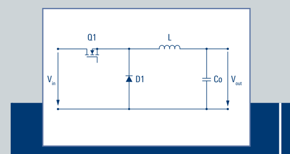
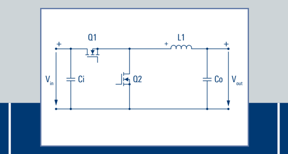
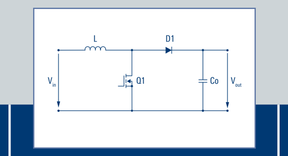
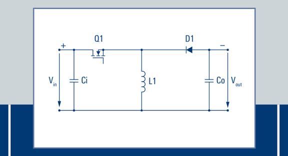
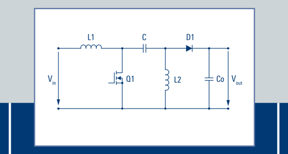
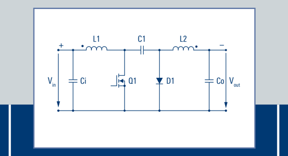
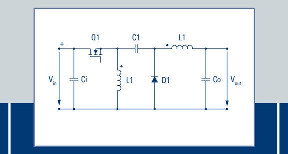
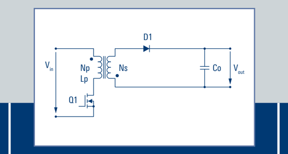
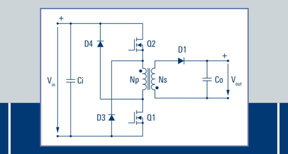
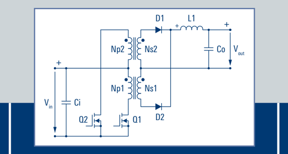
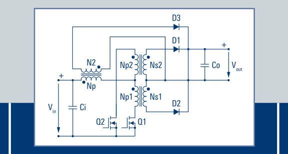
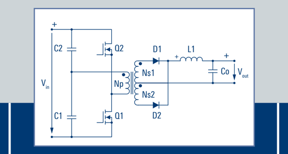
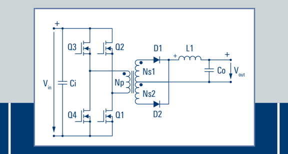
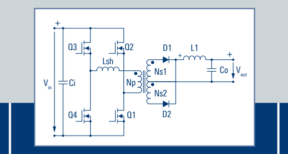
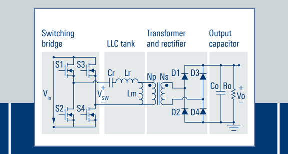
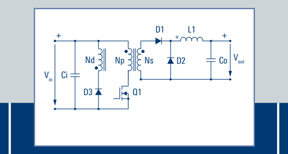
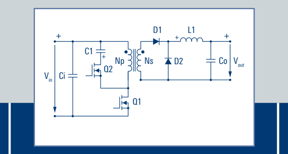
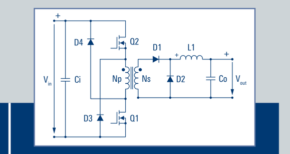
POWER ELECTRONICS DESIGN AND TESTING

For more information:

