Application Note

Parallel Operation of the Buck-Boost Converters Using LM5177 Buck-Boost Controller

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ABSTRACT

The synchronous 4-switch buck-boost controller LM5177 operates over a wide input voltage range and can support battery backup systems, solar power, industrial personal computers (IPCs), and many other applications. LM5177 produces a regulated output voltage at, above, or below the input voltage. Paralleling two or more LM5177 converters is an attractive way to support a higher power level. This application note shows how this can be done to achieve well-balanced load sharing between the paralleled converters within a 10% error. Design guidelines are given to help readers to design properly for practical applications.

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1 Introduction

The LM5177 device is a wide input voltage range, four-switch buck-boost controller IC with integrated drivers for N-channel MOSFETs.

One single LM5177 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 LM5177 converters evenly share the total load power. This application report shows how to configure and interconnect the LM5177 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 LM5177 converters.

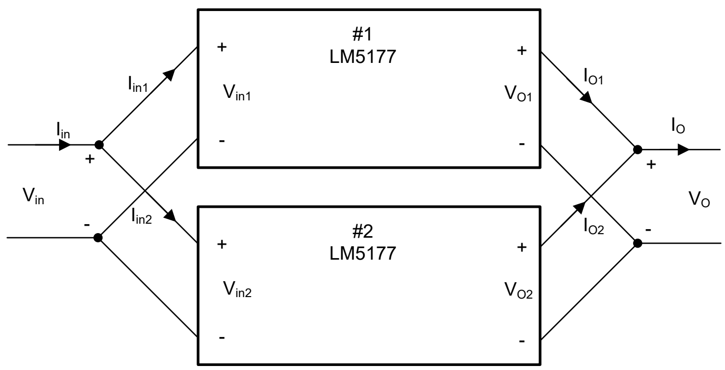

Figure 2-1. Two Parallel LM5177 Converters as Power Supply

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.

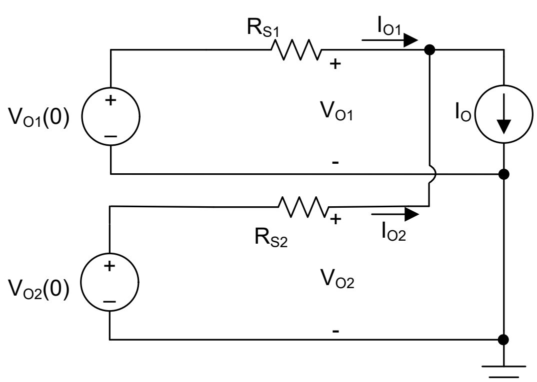

Figure 2-2. Equivalent Model

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

When operating the LM5177 converters in multiphase operation the clock needs to be provided from external with a phase shift between the clock for the different Controller of 360 Degree or Number of Phases. Thus, the clock can be generated by different circuits, but in this implementation, the LMC555 timer device is used. This device is capable of producing a 3 MHz frequency. The LMC555 is designed to operate in the astable mode as shown in Figure 2-3. This mode generates a clock of a fixed frequency and duty cycle. The design includes a shunt diode with a resistor (R101) which improves the duty cycle of the clock signal. To change the frequency and duty cycle to a desired value, the proper value for C70, R85, and R101 need to be selected. Hence, the values shown in Figure 2-3 are selected to generate a frequency of 400 kHz with a duty cycle of 50%. A TLC555 Component Calculator Tool for the ease design of the clock generation circuit is available for download. The calculator is designed for the TLC555 device which supports 2 MHz frequency in astable mode, but the calculator can be used for all 555 timer devices with slight variation. For two-stage parallel operation, a simple LMC555 timer and inverter are enough like shown in the Figure 2-3.

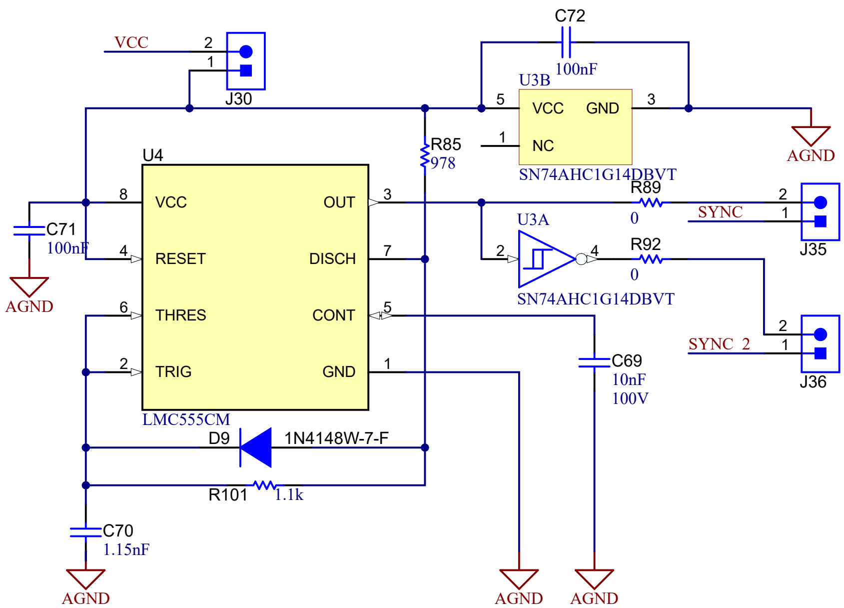

Figure 2-3. 2-Phase Clock Generator

For multi-phases in a parallel operation, a clock with a counter can be used as shown in Figure 2-4. The outputs of the clock source are connected to the SYNC pin of each LM5177 device to have a proper clock input.

