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Circuit And Packaging Innovations Plus Latest MOSFETs Optimize DC-DC Converters For Space-Constrained Designs

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The world is shrinking and all the electronic equipment with it. PCB real estate is at a premium as circuit functionality and density increases. The prime real estate is devoted to the core functionality of the application such as microprocessors, FPGAs, ASICs and their associated high-speed data paths and support components. The very necessary, yet unwanted, power supplies are forced to squeeze into the limited space left behind. Furthermore, as functionality and density increase, the power consumption must increase correspondingly. Of equal importance is the ease of design and robustness. This poses a challenge for power supply designers: how to supply more power in a smaller area while maintaining a common, easy design?

Addressing the issue of space, the answer, in theory, is simple: increase efficiency while, at the same time, increasing switching frequency. In practice for 12-V systems, this is a very difficult goal to achieve as higher efficiency and higher switching frequency can be considered mutually exclusive.

Complex applications typically require many power supplies to feed the multitude of subsystems and each has a slightly different requirement due to a variation in output voltage or output current. The converter design challenge is to find a common platform that is easily scalable across a wide current range while minimizing space, maximizing efficiency and providing industrial-level robustness.

Nevertheless, this was precisely the task given to the designers of IR’s third-generation SupIRBuck point-of-load (POL) integrated voltage regulators. They are a family of step-down converters with integrated MOSFETs that address a wide current range from 1 A to 25 A.

The solution pulled together innovation in three areas: IC switching regulator circuit design, high-efficiency MOSFETs and IC packaging. This article describes how these innovations were leveraged in the development of the IR3847, a 25-A point-of-load buck converter that is the newest member of the Gen 3 SupIRBuck family. Benefits of the new PWM modulator design, a higher-voltage internal gate drive, and proprietary package design are discussed here along with other device features that enable the IR3847 to address requirements of thermally and space constrained applications.

To support the selection and design in of the IR3847 and other SupIRBuck family members, a free online design tool is offered at International Rectifier’s website. Following the discussion of the IR3847, a demonstration of this tool is presented.

PWM Modulator Minimizes Jitter

First, to allow an increase in switching frequency to 1 MHz and higher while still operating from a high input voltage such as 12 V, IR designed a patented modulator scheme that can create very small on-time pulses (as short as 50 ns) that are free of jitter.

To illustrate the challenge here, consider that a 1-MHz design that converts power from a 12-V supply to a 1-V output requires an 83-ns pulse width and hence can tolerate very little jitter. Standard PWM schemes commonly have about 30 ns to 40 ns of jitter under these conditions, which is unusable for this application.

This high level of jitter is clearly illustrated in Fig. 1a, where the jitter in a standard converter causes pulse skipping leading to excessive ripple. In contrast, Fig. 1b, shows that the patented PWM modulator in a Gen 3 SupIRBuck provides a clean, well-controlled output ripple under the same conditions. The PWM modulator circuit within the Gen 3 SupIRBuck family produces only 4 ns of jitter, a reduction of 90% compared to standard solutions (Fig. 2.) This has the dual benefit of reducing output voltage ripple by approximately 30% as well as allowing 1-MHz or higher frequency/higher bandwidth operation for smaller size, better transient response and fewer output capacitors.

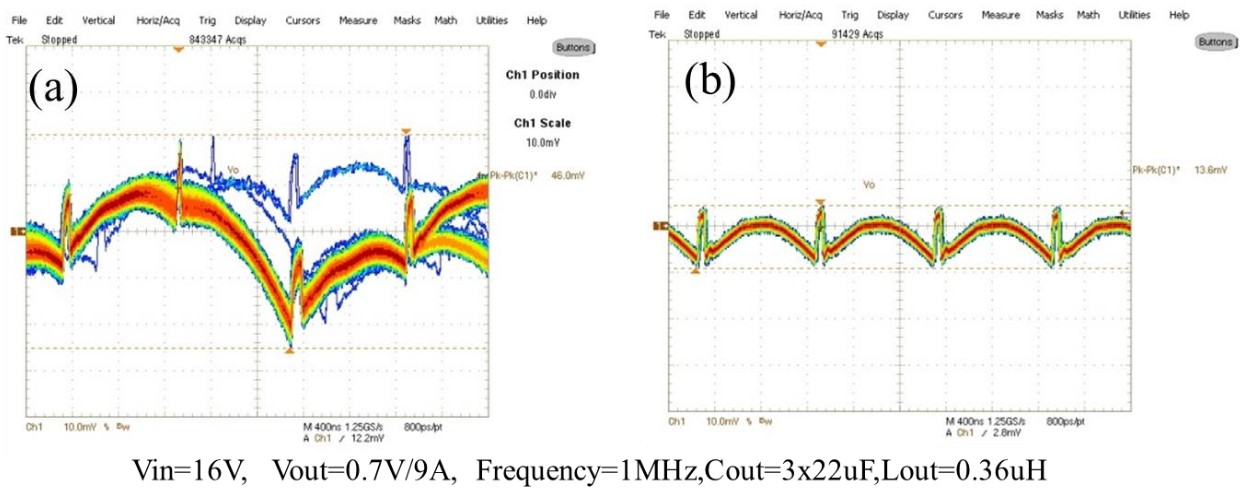


Fig. 1. Output ripple for 1-MHz, 16-V input to 0.7-V output operation for a standard converter (a) and an IR Gen 3 SupIRBuck (b).

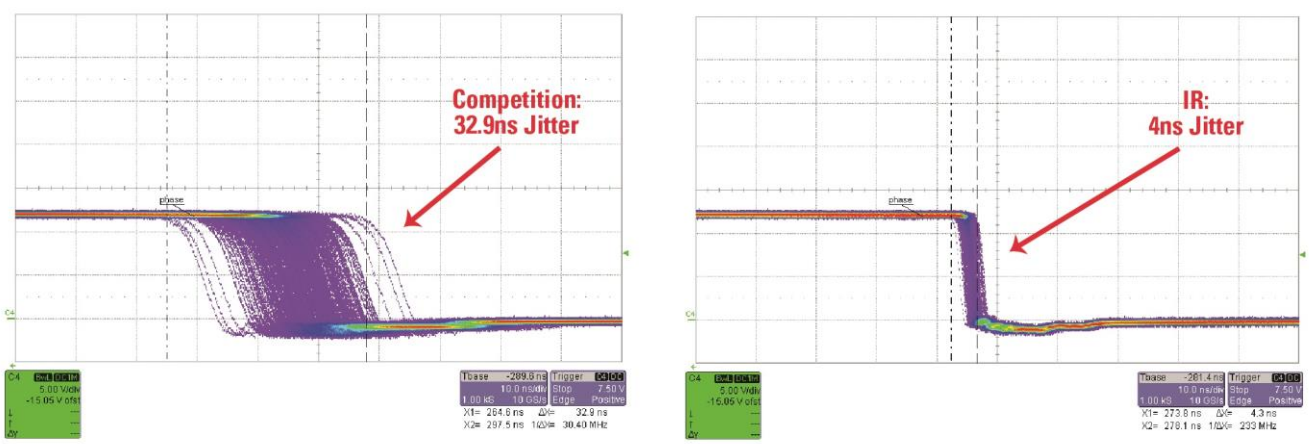


Fig. 2. In stepping down a 16-V input to a 0.7-V output, IR's Gen 3 SupIRBuck converter produces only 4 ns of jitter versus 32.9 ns of jitter for a competing buck converter design as shown in these switching-node voltage measurements.

