

Defining PowerWise® Performance-to-Power Product Metrics

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Introduction

As with all things that are held to standards, a measurement must be established to compare similar items. For example, a standard for measuring acceleration of an automobile is the 0 to 60 miles per hour (MPH) or 0 to 100 kilometers per hour (KPH) in units of seconds. This measurement notes the number of seconds to accelerate from a complete stop to 60 MPH (100 KPH). Using this metric, a buyer could then evaluate the value of several aspects of a vehicle such as horsepower-to-weight ratio, traction control, effects of all-wheel drive, and other features in a single unit of measure.

As the need for more energy-efficient equipment increases, similar methods will be required to determine the best power-to-performance ratio of a component or system. National Semiconductor has developed product efficiency metrics as a means for measuring a device's power consumption to its level of performance. The top tier of products within these metrics are classified as members of the PowerWise® product family. *Table 1* shows the various component families and the associated metrics and performance thresholds used to select the highest performance-to-power ratio products.

Switching Regulator Metrics

Power conversion is the simplest performance metric to understand. There is only the power out (P_{OUT}) divided by the power in (P_{IN}) which yields percent efficiency. Most modern integrated switchers have efficiencies greater than 80%; however, to be best-in-class, efficiencies need to reach 85% to 95% or better. Integrated circuit (IC) designers accomplish this through various internal architectures and the ability to lower the quiescent current when loads are light through switching modes or by entering sleep mode. To be considered a PowerWise brand switching regulator, National has set the bar by category, based on topology or application.

Switching Regulator Metrics – High V_{IN} to V_{OUT} Ratio

In a buck topology where the input voltage is much higher than the output voltage ($V_{IN} / V_{OUT} \geq 7$), the duty cycle of

the system is very small. This limitation presents designers difficulty in achieving high efficiencies at low duty cycles. Issues include accurately sensing the current limit, adequate drive and on time of the high-side switch and minimizing, the dead time (time used to prevent shoot through current) between the high- and low-side switch.

In a boost topology, where the output is much higher than the input ($V_{OUT} / V_{IN} \geq 7$), large currents are present in the switch to achieve the desired output voltage (and load current). To be efficient in moving this current, FETs with very low on resistance are required. This is usually accomplished by making the FETs larger or by process selection. Additionally, challenges in achieving high efficiency for boost regulator designs are similar to those of buck regulators and require similar considerations.

In both of these applications, if a device used in a correctly engineered power supply is capable of reaching efficiencies above 85%, it is considered an excellent example and a member of the PowerWise product family. The regulator IC is only one part of a complex system of components, so correctly matching the additional passive components (such as the inductor and output capacitor) is critical. National provides tools such as its online WEBENCH® design environment to assist engineers in making these calculations.

Switching Regulator Metrics – Switching Frequencies above 2 MHz

There are system tradeoffs when selecting the switching frequency of a switched power converter. In converter designs with a given ripple current, as switching frequency increases, the chosen inductance value should decrease as shown in the equation below. However, hysteretic losses in the inductor and gate drive currents increase with frequency, directly

$$\Delta I_L = \frac{1}{f \cdot L} V_{OUT} \left(1 - \frac{V_{OUT}}{V_{IN}} \right)$$



Table 1

Efficiency Ratings for PowerWise® Products

Product Family	Metric	Threshold	Units
Power Management			
Switching Regulators/Controllers ($V_{IN}/V_{OUT} \geq 7$)	Peak Efficiency	≥ 85	%
Switching Regulators/Controllers ($F_{SW} \geq 2$ MHz, $V_{IN}/V_{OUT} \geq 1.5$)		≥ 90	
Switching Regulators/Controllers (all others, $V_{IN}/V_{OUT} \geq 1.5$)		≥ 95	
Switching Controllers for Isolated Power Supplies		≥ 90	
Low-Noise Linear Regulators	$\frac{e_n}{P_{out}}$	≤ 10	$\mu V_{RMS}/mW$
LED Lighting*			
LED Drivers (boost)	Peak Efficiency	≥ 85	%
LED Drivers (buck)		≥ 90	
LED Drivers (buck-boost)		≥ 80	
Data Conversion			
Giga-Sample ADCs	$\frac{P}{2^{ENOB} \cdot F_s \cdot ch}$	≤ 9	$\mu J/\text{conversion}$
High-Speed ADCs		≤ 2.5	
Low-Power ADCs ($INL \leq \pm 2$ LSB)		≤ 3.5	
Amplifiers and Comparators			
Op Amps	$\frac{I_{cc}}{GBW \cdot ch}$	≤ 120	$\mu A/\text{MHz}$
Micropower Amplifiers ($I_{CC} < 11 \mu A$)		≤ 100	
Low-Noise Amplifiers ($e_n < 4$ nV/ $\sqrt{\text{Hz}}$)		≤ 145	
Precision Amplifiers ($V_{OS} < 0.2$ mV) [†]		≤ 127	
Current Feedback		≤ 7	
Decompensated Amplifiers		≤ 3.3	
Comparators	$\frac{I_{cc} \cdot t_{resp}}{ch}$	≤ 20	$\mu A \cdot \mu S$
Interface			
Equalizers	$\frac{P}{T_r \cdot ch}$	≤ 20	$\mu J/\text{bit}$
Buffers		≤ 40	
Timing/Clocking Solutions			
Clock Jitter Cleaners, Generators, Distributors, and PLL+VCO	$\frac{P \cdot t_j}{ch}$	≤ 120	$mW \cdot pS$
Audio			
Class-D Amplifiers	Efficiency	≥ 85	%
Low Noise Audio Amplifiers ($V_{CC} \geq 30V$, $GBW \geq 40$ MHz)	$\frac{P}{dbLIN \cdot ch}$	≤ 0.88	$mW/dbLIN$
Low Noise Audio Amplifiers ($V_{CC} \leq 5V$, $GBW \geq 4$ MHz)		≤ 0.04	
Far-Field Noise Suppression Microphone Amplifiers	$\frac{P}{dbSUP \cdot ch}$	≤ 0.17	$mW/dbSUP$

