Network Power for Automobile

ECE445 Design Document - Spring 2024

Project #26

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Contents:

Introduction

Problem

The production rate of electric vehicles has seen a great increase in recent years[1]. Manufacturers are looking for ways to optimize the power distribution network on vehicles. A common issue found on un-optimized platforms is the need for many “power-rails”, which service various devices and sensors rated for different voltages. As electric and autonomous vehicles grow more complex, the need for more such rails can grow.

The members of this team are also involved in Illini Electric Motorsports (IEM), an RSO that builds prototype electric race cars. The 2024 vehicle produced by the team has a low-voltage (LV) power system based on a lead-acid battery having 24-29V range that is distributed throughout the vehicle over 12V and 24V power-rails. The voltage conversion was achieved using two off-the-shelf, centralized DC/DC converters.

Despite having three separate power rails, the system described above is still insufficient at servicing the needs of the overall system. Many sensors, microcontrollers and other powered devices on the vehicle require 3.3-5V, previously achieved through the use of individual linear regulators for each device/PCB.

Solution

We will create a system that services the specific and *unique* needs of modern EVs. Our solution is to distribute the vehicles LV battery output as a single rail, and have more localized, controllable DC/DC converters with different output levels. Each local converter will have four outputs, where each may be configured via software to one of four voltage levels: 3.3V, 5V, 12V and 24V. This creates a single versatile product that can be modified for the specific needs of each use case.

As an example, the front portion of a hypothetical EV may require 12V to power lights, 3.3V to service a wheel speed sensor, and 24V to power a fan. Thus, we can command output one to 12V, two to 3.3V and three to 24V. Unused outputs may be turned off. The advantage of this system is twofold - it simplifies the power distribution over the large portion of the vehicle and it allows flexibility by configuring the device to serve the needs of the specific collection of devices in its vicinity. Thus, this single solution can serve not just our IEM vehicle, but a whole slew of production EVs.

Visual Aid

The following two figures contrast a vehicle before and after the described solution is incorporated. The vehicle incorporating this project showcases simplified harnessing, data feedback, and a simplified voltage conversion schema.

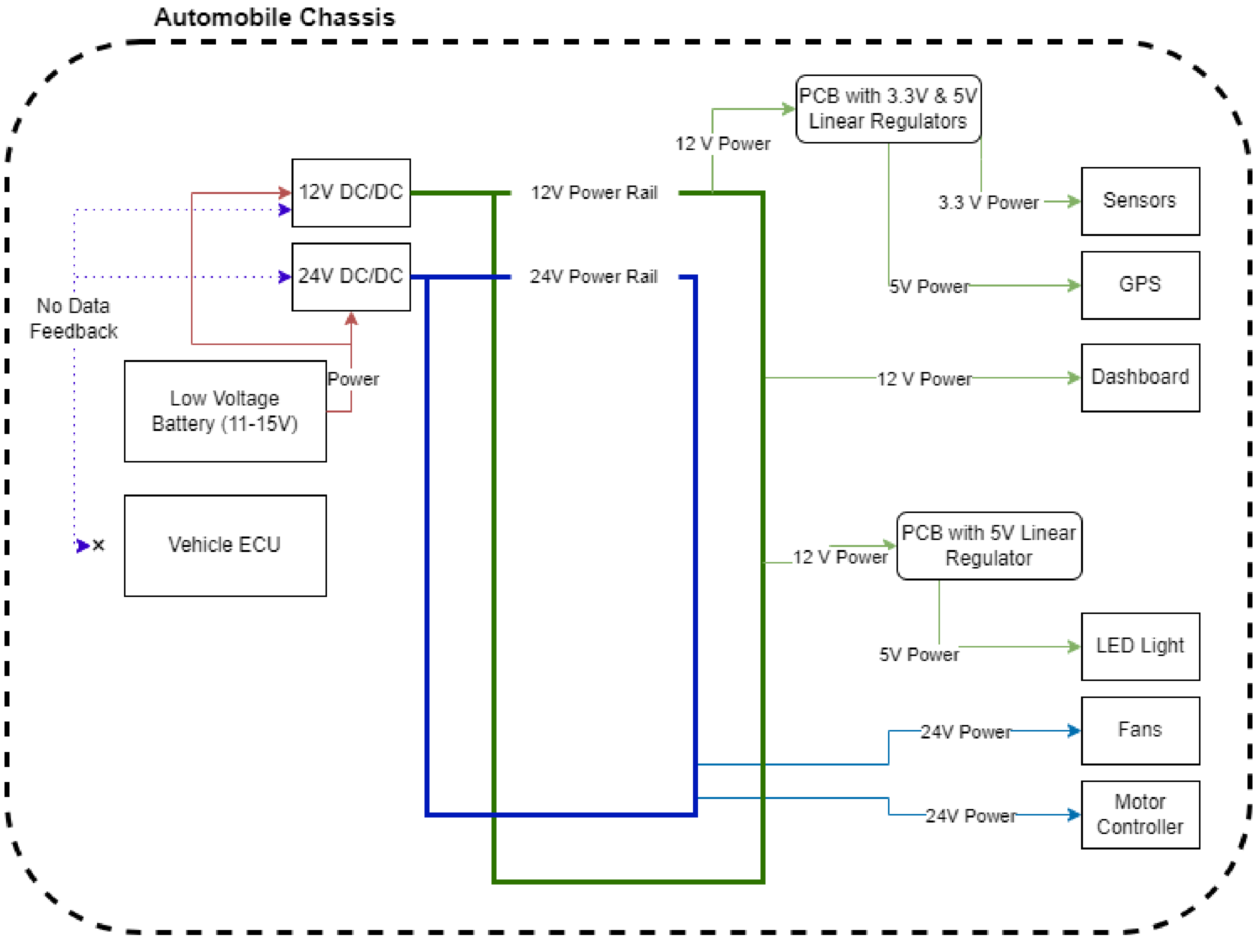


Fig. 1: Current status of the IEM 2024 vehicle, with its power harnessing depicted. The vehicle ECU gets no feedback from the system about power consumption.

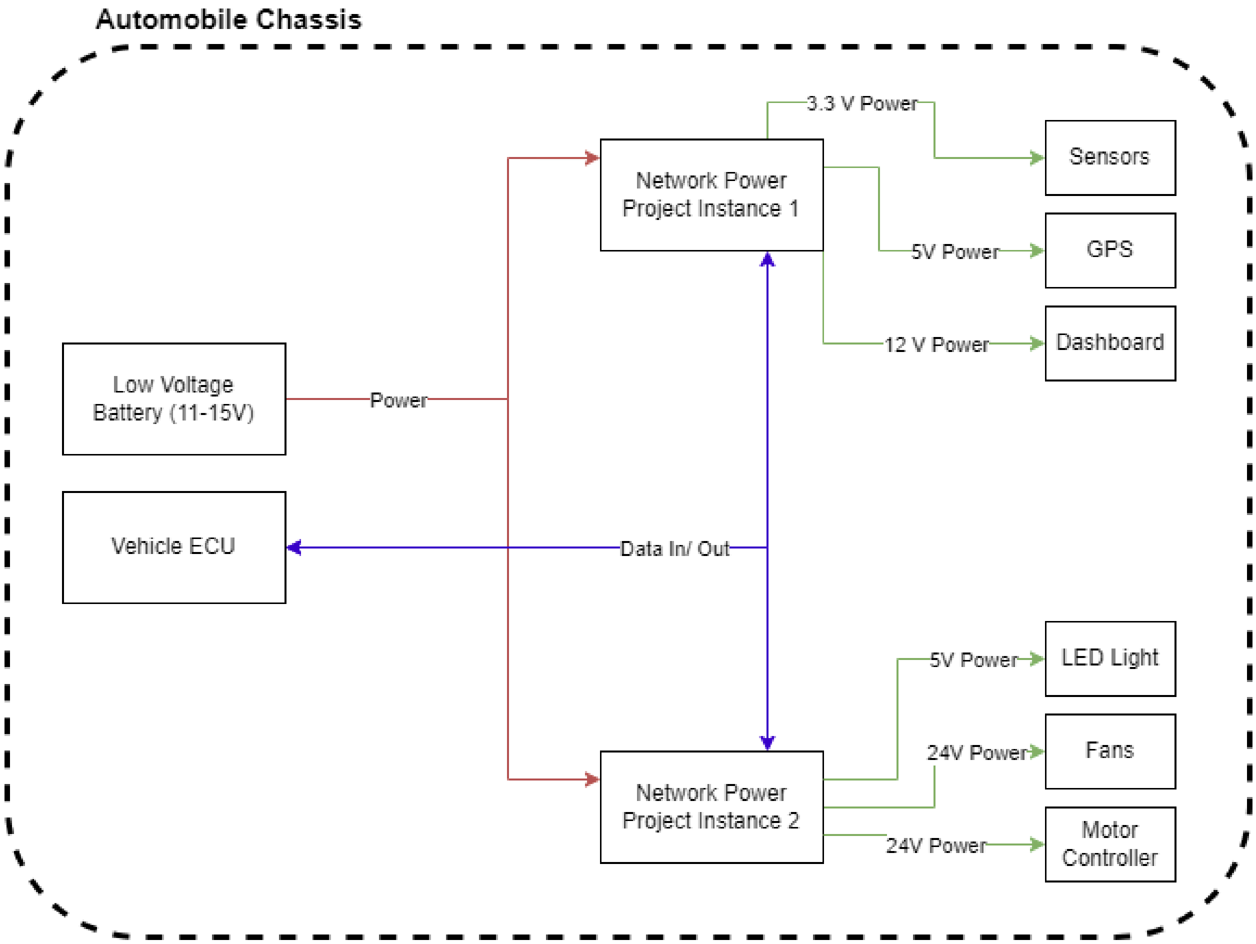


Fig. 2: After incorporating the project onto the vehicle, the voltage conversion and wiring required is simplified. Additional data about power usage and duty cycle is also collected by the Vehicle ECU.

A simplified harness (Fig. 2) will have less mass, complexity, and losses involved with it. Additionally, the dedicated 3.3V and 5V converters will give the system an efficiency boost over the current LDO-based system. These efficiency improvements can then be translated into better-optimized LV batteries and lighter vehicles.

High Level Requirements

The success of this project will be measured against the following criteria:

1. Communication with the solution over Controller Area Network (CAN).
    a. Independent control over each voltage output.
    b. Voltage/current usage data received at 20Hz.

c. Visualization of voltage/current usage data by the user within the accuracy provided by the E-meter chip

2. Supply up to 2A of current on all active rails simultaneously. Outputs should have less than +/-5% voltage ripple and +/-5% current ripple on the load compared to software setpoint.
3. Stay below 60° Celsius while providing 2A on all active rails for 60 minutes.

Design

Block Design

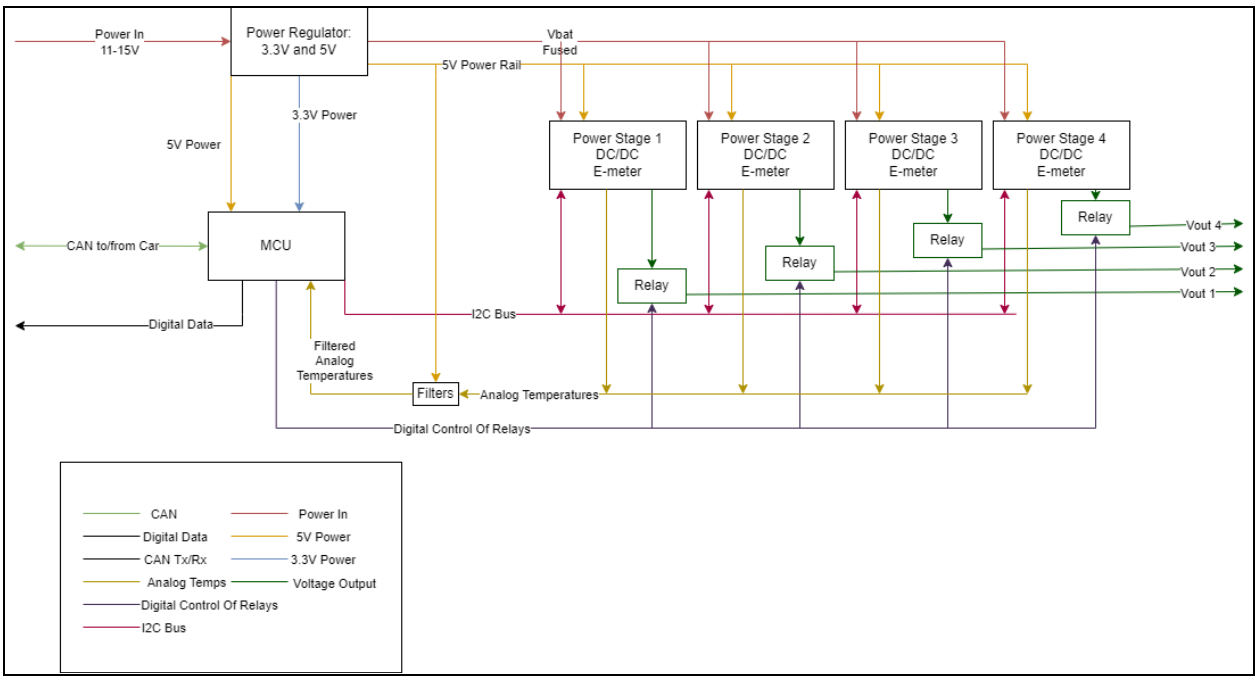


Fig. 3: High-level block diagram of the project

As a black box, our project will have three inputs and five outputs.

Inputs:

1. Power In

This is how the project will be powered. In the application setting, this will be the voltage leads from the automobile's LV system. However, for demonstration purposes, we will be simulating this with a DC power supply.

2. CAN Bus

This is the protocol the rest of the automobile/user will use to communicate with the project. Defined messages will allow a user to enable/disable any output independently, and set its voltage output. Additionally, the user will receive voltage, current, and temperature statistics from each Power Stage.

3. Digital Data Input

The digital input could be used for a digital enable signal, which could be tied to the ignition of the car to enable the device when the car turns on.

Outputs:

1. Vout 1-4

Each output consists of a relay-controlled voltage source. Voltage control is achieved through the use of four buck-boost DC/DC converters, commanded by the MCU over I2C. The details of this will be discussed further under the "Powerstage Subsystem" section.

2. Digital Data Output

The digital output can be used as an alarm pin, indicating issues with the device even if the CAN bus fails.

Physical Design

There will be two major PCBs on the project. There will be one backplane PCB that will house the MCU, MCU Power, and Filter subsystems. There will be 4 identical powerstage PCBs that will house the Powerstage and Relay subsystems. The powerstage PCBs will connect into the backplane and provide power to the devices connected to the project.

The only specific physical constraints on this project are with regards to temperature. We based our target maximum temperature on the FSAE ruleset [2], which deems temperatures above 60°C as requiring special enclosures. The required heat rejection of our converters will be analyzed in the "Tolerance Analysis" section of this document.

MCU Subsystem

The MCU, or microcontroller, subsystem will be the brain of the project. It is responsible for controlling each power stage board individually over the I2C protocol, as well as reading output information, such as voltage and power, from the e-meter chips. Furthermore, it must also read the output voltage from the thermistors on the boards, and perform the necessary conversions to temperature.

The MCU is also responsible for communicating with the rest of the car over CAN bus. It will receive commands, such as setting voltage levels or turning an output on/off, and will output the information it is receiving from the power stage boards so the rest of the car can receive precise information regarding the current power usage for each power stage.

The MCU will also monitor the output voltages, currents, and temperatures to ensure that everything is operating properly, and will forcefully shut down any power stage board that is encountering a problematic issue. When doing so, it will send a CAN message explaining the error, as well as set its alarm GPIO output to high, indicating an issue has occurred even if CAN communication has failed.

This alarm pin will also be set to high if the MCU detects it is no longer properly connected to the CAN bus, and it will shut down the outputs as a safety precaution.

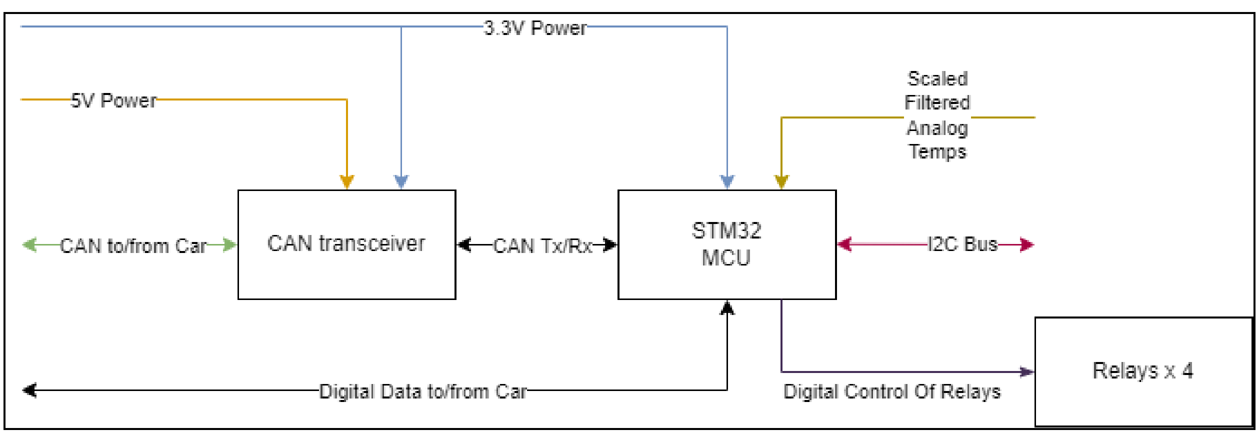


Fig. 4: The MCU subsystem will serve as the central hub for the project's digital and analog I/O

Specific model numbers for each device are specified in the 'Costs' section of this document.

