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APRIL 2016

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EDITORIAL

Test extends from mmWave R&D to life-cycle management

National Instruments has released its Automated Test Outlook 2016 (ATO 2016), an overview of key technologies—based on feedback from the NI customer base of more than 35,000 companies—that will have an impact on the test industry.

NI identified five key areas: standardized platforms for characterization and development, test-management software, production-test data, life-cycle management, and mmWave test strategies. ATO 2016 addresses these areas in five articles.

The article on standardized platforms notes that a 1983-era cellphone cost about $10,000 in today's dollars. Prices have dropped drastically, but the NI report states that test costs can represent nearly half the cost of goods sold. If a company doesn't consider a common-platform approach to test, NI contends, it may leave money on the table.

When it comes to software, the NI report notes that Fortran was quite successful, leading to Pascal, C, Atlas, and others with varying levels of abstraction. In addition, LabVIEW was developed for test, measurement, and control applications while Python supported quick code-scripting tasks. Test-management software, the NI report states, can "… act as a Rosetta Stone of sorts between different languages."

An article contributed by David Park, vice president of worldwide marketing at Optimal+, notes that even a seemingly trivial problem such as probe-card or load-board failure can, if undetected, lead to significant problems that ripple throughout the supply chain. Big data analytics can help mitigate the problems. Mike Santori, Business and Technology Fellow at NI, comments, "Companies like Optimal+ are delivering on the promise of big data for semiconductor manufacturing by providing near real-time ability to analyze and act on the insights in the data, lowering the cost of test, and improving the product quality."

The article on life-cycle management cites the stunning 2015 DoD announcement that the B-52, introduced in 1952, may be in service until 2044. In contrast, Windows XP was supported for about 13 years. Consequently, test systems for legacy systems often embody several OSs—perhaps one for each box instrument. Modular architectures, the NI report notes, open the door to a single OS controlling multiple instruments.

The cover article in this issue (page 10) elaborates on the life-cycle considerations for long-lived systems in military/aerospace industries. That article quotes Mike Dewey, director of marketing at Marvin Test Solutions, as saying, "One of the primary issues we see is the on-going requirement to address legacy test needs, and more specifically, how can this be done cost effectively when there might be hundreds of existing TPSs that need to be supported or upgraded to work with new test platforms?"

Indeed, ATO 2016 quotes Wilkes University Associate Professor of Electrical Engineering David R. Carey as saying, "The cost to rewrite a TPS due to the replacement of legacy/obsolete instrumentation in a test system is approximately $150k/TPS."

The final article in ATO 2016 deals with mmWave test strategies (from 24 to 86 GHz), and it focus on connectivity and communications protocols such as WiGig (IEEE 802.11ad). It cites NI R&D manager and IEEE Fellow Amarpal (Paul) Khanna as saying, "Millimeter wave research has presented a myriad of technology proposals, which continue to evolve, and since frequencies of operation and bandwidths have not been finalized, flexible systems for characterization, V&V, and production testing will prove to be invaluable in their ability to remain nimble during the establishment of standards."

You may have different topics that you think are key to test in 2016, or you may have different solutions to the issues ATO 2016 addresses. There are several venues to raise your own opinions. For example, Khanna at NI is serving as the general chair of this year's International Microwave Symposium (IMS 2016), scheduled for May 22-27 in San Francisco. The topics also will undoubtedly be addressed at NIWeek Aug. 1-4 in Austin. And as always, you are invited to comment at my blog at the link below.

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EE Statistics Insight

9 million

Approximate number of broadband subscribers using DOCSIS 3.1 equipment by 2017

(Source: ABI Research)

$5.5 billion

Market for printed and flexible electronics in vehicles by 2026

621

Miles of French road planned to be paved with photovoltaic panels over the next five years

(Source: IDTechEx)

31,464

Number of robots ordered from North American companies during 2015

$1.8 billion

Value of the robots ordered from North American companies during 2015

(Source: Robotic Industries Association)

35 billion

Number of semiconductor devices analyzed by Optimal+ on behalf of customers in 2015

(Source: Optimal+)

214.6 million

Wearable device units expected to ship in 2019

(Source: IDC)

1 billion

Forecast number of mobile proximity payment users by 2019

(Source: Ovum)

WPI wins NAE's $500,000 Bernard M. Gordon education prize

The National Academy of Engineering's 2016 Bernard M. Gordon Prize for Innovation in Engineering and Technology Education is being awarded to Worcester Polytechnic Institute educators Diran Apelian, Arthur C. Heinricher, Richard F. Vaz, and Kristin K. Wobbe "… for a project-based engineering curriculum developing leadership, innovative problem-solving, interdisciplinary collaboration, and global competencies." The $500,000 annual award recognizes new modalities and experiments in education that develop effective engineering leaders.

Courtesy of the National Academy of Engineering

"I am pleased to recognize the 2016 Gordon Prize recipients and Worcester Polytechnic Institute for their transformational work in educating students to tackle society's greatest challenges and developing thoughtful and well-equipped engineering leaders," said NAE President C.D. Mote Jr.

The project-based engineering curriculum at WPI prepares 21st century leaders to tackle global issues through interdisciplinary collaboration, communication, and critical thinking. The institute's engineering program engages students with a specially designed sequence in which first-year students complete projects on topics such as energy and water; second-year capstones focus on the humanities and arts; junior-year interdisciplinary projects relate technology to society; and senior design projects are done in conjunction with external sponsors, providing relevant experience upon graduation. Last year, WPI launched its Institute on Project-Based Learning, an initiative to help other colleges and universities make progress toward implementing project-based learning on their campuses.

The Gordon Prize was established in 2001 as a biennial prize acknowledging new modalities and experiments in education that develop effective engineering leaders. Recognizing the potential to spur a revolution in engineering education, NAE announced in 2003 that the prize would be awarded annually.

COMSOL Multiphysics now available on Rescale's cloud

COMSOL has announced the availability of COMSOL Multiphysics software on Rescale simulation platforms through a collaboration with COMSOL, creators of the robust, physics-based modeling and simulation software.

COMSOL Multiphysics is an all-inclusive modeling software, based on numerical methods, for simulating physics-based problems. With COMSOL Multiphysics, users are able to account for coupled or multiphysics phenomena. The simulation suite is further expandable with more than 30 add-on products for simulating electrical, mechanical, fluid flow, and chemical applications allowing for unlimited multiphysics combinations.

"For customers seeking HPC resources for bigger analyses, this important initiative with Rescale allows our users to take full advantage of both the COMSOL Multiphysics software and Rescale's secure and flexible simulation environments," said Phil Kinnane, COMSOL's vice president of business development.

IDT and CERN speed and improve analytics at Large Hadron Collider

Integrated Device Technology (IDT) announced that it has developed with the European Organization for Nuclear Research (CERN) a low-latency platform to speed and improve the management of analytics at the organization's Large Hadron Collider (LHC) and data center. Created at IDT's Open HPAC Lab and built upon the company's RapidIO technology, the platform marks the first major milestone in the three-year collaboration between IDT and CERN openlab.

CERN openlab is a unique public-private partnership that accelerates the development of cutting-edge solutions for the worldwide LHC community and wider scientific research. Through CERN openlab, CERN collaborates with leading ICT companies and research institutes.

Courtesy of IDT

"The key to achieving better data analytics performance is having superior real-time interconnect with low, deterministic latency," said Alberto Di Meglio, head of CERN openlab. "With its optimized usage of interconnects and processor resources, this first deliverable in our collaboration with IDT will provide us with the baseline computing platform that will scale to enable better usage of our analytics data."

RapidIO technology provides a low-latency connection with deterministic transfer between clusters of computer processors, dramatically speeding the movement and processing of data. The new platform is based on x86 processing, a 200-GBaud RapidIO interconnect fabric, IDT's low-power RapidIO network interface card, and CERN's root analytics framework. The initial development is based on a small number of nodes that can be scaled to a much larger number of nodes at rack scale.

In subsequent phases of the three-year program, IDT and CERN engineers will build out larger scale computing systems with optimized performance and begin using the low-latency rack scale processing power system to analyze data.

imec and Cloudtag collaborate on frictionless wearables

Courtesy of imec

Cloudtag, the company that brings accurate data and personalization to the health, wellbeing, and fitness markets, and imec, the nanoelectronics research center, have presented the first results of their collaboration on accurate frictionless wearable health solutions. Cloudtag Track, a new wearable fitness tracker launched at CES 2016, combines fitness and health monitoring with design to pave the way to innovation in fitness wearables as well as in the care, cure, and prevention cycle by providing immediate access to accurate medical data and personalized feedback.

"imec and Holst Centre develop ultra-small low-power, high-quality sensors and specialized algorithms that turn data into valuable knowledge, paving the way to next-generation wearables that offer medical-quality data monitoring in a frictionless way. These sophisticated wearables can support doctors in diagnosis and follow-up of illnesses, and they offer a huge opportunity in illness prevention by serving as a virtual personal coach," stated Chris Van Hoof, program director of imec's wearable health program. "Our collaboration with Cloudtag is an exciting example of how imec's technology can support the industry in realizing the next generation of wearable devices."

GOEPEL electronic protects Spartan-6 FPGAs against IP theft

GOEPEL electronic now supports Xilinx Spartan-6 FPGAs in protection against potential attackers and theft of intellectual property (IP) through the AES Programmer (Advanced Encryption Standard).

The GOEPEL Xilinx Spartan-6 AES Programmer is a tool integrated into the SYSTEM CASCON JTAG/boundary-scan software platform. It allows programming of the one-time programmable eFUSE register with a unique 256-bit AES key, via secure JTAG access. After arming, the FPGA can only accept the encoded bit streams because the arming of the AES mechanism is an irreversible process. This results in maximum security during the authentication and encryption of FPGA programming data as well as once it is safely locked within the device.

AES is supported by the National Institute of Standards and Technology and the U.S. Department of Commerce. By using the Xilinx AES feature, the FPGA design of the Spartan-6 is protected against potential attackers. Without corresponding AES keys, bit streams cannot be analyzed, whereby the encrypted designs are hedged against re-engineering, cloning, and copying.

Dongguan Huabel selects Aegis FactoryLogix software

Aegis announced that its FactoryLogix software was chosen over software from other MES providers, both local and international, as Dongguan Huabel's MES provider.

Huabel's previous experience with MES had been unsuccessful, Aegis reported, and this, combined with Huabel's own in-house software reaching the limit of its capabilities, led the company to embark on a detailed search for an MES provider. This decision is part of a lean manufacturing philosophy that will help Huabel reduce waste and improve efficiency. "We found that Aegis is very strong in process control and management" said the vice president of Huabel's Engineering Center Division, adding, "During the bid, the whole Aegis team acted very professionally, boosting our confidence in choosing Aegis as our MES provider."

Huabel will deploy FactoryLogix across its entire facility, which includes 31 SMT lines. Data will be collected via xLink, enabling reliable and efficient data processing. Huabel will roll out FactoryLogix throughout the enterprise including NPI, material logistics, production, SMT lines management, analytics, dashboard monitoring, and integration with xLink and xTend as well as inForce line terminals and scanners for fail-safe process interlocking and alarming.

Improving musical synchronization with mathematical modeling

Music functions as a universal connector that pervades most cultures. More specifically, rhythm and synchronization—both within and beyond the realm of music—are forms of communication that stimulate brain activity.

In a recently published paper in the *SIAM Journal on Applied Mathematics*, authors Donald Drew, Kevin Dolch, and Maury Castro propose a stochastic differential-equation model that simulates how musical performers in a large ensemble sustain tempo and phase while responding to a conductor, other musicians, and additional distractions modeled as "noise."

Tektronix and TE SubCom partner on optical modulation analysis

Tektronix announced that TE SubCom, a TE Connectivity company and an industry pioneer in undersea communications technology, will be deploying the industry's first commercially available 70-GHz oscilloscopes using Tektronix patented Asynchronous Time Interleaving technology in a coherent optical evaluation program designed to increase throughput of the world's fastest optical submarine network systems. For TE SubCom's engineers working in the fields of optical modulation analysis and advanced research, these new DPO70000SX low-profile oscilloscopes provide a scalable multi-unit configuration for ultra-high-frequency signal fidelity needed in optical submarine network designs.

With optical speeds already in the hundreds of Gb/s range and research efforts working to achieve Tb/s speeds, optical communications design is one of the main applications demanding higher-speed test and measurement instrumentation solutions, including the capability to synchronize multiple high-performance oscilloscopes. **EE**

For more on these and other news items, visit www.evaluationengineering.com/category/industry-update/

Exercising the power to interfere

By Tom Lecklider, Senior Technical Editor

An amplifier is used to increase the power level of the input signal for many reasons. George Bollendorf, marketing and business development manager at EMPOWER RF Systems, discussed a few. He said, "The need for higher power levels is driven by several factors including the trend in EMC compliance requirements for testing at higher field strengths spurred by the electrification of vehicles and more generally the increasing proliferation of RF and microwave energy in our environment. Additionally, longer test distances arising from the desire to radiate entire vehicles and systems are also an important factor adding to the need for more RF amplifier power. Automotive HIRF 600 V/m is a good example as well as the recent extension of the IEC specification to test more products to 6 GHz at higher field strengths."

As test requirements change, so too do amplifier designs. Dan Eckersley, project engineer at Vectawave Technology, said the company had used the latest-generation LDMOS devices in the 500-W Model VBA 2700/3100-500 class AB amplifier. When used with a suitable antenna and chamber, it is capable of delivering a 600-V/m field, primarily required during 2.7-GHz to 3.1-GHz S-band automotive radar pulse EMC testing. Similar technology is used in the 1-kW Model VBA 1200/1400-1000, which operates in the 1.2-GHz to 1.4-GHz L band (**Figure 1**).

Figure 1. VBA 1200/1400 amplifier
Courtesy of Vectawave Technology

In addition to LDMOS, new EMC amplifiers also are taking advantage of the latest GaN devices to achieve both higher bandwidth and power. According to Dr. Wolfram Titze, director of product management transmitter and amplifier systems at Rohde & Schwarz, "For EMC applications, class A typically is used due to the linearity and robustness requirements." He explained that because class A amplifiers are the least efficient of the classes, cooling is key to achieving a compact and lightweight design. As an example of what's possible, a 500-W R&S amplifier operating from 80 MHz to 1 GHz is available in the Model BBA150-BC500 4U-high desktop unit (**Figure 2**).

Figure 2. BBA 150 broadband amplifier
Courtesy of Rohde & Schwarz

Linearity

At a sufficiently large input level, an amplifier's output will have dropped by 1 dB below the amplitude it would have had were the amplifier perfectly linear. This is the P1dB point and generally considered to be the highest power level that still provides a reasonably linear output signal. The output has become compressed by 1 dB.

As shown in **Figure 3**, based on the AR RF/Microwave Instrumentation Model 10,000A225A-A, the P1dB point for this 10-kW LDMOS amplifier occurs at a -0.5-dBm input level with the gain set to the 70-dB maximum. The output power at the P1dB point is 7,000 W, corresponding to 68.5 dBm. The actual power curve intersects the P1dB point at this value but the figure is only approximate between there and the 70-dBm saturation level.

Many manufacturers specify amplifiers in the same way as AR—they quote maximum gain and the P1dB point. In contrast, R&S equates the two values on the assumption that if the amplifier is going to be used for EMC testing, then it will be operated at its P1dB point, and that's the highest power level of interest to the test engineer.

