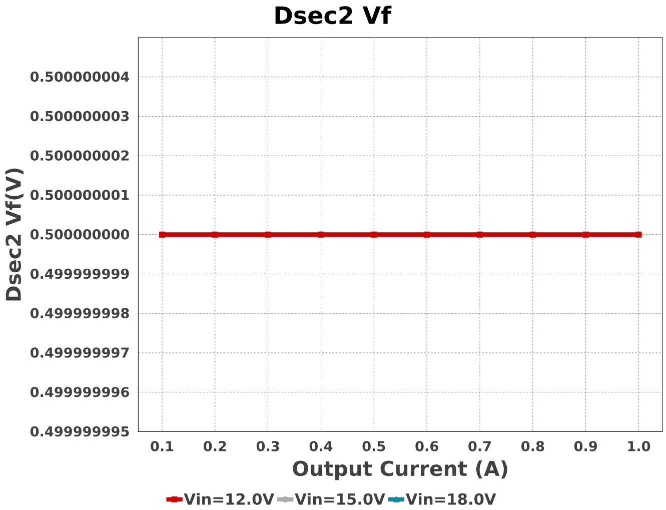

Toff
Toff(us)
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V

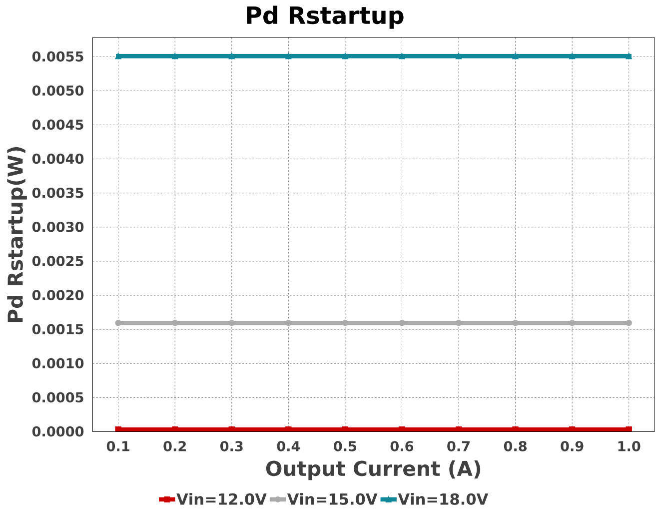

Iin Avg
Iin Avg(A)
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V

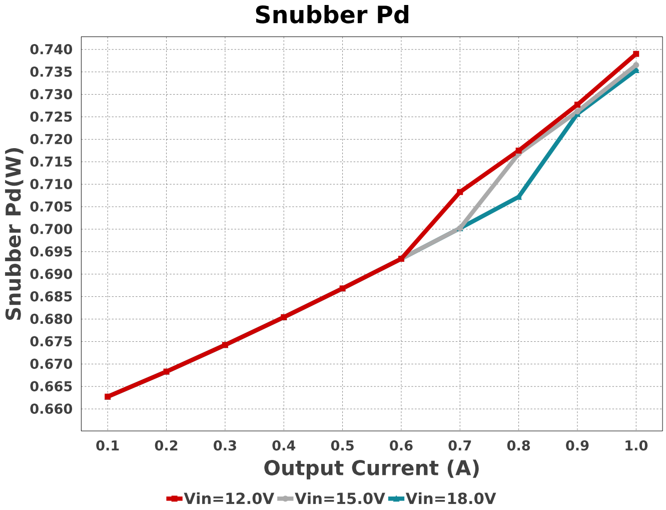

IC Tj
IC Tj(degC)
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V

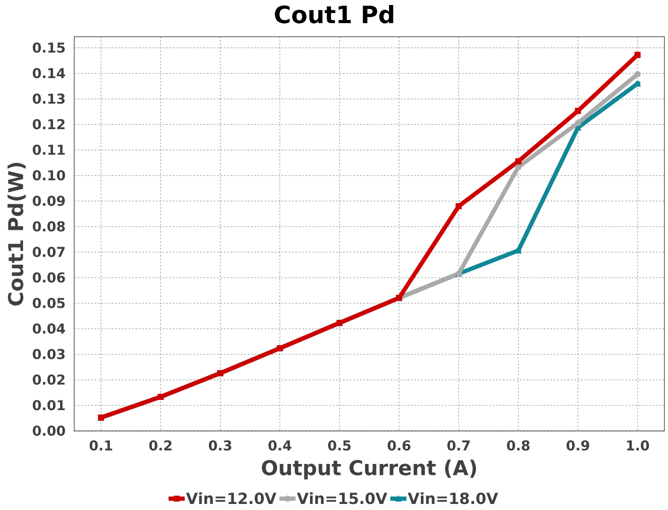

M1 TjOP
M1 TjOP(degC)
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V

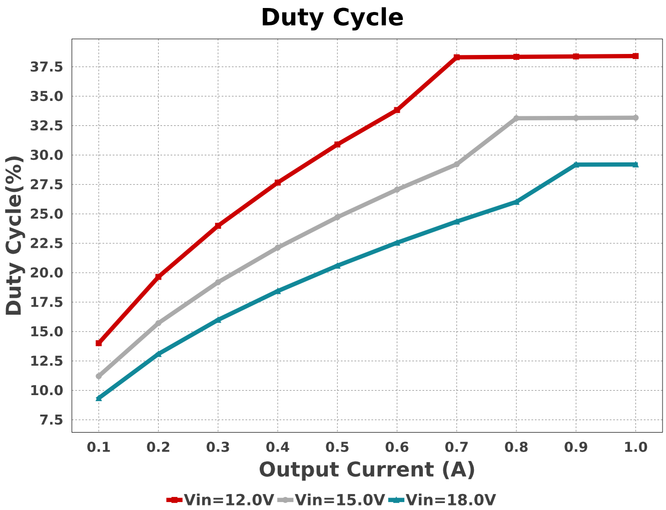

Dsec2 Pd
Dsec2 Pd(W)
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V

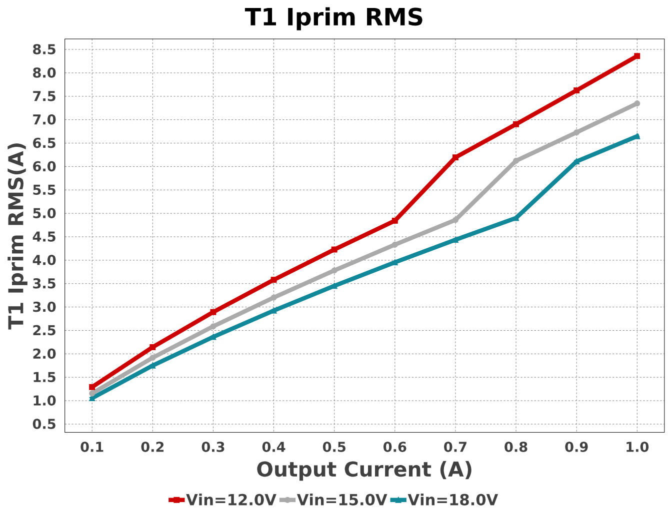

