E-Tracker Reference Design

Automotive Tracker with Linear Charger

Contents

1 Overview

1.1 Description

Tracking the location of different types of vehicles is an increasingly popular application for multiple purposes, such as control of transport trucks or anti-theft security. However, this presents two challenges in electronic design. First, the system must be able to track a vehicle's location when the car battery is turned off. Second, the GSM modules that establish communication with the receiver station have strict operating input voltage ranges.

The first challenge of this design is to maintain communication when the car battery is off. The solution presented in this reference design consists of adding an external Li-ion battery pack, that supplies the required power to the GSM module when the car battery is turned off, and a battery charger to maintain the battery charge. For example, if a car battery supplies 12V, the battery charger and the GSM module receive power from the battery, and the external battery enters in charging mode. When the car battery is disconnected, the external battery pack supplies the power to the GSM module.

The second challenge consists of adjusting the input voltages of the battery charger and the GSM module while considering their specifications. Generally, GSM modules have an operating input voltage range between 3.4V and 4.2V, while the battery charger voltage ranges between 4.05V and 6.05V. This means that a buck converter is required to decrease the input voltage from 12V (car battery) to 4.2V. On the other side, it is also needed to protect the GSM module from load transients. Because of this, a diode is added to decrease the voltage at the buck's output below 4V.

This reference design will help engineers design a simple power stage for a common e-tracker that can track the location of different vehicles.

1.2 Features

- Wide 4.2V to 36V Operating Input Range
- 3A Continuous Output Current
- 350kHz to 2.5MHz Configurable Buck Switching Frequency
- Second-Order EMI Filter
- Reverse Polarity Protection
- Fully Autonomous Charger
- Configurable 30mA to 1A Charge Current

1.3 Applications

- Car Tracking
- Internet Connectivity
- 2G Communications (Calls, SMS, and MMS)
- Telematic Services

Figure 1: MPS E-Tracker Reference Design Board

2 Reference Design

2.1 Block Diagram

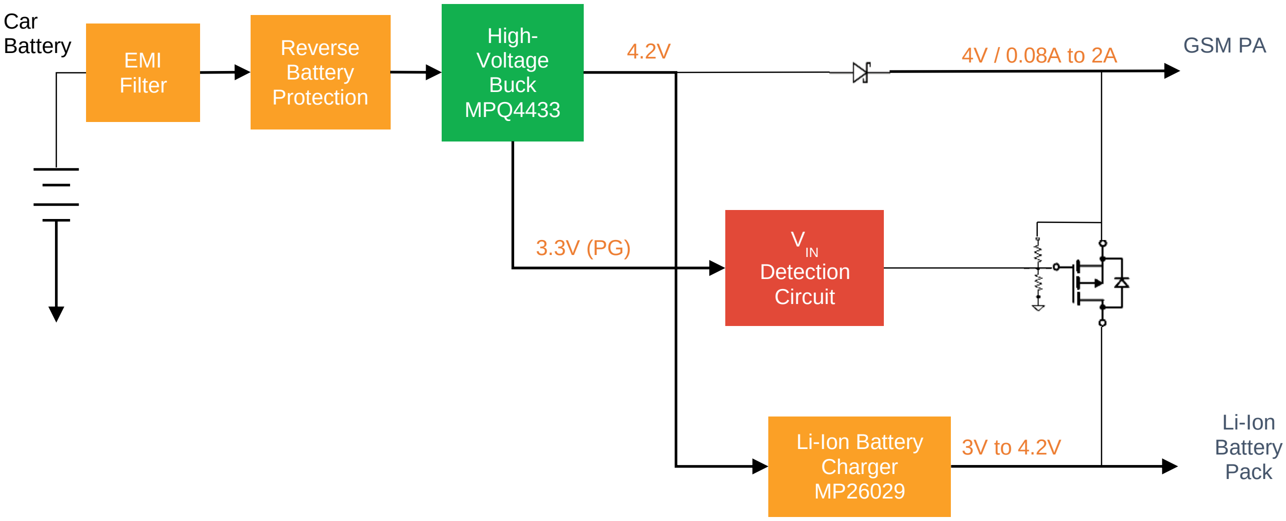


Figure 2: Block Diagram

The circuit contains five main blocks. First, a buck converter reduces the supply voltage from 12V (supplied by the car battery) to a stable 4.2V. The design limits the input voltage to 36V (due to the selected step-down converter specifications). However, the design can be modified to reach higher input voltages without significant alterations to the PCB design. Second, a Li-ion battery charger maintains the charge of the external battery pack. Third, the V_{IN} detection circuit detects the state of the car battery to activate the Li-ion battery pack supply. Finally, the EMI filter and the reverse battery protection feature protect the circuit from suboptimal operation.

2.2 Related Solutions

This reference design is based on the following MPS solutions:

Table 1: System Specifications

MPS Integrated Circuit	Description
MPQ4433	Synchronous buck converter with a wide input voltage range and up to 3A of output current.
MP26029	Li-ion/Li-polymer battery charger IC with thermal regulation.

2.3 System Specifications

Table 2: System Specifications

Parameter	Specification
Input voltage range	4.2V to 36V
Output voltage range	3.3V to 4.1V
Nominal load	4V/80mA
Maximum peak output current (1)	3000mA
Switching frequency	450kHz (under nominal conditions)
Board form factor	100mmx100mmx2mm
Converter efficiency (V_{IN} = 12V)	94%
4V output ripple	31.25mV
Load transient (2A to 80mA)	270mV
Charge current range	30mA to 1A (set to 110mA)
Battery voltage	3.6V to 4.2V (set to 4.2V)
VIN quiescent current (I_{LOAD} = 0A)	700µA
Li-ion battery quiescent current	45µA
Shutdown current (MPQ4433 off)	2µA

Note:

1) This design can support loads greater than 3A, but this causes the maximum output voltage to have a transient overshoot that exceeds 4.2V. If the maximum load transient is expected to exceed 3A, ensure that the voltage overshoot after a load dump event does not exceed the RF IC's maximum input voltage rating.

3 Design

3.1 Selecting the Input Capacitor (Buck Converter)

The buck converter has a discontinuous input current, and requires input capacitors to supply AC current to the converter while maintaining the DC input voltage. The placement of these input capacitors also reduces noise at the input stage. It is recommended to use low-ESR capacitors, such as ceramic capacitors with X5R or X7R dielectrics, due to their low ESR and small temperature coefficients. These capacitors should be between 4.7µF and 10µF (e.g. four 4.7µF capacitors in parallel configuration). It is also recommended to place smaller capacitors (e.g. 0.1µF) as close as possible to the input pin. This absorbs the high-frequency switching noise.

Since input capacitors absorb the input switching current, an adequate ripple current rating is also required. For this reason, they must have an RMS current rating greater than half of the maximum load current.