An 80% AM modulated signal often is used in EMC testing. The peak envelope power (PEP)—the power level when the modulation is at its maximum—is 5.09 dB above the CW power, and the average power with 80% modulation is 1.2 dB higher than the CW power. These higher levels will determine the amplifier power you need.

Reference 1 includes an example of a 50-W CW signal with 80% AM modulation, as shown in **Figure 4**. For this example, PEP = 161.5 W (50 W + 5.09 dB), and average power = 66 W (50 W + 1.2 dB). Although the CW power is only 50 W, an amplifier with P1dB = 160 W is needed to ensure that the modulation peaks are not compressed.

A common definition of amplifier linearity assumes that only the fundamental and third harmonic terms of a power series are needed.[2] This is approximately true for solid-state amplifiers. Starting with the transfer function in equation 1, and substituting a trigonometric identity for $\cos^3$, a couple of relationships can be derived:

$$O(\omega t)=GV\cos(\omega t)-D_3 V^3 \cos^3(\omega t) \qquad \textbf{(1)}$$

where: V = input amplitude
O = output amplitude
G = gain
D_3 = third-order distortion

The point labeled TOI in Figure 3 is the intersection between the amplifier's linear transfer function and the output level that would be caused by the third-order term alone. For the AR 10,000A225A-A, the typical TOI is specified as 77 dBm. More generally, the power at the intersection is proportional to

$$V^2 = \frac{4G}{3D_3} \qquad \textbf{(2)}$$

TOI is a power level indicated by the V^2 in equation 2. For small amounts of third-order distortion—small D_3—TOI will be larger than the amplifier's saturated output power so it is only a theoretical point; it can never actually be reached by the amplifier.

From the equations, you also can show that TOI occurs at a power level about 9.5 dB higher than the P1dB point. For the AR amplifier, the difference is 8.5 dB, indicating that the output isn't exactly described by equation 1. Nevertheless, TOI is a good indication of linearity: the higher, the better.

Some amplifier datasheets also list a P3dB point. For an amplifier with its P1dB point only slightly below the maximum saturated output level, the P3dB point is very close to saturation. This isn't the case for many higher-distortion traveling wave tube amplifiers that may have the P1dB point as much as 6 dB below saturation.

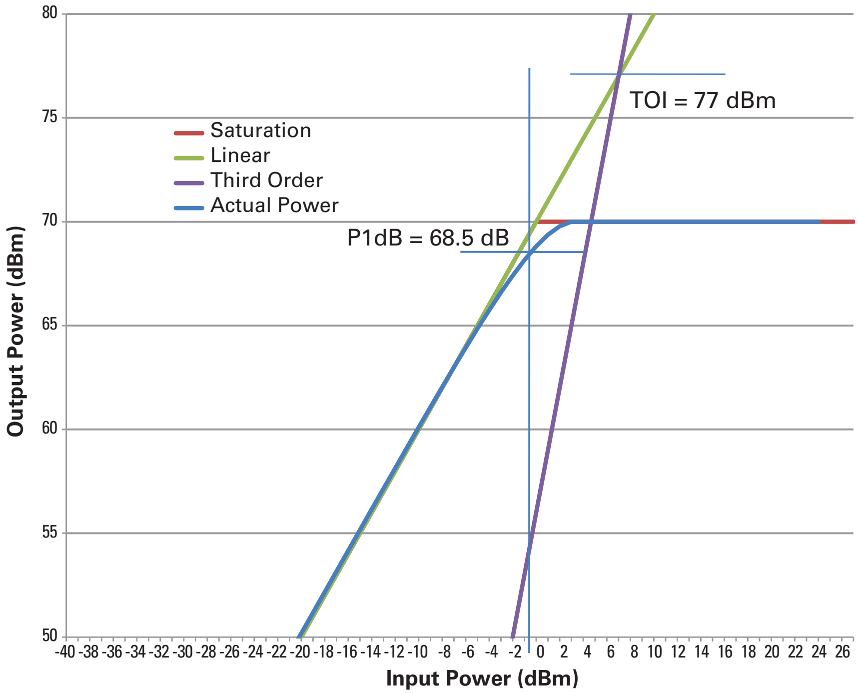

Figure 3. Graphical relationship of P1dB, TOI, and maximum saturated power for Model 10,000A225A-A amplifier
Courtesy of AR RF/Microwave Instrumentation

Efficiency

High-power amplifiers typically consist of several lower power assemblies and a means to combine the power output from each. Vectawave's Eckersley said the combiner in some of his company's amplifiers was based on a stripline design that used high thermal conductivity circuit board materials.

EMPOWER's Bollendorf explained, "Efficiency gains come from patented technology replacing lossy internal RF cables and connectors with PCB technology connecting the driver, splitter, RF palettes, and combiner. Efficiency gains above 1 GHz come from an in-house custom-designed combiner with proprietary coating techniques. This patented architecture results in typical loss savings of 0.5 dB, which amounts to over 100 watts on a 1-kW system."

Dr. Titze from R&S said, "To achieve very high power levels, several [high-power amplifiers] are combined with dedicated RF combiners. The required design parameters for a combiner such as good input matching, broad bandwidth, low losses, and decoupled inputs are contradicting requirements due to fundamental laws of physics. If we talk about broadband amplifiers that operate over several octaves, broadband bridge networks and cascaded Wilkinson combiners are candidates to fulfill this job. For very high power combiners, for example, in the kW range, a low loss coaxial system is the preferred architecture."

Cap Wireless, now part of TriQuint Semiconductor, developed the Spatium amplifier that uses spatial power combining to sum the outputs from several radially oriented MMIC amplifiers. The advantages of the technique include providing relatively high power in a small package as well as broadband operation. In this approach, the output fields are directly combined. A CAP Wireless paper on the TriQuint website describes the Spatium structure as "an antipodal finline antenna array."[3]

Taking a planar approach to field combining, ETS Lindgren's EMField Generator adds the fields generated by three parallel flat antennas, eliminating an EMC test engineer's usual worries about "… amplifier power levels, 1-dB compression points, cable losses, and illumination areas."[1] Four models address combinations of the 1-GHz to 3-GHz or 1-GHz to 6-GHz frequency ranges and 1-m or 10-m test distances (**Figure 5**).

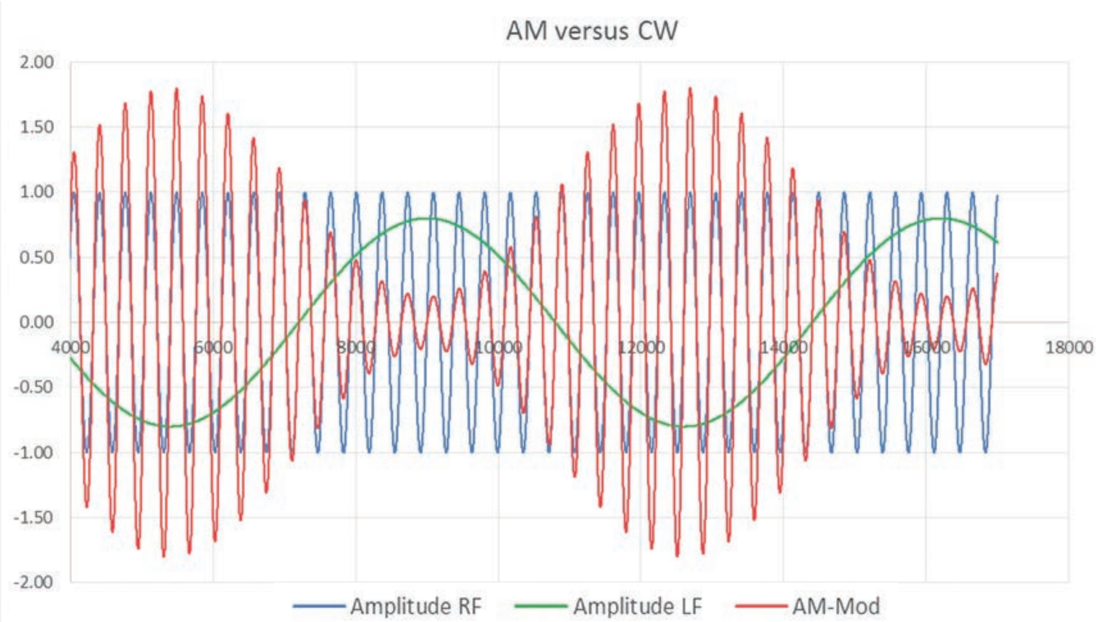

Figure 4. CW and 80% AM modulated signal
Courtesy of ETS-Lindgren

At high power levels, even coaxial connectors can be a problem. Dr. Titze added, "You also have to take into account that the output power of a high-power amplifier system often reaches the limits of the specifications of the available RF connectors because connectors with a high power handling capability are frequency limited due to their mechanical dimensions. These limits can especially be reached under continuous operation together with bad VSWR conditions. Rohde & Schwarz takes particular care that the connector chosen can handle both the thermal stress and the high voltage that may occur at the connector for continuous operation, even under bad VSWR conditions."

AR also uses proprietary combiner techniques. In addition, the company's Joe Diesso, corporate vice president of marketing, explained that, "… gains also are attributed to a number of other factors, such as the use of either die or packaged transistors, design, simulation tools, and manufacturing techniques."

A further factor used by EMPOWER is digitally controlled bias currents to achieve the best balance of linearity, power, and efficiency. The company's Bollendorf said that this was a design strategy that remains a capability in EMPOWER's manufactured amplifiers, with the added benefit that the company can remotely configure IDD and VDD for efficiency and linearity trade-offs if a customer's requirements change.

Output protection and VSWR

Reflections are caused by impedance mismatches, which commonly occur in EMC testing:

$$\Gamma = \frac{V_r}{V_f} \qquad (3)$$

where: Γ = reflection coefficient
V_r = reflected voltage
V_f = forward voltage

For perfectly matched impedances, $\Gamma = 0$. For a short, $\Gamma = -1$ (the signal is reflected 180 degrees out of phase), and for an open, $\Gamma = +1$ (the signal is reflected in phase). The voltage standing wave ratio is defined as

$$VSWR = \frac{|V\max|}{|V\min|} = \frac{1+|\Gamma|}{1-|\Gamma|} \qquad (4)$$

For $\Gamma = 0.7143$, VSWR = 6, and the amount of reflected power is 50%. In a class A amplifier, the theoretical efficiency is only 50% with actual efficiency in the 20% to 30% range, so output devices tend to be large and robust. When operated well within their safe operating areas (SOA), there is sufficient margin that high amounts of reflected power can be absorbed.

Figure 5. EMField generator
Courtesy of ETS-Lindgren

Returning to the 50-W example from reference 1, because the average power that the 160-W amplifier's output stage provides is only 66 W (50 W + 1.2 dB), a large amount of reflected power can be accommodated. In the example, a VSWR of 6 is assumed, giving 50% reflection—so an additional 33 W is dissipated in the output stages.

Class AB amplifiers can have actual efficiencies around 60%. This seems to be a big advantage, and it can be. With higher efficiency, it's possible to use smaller devices and less heatsinking, a perfectly adequate combination for CW operation. However, with high VSWR values, the devices may be driven outside of their SOA. To avoid this, according to reference 1, "… class AB amplifiers are fitted with a VSWR protection system that lowers the drive to the final stage and reduces the average power that must be dissipated."

As an example of a typical amplifier rating, AR's 10,000A225A-A datasheet quotes mismatch tolerance as "100% rated power without foldback up to 6.0:1 mismatch," above which reflected power may be limited to 5,000 W. Further, the amplifier is limited to 3,000 W reflected power from 100 MHz to 225 MHz. The company's Diesso added, "To ensure performance of the amplifiers, each amplifier is tested to [withstand] … severe mismatches prior to customer delivery. The ability to continue operation when subjected to mismatches as extreme as opens and shorts is a significant advantage."

Vectawave's Eckersley discussed output protection for the company's amplifiers. He said, "In the case of the narrowband, Class AB [500-W S-band and 1-kW L-band] amplifiers …, it is straightforward to provide protection against output mismatches. Microwave circulators can, over a narrow frequency range, direct reflected power to a separate, matched load and are fitted to these amplifiers. The overwhelming majority of Vectawave's amplifiers operate in Class A. The device currents are regulated and fixed and will remain so under any level of reflected power, producing no additional thermal stress on the devices under severe mismatch conditions."

All R&S amplifiers, according to Dr. Titze, are designed "… to operate on a VSWR >6 at full output power without any damage in a 24/7 mode. For higher VSWR, they may fold back dependent on the mismatch but will always deliver at least half their nominal output power, even under short or open conditions…. This kind of behavior can be achieved by monitoring closely the main parameters of the transistors in the amplifier and the forward and reflected power at the output."

Finally, EMPOWER's Bollendorf explained what he termed smart protection. He said that the protection method in his company's amplifiers varies, "depending on the input signal modulation to maximize output power for that modulation scheme. For example, multitone inputs, AM, FM, pulse, digital modulation—all have different methods of self-protection that are based on real-time digital filtering and digital signal processing algorithms that are implemented in our input and output peak detector design." Measurements internal to the company's Next Gen amplifiers, such as the 1-kW Model BBS3K4AUT, provide automatic gain control that can significantly reduce test time.