The new family integrates IR's power MOSFETs and drives them with an internally generated 6.8-V gate drive. This allows the Gen 3 SupIRBuck family, without any extra external circuitry, to obtain market-leading efficiencies (Fig. 3) when compared with traditional buck-converter solutions, which are generally limited to a 5-V gate drive.

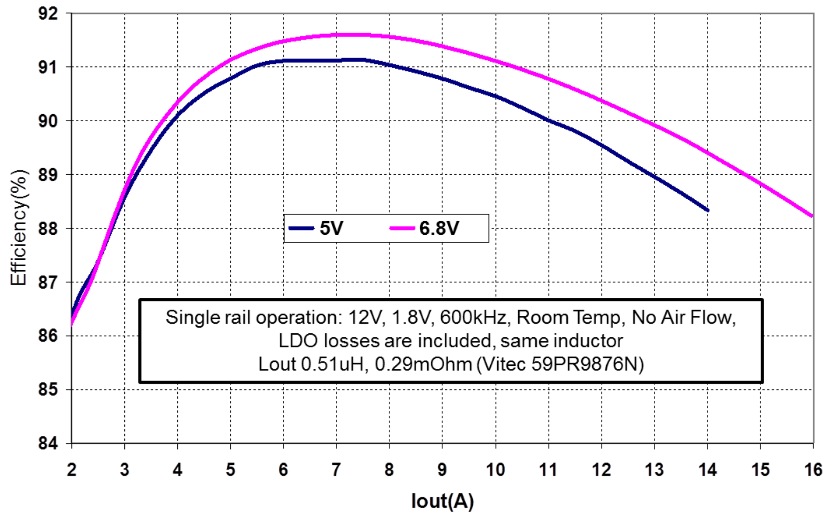


Fig. 3. A Gen 3 SupIRbuck converter leverages its internally generated 6.8-V drive to achieve greater efficiency than a competing solution with the typical 5-V gate drive.

A More Thermally Efficient Package

Standard packaging techniques to dissipate heat are sufficient for the low-power current rails in the 1-A to 16-A current range. However, for a high-power rail such as 25 A, which is generated by the IR3847 SupIRbuck, more-advanced thermal performance is required. In this case, a proprietary package design (Fig. 4) enables the IR3847 to limit junction temperature rise to 50°C while delivering the rated 25-A output. In this design, the synchronous MOSFET is flipped in a "source down" configuration while the control MOSFET remains in a traditional "drain down" configuration.

The majority of the heat is generated in the source of the synchronous MOSFET and is thus conducted immediately out of the package and down into the ground plane rather than through the silicon die like competing solutions. The source of the control MOSFET is connected to the drain of the synchronous MOSFET by a single copper clip, which is in turn connected to the switch node. This helps conduct the heat from the control MOSFET as well as providing an extremely low resistance electrical connection between the MOSFETs and the switch node.

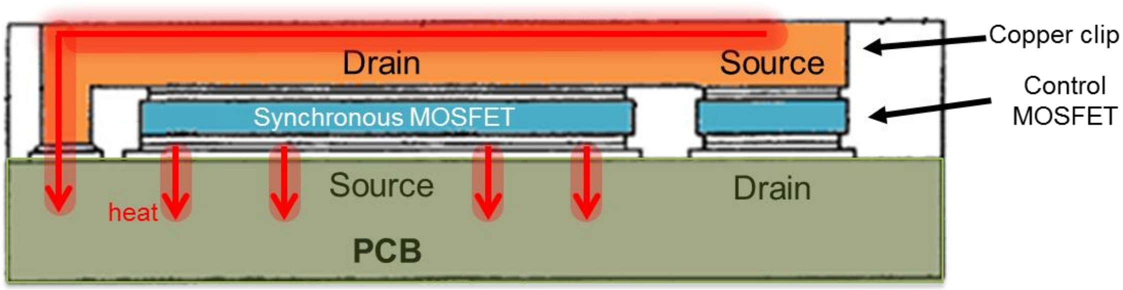


Fig. 4. A proprietary package maximizes thermal and electrical conduction for the 25-A IR3847 SupIRbuck.

As a result of the new thermally enhanced package with copper clip, innovations in the controller for greater than 1-MHz switching frequency and IR's latest Generation 12.5 MOSFETS, the IR3847 can operate at 25 A without a heatsink. Moreover, the IR3847 reduces PCB size by 70% when compared to discrete solutions that use a controller and power MOSFETs. A complete 25-A power supply solution can now be implemented in as little as 168 mm^2 with the IR3847 (Fig. 5.)

Fig. 5. With its 1-Mhz switching frequency, the IR3847 shrinks the PCB footprint required for a 25-A point-of-load converter so that it can be implemented in as little as 168 mm² of board space.

The new third-generation SupIRBuck family is qualified for the industrial market with operating junction temperatures of -40ºC to 125ºC. They can be configured for operation from a single input voltage in the 5-V to 21-V range, or can operate from an extended input range of 1 V to 21 V, if an external 5-V bias is provided. The Gen 3 SupIRBucks feature post-package precision dead-time trimming to minimize efficiency losses, and internal smart LDO to optimize efficiency across the entire load range. True differential remote sense is provided in the IR3847, as this is essential for high-current applications (Fig. 6.)

The third-gen SupIRBuck converters also offer 0.5% reference voltage accuracy over a 25°C to 105°C temperature range and input feed-forward and ultra-low jitter combine to enable total output voltage accuracy better than 3% over line, load, and temperature. In contrast, competing devices typically can only 5% accuracy (at best) across line, load and temperature.