3.2 Selecting the Inductor (Buck Converter)

Selecting the buck converter's inductor is vital to reduce the inductor's ripple current. The inductor must have as large of a value as possible to achieve low ΔI_L and low output voltage ripple. Calculate the inductance with Equation (1):

$$L = \frac{V_{OUT}}{f_{SW} \times \Delta I_L} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right) \tag{1}$$

Where V_{OUT} is the converter's output voltage (typically 4.2V), V_{IN} is the converter's input voltage (typically 12V), f_{SW} is the switching frequency (typically 454kHz), and ΔI_L is the peak-to-peak inductor ripple current.

Larger-value inductors have a larger physical size, higher series resistance, and lower saturation current. Do not use larger-value inductors that could reduce the converter's efficiency (due to high DC resistance). A good rule to determine the inductor value is to make the inductor's ripple current approximately 30% of the maximum load current.

For this application, a 8.2µH inductor is an optimal compromise between ripple current and losses.

3.3 Selecting the Output Capacitor (Buck Converter)

The output capacitors maintain the DC output voltage and affect the converter's output ripple. Because the GSM modules in this application must have a supply voltage below 4.2V, the output ripple is an important requirement, and the output capacitors must be selected to obtain a low output voltage ripple. It is recommended to use larger-value, low-ESR capacitors, such as MLCC capacitors with X5R or X7R dielectrics.

The output capacitor should be selected after considering how it affects system stability. For this design, it is recommended to use two 22µF MLCC capacitors placed in parallel.

3.4 Setting the Output Voltage (Buck Converter)

The buck converter's output voltage is set with an external resistor divider connected to the FB pin. Refer to the MPQ4433 datasheet to determine the size of the resistor divider.

For this application, the output voltage must to be set to 4.2V to avoid exceeding the maximum input voltage of the GSM module while still remaining inside the input voltage range of the battery charger. This means that R_{FB1} should be 52.3kΩ, and R_{FB2} should be 12kΩ.

3.5 Setting the Switching Frequency (Buck Converter)

The converter's switching frequency is set by connecting an external resistor (R_{FREQ}) between the FREQ pin and ground, calculated with Equation (2):

$$R_{FREQ}(k\Omega) = \frac{170000}{f_{SW}^{1.11}(kHz)} \tag{2}$$

It is important to account for the tradeoff between the EMC issues and the inductor ripple current (ΔI_L) when selecting the switching frequency. The EMC performance can be negatively affected by a high switching frequency, while ΔI_L improves at high frequencies (see Equation (1) on page 5).

In this application, R_{FREQ} = 191kΩ, which makes f_{SW} = 454kHz.

3.6 Selecting the Thermal Protection Circuit (Battery Charger)

The MP26029 continuously monitors the battery's temperature by measuring the voltage at the NTC pin. The voltage is typically determined by a negative temperature coefficient (NTC) thermistor and external voltage dividers. If V_{NTC} exceeds V_{HOT} or drops below V_{COLD}, the IC suspends charging. By selecting the resistor divider values, the designer can set the operating temperature range for the batteries.

The resistor dividers (R_{T1} and R_{T2}) can be estimated with Equation (3) and Equation (4), respectively:

$$R_{T1} = \frac{R_{NTC_{HOT}} \times R_{NTC_{COLD}} \times (V_{COLD} - V_{HOT})}{V_{COLD} \times V_{HOT} \times \left(R_{NTC_{COLD}} - R_{NTC_{HOT}}\right)} \tag{3}$$

$$R_{T2} = \frac{R_{NTC_{HOT}} \times R_{NTC_{COLD}} \times (V_{COLD} - V_{HOT})}{R_{NTC_{COLD}} \times V_{HOT} \times (1 - V_{COLD}) - R_{NTC_{HOT}} \times V_{COLD} \times (1 - V_{HOT})} \tag{4}$$

Where R_{T1} and R_{T2} are the resistor divider values, R_{NTC_HOT} and R_{NTC_COLD} are the NTC values at the maximum and minimum allowed temperatures, respectively, and V_{COLD} and V_{HOT} are predefined values (refer to the MP26029 datasheet for more details). V_{HOT} and V_{COLD} are the percentages of the V_{IN} rising and falling thresholds that limit the operating temperature range of the IC (61.5% and 28.5%, respectively).

This application has been designed for the 103AT thermistor, with a battery temperature range between -20°C and +60°C (R_{NTC_HOT} = 3.02kΩ and R_{NTC_COLD} = 67.77kΩ). Finally, R_{T1} = 5.9kΩ and R_{T2} = 11kΩ.

3.7 Setting the Charge Current (Battery Charger)

Set the charge current (I_{CC}) by connecting a resistor between the ISET and GND pins. Calculate I_{CC} with Equation (5):

$$I_{CC}(mA) = 3200 \times R_{ISET}(k\Omega)^{-1.05} \tag{5}$$

Where I_{CC} is the charge current during constant current charge (phase 2), and R_{ISET} is the resistor placed between the ISET and GND pins.

An issue with this design step is that the tolerance of the I_{CC} setting is ±10%. For this reason, and with the aim to add variability to the design, the charge current can vary between 30mA and 1A by placing four resistors placed in a parallel configuration, and connecting or disconnecting them as required.

The start-up configuration is complete with an R_{ISET} of 24.9kΩ, which means I_{CC} = 110mA.

3.8 Selecting the Diode

The buck converter's output voltage is set to 4.2V to supply enough voltage to the battery charger while not exceeding the maximum allowed input voltage of the GSM module (4.2V). However, it is recommended to reduce the supply voltage of the GSM module below 4.2V to protect it from load transients without reducing the input voltage of the battery charger. This means that the converter's output voltage (typically 4.2V) should be maintained at the input of the battery charger, but reduced to 4V at the input of the GSM module.

Place a diode between the buck converter and GSM module to reduce the output voltage from 4.2V to 4V. This relationship can be calculated with Equation (6):

$$V_{GSM} = V_{BUCK} - V_{FD} \tag{6}$$

Where V_{GSM} is the input voltage of the GSM module, V_{BUCK} is the output voltage of the converter, and V_{FD} is the forward voltage of the diode.

When selecting the diode, consider two conditions. First, the diode's forward current must be greater than the maximum load current of the GSM module (typically 2A). Second, the forward voltage must be sufficient to protect the GSM module from load transients, but cannot be so high that it heavily reduces system efficiency.

3.9 Selecting the MOSFET

The MOSFET is used as a switch to change the supply source between the external battery pack and the buck converter. Select a MOSFET that does not dissipate too much power when the car battery is disconnected and the GSM module is being powered by the external battery pack. The MOSFET must behave as a short circuit when the car battery is disconnected, but must behave as an open circuit when the car battery supplies 12V. This means that the on resistance ($R_{DS(ON)}$) and the leakage current must be as small as possible.

