Highest-performing radiation hardened R9 Si MOSFETs enable improved efficiency and easy reusability in heritage DC-DC converter

About this document

Scope and purpose

This document provides information on a prototype of DC-DC converter built by IR HiRel having a peak efficiency of 94.55%.

Intended audience

This document is meant for IR HiRel's current and potential consumers to illustrate the high-performance and easy reusability of R9 Si MOSFETs in rad hard DC-DC converters.

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1 HiRel electronics for space

Electrical power systems in space operate in radiation environments and have to survive their mission duration. This is especially important for larger satellites such as communication, earth observation, etc. in which costs are high and redundancy is limited. They need reliable power electronics to meet power requirements of the satellite. IR HiRel has a flight-proven heritage in delivering high-reliability electronics for space and has the largest portfolio of space-grade electronics. To improve performance of the system, newer radiation hardened (rad hard) MOSFETs with enhanced efficiency and packaging are continuously developed.

It is challenging to deliver a higher performing electrical power system for space in a short time. The design engineers need to balance resources they spend on optimizing gate-drive circuit and board layout. To demonstrate high-efficiency and drop-in reusability of the latest rad hard MOSFETs, a prototype of a 24V, 260W radiation hardened DC-DC converter is built for space applications. This is based on an existing PWB layout of a DC-DC converter which is flight-proven and delivers 195W output power using IR HiRel’s rad hard R5 Si MOSFETs. The latest converter’s improved efficiency is driven by IR HiRel’s rad hard R9 Si MOSFETs in an SMD-0.5e package. Compared to previous design, only MOSFETs are replaced in power stage and few circuit components in gate-driver are changed. A peak efficiency of 94.55% is observed at room temperature which includes losses in power stage, control stage and auxiliary power supply.

