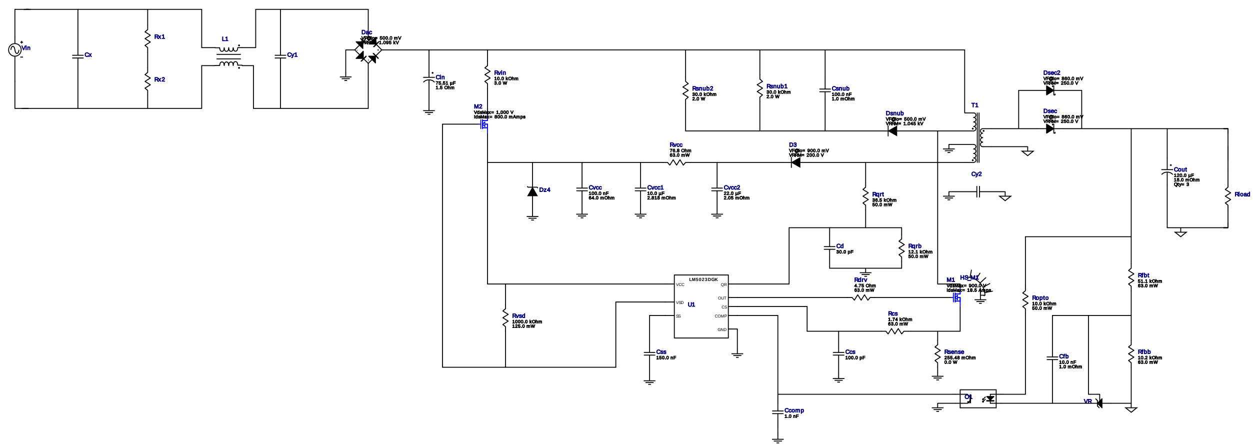
TEXAS INSTRUMENTS

# WEBENCH® Design Report

VinMin = 85.0V
VinMax = 484.0V
Vout = 15.0V
Iout = 2.5A

Device = LM5023MMX-2/NOPB
Topology = Flyback
Created = 2021-06-21 22:24:33.848
BOM Cost = NA
BOM Count = 39
Total Pd = 5.05W

Design : 38 LM5023MMX-2/NOPB
LM5023MMX-2/NOPB 85V-484V to 15.00V @ 2.5A



1. The EMI filter shown in the schematic is a placeholder. It has not yet been designed for the application.

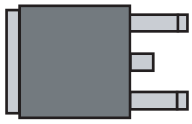
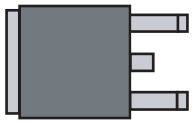
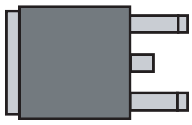
## Design Alerts

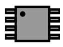
### Component Selection Information

Click on the transformer symbol in the schematic and select "Explore Transformer Core/Bobbin Selection" to design using specific transformer cores and bobbin.

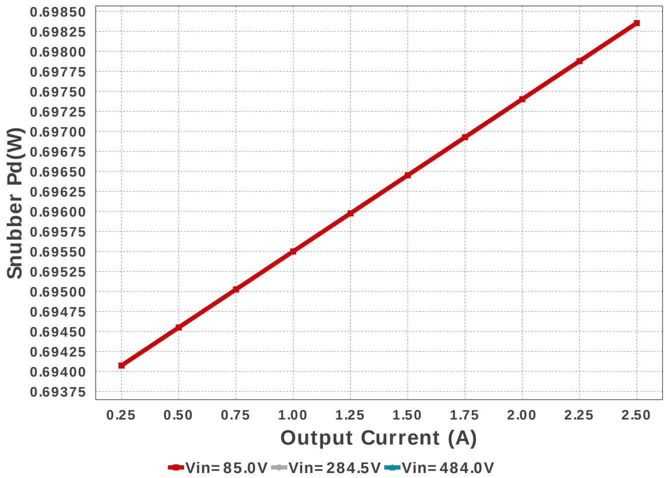
## Electrical BOM

| Name | Manufacturer | Part Number | Properties | Qty | Price | Footprint |
|---|---|---|---|---|---|---|
| Ccomp | MuRata | GRM1555C1H102JA01J<br>Series= C0G/NP0 | Cap= 1.0 nF<br>VDC= 50.0 V<br>IRMS= 0.0 A | 1 | $0.01 | 0402 3 mm² |
| Ccs | Samsung Electro-Mechanics | CL21C101JBANNNC<br>Series= C0G/NP0 | Cap= 100.0 pF<br>VDC= 50.0 V<br>IRMS= 0.0 A | 1 | $0.01 | 0805 7 mm² |
| Cd | Samsung Electro-Mechanics | CL21C300JBANNNC<br>Series= C0G/NP0 | Cap= 30.0 pF<br>VDC= 50.0 V<br>IRMS= 0.0 A | 1 | $0.01 | 0805 7 mm² |
| Cfb | MuRata | GRM033R70J103KA01D<br>Series= X7R | Cap= 10.0 nF<br>ESR= 1.0 mOhm<br>VDC= 6.3 V<br>IRMS= 0.0 A | 1 | $0.01 | 0201 2 mm² |
| Cin | CUSTOM | CUSTOM<br>Series= ? | Cap= 75.51 uF<br>ESR= 1.5005 Ohm<br>VDC= 718.7 V<br>IRMS= 1.03031 A | 1 | NA | CUSTOM 0 mm² |
| Cout | Panasonic | 35SEPF120M<br>Series= SEPF | Cap= 120.0 uF<br>ESR= 18.0 mOhm<br>VDC= 35.0 V<br>IRMS= 4.4 A | 3 | $0.69 | SEPF_F13 144 mm² |
| Csnub | MuRata | GRM43DR72J104KW01L<br>Series= X7R | Cap= 100.0 nF<br>ESR= 1.0 mOhm<br>VDC= 630.0 V<br>IRMS= 0.0 A | 1 | $0.53 | 1812 23 mm² |
| Css | Panasonic | ECPU1C154MA5<br>Series= ECPU(A) | Cap= 150.0 nF<br>VDC= 16.0 V<br>IRMS= 0.0 A | 1 | $0.17 | 1206 11 mm² |