3.10 Schematic

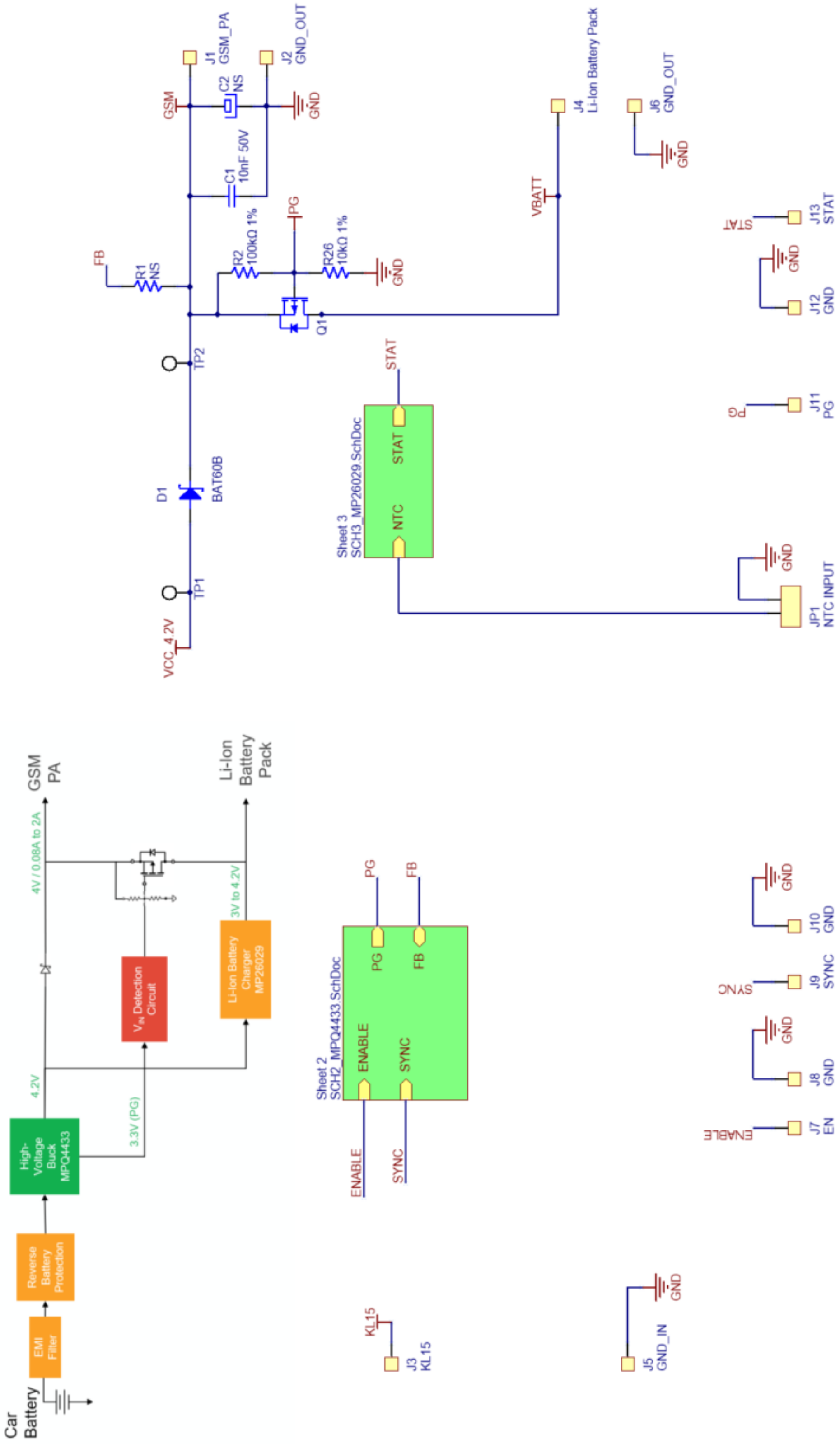


Figure 3: E-Tracker Schematic (Page 1)

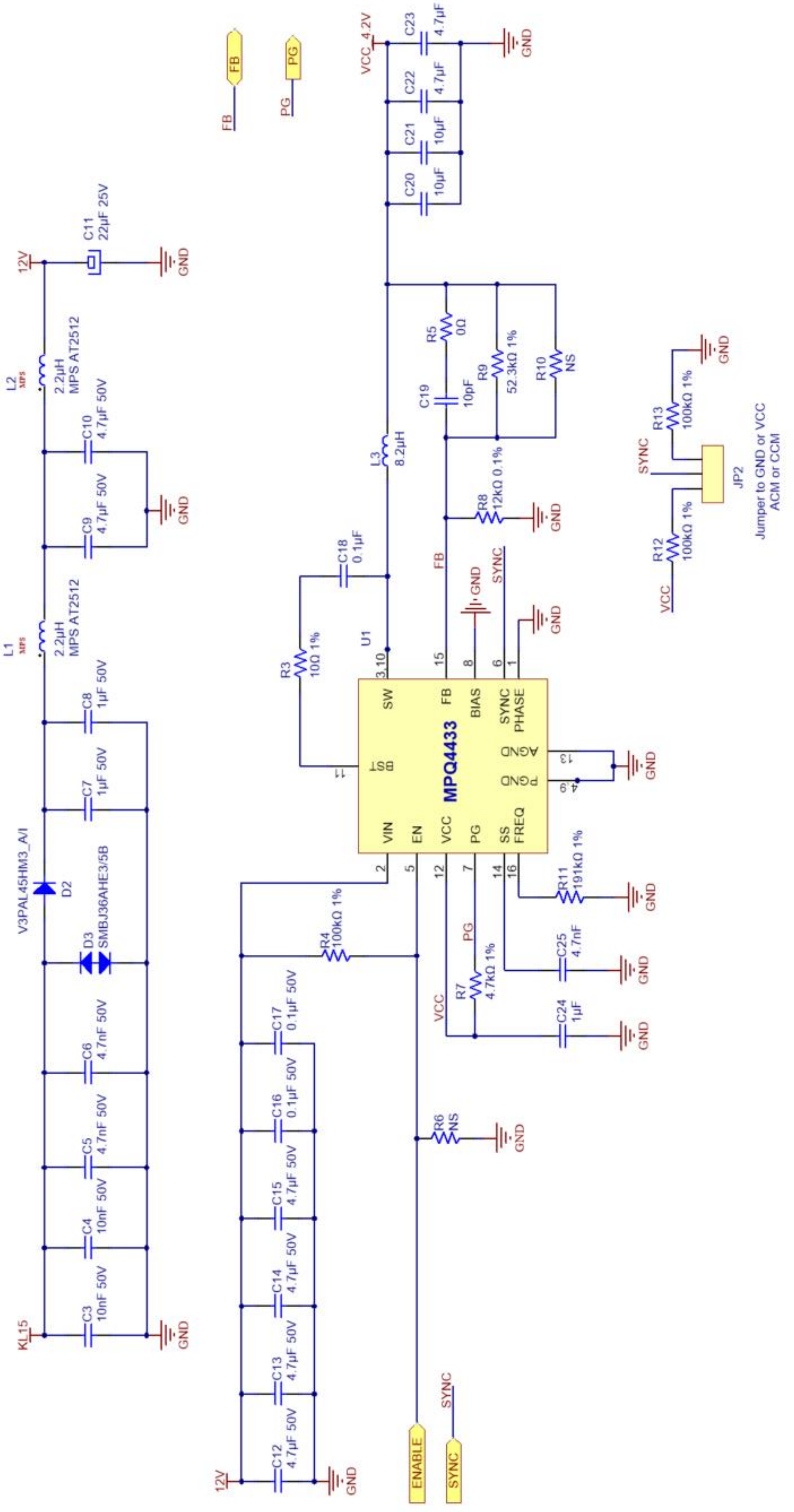


Figure 4: E-Tracker Schematic (Page 2)

