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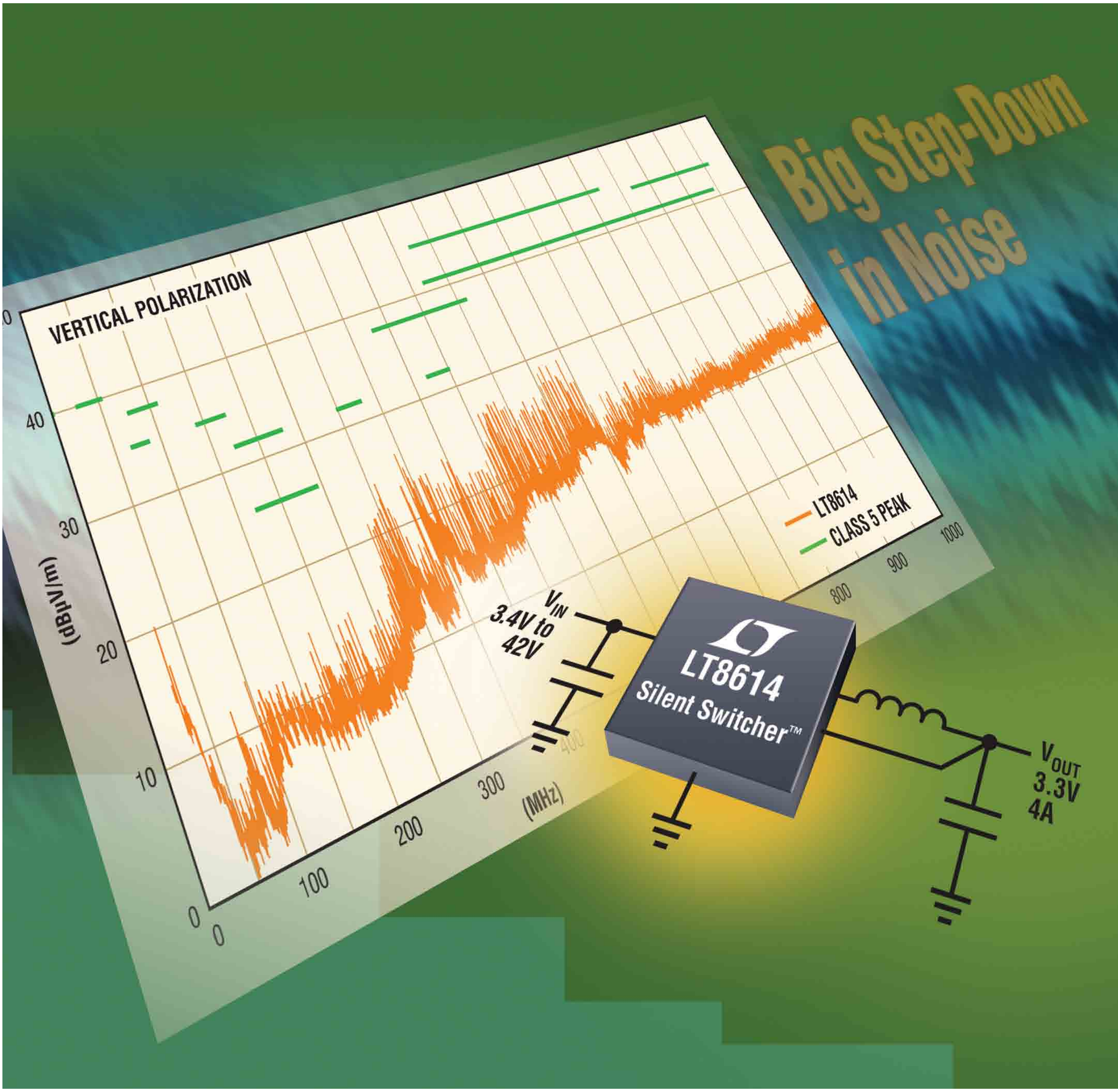
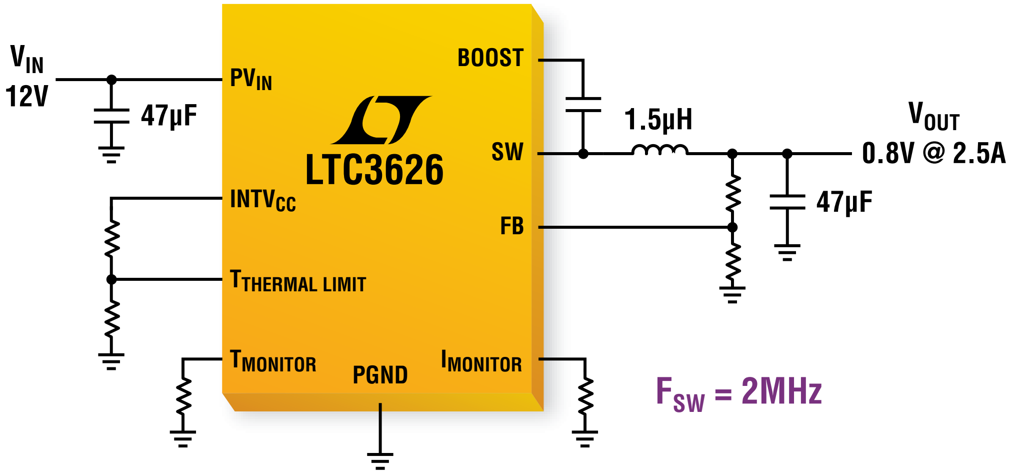
January/February 2014



Special Report: Test & Measurement (pg 33)

20V, 2.5A SWITCHER+



Programmable Input & Output Current Limits and Monitoring with Die Temp Sensing

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- Up to 2.5A Output Current
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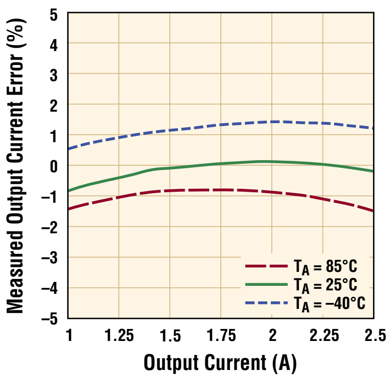
  - Programmable Average Input/Output Current Limit
  - Die Temp Monitor and Programmable Limit (TSET)

Output Current Monitor Error



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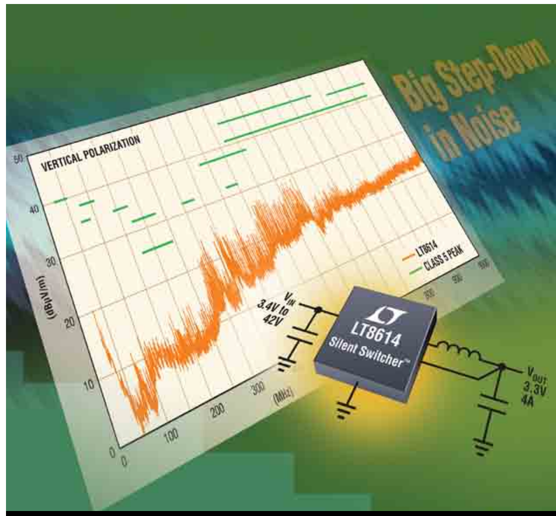

COVER STORY

Reduce EMI & improve efficiency with a switcher design (pg 12)

Highlighted Products News, Industry News and more web-only content, to:

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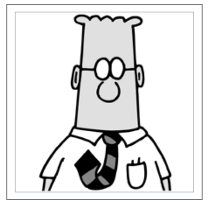

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AGS Media Group
146 Charles Street
Annapolis, MD 21401 USA
Tel: +410.295.0177
Fax: +510.217.3608
www.powersystemsdesign.com

Editorial Director
Alix Paultre, Editorial Director,
Power Systems Design
alixp@powersystemsdesign.com

Contributing Editors
Liu Hong, Editor-in-Chief,
Power Systems Design China
powersdc@126.com

Ryan Sanderson, IMS Research
ryan.sanderson@imsresearch.com

Dr. Ray Ridley, Ridley Engineering
RRidley@ridleyengineerng.com

Publishing Director
Jim Graham
jim.graham@powersystemsdesign.com

Publisher
Julia Stocks
Julia.stocks@powersystemsdesign.com

Production Manager
Chris Corneal
chris.corneal@powersystemsdesign.com

Circulation Management
Chris Corneal
chris.corneal@powersystemsdesign.com

Magazine Design
Louis C. Geiger
louis@agencyofrecord.com

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Volume 11, Issue 01

No precision without feedback

Testing and measuring (T&M) is as old as craft. From the cook tasting the broth to the astronomer shooting a laser beam at the moon, knowing by testing is the only way to determine if one has the quality, quantity, or fit desired in the finished product. Even great mysteries of ancient civilization such as the Great Pyramid and Puma Punku are as amazing for their precision as they are for their materials or construction methods.

Today, the value T&M to the design industry cannot be higher. Regardless of application area, there is a growing lack of tolerance for marginal performance in devices. Even in precision application spaces like military/aerospace and medicine, the goals have for the most part been compliance to specifications over performance. Drivers such as the migration to advanced portable devices and the increased cost of energy inefficiency have changed this perspective significantly.

The current design environment is very challenging to the engineer, as most products no linger end at the inside of the package, but must cooperate and interact with the greater world. Nowadays you can't "only" design for core device functionality, you have to take into consideration additional factors such as energy management for battery life or operating cost and system-level communication, command, and control.

These are not minor considerations. Every subsystem's performance impacts the energy efficiency of the system, and performance is impacted by factors such as RF energy expenditure, antenna matching, proper use of duty cycles, low standby power, and even the bandwidth required to perform basic station-keeping tasks. Having an efficient device with an inefficient communications protocol destroys any advantages of the product, just as having a great RF management system doesn't help if the battery-management subsystem can't properly handle storage management. Everything is important in the equation, as there is no longer any margin for inefficiency.

The good news is that there are more and better test & measurement tools, technologies, and methodologies out there to enable the designer to do their job better. You can get high-definition oscilloscopes that combine multiple channels of flexible mixed signal capabilities with high definition, high-speed information capture with tools for playback and analysis, and precision power analyzers. Online design and development tools from the manufacturers now allow you to perform advanced simulation that could previously only be done in a lab.

We've got some good articles on the subject in this month's issue as well. We've got an article on choosing and using oscilloscope probes well, as proper tool selection is critical to doing the job properly, and test is no exception. In fact, your T&M toolset should be the most sophisticated devices in your facility, as you cannot achieve high tolerances, even with the best manufacturing equipment on the planet, if your baseline measurements are off. We also have an article on tackling three-phase power measurements as well as an interesting approach to power quality, as there is always room for improvement in the space.

Best Regards,

Alix Paultre

Editorial Director, Power Systems Design
alixp@powersystemsdesign.com

Smart-phone-based Circuit Breaker Analyzer uses vibration analysis

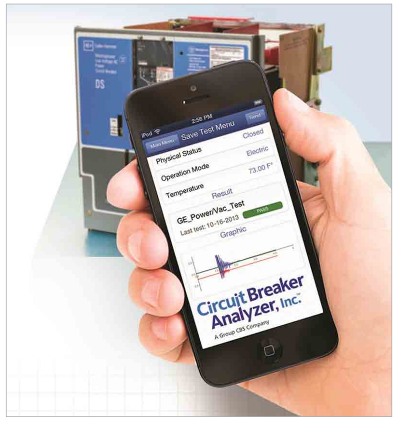
Circuit Breaker Analyzer, developer of CBAnalyzer, presented as the world’s first smart phone-based application for testing circuit breaker performance based on vibration analysis, has won the Occupational Health & Safety New Product of the Year Award in the Environmental, Health & Safety (EHS) Software category.

"With Circuit Breaker Analyzer only being in business a couple of years, it’s hard to capture what it means to win a prestigious safety award like Occupational Health & Safety magazine's Product of the Year," says Natalie Berg, Operations Manager at Circuit Breaker Analyzer Inc. "But I guess the most important aspect of this happy event is that, thanks to this award, more electricians and safety personnel will learn that they don't have to spend tens of thousands of dollars on circuit breaker testing equipment to verify the safe operation of their electrical equipment. By combining the CBAnalyzer app with a smart phone and other portable devices, we can help make circuit breaker testing more common, and that means saving more lives and avoiding more downtime.”

A panel of judges considered criteria such as overall value, innovation, ease of use, and quality when evaluating the contest entries. "I believe these awards, which are now in their fifth year and are judged by an independent panel of veteran safety professionals, recognize outstanding new products from across the spectrum of the U.S. safety and health industry,” says Jerry Laws, Editor of Occupational Health & Safety magazine. “The growth and breadth of this annual contest serve as recognition that leading manufacturers continue to introduce more and more exciting and innovative protective products for this country's workers."

Benefits include:

1. Simple operation requiring minimal training
2. Very portable - it's an iPhone or iPod Touch!
3. modification of the circuit breaker is required
4. No electrical connections are required
5. Removal of the circuit breaker from its mounting or cubicle is not required
6. Testing can be performed during routine switching
7. Data is sent via internet to the users account where it is analyzed and compared with a known good profile (KGP) for that type of circuit breaker to determine:
    a. Overall mechanical condition
    b. Breaker timing: opening and closing speed
    c. First trip testing data for arc flash compliance
    d. Arc flash study validation checks



Using the accelerometer inside every iPhone, new-model iPod Touch, and select industrial handheld tablets, the CBAnalyzer app captures vibration data in all three axes and across time. By comparing the precision 3D vibration information to a database of approximately 200 known good profiles and/or the vibration signature of the breaker’s “first trip” operation, pattern recognition algorithms can determine overall mechanical condition, breaker timing (opening and closing time), first trip testing data for arc-flash compliance, and arc-flash study validation checks.

Circuit Breaker Analyzer
www.cbanalyzer.com

Characterizing Piezoelectric materials for faster computing

By: Professor Markys Cain, National Physical Laboratory

Due to a decade of stagnation in semiconductor transistor performance, computational processing power has failed to increase by more than a few percent since 2003. Now a new European research project looks to speed up the commercialization of revolutionary electronics that could finally provide a route to faster, more reliable and greener computing.

The aim of the Nanostrain project is to advance commercial opportunities arising from controlled strain in nano-scale piezoelectric materials (materials that change their shape, or 'strain' in response to applied voltages). Transistors made out of these materials could operate at one-tenth of the voltage of today's CMOS equivalent, consuming 100 times less power as they do so.

Efforts to develop silicon based computer components at higher speeds have reached a ceiling. Of course there are other solutions out there, including carbon nanotubes and graphene. However, because Piezoelectric materials have been known about for much longer (around 100 years), they benefit from a far greater foundation of scientific understanding which commercial research and development teams are starting to taking advantage of.

Progress in these areas is dependent on the development of new and more accurate measurements and best practice to better understand how these materials work and how they can be exploited. To address this 'final piece of the jigsaw' Nanostrain brings together European national laboratories, world class research instrument facilities and commercial companies, to provide highly accurate measurements of how exactly Piezoelectric materials strain at the nano-scale, and subsequently drive the commercialization of next generation electronic devices.

Using a range of novel techniques, the Nanostrain project will develop new tools for the characterization of nano-strain under industrially relevant conditions of high stress, and electric fields. If the Nanostrain project is successful and helps bring forward the new technologies currently in development, the average computer or laptop user could enjoy a wealth of benefits that accompany greater processing power. These include faster internet access, reduced device weight, longer battery life and lower energy consumption.

As well as these performance improvements, for large industry users there is also the potential to make significant inroads into the carbon footprint of data farms which currently account for 1% of total global energy usage. With the energy efficiency potential on offer in the coming decade from these nano-straining piezoelectric materials, the opportunity is there to cut this energy consumption by a factor of five or even more.

Our European-wide approach ensures greater collaboration, building on existing infrastructure such as the Piezo Institute and involving experts distributed throughout Europe- something that could not be achieved by a commercial organization alone.

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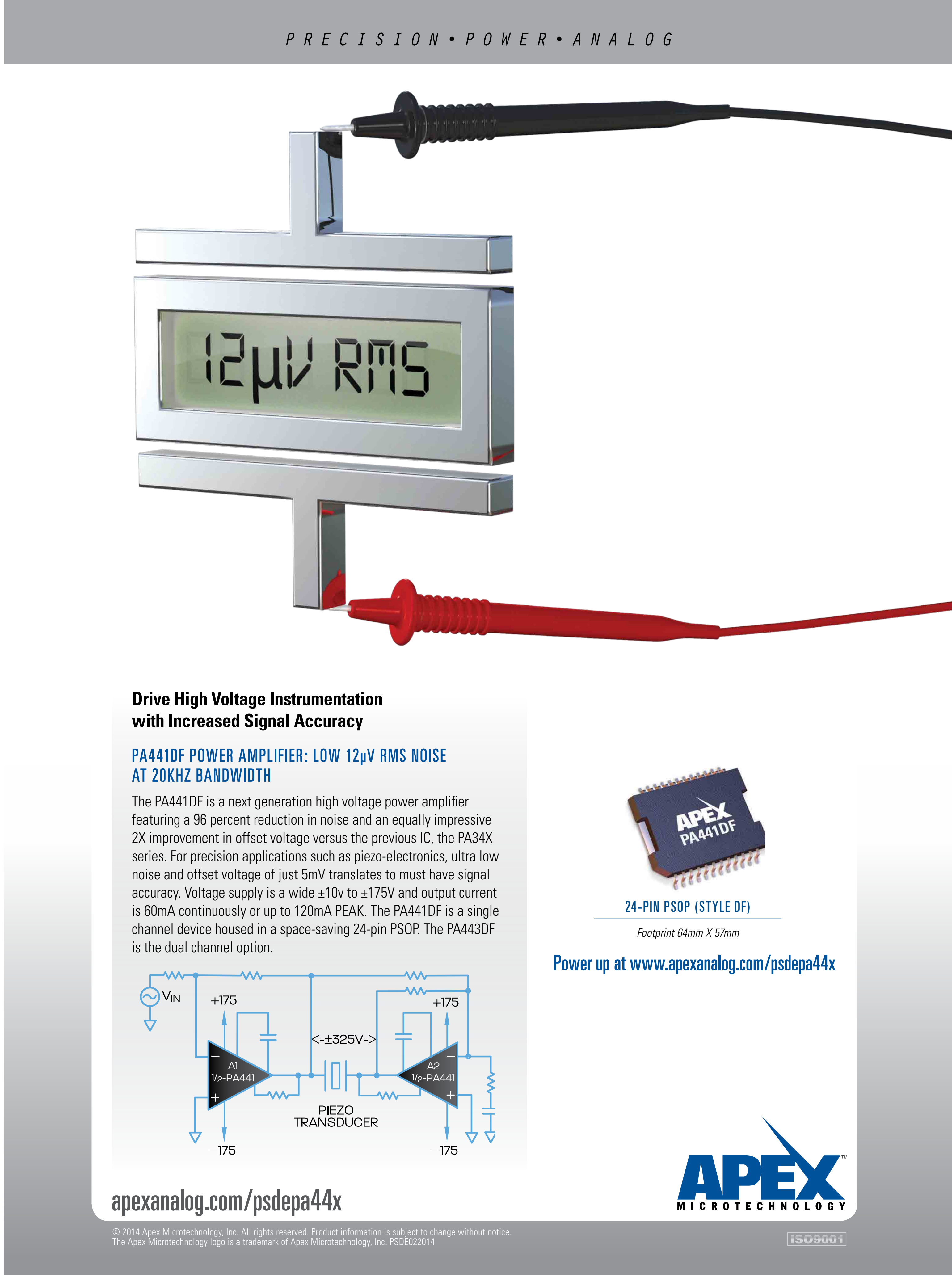

Three Key Opportunities in the Industrial Market for 2014 and Beyond

By: Ryan Sanderson, IHS

2013 marked a year of recovery for many power electronic manufacturers following a weak end to 2012 and a global decline. Recovery, however, was slow in the majority of sectors as economic growth, particularly in Europe, remained unstable, keeping spending confidence low at both a consumer and business level. Demand for many industrial applications remained weak and as we head into 2014 there are no early signs of a rapid change. There are, however, a number of key markets which are predicted to provide substantial growth in the year ahead and beyond.

