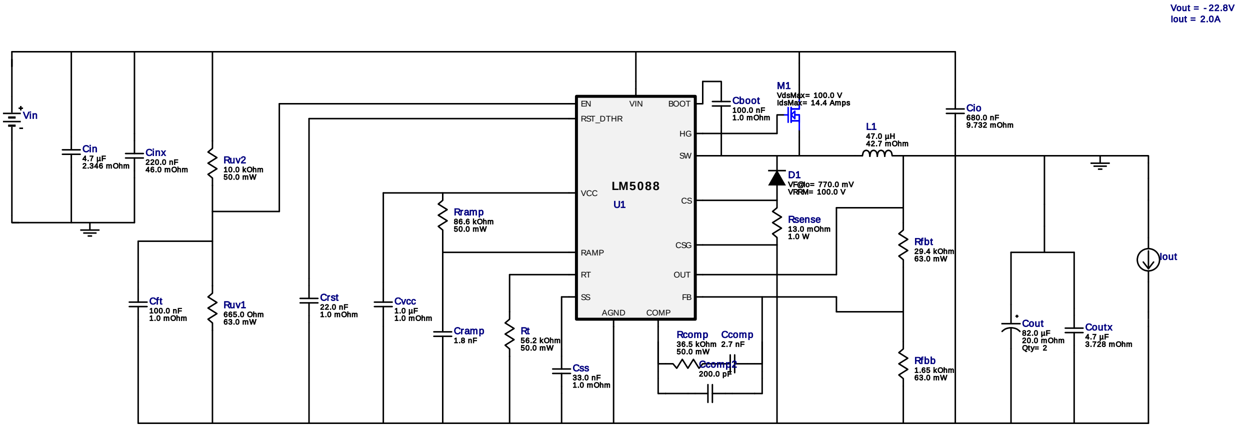
TEXAS INSTRUMENTS

WEBENCH ® Design Report

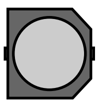
VinMin = 24.0V
VinMax = 31.0V
Vout = -22.8V
Iout = 2.0A

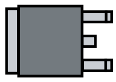
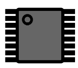
Device = LM5088MH-2/NOPB
Topology = Inverting_Buck_Boost
Created = 2020-06-17 05:52:39.912
BOM Cost = $7.20
BOM Count = 26
Total Pd = 3.68W

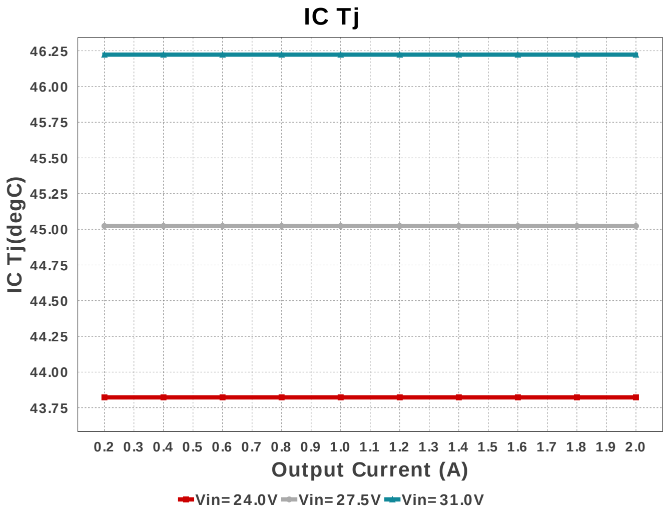
Design : 67 LM5088MH-2/NOPB
LM5088MH-2/NOPB 24V-31V to -22.80V @ 2A