CONVERTER TYPES

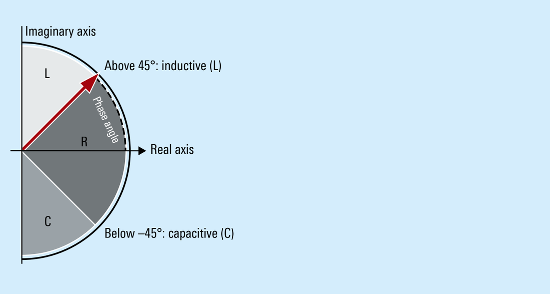



















	Non-isolated converters							Flyback converters	
Topology	Buck	Synchronous buck	Boost	Buck-boost (inverting)	SEPIC	Ćuk (inverting)	Zeta	Flyback	Two switch flyback
Transfer function (V_{out}/V_{in})	D	D	$\frac{1}{1-D}$	$\frac{-D}{1-D}$	$\frac{D}{1-D}$	$\frac{-D}{1-D}$	$\frac{D}{1-D}$	$\frac{1}{N}\cdot\frac{D}{1-D}$	$\frac{1}{N}\cdot\frac{D}{1-D}$
Typical maximum duty cycle	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.45
Conversion direction	step-down	step-down	step-up	step-down/step-up	step-down/step-up	step-down/step-up	step-down/step-up	step-down/step-up	step-down/step-up
Multiple outputs	–	–	–	–	–	–	–	•	•
Typically achievable efficiency	up to 95%	up to 97%	up to 97%	up to 95%	up to 93%	up to 93%	up to 90%	up to 85%	up to 90%
Cost	●○○○○○	●●○○○○	●○○○○○	●○○○○○	●●○○○○	●●○○○○	●●○○○○	●●●○○○	●●●◐○○
Typical power level	up to 250 W	up to 500 W	up to 500 W	up to 100 W	up to 100 W	up to 100 W	up to 50 W	up to 250 W	up to 250 W
Advantages/applications	▸ versatile, simplest possible design	▸ higher efficiency than buck converter	▸ often used for power factor correction	▸ for applications requiring negative output voltages, e.g. audio amplifiers, instrumentation amplifiers, line drivers and receivers	▸ wide input voltage range compared to buck/boost converter ▸ positive output voltage unlike buck-boost converter ▸ capacitive (non DC) coupling between input and output	▸ wide input voltage range compared to buck/boost converter ▸ capacitive (non DC) coupling between input and output ▸ for applications requiring negative output voltages, e.g. audio amplifiers, instrumentation amplifiers, line drivers and receivers	▸ wide input voltage range compared to buck/boost converter ▸ positive output voltage unlike Ćuk converter ▸ capacitive (non DC) coupling between input and output	▸ versatile and simple ▸ wide input voltage range due to transformer ▸ few components needed ▸ low cost design if several output voltages are required ▸ power factor correction for low power applications	▸ wide input voltage range due to transformer ▸ no snubber needed ▸ less voltage stress on switches because of diode clamping ▸ leakage energy is returned to input ▸ low cost design if several output voltages are required
Disadvantages	▸ high-side switch	▸ high-side switch ▸ less efficient under small load conditions	▸ large output capacitor necessary ▸ limited loop gain/cross-over frequency due to right half plane zero	▸ high-side switch ▸ large output capacitor necessary ▸ limited loop gain/cross-over frequency due to right half plane zero	▸ large output capacitor necessary ▸ limited loop gain/cross-over frequency due to right half plane zero ▸ two control loops required	▸ limited loop gain/cross-over frequency due to right half plane zero ▸ two control loops required	▸ high-side switch	▸ large output capacitor necessary ▸ limited loop gain/cross-over frequency due to right half plane zero ▸ larger transformer required for energy storage ▸ switching elements must be rated for higher voltages	▸ high-side switch ▸ large output capacitor necessary ▸ limited loop gain/cross-over frequency due to right half plane zero ▸ larger transformer required for energy storage

