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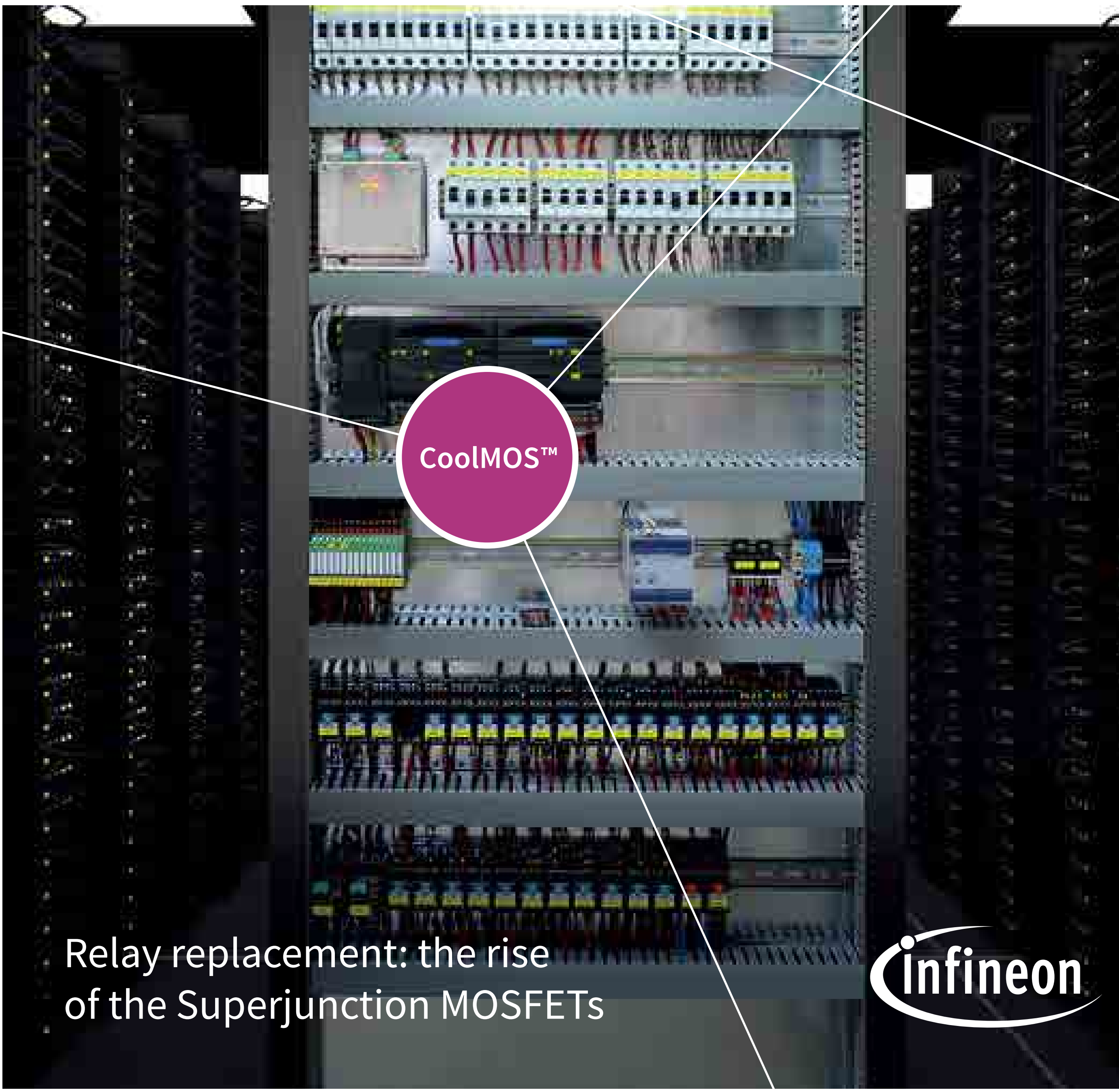

Special Report: IoT + Wearables (pg 31)

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Visit us online for exclusive content; Industry News, Products, Reviews, and full PSD archives and back issues

2 **VIEWpoint**
Connecting Everything with Everything
By Jason Lomberg, North American Editor, PSD

3 **MARKETwatch**
Are Data & Metrics Good for IoT and Wearables?
By Kevin Parmenter, Field Applications Manager, Taiwan Semiconductor

13 **RF Power**
Pick a Plug 'n' Play Linearizer for Your 5G RF Power Amplifier
By Thomas Maudoux & Michael Jackson, Maxim Integrated

20 **Wide-Bandgap Semis**
GaN in Space
By: Steve Taranovich, Eta Kappa Nu Member and an IEEE Life Senior Member

COVER STORY

4 **Moving from Electromechanical to Solid-State in Relays and Circuit Breakers**
By Giovanbattista Mattiussi, Product Marketing Manager, Infineon Technologies

TECHNICAL FEATURES

8 **Energy Efficiency**
Super Barrier Rectifiers Deliver Design-Free Efficiency
By Shane Timmons, Product Marketing Manager, Diodes Incorporated