The total AC-DC and DC-DC power supply market for industrial applications declined in 2013 and is forecast to grow by just 1.4% in 2014. In contrast, the market for digital power supplies in industrial applications grew by 50% in 2013 and is predicted to grow by 40% in 2014 as strong adoption and transition to digital power solutions continue. This is projected to drive an additional $40 million in the market for digital power supplies in 2014. A similar market size for digital power ICs in industrial applications is forecast, though with a slightly higher projected annual growth of almost 60%. This includes digital power ICs used in both board level solutions and those used in digital power supplies.

The industrial battery market includes those used in stationary, automotive and motive applications. It was worth $38 billion in total in 2013 and is projected to almost double by 2017. The fastest growing sector is energy and infrastructure, forecast to grow by 50% in 2014 to be worth $2.5 billion. The majority of this growth is predicted to come from increased demand for energy storage, in particular that related to renewable energy and grid stabilization. The proportion of the industrial battery market accounted for by lead-acid batteries remains by far the largest. Growth of 60% is however forecast for lithium-ion batteries in 2014 and the market is projected to grow by a factor of four from 2013 to 2017. This is predicted to drive increased opportunities for battery management solution providers and IC manufacturers.

Wireless power is currently most often associated with the charging of consumer applications, such as mobile phones, typically by inductive technology. The technology can however potentially be used to power/charge any type of electronic device and is finding its way into some niche applications in the industrial sector. Specific applications include the replacement of mechanical slip rings in wind turbines and a number of medical applications which can help to reduce the risk of infection associated with intrusive procedures. The wireless power market is currently in its infancy but one which IHS predicts to grow rapidly to be worth $10 billion in 2023.

As we enter 2014 I wish you a Happy New Year and every success for the year ahead.

www.ihs.com

Results of a power supply failure survey

By: Dr. Ray Ridley, President, Ridley Engineering

We here at Ridley Engineering recently conducted a survey with a group of almost 3,000 active power supply design engineers to discover the various reasons and circumstances they have encountered power supplies that failed. The experiences the engineers shared with us were very enlightening, and this article summarizes our findings.

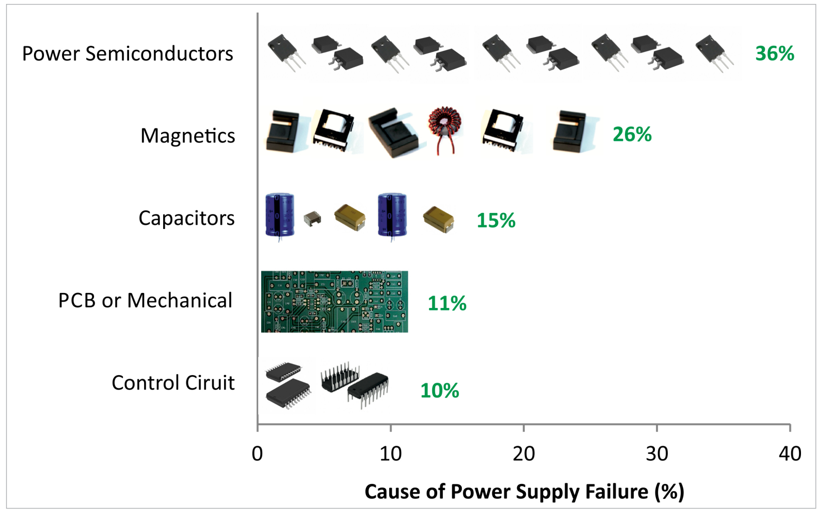

Figure 1: Survey Results for the Cause of Power Supply Failures

Power Supply Failure Survey

Eight months ago, we created the LinkedInTM site "POWER SUPPLY DESIGN CENTER" [1]. As of January, 2014, there were almost 3000 members registered, many of whom have more than 30 years design experience with switching power supplies. Being a very active and vocal group, it has become a valuable resource for design help, as well as keeping up with the changes in the industry.

While power supplies are a mature technology, they continue to be plagued with field failures. When something stops working in an electronics system, the power supply is the usual suspect. In order to find out why this is still a problem in our industry, we went directly to the subject in question with the LinkedIn group:

"Why do power supplies Fail?" To keep the survey simple, five choices were offered for vote. The response was very positive, and a lively discussion followed that is still going on now. **Figure 1** shows a bar chart of the results of the survey.

Responses in order of dominance:

Power semiconductors. 36%. This is not surprising. The semiconductors are placed under extreme stress in power supplies and are usually operated very close to their maximum capability.

Magnetics. 26%. The majority of power magnetics are custom-designed with hand-wound construction. This can lead to many issues. In a future article, we will discuss these issues in detail.

Capacitors. 15%. All capacitor technologies have some fundamental flaws if they are not properly designed into the circuit. This will also be discussed in a future article.

Mechanical and PCB Issues. 11%.
Control Circuits. 10%.

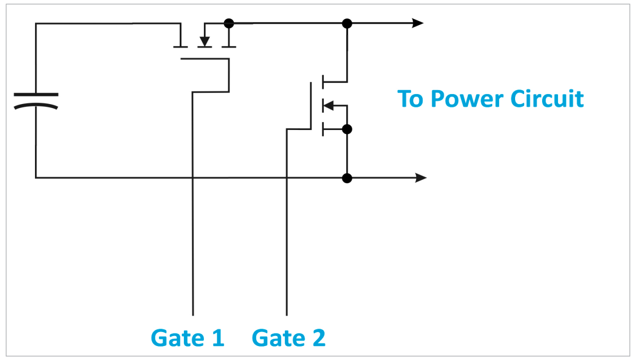

Figure 2: Power Supply Circuit with Two FETs in Series with a Voltage Source.

Power Semiconductor Failures

While semiconductors topped the list above, this should not lead to the conclusion that they are poorly-built components. They are simply in the firing line of anything that might go wrong in the power supply design, and are almost always collateral victims.

Consider the circuit in **Figure 2**. Two fets are connected in series with a low impedance input source. This could be a switch and synchronous rectifier circuit for the front end of a buck converter, or the two fets forming a half-bridge switch pair from an offline source. With this arrangement, there is a tremendous amount of power capability available.

For example, with a 12 V input and two 1-mΩ fets, if both parts are turned on at the same time, the peak power dissipation is 72 kW. When driving synchronous rectifiers or half-bridge circuits, the intent is to drive the fets with as close to 50% duty cycle as possible. Small amounts of noise or controller errors can lead to inadvertent overlap of the drives, resulting in a short circuit. The results are usually catastrophic for semiconductors. In this case, the semiconductors are not the cause of the failure, but the result of improper operation.

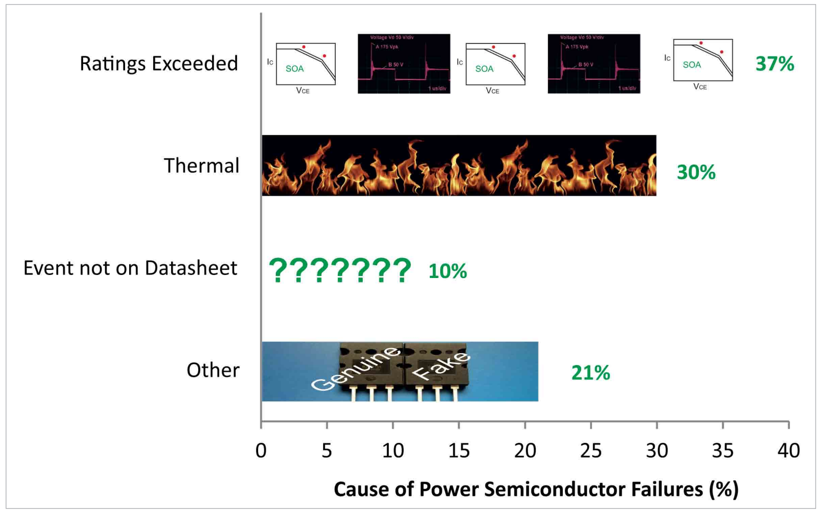

Figure 3: Survey Results for Causes of Semiconductor Failures in Power Supplies

A follow-on survey was conducted to find out what causes the high incidence of failures in semiconductors. The results of this survey are shown in **Figure 3**.

Responses, in order of dominance, are as follows:

Operating beyond specifications. 67%. Either electrically or thermally, this category dominates the observed failures. Overvoltage on the drain, or overvoltage on the gate are typical examples of how the devices can be electrically overstressed. Thermal failures of the semiconductors are caused by inadequate cooling, or an insufficient package size. Neither the overstress or the thermal failures are usually the fault of the semiconductor suppliers. This is a problem with the design of the power supply itself.

Inadequate specs on datasheets. 10%. The unspecified failures have a wide range of possible causes. For example, the reverse recovery characteristics of the antiparallel diode of a fet may be inadequately detailed for an application.

Other. 11%. In this category falls the serious problem of counterfeit parts. Several recent conferences sponsored by the Society of Automotive Engineers and others have highlighted the growing problem of counterfeit parts entering the supply chain. There are many horror stories, including brokers who ship reels of parts where the first few feet of parts on the reel will be legitimate parts and the rest will be counterfeit. This problem is multiplying. Engineers are often called in to fix "design problems" caused by inferior devices.

Summary

The survey results in this article highlight the major causes of failures. Specifically, we discovered the causes perceived to be dominant factors experienced by a large group of engineers.

It is easy for newcomers to the field to be overwhelmed by the wide array of problems they face in design. We will continue conducting surveys within the peer groups available to us to uncover new sources of information and assistance in solving these problems. By discussing our experiences with others and sharing results, we can only hope to become better and more efficient design engineers.

www.ridleyengineering.com

References

1. LinkedIn group "POWER SUPPLY DESIGN CENTER" www.linkedin.com/groups?gid=4860717
2. Ridley Engineering website www.ridleyengineering.com
3. Power supply workshops and training http://www.ridleyengineering.com/workshops.html

Reduce EMI & improve efficiency with a switcher design

The switching regulator is typically the first active component on the input power bus line

By: Christian Kueck, Linear Technology

Switching regulators are an excellent replacement for linear regulators in areas where low heat dissipation and high efficiency are valued. The switching regulator is typically the first active component on the input power bus line, and therefore has a significant impact on the EMI performance of the complete converter circuit.

Modern input filter components in surface mount technology have better performance than through-hole parts, but this improvement is outpaced by the increase in operating switching frequencies of switching regulators. Higher efficiency and low minimum on- and off-times result in higher harmonic content due to the faster switch transitions. For every doubling in switching frequency, the EMI becomes 6dB worse when all other parameters, such as switch capacity and transition times, remain constant. The wideband EMI behaves like a first order high pass with 20dB higher emissions if the switching frequency increases by 10x.

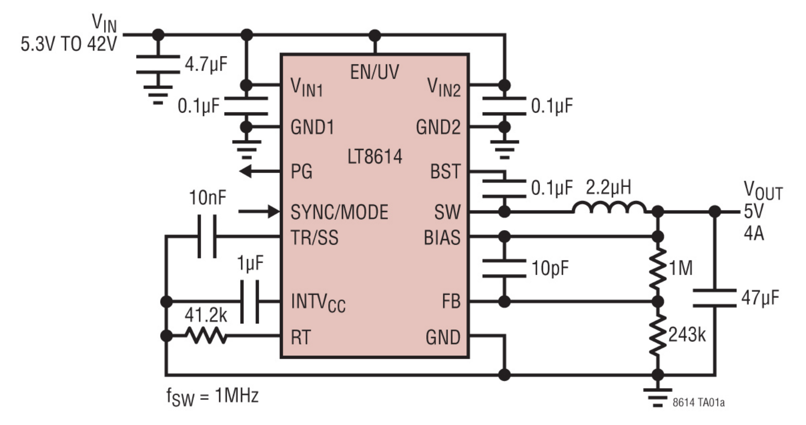

Figure 1: The LT8614 Silent Switcher minimizes EMI/EMC emissions while delivering high efficiency at frequencies up to 3MHz.

Savvy PCB designers will make the hot loops small and use shielding GND layers as close to the active layer as possible; nevertheless pinout, package construction, thermal design requirements, and the package sizes needed for adequate energy storage in decoupling components dictate a certain minimum hot loop size.

Unwanted magnetic coupling

To make layout even more challenging, on a typical planar printed circuit board the magnetic or transformer style coupling between traces above 30MHz will diminish all filter efforts, since the higher the harmonic frequencies are, the more effective unwanted magnetic coupling becomes. The tried and true solution is to use a shielding box for the complete circuit. Of course, this adds costs, increases required board space, makes thermal management and testing more difficult, and introduces additional assembly costs. Another frequently used method is to slow down the switching edges. This has the undesired effect of reducing the efficiency, increasing minimum on-, off-times, as well as the required dead times, and compromises the potential current control loop speed.

By using a device like Linear's latest LT8614 Silent Switcher™ regulator, you can have the effect

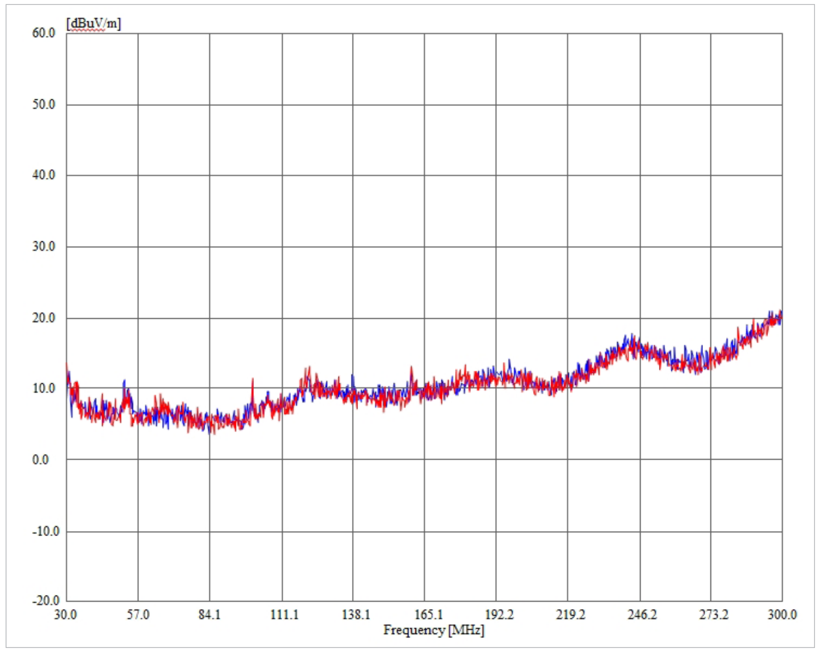

Figure 2: Blue trace is the noise floor; red trace is the LT8614 board at CISPR25 radiated measurement in an anechoic chamber.

of a shielded box without using a shield and also eliminate the above-mentioned draw-backs (see **Figure 1**).

The LT8614 has a low IQ of only 2.5µA operating current. This is the total supply current consumed by the device, in regulation, with no load. The device features the same ultralow dropout of the product family, which is only limited by the internal top switch. Unlike alternative solutions, the LT8614's $R_{DS(ON)}$ is not limited by maximum duty cycle and minimum off-times. The part skips its switch-off cycles in dropout and performs only the minimum required off cycles to keep the internal top switch boost stage voltage sustained, as shown in **Figure 6.**

At the same time, the minimum operating input voltage is 2.9V typical (3.4V max.) and the device can supply a 3.3V rail with the part in dropout. The LT8614 is higher efficiency than the LT8610/11 at high currents, since its total switch resistance is lower. It can also be synchronized to an external frequency operating from 200KHz to 3MHz.

The AC switch losses are low so it can be operated at high switching frequencies without much efficiency loss. In EMI-sensitive applications such as automotive environments, a good balance can be attained and the LT8614 can run either below the AM band for even lower EMI, or above the AM band. In a setup with 700KHz operating switching frequency, the standard LT8614 demo board does not exceed the noise floor in a CISPR25 measurement.

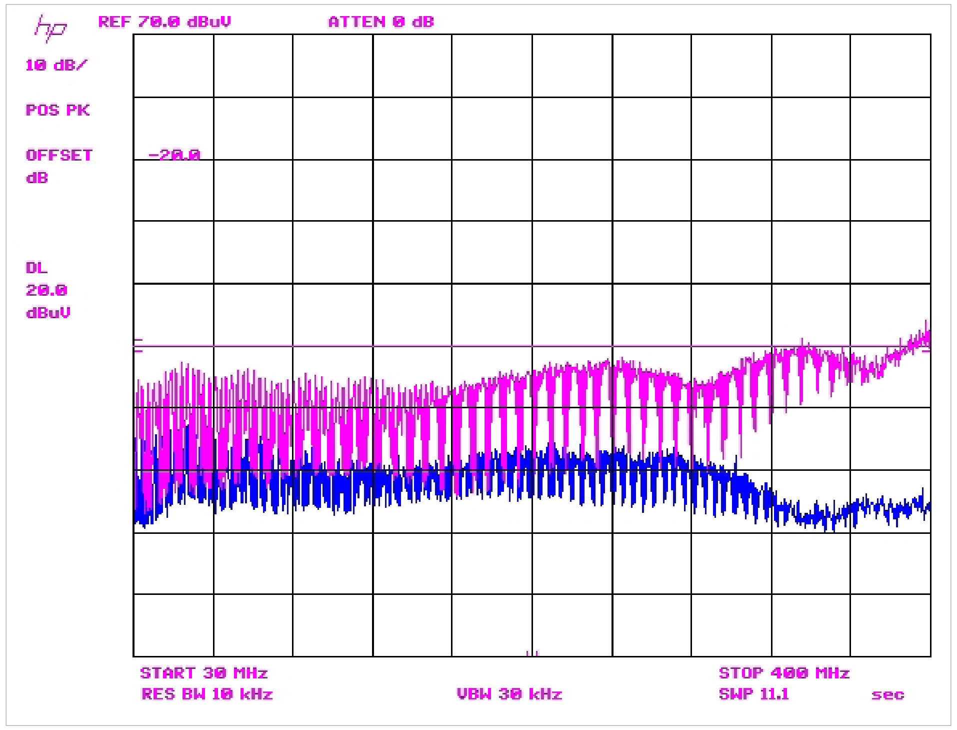

Figure 3: Blue trace is the LT8614, purple trace is the LT8610; both 13.5Vin, 3.3V out at 2.2A load.