2 Converter design

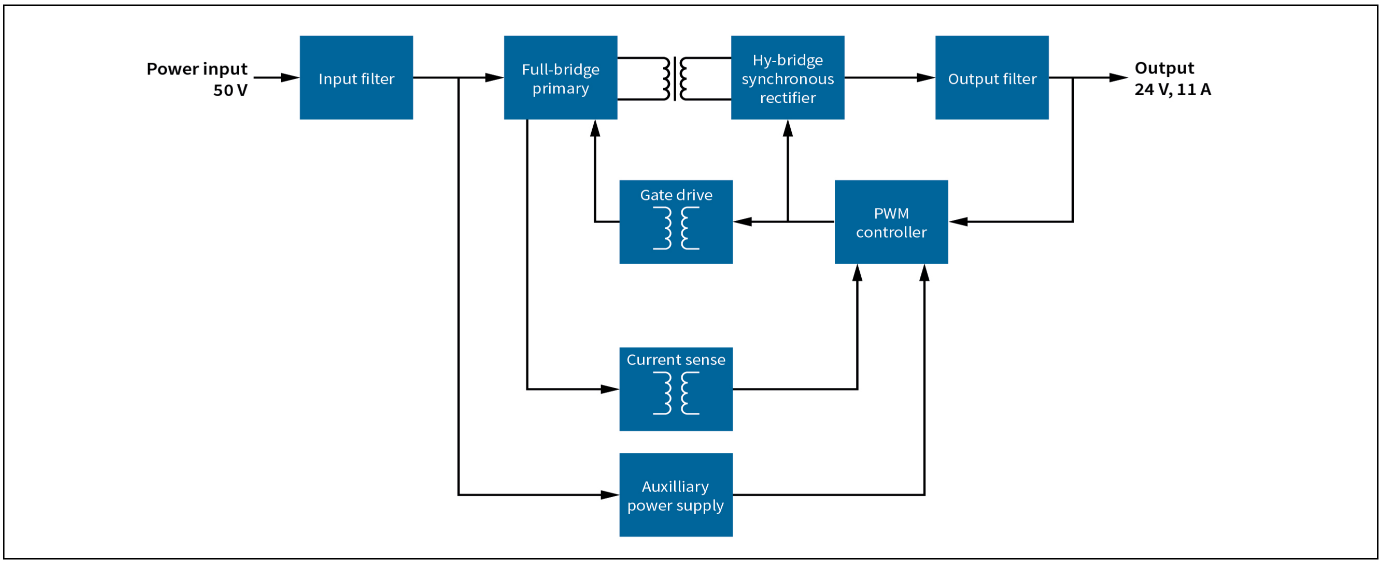


Figure 1 Block schematic of IR HiRel's rad hard 260W isolated DC-DC converter

The DC-DC converter in its power stage uses a full-bridge with Hy-bridge (current doubler) synchronous rectifier. The power topology selection is based on three criteria: galvanic isolation, higher power conversion efficiency and improved thermal performance. It has a 50V input and single 24V output voltage and uses peak current mode control for closed-loop control. Space-qualified integrated magnetics are used for galvanic isolation between full-bridge and Hy-bridge.

Parameters	Conditions	Minimum	Maximum	Unit
Input voltage	Steady-state	48	52	V
Output voltage	Steady-state	24 ± 0.01		V
Output current	Steady-state	0	11	A
Switching frequency	Steady-state	120		Hz
Power efficiency	Load: 37% to 100% Temperature: -45°C to +85°C	93	95.5	%

100V, 35A rad hard R9 MOSFETs (IRHNKC9A7130) are used in power stage to reduce power losses. The part has low $R_{DS(on)}$ (34 mΩ), 48nC gate charge at room temperature and is rated for 100 krad TID and immune to SEE upto LET of 90 MeV/mg/cm^2. The switching frequency is 120 kHz.

Figure 2 Radiation hardened Si MOSFET – SMD-0.5e

The current doubler output stage efficiently provides high-current output. Each inductor has to handle only half of the output current (+ switching current ripple). This reduced the height profile of magnetics and saves board space. Compared to center-tapped transformer in output stage, current doubler stage transformer is fully utilized and has lower leakage inductance. The design specifications are standard and have been deployed for various applications in space.

