Accelerate development time

through reuse of flight-proven designs with new gen R9 rad hard Si MOSFETs

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IOR HiRel
An Infineon Technologies Company

Speaker introduction

› Andrew Popp is Director of Discrete Space Power Products for IR HiRel, an Infineon Technologies company

› Andrew leads IR HiRel's development of new silicon and GaN-based FET solutions for the Space Industry

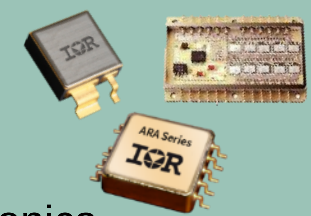
Agenda

1. High reliability electronics for space
2. Project motivation
3. Converter design
4. Measurements and performance
5. Power conversion efficiency

About IR HiRel

What we do

- Radiation-hardened semiconductor-based power conversion for high-reliability applications in space and other extreme environments
  - Rad hard MOSFETs
  - DC-DC hybrid converters
  - Custom PWB-based power supplies
  - Ruggedized industrial modules



- Specialized expertise in radiation-hardened power electronics
- Broad selection of solutions certified to industry standards for global customers

Why customers trust IR HiRel

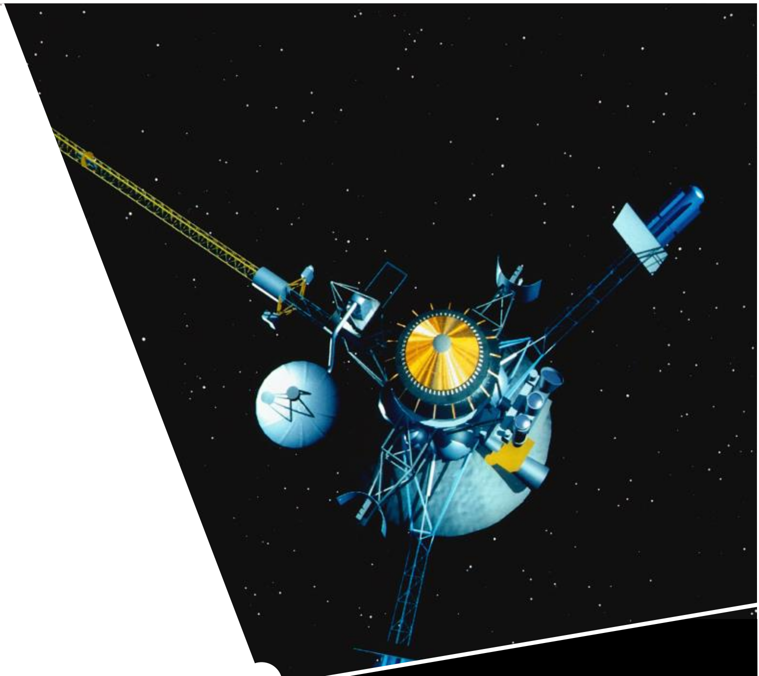
- World-class space heritage, flight-proven globally in thousands of programs
- Demonstrated track record of high-reliability products, portfolio longevity and long-term customer commitment
- Flexible model to tailor solutions to specific customer needs
- Minimizing risk with fully qualified, documented products to expedite approvals

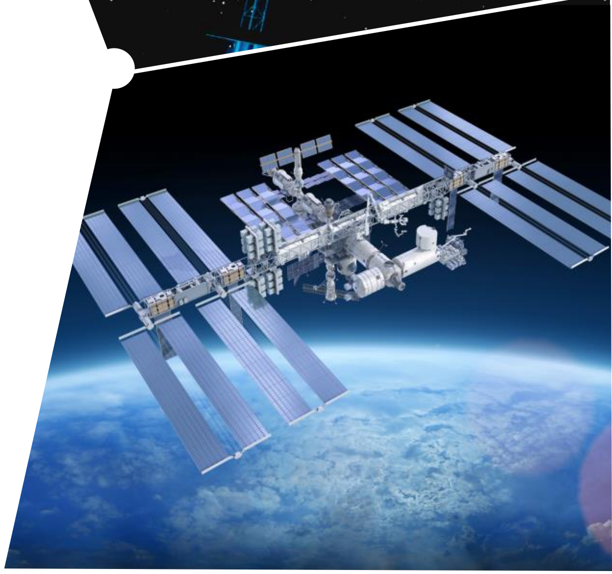
Committed to our markets

- Global access to dedicated customer support team, including sales, applications support, quality and customer service
- Certification to industry standards, including MIL-PRF-38534, MIL-PRF-19500