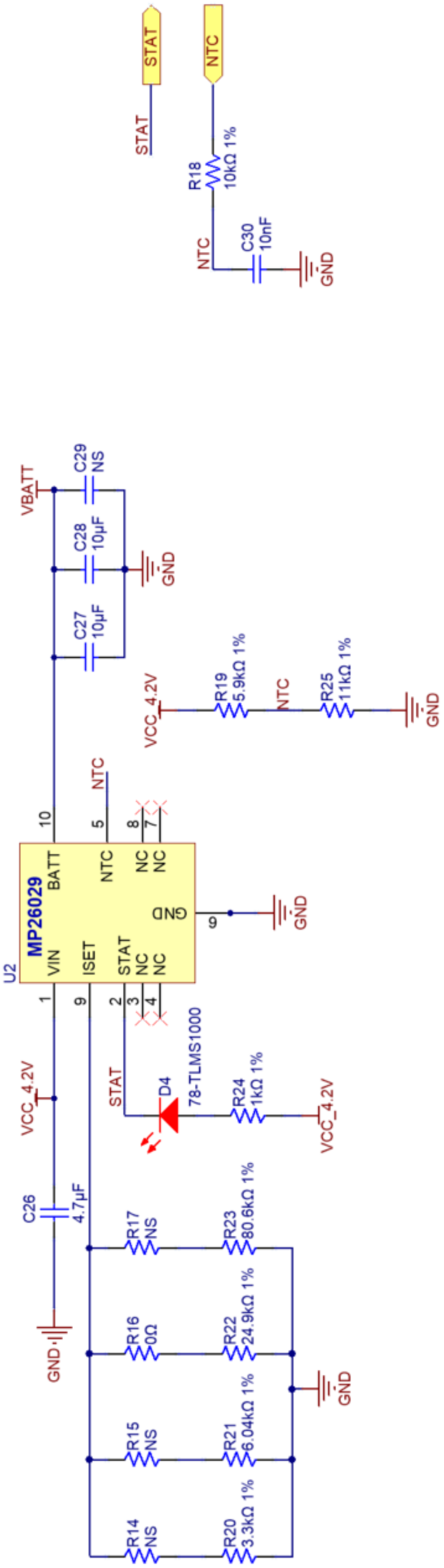


Figure 5: E-Tracker Schematic (Page 3)

3.11 BOM

Ref	Qty	Value	Package	Manufacturer	Manufacturer PN
C1, C3, C4	3	10nF, 50V	0603	Yageo	CC0603KRX7R9BB103
C5, C6, C25	2	4.7nF, 50V	0603	KEMET	C0603C472J5RACTU
C7, C8, C24	3	1µF, 50V	0603	Murata	GCM21BR71H105KA03L
C9, C10, C12, C13, C14, C15, C22, C23, C26	9	4.7µF, 50V	0805	Murata	GRM21BR61H475KE51L
C11	1	22µF, 25V	5mmx5.8mm	Panasonic	EEE-FP1E220AR
C16, C17, C18	3	0.1µF, 50V	0603	KEMET	C0603C104K5RACTU
C19	1	10pF	0603	Yageo	CC0603JRNPO9BN100
C20, C21	2	10µF	1210	KEMET	C1210C106K8RACTU
C27, C28	2	10µF	0805	Murata	GRM21BR61E106KA73L
C30	1	10nF	0603	AVX	06035C103KAT2A
D1	1	BAT60B	SOD-323	Infineon	BAT60B
D2	1	V3PAL45HM3_A/I	DO-221BC	Vishay	V3PAL45HM3_A/I
D3	1	SMBJ36AHE3/5B	DO-214AA	Vishay	SMBJ36AHE3/5B
D4	1	TLMS1000-GS08	0603	Vishay	TLMS1000-GS08
L1, L2	2	2.2µH, 2.6A	AT2514	MPS	MPL-AT2514-2R2
L3	1	8.2µH, 3.4A	XAL4040	Coilcraft	XAL4040-822MEC
Q1	1	NVGS5120PT1G	TSOP-6	ON Semiconductor	NVGS5120PT1G
R2, R4, R12, R13	4	100kΩ, 1%	0603	Yageo	RC0603FR-07100KL
R3	1	10Ω, 1%	0603	Vishay	CRCW060310R0FKEA
R5, R16	2	0Ω	0603	Panasonic	ERJ-3GEY0R00V
R7	1	4.7kΩ, 1%	0603	Panasonic	ERJ-3EKF4701V
R8	1	12kΩ, 0.1%	0603	Panasonic	ERA-3AEB123V
R9	1	52.3kΩ, 1%	0603	Vishay	CRCW060352K3FKEA
R11	1	191kΩ, 1%	0603	Vishay	CRCW0603191KFKEA
R18, R26	2	10kΩ, 1%	0603	Panasonic	ERJ-3EKF1002V
R19	1	5.9kΩ, 1%	0603	Panasonic	ERJ-3EKF5901V
R20	1	3.3kΩ, 1%	0603	Panasonic	ERJ-3EKF3301V
R21	1	6.04kΩ, 1%	0603	Panasonic	ERJ-3EKF6041V
R22	1	24.9kΩ, 1%	0603	Panasonic	ERJ-3EKF2492V

R23	1	80.6kΩ, 1%	0603	Panasonic	ERJ-3EKF8062V
R24	1	1kΩ, 1%	0603	Panasonic	ERJ-3EKF1001V
R25	1	11kΩ, 1%	0603	Vishay	CRCW060311K0FKEA
U1	1	MPQ4433	QFN-16 (3mmx4mm)	MPS	MPQ4433GL–Z
U2	1	MP26029	QFN-10 (3mmx3mm)	MPS	MP26029GQ-0000

