Generating Isolated Supplies for Industrial Applications Using the SiC462 in an Isolated Buck Topology

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INTRODUCTION

Industrial power applications typically require a high input voltage. Standard voltage rails are 24 V, 36 V, and 48 V. The DC/DC step-down (buck) switching regulators and controllers used to power circuitry in industrial applications are required to provide the solid, reliable performance needed for environments subject to noise, power surges, and outages.

It is common for the power supply requirements in industrial systems to be quite complex. Galvanic isolation is often needed to meet safety standards, as well as to break ground loop interference for noise-sensitive applications.

For example, in new factory automation systems such as PLCs and I/O modules, an increasing number of I/O channels is driving higher sensing accuracy. As a result, isolation between different voltages is preferred for digital / analog signal isolation or channel to channel isolation to prevent noise interference from a common ground (see Fig. 1).

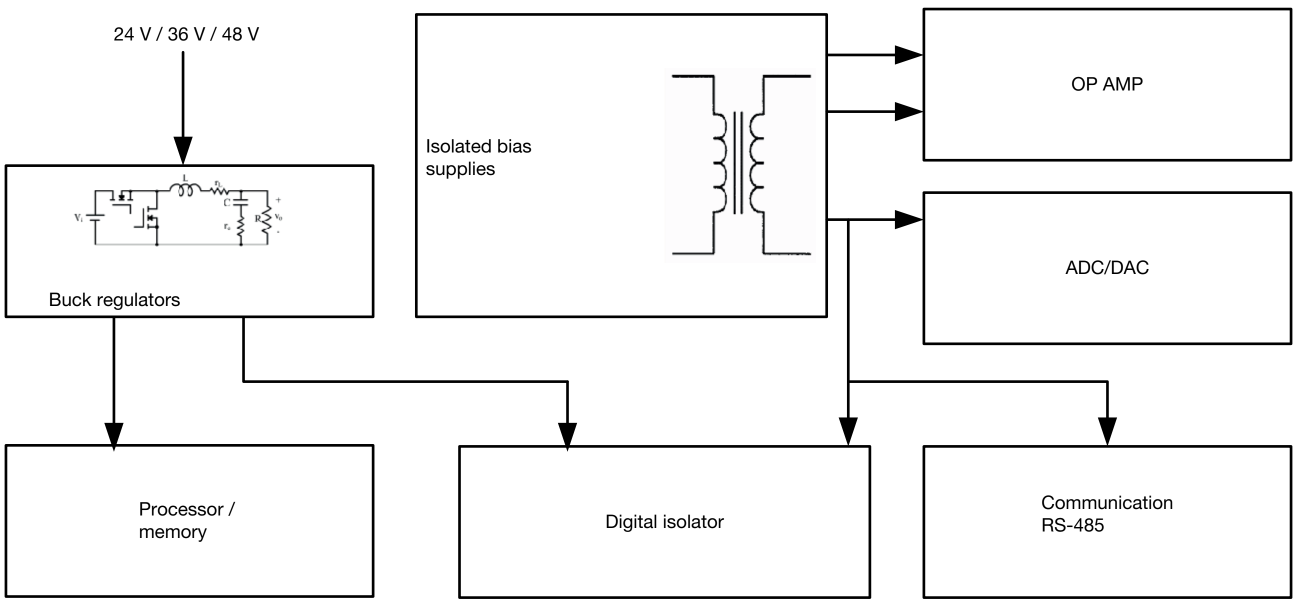

Fig. 1

The traditional way to achieve these isolated supplies would be to use a flyback converter of the main supply to generate the various voltages needed by the bias supply. Flyback designs typically utilize asymmetric transformer turn ratios for primary and secondary power windings, with an optocoupler and reference, or an auxiliary winding for feedback regulation. Additionally, flyback converters need an elaborate compensation design for stability. This results in a tedious design process and a bulky solution with a higher component count and cost.

This article explores a simpler way to achieve isolated voltages without the use of a flyback topology.