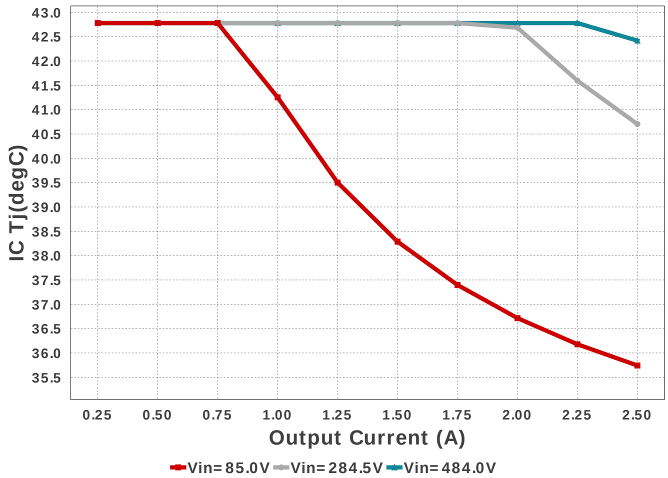
| Name | Manufacturer | Part Number | Properties | Qty | Price | Footprint |
|---|---|---|---|---|---|---|
| Cvcc | Kemet | C0805C104M5RACTU<br>Series= X7R | Cap= 100.0 nF<br>ESR= 64.0 mOhm<br>VDC= 50.0 V<br>IRMS= 1.64 A | 1 | $0.01 | 0805 7 mm² |
| Cvcc1 | TDK | C2012X5R1V106K085AC<br>Series= X5R | Cap= 10.0 uF<br>ESR= 2.818 mOhm<br>VDC= 35.0 V<br>IRMS= 3.8868 A | 1 | $0.17 | 0805 7 mm² |
| Cvcc2 | TDK | C2012X5R1V226M125AC<br>Series= X5R | Cap= 22.0 uF<br>ESR= 2.05 mOhm<br>VDC= 35.0 V<br>IRMS= 4.5559 A | 1 | $0.33 | 0805 7 mm² |
| D3 | Fairchild Semiconductor | S320 | VF@Io= 900.0 mV<br>VRRM= 200.0 V | 1 | $0.25 | <br>SMB 44 mm² |
| Dac | CUSTOM | CUSTOM | VF@Io= 500.0 mV<br>VRRM= 1.095 kV | 1 | NA | CUSTOM 0 mm² |
| Dsec | ON Semiconductor | MBRB40250TG | VF@Io= 860.0 mV<br>VRRM= 250.0 V | 1 | $0.94 | <br>DDPAK 210 mm² |
| Dsec2 | ON Semiconductor | MBRB40250TG | VF@Io= 860.0 mV<br>VRRM= 250.0 V | 1 | $0.94 | <br>DDPAK 210 mm² |
| Dsnub | CUSTOM | CUSTOM | VF@Io= 500.0 mV<br>VRRM= 1.045 kV | 1 | NA | CUSTOM 0 mm² |
| Dz4 | ON Semiconductor | MMBZ5244BLT1G | Zener | 1 | $0.02 | <br>SOT-23 14 mm² |
| HS_M1 | Aavid | 576602B00000G | Heatsink | 1 | $0.59 | <br>576602 403 mm² |
| M1 | STMicroelectronics | STP21N90K5 | VdsMax= 900.0 V<br>IdsMax= 18.5 Amps | 1 | NA | TO-220 0 mm² |
| M2 | IXYS | IXTA08N100D2 | VdsMax= 1,000.0 V<br>IdsMax= 800.0 mAmps | 1 | $0.80 | <br>DDPAK 210 mm² |
| O1 | Fairchild Semiconductor | FOD817A | Optocoupler | 1 | $0.11 | <br>DIP-4 71 mm² |
| Rcs | Vishay-Dale | CRCW04021K74FKED<br>Series= CRCW..e3 | Res= 1.74 kOhm<br>Power= 63.0 mW<br>Tolerance= 1.0% | 1 | $0.01 | 0402 3 mm² |
| Rdrv | Vishay-Dale | CRCW04024R75FKED<br>Series= CRCW..e3 | Res= 4.75 Ohm<br>Power= 63.0 mW<br>Tolerance= 1.0% | 1 | $0.01 | 0402 3 mm² |

| Name | Manufacturer | Part Number | Properties | Qty | Price | Footprint |
|---|---|---|---|---|---|---|
| Rfbb | Vishay-Dale | CRCW040210K2FKED<br>Series= CRCW..e3 | Res= 10.2 kOhm<br>Power= 63.0 mW<br>Tolerance= 1.0% | 1 | $0.01 | 0402 3 mm² |
| Rfbt | Vishay-Dale | CRCW040251K1FKED<br>Series= CRCW..e3 | Res= 51.1 kOhm<br>Power= 63.0 mW<br>Tolerance= 1.0% | 1 | $0.01 | 0402 3 mm² |
| Ropto | Yageo | RC0201FR-0710KL<br>Series= ? | Res= 10.0 kOhm<br>Power= 50.0 mW<br>Tolerance= 1.0% | 1 | $0.01 | 0201 2 mm² |
| Rqrb | Yageo | RC0201FR-0712K1L<br>Series= ? | Res= 12.1 kOhm<br>Power= 50.0 mW<br>Tolerance= 1.0% | 1 | $0.01 | 0201 2 mm² |
| Rqrt | Yageo | RC0201FR-0736K5L<br>Series= ? | Res= 36.5 kOhm<br>Power= 50.0 mW<br>Tolerance= 1.0% | 1 | $0.01 | 0201 2 mm² |
| Rsense | CUSTOM | CUSTOM<br>Series= ? | Res= 255.48 mOhm<br>Power= 0.0 W<br>Tolerance= 0.0% | 1 | NA | CUSTOM 0 mm² |
| Rsnub1 | Stackpole Electronics Inc | RSMF2JT30K0<br>Series= ? | Res= 30.0 kOhm<br>Power= 2.0 W<br>Tolerance= 5.0% | 1 | $0.03 | <br>RSMF2 148 mm² |
| Rsnub2 | Stackpole Electronics Inc | RSMF2JT30K0<br>Series= ? | Res= 30.0 kOhm<br>Power= 2.0 W<br>Tolerance= 5.0% | 1 | $0.03 | <br>RSMF2 148 mm² |
| Rvcc | Vishay-Dale | CRCW040276R8FKED<br>Series= CRCW..e3 | Res= 76.8 Ohm<br>Power= 63.0 mW<br>Tolerance= 1.0% | 1 | $0.01 | 0402 3 mm² |
| Rvin | Vishay-Bccomponents | PR03000201002JAC00<br>Series= ? | Res= 10.0 kOhm<br>Power= 3.0 W<br>Tolerance= 5.0% | 1 | $0.17 | <br>PR03 197 mm² |
| Rvsd | Vishay-Dale | CRCW08051M00FKEA<br>Series= CRCW..e3 | Res= 1000.0 kOhm<br>Power= 125.0 mW<br>Tolerance= 1.0% | 1 | $0.01 | 0805 7 mm² |
| T1 | Core=TDK ,<br>CoilFormer=TDK | Core=B65847A0000R087 ,<br>CoilFormer=B65848D1010D001 | Lp= 817.0 µH<br>Turns Ratio(Nas)= 7:9<br>Turns Ratio(Nps)= 68:9<br>Npri= 68.0<br>Naux= 7.0<br>Nsec= 9.0 | 1 | $3.20 | <br>TDK_B65839 714 mm² |
| U1 | Texas Instruments | LM5023MMX-2/NOPB | Switcher | 1 | $0.42 | <br>DGK0008A 24 mm² |
| VR | Texas Instruments | TL431IDBVR | Voltage References | 1 | $0.07 | <br>R-PDSO-G3 16 mm² |

