

Performance Benchmarking of Si IGBT and SiC MOSFET in a 1200 V / 600 A Automotive EVD Power Module

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Introduction

- 1200 V traction inverters demand compact, high-efficiency modules: the Si IGBT is the established solution, the SiC MOSFET cuts switching loss but costs more per semiconductor area.
- Both chipsets are built into the **same** 1200 V / 600 A EVD (Electric Vehicle Drive) direct-cooled package (Fig. 1), so only the semiconductor differs.
- The benchmark accounts for **raw material costs, energy consumption under realistic drive cycles**, and the resulting **total cost of ownership**.

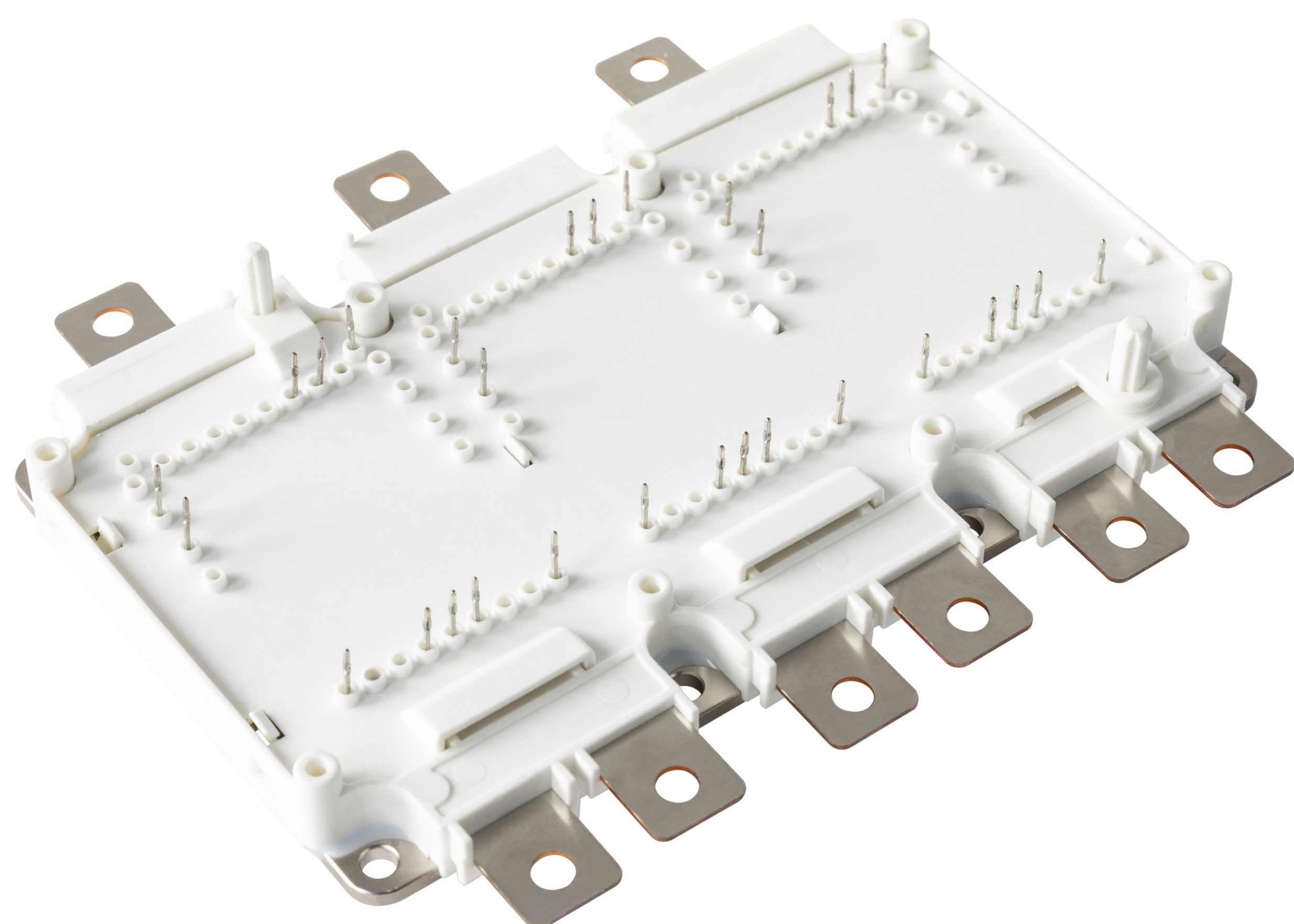


Fig. 1 Assembled 1200 V / 600 A EVD direct-cooled power module, housing either the Si (IGBT and diode) chipset or the SiC MOSFETs.