Dsec2 Vf
Dsec2 Vf(V)
0.500000004
0.500000003
0.500000002
0.500000001
0.500000000
0.499999999
0.499999998
0.499999997
0.499999996
0.499999995
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V

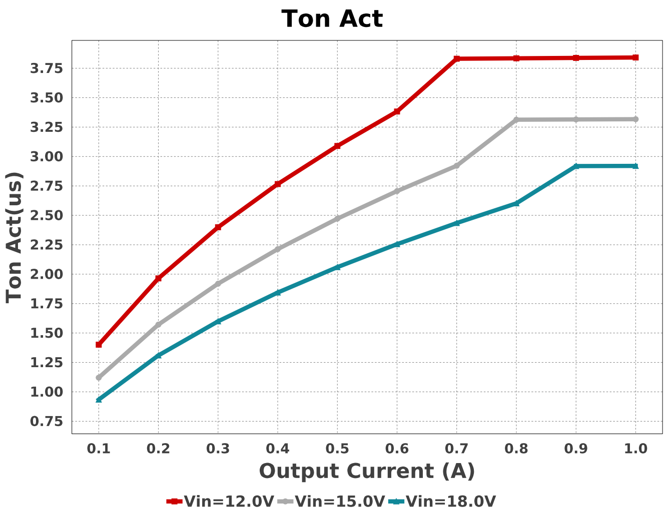

Pd Rstartup
Pd Rstartup(W)
0.0055
0.0050
0.0045
0.0040
0.0035
0.0030
0.0025
0.0020
0.0015
0.0010
0.0005
0.0000
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V

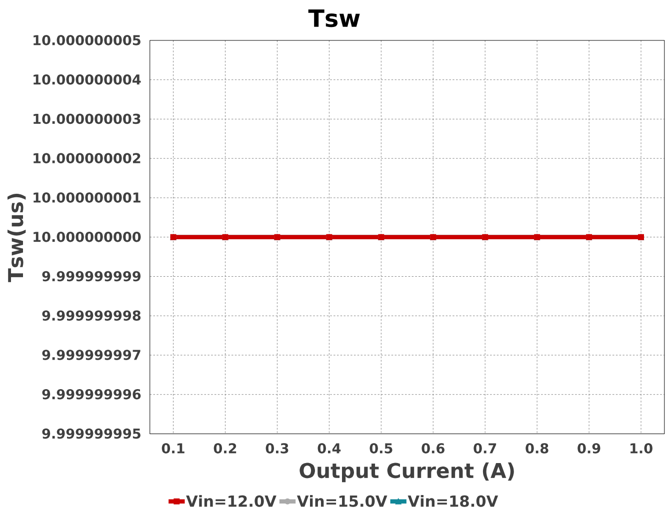

Snubber Pd
Snubber Pd(W)
0.740
0.735
0.730
0.725
0.720
0.715
0.710
0.705
0.700
0.695
0.690
0.685
0.680
0.675
0.670
0.665
0.660
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V

