Application Note

Parallel Operation of the Buck-Boost Converters Using LM51772 Buck-Boost Controller

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ABSTRACT

This application note explores how to implement the parallel operation of buck-boost converters using the LM51772 Buck-Boost Controller IC. The LM51772 is designed to handle a wide range of input voltages and can operate in buck, boost, or buck-boost modes, making the device a flexible choice for various power supply designs. When higher output currents or system redundancy are needed, using multiple LM51772 controllers in parallel can be an effective design. This document guides users through the practical steps of setting up parallel operation with the LM51772, focusing on key factors like verify the controllers share current evenly, maintain loop stability, and manage heat dissipation. This application note also addresses the challenges of parallel operation, particularly the potential for current-sharing errors, and offers practical advice on reducing these errors. Real-world design examples, simulation results, and experimental data are presented to demonstrate the effectiveness of the proposed configurations.

By following the guidelines in this application note, designers can optimize power delivery and verify reliable operation in demanding power conversion applications.

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1 Introduction

The LM51772 device is a wide input voltage range, four-switch buck-boost controller IC with integrated drivers for N-channel MOSFETs.

One single LM51772 converter can deliver power greater than 200 W. To get higher output power, parallel power stages are needed to solve the excessive board heating problem because of the increased switching and conduction losses. Parallel operation of power stages can also provide many other benefits like: enhanced modularity, design flexibility, and minimized component ratings. These benefits can be realized only if the LM51772 converters evenly share the total load power. This application report shows how to configure and interconnect the LM51772 devices to get a well-balanced load-sharing. Test results show less than a 10% error in load sharing without sacrificing the overall performance.

2 Parallel or Multiphase Power Stages

2.1 Paralleling Power Stages

2.1.1 Load Balancing Requirement

Paralleling the power converters means the equal sharing of the load current, while the output voltages are the same. Figure 2-1 demonstrates the integration of two parallel LM51772 converters.

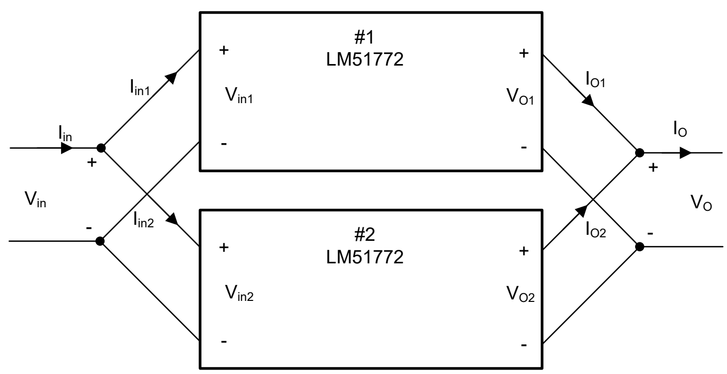

Figure 2-1. Two Parallel LM51772 Converters as Power Supply

This power supply can be modeled as a current source feeding into a common output capacitor. With the shared feedback of the output voltage the power stages are well aligned, with only slightly different of the output current balance due to device variances.

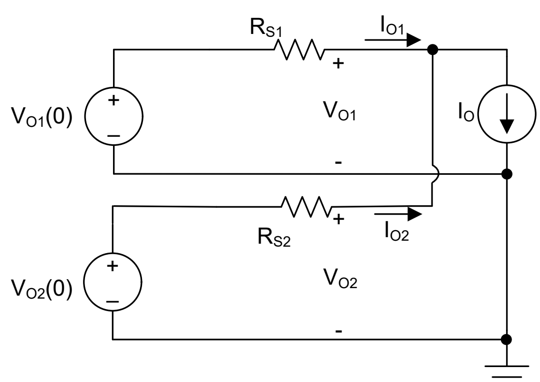

Figure 2-2. Equivalent Model

All power stages need to be build identical with the identical inductor values and input or output capacitors so that the output variance is small enough to provide a good load balance when paralleling two or more power stages.

2.2 Clock Generation

For an implemention of two phases, the best current balance can be obtained when running with 180 degree phase shift between the two controllers. With the R2D interface, the LM51772 can be configured to output the clock on the SYNC pin or to use the clock provided at the SYNC pin with inverted polarity. Based on that, a 2-phase operation can be easily implemented without additional external hardware. For that, the SYNC pin of both controllers needs to be connected. The first device is then configured to output the clock with EN_SYNC_OUT set to enabled, and the second device is set to use the clock on SYNC on the falling edge with SYNC_IN_FALLING set to enabled by R2D setting on CFG2 pin.

When operating the LM51772 converters with more then two phases, the clock needs to be provided from external with a phase shift between the clock for the different controllers of 360 degree or number of phases. A implementation for a clock generataion for more phases is shown in the Parallel Operation of the Buck-Boost Converters Using LM5177 Buck-Boost Controller application note.