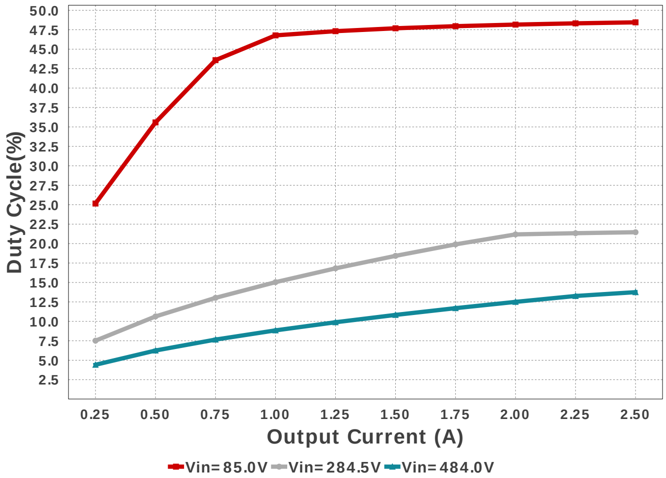
## Snubber Pd



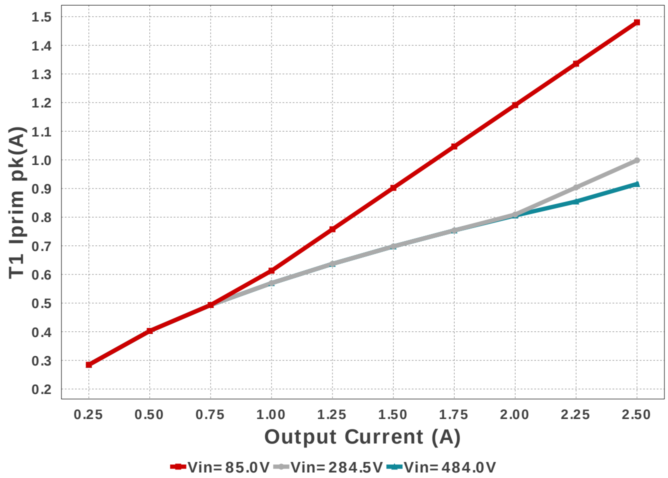

## IC Tj



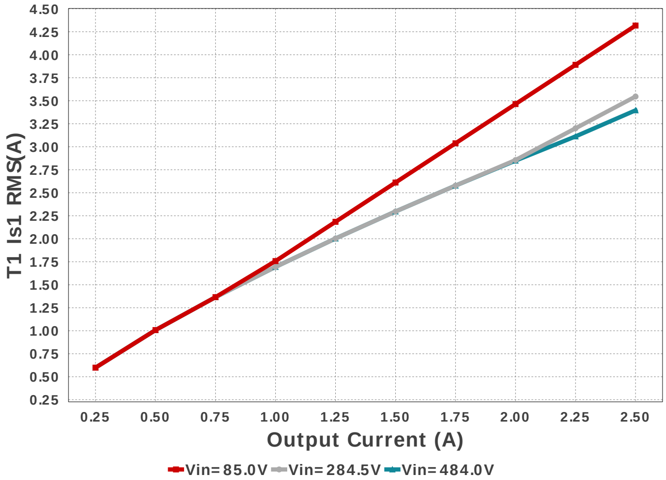

## Duty Cycle



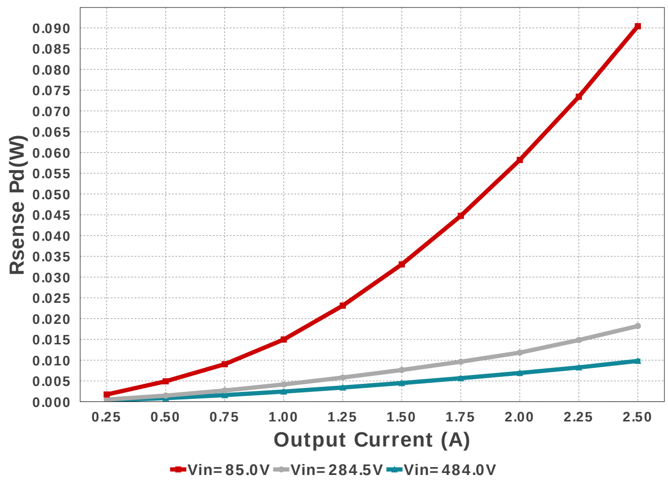

## T1 Iprim pk

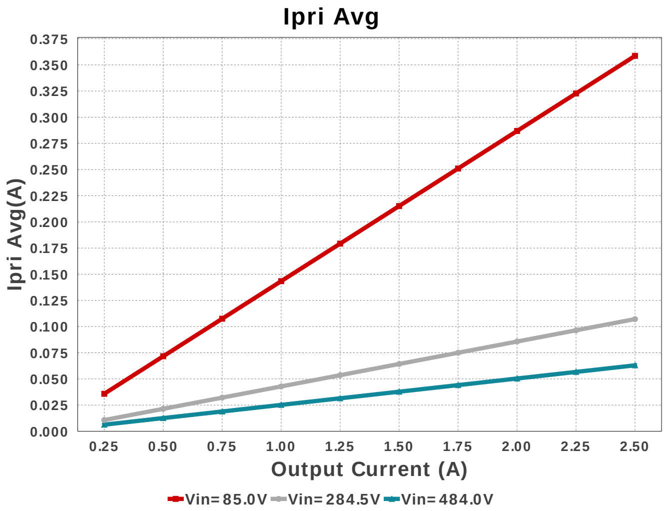


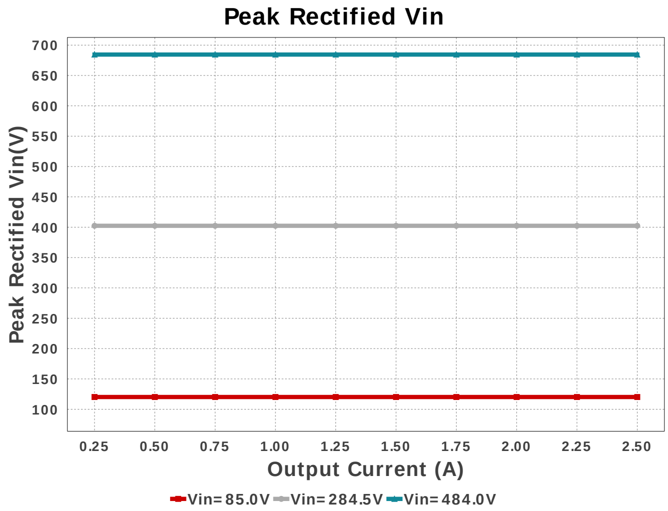

## T1 Is1 RMS

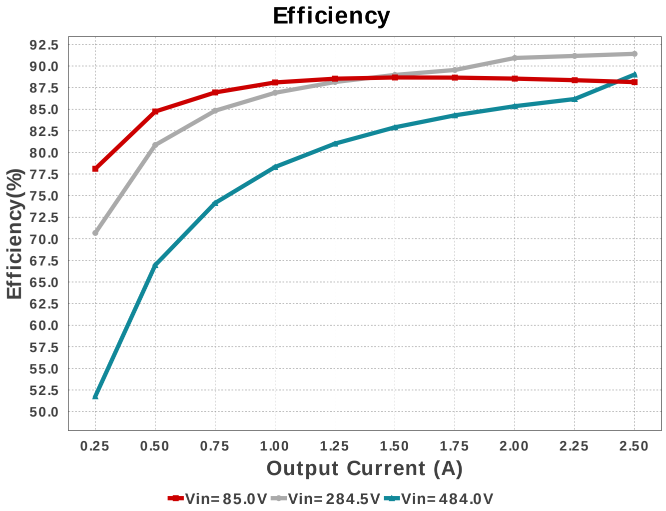


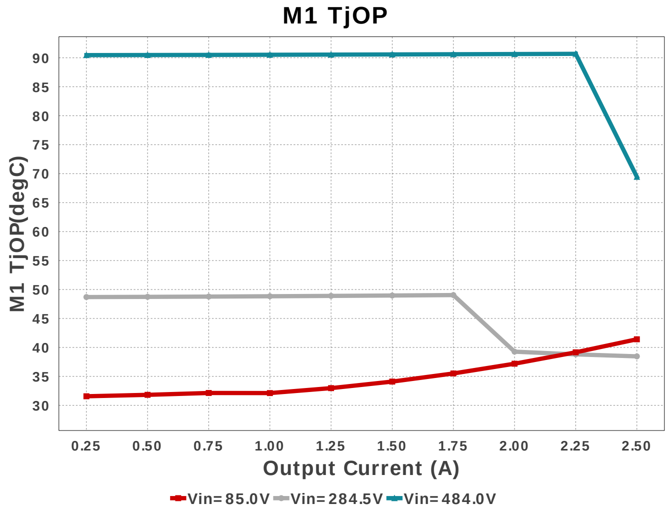

## Rsense Pd

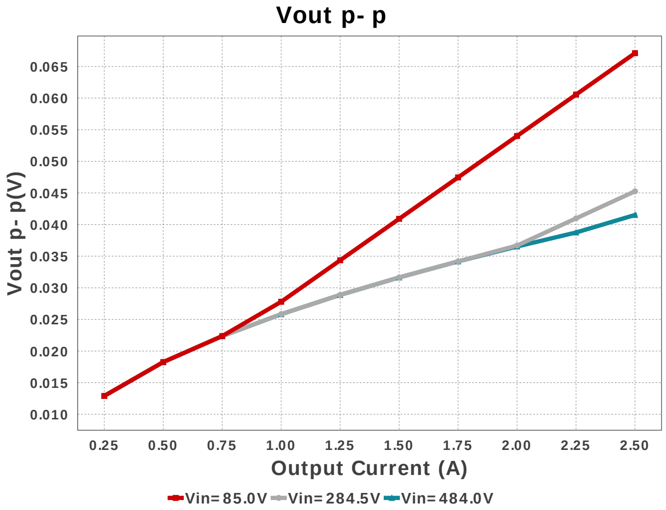


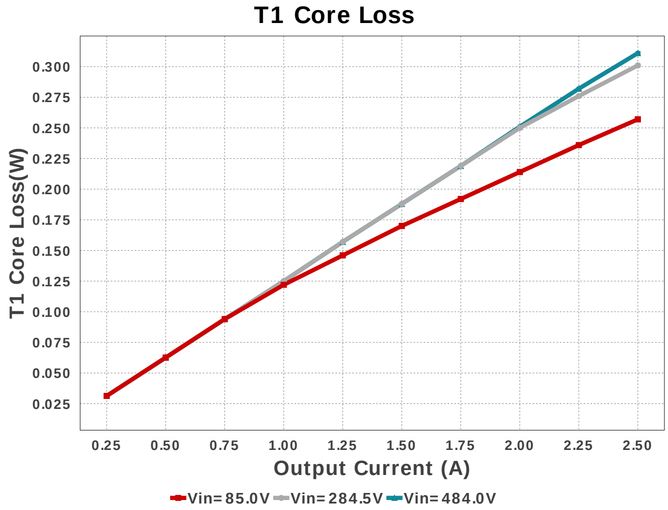

Ipri Avg
Ipri Avg(A)
Output Current (A)