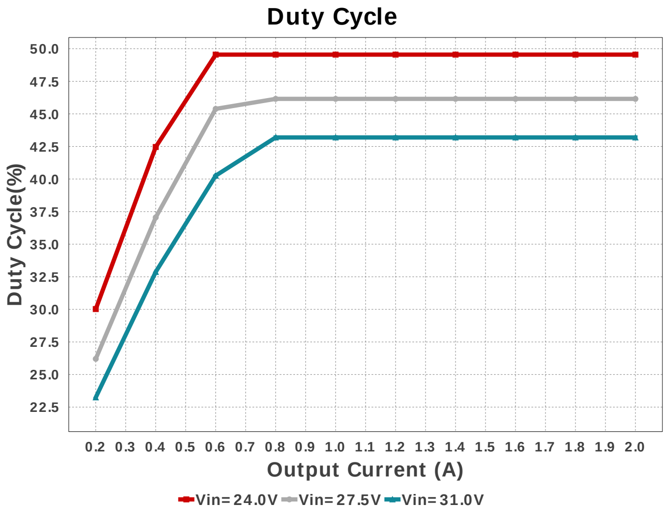


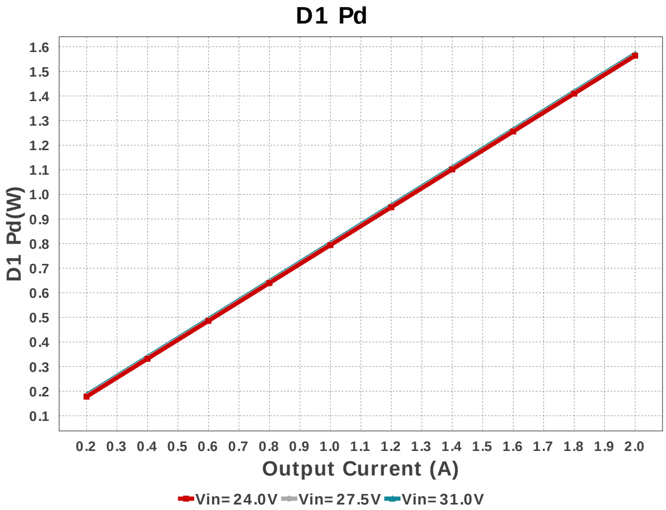
Electrical BOM

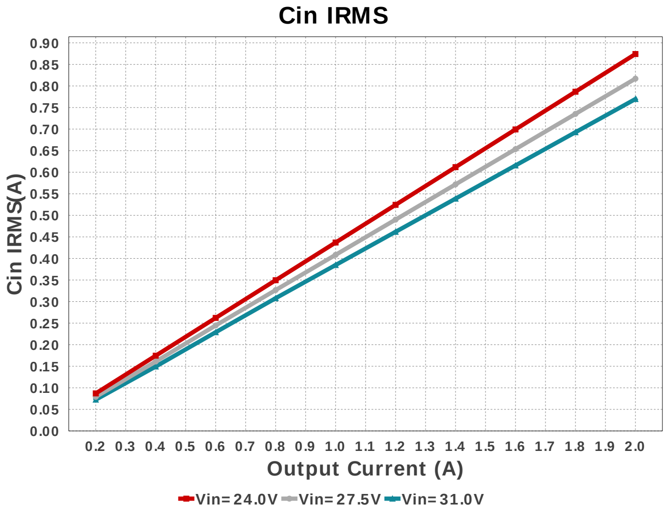
Name	Manufacturer	Part Number	Properties	Qty	Price	Footprint
Cboot	Yageo	CC0805KRX7R9BB104 Series= X7R	Cap= 100.0 nF ESR= 1.0 mOhm VDC= 50.0 V IRMS= 0.0 A	1	$0.02	0805 7 mm^2
Ccomp	TDK	C2012C0G1H272J060AA Series= C0G/NP0	Cap= 2.7 nF VDC= 50.0 V IRMS= 0.0 A	1	$0.03	0805 7 mm^2
Ccomp2	Samsung Electro-Mechanics	CL05C201JB5NNNC Series= C0G/NP0	Cap= 200.0 pF VDC= 50.0 V IRMS= 0.0 A	1	$0.01	0402 3 mm^2
Cft	MuRata	GRM155R71C104KA88D Series= X7R	Cap= 100.0 nF ESR= 1.0 mOhm VDC= 16.0 V IRMS= 0.0 A	1	$0.01	0402 3 mm^2
Cin	TDK	C2012X6S1H475K125AC Series= X6S	Cap= 4.7 uF ESR= 2.346 mOhm VDC= 50.0 V IRMS= 4.2602 A	1	$0.18	0805 7 mm^2
Cinx	Kemet	C0805C224K5RACTU Series= X7R	Cap= 220.0 nF ESR= 46.0 mOhm VDC= 50.0 V IRMS= 2.65 A	1	$0.03	0805 7 mm^2
Cio	TDK	C2012X7S2A684K125AB Series= X7S	Cap= 680.0 nF ESR= 9.732 mOhm VDC= 100.0 V IRMS= 2.0961 A	1	$0.10	0805 7 mm^2
Cout	Panasonic	35SVPF82M Series= SVPF	Cap= 82.0 uF ESR= 20.0 mOhm VDC= 35.0 V IRMS= 4.0 A	2	$0.63	 CAPSMT_62_E12 106 mm^2
Coutx	TDK	C1608X5R1V475K080AC Series= X5R	Cap= 4.7 uF ESR= 3.728 mOhm VDC= 35.0 V IRMS= 2.69359 A	1	$0.10	0603 5 mm^2
Cramp	TDK	C2012C0G1H182K060AA Series= C0G/NP0	Cap= 1.8 nF VDC= 50.0 V IRMS= 0.0 A	1	$0.04	0805 7 mm^2

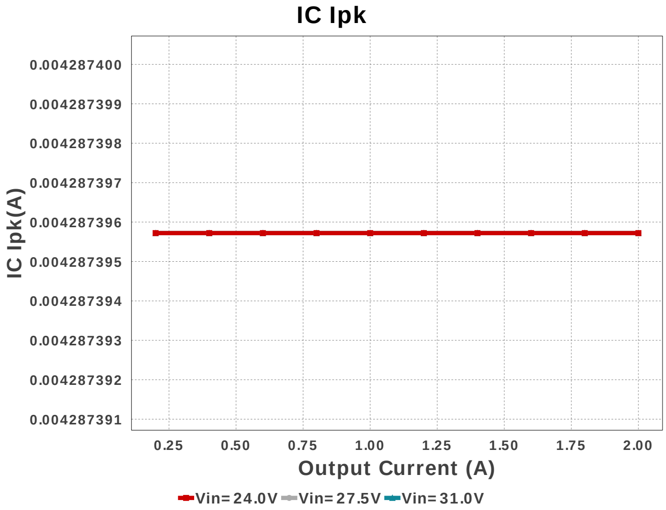
Name	Manufacturer	Part Number	Properties	Qty	Price	Footprint
Crst	MuRata	GRM033R60J223KE01D Series= X5R	Cap= 22.0 nF ESR= 1.0 mOhm VDC= 6.3 V IRMS= 0.0 A	1	$0.01	0201 2 mm^2
Css	MuRata	GRM155R71E333KA88D Series= X7R	Cap= 33.0 nF ESR= 1.0 mOhm VDC= 25.0 V IRMS= 0.0 A	1	$0.01	0402 3 mm^2
Cvcc	Taiyo Yuden	EMK107B7105KA-T Series= X7R	Cap= 1.0 uF ESR= 1.0 mOhm VDC= 16.0 V IRMS= 0.0 A	1	$0.02	0603 5 mm^2
D1	Vishay-Semiconductor	50WQ10FNPBF	VF@Io= 770.0 mV VRRM= 100.0 V	1	$0.80	 DPAK 102 mm^2
L1	Vishay-Dale	IHLP6767DZER470M11	L= 47.0 µH 42.7 mOhm	1	$2.54	 IHLP-6767DZ 369 mm^2
M1	Texas Instruments	CSD19538Q2	VdsMax= 100.0 V IdsMax= 14.4 Amps	1	$0.15	DQK0006C 9 mm^2
Rcomp	Yageo	RC0201FR-0736K5L Series= ?	Res= 36.5 kOhm Power= 50.0 mW Tolerance= 1.0%	1	$0.01	0201 2 mm^2
Rfbb	Vishay-Dale	CRCW04021K65FKED Series= CRCW..e3	Res= 1.65 kOhm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm^2
Rfbt	Vishay-Dale	CRCW040229K4FKED Series= CRCW..e3	Res= 29.4 kOhm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm^2
Rramp	Yageo	RC0201FR-0786K6L Series= ?	Res= 86.6 kOhm Power= 50.0 mW Tolerance= 1.0%	1	$0.01	0201 2 mm^2
Rsense	Susumu Co Ltd	PRL1632-R013-F-T1 Series= PRL1632	Res= 13.0 mOhm Power= 1.0 W Tolerance= 1.0%	1	$0.20	0612 11 mm^2
Rt	Yageo	RC0201FR-0756K2L Series= ?	Res= 56.2 kOhm Power= 50.0 mW Tolerance= 1.0%	1	$0.01	0201 2 mm^2
Ruv1	Vishay-Dale	CRCW0402665RFKED Series= CRCW..e3	Res= 665.0 Ohm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm^2
Ruv2	Yageo	RC0201FR-0710KL Series= ?	Res= 10.0 kOhm Power= 50.0 mW Tolerance= 1.0%	1	$0.01	0201 2 mm^2
U1	Texas Instruments	LM5088MH-2/NOPB	Switcher	1	$1.55	 MXA16A 59 mm^2