Failure-free performance for space applications

- Power electronics in highly reliable space vehicles must survive and perform to specification in the harshest environments
  - Severe thermal, mechanical and radiation conditions
  - Mission lifetimes 15 years+
  - Especially important for high cost, limited redundancy satellites and vehicles
- To improve system efficiency, IR HiRel continuously develops newer radiation hardened (rad hard) MOSFETs with enhanced performance and packaging





Project motivation: improve system performance and efficiency with minimal circuit component changes

- **Unique challenges in high reliability applications**
  - Balance resources spent to optimize gate-driver circuit and board layout
  - Expedite time to deploy electrical power system for newer projects
  - Improve system performance with minimal circuit component changes

- **DC-DC converter base hardware**
  - Existing printed wiring board (PWB) layout
    - 190W output power
    - Flight-proven design
    - Used IR HiRel's R5 Si MOSFETs
- **Design goals**
  - Use same converter topology and control strategy
  - <u>Replace R5 with R9 Si MOSFETs</u>
  - Minimal changes to other circuit components

Demonstrate competitive peak performance in heritage isolated DC-DC converter

- **260W rad hard DC-DC converter**
  - Full-bridge with current doubler synchronous rectifier
  - Single 24V output voltage with peak current mode for closed-loop control
  - Power stage with IR HiRel’s latest generation rad hard R9 MOSFETs in SMD-0.5e package

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

Table 1. Key DC-DC converter specifications

Maximize design reuse and improve performance

- Main driving factors for topology selection
  - Galvanic isolation
  - Higher power conversion efficiency
  - Improved thermal performance