Vin= 85.0V Vin= 284.5V Vin= 484.0V


Peak Rectified Vin
Peak Rectified Vin(V)
Output Current (A)
Vin= 85.0V Vin= 284.5V Vin= 484.0V

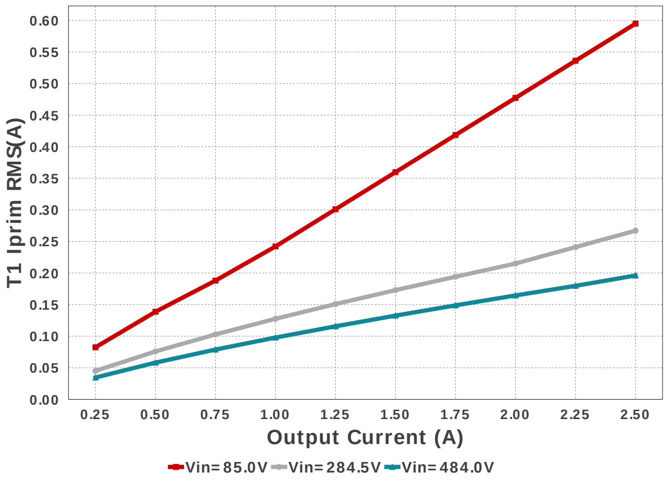

Efficiency
Efficiency(%)
Output Current (A)
Vin= 85.0V Vin= 284.5V Vin= 484.0V


M1 TjOP
M1 TjOP(degC)
Output Current (A)
Vin= 85.0V Vin= 284.5V Vin= 484.0V

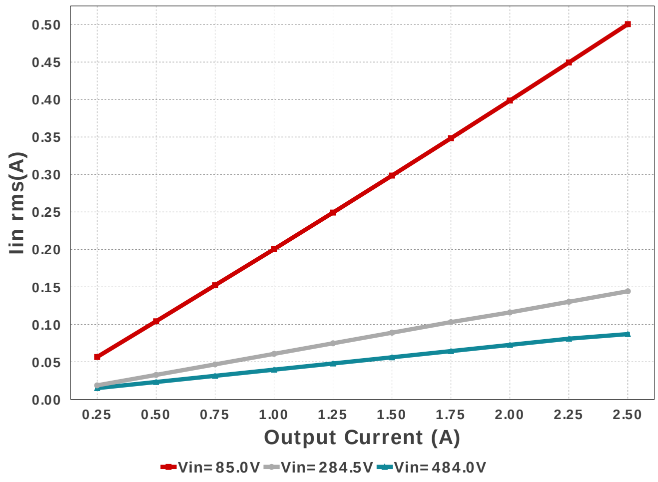

Vout p- p
Vout p- p(V)
Output Current (A)
Vin= 85.0V Vin= 284.5V Vin= 484.0V


T1 Core Loss
T1 Core Loss(W)
Output Current (A)
Vin= 85.0V Vin= 284.5V Vin= 484.0V