2.3 Interconnection of the Power Stages

Apart from the similar components for power stages, the individual power stage needs some interconnection between each other to make sure proper load sharing and to avoid phase overloads during the parallel operation of the converters. Thus, the several pins functions which need to be shared between the devices is shown in Table 2-1.

Table 2-1. Shared Pins

Pin Function	Pin Name	Comment
Softstart	SS/ATRK	Shared soft-start capacitor
Compensation	COMP	Shared compensations network
Enable / undervoltage lock out	EN/UVLO	Same voltage level
VIN Feedback	VIN-FB	Shared voltage divider circuit
Feedback	FB	Shared voltage divider circuit
Output voltage	VOUT	Shared output
Input voltage	VIN	Shared input
Bias voltage	BIAS	Same voltage level

Moreover, there are some other pins that need to be set for accurate parallel operation as shown in Table 2-2.

Table 2-2. Other Pins

Pin Function	Pin Name	Comment
RT	RT	Must use the same value for all devices
External clock	SYNC	To make sure a good load balancing the clock must be phase shifted by 360/n [n = number of power stages]
Slope compensation	SLOPE	Must use the same value for all devices

3 Application Implementation

To demonstrate the practical implementation for the parallel operation of two buck-boost converters using LM51772 devices, an evaluation module is designed based on the block diagram shown in Figure 3-1. The designed setup has an overall power rating of 200W and an output voltage of 20V. Additionally, the selected peak current limit for each converter is 20A.