Static Characteristics

- The IGBT shows a knee-voltage offset, while the unipolar SiC shows linear output characteristics, with far smaller V_{DS} drop at the light loads that dominate real driving.

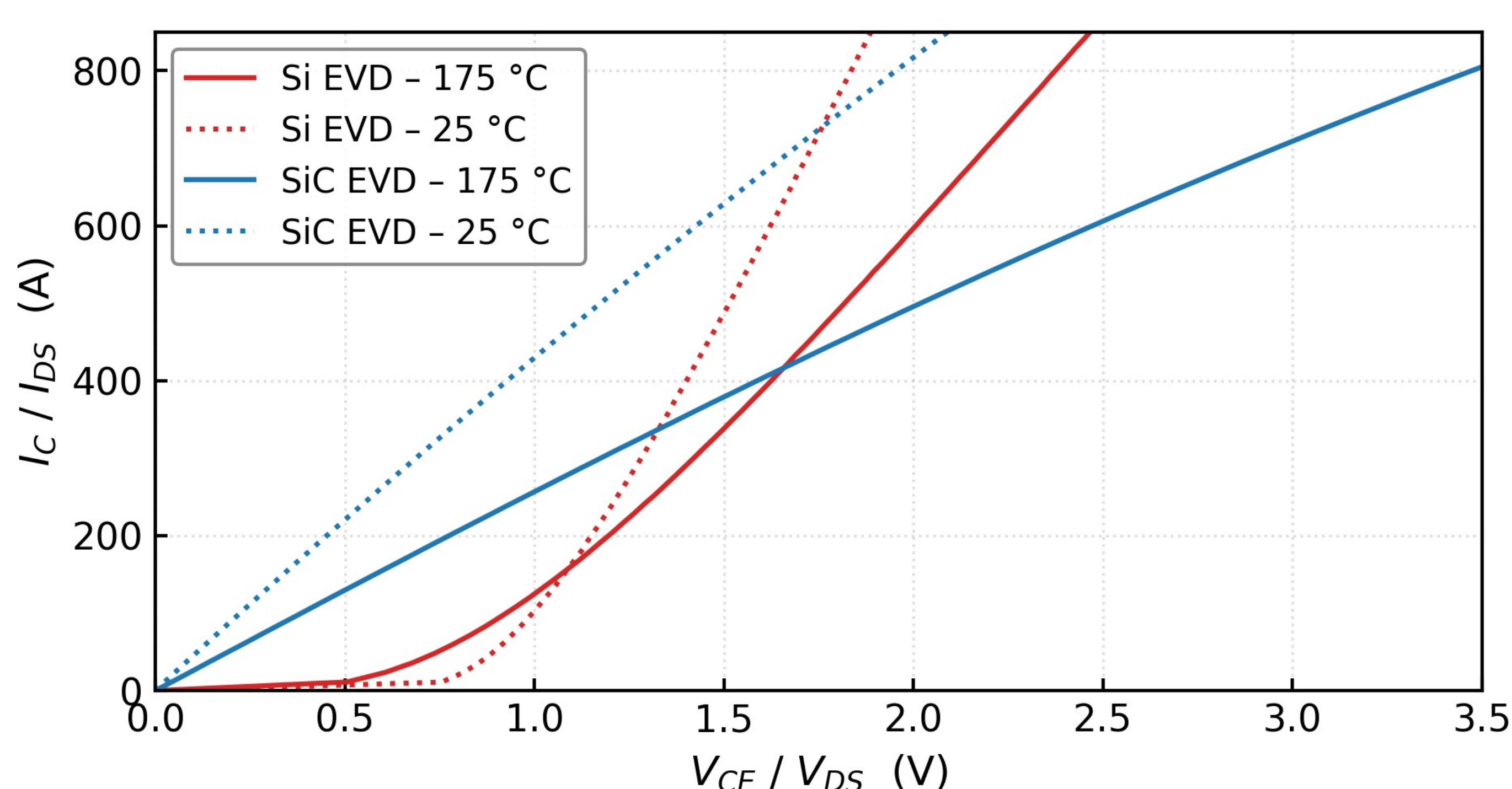


Fig. 2 Output characteristics of Si EVD ($V_{GE} = 15$ V) and SiC EVD ($V_{GS} = 18$ V). Dotted: 25 °C, solid: 175 °C. The positive temperature coefficient of both is favourable for paralleling.