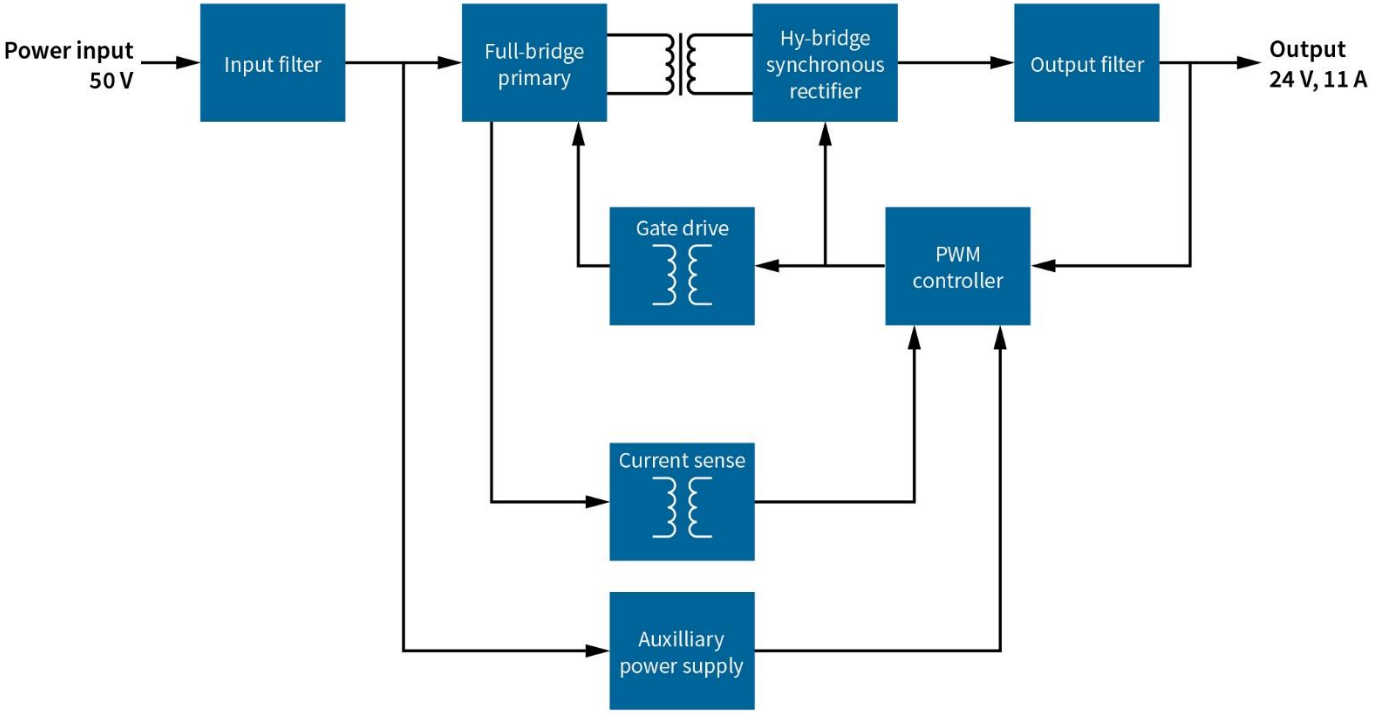


Figure 1. Block schematic of IR HiRel's rad hard 260W isolated DC-DC converter

Power stage topology improves thermal performance

- Current doubler output stage efficiently provides high-current output
  - Each inductor has to handle only half of output current (plus switching current ripple)
  - Reduces the height profile, 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 used for various space applications

100V, 35A rad hard R9 MOSFET (IRHNKC9A7130)	
Low $R_{DS(on)}$	34 mΩ
Gate charge	48 nC at room temp
TID	100krad
SEE	Up to 90 MeV/mg/cm² LET

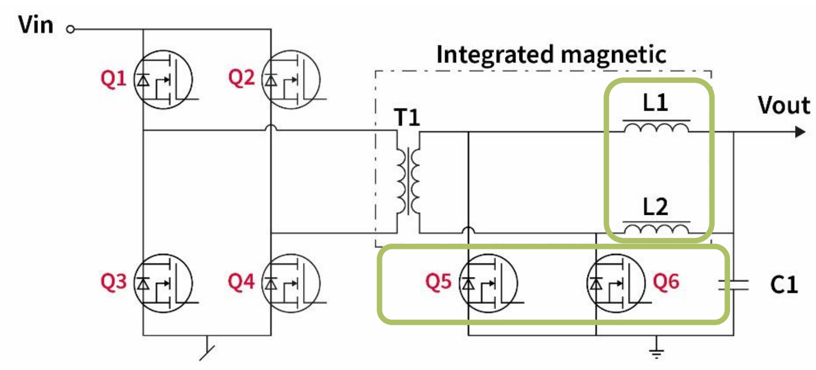


Figure 2. Power stage schematic (simplified)

Minimize transients with peak current mode control

- **Control stage**
  - Current mode control used to ensure that current through both inductors is the same
  - Closed-loop control
    - UC1825 rad hard controller IC
    - Peak current mode with slope compensation
    - Limits duty-cycle for each PWM output
  - Current through the switches is measured using current sense transformer
  - PWM signals are generated by gate drive transformer

- **EMI filter**
  - Input filter uses 2nd order LC filter with LR dampening
  - The selected topology means that EMI 1st harmonic for both input and output is twice the switching frequency

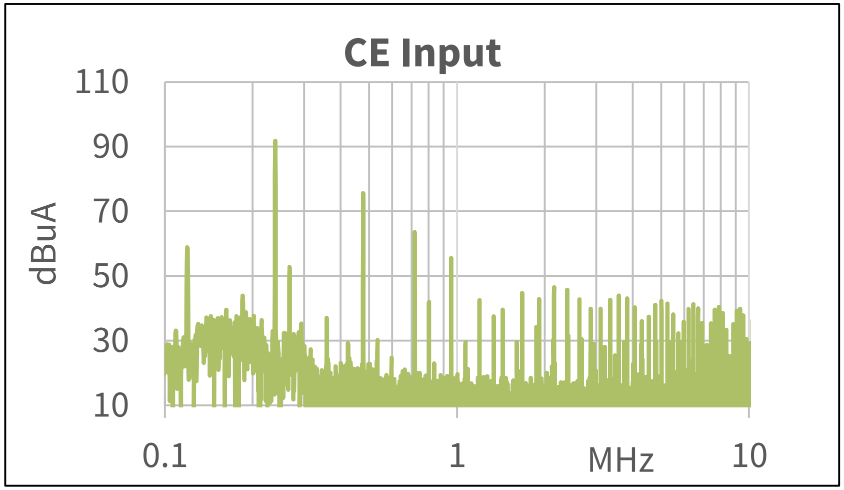


Figure 3. Conducted EMI at input of DC-DC converter

Stable and nominal waveforms

- Amobeads are used in series with drain of MOSFETs to reduce the overshoot in drain-source voltage
- Converter efficiency can be improved by optimizing/reducing amobead size, but at the expense of voltage overshoot
- For low-side switch in full-bridge primary, a nominal voltage (during off-state) of 50V is noted (Ch2)