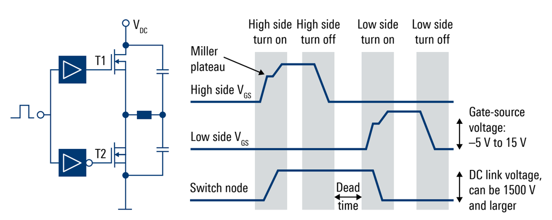
	High power converters						Forward converters		
Topology	Push-pull	Weinberg	Half bridge	Full bridge	Phase shifted full bridge	Resonant LLC	Forward	Active clamp forward	Two switch forward
Transfer function (V_{out}/V_{in})	$\frac{D}{N}$	$\frac{D}{N}$	$\frac{D}{N}$	$\frac{D}{N}$	$\frac{D}{N}$	frequency dependent, based on resonant tank transfer function	$\frac{D}{N}$	$\frac{D}{N}$	$\frac{D}{N}$
Typical maximum duty cycle	0.45	0.45	0.45	0.45	90° phase shift = 0.5 180° phase shift = 1.0	0.45	0.45	0.7	0.45
Conversion direction	step-down/step-up	step-down/step-up	step-down/step-up	step-down/step-up	step-down/step-up	step-down/step-up	step-down/step-up	step-down/step-up	step-down/step-up
Multiple outputs	•	•	•	•	•	•	•	•	•
Typically achievable efficiency	up to 90%	up to 92%	up to 92%	up to 95%	up to 97%	up to 97%	up to 85%	up to 90%	up to 92%
Cost	●●●●○○	●●●●○○	●●●●○○	●●●●●●	●●●●●●	●●●●●○	●●●○○○	●●●◐○○	●●●◐○○
Typical power level	up to 500 W	up to 5 kW	up to 1 kW	up to several kW	up to several kW	up to several kW	up to 150 W	up to 500 W	up to 500 W
Advantages/applications	▸ low-side switches only	▸ low-side switches only ▸ fault tolerant topology, no risk of shoot-through ▸ often considered for high-reliability applications such as in aerospace	▸ better transformer utilization ▸ no flux walking problems	▸ better transformer utilization ▸ no flux walking problems ▸ twice the output power compared to half bridge	▸ soft switching provides very high efficiency levels ▸ advantageous for step-down applications with high DC bus voltages such as in data center applications ▸ suitable for low and high output voltages	▸ soft switching provides very high efficiency levels ▸ advantageous for step-down applications with high DC bus voltages such as in data center applications ▸ best efficiency at constant load condition ▸ best suited for high output voltages	▸ wide input voltage range due to transformer	▸ wide input voltage range due to transformer ▸ no snubber required ▸ less voltage stress on switches because of high-side switch clamping ▸ leakage energy is returned to input	▸ wide input voltage range due to transformer ▸ less voltage stress on switches because of diode clamping ▸ leakage energy is returned to input
Disadvantages	▸ large output capacitor necessary ▸ flux walking can occur	▸ large output capacitor necessary ▸ switching elements must be rated for higher voltages			▸ complex design	▸ more complex design than phase shifted full bridge	▸ switching elements must be rated for higher voltages	▸ high-side switch	▸ high-side switch

MOST IMPORTANT MEASUREMENTS

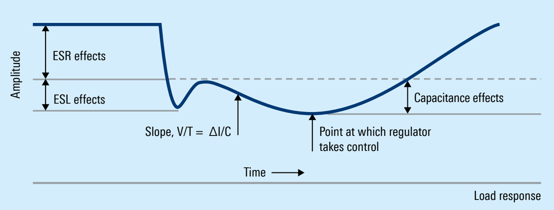
Applications



Component characterization
Passive components are the building blocks for every power electronics circuit. Verifying component parameters under different conditions is an essential first step to making sure that the design will not fail in real life. LCR meters and vector network analyzers are the instruments of choice for this task; accurate power supplies are also vital.

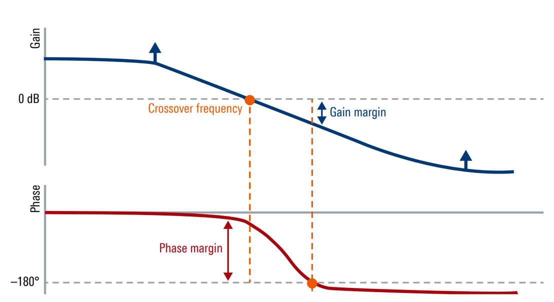


Switching analysis
Analyzing power transistor switching behavior is important to minimizing switching losses, optimizing dead time and verifying design robustness. Higher switching speeds also have a major impact on EMI; finding the right trade-off is a design decision. An oscilloscope with EMI analysis capabilities and suitable differential probes is ideal for switching analysis.