12 **Power Supplies**
Adjustable Power Supplies Based on the Common Buck Converter
By Victor Khasiev, Senior Applications Engineer, Analog Devices

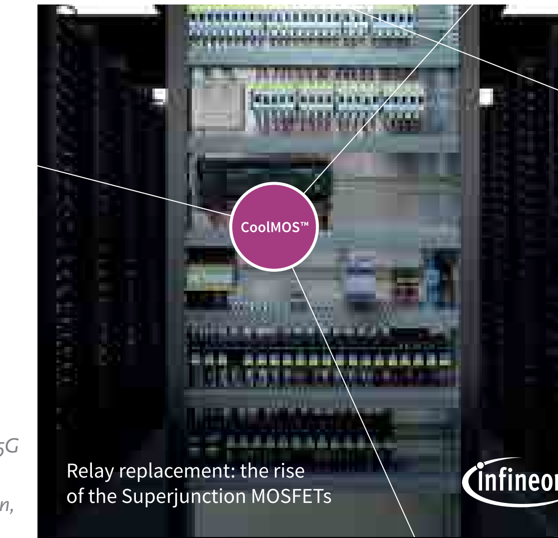
SPECIAL REPORT:
IoT + WEARABLES

32 **Powering Advanced Healthcare Devices**
By Tony Armstrong, Analog Devices Inc.

36 **Mobile Diagnostic Technology Can Deliver Hypertension Screening**
By Dr Chris Elliott FREng, Leman Micro Devices SA

40 **Power Requirements of Biosensor-Based Wearables**
By Rakesh Sethi, Vice President, General Manager R&D, TDK U.S.A. Corporation

43 **Protecting Manufacturers Appliance Products from Cyberattacks**
By Alan Grau, VP of IoT, Embedded Systems, Sectigo



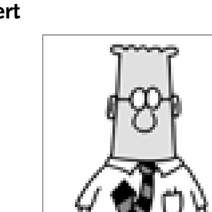
COVER STORY
Moving from Electromechanical to Solid-State in Relays and Circuit Breakers (pg 4)

Highlighted Products News, Industry News and more web-only content, to:
www.powersystemsdesign.com

47 **Augmented Reality and the Internet of Things (IoT): Connecting to Circuit Protection**
By James Colby, Manager of Business Development, Littelfuse, Inc.

52 **FINALthought**
Defining the Internet of Things
By Jason Lomberg, North American Editor, PSD

52 **Dilbert**



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Volume 11, Issue 9

Connecting Everything with Everything

This month's Internet of Things topic is a great segue into December's automotive focus. Few sectors benefit more from the IoT than transportation. But in truth, the IoT will affect nearly everything we do – hence the IoT's nom de plume, the Internet of Everything.

And not surprisingly, this month's contributors approach the IoT from very different perspectives.

If the automotive space is the most financially lucrative beneficiary of the IoT, the medical segment is arguably the most beneficial to humanity at large. The ability for everything to network with everything could have profound ramifications for early detection of disease, and nowhere is that more apparent than the boom in medical wearables.

Rakesh Sethi, with TDK, discusses these devices (and tips for extending their battery life) with "Power Requirements of Biosensor-based Wearables."

As Sethi mentions, wireless medical devices are part of the broader adoption of telemedicine, but if these wearables are to serve the greater cause of disease prevention and diagnostics or take part in clinical trials, they have to "provide uninterrupted data beyond what is the current, typical battery life for wearables operating in pulse detection mode."

Thus, power – as in most areas – is absolutely paramount.

"The current power design challenge of achieving a minimum two-week life span for 50mAh to 200mAh battery-based devices with pulse-measuring capability is daunting," Sethi says.

Of course, the most obvious problem with literally connecting everything with everything is the formidable cyber risk, and Sectigo's Alan Grau addresses "How Manufacturers Can Protect Their Appliance Products from Cyberattacks."

If our relatively primitive computer networks present an irresistible target for hackers, imagine the danger when every appliance, wearable, home, and car is intertwined in one global web. Grau notes that most in-home appliances cannot be fixed once they are infected – botnet attacks "target any connected appliances and small IoT devices within a home or a business," and these cyber assaults can scale up to shut down a nation's power grid.

One of the coolest new technologies – that'll receive a huge facelift from the IoT – is augmented reality.

James Colby, with Littelfuse, covers that and more with "Augmented Reality and the Internet of Things (IoT): Connecting to Circuit Protection."

An AR system that's, no pun intended, augmented with the IoT, could bring navigation, facial recognition, fitness tracking, first-person photos and videos, health-sensing, and travel applications into our lives in a way that's more seamless than we ever thought possible.

Best Regards,

Jason Lomberg
North American Editor, PSD

Are Data & Metrics Good for IoT and Wearables?

By: Kevin Parmenter, Field Applications Manager, Taiwan Semiconductor

There are now more things online than people. How much water does an individual appliance or shower use? Why was the water bill so high? Home water usage used to be just whatever the water company main meter says it is. I just saw a promotion for a smart IoT enabled point of use real time water meter. This is a connected smart home IoT device that learns and reports your water usage habits and provides helpful advice. It also catches those elusive leaks in toilet valves etc. There are similar devices for your electric service.