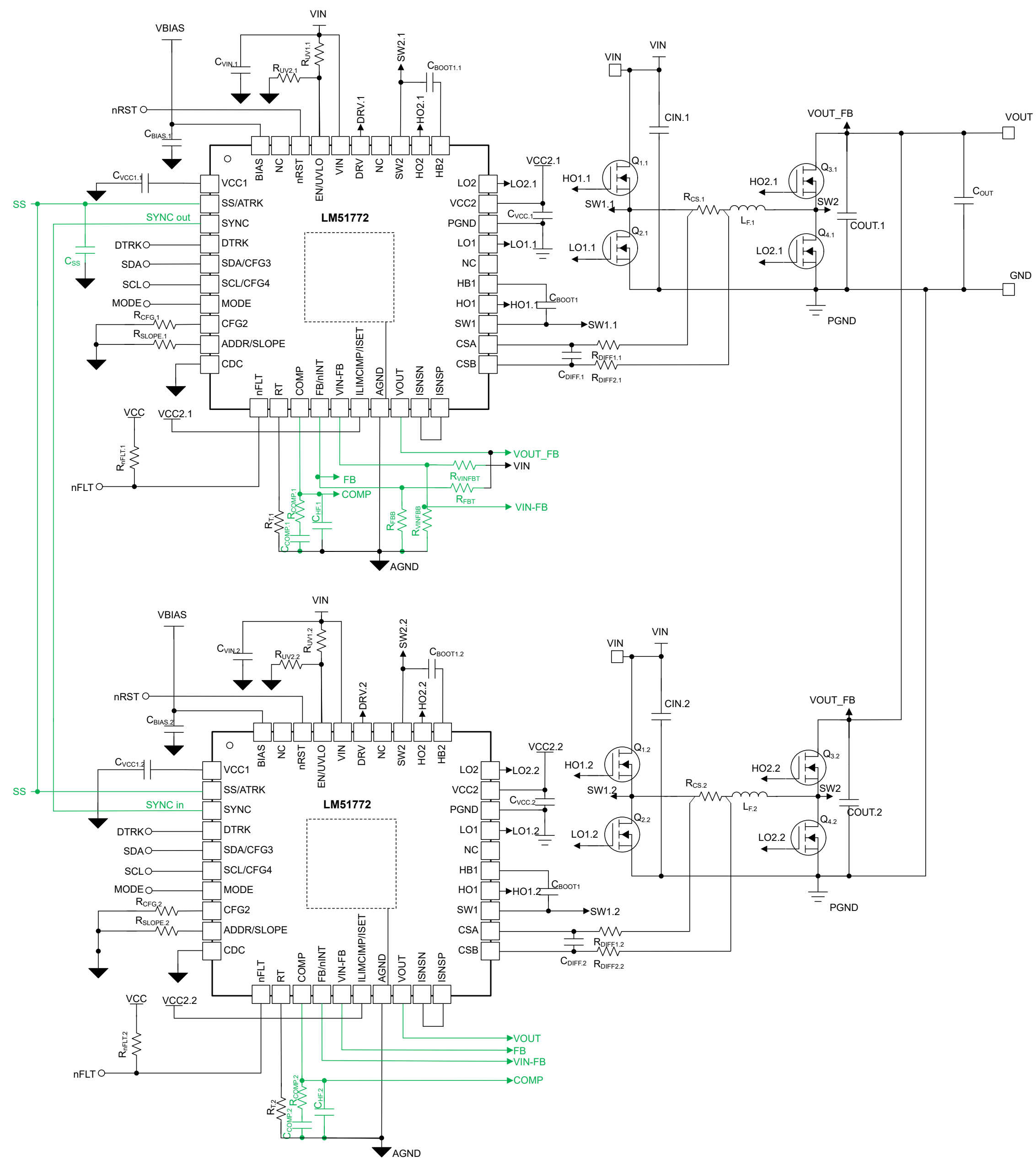

Figure 3-1. Block Diagram of Two LM51772 in Parallel Operation

The value for the external components used in the power stage and with LM51772 controller can easily selected by using the LM51772 Buck-Boost Quickstart Calculator Tool. These values need to be calculated for an individual power stage. Therefore, the total load current value can be divided by the number of power stages to calculate the external component values for each converter. Apart from this, some components required a special setting, as mentioned below.

3.1 Soft-start Capacitor

To get the soft-start capacitor value, multiply the suggested C_{SS} value by the number of power stages to be implemented.

3.2 Compensation

The calculated compensation components need to be added to each power stage and the COMP pin of the individual power stages needs to be connect.

The compensation network can be combined. In this case, the values for the Resistors needs to be divided and the values of the Capacitors needs to be multiplied by the number of power stages.

Note

This process only needs to be done if the noise level can be kept very low the power stages only have very short connections in-between.

3.3 Input and Output Capacitor

Input and output capacitors must be placed close to the individual power stage with the calculated value on each power stage. A common input and or output capacitor can be used but part of the capacitor value must still be placed locally to each power stage.

3.4 Usage of the Average Current Sensor

The current monitor (IMONLIM) function can be enabled when operating power stages in parallel and being used in multiple options. With two power stages, the following options are possible:

- None used - both disabled
- Only one used as current monitor, second is disabled
- First current monitor used for input current sensing, second current monitor used for output current sensing

The configuration with the current monitor on the input and the current monitor on the output is shown in Figure 3-1.

4 Test Results

4.1 Load Current Balancing

The test results of the relative error between 180° out-of-phase and in-phase load currents for different converter topologies is shown in Figure 4-1. The error is less than 10% when the total load current is above 2A for all input voltage conditions, but the buck-boost region (V_{IN} = 20V) has the least relative error. Similarly, the test results of the load distribution of two phases under different input voltage conditions is shown in Figure 4-2. The load distribution between phases seems to be equal, but variation is seen among phases of different input voltage levels, especially for the high load currents.

