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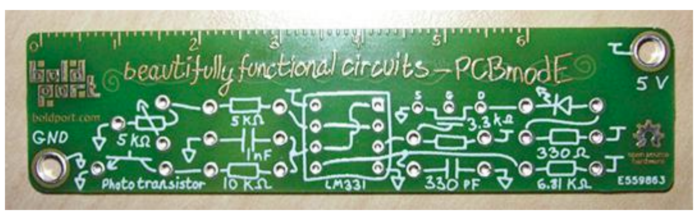

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To provide the most current, accurate, and in-depth technical coverage of the key emerging technologies that engineers need to design tomorrow's products today.

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Aston Martin Builds Submersible with a Touch of Bond

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http://www.electronicdesign.com/automotive/aston-martin-builds-submersible-touch-bond

How to Create Automatic Direction Control for RS-485 Interfaces

This article explores methodology for adding RS-485 capability to a PC’s RS-232 serial port by implementing automatic direction control. Using a single 6-pin MCU along with code that’s less complex to develop, the solution offers the advantages of fewer components and lower cost.

http://www.electronicdesign.com/embedded-revolution/how-create-automatic-direction-control-rs-485-interfaces

Mining for Data? Lefdal Mine Becomes Container-Based Data Center

Norway’s Lefdal mine once was a source for minerals, but now it’s a data center. Created jointly by IBM, Rittal, and Lefdal, the massive mine—120,000-m^2—could house up to 1,500 containers.

http://www.electronicdesign.com/industrial-automation/mining-data-lefdal-mine-becomes-container-based-data-center

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Facebook’s and Alibaba’s investment in semiconductor design capabilities reveals a growing trend that could further invigorate the industry.

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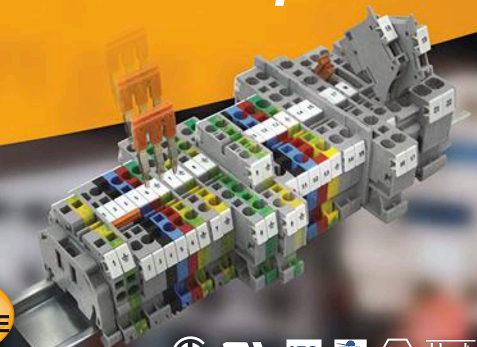

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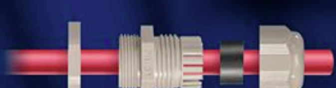

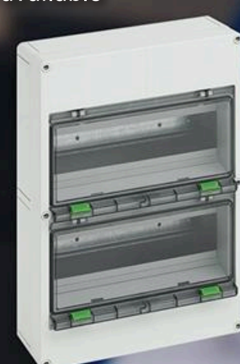


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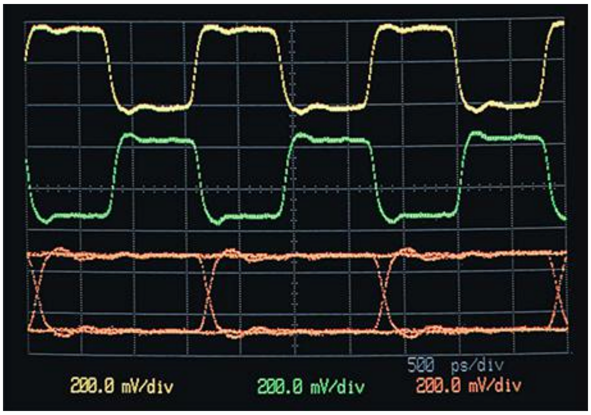

Plot shows complementary clocks and PRBS (opt. 01) outputs at 622.08 Mb/s with LVDS levels. Traces have transition times of 80 ps and jitter less than 1 ps (rms).

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Editorial

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All Simulations Are Not Created Equal

Simulations are extremely useful in all aspects of embedded development, from checking the power and timing of new chips to running software on chips yet to exist. They allow airplanes to be designed so that assemblies work the first time they're constructed. Simulations can also provide test environments for applications like self-driving cars, where the consequences of premature real-world testing have been deadly.

Simulations are approximations, and the depth and quality of the simulation dictates the compute requirements needed to deliver the simulation. Even our growing cloud-computing resources pale in comparison to the actual requirements of simulating even part of our world, let alone Matrix-style virtual reality.

Selecting the proper level of detail for simulations affects the performance requirements. It's often unnecessary to simulate all aspects of the environment to the same degree to get good results. For example, foveated rendering is now used in virtual-reality rendering. The approach uses eye-tracking feedback to determine where a person is looking; therefore, the software can spend more time to generate a better image in that area while spending less time rendering the image areas only viewed peripherally.

Quanergy and Metamoto collaborated to create a self-driving car simulation.

Metamoto is one of many companies delivering multi-sensor simulation for automotive applications *(see figure)* that will be critical to the success of self-driving cars. These simulation environments need to support LiDAR, radar, ultrasonic, and camera device inputs in addition to GPS signals so that the hardware and software being developed for the vehicle can be tested. Having self-driving cars running around real streets may seem high tech, but rarely do these platforms have sufficient testing done before they hit the real road.

Real-world testing used to be the only way to go because simulations were often inadequate. In many cases, that's still true, but developers need to consider what's possible and how to take advantage of simulation since it's safer and usually more cost-effective in the long run.

The challenge of simulated environments is creating a path for collaboration with industry sources of hardware and software related to the simulation environment. For example, Metamoto works with companies like LiDAR provider Quanergy to develop simulated models that match the performance of real hardware being delivered by LiDAR companies. The models needn't simulate how the devices work internally—only how they relate and perform with respect to the other software and hardware in the simulation.

All simulations are not created equal, but most can be very useful in the right context. ed

News

STARTUP RAISES $12 MILLION to Make Most of Embedded Hardware

As the pace of processor development slows, many companies are betting that custom silicon can cut the cost of machine learning in embedded devices and give them independence from the internet. But even though millions of dollars are pouring into new chips, some argue there is nothing wrong with existing hardware.

The problem is that software is too rough around the edges, and increasingly investors are onboard with startups trying to change that. Seattle, Washington-based XNOR, which has designed neural networks that consume a fraction of the memory and power, announced on Tuesday that it raised $12 million in venture funding.

Founded by former scientists at the Allen Institute for Artificial Intelligence, XNOR is trying to trim the fat from machine learning models so that they

run on hardware as simple and low cost as the Raspberry Pi. That puts it directly in the path of companies creating custom chips that can accelerate neural networks and could cost much more than existing chips.

XNOR is also trying to develop a software platform that allows anyone to integrate state-of-the-art inference models into security cameras, drones and other devices. The toolkit is scheduled to be released before the end of the year, and the company has partnered with semiconductor companies, including Ambarella, to make the algorithms compatible with their products.

"Our 'A.I. everywhere for everyone' technology eliminates the need for internet connectivity, runs on inexpensive hardware platforms and eliminates latency inherent in traditional cloud based A.I. systems," said Ali Farhadi, founder and chief executive of XNOR, which previously raised $2.6 million in seed funding.

Taking machine learning out of the cloud would allow drones to scan farmland to pinpoint failing crops and recommend optimum harvest time without being connected to the internet, said XNOR. Smartwatches could measure vital signs without wasting energy to send raw data to the cloud, and smart speakers could perform simple voice recognition and control functions. ■

GOOGLE OFFERS NVIDIA'S LATEST CHIP Over the Cloud

SINCE GOOGLE ANNOUNCED that it would install custom chips for machine learning in its data centers, the semiconductor industry has wondered how many Nvidia GPUs they would replace. While Google still has not answered that question, the company keeps on buying the parallel processors, which can accelerate training operations in machine learning.

Google recently started to offer Nvidia's latest product, the Tesla V100, over its cloud on a limited basis before general availability. The chip is based on Nvidia's Volta architecture, which uses custom tensor cores for accelerating deep neural networks, and succeeds its previous Pascal architecture, which was introduced about two years ago.

Web Services, the leader in the cloud computing space, offers the new hardware to customers. For now, Google charges less to rent its custom accelerators over the cloud than Nvidia's Tesla V100. The cost of Google's Cloud TPU – which puts four chips together to provide 180 trillion operations per second – is $6.88 per hour.

Nvidia's Tesla V100 can handle more operations per second than the discrete chips inside Google's Cloud TPU, so the price per trillion operations favors Nvidia. The graphics processor – which was introduced by the company's chief executive Jensen Huang last year and can provide 125 trillion operations per second – costs $2.48 per hour on Google's cloud.

But without common benchmarks, there are limits to comparing Nvidia's chips with Google's system. Last month, researchers reported that the Cloud TPU could train an image recognition algorithm slightly faster than four Tesla V100s. They added that using Google's four TPUs is cheaper than renting an equivalent number of Tesla V100s on Amazon's cloud.

Nvidia recently said that researchers had trained an image recognition algorithm on ResNet-50, a massive collection of images widely used to measure the performance of machine learning hardware and software, in record time using a single Tesla accelerator. They added the Tesla V100 was four times faster than chips based on Nvidia's Pascal architecture. ■

LOU FRENZEL | Contributing Editor

Cables Be Gone: Wireless Charging Charges On

Though still a work in progress, the greater convenience of wireless is pushing harder against the ubiquitous task of cable charging.

Nikola Tesla was right—you can transfer electrical power wirelessly. He demonstrated it in several ways in the late 19th century. Yet, as usual, he was ahead of his time. Up until recently, that work was generally lost, ignored, or dismissed. Now researchers and developers are finally finding ways to make wireless power transfer happen in a practical manner.

Wireless power transfer is used primarily to charge batteries in an incredible range of products. The earliest applications were plain inductive chargers in electric toothbrushes and shavers. Today, most wireless chargers are for smartphones, wearables, and even laptops. Other consumer targets include hearing aids and golf carts. One application that makes sense is wireless charging for hybrid electric vehicles (HEVs) and full electric vehicles (EVs). And a common industrial application is wireless charging of electric forklifts.

This article takes a look at the concepts behind the technology and provides an update on this movement today.

THE THEORY OF WIRELESS POWER

There are two basic ways to transfer electrical energy without wires: near field and far field. The near-field method is basically just magnetic coupling. The operation is that of a transformer, where a transmitter (TX) coil is the primary winding and a receiver (RX) coil is the secondary winding.

The power transfer is wireless; no direct electrical connection exists between the transmitter and receiver. However, the key to making this work well is to keep the distance between TX and RX as short as possible, and to ensure that the two coils are optimally aligned. The amount of power transferred and the overall efficiency of the process depends on the amount of coupling between coils. Typical coupling is in the 0.3-0.6 range.

Far-field transmission is real radio rather than just magnetic-field induction. In far field, the TX antenna creates both electric and magnetic fields at a right angle to one another. At some distance from the antenna, usually several wavelengths, the fields break away and travel together through space to the RX antenna that captures the signal and generates a small useful voltage.

The problem with the far field is that the power level drops off at the square of the distance between TX and RX. To be usable, the far field or RF method must transmit higher power and keep the distances as short as is practical.

