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Feedback Techniques for Crossing the Isolation Boundary

— By Robert Bell, Applications Engineer

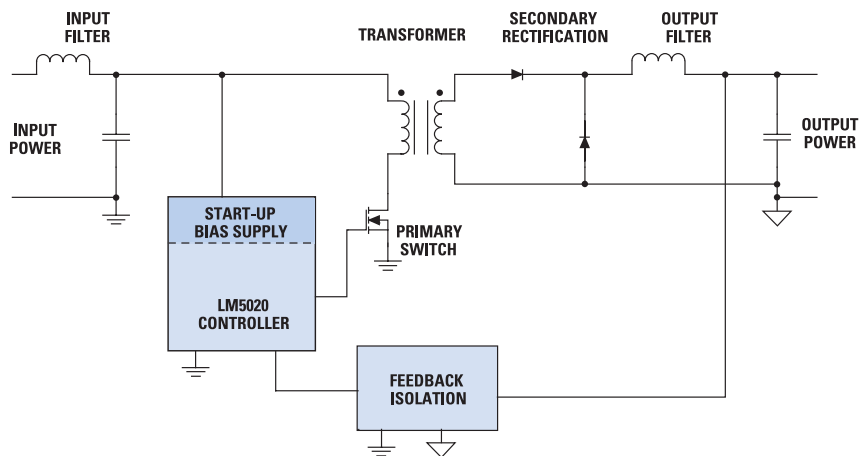


Figure 1: Isolated power converter with controller primary side referenced

Power converters are often categorized into two basic types: isolated and non-isolated. These categories refer to the relationship between the input power ground and the output power ground. Many applications require isolation between the grounds. In large systems with multiple power rails, isolation between the grounds eases single point grounding, preventing ground loops. Often the isolation requirement is specified from various safety agencies. The grounds must be isolated such that a potential of 1500 volts or more applied between the grounds shows no indication of breakdown. An isolated power-converter design imposes several additional challenges on the power-supply designer. Isolated power converters are implemented with transformer-based topologies. Some of the more commonly used topologies are flyback, forward, push-pull, current-fed push-pull and half-bridge and full-bridge. Transmitting power or feedback information from one ground reference to the other is often referred to as “Crossing the Isolation Boundary.”

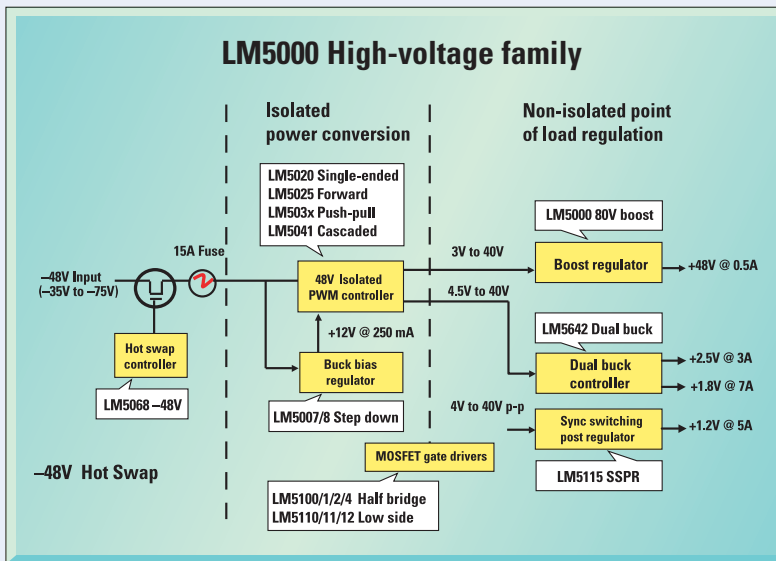
All isolated switching power converters include an input filter, output filter,

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Powering DSPs & FPGAs

100V Regulators, PWM controllers and MOSFET drivers

Flexible high-voltage power conversion solutions



Key benefits

- Highly integrated, using minimal external components
- >90% efficient at full loads
- Available in tiny LLP® chip-scale packaging with thermal resistance down to 40°C/W

Ideal for a wide variety of topologies including traditional buck, boost forward, and flyback as well as high-performance current-fed push-pull, half-bridge, and full-bridge