Summary

Among the many factors influencing the selection of EMC amplifiers, the P1dB power rating and high VSWR tolerance are near the top of the list. Size and weight also can be important factors, as Bollendorf commented. "High power density is an advantage in airborne and land mobile electronic warfare, radar, and communications." He concluded, "In the compliance lab environment, the ability to move a kilowatt amplifier around the facility on a cart is an advantage if not a necessity, and being able to power it with single-phase 208 V is very convenient and reduces the power bill." **EE**

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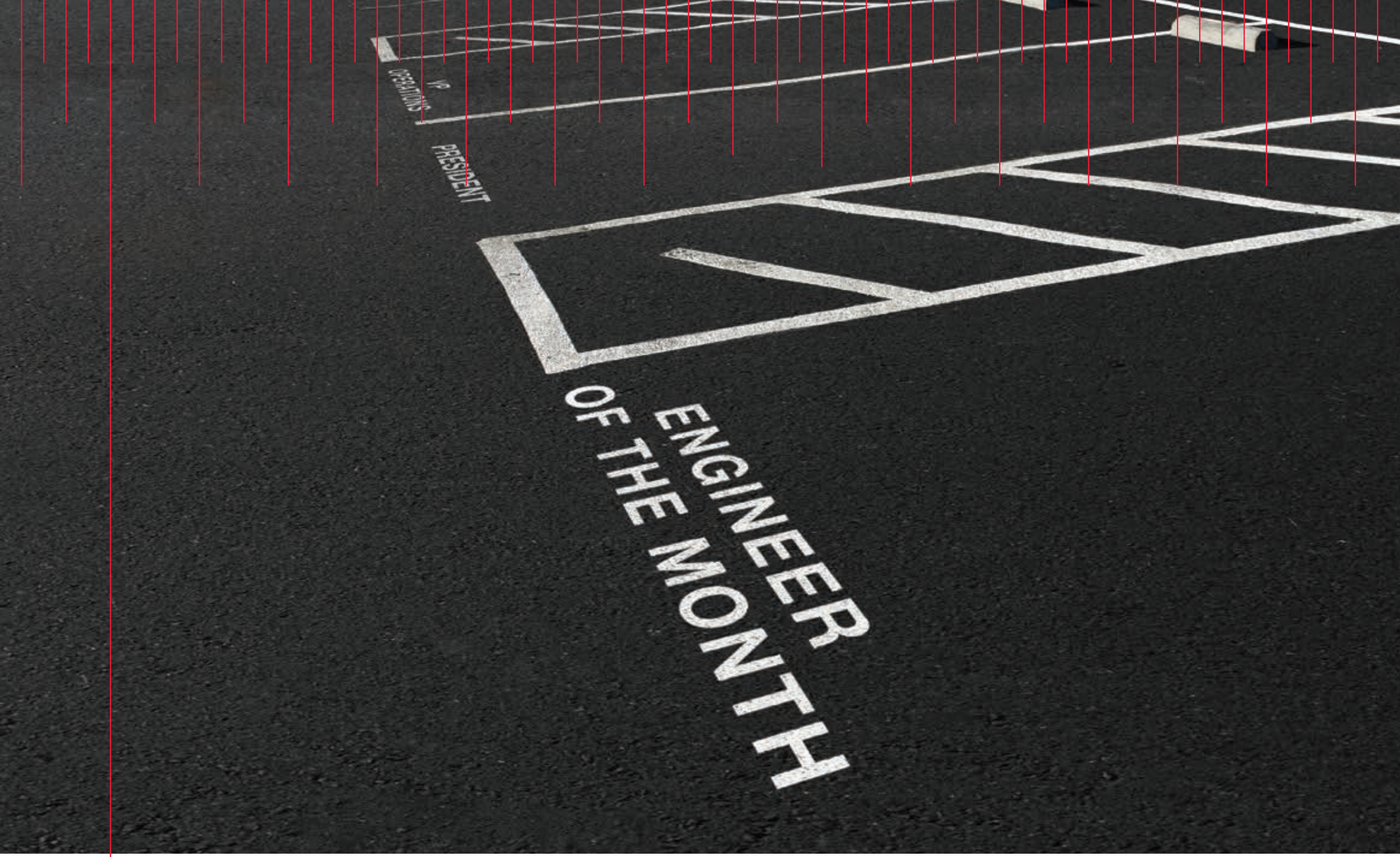

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Supporting the past, building the future

By Rick Nelson, Executive Editor

Engineers working on military and aerospace applications need to do more with less as they upgrade legacy ATE systems or acquire new ones while preserving their test-program-set (TPS) investment. Many products and techniques that can help them were the focus of Autotestcon 2015 last November in National Harbor, MD, and since the show's conclusion, companies have continued to emphasize hardware and software for the MIL/aero industry.

Steve Fairbanks, senior director of marketing, Products and Instrumentation at Astronics, said, "With the reduced availability of federal funds to support defense systems, our customers are forced to rely on older technology and rely on it far past its initial design lifetime. These systems represent a logistical challenge with obsolescence and parts availability as well as retiring experts. The main concern we hear is customers wondering how to bring support systems forward in technology at the lowest possible cost. They're interested not only in maintaining all of the original functionality, but also in evolving that technology forward to remain relevant as future capabilities arise."

Mike Dewey, director of marketing at Marvin Test Solutions (MTS), said, "One of the primary issues we see is the ongoing requirement to address legacy test needs. More specifically, how can this be done cost effectively when there might be hundreds of existing TPSs that need to be supported or upgraded to work with new test platforms? The requirement to address both legacy and future test needs is driving the search for creative test solutions that are more efficient, flexible, and usable across multiple platforms and programs. These requirements are being seen from the flightline to the factory."

And Herman vanEijkelenburg, director of marketing for Pacific Power Source, said, "An overriding theme fairly evident [at Autotestcon] was the need to support older ATE systems and platforms for a longer time than what was originally planned. This is driven by lack of funding for new programs due to sequestration and budget cuts. This is shifting increased focus from developing new test systems to upgrading and supporting existing aging testers. As a result, T&M equipment manufacturers are asked to support their products for long periods of time, far longer than would be the case for commercial test applications."

Freedom 2 factory and depot-level test system
Courtesy of Astronics

From night-vision goggles to jet engines

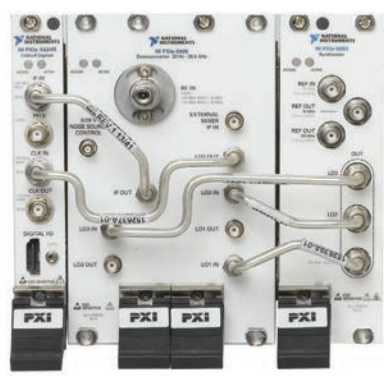
At Autotestcon, Astronics demonstrated a variety of products including test instruments, radio test sets, an engine test stand, and general-purpose depot and factory ATE including the Freedom 2 system. For example, Fairbanks said, the ATS 3000 Series of Radio Test Sets are deployed for field and depot testing of tactical military radios. "The Freedom 2 is a factory and depot-level test solution designed to be open, modular, and scalable to meet any demanding test requirement," he said. "Based on a common core approach of critical hardware and software, the Freedom 2 can be easily customized for virtually any test application—from night vision goggles to jet engines."

Fairbanks also said that Astronics is leveraging TPS capability and investments with the introduction of new products like the Astronics 2461 PXIe-based Frequency Time Interval Counter (FTIC). "We've collaborated with National Instruments to replace older VXIbus technology with the modern PXI-based instrumentation for tomorrow's military systems," he said. "The new Astronics 2461 FTIC streamlines military/aerospace test development with smaller, lighter, next-gen PXI technology." This new product is modeled after the previous VXI-based version, the Astronics VXIbus 200-MHz Universal Counter. Designed for full TPS compatibility, this new FTIC will replace existing VXI-based FTICs in a newer PXI-based subsystem. Fairbanks added, "Customers can purchase the Astronics FTIC for PXI Express and future products expected to become available as a result of the collaboration, as well as support service, through the worldwide NI sales channel."

For its part, National Instruments highlighted a variety of new products and technologies designed for MIL/aero system design and test engineers in addition to the new FTIC. Ravichandran Raghavan, senior product manager for automated test systems, highlighted in particular a 26.5-GHz vector signal and spectrum analyzer, a fast-switching RF signal generator, an 18-slot PXI Express chassis, and the latest FlexRIO controller that features an embedded processor and Xilinx FPGA.

"The FlexRIO controller particularly resonated with Autotestcon attendees," he said. "The controller delivers high-performance I/O, a powerful Xilinx FPGA, and an embedded processor in a form factor optimized for deployment."

Raghavan said NI provides more than 600 PXI instruments ranging from DC to 26.5 GHz, "… and we sell nearly all of them into aerospace/defense applications." He cited as an example the new PXIe-5668R 26.5-GHz vector signal analyzer, which includes a user-programmable Kintex-7 FPGA. Aerospace/defense engineers can target the instrument to be a best-in-class real-time spectrum analyzer with industry-leading 765-MHz bandwidth, he said, or implement a custom pulse-measurement capability to make the instrument a world-class radar test head. "The versatility



PXIe-5668R 26.5-GHz vector signal analyzer
Courtesy of National Instruments

of software-designed instruments like the PXIe-5668R provides a unique value to aero/defense engineers not only in meeting new technology demands, but also in emulating niche legacy instrument features for obsolescence management and TPS migration," he concluded.

According to Dewey at MTS, products that drew particular interest at Autotestcon included the new GX5296 PXI digital subsystem which, he said, features the highest digital test capability in the industry as well as per-pin timing and PMU capability. "Also attracting attention was our GENASYS switching subsystem, the GX7016, which combines the flexibility of the PXI architecture with a high-density, hybrid pin switching architecture, which offers more than 4,000 UUT connection points within a single, compact 6U PXI chassis," Dewey said. "This platform effectively addresses the capabilities associated with legacy, closed-architecture ATE systems while offering the flexibility and performance needed for next-generation functional test applications."

He said attendees also showed strong interest in the ultra-rugged, PXI-based MTS-207 platform and its derivatives, such as the MTS-206/916 test set, which support a range of flightline test applications including armament and avionics test for the A-10 aircraft as well as I-level test for the Maverick missile.

For software products, Dewey said, "There was interest in our TPS conversion tools for rehosting/converting test programs and digital test vectors associated with legacy test systems. In addition, the company has introduced a new version of ATEasy called ATEasy-Lite, which Dewey described as a full featured, cost-effective test-executive/test-development environment designed specifically for OEM suppliers of functional test systems.

MTS-206 Maverick/Hellfire field test set
Courtesy of Marvin Test Solutions

Focusing on RF/microwave

John Stratton, business development manager for defense and aerospace at Keysight Technologies, said, "One of the issues that seemed to be of high interest was Keysight's approach to common instruments for RF and microwave testing for the military. Keysight's high-performance PXI-based instruments were designed to meet the combined specifications of all the individual services. We used the specifications of all Keysight's legacy box instruments (used in CASS, VDATS, GPATS, and NGATS) as design requirements as we developed our latest instrumentation. Of particular interest was how Keysight was able to get 50-GHz capability into a PXI form factor. This highly configurable design allows our customers to only add the capability they need and insert new performance without replacing what is in their current system."

Stratton said Keysight continues to invest in the MIL/aero test marketplace. Recent introductions include fast switching synthesizers that focus on the radar and EW marketplace. "Additionally," he said, "Keysight just introduced a new MIL Radio Reference solution, which is focused at the radio and avionics manufacturers and support organizations."

Also during Autotestcon, he added, Keysight debuted the M9393A PXIe 50-GHz vector signal analyzer, which addresses a number of military segments including radar, EW, and satellite manufacturing.

vanEijkelenburg of Pacific Power Source highlighted ways in which his company helps customers support their products for long periods of time. "Several of our programmable AC power sources have been deployed in these ATE systems for 30+ years, and we continue to support these with service, spares, upgrades, and in many cases new production units," he said. "One key advantage PPS offers is a common user interface and programming syntax across its entire product line, making upgrades easy without impacting TPSs."

M9393A PXIe 50-GHz vector signal analyzer
Courtesy of Keysight Technologies

Some recent introductions by Pacific Power Source include a line of compact, single-phase rack-mounted AC power sources with higher power density than competing models, he said. For example, the ADX Series provides cost-effective programmable power for both bench and ATE. "These models ranging in power from 1 kVA to 1.8 kVA garnered much attention at the exhibit due to size and pricing," he added.

From breakout boxes to interconnect

Bob Stasonis, director of sales and marketing at Pickering Interfaces, said at Autotestcon the company introduced a modular breakout system, which was designed in partnership with Opal-RT for hardware in the loop simulation testing applications. "There was strong interest by many of the prime military contractors and systems integrators," he said.

Stasonis added, "Our products generally are aimed at a broad range of applications and industries. In most cases, we do not normally produce products strictly for MIL/aero customers. We have had a lot of success with MIL/aero customers in the areas of high-density low-power matrix switching (using our BRIC family of matrices)." He added that the company also has had success in high-current (10 A or greater) applications and sensor emulation (more specifically, strain-gage emulation).

Chris Gibson, product manager for data acquisition at VTI Instruments, said VTI presented its new ruggedized data-acquisition instruments, including the RX0124 24-channel high-performance

Modular breakout system
Courtesy of Pickering Interfaces

RX0124 bridge
Courtesy of VTI Instruments

bridge, for aerospace test. "We featured two 24-channel dynamic strain and charge input measurement devices as well as a 32-channel precision thermocouple and voltage instrument," he said. "The products … have drawn considerable interest, particularly in jet engine test applications in which there is a desire to move the data-acquisition instrumentation as close to the test article as possible. To do this, we provide an Ethernet/LXI interface so the instrumentation can be distributed across the engine and implement IEEE 1588 to synchronize all measurements. The devices are rated to operate in an environment extending between -20°C and +60°C."

Huntron demonstrated its latest power-off Huntron Trackers and automated test systems and highlighted the new AACAT robotic test system for functional test. "The AACAT system provides a path for rehosting legacy tests, efficiently and effectively reducing the overall time to rehost the original test," said Jim Crosson, sales and marketing manager for Huntron.

Other demonstrations included a data-streaming test system featuring ADLINK's PXES-2590 nine-slot 3U PXI Express chassis with a PXIe-3975 controller; the PXI-9527 24-bit, high-resolution dynamic signal acquisition (DSA) module; the MXC-6300 fanless, embedded computer; and the PCIe-PXIe-8638 PCI Express-to-PXI Express expansion kit. A dynamic rotor balance analysis system featured ADLINK's USB-2405 DSA module demo kit, the MXC-6300 fanless, an expandable computer, and Vibrant Technology software.

JTAG Technologies demonstrated its mixed-signal JTAG tester, the JT 5705, which combines a JTAG TAP controller plus digital and analog I/O in a compact desktop package. The company also highlighted its other boundary-scan controllers as well as software support for Teradyne's Di-050 and HSSub hardware. And Wireless Telecom Group highlighted its RF peak power meters and RF/analog AWGN noise generators, representing its Boonton and Noisecom brands including the Boonton 55 Series USB peak power sensor.

Interconnect technology was a focus as well. MAC Panel showcased its APEX hybrid combination contact-pin connector announced at NIWeek 2015. The company said a key to achieving maximum value from PXI-based ATE is using the same instrumentation with interchangeable mechanics to test multiple products, adding that the APEX hybrid connector with combinational contact-pin support reduces costs of test with its flexible configuration capability. The APEX hybrid delivers a modular cabled mass interconnect that handles electrical signals from DC to RF, and it is suited for high connector-reinsertion environments found in high-volume product test. In addition, MTS demonstrated its GX7016 with a MAC Panel Scout receiver.

Virginia Panel highlighted its new i2 MX connector, which, the company said, builds upon the success of the popular i2 Micro iCon, offering a configurable connector in the same 0.8-inch footprint. Combined with its slimmer metal engagement knob and its oblong cable exit, the i2 MX provides maximum cable bundle clearance and improved stackability. And Teradyne, which highlighted its HSSub high-speed subsystem, also presented a paper on introducing PXI instrumentation into an existing VXI tester that incorporates the VPC Series 90 interface.[1]

Continuing innovation

Since the show, companies have continued highlighting products for MIL/aero applications. For example, Universal Switching introduced its System MS2010A— a high-performance DC to 18-GHz coaxial blocking matrix designed for high reliability and very low MTTR. It is available in configurations from 4x4 to 10x10 in a compact 2RU unit. It finds use in automated test equipment, ground stations, telecom equipment, uplink or downlink antenna feeds, communication centers, and satellite installations.

Dave Sigillo, vice president, Seica USA, described his company as a supplier of large ATE solutions for MIL/aero applications at the I-Level and D-Level, both for legacy replacement and for new, high-performance technologies. "Taking advantage of our common hardware and software architecture and of the openness of our systems, we have now scaled down these architectures to the MINI Line, keeping the same performance," he said. The MINI Line offers functional, high-speed, in-circuit, and JTAG test capabilities on a compact architecture. MINI Line equipment can be configured as a standalone, benchtop, or portable tester, or it can be used as a building block for other special to-type test equipment designs or upgrades. The MINI Line operates either under the full suite of the company's VIVA proprietary environment or under the NI LabVIEW/TestStand. Sigillo added, "While it supports direct conversion of legacy test languages or simulators, it can be directly programmed from an Excel spreadsheet, from the Python test language, and more."