Other advanced features include external clock synchronization, sequencing, tracking, output voltage margining, pre-biased start-up capability, input voltage aware enable, adjustable OVP and internal soft start. The Gen 3 SupIRBucks also feature true output voltage sensing via a dedicated sense pin (VSNS). This provides a robust solution to guarantee that the output voltage is monitored under all conditions, especially if the feedback line is broken, which would otherwise result in a catastrophic overvoltage like traditional competing products.

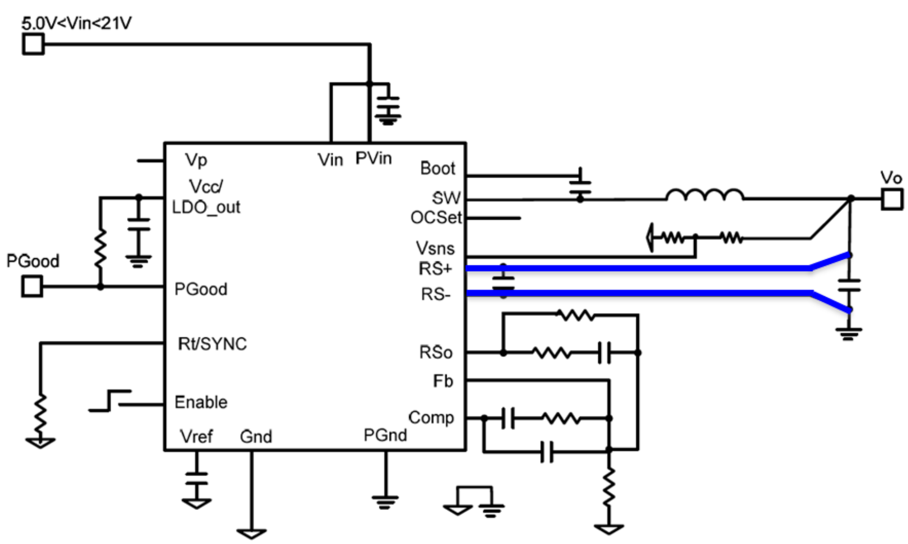


Fig. 6. True differential remote sense for the IR3847.

Voltage spikes at the switch node are a leading cause of stress on the MOSFETs. Entirely monolithic products, where the MOSFETs are integrated onto the same silicon as the controller, are particularly sensitive to such spikes. These types of products generally have reduced input voltage and switch-node ratings to avoid stress. However, the reduced ratings cannot be used in many applications.

A more-robust approach is to separate the controller silicon from the MOSFET silicon. Thus, the MOSFETs can use a higher-voltage process and can be rated higher since they see the spikes while the controller can be on a lower-voltage process. This is the approach employed by the Gen 3 SupIRBucks, where three discrete pieces of silicon (controller, synchronous MOSFET and control MOSFET) are integrated at the package level (Fig. 7.) This provides a much higher level of robustness.

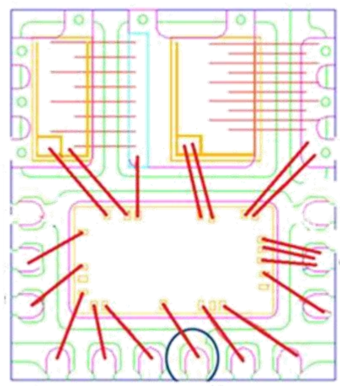


Fig. 7. Package-level integration of controller and MOSFETs for increased robustness over monolithic silicon solutions.

In addition to delivering benchmark performance and power density, the third-generation SupIrBuck family simplifies the design process. The same engine and functions are replicated in each product within the family so that a designer has immediate familiarity and can freely reuse knowledge gleaned across the product range. Some of the parts are footprint compatible to further enhance reuse or to allow for last-minute changes in power rating (see the table.)

In addition, a free online design tool (available at http://mypower.irf.com/SupIRBuck) speeds design for fast time to market. The tool provides schematics, bill of materials (BOM), and electrical and thermal simulation and allows users to customize design input, components selection, layout placement and inputs. The use of this design tool is described in detail in the following section.

Table. Gen 3 SupIRBuck product family.

Model	Max current rating	QFN package dimensions	Footprint compatibility
IR3897	4 A	4 mm x 5 mm	These three devices are footprint compatible.
IR3898	6 A		
IR3899	9 A		
IR3894	12 A	5 mm x 6 mm	These two devices are footprint compatible.
IR3895	16 A		
IR3847	25 A	5 mm x 6 mm	Not footprint compatible with the lower current models

Online Tool Speeds POL Converter Design

The SupIRBuck online design tool is accessed from International Rectifier's website (Fig. 8.) Usually, the first challenge that a system designer faces is to select the optimum dc-dc converter for the application. As there are many available with varying features and performance, making the right choice is not as trivial as it might appear. Thus, the designer's first step in using the SupIRBuck online design tool is to complete a simple questionnaire (Fig. 9) to define the application so that the tool can perform two functions.

One function is to recommend the best part (Fig. 10). The other purpose of this step is to enable the tool to select the application components and values (Fig. 11) based upon a default performance target that is common in the industry. Specifically, the tool assumes specifications such as a 50% load step with 4% maximum output deviation, 1.5% output ripple, and a loop bandwidth that is 10% of the switching frequency. Starting with these default specifications saves a great deal of valuable time as the designer no longer has to wade through the design calculation details in the datasheet to determine the best component values.

Fig. 8. The SupIRBuck Design Tool is accessed from www.irf.com.