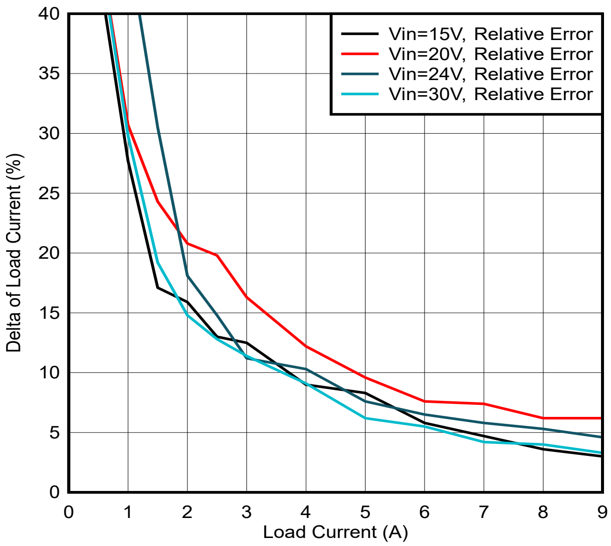

Figure 4-1. Error of Load Currents with (I_{Phase1} - I_{Phase2})/I_{Load}

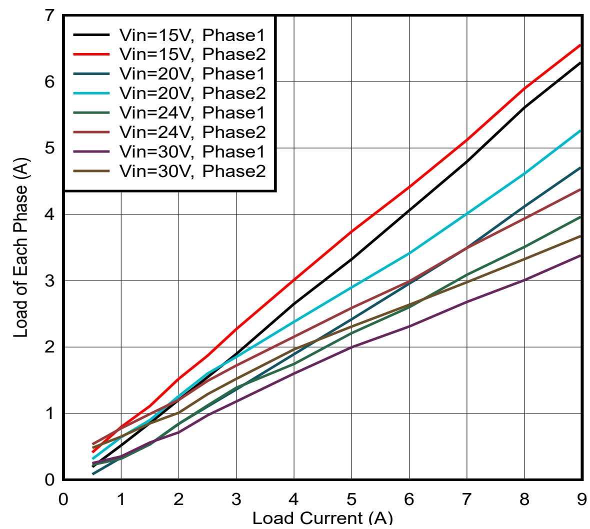

Figure 4-2. Load Distribution of the two Phases

4.2 Inductor Current

The inductor current for different converter topologies at 2A and 10A load currents. The inductor current shown in all figures verifies the accurate load sharing and phase shift of 180 degrees among two parallel phases. A small error in the inductor peak current can be seen through the scope plots. This error is caused by the slight variation in the selected inductor values. Therefore, TI recommends to use the same inductor value with similar tolerance for the parallel operation. Also, in all input voltage conditions, no prominent ripple is seen in the output voltage of the parallel operation. Thus, this confirms the quality of output voltage regulation of LM51772 converters in a parallel fashion.

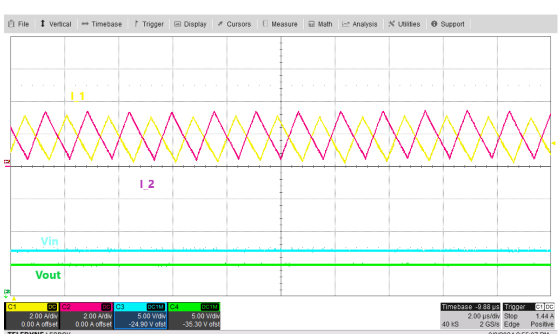

Figure 4-3. Inductor Current in Boost Region (V_{IN}=12 V and 2A Load)

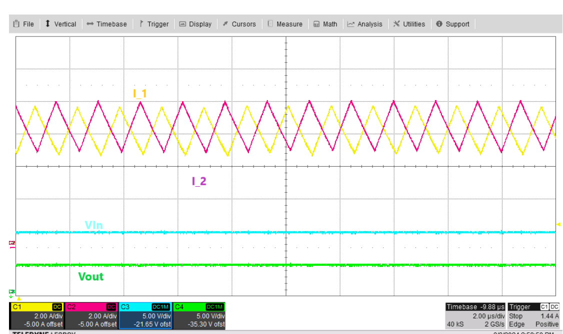

Figure 4-4. Inductor Current in Boost Region (V_{IN}=12V and 8A Load)

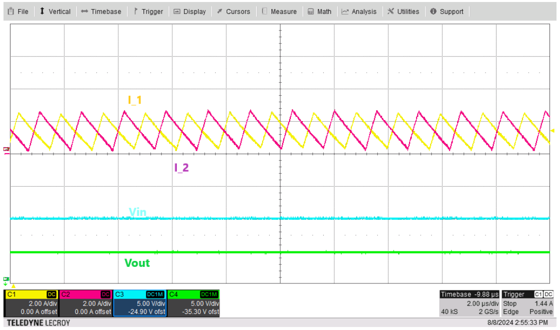

Figure 4-5. Inductor Current in Boost Region (V_{IN}=15V and 2A Load)

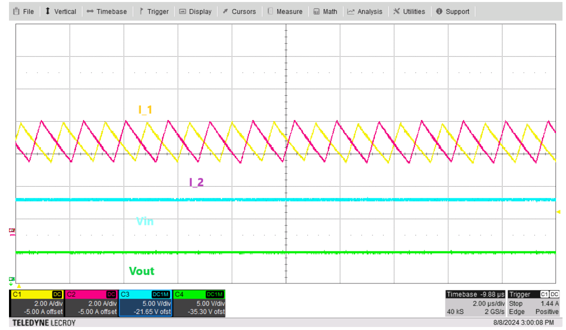

Figure 4-6. Inductor Current in Boost Region (V_{IN}=15V and 8A Load)

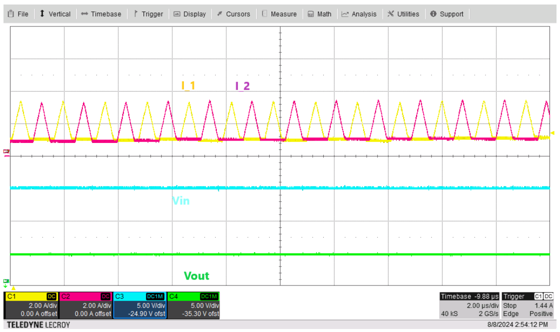

Figure 4-7. Inductor Current in Buck-Boost Region (V_{IN}=20V and 2A Load)