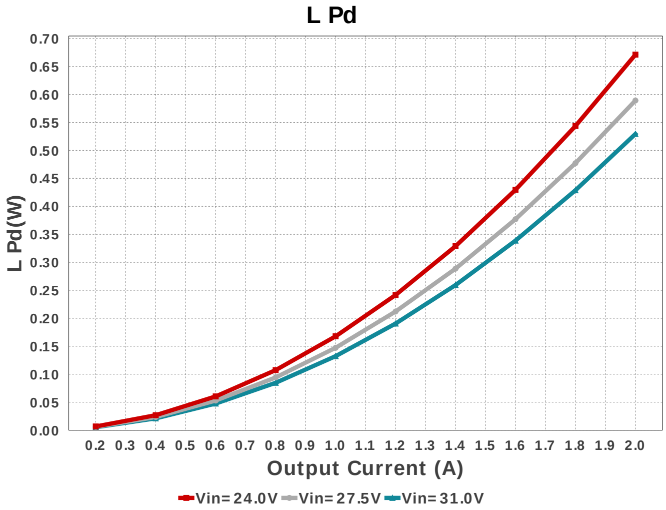

IC Tj
IC Tj(degC)
46.25
46.00
45.75
45.50
45.25
45.00
44.75
44.50
44.25
44.00
43.75
0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0
Output Current (A)
Vin=24.0V Vin=27.5V Vin=31.0V

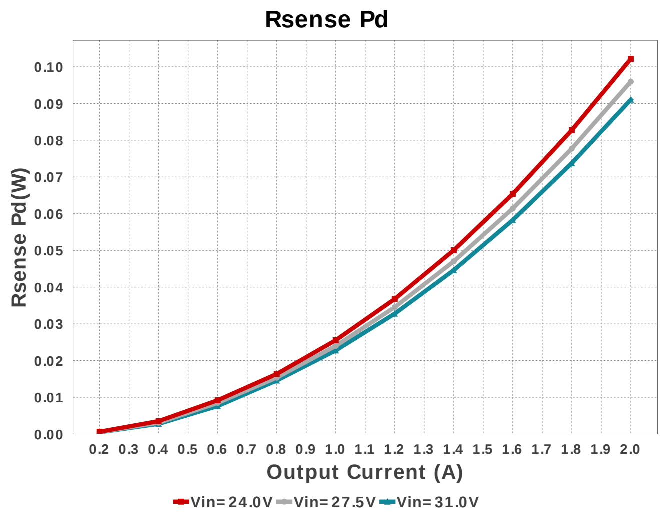

Duty Cycle
Duty Cycle(%)
50.0
47.5
45.0
42.5
40.0
37.5
35.0
32.5
30.0
27.5
25.0
22.5
0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0
Output Current (A)
Vin=24.0V Vin=27.5V Vin=31.0V

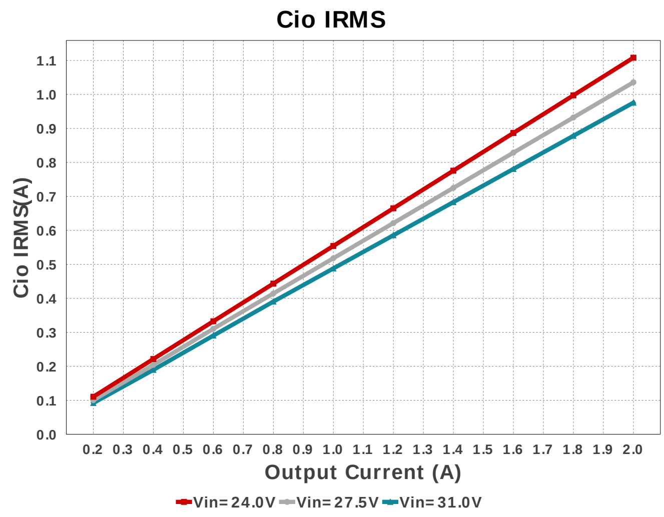

D1 Pd
D1 Pd(W)
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0
Output Current (A)
Vin=24.0V Vin=27.5V Vin=31.0V

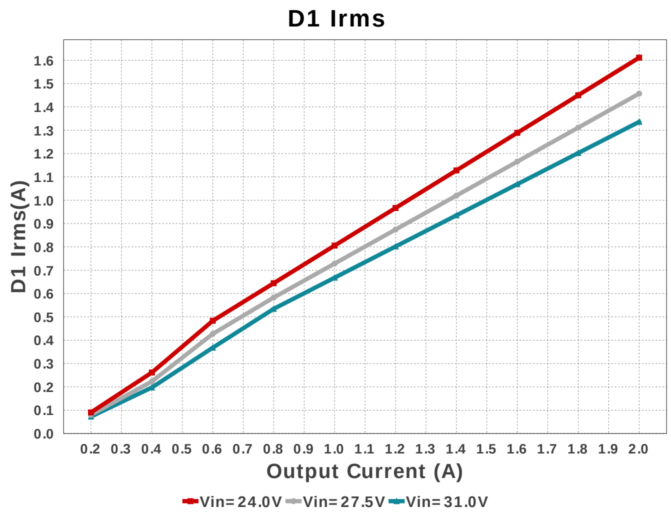

Cin IRMS
Cin IRMS(A)
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0
Output Current (A)
Vin=24.0V Vin=27.5V Vin=31.0V

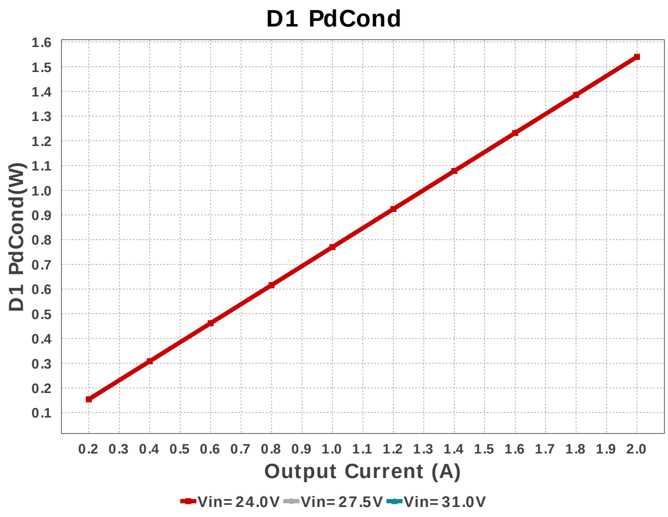

IC Ipk
IC Ipk(A)
0.004287400
0.004287399
0.004287398
0.004287397
0.004287396
0.004287395
0.004287394
0.004287393
0.004287392
0.004287391
0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00
Output Current (A)
Vin=24.0V Vin=27.5V Vin=31.0V