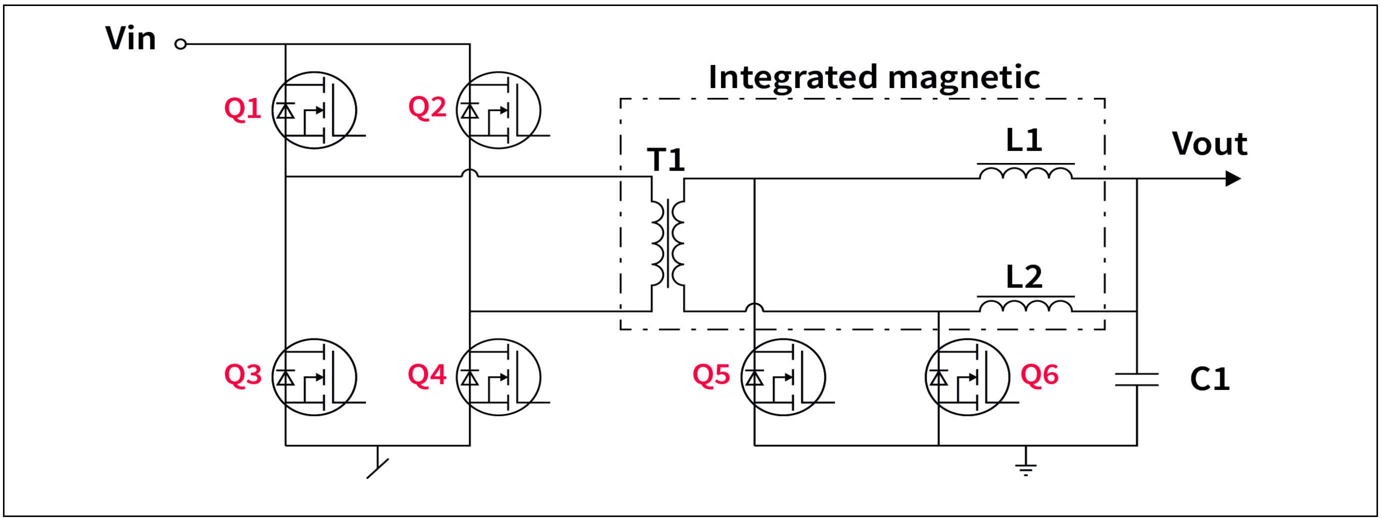
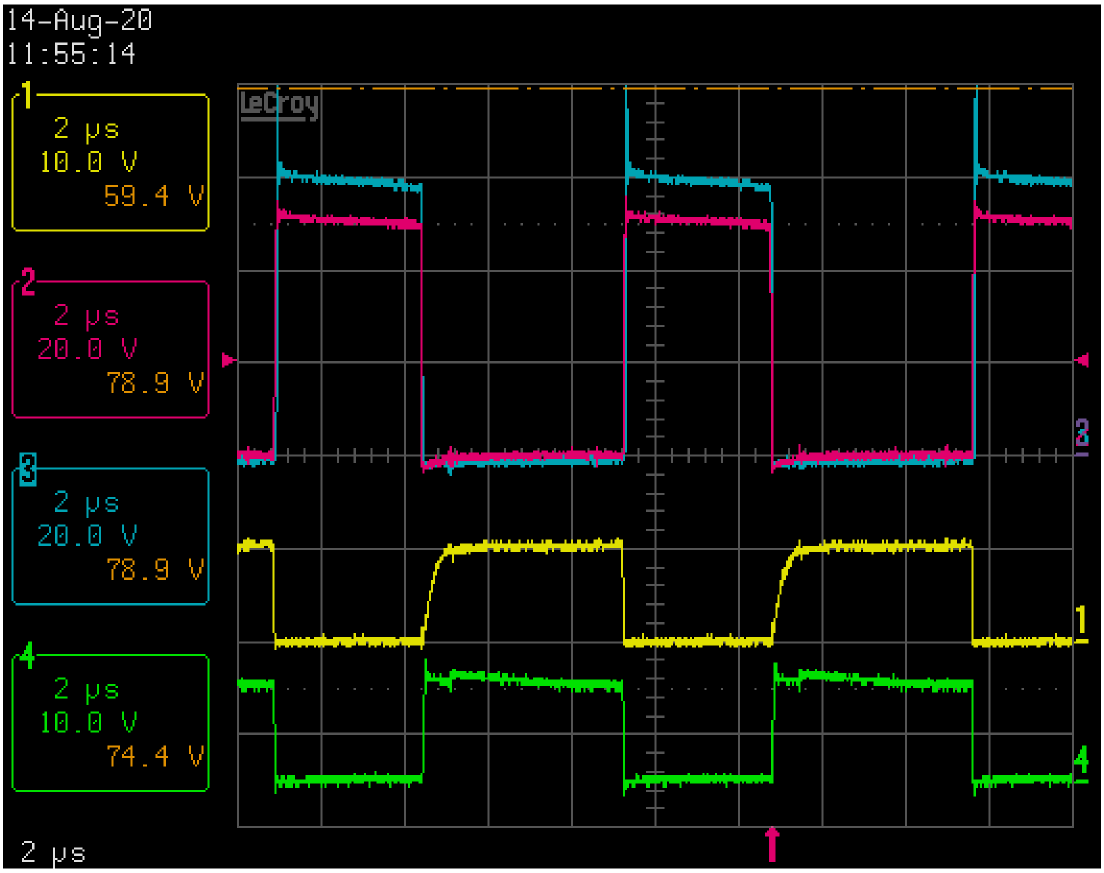


Figure 3 Power stage schematic (simplified)

For closed-loop control, UC1825 rad hard controller IC is used. Current model control ensures that current through both inductors is the same. The controller is used in peak current mode with slope compensation and limits the duty-cycle for each PWM output. Current through the switches is measured using current sense transformer while PWM signals are generated by gate drive transformer.

3 Waveforms

Amobeads are used in series with drain of MOSFETs to reduce the overshoot in drain-source voltage. Figure 4 shows the gate and drain voltages across switches in full-bridge (Ch1, Ch2) and synchronous rectifier (Ch3, Ch4). From the waveform of Ch3, a peak voltage of 78.9V and nominal voltage (during off-state) of 60V is noted. For low-side switch in full-bridge primary, a nominal voltage (during off-state) of 50V is noted (Ch2). Converter efficiency can be improved by optimizing/reducing amobead size, but at the expense of voltage overshoot. There's a tradeoff here between voltage overshoot across MOSFET and the overall efficiency.