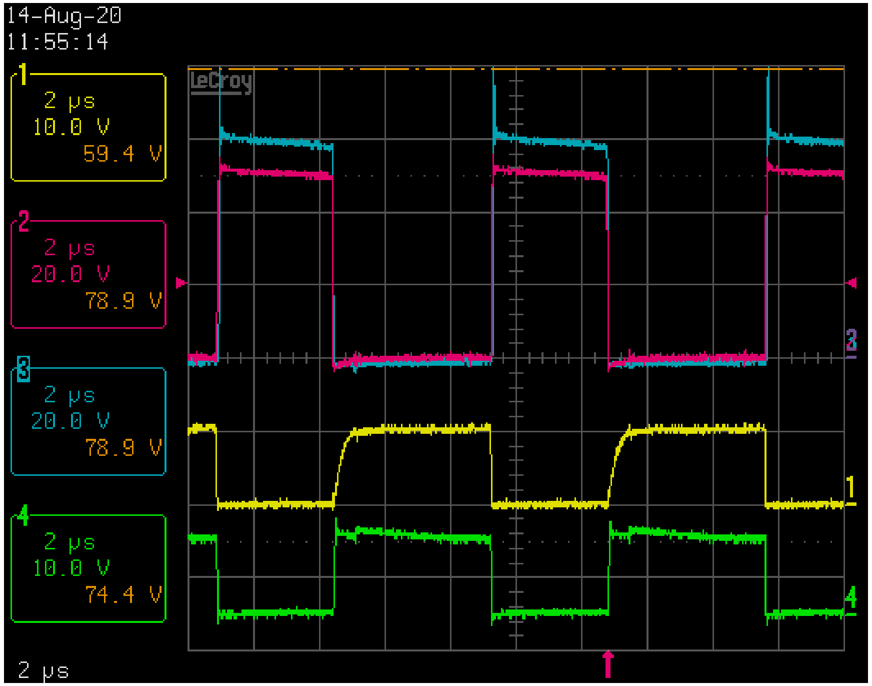


Figure 4. Gate and drain voltage waveforms across MOSFETs Q4, Q6

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

Minimize output voltage ripple

- With two output inductors operating in parallel and 180° phase shifted
  - Output ripple frequency is 2x the switching frequency
  - Output ripple current through capacitor is reduced
  - Output ripple voltage is reduced
  - Reduces the size of output capacitor required
- For an output of 24V, peak-to-peak voltage ripple of 25.7mV (1.46mV rms) is observed

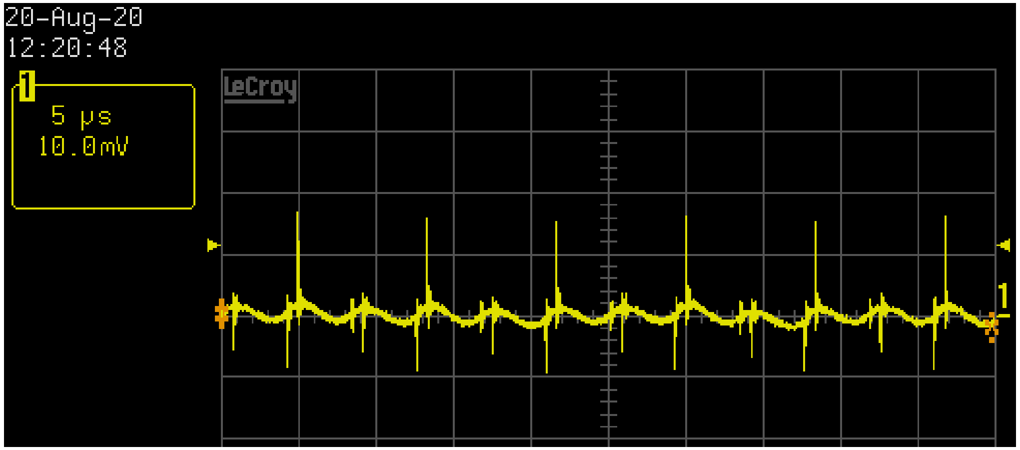


*Figure 5. Output voltage ripple**

**The asymmetry observed in the waveform of output voltage ripple is due to the noise from the main transformer being picked up by the measuring probe at output.*

Power conversion efficiency
based on parameter values at room temperature

Rad hard MOSFET generation	Max load	Operating efficiency
R9	**260W**	**95.49%**
R5	195W	94.89%
R9	195W	95.89%