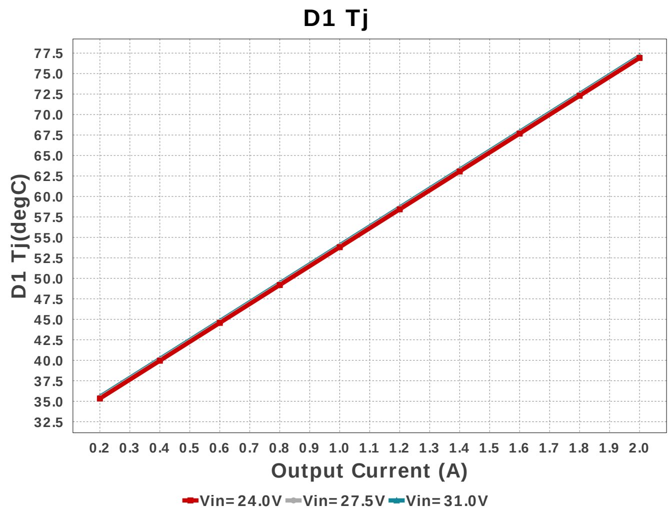

L Pd
L Pd(W)
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0
Output Current (A)
Vin=24.0V Vin=27.5V Vin=31.0V

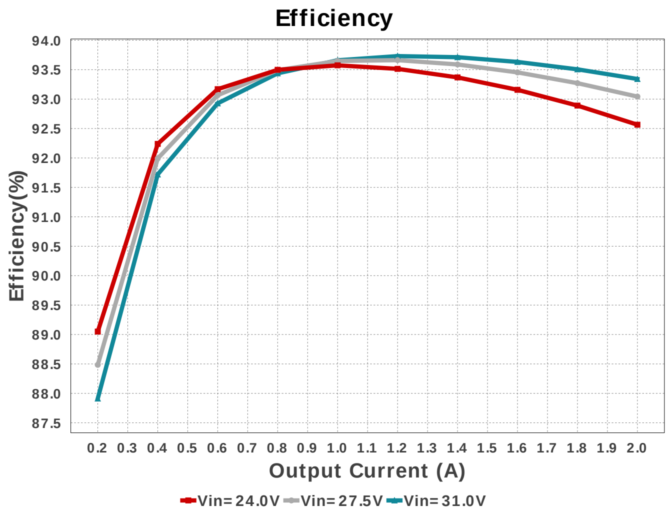

Rsense Pd
Rsense Pd(W)
Output Current (A)
Vin=24.0V Vin=27.5V Vin=31.0V

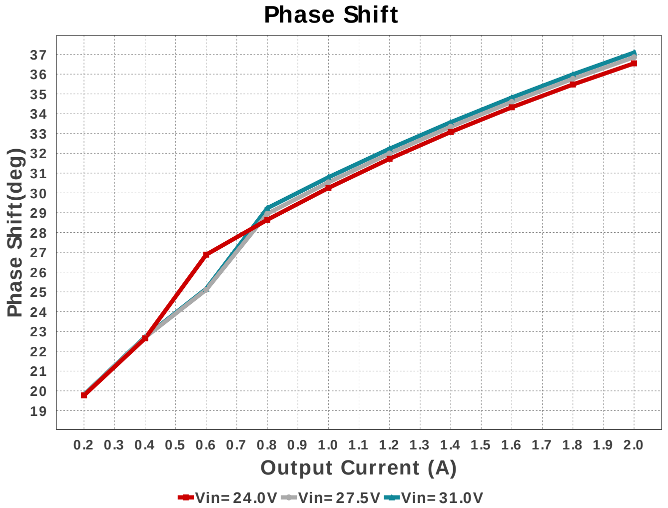

Cio IRMS
Cio IRMS(A)
Output Current (A)
Vin=24.0V Vin=27.5V Vin=31.0V

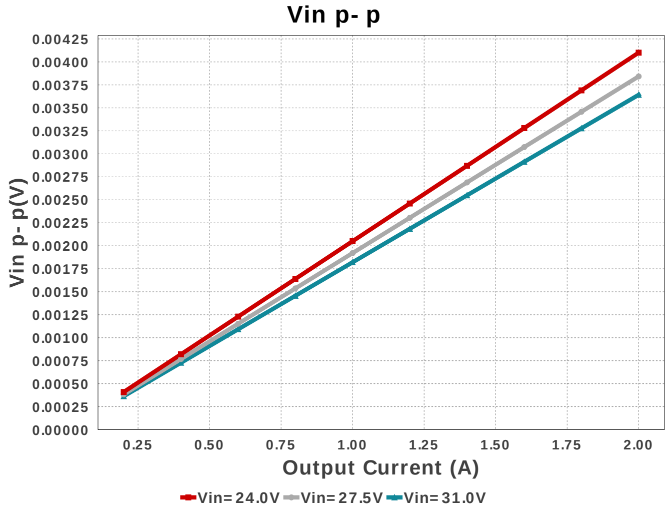

D1 Irms
D1 Irms(A)
Output Current (A)
Vin=24.0V Vin=27.5V Vin=31.0V

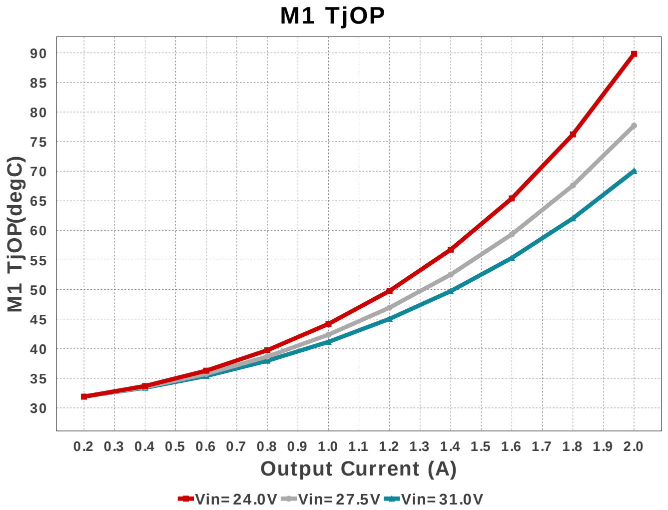

D1 PdCond
D1 PdCond(W)
Output Current (A)
Vin=24.0V Vin=27.5V Vin=31.0V

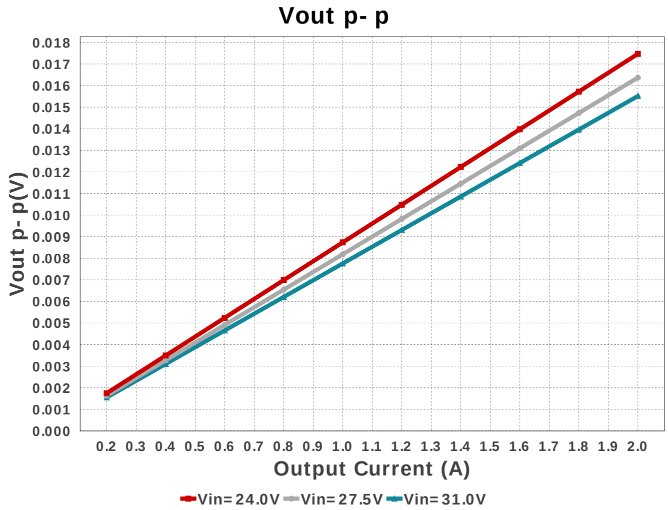

D1 Tj
D1 Tj(degC)
Output Current (A)
Vin=24.0V Vin=27.5V Vin=31.0V

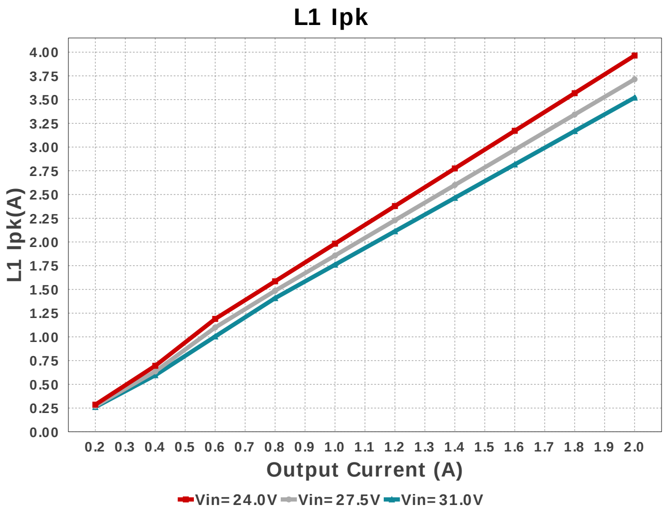

Efficiency
Efficiency(%)
Output Current (A)
Vin=24.0V Vin=27.5V Vin=31.0V

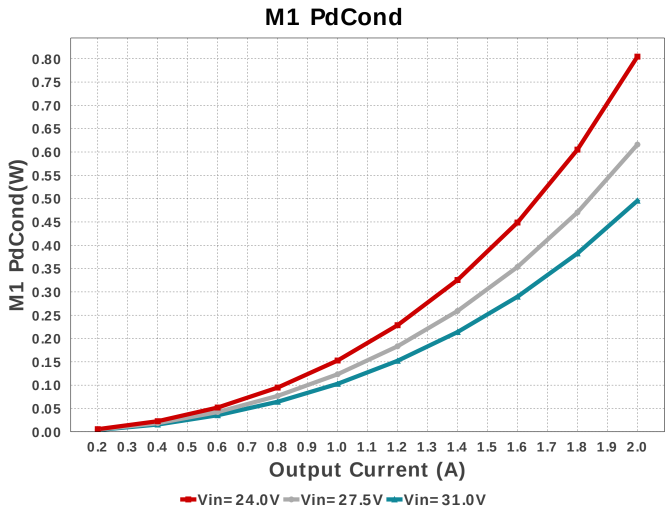

Phase Shift
Phase Shift(deg)
Output Current (A)
Vin=24.0V Vin=27.5V Vin=31.0V

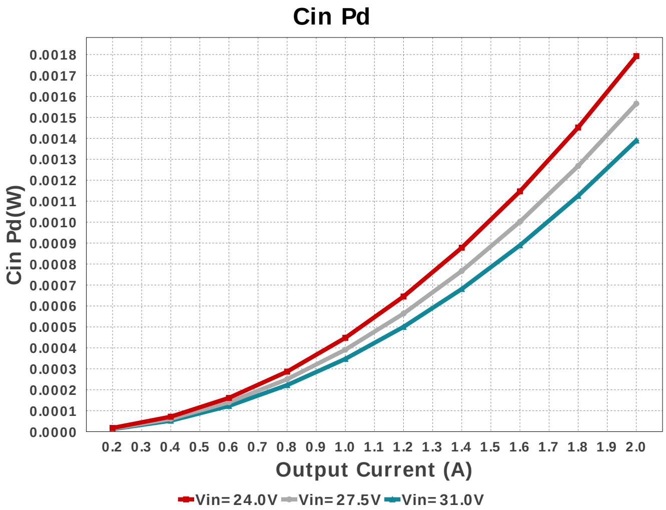

Vin p-p
Vin p-p(V)
Output Current (A)
Vin=24.0V Vin=27.5V Vin=31.0V

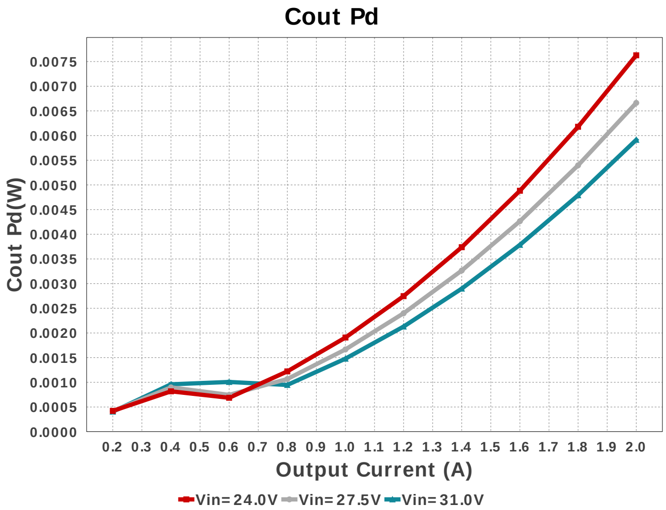

M1 TjOP
M1 TjOP(degC)
Output Current (A)
Vin=24.0V Vin=27.5V Vin=31.0V

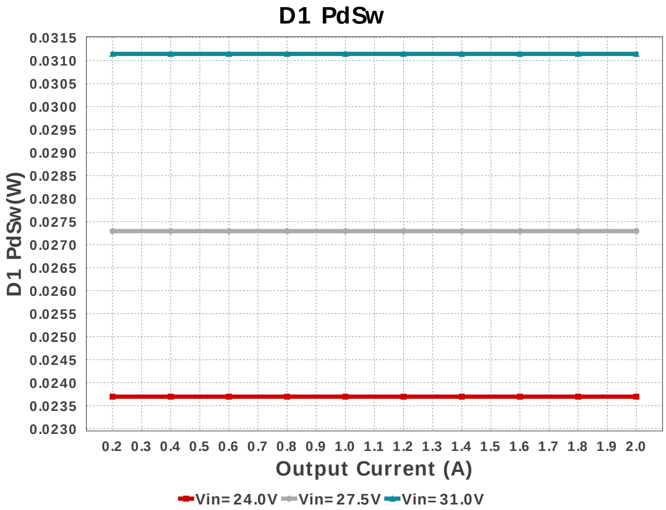

Vout p-p
Vout p-p(V)
Output Current (A)