THE IMPORTANCE OF RESONANCE

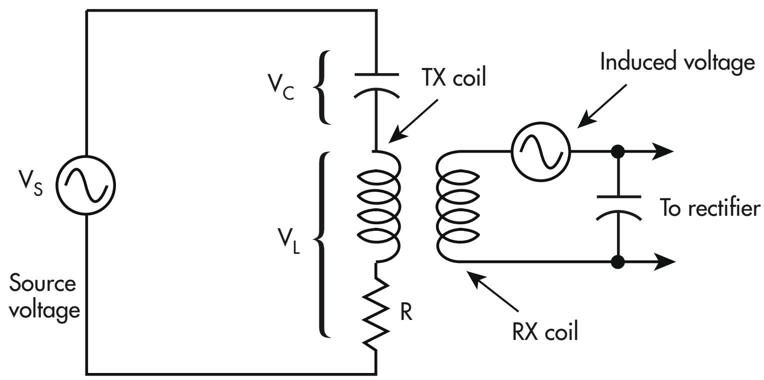
To improve the energy transfer between near field coils the principle of resonance is deployed. A capacitor is added to the primary and secondary coils to produce resonance. Recall that the resonant frequency is a function of the inductance (L) and capacitance (C) values:

$$f = 1/2\pi\sqrt{(LC)}$$

Series resonant circuits are the most common in wireless chargers *(Fig. 1)*. When $X_L = X_C$ at resonance, the voltage drops across the ideal inductor and capacitor are equal. Therefore, their effects cancel producing zero opposition to current. In practice, the coil resistance (R) limits the current. It's the Q of the coil that determines the amount of current produced:

$$Q = X_L / R$$

$$X_L = 2\pi fL$$



1. The schematic shows how series resonant circuits are used in resonant wireless power coupling.

The varying magnetic field of the primary coil induces a voltage into the secondary coil. This voltage appears in series with the coil and capacitor, forming a series resonant circuit. The output is taken from the voltage across the capacitor. If the Q is high, a high current flows and the resonance phenomenon produces a resonant voltage step-up across the capacitor. This voltage then goes on to be rectified into dc and used for battery charging. The amount of voltage step-up is given by:

$$V_C = QVs$$

where VC is the capacitor voltage and Vs is the circuit source voltage; in this case, the induced voltage.

Overall, resonant systems produce higher wattage capabilities and greater efficiency. While the critical physical factor is the placement of the two coils with respect to one another, resonant systems are more tolerant of placement and can work over greater distances than plain inductive chargers.

WIRELESS CHARGING

So far, the main use of this inductive power transfer is battery charging. Special circuits and charging products make it possible to charge the batteries in smartphones, watches, and other wearables without a cable. The charging unit, called a charging pad, contains the TX coil and related circuitry and operates from the ac mains. The smartphone or other device contains the RX coil and the battery-charging circuitry. You simply drop the phone on the pad and go.

You must be sure the coils are properly aligned for the best transfer of power. If not, less power is transferred and charging time is longer. Most pads have visual or physical clues to help you place the device in the optimum position.

Another solution is to use multiple TX coils in the charging pad to cover a wider area. These may overlap to ensure that wherever you place the phone on the pad, you will get a good transfer.

One new trend is wireless charging in cars. Multiple auto manufacturers are now building in wireless-charging pads or bins. Currently, most high-end smartphones like the Apple iPhone 8 and X and Samsung Galaxy S8 have integral wireless charging. Some fitness and other watches also contain coils and charging circuits.

THE STANDARDS

Early development efforts in wireless charging produced multiple methods and systems. The most widely used standard is called Qi (pronounced "chee"). Developed by the Wireless Power Consortium (WPC), the standard is implemented in chips by multiple semiconductor manufacturers and built into over 200 million smartphones. The WPC tests and certifies Qi-based products to ensure full interoperability between the many Qi products. Here's a summary of the basic features:

- Three basic power levels: 0 to 5 W, 0 to 15 W, and 0 to 120 W.
- Low-power versions work with coil separation of 5 mm (best when coils are aligned) and a maximum of 40 mm (1.57 in.).
- Frequency of operation: 110 to 205 kHz (typical ~140 kHz). Resonant coupling.
- Data communications link between TX and RX. (RX can inform TX of power needs; RX can inform TX when charging is complete.) Backscatter ASK modulation data link with a rate of 2 kb/s.

Figure 2 shows a simplified block diagram of a Qi charger and smartphone target.

The other major standard is from the AirFuel Alliance, an organization formed by the merger of Alliance for Wireless Power (A4WP) and Power Matters Alliance (PMA) in 2015. While not as widely used, it's a variation that offers some benefits such as the ability to charge multiple devices simultaneously. AirFuel also tests and certifies devices to for compatibility. Features of its Resonant standard include:

- Six classes of power levels from 2 to 70 W.
- Works with coil separation up to 50 mm (2 in.).
- Frequency of operation: 6.78 MHz. Resonant coupling.
- Greater flexibility in coil alignment and ability to charge multiple devices at a time.
- Data communications link between TX and RX is Bluetooth Low Energy. (RX can inform TX of power needs; RX can inform TX when charging is complete.) Data rate of 1 Mb/s.

For more details on the standards, contact AirFuel and WPC at *www.airfuel.org* and *www.wirelesspowerconsortium.org*, respectively.

Multiple other proprietary technologies exist, but they're not universal standards. Representative of these is the system of PowerbyProxi, a New Zealand company. Its system is resonant at about 130 kHz, and range is best at less than a centimeter. Backscatter ASK modulation is used for the data communications. Overall, it's similar to Qi. Apple recently acquired PowerbyProxi, but the Apple iPhone 8 and X use Qi, not the PowerbyProxi standard.

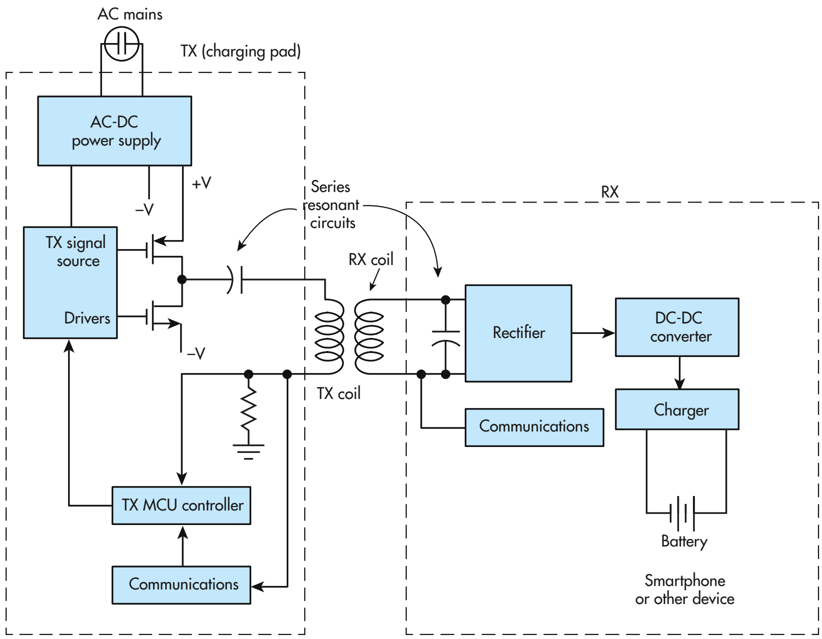
FAR-FIELD WIRELESS CHARGING

Only recently has practical RF far-field charging become available. This means charging at some distance more than a few inches. One accepted definition of far field is any distance beyond the following:

$$\text{Far Field} > 2D^2/\lambda$$

D is the largest dimension of the transmitter or receiver antennas, and wavelength (λ) in meters is $\lambda = 300/f_{MHz}$.

Two new systems show what can be done today. First is the long-range system from Powercast Corp. Its PowerSpot transmitter generates a 3-W direct-sequence spread-spectrum (DSSS) signal in the 915-MHz ISM unlicensed band (FCC Part 15).



2. These are the major components of a wireless charging application. The ac mains voltage is converted to dc to power the transmitter (TX) that generates the high-frequency ac applied to the TX coil. The RX coil receives the oscillating magnetic field and produces a signal that's rectified into dc and used to operate the charger inside the smartphone or other device to be charged. A communications link is provided between RX and TX.

3. The PowerSpot long-range charger by Powercast creates a charging zone up to 80 feet away, accommodating the charging of multiple devices.

The signal gets a boost from the 6-dBi gain directional antenna that produces a 70-deg. beam. It creates a charging zone up to 80 feet away, where objects can be placed for recharging without a mat or pad *(Fig. 3)*. The devices to be charged contain the matching Powercast receiver chip that converts the signal into dc for charging.

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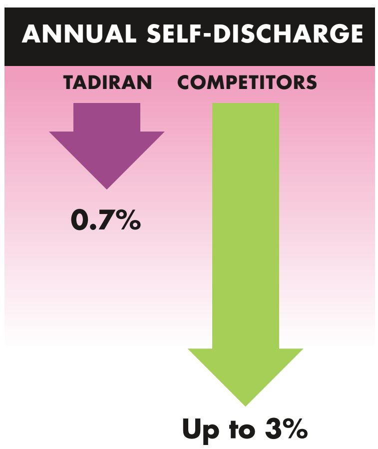

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* Tadiran LiSOCL2 batteries feature the lowest annual self-discharge rate of any competitive battery, less than 1% per year, enabling these batteries to operate over 40 years depending on device operating usage. However, this is not an expressed or implied warranty, as each application differs in terms of annual energy consumption and/or operating environment.

This new system can handle up to about 30 products depending on their requirements. Charge times will vary with distance between devices and transmitter, but generally most devices will charge fully overnight.

Another far-field charging product comes from Energous Corp. Its WattUp system uses the unlicensed 5.85- to 5.875-GHz band (FCC Part 18). The system's most effective range is from a few inches up to 3 feet, but it can cover up to 15 feet with a weaker signal and longer charging. The 90-deg. beam-width antenna pattern creates a charging zone into which multiple devices can be placed. Again, the devices must contain the WattUp receivers. Bluetooth Low Energy is used as the link

CORDLESS CHARGERS: AN ALTERNATE VIEW

JUST WHAT IS wrong with cabled chargers? Wireless chargers are cool technology, for sure. And they do offer some convenience. However, they seem to be solving a problem that doesn't exist. How hard is it to use a wired charger? You just plug it in. We all do it every day, mostly without thinking.

Technology lets us do things that don't necessarily need doing. We do it because we can. Besides, electronic engineers need continuous challenges. And as it turns out, there are many customers for those cool new products, needed or not. As a result, dozens of companies are now pursuing the complex wireless-charging space.

Here's a breakdown of the real pros and cons of wireless charging:

PRO

- Convenience.
- No messy cables that always seem to get lost.

Ability to charge multiple devices with one charger instead of the multiple cables usually needed.

CON

- More expensive than a plain old cable charger.
- Charging pads not as portable as a cable.
- Uses more power than a cable charger.
- Careful positioning of the devices on the charger is a nuisance.
- Adds to the growing cloud of EMI.

Despite whatever downsides are perceived, most market projections are rosy. Market research firm Technavio says that the market will grow by more than 33% by 2020. And ABI Research forecasts over 700 million wireless chargeable devices by 2020.

> For these new far-field systems to catch on, their receivers must be incorporated into the devices to be charged. This may take some time, but the convenience of long-range charging makes them an attractive alternative.

between transmitter and receivers.

For these new far-field systems to catch on, their receivers must be incorporated into the devices to be charged. This may take some time, but the convenience of long-range charging makes them an attractive alternative.

WIRELESS CHARGING OF ELECTRIC VEHICLES

One big target for wireless charging is electric vehicles (EVs), and, in fact, a wireless-charging grid is slowly emerging. Today, EV charging is done via heavy-duty cables. But new developments are gradually changing the landscape.

For example, BMW's and Volkswagen's electric and hybrid models will eventually incorporate a charging receiver and coil that will match up with a charging pad on the garage floor or in the driveway. Public charging stations would use a similar arrangement. Pad alignment is critical for the fastest and most efficient charging. There's even a vision of embedding charging pads into roads and at intersections or in parking lots for a quick charge.

An alternative approach to coils is being investigated that uses capacitive coupling instead of magnetic induction. One capacitor plate is located on the bottom of the vehicle and the other plate is on the charger. Capacitive coupling allows higher frequencies to be used. However, plate alignment is critical and movement or changes produce capacitance variations that require active impedance matching to provide an efficient transfer of power.

One company developing automotive chargers is WiTricity Corp. Its patented resonant technology, developed at MIT, is a good fit for EV charging pads. It's more forgiving of coil alignment and can transfer kilowatts of power efficiently at distances of 10 to 20 cm. It can also penetrate concrete, asphalt, and wood. ed

WILLIAM WONG | Senior Technology Editor

Machine Learning Invades Embedded Applications

Machine-learning applications on the edge are becoming more common and taking advantage of existing hardware.