Part Number	Description	Comments
Integrated switching regulators		
LM5000	80V, 2A switch PWM boost	Ideal for flyback and boost topologies, 3.1V to 40V input range
LM5007/8	80V/100V 400 mA buck	High efficiency and constant-frequency PFM operation ideal for 48V input bias regulators
Switching regulator PWM controllers (100V)		
LM5020	Single-ended current-mode	Ideal controller for forward and flyback topologies
LM5025	Forward active-clamp voltage-mode	Programmable drive for P-or-N-type clamp switch
LM5030/33	Alternating outputs, current-mode/voltage-mode	Integrated drivers, opto-coupler interface
LM5041	Buck-fed push-pull current-mode	Ideal for current-fed push-pull topologies or buck pre-regulated full-bridge and half-bridge converters
MOSFET drivers		
LM5100/1/2/4	Dual FET drivers for 100V synchronous buck and bridge topologies	Family of high-speed, low-side/high-side 2A FET drivers with programmable delay, single and dual inputs
LM5110/11	5A dual low-side FET driver with negative output capability	High-speed compound gate driver for forward, push-pull and other low-side topologies
Hot-swap controllers		
LM5068	-48V hot-swap controller	Integrates a 100V start-up regulator with an active current control loop and under-voltage/over-voltage protection

Feedback techniques for crossing the isolation boundary

transformer, primary side switch, secondary side rectification, and a controller. The center of the converter is the controller, which can be referenced to either the primary or the secondary side ground. *Figure 1* shows a primary side referenced configuration and *Figure 2* shows a secondary side referenced configuration. Both configurations use a scheme where bias power for the controller is initially derived from a startup circuit, before a more efficient auxiliary winding takes over once normal

somewhat controlled manner. As the switching commences the auxiliary winding will provide the required bias power to the controller, which will then take control of the main switch. This approach of blindly starting the main switch can have problems with overshoots, short-circuit, and excessive loading conditions.

Why would a designer want to configure a converter with a secondary side referenced controller? Notice in *Figure 1* that a feedback signal must be isolated and brought over from the secondary ground to the primary ground. This feedback will suffer from some phase delay, which will limit the control loop bandwidth and ultimately the transient response of the converter. Many converters today use FETs for secondary rectification, instead of the diodes shown. These synchronous rectifier FETs require carefully controlled gate drive, which can be derived directly from the secondary side controller, leading to optimized control timing. A secondary side controller scheme is more complex, but can have higher performance than a primary side referenced controller.

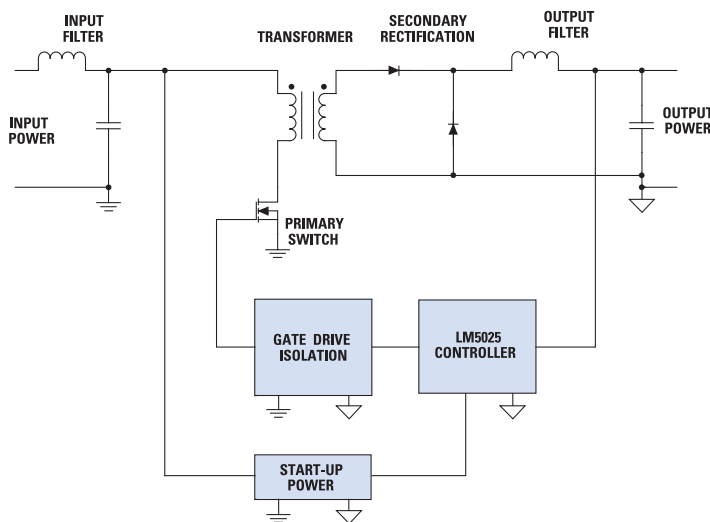


Figure 2: Isolated power converter with controller secondary side referenced

operation is reached. The problem with the secondary side referenced controller is that the bias power must be derived from the primary side power (the wrong ground), upon initial power up. This problem can be overcome with a separate isolated bias power converter to supply the few Watts needed for the controller. The separate bias supply ensures an orderly startup under all conditions. A second approach to derive bias power for the secondary controller is to design a scheme, allowing the main primary side switch to start switching immediately upon power application in a

