Application Note

Power Supply Designs for eBike That Meet the New GB42295 National Standard

Joyce Chen, Aurora Tie, Bella He

ABSTRACT

In January 2024, China began to implement the new national standard GB42295 for electric bicycles (eBikes). This standard changed the maximum voltage of the main circuit of the vehicle and the secondary circuit. As a result, a new power rail must be added to the DCDC power supply circuit in the eBike battery pack system. Figure 1-1 shows the block diagram of the battery pack portion of the eBike system. Newly added parts are marked in red. This application note combines the new national standards and eBike application requirements to provide a DCDC power supply circuit design scheme. Moreover, the document considers the requirements of eBike applications for design size and performance and provides specific designs. The design process and experimental results of each scheme are also shown. Customers can obtain the data from this application report, such as efficiency, thermal and so on.

Table of Contents

Trademarks

All trademarks are the property of their respective owners.

1 Introduction

On December 29, 2022, China published electrical safety requirements for electric bicycles (GB42295). Considering the safety of electricity use, the main circuit voltage of the eBike must not exceed 60V (DC), and the secondary circuit voltage must not exceed 35V (DC). Normally, electric bicycles are composed of battery pack, ABS controller, instrument panel, motor controller, headlights, and so on. The battery voltage is generally 48V, so the controllers, dashboards, and motor controllers under the old standard directly convert the voltage from 48V to 12V/5V through a buck product. However, according to the new national standard, the power supply voltage of the ABS controller and instrument panel cannot exceed 35V. Therefore, when designing the battery pack, other parts except the motor controller must convert the 48V voltage to a voltage below 35V (such as 33V or 12V) before connecting to the subsequent part.

There are two common designs now: The first one is to convert the battery voltage to 12V through a controller directly. The second one is to generate 12V and 33V voltage from the battery pack at the same time through two buck products. According to industry standards, the total power of this part is about 100W. In addition, since this part of the primary power supply is integrated into the battery pack, the temperature of the chip rises to room temperature (25°C) and must not exceed 55°C, and the overall volume must be as small as possible. Among them, the 33V power rail current of the second design is designed to vary from 1A to 3A according to customer requirements. When the output current is below 1.5A, use a buck converter to simplify the design. When the output current is 1.5A or above, a buck controller is required to ensure the thermal demand.

This application note provides corresponding designs for this application with TI buck products. Customers can modify the official EVM board and evaluate the performance directly. This application note provides actual test results such as efficiency, thermal, and the ripple of output voltage ripple.

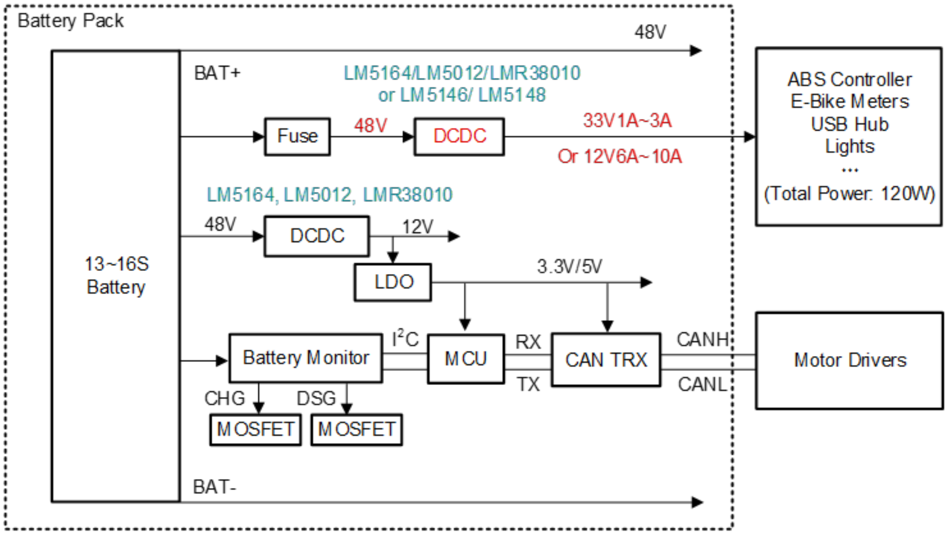

Figure 1-1. eBike Block Diagram

2 TI Proposal Designs

2.1 Design 1: Vo=12V, Io=8-10A

Because the input voltage is 48V, considering the margin, customers must select a buck controller with a withstand voltage of approximately 80-100V. LM5148 (maximum input voltage is 80V) and LM5146 (maximum input voltage is 100V) are both options.