Paul Groome, vice president, Digitaltest, said his company has recently introduced products that can have an impact in the MIL/aero test environment. For example, "Digitizer 2.0 provides the tools for MIL/aero manufacturers and support organizations to extend the life of important avionics and military systems by automatically regenerating CAD data from a loaded board," he said. The new generation of the company's nondestructive, reverse-engineering software was developed as part of the IN-PIKO project for maintenance of long-life products, conducted in conjunction with Fraunhofer IPK and other companies.[2] "Digitizer 2.0 can link with data from other systems [including optical and X-ray equipment] and provides new methods to determine unknown component values using new innovative metrology techniques," Groome said.

"In addition," he continued, "we have made some significant additions to our Condor flying probers to enhance our capabilities for MIL/aero environments. The New MTS505 Condor flying-probe system has a Z-axis enhanced conveyor, measurement systems, and fault coverage modules. Uniquely, for companies that require the highest quality of test, the new measurement system (AMU 5.0) when combined with FailSim allows users to achieve the highest most accurate fault coverage, which is quantified by FailSim, so you can be assured that all tests are finding the defects you expect them to. Our 'Soft Landing' features provided on the Z-axis allow you to control the pressure of the probe on the board, ensuring no marking in solder joints."

From factory to flightline, and from DC to many gigahertz, you can expect test equipment companies to continue delivering innovations for MIL/aero applications. *EE-Evaluation Engineering* will have an update on the topic in conjunction with Autotestcon 2016, scheduled for Sept. 12-15 in Anaheim, CA. **EE**

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A finite element analysis of copper pillar bump probing

By Krzysztof Dabrowiecki, Feinmetall

In 2001, IBM patented a method of using a double bump material structure to make a reliable joint between a chip and its package for bump pitch below 150 µm.[1] This invention improved the existing flip chip method in the electronic package industry, also developed by IBM circa1964, commonly called C4 (controlled collapse chip connection) technology. The C4 method is based purely on the reflow of solder bumps. During reflow, the solder bumps collapse without maintaining the initial height, sometimes creating shorts between adjacent bumps if the distance between them is too tight.

A new package connection process, known as copper pillar (CuP) technology, is a paramount component of flip chip interconnection for 28-nm wafer technology and 3D IC integration. The original concept of CuP described a bump structure as a copper post (pillar) with a solder cap on the top. The copper post is in contact with the chip structure and the solder cap with the package. Using the different level of melting temperature between two materials was an innovative idea of the IBM patent. Over the years, CuP technology had many improvements with more than 120 U.S. patents related to this process.

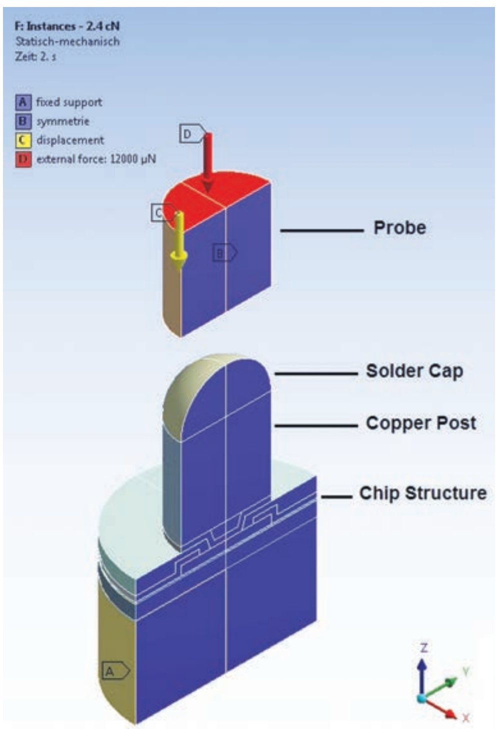

Figure 1. 3D model description with boundary conditions

The development of complex and advanced test probe cards requires a judicious combination of experimentation and modeling. The probe cards with 15,000 or more probes used for multi-DUT parallel tests are economical solutions that reduce the wafer test cost. The key to repeatable and high probe card performance is the probe design, which can minimize the damage of the very thin solder-cap layer and reduce the stresses in the bump structure during the wafer test, avoiding cracks and delamination of chip layers underneath the pillars.[2,3]

Finite element model of CuP bump

Today's finite element analysis (FEA) has become sufficiently mature to develop reliable insights into the mechanical integrity of composite structures such as CuP bumps and chips. The important advantage of FEM is the calculation of deflection, stress, and strain of the entire, very compound design. The graphical interpretation of the FE results allows a better understanding of the bump stress distribution as well as providing a better engineering assessment of the critical stresses for each material layer.[4]

The present study utilized the commercial finite element software ANSYS 15.0 to obtain the comprehensive results and introduce the bump geometry and material properties influencing the model response.

The study presents a model of a probe tip in contact against a hemispherical CuP bump and chip structure. The probe tip is flat and rigid and 50 µm in diameter. The CuP bump has a cylindrical shape with a hemispherical solder cap. The copper post diameter is 50 µm. The overall height of the CuP is 75 µm, including the copper post's 50-µm height and the solder cap layer's 25-µm thickness.

Both 2D and 3D ANSYS models have been developed for evaluation. To improve the efficiency of calculation, axisymmetric models were used.

The 2D model used PLANE183 (axisymmetric), SURF153, CONTA172, and TARGE169 parameters. The model meshing created 2,924 elements. The SOLID186, CONTA174, TARGE170 parameters were used for the 3D model, which had 20,875 mesh elements.

The fine model meshing is applied near the top of the solder cap. To ensure the accuracy of the analytical results and conduct convergence analysis, a mesh refinement was implemented. Primarily, the 2D model has been used to reduce the calculation time. The 3D model was used for graphical illustration of stresses and strains of the studied structure.

The model's material properties, except the solder cap, were considered to be linear-elastic, homogeneous, and isotropic. The solder cap is considered as a nonlinear, bilinear-elastic plastic material. A bilinear-elastic plastic material model accounts for strain hardening of the material beyond its yield point. The maximum stress of each material layer has been determined by the von Mises stress criterion.

Figure 1 shows the sectional 3D model with boundary constraints. The model nodes at the base of the silicon are fixed in all directions. The defined forces were applied vertically on the probe. Deformable-deformable contact and the augmented Lagrange method with an initial friction coefficient of 0.2 were used in the model setup. **Figure 2** is showing a close-up of the model meshing. The cor-

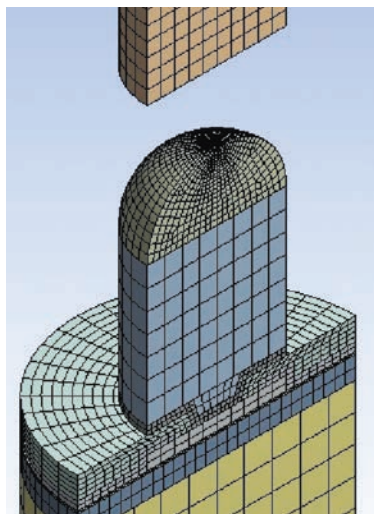

Figure 2. Meshing of 3D model

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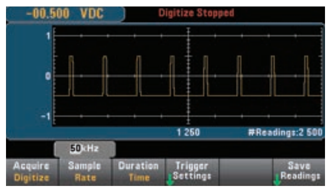
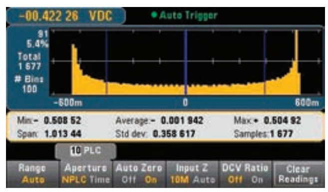


Trend chart



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Items	Modulus of Elasticity (E) [GPa]	Poisson's Ratio (v)
Silicon Die	131	0.28
Copper Pillar	121	0.34
Tin Cap	48	0.35
Oxide	72	0.16
Al Pad	72	0.33
SiN	270	0.28
Polyimide	3.5	0.35
UMB	135	0.33
ULK	8	0.20
Probe	110	0.37

Table 1. Material properties of Cu pillar interconnect

responding material properties such as modulus of elasticity and Poisson's ratio are listed in **Table 1**.

Results and discussion

The CuP bump structure is composed of several material layers, each with a distinct yield strength. The maximum stresses in each layer are calculated using a range of forces applied on the model from 0.5 cN to 6.6 cN. **Table 2** shows the yield strength and the FE calculated maximum stresses for each.

To verify the FE calculations, two probe cards were built with specific force values: 6.6 cN and 2.4 cN. The production wafer tests were conducted to define the solder cap deformation size and confirm that there were no cracks in the layers beneath. Extrinsic parameters, such as the strain rate and testing temperature and intrinsic parameters like the microstructure, were kept constant.

The FE model with applied force of 6.6 cN calculated the total deformation size of the solder cap as 26.6 µm in diameter and deformation depth as 4.53 µm. In tribology, deformation depth is called interference. After wafer sorting, the measured bump deformation diameter was 26 µm. Based on the manufacturing specification and guidelines, a deformation this size was too large and failed an optical test.

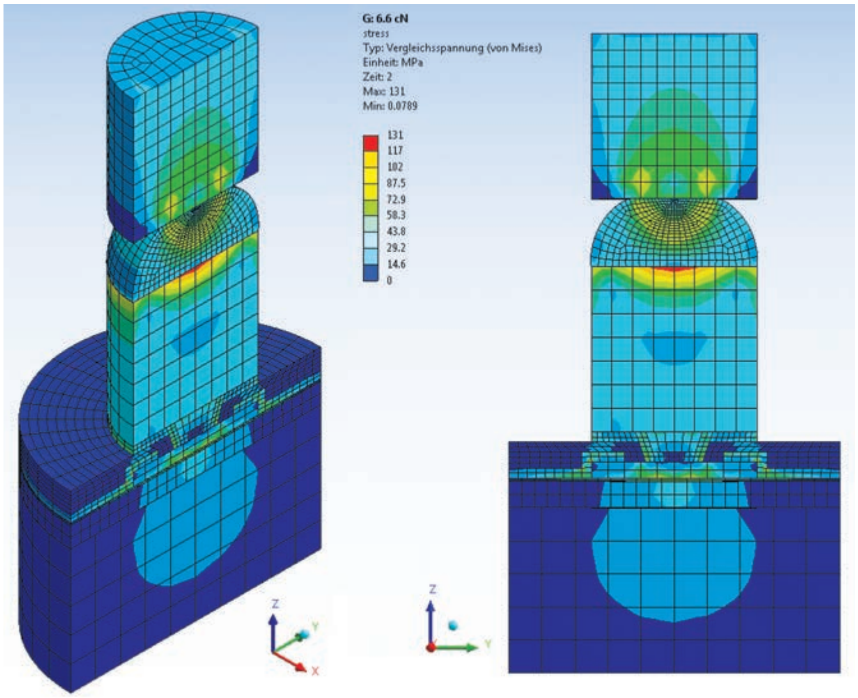

Figure 3. 3D model stress distribution with contact force 6.6 cN

Figure 3 depicts a color-graded stress distribution map of the described 3D model. It is important to notice the high stresses in the copper post which might induce delamination between the solder cap and the CuP. The extent of the stress is quite large, reaching down to the silicon and causing high stresses in all layers. The maximum stresses in the solder cap, CuP, and UBM are beyond the yield strength point. Even if low plastic deformation of the solder cap is harmless, the high stresses in the layers underneath the post are dangerous and could lead to failure. Some production reports have described these types of failures when probe cards were used with probes having high spring forces.

Figure 4 shows the stress distribution in the model with applied force of 2.4 cN. The calculated deformation diameter of the solder cap was 18.2 µm with1.74 µm of interference. The production wafer measurements revealed deformation 18 µm in diameter. The manufacturing metrology has accepted this size of bump deformation. The wafer post-process development has shown that there were no cracks or delamination in any intermetallic layers. When using the lower spring force, the maximum stresses in the CuP are shallow and below the yield points.

Figure 5 compares the FE model and production wafer measurements of bump deformation diameter as a function of contact force. The green curve depicts the model calculations and the red curve production measurements. The results of simulation are correlated quite well with wafer post-process readings, though they are slightly different in magnitude.

Figure 6 illustrates the FE model calculated interference as a function of deformed bump diameter. Initially, at small interference, the solder cap is deformed rapidly with a high strain rate. Eventually, as interference increases

Material Layer	Yield/TS Strength [MPa]	Max Material Stress at CF = 6.6 cN [MPa]	Max Material Stress at CF = 5.0 cN [MPa]	Max Material Stress at CF = 3.0 cN [MPa]	Max Material Stress at CF = 2.4 cN [MPa]	Max Material Stress at CF = 0.5 cN [MPa]
Silicon Die	7000 (UTS)	24	19	11	9	2
Copper Pillar	70	131	105	69	57	4
Solder Cap	24	90	82	71	67	44
Aluminum Oxide	205	78	59	36	29	6
Al Pad	414	78	60	37	29	6
SiN	86	65	58	42	21	7
Polyimide	69	27	21	13	10	2
UBM	32	90	74	57	24	11
ULK	96	32	25	15	12	2
Contact Probe	750 (UTS)	111	104	84.3	84	66

Table 2. FE calculated maximum stresses

above 0.4 µm, the bump strain rate swiftly begins to decrease.

Conclusion

This work presents a finite element model of a CuP bump in contact with the flat rigid surface of a probe tip. The FE simulation calculations were compared with production wafer test results. The subsequent plots indicated that the FE modeling correlates well with the wafer floor test data. It was concluded that this FE model is reasonably accurate as an assessment tool for engineering probe card analysis.