Ch1 – Gate voltage (Q4) – Low-side switch in full-bridge
Ch2 – Drain voltage (Q4) – Low-side switch in full-bridge
Ch3 – Drain voltage (Q6) – Low-side switch in synchronous rectifier
Ch4 – Gate voltage (Q6) – Low-side switch in synchronous rectifier

Figure 4 Gate and drain voltage waveforms across MOSFET Q4, Q6

With two output inductors operating in parallel and 180° phase shifted, output ripple frequency is twice the switching frequency. Hence, the output ripple current through capacitor is reduced. This reduced the output ripple voltage and consequently the size of output capacitor. Reduced output ripple current also lowers the noise level at output, resulting in lower radiation emissions. For an output of 24V, peak-to-peak voltage ripple of 25.7mV (1.46mV rms) is observed (see Figure 5).

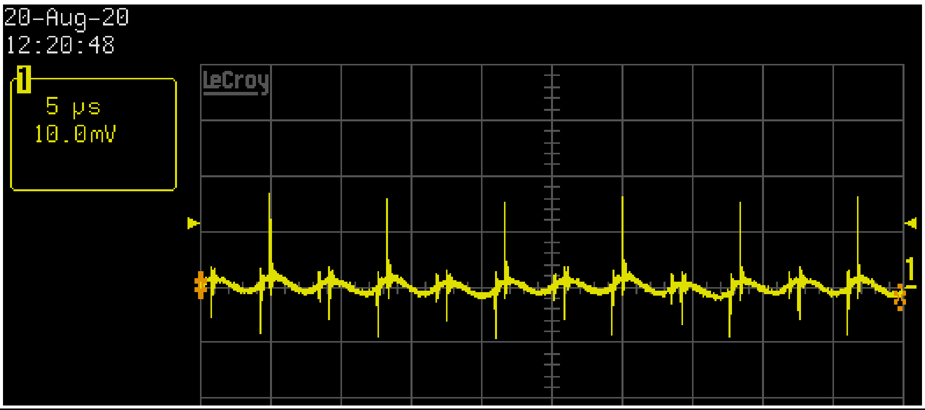


Figure 5 Output voltage ripple

4 Power losses

Based on values of parameters at room temperature, theoretical power losses in different components of the circuit are calculated. Figure 6 shows the distribution of losses in DC-DC converter delivering 260W load and operating at efficiency of 95.49%.

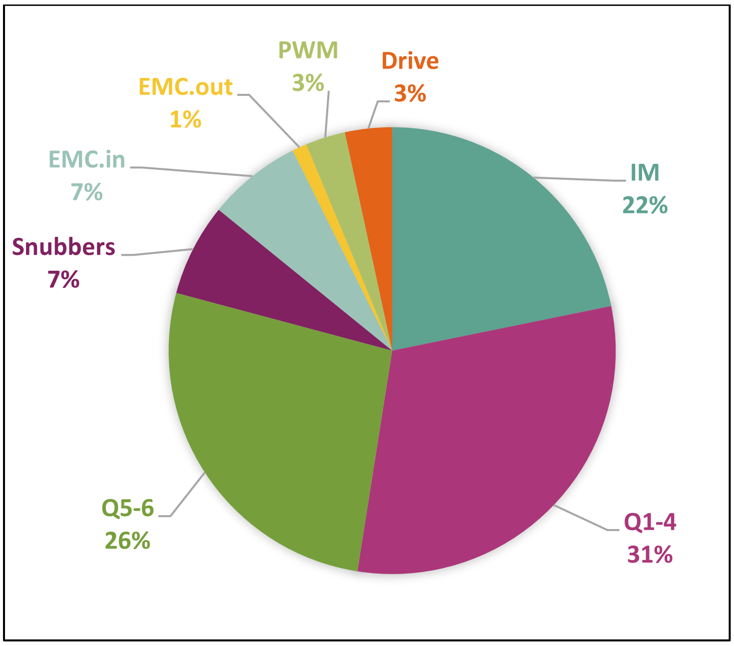


Table 2 R9 power budget at 260W load

Loss distribution	
Component	**Power (W)**
IM	2.721
Q1-4	3.830
Q5-6	3.329
Snubbers	0.836
EMC.in	0.849
EMC.out	0.132
PWM	0.360
Drive	0.424
Total	12.48
P_{out}	264
P_{in}	276.48
Efficiency (%)	**95.49**