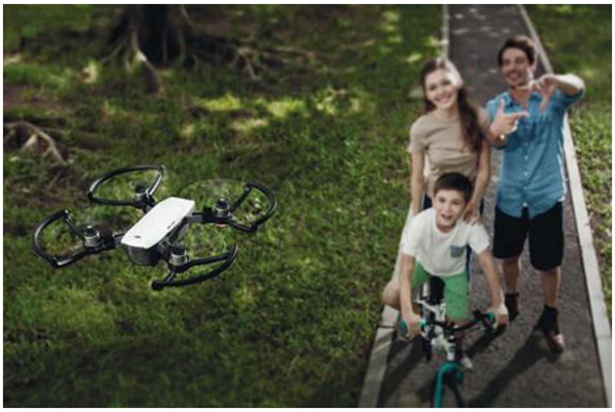
Two things have moved deep-neural-network-based (DNN) machine learning (ML) from research to mainstream. The first is improved computing power, especially general-purpose GPU (GPGPU) improvements. The second is wider distribution of ML software, especially open-source software.

Quite a few applications are driving adoption of ML, including advanced driver-assistance systems (ADAS) and self-driving cars, big-data analysis, surveillance, and improving processes from audio noise reduction to natural language processing. Many of these applications utilize arrays of GPGPUs and special ML hardware, especially for handling training that uses large amounts of data to create models that require significantly less processing power to perform a range of recognition and other ML-related tasks.

For example, Au-Zone Technologies' DeepView takes advantage of the GPUs in NXP's i.MX8. The i.MX8 is ideal for many embedded applications, and its dual GPU allows it to split video display and ML chores if necessary. The DeepView toolkit can be used for applications like industrial vision processing or ADAS. It's optimized for the i.MX8, like the one found on Digi International's ConnectCore i.MX53 *(Fig. 1)*, but also works on other platforms.

ML video processing requires hefty processing power that ML DSPs, like Cadence's Vision C5, and GPUs can provide even on single-chip SoCs. Specialized hardware such as Intel's Movidius machine-learning vision chip delivers even more performance using less power, suiting it for real-time video processing in drones like DJI's tiny SPARK *(Fig. 2)*.

1. Digi International's ConnectCore i.MX53/Wi-i.MX53 runs NXP's i.MX8, which is able to handle machine-learning chores.



2. DJI's SPARK uses Intel's Movidius vision chip to augment everything from object identification to gesture recognition.

One of the other two alternatives to H2O is to employ existing models that may be trained or have been trained and use them on embedded platforms. The other option is to build a new model from scratch, which can take a good bit of expertise and experimentation.

Many ML applications are able to run without this heavy-duty hardware. Of course, these applications can't be processing 4K video streams either. On the other hand, doing basic image recognition on a low-resolution image that's taken once a second is something that many platforms (e.g., an ARM Cortex-M4F) can easily handle.

OPEN SOURCE

A number of ML frameworks—Caffe and TensorFlow, to name two—are open-source projects. However, many products are not. Nonetheless, quite a few open-source ML models are available for a host of applications that have already been trained. These are often used in applications like academic robot research programs, where cost could eliminate the use of some tools.

Still, many open-source projects build on these frameworks, such as H2O.ai's H2O. H2O is a tool that greatly simplifies the creation and tuning of ML models that would otherwise require someone with significant ML experience. H2O's AutoML brings the creation of ML models to a higher level, enabling non-ML experts to more easily select and refine models and train them.

One of the other two alternatives to H2O is to employ existing models that may be trained or have been trained and use them on embedded platforms. The other option is to build a new model from scratch, which can take a good bit of expertise and experimentation.

ML doesn't fit into every application, and not all embedded platforms will have the memory or computing power to incorporate ML technology where appropriate. However, the improving hardware and availability of ML software makes it possible to use the technology in more applications these days. ed

CABE ATWELL | Contributing Editor

Connectors Toughen Up to Battle the Elements

Manufacturers focus in on durable contacts, rugged shells, watertight seals, and different types of locking mechanisms to enable connectors to handle harsh environments.

Rugged and harsh environments can wreak havoc on electrical systems and their connectors—vibration, temperature extremes, chemicals, and other fluids can (and will) render those systems useless if their connections become compromised. Nearly every industry has some form of environment that's detrimental to sophisticated electronic systems, and because they're the entry point to those systems, connectors are on the front lines.

Applications in mining are subjected to dust, shock, and vibration; offshore oil rigs and other marine services have to deal with saltwater corrosiveness; and aerospace applications routinely undergo extreme temperature and pressure fluctuations. As a result, connectors have been designed to withstand those environments and maintain their integrity.

To help defend connectors against hazardous operating conditions, manufacturers have added new features in their designs, which include durable contacts, rugged metal or thermoplastic shells, watertight seals, and various locking mechanisms.

Rugged metal casings and thermoplastic shells need to be manufactured from quality materials to withstand years of exposure to harsh environments. Metal housings must be able to stand up against repeated shock, vibration and sudden impact, while thermoplastic needs to be engineered to defend against chemicals/fluids and temperature extremes. Depending on the application, these can come in many different forms, including rectangular and cylindrical body shapes, and feature secure locking systems to keep them mated.

Shells and casings can be manufactured using a variety of materials to meet the requirements of their operating environment. Common metals range from aluminum and stainless steel to brass and titanium, while thermoplastics and composites include nylon and glass-filled polymers such as PEEK, PEI, and PPS.

Fluid-resistant seals are critical for operation in harsh environments, as they help mitigate any intrusion from dust, chemicals, and water. Silicone seals and grommets need to function flawlessly to provide a maximum seal to outside contamination. They must also retain their flexibility across a wide range of temperature extremes without degradation.

Harsh-environment connectors are designed to withstand volatile environments and have undergone rigorous testing before deployment, giving engineers and end-users increased confidence.

This metal high-voltage power connector features a spring-loaded internal locking mechanism and protective plastic end caps.

THE GENUINE ARTICLE.

Contact alignment is another crucial element for electrical connectors intended for rugged environments. Locking mechanisms that snap onto or into the mating surface help to ensure the internal contacts slide together perfectly when mated, with some producing an audible click when successfully engaged. These include threaded coupling rings, push-latches, lever locks, and jackscrews that clamp the connector and surface together. Many connectors are also outfitted with wedge locks and TPAs (terminal position assurance) that offer additional keying options and further connection stability with both the contact barrel and mating surface.

Internal contacts or pins represent another vital aspect of harsh environment connectors. If the flow of signal or power becomes disrupted, then the

The MIL-DTL-38999 nickel plated polymer connector is designed for use in rugged environments. *(Source: Abaillieul via Wikipedia)*

Choosing the right connectors is paramount when operating in harsh environments such as this sea-based oil rig. *(Source: Jim Hatter via Wikipedia)* electrical equipment and applications will fail. Contacts often consist of different metals that resist corrosion and offer superior power and signal transmission, with one to form the shape and the other for plating. They come in a wide range of metals; however, copper forms and nickel plating are the most common.

Harsh and rugged connectors are manufactured under strict regulations that must adhere to industry standards, which falls under the International Protection Marking or IP Code delegated by the International Electrotechnical Commision (IEC). The codes feature a pair of digits to signify robust particle protection and liquid ingress protection. Therefore, an IP rating of IP67 designates the connector is entirely secure against solid debris and can be submerged in fluid up to one meter in depth.

The European Union has gone beyond the IP rating system to include the ATEX directive, which outlines protections against explosions in the working environments. Connectors must be designed and tested to ensure no electrical arcing or sparking can happen in volatile situations where flammable gases, vapors, and other explosive materials are present. The directive offers a similar number system as IP codes, but is broken down into six zones ranging from 0 (places where flammable gas, vapors, and mist are continuously present) to Zone 22 (places where explosive dust may be present for short periods of time).

Harsh-environment connectors are designed with engineers in mind, meaning they're as easy to use and service in the field as they are on the manufacturing floor. This helps reduce the training and service time in the field. At the same time, it aids in lowering the costs associated with equipment servicing and training processes, thereby improving efficiency.

When choosing the right connector, careful consideration of the environment is mandatory. Asking the right questions can help determine the optimal connector. Some of the questions engineers should be asking include:

What kind of terminations and types are necessary?

Are there size or space constraints?

Is sealing needed for protection against water or other fluids?

Is the connector for signal or electrical purposes?

Although the selection criteria are extensive and can quickly become confusing, most manufacturers offer services to guide you through the myriad options to pinpoint the most efficient connector design. ed

Enhance your IMS Experience with these

5G Summit, Tuesday, 12 June 2018; Room 103

The 5G Summit, at the Pennsylvania Convention Center in Philadelphia, is an IEEE event that is organized by two of IEEE's largest societies – MTT-S and ComSoc. This special collaboration, for the second year running, complements MTT-S' "hardware and systems" focus with ComSoc's "networking and services" focus. The one-day Summit features talks from experts from government, academia, and industry experts on various aspects of 5G services and applications. It's further complemented by the 5G Pavilion at the IMS2018 exhibition where table top demonstrations and "fire-side" chats are presented at the 5G theater.

5G Summit Speakers:

"Bringing the World Closer Together"
Jin Bains
Head of Connectivity, SCL, Facebook

"AT&T Perspectives on 5G Services"
David Lu
Vice President, AT&T

Other featured presentations from Huawei, GM, Keysight, NI, Global Foundries, MACOM as well as academia will include following topics:

- Spectrum/Regulatory
- Infrastructure/Trials, Applications
- Technologies, Circuits, Systems
- Design, Test & Measurement Challenges
- Test-bed Services for 5G

Lunchtime Panel session: "mmWave Radios in Smartphones: What they will look like in 2, 5, and 10 years"

RF Boot Camp, Monday, 11 June 2018; Room 109B

This one-day course is ideal for newcomers to the microwave world, such as technicians, new engineers, college students, engineers changing their career path, as well as marketing and sales professionals looking to become more comfortable in customer interactions involving RF & Microwave circuit, and system concepts and terminology. The format of the RF Boot Camp is like that of a workshop or short course, with multiple presenters from industry and academia presenting on a variety of topics including:

- The RF/Microwave Signal Chain
- Network Characteristics, Analysis and Measurement
- Fundamentals of RF Simulation
- Impedance Matching & Device Modeling Basics
- Introduction to RF and Microwave Filters
- Spectral Analysis and Receiver Technology
- Signal Generation
- Modulation and Vector Signal Analysis
- Microwave Antenna Basics
- Introduction to Radar and Radar Measurements

For complete details on IMS and Microwave Week visit www.ims2018.org

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Physicians Panel Session:

Utilization of RF/Microwaves in Medicine, Thursday, 14 June 2018; Room 204B

Over the past three decades, collaboration between physicians and engineers has increased dramatically, to the benefit of our society. Biomedical engineering departments, the majority of which found in engineering schools and some within medical schools, offer seemingly unlimited opportunities and continue to attract a large number of students. To benefit from the merits of interdisciplinary cooperation and facilitate the transfer of technology to the market, existing large corporations, start-up medical companies, and research funding agencies now demand strong collaboration between engineers and physicians. With this in mind, IMS 2018 has made the subject of RF/ microwaves in Medicine a major theme of the conference. The physicians on this panel will discuss the use of RF/microwaves in their respective fields. Topics ranging from microwave hyperthermia therapy for reoccurrences of breast cancer, advances in RF renal denervation, to back pain management using RF, will be highlighted!