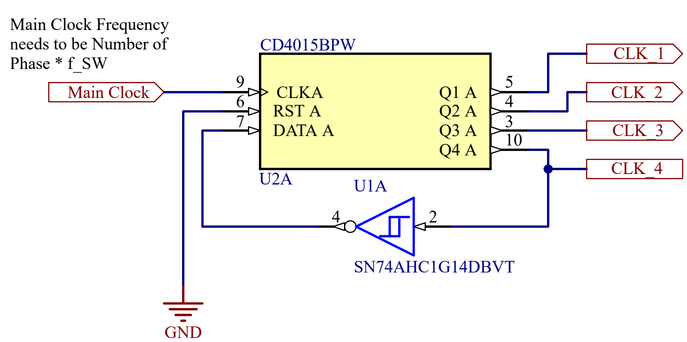

Figure 2-4. Multiphase Clock Generator

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 Table 2-1 shows the several pins functions which need to be shared between the devices.

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
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 as shown in Table 2-2 for accurate parallel operation.

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 LM5177 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 300 W and an output voltage of 16 V. Additionally, the selected peak current limit and the average current limit for each converter is 25 A and 3 A, respectively.

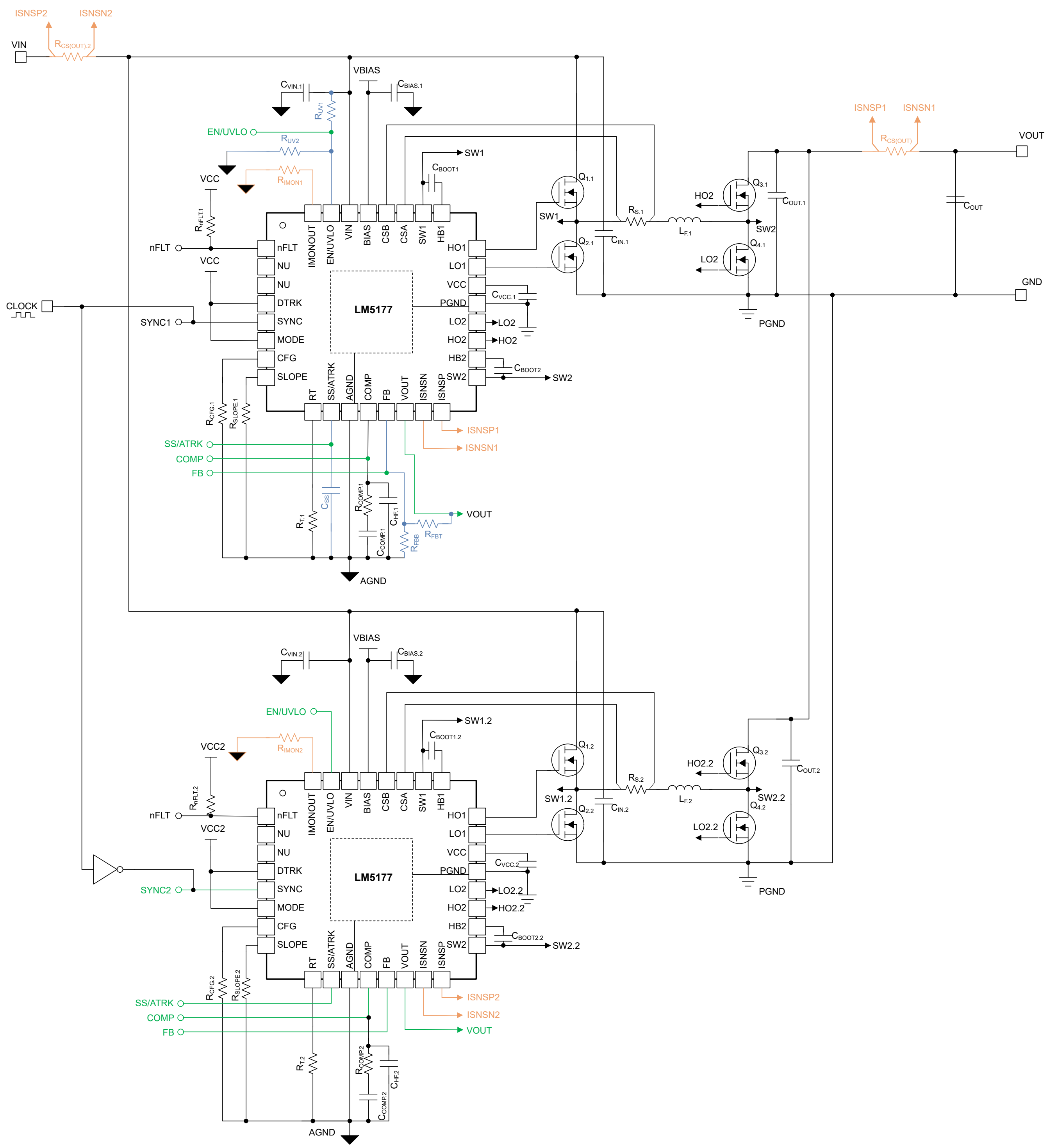

Figure 3-1. Block Diagram of Two LM5177 in Parallel Operation

The value for the external components used in the power stage and with LM5177 controller can easily selected by using the LM5177 BuckBoost Quickstart Calculator Tool. Additionally, the customer can calculate these component values using the formulas shown in the application note How to Design Synchronous, Non-Inverting 4-Switch Buck-Boost Converter Using the LM5177x. 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. So with two power stages following options can be possible:

- none used - both disabled
- only one used as current monitor, second is disabled
- first current monitor used for input current sensing, second used for output current sensing

In Figure 3-1, a configuration with the current monitor on the input and the current monitor on the output is shown.

4 Test Results

4.1 Load Current Balancing

Figure 4-1 shows the test results of the relative error between 180° out-of-phase and in-phase load currents for different converter topologies. The error is less than 10% when the total load current is above 2 A for all input voltage conditions, but the buck-boost region (V_{IN} =16 V) has the least relative error. Similarly, Figure 4-2 shows the test results of the load distribution of two phases under different input voltage conditions. 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.

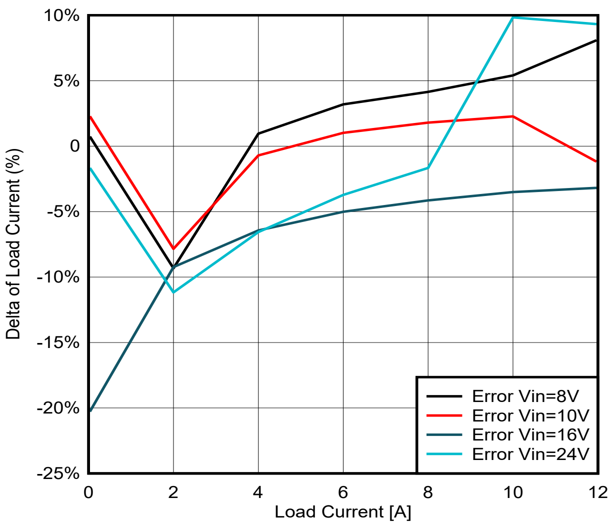

Figure 4-1. Error of Load Currents

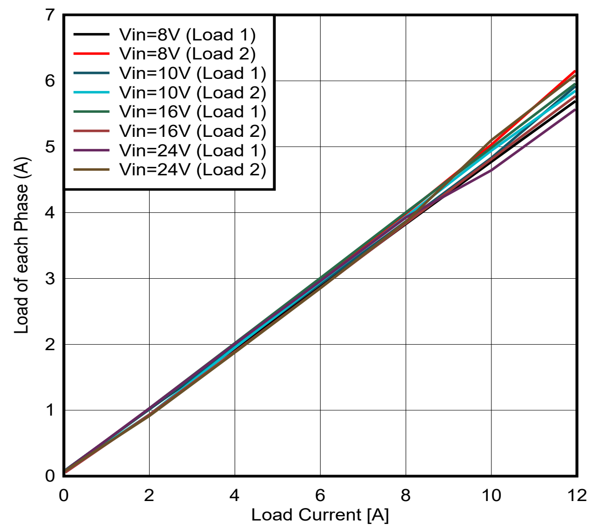

Figure 4-2. Load Distribution of Two Phases

4.2 Inductor Current

Figure 4-3 through Figure 4-10 shows the inductor current for different converter topologies at 2 A and 10 A 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. The measured inductor value for phase 1 and phase 2 is 3.631 µH and 3.654 µH, respectively. Therefore, it is recommended 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, it confirms the quality of output voltage regulation of LM5177 converters in a parallel fashion.

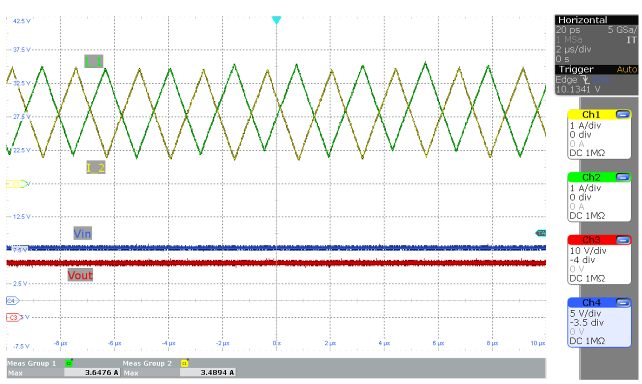

Figure 4-3. Inductor Current in Boost Region (V_{IN}=8 V and 2 A Load)

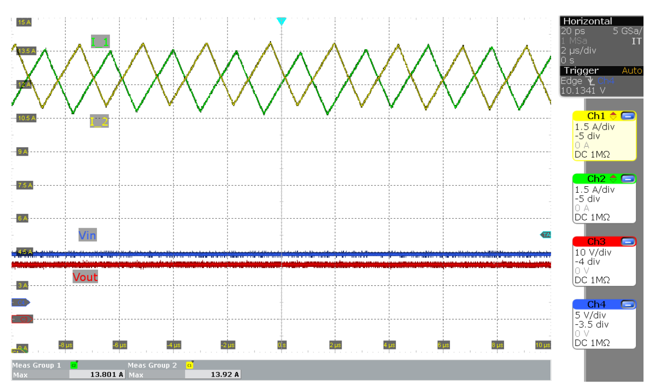

Figure 4-4. Inductor Current in Boost Region (V_{IN}=8 V and 10 A Load)