Requirements	Verification
Use I2C to communicate with the E-meters and DC/DC Controller ICs on each Powerstage board.	- Demonstrate voltage control over DC/DC output by sending I2C data in STM's software debug mode - Receive data from E-meter over I2C by viewing received data in STM's software debug mode
Send and receive CAN messages.	- Create a test CAN bus, sending and receiving signals using a laptop and custom viewing and controlling software with an off the shelf CAN to USB adapter. - Configure a custom CAN message with a specific message ID and decode format for data received from the E-meter module.
Read analog temperatures.	- Receive analog voltage from thermistors, viewing received voltage on laptop in remote debug mode, or on custom viewing software. - Convert STM's ADC reading into a temperature value in Celsius. - Measure error between system's reading and an external temperature reading (thermal camera) less than 10%.
Open/close the relays using the digital GPIO pins on the MCU	- Measure continuity of the circuit using probe points and a portable voltmeter while actuating the relay.
Send digital signals out of the device (alarm signal).	- View the alarm signal on an oscilloscope as it is set high/low by the STM. - Verify the alarm signal is automatically set by the STM when reading temperature greater than 60°C. Temperature reading can be spoofed using a potentiometer instead of the thermistor.

Table 1: MCU System Requirements.

MCU Power Subsystem

The power subsystem consists of 3 items. There is a fuse from the input from the lead acid battery to protect the PCB and components. The 3.3V LDO will power the CAN transceiver and the MCU. The 5V LDO will provide power for the CAN transceiver and the controllers in the DC/DC modules. These LDOs will not be connected to the loads. For power draws of each component on these rails, see Appendix A.

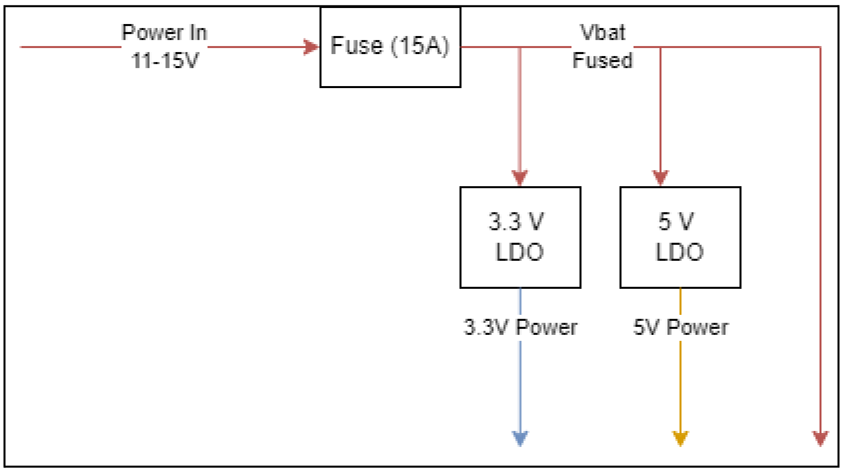


Fig. 5: MCU Power Subsystem diagram. This subsystem powers the MCU and provides overcurrent protection.

Requirements	Verification
Provide 5V +/-10% at a 500 mA load while keeping the LDO under 60°C.	- Connect the net to an electronic load and then produce a 500mA current draw. Let the load run for an hour and measure temperature with an IR camera. - Use an oscilloscope to verify voltage output is within tolerance.
Provide 3.3V +/-10% at a 300 mA load while keeping the LDO under 60°C.	- Connect the net to an electronic load and then produce a 300mA current draw. Let the load run for an hour and measure temperature with an IR camera. - Use an oscilloscope to verify voltage output is within tolerance.

Table 2: MCU Power Subsystem Requirements

Filter Subsystem

The filters will be made using Op-Amps and RC LPF filters to help remove most of the switching noise, if any. An Op-Amp will also bring the 5V down to 3.3V to bring the 5V thermistor reading down to 3.3V. The readings will start on the powerstage boards and go into the backplane, where these Op-Amps will be. After it is passed into the MCU. We chose the 10 kHz cutoff frequency for the RC filter because we see noise from the switches on the inverters at 16 kHz on the car. The STMs internal SMPS produces noise from 15 kHz to 1 MHz, which is also why the 10 kHz cutoff was chosen. The Amplifying Op-Amp will also let us adjust the gain of the filter to better utilize the full range of the 3.3V ADC on the STM.

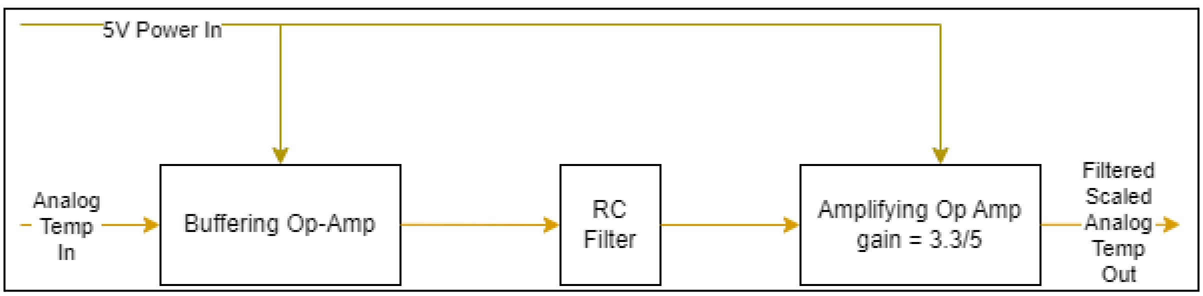


Fig. 6: Filter Subsystem diagram. Filtering the thermistor reading gives us more reliable results, a key factor in the main safety subsystem of the project.

Requirements	Verification
Detects when the Powerstage is not plugged in with a pull up resistor on the input.	- Unplug the Powerstage and view that the alarm signal is raised on an oscilloscope.
Scale down the 5V signal to a 3.3V signal.	- Measure the voltage out of the 'Buffering Op-Amp' and the 'Amplifying Op-Amp' on an oscilloscope. - Verify that the measured voltage is scaled correctly based on the measurement.
Read in analog temperatures.	- See MCU Subsystem.

Table 3: Filter Subsystem Requirements

Powerstage Subsystem

The secondary boards/Powerstage is the other major subsystem. They connect to the main board and, depending on which module is selected, will output different voltages. These boards are meant to be as simple as possible to ensure a small and cheap form factor for the final product. The voltage from the battery will enter the PCB, which then goes into the DC/DC module. The converted output voltage and current will flow into a shunt which is then connected to a load. There is a power meter (E-meter) chip that reports voltage, current and power usage to the MCU over an I2C bus. There is a thermistor to provide analog temperature readings to the MCU. The output voltage of the DC/DC module can be set with I2C.

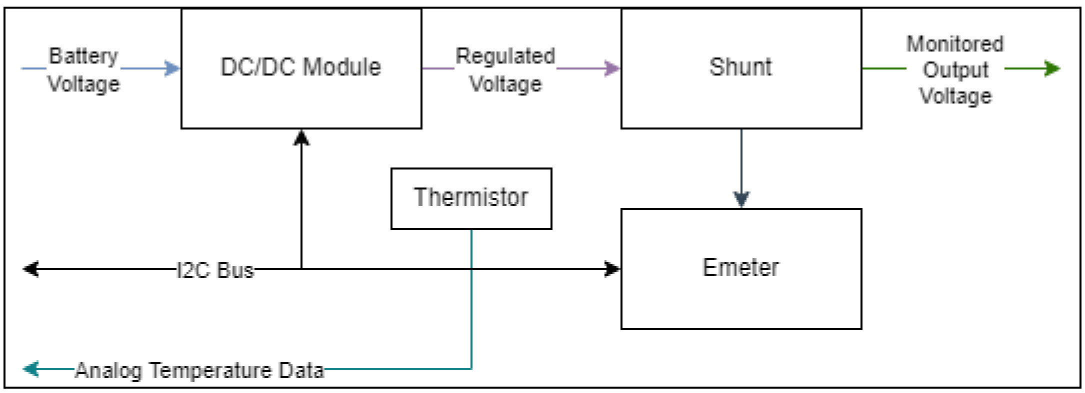


Fig. 7: Powerstage Subsystem diagram

Requirements	Verification
Use I2C to communicate with the E-meters and DC/DC Controller ICs on the powerstage.	- See MCU subsystem.
Outputs should have less than +/-5% voltage ripple compared to software setpoint.	- Send a CAN message to MCU to command one output to turn on at voltage X, where X can be 3.3V, 5V, 12V or 24V. - Measure open circuit voltage using an oscilloscope. - Connect output to a resistive load and measure voltage using an oscilloscope.
Supply up to 2A of current on all active rails simultaneously. +/-5% current ripple on the load.	- Send a CAN message to MCU to supply 4 resistive loads with 2A.

Temperature of all components must stay below 60° Celsius while providing 2A on all active rails for 60 minutes.	- Set up 4 resistive loads, and supply each with 2A for 60 minutes. Measure temperature of the board with an IR camera.

Table 4: Powerstage Subsystem Requirements

Relay Subsystem

The relays are used to disconnect the load from the DC/DC, while also disabling the DC/DC at the same time. The MCU will send a digital signal to the powerstage and relay to turn off and disconnect the power supply. The battery input will be used to turn the relay on and off.

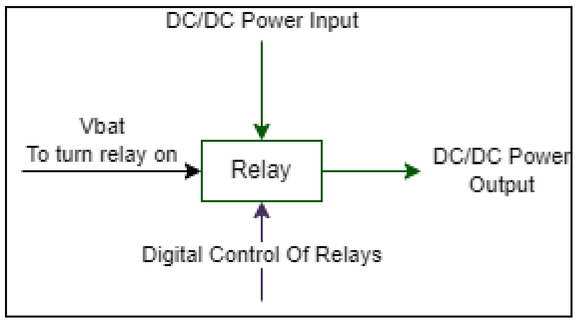


Fig. 8: Relay Subsystem diagram

Requirements	Verification
Relays can be actuated via CAN commands.	- Individual outputs can be toggled from the CAN based viewing and controlling tool
Relays are automatically opened in the event of a failure / alarm condition.	- Measure the voltage output from the device when temperature rises above 60°C. Temperature reading can be spoofed using a potentiometer instead of the thermistor. Hi dhruv

Table 5: Relay Subsystem Requirements

Tolerance Analysis

DC/DC Output Tolerance

For the component analysis, we will consider two cases, 3.3V and 24V output, both at 30°C and a 2A output. We chose to use the 3.3V and 24V test cases since they are on the extreme ends for the duty ratio TODO:Citation. We chose 30°C as a warm ambient temperature since it will operate in an enclosure in the summer. The operating values are derived from TI WeBench Power Designer Tool.

Vout	Duty Cycle at Vin = 11V
3.3V	0.231
5V	0.312
12V	0.521
24V	0.685

Table 6: Duty Cycle for different outputs

The tool lets us set up parameters with the controller and passives then calculates operating values based on operating conditions such as temperature and voltages. Details of the setup can be found in Appendix C.

Operating Values	3.3V Output	24V output
Inductor Current Peak-Peak	818.48 mA	2.526 A
Average Input Current	669.48 mA	4.588 A
Voltage output Peak-Peak	3.677 mV	15.692 mV
Output Capacitor Peak-Peak Current	117.742 mA	1.598 A
Total Power Dissipation	764.265 mW	2.467 W
Duty Cycle	31.466 %	56.477 %
Average MOSFET power loss	269.0755 mW	443.175 mW
Efficiency	89.622 %	95.112%
Conduction Mode	CCM	CCM

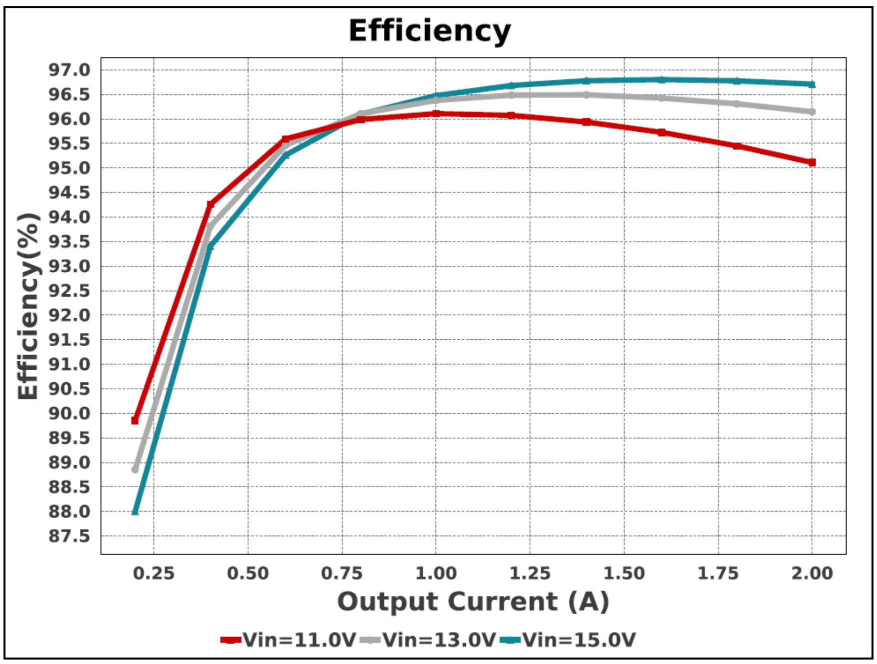
Table 7: Voltage tolerance analysis data

Operating Temperature Tolerance

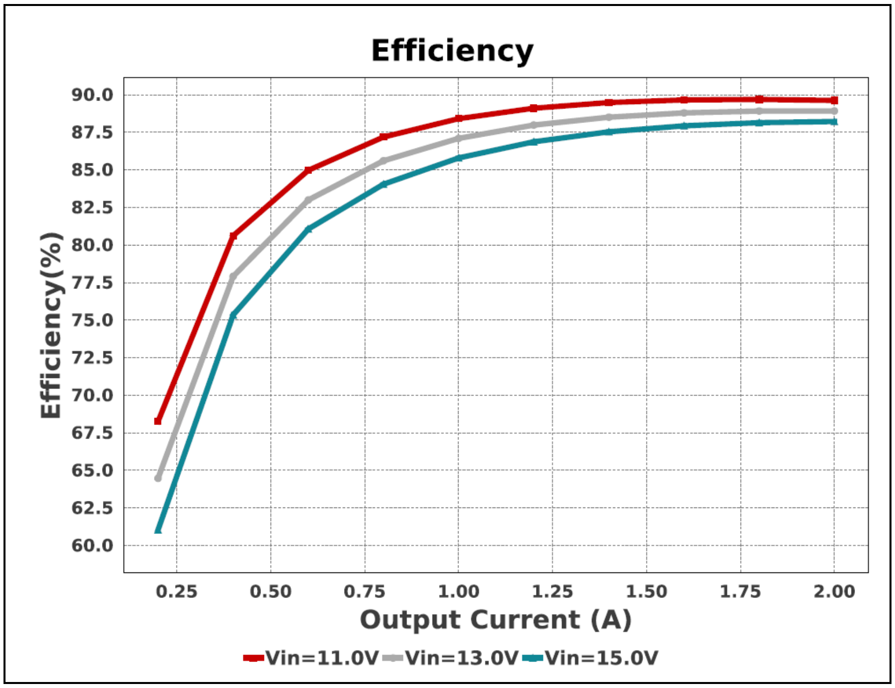
Our project is to essentially design a variable power supply. Therefore, ensuring that our electronic components are operating within safe thermal limits is important to the success and safety of our project.

We will be analyzing the most expensive/vulnerable component of the system, the actual DC/DC control module. The simulations in Appendix C show that we achieve our worst-case heat output when Vin = 11V, Vout = 24V, Iout = 2A.

Heat Output Calculations:



DC/DC Efficiency Curves at Vout=24V. See Appendix C for further details.



DC/DC Efficiency Curves at Vout=3.3V. See Appendix C for further details.