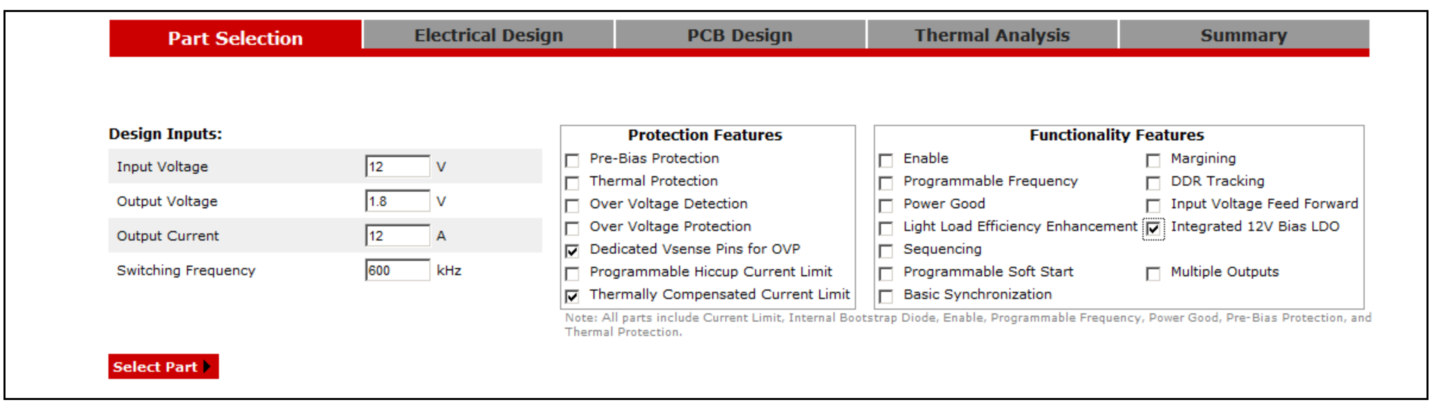
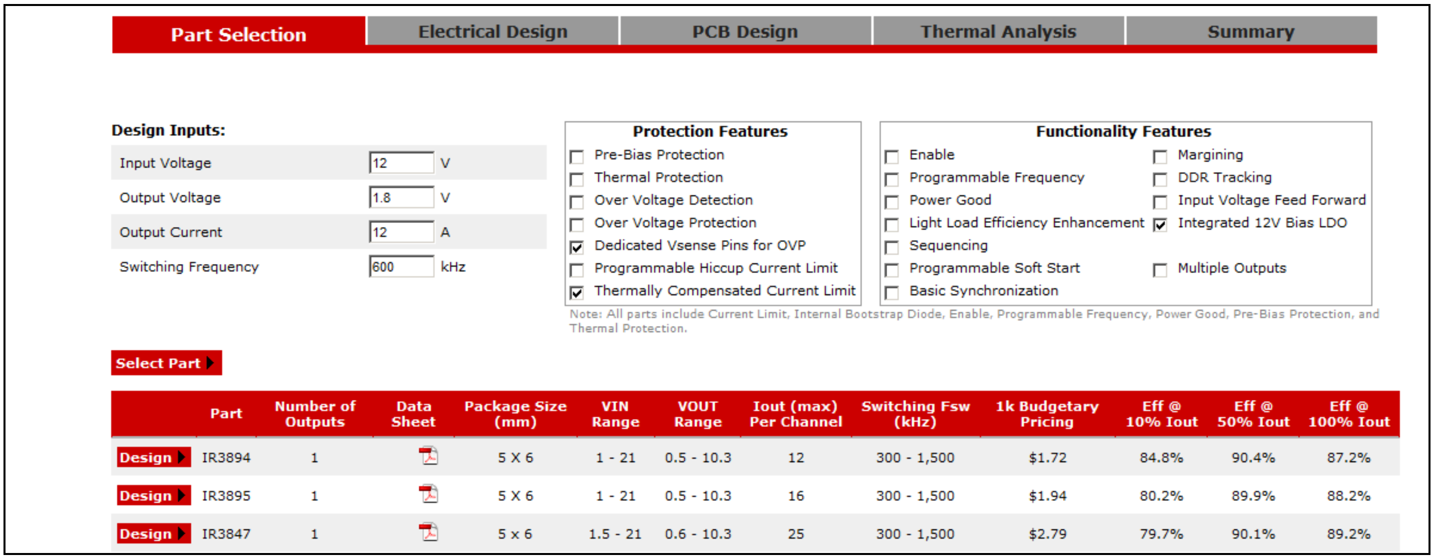


Fig. 9. The designer completes a simple questionnaire to specify the basic design criteria.



	Part	Number of Outputs	Data Sheet	Package Size (mm)	VIN Range	VOUT Range	Iout (max) Per Channel	Switching Fsw (kHz)	1k Budgetary Pricing	Eff @ 10% Iout	Eff @ 50% Iout	Eff @ 100% Iout
Design	IR3894	1		5 X 6	1 - 21	0.5 - 10.3	12	300 - 1,500	$1.72	84.8%	90.4%	87.2%
Design	IR3895	1		5 X 6	1 - 21	0.5 - 10.3	16	300 - 1,500	$1.94	80.2%	89.9%	88.2%
Design	IR3847	1		5 x 6	1.5 - 21	0.6 - 10.3	25	300 - 1,500	$2.79	79.7%	90.1%	89.2%

Fig. 10. The design tool generates a list of the SupIRbuck devices that meet the designer's criteria, helping the designer to select the optimum converter for the application.