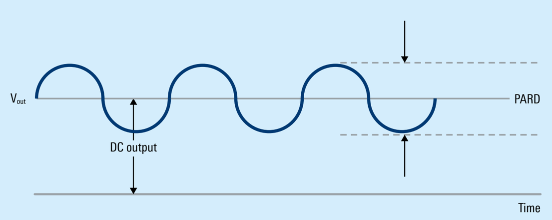


Load transient testing
Load transient testing is required to verify that a design fulfills output voltage tolerance requirements, including for fast changing load conditions. In particular, when power supplies for high-speed designs have very tight voltage tolerance windows, load transient tests can be critical.

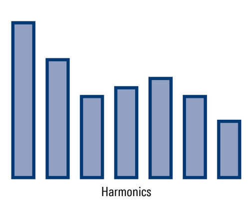
Applications



Control loop stability
Verifying control loop stability is essential and should ideally be performed under different load conditions. Oscilloscopes capable of generating Bode plots are efficient tools for this task.

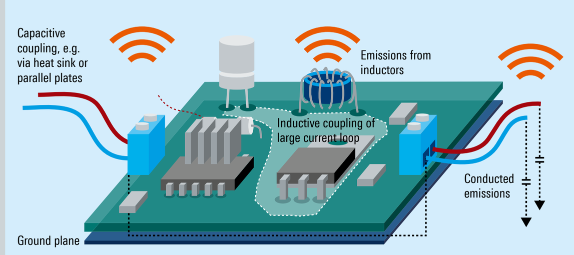


Input/output ripple and power integrity
Input and output ripple measurements are performed on every power supply design; high-speed circuits with CPUs, ASICs or FPGAs have very strict requirements regarding ripple. Oscilloscopes with high acquisition rates and advanced FFT capabilities, plus dedicated power rail probes, help verify compliance with requirements.

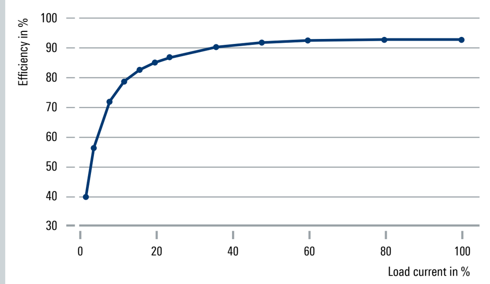


Compliance testing
Verifying compliance with standards such as IEC/EN 61000-3-2 is essential to obtain type approval for any device with a power converter. Inrush current and harmonic currents are typically included in product specifications and need to be verified. Oscilloscopes and power analyzers offer dedicated compliance test capabilities.

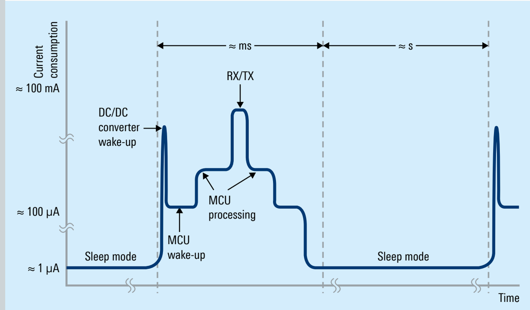
Applications



EMI debugging and precompliance testing
EMI is a key issue in power electronics design. Fast switching with high currents in particular can result in emissions that increase with increasing switching speeds. Addressing EMI early in the development cycle is essential to avoid costly redesigns. Oscilloscopes with powerful FFT functions offer the necessary capabilities for R&D; spectrum analyzers and EMI test receivers provide exacting precompliance testing for prototypes.