Since LM5148 and LM5149 are pin-to-pin products, the LM5149EVM can be used to evaluate the 12V/8A output design without modifying the EVM board. Note that during the test, short the CNFG pin to GND through a jumper cap to disable the AEF function of the LM5149 and simulate the performance of the LM5148. If required, directly replace the LM5149 with the LM5148 on the EVM board for evaluation. For 100V withstand voltage products, customers can directly use the LM5146EVM to evaluate the 12V/8A output design. For detailed test results and EVM board design, see *LM5149-Q1 Buck Controller Evaluation Module User's Guide* and *LM5146-Q1EVM User's Guide*.

2.2 Design 2: Vo = 33V, Io < 1.5A

For 33V output voltage, the greater the output current, the greater the temperature rise of the product at room temperature. Generally, considering the thermal performance requirement in actual application, there are several different DCDC power supply designs for synchronous and asynchronous converters (Io < 1.5A) or controllers (Io ≥ 1.5A).

2.2.1 Vo=33V, Io=1A (LMR38010), Io=0.8A (LM5164)

LMR38010 is an 80V peak-current mode synchronous buck converter, LM5164 a 100V constant on-time (COT) mode synchronous buck converter. LMR38010 and LM5164 are almost pin-to-pin, considering small size request, design a two layer PCB board (1.7cm × 1.9cm) which features high temperature performance both for LMR38020 and LM5164. The schematic and PCB 3D picture are shown in Figure 2-1 and Figure 2-2. The design parameters of LMR38010 and LM5164 are listed in Table 2-1.

Table 2-1. Design Parameters of LM5164 and LMR38010

Item	LM5164	LMR38010
R7	274kohm	88.7kohm
L1	Wurth-7447709680 68uH (3.2A, 89mohm)	Wurth-7447709680 68uH (3.2A, 89mohm)
R9	30.9kohm	25.5kohm
R4	523kohm	NC
C4	3.3nF, 100V	NC
C16	56pF, 50V	NC