The **Figure 2** measurements were taken in an anechoic chamber 12V in 3.3V out at 2A with a fixed switching frequency of 700kHz.

To compare the LT8614 Silent Switcher technology against a current state-of-the-art switching regulator, the part was measured against an LT8610. The test was performed in a GTEM cell using the same load, input voltage and the same inductor on the standard demo boards for both parts.

One can see that up to a 20dB improvement is made using the LT8614 Silent Switcher technology compared to the already very good EMI performance of the LT8610, especially in the more difficult to manage higher frequency area. This enables simpler and more compact designs where the LT8614 switching power supply needs less filtering and distance compared to other sensitive systems in the overall design.

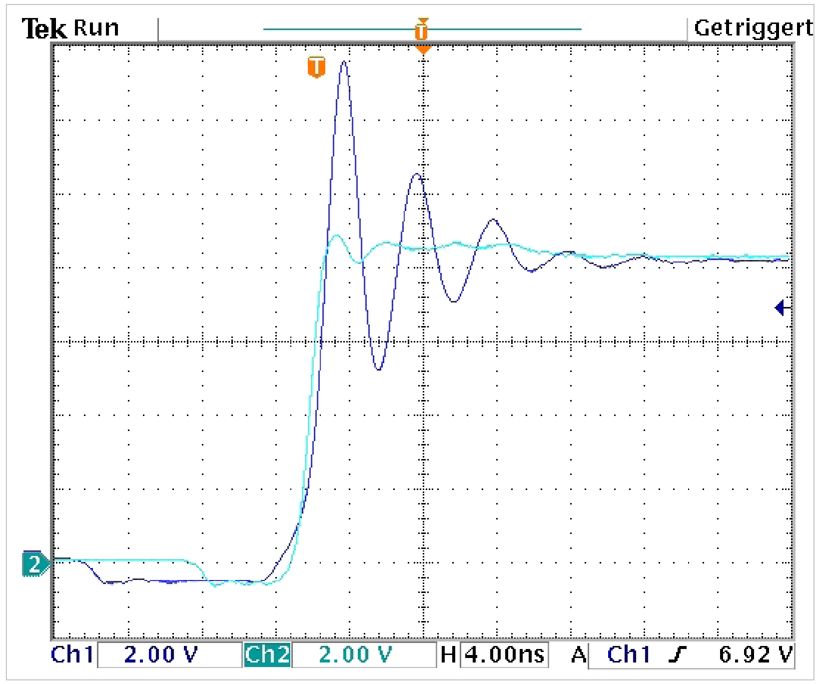

Figure 4: Ch1: LT8610, Ch2: LT8614 switch node rising edge both at 8.4V in, 3.3Vout at 2.2A

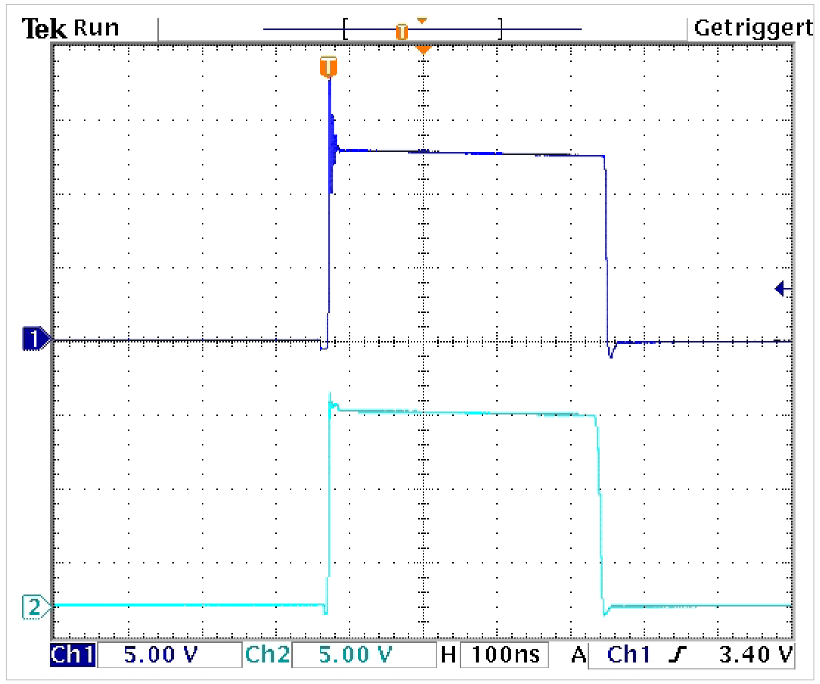

Figure 5: 3 Ch1: LT8610, Ch2: LT8614, both at 13.2V in, 3.3V 2.2A out.

In the time domain, the LT8614 shows very benign behavior on the switch node edges, as shown in **Figure 4**.

Even at 4ns/div the LT8614 Silent Switcher regulator shows very low ringing (see Ch2 in **Figure 3**). The LT8610 has a good damped ringing (Ch1, **Figure 3**) but one can see the higher energy stored

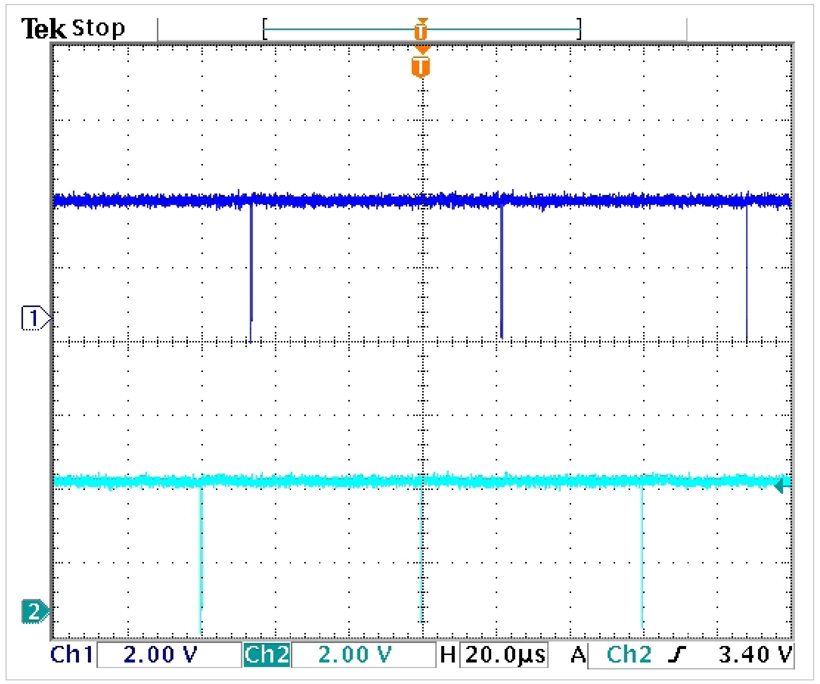

Figure 6: 3 Ch1: LT8610, Ch2: LT8614 switch node dropout behavior

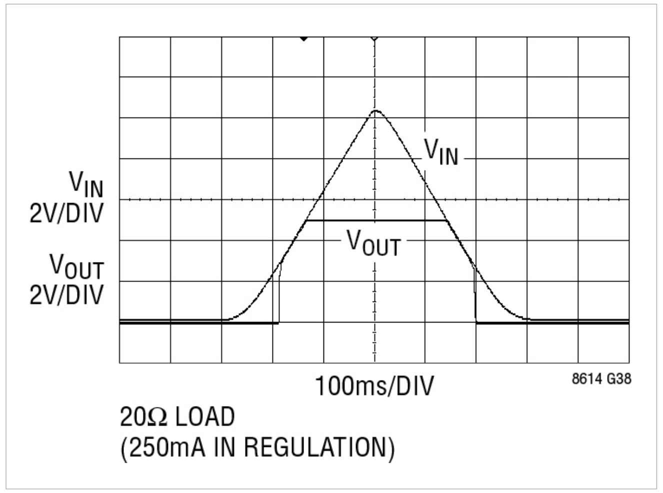

Figure 7: LT8614 dropout behavior

in the hot loop compared to the LT8614 in Ch2.

Figure 5 shows the switch node at 13.2V in. One can see the extremely low deviation from the ideal square wave of the LT8614, shown in Ch2. All time domain measurements in Figures 3 to 5 are done with 500MHz Tektronix P6139A probes with close probe tip shield connection to the PCB GND plane, both on the standard demo boards.

Besides their 42V absolute maximum input voltage rating in automotive environments, the dropout behavior is also very important. Often critical 3.3V logic supplies need to be supported through cold crank situations. The LT8614 Silent Switcher regulator maintains the close to ideal behavior of the LT861x family in this case. Instead of higher undervoltage lockout voltages and maximum duty cycle clamps of alternative parts, the LT8610/11/14 devices operate down to 3.4V and start skipping off cycles as soon as necessary, as shown in **Figure 6**. This results in the ideal dropout behavior, as shown in **Figure 7**.

The LT8614's low minimum on-time of 30ns enables large step-down ratios even at high switching frequencies. As a result, it can supply logic core voltages with a single step-down from inputs up to 42V.

In conclusion, the LT8614 Silent Switcher regulator reduces EMI from current state-of-the-art switching regulators by more than 20dB, while increasing conversion efficiencies with no drawbacks. A 10x improvement of EMI in the frequency range above 30MHz is attained without compromising minimum on- and off-times or efficiency in the same board area. This is accomplished with no special components or shielding, representing a significant breakthrough in switching regulator design. This level of performance in a single IC has not been possible until now. This is just the sort of breakthrough product that allows end-system designers to take their products to the next level.

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Using firmware for efficiency in battery-powered devices

Processors have many different power modes depending on what is required

By: Dave McGownd, Agilent Technologies

Battery powered products are commonplace today. Whether it's a pace maker, smoke detector, cell phone, or high-end computing device, battery life is a big concern. Electronic hardware has evolved to handle these low power needs. Processors have many different power modes depending on what is required. And RF transceiver chips have different power needs depending on whether it's waiting for a signal, sending a signal, or receiving a signal.

For devices that are powered by the ac line, firmware can be written that is somewhat wasteful of power. For example, the firmware has the luxury of using infinite loops. These loops may perform repetitive tasks to wait for some condition to occur. Loops may implement a clock function that causes a subroutine to be called every minute. Conversely, devices that are powered from batteries must employ techniques in firmware to maximize battery runtime. This firmware must avoid these loops due to processor power needs. The proper technique is to put the processor in a low power idle mode and have timer interrupts wake the processor when it needs to do something. Repetitive tasks need to be triggered with a timer that undertake the action and then put the processor back in a low power idle mode.

Peripheral management

Another technique used by developers of ac-powered devices is to turn on all peripheral chips at boot up and leave them in normal mode indefinitely. This simplifies the firmware but causes higher than needed power consumption. Like the processor, peripheral chips should be kept at the lowest power state possible. RF transceiver chips use a lot of power when transmitting and receiving signals, but can use less power waiting for a signal if in the proper state.

Low power RF transceiver chips have the capability to "Wake On Radio". For example, Intel's CC2500 RF transceiver uses 1.5mA when in idle mode. In sleep mode where Wake On Radio is used, it uses 900 nA. This is a difference greater than three orders of magnitude, so it is important to put the radio to sleep rather than letting it maintain a power consuming idle state. Thus, to optimize power consumption requires more complex firmware that actively manages peripheral chip power states.

Debugging tools must also be improved when developing low power applications. Cross-compilers and debuggers do a good job providing insight into functional defects, but are inadequate at identifying power usage defects. Debuggers don't provide insight that a RF transceiver chip has been left on, or whether a processor has been left in the wrong power mode, or if a timer interrupt is consuming too much power. To understand total power consumption, another debugging tool must be used: A DC Power Analyzer.

A DC Power Analyzer provides the developer with a visualization of power consumption as the device runs. To illustrate the DC Power Analyzer's effectiveness, consider a capability many battery powered products implement: product Self-test. If Self-test has to put an RF

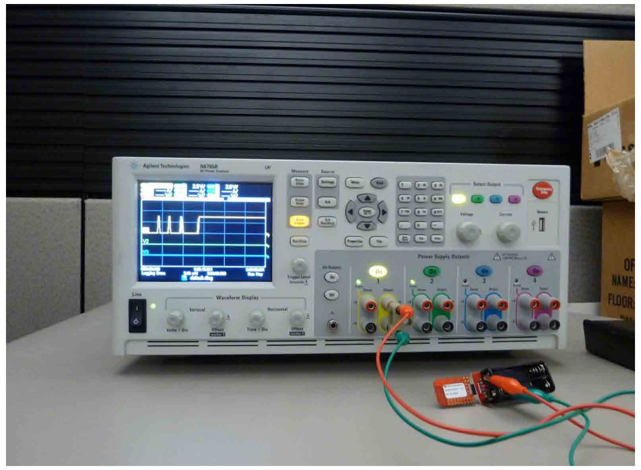
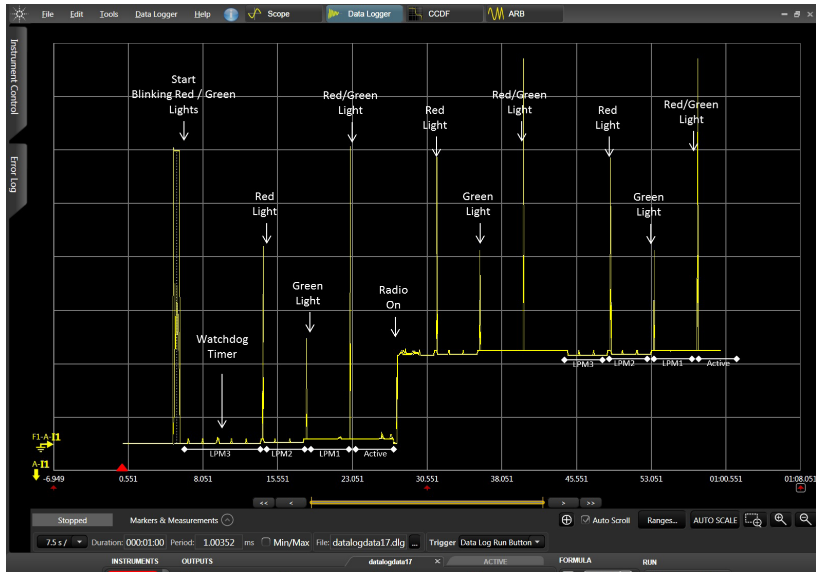


Figure 1: Test setup to measure power consumption of MSP430 processor and CC2500 RF transceiver.

transceiver in idle mode to run a test but forgets to put it back into sleep mode after the test, battery life will be adversely affected. These programming defects are difficult to identify. DC Power Analyzers assist a developer by clearly showing power usage before and after Self-test has executed. A quick glance at a power consumption vs time will clearly show the problem, as the device will be consuming almost 1.5 mA extra after Self-test is completed.

To demonstrate how to detect excessive power usage, we used the Agilent N6705B DC Power Analyzer along with the Agilent 14585A Control and Analysis Software. The test setup is shown below (see **Figure 1**). First, a simple program was developed to execute on the Intel MSP430 processor, which supports five low power modes. Acting as a peripheral chip to the MSP430, the Intel CC2500 RF transceiver supports a wide range of configurations, including Wake On Radio.

Once everything is connected, we started Agilent's 14585 Control and Analysis Software and hit the power on button for channel 1. We allowed the instrument and software to collect current data for approximately one minute. The software showed power usage as the MSP430 program executes our program (see **Figure 2**).



7.5 s / Duration: 000:01:00 Period: 1.00352 ms ☐ Min/Max File: datalogdata17.dlg Trigger Data Log Run Button

Figure 2: The waveform shows current consumption vs time for the functioning MSP430 processor and CC2500 RF transceiver.

The executing program begins by flashing two LEDS to indicate program execution has begun. This flashing can be seen approximately 5 seconds into the chart. From there, the processor is put into low power mode 3 for approximately 4.5 seconds and then low power mode 2 for another 4.5 seconds. This power mode change is done by a watchdog timer event that wakes up every 1.5 seconds. The short regular blips in the chart show the watchdog timer executing its programmed logic. Throughout the 1 minute program the watchdog timer will cause a change to a different power mode every 4.5 seconds. These power mode changes are marked by flashing LEDs that are clearly seen in the chart.

For most power modes the watchdog timer events are very easy to detect. They can be seen as small power spikes approximately 1.5 seconds apart. At 23 seconds, the watchdog timer spikes disappear. This is due to the processor being put in active mode, which is the mode interrupts, such as the watchdog timer, execute. At 27 seconds the watchdog timer spikes reappear as a result of the processor being put back into a low power mode. At approximately 28 seconds into the test, the RF transceiver is put into idle mode. This causes the current to rise significantly; from 1 μA to 1.5 mA. Although this is a change of 1000 times, or three orders of magnitude, events such as the watchdog timer can still be seen, thanks to the wide dynamic range for measuring current provided by the Agilent N6705B DC Power Analyzer. This allows the user to see important details whether the system is drawing microamps or milliamps or even amperes of current. With this tool, the developer can determine power modes of both chips, even though one chip uses much more power.

Time	Marker 1 11.221361 s Avg	Measurements Between Markers Δ = 911.196 ms Freq = 1.097 Hz Min	 Avg	 Max	 Peak to Peak	 Charge / Energy	Marker 2 12.132557 s Avg
A-I1		---	---	---	---	---	
F1-A-I1	410 nA	363 nA	453 nA	531 nA	168 nA	115 pA h	483 nA

2.002 s / Duration: 000:01:00 Period: 1.00352 ms ☐ Min/Max File: datalogdata17.dlg Trigger Data Log Run Button

I1 20 μA /

F1 1 V /
F2 1 V /
F3 1 V /

Figure 3: Another screenshot of the Agilent 14585A Control and Analysis Software.

The insight this chart provides allows developers to verify program correctness that is not possible with traditional debugging and test tools. DC Power Analyzers allow users to identify what power mode a processor is in, the frequency and duration of timer events, and when peripherals chips are turned on and off. They can also measure total power usage over a period of time so battery life can be accurately predicted. An interesting observation with this chart is the high power usage of the LED's. This reminds us that that lighting up LED's should be limited for power-conscious applications.