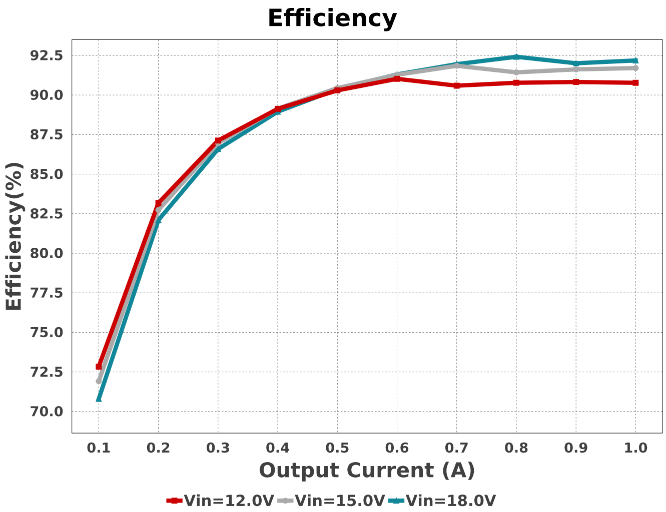

Cout1 Pd
Cout1 Pd(W)
0.15
0.14
0.13
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V

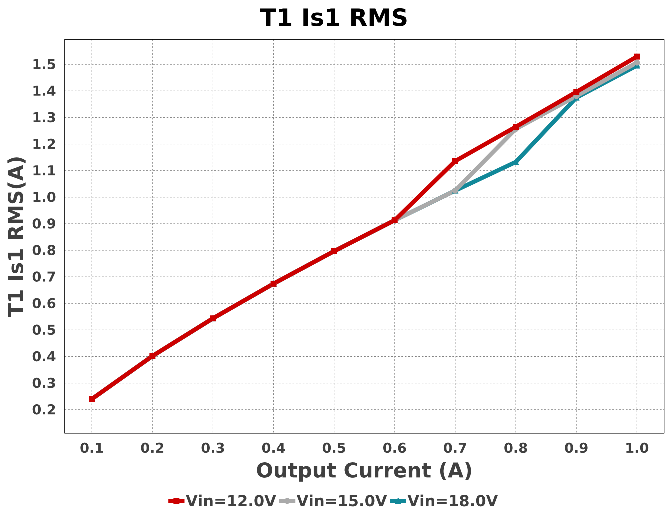

Duty Cycle
Duty Cycle(%)
37.5
35.0
32.5
30.0
27.5
25.0
22.5
20.0
17.5
15.0
12.5
10.0
7.5
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V

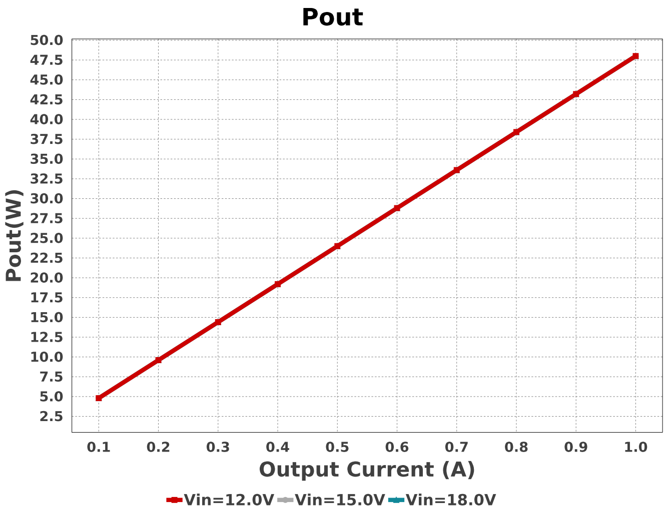

T1 Iprim RMS
T1 Iprim RMS(A)
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V