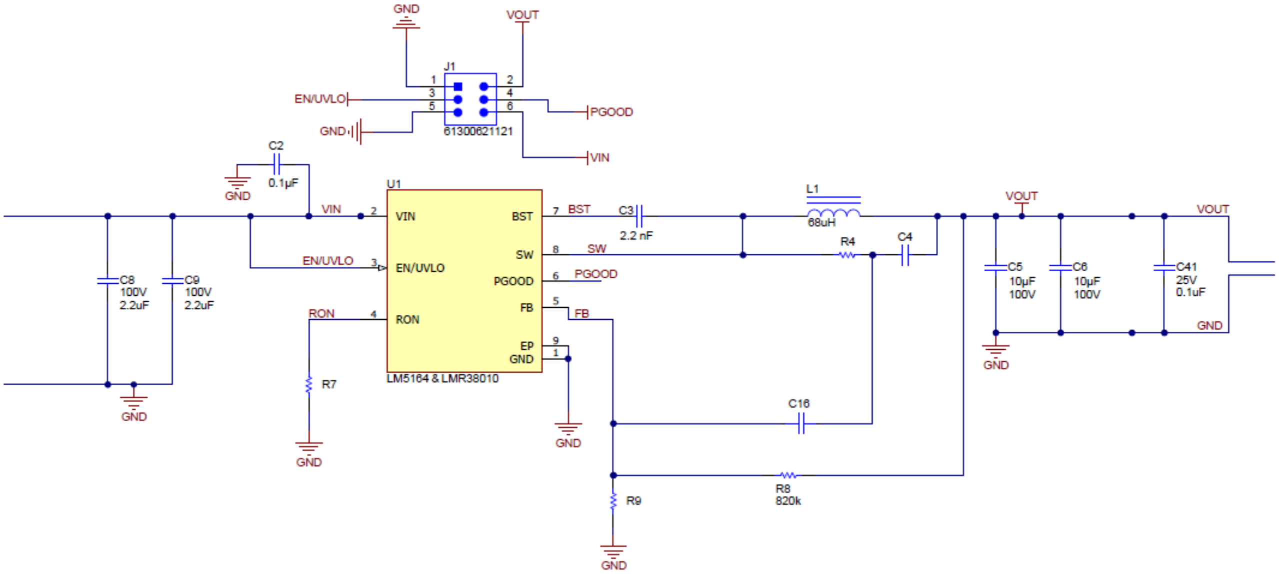

Figure 2-1. Schematic of LMR38010 and LM5164

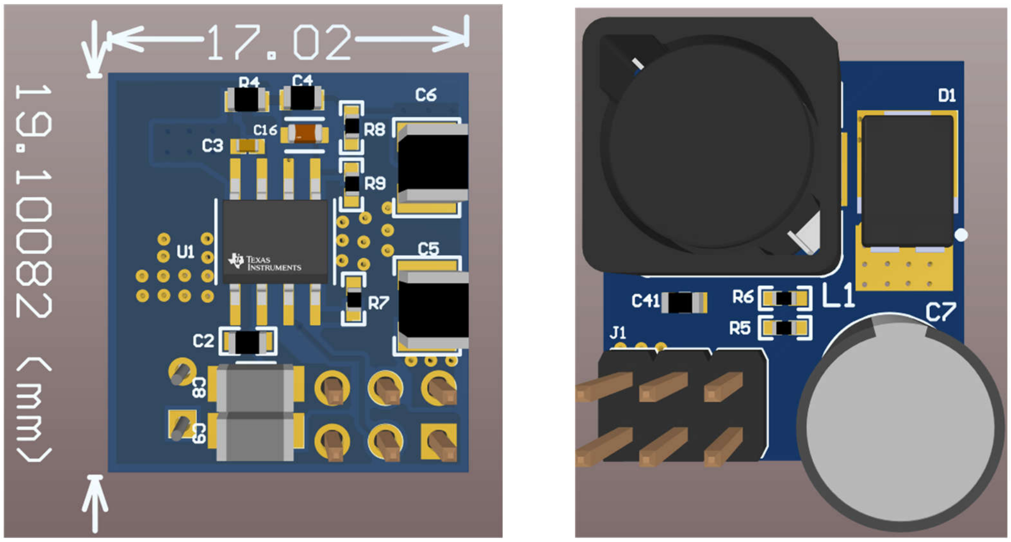

Figure 2-2. 3D PCB Board

The detail design method is shown in the following sections.

2.2.1.1 Switching Frequency (RON)

The switching frequency of the LMR38020 can be programmed by the R_T resistor from the RT/SYNC pin and GND pin. The RT/SYNC pin cannot be left floating or shorted to ground. To determine the timing resistance for a given switching frequency, use Equation 1.

$$R_T(\mathrm{k\Omega}) = 30970 \times f_{SW}(kHz)^{-1.027} = 30970 \times 300^{-1.027} = 88.49\mathrm{k\Omega} \tag{1}$$

Select R_T as 88.7kΩ.

2.2.1.2 FB for Adjustable Output

The output voltage of the LMR38020 is externally adjustable using an external resistor divider network. V_{REF} of LMR38020 is nominally 1V. Select R_{FBB} to be 10kΩ, and is used to select R_{FBT}.

$$R_{FBT}(\mathrm{k\Omega}) = R_{FBT}(\mathrm{k\Omega}) \times \left[\frac{V_{OUT}}{V_{REF}} - 1\right] = 10 \times \left[\frac{33}{1} - 1\right] = 320\mathrm{k\Omega} \tag{2}$$

Select R_{FBT} as 324kΩ.