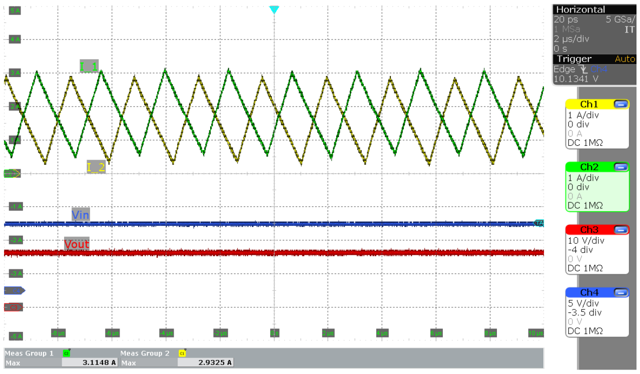

Figure 4-5. Inductor Current in Boost Region (V_{IN}=10 V and 2 A Load)

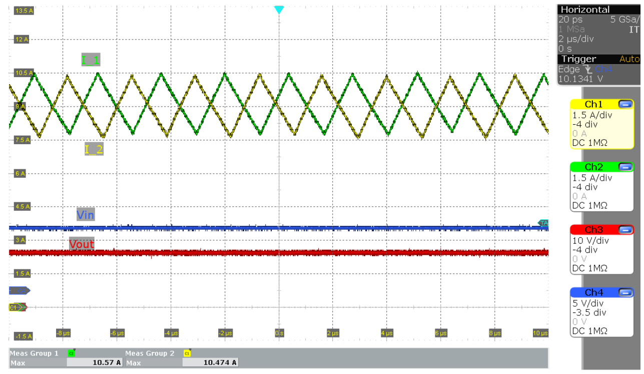

Figure 4-6. Inductor Current in Boost Region (V_{IN}=10 V and 10 A Load)

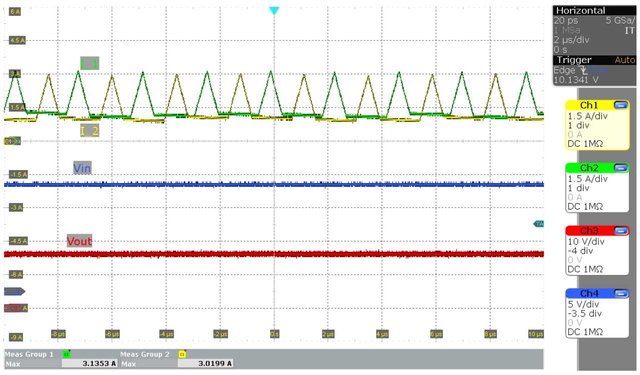

Figure 4-7. Inductor Current in Buck-Boost Region (V_{IN}=16 V and 2 A Load)

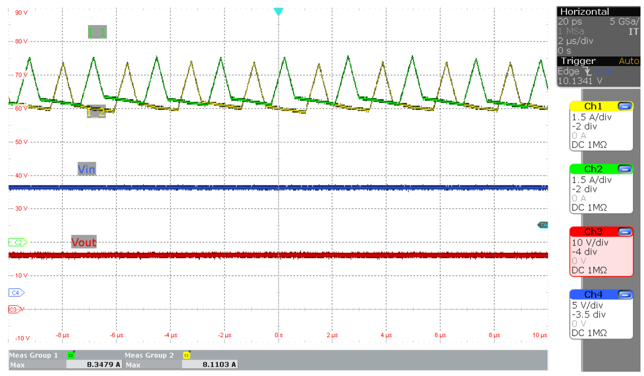

Figure 4-8. Inductor Current in Buck-Boost Region (V_{IN}=16 V and 10 A Load)

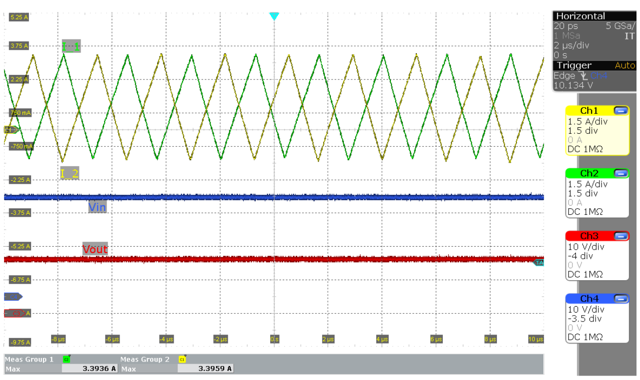

Figure 4-9. Inductor Current in Buck Region (V_{IN}=30 V and 2 A Load)