Figure 6 Power losses distribution in 260W DC-DC converter with R9 MOSFET (IRHNKC9A7130)

In order to realize the performance improvement compared to previous generation of rad hard MOSFETs, loss distribution with 100V R5 MOSFET (IRHNJ57130) are calculated (see Figure 7) with equivalent circuit configuration. The equivalent converter using R5 MOSFET can deliver maximum load power of 195W at 94.89% efficiency.

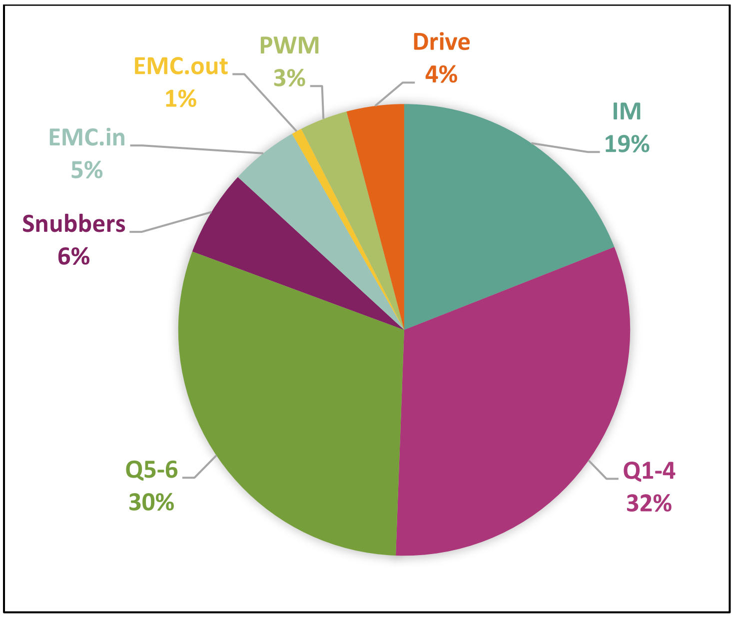


Table 3 R5 power budget at 195W load*

Loss distribution	
Component	**Power (W)**
IM	2.000
Q1-4	3.160
Q5-6	3.160
Snubbers	0.651
EMC.in	0.516
EMC.out	0.077
PWM	0.360
Drive	0.432
Total	10.52
P_{out}	195.4
P_{in}	205.88
Efficiency (%)	**94.98**

Figure 7 Power losses distribution in 195W DC-DC converter using R5 MOSFET (IRHNJ57130)

Here, R9 MOSFET exceeds the load capability compared to R5 MOSFET. Efficiency of DC-DC converter with R9 MOSFET at 195W is calculated to be 95.89%. This marks an efficiency improvement of 1% with R9 MOSFET.

5 Results

The theoretical calculations comparing performance of DC-DC converter using R9 rad hard Si MOSFETs and previous generations are visually summarized in Figure 8. Each newer generation MOSFET shows improved efficiency as well as higher load capability.