In **Figure 3**, the markers help us to see the power mode in which the processor is running. After zooming in on the chart, the markers allowed us to make an average current measurement between two watchdog timer events. The average current between the two markers in 453 nA. This measurement confirms that the MSP430 is in low power mode 3.

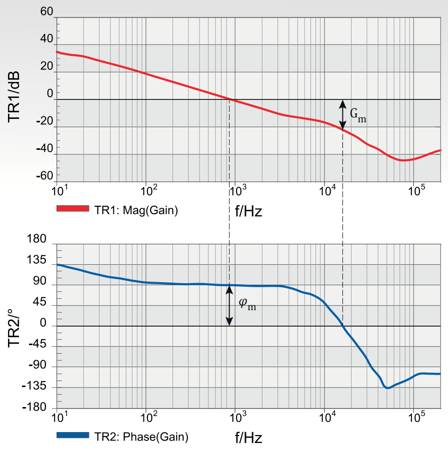
Time	Marker 1 7.04471 s Avg	Measurements Between Markers Δ = 19.829555 s Min	 Avg	 Max	 Peak to Peak	 Charge / Energy	Marker 2 26.874266 s Avg
A-I1		---	---	---	---	---	
F1-A-I1	976 nA	363 nA	59.942 μA	5.555749 mA	5.555387 mA	330 nA h	88.314 μA

6.056 s / Duration: 000:00:30 Period: 1 ms ☐ Min/Max File: datalogdata17.dlg Trigger Data Log Run Button

I1 977 μA /

F1 171 mV /
F2 171 mV /
F3 171 mV /

Figure 4: The Agilent 14585A Control and Analysis Software can be used to determine battery runtime.



Measurements can also be made that include the watchdog timer events. This allows a user to compare battery life versus watchdog timer frequency. This particular example has the watchdog timer executing every 1.5 seconds. The program can be rerun with the watchdog timer occurring every 0.5 seconds. The ratio between these measurements would provide the developer insight into how increasing watchdog timer frequency will affect battery life. This is beneficial information when one is trying to maximize battery life.

Another battery life question a firmware developer will need to answer is how long will the product run on a set of batteries. The Agilent 14585A Control and Analysis Software can also be used to determine overall battery runtime (see **Figure 4**). The first measurement uses two markers to measure the average current usage while the RF transceiver chip is off. The average current usage is approximate 60 μA over a period of one second. Assuming the product uses two standard AA batteries that are rated at 2400mAH, we would expect the product to run for 9 years in these low power modes.

If we move the markers so they measure the power usage while the RF transceiver is in idle mode we find it uses an average of 1.7 mA over a period of one second. This translates to a battery life of 117 days. If we put the RF transceiver into sleep mode and used Wake On Radio rather than idle mode, battery life could have been extended to 3 years and still have been able to respond to incoming signals. This emphasizes the importance of Wake On Radio.

When a firmware developer is tasked with developing a battery-powered product, they need to be aware that the firmware may need to change considerably to insure the product has acceptable battery life. Important guidelines to keep in mind are:

- Avoid loops and use interrupts to launch program logic. Interrupt timers are a good way to launch repetitive logic.
- Always keep the processor and peripheral chips in the lowest acceptable power state. For chips such as RF transceivers, use the Wake On Radio capability when the product needs to support asynchronous radio communication.
- Improve your development toolset to include a DC Power Analyzer. This will decrease debugging time need to track down hard-to-find power defects and provide the necessary data to predict battery life.

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IGBTs impact efficiency and ruggedness in solar inverter apps

Efficiency directly relates to income generation, so device performance is paramount

By: Satyavrat Laud, Renesas

In terms of performance requirements for a power device, a solar inverter is one of the most demanding industrial applications. First, for a grid tie inverter, efficiency directly relates to income generation, so device performance is paramount. Also a long and reliable life, on the order of 20 years or more, for the inverter is crucial. Meeting these requirements is a task for which the latest generation of IGBTs is ideally suited. Typical Solar Inverter: **Figure 1** shows the basic topology of a single-phase H bridge inverter (a three-phase output inverter simply adds another half bridge leg to this topology). This is a common and representative topology of most solar inverters with single phase, 60 Hz, 208 V or 240 V (RMS) voltage output in the 1 to 5 kW power output range.

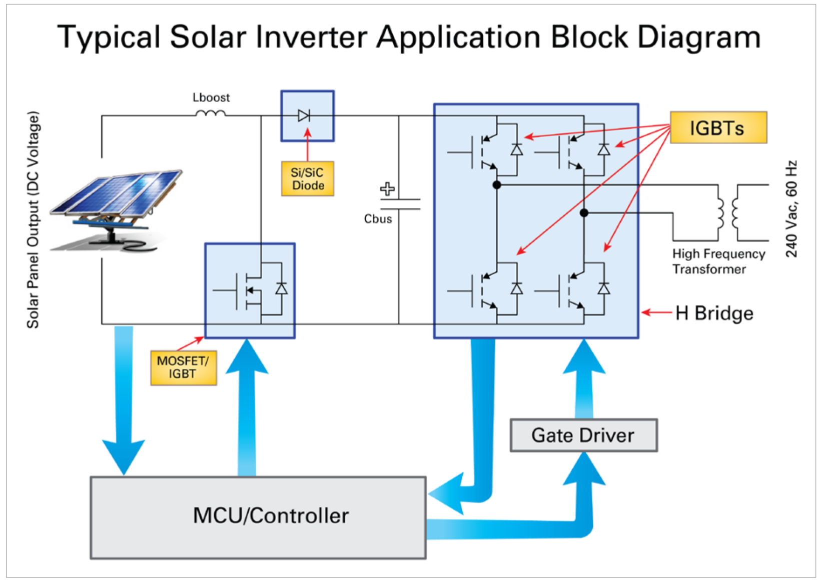


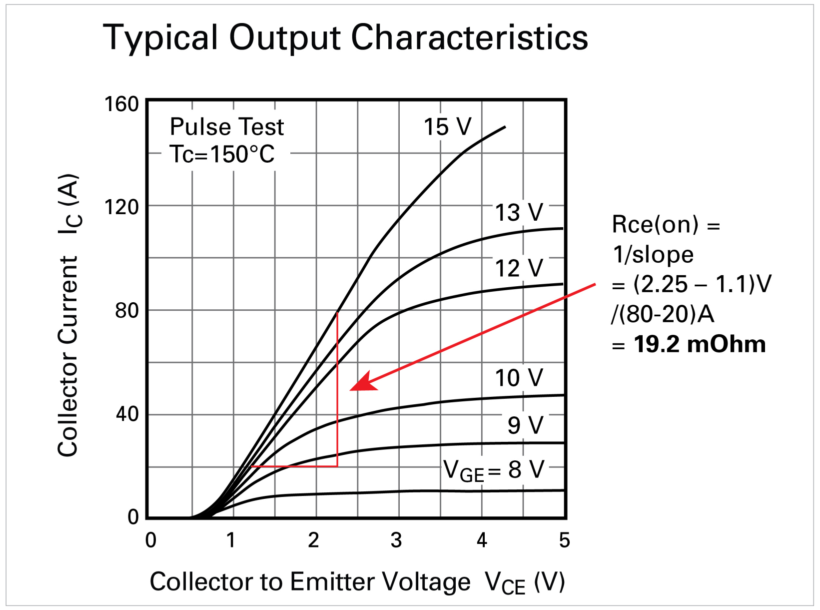
Figure 1: Typical single-phase H bridge topology solar inverter

In this topology, the power devices (i.e. IGBTs co-packed with an antiparallel Fast Recovery Diode) are typically pulse width modulated at a frequency in the 20 to 40 kHz range, resulting in conduction and switching losses in each device which have to be minimized. Further, a long inverter life demands device ruggedness and operating temperatures be considered. For this, IGBT ruggedness defined by the length of time it can withstand a short circuit across its collector and emitter terminals, and IGBT operating junction temperatures are the key factors (the cooler the device runs the longer its operating life).

As an example, an H bridge topology solar inverter with a 240Vac, 5kW, 60Hz, single-phase output is considered. A target efficiency of ≥ 95% at rated power output is set as a requirement, and the implications for the IGBTs in terms of loss and ruggedness are analyzed.

Loss Analysis

For a goal of ≥ 95% inverter efficiency at rated power output, the total device losses need to be limited to about 264W. This requires that the power loss/IGBT needs to be under 66W. Assuming a nominal DC bus voltage of 450V and a maximum DC bus voltage of 500V, a 600V or preferably a 650V rated IGBT+FRD co-packaged in a TO247 or similar type package would be preferred as the power device (a 650V rating would pro-



Rce(on) =
1/slope
= (2.25 – 1.1)V
/(80-20)A
= **19.2 mOhm**

Figure 2: Typical Output Characteristics at Tc = 150°C (from the datasheet of RJH65S04DPQ)

vide additional headroom and help in better withstanding transient over voltages). An example of such a device is the Renesas RJH65S04DPQ.

Given the rated power output of 5,000W @ 240Vac, and assuming a unity power factor, the rated RMS output current will be around 21Arms. For a sinusoidal current waveform, this translates into an average current of about 19 A. To calculate the conduction losses, we need to refer to the IGBT's forward characteristics. This is as shown in **Figure 2** (at an elevated Tc of 150°C):

It can be seen that the Vce(sat) at the 19 A current level is around 1.1V even at the elevated junction temperature of 150°C. But we also need to estimate an equivalent 'Rce(on)' to estimate the conduction loss. This is an equivalent forward resistance of the IGBT (analogous to the 'Rdson' of a MOSFET) in the linear portion of its curve. This 'Rceon' can be estimated to be 19.2 mOhm as shown in **Figure 2**. We can now estimate the conduction losses in each IGBT as a first order estimate as:

Pcond = Vce(zero) x Ic,average + (Icrms)2 x Rce(on)

Where Vce(zero) is the initial voltage drop that is inherent to the IGBT (equivalent to the 'knee' of a diode's forward characteristics)

= (0.7 V x 19 A) + ((21 A)2
x (19.2 mOhm))
= 21.8 W

The switching loss estimation is a bit more involved and generally requires actual bench testing and measurements. Still, for our first order loss estimation purposes, datasheet switching loss information is sufficient. **Table 1** shows the datasheet switching energy loss information:

It can be seen that the test conditions under which the total switching energy (Etotal = Eon + Eoff) is characterized is different from the assumed operating conditions. This requires scaling of this loss to the nominal bus voltage (450 V), the switched current level (~ 25 A), and the case temperature (100 C). The scaling of the loss to the bus voltage is relatively straight forward and can be done as follows:

Etotal_scaled(Vdc) = Etotal x (Vnominal/Vtest) = 2.5 mJ x (450 / 400) = 2.81 mJ approximately

Item	Symbol	Min	Typ	Max	Unit	Test Conditions
Turn-on delay time	$t_{d(on)}$	—	20	—	ns	V_{CC} = 400 V V_{GE} = ±15 V I_C = 50 A Rg = 5 Ω T_C = 150°C (Inductive load) Note5
Rise time	t_r	—	25	—	ns	
Turn-off delay time	$t_{d(off)}$	—	180	—	ns	
Fall time	t_f	—	100	—	ns	
Turn-on energy	E_{on}	—	1.05	—	mJ	
Turn-off energy	E_{off}	—	1.45	—	mJ	
Total switching energy	E_{total}	—	2.50	—	mJ	

Table 1: Switching Times and Energy Loss Information (from the datasheet of RJH65S04DPQ)

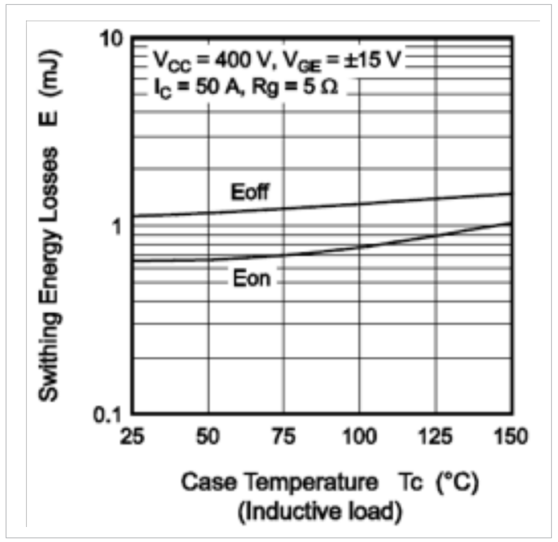


Figure 3a

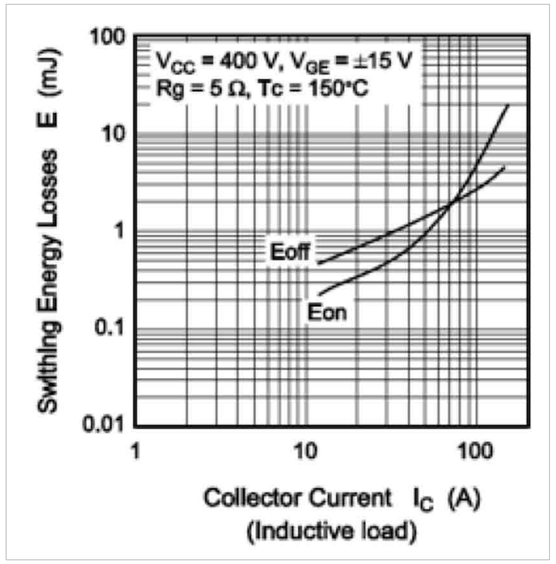


Figure 3b

Figure 3a, 3b: Switching Loss vs. Tc and Ic (from the datasheet of RJH65S04DPQ)

The switching loss dependence with the collector current and case temperature is not linear. Fortunately, the datasheet provides guidance in these regards in the form of characterization of the switching loss over temperature and current as shown in **Figure 3**:

As a first order estimate, it can be seen that Eon decreases by about 20% from 150 C to 100 C but Eoff only marginally decreases by less than 5%. Accordingly if we break up the total switching loss of 2.81 mJ into the Eon and Eoff components, it would be as follows:

Eon_scaled(Vdc) = (1.05/(1.05+1.45)) x 2.81 mJ = 1.18 mJ
Eoff_scaled(Vdc) = 2.81 mJ – 1.18 mJ = 1.63 mJ

If we now consider the impact of the lower operating case temperature we have:
Eon_scaled(Vdc,Tc) = 1.18 mJ x 0.8 = 944 μJ
Eoff_scaled(Vdc,Tc) = 1.63 mJ x 0.95 = 1.55 mJ

We further scale this loss for a switched current level of 25A (as compared to the datasheet loss values specified at 50A), using **Figure 3** (Loss vs. Ic curves). It is seen that the Eon reduces by about 60%, and the Eoff decreases by about 50%, at the lower switched current of around 25A. Thus we have:

Eon_scaled(Vdc,Tc,Ic) = 944 μJ x 0.4 = 378 μJ
Eoff_scaled(Vdc,Tc,Ic) = = 1.55 mJ x 0.5 = 780 μJ
Etotal_scaled(Vdc,Tc,Ic) = 378 μJ + 780 μJ = 1.16 mJ

From the efficiency target set out initially, we had estimated a total loss budget of 66 W per device. Given that the conduction loss per device is about 21.8 W, we have a switching loss budget of 44.2 W/device. We now set a suitable PWM switching frequency as per below:

Psw = 44.2 W = Etotal_scaled(Vdc,Tc,Ic) x Fsw
Fsw = (Psw/Etotal_scaled(Vdc,Tc,Ic))
= (44.2 W/1.16 mJ)
= 38.1 kHz (approximately)

Generally, a switching frequency above say 20kHz or higher is preferable from an output inductor size and current ripple perspective. However, in this case we could switch even higher at say 25kHz and still remain well within the switching loss budget as shown below:

Psw = 1.16 mJ x 25 kHz
= 29 W

Ruggedness and Operational Junction Temperature:

In the event of a short circuit, the IGBT in question sees the entire DC bus voltage across it, and has to withstand the short circuit current. This is an extremely severe condition for the IGBT as it has to be able to withstand many kW of

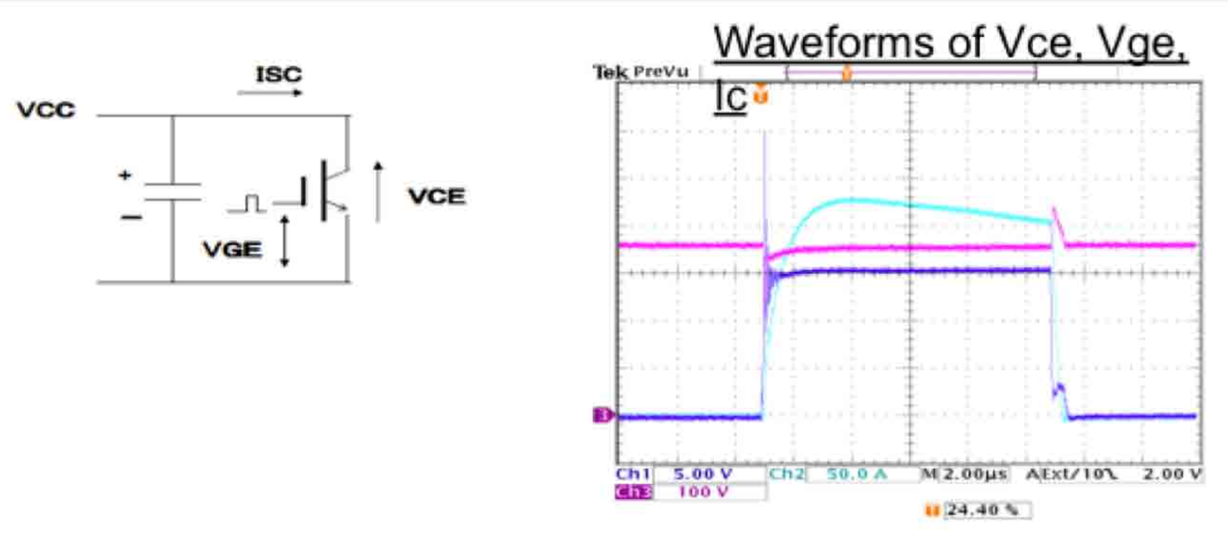


Figure 4: Short Circuit Test Circuit and Waveforms (RJH65S04DPQ)

power dissipation till the time the controller or driver detects the condition and turns it off. While many IGBTs have a 5µs short circuit time withstand capability, a 10µs withstand capability would be preferred from a ruggedness perspective. However, the penalty of a high short circuit withstand capability is generally a higher Vce(sat) and hence higher loss. In this regards, the RJH65S04DPQ is quite remarkable given its relatively low saturation voltage (1.5 V typical at 50 A), while still being able to withstand a 10 µs short circuit event. **Figure 4** shows the test circuit and actual Vce, Vge, and Ic waveforms during a short circuit test conducted on the RJH65S04DPQ:

Operational Junction Temperature

Operating junction temperature is one of key aspects related to silicon device long-term reliability, and for any silicon-based semiconductor power device, the cooler it runs, the longer its expected operational life. This is well known by most circuit designers and is based on long-term reliability studies in literature. In the given example, the junction temperature of the IGBTs can be estimated using the calculated power losses and the datasheet thermal impedance as follows:

$Tj = Tcase + Pdiss \times Rthjc$

Where Tc is assumed as 100 C and Rthjc is the thermal resistance from junction to case as shown in **Table 2**.