*modeled calculations

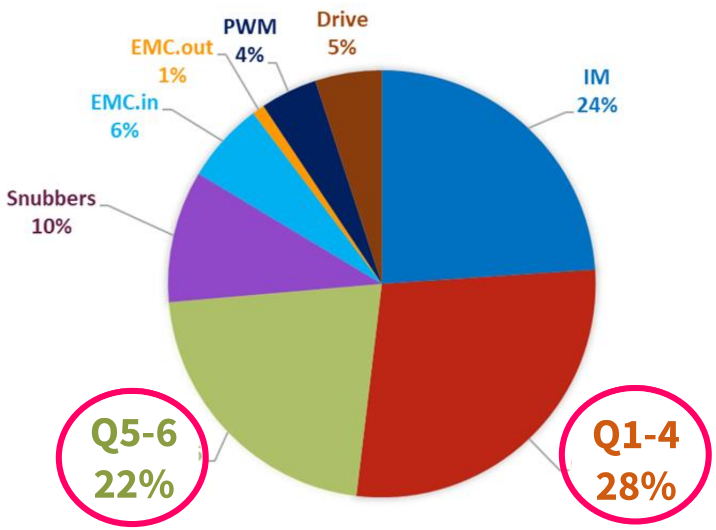


*Figure 6. Power losses distribution in 195W DC-DC converter with **R9 MOSFET (IRHNKC9A7130)***

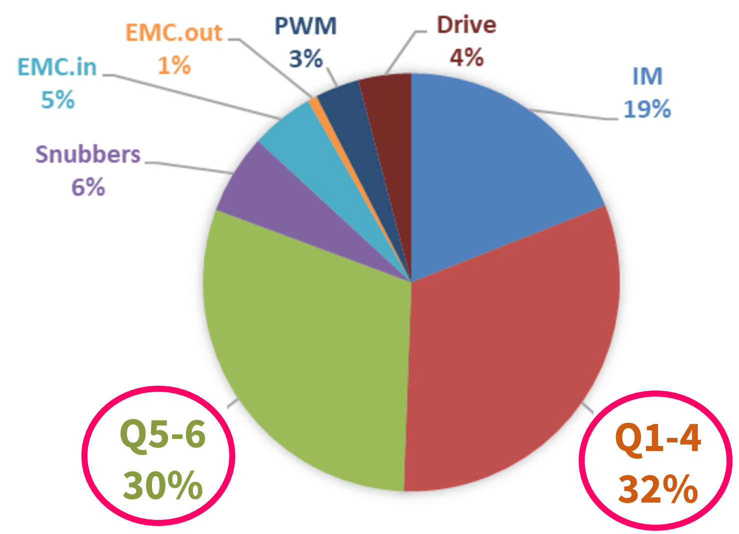


*Figure 7. Power losses distribution in 195W DC-DC converter using **R5 MOSFET (IRHNJ57130)***

Power conversion efficiency

comparing R9-based DC-DC converter to prior MOSFET generations

- **R9 MOSFET delivers the highest efficiency and greatest output power**
- Each newer generation Si MOSFET shows
  - improved efficiency
  - higher load capability
- Circuit reuse enables faster system design and approvals while delivering improved performance and reliability