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ISOLATED SYNCHRONOUS BUCK CONVERTER

An isolated buck converter uses a synchronous buck converter with coupled inductor windings to create isolated outputs (see Fig. 2). Isolated converters utilizing this topology use a smaller transformer for an equivalent power transfer, as the transformer's primary and secondary turn ratios are better matched. There is no need for an optocoupler or auxiliary winding, as the secondary output closely tracks the primary regulated output voltage, resulting in a smaller solution size and lower cost.

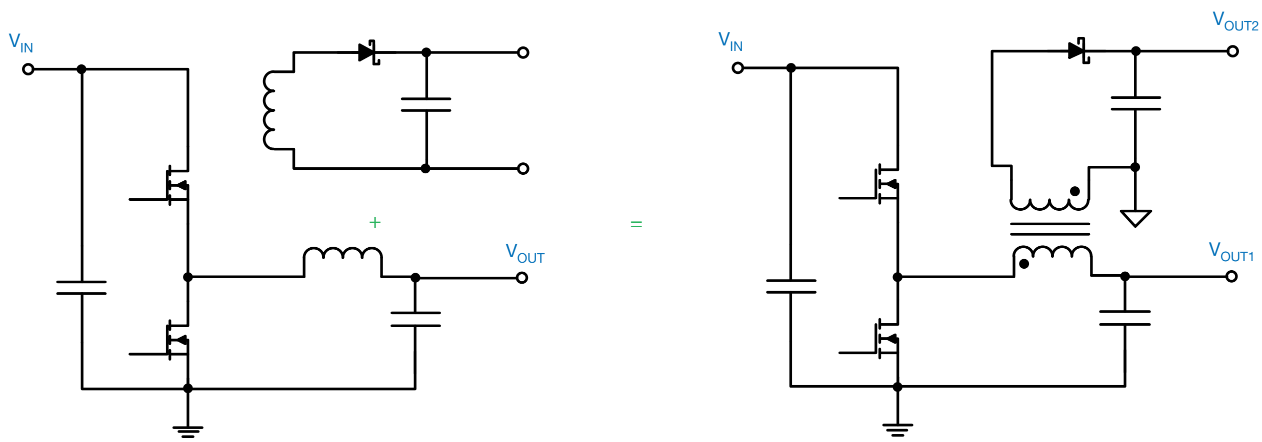

Fig. 2 - An isolated synchronous buck converter generating two outputs

This topology has several advantages, including:

- Easy to generate, isolated positive and negative supplies
- The primary side supply is available to power loads that do not require isolation from V_{IN}
- Simplified design compared with the traditional flyback approach
- Fewer components and a smaller solution size compared to a flyback topology

To showcase the ease of designing such a power supply, we will use as an example the SiC462, which is the 6 A member of a family of fully integrated synchronous buck regulators. These devices offer high power conversion efficiency and high power density with low electrical parasitics due to both excellent silicon (MOSFETs and drivers) and packaging design techniques.

The power stages used in this family can supply 3 A to 10 A of continuous current, depending on the model number. Their output voltage is adjustable from 0.8 V to 0.9 x V_{IN}, with an input range from 4.5 V to 60 V. These devices offer such features as multiple power saving modes for very low output current operation, adjustable operating frequency, fast transient response, cycle by cycle current limiting, adjustable current limit, OVP, OTP, UVP, Power Good and enable signals, tracking, sequencing, an ultrasonic mode for a minimum operating frequency of 25 kHz to avoid audible noise, soft start, and the use of an all-ceramic capacitor solution for both input and output. This flexibility allows us to create a design that generates two well-generated outputs, one isolated.