Using the graph above, we can calculate the heat output using the following formula:

$$Power\ loss\ =\ Heat\ out$$

$$Heat\ out\ =\frac{Power\ delivered}{Efficiency}\ -\ Power\ delivered$$

$$Heat\ out\ =\ \frac{V_{out}I_{out}}{Efficiency}\ -V_{out}I_{out}$$

$$Heat\ out\ =\ \frac{24*2}{0.95}\ -\ 24\ *\ 2$$

$$Heat\ out\ =\ 2.53W$$

Therefore, we can use 2.53W max output as our worst-case heat rejection requirement. This heat is being rejected by the switches, inductors and capacitors of the system. However, as a conservative measure, we can assume all these losses are concentrated in the four switches. Assuming a warm ambient temperature of 30°C, we can use this to calculate the required heatsink. The calculations were done using a MATLAB script attached in Appendix B.

```
Command Window
Max_Required_Thermal_Res =

   47.4308


No_Heatsink_R =

    60


DCDC_Temp =

42.65

fx >>
```

Fig. 9: Temperature tolerance analysis. Thermal resistance of a single switch given in its datasheet [5].

Since the thermal resistance of having no heatsink is much larger than the required resistance to dissipate the estimated amount of heat, we must therefore employ a cooling system to maintain our operating temperature.

The simplest solution here is a passive heatsink, which can be easily purchased from Digikey. An example of such a heatsink is [4]:

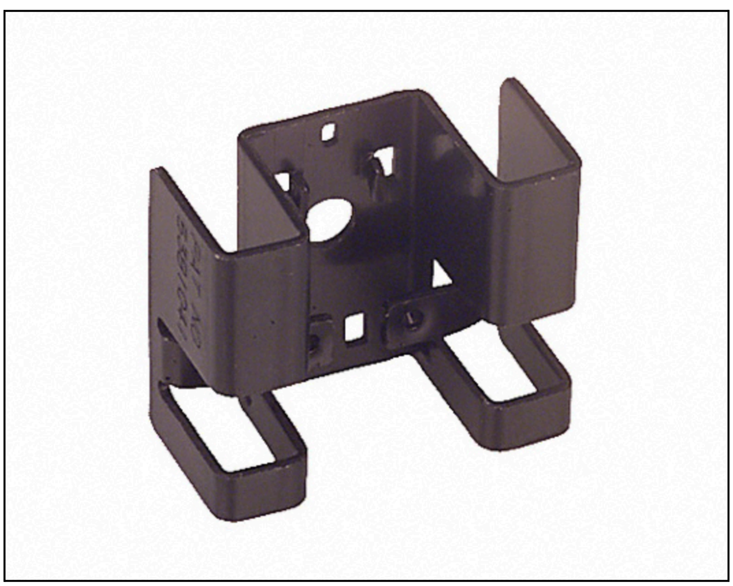


Fig. 10: This heatsink has a thermal resistance of 20°C/W [4]

Thus, this heatsink will fulfill our requirements.

Costs

For the development cost, we will be assuming that it would take a group of 3 junior engineers 12 weeks working approximately 15 hours a week, with an average salary of $40 per hour. This would come out to a man-hour cost of 540 hours, or $21,600, before any benefits or taxes that have to be paid by the employer. This also represents the cost if the engineers are employed by the company needing the product, and the man-hour cost would likely be much higher if a company contracted another company to design such a product.

BOM:

MCU, MCU Power, Filter Subsystems:

Part Number	Manufacturer	Quantity	Extended Price	Link
TCAN1044AEVDRQ1	TI	1	$1.60	Link
744235900	Würth Elektronik	1	$1.80	Link
DIODE-SOT23_PESD1CAN	Nexperia USA Inc.	1	$0.37	Link
STM32F103	ST	1	$6.07	Link
SPX1117M3-L-5-0/TR	MaxLinear, Inc.	1	$0.40	Link
MPSS-08-16-L-12.00-SR	Samtec Inc.	1	$18.62	Link
LM2902LVQDRQ1	TI	2	$0.232	Link
REF2033QDDCRQ1	TI	1	$3.69	Link
3413.0330.22	SCHURTER Inc.	1	$0.52	Link
SWD 0.05" Pitch Connector - 10 Pin SMT Box Header	Adafruit	1	$1.50	Link

Powerstage, Relay Subsystems:

Description	Manufacturer	Quantity	Extended Price	Link
J1031C5VDC.15S	CIT Relay and Switch	4	$1.28	Link
LM51772	TI	4	$4.988	Link
INA780B	TI	4	$2.525	Link
IPZ40N04S5L-4R8	Infineon	16	$0.94	Link
XAL8080-682ME	Coilcraft	4	$5.38	Link
NCU15XH103F6SRC	Murata Electronics	4	$0.10	Link
TSW-110-08-F-D-RA	Samtec	8	$1.54	Link

Schedule

Week	Task	Person
2/19	Design Document, resubmit Project Proposal	Everyone
2/26	Design Review	Everyone
	PCB Schematics	Akash, Dhruv
	Order components	Everyone
3/4	Powerstage PCB Layout	Akash
	Backplane PCB Layout	Dhruv
	I2C STM Drivers, CAN message definitions	Constantin
3/11	Review PCBs and submit order	Everyone
3/18	Backplane MCU I/O testing	Constantin, Dhruv
3/25	PCB manufacturing	Everyone
4/1	PCB revisions (if necessary)	Akash, Dhruv
	Data visualizer	Constantin
4/8	Final Debugging / Assembly	Everyone
4/15	Mock Demo	Everyone

4/22	Final Demo / Mock Presentation	Everyone
4/29	Final Presentation	Everyone

Ethics and Safety

Some important safety features to implement in this project are overcurrent, overvoltage, short circuit, and thermal protections. These are all necessary to ensure the safety of the users, and the protection of the components both on this board, and on any devices connected to it.

The FSAE documentation [2] contains specific language around electrical safety and overcurrent protection. Below are references to some applicable regulations:

EV.6.6.1 All electrical systems (both Low Voltage and High Voltage) must have appropriate Overcurrent Protection/Fusing.

EV.6.6.2 Unless otherwise allowed in the Rules, all Overcurrent Protection devices must:

a. Be rated for the highest voltage in the systems they protect. Overcurrent Protection devices used for DC must be rated for DC and must carry a DC rating equal to or more than the system voltage.

b. Have a continuous current rating less than or equal to the continuous current rating of any electrical component that it protects.

c. Have an interrupt current rating higher than the theoretical short circuit current of the system that it protects.

The modular board will solve a few common ethical issues that are becoming very common in the electronics industry. It will make it easily serviceable and repairable, meaning if a secondary or a primary board fails, the other boards connected to it can be reused, thereby greatly reducing waste and cost. This will notably ensure we meet the first point in the IEEE Code of Ethics [3], which states the desire to “hold paramount the safety, health, and welfare of the public” and to “strive to comply with ethical design and sustainable development practices”.

Citations

[1] “EVs Forecast to Account for Two Thirds of Global Light-Vehicle Sales in 2035.” EV-Volumes - The Electric Vehicle World Sales Database, 21 November 2023, https://www.ev-volumes.com/. Accessed 22 February, 2024.

[2] “Formula SAE Rules 2024 Version 1.0.” FSAEOnline.com, 1 September 2023, https://www.fsaeonline.com/cdsweb/gen/DownloadDocument.aspx?DocumentID=369d01c0-589d-4ebe-b8d4-b07544f4a52b. Accessed 22 February, 2024.

[3] *IEEE code of Ethics*. IEEE. (n.d.). https://www.ieee.org/about/corporate/governance/p7-8.html/. Accessed 22 February 20, 2024

[4] “235-85AB Wakefield-Vette | Fans, Thermal Management.” DigiKey, https://www.digikey.com/en/products/detail/wakefield-vette/235-85AB/340314. Accessed 22 February 2024.

[5] “OptiMOS -5 Power-Transistor.” Infineon Technologies, 27 July 2015, https://www.infineon.com/dgdl/Infineon-IPZ40N04S5L-4R8-DS-v01_00-EN.pdf?fileId=5546d4624cb7f111014d66011b3e4894. Accessed 22 February 2024.

Appendix A: MCU Power Subsystem Current Draws

Major Power Draws on the 3.3V lines

Chip/ IC	Current Draw	Quantity	Total Current Draw
STM32F103C8Tx	150 mA	1	150 mA
TCAN1044AEVDRQ1	300 µA	1	300 µA

Major Power Draws on the 5V lines

Chip/ IC	Current Draw	Quantity	Total Current Draw
TCAN1044AEVDRQ1	80 mA	1	80 mA
LM2902LV-Q1	40 mA (short circuit)	8	320 mA
INA219	5 mA	4	20 mA
NCU15XV103E60RC	0.5 mA	4	2 mA

Appendix B: Thermal Tolerance Script

```
%2024 Senior Design Heatsink Calculations

% Establish constants
Max_T=60; %Celsius -Maximum desired temperature of chip
Ambient_Temperature=30; %Celsius
DCDC_Power=2.53/4; %W -Max heat power
hc=5.5; %W/(m^2*K) -natural air convection coefficient (Air, free)
Area1=12e-6; %m^2 -Surface area of convection surface (Accumulator)

%Given power, temp difference, we can calculate the
%theoretical max value of Max_Required_Thermal_Res that allows the resistor to stay below max
%temp.

%Formula: (T_resistor - T_air) / Precharge_Power = Thermal Resistance between chip and air

%Max thermal resistance of heatsink that prevents resistor from overheating
Max_Required_Thermal_Res = ((Max_T - Ambient_Temperature) / DCDC_Power)  %C/W


%Thermal resistance of no heatsink
No_Heatsink_R = 60      %C/W - from datasheet

%Calculate Maximum Temp with Chosen Heatsink
Chosen_Heatsink_R = 20; %C/W
syms T
Eqn1=(T-Ambient_Temperature)==DCDC_Power*(Chosen_Heatsink_R);
DCDC_Temp=vpasolve(Eqn1, T)    %C
```

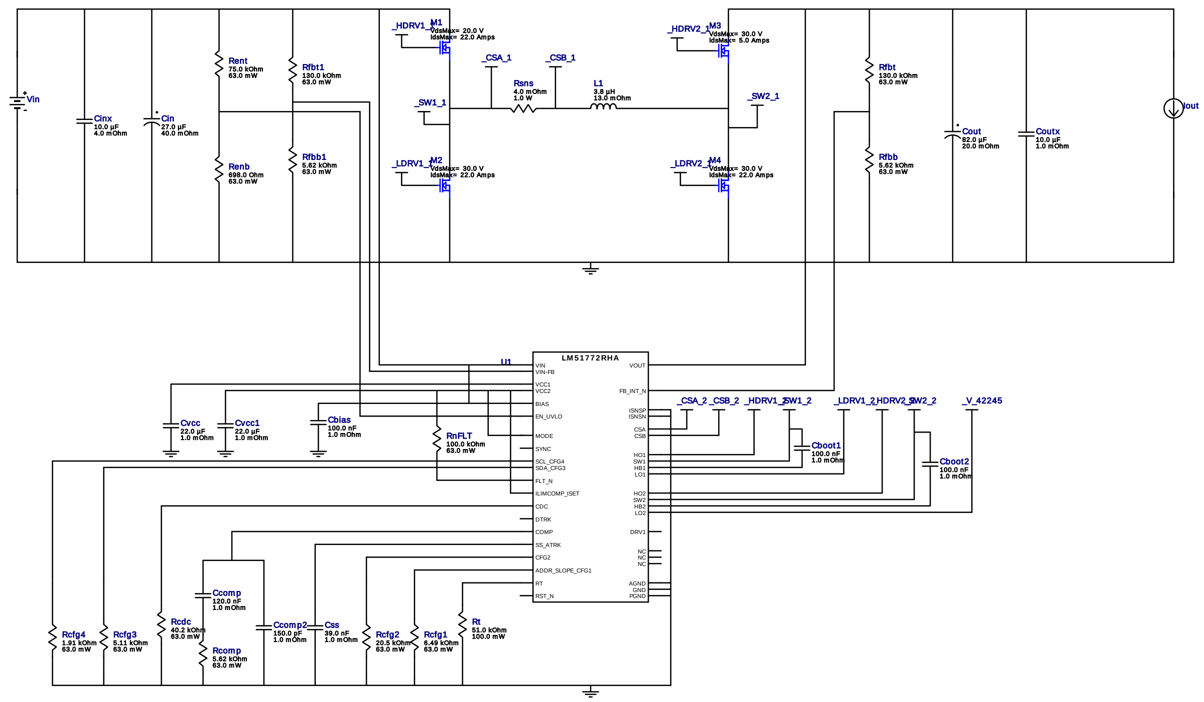
Appendix C: TI WeBench DC/DC Tolerance Analysis

VinMin = 11.0V
VinMax = 15.0V
Vout = 24.0V
Iout = 2.0A

Device = LM51772RHAR
Topology = Buck_Boost
Created = 2024-02-19 19:13:43.021
BOM Cost = $7.13
BOM Count = 34
Total Pd = 2.47W

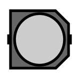
WEBENCH ® Design Report

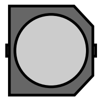
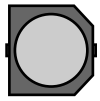
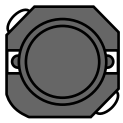
Design : 1 LM51772RHAR
LM51772RHAR 11V-15V to 24.00V @ 2A



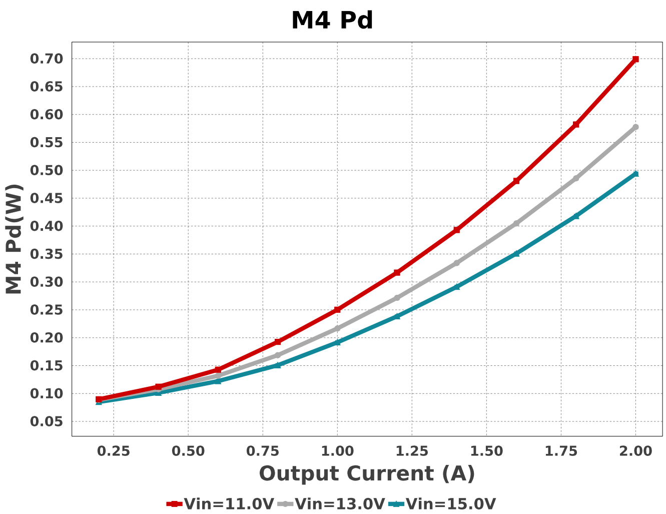
1. The LM51772 feature AutoMode for better light load efficiency. The operating point calculated in AutoMode configuration are estimate.

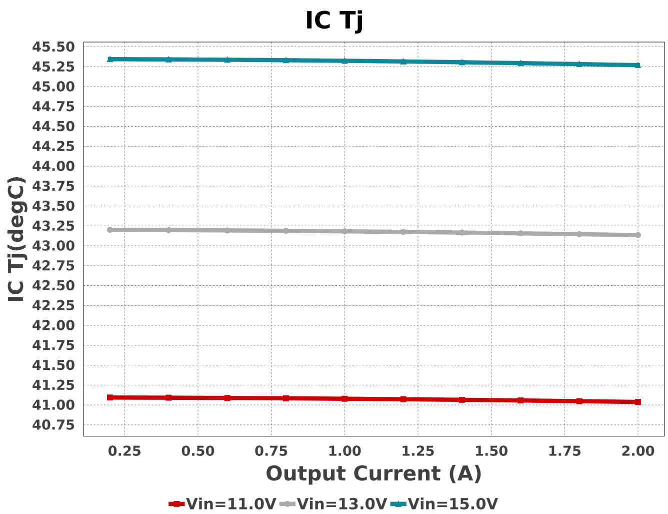
Electrical BOM

Name	Manufacturer	Part Number	Properties	Qty	Price	Footprint
Cbias	MuRata	GRM155R71A104KA01D Series= X7R	Cap= 100.0 nF ESR= 1.0 mOhm VDC= 10.0 V IRMS= 0.0 A	1	$0.01	0402 3 mm^2
Cboot1	Taiyo Yuden	EMK107B7104KA-T Series= X7R	Cap= 100.0 nF ESR= 1.0 mOhm VDC= 16.0 V IRMS= 0.0 A	1	$0.01	0603 5 mm^2
Cboot2	Taiyo Yuden	EMK107B7104KA-T Series= X7R	Cap= 100.0 nF ESR= 1.0 mOhm VDC= 16.0 V IRMS= 0.0 A	1	$0.01	0603 5 mm^2
Ccomp	MuRata	GRM188R71C124KA01D Series= X7R	Cap= 120.0 nF ESR= 1.0 mOhm VDC= 16.0 V IRMS= 0.0 A	1	$0.02	0603 5 mm^2
Ccomp2	MuRata	GRM1555C1H151JA01D Series= C0G/NP0	Cap= 150.0 pF ESR= 1.0 mOhm VDC= 50.0 V IRMS= 0.0 A	1	$0.01	0402 3 mm^2
Cin	Panasonic	25SVPF27MX Series= SVPF	Cap= 27.0 uF ESR= 40.0 mOhm VDC= 25.0 V IRMS= 2.45 A	1	$0.47	 CAPSMT_62_E61 53 mm^2

