Next Generation Switched-Capacitor Power Conversion ICs

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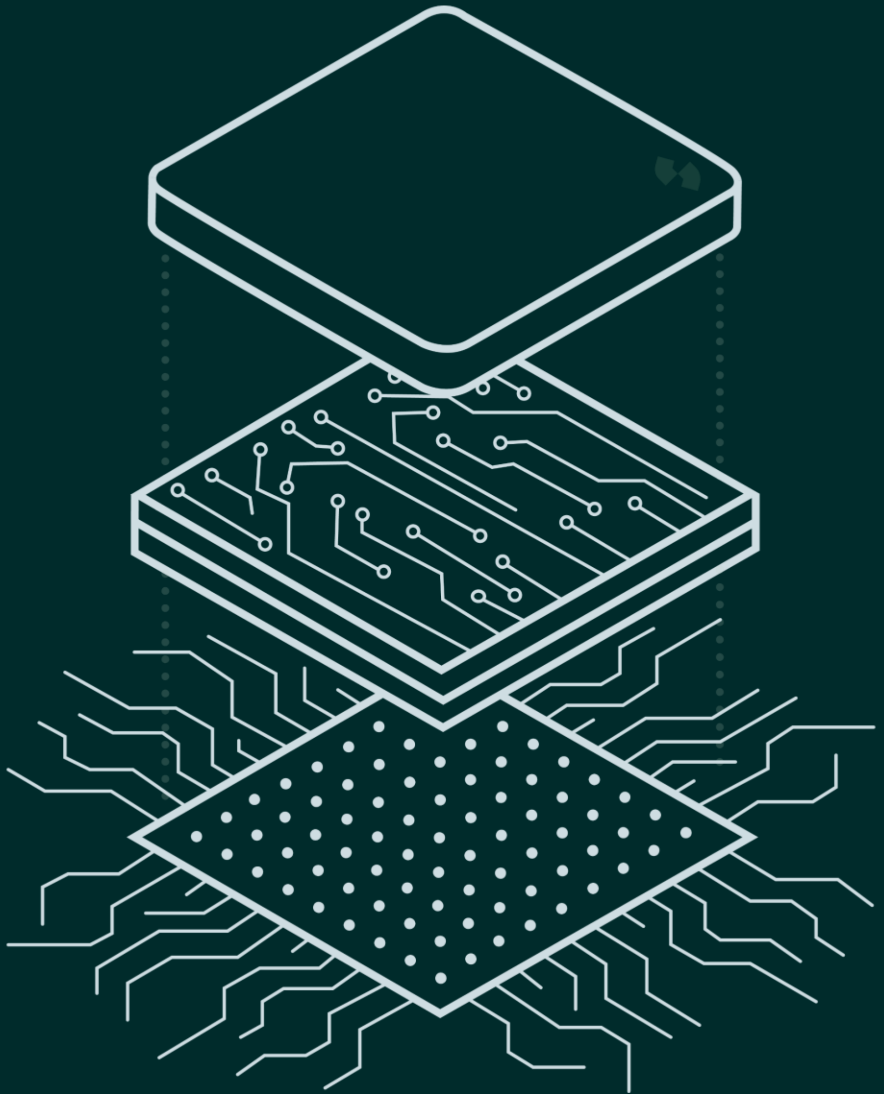

Skycore®

PwrSoC 2023
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Agenda

- Power conversion demands
- Trends: Better Switches, Passives and Topologies
- Enabler: Switched-Capacitor Power Conversion ICs
- Implementation examples
- Other applications