The basic requirements for this design are:

- V_{IN}: 32 V to 56 V
- V_{OUT}: 12 V at 2 A and an isolated 5 V at 1 A (referred to as Iso +5)
- Min. load: 10 % of full load values

The design is based on a buck regulator with a dual winding inductor. The "flyback" aspect of the inductor is used to generate another output. This is a continuous flyback design, as the SiC462 is always operating in full synchronous mode, even under no-load conditions. This is possible due to the "mode" feature of the regulator. This feature allows operation in different modes, depending on requirements. There are two modes: "power save," where the regulator can go into deep discontinuous operation with energy being transferred to the output only a few times per second, and "continuous mode," where energy transfer occurs in every switching cycle. The continuous operation is not as efficient at light loads; however, this mode of operation allows for an improved transient response and the ability to add flyback windings that are suitable at light or zero loads.

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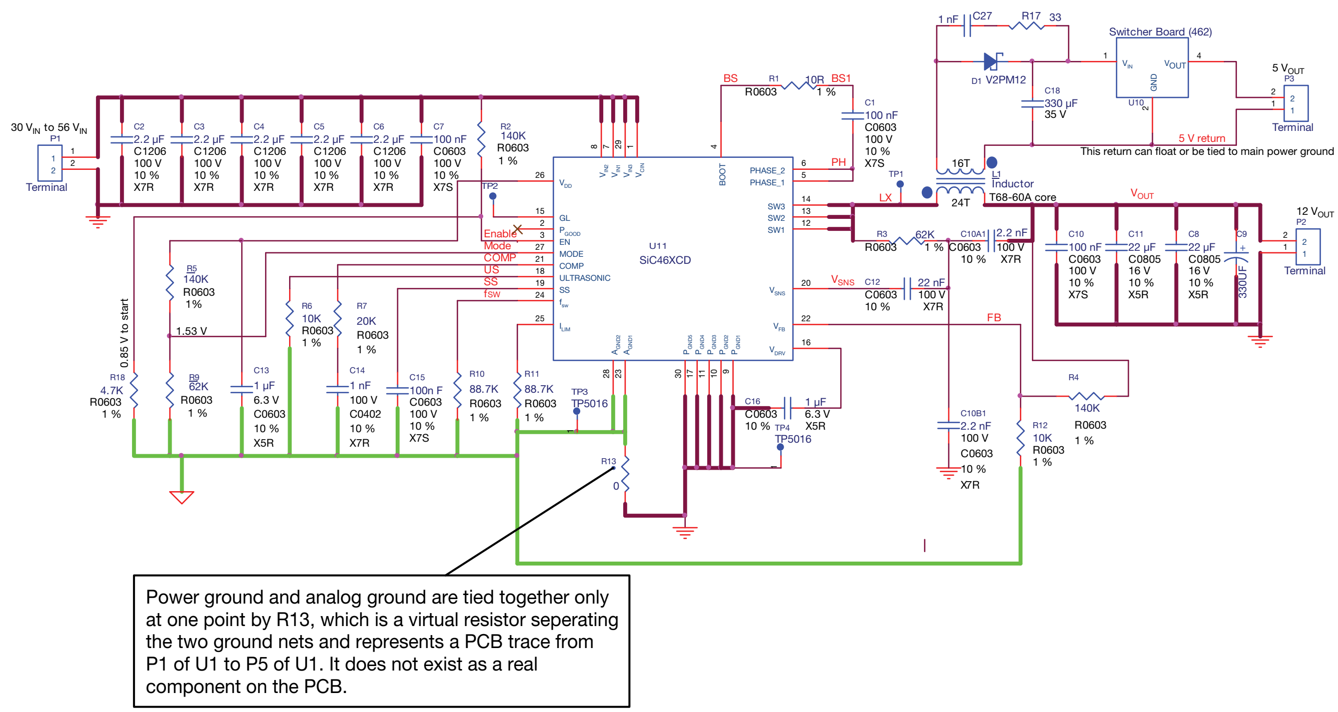
In Fig. 3 below, the inductor, L1, consists of a high temperature powder toroidal core with 24-turn “primary” and 16-turn “secondary” bifilar windings. The design of this inductor was created specifically for this project (non-standard) and was built in our lab. Since the main regulator loop controls the voltage during the time the low side switch is on, the flyback voltage remains constant by virtue of the main control loop. With 24 turns on the primary, there are 12 V / 24 turns = 0.5 V per turn. On the flyback winding then, 16 turns x 0.5 V per turn = 8 V. Taking into account the drop of the diode, D1, of 0.65 V, we wind up with 7.35 V. In addition, there is drop in the winding DCR and the coupling coefficient of the inductor. This gets us to about 6.5 V or so. Note the “blue dots” next to L1 indicating phasing of the windings.