Now everything including your car, everything you own use or wear can have an IP address and or wireless connection to feed big data back to a server.

This is driving advancements in miniaturization of packages, batteries technology that can last decades, wireless charging, semiconductor devices which consume less energy than ever before so they can run from almost nothing and energy harvesting technology to scavenge energy to power devices.

The business opportunity is of course monitoring trends, monitoring you and getting more data on you that can be sold i.e. monetizing you and your behavior. The question, who owns the data – your data? Wearables including smart watches, smart clothing and just another name for wearable IoT devices of all sorts – the goal is the same, give the end user benefit and monitor and monetize you and your info what do we do with all the data collected on stuff and us?

In a recent Harvard Business Review article titled, "Don't Let Metrics Undermine Your Business". https://hbr.org/2019/09/dont-let-metrics-undermine-your-business

Here are the high priests of metrics on top of analytics fed to SAP, Oracle and Microsoft.

Aren't these the same guys whose disciples made everyone in the organization stop what they were doing and collect measure and analyze data while every other activity a customer could notice was less important?

"If we can't measure it, we can't manage it?" Wait, how did we run multibillion-dollar successful companies before this all existed? The article makes some good points yet I can't help but think that Harvard might be a bit like the firefighter that sets the fire so they can be heroes to put it out.

Never enough data –metrics. If we have all the data, why not let computers make the decision for free or maybe we can just talk to the customers?

So, speaking of common sense, and my overall point is just because I can give my toaster an IP address and command it verbally with my Google or Alexa echo connected device, should I?

Do we have the wisdom of what to do with all the data generated and what about rural areas with limited or no Internet connections? How will all this data be use and misused and hacked? What if the wearable products violate HIPAA rules on data security on your health. Data, data and metrics everywhere and not a drop to drink. The technology and capabilities astounding however, maybe a return to common sense might be in order. How about a course on that? Can we find anyone left to teach it?

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Moving from Electromechanical to Solid-State in Relays and Circuit Breakers

As a mature technology, however they continue to suffer from some inherent weaknesses

By: Giovanbattista Mattiussi, Product Marketing Manager, Infineon Technologies

As a mature technology, electromechanical relays and circuit breakers are well established, however they continue to suffer from some inherent weaknesses. Moving to solid-state technology can address these but introduces its own challenges. So, what is the right solution?

In the movies, whenever the lights go out or power is lost in a dramatic way, it is normally accompanied by a loud and helpful 'clunk' on the soundtrack, just so the viewer understands exactly what's happened. In general, that is an accurate representation because high-voltage relays and circuit breakers are still largely electromechanical in nature. Apart from the legacy associated with using electromechanical solutions, the prevailing opinion in the engineering domain is that semiconductor technology is inappropriate for high-voltage switching applications. However, recent technological developments are helping to change the facts that influence this impression, as we explain here.

Figure 1: Contact wear in an electromechanical relay (courtesy of Eaton Corporation)

Electromechanical versus solid-state

As a foundation for that explanation, it is worth reviewing what an electromechanical relay or circuit breaker is and how its solid-state counterpart is developing. The noise associated with an electromechanical solution comes from the physical nature of the relay; using electromagnetism to attract/repel metal contacts which move at speed.

The amount of mechanical movement involved could be seen as a point of failure and, in practice, it is, but the main point of fatigue will likely be the surfaces of the contacts, as the high voltages they pass can arc as they come into close proximity, jumping the airgap before full contact is made.

The same phenomenon is present when the contacts are forced open. The main point to appreciate here is that the voltage, whether AC or DC, is present at the contacts during actuation. If no provision for zero voltage switching (in the case of an AC voltage) is made, there will likely be arching every time the relay is activated. This can rapidly degrade the contacts and even cause them to fuse together. Even in less extreme cases, the resistance between the contacts is likely to increase over time and with use, causing their behaviour to become unpredictable.

Ultimately, the fatigue endured due to wear and usage is likely to lead to failure. This results in the manufacturer giving a finite lifetime for the device.

Similarly, an electromechanical relay can suffer from contact bounce, in the same way a low-voltage switch might. However, when switching high voltages, debounce is less easily implemented.

Solid-state switches, on the other hand, will often implement zero voltage switching to ensure the device starts conducting when the voltage (or current, which is likely to be out of phase with the voltage) is at its lowest. Even when working on DC voltages and currents, the switch-on time is more easily controlled with a solid-state switch. The aim here is to avoid inrush currents that may cause other systemic issues, but the net effect is the relay or circuit breaker is much more reliable over its entire lifetime which, incidentally, is likely to be much longer than an electromechanical alternative.