3.12 PCB Layout

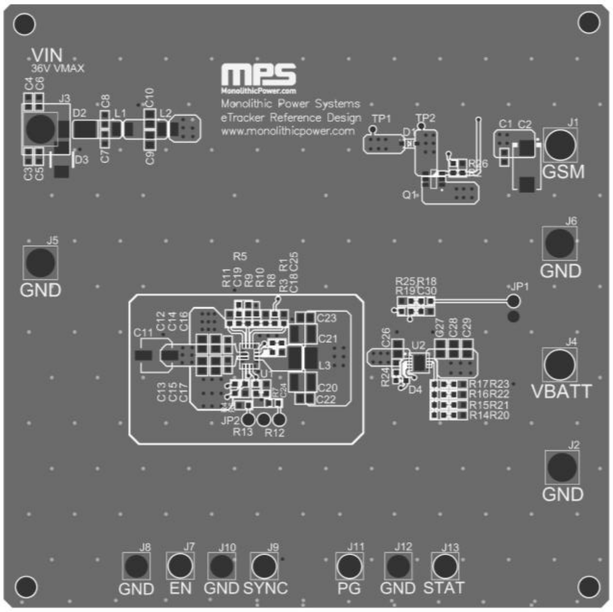


Figure 6: PCB Layer 1

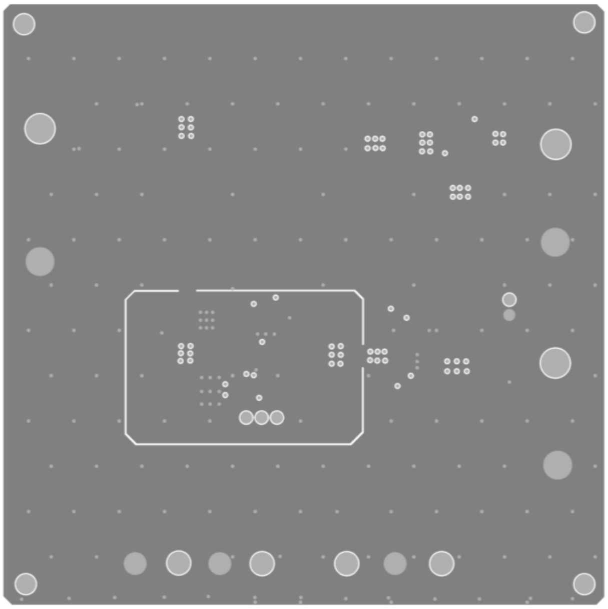


Figure 7: PCB Layer 2

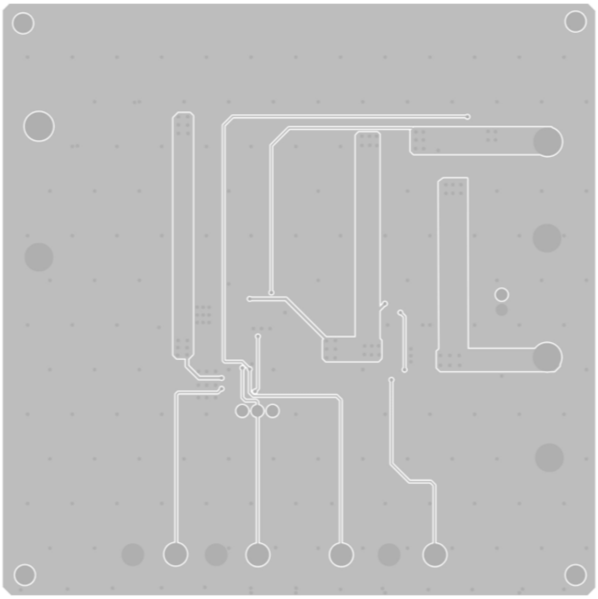


Figure 8: PCB Layer 3

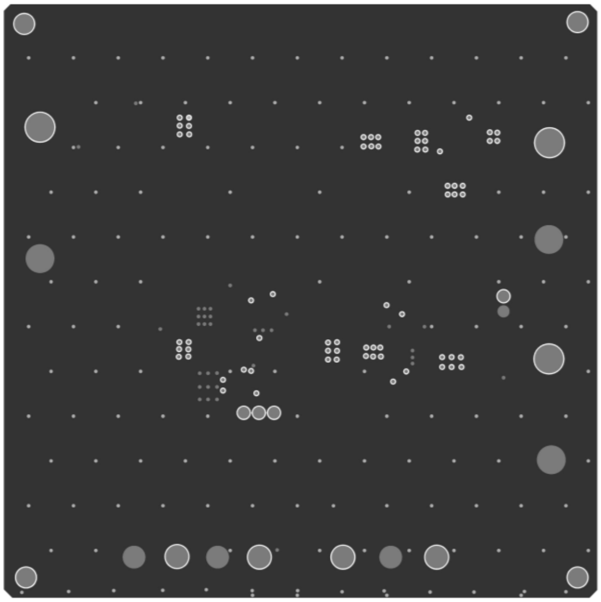


Figure 9: PCB Layer 4

4 Test Results

4.1 Efficiency and Regulation

V_{OUT} = 4.2V, L = 8.2µH, f_{SW} = 454kHz, T_A = 25°C.

Figure 10: Efficiency vs. Load Current
Buck converter

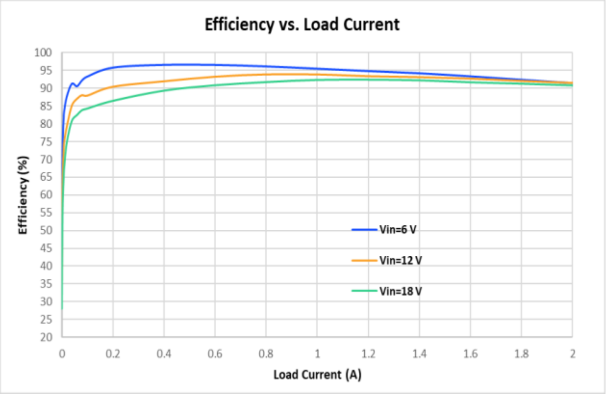


Figure 11: Efficiency vs. Load Current
System without external Li-ion battery pack connected