2.2.1.3 Inductor Selection

Equation 3 can be used to determine the value of inductance. The constant K is the percentage of inductor current ripple. For this example, select K = 0.35 and find an inductance of L = 98 µH. Select the next standard value of L = 100µH.

$$\mathrm{L} = \frac{(V_{IN} - V_{OUT})}{f_{SW} \times K \times I_{OUTMAX}} \cdot \frac{V_{OUT}}{V_{IN}} = \frac{(48 - 33)}{300 \times 0.3 \times 1} \times \frac{33}{48} = 98uH \tag{3}$$

The saturation current rating of the chosen inductor is 2.4A which is larger than high-side switch current limit, I_{SC}.

2.2.1.4 Output Capacitor Selection

For more designs for eBike application, a 68uf electrolytic capacitor and a 1uf ceramic capacitor are for 33V output design. And the voltage rate of capacitors must need to be 50V or larger.

2.2.1.5 Input Capacitor Selection

The ceramic input capacitors provide a low impedance source to the regulator in addition to supplying the ripple current and isolating switching noise from other circuits.

Input capacitor must be rated for at least the maximum input voltage that the application requires, preferably twice the maximum input voltage.

A small case size 100nF to 220nF ceramic capacitor must be used at the input, as close as possible to the regulator. This provides a high frequency bypass for the control circuits internal to the device.

Besides, the moderate ESR of electrolytic capacitor on the input in parallel with the ceramics can help damp any ringing on the input supply caused by the long power leads. The use of this additional capacitor also helps with voltage dips caused by input supplies with unusually high impedance.

For eBike applications, two parallel 2.2µF, 100V, X7R ceramic capacitor and 33uF, 100V, 0.7Ω, X7R electrolytic capacitor are selected. The 100nF must also be rated at 100V with an X7R dielectric.

2.2.1.6 CBOOT Selection

The LMR38020 requires a bootstrap capacitor connected between the BOOT pin and the SW pin. This capacitor stores energy that is used to supply the gate drivers for the power MOSFETs. A high-quality ceramic capacitor of 100nF and 50V is selected.

2.2.2 Vo=33V, Io=2.5A (LM5148)

LM5148 and LM5149 are 80V current mode synchronous buck controllers. LM5149 has an on-board active EMI filter (AEF). The value of the AEF is that the AEF can reduce the size of the differential mode filter typically used for EMI mitigation. These two devices are the same besides AEF function. So, customer can use Figure 2-3 to make changes on LM5149EVM for evaluating.

The efficiency of LM5148 are shown in the LM5148 calculation tool.