$Tj = 100\ C + [(21.8\ W + 29\ W) \times 0.2\ C/W]$
$= 110.2\ C$

Given that the allowed maximum junction temperature for this IGBT is 175 C, the device has ample headroom available in terms of this rating and can be considered to be running cool. This will help from the perspective of a long operating life for the device.

A solar inverter is one of the most demanding applications for a power device. The conflicting demands of high performance, efficiency, and device robustness are best satisfied with the latest generation of trench gate high-conductivity IGBTs. While there are newer technologies on the horizon such as SiC, IGBTs are still very relevant to this application area and will likely continue to be so in the foreseeable future.

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Item	Symbol	Ratings	Unit
Junction to case thermal resistance (IGBT)	θj-c Note2	0.20	°C /W

Table 2: Junction to Case thermal Resistance (from the datasheet of RJH65S04DPQ)

The Perfect Wave

Demand for active PFC circuits in electric drives is on the rise

By: Andreas Johannsen, Vincotec

PFC circuits are finding their way into more and more electronic drives. Of course, the best choice of components will always depend on the given application - what's right for one may be wrong for another. And what's more, power semiconductors can also influence each other.

Demand for active PFC circuits in electric drives is on the rise. Regulations such as EN61000-3-2, more rigorous requirements for electro-magnetic compatibility, and the need for greater energy efficiency are driving this demand. Active PFC circuits also afford engineers the opportunity to source more power from the same power supply.

Fundamental selection criteria

Again, the choice of power semiconductor depends largely on the application and the engineering objectives as outlined above. Static and dynamic losses incurred during electrical conduction and switching vary from component to component. This variance is also contingent upon the load and switching frequency. The individual hardware components' properties have an impact. The ways in which they interact also factor into the loss equation, as a closer look at the boost diode's influence on losses at the boost switch reveals. Reverse recovery time (t_{rr}) is the period that elapses from the moment forward-flowing current is reversed to the point when the diode shuts off altogether.

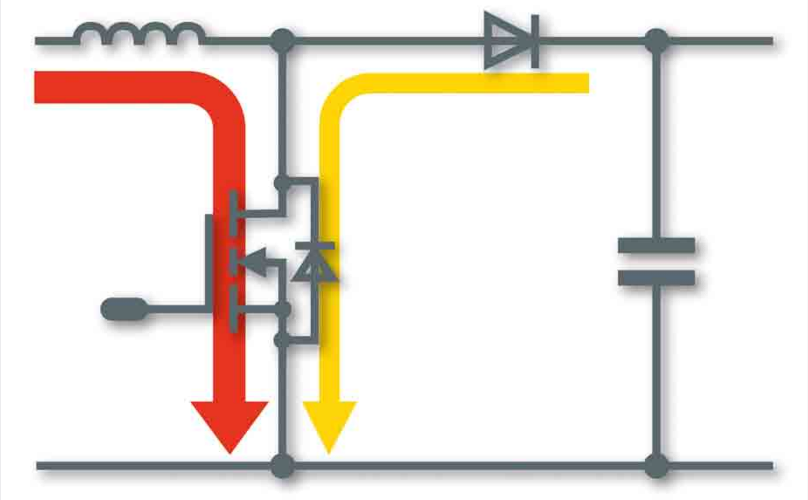

Figure 1: The load current (red) and the reverse current (yellow) flows right after the main switch shuts

Before that point is reached, some reverse recovery current (I_{rr}) flows upstream; that is, against the forward current stop. As **Figure 1** illustrates, this current, like the load current, then flows off from the boost switch. This generates added losses in the switch on top of the actual switching and conduction losses. These additional losses can be considerable, particularly in fast-switching MOSFETs used for high switching frequencies. In this scenario, a slow boost diode would have a major adverse effect on the losses incurred at the switch and thereby impede the switch's peak performance capability. In other words, a fast diode significantly improves the entire PFC circuit's efficiency. Losses may be reduced in multiples of ten percent, depending on the application.

Consideration must be given to the semiconductor's peak performance capability, which brings other key influencing factors into play. Static and dynamic losses, for example, also hinge on the temperature of the semiconductor. Its temperature, in turn, is determined to great extent by its

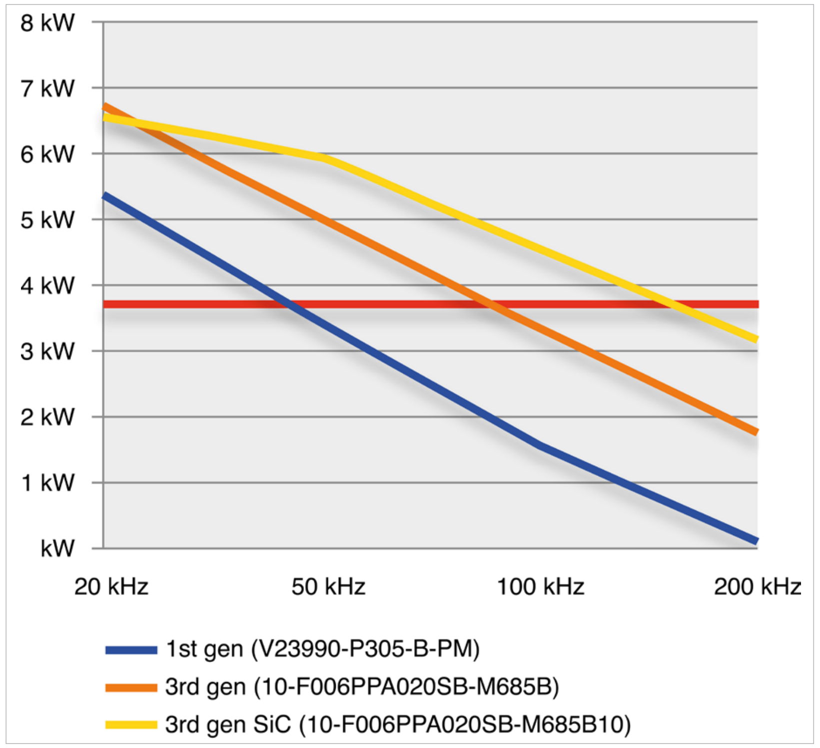

Figure 2: Max output with a 230V input

thermal resistance. A semiconductor is usually mounted on a heatsink, the temperature of which can be deemed more or less constant, contingent upon its material and size. The size of the semiconductor and its interface to the heatsink determine precisely the amount of thermal resistance and therefore the temperature at specific losses. With the benefit of very good cooling, a semiconductor can achieve much higher performance.

As the preceding explanations would suggest, the calculations necessary to select the right components are anything but simple. This is why engineers appreciate the opportunity to simulate the application in advance. Manufacturers of power semiconductor components provide various means of doing this. Vincotech furnishes the integrated simulation environment flowISE, a simple way of testing the company's products with a range of application parameters. The following section looks at simulations of a few typical PFC applications to illustrate the problems of component selection outlined above.

Visualization by simulation

Vincotech has for years offered modules engineered specifically for PFC in drive applications. Modules labeled with the designation PIM+PFC contain all the power semiconductors required for these applications, including input rectifiers, PFC switches and diodes, and three-phase inverters. In addition, a ceramic capacitor is integrated into the intermediate circuit to improve the PFC circuit's switching behavior and EMC. There are now three generations of modules, each reflecting the next rung up the technology ladder for evolving semiconductors. A comparison of these modules' properties in different situations affords insight into the influencing factors described in the foregoing section.

The first use case is a circuit in a 230 V power supply. The PFC circuit extracts sine-wave input current to provide conditioned power. This comparison shows a first-generation module (V23990-P305-B-PM) and two modules of the latest (third) generation (10-F006PPA020SB-M685B and 10-F006PPA020SB-M685B10 with SiC diode). The simulation clearly illustrates the advantages of the new semiconductor (see **Figure 2**). While the old module's ability to extract all the power available from a 16-A-fused line diminishes at a switching frequency of 50 kHz (230 V * 16 A = 3.68 kW, red line), the module with the SiC boost diode is able to continuing extracting full power up to nearly 200 kHz.

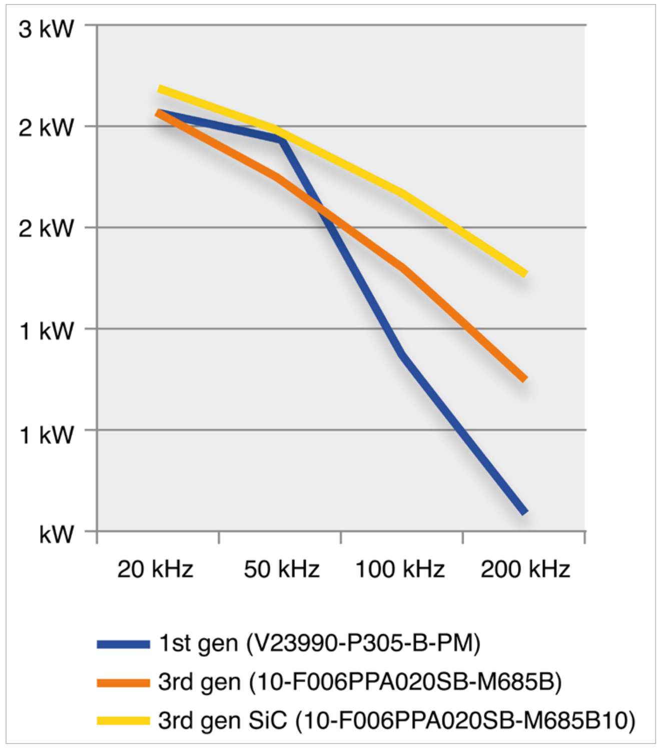

Figure 3: Max output with a 110V input

The performance of the new module without the SiC is about midway between these two benchmark point. Note, though, that it is also significantly cheaper. The new module with standard components now costs just 85% of the V23990-P305-C-PM's original price, but there is a slight premium to be paid for SiC technology. The moderate price increase of 10% buys significantly higher performance and efficiency. At 50 kHz and given the theoretical maximum input power of 3.68 kW, the transistor and diode in the old module generate 53 W losses. Those in the new module with the standard technology generate 44 W, and those in the SiC diode just 33 W. Less energy is wasted when losses are lower, and cooling requires a lot less effort.

PFC circuits also serve another very important purpose: to significantly increase the intermediate circuit voltage in proportion to the line voltage. For one, this may be necessary to operate a device in countries with different mains voltages. This independence from the mains voltage has other benefits beyond that: Higher-voltage motors may be operated at lower coil currents to significantly increase efficiency.

In addition, motors can always be run at their most favorable operating points. Voltage has been reduced to 110 V to simulate this use case, thereby resulting in a slightly different comparison (see **Figure 3**). While the latest-generation modules outperformed the old module in all previously studied cases, in this instance the older generation can keep pace with the younger, at least up to a switching frequency of 50 kHz. The old technology's powers only begin to wane significantly at higher frequencies.

A closer look at the individual components' losses is necessary to get to the bottom of this. At low frequencies, the losses in the MOSFET dominate in all modules. This benefits the old module because the MOSFET has more than twice as much area and can therefore give off a lot more heat to the heatsink (61 W vs. 41 W). The drawbacks of the slow boost diode are apparent at higher switching

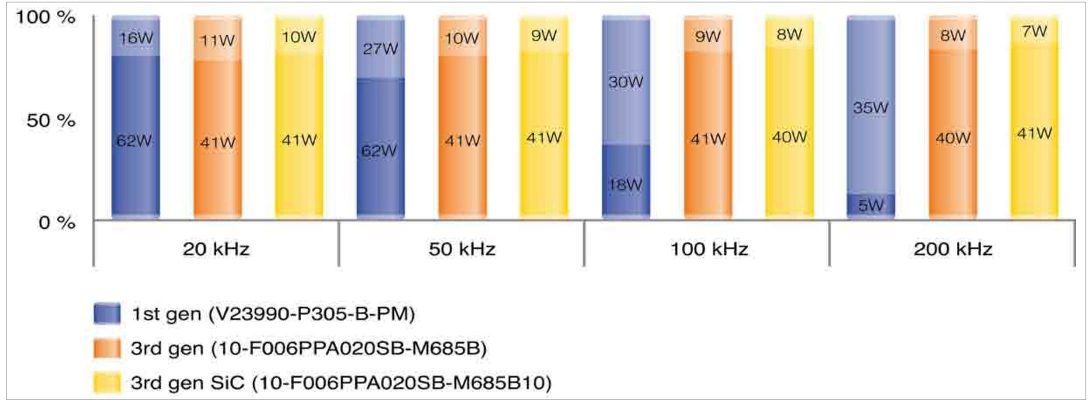

Figure 4: Losses by component at different switching frequencies

frequencies, where it is pushed to the limits of its thermal load handling capacity.

A comparison of the two new modules reveals the key benefits of SiC technology. The MOSFET is clearly the limiting component for both modules over the entire frequency range examined here. However, each MOSFET reaches its peak capacity at different output power levels. This is attributable to the interaction between the boost diode and boost switch. The SiC diode shuts down much faster (13 ns vs. 46 ns) and has a significantly lower reverse recover charge Qrr (0.13 µC vs. 0.57 µC). The energy flowing from and through the diode during reverse recovery must flow through the MOSFET, where it generates higher losses. This explains why the module with the SiC diode is able to produce 40% higher output power at about the same losses. **Figure 4** illustrates the MOSFET and diode's proportional share of losses.

Conclusion

Efficiency may be increased markedly with the benefit of ever more advanced semiconductors such as SiC diodes, fast IGBTs and MOSFETs with lower dynamic losses. These gains can be achieved with the same or lower costs for components. As the above examples have shown, the given application and the interaction among components have to be taken into account when choosing components. Good cooling also matters because it has such a decisive influence on the semiconductors' performance. Power modules are a very good solution because they allow for a simple, insulated interface and low-inductance connections among all other components, all of which helps achieve optimum electrical performance. Equipped with the right semiconductors, they can be used to create highly efficient systems with long lifespans at low overall cost.

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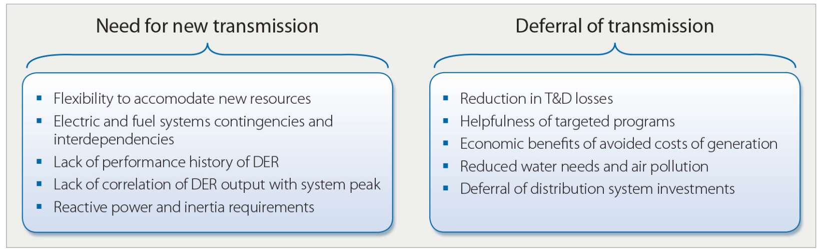
Distributed energy resources will reduce transmission needs

Properly matching DER generation with central station resources can reduce long-range requirements

By: Kiran Kumaraswamy, ICF International

The rapid growth of distributed energy resources (DER) is raising concerns over the viability and necessity of new transmission lines. ICF International's review and analysis of case studies concludes that targeted DER programs will reduce the need for transmission and distribution (T&D) investments in certain areas. Carefully tailored programs can match DER generation with central station resources in a way that reduces new transmission requirements.


Need for new transmission

- Flexibility to accomodate new resources
- Electric and fuel systems contingencies and interdependencies
- Lack of performance history of DER
- Lack of correlation of DER output with system peak
- Reactive power and inertia requirements

Deferral of transmission

- Reduction in T&D losses
- Helpfulness of targeted programs
- Economic benefits of avoided costs of generation
- Reduced water needs and air pollution
- Deferral of distribution system investments

Figure 1: Comparison of Transmission and Non-Transmission alternatives

Organized development

When DER growth is unorganized (most is today), it does not provide adequate reliability benefits given the changing generation landscape. In light of a significantly changing generation profile due to projected coal unit retirements, additional renewables, and high levels of gas generation, new transmission lines provide an adequate level of flexibility to the system to transfer power from generation to load centers. Aging infrastructure in several regions across the country combined with potential system contingencies also necessitate new transmission lines to be built. Finally, commissions and utilities need to consider regional issues related to electric system contingencies while evaluating transmission needs in the face of growing DER.

Benefits of transmission

Transmission lines have long-standing defined benefits, include providing system redundancy during periods of contingencies (loss of large generation or transmission facilities), enabling development of economic generation options, and increasing optionality on the power supply side. Recent extreme weather events have caused significant damage to the electrical infrastructure across the United States and have resulted in outages for a large number of customers. These events underline the benefit of a resilient transmission and distribution system. Although DER could provide for certain benefit categories like improved system resiliency, certain factors should be considered such as the flexibility of accommodating new resources where traditional transmission scores better in comparison (see **Figure 1**).

DER benefits to system reliability

DER can provide reliability benefits to the system in the form of deferred T&D upgrades if targeted in specific localities. The class of DER that includes energy efficiency (EE), demand response, solar photovoltaics (PV), and combined heat and power (CHP) applications has the effect of reducing peak demand by providing appropriate incentives to customers to lower energy

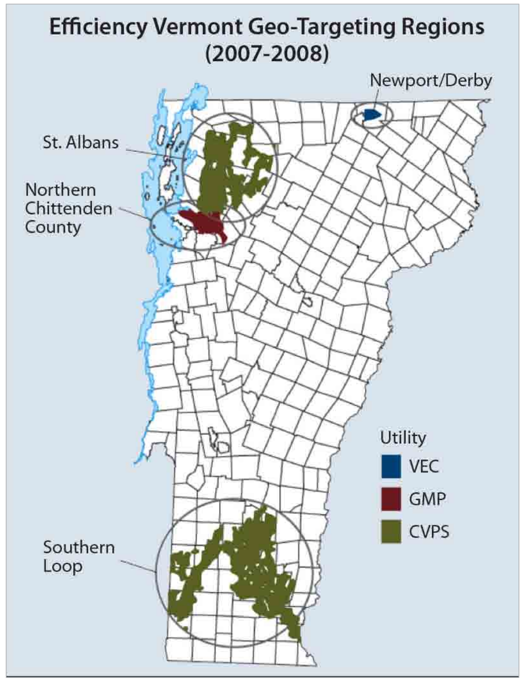


Figure 2: iCF's forecast of DER penetration

consumption during stressed grid conditions. The distributed nature of these resources also provides a higher degree of security of supply because minimal common mode contingencies (like loss of fuel for conventional generation) occur.

DER is likely to become much more pervasive. ICF forecasts increasing levels of DER to reach the marketplace in the next few years (see **Figure 2**). Falling capital costs of certain categories of DER such as solar PV and policy initiatives for CHP, EE, Electric Vehicles (EV), and other applications are causing an unprecedented shift in terms of the balance between the nation's central and distributed generation resources.