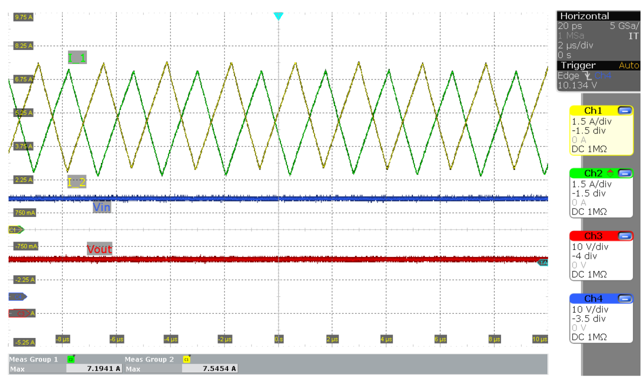

Figure 4-10. Inductor Current in Buck Region (V_{IN}=30 V and 10 A Load)

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 (Figure 4-11 to Figure 4-18) are taken of EVM for normal and extreme load conditions under different LM5177 converter topologies. The maximum operating temperature of LM5177 is 120 degrees Celsius. The results show that the maximum load current capability in boost mode is limit to 12 A because of the peak current limiter, and have a high temperature under extreme load (12 A) conditions compared to the buck and buck-boost modes.

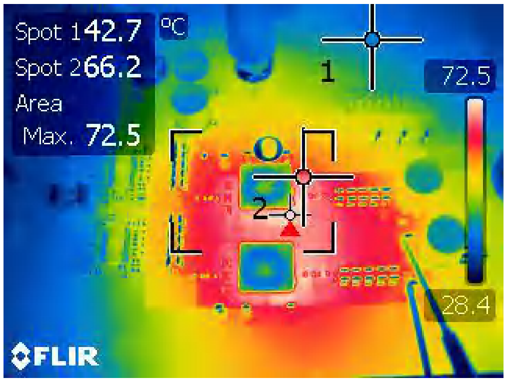

Figure 4-11. Thermal Condition in Boost Region (V_{IN}=8 V and 8 A Load)

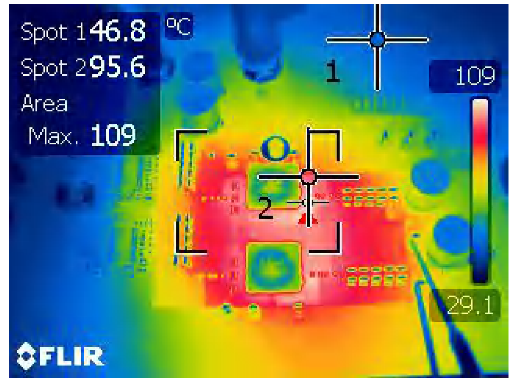

Figure 4-12. Thermal Condition in Boost Region (V_{IN}=8 V and 12 A Load)

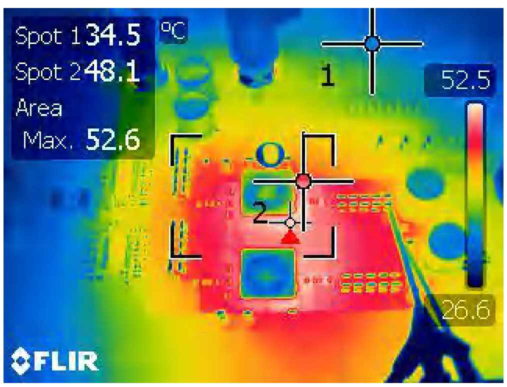

Figure 4-13. Thermal Condition in Boost Region (V_{IN}=10 V and 8 A Load)

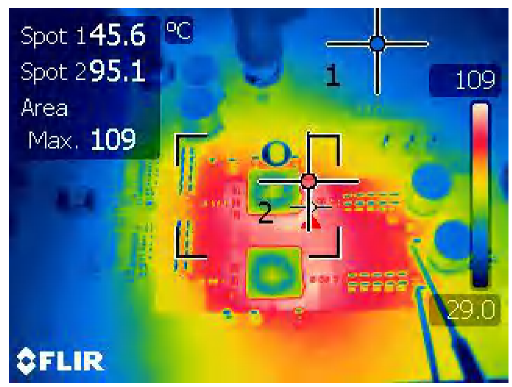

Figure 4-14. Thermal Condition in Boost Region (V_{IN}=10 V and 14 A Load)

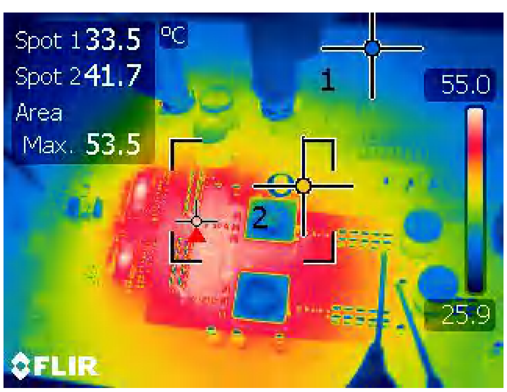

Figure 4-15. Thermal Condition in Buck-Boost Region (V_{IN}=16 V and 8 A Load)