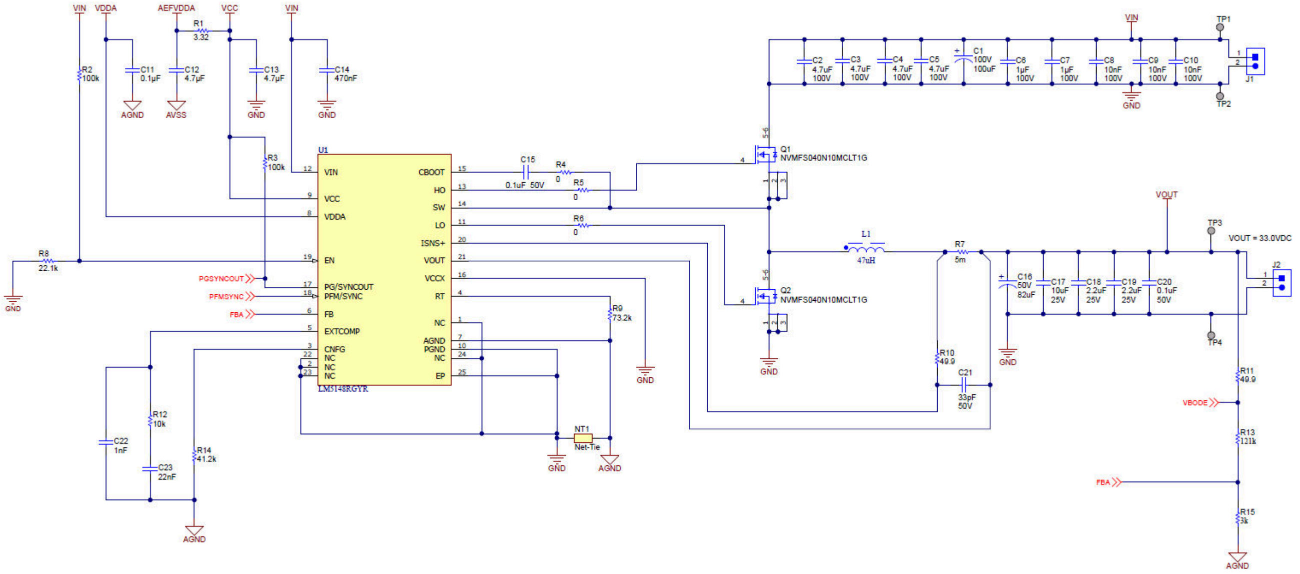

Figure 2-3. LM5148 Schematic

The detail design method is shown in the following sections.

2.2.2.1 Inductor Selection

For most applications, choose a buck inductance such that the inductor ripple current, ΔI_L, is between 30% to 50% of the maximum DC output current at nominal input voltage. Choose the inductance using based on a peak inductor current given by Equation 4 and Equation 5.

$$L_O = \frac{V_{OUT}}{\Delta I_L F_{SW}}\left(1 - \frac{V_{OUT}}{V_{IN}}\right) \tag{4}$$

$$I_{L(PEAK)} = I_{OUT} + \frac{\Delta I_L}{2} \tag{5}$$

Check the inductor data sheet to make sure that the saturation current of the inductor is well above the peak inductor current of a particular design.

2.2.2.2 PCM Special Slope Compensation

The LM5149-Q1 provides internal slope compensation for stable operation with peak current-mode control and a duty cycle greater than 50%. Calculate the buck inductance to provide a slope compensation contribution equal to one time the inductor downslope using Equation 6.

$$L_{o-IDEAL}(uH) = \frac{V_{OUT}(V) R_S(mohm)}{24 F_{SW}(MHz)} \tag{6}$$

2.2.2.3 MOSFET Selection

For most applications

1. Select the MOSFET with appropriate withstand voltage and current according to the application requirements. For example, LM5148 is an 80V product, and the $V_{(BR)DSS}$ of MOSFET can also be selected as 80V. I_{DMAX} can be selected according to the requirements.
2. According to the driving voltage of the chip, check the V_{GS} and Q_G curves of the selected MOSFET. Also need to check the typ. output characteristics (I_D versus V_{DS}) of the MOSFET under different V_{GS}. This verifies that the MOSFET can be turned on under the driving voltage provided by the controller.
3. For the same MOSFET, the Q_G, Q_{oss}, Q_{RR} and $R_{DS(on)}$ are inversely proportional. These parameters affect the power loss. The MOSFET-related power losses for one channel are summarized by the equations listed in Table 2-2, where suffixes one and two represent high-side and low-side MOSFET parameters, respectively.

Table 2-2. Buck Regulator MOSFET Power Losses

Power Loss Mode	High-Side MOSFET	Low-Side MOSFET
MOSFET conduction(2)(3)	$P_{cond1} = D \cdot \left(I_{OUT}^2 + \frac{\Delta I_L^2}{12} \right) \cdot R_{DS(on)1}$	$P_{cond2} = D' \cdot \left(I_{OUT}^2 + \frac{\Delta I_L^2}{12} \right) \cdot R_{DS(on)2}$
MOSFET switching	$P_{sw1} = \frac{V_{IN} \cdot F_{SW}}{2} \left[\left(I_{OUT} - \frac{\Delta I_L}{2} \right) \cdot t_R + \left(I_{OUT} + \frac{\Delta I_L}{2} \right) \cdot t_F \right]$	Negligible
MOSFET gate drive(1)	$P_{Gate1} = V_{CC} \cdot F_{SW} \cdot Q_{G1}$	$P_{Gate2} = V_{CC} \cdot F_{SW} \cdot Q_{G2}$
MOSFET output charge(4)	$P_{Coss} = F_{SW} \cdot \left(V_{IN} \cdot Q_{oss2} + E_{oss1} - E_{oss2} \right)$	
Body diode conduction	N/A	$P_{cond_{BD}} = V_F \cdot F_{SW} \left[\left(I_{OUT} + \frac{\Delta I_L}{2} \right) \cdot t_{dt1} + \left(I_{OUT} - \frac{\Delta I_L}{2} \right) \cdot t_{dt2} \right]$
Body diode reverse recovery(5)	$P_{RR} = V_{IN} \cdot F_{SW} \cdot Q_{RR2}$	