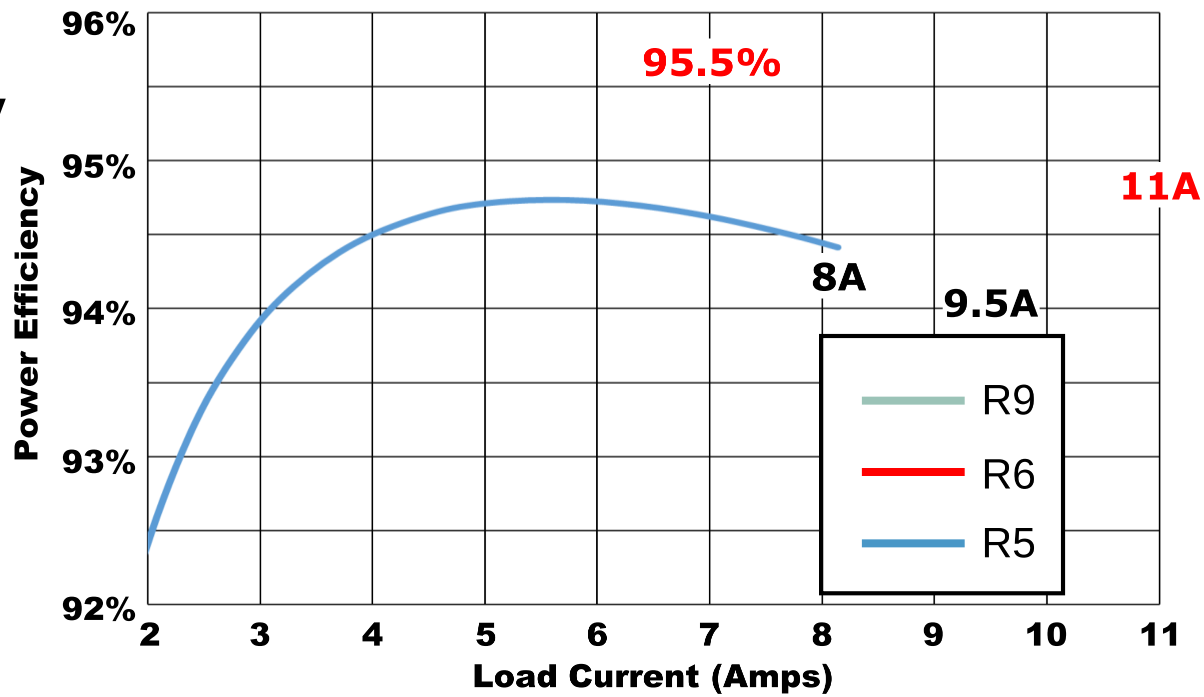


Figure 8. Modeled efficiency vs. load curve of rad hard DC-DC converter at 25°C baseplate temperature (V_{out} = 24V)

