LM3203,LM3204,LM3205

Optimizing RF Power Amplifier System Efficiency Using DC-DC Converters

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No. 110

Optimizing RF Power Amplifier System Efficiency Using DC-DC Converters

— *By Mathew Jacob, Applications Engineering Manager*

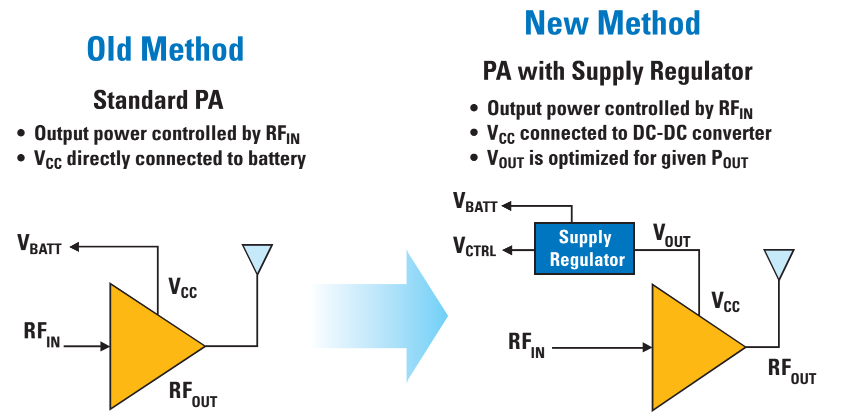

Figure 1. Old Method vs New Method

RF power amplifiers used in CDMA / WCDMA cellular standards have been traditionally powered directly from the battery. This makes system implementation easy but the requirement for linear power amplifiers in such standards have intrinsic inefficiencies throughout the transmit power spectrum.

Cellular standards have been evolving with transmission speeds that started from 14.4 kbps in CDMA-1 to 2 Mbps in CDMA2000/WCDMA. Apart from this, cellular providers have increased the services bundled with the 3G phones in order to increase the average revenue per subscriber. At the same time, the talk time and battery life is expected to be improved with the same or slightly higher capacity batteries. This makes system design challenging. System designers have to be very cautious and perform a power survey of each and every component on the phone board. The RF Power Amplifier (RF PA) powered directly from the battery is a major concern from the power budget perspective.

The modulation schemes used in CDMA and WCDMA result in an amplitude-modulated signal that exhibits a non-constant amplitude envelope. In order to preserve signal integrity and further spectral re-growth, a linear

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Dynamic Power Management of RF Power Amplifiers

Feature-Rich LM320x Family Enhances Battery Life in Portable Applications

Family Features

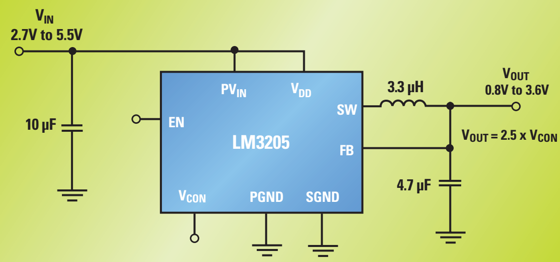
- Dynamically adjustable output voltage optimizes RF PA power levels for increased battery life
- Bypass mode maintains maximum output power regardless of battery voltage
- 2 MHz Switching frequency minimizes external components and complies with spectral emission requirements

Ideal for powering RF power amplifiers in cell phones, smart PDA phones, GPS systems, two-way radios, and portable communications systems

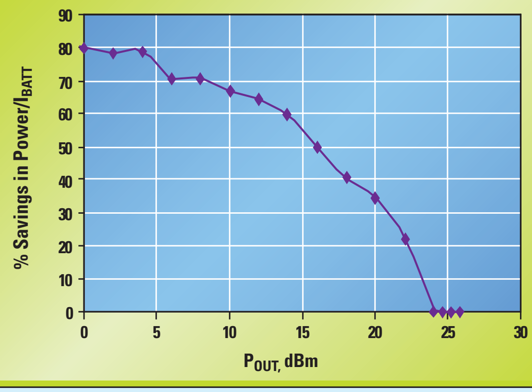
Family Highlight:

DC-DC converters deliver up to 5X transmit time in RF PAs

LM3205 Application Circuit



RF PA System Power Savings



Step-Down Switching Regulators for RF Power Amplifiers

Product ID	Description	V_{IN} Min	V_{IN} Max	V_{OUT}	I_{OUT} (mA)	Bypass Modes	Packaging
LM3200	Dynamically adjustable output voltages, 2.2 µH inductor	2.7	5.5	Adj (0.8 to 3.6V)	500	Forced and automatic	micro SMD-10
LM3202	Miniature, adjustable, step-down DC-DC converter	2.7	5.5	Adj (1.3 to 3.16)	650	None	micro SMD-8
LM3203	Miniature, adjustable, step-down DC-DC converter	2.7	5.5	Adj (0.8 to 3.6)	500	Forced	micro SMD-10
LM3204	Miniature, adjustable, step-down DC-DC converter	2.7	5.5	Adj (0.8 to 3.6)	355/500	Forced and automatic	micro SMD-10
LM3205	Miniature, adjustable, step-down DC-DC converter	2.7	5.5	Adj (0.8 to 3.6)	650	None	micro SMD-8

power amplifier is necessary. However, power efficiency is traded off because power amplifiers operate efficiently when operated in gain compression. To meet the required linearity, the operating transmit power is backed off from the power amplifier's compression point that causes an overall reduction in efficiency. When the handset is operating in transmit mode, the RF power section consumes up to 65% of the overall power budget as a result of the PA's intrinsic inefficiencies.

For this reason, linear PAs are ideal candidates to be powered with a magnetic buck converter which will dramatically increase efficiency of the system.

Power-Added Efficiency (PAE) is a key performance metric of a power amplifier.

$$PAE\ (\%) = (P_{OUT} - P_{IN}) / Pdc$$

The key in using a DC-DC converter (PA supply regulator) is to reduce the Pdc factor in the denominator. When the PA is connected directly to the battery, Pdc=Vbatt*Ibatt and, when it is powered by a PA supply regulator, Pdc=Vo*Io. Now it can be seen that for increasing the PAE we have to have a low Vo and Io compared to Vbatt and Ibatt. This is achieved by lowering the output voltage of the PA supply regulator at lower transmitted RF power levels. This in turn reduces Io (current drawn by the PA) and results in a much lower input current drawn from the battery due to the inherent high efficiency of the DC-DC converter.

It is important to consider the power probability profile (see *Figure 2*) for the modulation methods to really understand the impact of savings in powering a PA with a supply regulator. The profiles are different for urban and rural regions.

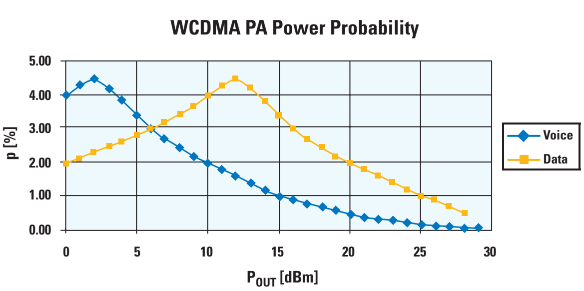


Figure 2. PA transmits low power levels for a high percentage of time in a typical cellular phone which reinforces the savings possible with a PA supply regulator

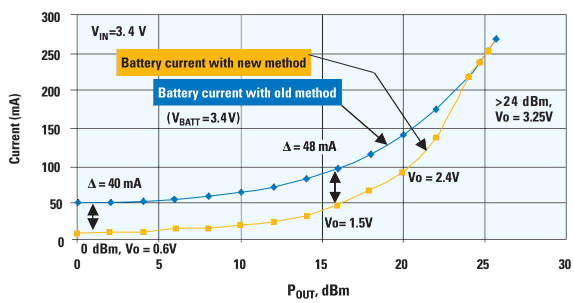


Figure 3. Savings in battery current when the DC-DC converter is used for powering the PA

As shown in *Figure 3*, the output voltage of the DC-DC converter has to be varied as the transmitted power levels are changed to maintain the Adjacent Channel Power/leakage Ratio (ACPR) specifications. The savings in battery current can be as high as 50 mA in the 0 dBm to 20 dBm power levels. *Figure 2* shows that the PA is operating in this band of power levels for a majority of its time.