Vin=24.0V Vin=27.5V Vin=31.0V

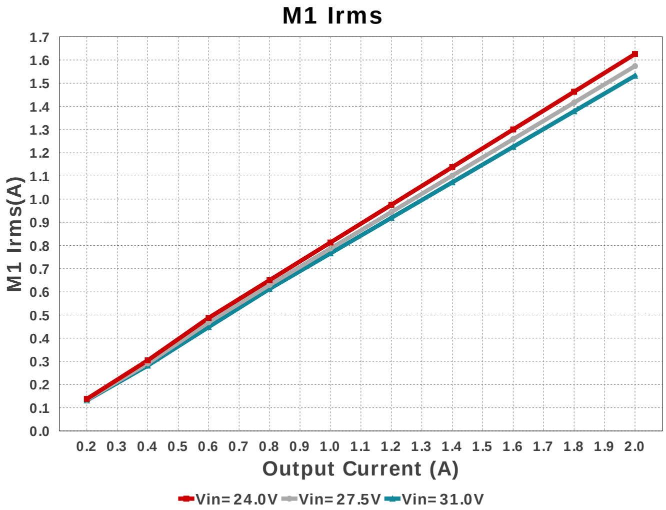

L1 Ipk
L1 Ipk(A)
Output Current (A)
Vin=24.0V Vin=27.5V Vin=31.0V

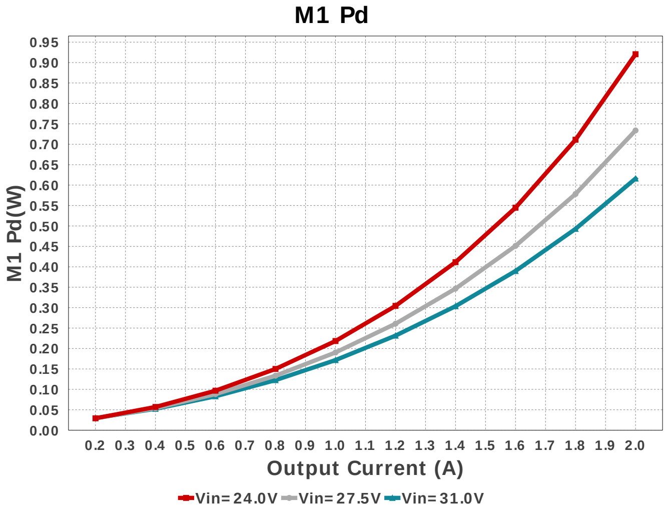

M1 PdCond
M1 PdCond(W)
Output Current (A)
Vin=24.0V Vin=27.5V Vin=31.0V

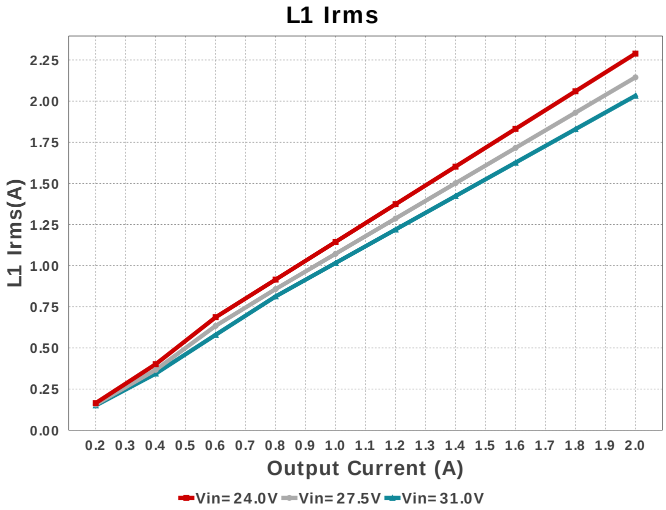

Cin Pd
Cin Pd(W)
Output Current (A)
Vin=24.0V Vin=27.5V Vin=31.0V

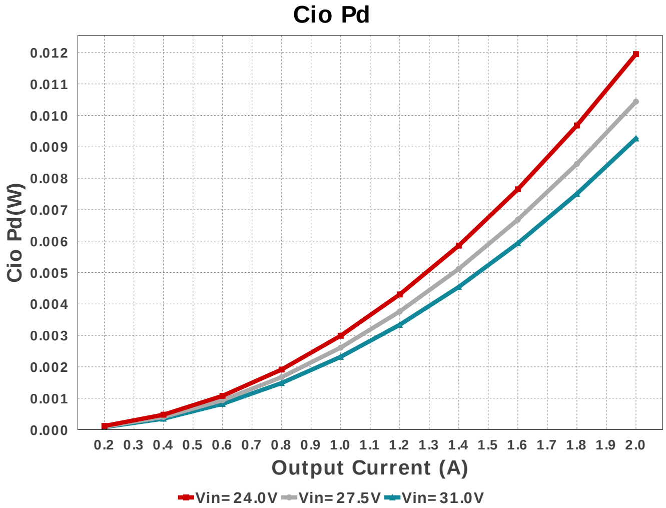

Cout Pd
Cout Pd(W)
Output Current (A)
Vin=24.0V Vin=27.5V Vin=31.0V

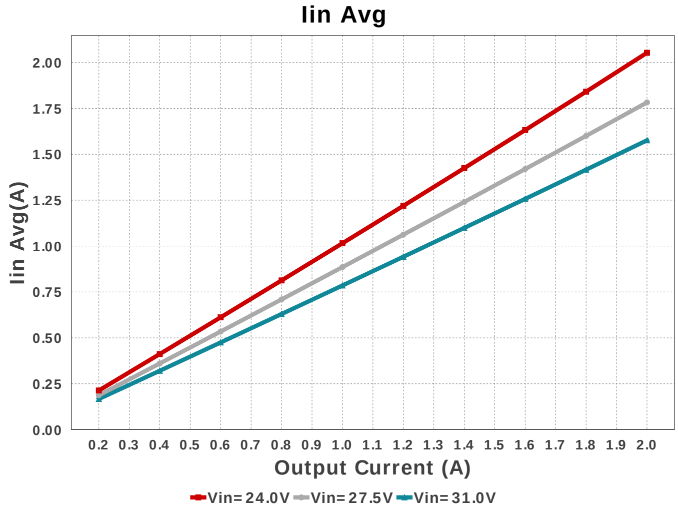

D1 PdSw
D1 PdSw(W)
Output Current (A)
Vin=24.0V Vin=27.5V Vin=31.0V

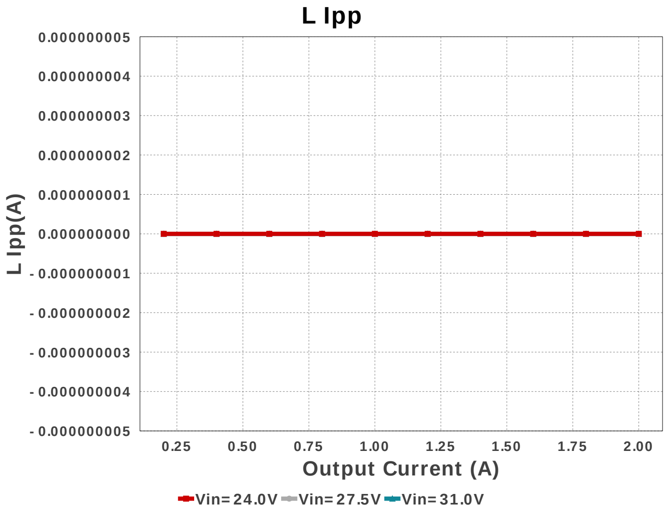

M1 Irms
M1 Irms(A)
Output Current (A)
Vin=24.0V Vin=27.5V Vin=31.0V

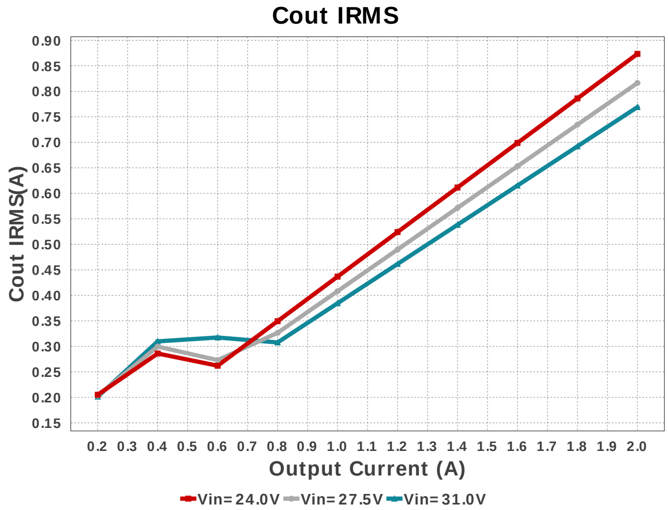

M1 Pd
M1 Pd(W)
Output Current (A)
Vin=24.0V Vin=27.5V Vin=31.0V

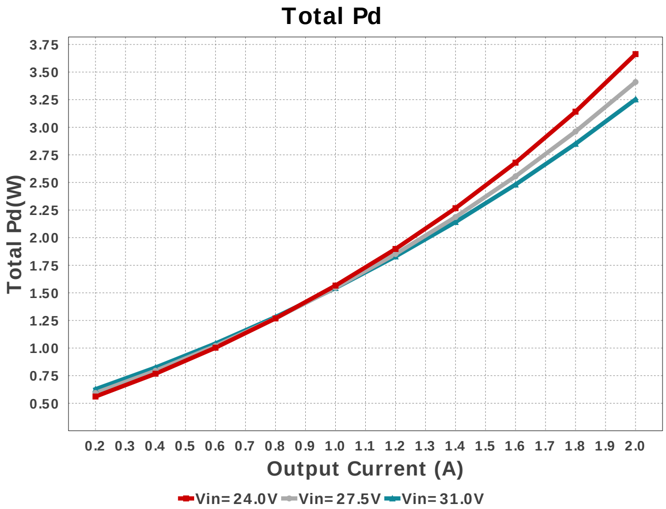

L1 Irms
L1 Irms(A)
Output Current (A)
Vin=24.0V Vin=27.5V Vin=31.0V

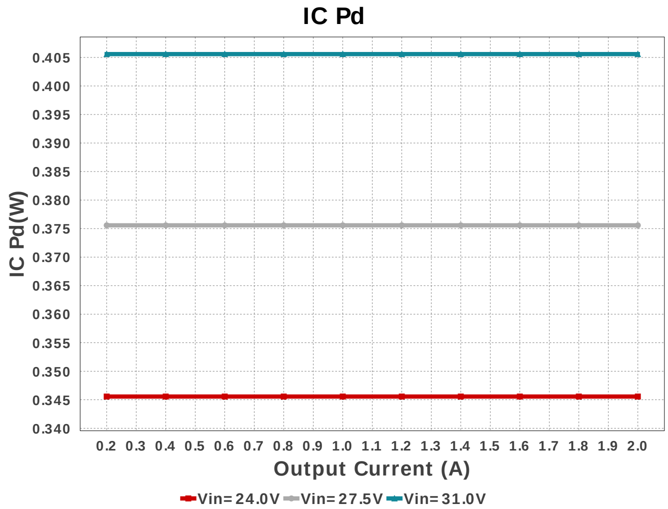

Cio Pd
Cio Pd(W)
Output Current (A)
Vin=24.0V Vin=27.5V Vin=31.0V

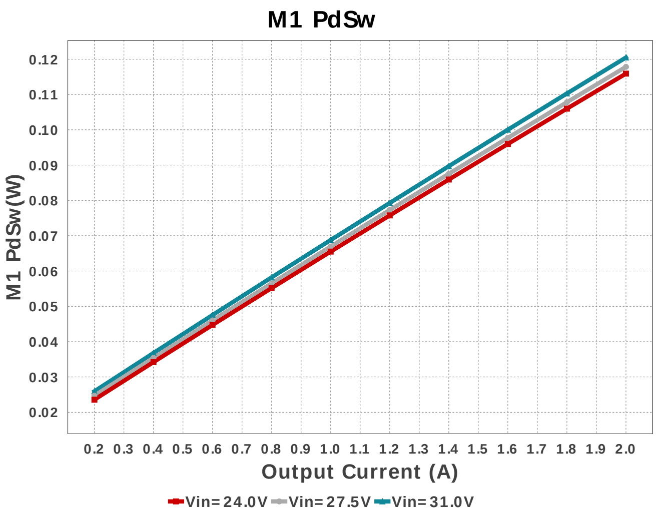

Iin Avg
Iin Avg(A)
Output Current (A)
Vin=24.0V Vin=27.5V Vin=31.0V

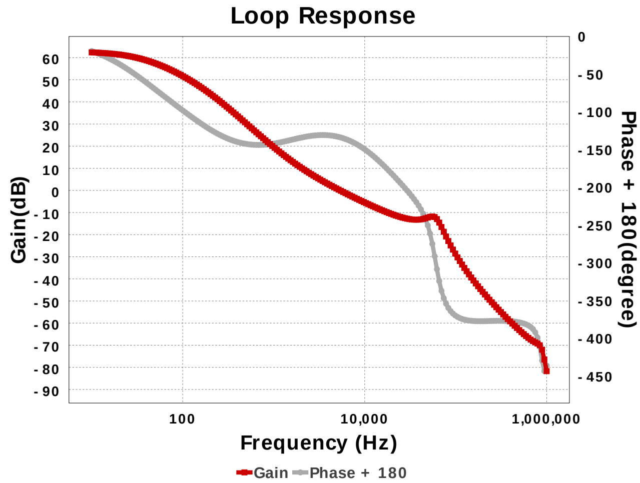

L Ipp
L Ipp(A)
Output Current (A)
Vin=24.0V Vin=27.5V Vin=31.0V


Cout IRMS