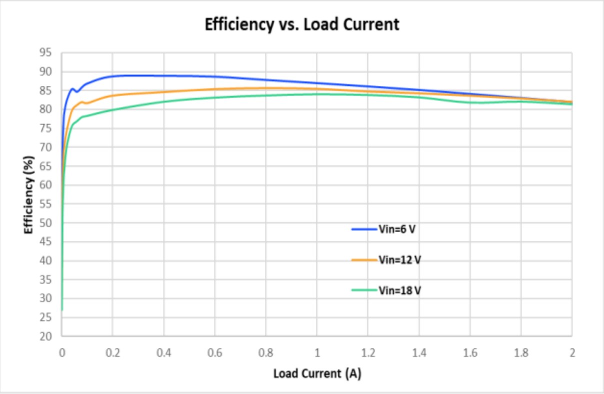


Figure 12: Line Regulation
Buck converter

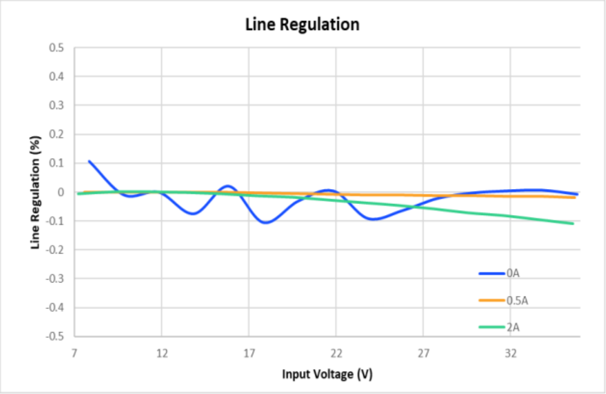


Figure 13: Line Regulation
System without external Li-ion battery pack connected

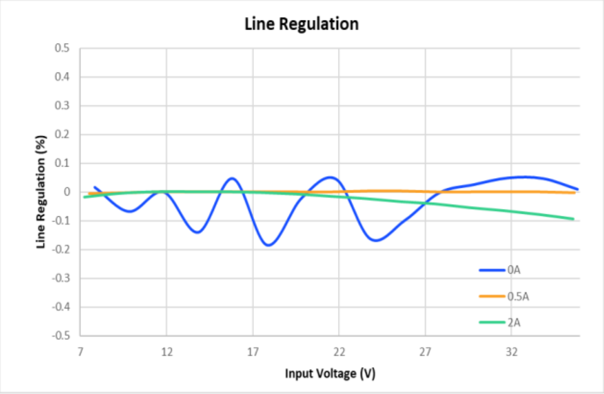
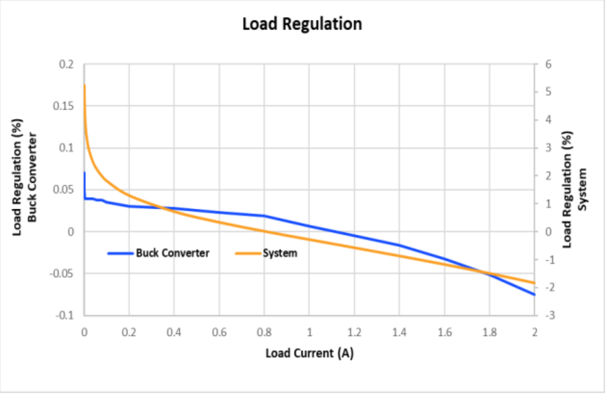


Figure 14: Load Regulation
System without external Li-ion battery pack connected



4.2 Time Domain Waveforms

V_{IN} = 12V, V_{OUT} = 4.2V, L = 8.2µH, f_{SW} = 454kHz, T_A = 25°C.

Figure 12: Steady State (Buck)

I_{LOAD} = 0A, AAM mode

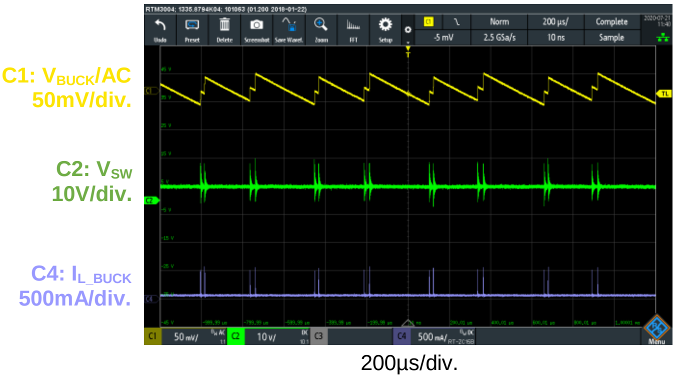


Figure 13: Steady State (Buck)

I_{LOAD} = 2A, CCM mode

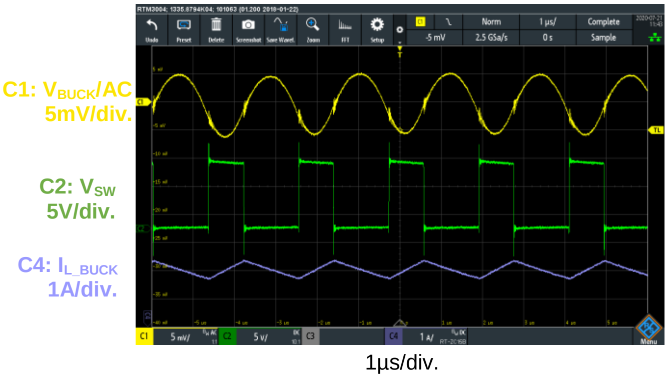


Figure 14: Start-Up through VIN (Buck)

I_{LOAD} = 0A

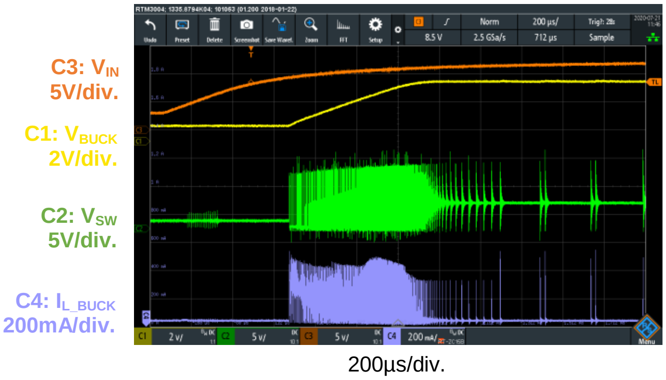


Figure 15: Start-Up through VIN (Buck)

I_{LOAD} = 2A

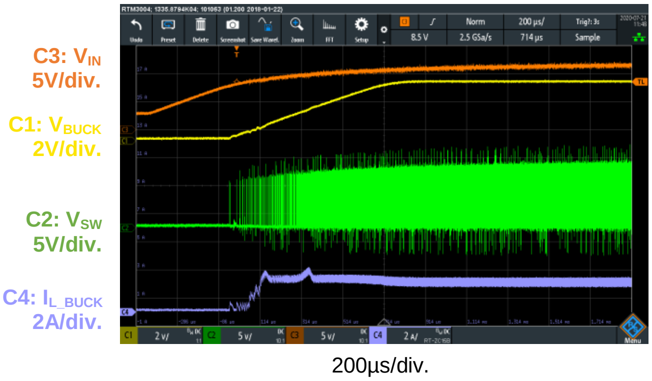


Figure 16: Shutdown through VIN (Buck)

I_{LOAD} = 0A

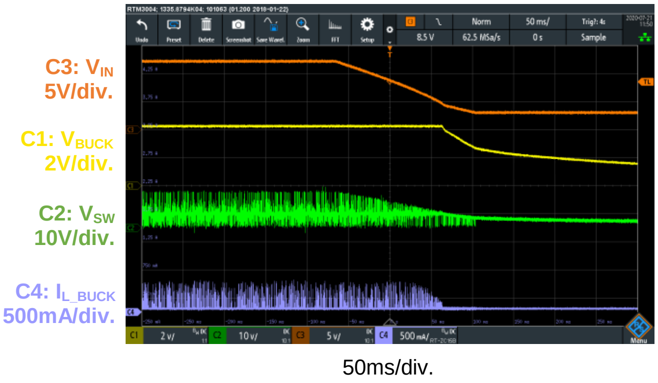


Figure 20: Shutdown through VIN (Buck)