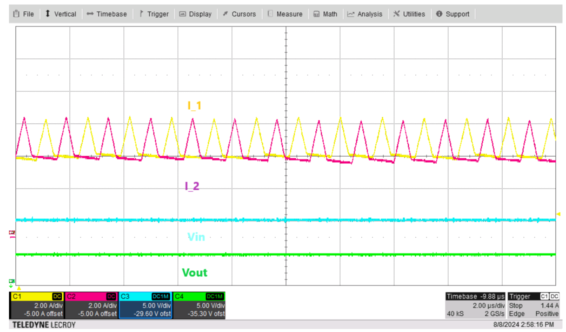

Figure 4-8. Inductor Current in Buck-Boost Region (V_{IN}=20V and 8A Load)

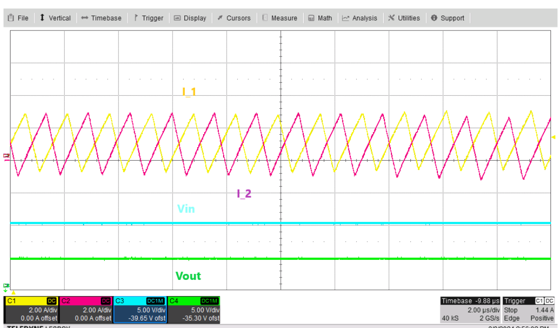

Figure 4-9. Inductor Current in Buck Region (V_{IN}=30V and 2A Load)

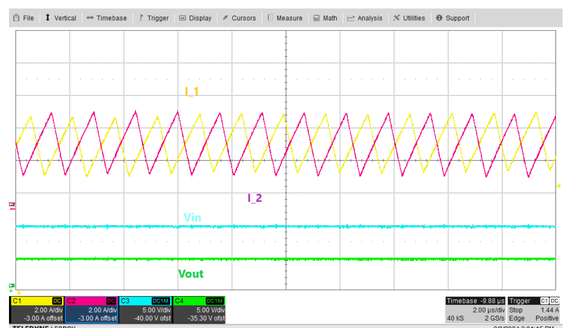

Figure 4-10. Inductor Current in Buck Region (V_{IN}=30V and 8A Load)

4.3 Thermal Images

4.3.1 Dual Phase Operation at Variable Load

To verify the thermal stability of the EVM with parallel operation and load sharing, thermal images are taken of EVM for normal and extreme load conditions under different LM51772 converter topologies as shown in Figure 4-11 to Figure 4-18. The maximum operating temperature of LM51772 is 120 degrees Celsius.

The thermal analysis reveals that the maximum load current capability in boost mode is constrained to 8A, primarily due to the peak current limiter. Under extreme load conditions, the boost mode exhibits higher temperatures compared to the buck and buck-boost modes. This increased thermal stress under high load conditions underscores the need for adequate thermal management when operating in boost mode to verify reliable performance and prevent overheating.

Figure 4-11. Thermal Condition in Boost Region (V_{IN}=12V and 2A Load)

Figure 4-12. Thermal Condition in Boost Region (V_{IN}=12V and 8A Load)

Figure 4-13. Thermal Condition in Boost Region (V_{IN}=15V and 2A Load)

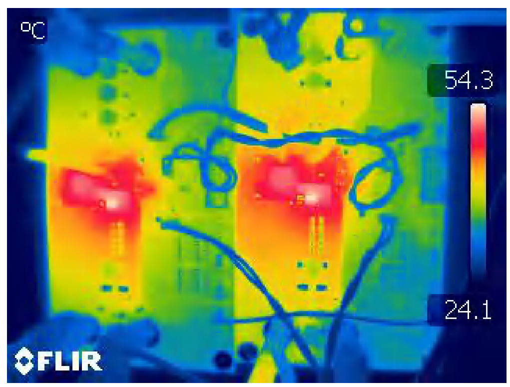

Figure 4-14. Thermal Condition in Boost Region (V_{IN}=15V and 8A Load)

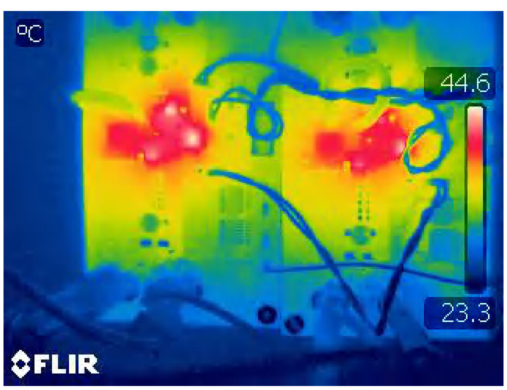

Figure 4-15. Thermal Condition in Buck-Boost Region (V_{IN}=20V and 2A Load)