Power Conversion Performance Demands

Automotive & EVs

Smart devices & Laptops

Data centers & HPC

Energy Storage Systems

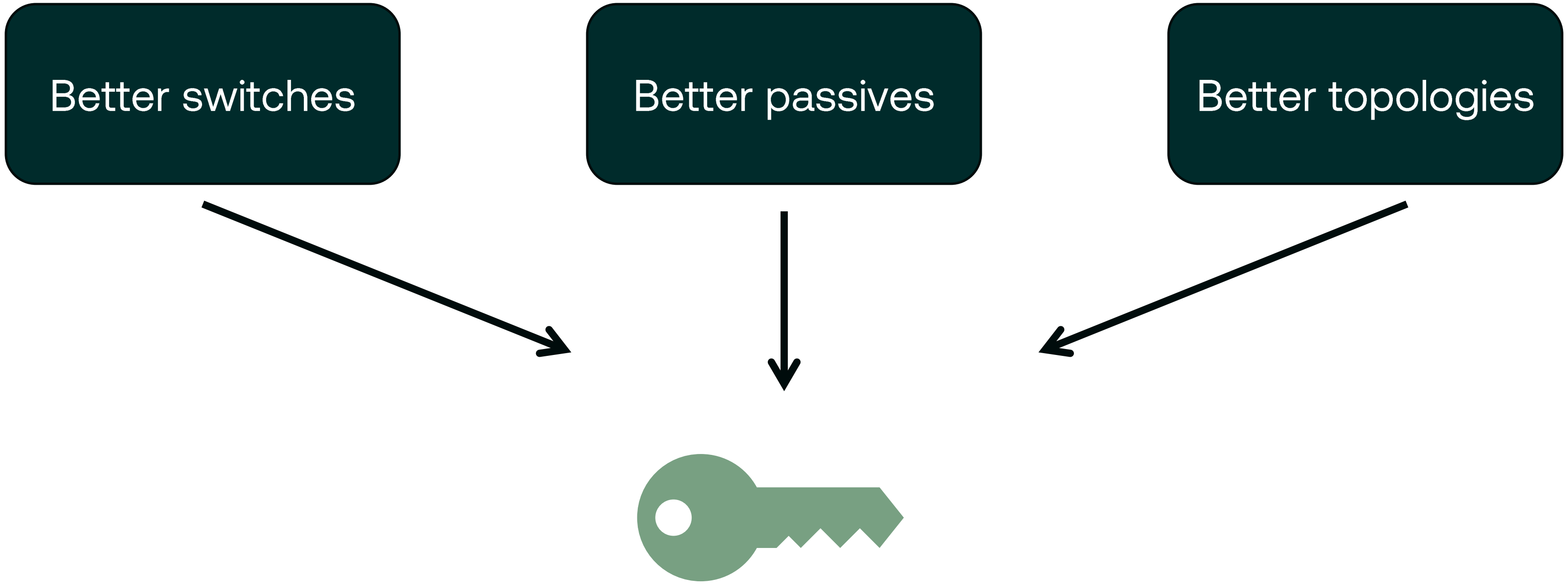
Efficiency ↑↑

Power density ↑↑

Size ↓↓

Cost ↓↓

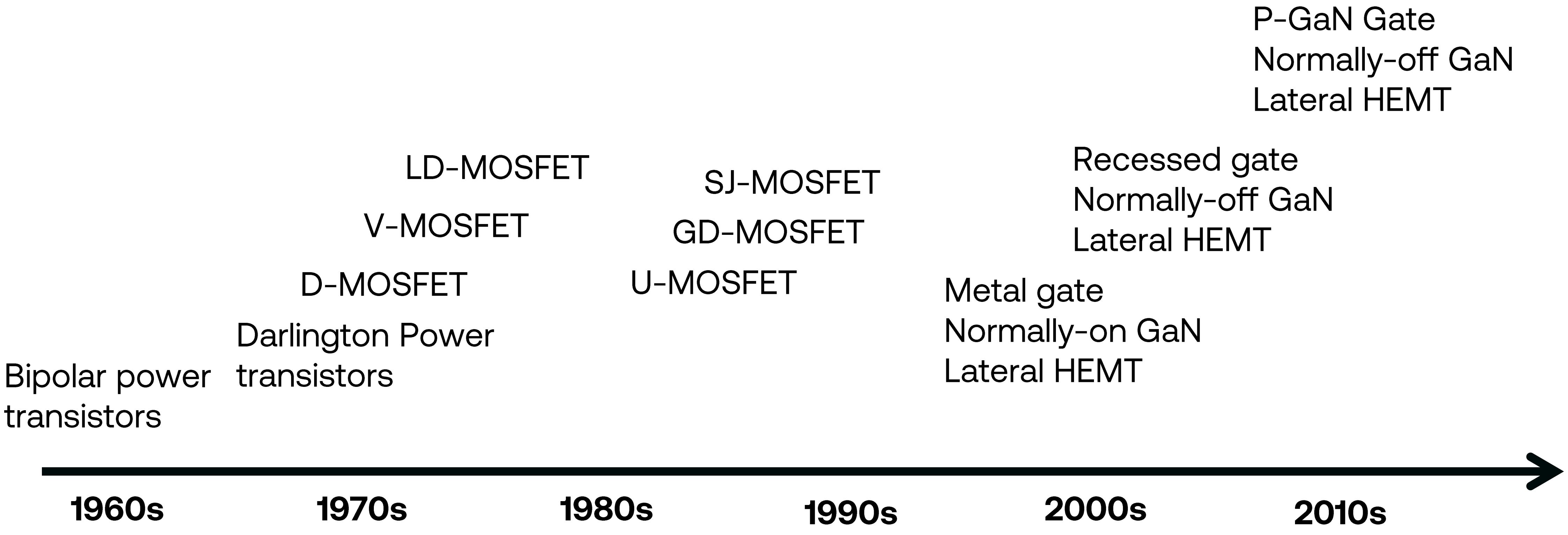
Trends – Power conversion improvements



Power stage, driver & control integration

Trends – Better Switches

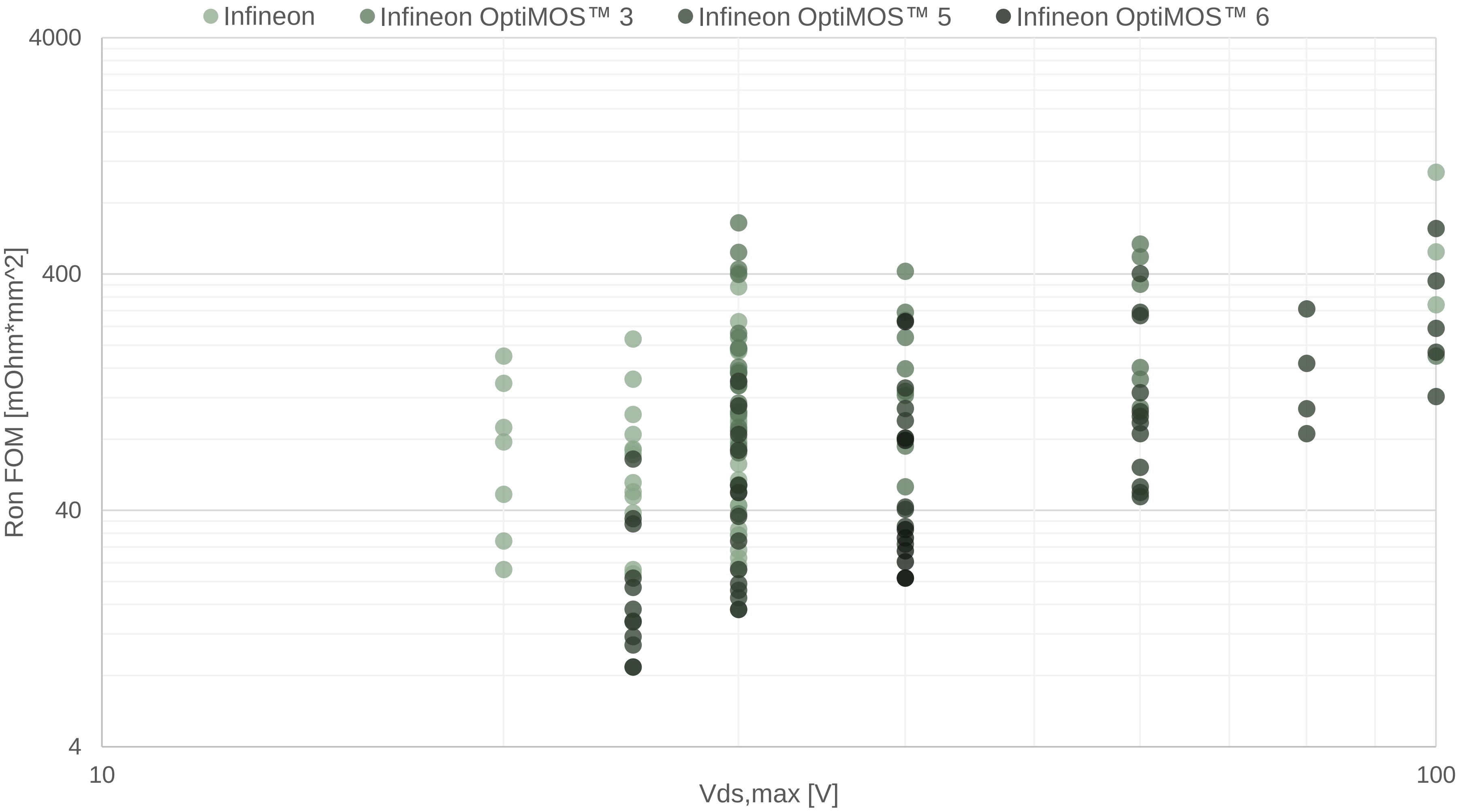
Timeline of selected power transistor innovations



B. J. Baliga, "History and Emerging Designs of Power Transistors", IEEE Electron Devices Society, 2022
M. S. Adler, K. W. Owyang, B. J. Baliga and R. A. Kokosa, "The evolution of power device technology," IEEE Transactions on Electron Devices, 1984

Trends – Better Switches

Both MOS and GaN push the limit of conduction density.



** Only Ron FOM plotted as an example of a performance metric.*

Trends – Better Switches

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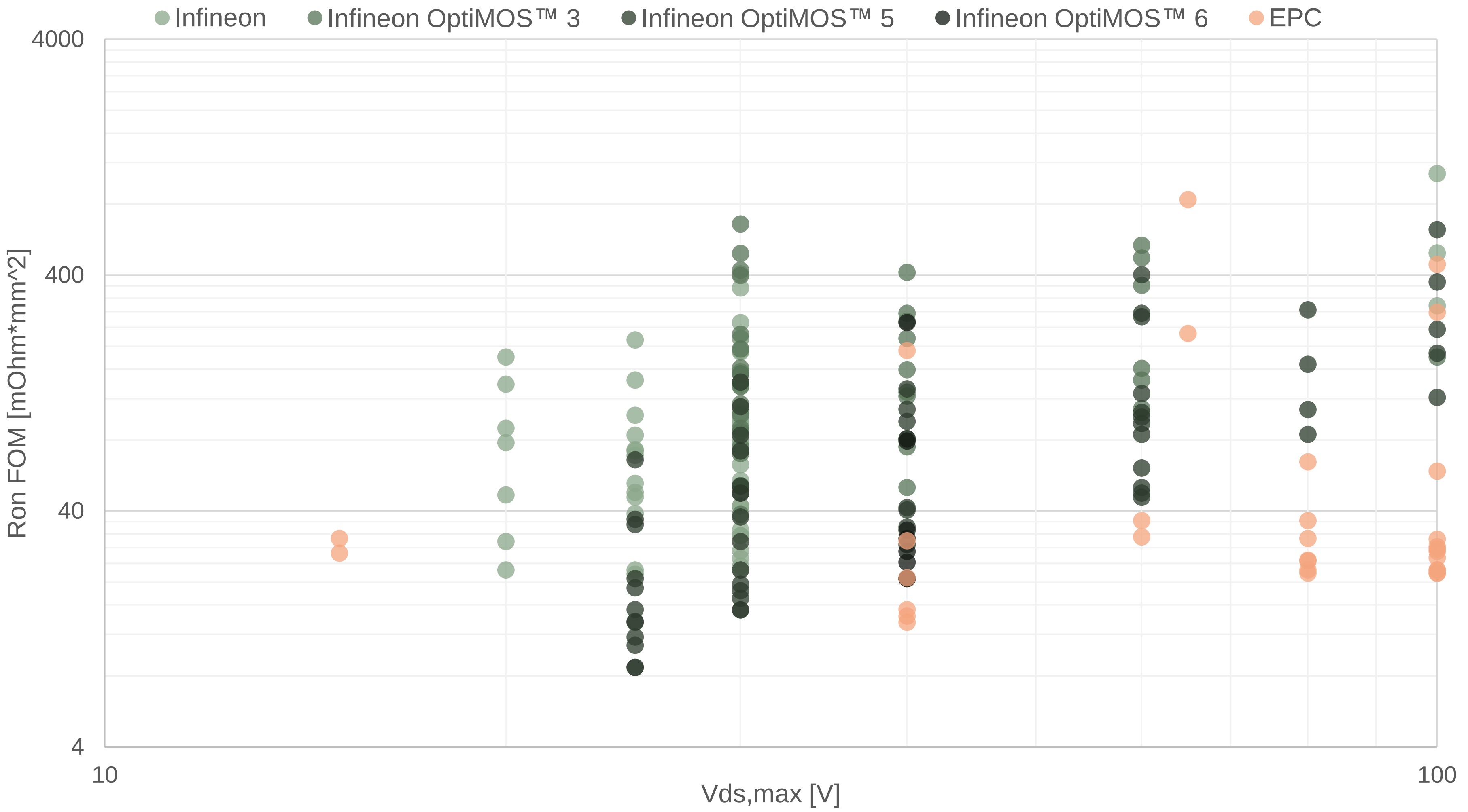

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Trends – Better Switches

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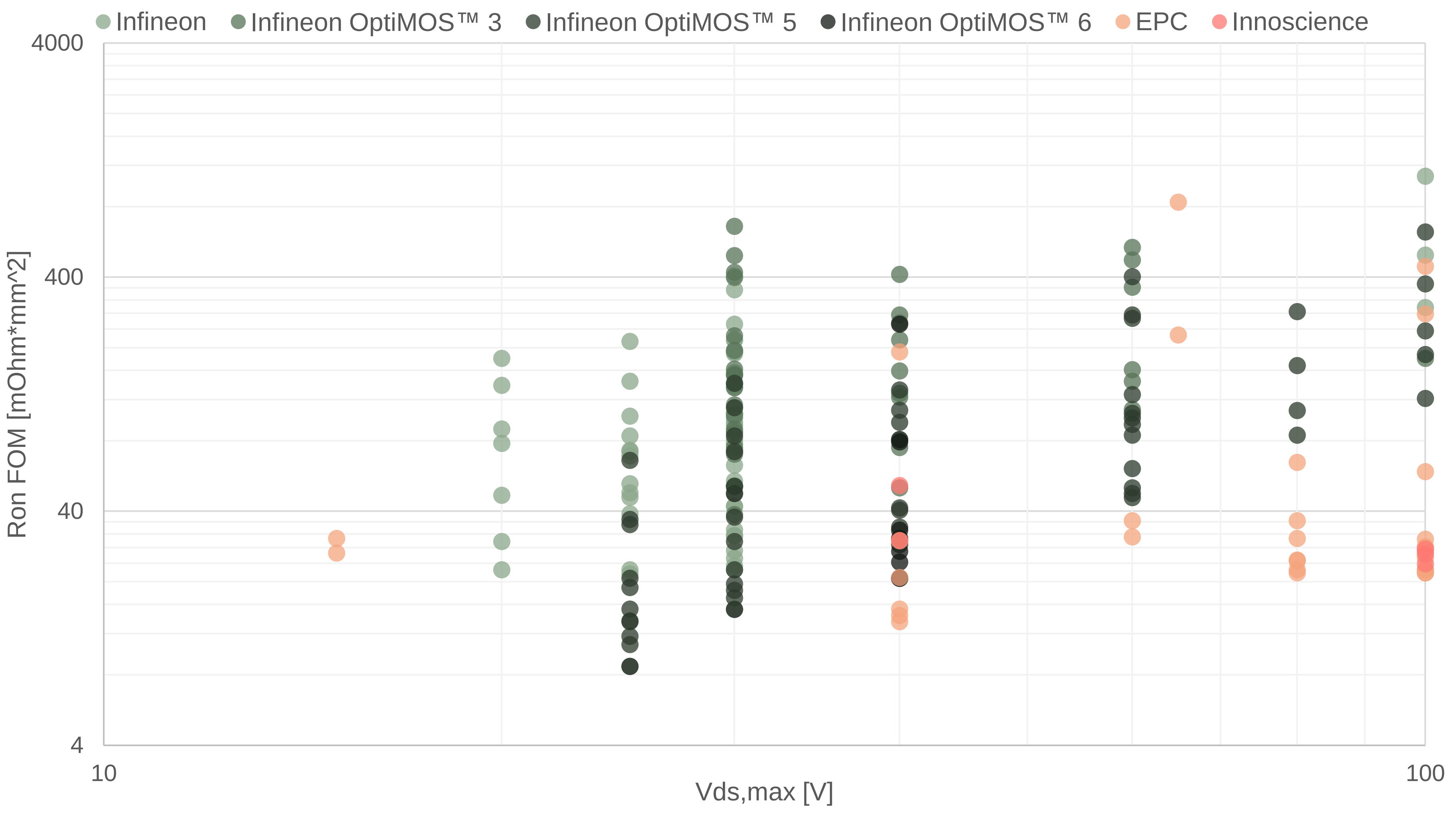