I_{LOAD} = 2A

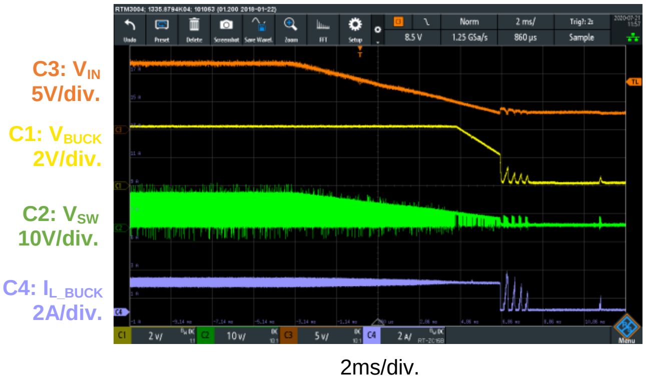
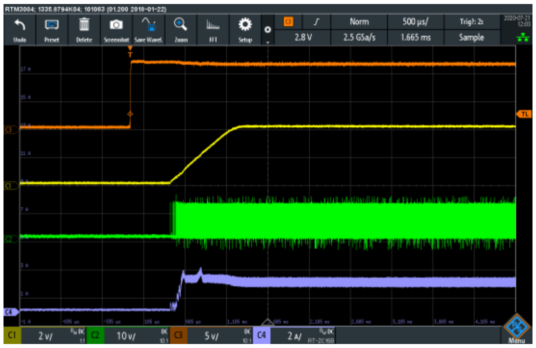


Figure 21: Start-Up through EN (Buck)

I_{LOAD} = 2A



C3: EN
5V/div.

C1: V_{BUCK}
2V/div.

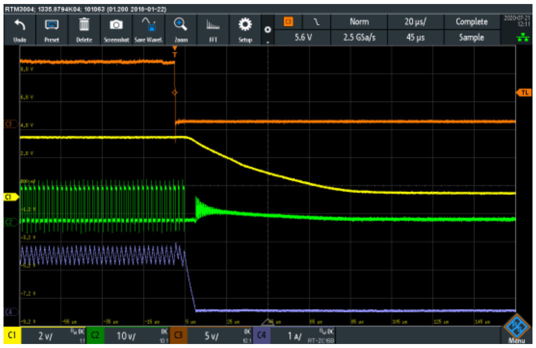
C2: V_{SW}
10V/div.

C4: I_{L_BUCK}
2A/div.

500µs/div.

Figure 22: Shutdown through EN (Buck)

I_{LOAD} = 2A



C3: EN
5V/div.

C1: V_{BUCK}
2V/div.

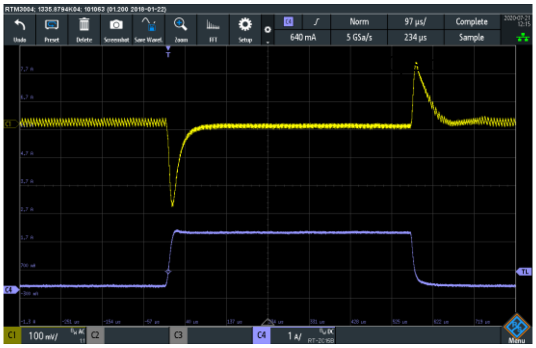
C2: V_{SW}
10V/div.

C4: I_{L_BUCK}
1A/div.

20µs/div.

Figure 23: Load Transient (Buck)

I_{SYS} = 80mA to 2A



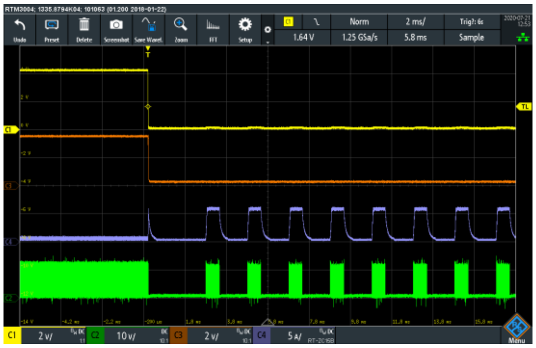
C1:
V_{BUCK}/AC
100mV/div.

C4: I_{LOAD}
1A/div.

97µs/div.

Figure 24: SCP Entry (Buck)

I_{LOAD} = 80mA to short-circuit



C1: V_{BUCK}
2V/div.

C3: PG
2V/div.

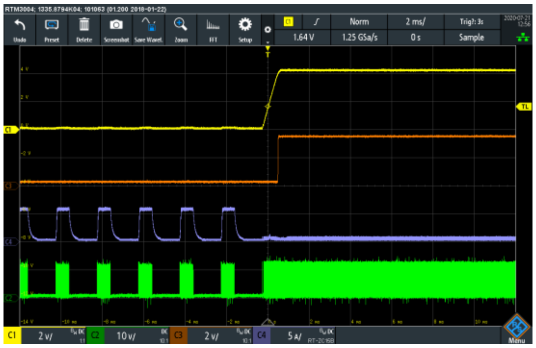
C4: I_{L_BUCK}
5A/div.

C2: V_{SW}
10V/div.

2ms/div.

Figure 25: SCP Recovery (Buck)

I_{LOAD} = short-circuit to 80mA



C1: V_{BUCK}
2V/div.

C3: PG
2V/div.

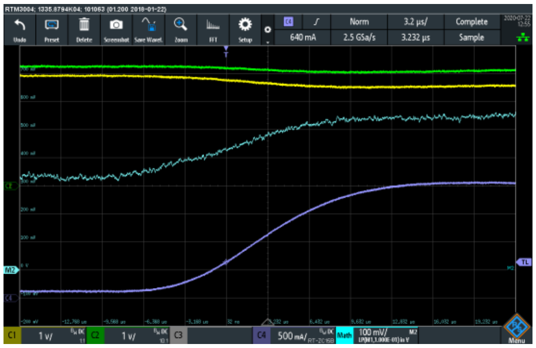
C4: I_{L_BUCK}
5A/div.

C2: V_{SW}
10V/div.

2ms/div.

Figure 26: Forward Voltage Diode

V_{IN} = 12V, I_{LOAD} = 0mA to 2A



C2: V_{BUCK}
1V/div.

C1: V_{GSM}
1V/div.

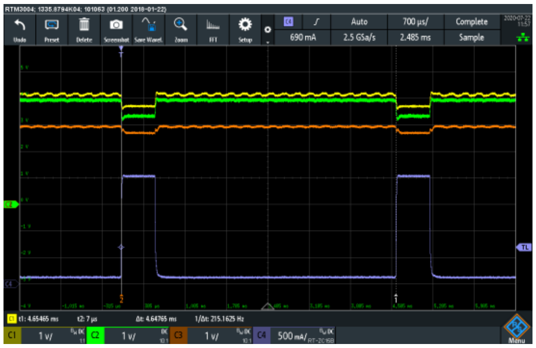
Meas
(C2-C1)
100mV/div.

C4: I_{OUT}
500mA/div.

3.2µs/div.

Figure 27: PG at Load Transient

V_{IN} = 4.5V, I_{LOAD} = 80mA to 2A



C1: V_{BUCK} 1V/div.