As can be observed in the performance characterization below, input capacitor stress is greatly increased in this type of design. A snubber consisting of C27 and R17 will be needed across the diode, D1, used in the flyback output due to leakage inductance. There will need to be a snubber consisting of C17 and R8 from the LX node to the power ground to limit the peak value of the voltage that the SiC462 is subjected to due to device parasitics.



Brown nets indicate heavy traces / planes for high current;
Green net indicates analog ground plane

Fig. 3 - Schematic of a dual output regulator

The effect of the flyback winding on circuit operation is to make the inductor look like less than its nominal value. In all oscillographs below, the trace legend is as follows (refer to Fig. 3 for circuit nets):

- Ch1, yellow: inductor current in the Lx node
- Ch2, blue: voltage at Lx node
- Ch4, green: flyback winding voltage between 5 V return and the anode of D1

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Here is a map of the legend above:

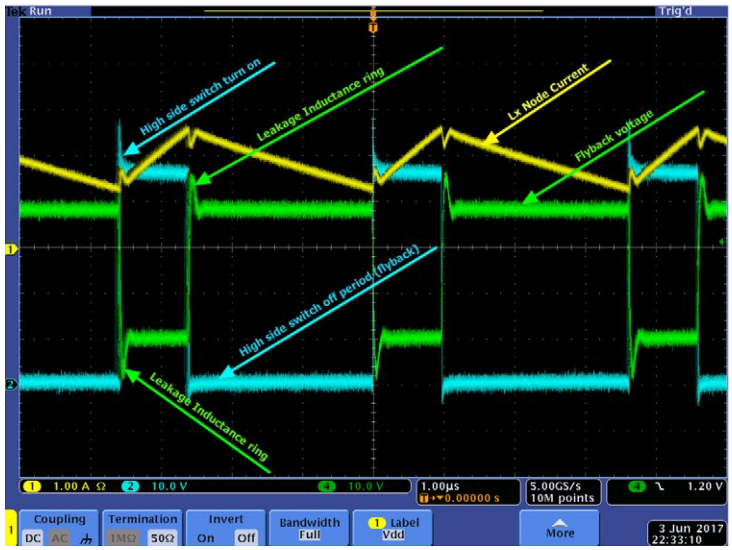

Fig. 4 - Waveform legend map

Here are some example waveforms showing operation of the circuit:

Fig. 5 - Waveform with no load on Iso +5 and 0 A on main +12 45 V_{IN}

Fig. 5 above shows a "normal" looking buck running in continuous current mode. The average current is zero.

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Now we will increase current in the +12 output (primary), only leaving the +5 Iso at zero:

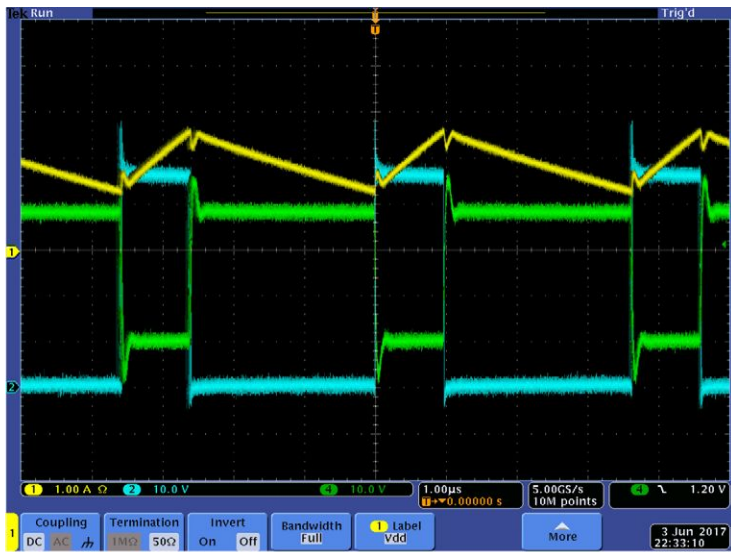

Fig. 6 - Waveform with no load on Iso +5 and 2 A on main +12 at 45 V_{IN}

In Fig. 6 above, the peak to peak current in the main winding of L1 remains constant, but the average current increases.

Now we will add current to the flyback winding by increasing the load on the +5 Iso but lowering the main current to zero:

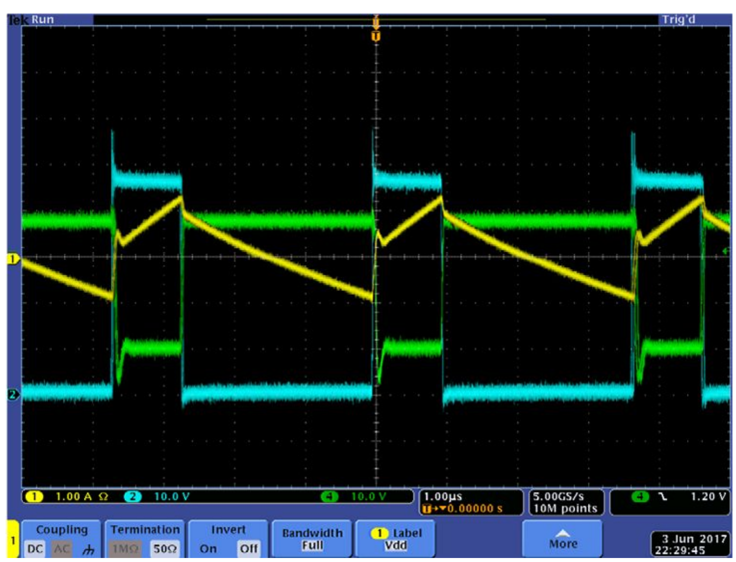

Fig. 7 - Waveform with a full load (1 A) on Iso +5 and 0 A on main +12 at 45 V_{IN}

Compare Fig. 7 to Fig. 6 and notice the increase in peak to peak current.

The next oscillograph shows both outputs at full load. Notice that the peak to peak current is about the same as Fig. 6, but now the average value of the current has increased.

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Fig. 8 - Waveform with a full load (1 A) on Iso +5 and 2 A on main +12 45 V_{IN}

As can be observed in Fig. 5 through Fig. 8 above, the flyback voltage does not substantially change over all of the required operating conditions.

Efficiency over the input voltage range is quite flat.

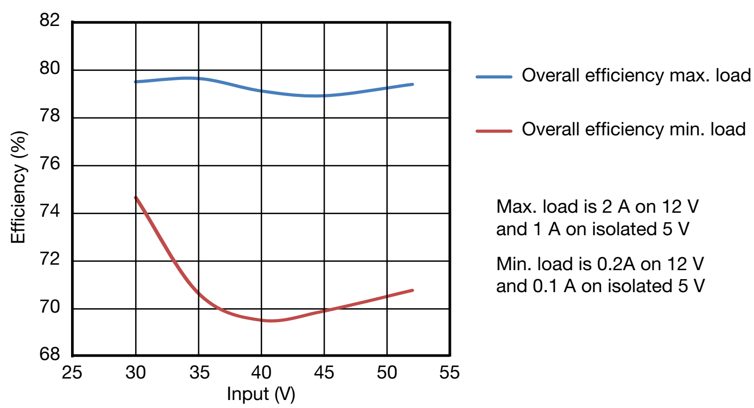

Fig. 9 - Efficiency over the input voltage range and load range (includes secondary switching regulator, U10)