It helps to understand the configuration of stresses and strains in the CuP bump and chip structure. This study reveals that an appropriate analysis of a real probe card combined with modeling can improve the design and reduce wafer test failures. Furthermore, the described approach can be a good reference and guide for future design analysis of fine-pitch interconnections, CuPs, and micro-bumps. **EE**

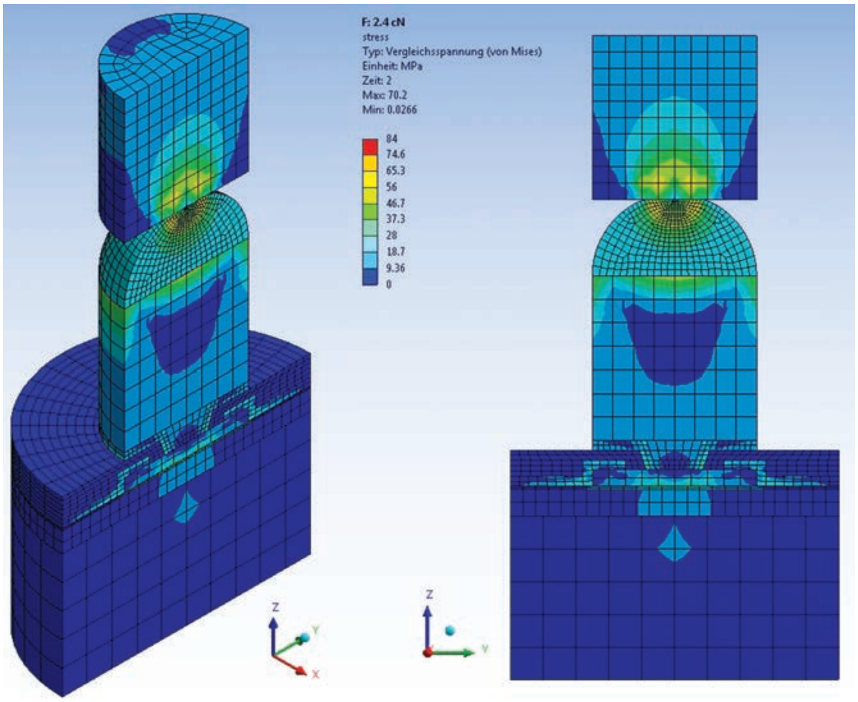

Figure 4. 3D model stress distribution with contact force 2.4 cN

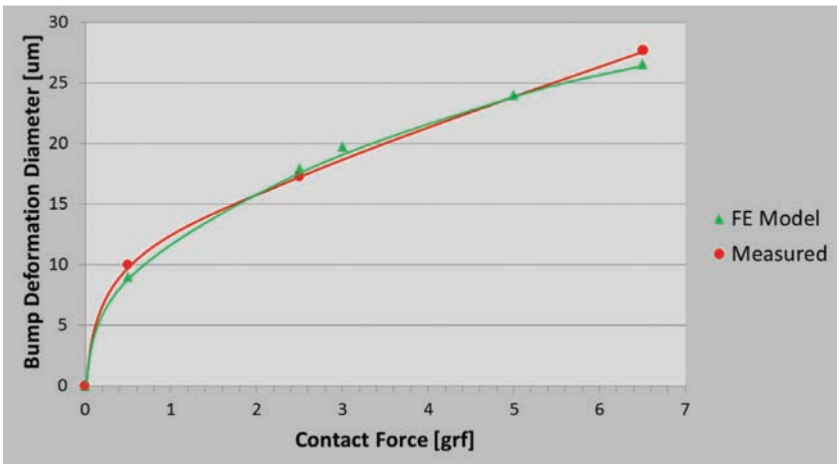

Figure 5. Deformed bump diameter vs. contact force

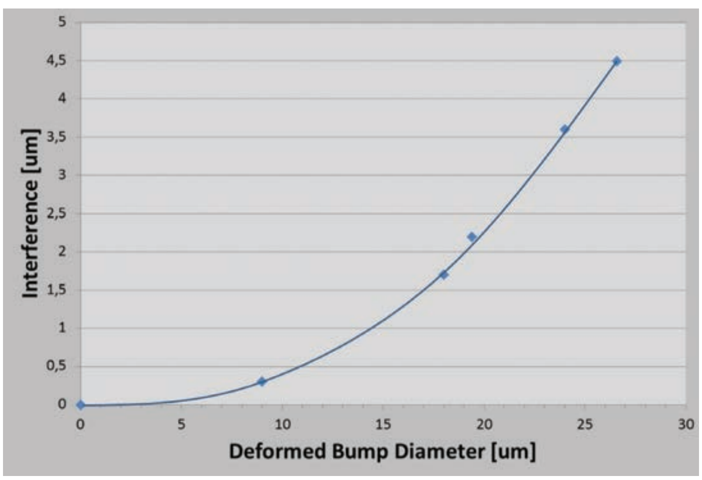

Figure 6. Deformed bump diameter vs. bump interference

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Author's note

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About the author

Krzysztof Dabrowiecki is the product manager at Feinmetall, Germany. He has been working in the probe card industry for 20 years as a part of the R&D and engineering teams for several products such as DuraProbe, VertaProbe, VertProbe, and MEMSProbe. Mr. Dabrowiecki earned an MSc in mechanical engineering from Gdansk University of Technology, is a member of ASME and IEEE, has authored numerous presentations in the areas of wafer test solutions, and holds four U.S. patents related to wafer sort and package test solutions.

What is a reed relay?

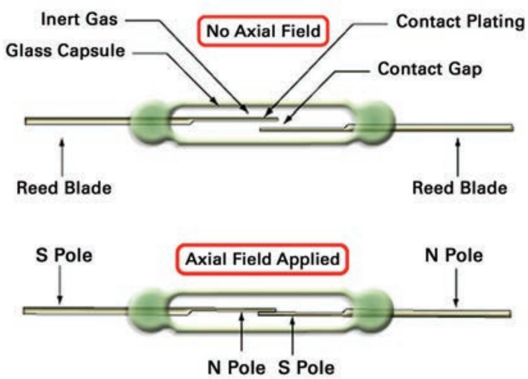
By Graham Dale, Pickering Electronics

Reed relays contain a reed switch, a coil for creating a magnetic field, an optional diode for handling back EMF from the coil, and an encapsulating package with connection terminals. In many ways, a reed relay, if used correctly, is a near perfect device with a low-resistance metallic switch path and inherent isolation between the control voltage operating the coil and the signal being switched.

The reed switch explained

The reed switch has two shaped metal blades made of a ferromagnetic material (roughly 50:50 nickel iron) and a glass envelope that holds the metal blades in place and provides a hermetic seal that prevents any contaminants from entering the critical contact area inside the glass envelope. Most (but not all) reed switches have open contacts in their normal state.

If a magnetic field is applied along the axis of the reed blades, the field is intensified in the reed blades because of their ferromagnetic nature, the open contacts of the reed blades are attracted to each other, and the blades deflect to close the gap. With enough applied field, the blades touch, and electrical contact is made.



Reed relay without (top) and with (bottom) magnetic field applied

The only movable part in the reed switch is the deflection of the blades; there are no pivot points or materials trying to slide past each other. The contact area is enclosed in a hermetically sealed envelope with inert gasses, or in the case of high-voltage switches a vacuum, so the switch area is sealed against external contamination. This gives the reed switch an exceptionally long mechanical life.

Another reed switch design variable is size. Longer switches do not have to deflect the blades as far (measured by angle of deflection) as short switches to close a given gap size between the blades. Short reeds often are made of thinner materials so they deflect more easily, but this clearly has an impact on their rating and contact area. Smaller reed switches allow smaller relays to be constructed—an important consideration where space is critical. The larger switches may be more mechanically robust and have greater contact area, improving their signal-carrying capability.

Various plating materials and methods are used for the switch contact areas: most commonly, rhodium, iridium, or ruthenium—all rare platinum group metals. These all provide hard, wear-resistant surfaces with good resistance stability for a long life, often into billions of operations. For very high voltages, 5 kV to 15 kV, tungsten tends to be the preferred material due to its very high melting point and resistance to welding through arcing across the contacts. Reed switch contacts can be coated by either electroplating or vacuum deposition (sputtering). Pickering Electronics' relays intended for low-level instrumentation use sputtered ruthenium contacts.

Generating the magnetic field

To operate a relay, a magnetic field needs to be created that is capable of closing the reed switch contacts. Reed switches can be used with permanent magnets (for example, to detect doors closing), but for the reed relays, the field is generated by a coil, which can have a current passed through in response to a control signal. The coil surrounds the reed switch and generates the axial magnetic field needed to close the reed contacts.

Different reed switches require different levels of magnetic field to close the contacts, and this usually is quoted in terms of the ampere turns (AT)—simply the product of the current flowing in the coil multiplied by the number of turns. Stiffer reed switches for higher power levels or high-voltage switches with larger contact gaps usually require higher AT numbers to operate, so the coils need more power.

Changing the wire gage for the coil and the number of turns creates relays with different drive-voltage requirements and coil powers. The resistance of the wire coil controls the amount of steady-state current flowing through the coil and therefore the power the coil consumes when the contacts are closed. Whenever fine wires are used in Pickering Electronics relays, the termination leads from the coils are skeined with several strands of wire twisted together to increase their physical strength. There can be hundreds, thousands, or even tens of thousands of turns.

Packaging reed relays

Most Pickering reed relays are constructed using former-less coils, which dispense with the usual supporting bobbin. This leaves more room for the coil winding, permitting smaller relays or higher coil resistance figures. Reed relays are available in many package styles such as dual-in-line, single-in-line, and surface-mount.

Often, reed relays are molded using very hard materials that can cause stresses on the delicate glass/metal seal of the reed switch capsule with the risk of damage. Pickering, instead, uses a soft inner encapsulation, which provides a buffer to protect the switch. Without this, stresses can distort the reed switch slightly, thereby changing the contact area and degrading performance and contact resistance stability. An internal mu-metal magnetic screen enables Pickering relays to be stacked closely together without the magnetic field from one relay affecting adjacent parts. This allows the highest level of packing density.

The second article in this two-part series will look at the future of reed relays and compare them with other switching technologies.

About the author

Graham Dale began his career in telecommunications with the U.K. Ministry of Defense. In the 1970s while working on a research project at The University of Essex sponsored by the British General Post Office (later to become British Telecom), he met John Moore, the founder of Pickering Electronics. This was in the early days of computer-controlled switching systems, and the project became a user of Pickering reed relays. Dale started working for Pickering at the beginning of 1975 and remains with the company today as a technical director and applications engineer. **EE**

A closer look at P = I x V

By Tom Lecklider, Senior Technical Editor

It's not always obvious that AC power measurements involve high frequencies, although the number of applications that do continues to increase as more semiconductors are applied to power control. Variable frequency drives (VFD) for electric motors present this kind of challenge.

VFDs have become popular because they enable very efficient motor speed control while also providing the torque that the load requires. Estimates vary, but about 45% of the power generated in the world runs electric motors, so improving efficiency by even a small amount can have huge benefits overall.

To achieve high efficiency, semiconductor switches should be on or off. This is the reason that so many electronic control systems use pulse width modulation (PWM) to drive loads like motors. The VFD's output pulses are integrated by the motor's inductance, approximating a variable frequency sine wave. **Figure 1** is an Excel-generated graphic that gives the general idea. The figure represents a bipolar PWM system. There also are unipolar PWM drives in which the output is offset from ground by the peak AC voltage.

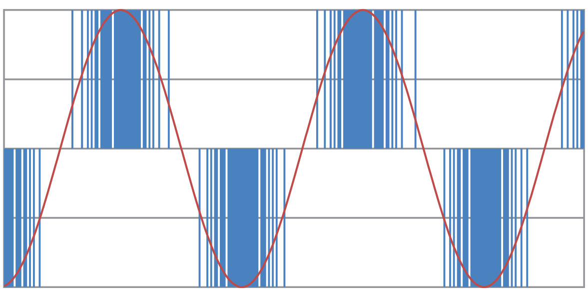


Figure 1. VFD output PWM signal

In either case, the frequencies associated with PWM output pulses are much higher than the fundamental motor frequency. According to an ABB application note,[1] some VFDs produce rise times as fast as 0.1 µs. These drives have a correspondingly high rate of voltage change (dV/dt), which stresses a motor's insulation and can eventually cause it to fail.

When a fast pulse edge is applied to a motor, a large voltage overshoot is developed across the series inductance of the power lead and the motor. In addition, because of the impedance mismatches between the VFD output and the motor/power lead circuit, oscillation will follow the overshoot. As reference 1 stated, "In commercial buildings, a high switching frequency can generate excessive levels of RFI and EMI. Such interference is reduced by using a lower PWM switching frequency. When a VFD is designed to operate at a lower switching frequency, it can produce PWM pulses with a longer rise time and so a lower dV/dt. This results in a lower peak voltage at the motor."

To investigate the efficiency of a motor being controlled by a VFD, you need a power analyzer that simultaneously measures the input power, typically 3-Φ in an industrial application, as well as the motor's mechanical output power—torque multiplied by RPM.

Power

AC voltage and current are reported as RMS quantities. The general formula for discrete samples is familiar

$$V_{RMS} = SQRT\left(\left(\frac{1}{n}\right) * \sum_{i=1}^{i=n} v_i^2\right)$$

but doesn't tell the whole story. Accurate AC measurements require sampling that is synchronous with the fundamental frequency. Or, if the sampling isn't directly related to the fundamental frequency, at least the fundamental must be known so that samples can be associated with each cycle.

Apparent power = V_{RMS} x I_{RMS}. True power is proportional to the sum of the products of simultaneous current and voltage samples during one cycle. True and apparent power are different in most power applications because voltage and current generally are not completely in phase—one lags or leads the other. This gives rise to the relationship

true power = V_{RMS} x I_{RMS} x cosØ
where: cosØ = the power factor
Ø = the phase angle between voltage and current

The vector difference between true and apparent power is called reactive power—measured in VARs—and equal to V_{RMS} x I_{RMS} x sinØ.

Applications such as measuring VFD-motor efficiency present a problem. On the one hand, high frequencies are involved that may affect power calculations if the voltage and current at those frequencies are in phase. On the other hand, the fundamental must be accurately known to compute RMS values. Power analyzers address these conflicting requirements in several ways.

Many measurements can be derived from the basic data. As an example of what's possible, Keysight Technologies' IntegraVision PA2200 Series analyzers can display voltage and current; true, apparent, and reactive power; harmonics; crest factor; power factor; duty cycle; and period and frequency. In addition, the PA2200 can apply a wide range of mathematical operations on waveforms such as addition, subtraction, multiplication, derivative, integral, FFT, and square root.

Some analyzers filter the AC input to eliminate high frequencies and base their measurements on what's left. This approach avoids aliasing and makes it easy to determine the fundamental frequency and the corresponding RMS values. Of course, any high-frequency power contributions are lost.

In contrast, ZES Zimmer has adopted a two-path design for the Model LMG670 precision power analyzer in which the input simultaneously is digitized both by a high-speed ADC as well as by a low-speed ADC. One path provides anti-aliasing and determines the fundamental frequency, and the other accounts for all the signal information. The LMG670 and Fluke's Norma 4000/5000 analyzers, among others, have very large analog bandwidths compared to their sampling speeds.

Aliasing

If you intend to determine a signal's frequency content via FFT or DFT means, the sampling process must obey Nyquist's criterion—the highest signal frequency is less than one half of the sampling rate (fs/2). If frequencies higher than fs/2 are present, they will alias back into lower Nyquist bands, distorting any further analysis.

In an analyzer that simply digitizes the input and computes all measurement values from that data, Nyquist applies. So, in this type of analyzer, either the sampling frequency must be very high or the anti-alias filter may eliminate some of the high-frequency signal content. Chroma ATE's Model 66202 power meter includes both a low-current shunt with ranges up to 2 A and a high-current shunt with up to a 20-A range. This 16-bit instrument has a 10-kHz bandwidth and a 240-kHz sample rate.

As stated in the Hioki PW6001 datasheet, the analyzer uses an 18-bit ADC sampled at a 5-MHz rate to provide a 2-MHz bandwidth and ensure there can be no alias errors. The instrument features digital processing that independently determines period, wideband power analysis, harmonic analysis, and waveform analysis without interaction and with a 10-ms data update speed.

If you are only interested in scalar time-domain quantities such as power, Nyquist doesn't apply. Fluke, ZES Zimmer, and other similar analyzers don't have to apply anti-alias filtering when computing power. They do need to accurately determine the fundamental frequency so that the voltage and current RMS values can be calculated. This can be accomplished, as described in a Newtons4th (N4L) application note,[2] by using "… a proprietary windowing algorithm based upon the DFT, as well as dual FPGA/DSP signal processing techniques to adjust the acquisition window size to the fundamental time period of the power waveform. For example, if a 1-s update rate is selected by the user, N4L power analyzers are capable of adjusting the acquisition window size in 500-ns steps around the 1-s selected update rate to ensure that complete cycles are captured."

Figure 2 shows waveforms from an Excel experiment that computed RMS values for various over-sampling and under-sampling ratios. Linear interpolation was added to link the sample points. As expected, aliasing is easily seen with the 1.7:1 ratio. The data points were computed as SIN(ROW()/10), which corresponds to 20 π samples per cycle—about 62.8. 50,000 samples were calculated, but only 49,951 (795x20 π) were used to determine the RMS value that was in error by 2.9 ppm compared to (SQRT(2))/2.