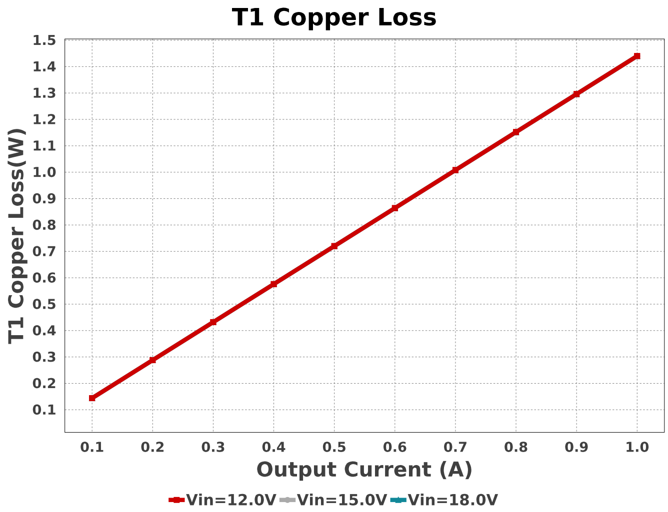

Ton Act
Ton Act(us)
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V

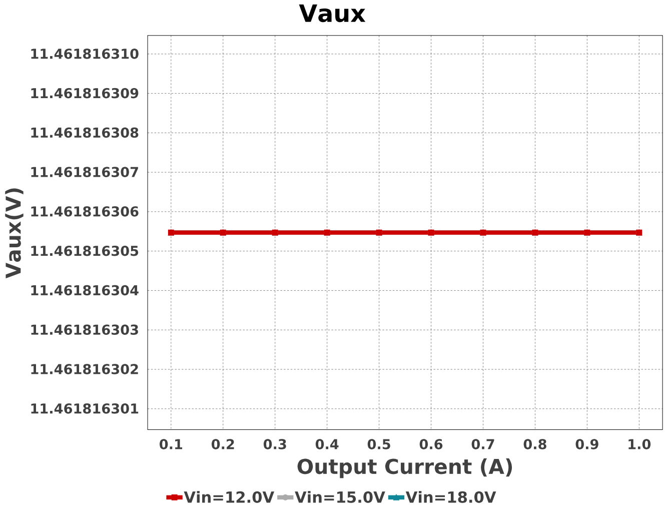

Tsw
Tsw(us)
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V

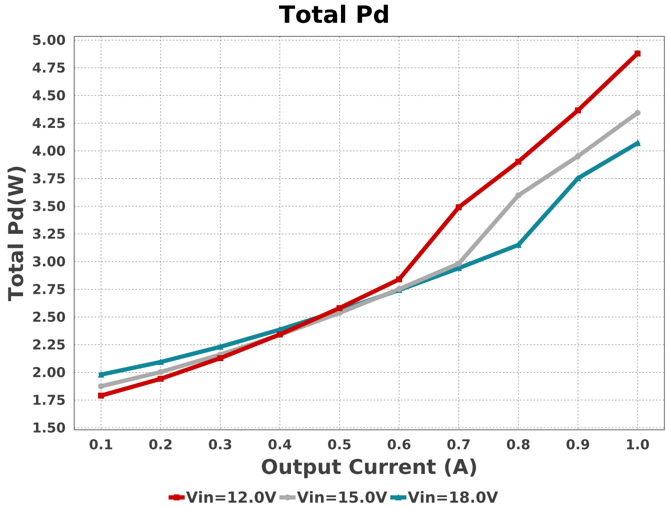

Efficiency
Efficiency(%)
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V

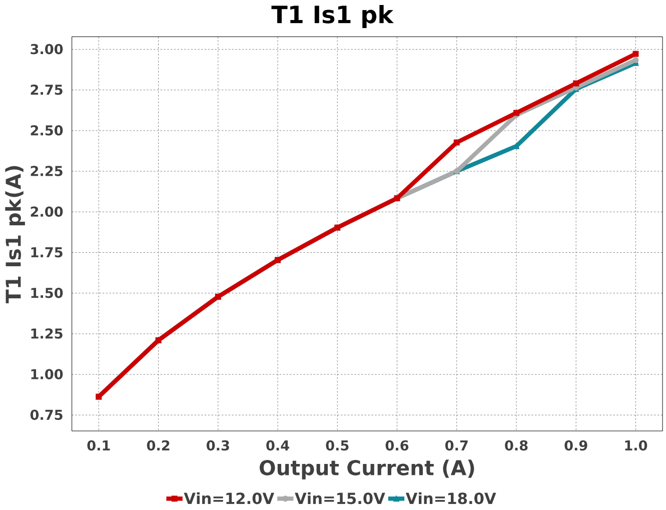

T1 Is1 RMS
T1 Is1 RMS(A)
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V

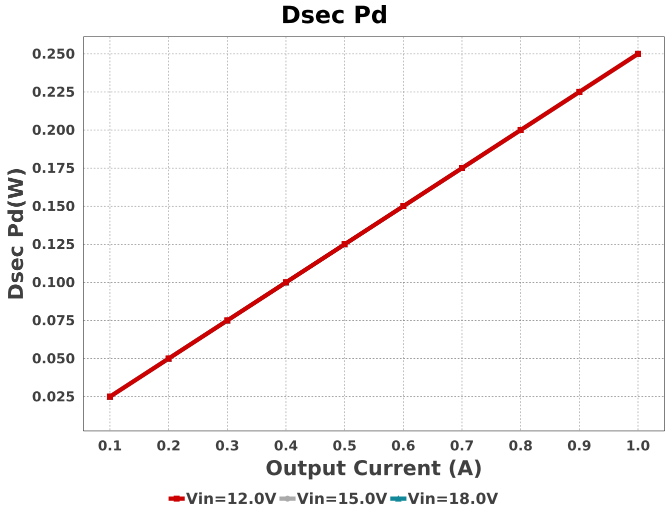

Pout
Pout(W)
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V

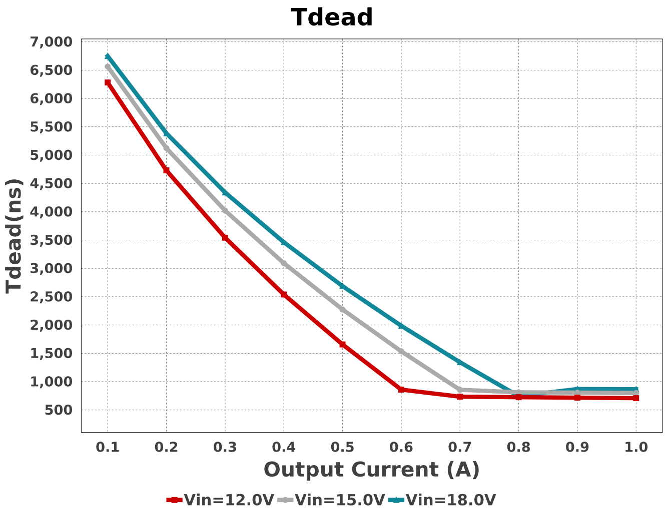

T1 Copper Loss
T1 Copper Loss(W)