Switching Performance

- Turn-off at 800 V, 600 A, $T_j = 175$ °C, $L_o = 35$ nH: SiC shows a faster voltage rise and current fall with **no tail current** (Fig. 3).
- The IGBT current tail, given by the recombination of the stored minority carriers in the drift region once the channel is off, determines higher turn-off loss.

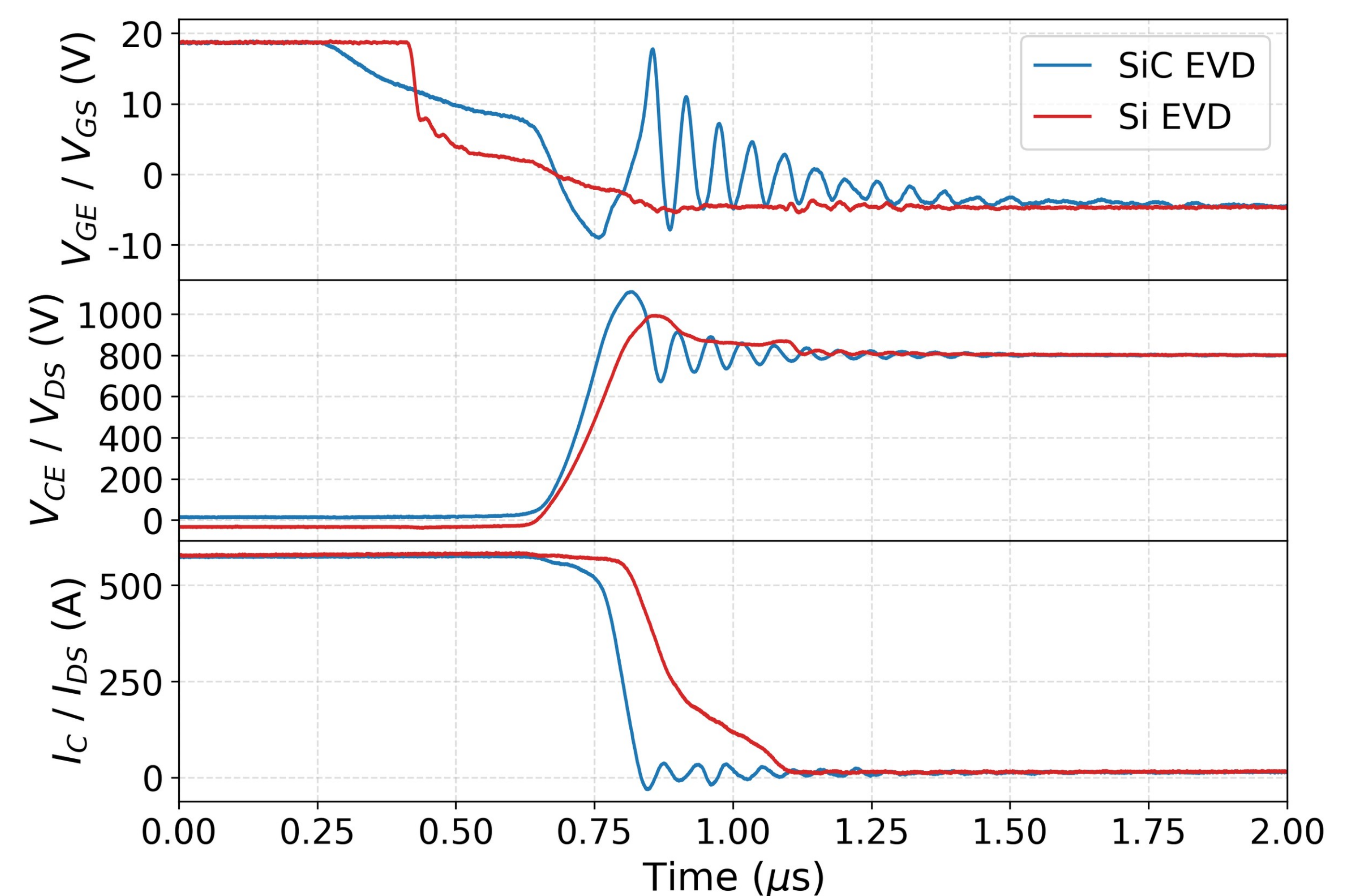


Fig. 3 Turn-off waveforms at 800 V, 600 A, 175 °C, $L_o = 35$ nH.

- At turn-on the Si switching losses are dominated by the reverse-recovery charge of the bipolar freewheeling diode and a broader V_{CE} fall tail (Fig. 4).
- The SiC body diode stores far less charge, so the current overshoot stays small and the SiC EVD reaches **$\approx 3\times$ lower turn-on loss** at comparable di/dt.