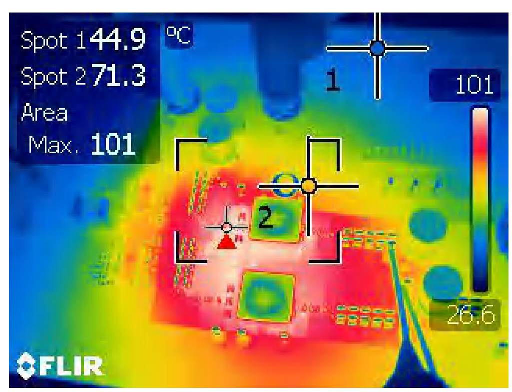

Figure 4-16. Thermal Condition in Buck-Boost Region (V_{IN}=16 V and 18 A Load)

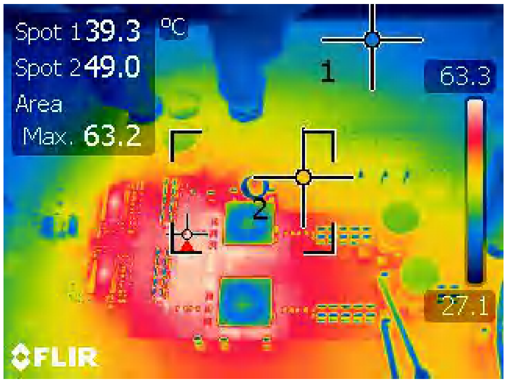

Figure 4-17. Thermal Condition in Buck Region (V_{IN}=24 V and 8 A Load)

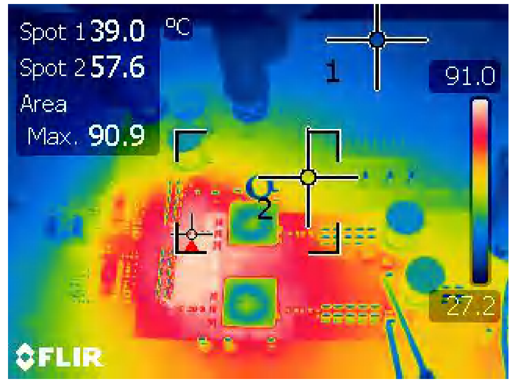

Figure 4-18. Thermal Condition in Buck Region (V_{IN}=24 V and 18 A Load)

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 from Figure 4-19 to Figure 4-34 show that the dual-phase operation has a lower temperature in comparison to the single-phase operation at the same load profile. 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.

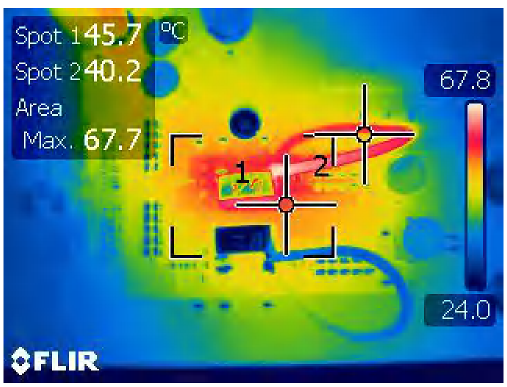

Figure 4-19. Thermal Condition in Single Phase Boost (V_{IN}=8 V and 4 A Load)

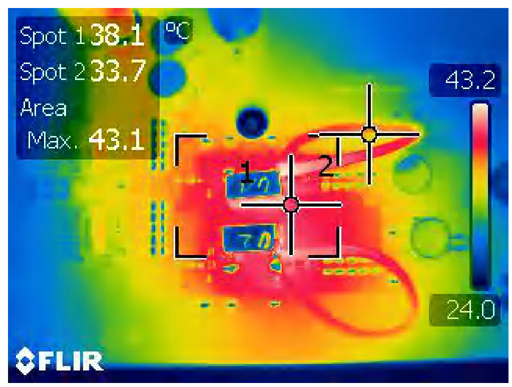

Figure 4-20. Thermal Condition in Dual Phase Boost (V_{IN}=8 V and 4 A Load)

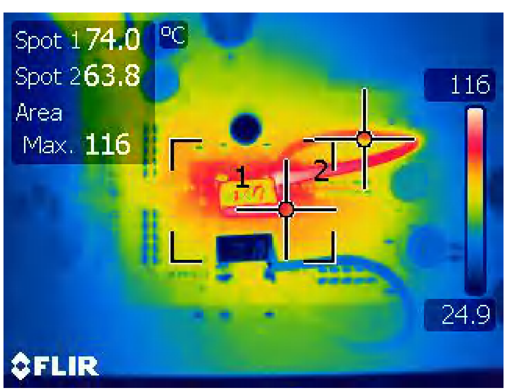

Figure 4-21. Thermal Condition in Single Phase Boost (V_{IN}Vin=8 V and 6 A Load)

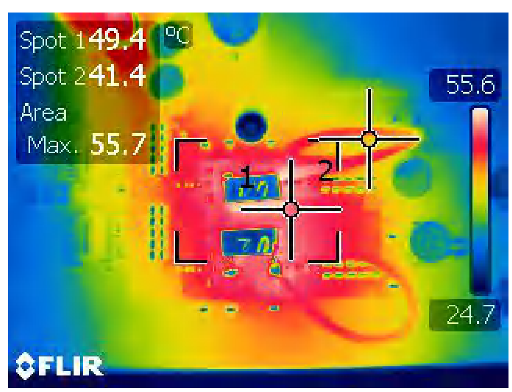

Figure 4-22. Thermal Condition in Dual Phase Boost (V_{IN}=8 V and 6 A Load)