C2: V_{GSM} 1V/div.

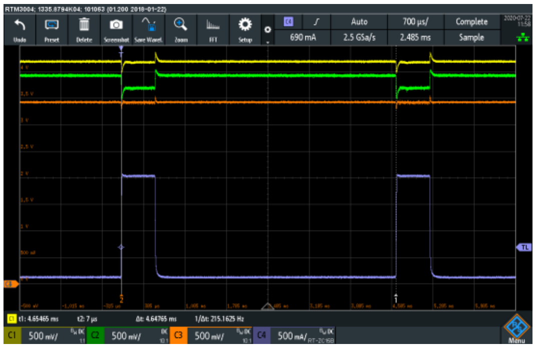
C3: PG 1V/div.

C4: I_{L_BUCK} 500mA/div.

700µs/div.

Figure 28: PG at Load Transient

V_{IN} = 12V, I_{LOAD} = 80mA to 2A



C1: V_{BUCK} 500mV/div.

C2: V_{GSM} 500mV/div.

C3: PG 500mV/div.

C4: I_{L_BUCK} 500mA/div.

700µs/div.

Figure 29: Load Transient (Battery)

I_{LOAD} = 80mA to 2A

C3: V_{BATT} 500mV/div.

C1: V_{GSM} 500mV/div.

C4: I_{OUT} 500mA/div.

700µs/div.

Figure 30: Battery Transition

V_{IN} = 12V to 0V, I_{OUT} = 80mA to 2A

C1: V_{GSM} 500mV/div.

C2: V_{IN} 5V/div.

C3: I_{LOAD} 1A/div.

C4: PG 2V/div.

4.8ms/div.

Figure 31: Battery Transition

V_{IN} = 0V to 12V, I_{OUT} = 80mA to 2A

C1: V_{GSM} 500mV/div.

C2: V_{IN} 5V/div.

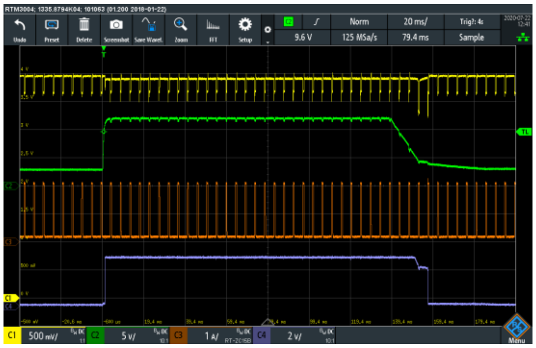
C3: I_{LOAD} 1A/div.

C4: PG 2V/div.

2.1ms/div.

Figure 32: Battery Transition

V_{IN} = 0V to 12V to 0V, I_{OUT} = 80mA to 2A



C1: V_{GSM} 500mV/div.

C2: V_{IN} 5V/div.

C3: I_{LOAD} 1A/div.

C4: PG 2V/div.

20ms/div.

4.3 EMC Measurements

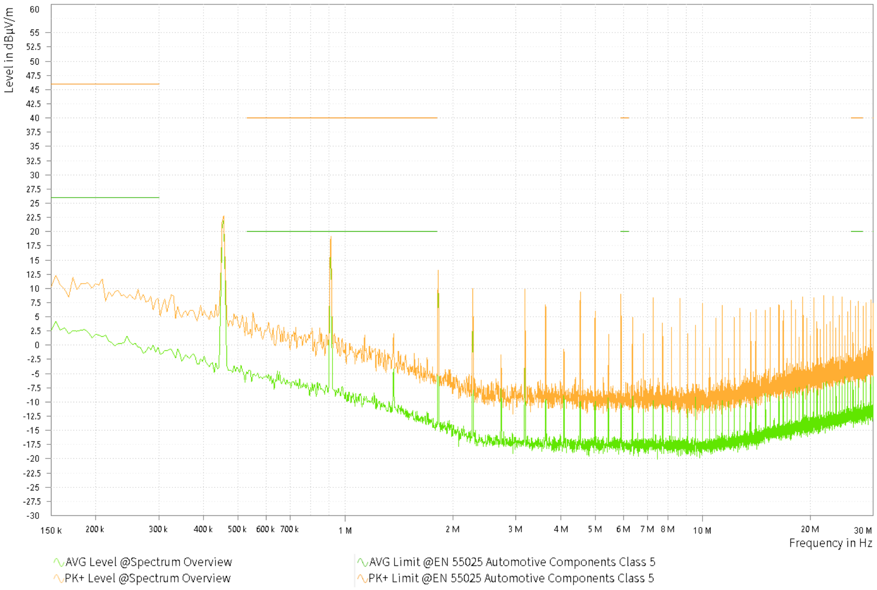
V_{IN} = 13.5V, V_{OUT} = 4.2V, L = 8.2µH, C_{OUT} = 30µF, f_{SW} = 454kHz, T_A = 25°C.

Figure 33: CISPR25 Class 5 Conducted Emissions

150kHz to 108MHz

Figure 34: CISPR25 Class 5 Radiated Emissions

150kHz to 30MHz



5 Start-Up

1. Set the power supply to 12V. The evaluation board can tolerate up to 36V (load dump transient).
2. Connect the power supply terminals to:
   a. Positive (+): VIN
   b. Negative (-): GND
3. Connect the load terminals to:
   a. Positive (+): GSM
   b. Negative (-): GND
4. Connect the external battery pack to:
   a. Positive (+): VBATT
   b. Negative (-): GND
5. Turn the power supply on after making the connections.
6. To use the enable function, apply a digital input to the EN pin. Drive EN above 1.05V to turn the regulator on; drive EN below 0.93V to turn the regulator off.
7. The MPQ4433's oscillating frequency can be configured by an external resistor (R11). Calculate the value for this resistor with Equation (3) on page 6.
8. To use the SYNC function, apply a 350kHz to 2.5MHz clock to the SYNC pin to synchronize the internal oscillator frequency to the external clock. The external clock frequency should be at least 250kHz greater than the oscillating frequency set by R11. The SYNC pin can also be used to select between forced continuous conduction mode (FCCM) and advanced asynchronous mode (AAM). To choose FCCM, drive the SYNC pin high before the chip starts. To choose AAM, drive the SYNC pin low or leave it floating. The jumper (JP2) can be set to allow the user to easily alternate between AAM and FCCM.
9. The buck converter output voltage is set by the external resistor divider (R8 and R9). R10 can be used to quickly modify the output voltage by soldering the suited resistor in parallel to R9.
10. To change the MP26029's constant charge current, modify the resistance connected to the ISET pin, calculated with Equation (6) on page 6. The design contains four resistors placed in parallel (R20, R21, R22, and R23), which allow the user to easily change I_{CC} by connecting or disconnecting the four resistors.
11. Connect a 103AT thermistor to JP1 to control the battery temperature and stop the charging when the battery temperature is outside the safe range. If temperature control is not required, connect a 10kΩ resistor at JP1.

6 Disclaimer

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