With 20 π samples per cycle, there was no danger of correlation at any decimated sample rate, but prime numbers were chosen anyway—the sampling rate was reduced by a factor of 17, 29, and 37 to give ratios of 3.696:1, 2.167:1, and 1.698:1, respectively. The corresponding RMS values were calculated for 795 cycles with errors of 34.2 ppm, 3.7 ppm, and 84 ppm.

Accuracy

It's easy to see how the interaction between sampling rate and acquisition window time can affect accuracy, especially if the sample rate is relatively low. As the acquisition window is made smaller, the relationship between the asynchronous samples and the individual signal cycles has less time to average. In other words, some cycles will have one more sample than others. Synchronizing the sampling rate to the fundamental frequency or increasing the sample rate minimizes the error.

An N4L application note[3] succinctly deals with accuracy: "While the digital design of any digital instrument is clearly important, the accuracy of all these instruments is dictated by the analog design and calibration." In particular, the capacitance of voltage inputs and the inductance of current inputs limit achievable performance.

Nevertheless, how the digitized data is analyzed also makes a difference. According to the PPA3500 datasheet, N4L selected the DFT for signal decomposition because it is not restricted to the 2^n sample window size as is the FFT. As a result, the DFT is capable of minimal leakage without the need for error-prone window filtering functions.

Current shunt design is the subject of another N4L application note.[4] The company has developed a wideband planar shunt that features a high degree of magnetic field cancellation and yet is relatively simple to construct. According to reference 4, the shunt inductance is about 250 pH, much less than several competing shunts. This very low value contributes to negligible impedance change vs. frequency up to at least 1 MHz as well as minimal phase change.

Coaxial designs also achieve very good magnetic field cancellation as is evident in the performance of Fluke's A40B series of precision current shunts for use with current from 1 mA to 100 A. These are metrology-grade shunts with approximate inductances of 1.4 nH for a 20-A shunt, 550 pH for 50 A, and 300 pH for 100 A. These values were calculated from the nominal resistances and the maximum 1.25 degree typical phase displacement at 100 kHz.

Built-in current shunts are well suited to typical power analysis applications but generally do not have this level of performance. For example, the Tektronix PA1000 power analyzer specifies typical RMS current measurement accuracy as ±0.1% of reading ± 0.1% of range ± 0.02% x F(kHz) of reading. So, for the 10-A range at 100 kHz, assuming a 5-A reading, the worst-case error is 5 mA + 10 mA + 100 mA = 115 mA or 2.3% error.

Yokogawa's WT3000E Series specifies the impedance of the 2-A input module as 500 mΩ + 70 nH and 5.5 mΩ + 30 nH for the 30-A module. For the 30-A module on the 10-A range, the maximum error is listed as 0.012% x F(kHz) of reading + 0.2% of range. So, for the 10-A range, 5-A reading at 100 kHz example, the error is 60 mA + 20 mA = 80 mA or 1.6% error.

Hioki's PW6001 uses external current probes. For the same example, the instrument's basic current accuracy specification is 0.01% x F(kHz) of reading + 0.2% of range. To that, you need to add the probe's accuracy. The 50-A precision current probe accuracy is 2% of reading + 0.05% of range. The probe by itself contributes 100 mA + 5 mA = 105 mA or 2.1%.

To put the importance of a shunt's frequency response into perspective, the N4L PPA3500 has a built-in 30-A shunt, and the current accuracy is specified as 0.04% of reading + 0.1% of range + 0.005% x F(kHz) of reading + 900 µA. For the 10-A range, 5-A reading example, the error is 2 mA + 10 mA + 25 mA + 0.9 mA = 37.9 mA or 0.76% error.

In all the calculations, the error can be minimized by choosing a measurement range that causes the input to be as close to full scale as possible. If each instrument had a 5-A range, the PA1000, WT3000E, PW6001, and PPA3500 errors would reduce to 2.2%, 1.4%, 2.05%, and 0.66%, respectively.

Instrument choices

If you really need to make accurate high-frequency power measurements, your choice of instruments is relatively small. On the other hand, if you're more interested in finding an analyzer with good accuracy at the usual AC power frequencies, there are lots of models available.

Power quality analyzers address applications such as voltage and current transient studies, fault recording, inrush, motor testing, harmonic analysis, distor-

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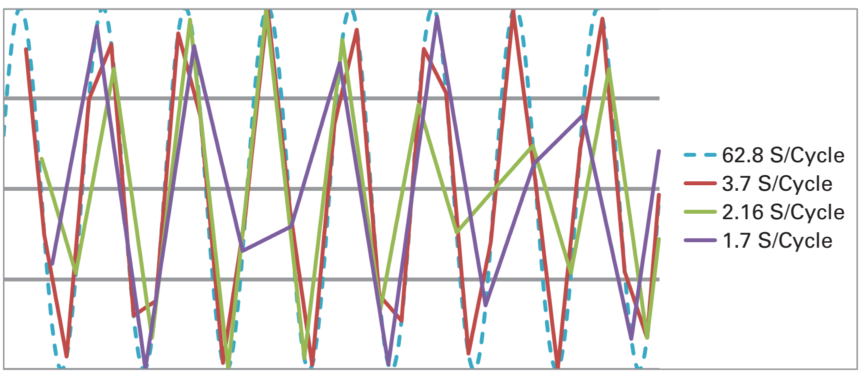


Figure 2. Over- and Under-sampled sine wave

continued from page 21

tion analysis, and demand/energy/load studies. They provide many of the same measurements as power analyzers, but the emphasis is different.

Dranetz HDPQ 16-bit analyzers use 512 samples/cycle for both voltage and current at 50 Hz and 60 Hz. The Explorer 400 model in the series also supports 400-Hz monitoring and capture of transients as fast as 1 µs. Displayed quantities include real, apparent, and reactive power; power factor; displacement power factor; demand in W; and energy in Wh. Distortion is an important power quality indicator and expressed as total harmonic distortion and individual harmonic amplitude through the 63rd for current and the 127th for voltage.

Summit Technology's PK45014 PowerSight PS4500 power quality analyzer features continuous and simultaneous analysis of harmonics, transients, RMS V and I, power, and power quality. This handheld instrument has four current inputs and three voltage inputs, calculates harmonics to 3,900 Hz, communicates with your PC via Bluetooth, and boasts a CAT IV safety rating.

The Model PQ3470 three-phase power and harmonics analyzer from Extech also is handheld and includes a large dot-matrix, sun-readable, graphical, backlit LCD. Current input is via a selection of clamp-on probes or current transformers (CTs). Up to 35 parameters are available including V phase-to-phase and V phase-to-ground; kW, kVA, kVAR, and power factor per phase; and energy—kWh and kVAh.

Combining logging and power quality analysis, Hioki's PW3198 analyzer provides monitoring for several weeks to catch infrequent dips, sags, and swells. Applications up to three-phase, four-wire are supported by four V and four I inputs (via clamp-on probes) for 50-Hz, 60-Hz, and 400-Hz fundamental frequencies. RMS measurements are refreshed each half-cycle and use a 200-kHz sampling rate. Transients are defined as containing frequencies between 5 kHz and 700 kHz and are captured with a 2-MHz sampling rate. Active power accuracy is specified as ±0.2% of reading ±0.1% of range + clamp-on sensor accuracy.

If you need to investigate power quality problems and also are concerned about ground and insulation resistance, Amprobe's Model DM-III Multitest F power quality recorder may be useful. In addition to ±1% reading + two digits active, reactive, and apparent power accuracy, capabilities include ground resistivity measurements from 0.6 Ωm to 0.1 kΩm as well as insulation resistance measurements up to 1,999 MΩ with a 1-kV DC test voltage. A 3,000-A flexible 7-inch diameter CT is supplied as standard, and both 1,000-A and 100-A clamp-on CTs are optionally available.

Summary

Several types of power measuring instruments exist, and it's important to choose the right type for your application. Power quality analyzers generally deal with standard supply frequencies and highlight harmonics and anomalies such as dropouts, sags, and transients. These analyzers also can help determine the amount of power factor correction that is optimum in an industrial setting.

When variable frequencies are involved and especially if the overall efficiency of an electromechanical system must be measured, a power analyzer (as distinct from a power quality analyzer) is needed. These instruments handle VFD applications from single-phase through six-phase plus motor RPM and torque. **EE**

References

1. Fonstad, K., *Variable Frequency Drives and Motor Insulation Stress*, ABB, White Paper, August 2011.
2. *Efficiency Measurement of Traction Motors*, Newtons4th, Application Note 32, January 2016.
3. *Expanded Nyquist Sampling Theory*, Newtons4th, Application Note 31, January 2015.
4. *Innovative shunt design techniques optimise power measurement accuracy*, Newtons4th, Application Note 12, January 2012.

Components, subassemblies aid EMC compliance

By Rick Nelson, Executive Editor

EMC instrument portfolio presented at EMV 2016
Courtesy of Rohde & Schwarz

The Test Instruments Special Report in this issue provides an in-depth look at amplifiers for EMC applications. And EMV 2016, held Feb. 23-25 in Düsseldorf, was a forum for exhibiting other instrument types. For example, Rohde & Schwarz showcased its R&S ESR EMI test receivers, which offer frequency ranges from 9 kHz to 3.6 GHz/7 GHz/26.5 GHz and can perform disturbance measurements in just a few seconds for standards-compliant EMC certifications. The company also highlighted its standardized R&S CEMS100 test platform—an off-the-shelf solution for radiated emissions measurements in line with IEC/EN 61000-4-3.

Also on display was R&S AdVISE (automated video inspection system for EMC), a video-based system for monitoring DUT reactions in automated EMC test environments. R&S AdVISE can complement an R&S EMC32 software-based system or operate as a standalone solution. Rohde & Schwarz also demonstrated the R&S BBL200 and R&S BBA150 from its broadband amplifier family; they cover power levels from 15 W to 10 kW in the frequency range from 9 kHz to 6 GHz.

When you apply such instruments to compliance or precompliance test, you hope that your products perform properly. To help ensure that they do, or to alleviate problems you find during test, you can employ components that help mitigate interference (such as chokes) or assemblies (such as power supplies) designed to meet emissions requirements.

In addition, you will want to ensure your devices are protected with regard to electrostatic-discharge events. Andrea Onetti, group vice president and general manager, Volume MEMS Division, STMicroelectronics, addressed this point with respect to the new interface IC for USB Type-C. “Knowing well the frustration of being surrounded by numerous different cables with very limited interoperability, ST, as a member of the USB-IF board of directors and an active player on the USB Implementers Forum, is working aggressively to build a strong and flexible portfolio of USB Type-C and power-delivery solutions that includes our STM32 microcontroller, ESD protection devices, and power-management products,” Onetti said. “The new STUSB16 family embeds higher levels of circuit protection and a customer-configurable nonvolatile memory, which enable IC configuration at power-up without software support.”

Following is a sampling of products that can help you meet emissions requirements while ensuring the safety of your devices.

Medical power supplies

New members of the Medline family include the OFM30 30-W (45-W peak) extra-low-leakage power supplies, which meet medical-system CF (Cardiac Floating)-class requirements, feature Class II double isolation, and are UL/IEC 60601-1 medically approved.

The vendor points out the difficulty of achieving low-leakage current while meeting EMC requirements, adding that the OFM30’s innovative design limits leakage current to less than 10 µA while achieving an EMC Class B average margin of 6 dB. Employing low-power-loss switching topology, the OFM30 Series has an efficiency up to 88%, fulfilling the Green Mode requirements of IEC 60950-1, CEC Level V, EISA, and ErP. Zero-load power consumption is below 0.3 W. The OFM30 series includes three models: OFM305025 delivering 12 V, the OFM305026 delivering 15 V, and the OFM305028 delivering 24 V. All products can be connected in parallel without any external components.

In addition, the Medline OFM225 225-W Series supplies, which meet BF (Body Floating)-class, now offer two more voltages: 12 V at 11.25 A (21.66 A peak) and 15 V at 6.66 A (19 A peak).
Powerbox, www.rsleads.com/604ee-176

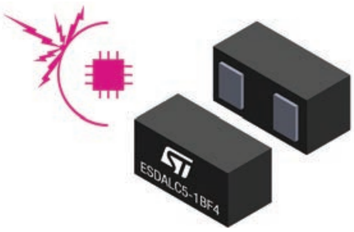
USB Type-C receptacle

The Top-Mount SuperSpeed Universal Serial Bus 3.1 Type C receptacle adds to the vendor's line of USB I/O sockets. The USB 3.1 is 2x faster (up to 10 Gb/s) than USB 3.0 with more efficient data transfer, higher throughput, and improved I/O power efficiency. Features of the new receptacle include a USB 3.1 top-mount, hybrid layout; a full-metal housing with enhanced EMI/RFI prevention; and a reversible USB Type-C connector (which has no polarization so cables with Type-C plugs may be connected regardless of orientation). The socket maintains backward compatibility with previous USB versions and provides optimized power efficiency to reduce drain on portable device batteries. It supports storage, smartphone, tablet, notebook, docking, automotive, and home-entertainment applications.

The sockets come packaged on tape-and-reel, 550 parts per 13-inch reel. The vendor also carries the Mid-Mount SuperSpeed USB 3.1 Type-C sockets featuring a full metal housing with enhanced EMI/RFI prevention. **Mill-Max, www.rsleads.com/604ee-177**

ESD diode

The new ESDALC5-1BF4 is a single-line ESD diode in a 0201 package, which sustains a 16-kV ESD surge. It combines a low parasitic capacitance of 12 pF with an efficient clamping voltage of 14 V just 30 ns after an 8-kV ESD discharge. A maximum leakage current of 100 nA helps minimize the overall system power consumption. The device's bidirectional diode structure makes it compatible with positive and negative polarity signals. The 0201 surface-mount package, measuring only 0.3 mm x 0.8 mm, features a 16-kV capability and is suited for applications requiring a compact PCB form factor and strong ESD robustness. The devices are available from distributor Rutronik. **STMicroelectronics, www.rsleads.com/604ee-178**



High-current choke

The new DKIH Series current-compensated chokes for PCB mounting are available for single- and three-phase applications with rated currents from 10 A to 50 A. The chokes are designed to suppress EMI noise caused by power applications on the PCB and, due to their open design, are lightweight and compact.

Like all other aspects of electronic design, the power portion often is built today using discrete components on PCBs. With the trending integration of components to achieve smaller and smaller form factors, thermal problems and high currents on the PCB can arise. It also becomes increasingly challenging to meet EMC requirements with a filter package due to the resulting space constraints; therefore, a filter on a PCB with discrete components is a good solution. The capacitors and a common-mode choke, with asymmetrical effective inductance, are very effective to dampen EMI noise.

The common-mode chokes are easily placed on the PCB with through-hole technology and designed and approved according to IEC 60938, UL 1283, and CSA 22.2 no. 8. The voltage rating is 300 VAC (IEC, UL), 250 VAC (CSA), and 425 VDC. Inductance ratings range from 0.30 mH to 0.90 mH. **Schurter, www.rsleads.com/604ee-179**

Beryllium copper shielding

The mechanical and electrical properties of beryllium copper make it the material of choice for EMI/RFI shielding products as well as for battery contacts, grounding clips, connector contacts, and ESD clips.