Panelists:

1. Andrew Ng, Thomas Jefferson University Hospital, Philadelphia, PA
2. Daniel Frisch, Thomas Jefferson University Hospital, Philadelphia, PA
3. Donald Mitchell, Thomas Jefferson University Hospital, Philadelphia, PA
4. Ernest Rosato, Thomas Jefferson University Hospital, Philadelphia, PA
5. Eugene Viscusi, Thomas Jefferson University Hospital, Philadelphia, PA
6. Francis Kralick, Neurological Surgery, Shore Medical Center, Brigantine, NJ
7. Hamid RS Hosseinzadeh, School of Osteopathic Medicine, Stratford, NJ
8. Mark Hurwitz, Thomas Jefferson University Hospital, Philadelphia, PA
9. Nicholas Ruggiero, Thomas Jefferson University Hospital, Philadelphia, PA
10. William Jow, Medifocus Inc., Columbia, MD

Exhibition Dates and Hours

Tuesday, 12 June 2018	09:30 to 17:00
Wednesday, 13 June 2018	09:30 to 17:00
Exhibit-Only Time:	13:30 to 15:10
Industry Hosted Reception:	17:00 to 18:00
Thursday, 14 June	09:30 to 15:00

MicroApps

The Microwave Application seminars (MicroApps) offered Tuesday, 12 June through Thursday, 14 June, 2018, provide a unique forum for the exchange of ideas and practical knowledge related to the design, development, production, and test of products and services. MicroApps seminars are presented by technical experts from IMS2018 exhibitors with a focus on providing practical information, design, and test techniques that practicing engineers and technicians can apply to solve the current issues in their projects and products.

Industry Workshops

The Industry Workshops are 2-hour industry-led presentations featuring hands-on, practical solutions often including live demonstrations and attendee participation. These Workshops are open to all registered Microwave Week attendees at a nominal charge.

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BILL SCHWEBER | Contributing Editor

Using Resistors for Current Sensing: It's More Than Just I=V/R

Sensing current by measuring voltage across a resistor is simple and elegant, but issues arise with the electrical interface, sizing and selection, and thermal/mechanical considerations.

Measuring dynamic current flow has always been an important parameter for managing system performance, and doing so has become even more so with the proliferation of smarter management functions for devices and systems. The most-common way to accurately make this measurement is by using a sense resistor of known value inserted in series with the load, then measuring the IR voltage drop across this resistor. By applying Ohm's law, determination of the current flow is simple—or at least that's how it seems.

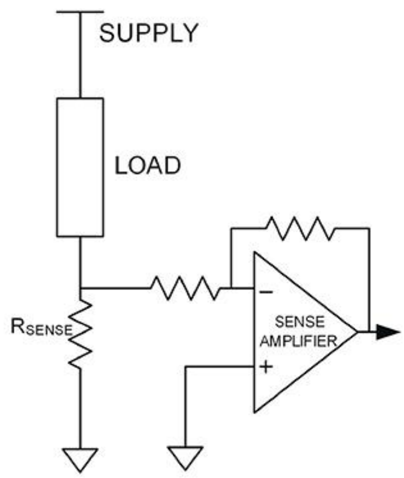
While using a resistor is an effective and direct basis for such sensing, it also has many design issues and subtleties despite its clarity. These span the electrical interface, resistor sizing and selection, and many mechanical considerations:

THE ELECTRICAL INTERFACE

Do you go with high-side or low-side sensing? In low-side sensing, the resistor is placed between the load and "ground" (or, in many cases, circuit "common") *(Fig. 1)*, which enables the voltage-sensing circuit to also be connected directly to ground. While components in this topology aren't subject to any high-voltage issues, it's often undesirable and even unacceptable, for two reasons.

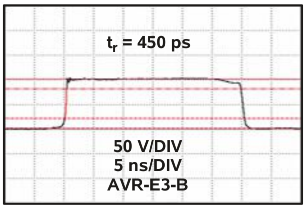
First, doing so means the load itself isn't grounded, which is impractical for mechanical reasons in many installations. For example, having an ungrounded starter motor in a car and insulating it from the chassis is a design and mounting challenge. It also mandates the need for a return wire that can carry the load current back to the source, rather than using the chassis. Second, even if wiring and mounting aren't considerations, placing any resistance between the load and ground (common) negatively affects the control-loop dynamics and control.

The solution is to use high-side sensing, with the resistor instead placed between the power rail and the load *(Fig. 2)*. This eliminates the problems created by ungrounding the load, but

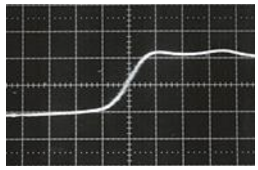


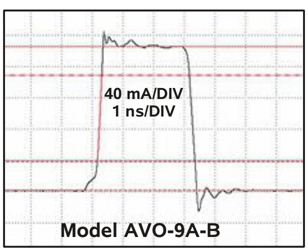
1. Low-side sensing places the resistor between the load and common; it simplifies the interface to the voltage-reading analog front end but brings problems with load integrity and control.

a new issue arises. The circuitry that senses the voltage across that resistor now can't be grounded, which means a differential or instrumentation amplifier is used. This amplifier must have a common-mode voltage (CMV) rating that's higher than the rail voltage. In

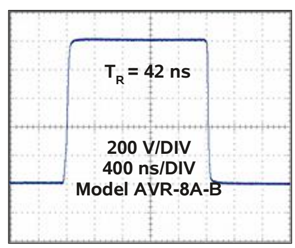


t_r = 450 ps
50 V/DIV
5 ns/DIV
AVR-E3-B

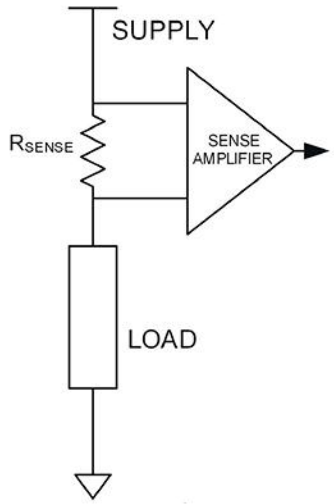




40 mA/DIV
1 ns/DIV
Model AVO-9A-B



T_R = 42 ns
200 V/DIV
400 ns/DIV
Model AVR-8A-B



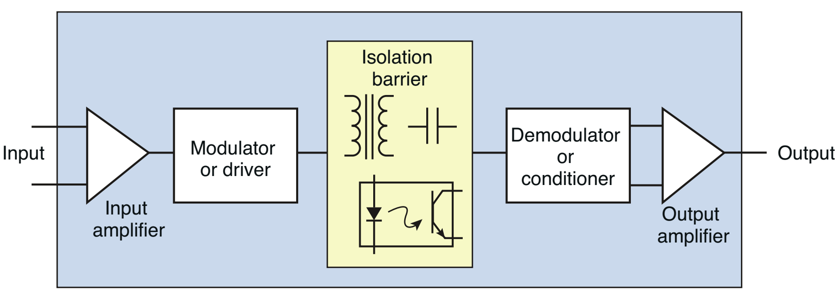
2. High-side sensing is the more commonly used approach, despite the fact that it brings new issues of common-mode voltage.

general, if the rail voltage is higher than the CMV rating of standard ICs (typically, about 100 V), then more complicated approaches to providing this interface are needed.

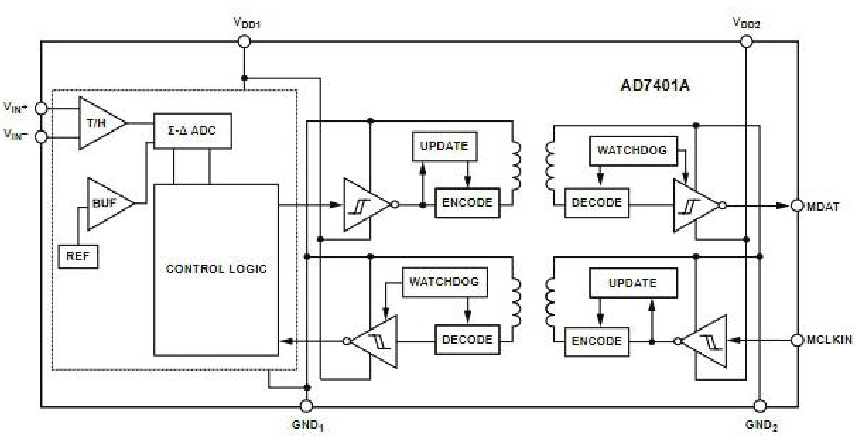
An alternate approach is to use interface circuitry that includes galvanic isolation between the sensing amplifier input and output *(Fig. 3)*. This means no ohmic path exists between the two analog sections—it appears like a non-isolated amplifier, except for the internal isolation.

The approach brings other beneficial features as well: It greatly improves system performance by eliminating ground loops and associated issues; simplifies subsequent circuitry, and eases or eliminates safety-related layout and wiring requirements on clearance and creepage; adds an electrical safety barrier between the high voltage and the rest of the system; and is mandated by safety and regulatory standards in many applications.

Isolation can be implemented using an all-analog isolation amplifier; alternatively, a subcircuit comprised of a non-isolated amplifier followed by an analog-to-digital converter and isolator (which may use optical, capacitive, magnetic principles), all operating from an isolated power supply that's independent of the main supply, can be used *(Fig. 4)*. Regardless of the isolation solution selected, the voltage-sensing circuit for higher rail voltages can become complicated with respect to BOM and layout, but there often is no other practical option.



3. Galvanic isolation can be achieved in several ways. Regardless of approach used, the result is signal information is passed across a barrier without any ohmic path between input and output.



4. Isolation is sometimes implemented in the digital domain using an isolated front end (amplifier, ADC, isolator) and an isolated power supply. This AD7401A places all of the needed functions in a single package. *(Courtesy of Analog Devices Inc.)*

RESISTOR SIZING AND SELECTION

Ideally, the sensing resistor value should be relatively large so that the resultant voltage drop will also be large, thus minimizing effects of circuit and system noise on the sensed voltage, as well as maximizing its dynamic range. However, a larger value at a given current also means there is less voltage—and thus less available power—for the load due to IR drop, as well as I^2R resistor self-heating, wasted power, and added thermal load. It's clearly a tradeoff and compromise situation.

In practice, it's generally desirable to keep the maximum voltage across the sensing resistor to 100 mV or below, so that the corresponding resistor values are in the tens-of-milliohms range and even lower. Sense resistors are widely available in these small values; even 1-mΩ and lower resistors are standard catalog offerings *(Fig. 5)*. At these low values, even the resistance of the ohmic contacts of the sensing circuitry is a factor in the calculations.

The dilemma of resistor selection doesn't end with determining a value that balances the tradeoffs between voltage and power loss versus readout range. First, the resistor dissipation creates

Design Note

Active Rectifier Controller with Ultrafast Transient Response and Low Power Dissipation

Bin Wu

Introduction

The LT8672 is an active rectifier controller that (along with a MOSFET) provides reverse current protection and rectification for power supplies in automotive environments. This job is traditionally taken on by a Schottky diode, over which the LT8672's active protection has a number of advantages:

- Minimal power dissipation
- Small, predictable, regulated 20mV voltage drop

The LT8672 also includes a number of features to satisfy supply rail requirements in automotive environments:

- Reverse input protection to –40V
- Wide input operation range: 3V to 42V
- Ultrafast transient response
- Rectifies $6V_{P-P}$ up to 50kHz; rectifies $2V_{P-P}$ up to 100kHz
- Integrated boost regulator for the FET driver performs better than charge pump devices

Figure 1 shows a complete protection solution.

Fast Response for Input Ripple Rectification

Automotive standards—ISO 16750 or LV124—specify that automotive electronic control units (ECUs) may face a supply with a superimposed AC ripple of up to $6V_{P-P}$ at up to 30kHz. The LT8672's gate driver that controls the external MOSFET is strong enough to handle ripple frequencies of up to 100kHz, which minimizes reverse current. An example of such an AC ripple rectification is shown in Figure 2.