ch = number of channels

dbLIN = Amplifier Linearity

dbSUP = Noise Suppression

 e_n = output noise

ENOB = Effective Number of Bits

 F_s = sampling frequency (usually the max sampling rate of the device)

GBW = Gain Bandwidth Product

 I_{cc} = supply currentINL_{range} = range of the Integral Non-Linearity

P = power

 T_r = transfer rate t_j = jitter performance t_{resp} = response time

Note: *LED drivers must meet the efficiency ratings and have an additional power-saving feature to qualify as a PowerWise product.

affecting the efficiency of the power conversion. Managing these tradeoffs well can yield power converters with efficiencies above 90%, which is the metric for this group of switching regulators to be members of the PowerWise family.

Low-Noise Low Dropout Regulator Metrics

The use of a low-dropout regulator (LDO) may not seem to be an energy-efficient design; however, there are times when LDOs are the best fit for a system. This occurs in applications where low noise is critical to the operation of the system. This class of LDO regulators is specifically designed for sensitive analog load applications such as RF transceivers, precision amplifiers, and data converters where the output noise is a key parameter for operation. Since power is required to reduce noise, a slightly different metric is used. This includes the output noise (e_n) which is expressed in microvolts Root Mean Square (RMS) divided by the maximum output power. The better the noise figure for a given output power, the better the performance of the device.

LED Drivers

There are various ways to improve the efficiency of lighting systems. One simple way is to move away from incandescent bulbs to LEDs (Light Emitting Diodes). Modern LEDs exceed the lumens/watt of incandescent lighting providing efficient replacement in many applications such as traffic lights, automotive lighting, signage, and other general illumination. Since LED light is proportional to the current through them and they have a nonlinear voltage to current relationship, maintaining constant current is essential to maintain a given light output and color purity.

LEDs may be used in various applications and therefore require different topologies in switching converters to provide the necessary current. As shown in *Table 1*, when using an LED in a flash mode, such as in a digital camera, high current pulses are common requiring an efficiency of 90% or greater. These devices also require flash duration control to be a member of the PowerWise product family. In applications where there are a large string of LEDs, a boost topology is required which places additional requirements on the switching converter. In this mode, an efficiency of 85% or better provides excellent performance.

Additionally, some applications require both boosting when a voltage source is low or running in buck (step-down) mode when the input voltage is high. This is common in battery operated devices. This also puts additional requirements on the converter and lowers the overall efficiency. In this LED topology, an efficiency of 80% or better is considered very good and difficult to achieve. Similar to buck switching regulators, LED drivers that always run in buck mode (high

input voltage to current out) may see higher efficiencies and values of 90% or higher as best-in-class performance. Along with efficiency, LED drivers must also have power-saving features such as sophisticated dimming control, automatic ambient light adjustment to qualify as PowerWise products.

Data Converter Metrics

The industry figure of merit for data conversion devices and systems is based on the amount of energy consumed per conversion cycle. This metric targets systems that rely on the AC performance of the converter, thus the dependency on Effective Number of Bits (ENOB). This metric is expressed in pico-joules per conversion (pJ/conversion). It can be calculated by either the ENOB or the Signal-to-Noise and Distortion (SINAD) of the converter.

$$\frac{P \cdot 10^{12}}{2^{ENOB} \cdot f_s \cdot ch} = \frac{P \cdot 10^{12}}{2^{\left(\frac{SINAD-1.76}{6.02}\right)} \cdot f_s \cdot ch}$$

The equations above utilize the International System (SI) of units for power and frequency and result in picojoules (pJ) per conversion. Above, P is power consumed by the device or system in watts, ENOB is the effective number of bits for the converter or conversion system and f_s is the max sampling frequency (Hz). The value ch is the number of channels in the converter to normalize all values to a single channel. The SINAD also may be used to calculate this term (as shown in the second equation) since:

$$ENOB = \frac{SINAD - 1.76}{6.02}$$

Amplifier Metrics

Processing analog signals requires amplifiers to scale or filter, detect, add gain or otherwise modify the signal in a predictable way without distortion. There are many classes of amplifiers, including general purpose, low noise, precision, and high-speed current feedback. The overall performance metric for any amplifier is based on the ability to pass signals without distortion. This metric is tied to the bandwidth so the common performance metric used by National is the gain bandwidth product along with the power it takes to run a single channel of the amplifier.