Lines Are Needed Even with NTAs

The need for the Greater Springfield Reliability project (GSRP) was largely driven by double-circuit transmission tower contingencies in the local area of Springfield, Ma. These old tower configurations were built several decades ago, and certain types of tower contingencies were creating reliability violations in the system. The proposed transmission solution would replace the towers and provide high-voltage reinforcement in the same corridor.

The regulatory commissions in the Southern New England states require an analysis of NTA's while considering the construction of high voltage transmission projects. in the analysis of potential alternatives for this project, the local utility (Northeast Utilities) concluded that DER (mainly energy efficiency and demand response) did not have the capability to offset the need for the proposed transmission project. Detailed analysis indicated that the level of DER projected in the region did not provide an adequate level of reliability required based on the North American Electric Reliability Corporation's transmission planning standards. Subsequently, the project secured all the approvals and now is under construction.

In the same New England region, ISO-New England (ISO-NE) performed an analysis related to the need for transmission upgrades in the New Hampshire-Vermont areas. ISO-NE identified specific locations in the grid where potential addition of DER could provide a level of reliability comparable to that of proposed transmission projects. In this case, if targeted and planned development of DER occurred at specific locations, the possibility existed for deferring new transmission projects.

Historically, Vermont has implemented "geo-targeted" energy efficiency programs to target specific regions for peak demand reductions (see **Figure 3**).

Maine example: NTA defers transmission need

Targeted and planned deployment of DER sources could offer reliability benefits that could offset or defer the need for T&D investments. Consider the example of Maine. In April 2012, the Maine Public Utilities Commission approved a pilot NTA program to defer investment in new transmission lines in the Boothbay region. This region of Central Maine Power's (CMP) electric grid is served primarily by a single transmission line. The growth of electric load during the summer season in this region would have necessitated transmission system upgrades to meet electric demand during peak hours. CMP identified approximately $18 million to upgrade a 34.5 kV transmission line from Newcastle to Boothbay Harbor (Line#23) for load serving needs. The commission-approved pilot NTA project comprises the development of 2 MW of DER (2 MW of net load reduction), primarily distributed generation, energy conservation, and demand response that would offset the $18 million transmission need in the Boothbay region.

However, much of the DER program development that happens across the country is not targeted and occurs as a function of customer propensity to invest in technologies. Demographics, income levels, and incentives in the form of state or federal subsidies largely drive development trends of DER. in order to be considered as a strong competitor for T&D investments, these resources need to be analyzed, planned, and developed in a manner similar to traditional T&D systems planning performed in utilities.

Not All DERs and NTAs Are Equal in Terms of Reliability Value

DER impact on transmission will vary vastly by region. Reliability needs in the transmission system are studied and analyzed using contingency analysis performed on industry standard modeling tools. as part of this exercise, transmission planners assume the outage of multiple elements in the system and study the line flows and voltages at substations to ensure that they are within acceptable limits. When these values are out of limit, they trigger the need for potential transmission solutions.

While doing such an analysis, planners consider varying demand conditions, combinations of contingencies, and other externalities in the system (like imports and exports). Due to the nature of contingencies, peak demand, and other externalities, needs vary significantly by region and local system conditions. among the key concerns that complicate the comparison of transmission and DER are the lack of performance history and the variability of these resources across regions.

In several markets, regional transmission planning organizations have not yet fully finalized appropriate methods to reflect DER in long-term reliability planning studies. Resources such as rooftop solar PV also exhibit substantial variation in performance across the United States, even between markets with rapid solar PV growth. For example, residential solar PV systems net annual average capacity factors in Southern California and New Jersey are typically 18 percent and 14 percent, respectively, although the magnitude of annual generation varies by state.

Common frame of reference needed

For an effective study of DER as an option against transmission, utilities and other stakeholders involved in the process must fully agree upon the underlying set of assumptions and modeling methods. Distributed energy resources can be considered as NTAs because they provide capacity on the supply side to the electric system during periods of need.

Federal policy in the form of Federal Energy Regulatory Commission Order 1000 requires transmission providers and utilities across the country to actively consider DER as potential NTA options. This provision allows DER to have an equal footing to compete against transmission. Can these resources really offset the need for high-voltage transmission? Will a time occur when no new transmission lines are necessary because every structure has a solar panel on its rooftop? The answer depends on the reliability of the distributed resource and its location in the network.

Only targeted programs that add resources at specific substations in the grid have the capacity to provide reliability benefits in a manner similar to transmission lines. Other generic programs that lead to overall growth in DER will not have a significant impact on the need for transmission projects.

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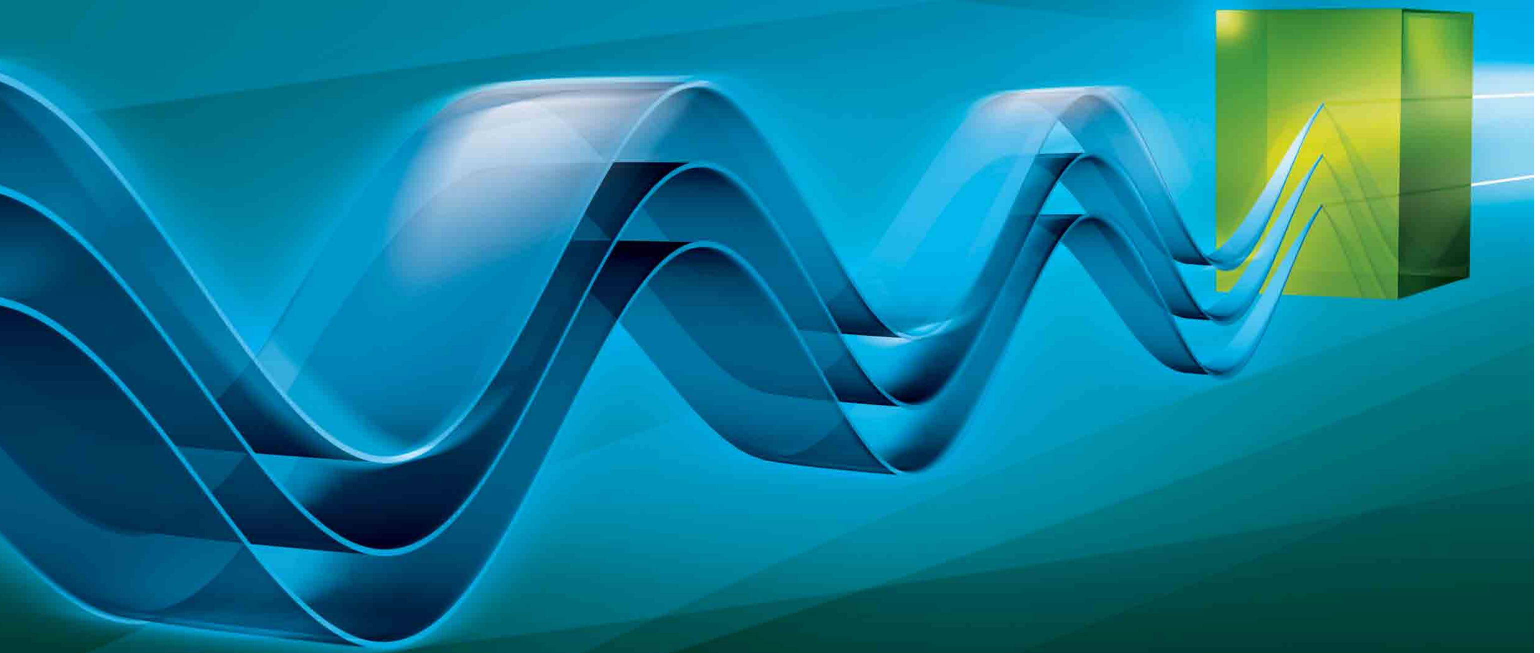

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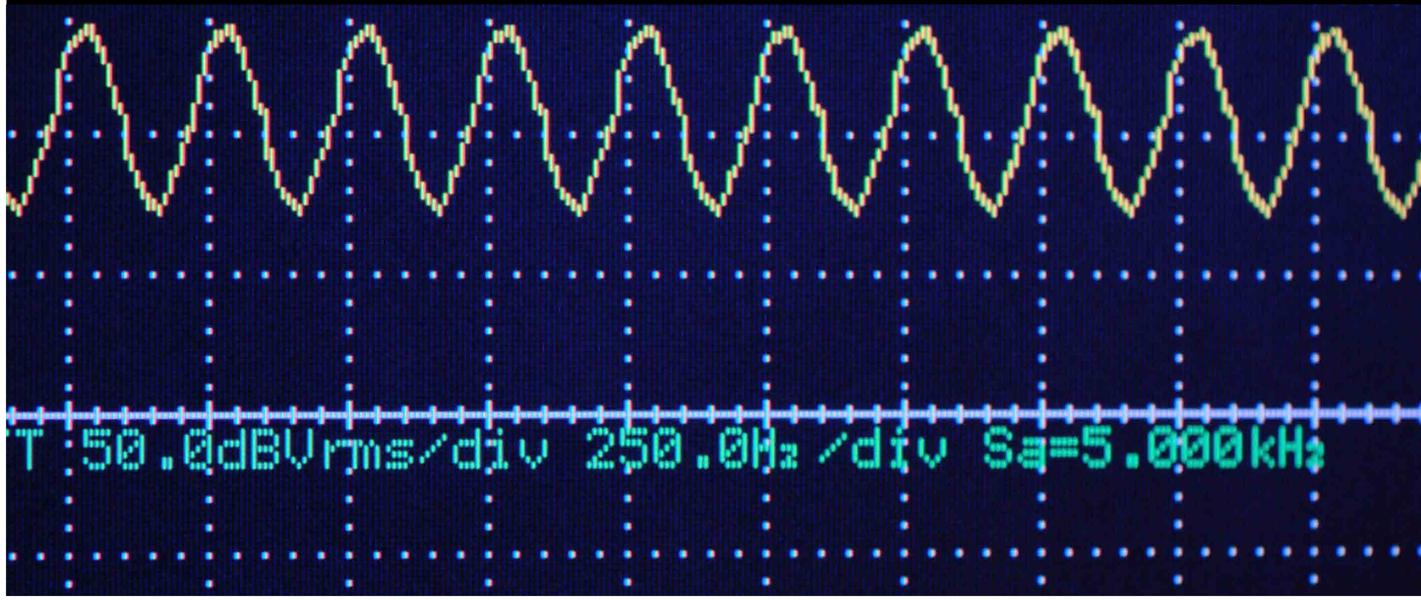

Inside:

Implementing a More Advanced Approach to the Analysis of Power Quality

Decentralized renewable energy sources can lead to supply difficulties

By: Oliver Lanz, Livingston

The world is becoming increasingly reliant on consumption of huge quantities of power in order to satisfy a wide range of needs (with the European Union alone accountable for 2,858TW-hours annually). In many cases it now comes via decentralized renewable energy sources, such as wind, hydro-electric, geothermal and solar - which are not continuously available, but intermittent in nature. This leads to certain supply difficulties. At the same time migration to complex 'smart grid' technology also sets new challenges in terms of maintaining a steady stream of electricity that proves acceptable to the customer base, especially for sites possessing particularly large consumption profiles. Voltage surges/sags and loss of service continuity are symptomatic. The need for in-depth, methodical analysis of power quality to combat this has now become critical throughout the entire supply hierarchy.

Infrastructure issues

Numerous different elements make up the infrastructure responsible for generating/distributing electricity. These include generators, transformers, switchgear and cabling. How well each of these elements works within the system must be evaluated on a regular basis to ensure the grid operates with a high degree of accuracy (see **Figure 1**). Through power quality analysis, engineering professionals can scrutinize the efficiency of complex systems and uncover evidence of possible energy wastage - whether it is due to poorly implemented system design or because of individual components parts becoming worn out over time. It is then possible for them to implement more efficient, better-balanced systems and, in the process, significantly reduce their overheads.

Figure 1: System infrastructure must be evaluated on a regular basis to ensure the grid operates with a high degree of accuracy

Motivation for Power Quality Analysis

In modern three-phase AC electrical supply networks the voltage and current signals should ideally be very close approximations of pure sine waves. Also there should not be any phase shift witnessed between the voltage and current. Considerable losses will ensue if optimized conditions are not kept too - detrimentally effecting the system's on-going operation. The efficiency levels reached will be below what is theoretically achievable and the system's life expectancy will be unnecessarily shortened. Both of these dynamics have obvious financial penalties associated with them.

Through thorough checking of the quality of power passing through the system, it is possible to assess the operational integrity of deployed equipment and identify where potential problems could arise in the future. The time between servicing can subsequently be increased and any monetary loss constituted by system downtime mitigated. Alternatively improvements in operational efficiency made to a system by altering its composure (replacing parts, etc.) can be assessed.

There can be a multitude of underlying reasons why analysis procedures of this kind are embarked upon. In addition to utility companies looking to control/deal with anything that poses a negative effect on their profitability, countless other organizations are now starting to rely on it. Electrical systems in hospitals, factories, university campuses, industrial processing plants, apartment buildings, and offices need to habitually make use of it. Deployed infrastructure will be in place for several decades. This infrastructure is exposed to operational stresses constantly and, as it ages, there will be deterioration in its functional effectiveness. Often located in outdoor environments, it is left vulnerable to harsh weather conditions, as well as extreme temperatures - leading to increased likelihood of failure.

The stakes can be high should the power supplied exhibit poor quality characteristics. If the outcome of this is, for example, a hospital having an unreliable supply to its critical patient care equipment or conversely a manufacturing facility's production lines being brought to a halt, the costs involved (either to human life or brand reputation) can be incredibly severe. Utility company's clients can have service level agreements put in place outlining the minimum specifications for the quality of the electrical power they are supplied with. Performing in-house analysis can serve as a way of ensuring that agreed service levels continue to be maintained by the utility.

Industry standards have been introduced, through which the precise testing techniques required for fully effective power quality analysis can be defined. Currently, the higher more profile of these are IEC61000-4-30, IEC61000-4-15 and IEC61000-4-7 and EN 50160. They provide a common framework which means there are no inconsistencies in the conclusions that test engineers come to, based on the same captured data, because of differences in the test procedures followed. EN 50160 is based on voltage measurements, while the derivatives of IEC 61000 add the dimension of current into the equation.

Major Power Quality Issues & Sources

A variety of different phenomena exist which can be responsible for power quality issues emerging in electrical generation/distribution systems. Among them are:

Voltage Imbalances: This results from uneven loading of the phases in a three-phase electrical system. It can cause motor overheating and thereby shorten the lifespan of equipment. Imbalance problems can be straightened out by redistribution of loads onto different phases, so that there is an equal apportioned current drawn on each one. They can also be tackled by having special transformers installed.

Harmonic Distortions: This occurs when non-linear loads alter the current signal so that it is no longer sinusoidal - with harmonic current flow through components in the system ensuing. As a consequence there can be an overheating of these components - the tripping of circuit breakers/protection relays and a marked heightening in the likelihood of system failures arising. Problems of a harmonic nature can be handled through implementation of better thought out designs. Sadly the impact of harmonics is rarely considered that early on, more often they are only attended to as an afterthought. If signs of distortion are witnessed within a system once it has already been deployed, it will be necessary for harmonic filtering (either passive or active) to be retrofitted.

Neutral Currents: Due to the imbalance and harmonics already discussed, current can be caused to flow in neutral conductors, which are not designed for such things. This current can contribute to energy losses coming from resistance in the cabling. Once again it can be remedied through use of either special transformers or filtering.

Voltage Transients: These can be sudden spikes in the signal brought about by electrostatic discharges. They can alternatively be oscillatory, instigated by a change in the steady-state condition of the current/voltage signal. If they are present, then the utilization of high performance surge protection mechanisms will be called for.

Load Switching: When a load is activated, the current drawn can potentially set off a notable drop in the voltage level observed. It can have serious functional implications for the system over time, with malfunctions in other parts of the system transpiring.

Reactive Power Losses: These come from a phase shift between voltage and current. Reactive energy hence flows back and forth through the system and expensive power compensation systems will be necessitated.

Selecting Effective Analyzing Tools

The scale of data involved in modern power analysis means that highly advanced pieces of test equipment are now essential. Early analysis hardware was just single-phase. This was because the principal technology lacked the capacity to cope with the fast Fourier transforms required by multi-phase operation. Thanks to incorporation of next generation semiconductor devices into the latest test kit, three-phase analysis is now becoming commonplace. The highly sophisticated analyzers currently found on the market integrate a broader range of features, with the ability to acquire voltage, current and frequency signals simultaneously at high speeds. They permit energy-auditing staff to carry out examination of longer waveforms and a greater number of parameters. A far better understanding of the electrical system can accordingly be grasped without any need for apportioning excessive human resources or unnecessary time being taken up.

Conclusion

It is vital that the efficiency of any system involved in the generation, conversion or conveyance of electrical energy is constantly kept at the highest performance levels. As the number of non-linear loads now appearing on utility's distribution networks continues to rise and overall complexity increases, the power quality characteristics of the electricity supplied are threatened. As we have seen, unacceptable power quality can stem from load imbalances within the system due to badly implemented design, harmonic distortions, reactive loads, excessive resistance in the wiring, currents flowing through neutral conductors and an array of other factors - all leading to significant losses. Provided that each of these is fully addressed, a highly efficient and reliable system for supplying electricity can be achieved.

The practice of power quality analysis has now become a key aspect of modern-day electrical network management. Engineers, through the employment of progressively refined analysis techniques and state-of-the-art test hardware, are able to gain total visibility. They can determine where areas of concern are situated and thereafter commence corrective actions to eradicate them. By utilizing equipment that is compliant with recognized standards they can be safe in the knowledge that models from different manufacturers will give consistent results.

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Tackling three-phase Power Measurements

Testing these systems requires an understanding of the different possible measurement connections

By: Faride Akretch, Tektronix

Understanding wiring configurations and making proper connections is critical to performing power measurements. Although single-phase electricity is used to supply common domestic and office electrical appliances, three-phase alternating current systems are almost universally used to distribute electrical power and to supply electricity directly to higher power equipment.

The principles behind three-phase systems are relatively straightforward, thorough testing of these systems requires an understanding of the differences across the possible measurement connections. Here we provide a quick overview of three-phase systems followed by details on measurement connections and tips for configuring equipment.

A quick three-phase system overview

Three-phase electricity consists of three AC voltages of identical frequency and similar amplitude. Each AC voltage phase is separated by 120° from the other. This separation can be represented by both a waveform and a vector diagram as shown in **Figure 1**.