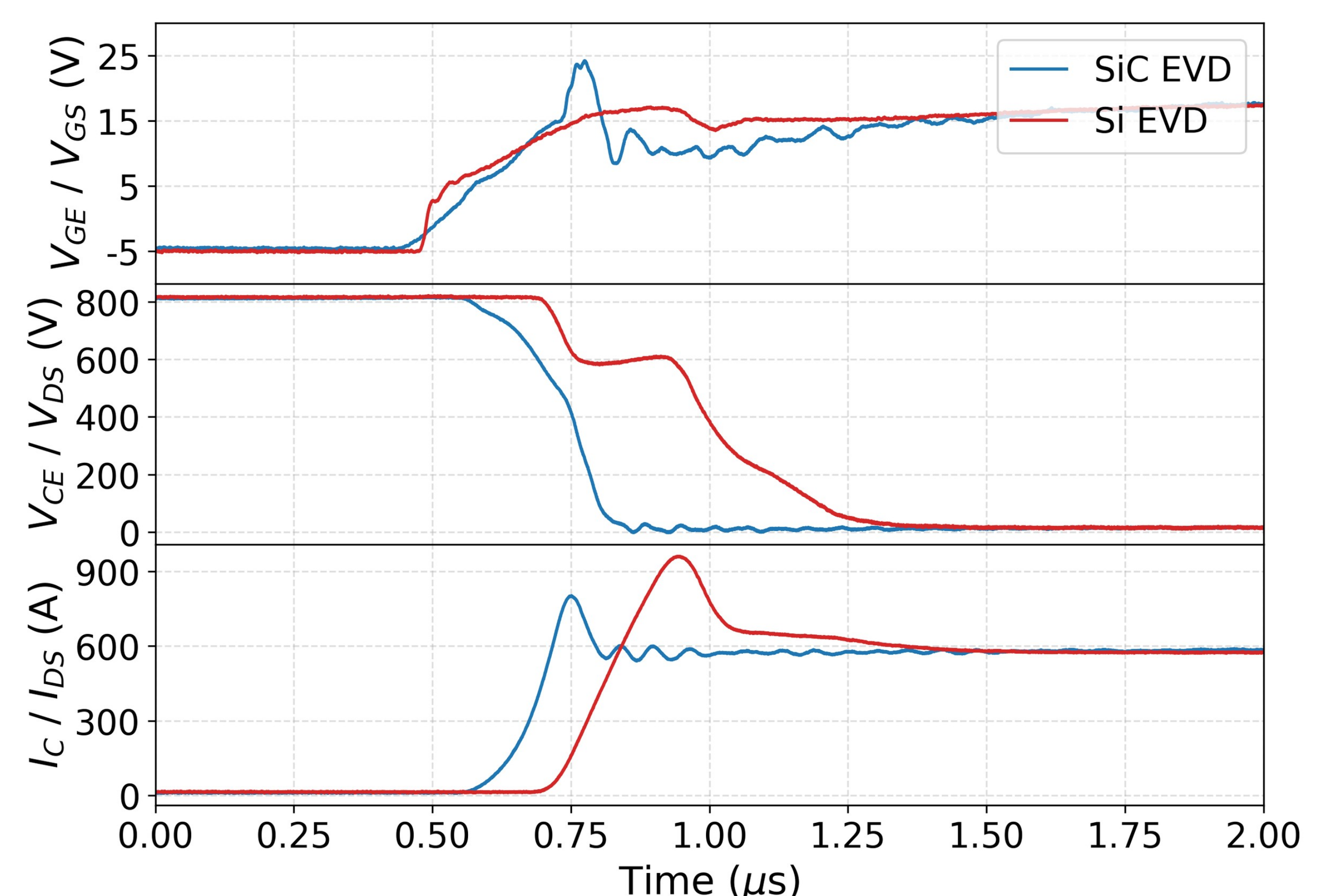


Fig. 4 Turn-on waveforms at 800 V, 600 A, 175 °C, $L_o = 35$ nH; 300 ns dead time for the SiC EVD.

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Packaging Design Optimization

- The die-free bill of material (case, terminals, baseplate, Si_3N_4 substrate) is identical for both variants.
- A **patented substrate and bond layout** contacts the chip source from two sides (Fig. 5): it **halves the wire current density** without costly copper wire and lowers stray inductance and chip-to-chip gate-source impedance, suppressing oscillation between paralleled dies.



Fig. 5 SiC chip bond layout. Left: classic. Right: EVD layout with 2× wire cross-section and halved current density.