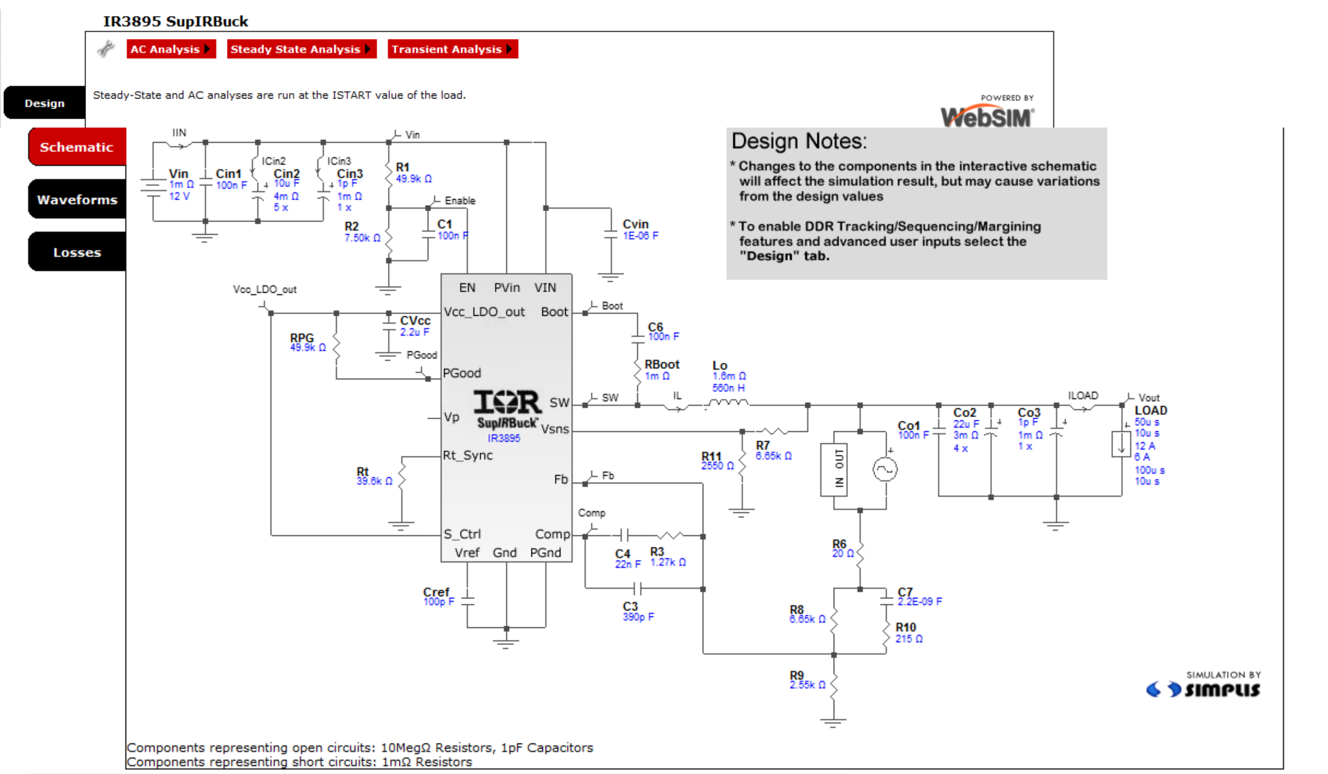


Fig. 11. For any converter model that meets the specified design criteria, the tool will automatically generate a full buck converter schematic that is pre-populated with recommended values.

At this point, the detailed design criteria, such as ripple and required transient response, can be tweaked to match the designer's requirements, if necessary (Fig. 12.)

The next step is to simulate the design in order to check that the electrical performance and stability meet the criteria specified. A Bode plot to determine phase margin and gain margin will confirm the stability of the design (Fig. 13.) Unlike traditional simulators such as Spice, there is no need to determine how to break the feedback loop and insert an ac component for the Bode plot analysis—IR's simulator automatically takes care of this so that the designer can simply focus on the results.

Running a steady-state analysis (Fig. 14) will confirm the ripple and running a transient analysis of a load-step response will confirm that the output voltage peak deviation is within the specified tolerance window. At any time, the designer has the opportunity to tweak the component values in the design to further optimize performance to his or her liking.

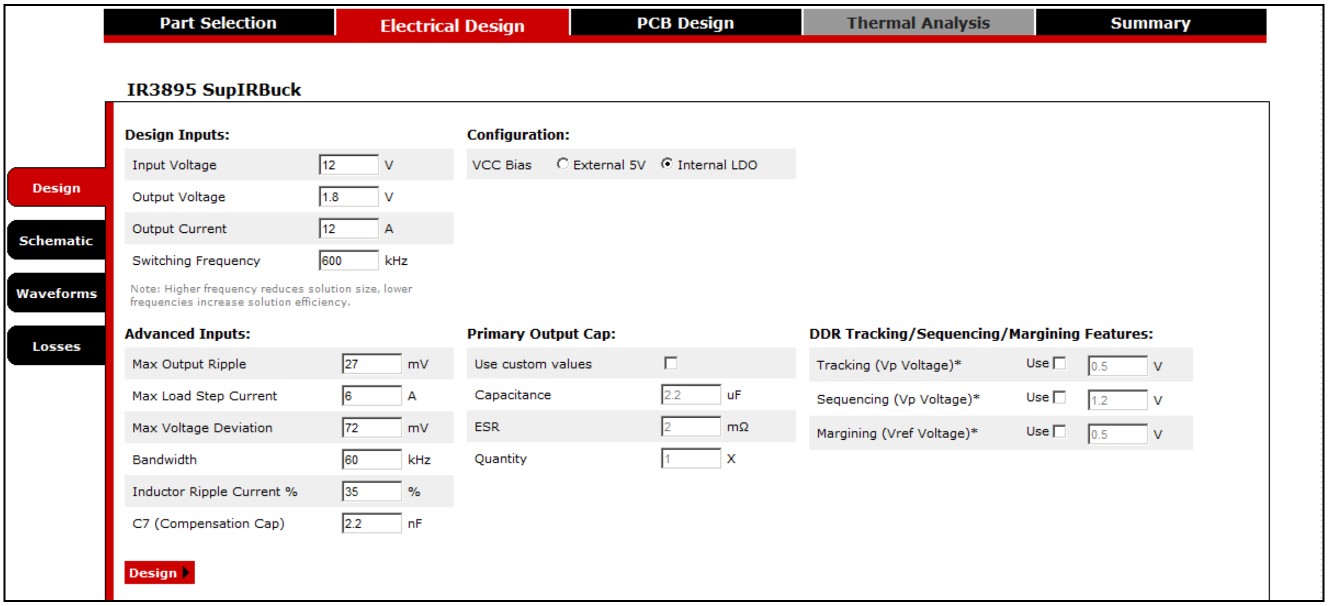


Fig. 12. During the course of power supply simulation, the design criteria can be refined to obtain the desired results.