** Only Ron FOM plotted as an example of a performance metric.*

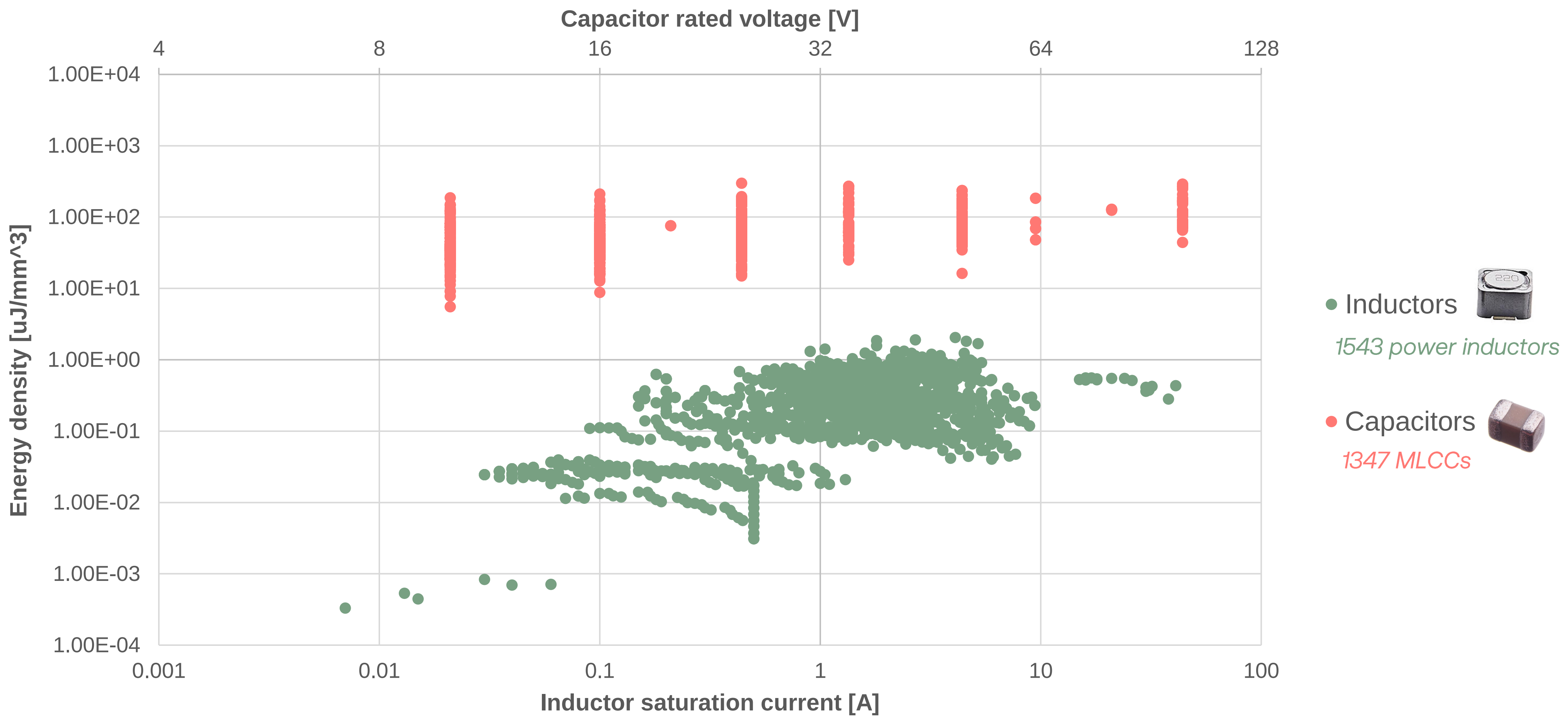
Trends – Better Passives

$$E_C = \frac{1}{2} V_{max}^2 \, C\Big|_{V=V_{max}}$$

$$E_L = \frac{1}{2} I_{sat}^2 L$$

Trends – Better Passives

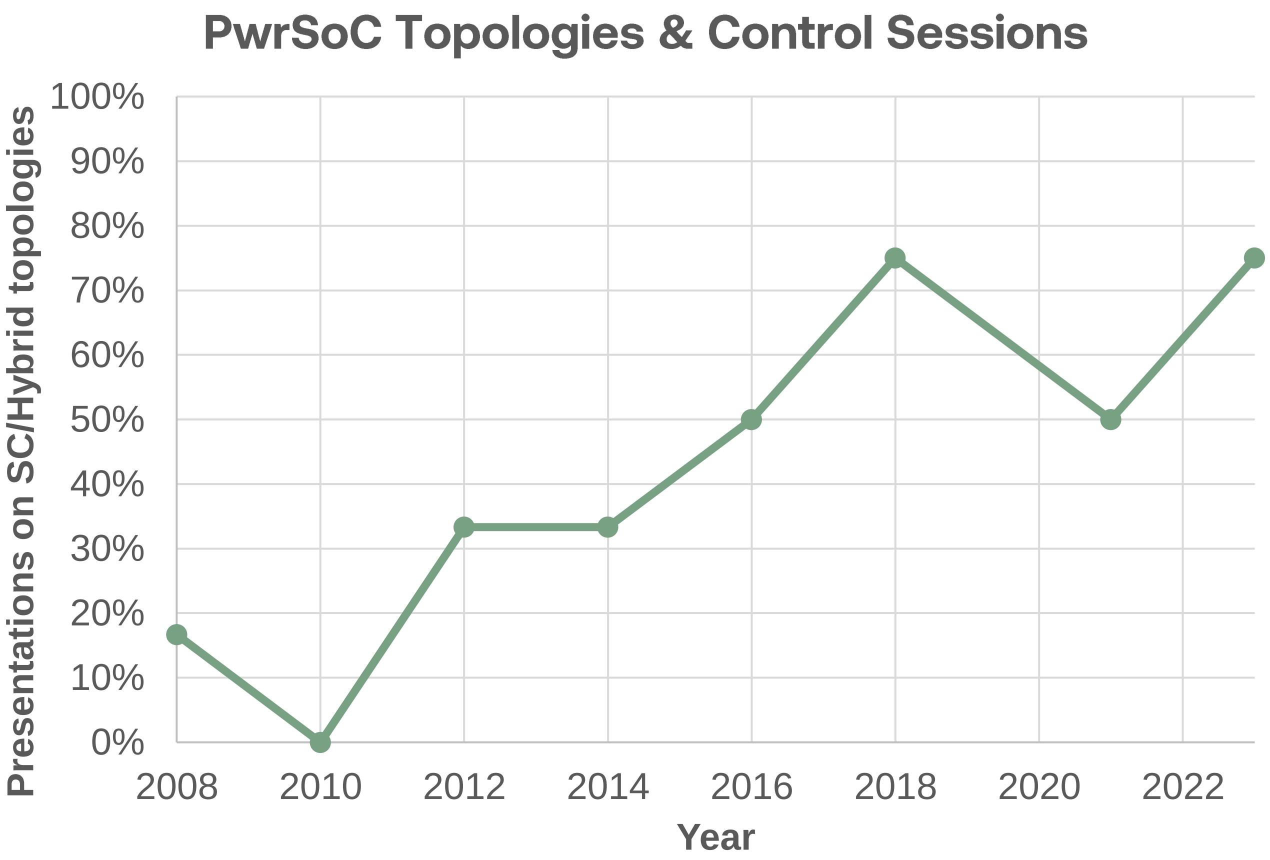
Energy density of commercially available inductors and capacitors.



** Includes DC bias degradation*

Trends – Better Topologies

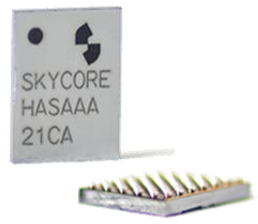
- Switched-capacitor (SC) converters can leverage the high energy-density of capacitors over inductors.
- Both SC and hybrid converters have seen a rising research interest.



Enabler: Switched-Capacitor Power Conversion ICs

Switched-Capacitor Power Conversion ICs

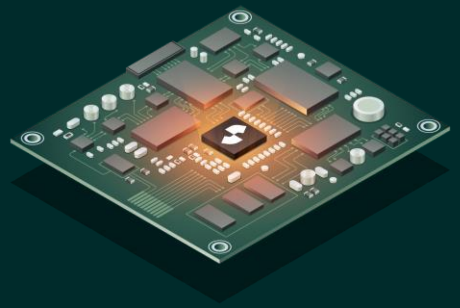
- Leverages capacitor energy storage density
- LDMOS and SOI enable efficient switch implementation
- Enables advanced topologies that require many switches
- Integration of features within the same IC
- Synergy with external switches, e.g., Si, GaN
- Reaches a wide range of applications