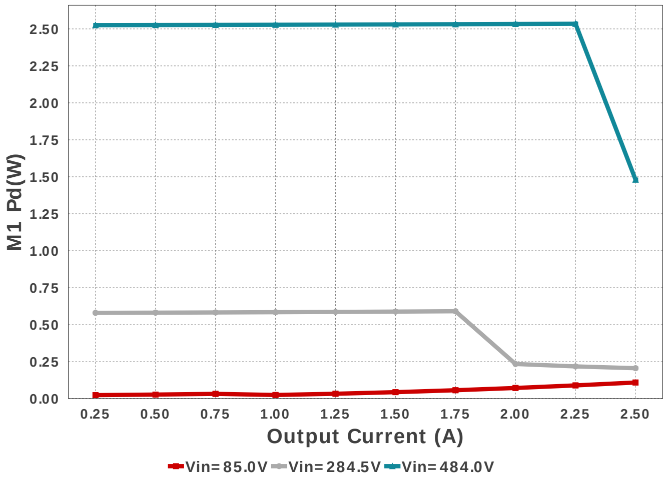
T1 Iprim RMS



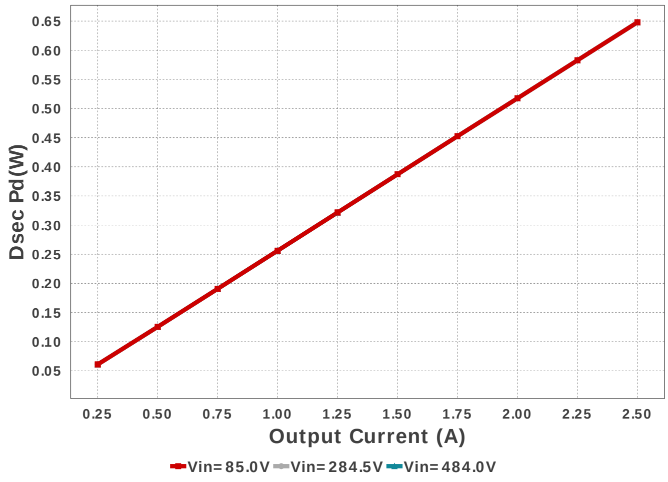

Iin rms



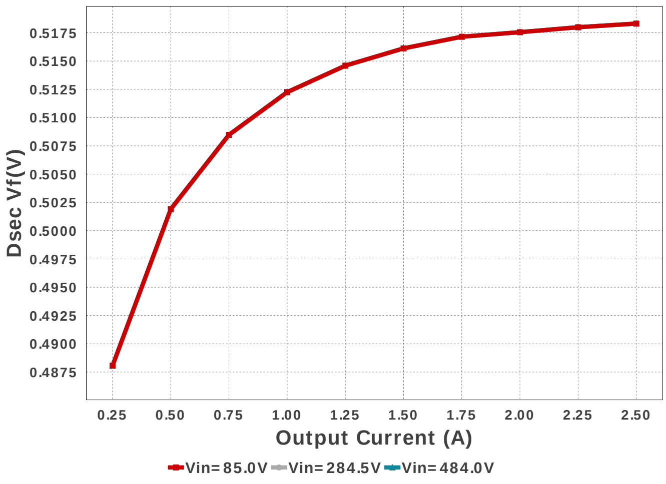

M1 Pd



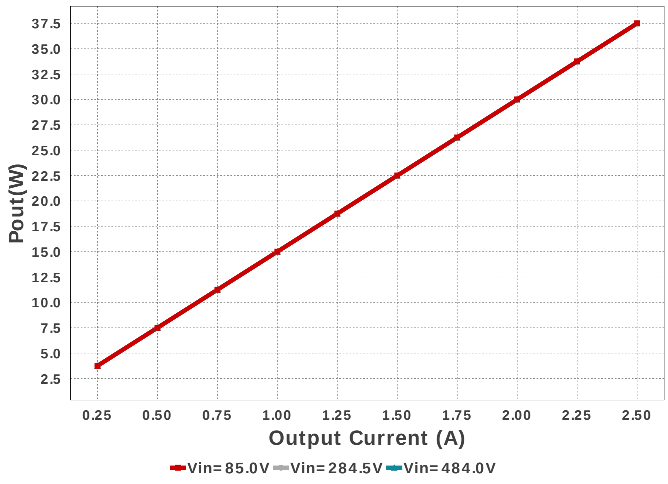

Dsec Pd



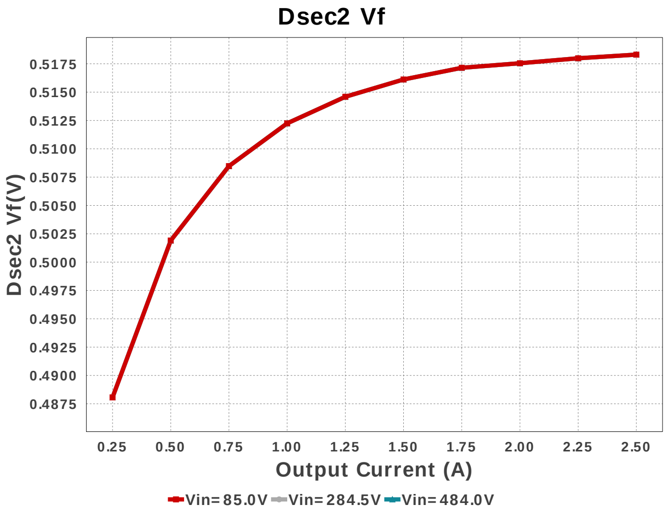

Dsec Vf

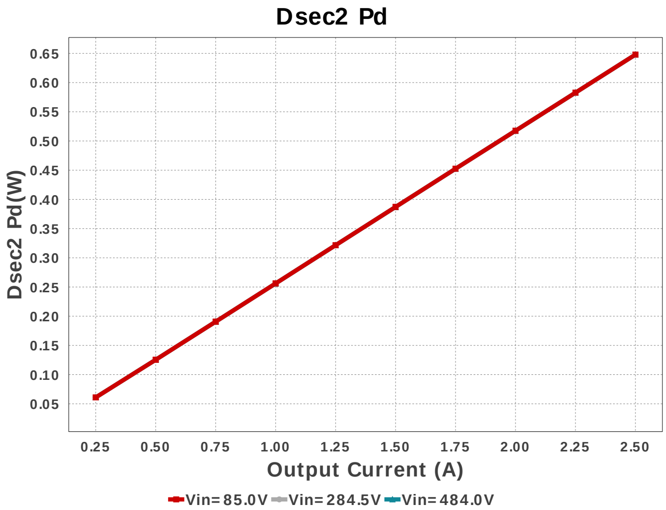


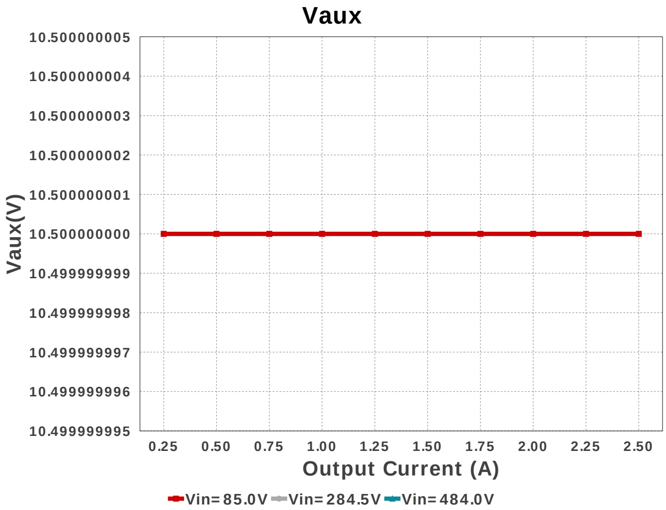

Pout

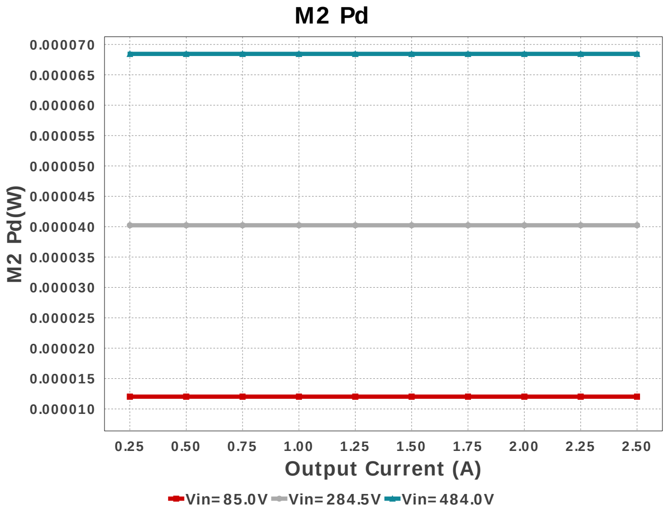


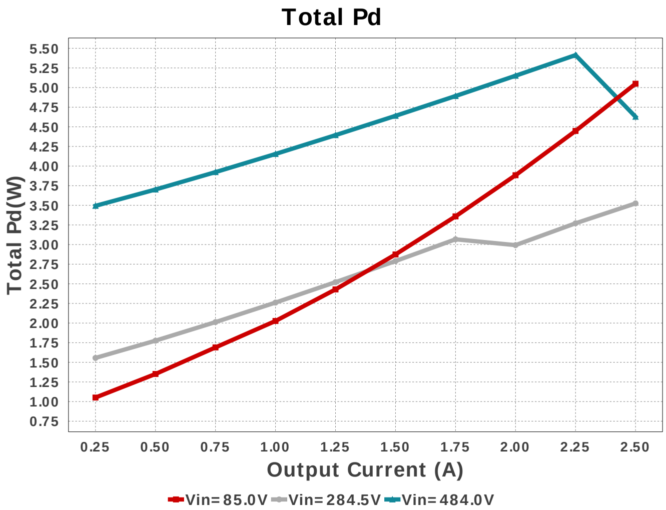

 