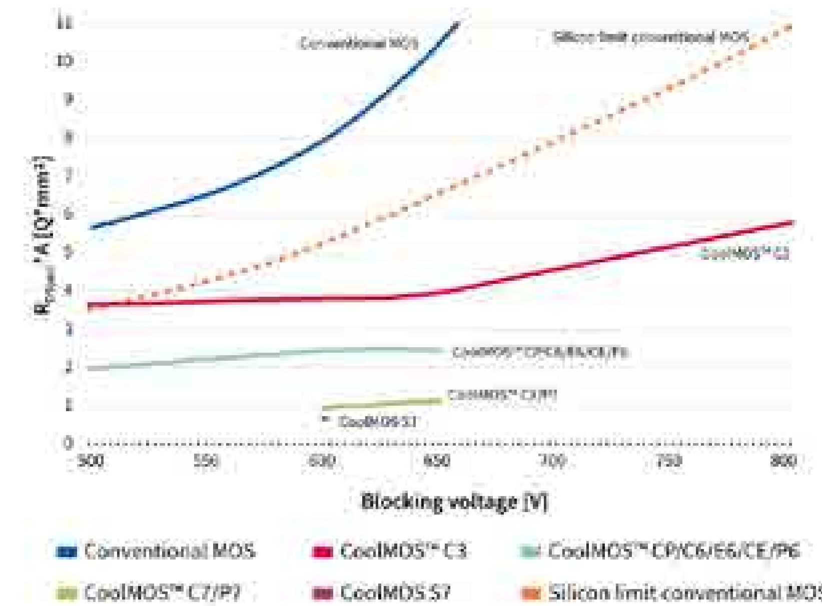


Figure 2: R_{DSon} x A improvement in Superjunction MOSFETs over time

There are good reasons why engineers still favour an electromechanical option and they are mainly related to cost, performance and functionality. In the case of cost, it is fair to say that a solid-state option will command a higher price than an electromechanical relay or circuit breaker, however when considered over the lifetime of the application and the Maintenance, Repair and Operations (MRO) cost associated with the function, an argument can be made for using solid-state. This is largely based on total system cost, weighed against the expected lifetime; an electromechanical relay may have an operational lifetime measured in the low hundreds of thousands of operations, while a solid-state relay's lifetime would be measured in the tens of millions.

Furthermore, the industry is approaching a point where it could offer price parity between the two technologies. While there is some innovation taking place with electromechanical designs, this is only helping to maintain the average selling price or, more realistically, increase it. Meanwhile, the average selling price of a solid-state solution is on a downward curve.

In terms of performance, the parameter that is most often cited is power loss due to the resistance of the conduction path. For an electromechanical device, this resistance will initially be low but inevitably increase over time, due to the reasons outlined above. For

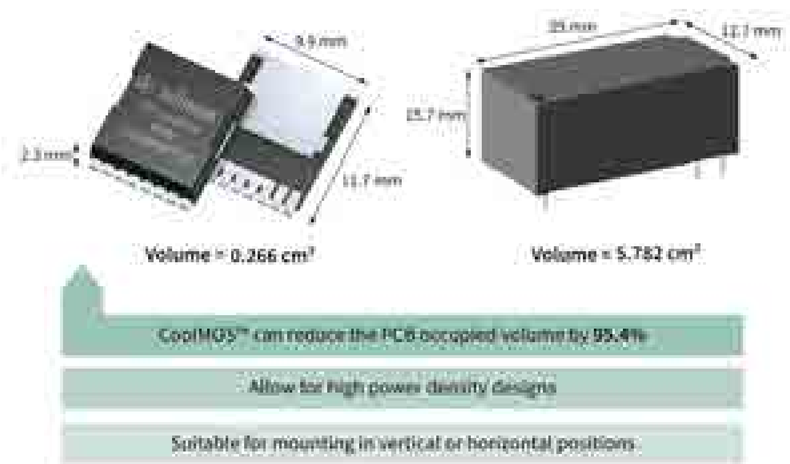


Figure 3: Solid-state relays provide significant reductions in volume

a solid-state solution, the power losses experienced are directly related to the on-resistance, which is defined by the type of semiconductor used and the size of the power transistor's channel; both these features influence the cost. While the on-resistance isn't subject to change over the lifetime of the device, it is finite and subject to the design requirements. Ideally, the conductions losses and the semiconductor cost should both be low, and can be summarised by the figure of merit, referred to as the on-resistance by area, or Rds(on) x A. This is a major focus for semiconductor manufacturers, and something Infineon has addressed through its CoolMOS™ technology platform, as explained in more detail in the next section.

An additional concern is safety. Solid-state solutions switch significantly faster than an electromechanical device, as there are no moving parts. While faster response times are clearly advantageous, this comes with the disadvantage of not having any physical disconnection between the input and output. In many applications where human contact with the machine is possible, safety regulations will specify galvanic insulation between the high-voltage input and the output.

Galvanic insulation is most frequently implemented as an airgap, or a physical space between conducting elements. This remains one area where solid-state technology is at a disadvantage, however it has given rise to the concept of the hybrid circuit breaker or relay, which uses a solid-state device to switch the high voltage and a smaller, lower cost electromechanical relay to provide the galvanic insulation at the output, which can be switched when no voltage is present, thereby extending its useful lifetime.