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V

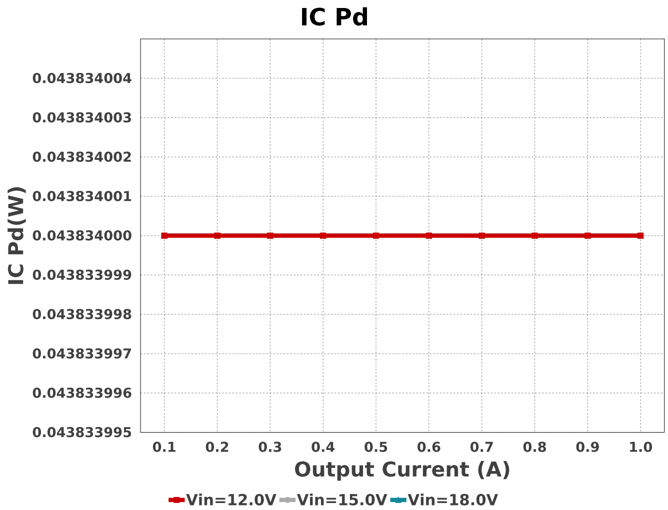

Vaux
Vaux(V)
11.461816310
11.461816309
11.461816308
11.461816307
11.461816306
11.461816305
11.461816304
11.461816303
11.461816302
11.461816301
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V

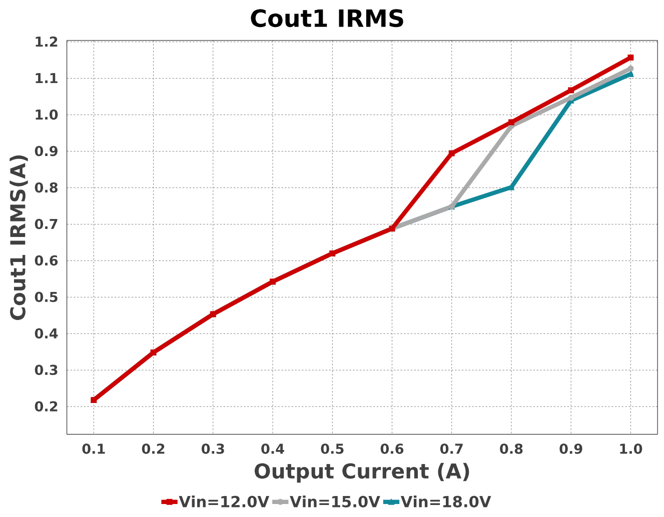

Total Pd
Total Pd(W)
5.00 4.75 4.50 4.25 4.00 3.75 3.50 3.25 3.00 2.75 2.50 2.25 2.00 1.75 1.50
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V

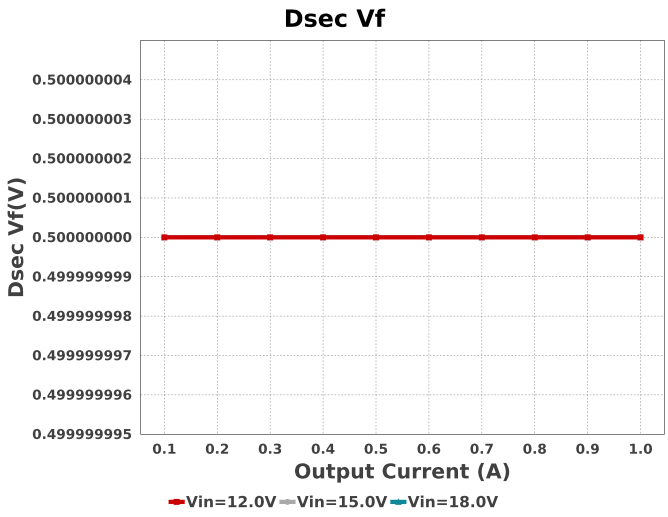

T1 Is1 pk
T1 Is1 pk(A)
3.00 2.75 2.50 2.25 2.00 1.75 1.50 1.25 1.00 0.75
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V