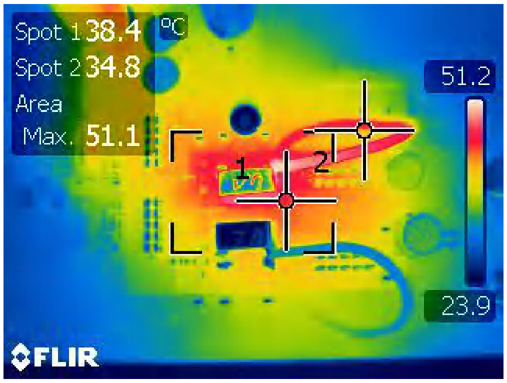

Figure 4-23. Thermal Condition in Single Phase Boost (V_{IN}=10 V and 4 A Load)

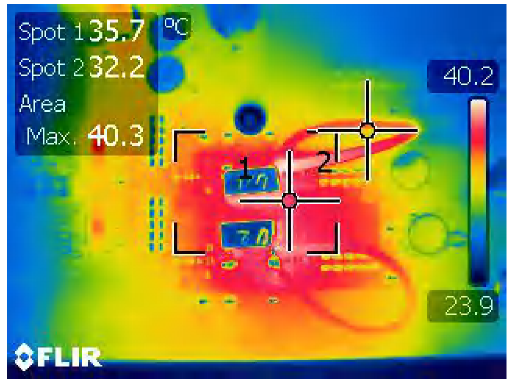

Figure 4-24. Thermal Condition in Dual Phase Boost (V_{IN}=10 V and 4 A Load)

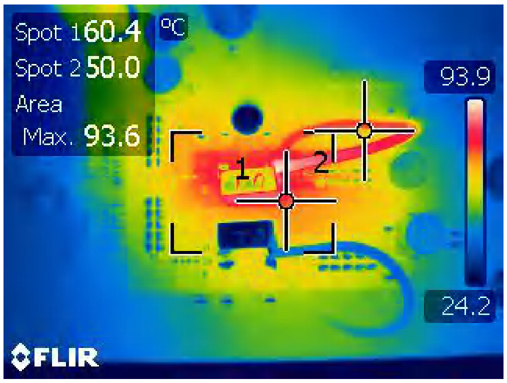

Figure 4-25. Thermal Condition in Single Phase Boost (V_{IN}=10 V and 7 A Load)

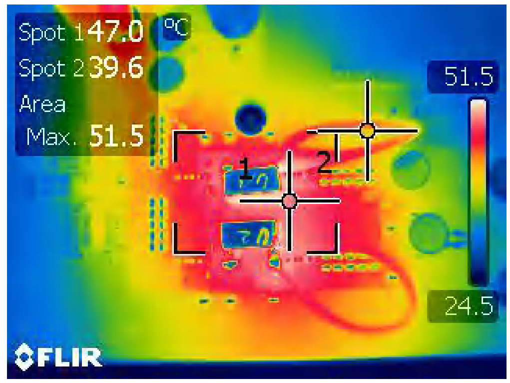

Figure 4-26. Thermal Condition in Dual Phase Boost (V_{IN}=10 V and 7 A Load)

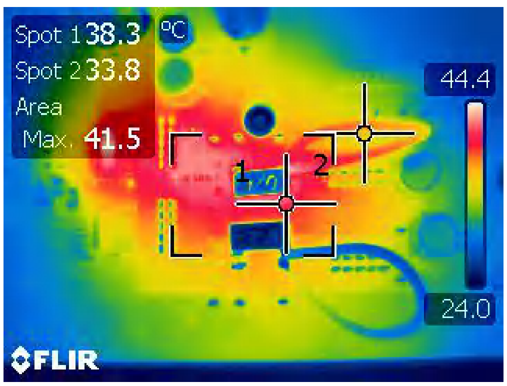

Figure 4-27. Thermal Condition in Single Phase Buck-Boost (V_{IN}=16 V and 4 A Load)

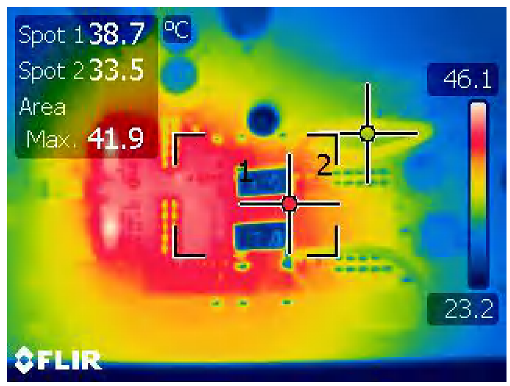

Figure 4-28. Thermal Condition in Dual Phase Buck-Boost (V_{IN}=16 V and 4 A Load)