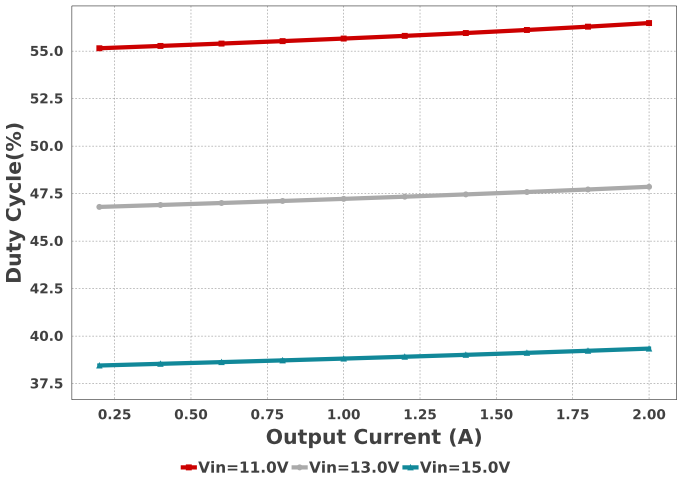
Name	Manufacturer	Part Number	Properties	Qty	Price	Footprint
Cinx	MuRata	GRM21BR61E106MA73L Series= X5R	Cap= 10.0 uF ESR= 4.0 mOhm VDC= 25.0 V IRMS= 2.8 A	1	$0.04	0805 7 mm²
Cout	Panasonic	35SVPF82M Series= SVPF	Cap= 82.0 uF ESR= 20.0 mOhm VDC= 35.0 V IRMS= 4.0 A	1	$1.17	 CAPSMT_62_E12 106 mm²
Cout	Panasonic	35SVPF82M Series= SVPF	Cap= 82.0 uF ESR= 20.0 mOhm VDC= 35.0 V IRMS= 4.0 A	1	$1.17	 CAPSMT_62_E12 106 mm²
Coutx	TDK	C3225X7R1H106M250AC Series= X7R	Cap= 10.0 uF ESR= 1.0 mOhm VDC= 50.0 V IRMS= 5.0 A	1	$0.27	1210 15 mm²
Css	MuRata	GRM155R71C393KA01D Series= X7R	Cap= 39.0 nF ESR= 1.0 mOhm VDC= 16.0 V IRMS= 0.0 A	1	$0.01	0402 3 mm²
Cvcc	MuRata	GRM188R60J226MEA0D Series= X5R	Cap= 22.0 uF ESR= 1.0 mOhm VDC= 6.3 V IRMS= 6.0 A	1	$0.04	0603 5 mm²
Cvcc1	MuRata	GRM188R60J226MEA0D Series= X5R	Cap= 22.0 uF ESR= 1.0 mOhm VDC= 6.3 V IRMS= 6.0 A	1	$0.04	0603 5 mm²
L1	Coiltronics	DR1040-3R8-R	L= 3.8 µH 13.0 mOhm	1	$0.49	 DR1040 154 mm²
M1	Texas Instruments	CSD15571Q2	VdsMax= 20.0 V IdsMax= 22.0 Amps	1	$0.08	DQK0006C 9 mm²
M2	Texas Instruments	CSD17571Q2	VdsMax= 30.0 V IdsMax= 22.0 Amps	1	$0.08	DQK0006C 9 mm²
M3	Texas Instruments	CSD17313Q2	VdsMax= 30.0 V IdsMax= 5.0 Amps	1	$0.11	DQK0006C 9 mm²
M4	Texas Instruments	CSD17571Q2	VdsMax= 30.0 V IdsMax= 22.0 Amps	1	$0.08	DQK0006C 9 mm²
Rcdc	Vishay-Dale	CRCW040240K2FKED Series= CRCW..e3	Res= 40.2 kOhm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm²
Rcfg1	Vishay-Dale	CRCW04026K49FKED Series= CRCW..e3	Res= 6.49 kOhm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm²
Rcfg2	Vishay-Dale	CRCW040220K5FKED Series= CRCW..e3	Res= 20.5 kOhm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm²
Rcfg3	Vishay-Dale	CRCW04025K11FKED Series= CRCW..e3	Res= 5.11 kOhm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm²
Rcfg4	Vishay-Dale	CRCW04021K91FKED Series= CRCW..e3	Res= 1.91 kOhm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm²
Rcomp	Vishay-Dale	CRCW04025K62FKED Series= CRCW..e3	Res= 5.62 kOhm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm²

Name	Manufacturer	Part Number	Properties	Qty	Price	Footprint
Renb	Vishay-Dale	CRCW0402698RFKED Series= CRCW..e3	Res= 698.0 Ohm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm^2
Rent	Vishay-Dale	CRCW040275K0FKED Series= CRCW..e3	Res= 75.0 kOhm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm^2
Rfbb	Vishay-Dale	CRCW04025K62FKED Series= CRCW..e3	Res= 5.62 kOhm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm^2
Rfbb1	Vishay-Dale	CRCW04025K62FKED Series= CRCW..e3	Res= 5.62 kOhm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm^2
Rfbt	Vishay-Dale	CRCW0402130KFKED Series= CRCW..e3	Res= 130.0 kOhm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm^2
Rfbt1	Vishay-Dale	CRCW0402130KFKED Series= CRCW..e3	Res= 130.0 kOhm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm^2
RnFLT	Vishay-Dale	CRCW0402100KFKED Series= CRCW..e3	Res= 100.0 kOhm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm^2
Rsns	Panasonic	ERJ-M1WTF4M0U Series= ERJ	Res= 4.0 mOhm Power= 1.0 W Tolerance= 1.0%	1	$0.17	2512 43 mm^2
Rt	Yageo	RC0603FR-0751KL Series= ?	Res= 51.0 kOhm Power= 100.0 mW Tolerance= 1.0%	1	$0.01	0603 5 mm^2
U1	Texas Instruments	LM51772RHAR	Switcher	1	$2.71	RHA0040P 64 mm^2

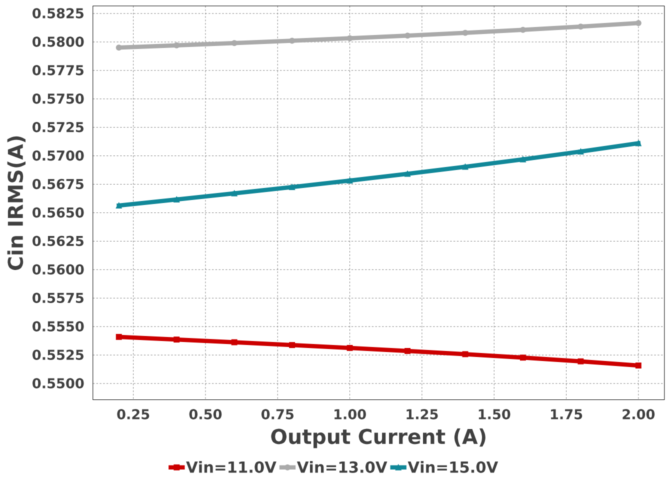




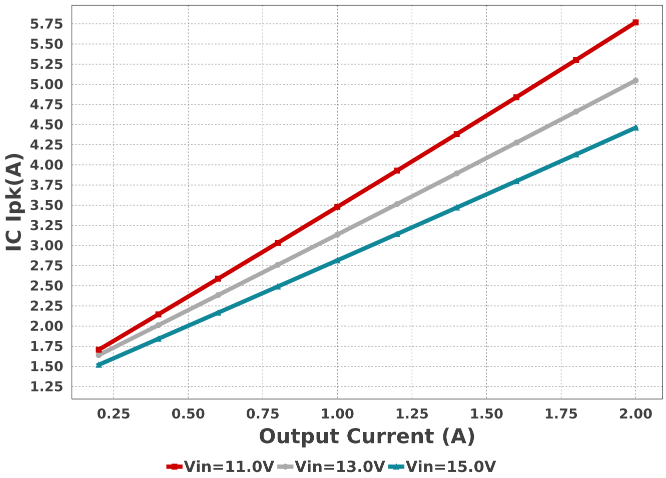
Duty Cycle



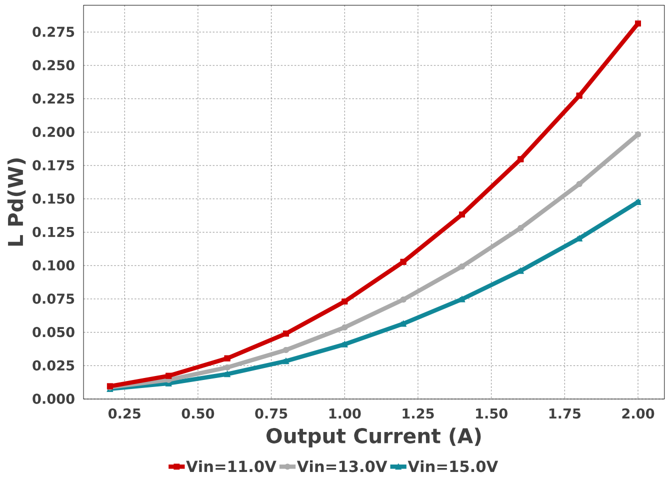
Cin IRMS



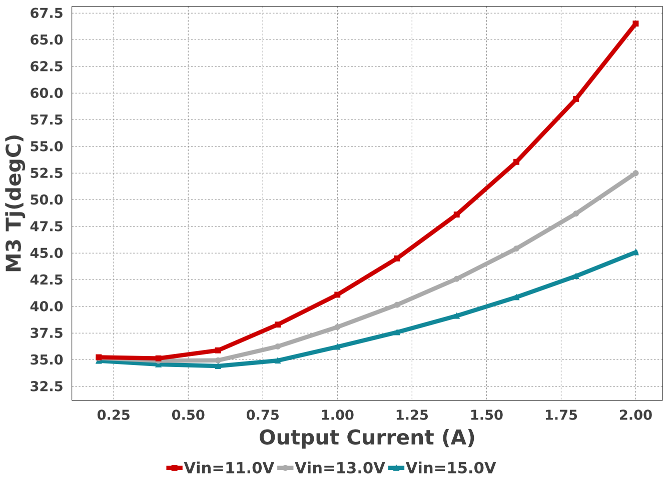
IC Ipk



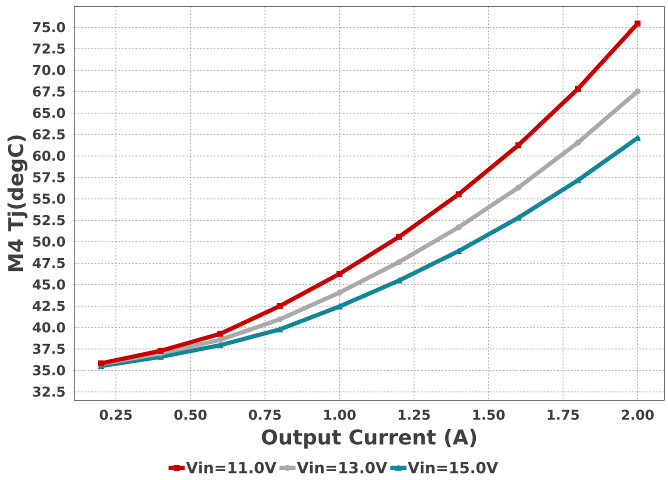
L Pd

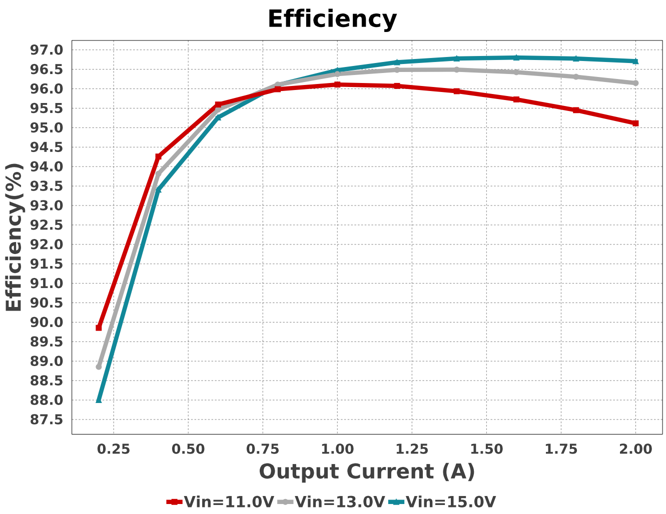


M3 Tj

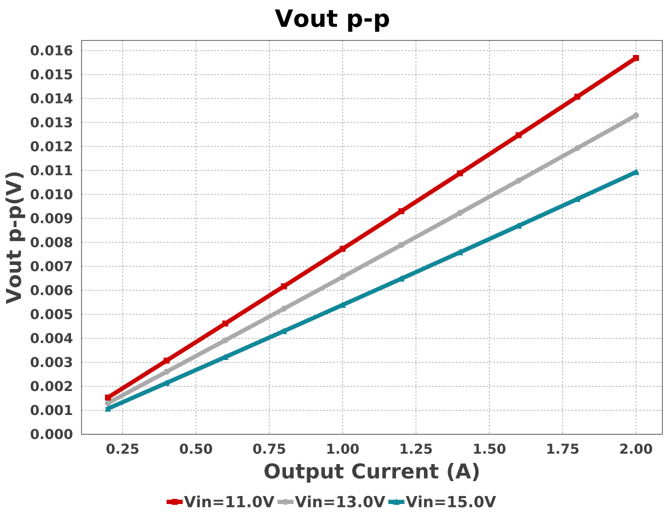


M4 Tj

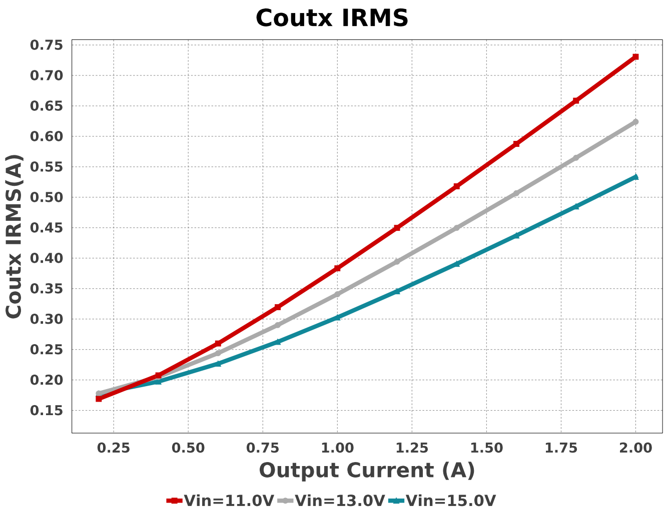




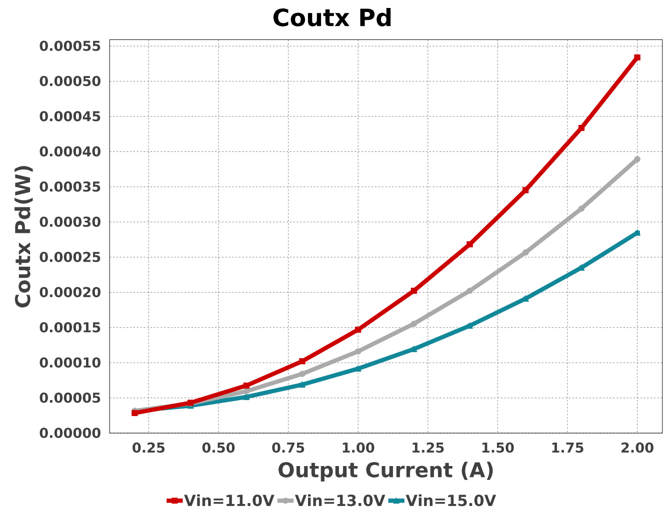
Efficiency
Efficiency(%)
Output Current (A)
Vin=11.0V
Vin=13.0V
Vin=15.0V



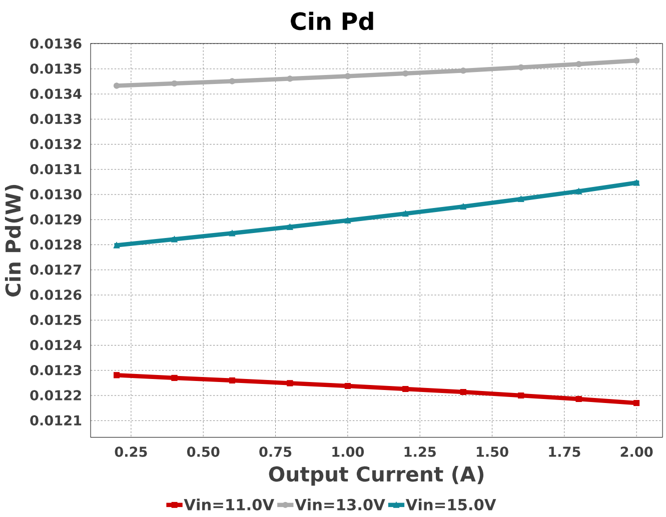
Vout p-p
Vout p-p(V)
Output Current (A)
Vin=11.0V
Vin=13.0V
Vin=15.0V