Cout IRMS(A)
Output Current (A)
Vin=24.0V Vin=27.5V Vin=31.0V


Total Pd
Total Pd(W)
Output Current (A)
Vin=24.0V Vin=27.5V Vin=31.0V


IC Pd
IC Pd(W)
Output Current (A)
Vin=24.0V Vin=27.5V Vin=31.0V





Operating Values

#	Name	Value	Category	Description
1.	Cin IRMS	874.087 mA	Capacitor	Input capacitor RMS ripple current
2.	Cin Pd	1.792 mW	Capacitor	Input capacitor power dissipation
3.	Cio IRMS	1.108 A	Capacitor	Input to output capacitor RMS ripple current
4.	Cio Pd	11.949 mW	Capacitor	Input to output capacitor power dissipation
5.	Cout IRMS	873.321 mA	Capacitor	Output capacitor RMS ripple current
6.	Cout Pd	7.627 mW	Capacitor	Output capacitor power dissipation
7.	D1 Irms	1.611 A	Current	D1 Irms
8.	D1 Pd	1.565 W	Diode	Diode power dissipation
9.	D1 PdCond	1.54 W	Diode	Diode conduction losses
10.	D1 PdSw	25.088 mW	Diode	Diode switching losses
11.	D1 Tj	76.953 degC	Diode	D1 junction temperature
12.	IC Ipk	4.316 mA	IC	Peak switch current in IC
13.	IC Pd	408.294 mW	IC	IC power dissipation
14.	IC Tj	46.332 degC	IC	IC junction temperature
15.	IC Tolerance	18.0 mV	IC	IC Feedback Tolerance
16.	Iin Avg	2.053 A	IC	Average input current
17.	L Ipp	0.0 A	Inductor	Peak-to-peak output inductor ripple current
18.	L Pd	671.014 mW	Inductor	Inductor power dissipation