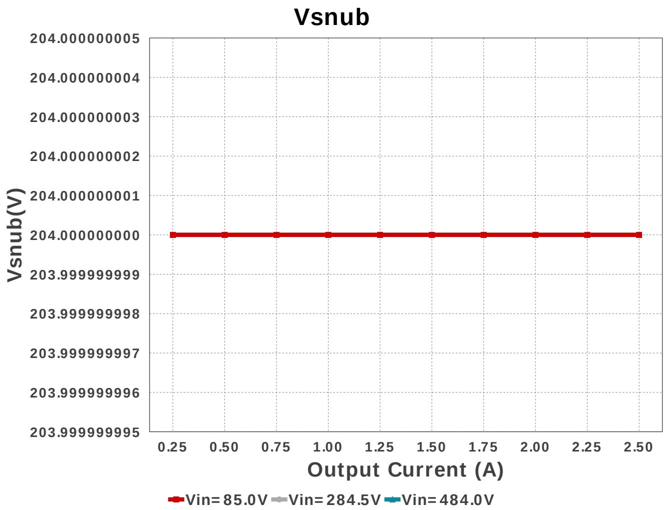

Dsec2 Vf
Dsec2 Vf(V)
0.5175
0.5150
0.5125
0.5100
0.5075
0.5050
0.5025
0.5000
0.4975
0.4950
0.4925
0.4900
0.4875
0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00 2.25 2.50
Output Current (A)
Vin=85.0V Vin=284.5V Vin=484.0V


Dsec2 Pd
Dsec2 Pd(W)
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00 2.25 2.50
Output Current (A)
Vin=85.0V Vin=284.5V Vin=484.0V

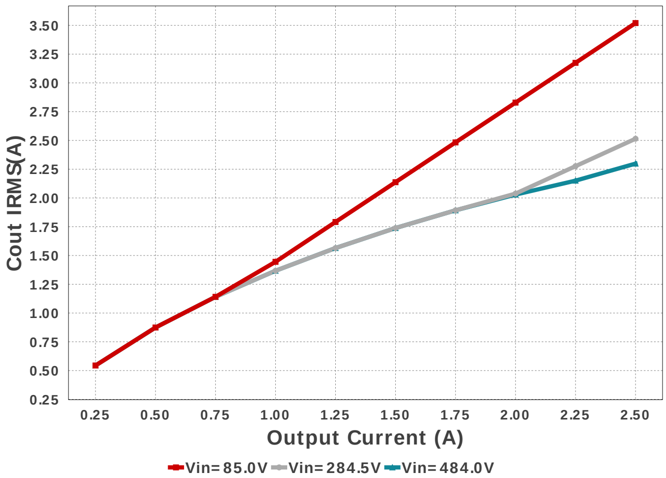

Vaux
Vaux(V)
10.500000005
10.500000004
10.500000003
10.500000002
10.500000001
10.500000000
10.499999999
10.499999998
10.499999997
10.499999996
10.499999995
0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00 2.25 2.50
Output Current (A)
Vin=85.0V Vin=284.5V Vin=484.0V


M2 Pd
M2 Pd(W)
0.000070
0.000065
0.000060
0.000055
0.000050
0.000045
0.000040
0.000035
0.000030
0.000025
0.000020
0.000015
0.000010
0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00 2.25 2.50
Output Current (A)
Vin=85.0V Vin=284.5V Vin=484.0V

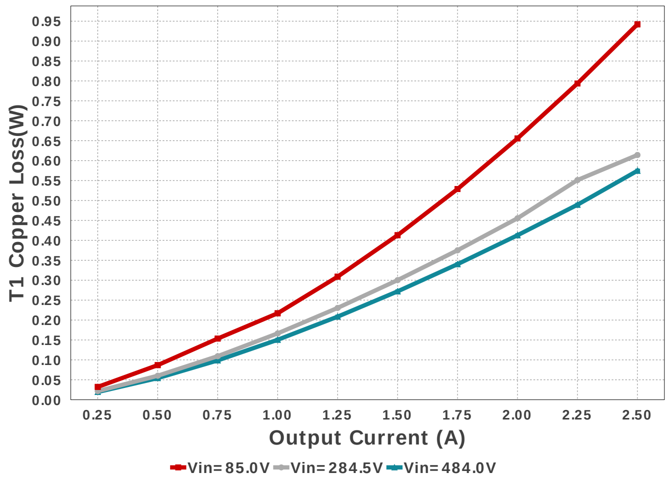

Total Pd
Total Pd(W)
5.50
5.25
5.00
4.75
4.50
4.25
4.00
3.75
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00 2.25 2.50
Output Current (A)
Vin=85.0V Vin=284.5V Vin=484.0V


Vsnub
Vsnub(V)
204.000000005
204.000000004
204.000000003
204.000000002
204.000000001
204.000000000
203.999999999
203.999999998
203.999999997
203.999999996
203.999999995
0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00 2.25 2.50
Output Current (A)
Vin=85.0V Vin=284.5V Vin=484.0V