Maximum Output Current and Cost per Ampere

- Maximum **continuous** RMS output current at fixed T_j is the **least favourable figure of merit for SiC** and does not capture the drive-cycle conditions of real traction applications. Full simulation conditions in the manuscript.
- At $T_j = 150^\circ\text{C}$ Si leads at low frequency (864 vs 746 A at 2 kHz) but derates steeply, while SiC holds 506 A at 20 kHz vs 301 A (Fig. 6). SiC starts $\approx 2\times$ more expensive per ampere, yet the cost/A curves cross at ≈ 18.4 kHz (150°C) and ≈ 16.8 kHz (110°C) (Fig. 7).

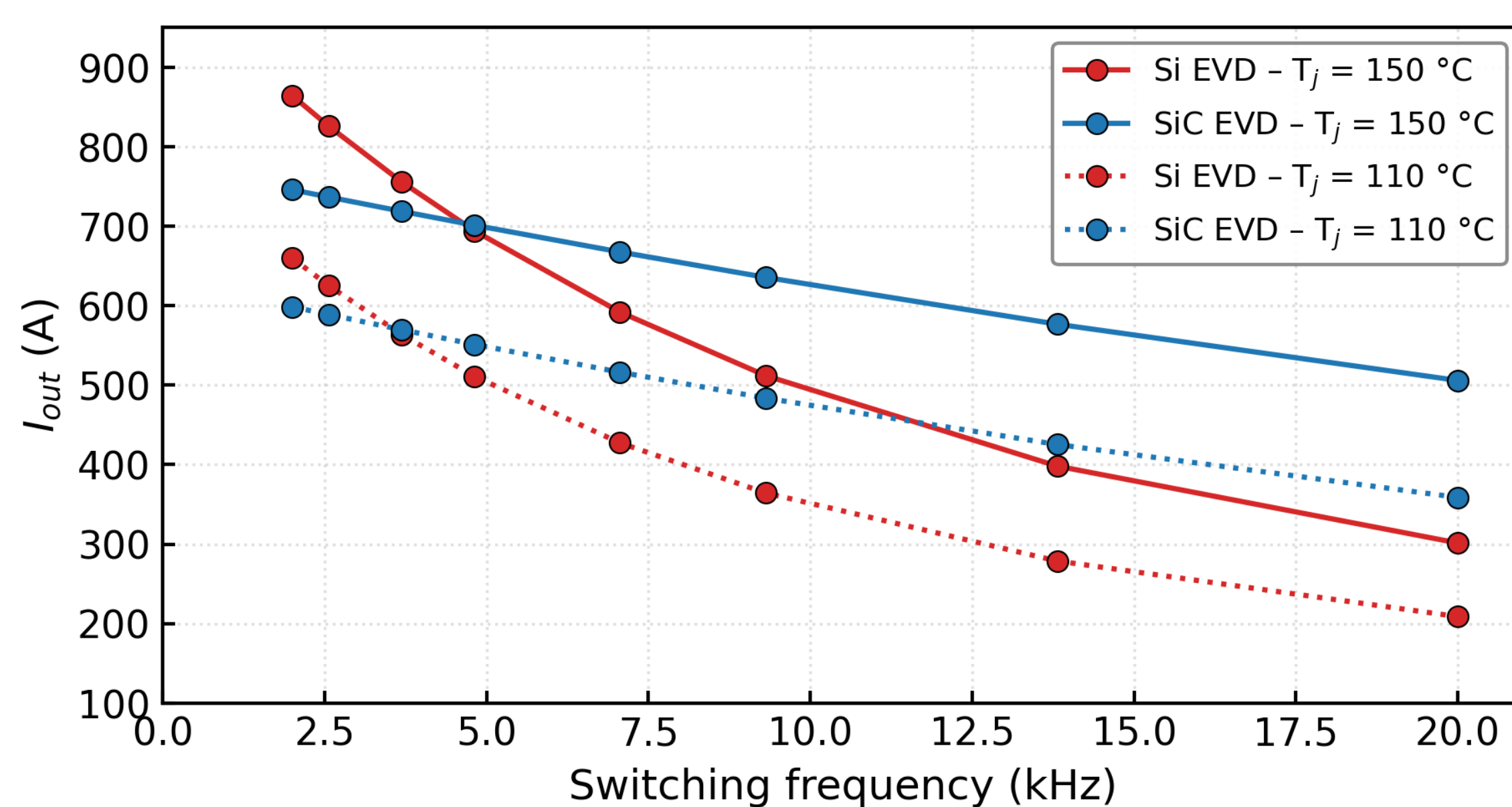


Fig. 6 Maximum RMS output current versus switching frequency at $T_j = 150^\circ\text{C}$ (solid) and 110°C (dotted).