19.	L1 Ipk	3.964 A	Inductor	Inductor peak current
20.	L1 Irms	2.289 A	Inductor	Inductor ripple current
21.	M1 Irms	1.626 A	Mosfet	M1 MOSFET Irms
22.	M1 Pd	929.801 mW	Mosfet	M1 MOSFET total power dissipation
23.	M1 PdCond	807.089 mW	Mosfet	M1 MOSFET conduction losses
24.	M1 PdSw	122.712 mW	Mosfet	M1 MOSFET switching losses
25.	M1 TjOP	90.438 degC	Mosfet	M1 MOSFET junction temperature
26.	IOUT_OP	2.0 A	Op Point	Iout operating point
27.	VIN_OP	24.0 V	Op Point	Vin operating point
28.	Total Pd	3.676 W	Power	Total Power Dissipation
29.	Rsense Pd	102.145 mW	Resistor	LED Current Rsns Power Dissipation
30.	BOM Count	26	System Information	Total Design BOM count
31.	Cross Freq	5.171 kHz	System Information	Bode plot crossover frequency
32.	Duty Cycle	49.548 %	System Information	Duty cycle
33.	Efficiency	92.54 %	System Information	Steady state efficiency
34.	FootPrint	840.0 mm^2	System Information	Total Foot Print Area of BOM components
35.	Frequency	120.0 kHz	System Information	Switching frequency
36.	Gain Marg	10.613 db	System Information	Bode Plot Gain Margin
37.	Mode	DCM	System Information	Conduction Mode
38.	Phase Marg	47.025 deg	System Information	Bode Plot Phase Margin
39.	Phase Shift	36.468 deg	System Information	Bode Plot Phase Shift