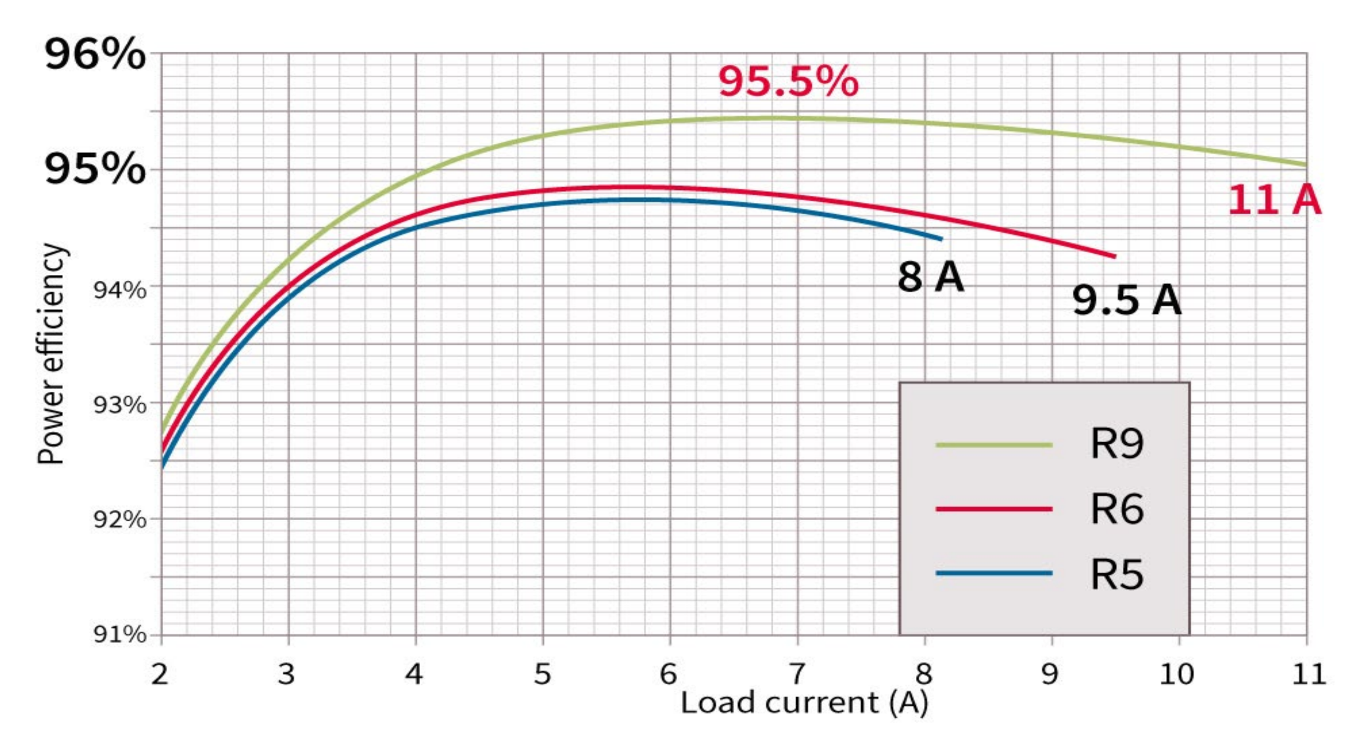


Figure 8 Modeled efficiency v/s load curve of rad hard DC-DC converter at 25°C baseplate temperature (V_{out} = 24V)

Table 4 Modeled efficiency comparison across different rad hard MOSFET generation

Rad hard MOSFET generation	Maximum load (output power)	Operating efficiency
R9	**260 W**	**95.49 %**
R5	195 W	94.89 %
R9	195 W	95.89 %

The efficiency v/s load curve of actual DC-DC converter with R5 and newer prototype built using R9 is shown in Figure 10. At 25°C, peak efficiency observed using R5 is 93.2 % while R9 drives peak power conversion efficiency to 94.89 %. Excluding the losses in auxiliary power supply, the observed efficiency is 94.55 %. In addition, a 33% increased load power capability is also observed. This study proves that higher performance can be realized reusing the same layout and swapping the older Si MOSFET with newer Si MOSFET. Circuit reuse enables faster system design and approvals while delivering improved performance and reliability.