Of course, there are many applications that do not require galvanic insulation. Also, existing regulations applicable to circuit breakers still assume an electromechanical device is being used and so do not fully consider the superior performance that solid-state offers. Once the regulations catch up with technology, they may well become less stringent in terms of the galvanic insulation requirements, depending on the application

The rise of Superjunction MOSFETs

Solid-state switches are implemented using transistors realised using a semiconducting substrate. To date the most widely used substrate is silicon, but the transistor configurations vary. For AC switching, particularly when implementing zero voltage switching, the Triac (or silicon-controlled rectifier, SCR) is the favoured device. MOSFETs constructed in a planar topology are commonly used for switching DC voltages, while IGBTs can and are used for both AC and DC switches.

However, all of these approaches incur losses due to the on-resistance of the channel, as explained earlier. These losses manifest as unwanted heat which must be dissipated, and that invariably leads to the use of a heatsink, requiring more space and an increase to the Bill of Materials.

A Superjunction MOSFET goes beyond the planar – or 'flat – manufacturing process based on a single p-n junction, to a structure that features multiple, vertical p-n junctions. As a result, the on-resistance is 'shared' across multiple parallel paths, which has the effect of lowering the overall on-resistance. Infineon has been a pioneer of the Superjunction MOSFET since the 1990s and has continued to develop the technology over all that time. It offers significant benefits when compared to other transistor topologies, specifically in the area of on-resistance by area. This leads to commensurately lower losses, which means it not only becomes more affordable but also allows it to be used in applications that are switching higher voltages and current, without the need for heat dissipation.

With its CoolMOS™ 7 technology, Infineon is leading the R_{DSon} x A race. Infineon is also about to release a new technology – the CoolMOS™ S7* – which promises to deliver even lower R_{DSon} x A and to successfully trade off switching losses for lower on resistance. In solid-state relay and circuit breaker applications, this perfectly matches the performance to the requirements, as relays and circuit breakers are not required to switch at high frequencies.

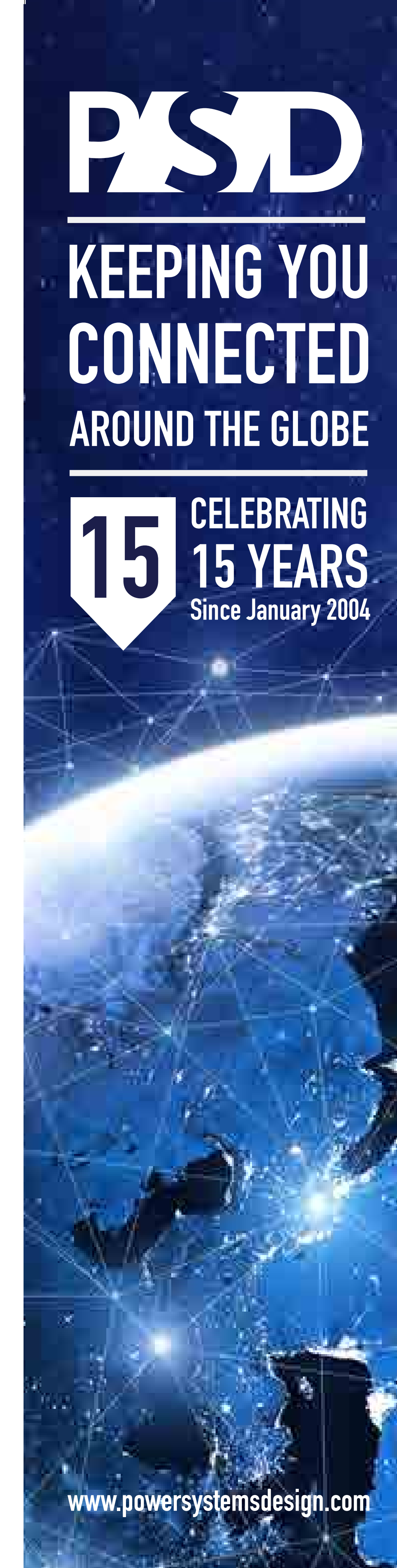
Conclusion

Using a solid-state device in a relay or hybrid circuit breaker has many benefits; it offers significantly faster switching times, eliminates arching and the noise associated with electromechanical devices, it is inherently more reliable and predictable, while delivering much longer lifetimes. Developments such as the CoolMOS™ 7 solution from Infineon are addressing the disadvantages that have traditionally limited its use.

The latest Superjunction MOSFET platform from Infineon is providing a breakthrough in solid-state relay and smart circuit breaker design. It offers an unprecedentedly low R_{DSon} x A figure of merit at a price point that will meet the needs of designers and their end markets. What's more, a solid-state relay will be far smaller than an electromechanical alternative, leading to a reduction in volume of over 95%.

Superjunction MOSFETs are just one example of the broad range of products Infineon offers, addressing the need for more innovation in the power domain. Solid-state relays and solid-state circuit breakers are becoming increasingly viable thanks to developments like CoolMOS ™ 7. Infineon has a long heritage of innovation and will continue to develop and deliver solutions that provide more for less.

Infineon Technologies
www.infineon.com/coolmos



Super Barrier Rectifiers Deliver Design-Free Efficiency

The Super Barrier Rectifier can be utilized in the same way as a Schottky diode while delivering significant and instant gains for a range of applications.