Low Power Dissipation Compared with a Schottky Diode

The performance of the LT8672 (using the IPD100N06S4-03 as external MOSFET) can be compared to a Schottky diode (CSHD10-45L) with the setup shown in Figure 3. Here, a 12V power supply at the input emulates the automotive voltage supply, and the output is loaded with a constant current of 10A. Thermal performance for both solutions at steady state is shown in Figure 4. Without cooling, the thermal performance of the LT8672 solution is far superior, reaching a peak temperature of only 36°C, while the Schottky diode solution reaches a much higher 95.1°C.

Extra Low Input Voltage Operation Capability

Automotive mission critical circuitry must be able to operate during cold crank conditions, when the car battery voltage can collapse to 3.2V. With this in mind, many automotive grade electronics are designed to operate down to 3V input. A Schottky's variable forward voltage drop can present a problem during cold crank, where this drop produces a downstream voltage of 2.5V to 3V, too low for some systems to operate. In contrast, a LT8672 solution guarantees the required 3V due to its regulated 20mV voltage drop, allowing easier circuit design and improved system robustness.

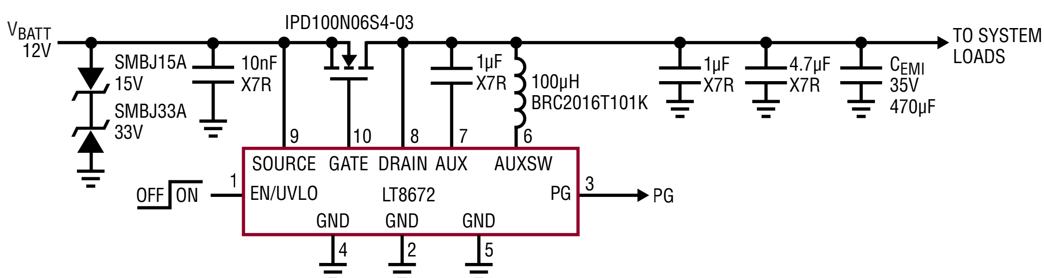


Figure 1. LT8672 Active Rectification/Reverse Protection Solution

02/18/572

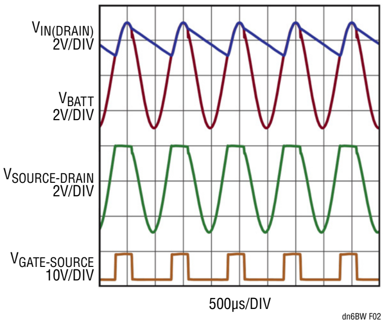


Figure 2. Rectification of Input Ripple

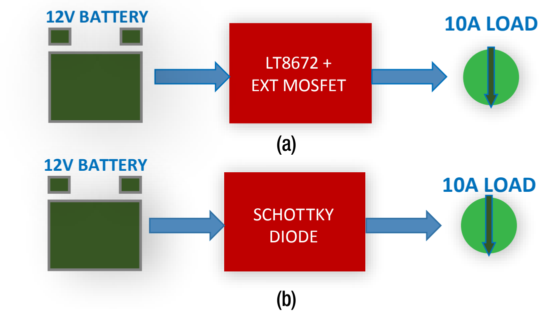
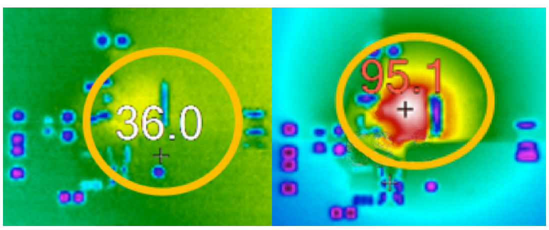


Figure 3. System Configuration (a) LT8672 Controlled System (b) Schottky Diode System



(a) (b)

Figure 4. Thermal Performance Comparison (a) LT8672 Controlled System (b) Schottky Diode System

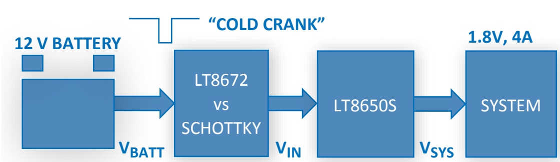


Figure 5. System Configuration for Cold Crank Test

Figure 5 shows a comparative cold crank test setup using an LT8650S step-down converter as the downstream test system. The LT8650S output is set to 1.8V at a constant load of 4A, and its minimum input operating requirement is 3V. The results are shown in Figure 6.

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When V_{BATT} drops to 3.2V, the LT8672 controlled system (a) maintains $V_{IN} > 3V$, allowing the LT8650S to keep its output V_{SYS} stable at 1.8V, while in the Schottky diode system (b) the input voltage V_{IN} of the LT8650S drops below its minimum operating voltage, preventing it from maintaining 1.8V at its output V_{SYS}.

Integrated Boost Regulator

Many alternative active rectifier controllers use a charge pump to power the gate driver. These solutions often cannot provide strong gate charging current and a regulated output voltage, limiting the frequency range and performance of continuous rectification. The LT8672's integrated boost regulator provides a tightly regulated gate driver voltage with strong gate driver current.

Conclusion

The LT8672 is able to rectify high frequency AC ripple on automotive supplies. It uses an integrated boost regulator to drive a MOSFET for ultrafast response during continuous rectification, an improvement over charge pump solutions. It provides rectification and reverse input protection with low power dissipation and an ultra-wide operational range (desirable for cold crank) in a tiny 10-lead MSOP package.

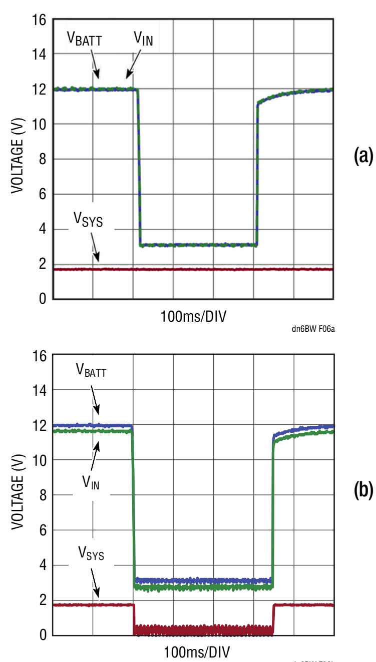

Figure 6 System Voltage Comparison Under "Cold Crank" (a) LT8672 Controlled System (b) Schottky Diode System

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6.	TTI	$2.25 billion
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8.	Smith & Associates	$1.5 billion
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37.	Air Electro Inc.	$29.48 million
38.	ASAP Semiconductor	$28.9 million
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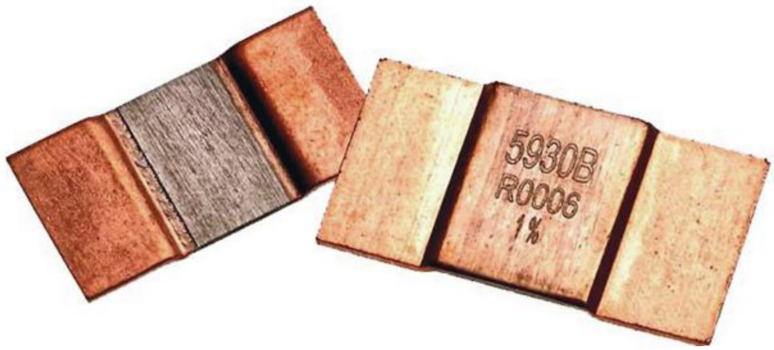
43.	Powertech Controls Co. Inc	$21 million
44.	CTrends, Inc.	$19.5 million
45.	Cumberland Electronics Strategic Supply Solutions Inc (CE3S)	$18.65 million
46.	Kensington Electronics	$18.5 million
47.	PUI (Projections Unlimited Inc.)	$18.47 million
48.	Gopher Electronics Company	$16.1 million
49.	Marine Air Supply	$14.8 million
50.	Advantage Electric Supply	$13 million

*In October 2016, Avnet closed its acquisition of Premier Farnell and the company's total includes Premier Farnell's revenue for fiscal year 2017. Source Today also lists Premier Farnell's global revenue separately

**SourceToday estimate of Future Electronics global revenue

Using a resistor for current sensing is a very educational example of the challenges of going from a solution that's very simple in principle, to one which works, works well, and works over the range of expected operating conditions of the application.



5. This 0.2-mΩ current-sense resistor handles up to 200 A and can dissipate 15 W. It measures 15 × 7.75 × 1.4 mm, and the special alloy construction features a TCR of ±100 ppm/°C. *(Courtesy of TT Electronics)*

self-heating, which means the selected resistor type must have a suitable power rating, and it must be derated at higher temperatures.

Also, any self-heating will cause the resistor to drift from its nominal value. How much it drifts depends on the material and construction of the sense resistor. A standard chip resistor has a temperature coefficient of resistance (TCR) of about ±500 ppm/°C (equal to 0.05%/°C), while standard sense resistors fabricated with special material and construction techniques are available with TCRs of ±100 ppm/°C, down to about ±20 ppm/°C. There are even precision-performance units offered (at a much-higher cost) down to ±1 ppm/°C.

Note that using a snip of copper wire or PC-board track might seem like a good way to get a milliohm-valued sense resistor at nearly zero cost. However, the TCR of copper is around 4000 ppm/°C (0.4%/°C), which is orders of magnitude inferior to a low-TCR sense resistor.

In some cases, a viable tactic for reducing the temperature rise due to self-heating is to use a larger-wattage, which will be less affected by self-heating. But these, too, have a somewhat higher component cost and larger footprint. The designer must do a careful analysis of the current, the dissipation, the effects of TCR, and any derating needed for long-term reliability and performance.

MECHANICAL CONSIDERATIONS

At very low current levels, the physical size of the current-sense resistor is about the same as other resistors. But physically larger resistors are needed as wattage rating increases, and this will have an impact on both PC-board layout—assuming the resistor is board-mounted—and the thermal situation of the both the resistor and its surroundings.

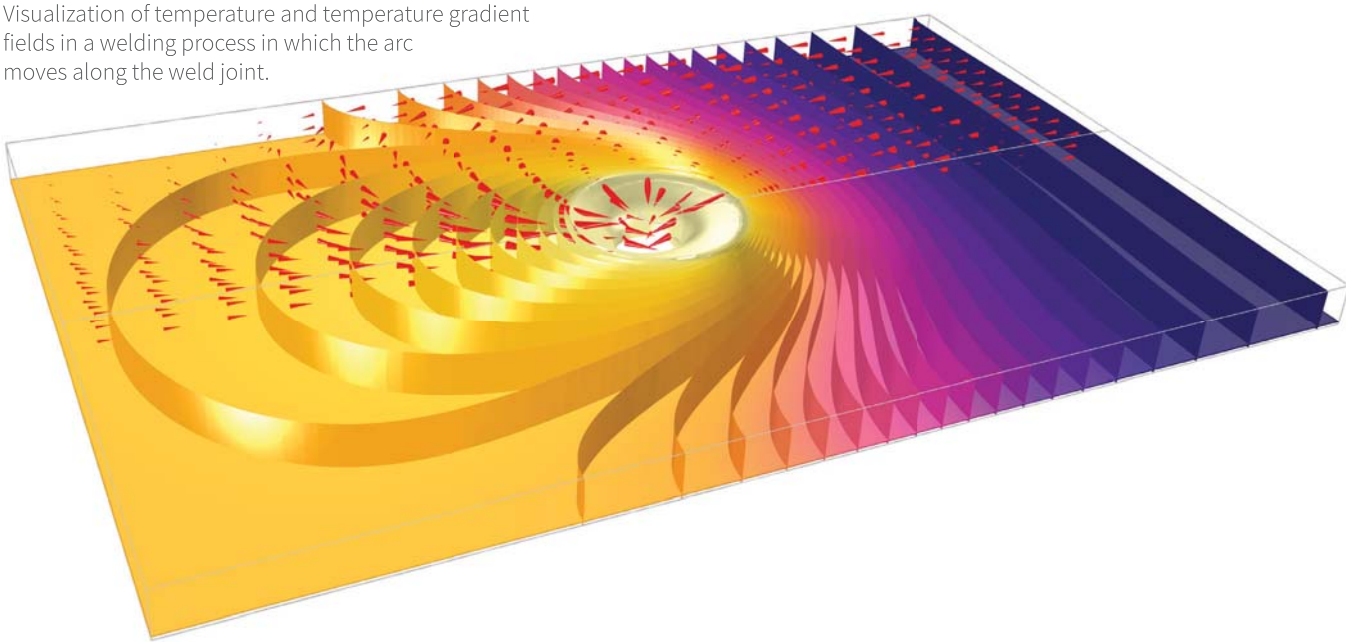
For the higher-rated resistors, placement and mounting becomes a serious issue; PC-board surface mounting may not be an option; and real estate and thermal issues increase significantly. Larger units may even need mounting brackets or hold-downs to keep motion and vibration effects down to an acceptable minimum.