Better switches

Better passives

Better topologies

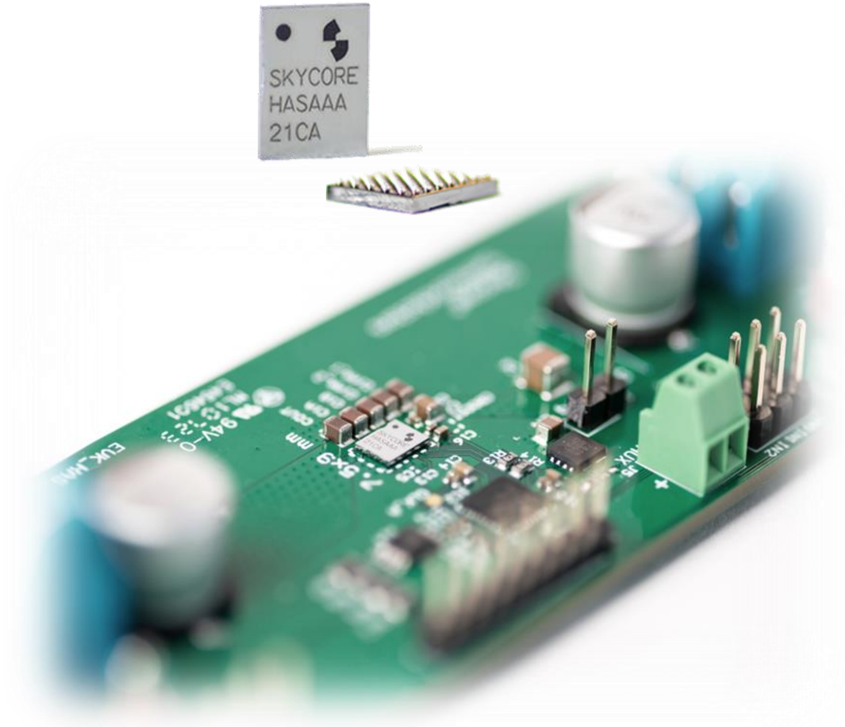


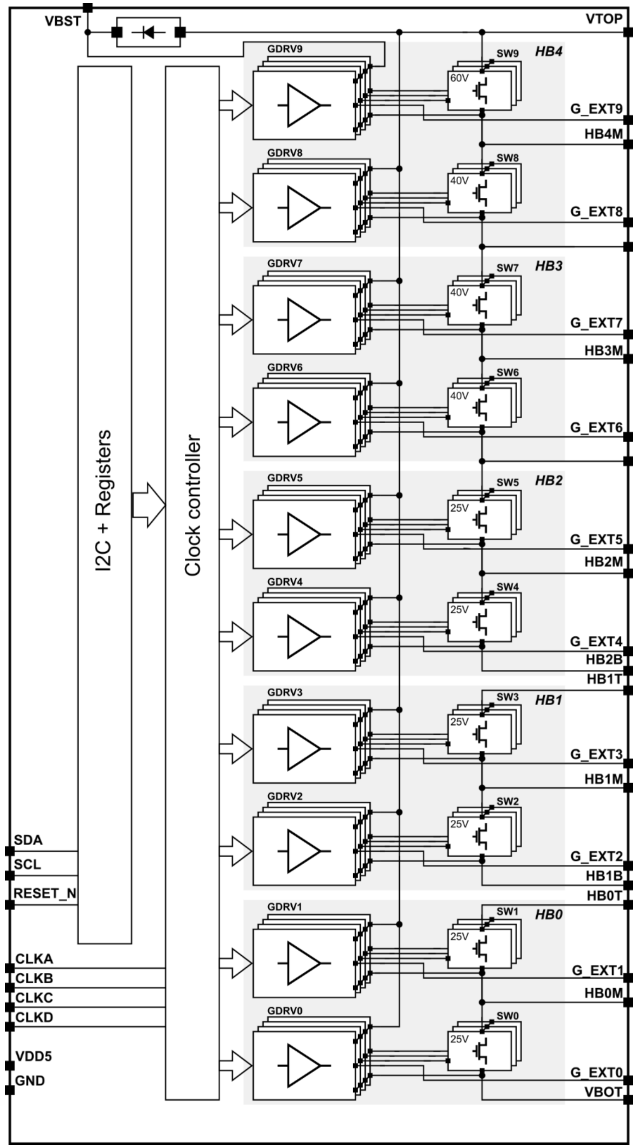
Performance achievable using Switched-Capacitor Power Conversion ICs

Hardware utilized: SCG10ECX

Key characteristics

- Multi-topology Switched-Capacitor IC
- 10-switch internal power stage
- 10 GaN/Si gate drivers
- Switch segmentation
- Advanced clock control
- I2C interface
- 3.55 x 4.61 x 0.61 mm^3 chip size
- WLCSP, 70 balls, 0.45 mm pitch
- **V_{in} = 12-100 V**



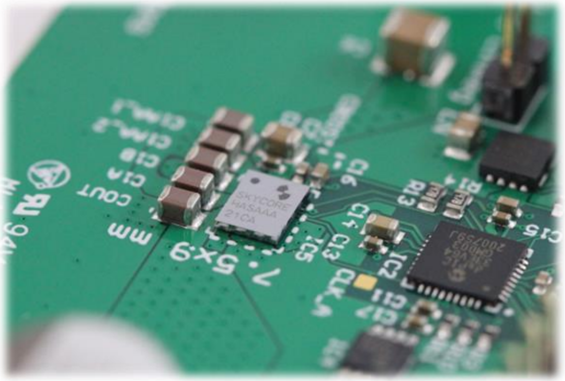


4:1 Dickson SC
48V to 12V, 0-4A

Implementation using SCPC-ICs

4:1 Dickson SC – Internal power stage

Implementation example

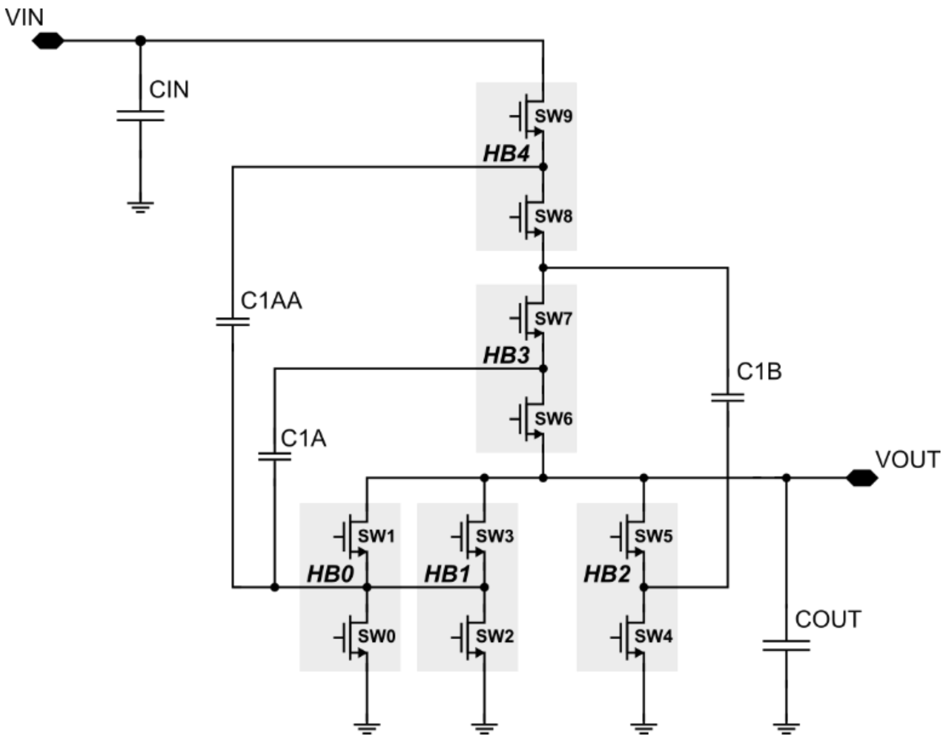


Application: 48 V to 12 V bus

- Voltage Conversion Ratio (VCR): 1/4
- Input voltage (V_{in}): 36 – 60 V
- Output voltage (V_{out}): 9 – 15 V
- Output current (I_{out}): 0 – 4 A

Implementation

- Size: 7.5 x 9.0 mm^2
- Thickness: 1.3 mm

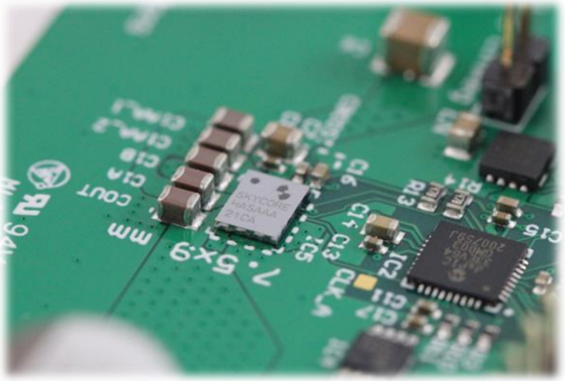


BOM:

- 1x SCG10ECX
- 2x GRM21BC71H475KE11K
- 2x GRM21BC71E106KE11
- 1x GRM155R72A472KA01D
- 1x GRM21BC8YA106ME11K

4:1 Dickson SC – Internal power stage

Implementation example



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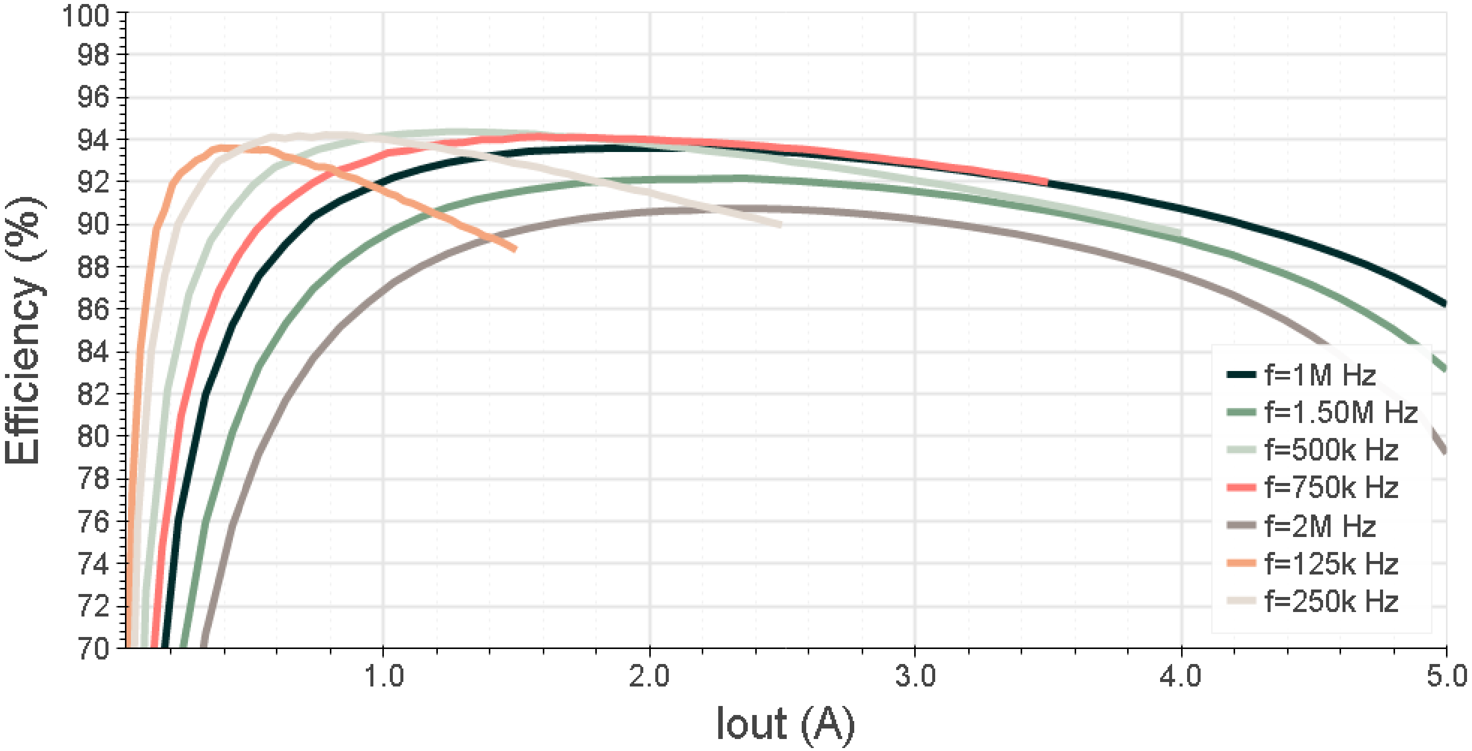
Implementation