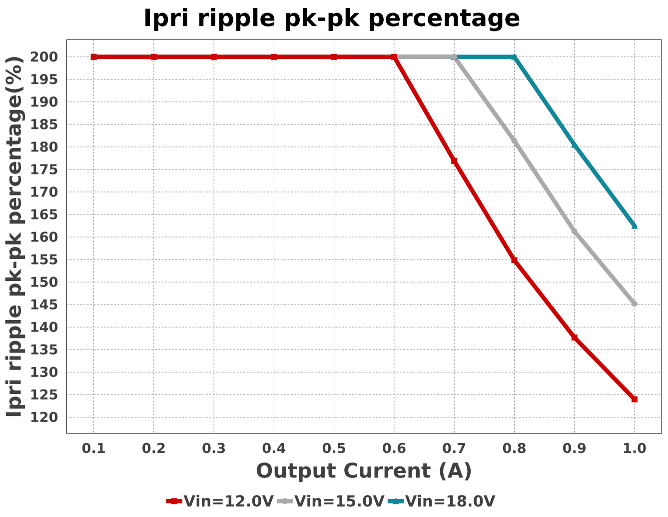

Dsec Pd
Dsec Pd(W)
0.250 0.225 0.200 0.175 0.150 0.125 0.100 0.075 0.050 0.025
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V

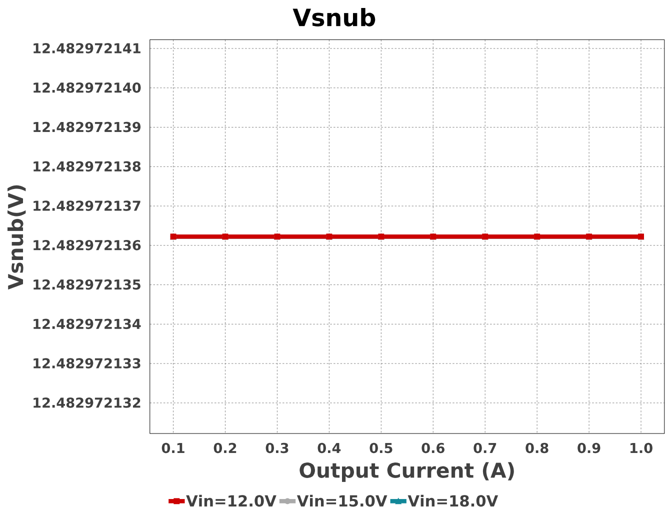

Tdead
Tdead(ns)
7,000 6,500 6,000 5,500 5,000 4,500 4,000 3,500 3,000 2,500 2,000 1,500 1,000 500
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V

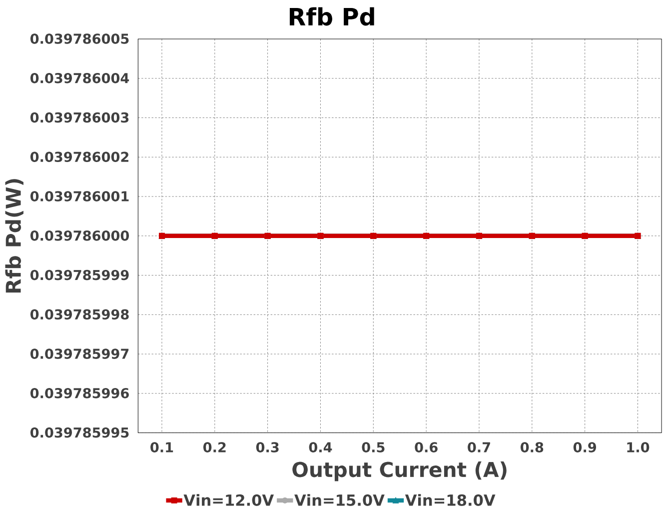

IC Pd
IC Pd(W)
0.043834004
0.043834003
0.043834002
0.043834001
0.043834000
0.043833999
0.043833998
0.043833997
0.043833996
0.043833995
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V