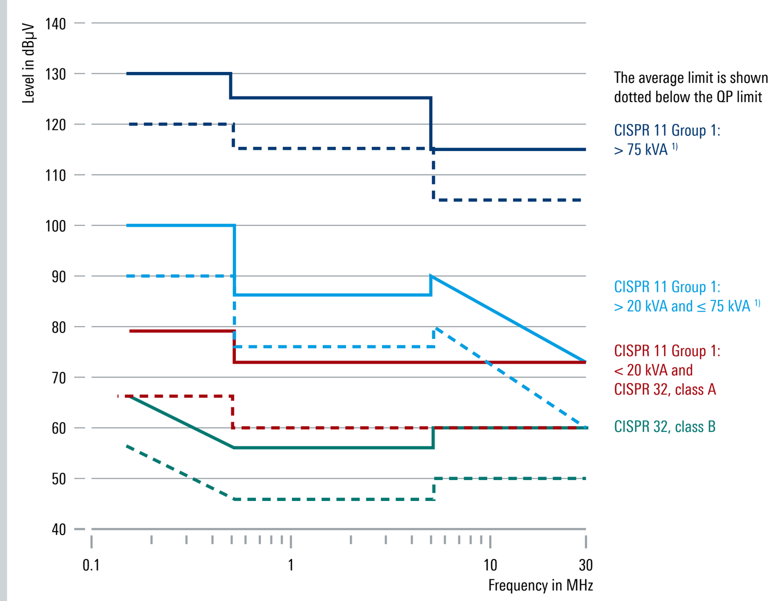
Efficiency analysis
High overall efficiency is an important design goal in power electronics. Power analyzers are the instruments of choice for this task. Two-quadrant power supplies can serve as simple yet effective tools to verify DC/DC converter efficiency.



Power consumption analysis
Battery life is key to real-world performance of e.g. mobile phones and many internet of things (IoT) devices. High-accuracy programmable power supplies and oscilloscopes with dedicated probing solutions and history functions are used to verify, analyze and troubleshoot power consumption.

REQUIREMENTS

Most important EMI standards

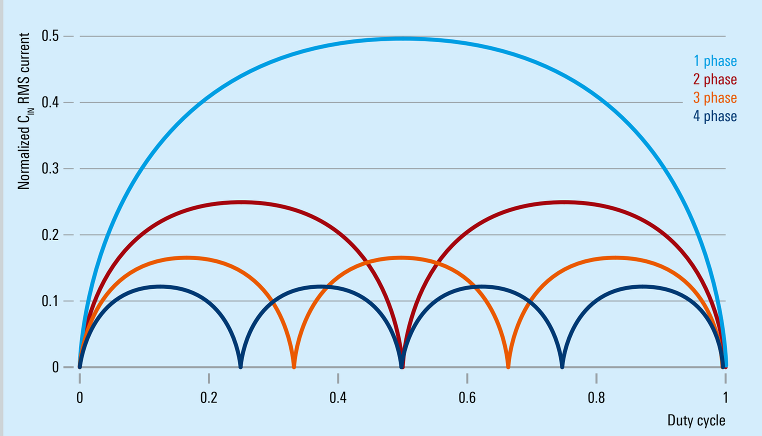


- CISPR 11: Industrial, scientific and medical (ISM) equipment and equipment using license-free ISM bands such as 2.4 GHz. Group 1: General purpose applications (e.g. standalone power supplies), class A (industrial) and class B (residential)
- CISPR 32: Multimedia equipment including IT (with integrated power supplies), class A (industrial) and class B (residential)

[1] These limits apply to equipment with a rated power > 20 kVA and intended for connection to a dedicated power transformer or generator not connected to low voltage (LV) overhead power lines.

Input ripple for power supplies connected in parallel

Normalized input capacitor (C_{IN}) RMS current versus operational duty cycle with one, two, three and four phases [2].



[2] Image source: Hegarty, Tim (17 November 2007). "Benefits of multiphasing buck converters – Part 1". EE Times. Retrieved 17 November 2020 from https://www.eetimes.com/benefits-of-multiphasing-buck-converters-part-1.

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