The difficulty of making the "simple" electrical connections shouldn't be overlooked either. When wires are carrying tens or even hundreds of amps, the connections between those wires and the resistor's terminations need careful planning and larger, more rugged surfaces, which, of course, may include screws and clamps. Just think of the typical internal-combustion car battery that must deliver over 100 A to start the car, from a modest 12-V battery. Even 100-mΩ contact resistance at the battery plus terminal translates to a supply loss of 1.2 V, in a scenario where there isn't much voltage headroom.

In addition, even though the sensed voltage is low, the common-mode voltage may not be low, and the connections may be carrying high currents. As a result, there are safety and access issues that will affect cabling, routing, possible short circuits, and accessibility. Further, the designer must plan where and how to connect the relatively thin-gauge voltage-sensing wires to the contacts that also carry the higher load current. Resistance of the sensing-wire contacts may look like resistance that's part of the sense resistor itself, and so the I = V/R calculations need to factor in this additional resistance. Even the TCR of any contacts can also be an issue in higher-accuracy situations.

Using a resistor for current sensing is a very educational example of the challenges of going from a solution that's very simple in principle, to one which works, works well, and works over the range of expected operating conditions of the application. Fortunately, it's also a solution that's used extensively, so many of the issues can be resolved by leveraging the experience of application engineers from resistor vendors or experts in high-current sensing.

Visualization of temperature and temperature gradient fields in a welding process in which the arc moves along the weld joint.



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MULTIPHYSICS MODELING OF A WELDING PROCESS

If you want to learn about the multiphysics modeling of a welding process, then tune into this webinar featuring guest speaker Stuart Brown of Veryst Engineering.

Modeling a complex thermomechanical process, such as welding, requires the inclusion of several coupled physics phenomena.

This webinar describes how multiphysics modeling enabled a simulation of a valve welding process, which was needed to determine how a toxic leak developed. The numerical simulation allowed a rapid bounding analysis of the welding process and generated heat that affected the polymeric seals. The simulation included the physical processes of the deposition of weld metal, melting of the base metal, radiative heating due to the high-temperature plasma arc, and heat of fusion of the solidifying weld as well as tracing the weld path at different amounts of material deposition and sizes of fusion zone.

During the webinar, we will show how to create the model in the COMSOL Multiphysics® software, describe the actual toxic release event, and discuss the testing that was done to correlate with the numerical simulation results. The webinar will conclude with a Q&A session.

SPEAKERS:

Stuart Brown, *Veryst Engineering*

Dr. Stuart Brown is the managing partner of Veryst Engineering®, LLC, an engineering consulting firm located in the Boston area. Veryst provides services in product design, manufacturing processes, and failure analysis. Dr. Brown's technical background includes mechanical engineering and materials science. He has consulted in manufacturing processes including metal and polymer manufacturing processes, semisolid materials, extrusion, powder metallurgy, drawing, forging, welding, and cold and hot rolling; using engineering analysis; computational modeling; experimentation; and materials characterization. He also has extensive research and development experience in thin films and microelectromechanical systems (MEMS). Prior to founding Veryst Engineering, Dr. Brown was the director of the Boston office of Exponent, Inc. Before Exponent, Dr. Brown was on the faculty of the Department of Materials Science and Engineering at MIT.

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Nicolas Huc, *COMSOL*

Nicolas Huc joined COMSOL France in 2004 and is currently the head of their development team. He is also the manager of the Heat Transfer Module. Nicolas studied engineering at ENSIMAG before receiving his PhD in living system modeling from Joseph Fourier University.

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VOLKER E. GOLLER | Systems Applications Engineer, Analog Devices Inc.
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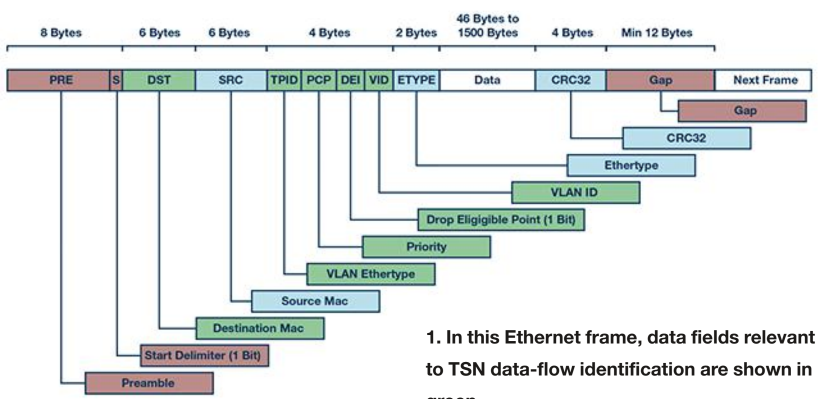
What's the Difference Between Ethernet and Time-Sensitive Networking?

Though its exact format for widespread use needs to be ironed out, TSN is primed to take over for standard Ethernet in industrial settings due to its superiority in terms of latency.

These days, anyone working in industrial communications is bound to come up against the topic of time-sensitive networking (TSN). TSN will definitely get here. The only thing that still must be clarified is when and in what form. However, even today, the its advantages for industrial communications aren't always clear.



1. In this Ethernet frame, data fields relevant to TSN data-flow identification are shown in green.

HISTORY

Ethernet was introduced to offices in the early 1980s and quickly became very popular due to its high throughput of (at that time) a sensational 10 Mb/s. However, this Ethernet wasn't practical for real-time applications because it used a common medium known as a party line. Collisions occurring at high utilization rates caused problems in office settings.

In the next step of its development, collisions were eliminated through the introduction of switched networks. In addition, with quality of service (QoS), Ethernet datagram prioritization was introduced *(Fig. 1)*.

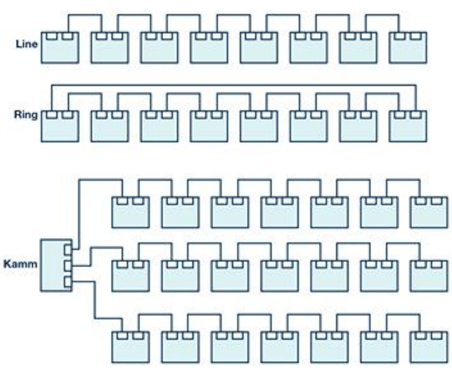
For industrial applications, guaranteed latency is particularly important. Despite QoS, standard Ethernet as used in offices can only guarantee latencies up to a certain point, especially with high network utilization.

There are several reasons for this, with the main issues being the store-and-forward strategy commonly used in commercial multiport switches and the fact that it's impossible to reserve bandwidth.

Store and forward means that a switch receives a complete datagram before forwarding it. This has advantages in terms of processing in the switch, but it also brings potential problems that can negatively impact latency and reliability:

- When going through a switch, a datagram is delayed by an amount depending on its length. If switches are cascaded, the effect is magnified.
- Because a switch doesn't have an infinite storage capacity, it can reject datagrams if the network is experiencing overutilization (too much traffic); this means that datagrams—even those given higher priority—can simply be lost.
- Long datagrams can block a port for relatively long times.

Switch cascading posed a challenge in industrial environments right from the start. Apart from the star topology used in the IT field, line, ring, and tree topologies are frequently used in automation *(Fig. 2)*. These adapted topologies significantly reduce Ethernet installation wiring requirements and costs. Hence, in industry, two-port switches employing a cut-through strategy are integrated into field devices. Cut-through means that datagrams are forwarded before being completely received.



2. Among the frequently used topologies in automation are line and ring.

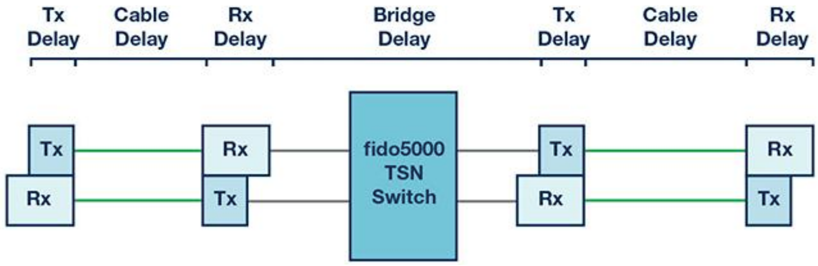
ONE SIZE FITS IT ALL: INDUSTRIAL ETHERNET UP TO NOW

Because classic Ethernet did not have sufficient capabilities for bandwidth reservation, automation experts began developing their own Ethernet extensions in 2000. However, the paths they took differed greatly. Differentiation is made between the following approaches:

- Protocols using Ethernet as a transport medium for a fieldbus. These protocols claim complete control over the Ethernet medium for themselves. Classic TCP/IP communications are only possible in piggyback style via the fieldbus (EtherCAT and POWERLINK) or through a channel assigned by the fieldbus (Sercos). Bandwidth control is firmly in the hands of the fieldbus.

- Protocols that guarantee bandwidth reservation through a time slicing procedure on the Ethernet *(Fig. 3)*. PROFINET IRT should be mentioned here. IRT enables hard deterministic real-time data transmission on the same cable on which soft real-time or background traffic is operated. A precise timing model for the transmission paths is necessary for planning of the time slices.
- Protocols based on sharing of the Ethernet cable. These protocols use QoS and are at home in factory- and process-automation applications. PROFINET RT and EtherNet/IP are noteworthy examples. These protocols are limited to the range of soft real time (cycle time ≥ 1 ms).

For these standards, special hardware support and, thus, special ASICs are needed. Because PROFINET RT and EtherNet/IP are also based on the embedded two-port switch with cut-through, they're also not exempt here.



3. PHYs, cables, and switches contribute to delays in data transmission. This must be considered with the time slot method (PROFINET IRT and TSN time aware shaper (TAS).

ENTER TSN

With TSN, extensions for standard Ethernet in accordance with IEEE 802.1 that break free of past limitations have successfully been developed. Thus, there's now a standardized layer 2 in the ISO 7-layer model with upward compatibility to the previous Ethernet and hard real-time capability. With 802.1AS-rev, TSN also defines an interoperable, uniform method for synchronizing distributed clocks in the network.

Because best effort communication always takes place with TSN, the common use of a cable is possible for hard real-time applications, as well as all other applications (web server, SSH, etc.). TSN is not dissimilar to PROFINET IRT

in that regard, and it offers comparable performance.

What's new with TSN is the need for more extensive network configuration. Centralized or decentralized configuration is possible. Both types of configuration are currently being discussed and implemented. Interoperability between the two configuration mechanisms is a future development goal.