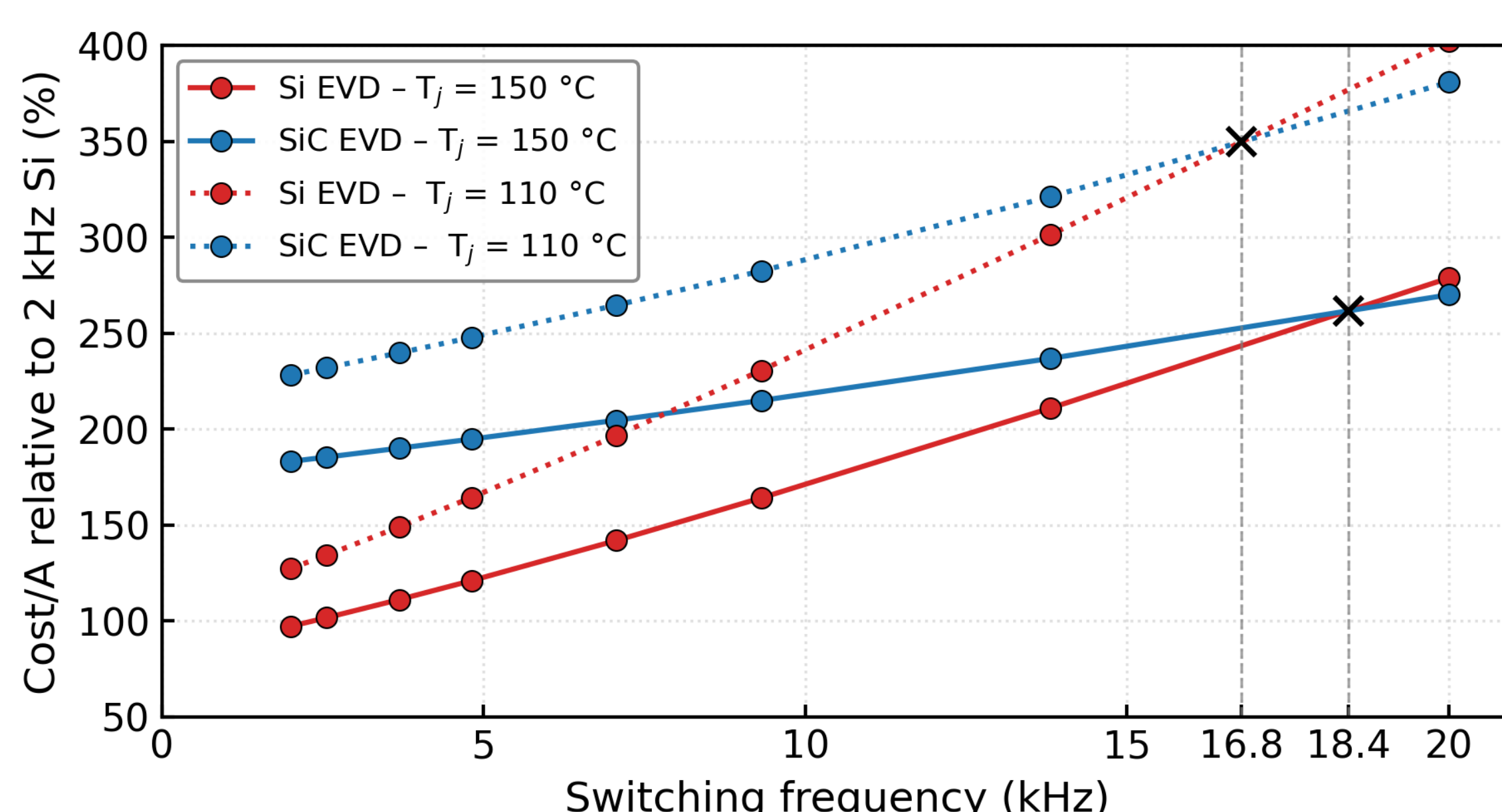


Fig. 7 Module cost per ampere versus switching frequency, normalized to the Si EVD at 2 kHz; $T_j = 150^\circ\text{C}$ (solid) and 110°C (dotted).