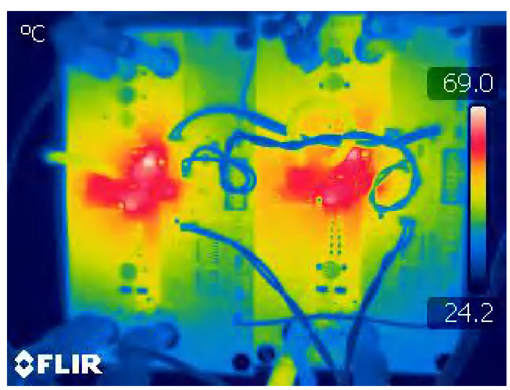

Figure 4-16. Thermal Condition in Buck-Boost Region (V_{IN}=20V and 8A Load)

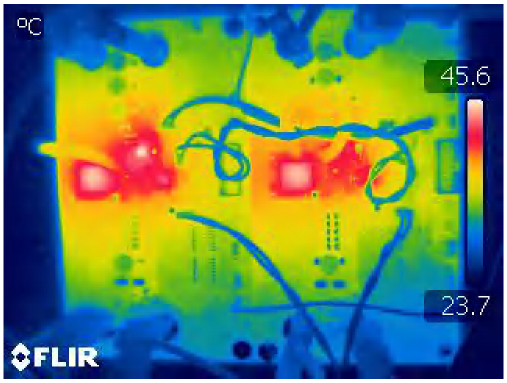

Figure 4-17. Thermal Condition in Buck Region (V_{IN}=30V and 2A Load)

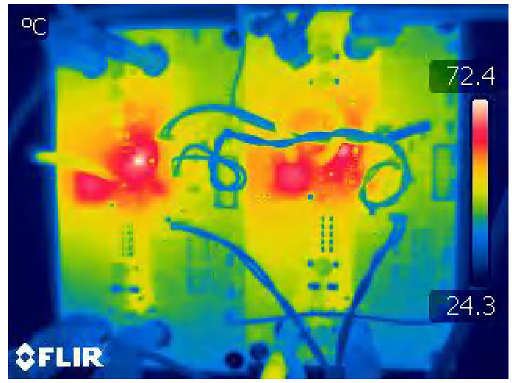

Figure 4-18. Thermal Condition in Buck Region (V_{IN}=30V and 8A Load)

4.3.2 Comparison Between Single Phase and Dual Phase Operation

The thermal images are taken for both single-phase and dual-phase operations, to verify the thermal efficiency of the dual-phase operation. The thermal tests are taken for single phase and dual phase in buck, buck-boost, and boost operation at variable load. The thermal images show that the dual-phase operation has a lower temperature in comparison to the single-phase operation at the same load profile, as shown in Figure 4-19 to Figure 4-34. The equal load sharing of the total load current among two converters in dual phase results in less thermal losses and enhance the overall thermal efficiency of the converter.

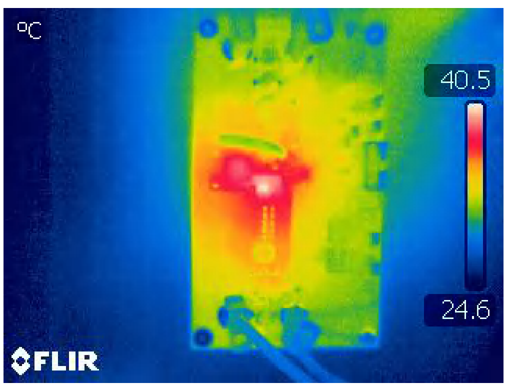

Figure 4-19. Thermal Condition in Single Phase Boost (V_{IN}=12V and 2A Load)

Figure 4-20. Thermal Condition in Dual Phase Boost (V_{IN}=12V and 2A Load)

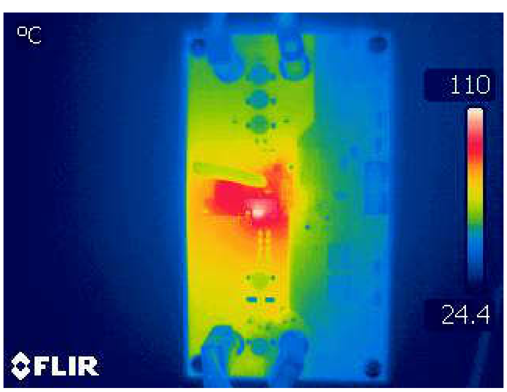

Figure 4-21. Thermal Condition in Single Phase Boost (V_{IN}Vin=12V and 8A Load)