PRACTICAL ADVANTAGES

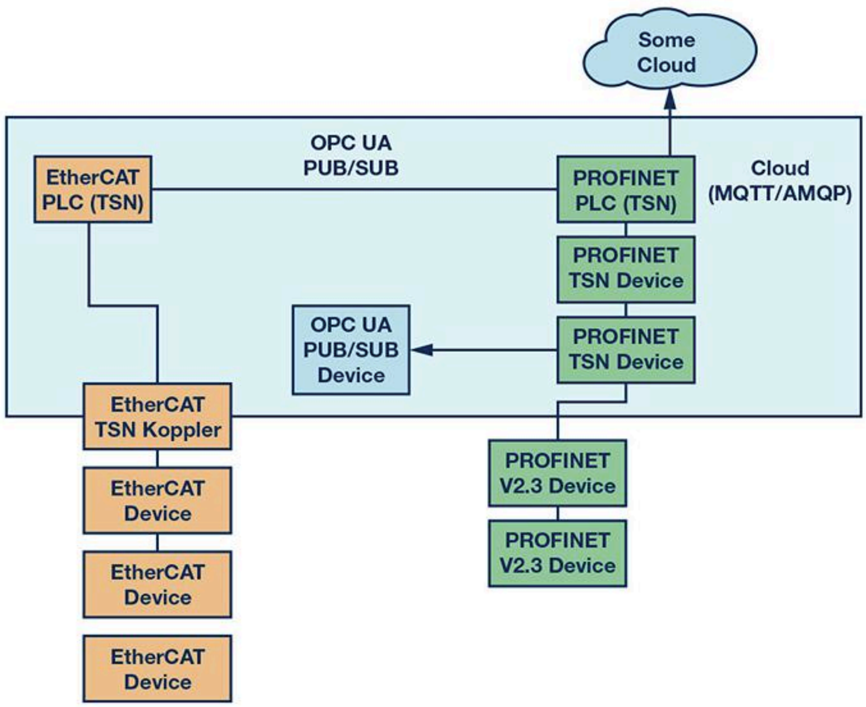
The most common answer is that with a larger market, less expensive network interfaces also appear on the market. After all, TSN will also be found in building automation and the automotive industry in the future. As a matter of fact, the market for embedded TSN solutions is expected to be significantly bigger than the current market for all industrial Ethernet solutions put together.

The greatest technical advantage of TSN over previous industrial Ethernet methods is its scalability. Unlike current industrial networks, TSN was not defined for a specific transmission rate. TSN can be used for 100 Mb/s just as for 1 Gb/s, 10 Mb/s, or 5 Gb/s.

It also enables topologies to be better optimized because now adapted data rates can be selected for various segments. Whether it's Gb/s, 100 Mb/s, or 10 Mb/s, a unified layer 2—IEEE802.1/TSN—is used.

A uniform network infrastructure also helps personnel tasked with setting up and maintaining the network. That's because, thanks to TSN, solutions can now be used in sectors other than automation: building, process, and factory automation, as well as energy distribution.

This prompts the next advantage—the training factor. TSN is already a topic at many universities, mostly in the research stage. However, technical and vocational colleges are already showing interest in this topic. It can



4. The TSN segment is combined with PROFINET and EtherCAT.

be safely said that TSN will become basic knowledge for engineers, technicians, and skilled workers. Retraining for different fieldbuses will no longer be necessary.

BROWNFIELD, OR WHAT WILL HAPPEN TO TODAY'S PROTOCOLS?

In nearly all TSN-related working groups, there's recurring theme: How to safeguard the transition to TSN and the supply to existing installations, such as Brownfield applications?

On all sides, emphasis is being placed on making it possible for customers to easily and smoothly transition to TSN. It can already be said today that the existing industrial Ethernet protocols aren't just going to vanish overnight. On the contrary, anyone using PROFINET, EtherNet/IP, EtherCAT, or a similarly widespread industrial Ethernet protocol today can safely assume that he or she will also be able to operate networks with these protocols— and receive support and replacement parts—in 10 years' time.

All industrial Ethernet organizations provide models that describe how existing plants can cooperate with new TSN-based devices. The interface to the existing industrial network is made by a gateway (Sercos), with a coupler (EtherCAT), or without any special hardware (PROFINET RT) *(Fig. 4)*. In particular, PROFINET and EtherNet/IP plan to make their complete protocols available right on TSN as layer 2. This makes stepwise transition to TSN possible.

CONCLUSION

TSN will be found everywhere in new installations, as well as in the form of islands or segments introduced incrementally into existing installations.

However, with TSN, there will be new players in the industrial Ethernet field. OPC UA with new transport protocol PUB/SUB, in conjunction with TSN, is already a competitor to classic protocols. For the manufacturers of field devices, this means that the classic industrial Ethernet solutions, as well as TSN and the new players, must be supported. ed

VOLKER E. Goller, a systems applications engineer with Analog Devices, has over 30 years of experience with a diverse set of industrial applications ranging from complex motion control and embedded sensors to time-sensitive-networking technology. A software developer by trade, Volker has developed a wide variety of communication protocols and stacks for wireless and wired applications while actively engaging in fielding new communication standards through his involvement with leading industry organizations. He can be reached at volker.goller@analog.com.

PAUL RAKO | Contributing Editor

What's All This LM331 Stuff, Anyhow?

The classic LM331 can be a great learning tool when it comes to voltage-to-frequency conversion—one of main pillars of analog design.

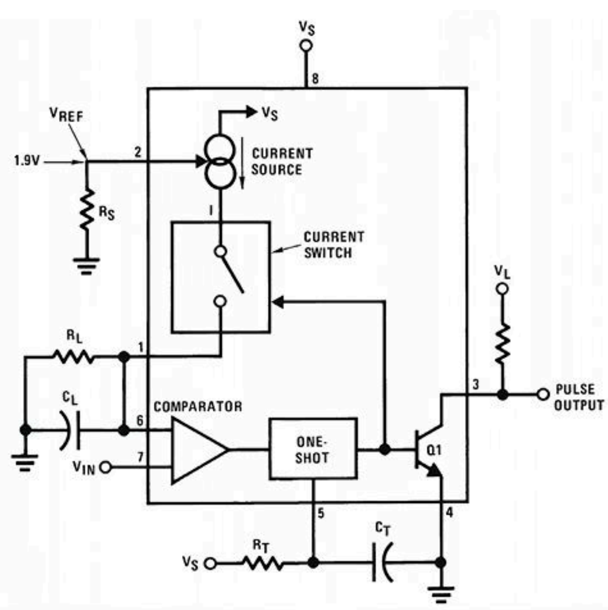
Bob Pease had a special love for voltage-to-frequency converter circuitry. I did a vamp on his writing in an article of my own. If you want to measure a voltage in a remote location, it might be easier to send a series of pulses over a long wire, rather than send the voltage itself. The pulses are more resistant to noise, and you can clean the noise out of the pulse signal easier than try to reject noise out of a pure analog voltage. V-to-F circuits also have great dynamic range and will work over several decades of frequency.

Measuring a pulse-train frequency just requires a microcontroller or logic circuit using a cheap accurate crystal. That can be more cost-effective than measuring a voltage, where you need an accurate reference chip.

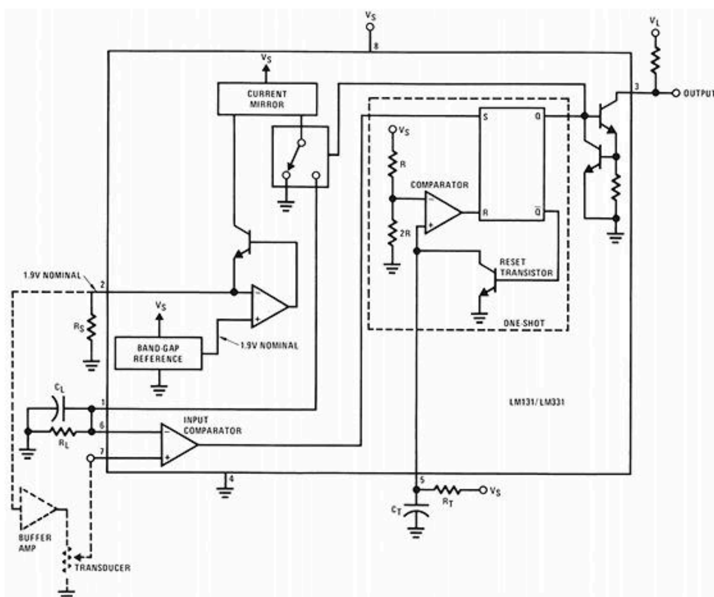
Still, your system might have an accurate reference anyway. When I designed automotive diagnostic equipment at HP, I noted that, "You need a rock and a ref." This was a jaunty shorthand to say you needed a quartz crystal oscillator for accurate time, and a good reference to measure voltage. With those two, you can derive current, and power, and most of whatever else you want to measure. In a way, using a V-to-F converter means you're pushing the reference requirement to the sensing chip. If you can develop an accurate V-to-F circuit, then you don't need a separate reference chip.

Saying the V-to-F has great dynamic range is a way of saying the output is very linear. It's accurate over a wide range of input voltages and output frequencies. That's a great deal, compared to the headaches of ensuring a sampled data system remains accurate no matter the range of the input voltage. Once you add attenuation and range amplifiers to a system, things get pretty difficult and complicated.

I tried to use analog switches to make an attenuator in that HP diagnostic equipment I worked on. I had all kinds of problems with stray capacitance and accuracy issues, so I called Jim

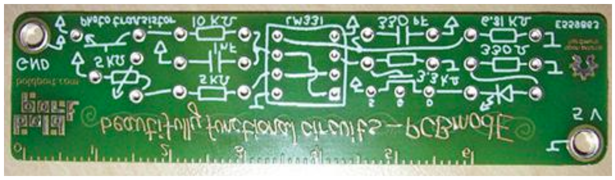


1. The block diagram of the LM331 represents a relaxation oscillator that will change frequency with input voltage. The output is a pulse train, not a square wave; hence the one-shot. *(Courtesy of Texas Instruments)*



2. A more detailed block diagram of the LM331 reveals the R-S flip-flop, the internal bandgap voltage reference, and a current mirror. The bandgap output voltage is available on pin 2, which you also use to set the internal current mirror with a load resistor. *(Courtesy of Texas Instruments)*

Williams at Linear Technology, now part of Analog Devices. He asked what I heard when I changed the vertical range on my Tektronix scope. I said that I heard relays clicking. Williams said they used relays since doing a solid-state attenuator is nearly impossible for high frequencies and voltages. Using a V-to-F converter might save you all of these headaches.



3. The folks at Boldport make a nifty kit based on a Pease application circuit in the LM331 datasheet.

THE LM331 AND V-TO-F

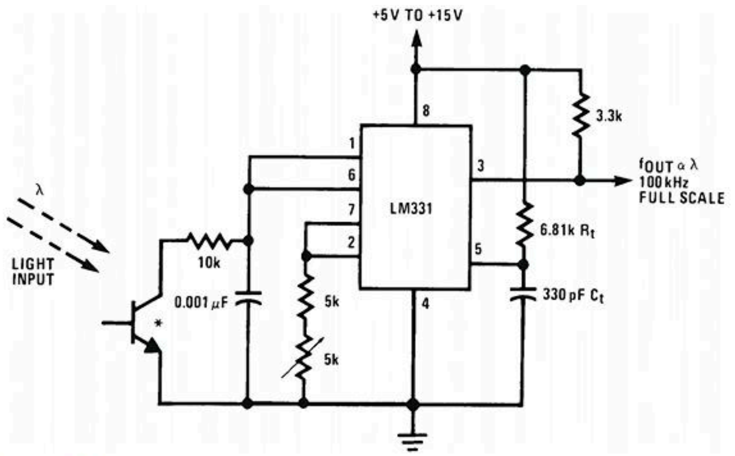
To understand V-to-F conversion, the LM331 datasheet is a great place to start. The applications section was written by Pease. Several application notes published by Texas Instruments were most likely also written by Pease. These notes are all linked to on the LM331 product page. The fundamental app note, "Versatile Monolithic V/Fs can Compute as Well as Convert With High Accuracy," was released in 1980, at the same time as the part. The app note shows both a simple and detailed block diagram of the part *(Figs. 1 and 2)*.