The material provides shielding effectiveness over a broad frequency range. Tech-Etch's in-house tool-and-die department offers bending capabilities for forming intricate sharp bends in tempers from annealed to full-hard. Component parts then are heat-treated in an inert atmosphere to enhance spring properties, permitting greater deflection without compression set while achieving close dimensional control. Finally, the company's plating department can apply finishes including tin, silver, zinc, sulfamate nickel, electroless nickel, palladium nickel, and gold. The company offers precision engineered parts as well as a complete line of standard EMI/RFI shielding products. **Tech-Etch, www.rsleads.com/604ee-180**

Rail-mount power supplies

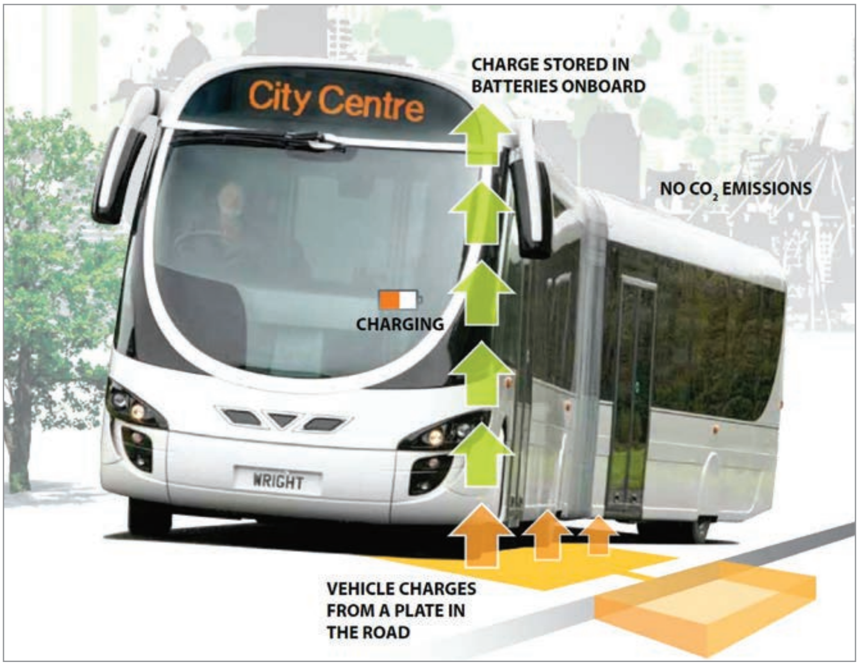
The DRF/HL DIN rail-mount power supplies are certified for use in potentially explosive atmospheres and marine applications. The products have been tested to ISA 12.12.01, IEC/EN 60079-0:2011, IEC/EN 60079-15:2010, and *Guidelines for the Performance of Type Approvals—Test Requirements for Electrical/Electronic Equipment and Systems* (VI-7-2).

The 24-V output DRF/HL series is available in three power levels: 120 W, 240 W, and 480 W; they can deliver a peak power of 150% for four seconds. The overload characteristic is constant-current style suitable for driving motors and other nonlinear loads. The supplies operate from a universal input of 85 to 264 VAC (300 VAC for five seconds) and are compliant to EN 61000-3-2. Efficiency levels are as high as 94%, and standby power consumption is between <0.5 W and <0.75 W.

Housed in a metal enclosure, the DRF models offer slim case designs ranging from 36.5 mm to 82 mm in width, saving vital space on the DIN rail. All models share a common 123.4-mm height and 115.4-mm depth. In addition, they have been rigorously tested for shock and vibration while mounted on the rail. Additional safety certifications include UL 508 and IEC/UL/EN 60950-1 (2nd Ed.), and the supplies are CE marked in accordance with the LV Directive, the EMC Directive, and the RoHS2 Directive. The DIN rail power supplies meet EN 55022 and CISPR22 Class B for conducted and radiated EMI. **TDK-Lambda Americas, www.rsleads.com/604ee-181 EE**

Extending renewable energy's reach

By Tom Lecklider, Senior Technical Editor



WrightBus with inductive charging capability
Courtesy of The Wright Group

If you believe the large number of experts forecasting the end of driving as we know it, autonomous, shared lease, totally electric vehicles (EV) will be here very soon. Certainly, EVs can be a practical alternative for many people who only travel short distances from home. And, EVs have the added bonus of forming part of a renewable energy storage network—cars not needed for a few hours can act as energy sources, driving some of their stored energy back onto the power grid.

Inductive charging

A related EV feature is wireless charging—either statically when you park your car over a charging area or more interestingly—and futuristically—as you drive along. The technology responsible for wireless EV charging is based on coupled magnetic circuits. A recent article[1] discussed a BMW inductive charging system with a 3.3-kW capability. As stated in the article, "Inductive charging re-energizes an EV's battery with a magnetic field rather than a wire from car to power source. It's achieved by fitting a primary coil in a floor-plate over which a car can park and a secondary coil on the underside of the car itself. An alternating magnetic field is generated between the two coils, which creates electricity that is then sent to the BMW's on-board battery."

According to the article, the BMW system is claimed to cause less electromagnetic radiation than a kitchen hotplate, and the field strength is well within regulatory limits. Optimum alignment is required and "… a parking assist in the electric BWM will tell drivers where to park."

The Plugless Level 2 EV charging system from Evatran transfers 3.3 kW via a floor-mounted parking pad and an adapter that is permanently installed under the car. Charging automatically starts when the pad and adapter are aligned and will not occur if metallic objects are close to the parking pad and/or the EV also is plugged in to charge. Rather than the alignment indicator being located in the car as BMW has done, the Evatran control panel is mounted on a wall or an optional pedestal.

A June 2015 Frost & Sullivan report[2] forecast a 126.6% CAGR for inductive charging between 2012 and 2020. "OEMs such as Renault, Nissan, Daimler, Volvo, BMW, and Toyota are working on the development of inductive charging for future EVs, and more than 10 automakers have announced trial tests," said Frost & Sullivan Automotive and Transportation Senior Research Analyst Prajyot Sathe. "As a result, inductive charging will soon be available in cars either as an additional feature or as an inbuilt feature."

The report continued, "While in the short term 3.3 kilowatts inductive charging will be widely accepted to enable residential and semi-public charging, with time, vehicles will tilt toward 6.6 kilowatts to enable faster charging," said Sathe. "Inductive charging in stationary applications will also be most sought after in the near term, whereas dynamic or on-the-move charging will gain traction post-2020."

Whether all of the systems being developed can be grouped under the inductive charging term isn't clear. The biggest problems with simple inductive coupling are the restrictions on the distance between and alignment of the two coils. In contrast, a resonant system greatly relaxes both constraints.

For example, one research paper[3] commented, "… it is well documented that there are substantial limitations to an inductive power transfer scheme. The transfer distances are typically below 20 cm." This paper discussed the practicality of embedding charging coils in a roadway and concluded, "For safety reasons and in order to ensure that the road can still be used for other kinds of vehicles, the source needs to be buried below the pavement. Thus, the transfer distance in the inductive power transfer scheme is, in fact, not sufficient. The lateral tolerance of these schemes is also quite stringent, typically on the order of 10 cm."

On the other hand, these constraints are easily overcome in a controlled, static situation such as described in the BMW article. Vehicle ground clearance isn't an issue if the floor-mounted coil can be mounted at the correct height relative to the car's coil. In the United Kingdom, WrightBus is testing an inductive charging system that boosts the bus battery charge at each end of a 15-mile route.

As described in a BBC News article,[4] "There, the bus parks over plates buried in the road. The driver then lowers receiver plates on the bottom of the bus to within 4 cm of the road surface, and the bus is charged for around 10 minutes before resuming service. The system uses a process called inductive charging. Electricity passes through wire coils in the road plates, generating a magnetic field. This field induces a voltage across coils in the bus plates, and the vehicle's batteries are charged." The article concluded, "The new vehicles … will operate as part of a five-year trial programme led by the European division of Japanese company Mitsui and U.K. engineering group Arup."

The Wireless Power Consortium has developed the Qi charging standard supported by 232 companies. Having a common standard is very important for consumer products such as smart phones. A lot of the convenience of wireless charging is the freedom to charge just about any phone wherever a wireless charging capability is available. Obviously, this wouldn't work unless a standard could be agreed upon. For cars, it still makes sense to have a standard—for example, in a parking garage that offered charging. For home use, a standard only would become important if you had several cars or bought a new one of a different brand.

The Wireless Power Consortium uses the inductive charging terminology when they mean transformer coupling—a phone sitting directly on a charging mat with a separation of only a few millimeters between the primary and secondary coils. For larger distances, the consortium uses the term resonant mode operation.

Resonant power transfer

Unlike a transformer, which requires the primary and secondary coils to be very close to each other, a highly resonant wireless power transfer (HR-WPT) system still can achieve good efficiency even with tens of centimeters between primary and secondary coils. Both transformers and HR-WPT systems operate in the near- field region with primary-to-secondary separation much less than a wavelength.

Although wirelessly transferring power has been a persistent research goal for a long time, it was MIT Professor Marin Soljačić's 2006 work and subsequent 2007 publication of his experimental results that energized product development. WiTricity was formed in 2007 to commercialize the HR-WPT technology he and colleagues had developed.

A recent WiTricity paper[5] described the advantages this technology might afford to charging of autonomous undersea vehicles (AUVs). The authors speculated, "… one could imagine a fleet of AUVs monitoring an exclusion zone around a submarine or carrier group. There AUVs could survey an area, returning regularly to a 'mothership' which they might follow alongside to recharge and transfer collected data." Toyota has invested in WiTricity, and reference 1 includes a photo of a typical EV or hybrid charging application capable of transferring 3.3 kW.

In a resonant power system, the primary and secondary quality factors (Qs) need to be very high. Basically, Q is equal to energy stored divided by energy lost during one complete oscillating cycle. Some writers describe these kinds of systems as having evanescent fields. By using that term, they mean that very little of the oscillating energy is radiated. Instead, it is maintained between the two resonators: The oscillating field generated by the primary circuit excites the secondary circuit resonance, extracting energy from the primary circuit and transferring it to the load.

In experimental work done at Stanford University, researchers achieved 94% transfer efficiency between two resonators operating at 8.38 MHz and separated by 60 cm.[6] There were no nearby large metallic objects to influence this result as would be the case when wirelessly charging an EV. To investigate a more practical situation, large aluminum plates were added to the test setup, and the researchers found that similar large efficiencies still could be attained. The trick was to either arrange the plates symmetrically so that the resonators were each affected to the same degree or to adjust the electrical parameters of one of the resonators so they closely matched those of the other resonator. Matching the resonators, even if geometric symmetry wasn't possible, was the key to high performance.

And, Fulton Innovation, a member of the Alticor family of companies, has developed eCoupled technology. As described on the company's website, "… eCoupled technology includes an inductively coupled power circuit that dynamically seeks resonance, allowing the primary supply circuit to adapt its operation to match the needs of the devices it supplies. It does so by communicating with each device individually in real time, which allows the technology to determine not only power needs, but also factors such as the age of a battery or device and its charging lifecycles, in order to supply the optimal amount of power to keep a device at peak efficiency."

Fulton doesn't describe in detail what "dynamically seeking resonance" means, and there are a number of ways the primary resonance can be made to match that of the secondary. In reference 3, the comment is made, "… in the resonant inductive power transfer scheme … there is always a frequency where 100% power transfer takes place, as long as one is in the strong coupling regime where the coupling coefficient characterizing the wireless power transfer dominates the output coupling rate of the resonator."

Although this may be true, varying the operating frequency to achieve primary-secondary matching might not be practical. In a paper[7] that addressed this issue, the authors cited government regulations that "… strictly limit the radiating electric field strength of wireless applications outside specific bandwidths, which will be exceeded by these frequency tuning algorithms." Instead, this paper advocates the use of fixed-inductance low-pass π adaptive impedance matching networks working in conjunction with the primary and secondary resonators to maximize efficiency at a constant frequency.

Two algorithms were proposed to accomplish adaptive matching. In the first one, selections from a list of values can be chosen for the source and load capacitors. As stated in the paper, "The low-pass π-match topology allows for a fixed inductor value to be placed in the high-current path, and variable source and load capacitor values can control the impedance matching capabilities of the network. Additionally, the Q of the π-match network provides an extra degree of freedom to achieve wideband or narrowband impedance matching." The second algorithm uses constrained nonlinear optimization to compute component values that maximize the system's power transfer.

Summary

Wireless power transfer is a reality. How much power can be transferred across what distance and the cost to do so are the remaining concerns that research and commercial products will address over time. The U.K. bus trial has a few more years to run, during which the inductive car charging systems mentioned in the Frost & Sullivan report will enter service. How quickly the field of wireless vehicle charging grows may depend as much on adopting a common standard—as Qi provided for consumer devices—as it does on technical advances. **EE**

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Innovation drives high-speed simulation, measurement

Innovation as applied to high-speed digital design and test was a key topic at DesignCon, held Jan. 19-21 in Santa Clara, CA. Innovation also was the theme of a keynote address titled "The Key Building Blocks in Surviving/Thriving in the Era of Exponential Technologies" presented by Al Eisaian, CEO of IntelinAir, a company that provides farmers with "actionable intelligence from aerial information." Eisaian posited a "5C" framework for innovation, including caring, commitment, competency, creativity, and community.

In another keynote presentation, Pat Byrne, president of Tektronix, got specific about innovation for the DesignCon community with an address titled "Reduce Time to Market with Better Workflow Integration from Simulation to Test." He said that optimal integration of simulation and test will require a common analysis and visualization environment as well as high-quality measurement science. "Collaborate earlier and more deeply," he advised, adding that solutions are available today. A Tektronix spokesperson followed up by saying the company's TekScope Anywhere product can import simulation waveforms, enabling users to correlate their simulations with real-world data.

On the exhibit floor, Computer Simulation Technology (CST) demonstrated its view of how the simulation and measurement domains could be integrated. CST and Wild River Technology (WRT) presented the first results of their cooperative effort to demonstrate the correlation of simulation and measurement for high-speed digital design. Simulations in CST STUDIO SUITE can be verified against measurements using the WRT CMP-28 platform.

In other EDA-related news, Cadence and its channel partner EMA Design Automation both highlighted Cadence OrCAD Capture and Cadence Allegro PCB Designer 16.6 software. ANSYS focused its SIwave design platform for power integrity, signal integrity, and EMI analysis of electronic packages and PCBs as well as its ANSYS Icepak for thermal design. And Mentor Graphics demonstrated is HyperLynx tool for SerDes channel optimization, power- and signal-integrity analysis, electrical rule checking, and 3D electromagnetic extraction.

Keysight Technologies has long been a player in both simulation and measurement. At DesignCon, the company exhibited technologies that extend from EDA tools and physical-layer test software to BERTs, logic analyzers, oscilloscopes, and protocol analyzers and exercisers—with emphasis on the USB Type-C ecosystem, signal and power integrity, PAM-4 and 100G/400G data-center standards, and test and validation of the latest generation of PCIe and DDR/LPDDR standards.

Anritsu touted software/instrument integration by demonstrating its MP1800A BERT signal quality analyzer and software from Granite River Labs that simplify calibration so engineers can conduct high-quality reproducible receiver and jitter tolerance tests on high-speed devices. The new solution, which incorporates a noise signal source, a variable ISI channel, and a real-time oscilloscope, allows accurate evaluations to be conducted on next-generation PCIe Gen4, 100GbE, InfiniBand, and other high-speed serial interfaces for greater design confidence.