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Line regulation is excellent with a minimum load on the main +12 V output:

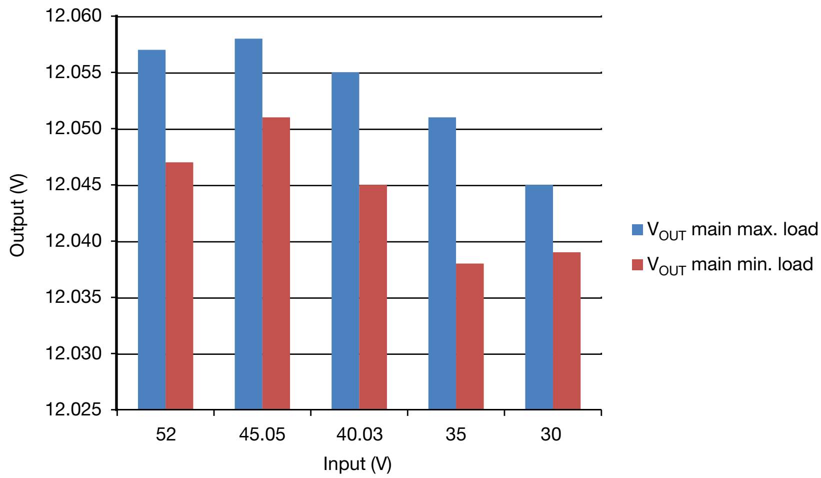

Fig. 10 - Main +12 V output voltage regulation over loading on all outputs and line voltage

The DC output voltage from the flyback winding across C18 is not as well-regulated as shown in Fig. 11. However, if the V_{IN} range of the input bus is not as wide as in this design, better regulation can be achieved. If a lower cost solution is needed, a linear regulator can be used in place of U10 to post-regulate the Iso +5 V rail.

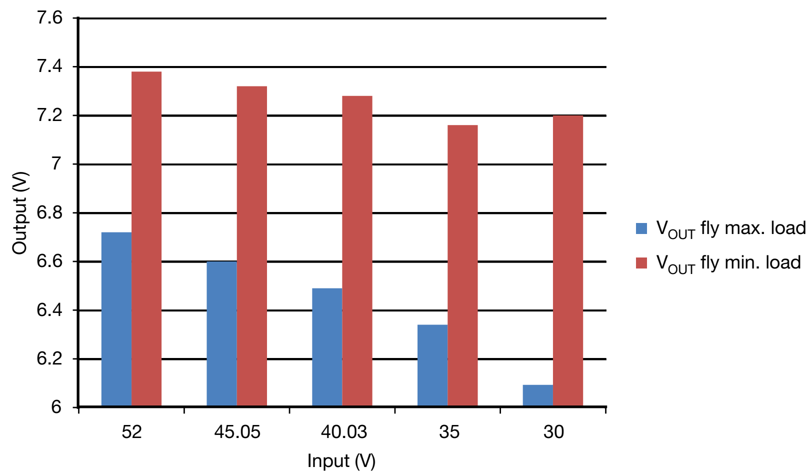

Fig. 11 - Flyback output voltage regulation on C18 over loading on all outputs and line voltage

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Fig. 12 is a thermal image of the breadboard operating at a full load and a 55 V input:

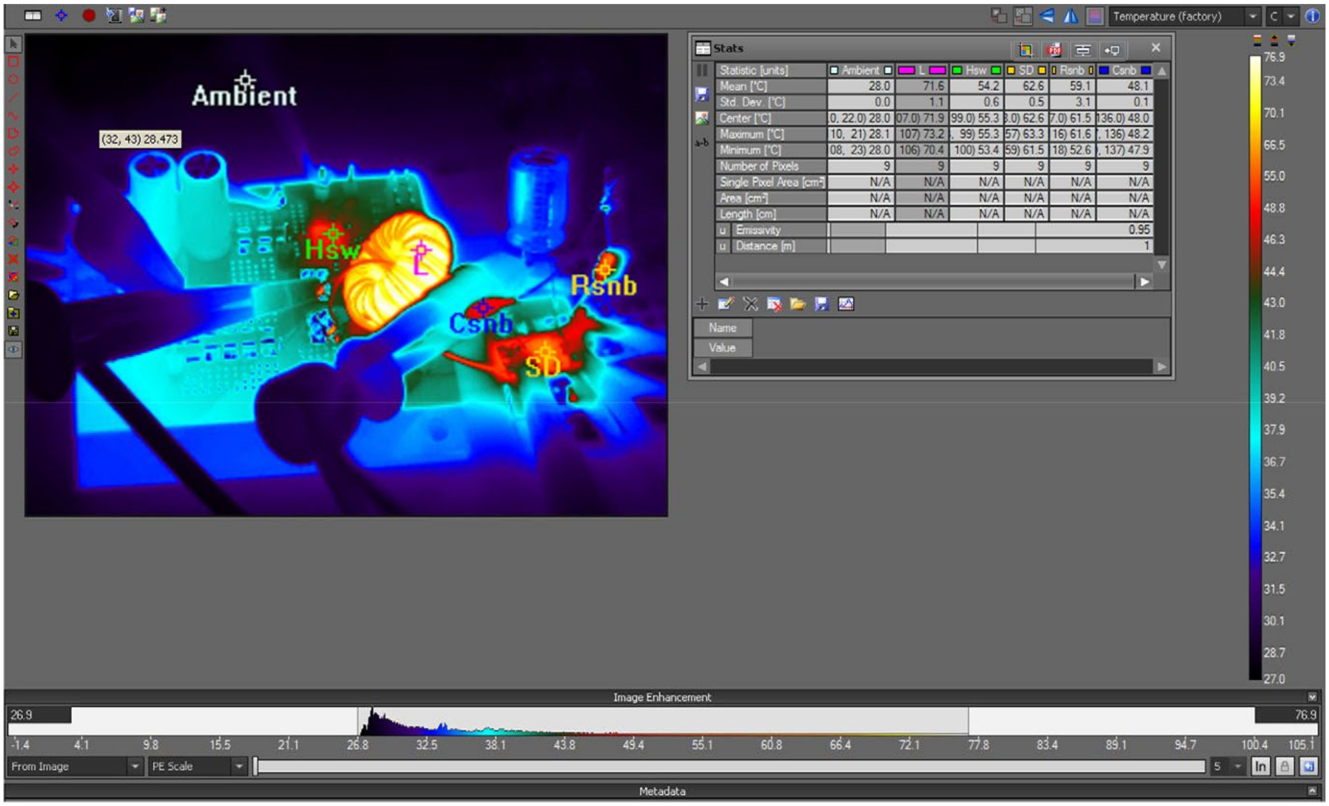

Fig. 12 - Thermal image at 55 V_{INPUT} and a full load on both outputs

- H_{sw} is the high side switch in the SiC462, U1
- L is the inductor temperature of L1
- SD is the temperature of the Schottky diode, D1
- R_{snb} is the temperature of the snubber resistor, R17
- C_{snb} is the temperature of the snubber capacitor, C27

CONCLUSION

PLCs and I/O module power supply designs have become quite complex with the need for multiple isolated voltages, floating bias voltages, and negative output voltages. PLCs are used extensively in factory automation, building automation, and process control. The need to supply various isolated rails for gate drivers, op-amps, and isolated communication interfaces such as RS-485, RS-232, etc. results in the need for a simpler way to achieve these voltages that also meets the requirements of low component count, small PCB size, and a compact, low profile design.

This breadboard design is an example of the new possibilities afforded by the introduction of higher voltage families of buck regulators, such as the SiC462.