Peak efficiency of 95% is observed at 22°C

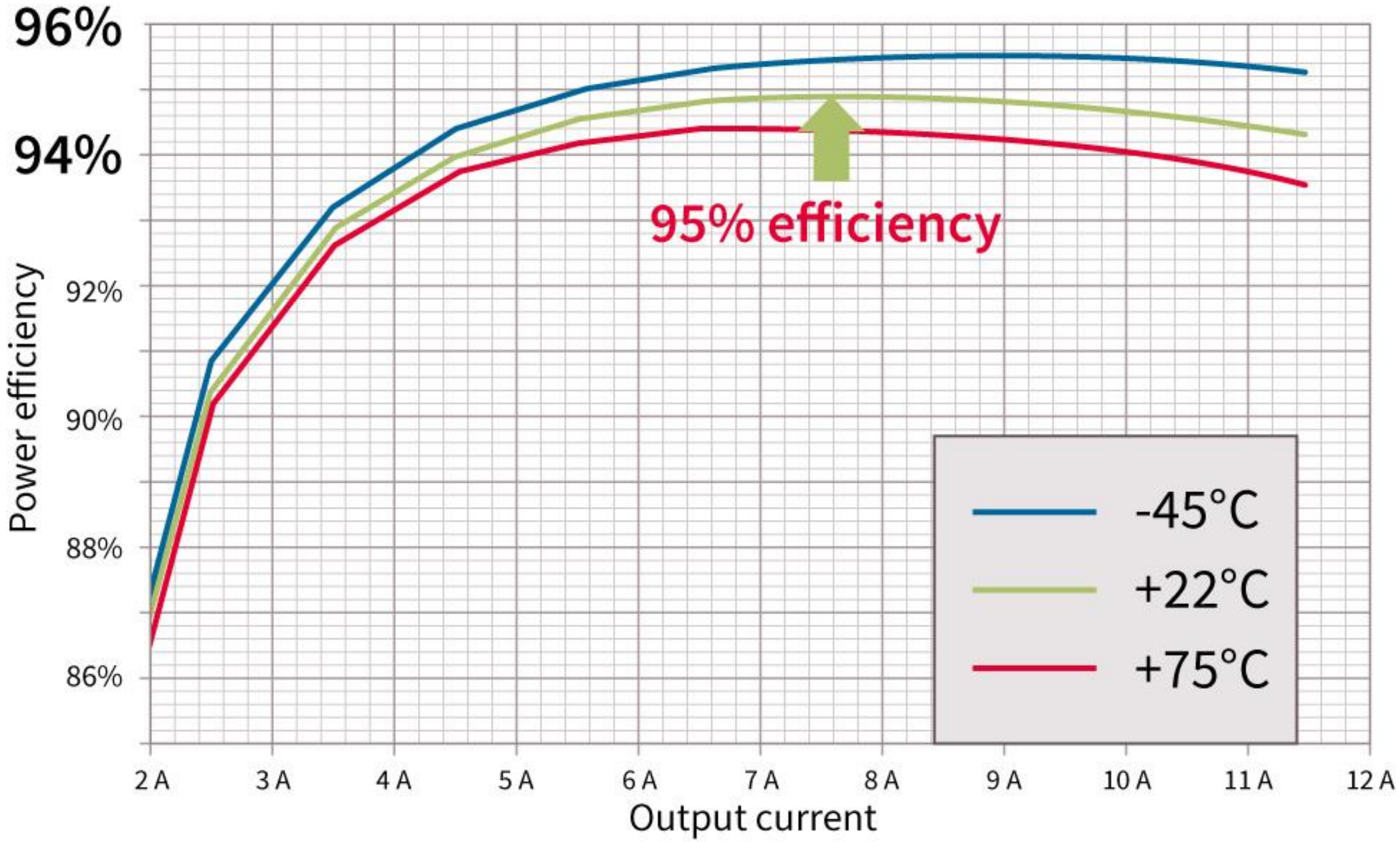


Figure 9. Measured efficiency vs. load curve
(without auxiliary power supply consumption)

R9 rad hard Si MOSFETs enable higher efficiency and power density in flight-proven designs

- This 260W DC-DC converter shows a best-in-class peak power conversion efficiency of 94.55% at room temperature

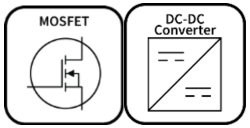
- Reuse heritage DC-DC converter designs easily with R9 Si MOSFETs
  - Improved power efficiency
  - Higher output power
  - Simple drop-in MOSFET replacement
  - Minimal circuitry changes
  - Low-risk upgrade path for immediate benefits

IR HiRel

R9 MOSFETs

Improve circuit performance

N-channel and P-channel



Portfolio innovations enable higher performance, greater power densities and design reuse

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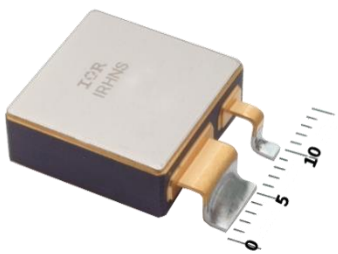
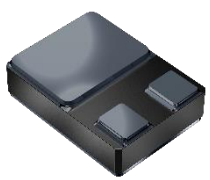


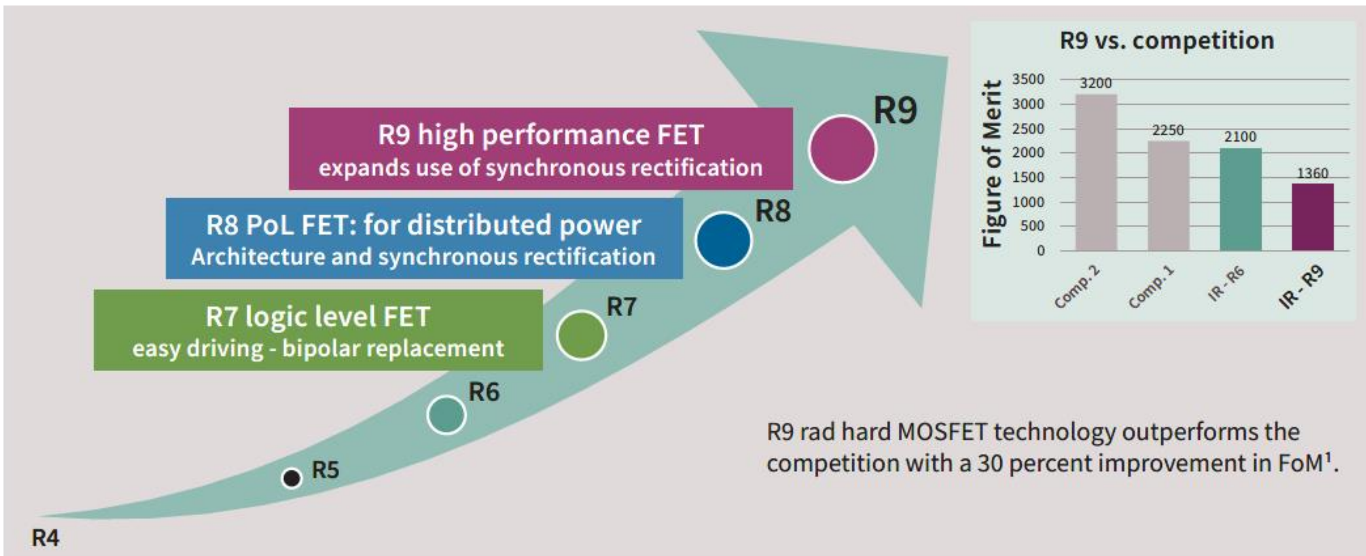
SupIR-SMD

Better than SMD-2 on Carrier, 37% smaller and 45% lighter

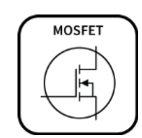


SMD-0.5e

Improved design Direct-to-PCB mounting



1 Figure of Merit is $R_{DS(on)}$ x Q_G (Gate Charge)



R9 offers designers more choices

R9 vs R5 N-channel

- Same electrical performance, smaller package size (SMD-0.2 v SMD-0.5)
- Same package size, better performance (FoM 0.81 v 1.35)
- Reduced BoM by using higher voltage device for lower voltage socket (100V v 60V)