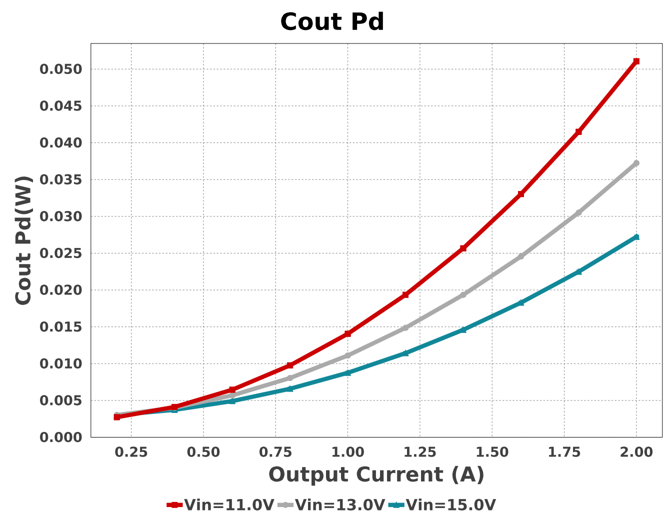
Coutx IRMS
Coutx IRMS(A)
Output Current (A)
Vin=11.0V
Vin=13.0V
Vin=15.0V



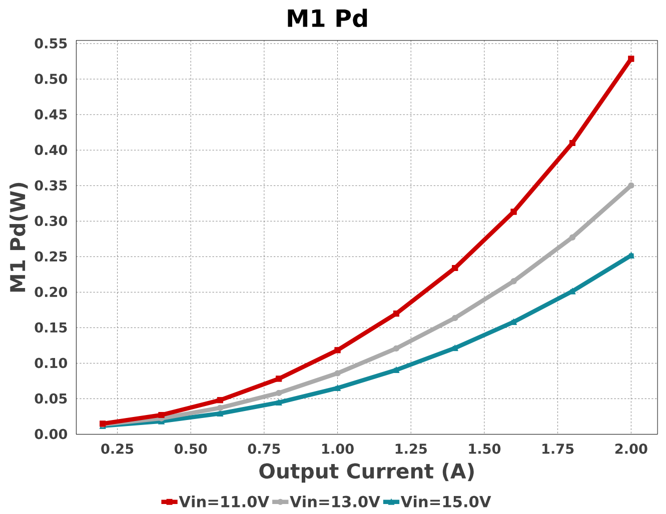
Coutx Pd
Coutx Pd(W)
Output Current (A)
Vin=11.0V
Vin=13.0V
Vin=15.0V

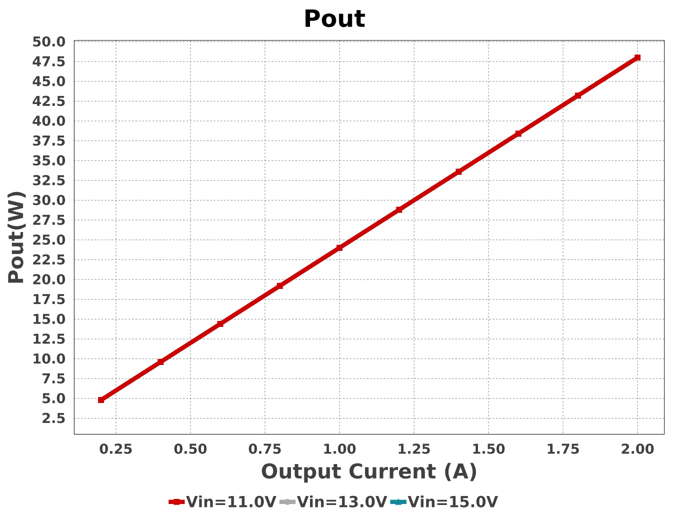


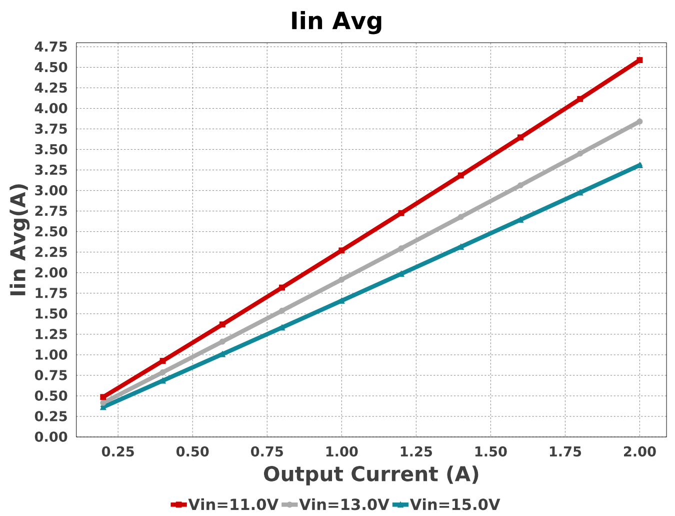
Cin Pd
Cin Pd(W)
Output Current (A)
Vin=11.0V
Vin=13.0V
Vin=15.0V

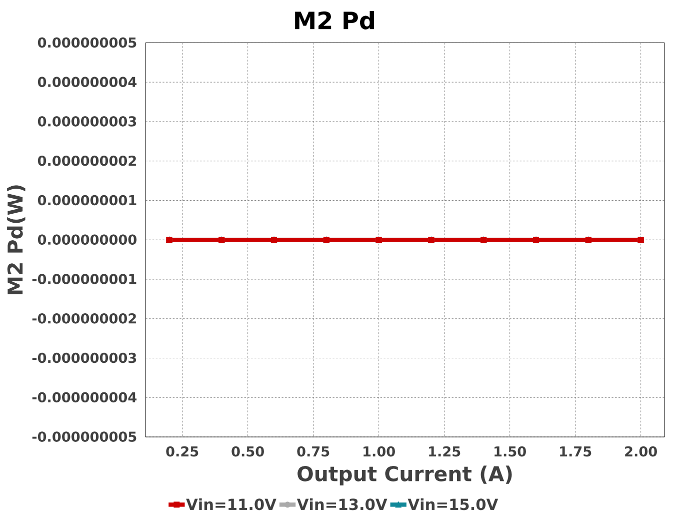


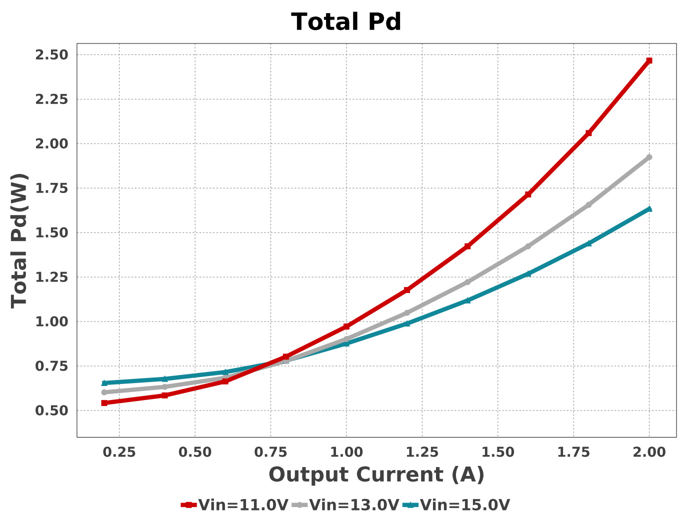
Cout Pd
Cout Pd(W)
Output Current (A)
Vin=11.0V
Vin=13.0V
Vin=15.0V

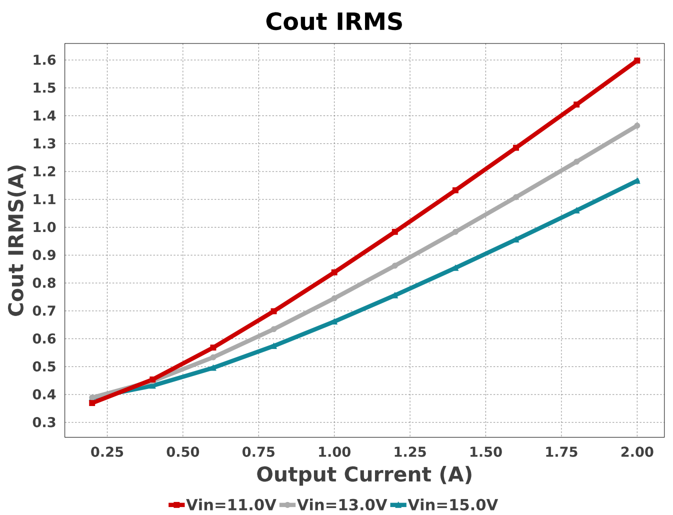

M1 Pd
M1 Pd(W)
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00
Output Current (A)
Vin=11.0V Vin=13.0V Vin=15.0V

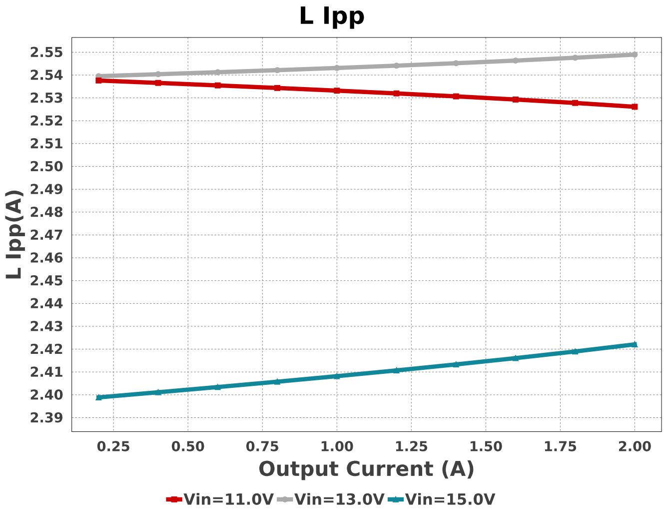

Pout
Pout(W)
50.0
47.5
45.0
42.5
40.0
37.5
35.0
32.5
30.0
27.5
25.0
22.5
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00
Output Current (A)
Vin=11.0V Vin=13.0V Vin=15.0V

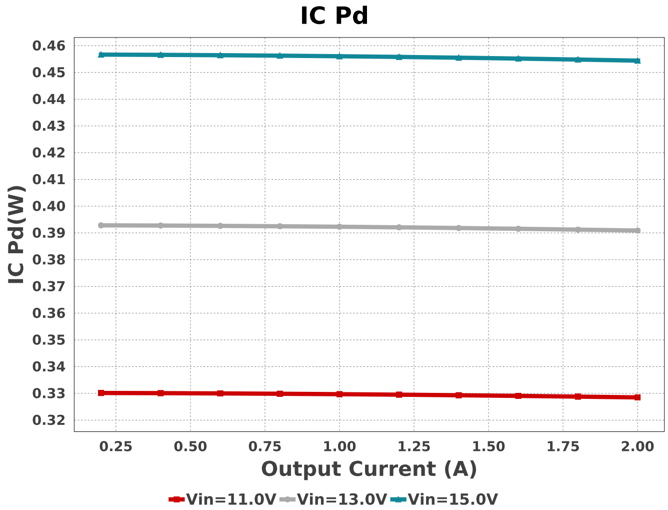

Iin Avg
Iin Avg(A)
4.75
4.50
4.25
4.00
3.75
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00
Output Current (A)
Vin=11.0V Vin=13.0V Vin=15.0V

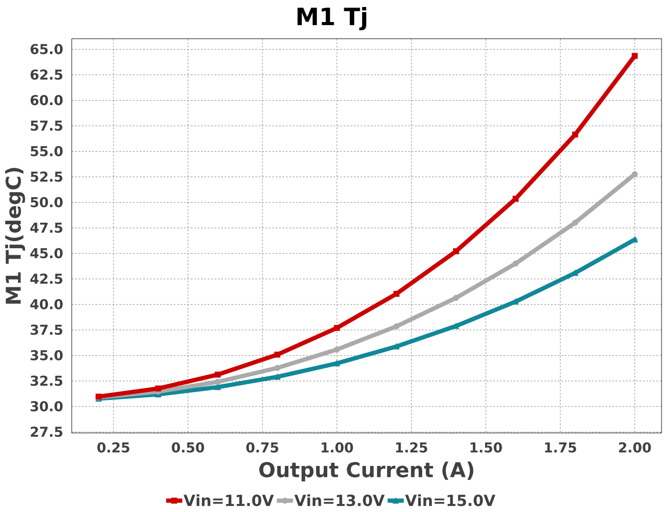

M2 Pd
M2 Pd(W)
0.000000005
0.000000004
0.000000003
0.000000002
0.000000001
0.000000000
-0.000000001
-0.000000002
-0.000000003
-0.000000004
-0.000000005
0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00
Output Current (A)
Vin=11.0V Vin=13.0V Vin=15.0V

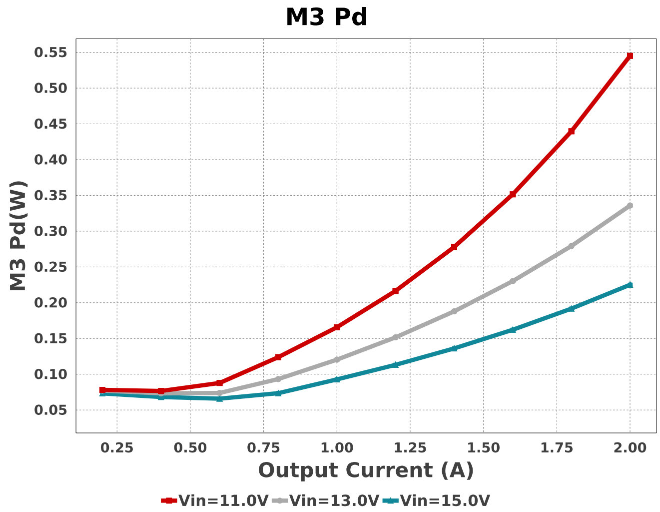

Total Pd
Total Pd(W)
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00
Output Current (A)
Vin=11.0V Vin=13.0V Vin=15.0V

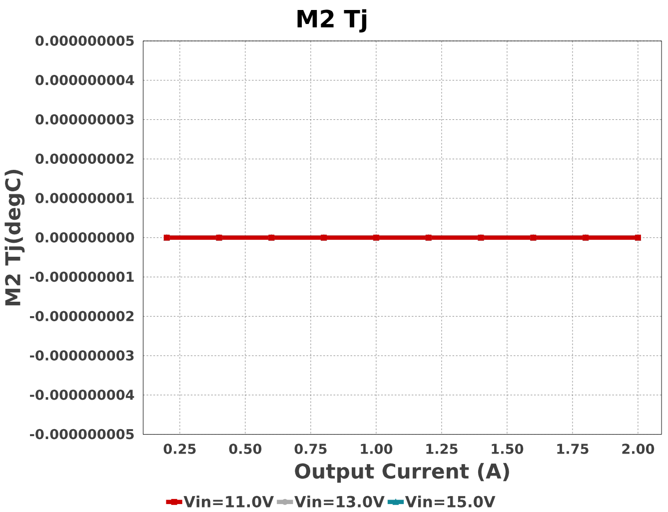

Cout IRMS
Cout IRMS(A)
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.25 0.50 0.75 1.00 1.25 1.50 1.75 2.00
Output Current (A)
Vin=11.0V Vin=13.0V Vin=15.0V

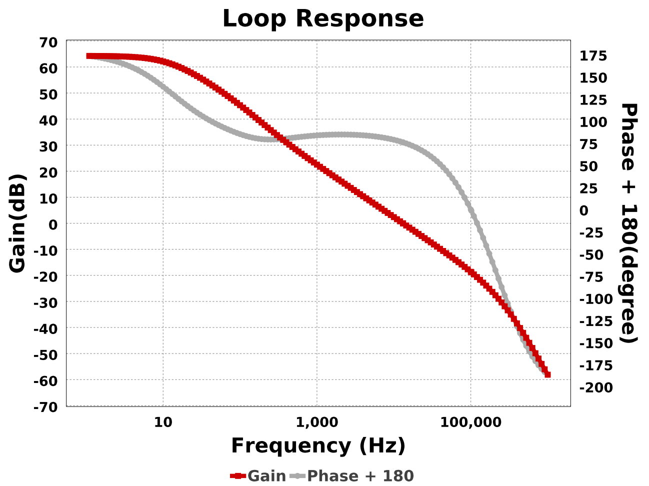












Operating Values

#	Name	Value	Category	Description
1.	Cin IRMS	551.581 mA	Capacitor	Input capacitor RMS ripple current
2.	Cin Pd	12.17 mW	Capacitor	Input capacitor power dissipation
3.	Cout IRMS	1.598 A	Capacitor	Output capacitor RMS ripple current
4.	Cout Pd	51.065 mW	Capacitor	Output capacitor power dissipation
5.	Coutx IRMS	730.644 mA	Capacitor	Output capacitor_x RMS ripple current
6.	Coutx Pd	533.84 µW	Capacitor	Output capacitor_x power loss
7.	IC Ipk	5.769 A	IC	Peak switch current in IC
8.	IC Pd	328.5 mW	IC	IC power dissipation
9.	IC Tj	41.038 degC	IC	IC junction temperature
10.	IC Tolerance	10.0 mV	IC	IC Feedback Tolerance
11.	ICThetaJA	33.6 degC/W	IC	IC junction-to-ambient thermal resistance