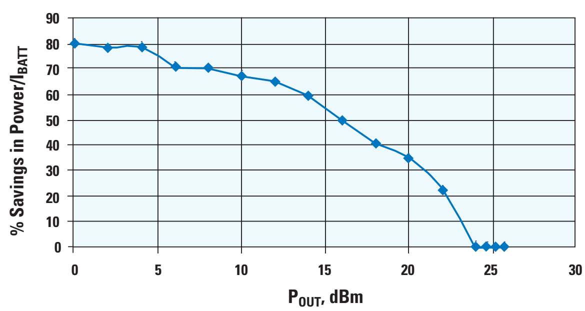


Figure 4. Percentage savings in power when the PA is powered by a PA supply regulator

So why do we have to change the voltage of the DC-DC converter as the transmitted power level is increased? The answer is that this change is needed to maintain the ACPR ratios. ACPR is used to characterize the distortion of power amplifiers and other subsystems for their tendency to cause interference with neighboring radio channels or

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Product Highlight:

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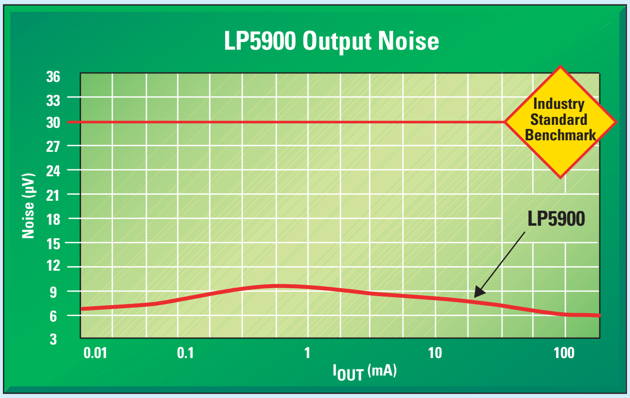
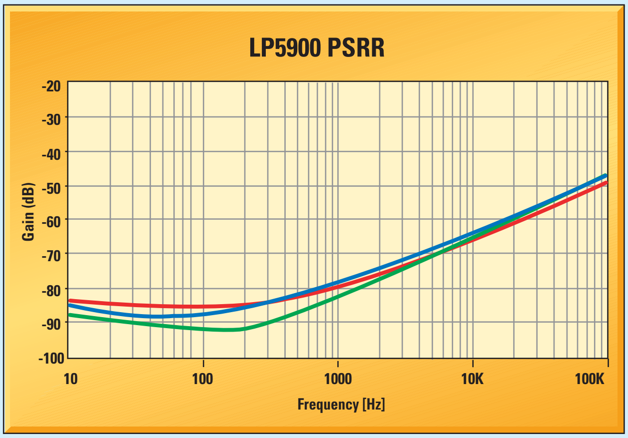
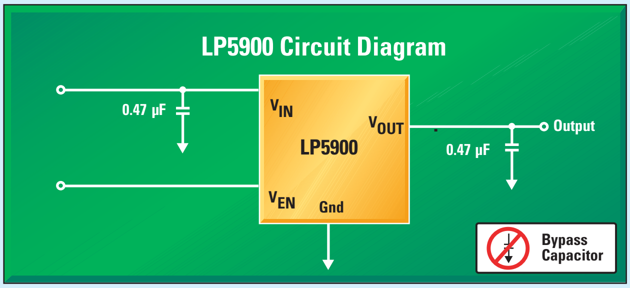