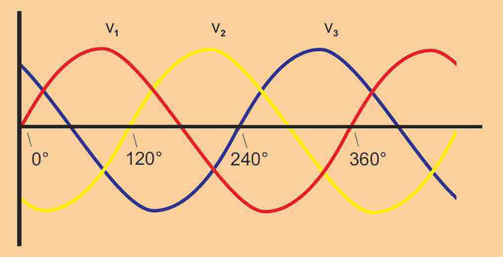

Figure 1a

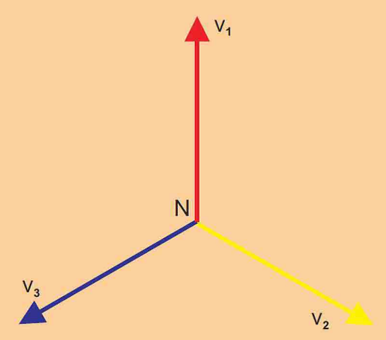

Figure 1b

Figure 1a,1b: Three-phase power can be represented by both waveforms and a vector diagram.

There are two main reasons for using three-phase systems:

1. The three vector-spaced voltages can be used to create a rotating field in a motor. As a result, motors can be started without the need for additional windings.
2. A three-phase system can be connected to a load so that the amount of copper connections required – and the transmission losses – are one half of what they would otherwise be.

To illustrate the second point, in **Figure 2** three single-phase systems are each supplying 100W to a load. The total load is 3 x 100W = 300W. To supply the power, 1 amp flows through six wires resulting in six units of loss.

But the story is much different when the three supplies are

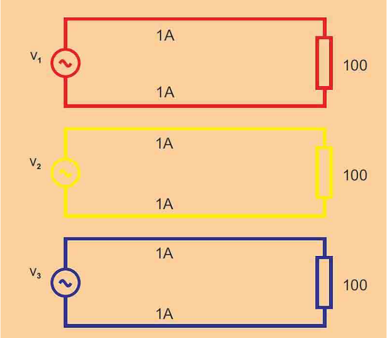

Figure 2: Three single phase power supplies result in six units of loss.

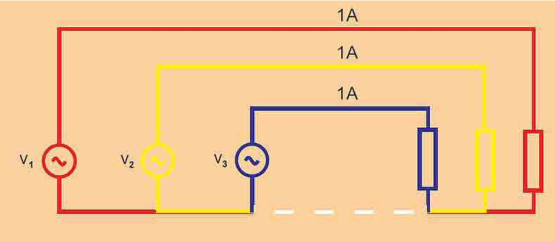

Figure 3: With a three-phase supply, the load is balanced for three units of loss.

connected to a common return. When the load current in each phase is the same the load is balanced. With the load balanced and the three currents phase shifted by 120° from each other, the sum of the current at any instant is zero and there is no current in the return line as shown in **Figure 3**.

In a three-phase 120° system, only three wires are required to transmit the power that would otherwise require six wires. One half of the copper is required and the wire transmission losses are halved.

Wye or Star Connections

A three-phase system with a common connection is normally drawn as shown in **Figure 4** and is known as a wye or star connection. The common point is called the wye, star or neutral point. This point is often grounded at the supply for safety reasons. In the real world, loads are not perfectly balanced and a fourth neutral wire is used to carry the resultant current. The neutral conductor may be considerably smaller than the three main conductors.

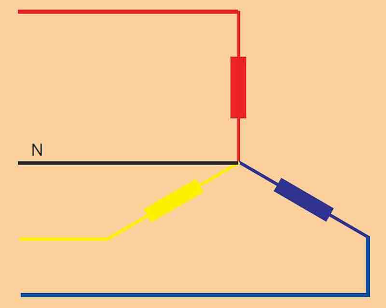

Figure 4: This is a typical wye or star connection for three phase with four wires.

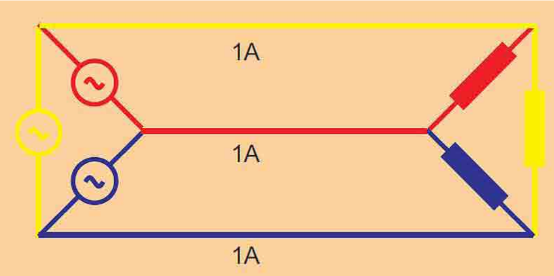

Figure 5: This is a typical delta connection for three phase with three wires.

Delta Connection

The three single-phase supplies discussed earlier could also be connected in series. The sum of the three 120° phase shifted voltages at any instant is zero. If the sum is zero, then both end points are at the same potential and may be joined together. The connection is usually drawn as shown in **Figure 5** and is known as a delta connection.

Wye and Delta Comparison

The wye configuration is used to distribute power to everyday single-phase appliances found in the home and office. Single-phase loads are connected to one leg of the wye between line and neutral. The total load on each phase is shared out as much as possible to present a balanced load to the primary three-phase supply.

The wye configuration can also supply single- or three-phase power to higher power loads at a higher voltage. The single-phase voltages are phase to neutral voltages. A higher phase-to-phase voltage is also available as shown by the black vector in **Figure 6**.

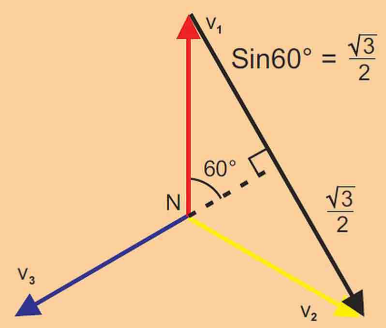

Figure 6: A higher phase to phase voltage is available as shown by the black vector, or V phase-phase = $\sqrt{3}$ x V phase-neutral

The delta configuration is most often used to supply higher power three-phase industrial loads. Different voltage combinations can be obtained from one three-phase delta supply by making connections or taps along the windings of the supply transformers. In the US, for example, a 240V delta system may have a split-phase or center-tapped winding to provide two 120V supplies. The center-tap may be grounded at the transformer for safety reasons. 208V is also available between the center tap and the third "high leg" of the delta connection.

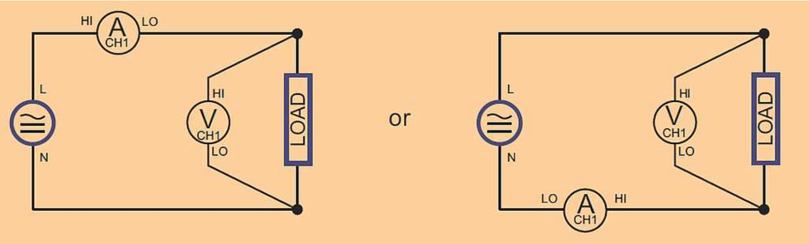

Figure 7: Connections for single-phase, two-wire and DC measurements.

Power Measurements

Power is measured in AC systems using wattmeters. Modern digital sampling wattmeters, including higher-end power analyzers, multiply instantaneous samples of voltage and current together to calculate instantaneous watts and then take an average of the instantaneous watts over one cycle to display the true power. Wattmeters provide accurate measurements of true power, apparent power, volt-amperes reactive, power factor, harmonics and many others over a broad range of wave shapes, frequencies and power factor. In order for power analyzers to give good results, you must be able to correctly identify the wiring configuration and connect the analyzer's wattmeters correctly.

Blondel's Theorem: Number of Wattmeters Required

In a single-phase system there are just two wires. Power is measured using a single wattmeter. In a three-wire system, two wattmeters are required. While there are cases where it is useful to have an additional wattmeter, in general, you can use the following rule: number of Wattmeters Required = No. of Wires -1

Single-Phase Wattmeter Connection

For single-phase measurements, only one wattmeter is required as shown in **Figure 7**. The system connection to the voltage and current terminals of the wattmeter is straightforward. The voltage terminals of the wattmeter are connected in parallel across the load and the current is passed through the current terminals which are in series with the load.

Single-Phase, Three-Wire Connection

In this system, the voltages are produced from one tapped transformer winding and all voltages are in phase. This is common in North American residential applications, where one 240V and two 120V supplies are available and may have different loads on each leg. To measure total power and other quantities, connect two wattmeters as shown in **Figure 8**.

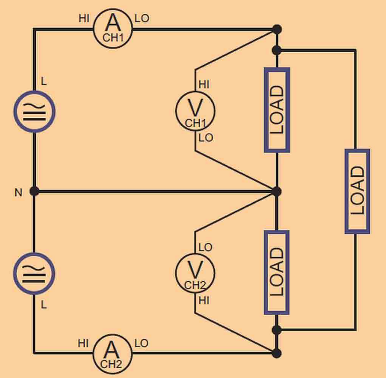

Figure 8: Connections for single-phase measurements with three wires.

Three-Phase Three-Wire Connection, Two Wattmeters

In cases where three wires are present, two wattmeters are required to measure total power. Connect the wattmeters as shown in **Figure 9**. The voltage terminals of the wattmeters are connected phase to phase.

Three-Phase Three-Wire Connection, Three Wattmeters

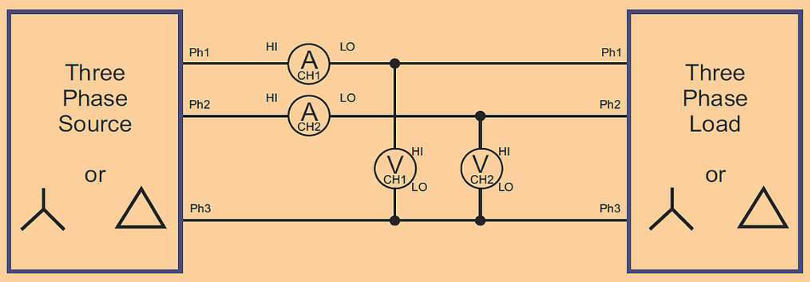

Figure 9: Connections for three-phase, three-wire measurements with two wattmeters.

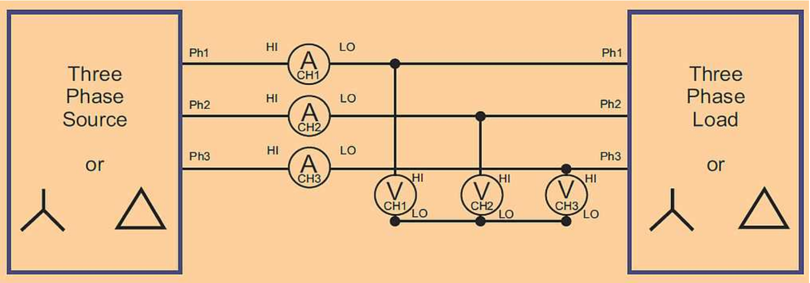

Figure 10: Connections for three-phase, three-wire measurement using three wattmeters.

Although only two wattmeters are required to measure total power in a three-wire system as shown earlier, it is sometimes convenient to use three wattmeters. In the connection shown in **Figure 10**, a false neutral has been created by connecting the voltage low terminals of all three wattmeters together.

The three-wire, three-wattmeter connection has the advantages of indicating the power in each phase, which is not possible in the two-wattmeter connection, and phase-to-neutral voltages.

Three-Phase, Four-Wire Connection

Three wattmeters are required to measure total watts in a four-wire system. The voltages measured are the true phase-to-neutral voltages. The phase-to-phase voltages can be accurately calculated from the phase-to-neutral voltages' amplitude and phase using vector mathematics. A modern power analyzer will also use Kirchoff's law to calculate the current flowing in the neutral line.

Proof for a Three-Wire Wye System

The instantaneous power measured by a wattmeter in a three-wire wye system as shown in **Figure 11** is the product of the instantaneous voltage and current samples.

Wattmeter 1 reading = $i_1 (v_1 - v_3)$

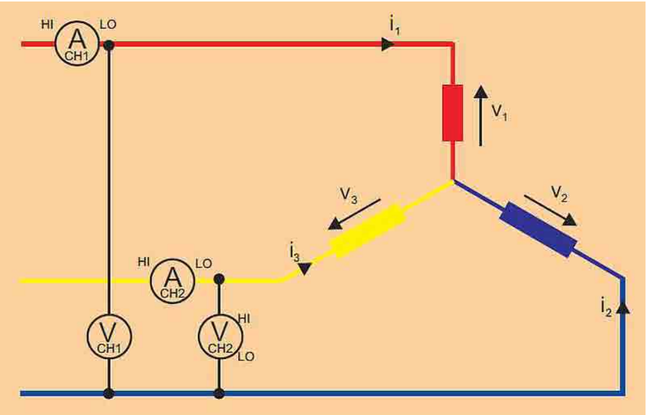

Figure 11: Three-wire wye system measurements.

Wattmeter 2 reading = $i_2 (v_2 - v_3)$

Sum of readings $W_1 + W_2 = i_1v_1 - i_1v_3 + i_2v_2 - i_2v_3$
$= i_1v_1 + i_2v_2 - (i_1 + i_2)\, v_3$
(From Kirchoff's law, $i_1 + i_2 + i_3 = 0$, so $i_1 + i_2 = -i_3$)
2 readings $W_1 + W_2 = i_1v_1 + i_2v_2 + i_3v_3$ = total instantaneous watts

Configuring Measurement Equipment

As discussed earlier, for a given number of wires, N, N-1 wattmeters are required to measure total quantities such as power. You must make sure you have sufficient number of channels and have them connected properly.

Modern multi-channel power analyzers can calculate total or sum quantities such as watts, volts, amps, volt-amperes and power factor directly using appropriate built-in formulas. The formulas are selected based on the wiring configuration, so setting the wiring is critical to get good total power measurements. A power analyzer with vector mathematics capability will also convert phase to neutral (or wye) quantities to phase to phase (or delta) quantities. The factor √3 can only be used to convert between systems or scale the measurements of only one wattmeter on balanced, linear systems. Understanding wiring configurations and making proper connections is critical to performing power measurements. Being familiar with common wiring systems, and remembering Blondel's Theorem will help you get the connections right and deliver results you can rely upon.

www.tek.com

Enabling facilities to diagnose motor issues easily

Advanced testers, analyzers, and motor diagnostics can be performed at the push of a button

By: Jacob Beck, Electrom Instruments

The electronic devices used to test and analyze electric motors and other equipment have become much more powerful than in the past. Yet, in many instances these sophisticated devices have also introduced a high degree of complexity for users, requiring that highly trained and experienced personnel perform the testing.

Many of today's devices are feature rich and capable of measuring and analyzing many factors, including surge comparisons, resistance, impedance and more. Unfortunately, not all of these potent systems are very user friendly, and some require a substantial investment (see **Figure 1**). "Today, you can spend up to $100,000 on a winding analyzer," says Mark Peden, president of Alliance Pump and Mechanical Service (Independence, MO), "but at the same time you could find a very robust model at a much lower price."

Figure 1: For utilities including water and wastewater treament plants, generation stations and power plants, a powerful portable winding analyzer and motor tester that is user-friendly and easy to use vital so that highly trained specialists are not required to perform tests.

Peden, whose company services utilities including water and wastewater treatment plants, as well as municipal, commercial and industrial pumping equipment, elected to do the latter, investing in a powerful portable winding analyzer and motor tester. Not only was the price in the lower range, but also the system is user-friendly and is easy enough to use that highly trained specialists are not required to operate it.

Living up to customer guarantees

"We're a motor shop, which means we clean motors and install or service windings," Peden explains. "We use an electronic analyzer to test the integrity of the motor windings, to ensure that they are going to provide our customers with dependable performance."

The motors Alliance Pump and Mechanical service have sometimes been subjected to harsh conditions, including excessive heat, debris, or occasional lightning strikes, all of

Figure 2: The iTIG II gives users the ability to perform a variety of tests from the most simple low resistance tests to Megohm (also called insulation resistance), Hipot and advanced Surge testing

which mean that windings have to be replaced. When a damaged or simply worn out pump and motor assembly arrives at the shop, Alliance technicians disassemble and thoroughly inspect the motor. The windings are then cleaned, baked and surge tested to make sure they are good.

"We have to be certain that the windings are good or six months later a motor could fail, and due to the comprehensive warranty we provide, we'd end up eating the cost of repairing the unit," Peden explains.

Peden says it takes a good analyzer to do a thorough test on the windings to make sure that the integrity of the motor windings is good. "I looked at several different models, and decided that the iTIG II looked like a pretty user-friendly unit that performed all of the tests and reports that we needed."

The iTIG II is a winding analyzer and motor tester from Electrom Instruments (Longmont, CO) that comes with varying options and output ranges from 4kV to 12kV. By adding Power Packs one can go to even higher voltages (see **Figure 2**).

Peden adds that using this winding analyzer and motor tester is like an insurance policy. "Once we've run the analyzer and everything passes there is no doubt that the motor is good. And it also assures the customer that we did comprehensive testing, and that everything checked out," Peden says. "After the testing the device gives us a printable report that we provide to our customer as documentation of what we found. It's part of the procedure we follow in motor repair."

Power plant applications

Clark Myers, an electrician at Twin Oaks Power, L.P. (Bremond, TX) a division of Optim Energy LLC, has been using Electrom winding analyzers for several years at the coal-fired power generation plant. The Electrom testers use high-frequency 60Hz surge pulses eliminating ionization dissipation and thus better simulating what motors are subject to during operation.

"This is really the only testing and analyzing device we use for checking motors," Myers says. "We also use it on the back of switchgear to ensure proper protection of the motor and the line. Typically this testing is done during a scheduled outage."

Myers, a 35-year veteran of power plant construction and operation, adds that the iTIG is quite user friendly, and does not require engineering expertise or extensive training to operate it successfully. "I'm not what you would call an expert as far as instrumentation is concerned," he says. "This particular instrument is pretty straightforward. Basically, the company just showed us how to use the device, and ever since it has been pretty much second nature."

Friendly but powerful

One of the big advantages of some of today's most advanced instruments is that they are both easy to operate and interpret, but also contain powerful features. The iTIG II that Alliance Pump and Mechanical purchased gives users the ability to perform a variety of tests from the most simple low resistance tests to Megohm (also called insulation resistance), Hipot and advanced Surge testing.

One of the key advantages of all iTIG models is that they use a 60 Hz surge pulse frequency, the same frequency as most motors operate at. This high pulse rate provides a sufficient frequency to overcome ionization dissipation and can thus isolate insulation weaknesses with more sensitivity, predicting future faults before low frequency testers, and also better simulates motor operating conditions.

One of the most significant ease-of-use features is that the iTIG II enables users to enter the surge test voltage, push a button, and let the machine run the test independently. Surge waveform ranges are automatically set for all models, which eliminates the need to specify configurations, push multiple buttons, or turn dials.

All tests can be done with one instrument; they are available in manual to fully automatic models. No additional items are required other than accessories, which can be added on at any time. Tests that can be performed on this system include Surge Comparison, DC Hipot, Step Voltage, Insulation Resistance (Meg test), Dielectric Absorption (DAR), Polarization Index (PI), Low resistance (Ohms), Impedance (Z), Phase Angle, Inductance (L), and Capacitance (C). Models have different features included and all can be upgraded to any higher-level model.

www.electrominst.com

Choose and use oscilloscope probes wisely

Each probe type has its own set of electrical characteristics

There are many kinds of oscilloscope probes on the market with differing functions and electrical/physical characteristics. Some suit low-frequency applications, while others function well at high frequencies or high voltages. In this article, we'll go over some of the salient characteristics of common probe types and provide some tips on which serve best in given circumstances.