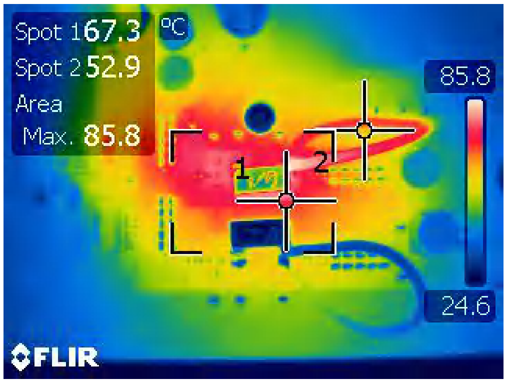

Figure 4-29. Thermal Condition in Single Phase Buck-Boost (V_{IN}=16 V and 9 A Load)

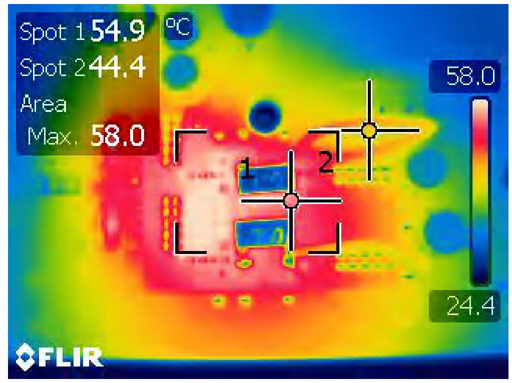

Figure 4-30. Thermal Condition in Dual Phase Buck-Boost (V_{IN}=16 V and 9 A Load)

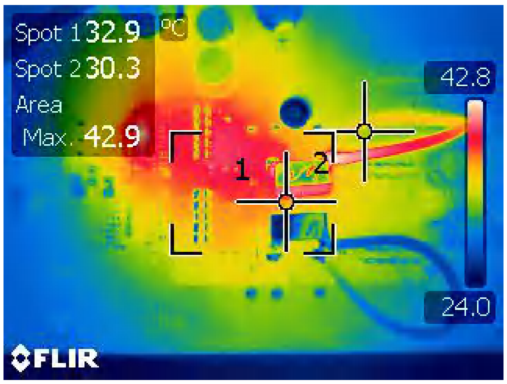

Figure 4-31. Thermal Condition in Single Phase Buck (V_{IN}=24 V and 4 A Load)

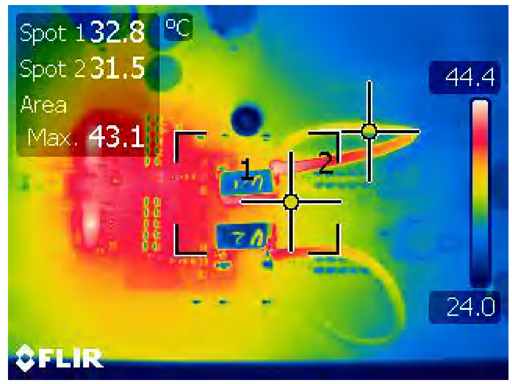

Figure 4-32. Thermal Condition in Dual Phase Buck (V_{IN}=24 V and 4 A Load)

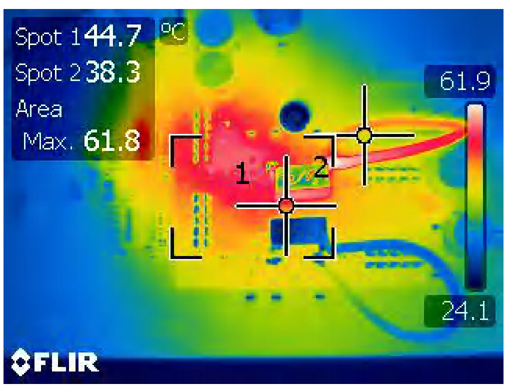

Figure 4-33. Thermal Condition in Single Phase Buck (V_{IN}=24 V and 9 A Load)

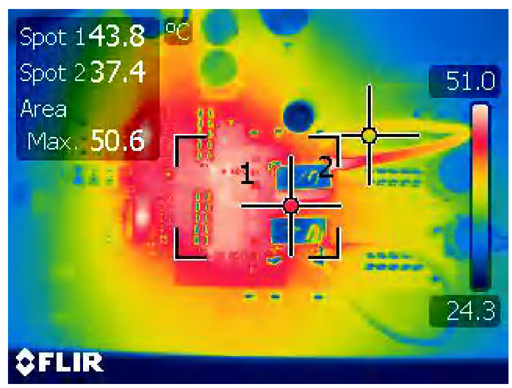

Figure 4-34. Thermal Condition in Dual Phase Buck (V_{IN}=24 V and 9 A Load)

5 Summary

With the results from the previous section, it has been shown that parallel operation using LM5177 converters can be done with a load sharing within 10% relative error. As per inductor current, a perfect 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, *LM5177 80-V Wide VIN Bidirectional 4-Switch Buck-Boost Controller* data sheet.
- Texas Instruments, *TLC555 Component Calculator Tool*.
- Texas Instruments, *How to Design Synchronous, Non-inverting 4-Switch Buck-Boost Converter Using the LM5177x* application note.
- Texas Instruments, *LM5177 BuckBoost Quickstart Calculator Tool*.
- Texas Instruments, *Constant Current Operation Using the Internal Current Limiter* application brief.

7 Revision History

Changes from Revision * (December 2023) to Revision A (February 2024)	Page
• Updated the numbering format for tables, figures, and cross-references throughout the document	1
• Updated compensation drawing in Block Diagram	5

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