By: Shane Timmons, Product Marketing Manager, Diodes Incorporated

Successive generations of power-semiconductor devices based on existing technologies strive to deliver incremental improvements in energy efficiency. Now there is a device, realized through proprietary technology, that enables power supplies to achieve a significant leap forward in performance and efficiency—the Super Barrier Rectifier (SBR).

Maximising power efficiency has become a key concern for designers of almost all types of electrical and electronic systems, such as mobile and smart appliances, automotive electronics, building automation, and data centres. In addition to improving energy ratings, greater power efficiency can also allow simplified thermal management, reduced size and weight, and longer battery runtime.

Focus on Automotive Lighting
The automotive sector is experiencing a wholesale shift towards LED-based external lighting, not least because it can deliver a reduction in electrical power consumption in vehicles. With the increased awareness of the need for energy efficiency, hybrid and electronic vehicle characteristics as well as the subsequent link between electronic power and fuel economy--or driving range--is becoming more widely understood.

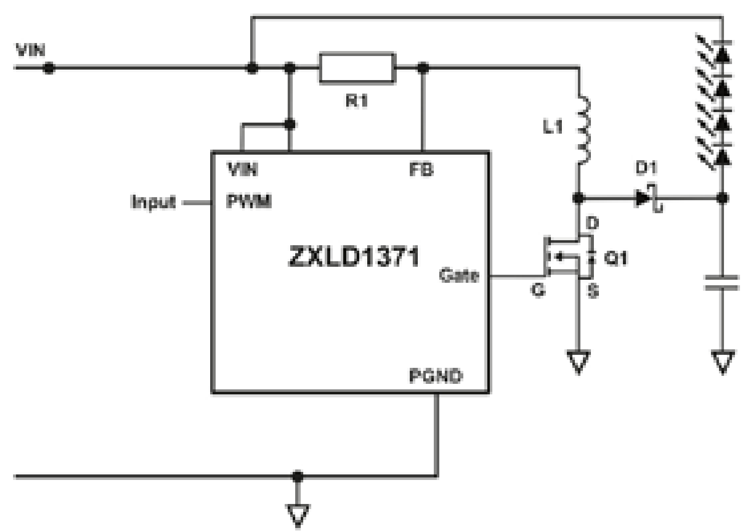


Figure 1: Simplified Schematic of Buck-Boost LED Driver for DRL Application

To encourage even wider market appeal, the industry is constantly seeking to further improve the efficiency of LED lighting systems and, in particular, Daytime Running Lamps (DRLs). As DRLs remain on continuously while the car is running, predominantly as a safety feature, they have also come to define the signature look of certain models and brands. As an 'always on' feature, one way to improve LED DRLs is to tackle the efficiency of power-conversion that takes place in the LED driver/controller circuitry.

A buck-boost topology is typically used in automotive applications to provide DC-DC conversion for various applications, including the drive voltage required for the LED string. **Figure 1** shows a simplified circuit featuring the ZXLD1371 buck-boost LED driver/controller from Diodes Incorporated. This is a generic circuit that normally contains a switching MOSFET (Q1) and a freewheeling diode (D1).

Because this is a boost converter, the peak current in the MOSFET and freewheeling diode is much greater than the average LED current, hence the conduction and switching losses of these two components can have a significant impact on the overall converter power consumption.

Historically, Schottky diodes have been selected as the most efficient option due to their lower forward voltage drop (V_F) and faster switching capability compared to conventional rectifier diodes; however, reverse leakage current is relatively high and increases with temperature.

While the Super Barrier Rectifier (SBR) behaves like a Schottky diode, the SBR delivers higher efficiency when used in switching converters, and although its construction means that the forward voltage and reverse recovery time are comparable, leakage current is much lower and more stable with increases in temperature. The avalanche capability is also significantly higher, leading to greater ruggedness. Table 1 compares the key parameters that govern freewheeling performance for an SBR and Schottky diode with similar reverse-voltage and current ratings.