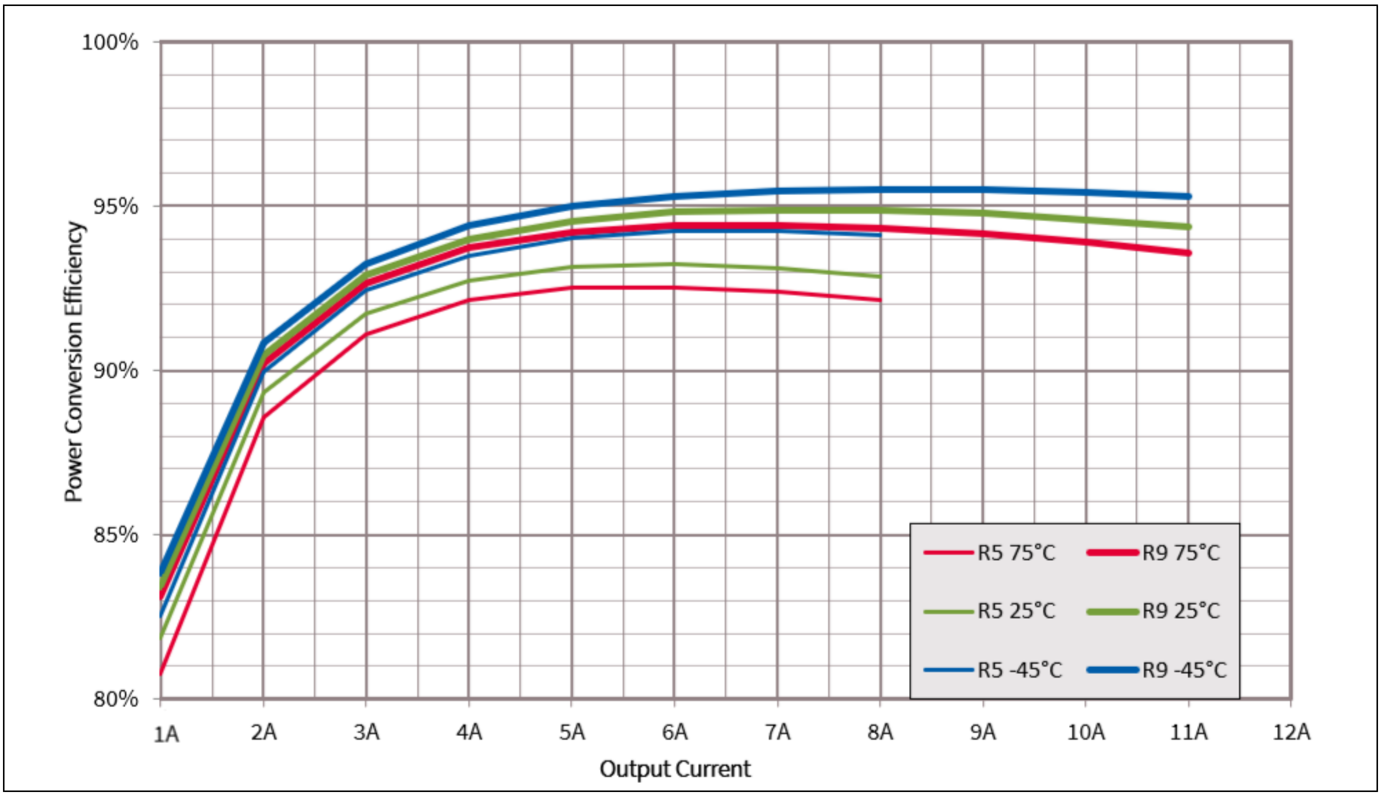


Figure 9 Actual efficiency v/s load curve (without auxiliary power supply consumption)

6 Conclusion

This study showed the ease of reusability in DC-DC converter design with R9 Si MOSFETs. With replacement of older generation MOSFET with comparable R9 MOSFET and minimal changes in the circuitry, an immediate improvement in efficiency is realized. Previously used heritage DC-DC converter design can be used and drop-in replacement will provide low-risk upgrade path resulting in immediate benefits.

Spacecraft operating in space for long amount of time need high-reliability in their electrical power system. Using IR HiRel's rad hard R9 Si MOSFETs, engineers can rely on their flight-proven design and enable higher performing systems with drop-in replacement of newer space discretes. The prototype of 260W DC-DC converter shows a best in class peak power conversion efficiency of 94.55% at room temperature. For the full R9 MOSFETs portfolio, see R9 rad hard Si MOSFETs.

Revision history

Document version	Date of release	Description of changes
	2021-09-22	Initial release
Rev 1.1	2021-09-22	Update figures

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