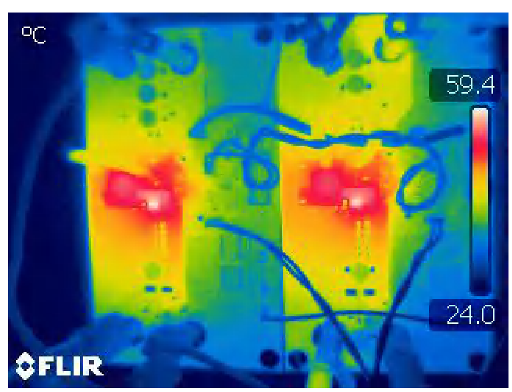

Figure 4-22. Thermal Condition in Dual Phase Boost (V_{IN}=12V and 8A Load)

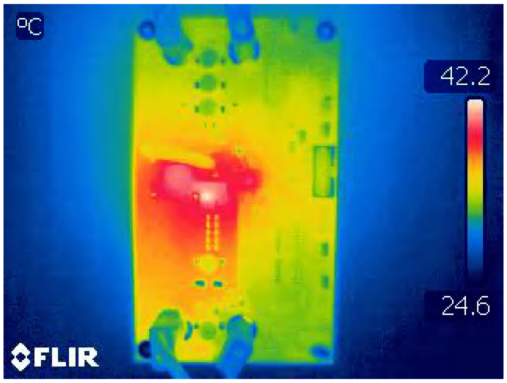

Figure 4-23. Thermal Condition in Single Phase Boost (V_{IN}=15V and 2A Load)

Figure 4-24. Thermal Condition in Dual Phase Boost (V_{IN}=15V and 2A Load)

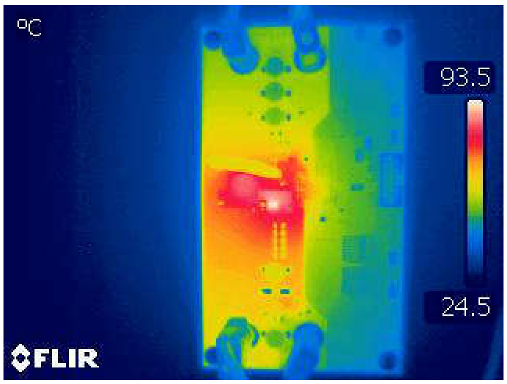

Figure 4-25. Thermal Condition in Single Phase Boost (V_{IN}=15V and 8A Load)

Figure 4-26. Thermal Condition in Dual Phase Boost (V_{IN}=15V and 8A Load)

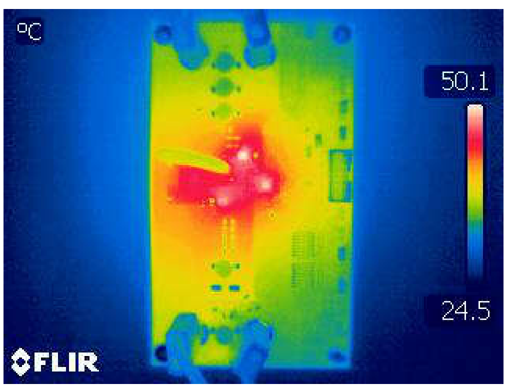

Figure 4-27. Thermal Condition in Single Phase Buck-Boost (V_{IN}=20V and 2A Load)

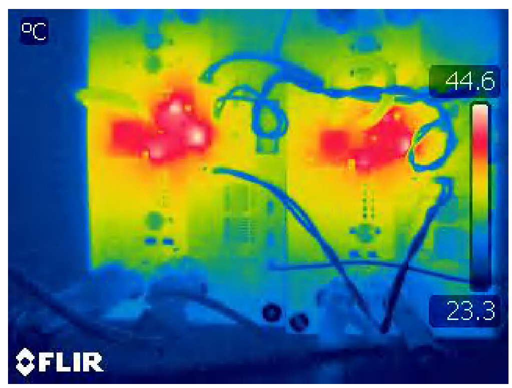

Figure 4-28. Thermal Condition in Dual Phase Buck-Boost (V_{IN}=20V and 2A Load)

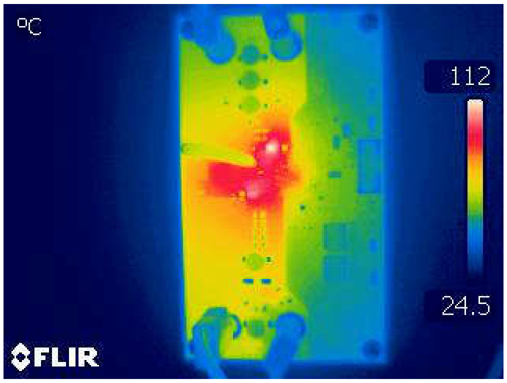

Figure 4-29. Thermal Condition in Single Phase Buck-Boost (V_{IN}=20V and 8A Load)