Optimizing RF Power Amplifier System Efficiency

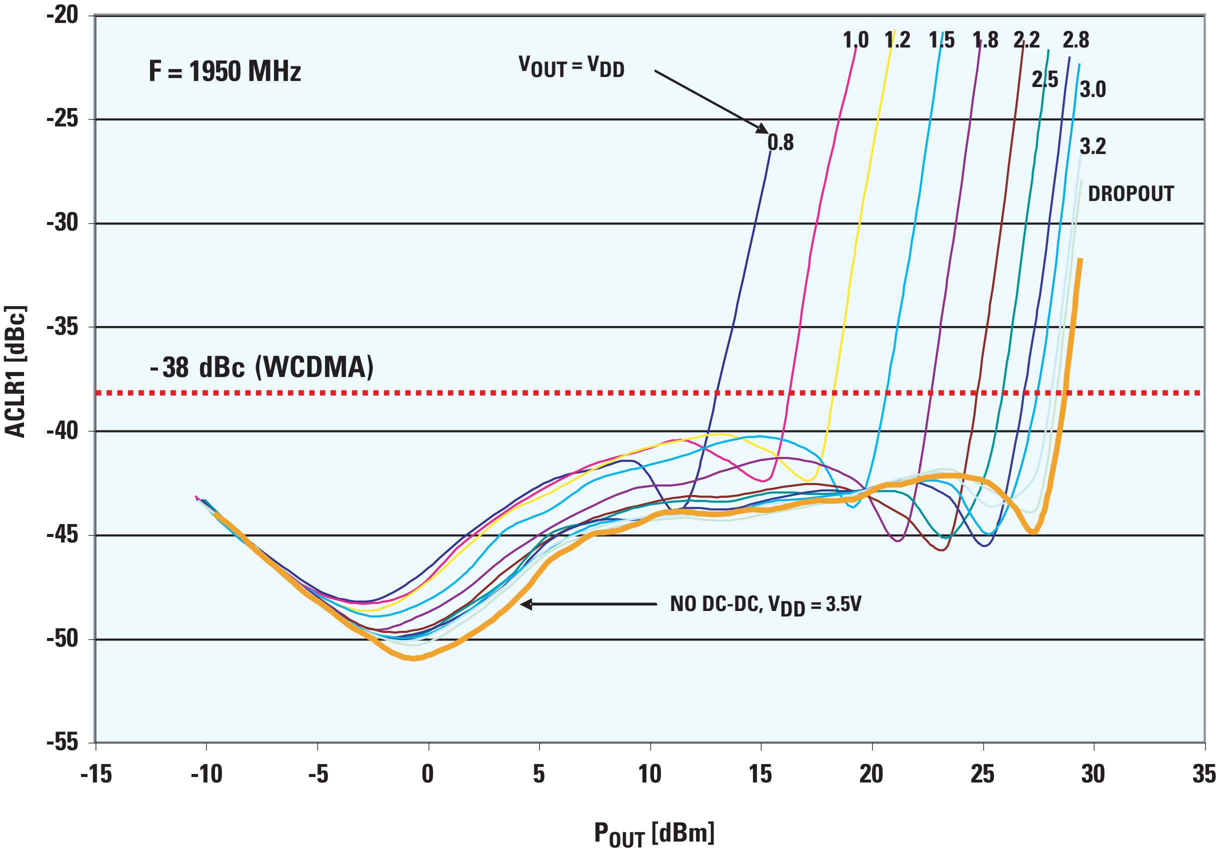


Figure 5. How ACLR is affected with respect to supply voltage to the PA and P_{OUT}

systems. It is specified as the ratio of the Power-Spectral Density (PSD) of the main channel to the PSD measured at several offset frequencies.

In ***Figure 5*** it can be seen that if the supply voltage to the PA is not increased as P_{OUT} is increased, the ACLR specifications cannot be met.

The system-level specification (3 GPP) for WCDMA is -34 dBc and, in order to preserve sufficient margin caused by temperature and device variances, the ACLR value of -38 dBc is used.

Key Requirements of Buck Converters for Powering RF Power Amplifiers

Buck converters that power RF PAs have specialized functions and are quite different from buck converters that power digital core processors. These differences arise in operating characteristics and parameters such as switching FET ON-resistances, current limit, transient response, modes of operation such as PFM/PWM, startup time, quiescent current, and dropout behavior. The following examples illustrate these differences:

- High efficiency over wide output voltage and load range

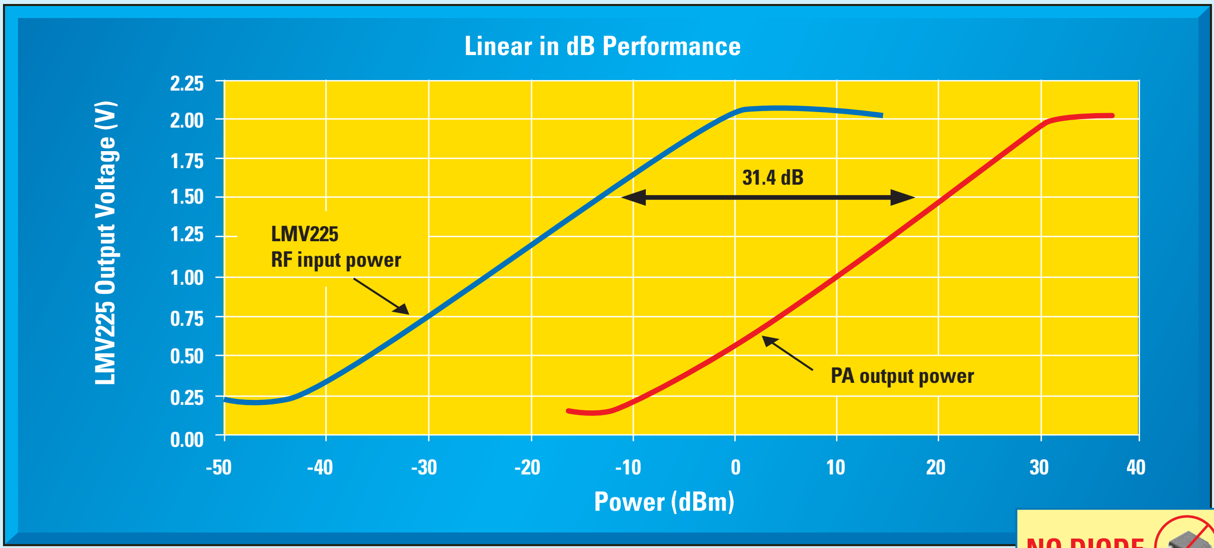
  Example: LM3205 has efficiency of 96% at V_{IN} = 4.2V, Vo = 3.4V, Io = 400 mA (high RF power) and 87% at V_{IN}=3.9V, Vo=1.5V, Io = 100 mA (low RF power).

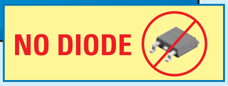
- Dynamic output voltage adjustment

  Example: In LM3205 the output voltage can be adjusted between 0.8V to 3.6V using a Vcon pin. The voltage gain from Vcon to Vo is 2.5.

Simplify System Calibration with RF Detector Family

Accurate and Stable RF Power Detectors for Portable Devices





Family Features

- LMV227 100% RF tested for accuracy
- 30 dB Linear-in-dB power detection range
- Multi-band operation from 450 MHz to 2 GHz
- Accurate temperature compensation
- Logarithmic amplifier and mean square RF detector technology

Ideal for use in handsets, wireless LAN, WiFi, PC and PDA module cards, and GPS navigation modules

Family Highlight:

Real-time transmitter power adjustments simplify system calibration in communications systems

AVAILABLE LEAD-FREE

Product ID	Application	Detector	Channel	Range	Package
LMV227	CDMA 2000, WCDMA, UMTS	Log amp	1	40 dB, 2.1 GHz	Micro SMD, LLP®
LMV225/226/228	CDMA, WCDMA, UMTS	Log amp	1	40 dB, 2.1 GHz	Micro SMD, LLP
LMV232	3G Mobile communications	Mean square	2	20 dB, 2.2 GHz	Micro SMD

Optimizing RF Power Amplifier System Efficiency

- 30 µs Output slew rate and settling (50 µs window in beginning of every 667 µs transmit cycle in which the Vcon adjustments must be completed) In WCDMA architecture, transmit power is adjusted by ±1 dB in every 667 µs as requested by the basestation.
- Low dropout and low ripple near 100% duty cycle *Example:* Low R_{DSON} PFET 140 mΩ (LM3205) or Bypass FET (LM3204) gives low dropout voltage and pulse-skipping schemes gives low ripple near 100% duty cycle.
- Low duty cycle operation for low output voltages *Example:* Minimum on time, 50 ns facilitates 10% duty cycle operation for output voltages of 0.8V and lower depending on the V_{IN} range.
- High switching frequency *Example:* 2 MHz switching frequency helps the use of smaller sized external components and meet spectral emission requirements.
- Fast turn on time to meet time mask for transmit ON/OFF *Example:* LM3203 has turn-on time of 50 µs for Vo = 3.4V from EN = low to high.