Some basic probe varieties:

Passive probe:

- Standard oscilloscope probe supplied by all scope manufacturers
- No active devices, only passive parts
- Physically and electrically robust; handles hundreds of volts
- Maximum bandwidth is 500 MHz but at the higher frequencies probe loading becomes an issue

Active Probe:

- Typically an optional probe that is powered by the oscilloscope
- Based on an active device such as a transistor or FET
- Not as robust as a passive probe but has much wider bandwidths and much lower capacitance
- The ideal probe for high frequency measurements

Differential Probe:

- Measures the difference between two signals when there is no ground reference
- Comes in two flavors: High voltage for floating measurements in a power supply, lighting ballast, motor drive, etc., and high bandwidth for differential serial data streams

Current Probe:

- Active device that measures the current in a signal rather than the voltage
- Three main types: Transformer based; Hall effect devices; or combination transformer/Hall effect
- Most modern clamp-on current probes are combination transformer/Hall effect types

How Probes Affect the DUT

Each probe type has its own set of electrical characteristics. When we attach a probe to a circuit or device under test, it becomes a part of the circuit and its characteristics affect that circuit or device. Probes transfer some of the energy present in the circuit to the oscilloscope input. Thus, to the signal source, the probe constitutes another load. This load on the circuit can change the signal's shape and/or change the behavior of the DUT.

Broadly speaking, there are three possible outcomes when we connect a probe to a circuit. In the best case, the oscilloscope accurately reproduces the signal on screen. However, the probe may alter the signal in a way that misleads us about what is present at the probing point. A worst-case outcome is that the operation of the DUT changes radically, causing a well-designed device or circuit to malfunction (or vice-versa).

Probes are designed with high resistance at the point of contact in the hope of reducing the energy drawn from the circuit and, thus, to reduce the loading. High input resistance is important but it only makes a difference at DC or at low frequency AC (see **Figure 1**). At different frequencies, different characteristics of the probe gain:

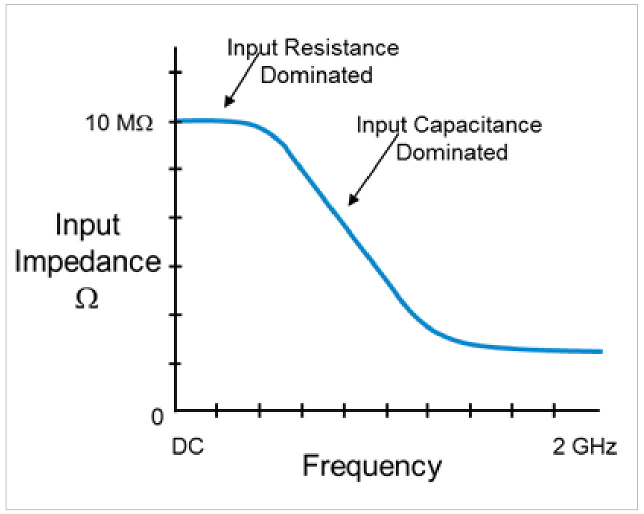

Figure 1: At different signal frequencies, different probe characteristics dominate the overall input impedance.

- At DC or low frequencies, the high input resistance dominates the overall impedance
- As frequency increases, the capacitance dominates the impedance and dramatically lowers the overall impedance
- The result of the high probe capacitance shows up in the signal shape seen on screen. At 1 Hz, the impedance of a passive probe is 10 MΩ. At 1 MHz, that value decreases to 17.4 kΩ. At 100 MHz, impedance is just 174Ω. With such a sharp drop off in overall impedance, it's not surprising that the probe can have such a dramatic impact on what's seen on screen (see **Figure 2**).

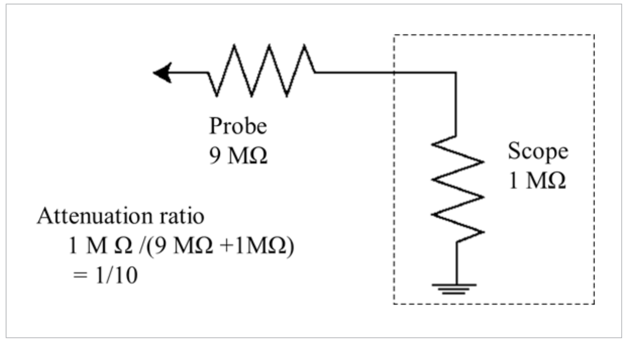

Figure 3: A characteristic impedance vs. frequency plot for a high impedance active probe

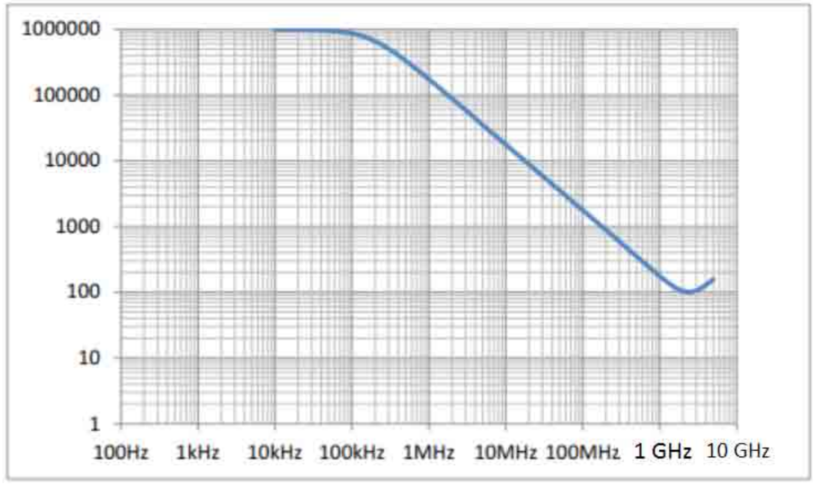

Figure 2: The typical high-impedance passive probe has a 10:1 attenuation factor

There's one more major piece to the puzzle of a probe's impact on the DUT: inductance. In typical measurement scenarios, you can't just connect the probe tip to the DUT unless you're trying to make a floating measurement. The probe's ground lead must be attached to earth ground, or as close as you can get to it. All measurements are fundamentally differential in that there has to be some kind of reference point to measure a voltage. In general, that reference point is earth ground.

Thus, it's important to be aware that any lead added to the probe tip or the ground wire adds inductance to the circuit. The inductance from leads can add overshoot and ringing to the signal seen on the oscilloscope's display. Moreover, leads can serve as antennas and pick up electrical noise from the environment. That noise may or may not be present in the circuit you're trying to measure. So keep leads as short as possible to minimize these unwelcome inductance effects.

Figure 4: High-voltage differential probes handle common-mode voltages up to 1 kVRMS.

Passive Probes: One Size Fits All

Now for a closer look at the passive probe. A passive probe essentially constitutes an attenuator circuit due to the probe impedance and the oscilloscope's impedance (see **Figure 3**). If the coupling of the probe to the oscilloscope is set incorrectly, the result can be a signal that is over-attenuated. Fortunately, modern passive probes automatically set the correct coupling and attenuation factor.

There also are high-impedance and low-capacitance (or low-impedance) passive probes on the market. High-impedance (Hi-Z) passive probes are the most commonly used oscilloscope probes and offer attenuation factors of 10:1 (X10) and/or 100:1 (X100), a typical maximum input voltage of 600V, and rated bandwidths of up to about 350MHz. But be wary at bandwidths above 50MHz; Hi-Z probes present an appreciable amount of capacitive loading at high frequencies.

Thus, Hi-Z passive probes are best suited to general-purpose applications at 50MHz or less. Because they use only passive components, they're pretty robust mechanically and electrically. They'll also give you a wide dynamic range, with the low end of the amplitude range limited by the probe's attenuation factor and the oscilloscope's vertical sensitivity.

Low-impedance (Low-Z) passive probes generally provide a 10:1 attenuation factor into the oscilloscope's 50-Ω input termination. Where the high impedance probe uses capacitive compensation to provide flat frequency response with minimum capacitive loading, the low capacitance probe uses transmission line techniques to achieve extremely wide bandwidth with very low capacitance. Low-Z passive probes are best suited for wide-bandwidth or fast-transient measurements in circuits that can drive 50-Ω impedances. In such cases, low-Z probes offer excellent frequency response. And, unlike Hi-Z probes, Low-Z probes do not require compensation to match the oscilloscope's input impedance.

When it comes to impedance matching at the oscilloscope's signal inputs, Hi-Z passive probes always have an adjustment trimmer capacitor located at the connector end. The trimmer implements a simple RC compensation scheme that matches the time constant of the RC circuit in the probe to the time constant of the probe input resistance and shunt capacitance. The adjustment compensates for the capacitive load of the oscilloscope's input. It forms a high-pass path to compensate for the low-pass nature of the oscilloscope input. As a result, the probe and oscilloscope combination becomes an all-pass filter. All oscilloscopes have a Cal (short for Calibration) output that provides a clean square wave for adjustment and compensation of passive probes. Adjusting the trimmer capacitor tunes the probe for that oscilloscope. Just turn the trimmer until you see a proper pulse shape on the display.

Active Probes: Higher Impedances

Passive probes are the basic, general-purpose probe type. However, active probes often suit more specialized applications. The main difference between the types is the passive probe contains no active components while the active probe contains an amplifier near the probe tip, most commonly based on a transistor or FET. Such probes typically provide higher overall impedance than passive types, presenting high resistance to DC voltages and low-frequency signals and low capacitance to high-frequency signals. Active probes have high resistance at the probe tip but terminate into the 50Ω input of the oscilloscope.

When considering active versus passive probes, probe impedance is an important factor. Passive probes provide the highest impedance below frequencies of 20 kHz. Their high input capacitance causes circuit loading at high frequencies or with low-frequency signals containing high-frequency content.

Meanwhile, active FET probes provide high impedance from DC to 20 kHz, maintaining that impedance out to about 1.5 GHz thanks to their low capacitance (see **Figure 3**). FET probes, then, are truly general-purpose probes at nearly all frequencies. Their low capacitive loading makes them usable on high-impedance circuits that would suffer severely from loading with passive probes.

Where should one use a passive probe vs. an active probe? Knowing which to use in a given measurement scenario avoids bad results or even damaging a probe:

- Passive probes are an excellent choice for low-frequency measurements, especially if high voltages may be encountered
- Active FET probes are better suited for measurements requiring high bandwidths
- Active FET probes are a great general-purpose choice for all frequencies out to the multi-GHz range, but watch out for higher voltages, which could damage the probe amplifier.

Differential Probes: When "Ground" is Relative

General-purpose single-ended probes (whether active or passive) can only accurately measure "ground-referenced" voltages. However, some measurements require probing test points with reference to each other, whether one of them is true earth ground or not. One example is VDS of a FET in a power supply; another is a serial-data link, when one is probing the positive and negative data lines of a differential signal. Here is where differential probes come into play. Among the most common are high-bandwidth types, high-voltage types, and those with differential amplifiers offering a high common-mode rejection ratio.

High-bandwidth differential probes are best suited for applications such as probing differential serial-data lines. To function effectively, high-bandwidth probes must deliver high dynamic range at the higher bandwidths and a large offset capability. Another must for such probes is extremely low probe noise and impedance characteristics that minimize loading.

High-voltage differential probes (see **Figure 4**) are built to handle common-mode voltages up to 1 kVRMS and 1.4 kV peak differential voltages (for example, Teledyne LeCroy's model ADP305). Such probes suit troubleshooting of low-frequency power electronics in cases where ground is elevated, or the location of true earth ground is unknown. When looking at high-voltage differential probes (or any high-voltage probes, for that matter), be mindful of safety ratings.

www.teledynelecroy.com

The future is green, don't hold it back

By: Alix Paultre, Editorial Director, PSD

There has been a lot of debate on the topic of "green" technology and its opportunities and challenges to the industry and society. On the one side, futurists and technology developers have been pushing for and developing the green technologies and the resulting solutions, and on the other a combination of neo-luddites and legacy technology supporters have been downplaying, and in some cases actively opposing, those same solutions. The time has come to end this nonsense.

The state of green tech

In solar alone, as reported by digitaljournal.com, the global solar PV installation is expected to reach 60.05 GW in 2018, growing at a CAGR of 10.7% from 2012 to 2018. Solar is now more cost-effective than coal in many cases, especially when looking at it from a "triple-bottom-line" analysis, a term that has become recognized in municipal asset management to emphasize the financial, social, and environmental aspects of a complete benefit/cost analysis, rather than only the financial aspects. When life-cycle costs of green tech in general are considered (including capital, O&M, and replacement costs over time) are taken into account, the cost savings of green tech compared to traditional infrastructure can be even more significant.

Fear isn't fact

The problem is that there are strong forces in the economy and society that are deliberately holding the development of next-generation green and renewable energy back for reasons that only make sense to those with a vested interest in legacy energy technologies. These people and organizations have kept green tech under a constant bombardment of doubt, fear, exaggeration, and outright falsehood. These same people forget that the first commercial VCR cost $50,000 back in the 50's, and the first cell phone cost $3,995 in '80's dollars. Early tech is always expensive, and to fearmonger against development merely due to first-generation product costs is myopic and misleading.

According to a study published in the Journal of Environmental Studies and Sciences, using the official U.S. government estimates of health and environmental costs from burning fossil fuels shows it's cheaper to replace a typical existing coal-fired power plant with a wind turbine than to keep the old plant running. And new electricity generation from wind could be more economically efficient than natural gas. However, there are those who want us to stay behind just to preserve the industries of the last century. I don't remember this altruism when the multi-billion-dollar film and photo-finishing industry disappeared.

Moving forward

Recently there have been a number of hatchet jobs in the general media against green technology based on nothing more than assumption and falsehoods about the state of the technology and the industry. The power electronics industry and the greater engineering community must push back against this negative atmosphere, as it will only serve to stifle development in the USA and guarantee that America will be buying its green tech from other countries in the future.

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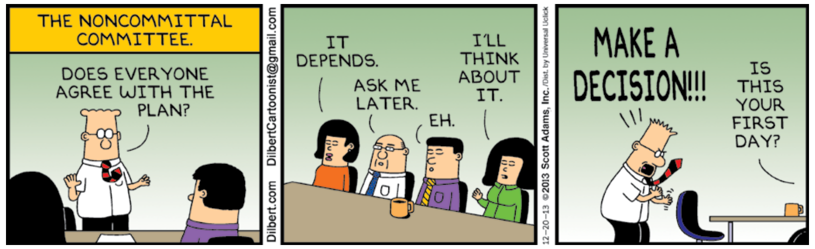

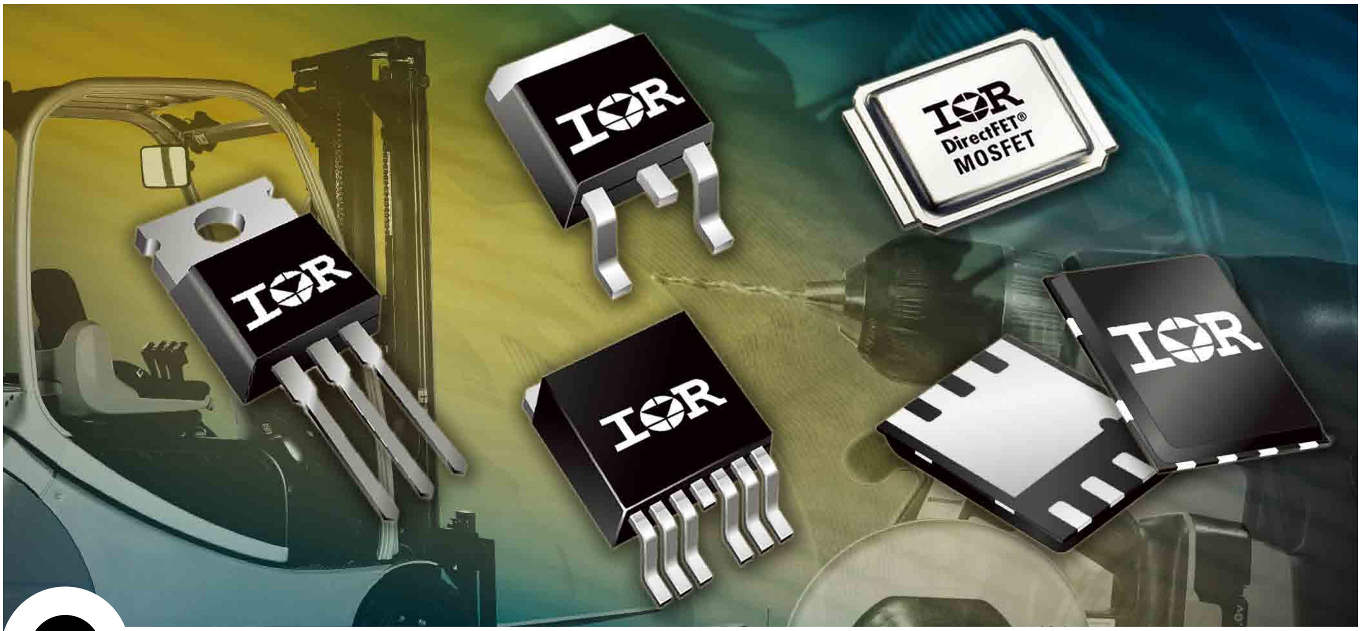

StrongIRFET™ Rugged, Reliable MOSFETs

Specifications

Part Number	B_{VDSS}	ID@ 25°C	$R_{DS(on)}$ max@ Vgs = 10V	Qg@ Vgs = 10V	Package
IRFH7004TRPbF	40 V	100 A	1.4 mΩ	134 nC	PQFN 5x6
IRFH7440TRPbF	40 V	85 A	2.4 mΩ	92 nC	PQFN 5x6
IRFH7446TRPbF	40 V	85 A	3.3 mΩ	65 nC	PQFN 5x6
IRF7946TRPbF	40 V	90 A	1.4 mΩ	141 nC	DirectFET Medium Can
IRFS7437TRLPbF	40 V	195 A	1.8 mΩ	150 nC	D^2-Pak
IRFS7440TRLPbF	40 V	120 A	2.8 mΩ	90 nC	D^2-Pak
IRFS7437TRL7PP	40 V	195 A	1.5 mΩ	150 nC	D^2-Pak 7pin
IRFR7440TRPbF	40 V	90 A	2.5 mΩ	89 nC	D-Pak
IRFB7430PbF	40 V	195 A	1.3 mΩ	300 nC	TO-220AB
IRFB7434PbF	40 V	195 A	1.6 mΩ	216 nC	TO-220AB
IRFB7437PbF	40 V	195 A	2 mΩ	150 nC	TO-220AB
IRFB7440PbF	40 V	120 A	2.5 mΩ	90 nC	TO-220AB
IRFB7446PbF	40 V	118 A	3.3 mΩ	62 nC	TO-220AB
IRFP7430PbF	40 V	195 A	1.3 mΩ	300 nC	TO-247

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