- Size: 7.5 x 9.0 mm^2
- Thickness: 1.3 mm

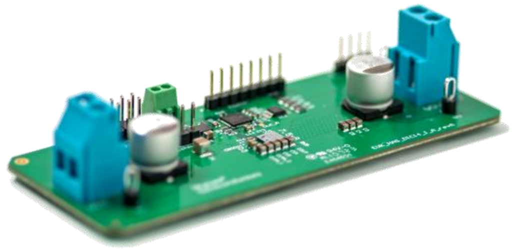
Performance

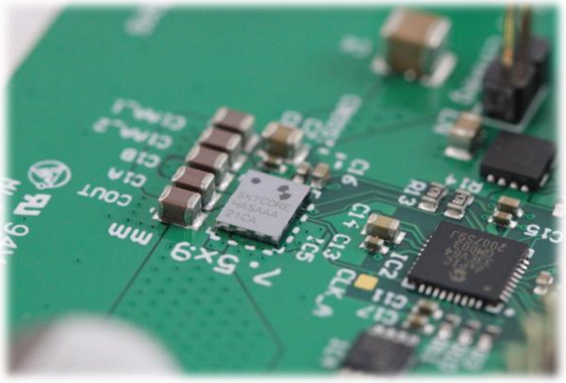
- Peak efficiency: **94.3 %**
- Power density: **431.6 W/cm^3**



4:1 Dickson SC – Internal power stage

Implementation example





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Implementation

- Size: 7.5 x 9.0 mm^2
- Thickness: 1.3 mm

Performance

- Peak efficiency: **94.3 %**
- Power density: **431.6 W/cm^3**

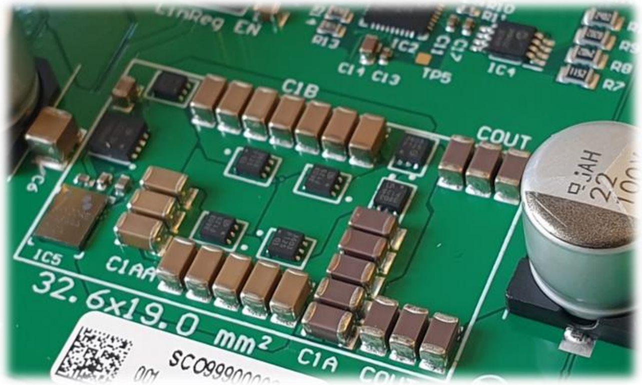
	Skycore	Murata	Maxim	TI	Maxim	Analog Devices
	EVK_HAS_DIC14_I_A	MYC0409	MAXM17575ALI	TPSM5601R5HRDAR	MAXM17505ALJ	LTM8050EY
Vin	**48**	48	48	48	48	48
Vout	**12.00**	12.00	12.00	12.00	12.00	12.00
Footprint [mm^2]	**68.40**	160.32	101.97	82.65	176.40	166.50
Thickness [mm]	**1.30**	2.00	2.95	4.00	2.80	4.92
Peak power [W]	**38.38**	69.32	18.00	18.00	20.00	24.00
Variable VCR	**No**	No	Yes	Yes	Yes	Yes
Power density [W/cm^3]	**431.60**	216.19	59.84	54.45	40.49	29.30
Peak efficiency [%]	**95.75**	96.62	87.79	89.51	89.20	88.33

4:1 Dickson SC + Si FETs
48V to 12V, 0-30A

Implementation using SCPC-ICs

4:1 Dickson SC – Int. + ext. Si FETs

Implementation example

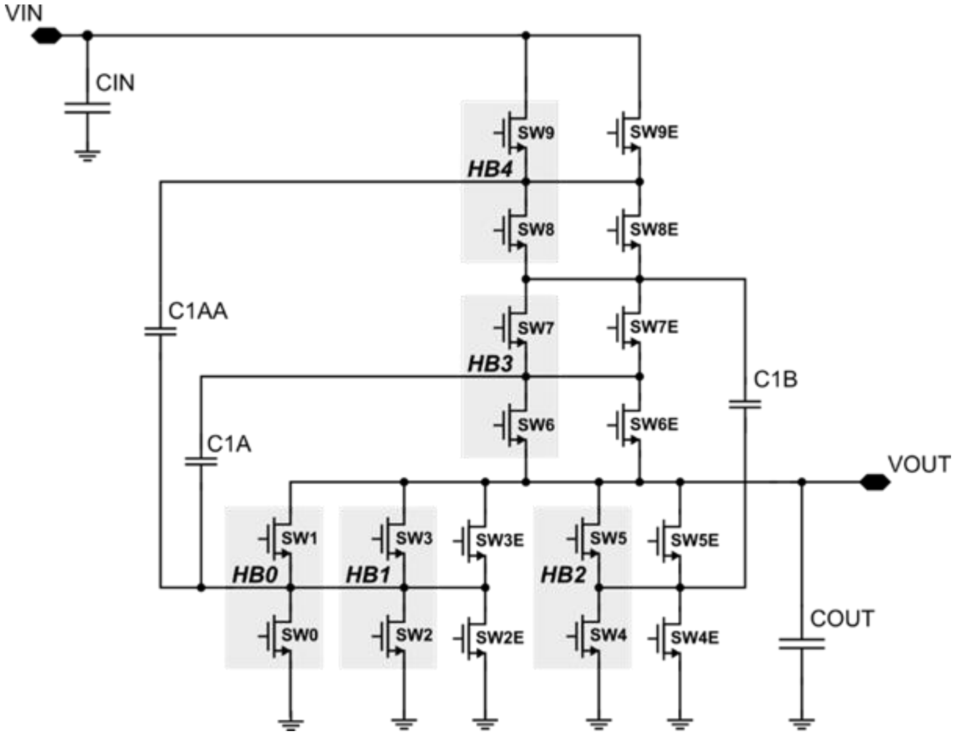


Application: 48 V to 12 V bus

- Voltage Conversion Ratio (VCR): 1/4
- Input voltage (V_{in}): 36 – 60 V
- Output voltage (V_{out}): 9 – 15 V
- Output current (I_{out}): 0 – 30 A

Implementation

- Size: 32.6 x 19 mm^2
- Thickness: 1.6 mm

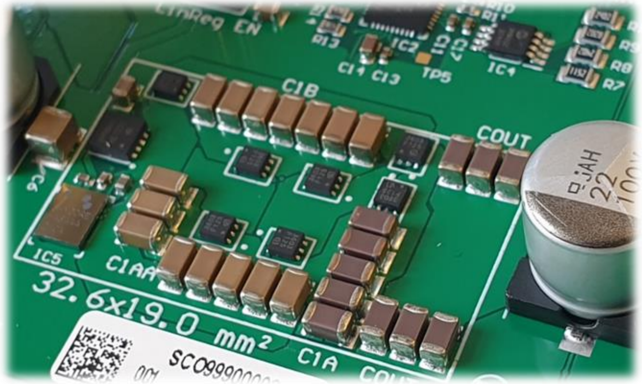


BOM:

- 1x SCG10ECX
- 7x ISK036N03LM5
- 1x BSZ099N06LS5
- 15x GRM31CD71H106KE11
- 12x GRM31CC71E226ME15
- 1x GRM155R61A106ME11D
- 1x GRM155R72A472KA01D