#	Name	Value	Category	Description
12.	Iin Avg	4.588 A	IC	Average input current
13.	L Ipp	2.526 A	Inductor	Peak-to-peak inductor ripple current
14.	L Pd	281.43 mW	Inductor	Inductor power dissipation
15.	M1 Pd	528.57 mW	Mosfet	M1 MOSFET total power dissipation
16.	M1 Tj	64.357 degC	Mosfet	M1 MOSFET junction temperature
17.	M2 Pd	0.0 W	Mosfet	M2 MOSFET total power dissipation
18.	M2 Tj	0.0 degC	Mosfet	M2 MOSFET junction temperature
19.	M3 Pd	545.05 mW	Mosfet	M1 MOSFET total power dissipation
20.	M3 Tj	66.519 degC	Mosfet	M1 MOSFET junction temperature
21.	M4 Pd	699.08 mW	Mosfet	M2 MOSFET total power dissipation
22.	M4 Tj	75.44 degC	Mosfet	M2 MOSFET junction temperature
23.	Cin Pd	12.17 mW	Power	Input capacitor power dissipation
24.	Cout Pd	51.065 mW	Power	Output capacitor power dissipation
25.	Coutx Pd	533.84 µW	Power	Output capacitor_x power loss
26.	IC Pd	328.5 mW	Power	IC power dissipation
27.	L Pd	281.43 mW	Power	Inductor power dissipation
28.	M1 Pd	528.57 mW	Power	M1 MOSFET total power dissipation
29.	M2 Pd	0.0 W	Power	M2 MOSFET total power dissipation
30.	M3 Pd	545.05 mW	Power	M1 MOSFET total power dissipation
31.	M4 Pd	699.08 mW	Power	M2 MOSFET total power dissipation
32.	Total Pd	2.467 W	Power	Total Power Dissipation
33.	BOM Count	34	System Information	Total Design BOM count
34.	Cross Freq	9.632 kHz	System Information	Bode plot crossover frequency
35.	Duty Cycle	56.477 %	System Information	Duty cycle
36.	Efficiency	95.112 %	System Information	Steady state efficiency
37.	FootPrint	660.0 mm^2	System Information	Total Foot Print Area of BOM components
38.	Frequency	617.64 kHz	System Information	Switching frequency
39.	Gain Marg	-17.926 dB	System Information	Bode Plot Gain Margin
40.	Iout	2.0 A	System Information	Iout operating point
41.	Low Freq Gain	61.518 dB	System Information	Gain at 1Hz
42.	Mode	CCM	System Information	Conduction Mode
43.	Phase Marg	77.604 deg	System Information	Bode Plot Phase Margin
44.	Pout	48.0 W	System Information	Total output power
45.	Total BOM	$7.13	System Information	Total BOM Cost
46.	Vin	11.0 V	System Information	Vin operating point
47.	Vout	24.0 V	System Information	Operational Output Voltage
48.	Vout Actual	24.132 V	System Information	Vout Actual calculated based on selected voltage divider resistors
49.	Vout Tolerance	2.956 %	System Information	Vout Tolerance based on IC Tolerance (no load) and voltage divider resistors if applicable
50.	Vout p-p	15.692 mV	System Information	Peak-to-peak output ripple voltage

Design Inputs

Name	Value	Description
Iout	2.0	Maximum Output Current
VinMax	15.0	Maximum input voltage
VinMin	11.0	Minimum input voltage
Vout	24.0	Output Voltage
base_pn	LM51772	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

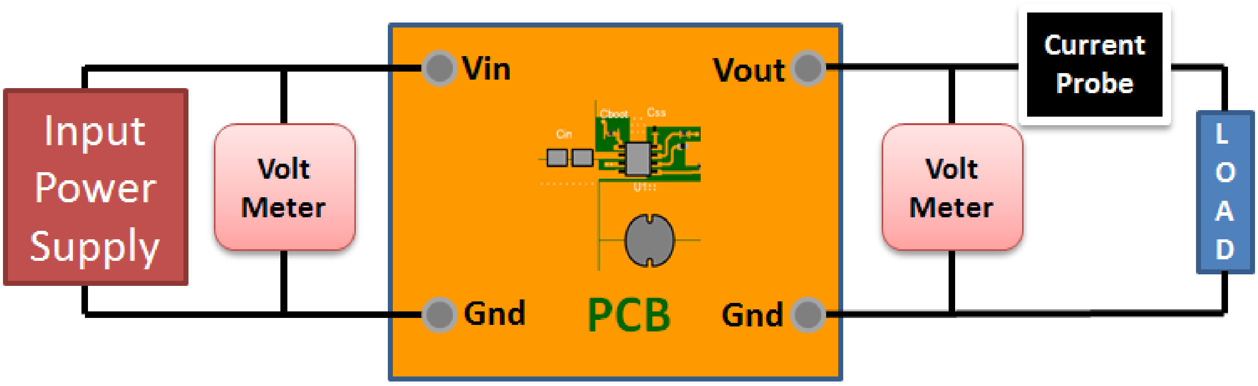
If board assembly is done in house it is best to tack down one terminal of a component on the board then solder the other terminal. For surface mount parts with large tabs, such as the DPAK, the tab on the back of the package should be pre-tinned with solder, then tacked into place by one of the pins. 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 11.0V 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 : 11390F3AE7B8F8E2AEC6E0F2D701EB1E[v1]

2. **LM51772** Product Folder : http://www.ti.com/product/LM51772 : contains the data sheet and other resources.

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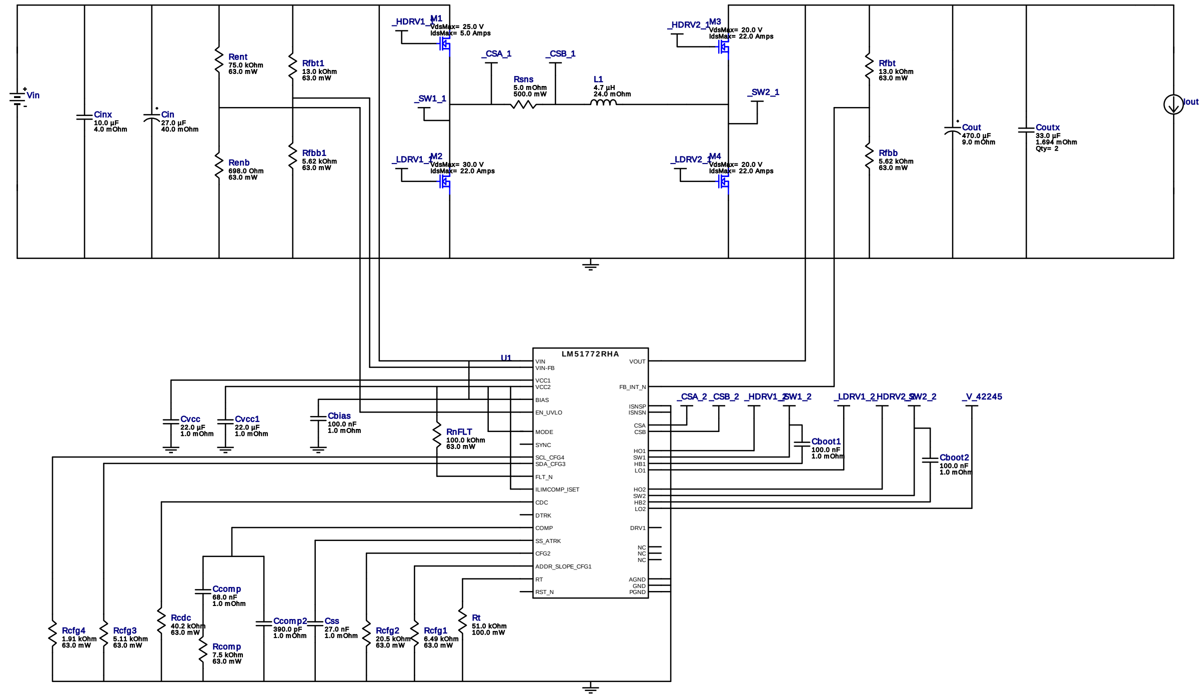
VinMin = 11.0V
VinMax = 15.0V
Vout = 3.3V
Iout = 2.0A

Device = LM51772RHAR
Topology = Buck_Boost
Created = 2024-02-21 16:46:27.328
BOM Cost = $6.12
BOM Count = 35
Total Pd = 0.76W

WEBENCH ® Design Report

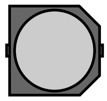
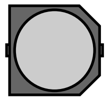
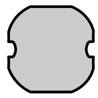
Design : 2 LM51772RHAR
LM51772RHAR 11V-15V to 3.30V @ 2A



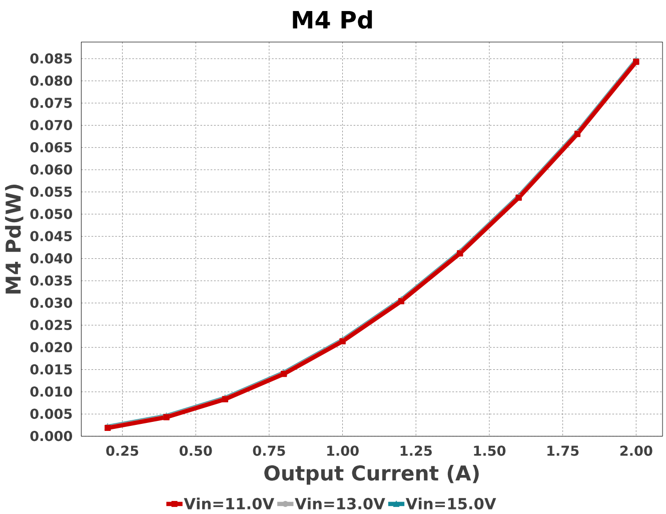
1. The LM51772 feature AutoMode for better light load efficiency. The operating point calculated in AutoMode configuration are estimate.

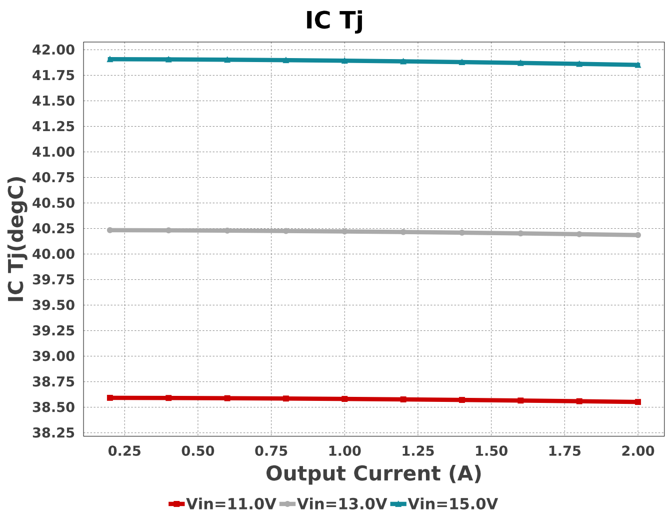
Electrical BOM

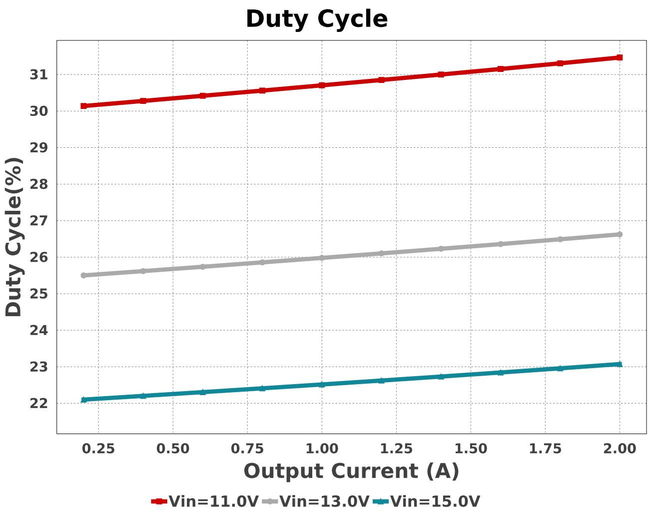
Name	Manufacturer	Part Number	Properties	Qty	Price	Footprint
Cbias	MuRata	GRM155R71A104KA01D Series= X7R	Cap= 100.0 nF ESR= 1.0 mOhm VDC= 10.0 V IRMS= 0.0 A	1	$0.01	0402 3 mm^2
Cboot1	Taiyo Yuden	EMK107B7104KA-T Series= X7R	Cap= 100.0 nF ESR= 1.0 mOhm VDC= 16.0 V IRMS= 0.0 A	1	$0.01	0603 5 mm^2
Cboot2	Taiyo Yuden	EMK107B7104KA-T Series= X7R	Cap= 100.0 nF ESR= 1.0 mOhm VDC= 16.0 V IRMS= 0.0 A	1	$0.01	0603 5 mm^2
Ccomp	MuRata	GRM155R71C683KA88D Series= X7R	Cap= 68.0 nF ESR= 1.0 mOhm VDC= 16.0 V IRMS= 0.0 A	1	$0.01	0402 3 mm^2
Ccomp2	MuRata	GRM155R71H391KA01D Series= X7R	Cap= 390.0 pF ESR= 1.0 mOhm VDC= 50.0 V IRMS= 0.0 A	1	$0.01	0402 3 mm^2
Cin	Panasonic	25SVPF27MX Series= SVPF	Cap= 27.0 uF ESR= 40.0 mOhm VDC= 25.0 V IRMS= 2.45 A	1	$0.47	CAPSMT_62_E61 53 mm^2

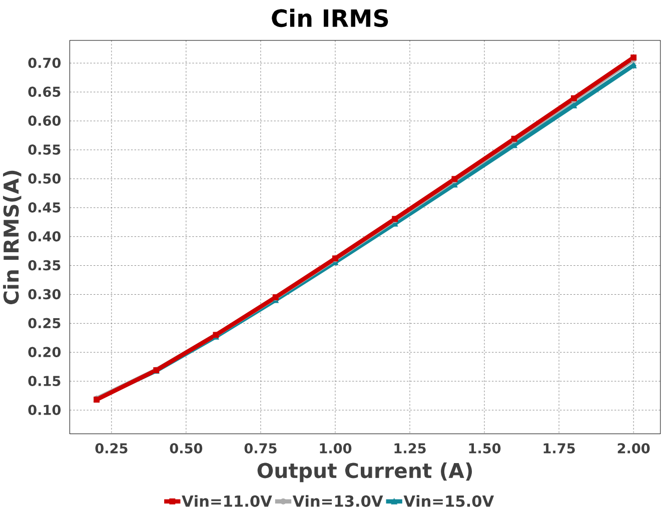
Name	Manufacturer	Part Number	Properties	Qty	Price	Footprint
Cinx	MuRata	GRM21BR61E106MA73L Series= X5R	Cap= 10.0 uF ESR= 4.0 mOhm VDC= 25.0 V IRMS= 2.8 A	1	$0.04	0805 7 mm²
Cout	Chemi-Con	APXF6R3ARA471MH80G Series= PXF	Cap= 470.0 uF ESR= 9.0 mOhm VDC= 6.3 V IRMS= 4.5 A	1	$0.44	 CAPSMT_62_H80 106 mm²
Cout	Chemi-Con	APXF6R3ARA471MH80G Series= PXF	Cap= 470.0 uF ESR= 9.0 mOhm VDC= 6.3 V IRMS= 4.5 A	1	$0.44	 CAPSMT_62_H80 106 mm²
Coutx	TDK	C2012X5R1A336M125AC Series= X5R	Cap= 33.0 uF ESR= 1.694 mOhm VDC= 10.0 V IRMS= 5.0128 A	2	$0.26	0805 7 mm²
Css	MuRata	GRM155R71C273KA01D Series= X7R	Cap= 27.0 nF ESR= 1.0 mOhm VDC= 16.0 V IRMS= 0.0 A	1	$0.01	0402 3 mm²
Cvcc	MuRata	GRM188R60J226MEA0D Series= X5R	Cap= 22.0 uF ESR= 1.0 mOhm VDC= 6.3 V IRMS= 6.0 A	1	$0.04	0603 5 mm²
Cvcc1	MuRata	GRM188R60J226MEA0D Series= X5R	Cap= 22.0 uF ESR= 1.0 mOhm VDC= 6.3 V IRMS= 6.0 A	1	$0.04	0603 5 mm²
L1	Bourns	SRN8040-4R7Y	L= 4.7 µH 24.0 mOhm	1	$0.33	 SRN8040 100 mm²
M1	Texas Instruments	CSD16301Q2	VdsMax= 25.0 V IdsMax= 5.0 Amps	1	$0.11	DQK0006C 9 mm²
M2	Texas Instruments	CSD17571Q2	VdsMax= 30.0 V IdsMax= 22.0 Amps	1	$0.08	DQK0006C 9 mm²
M3	Texas Instruments	CSD15571Q2	VdsMax= 20.0 V IdsMax= 22.0 Amps	1	$0.08	DQK0006C 9 mm²
M4	Texas Instruments	CSD15571Q2	VdsMax= 20.0 V IdsMax= 22.0 Amps	1	$0.08	DQK0006C 9 mm²
Rcdc	Vishay-Dale	CRCW040240K2FKED Series= CRCW..e3	Res= 40.2 kOhm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm²
Rcfg1	Vishay-Dale	CRCW04026K49FKED Series= CRCW..e3	Res= 6.49 kOhm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm²
Rcfg2	Vishay-Dale	CRCW040220K5FKED Series= CRCW..e3	Res= 20.5 kOhm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm²
Rcfg3	Vishay-Dale	CRCW04025K11FKED Series= CRCW..e3	Res= 5.11 kOhm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm²
Rcfg4	Vishay-Dale	CRCW04021K91FKED Series= CRCW..e3	Res= 1.91 kOhm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm²
Rcomp	Vishay-Dale	CRCW04027K50FKED Series= CRCW..e3	Res= 7.5 kOhm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm²