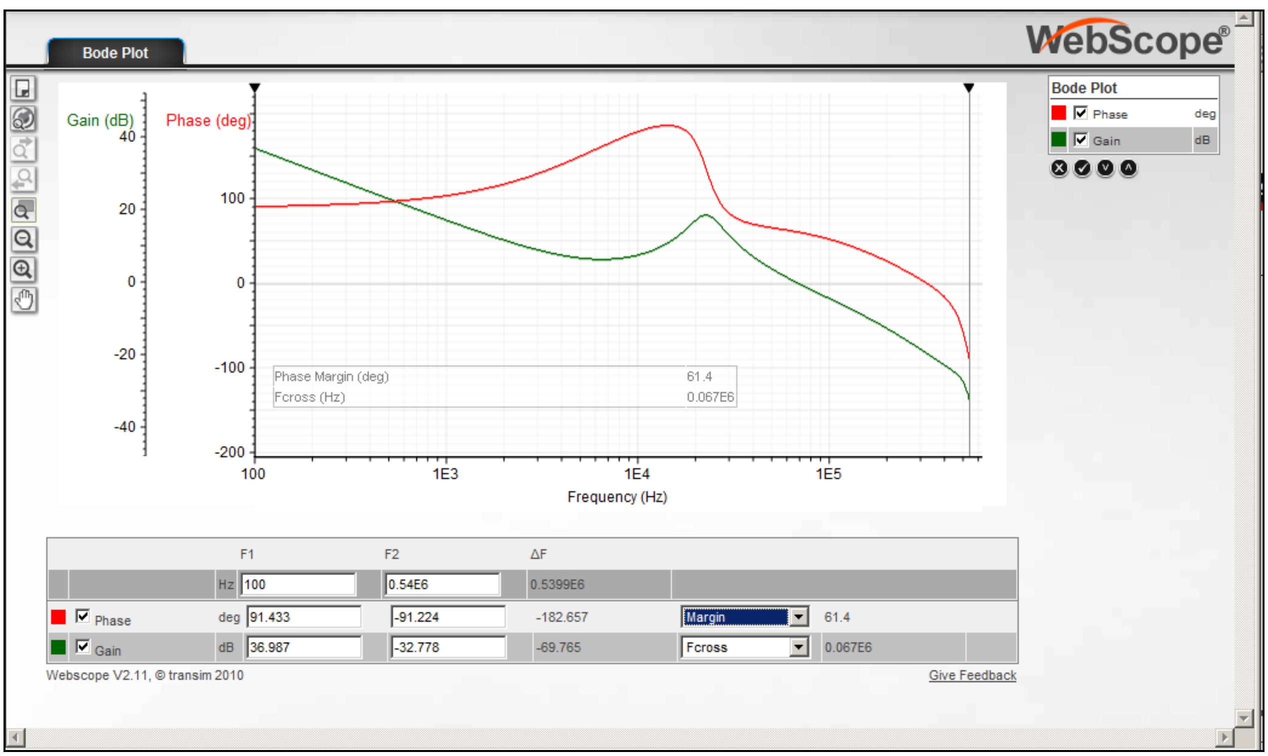


Fig. 13. The design tool generates Bode plots for ac stability analysis.

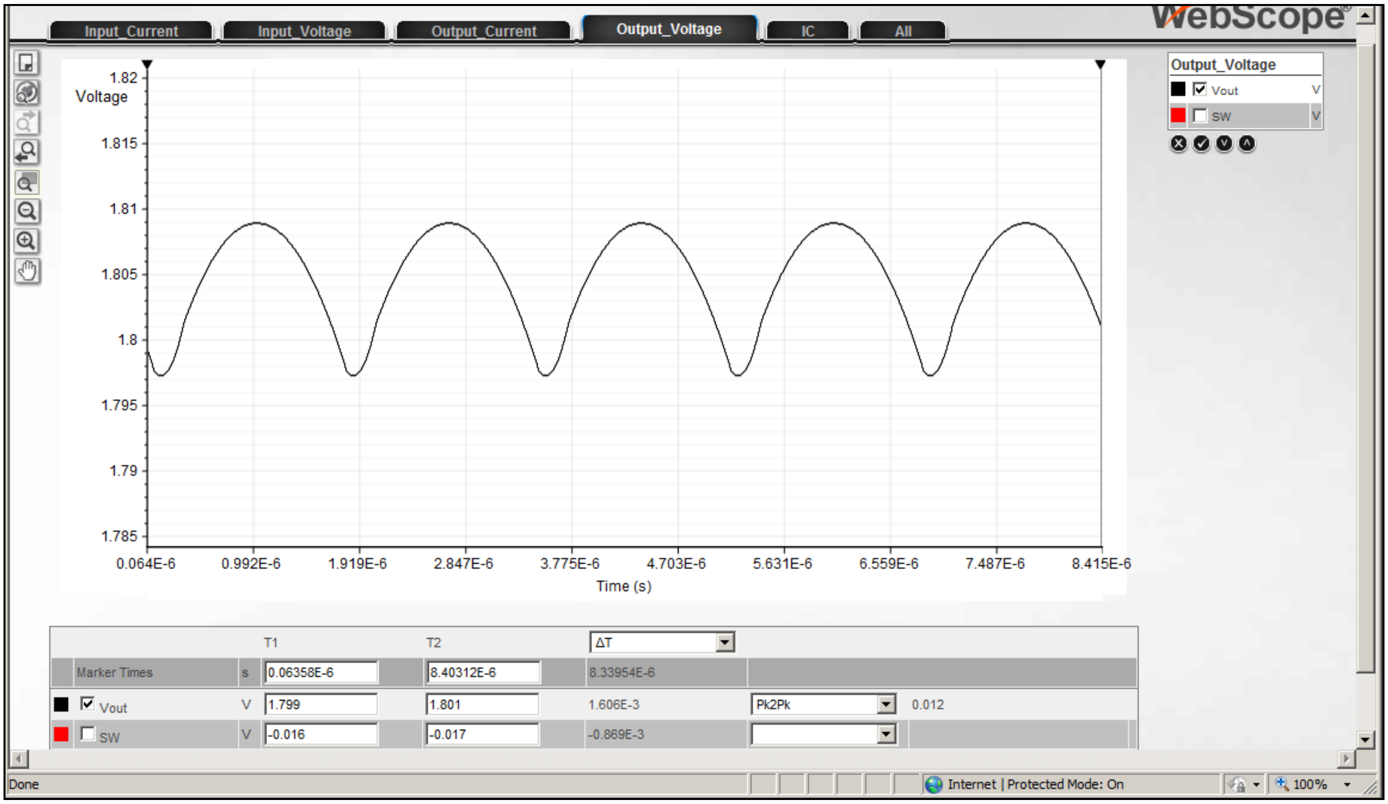


Fig. 14. Steady-state analysis verifies that output ripple is within the specified limit.

For power converters, understanding the thermal performance of the design is critical to ensure that the thermal specification is not exceeded under the application conditions. Usually the designer has to estimate the power loss based upon the datasheet efficiency curves, then use the thermal conductivity information of the package to estimate the silicon junction temperature and finally apply a derating safety factor to account for airflow and tolerance. The process is arduous and is somewhat of a guess!

Fortunately, the final step of the SupIRBuck online design tool eliminates the guesswork and provides a level of accuracy that cannot be achieved by simple hand calculations and approximations. In the final step, the designer is able to specify the expected airflow, the PCB layer count (Fig. 15) and even position other heat sources (Fig. 16) to accurately simulate and understand the thermal performance (Fig. 17) and power losses (Fig. 18)