4:1 Dickson SC – Int. + ext. Si FETs

Implementation example



Application: 48 V to 12 V bus

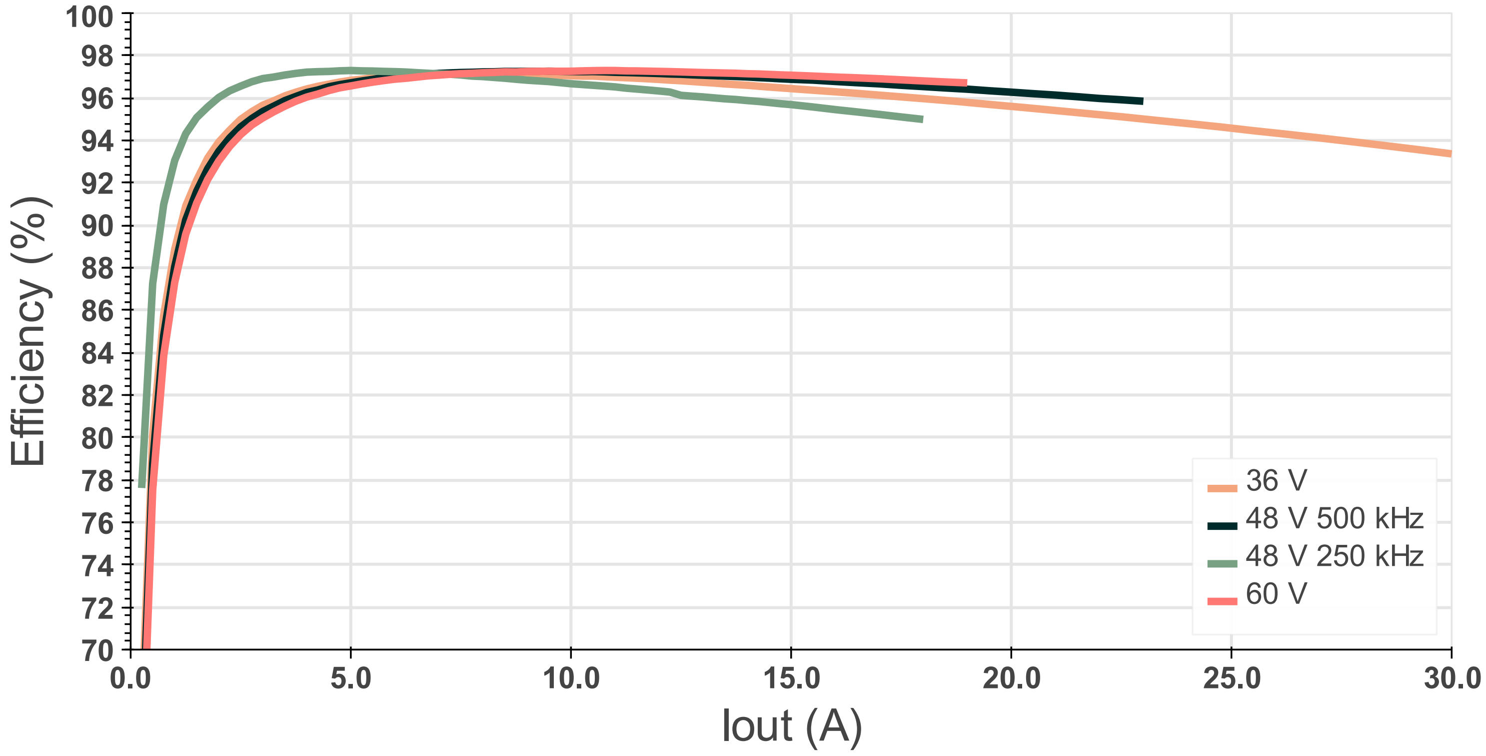
- Voltage Conversion Ratio (VCR): 1/4
- Input voltage (V_{in}): 36 – 60 V
- Output voltage (V_{out}): 9 – 15 V
- Output current (I_{out}): 0 – 30 A

Implementation

- Size: 32.6 x 19 mm^2
- Thickness: 1.6 mm

Performance

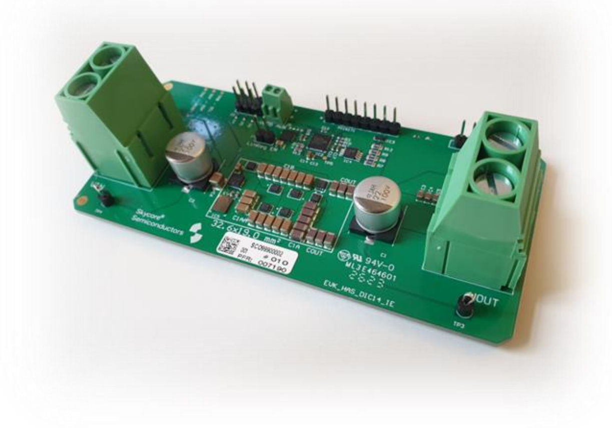
- Peak efficiency: **97.4 %**
- Power density: **286.8 W/cm^3***

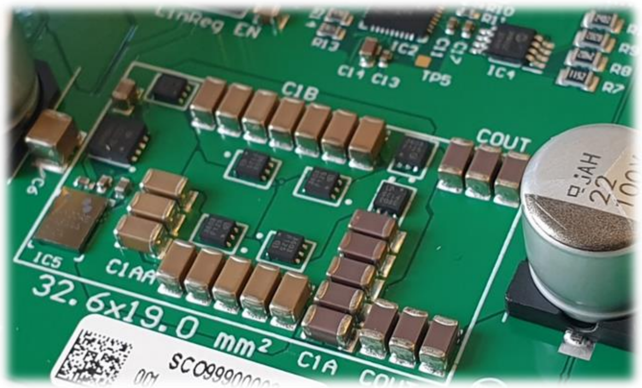


** Limitation on the maximum power to 300W due to measurement equipment. Estimated maximum power density without the 300W limitation* ***379.7 W/cm^3***

4:1 Dickson SC – Int. + ext. Si FETs

Implementation example





Application: 48 V to 12 V bus

- Voltage Conversion Ratio (VCR): 1/4
- Input voltage (V_{in}): 36 – 60 V
- Output voltage (V_{out}): 9 – 15 V
- Output current (I_{out}): 0 – 30 A

Implementation

- Size: 32.6 x 19 mm^2
- Thickness: 1.6 mm

Performance

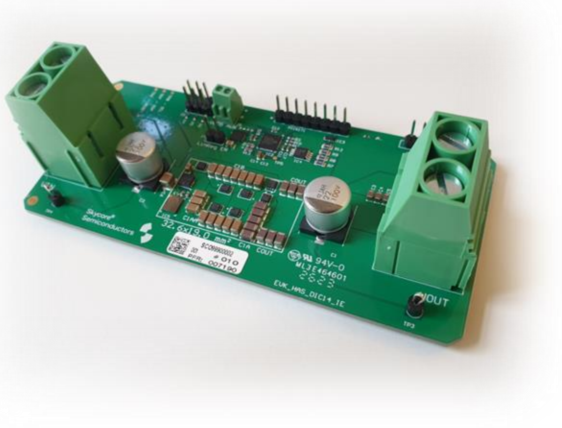
- Peak efficiency: **97.4 %**
- Power density: **286.8 W/cm^3***

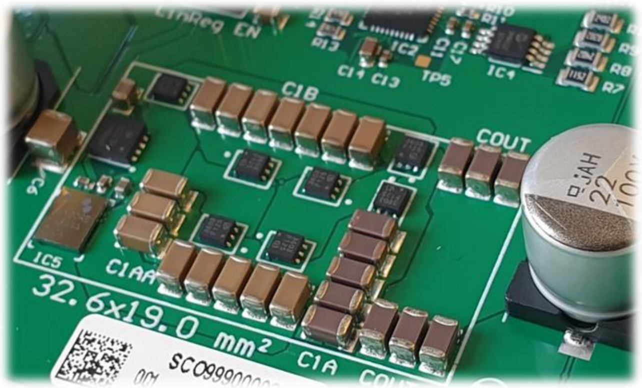
	Skycore	EPC	Flex	MPS	Infineon
	EVK_HAS_DIC14_IE_D	EPC9205	BMR313	MPC12106-54-0750-0220	1100W_4TO1_ZSC_QB
Vin	**48**	48	48	48	48
Vout	**12**	12	12	12	12
Footprint [mm^2]	**619.4**	297.0	420.7	432.0	2149.1
Thickness [mm]	**1.6**	5.0	7.6	9.1	10.0
Peak power [W]	**284.1***	120.0	949.5	1080.0	1034.9
Variable VCR	**No**	Yes	No	No	No
Power density [W/cm^3]	**286.8***	92.0	297.0	257.7	48.2
Peak efficiency [%]	**97.25**	95.8	97.3	0.0	98.3

** Limitation on the maximum power to 300W due to measurement equipment. Estimated maximum power density without the 300W limitation* ***379.7 W/cm^3***

4:1 Dickson SC – Int. + ext. Si FETs

Implementation example





Application: 54 V to 13.5 V bus

- Voltage Conversion Ratio (VCR): 1/4
- Input voltage (V_{in}): 36 – 60 V
- Output voltage (V_{out}): 9 – 15 V
- Output current (I_{out}): 0 – 30 A

Implementation

- Size: 32.6 x 19 mm^2
- Thickness: 1.6 mm

Performance

- Peak efficiency: **97.4 %**
- Power density: **286.8 W/cm^3***

	Skycore	Vicor	Vicor	Vicor	Flex
	EVK_HAS_DIC14_IE_D	NBM2317S60E1560 T0R	DCM3717S60E14G 5TN0	NBM2317S60D1565 T0R	BMR310
Vin	**54**	54	54	54	54
Vout	**13.5**	13.5	13.5	13.5	13.5
Footprint [mm^2]	**619.4**	508.2	818.4	508.2	1450.0
Thickness [mm]	**1.6**	7.4	7.4	7.4	10.3
Peak power [W]	**284.1***	810.0	665.0	877.5	860.0
Variable VCR	**No**	No	Yes	No	No
Power density [W/cm^3]	**286.8***	214.8	109.5	232.7	57.6
Peak efficiency [%]	**97.4**	97.9	97.2	97.4	98.0

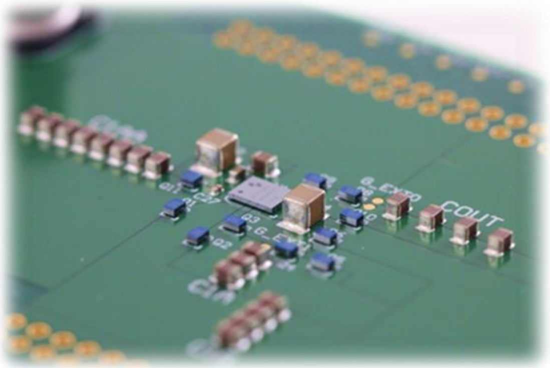
** Limitation on the maximum power to 300W due to measurement equipment. Estimated maximum power density without the 300W limitation* ***427 W/cm^3***