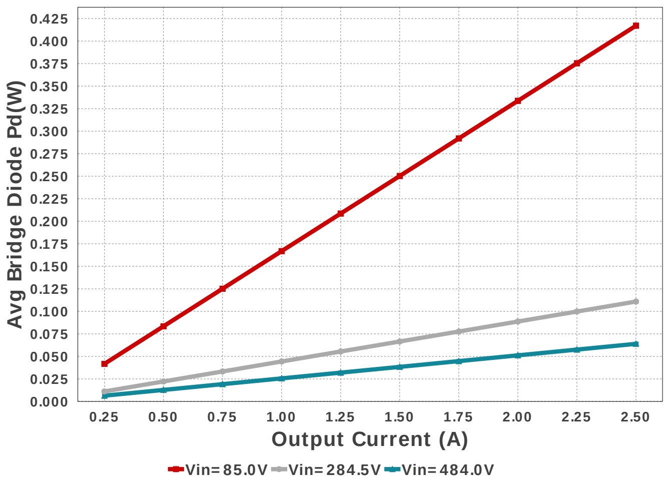
## Cout IRMS



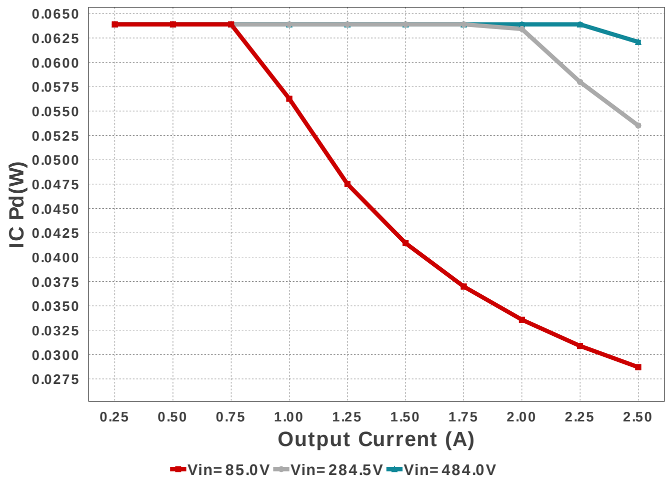

## T1 Copper Loss



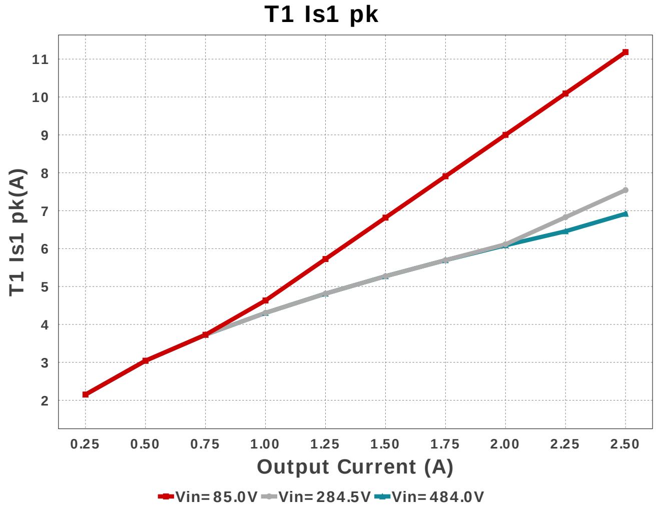

## Avg Bridge Diode Pd



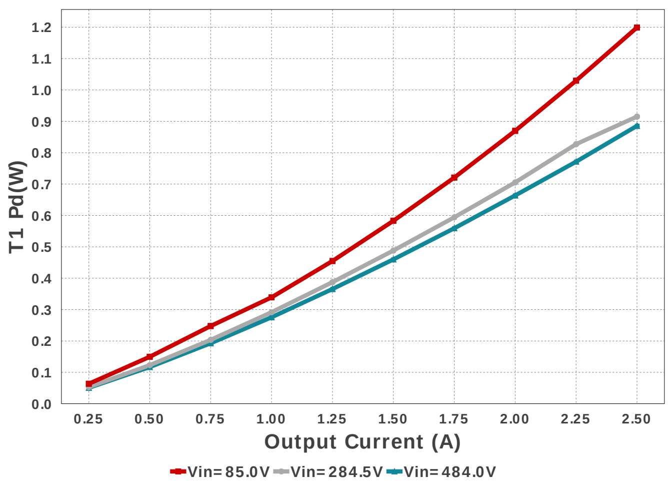

## IC Pd

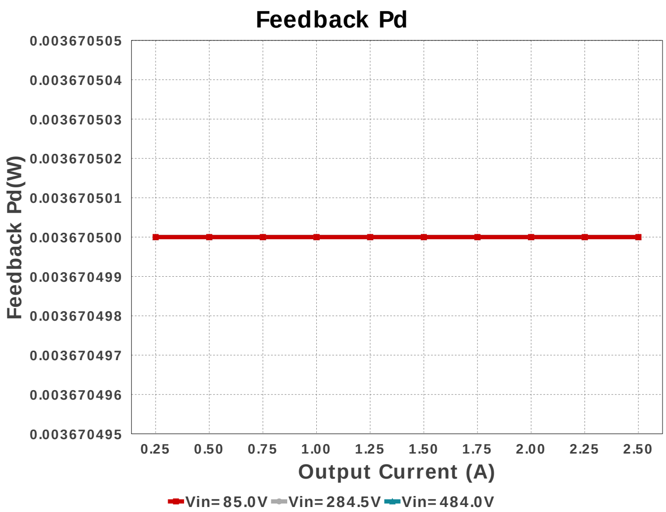



## T1 Is1 pk




## T1 Pd






## Operating Values

| # | Name | Value | Category | Description |
|---|---|---|---|---|
| 1. | BOM Count | 39 | | Total Design BOM count |
| 2. | Total BOM | NA | | Total BOM Cost |
| 3. | Cout IRMS | 3.52 A | Capacitor | Output capacitor RMS ripple current |
| 4. | Avg Bridge Diode Pd | 417.06 mW | Diode | Average Power Dissipation in the Bridge Diode over the AC Line Period |
| 5. | Dsec Pd | 647.89 mW | Diode | Secondary Diode Power Dissipation |
| 6. | Dsec Vf | 518.311 mV | Diode | Effective Forward Voltage Drop at the Operating Current |
| 7. | Dsec2 Pd | 647.89 mW | Diode | Secondary Diode Power Dissipation |
| 8. | Dsec2 Vf | 518.311 mV | Diode | Effective Forward Voltage Drop at the Operating Current |
| 9. | IC Pd | 28.708 mW | IC | IC power dissipation |
| 10. | IC Tj | 35.742 degC | IC | IC junction temperature |
| 11. | ICThetaJA | 200.0 degC/W | IC | IC junction-to-ambient thermal resistance |
| 12. | M1 Pd | 108.93 mW | Mosfet | M1 MOSFET total power dissipation |
| 13. | M1 TjOP | 41.409 degC | Mosfet | M1 MOSFET junction temperature |
| 14. | M2 Pd | 12.021 µW | Mosfet | M2 MOSFET total power dissipation |
| 15. | Avg Bridge Diode Pd | 417.06 mW | Power | Average Power Dissipation in the Bridge Diode over the AC Line Period |
| 16. | Dsec Pd | 647.89 mW | Power | Secondary Diode Power Dissipation |
| 17. | Dsec2 Pd | 647.89 mW | Power | Secondary Diode Power Dissipation |
| 18. | Feedback Pd | 3.67 mW | Power | Power Dissipation in Feedback Resistors |
| 19. | IC Pd | 28.708 mW | Power | IC power dissipation |
| 20. | M1 Pd | 108.93 mW | Power | M1 MOSFET total power dissipation |
| 21. | M2 Pd | 12.021 µW | Power | M2 MOSFET total power dissipation |
| 22. | Rsense Pd | 90.408 mW | Power | LED Current Rsns Power Dissipation |
| 23. | Snubber Pd | 698.354 mW | Power | Snubber Power Dissipation |
| 24. | T1 Copper Loss | 942.05 mW | Power | Transformer Copper Loss Power Dissipation |
| 25. | T1 Core Loss | 257.0 mW | Power | Transformer Core Loss Power Dissipation |
| 26. | T1 Pd | 1.199 W | Power | Estimated Losses in Transformer |
| 27. | Total Pd | 5.049 W | Power | Total Power Dissipation |
| 28. | Feedback Pd | 3.67 mW | Resistor | Power Dissipation in Feedback Resistors |
| 29. | Rsense Pd | 90.408 mW | Resistor | LED Current Rsns Power Dissipation |
| 30. | Duty Cycle | 48.451 % | System Information | Duty cycle |
| 31. | Efficiency | 88.134 % | System Information | Steady state efficiency |
| 32. | FootPrint | 3.057 k $mm^2$ | System Information | Total Foot Print Area of BOM components |
| 33. | Frequency | 48.159 kHz | System Information | Switching frequency |
| 34. | Iin rms | 500.57 mA | System Information | RMS Input Current |
| 35. | Iout | 2.5 A | System Information | Iout operating point |
| 36. | Mode | TM | System Information | Conduction Mode |
| 37. | Peak Rectified Vin | 120.207 V | System Information | Peak voltage seen at rectified input |
| 38. | Pout | 37.5 W | System Information | Total output power |
| 39. | Vin_RMS | 85.0 V | System Information | Vin operating point |
| 40. | Vout | 15.0 V | System Information | Operational Output Voltage |

| # | Name | Value | Category | Description |
|---|---|---|---|---|
| 41. | Vout Actual | 14.994 V | System Information | Vout Actual calculated based on selected voltage divider resistors |
| 42. | Vout Tolerance | 2.01 % | System Information | Vout Tolerance based on IC Tolerance (no load) and voltage divider resistors if applicable |
| 43. | Vout p-p | 67.105 mV | System Information | Peak-to-peak output ripple voltage |
| 44. | Vsnub | 204.0 V | System Information | Voltage Across the Snubber |
| 45. | Ipri Avg | 358.602 mA | Transformer | Average Current in Primary Winding over the complete Switching Period |
| 46. | T1 Copper Loss | 942.05 mW | Transformer | Transformer Copper Loss Power Dissipation |
| 47. | T1 Core Loss | 257.0 mW | Transformer | Transformer Core Loss Power Dissipation |
| 48. | T1 Iprim RMS | 594.879 mA | Transformer | Transformer Primary RMS Current |
| 49. | T1 Iprim pk | 1.48 A | Transformer | Transformer Primary Peak Current |
| 50. | T1 Is1 RMS | 4.317 A | Transformer | Transformer Secondary1 RMS Current |
| 51. | T1 Is1 pk | 11.184 A | Transformer | Transformer Secondary1 Peak Current |
| 52. | T1 Pd | 1.199 W | Transformer | Estimated Losses in Transformer |
| 53. | Vaux | 10.5 V | Transformer | Auxiliary Voltage |