A primary side referenced controller may reduce the converter complexity and cost. In this configuration, feedback from the output is brought back across the boundary with an optocoupler. The feedback signal that is most often returned across the boundary is not a signal proportional to the output voltage; rather it is a signal proportional to the difference between the output voltage and a reference voltage. If you attempt to bring the output voltage directly across the boundary, any inaccuracy caused by the isolation circuit will directly affect the regulation. Optocouplers have very wide current transfer ratio

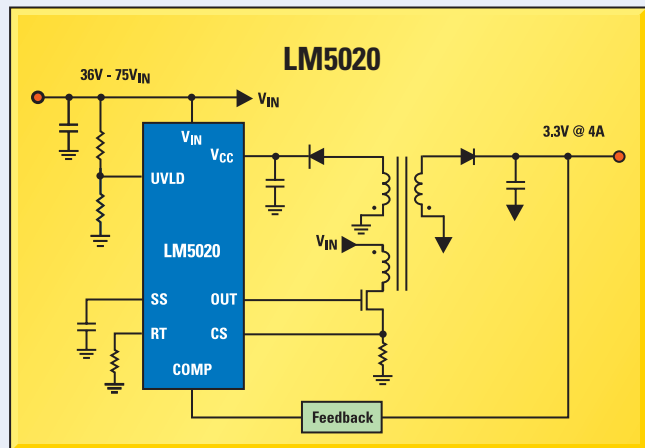
100V Forward or flyback PWM controllers

Highly integrated high-voltage controllers

- Internal 100V start-up bias regulator
- User-programmable UVLO threshold/hysteresis
- Higher current power MOSFET gate drivers
- 1 MHz oscillator Fsw set by a single resistor

LM5020 Current-mode controller

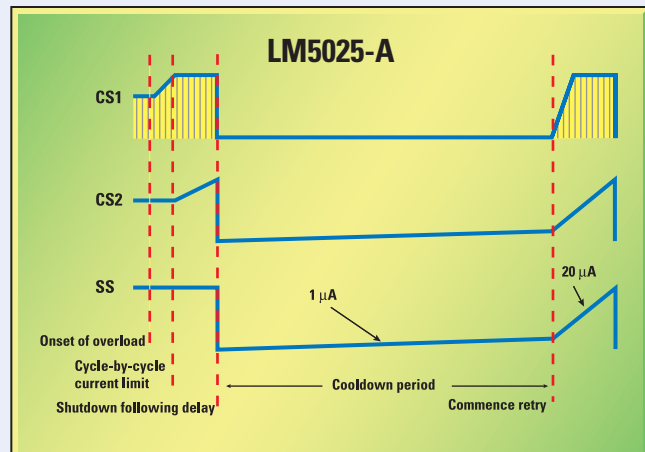
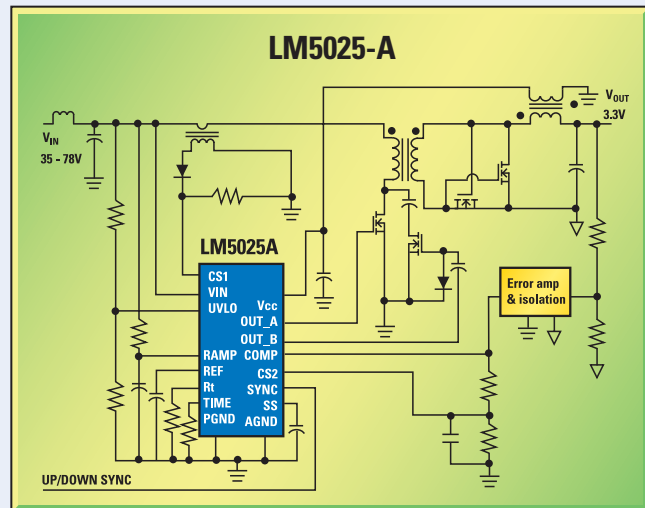
- For lower power single-ended forward and flyback converters
- 50% or 80% max duty-cycle clamp
- Packaged in tiny, thermally enhanced LLP-10 and MSOP-10



LM5025-A Active-clamp voltage-mode controller

- High-efficiency active clamp with new dual current limit scheme (see waveforms)
- Programmable driver for P-or-N-type clamp switch
- Volt*second clamp
- Packaged in tiny, thermally enhanced LLP-16 and MSOP-16

Ideal for use in telecom and industrial power converters, multi-output power converters, +42V automotive systems, and Power-over-Ethernet (PoE) devices



Feedback techniques for crossing the isolation boundary

tolerances with large temperature and aging variations. To create an error signal, the output voltage is compared to a fixed reference and multiplied by a large gain. This error signal, once returned across the boundary can be fed directly to the controller. Shown in *Figure 3a* and *3b* are the block diagrams of the two different feedback approaches. Typical gains are assigned to each block, A_{ISO} represents the gain of the isolation stage, A_{AMP} represents the gain of the error amp and A_{PWR} represents the gain of the pulse width modulator and the remainder of the power stage. The only difference between the two approaches is that the error amplifier and the isolation stage are transposed.