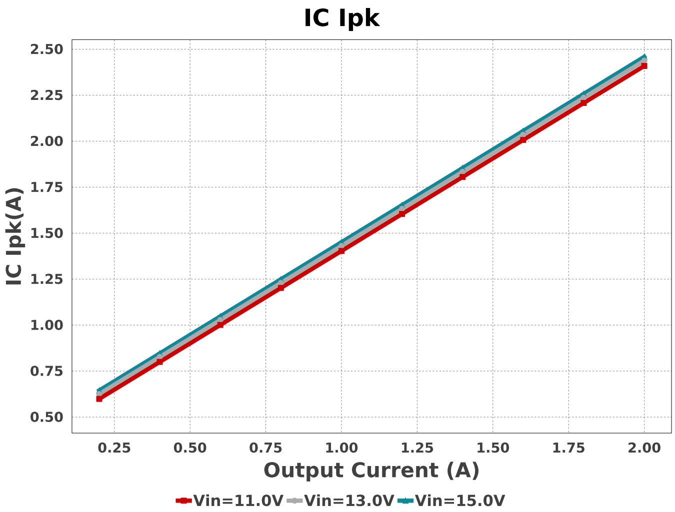
Name	Manufacturer	Part Number	Properties	Qty	Price	Footprint
Renb	Vishay-Dale	CRCW0402698RFKED Series= CRCW..e3	Res= 698.0 Ohm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm²
Rent	Vishay-Dale	CRCW040275K0FKED Series= CRCW..e3	Res= 75.0 kOhm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm²
Rfbb	Vishay-Dale	CRCW04025K62FKED Series= CRCW..e3	Res= 5.62 kOhm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm²
Rfbb1	Vishay-Dale	CRCW04025K62FKED Series= CRCW..e3	Res= 5.62 kOhm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm²
Rfbt	Vishay-Dale	CRCW040213K0FKED Series= CRCW..e3	Res= 13.0 kOhm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm²
Rfbt1	Vishay-Dale	CRCW040213K0FKED Series= CRCW..e3	Res= 13.0 kOhm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm²
RnFLT	Vishay-Dale	CRCW0402100KFKED Series= CRCW..e3	Res= 100.0 kOhm Power= 63.0 mW Tolerance= 1.0%	1	$0.01	0402 3 mm²
Rsns	Vishay-Dale	WSL20105L000FEA Series= WSL	Res= 5.0 mOhm Power= 500.0 mW Tolerance= 1.0%	1	$0.54	2010 32 mm²
Rt	Yageo	RC0603FR-0751KL Series= ?	Res= 51.0 kOhm Power= 100.0 mW Tolerance= 1.0%	1	$0.01	0603 5 mm²
U1	Texas Instruments	LM51772RHAR	Switcher	1	$2.71	RHA0040P 64 mm²

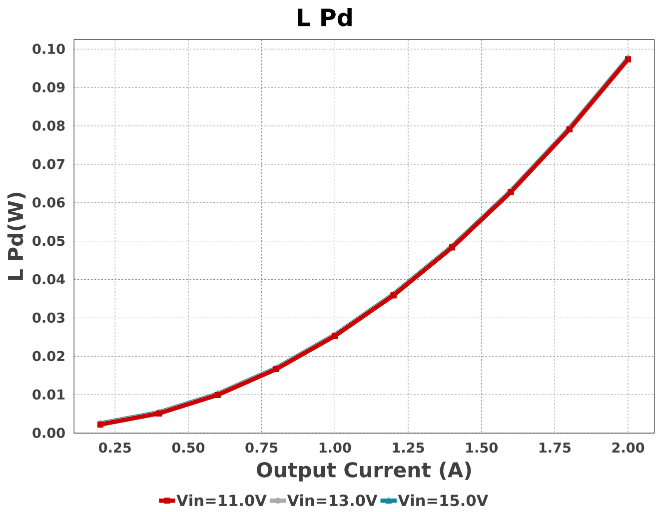


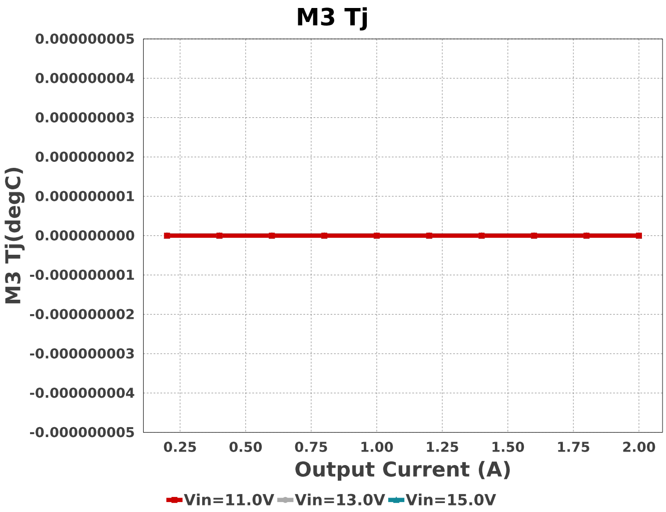


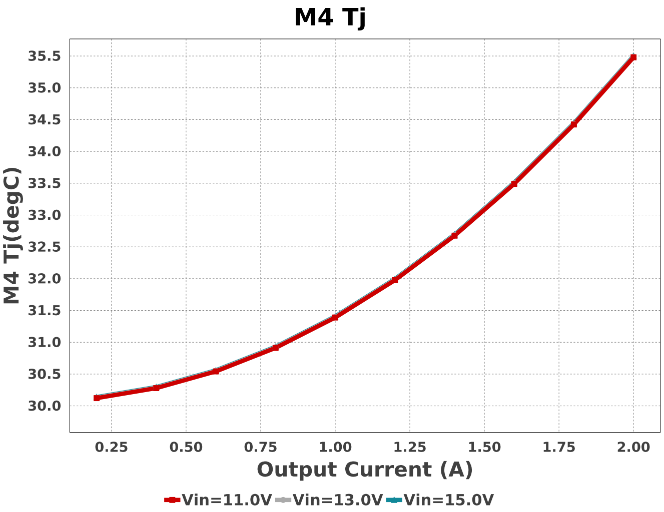

Duty Cycle
Duty Cycle(%)
31
30
29
28
27
26
25
24
23
22
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
Output Current (A)
Vin=11.0V
Vin=13.0V
Vin=15.0V


Cin IRMS
Cin IRMS(A)
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
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
Output Current (A)
Vin=11.0V
Vin=13.0V
Vin=15.0V

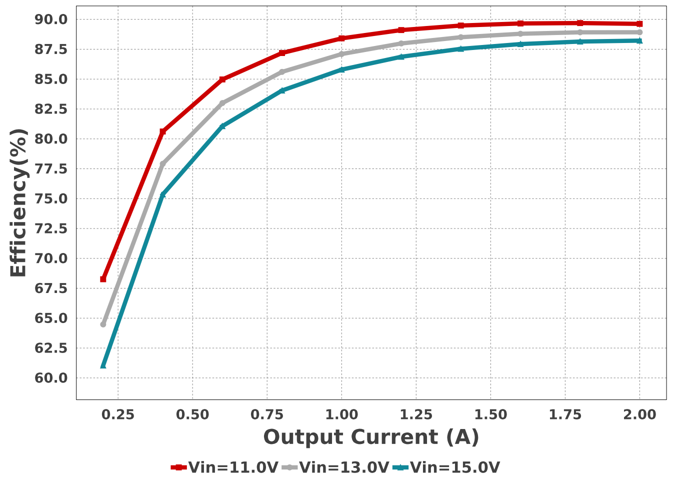

IC Ipk
IC Ipk(A)
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
Output Current (A)
Vin=11.0V
Vin=13.0V
Vin=15.0V


L Pd
L Pd(W)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
Output Current (A)
Vin=11.0V
Vin=13.0V
Vin=15.0V

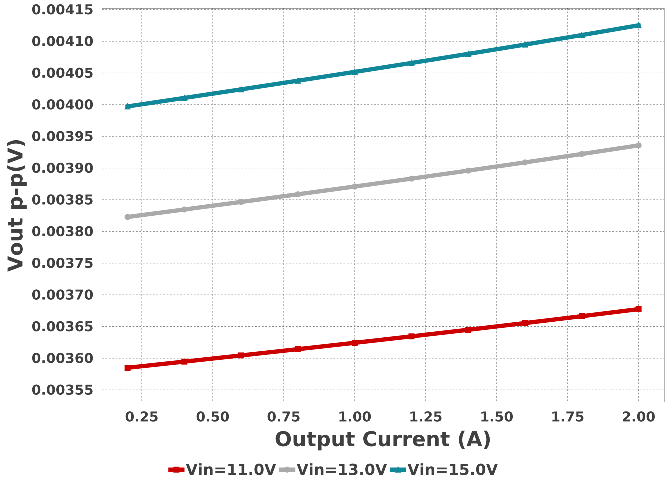

M3 Tj
M3 Tj(degC)
0.000000005
0.000000004
0.000000003
0.000000002
0.000000001
0.000000000
-0.000000001
-0.000000002
-0.000000003
-0.000000004
-0.000000005
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
Output Current (A)
Vin=11.0V
Vin=13.0V
Vin=15.0V


M4 Tj
M4 Tj(degC)
35.5
35.0
34.5
34.0
33.5
33.0
32.5
32.0
31.5
31.0
30.5
30.0
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
Output Current (A)
Vin=11.0V
Vin=13.0V
Vin=15.0V