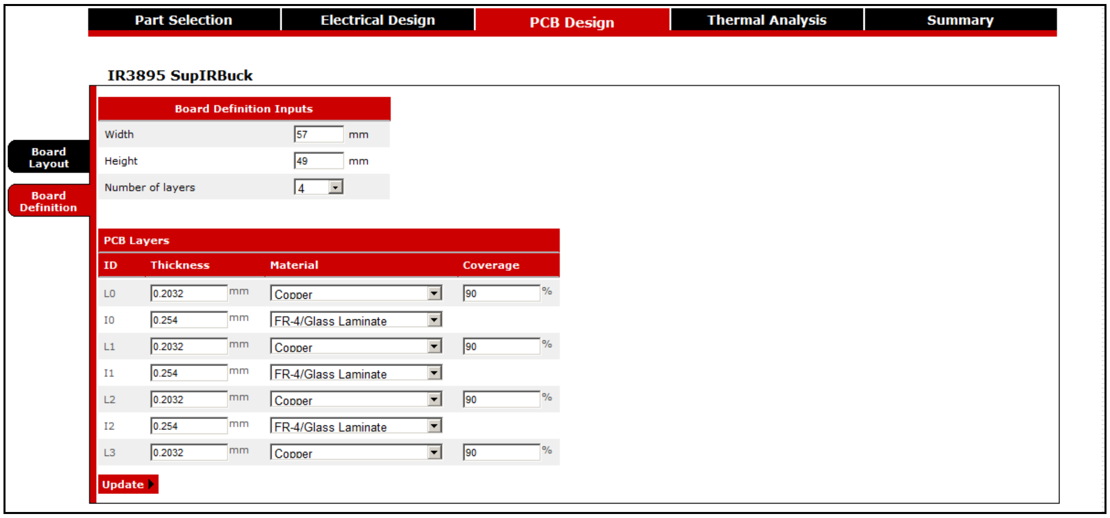


Fig. 15. The design tool simplifies thermal analysis. The first step for designers is to specify the PCB stack-up.

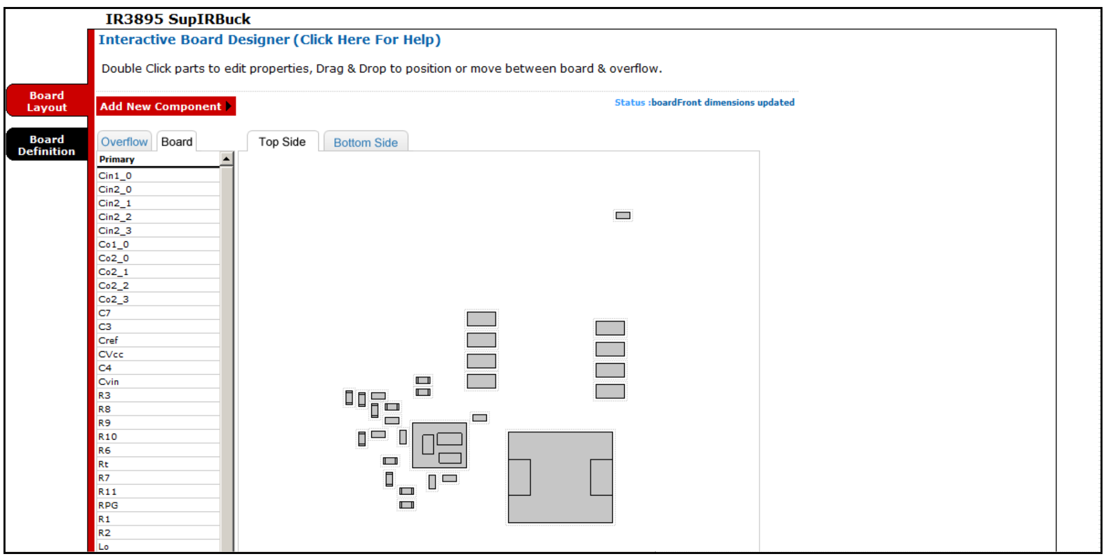


Fig. 16. Next, the designer specifies the positioning of components and heat sources.

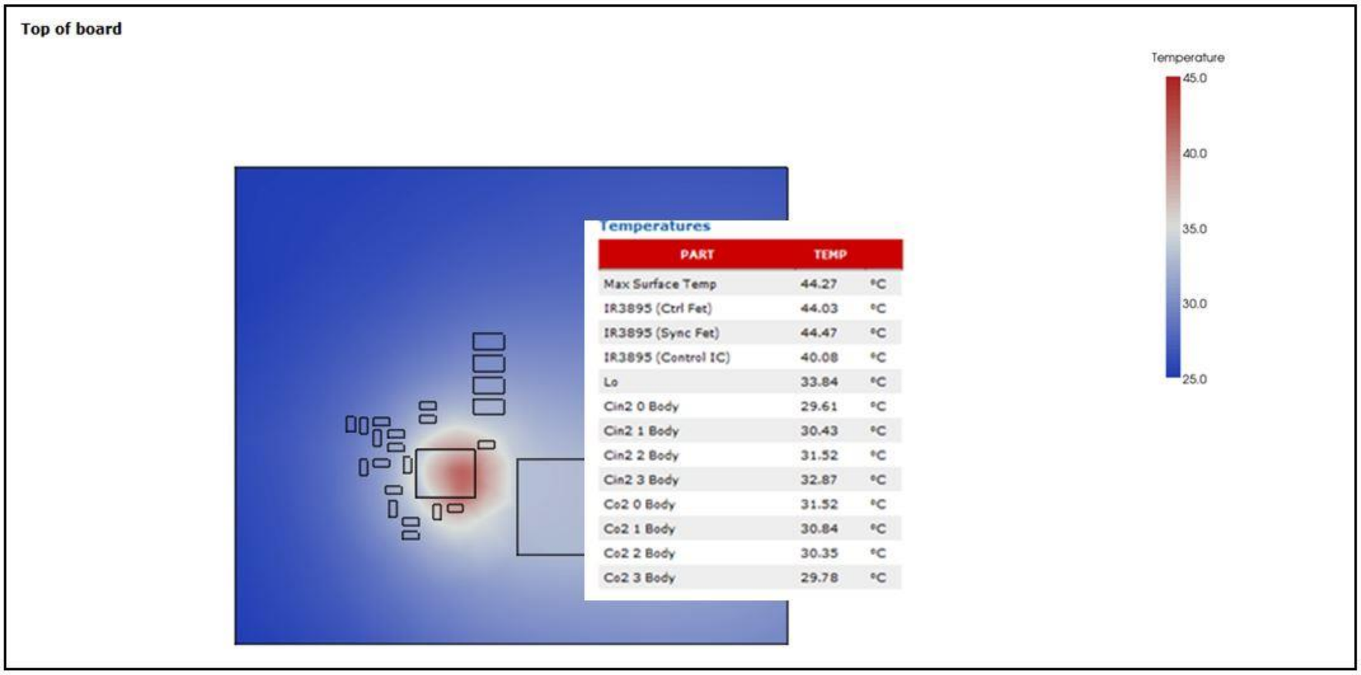


Fig. 17. Following the steps shown in Figs 15 and 16, the tool runs a thermal analaysis, generating results like those shown here.