40.	Total BOM	$7.2	System Information	Total BOM Cost

#	Name	Value	Category	Description
41.	Vin p-p	4.101 mV	System Information	Peak-to-peak input voltage
42.	Vout p-p	17.466 mV	System Information	Peak-to-peak output ripple voltage

Design Inputs

Name	Value	Description
Iout	2.0	Maximum Output Current
SoftStart	3.0 ms	Soft Start Time (ms)
VinMax	31.0	Maximum input voltage
VinMin	24.0	Minimum input voltage
Vout	-22.8	Output Voltage
base_pn	LM5088	Base Product Number
source	DC	Input Source Type
Ta	30.0	Ambient temperature
UserFsw	120.0 k	Customer Selected Frequency

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

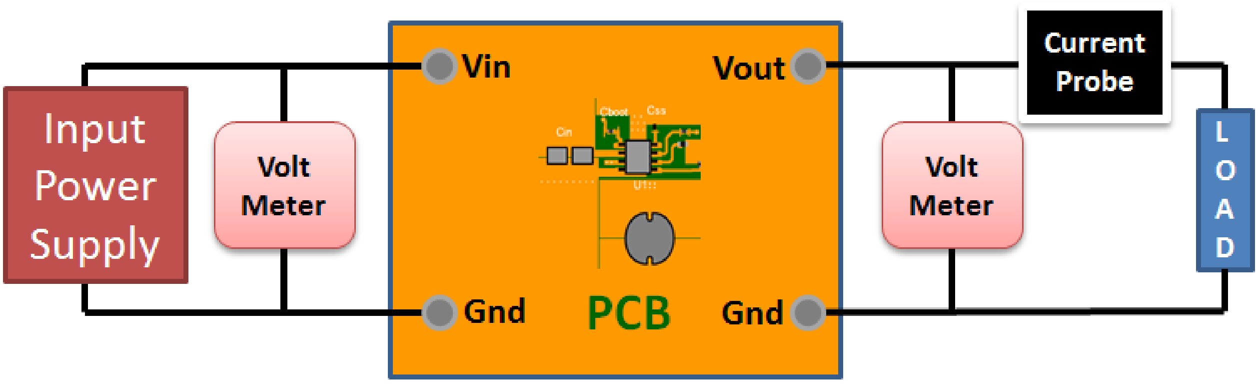
If board assembly is done in house it is best to tack down one terminal of a component on the board then solder the other terminal. For surface mount parts with large tabs, such as the DPAK, the tab on the back of the package should be pre-tinned with solder, then tacked into place by one of the pins. 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 24.0V 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 : FD7E8546FE5B4C7F[v1]

2. **LM5088** Product Folder : http://www.ti.com/product/LM5088 : contains the data sheet and other resources.

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