(1) Gate drive loss is apportioned based on the internal gate resistance of the MOSFET, externally-added series gate resistance and the relevant gate driver resistance of the device.
(2) MOSFET $R_{DS(on)}$ has a positive temperature coefficient of approximately 4500 ppm/°C. The MOSFET junction temperature, T_J, and its rise over ambient temperature is dependent upon the device total power dissipation and its thermal impedance. When operating at or near minimum input voltage, make sure that the MOSFET $R_{DS(on)}$ is rated at V_{GS} = 4.5V.
(3) D' = 1–D is the duty cycle complement.
(4) MOSFET output capacitances, C_{oss1} and C_{oss2}, are highly non-linear with voltage. These capacitances are charged losslessly by the inductor current at high-side MOSFET turn-off. During turn-on, however, a current flows from the input to charge C_{oss2} of the low-side MOSFET. E_{oss1}, the energy of C_{oss1}, is dissipated at turnon, but this is offset by the stored energy E_{oss2} on C_{oss2}.
(5) MOSFET body diode reverse recovery charge, Q_{RR}, depends on many parameters, particularly forward current, current transition speed, and temperature.

Customers must select the appropriate MOSFET according to the actual working conditions to reduce MOSFET power loss. It can also improve MOSFET thermal and system efficiency.

For the two application conditions of this application note, when the input voltage is 48V, the output voltage is 12V, and the output current is approximately 6-10A, the conduction time of the low-side MOSFET is much longer than that of the high-side MOSFET, and the conduction loss of the low-side MOSFET is larger. In addition, considering the reverse recovery loss of the low-side MOSFET, the Q_{RR} of the MOSFET cannot be too large. Therefore, the $R_{DS(on)}$ of the low-side MOSFET can be selected to be around 10mΩ and the Q_G to be around 30nC. The $R_{DS(on)}$ of the high-side MOSFET is around 20mΩ and the Q_G to be around 15nC. For details, see the LM5149EVM selection.

When the input voltage is 48V, the output voltage is 33V, and the output current is 2.5A, the conduction time of the high-side MOSFET is much longer than that of the low-side MOSFET, but because the output current is not large, the conduction loss accounts for a small proportion. Therefore, a MOSFET with a large $R_{DS(on)}$ (50mΩ) and small Q_{RR} (10nC) and Q_G (5nC) can be selected. NVMFS040N10MCLT1G was selected in actual application.

2.3 Design 3: Vo = 33V, Io = 1A and Vo = 12V, Io = 6A

Based on different output current requirements, different design selection can be referred to designs one and two.

3 Test Results and Performance Curves

Unless otherwise specified the following conditions apply: Ta= 25°C, Vin = 48V, Vo = 33V, fsw = 300kHz.