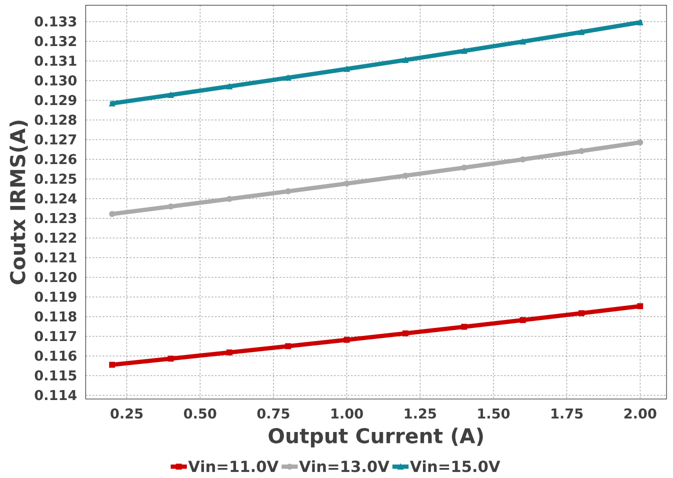
Efficiency



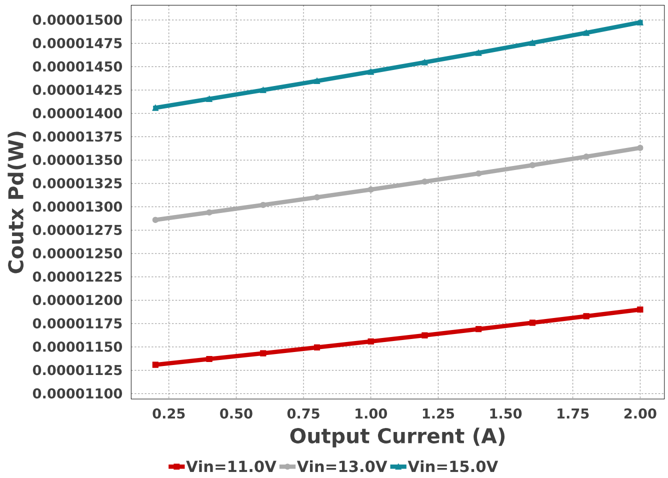
Vout p-p



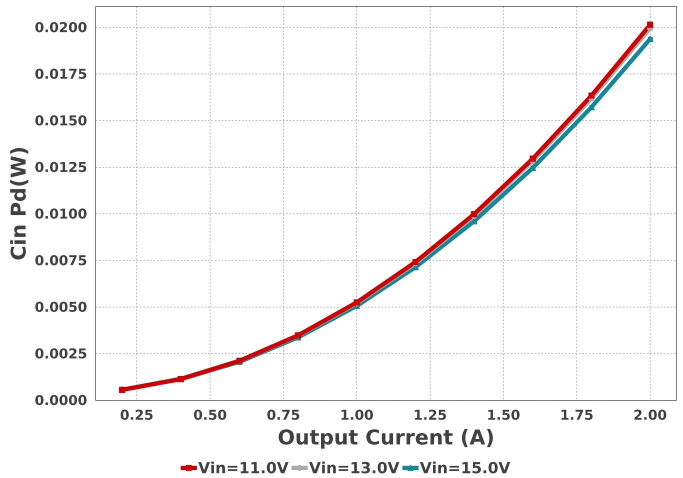
Coutx IRMS



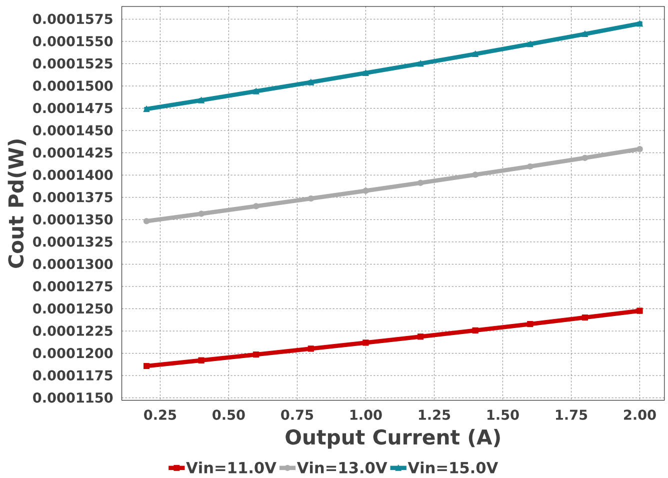
Coutx Pd



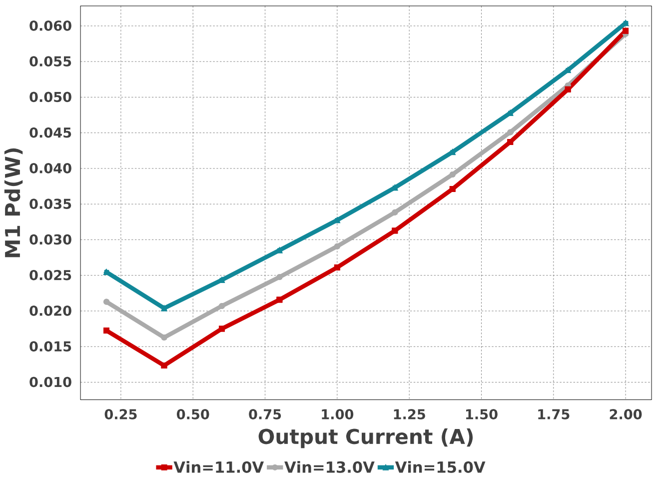
Cin Pd



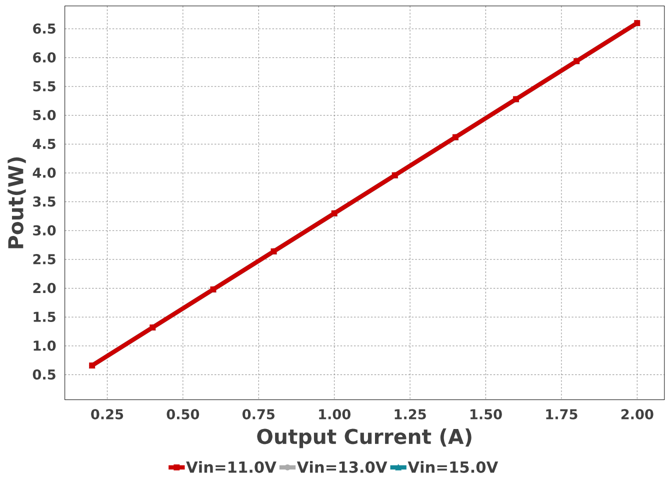
Cout Pd



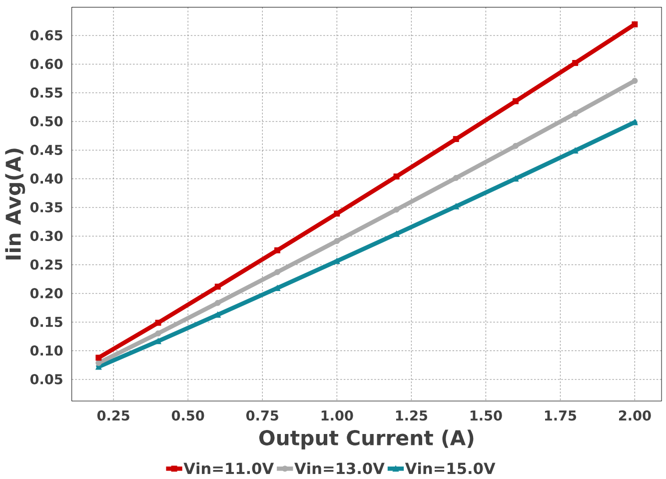
M1 Pd



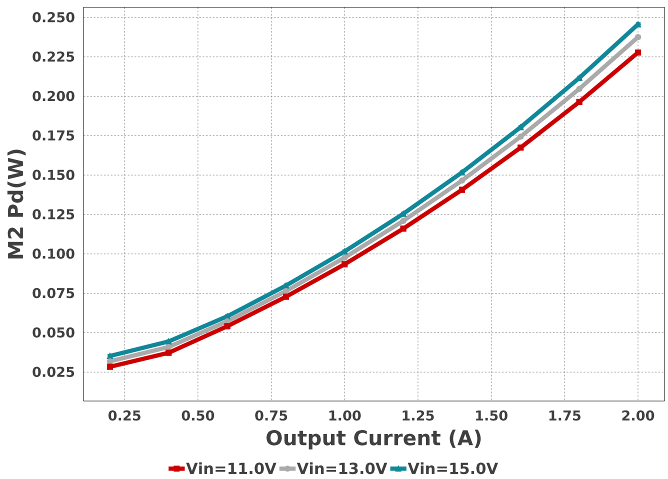
Pout



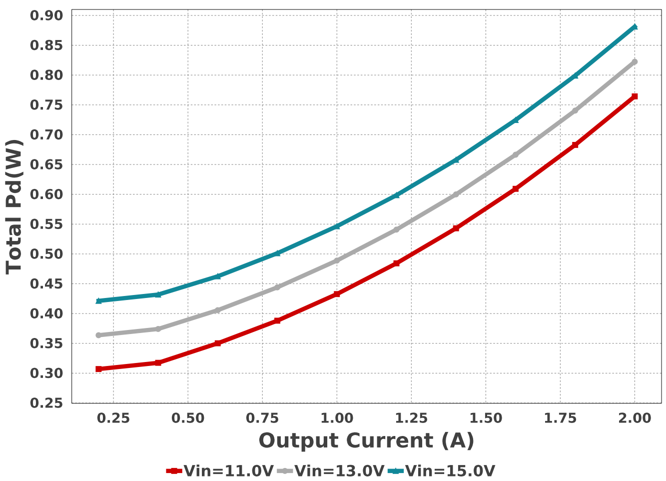
Iin Avg



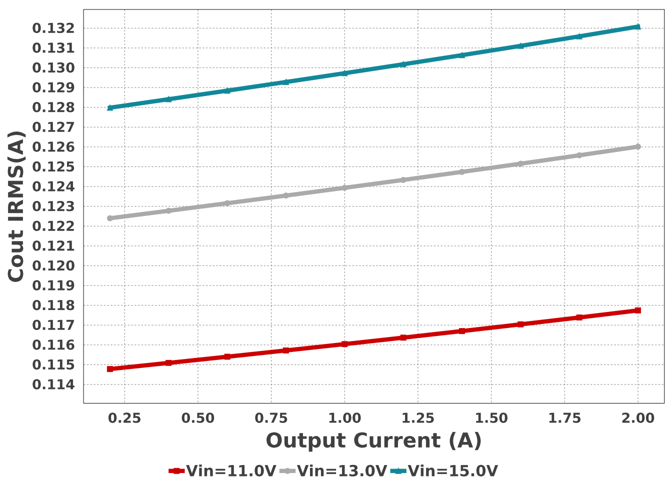
M2 Pd

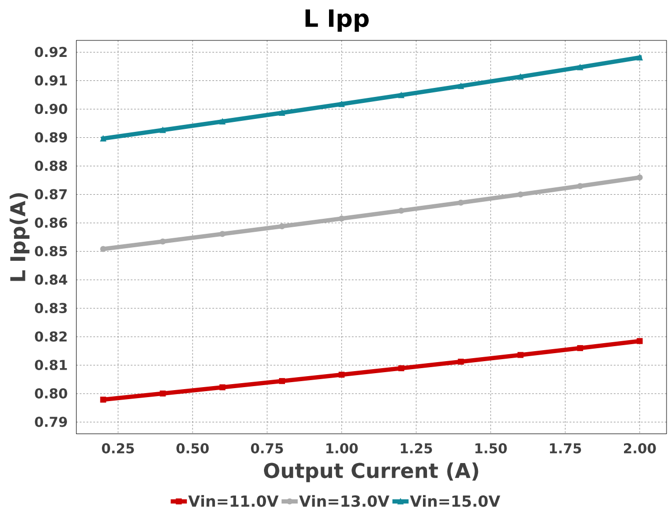


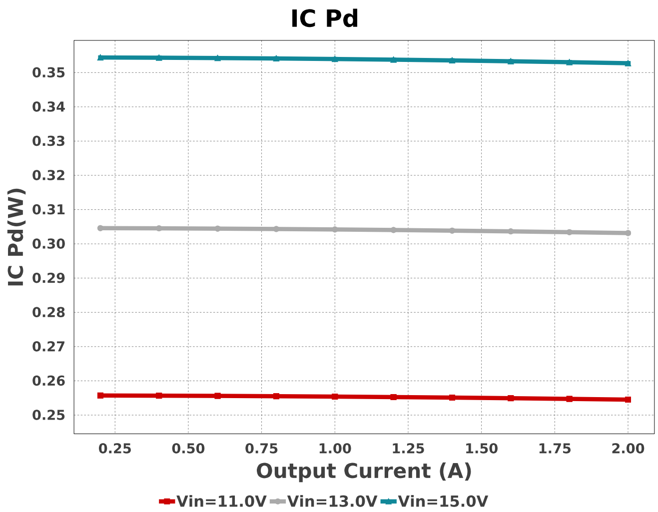
Total Pd

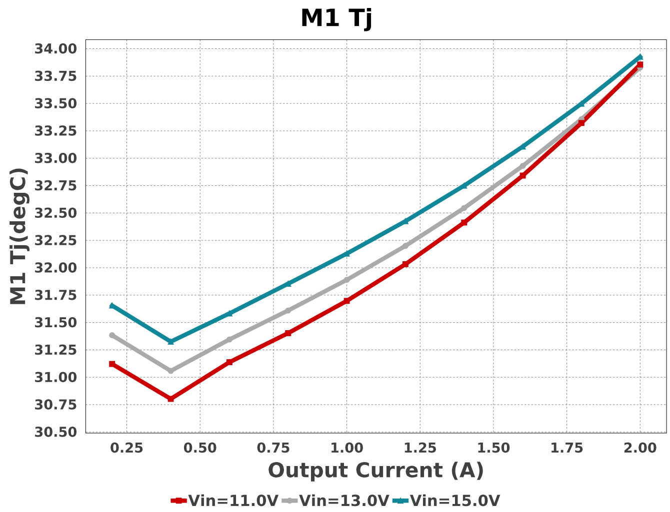


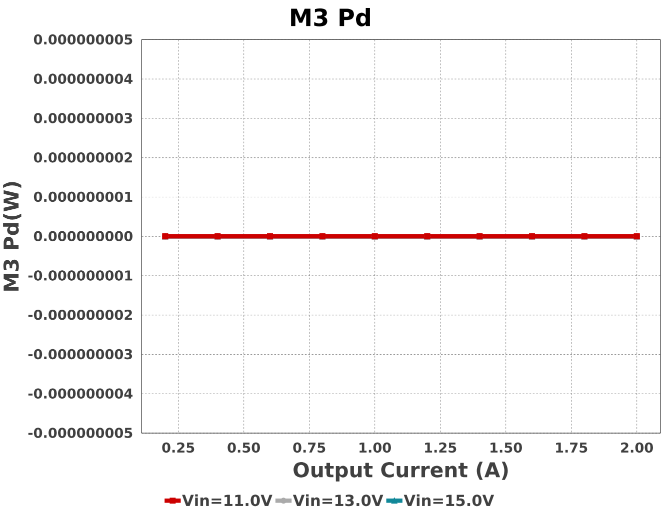
Cout IRMS

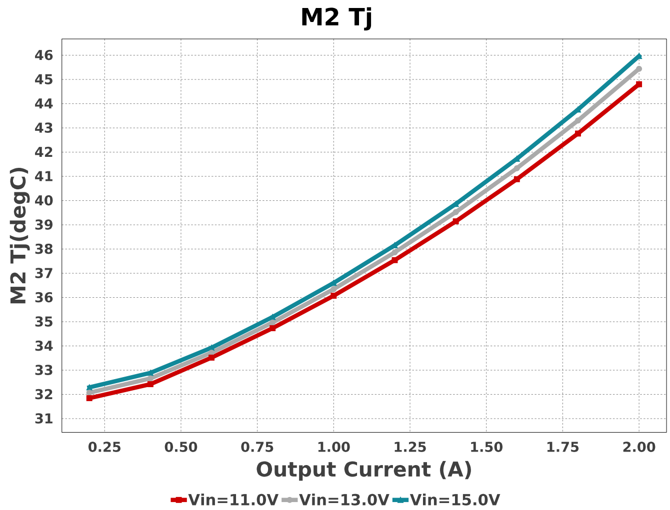


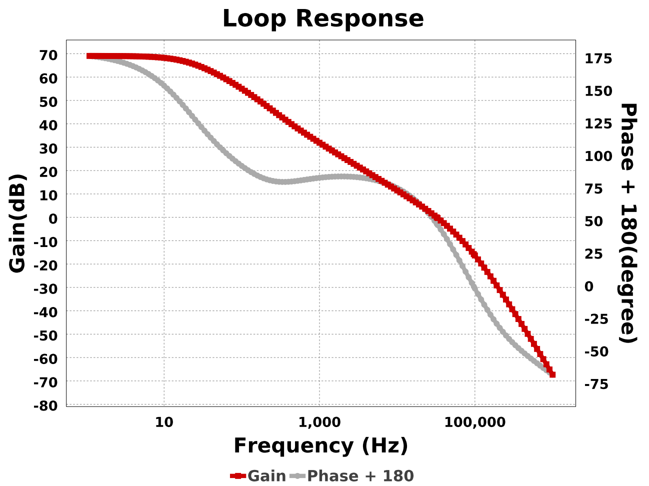












Operating Values

#	Name	Value	Category	Description
1.	Cin IRMS	709.627 mA	Capacitor	Input capacitor RMS ripple current
2.	Cin Pd	20.143 mW	Capacitor	Input capacitor power dissipation
3.	Cout IRMS	117.742 mA	Capacitor	Output capacitor RMS ripple current
4.	Cout Pd	124.77 µW	Capacitor	Output capacitor power dissipation
5.	Coutx IRMS	118.533 mA	Capacitor	Output capacitor_x RMS ripple current
6.	Coutx Pd	11.9 µW	Capacitor	Output capacitor_x power loss
7.	IC Ipk	2.409 A	IC	Peak switch current in IC
8.	IC Pd	254.52 mW	IC	IC power dissipation
9.	IC Tj	38.552 degC	IC	IC junction temperature
10.	IC Tolerance	10.0 mV	IC	IC Feedback Tolerance
11.	ICThetaJA	33.6 degC/W	IC	IC junction-to-ambient thermal resistance

#	Name	Value	Category	Description
12.	Iin Avg	669.48 mA	IC	Average input current
13.	L Ipp	818.48 mA	Inductor	Peak-to-peak inductor ripple current
14.	L Pd	97.34 mW	Inductor	Inductor power dissipation
15.	M1 Pd	59.31 mW	Mosfet	M1 MOSFET total power dissipation
16.	M1 Tj	33.855 degC	Mosfet	M1 MOSFET junction temperature
17.	M2 Pd	227.74 mW	Mosfet	M2 MOSFET total power dissipation
18.	M2 Tj	44.803 degC	Mosfet	M2 MOSFET junction temperature
19.	M3 Pd	0.0 W	Mosfet	M1 MOSFET total power dissipation
20.	M3 Tj	0.0 degC	Mosfet	M1 MOSFET junction temperature
21.	M4 Pd	84.297 mW	Mosfet	M2 MOSFET total power dissipation
22.	M4 Tj	35.479 degC	Mosfet	M2 MOSFET junction temperature
23.	Cin Pd	20.143 mW	Power	Input capacitor power dissipation
24.	Cout Pd	124.77 µW	Power	Output capacitor power dissipation
25.	Coutx Pd	11.9 µW	Power	Output capacitor_x power loss
26.	IC Pd	254.52 mW	Power	IC power dissipation
27.	L Pd	97.34 mW	Power	Inductor power dissipation
28.	M1 Pd	59.31 mW	Power	M1 MOSFET total power dissipation
29.	M2 Pd	227.74 mW	Power	M2 MOSFET total power dissipation
30.	M3 Pd	0.0 W	Power	M1 MOSFET total power dissipation
31.	M4 Pd	84.297 mW	Power	M2 MOSFET total power dissipation
32.	Total Pd	764.265 mW	Power	Total Power Dissipation
33.	BOM Count	35	System Information	Total Design BOM count
34.	Cross Freq	32.635 kHz	System Information	Bode plot crossover frequency
35.	Duty Cycle	31.466 %	System Information	Duty cycle
36.	Efficiency	89.622 %	System Information	Steady state efficiency
37.	FootPrint	592.0 mm^2	System Information	Total Foot Print Area of BOM components
38.	Frequency	617.64 kHz	System Information	Switching frequency
39.	Gain Marg	-15.903 dB	System Information	Bode Plot Gain Margin
40.	Iout	2.0 A	System Information	Iout operating point
41.	Low Freq Gain	69.165 dB	System Information	Gain at 1Hz
42.	Mode	CCM	System Information	Conduction Mode
43.	Phase Marg	48.319 deg	System Information	Bode Plot Phase Margin
44.	Pout	6.6 W	System Information	Total output power
45.	Total BOM	$6.12	System Information	Total BOM Cost
46.	Vin	11.0 V	System Information	Vin operating point
47.	Vout	3.3 V	System Information	Operational Output Voltage
48.	Vout Actual	3.313 V	System Information	Vout Actual calculated based on selected voltage divider resistors
49.	Vout Tolerance	2.425 %	System Information	Vout Tolerance based on IC Tolerance (no load) and voltage divider resistors if applicable
50.	Vout p-p	3.677 mV	System Information	Peak-to-peak output ripple voltage

Design Inputs

Name	Value	Description
Iout	2.0	Maximum Output Current
VinMax	15.0	Maximum input voltage
VinMin	11.0	Minimum input voltage
Vout	3.3	Output Voltage
base_pn	LM51772	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

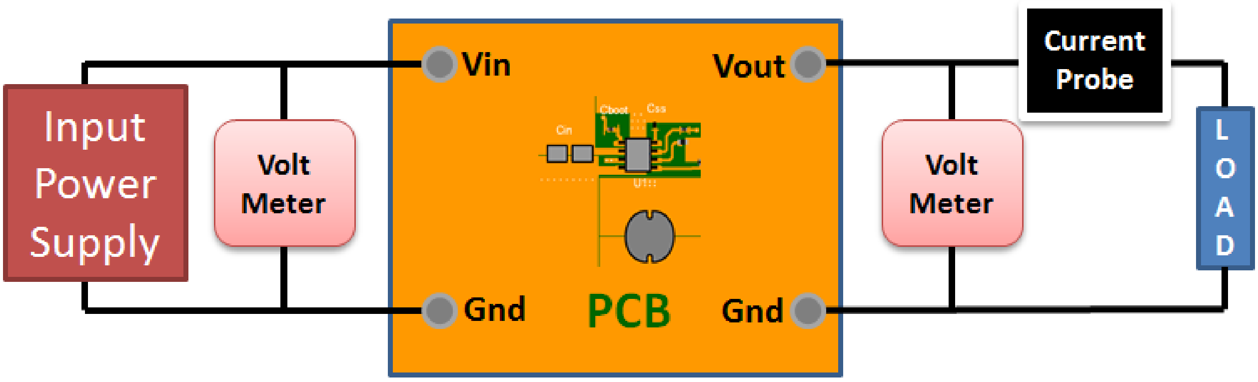
If board assembly is done in house it is best to tack down one terminal of a component on the board then solder the other terminal. For surface mount parts with large tabs, such as the DPAK, the tab on the back of the package should be pre-tinned with solder, then tacked into place by one of the pins. 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 11.0V 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 : 11390F3AE7B8F8E2AEC6E0F2D701EB1E[v1]

2. **LM51772** Product Folder : http://www.ti.com/product/LM51772 : contains the data sheet and other resources.

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