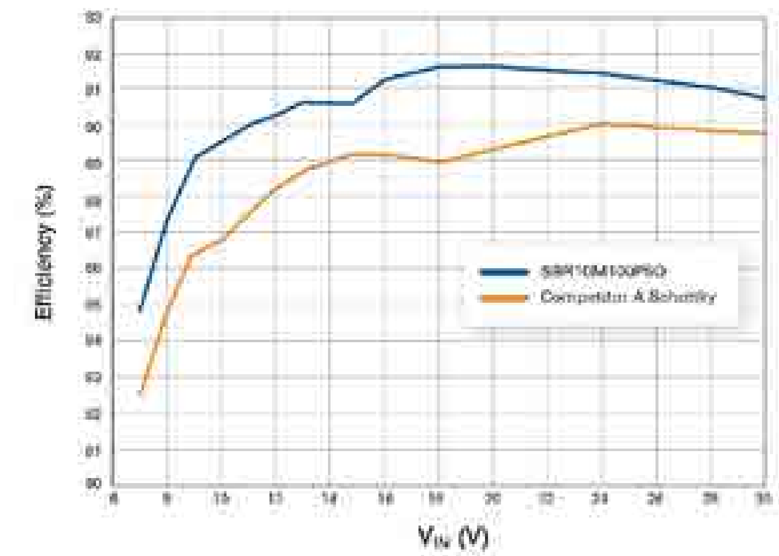


Figure 2: Efficiency Comparison at 25°C Ambient Temperature

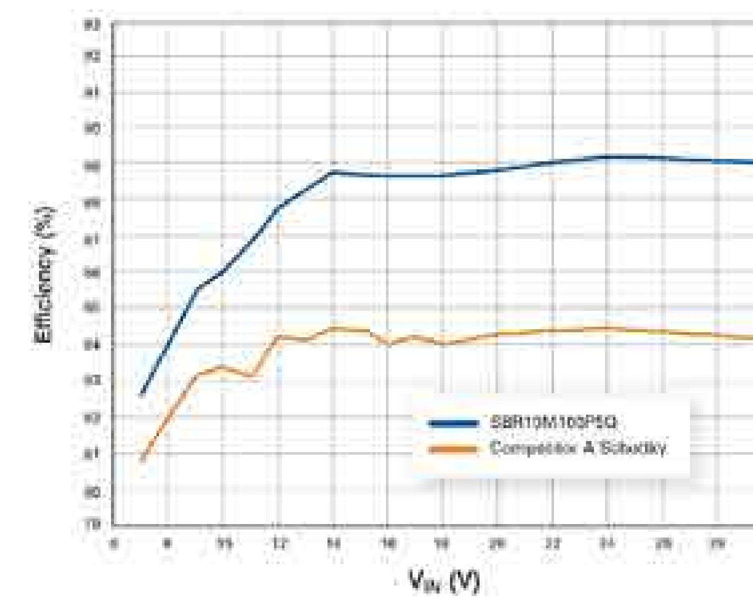


Figure 3: Efficiency Comparison at 85°C Ambient Temperature

SBR Under the Skin
SBR is a proprietary and patented Diodes Incorporated technology fabricated using a Metal Oxide Semiconductor (MOS) manufacturing process. The presence of the MOS channel forms a low potential barrier for majority carriers, resulting in forward-bias performance similar to that of the Schottky diode at low voltages. However, the leakage current is much lower due to overlapping P-N depletion layers and the absence of potential barrier reduction.

The SBR is represented by the same electronic schematic symbol

	Super Barrier Rectifier (SBR10M100P5Q)	10A/100V Schottky Diode
Typical Forward Voltage V_F(V) (I_F 1A @ 85°C)	0.50	0.50
Typical Forward Voltage V_F(V) (I_F 10A @ 85°C)	0.70	0.72
Typical Leakage Current I_R(µA) @ 85°C	1.7	18
Typical Leakage Current I_R(µA) @ 125°C	15	300
Avalanche Energy E_{AS}(mJ)	400	20
I_{FSM}(A)(square, 8.3ms/10ms)	220	200
Reverse Recovery Time t_{rr} (nS) (I_F=3A, di/dt=50A/µs, V_R=50V @ 85°C)	28.3	33.2
Reverse Recovery Charge Q_{rr} (nC) (I_F=3A, di/dt=50A/µs, V_R=50V @ 85°C)	9.4	14.1

Table 1: Comparing the Diodes Incorporated SBR with a Typical Schottky Diode

as the Schottky diode. In practice, the internal structure is like a MOSFET with the gate and source terminals connected together creating the SBR anode terminal. The MOSFET drain acts as the SBR cathode.

Other than displaying lower leakage with superior temperature stability and avalanche capability, an SBR behaves like a diode in any circuit, and as such it is a drop-in replacement for comparable Schottky devices. Without needing to redesign a PCB or add additional components, the SBR delivers immediate improvements in efficiency and a reduction in device case temperature that enables simplified thermal management and greater reliability.

Higher Efficiency, Cooler Running

Table 1 compared the SBR and Schottky diode in identical buck-boost DRL power supplies controlled by the ZXLD1371, as shown in Figure 1. The SBR shows a significant efficiency advantage, increasing at higher ambient temperatures where the Schottky circuit efficiency reduces by as much as 6%, as shown in **Figure 2** and **Figure 3**.

Plotting the efficiency of both circuits against ambient temperature (**Figure 4**) shows that the efficiency reduces with temperature due to a combination of increasing diode VF, leakage current, and switching loss, as well as overall system losses. The SBR's superior temperature stability minimises this loss of efficiency compared to the Schottky-diode circuit.

The SBR's superior efficiency delivers a twin benefit, both saving energy and resulting in lower device operating temperature. **Figure 5** shows how the SBR case temperature is consistently about 5°C lower than that of the Schottky diode across the full ambient-temperature range. This lower temperature allows the DRL designer greater freedom to manage heatsink size and cost while also achieving the desired system reliability.

Drop-In Upgrade from 10V to 300V

The Q series of SBRs, including the SBR10M100P5Q, are optimised for automotive applications; however, Diodes offers SBRs covering a wide variety of voltage ratings and package styles to deliver efficiency and reliability advantages for other sectors, such as industrial, consumer electronics, communications, and computer systems, and with environmental technology, such as bypass-diodes in solar panels. Extremely low VF minimises temperature rise to maintain system reliability, and the devices have a wide operating temperature window that ensures compliance with the solar-industry safety standard IEC 61730-2.