## Design Inputs

| Name | Value | Description |
|---|---|---|
| Iout | 2.5 | Maximum Output Current |
| VinMax | 484.0 | Maximum input voltage |
| VinMin | 85.0 | Minimum input voltage |
| Vout | 15.0 | Output Voltage |
| acFrequency | 50.0 | AC Frequency |
| base_pn | LM5023 | Base Product Number |
| source | AC | 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

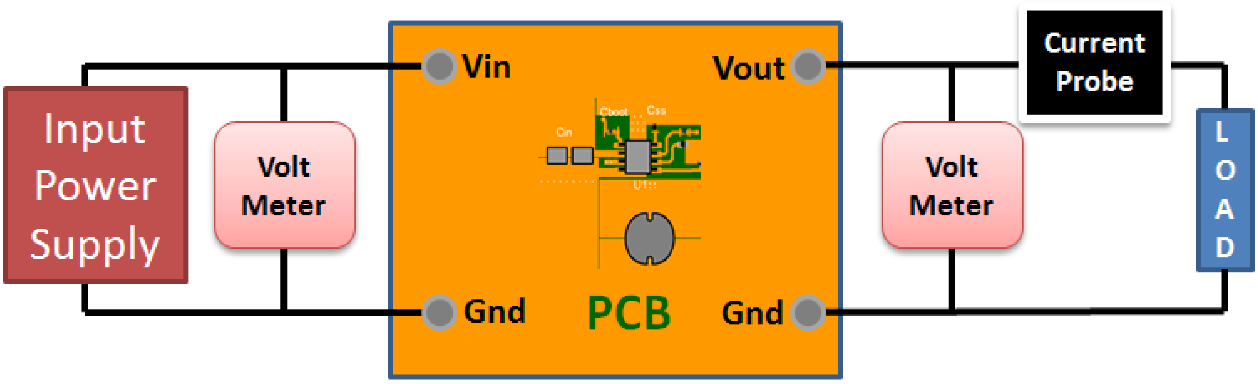
If board assembly is done in house it is best to tack down one terminal of a component on the board then solder the other terminal. For surface mount parts with large tabs, such as the DPAK, the tab on the back of the package should be pre-tinned with solder, then tacked into place by one of the pins. 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 85.0V 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.



# WEBENCH® Transformer Report

| # | Name | Value |
|---|---|---|
| 1. | Core Part Number | B65847A0000R087 |
| 2. | Core Manufacturer | TDK |
| 3. | Coil Former Part Number | B65848D1010D001 |
| 4. | Coil Former Manufacturer | TDK |

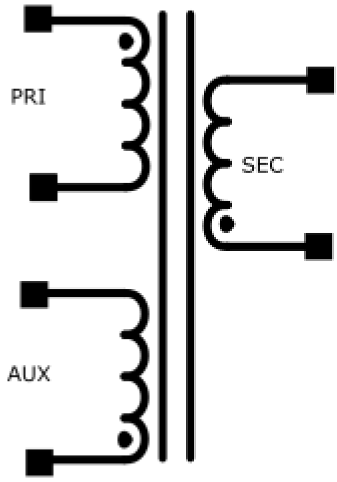
## Transformer Electrical Diagram

### Primary

| | |
|---|---|
| Turns | 68.0 |
| AWG | 26.0 |
| Layers | 3.0 |
| Strands | 1.0 |
| Insulation Type | Heavy Insulated Magnet Wire |

### Auxiliary

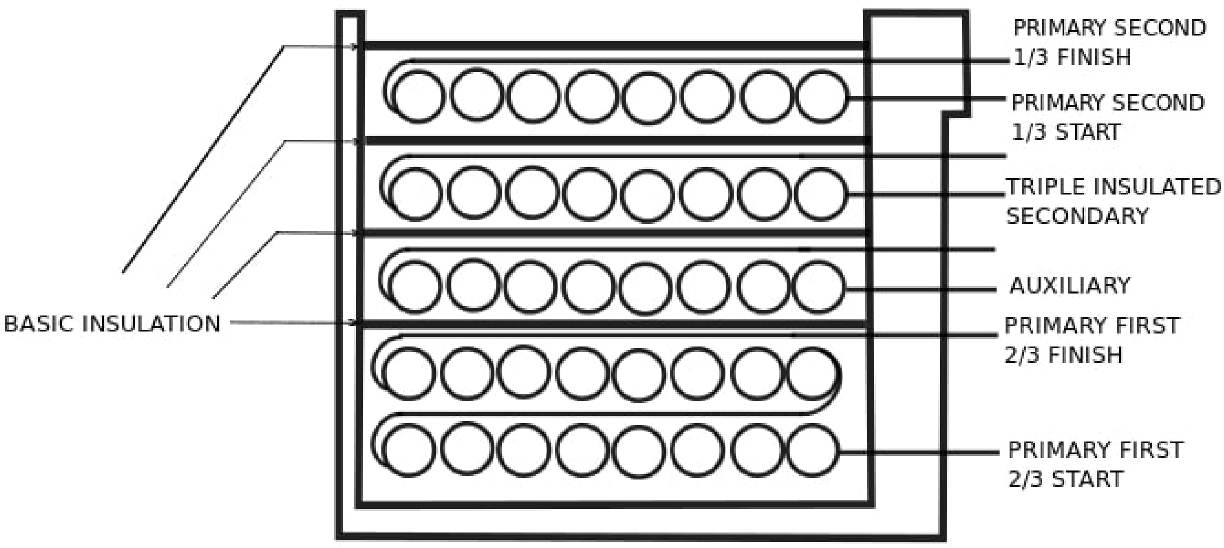
| | |
|---|---|
| Turns | 7.0 |
| AWG | 28.0 |
| Layers | 1.0 |
| Strands | 4.0 |
| Insulation Type | Heavy Insulated Magnet Wire |




### Secondary

| | |
|---|---|
| Turns | 9.0 |
| AWG | 28.0 |
| Layers | 1.0 |
| Strands | 2.0 |
| Insulation Type | Triple Insulated |

## Transformer Construction Diagram




## Winding Instruction

| Winding | AWG | Turns | Winding Orientation |
|---|---|---|---|
| Primary First 2/3.0 | 26.0 | 46 | Clockwise |
| Auxiliary | 28.0 | 7.0 | Counter Clockwise |
| Triple Insulated Secondary | 28.0 | 9.0 | Counter Clockwise |
| Primary Second 1/3.0 | 26.0 | 22 | Clockwise |

## Transformer Parameters

| # | Name | Value |
|---|---|---|
| 1. | Lpri | 8.17E-4H |
| 2. | Inductance Factor(Al) | 177.0nH |
| 3. | Npri | 68.0 |
| 4. | Nsec | 9.0 |
| 5. | Naux | 7.0 |
| 6. | Core Type | EP20 |
| 7. | Core Material | N87 |
| 8. | Bmax | 0.23T |
| 9. | Switching Frequency | 45.00kHz |
| 10. | DMax | 0.45 |
| 11. | Ipk(Primary) | 1.51A |
| 12. | Irms(Primary) | 0.58A |
| 13. | Ipk(Secondary) | 11.4A |
| 14. | Irms(Secondary) | 4.44A |

## Design Assistance

1. Master key : 235927DDE5FA19B1[v1]
2. **LM5023** Product Folder : http://www.ti.com/product/LM5023 : contains the data sheet and other resources.