You can also use the LM331 to make a frequency-to-voltage converter. The app note "Frequency-to-Voltage Converter Uses Sample-and-Hold to Improve Response and Ripple" shows how to remove the output ripple from the circuit while still keeping a speedy response time. You can think of it as a form of synchronous demodulation. It samples the output voltage at the same point in the ripple waveform. This note builds on the basic F-to-V app note, "V/F Converter ICs Handle Frequency-to-Voltage Needs."

Another vamp on the basic V-to-F converter is the current-to-frequency converter. There's another nice app note for that, "Wide-Range Current-to-Frequency Converters." The app note describes ways to build on the inherent wide dynamic range of the LM331 to make circuits that can work down to picoamperes of input current. While you have to add a lot of circuity to get that performance, it's a testament to the versatility of the LM331.

Going through the drawers of my home lab bench, I uncovered an LM331 voltage-to-frequency IC demo board given to me by the folks at Boldport *(Fig. 3)*. Dr. Saar Drimer, the electronic artist behind Boldport, packages the board in a handy kit that you can order from his website. The kit has a Bob Pease quote "My favorite programming language is solder." The kit is based on Figure 20 from the LM331 datasheet *(Fig. 4)*.

Drimer added an output LED so that you can see the output frequency change. Another difference is that while Pease called out a phototransistor, Drimer's kit uses a photo-conductive cell. Drimer also slowed down the frequency so that you can see the LED blink. Micah Scott has a video build of the kit, as does Lady-ada from Adafruit Industries.



*L14F-1, L14G-1 or L14H-1, photo transistor (General Electric Co.) or similar

4. This LM331 datasheet circuit is the basis for the Boldport kit. The kit substitutes a photocell for the photodiode, adds an output LED, and slows down the frequency so you can see the LED blink. (*Courtesy of Texas Instruments*)

5. Here's one of Jim Williams' working electronic art pieces from the book put together by his friend Len Sherman. It's as if a Digi-Key truck hit an Alexander Calder sculpture. *(Courtesy of Len Sherman)*

THE ART OF THE SCIENCE

Most of us have heard about STEM (science, technology, engineering, and math). I first heard the term "STEAM" from my pals at Evil Mad Scientist. The added "A" stands for "art." Boldport is an advocate of the artistic side of engineering, as evidenced by the whimsical traces on the LM331 Pease PCB (printed circuit board). While the artistic aspect of circuits seems to be blooming, it's nice to know that analog geniuses like Jim Williams used to make working sculptures out of electronic circuits decades ago. Williams' best friend, Len Sherman of Maxim Integrated, even made up a book of various Williams creations *(Fig. 5)*.

We analog folks also know there's art in the circuit theory and the mathematics that underlay the theory. It might be easier to buy a cheap microcontroller from Microchip, TI, or NXP than use an LM331. The thing is, the design and implementation of the LM331 is worth understanding just so you know the principles of analog design. While chips come and go, the principles of analog are timeless. ed

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ideas for design

Relay-Based ON/OFF Flip-Flop Remembers State During Power Failure

By TOMMY TYLER | Engineer, email: tomytyler@comcast.net

MANY VARIETIES OF ON/OFF control circuits use some form of flip-flop that responds to a pushbutton switch or other control input. These all have volatile memory and default to an OFF condition if power is turned off, and sometimes that's even the preferred situation. However, if your application must remember what it was doing when power failed and resume from where it left off when power is restored, you may have a problem.

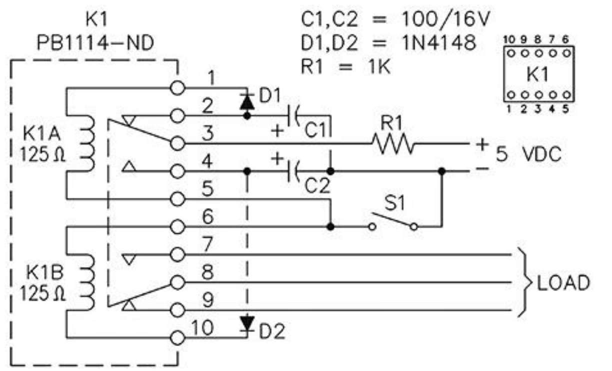
Here's a flip-flop circuit that remembers its state indefinitely when power is off. Furthermore, the circuit consumes no power at all, except for a brief instant when triggered from one state to the other. Thus, it's well-suited to battery power; a couple of lithium coin cells can provide years of battery life.

In the design *(Fig. 1),* K1 is a 5-V dc, dual-coil magnetic latching relay with DPDT contacts. If you search the various distributor offerings, there are about 70 different models of this type relay at coil voltages from 4.5 to 24 V dc, made by four manufacturers, and costing between $3 and $8 in single quantities. They are well built, sealed, very small, and typically have contacts rated for 2 A at up to 250 V ac.

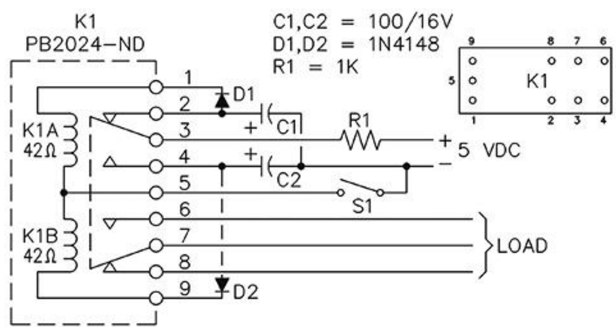
One set of contacts (pins 2, 3, and 4) are used to steer the flip-flop, and the other set (7, 8, and 9) are available for the end application. In the state shown, C1 has charged to 5 V through R1. Closing S1 discharges C1 through D1 to pulse the K1A coil, transferring the contacts. Then C2 charges through R1 to await the next closure of S1, which discharges C2 through D2 to pulse the K1B coil, returning the contacts to the original state.

This is not a high-speed circuit because of the setup time following a toggle. It was designed primarily for manual input and can toggle at least two times per second. Since power is applied to relay coils only briefly, the circuit tolerates overvoltage without harm, limited primarily by the capacitor voltage rating. When operated at 12 V dc, the circuit shown can toggle as fast as you can tap switch S1. On the other hand, if your application needs to restrict how fast something can be switched on and off, that can be easily limited by increasing the value of R1.

Component values are not very critical. C1 and C2 must store enough energy to pulse the relay, which has an operate time of 20 ms. R1 should be large enough that holding S1 closed does not allow capacitor voltage to rise above 10-20% of relay pull-in voltage.



1. This two-coil relay configuration provides a latching flip-flop action without active electronics and retains its state even after power is removed. Component values are not critical.



2. This modified version of the original circuit uses a larger center-tapped relay coil with four times the contact-current rating of the two-coil relay approach.

If you need more switching power than 2 A, *Figure 2* shows the circuit adapted to a relay that's four times bulkier and costs twice as much, but has contacts rated for 8 A at 250 V ac. This relay has a center-tapped coil instead of two separate coils, so the pin-out is different and the circuit must be modified slightly.

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Retrofitting Secure Storage

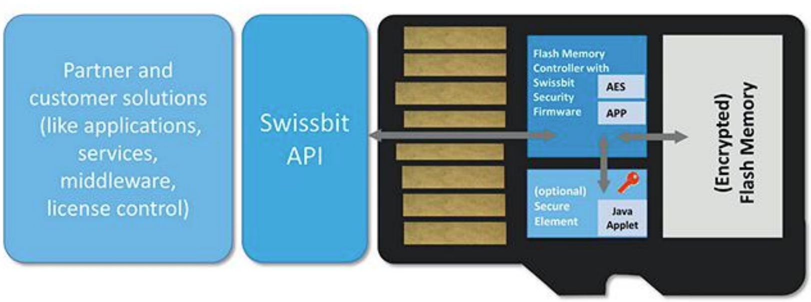
Protecting data from corruption, attack, and errors can be done using simple storage managed by software that takes these issues into account and incorporates features and methodologies to mitigate these problems. Sometimes these features are included in hardware, such as self-encrypting drives (SEDs) that encrypt and decrypt data once the drive is unlocked. Unfortunately, SEDs need additional, albeit minimal, software interaction to operate.

Swissbit's line of flash storage devices incorporates a number of useful security and reliability features, including the industrial data-protection (DP) edition *(see figure)*. The DP edition implements these features by putting a secure microcontroller between the host and storage. As a result, different features can be utilized by an application, often without requiring software modification.

For example, the CD-ROM-style write-once read-many (WORM) operation allows an application to append new data, but not modify existing information. In turn, a DP SD card can be utilized by a system that already writes its data or log to an SD card, but it now becomes impossible to change what was written. This assumes the application doesn't need to update anything, such as a directory entry.

A more advanced methodology can take advantage of the AES encryption support that can encrypt the data as it's written. A key and software to enable decryption can be used on another system when the SD card is moved to it, allowing the data to be examined. Such capability is useful in many accounting applications from voting machines to cash registers. Again, the software creating the log must not need to examine it, although it could read and transmit the encrypted data that could then be decrypted.

Swissbit's solution is configurable and supports additional features like PIN-protected storage and its own nonvolatile RAM (NVRAM) secure storage for keys. The approach used by the company can support features like secure update, since it's able to authenticate information written to its storage and only allow authenticated data to be utilized. This requires configuring the storage media and providing encrypted data, but it can be done transparently to the application using the storage device.



Swissbit's data-protection technology adds smart, secure storage management that can be transparent to existing applications.

Developers can take advantage of Swissbit's products, though the idea of providing an intelligent front end to storage isn't new. However, that task does tend to be overlooked.

Protection of serial nonvolatile storage is available from other vendors as well. Macronix has a password-protected SPI flash memory—protected blocks can only be written using the proper password. This allows secure-boot features to be incorporated into a system that boots from SPI storage.

By swapping an existing SPI or I^2C memory device for a secure device like Microchip's CryptoMemory, it's possible to modify an application so that it can take advantage of the chip's secure storage and authentication/encryption hardware. It's not as transparent as some of the earlier approaches, but can be incorporated often with minimal software modification.

Another option is to replace a serial flash storage device with a microcontroller. This is a bit more complex and overkill for many applications, but it's one way to retrofit custom security support similar functions found in Swissbit's solution. It may also offer other possibilities in terms of providing custom functionality.

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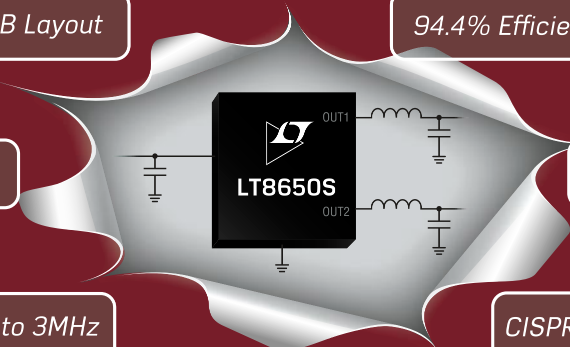

Part Number	V_{IN} Range (V)	I_{OUT} (A)	$V_{OUT(MIN)}$ (V)	Frequency	I_Q (µA)	Package
LT8609S	3.0 to 42	2A/3A Peak	0.8	200kHz to 2.2MHz	2.5	3x3 LQFN-16
LT8640S	3.4 to 65	6A/7A Peak	0.97	200kHz to 3MHz	2.5	4x4 LQFN-24
LT8643S	3.4 to 42	6A/7A Peak	0.97	200kHz to 3MHz	170	4x4 LQFN-24
LT8653S	3.0 to 42	2x2A/3A Peak	0.8	300kHz to 3MHz	6	3x4 LQFN-20
LT8650S	3.0 to 42	2x4A/6A Peak	0.8	200kHz to 3MHz	6.2	4x6 LQFN-32
LT8645S	3.4 to 65	8A	0.8	200kHz to 3MHz	2.5	4x6 LQFN-32
LT8642S	3.0 to 18	10A	0.8	200kHz to 3MHz	160	4x4 LQFN-24
LT8652S	3.0 to 18	2x9A	0.8	300kHz to 3MHz	20	4x7 LQFN-36

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