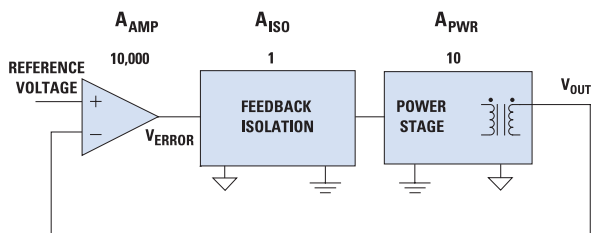


Figure 3a: Isolation of error signal feedback

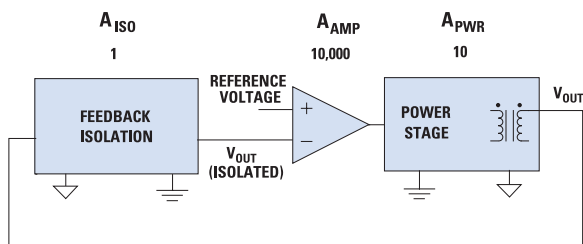


Figure 3b: Isolation of output voltage feedback

Figure 3a represents a power converter with the error amplifier on the secondary side. The static error of the output voltage, assuming an ideal reference and no offsets, is simply $1/(A_{AMP} \times A_{ISO} \times A_{PWR})$. In this example, the error is 0.001%. If

the gain of the isolation stage (A_{ISO}) decreases by a factor of two, the overall error increases to 0.002%. *Figure 3b* represents a power converter with the error amplifier and reference located on the primary side and an isolated copy of the output voltage is brought across the boundary. Now the isolation amplifier is part of the feedback network, not just part of the forward gain. In this configuration the initial error with ideal components is also 0.001%. But this time—if the isolation stage gain decreases by a factor of two—the system error increases 100%, doubling the output voltage.

Deriving a Feedback Signal

Several configurations are possible for deriving feedback on the secondary side and bringing that signal across the isolation boundary. The simplest approach is to bring a copy of the output voltage across the boundary using a zener diode and an optocoupler as shown in *Figure 4*. An increasing output voltage increases the current in the optocoupler diode, which leads to a reduced output signal of the primary controller's error amplifier. This simple, low-cost configuration is very inaccurate due to the zener diode and the optocoupler diode tolerances.

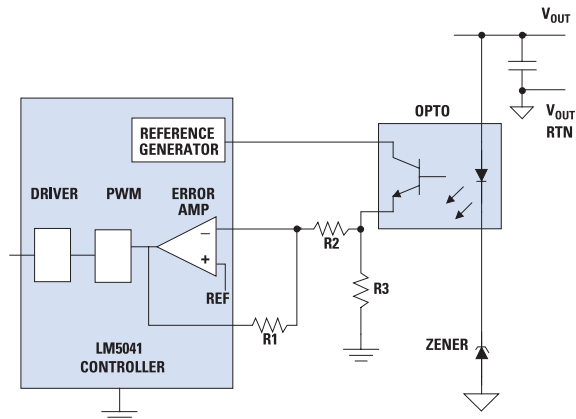
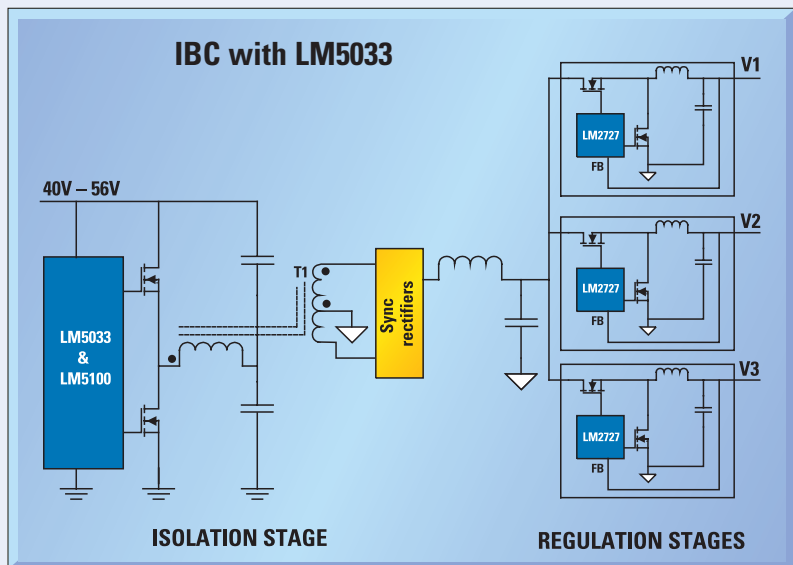