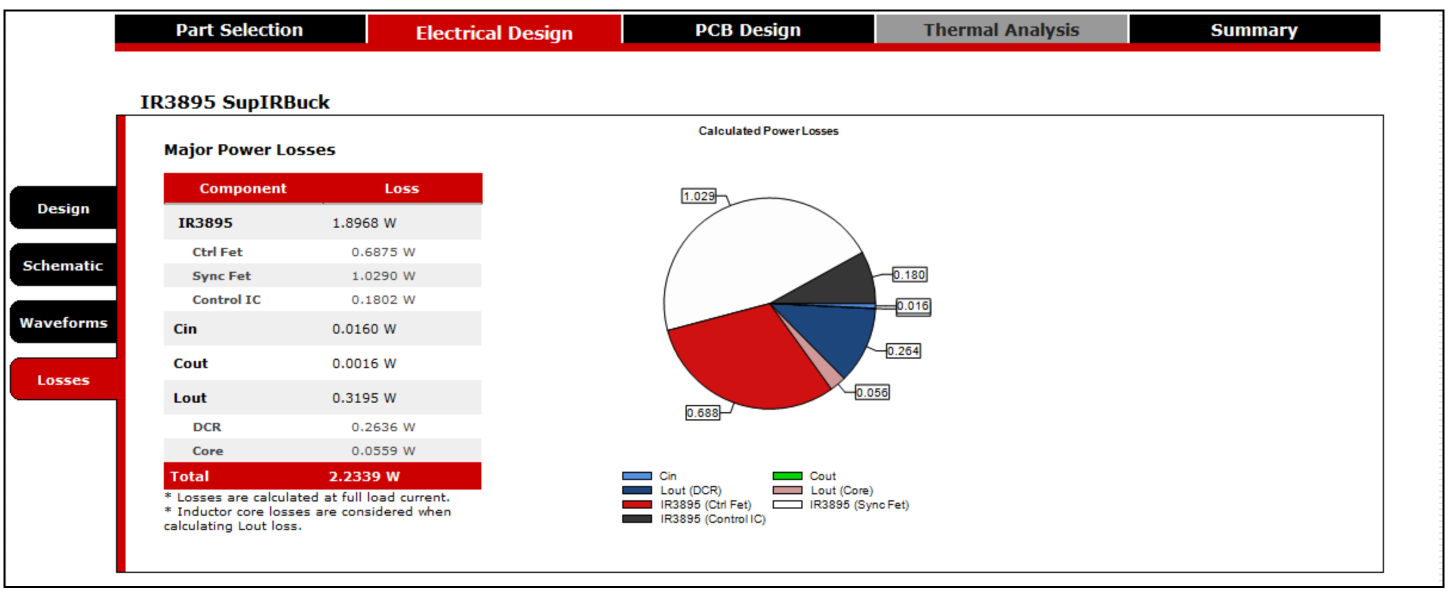


Figure 18. The design tool also provides a breakdown of power losses.

Once the design is complete, a Summary tab reports all the results including the schematic and bill of materials (BOM) (Fig. 19.) The results can be saved to PDF and the BOM can be exported to an Excel spreadsheet. File management tools allow designs to be saved and shared with multiple users. This simple, yet powerful online design tool speeds up the design process and vastly increases the chances of first-time right manufacture, saving both time and money.

Bill Of Materials

Ref	Supplier Part Number	Manufacturer	Qty	Value	Type
U1	IR3895	International Rectifier	1		IC
C1	C1608X7R1C104K	TDK Corporation	1	100nF	Capacitor
C3	GRM1885C1H391JA01D	Murata Electronics North America	1	390pF	Capacitor
C4	CGA5C2C0G1H223J	TDK	1	22nF	Capacitor
C6	C1608X7R1C104K	TDK Corporation	1	100nF	Capacitor
C7	C1005X7R1E222M	TDK	1	2.2E-09F	Capacitor
Cin1	C1608X7R1C104K	TDK Corporation	1	100nF	Capacitor
Cin2	GRM31CR71C106KAC7	Murata	5	10uF	Capacitor
Co1	C1608X7R1C104K	TDK Corporation	1	100nF	Capacitor
Co2	GRM31CR70J226KE19	Murata	4	22uF	Capacitor
Cref	C1608C0G1H101K	TDK	1	100pF	Capacitor
CVcc	C1005X5R0G225K	TDK	1	2.2uF	Capacitor
Cvin	C1005X6S0G105M	TDK	1	1E-06F	Capacitor
Lo	MPO104-R56	Delta	1	560nH	Inductor
R1	ERJ-S03F4992V	Panasonic - ECG	1	49.9kΩ	Resistor
R10	ERJ-S03F2150V	Panasonic - ECG	1	215Ω	Resistor
R11	ERJ-S03F2551V	Panasonic - ECG	1	2550Ω	Resistor
R2	ERJ-S03F7501V	Panasonic - ECG	1	7.50kΩ	Resistor
R3	ERJ-S03F1271V	Panasonic - ECG	1	1.27kΩ	Resistor
R6	ERJ-S03F20R0V	Panasonic - ECG	1	20Ω	Resistor
R7	ERJ-S03F6651V	Panasonic - ECG	1	6.65kΩ	Resistor
R8	ERJ-S03F6651V	Panasonic - ECG	1	6.65kΩ	Resistor
R9	ERJ-S03F2551V	Panasonic - ECG	1	2.55kΩ	Resistor
RPG	ERJ-S03F4992V	Panasonic - ECG	1	49.9kΩ	Resistor
Rt	Custom		1	30.6kΩ	Resistor

Fig. 19. Summary report of bill of materials for a complete SupIRbuck converter design.

About The Author

Ramesh Balasubramaniam joined International Rectifier in April 2011 through International Rectifier's acquisition of CHiL Semiconductor. After an initial assignment in strategic business development, Ramesh was tasked to provide marketing and business leadership for the Point of Load product group within the Enterprise Power Business Unit. In this role, Ramesh works closely with cross functional groups to define product roadmaps and strategies, bring products to market and drive sales and business growth.

Ramesh has over 20 years of experience in the power management industry including positions at Semtech, Seagate Technology and Philips Semiconductors (now NXP). Prior to joining International Rectifier, Ramesh led the digital power controllers marketing effort at CHiL Semiconductor. Ramesh has Masters degrees from the University of Southampton (UK) and the University of Glasgow (UK).

For further reading on point-of-load converters, see the How2Power Design Guide, select the Advanced Search option, go to Search by Design Guide Category and select "DC-DC converters" in the Power Supply Function category or select "Buck Converters" in the Popular Topics category.