100% Duty Cycle vs Bypass Mode

When the buck converter is operating at 100% duty cycle the dropout voltage is

$$\text{Dropout Voltage} = (R_{ON,P} + R_L) \bullet Io,$$

where $R_{ON,P}$ is the R_{DSON} of the PFET and R_L is the inductor DCR. For a PA supply regulator that has a bypass FET the dropout voltage in bypass mode is,

$$\text{Dropout Voltage} = (R_{ON,BYP}) \bullet Io,$$

where $R_{ON,BYP}$ is the R_{DSON} of the bypass FET. The bypass FET can be turned on automatically or manually. As shown, the key advantage in having a bypass mode is lower dropout voltages; which translates to longer talk times and lowering the low battery shutdown point for the phone. The alternative is to use low DCR inductors and a low R_{DSON} PFET.

Example Application Circuits

In this example, the baseband will have a lookup table scheme where it sets the output voltage depending on the output power levels required.

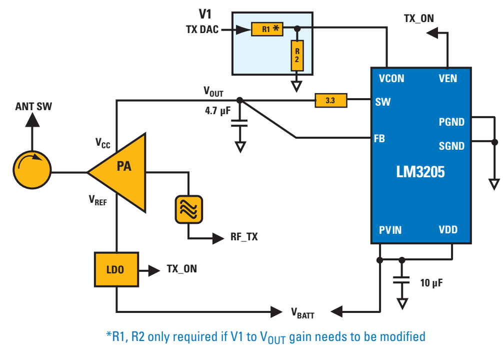


Figure 6. Baseband Controls Vo Directly

In this case, the power detector is part of a closed loop and sets the output voltage.

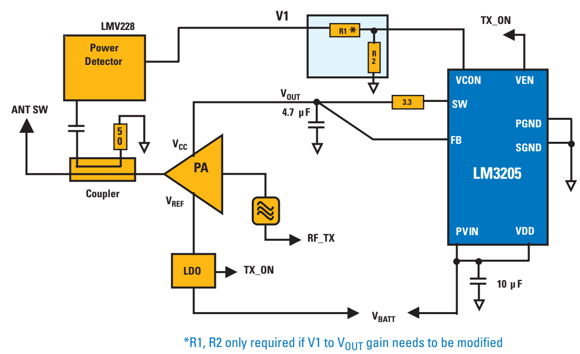


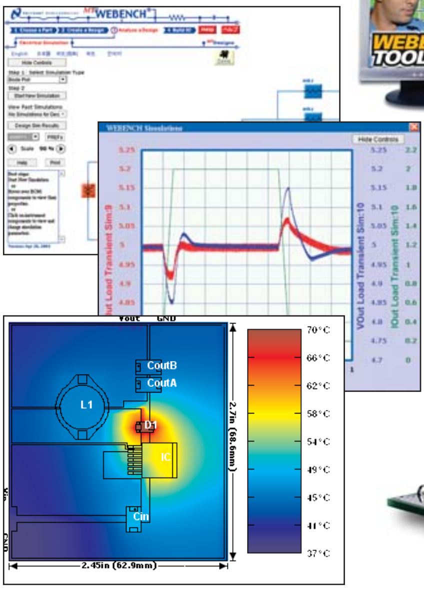
Figure 7. Using a Power Detector to Set Vo

Conclusion

DC-DC converters enhance the RF PA system efficiency in portable communication devices and support the addition of more features or functions by improving battery life. ■

For more information on Powering RF Power Amplifiers, visit www.national.com/onlineseminars to watch Mathew Jacobs' online seminar!

Power Design Tools



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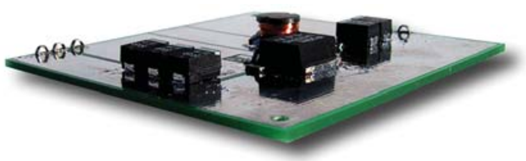

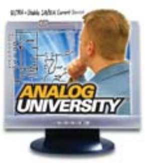

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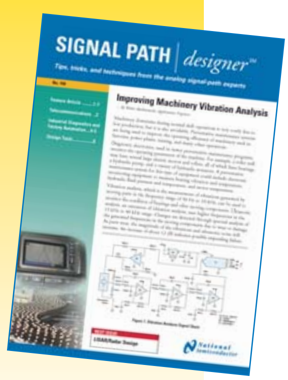

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