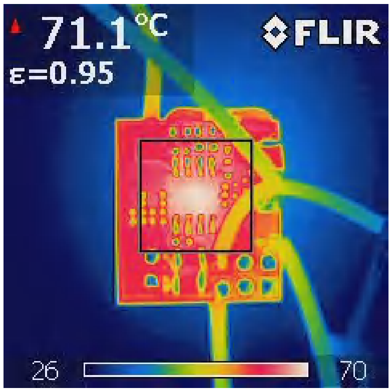

Figure 3-1. LMR38010 Thermal Performance with 1A Load

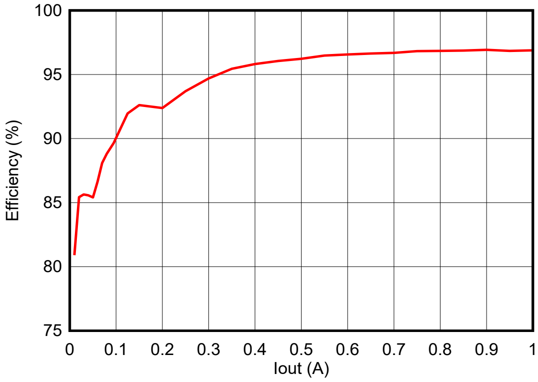

Figure 3-2. LMR38010 Efficiency vs Load Current

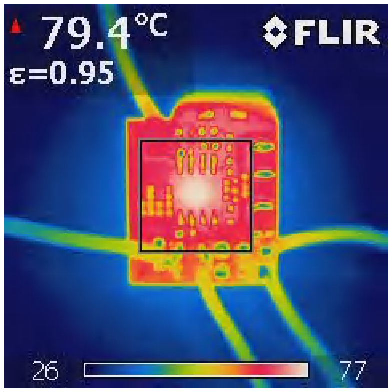

Figure 3-3. LM5164 Thermal Performance with 1A Load

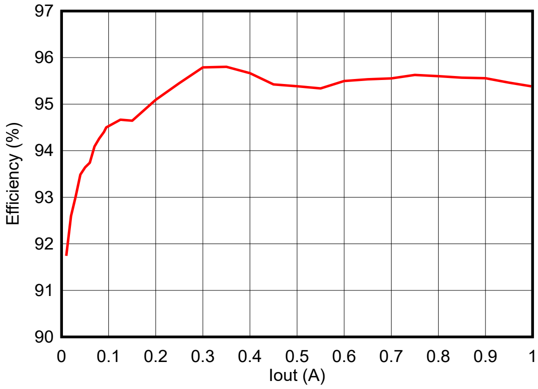

Figure 3-4. LM5164 Efficiency vs Load Current

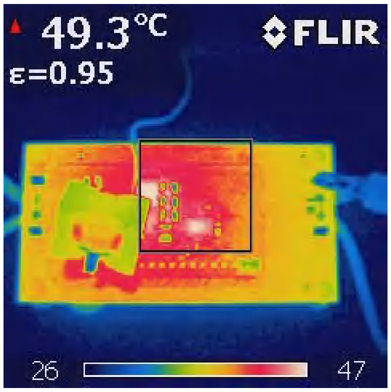

Figure 3-5. LM5148 Thermal Performance

Providing the full designs to meet the new standard, Table 3-1 lists the devices that TI recommends, which aims to meet the temperature rise below 55°C in 25°C, Vin = 48V condition. Customers can use this selection table to meet different requirements.

Table 3-1. Selection Guide Based on Different Vout and Iout Requirements

Vout Design	Ioutmax in eBike Applications	TI Recommended Device	VIN Range	Type	Control Method
12V	10A	LM5148	3.5V to 80V	Synchronous Controller	Peak Current Mode
12V	10A	LM5146	5.5V to 100V	Synchronous Controller	Voltage Mode
33V	3A	LM5145	6V to 75V	Synchronous Controller	Voltage Mode
33V	3A	LM5146	5.5V to 100V	Synchronous Controller	Voltage Mode
33V	2.5A	LM5148	3.5V to 80V	Synchronous Controller	Peak Current Mode
33V	1.3A	LM5012	6V to 100V	Non-synchronous controller	Constant on-time (COT)
33V	1A	LMR38010	4.2V to 100V	Synchronous Controller	Peak Current Mode
33V	0.8A	LM5164	6V to 100V	Synchronous Controller	Constant on-time (COT)

4 Summary

To satisfy the GB42295 national standard of eBikes, additional an 48V buck design is required. The key points in eBike application is mainly focused on size, thermal performance and efficiency. This application report highlights three traditional output voltage designs, which involves schematic and PCB design and test results.

5 References

- Texas Instruments, *LM5149-Q1 Buck Converter Evaluation Module User's Guide*, EVM user's guide
- Texas Instruments, *LM5146-Q1 EVM User's Guide*, EVM user's guide
- Texas Instruments, *LM5148-LM25148DESIGN-CALC*, calculation tool

IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES “AS IS” AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI’s products are provided subject to TI’s Terms of Sale or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI’s provision of these resources does not expand or otherwise alter TI’s applicable warranties or warranty disclaimers for TI products.

TI objects to and rejects any additional or different terms you may have proposed.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2025, Texas Instruments Incorporated