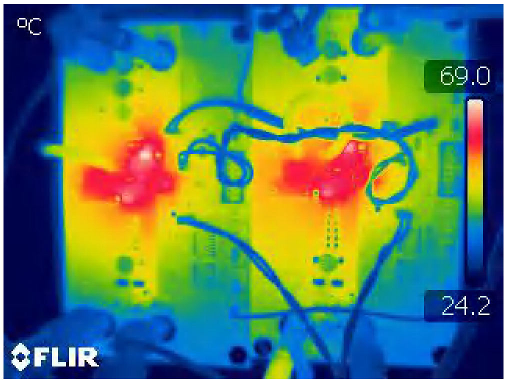

Figure 4-30. Thermal Condition in Dual Phase Buck-Boost (V_{IN}=20V and 8A Load)

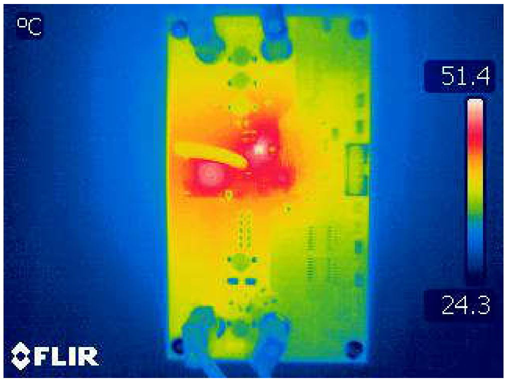

Figure 4-31. Thermal Condition in Single Phase Buck (V_{IN}=30V and 2A Load)

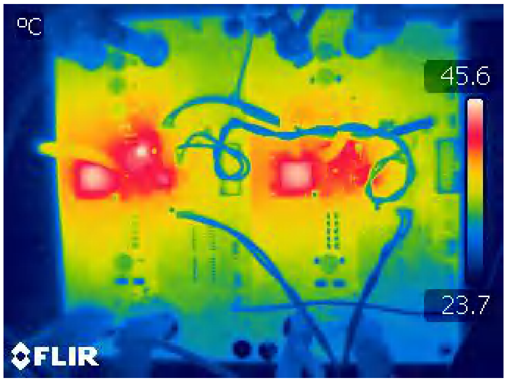

Figure 4-32. Thermal Condition in Dual Phase Buck (V_{IN}=30V and 2A Load)

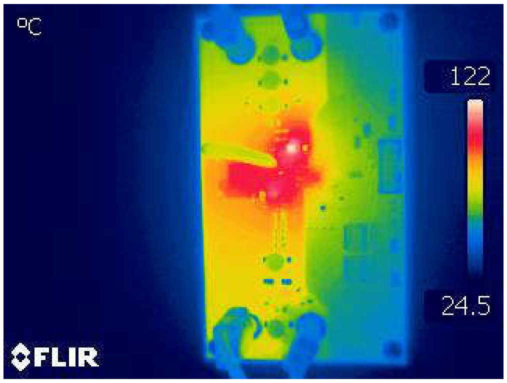

Figure 4-33. Thermal Condition in Single Phase Buck (V_{IN}=30V and 8A Load)

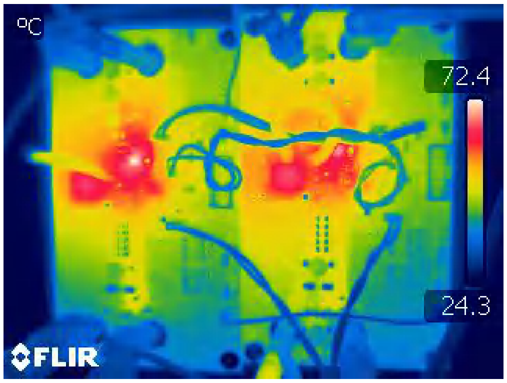

Figure 4-34. Thermal Condition in Dual Phase Buck (V_{IN}=30V and 8A Load)

5 Summary

With the results from the previous section, parallel operation using LM51772 converters can be done with a load sharing within 10% relative error. As per inductor current, a favorable synchronization between the phases can be seen with a slight variation in peak current value, which can be compensated by using a similar inductor. Additionally, the results from the thermal tests also confirm the thermal stability of the converters in a parallel fashion, but a slightly high temperature is measured for the boost region in comparison to the buck and buck-boost region. Moreover, the thermal comparison among single-phase and dual-phase operations confirms the high thermal efficiency and low losses in dual-phase operation.

6 References

- Texas Instruments, *LM51772 80V Wide VIN Bidirectional 4-Switch Buck-Boost Controller* data sheet.
- Texas Instruments, *TLC555 Component Calculator Tool.*
- Texas Instruments, *LM51772 Buck-Boost Quickstart Calculator Tool.*
- Texas Instruments, *Constant Current Operation Using the Internal Current Limiter* application brief.

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