Total Cost of Ownership

- A representative 250 kW commercial-vehicle drive cycle (Fig. 8), evaluated at $f_{sw} = 10$ kHz, gives $\approx 2.5\times$ **higher** semiconductor losses for the Si EVD (Fig. 9).
- $E = 5.1 - 2.1 = 3$ kWh are **saved per day** with the SiC module, which allows a 3 kWh smaller battery pack, worth ≈ 260 \$ per vehicle at 85 \$/kWh.

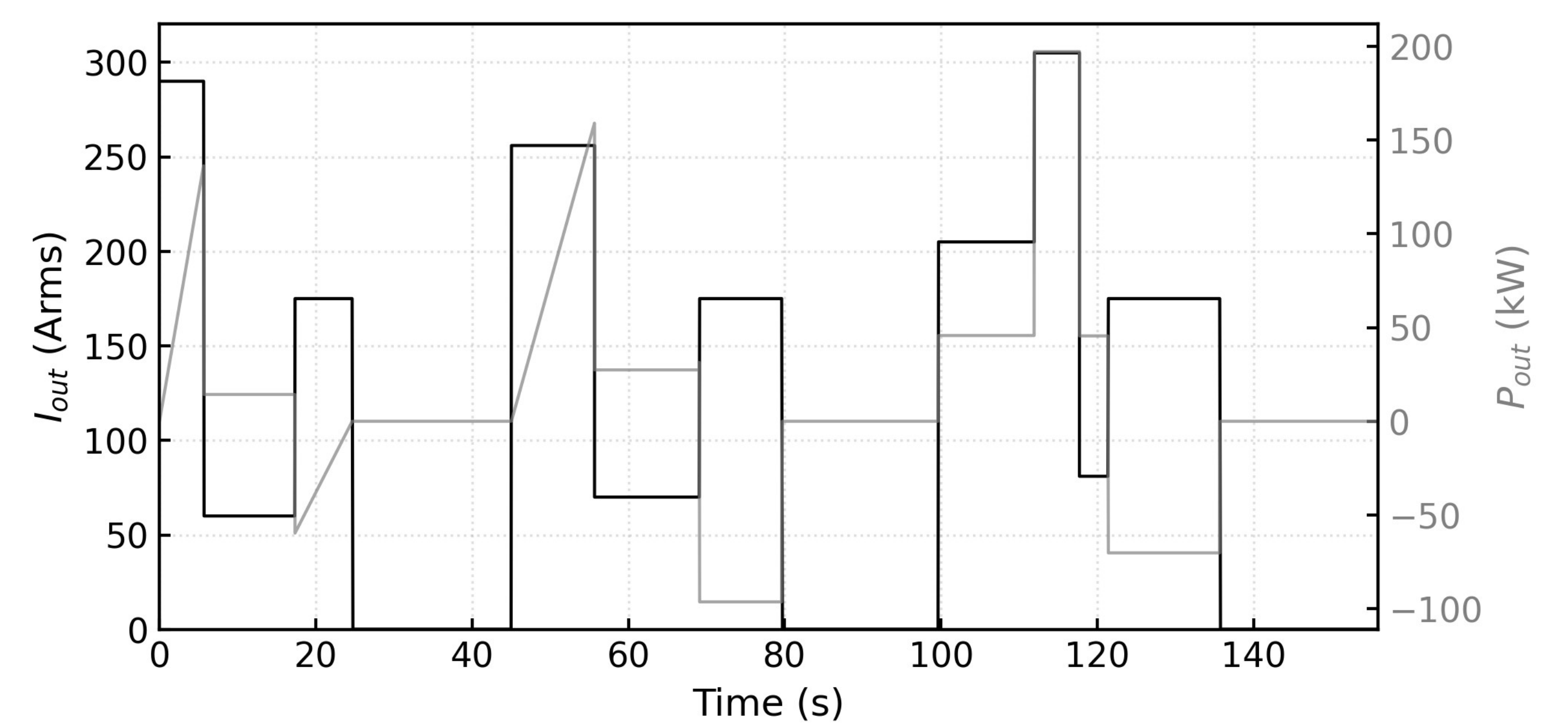


Fig. 8 Drive cycle used as load input: output current and output power versus time. Profile taken from M. Hruska et al., PCIM Europe 2022.