	R9	R5	R9	R9
Voltage	60V			100V
FoM	0.93	1.35	0.81	1.63
Id (A)	25	22	40	35
Package	SMD-0.2	SMD-0.5		
	IRHNMC9A7024	IRHNJC57034	IRHNJC9A7034	IRHNJC9A7130

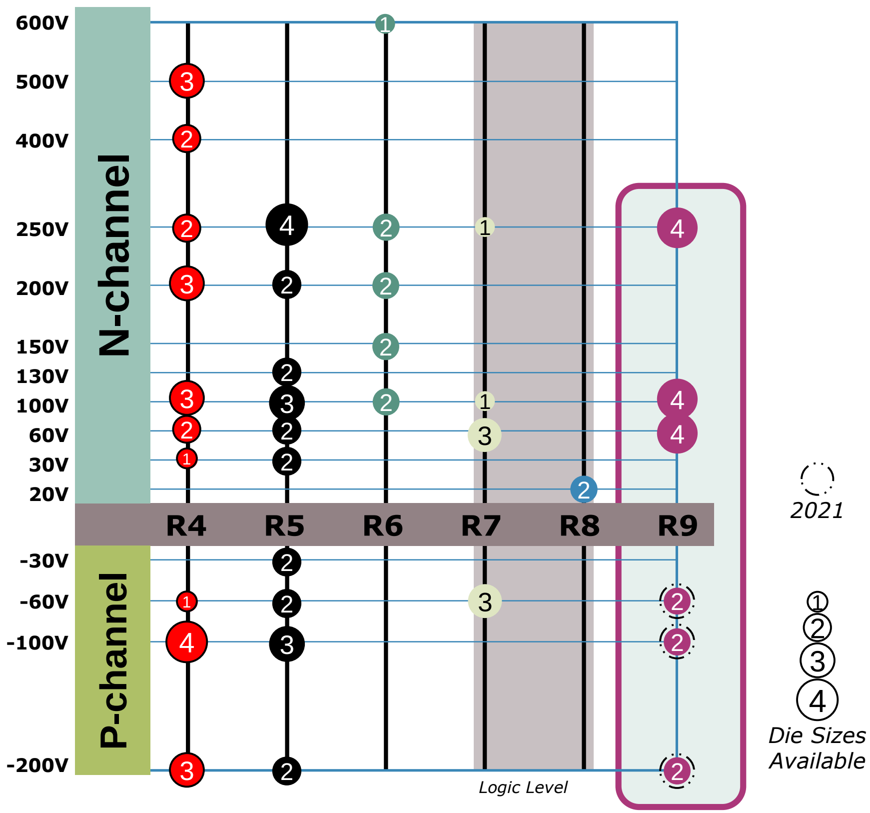
R9 offers designers more choices

R9 vs R5 vs R6 N-channel

› 100V requirements
  – R9 has improved FoM even with a smaller package
  – R9 can be used at higher current in the same package

	R9	R5	R6	R9
Voltage	100V			
FoM	1.26	3.0	2.1	1.63
Id (A)	23	22	22	35
Package	SMD-0.2	SMD-0.5		
	IRHNMC9A7120	IRHNJC57130	IRHNJC67130	IRHNJC9A7130

Industry-leading rad hard MOSFET product portfolio, most are available as DLA-qualified QPLs



N-channel: 20V to 600V

P-channel: -30V to -200V

- **R9** — **Best all-around Figure of Merit**
- **R8** — Designed for low voltage POL designs
- **R7** — Designed for logic level gate drives
- **R6** — Best performance for mid to high-voltage designs
- **R5** — Optimized performance for low to mid-voltage designs
- **R4** — All purpose MOSFET, legacy design with extensive space heritage

IR HiRel performs 100% screening of all components in accordance with specified quality levels, including MIL-PRF-19500 and MIL-STD-750

MOSFET

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