Figure 4: Zener diode/opto isolation

Two-stage DC-DC conversion: two solutions

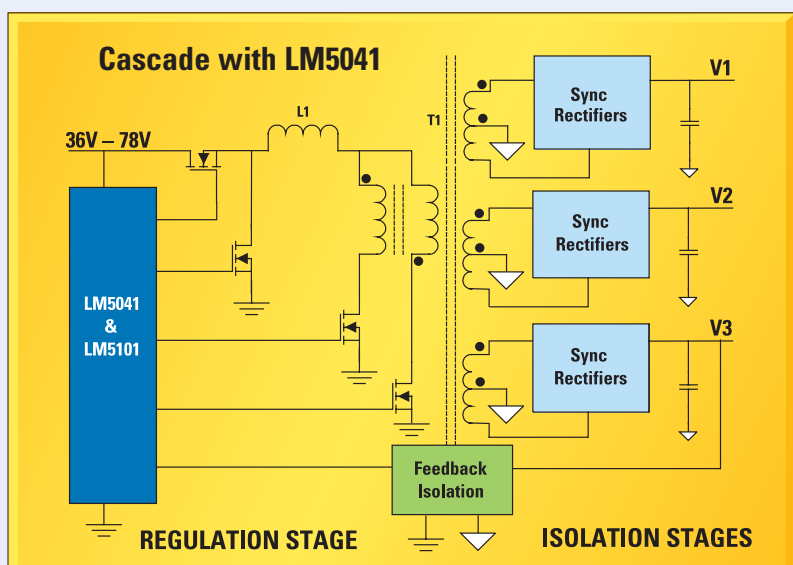
Intermediate bus converter (IBC) with LM5033

- Unregulated isolation stage feeds multiple non-isolated point-of-load (POL) converters
- Each output is independently regulated
- No feedback opto-coupler required to cross isolation boundary



Buck-fed cascade converters with LM5041

- Buck stage regulates input to push-pull or bridge isolation stage
- Accommodates wide input voltage range
- Single inductor shared by all outputs for L-C filtering
- Voltage stress on switches in isolation stage is independent of input voltage



Feedback techniques for crossing the isolation boundary

Figure 5 shows a much more accurate circuit using an error signal through the optocoupler. In this configuration, the zener diode is replaced with an LMV431 shunt regulator. The regulator shunts current through the device cathode when the voltage present at the feedback pin is 1.24V. The voltage divider, R4 and R5, scale the desired output voltage such that $V_{OUT} = 1.24 \cdot ((R4 + R5) / R5)$. This configuration is much more accurate than a zener diode configuration, as the initial tolerance of the LMV431 is as low as 0.5%. Loop compensation can be connected between the cathode and the feedback pins of the regulator. Very good results can be realized with this configuration, which is popular for medium performance applications.

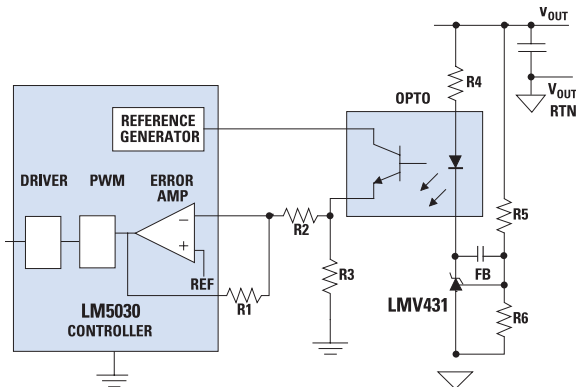


Figure 5: LMV431/opto isolation

Also, since the output of the LMV431 is a current, a limited amount of voltage feedback is available at the cathode pin. Adding a separate temperature compensated reference using the LM4050 and dual op amp, provides the ability to optimize the loop compensation (Figure 6). This error amplifier configuration provides high gain, high accuracy, and the ability to compensate the loop.