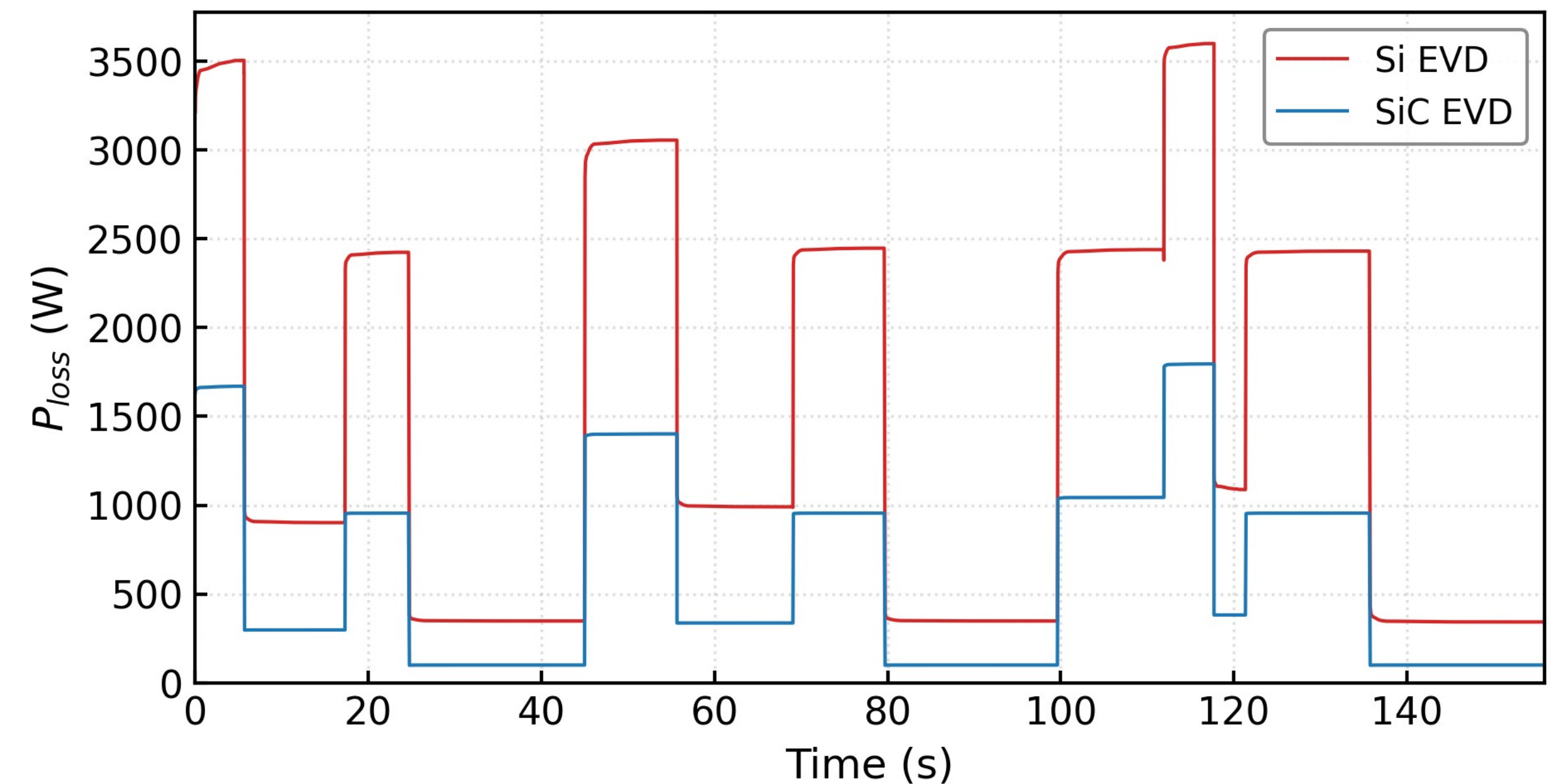


Fig. 9 Semiconductor losses of both EVD modules over the same drive cycle at $f_{sw} = 10$ kHz.

	EVD SiC	EVD IGBT	Basis
E_{cycle} (Wh)	26	64	1 cycle (2 min 30 s)
E_{day} (kWh)	2.1	5.1	80 cycles per day
E_{year} (kWh)	730	1790	350 days per year
Annual cost (\$)	58	143	0.08 \$/kWh (China)
Cost 10 years (\$)	584	1432	
Saving SiC (\$)	848		over 10 years

Table 1 TCO comparison of the EVD modules.

Conclusions

- Under realistic drive cycles the SiC EVD is **favourable from day one**: $\approx 2.5\times$ lower semiconductor losses save 3 kWh per day, worth ≈ 260 \$ of battery capacity at purchase plus 848 \$ of energy over ten years (Table 1).
- The physical reason is **bipolar conduction** in both Si devices: the stored charge must be removed at every commutation, as IGBT tail current at turn-off and diode reverse-recovery charge at turn-on. The unipolar SiC MOSFET stores no such charge.