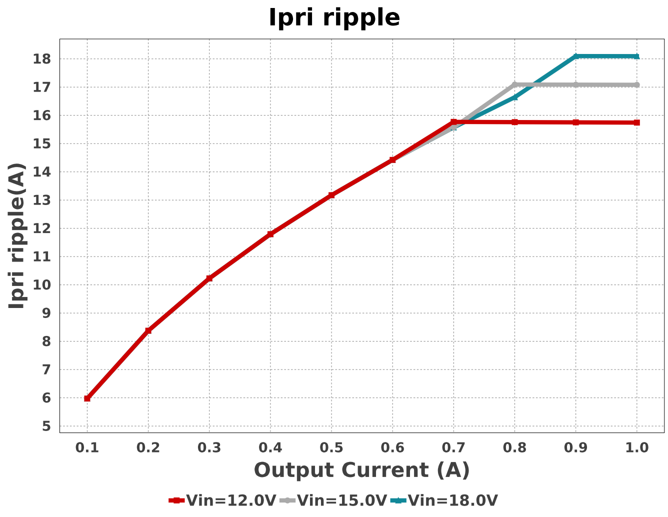

Cout1 IRMS
Cout1 IRMS(A)
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V

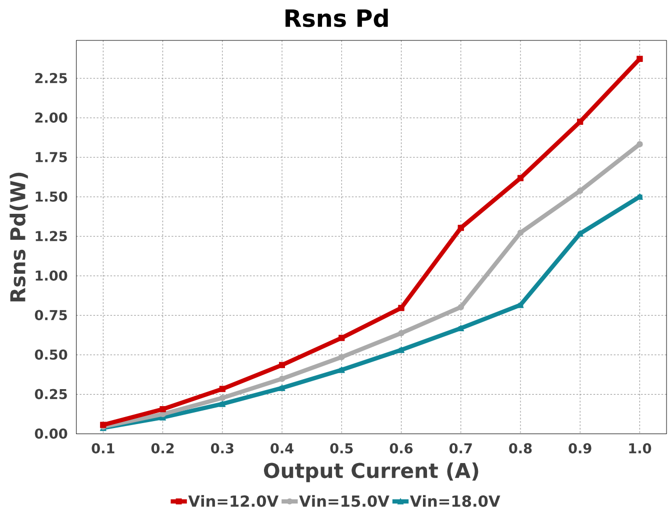

Dsec Vf
Dsec Vf(V)
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V

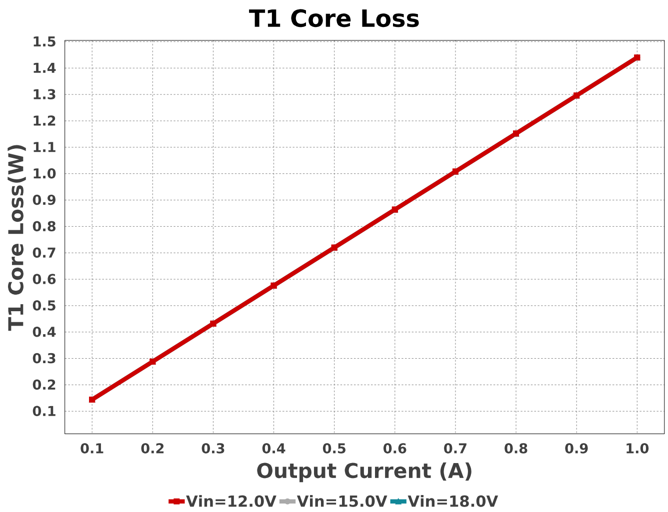

Ipri ripple pk-pk percentage
Ipri ripple pk-pk percentage(%)
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V