Since there are so many special variations of operational amplifiers, additional metrics must be used beyond the performance-to-power ratio. In *Table 1*, performance amplifiers have additional metrics (such as input voltage noise) next to the amplifier type which will be the threshold for any amplifier in that category.

Amplifiers will continue to improve in performance providing higher speeds or bandwidth at lower power. As applications move away from large supply rails, the overall power consumption will decrease providing the ability to improve the performance-to-power ratios. Amplifier IC design is trending toward single supply amplifiers with extremely large gain bandwidth products at very low power. These amplifiers will accomplish this through lower parasitic losses and improved internal architectures.

Comparator Metrics

Similar to amplifiers, comparators are judged on the speed at which the output changes state for a given supply current. The faster a comparator switches for a given current, the better its rating. For comparators to be considered part of the PowerWise product family, the output must switch from one state to the other with no more than 20 $\mu\text{S} \cdot \mu\text{A}$. This can also be thought of as 20 μA for every μS it takes to switch as a maximum. If a comparator switches in 5 μS and uses only 2 μA of current, the rating would be 10 $\mu\text{S} \cdot \mu\text{A}$, making it a PowerWise family device.

Equalizer and Data Buffer Metrics

The ability to move data over media efficiently at high speed is the metric for interface devices such as LVDS, Mobile Pixel Link (MPL), Current Mode Logic (CML) and others. Typically, more power is required to drive copper cable faster due to cable loss and non-linear effects. Improved drivers combined with the proper receivers and equalizers yield a higher value metric due to a higher data transfer rate, lower power or both.

The metric is defined as: $\frac{P}{T_r \cdot ch}$

Where P is power dissipation of the driver and T_r is the data transfer rate. To be a member of the PowerWise product family, a value of 20 pJ/bit (picojoules per bit transferred over the media) or better is required for equalizers and a value of 40 pJ/bit or better is required for data buffers. As CML technology progresses and further enhancements are made to equalizers which remove the dependency on pre-emphasis and de-emphasis, even higher performance will be achieved. There is still a great deal of life left in copper wires.

Timing Solution Metrics

As systems increase in performance and run at higher and higher speeds, accurate clocks are required to maintain proper synchronization and communication. Even data acquisition systems that use high performance ADCs require low jitter clocks – any jitter directly affects the performance of the system. The equation below defines the effects of jitter on

the Signal-to-Noise Ratio (SNR) of a data acquisition system:

$$SNR_{jitter} = 20 \text{ LOG} \left(\frac{1}{2\pi f_{\max} t_j} \right)$$

The metric chosen by National for clock conditioners includes the consumed power as well as the jitter performance as seen in *Table 1*. A value of 55 $\text{ps} \cdot \text{mW}$ per channel or better is required for a clock conditioner to be considered a member of the PowerWise product family. The lower the power or jitter of a clock conditioner, the higher the power/performance rating. These values are normalized to a single channel.

Audio Solution Metrics

There are several different classes of audio devices targeted toward lowering system power. These not only include low noise and class-D power amplifiers, but also include new technology such as analog-based far-field noise suppression. Class-D amplifiers are qualified as PowerWise products by their conversion efficiency. A power amplifier with greater than 85% conversion efficiency will qualify as a PowerWise family device.

For low-noise audio amplifiers, there are two classes – high voltage and low voltage. Both are qualified on their power consumption versus linearity – a very important parameter for audio.

The metric is defined as follows: $\frac{P}{LIN \cdot ch}$

Above P is the power consumed and LIN is the linearity of the amplifier (ch is the number of channels as before). The high-voltage devices ($V_{cc} \geq 30\text{V}$) should be less than 0.88 $\text{mW}/LIN_{\text{db}}$ and the low-voltage devices ($V_{cc} \leq 5\text{V}$) should be less than 0.04 $\text{mW}/LIN_{\text{db}}$.

Far-field noise suppression is a technology that uses multiple microphones to cancel out ambient noise, providing a higher signal-to-noise ratio in applications such as mobile phones.

Here the metric is: $\frac{P}{NS \cdot ch}$

Again, P is power consumed and NS is the level of noise suppression. Digital solutions can use as much as 10 to 20 times the power required by analog solutions for the same level of noise suppression. The Far-Field Noise Suppression (FFNS) PowerWise devices should have less than 0.17 mW/NS_{db} (DSP based solutions are around 2.25 mW/NS_{db}).

Conclusion

National has a rich technological history of designing energy-efficient ICs for applications where heat dissipation, size constraints, and system reliability are key design priorities. For the growing number of designs where energy-efficiency is a high consideration, National has developed the PowerWise line of products to make it easy for design engineers to select the products that use the least amount of power for the application. As requirements become more demanding, metrics for PowerWise products will become stricter. As more engineers move to higher energy-efficiency requirements, these metrics and products will provide guidance and solutions to these tough design challenges.

For more information on PowerWise technology, visit:
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