In addition, Anritsu and DVT Solutions demonstrated an integrated test solution that can conduct high-quality S-parameter measurements as well as time-domain analysis on high-speed PCBs, packages, and backplanes. The configuration featuring the Anritsu VectorStar VNA and the DVT PCB probing solution addresses the market need to accurately and efficiently perform signal-integrity tests on products used in emerging communications systems.

Teledyne LeCroy introduced several new products, including the HDA125 high-speed digital analyzer for its oscilloscope line, an interposer probe for analysis of PCIe External Cable 3.0 ports that utilize the new PCI Express External Cabling Specification Revision 3.0, and the Power Delivery Compliance Suite for the Voyager M310C SuperSpeed USB 3.1 protocol verification platform.

In other instrumentation news, National Instruments introduced its new high-performance model of the VirtualBench all-in-one instrument. The software-based VirtualBench combines a mixed-signal oscilloscope, function generator, digital multimeter, programmable DC power supply, and digital I/O. The new version includes a four-channel 350-MHz oscilloscope vs. a two-channel 100-MHz scope on the original version. In addition, Ethernet connectivity has been added. The new version also boosts the instrument's programmable power-supply current-output capability, offering +6-V, -25-V, and +25-V outputs at up to 3 A, 1 A, and 1 A, respectively (1 A, 0.5 A, and 0.5 A on the original model).

Rohde & Schwarz demonstrated its R&S FSWP phase-noise analyzer and VCO tester, which enables sensitive and fast phase-noise measurements. It also allows users to easily measure pulsed sources and residual phase noise of RF components. And Rigol highlighted its DS1000Z Series digital oscilloscopes, DSA800 Series spectrum analyzers, and DG1000 Series arbitrary waveform generators. Chroma showcased Wi-Fi and Bluetooth test and exhibited PXIe source-measure units and a test handler.

Companies also highlighted accessories such as cables and connectors. For example, HUBER+SUHNER exhibited its new VNA Sucotest 500V test-lead series, which joins the company's existing portfolio of assemblies including Sucoflex 100, Sucotest 18/18A, and Sucotest 26/40. The company demonstrated the flexibility of the Sucotest 500V leads in conjunction with an Agilent (now Keysight) FieldFox handheld analyzer.

Molex exhibited multiple connector sizes and shapes that support a wide range of data rates. In one demonstration incorporating Tektronix test equipment, the company highlighted the NeoPress high-speed mezzanine system operating at 28 Gb/s. And finally, in addition to addressing simulation and measurement integration, Tektronix showed PAM-4, NRZ, DDR4, and LPDDR4 applications on the exhibit floor. **EE**

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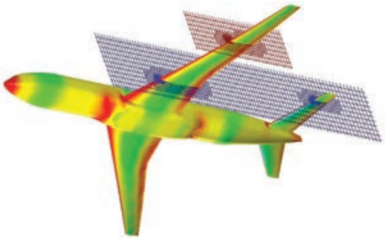


The latest release of front-loading computational-fluid-dynamics (CFD) FloEFD software offers greater accuracy and user productivity. Updated features in this new version include improved mesh handling, an enhanced transient solver, a robust EDA interface, and an interface to Abaqus finite-element-analysis software for stress analysis. Engineers and specialists in the automotive, aerospace, and electronics markets can directly benefit from the improved accuracy and productivity.

The latest version of FloEFD offers new capabilities for minimizing user time and effort spent on meshing. The FloEFD tool can automatically fill gaps of specified size to quickly make the model watertight, thereby eliminating the necessity to adjust the original geometry. The new equidistant refinement capability lets users build multilevel uniform meshes around the body or surface of the model with one click. The mesh preview visualization tool helps users achieve the desired mesh with ease and speed. **Mentor Graphics, www.rsleads.com/604ee-217**

Bluetooth reference design

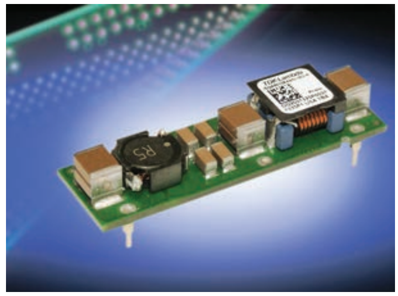
The latest 'nRFready Smart Remote 3' reference design makes the development of advanced Bluetooth Smart remotes as easy as clicking on a list of check-box options—minimizing time-to-market and unnecessary design risk. Targeting remote-control OEMs/ODMs and smart TV, set-top-box, and digital-media-device manufacturers, the nRFready Smart Remote 3 reference design delivers a rich, intuitive, and engaging end-user experience. It employs state-of-the-art voice input and speech recognition control, a six-axis motion-sensing air-mouse, multitouch trackpad technology, and 39 developer-programmable buttons and legacy IR hardware support (to control IR-only products). **Nordic Semiconductor, www.rsleads.com/604ee-218**

Hipot testers

The 290 Series hipot testers offer an improved interface that eliminates confusing menus and redundant button pushes, allowing manufacturers to set up and run production hipot tests in a matter of seconds. The 290 Series also provides common-sense security settings that make it easy to set permission levels. With a rugged and reliable design, the 290 testers are suited for production-line applications; an optional USB interface provides a simple way to automate a production line.

Prices start at $1,399 for a 5-kV AC hipot tester. **Slaughter, www.rsleads.com/604ee-219**

EMC filter



The PCB-mount DC-input iDQ48010A480V EMC filter is designed to reduce emissions from high-frequency DC/DC converters. It features high onboard capacitance that minimizes the need for additional external components and provides differential-mode filtering. It can be used in test-and-measurement, datacom, and telecom equipment.

The filter accommodates voltages up to 75 VDC, is rated at 10 A, and will operate at full current with natural convection in ambient temperatures from -40°C to +85°C. Differential-mode attenuation at 300 kHz is 63 dB with a 50-Ω source and load impedance. The package size is 50 mm long, 15 mm wide, and 10.8 mm high. The filters have 1,500-VDC input/output to ground isolation, allowing them to be used with either positive- or negative-grounded systems. A pin is provided to connect additional capacitance to increase common-mode attenuation. **TDK-Lambda, www.rsleads.com/604ee-220**

USB DAQ drivers

The vendor has extended driver support for its USB DAQ Series from Microsoft Windows to include Linux and Mac OS X operating systems, increasing the choices and flexibility for test-and-measurement users to develop specialized measurement and automation applications for different operating systems. The USB-powered plug-and-play DAQ modules deliver easy connection and accurate results for both portable measurement and machine-automation applications. Featuring built-in signal conditioning, the modules enable direct measurement of most frequently applied signal sources, reducing manpower requirements and associated development costs while increasing overall accuracy. **ADLINK Technology, www.rsleads.com/604ee-221**

RF amplifier

The PE15A7000 19-inch rack-mount variable-gain RF amplifier with performance from 100 MHz to 18 GHz is designed for lab use and various test-and-measurement applications. It offers broadband frequency coverage with high gain levels of 50 dB minimum over a temperature range of -40°C to +85°C. Integrated digitally controlled attenuators boost the dynamic range up to 60 dB in 1-dB steps. Typical performance includes 6.5-dB noise figure and +14-dBm output at P1dB. The package design supports a front-panel LED display with a manual control dial and SMA connectors and a nine-pin D-subminiature connector on the rear panel. It also is environmentally sealed and designed to meet a series of MIL-STD-202F test conditions. **Pasternack, www.rsleads.com/604ee-222**

DC electronic loads

The Keithley Series 2380 family of compact, standalone DC electronic loads complements the company's set of power test and measurement solutions. Available in 200-W, 250-W, and 750-W models, the new loads can handle a range of applications including performance verification, stress test, and environmental test of DC power sources, power components, and batteries in power-electronics, LED-lighting, automotive, and alternative-energy industries.

Using any of the Series 2380 models, engineers can test their device under multiple working modes using the same instrument. The operation modes include constant current, constant voltage, constant resistance, and constant power. The new instruments build confidence in measurement accuracy with 0.1-mV/0.01-mA voltage/current read-back resolution and 0.025%/0.05% voltage/current read-back accuracy. Prices start at $1,880. **Tektronix, www.rsleads.com/604ee-223**

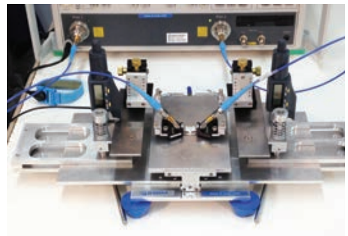
Filter/amplifier

The PFA-2 compact, rugged, and versatile dual-channel precision filter/amplifier offers a low-noise, high common-mode-rejection balanced differential input with programmable AC/DC input coupling, making it suitable for conditioning static or dynamic signal inputs. Sharp, programmable six-pole low-pass precision filters support two response characteristics, which are optimized for making time-domain (such as shock) or frequency-domain (such as anti-aliasing) measurements.

Gain is distributed before and after the filter, eliminating out-of-band energy such as transducer resonant peaking, which can cause nonlinearities due to clipping of the amplifier. Front-panel overload detectors alert the user to pre- and post-filter overload conditions that could otherwise be masked by the filter. The optional two-pole high-pass filter provides programmable low-frequency roll-off to attenuate sources of low-frequency noise. **Precision Filters, www.rsleads.com/604ee-224**

Reconfigurable probe station

The Model W4.0 x L6.5 mini probe station can be used to test a chip or small circuit board when a local lab probe station is not available. The 9-lb probe station has small footprint (X = 22 in., Y = 9 in., Z = 8 in.) and can be used at a desk or in a lab.



The probe station is fully manual and features a 4.0-in. x 6.5-in. test plate with vacuum holes and wide probe holder plates on each positioner with multiple holes for probe mounting. Both positioners slide back and forth in the X and Y directions and can be moved toward the DUT at an angle. The height positioning is accomplished via digital micrometers, and each positioner can be locked independently. This probe station is compatible with all standard wafer probes and many DC needle setups. **D-COAX, www.rsleads.com/604ee-225**

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By Rick Nelson, Executive Editor

Optogenetics probes offer insight to brain diseases

Optogenetics—the use of light to control living cells that have been genetically modified to be light-sensitive—could transform neuroscience if the technique could safely be applied to humans. The technology can help pave the way to a greater understanding of the brain and toward the development of novel treatments for brain disorders such as Alzheimer's, schizophrenia, autism, and epilepsy. Optogenetics requires, first, the genetic engineering of neurons to make them light-sensitive. The second step involves getting light to the sensitized cells.

This second step was the focus of research described by imec, KU Leuven, and Neuro-Electronics Research Flanders in a paper[1] presented at the 2015 IEEE International Electron Devices Meeting. The researchers presented a set of silicon neural probes that combines 12 monolithically integrated nanophotonic circuits, or optrodes (which optically stimulate single neurons), fabricated using a CMOS-compatible process. The fully integrated implantable probes enable optical stimulation and electronic detection of individual neurons.

The project builds on imec's work with artificial synapses and brain stimulation and recording probes extending back to 2007. Dries Braeken, team leader for the project at imec, said in a phone interview, "The work adds functionality and complexity to what we have done before." The brain is composed of many genetically and functionally distinct neuron types, and the new probes overcome the limitations of conventional probes, which cannot disambiguate recorded electrical signals with respect to their source. Braeken explained that optical stimulation can target very specific cell types vs. the more difficult-to-control electrical stimulation.

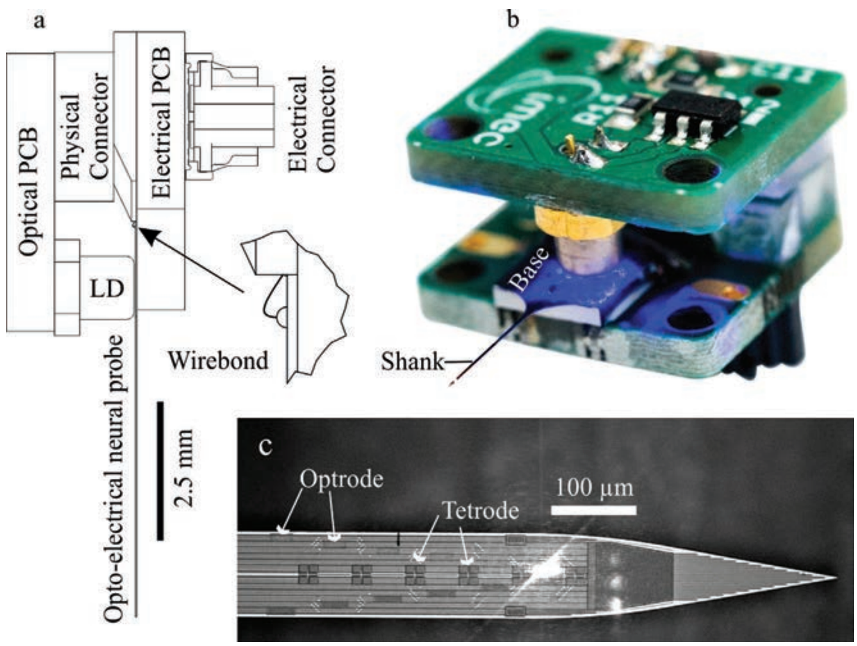
To build the probe, Braeken said the researchers integrated two CMOS processes: silicon nitride photonics and titanium nitride electrodes. The probes are 100 µm wide and 30 µm thick, containing 12 optrodes (6 x 20 μm^2 in size) and 24 electrodes (10 x 10 μm^2). The researchers packaged the circuitry, implanted it in a mouse brain, and successfully demonstrated that it could both drive and record neural activity (see the illustration).

According to Braeken, it's well-known that humans with Parkinson's disease are treated using electrical stimulation; the optogenetic approach could offer a much more efficient and effective way of treating any neural disease. The technique, he said, also has been tested on cardiac cells. "There could be many applications for this technology," he said.

Braeken said the imec and KU Leuven probes have been used experimentally on rodent brains, but he cited an article[2] commenting on moving optogenetics technology to human applications. For example, Circuit Therapeutics wants to begin clinical trials using optogenetics to treat chronic pain. And RetroSense Therapeutics plans to soon begin human trials of optogenetics for treating a genetic condition that causes blindness.

The development of probe technology is only one aspect of exploiting the promise of optogenetics. Edward S. Boyden, an MIT neuroscientist, found that his neural probing of a mouse brain was generating more data—a terabit per second—than his computers could handle.[3] Boyden worked with startup LeafLabs on the problem, leading to the development of a data-acquisition system called Willow for neuroscience applications. A Willow module communicates concurrently with as many as 32 industry-standard neural amplifier chips, and it contains an FPGA that processes 1,000+ channels of electrophysiological data. The FPGA writes data directly to a storage drive while simultaneously forwarding the data to a computer for real-time monitoring and feedback.

The application of the computer is described in the paper[4] by Boyden and several coauthors: "Here we present a novel architecture in which a digital processor receives data from an analog-to-digital converter and writes that data directly to hard drives, without the need for a personal computer to serve as an intermediary in the DAQ process." This minimalist architecture, they write, will facilitate the future scaling of electrophysiological recording. **EE**



Probe located on top of a printed circuit board (a), final system with the light output activated (b), and close-up of the electrode probe with a light output activated (c)
Courtesy of imec/IEDM Editor Press Center

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