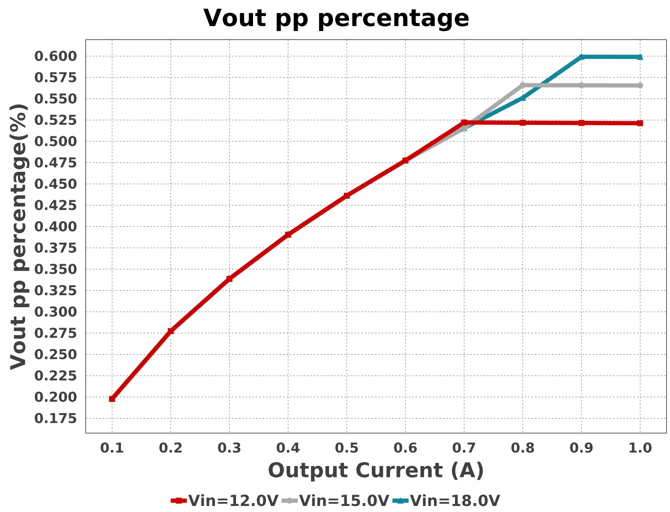

Vsnub
Vsnub(V)
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V

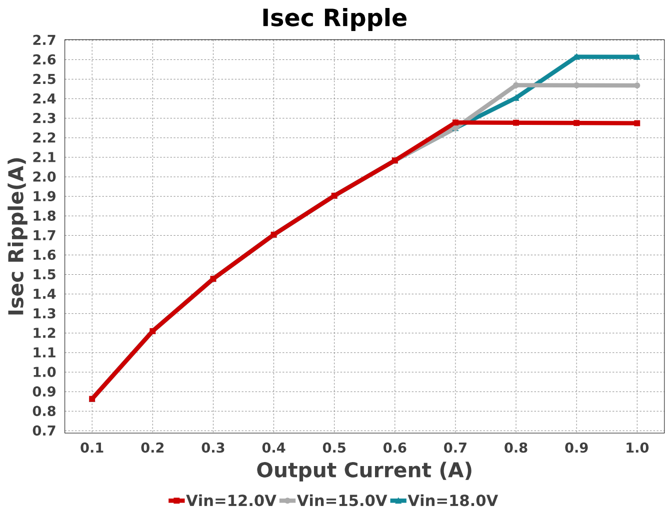

Rfb Pd
Rfb Pd(W)
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V

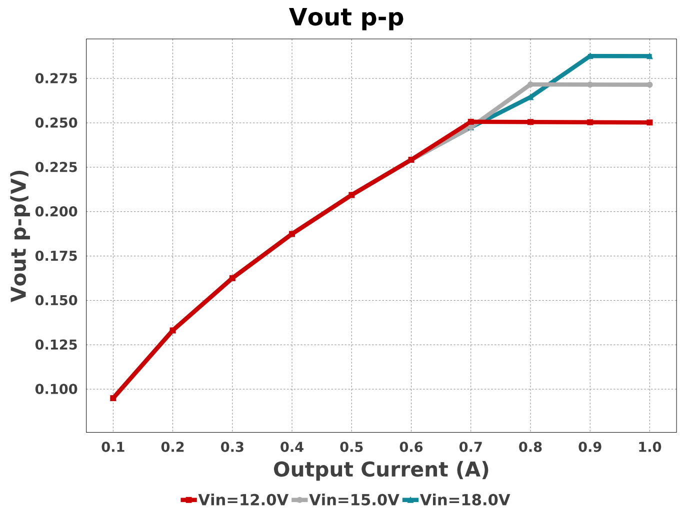

Ipri ripple
Ipri ripple(A)
Output Current (A)
Vin=12.0V Vin=15.0V Vin=18.0V

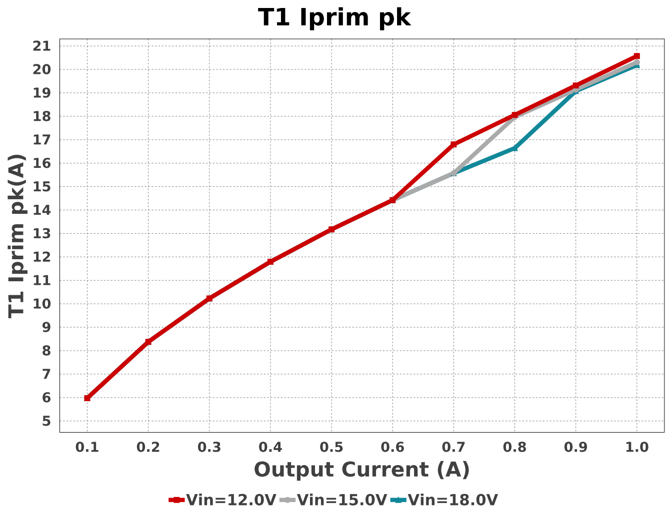












Operating Values

#	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

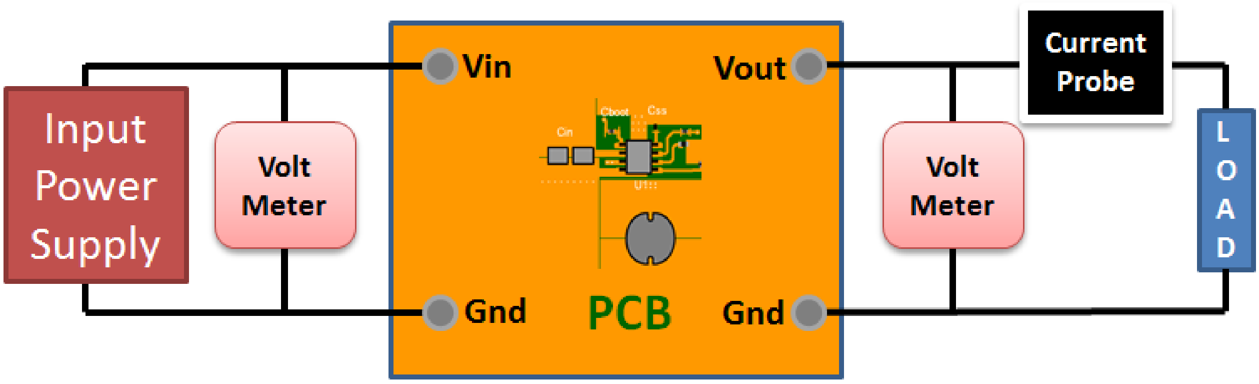
If board assembly is done in house it is best to tack down one terminal of a component on the board then solder the other terminal. For surface mount parts with large tabs, such as the DPAK, the tab on the back of the package should be pre-tinned with solder, then tacked into place by one of the pins. 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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