Experienced designers will notice that there are two feedback loops on the secondary. The cathode of the LMV431, which is configured as an integrator, represents a virtual earth. High frequency

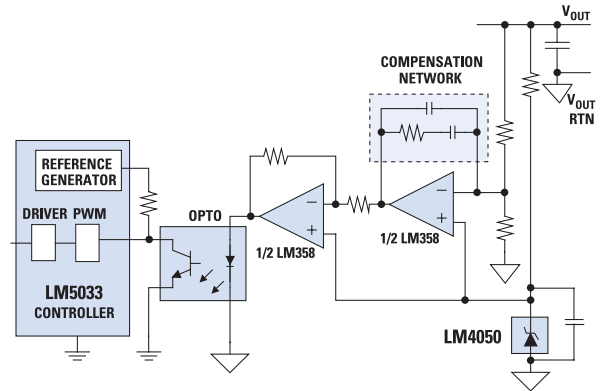
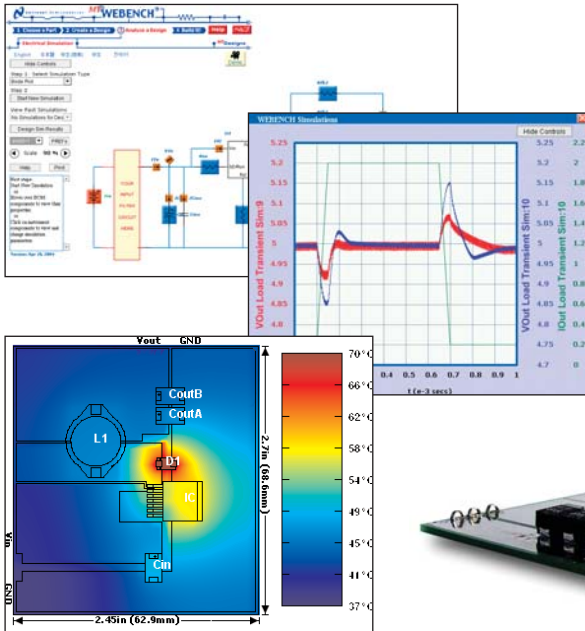


Figure 6: Dual op amp and reference/opto isolation

transitions on the anode of the LED will result directly in high frequency changes in the current flowing through it. This high frequency path exists in addition to the low frequency path through the resistor divider and should be accounted for in phase compensation and when injecting signals for overall loop gain phase measurements. For all configurations, the designer has to think through the start-up sequence, the condition when input power is initially applied. Initially, there will be no output voltage and no voltage to bias any secondary side circuits. The feedback must be such that under these conditions the polarity of the error signal requests full power. The dual op amp in Figure 6 ensures this request. Another consideration during startup is softstart. Slowing the rate of rise of the output voltage can be accomplished by increasing the capacitor across the reference device.

The best design approach for “crossing the (isolation) boundary” varies with each application. Many factors such as performance, complexity, and cost need to be considered. Evaluation of the isolation circuit against the system objectives is necessary throughout each stage of the design. Finally, careful test and measurement is necessary over all operating conditions, including fault conditions such as short circuits and overloads. ■

Power design tools

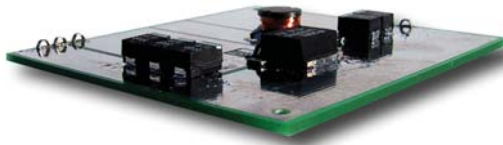


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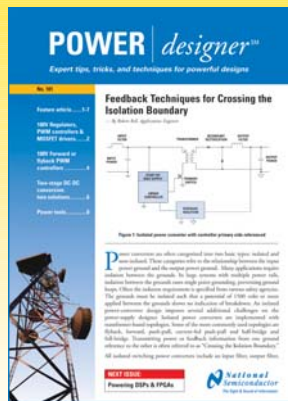
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