4:1 Dickson SC + GaN FETs
48V to 12V, 0-15A

Implementation using SCPC-ICs

4:1 Dickson SC – Int. + ext. GaN FETs

Implementation example

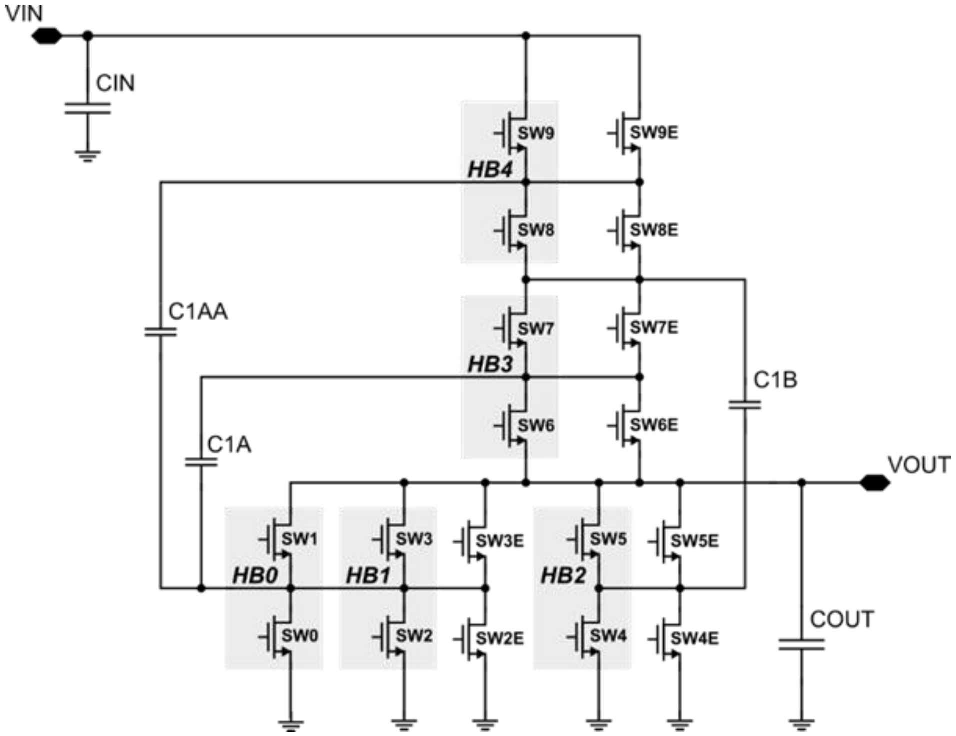


Application: 48 V to 12 V bus

- Voltage Conversion Ratio (VCR): 1/4
- Input voltage (V_{in}): 36 – 60 V
- Output voltage (V_{out}): 9 – 15 V
- Output current (I_{out}): 0 – 15 A

Implementation

- Size: Testboard*
- Thickness: 1.3 mm



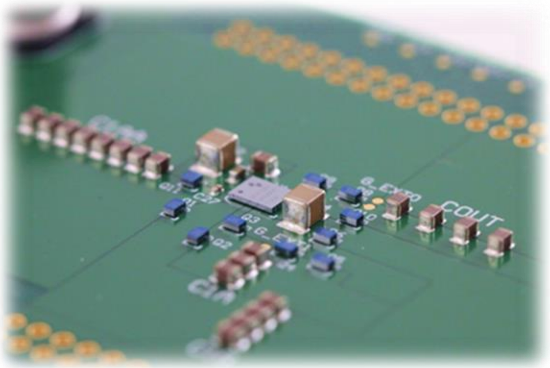
BOM:

- 1x SCG10ECX
- 9x EPC2014C
- 1x EPC2214
- 8x GRM21BC71H475KE11K
- 7x GRM21BC71E106KE11L
- 4x GRM21BC8YA106ME11K
- 1x GRM155R61A106ME11D
- 1x GRM155R72A472KA01D

** PCB layout of the testboard is not optimized, hence power converter size is not representative.*

4:1 Dickson SC – Int. + ext. GaN FETs

Implementation example



Application: 48 V to 12 V bus

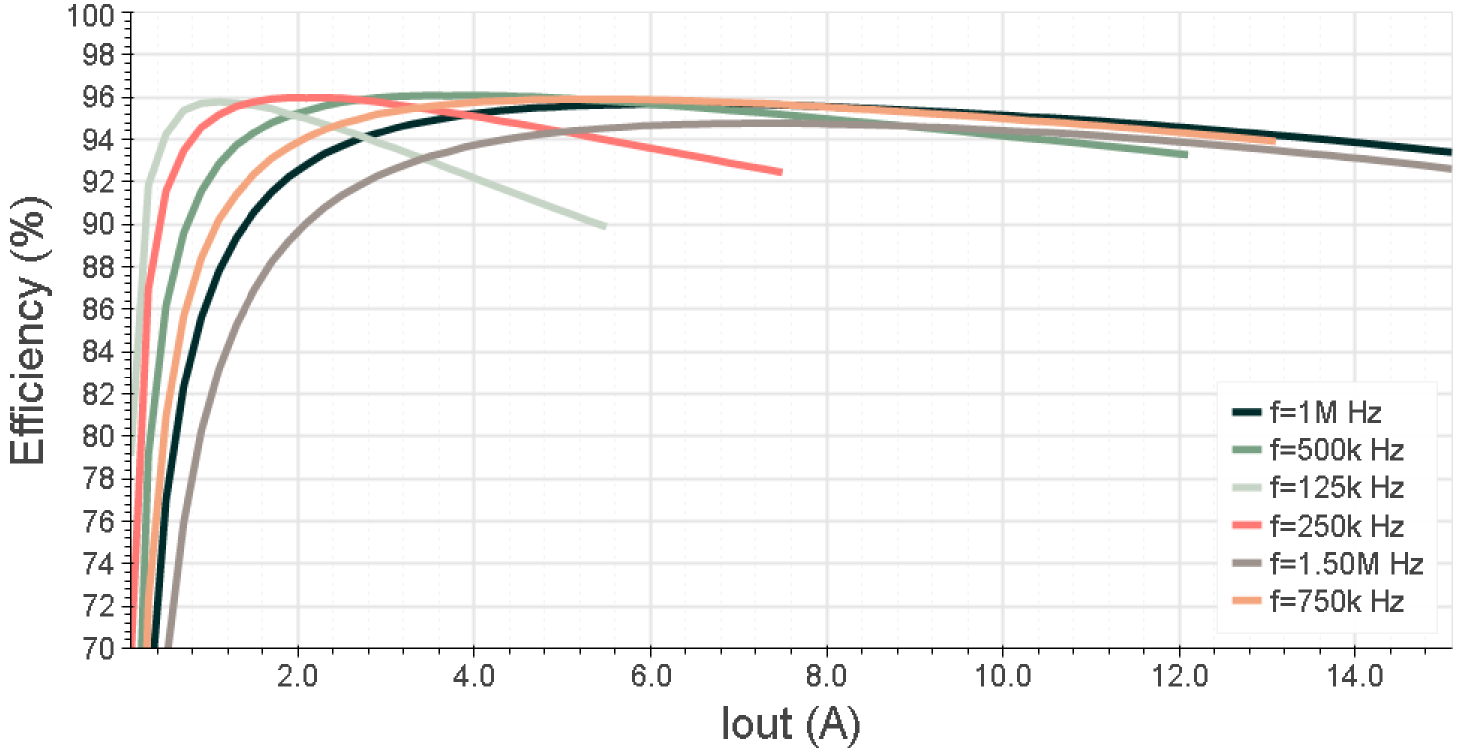
- Voltage Conversion Ratio (VCR): 1/4
- Input voltage (V_{in}): 36 – 60 V
- Output voltage (V_{out}): 9 – 15 V
- Output current (I_{out}): 0 – 15 A

Implementation

- Size: Testboard*
- Thickness: 1.3 mm

Performance

- Peak efficiency: **96.15 %**



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Other advanced topologies

Implementation enabled by SCPC-ICs

8:1 Symmetrical ladder – Ext. FETs

Implementation example - *Simulations*

Application: 48 V to 6 V

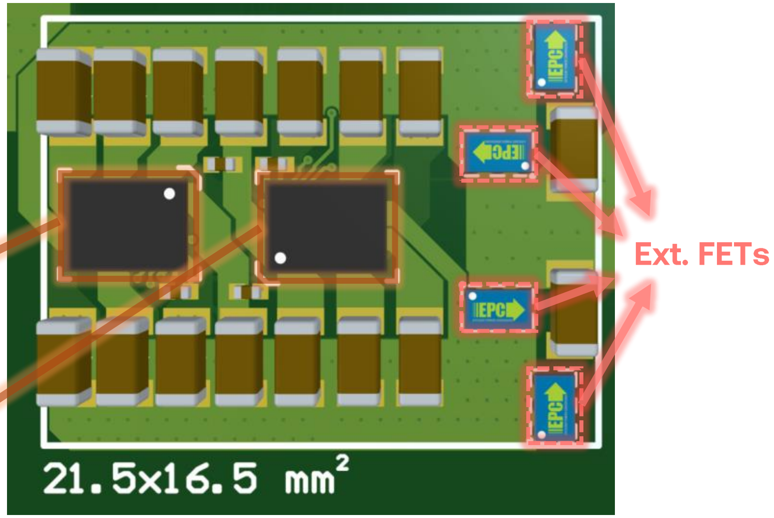
- Voltage Conversion Ratio (VCR): 1/8
- Input voltage (V_{in}): 36 – 60 V
- Output voltage (V_{out}): 4.5 – 7.5 V
- Output current (I_{out}): 0 – 20 A

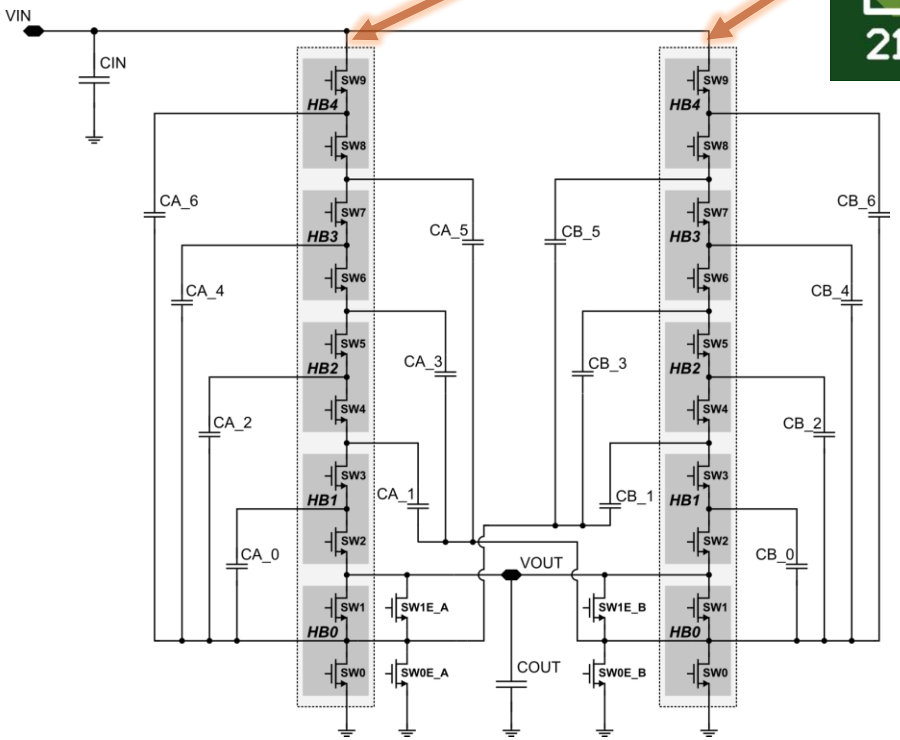
Implementation

- Size: 16.5 x 21.5 mm^2
- Thickness: 1.6 mm

Performance

- Peak efficiency: **94.8 %**
- Power density: **195.31 W/cm^3**





BOM:

- 2x SCG10ECX
- 4x EPC2055
- 10x GRM31CD71H106KE11K
- 6x GRM31CC71E226ME15L
- 2x GRM155R61A106ME11D
- 2x GRM155R72A472KA01D

8:1 Symmetrical ladder – Ext. FETs

Implementation example - *Simulations*

Application: 48 V to 6 V

- Voltage Conversion Ratio (VCR): 1/8
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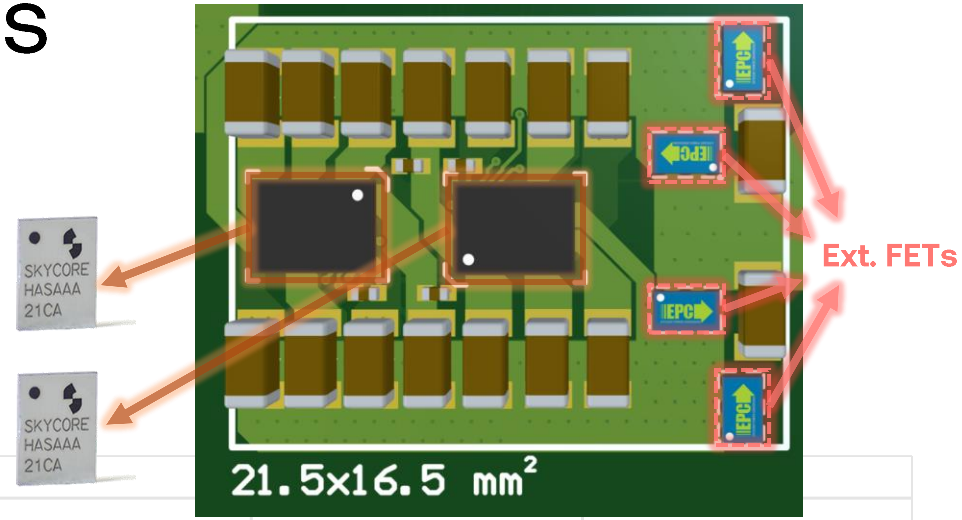
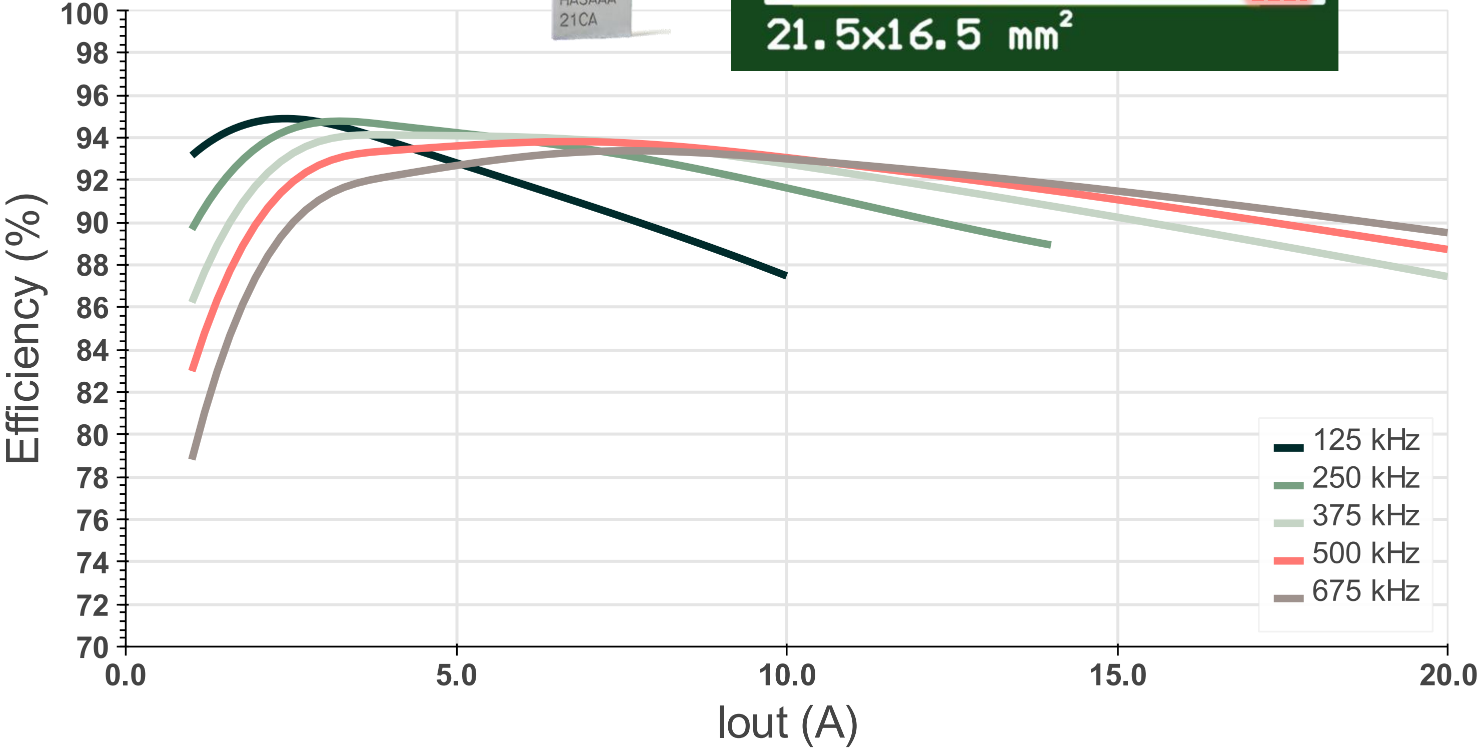
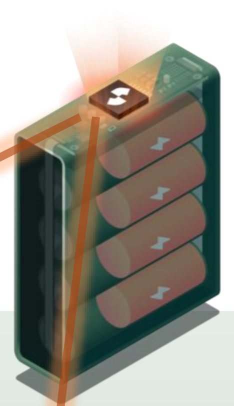




Active Battery Balancing

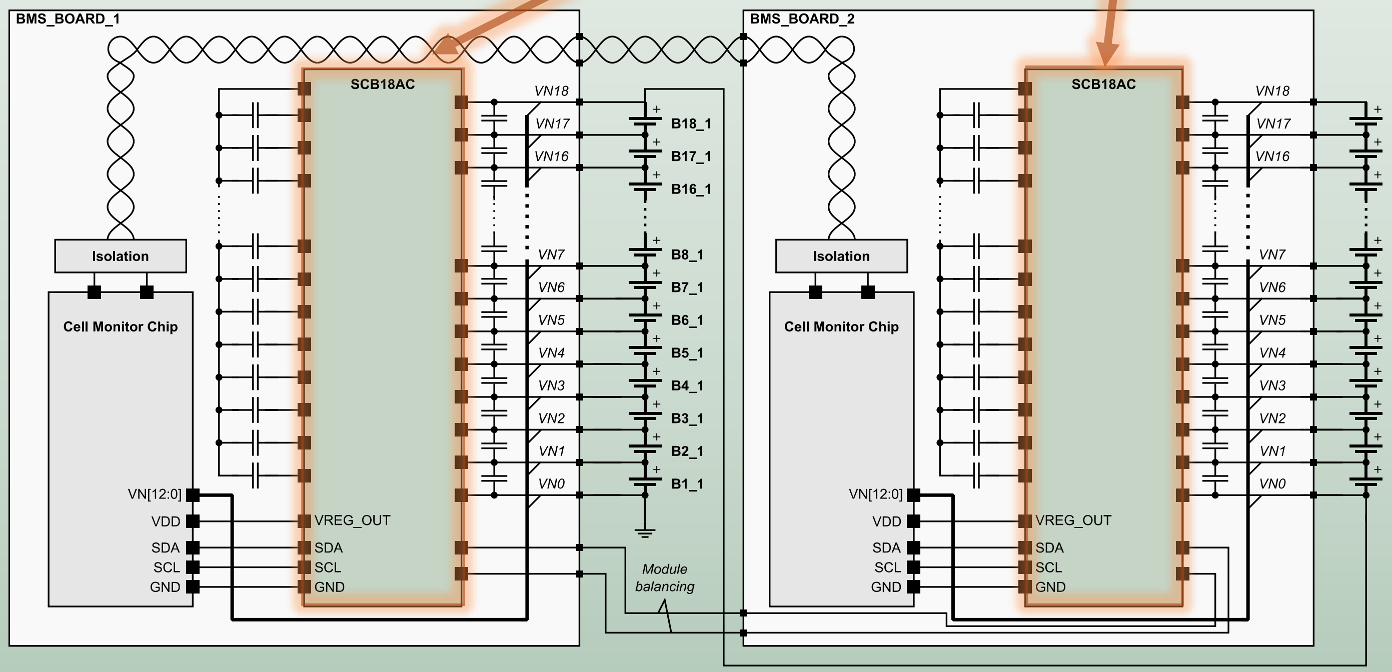
Other applications unlocked

Active Battery Balancing Applications



Active Battery Balancing IC

- Switched-capacitor-based balancing
- Active cell balancing, *e.g., 2-18 cells/module*
- Active inter-module balancing
- High-voltage battery systems supported
- Cell voltage range supported, *e.g., 2.5 - 5.0*
- **Applications:**
    - Electrical Vehicles (EVs)
    - Energy Storage Systems (ESS)



Summary

- Huge demand on power conversion performance
- Trends: Better switches, passives and topologies
- Enabler: Switched-Capacitor Power Conversion ICs
  - Unlock high performance switched-capacitor-based topologies
  - Leverage high energy density of capacitors
  - Leverage advancements in high-voltage manufacturing processes
  - High integration of power stage, gate drivers, clock controller, etc.
  - Synergy with external switches, e.g., Si, GaN
  - Reaches a wide range of applications

Better switches

Better passives

Better topologies

Skycore®

Thanks for your attention

Contact us: plm@skycore-semi.com

Website: www.skycore-semi.com/

Backup slide

Other possible topologies using the SCG10ECX

The half-bridges inside the SCG10ECX marked with a grey box. All switches (internal and external) are driven with the gate drivers of the SCG10ECX.