Devices in higher voltage ratings, up to 300V, are suited to applications such as switched-mode power supplies (SMPS) and solar inverters. In addition to superior efficiency and cooler surface temperature, SBRs have high surge-current ratings to withstand hazards, such as unpredictable power flow and lightning strikes.

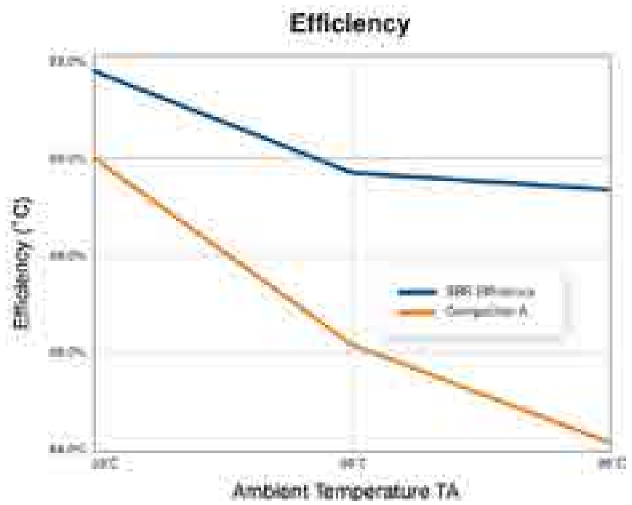


Figure 4: The SBR Efficiency is Greater at Higher Ambient Temperatures

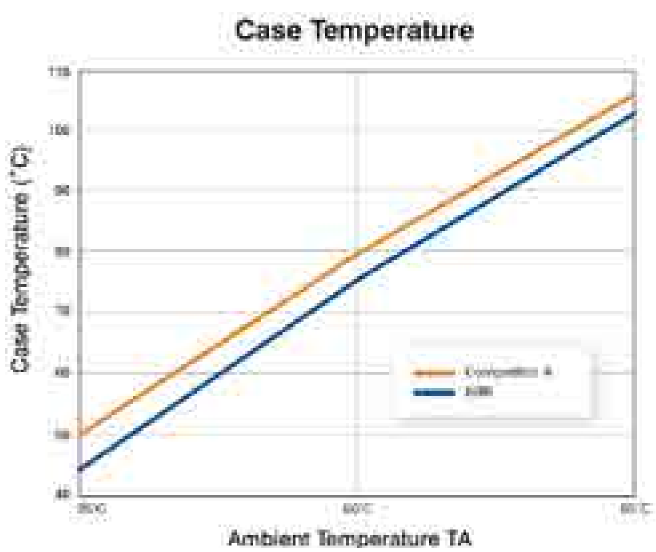


Figure 5: Lower SBR Case Temperature eases Thermal Management and Design for Reliability

Conclusion

In today's energy-conscious and efficiency-focused world, the SBR enables a valuable step-change in power conversion performance. With reduced leakage current, improved switching performance, comparable or lower VF, and outstanding temperature stability, the SBR offers superior efficiency without any additional design effort to deliver a reduced time to market for numerous applications. With the added advantage of cooler operating temperatures, power converters for systems covering automotive LED lighting, consumer adapters, and renewable energy systems can deliver superior performance and reliability while meeting the latest eco-design objectives and safety standards.

Diodes, Inc.
www.diodes.com

Adjustable Power Supplies Based on the Common Buck Converter

There are applications in automotive and industrial environments that require bipolar, adjustable two terminal power supplies

By: Victor Khasiev, Senior Applications Engineer, Analog Devices

A bench-top power supply (PS) tends to have an even number of terminals (ignoring the chassis port)—with one positive terminal and one negative terminal. Using a bench-top supply to produce a positive polarity output is easy: set the minus output to GND and the positive output voltage at the plus output. It is just as easy to produce a negative supply by reversing the setup. But what about producing a bipolar supply, where positive and negative voltages are both available to the load? This is relatively easy, too—just connect the positive terminal of one lab channel to the negative of another channel and call that GND. The other two terminals, minus and plus, are the positive and negative supplies, respectively. The result is a three-terminal bipolar power supply with available GND, positive, and negative voltage levels. Because three terminals are used, there must be some switch between positive and negative supplies downstream of the power supply.

What if an application calls for the same power supply terminal to be positive or negative—a setup where only two terminals are provided to the load? This is not a purely academic question. There are applications in automotive and industrial environments that require bipolar, adjustable two terminal power supplies. For instance, two terminal bipolar power supplies are used in applications ranging from exotic window tinting to test and measurement equipment.

As noted earlier, a traditional bipolar PS produces two outputs using three output terminals: positive, negative, and GND. In contrast, a single output power supply should be equipped with only two output terminals: one GND and another that can be positive or negative. In such applications, the output voltage can be regulated relative to the GND by a single control signal, in the full range from the minimum negative to maximum positive.

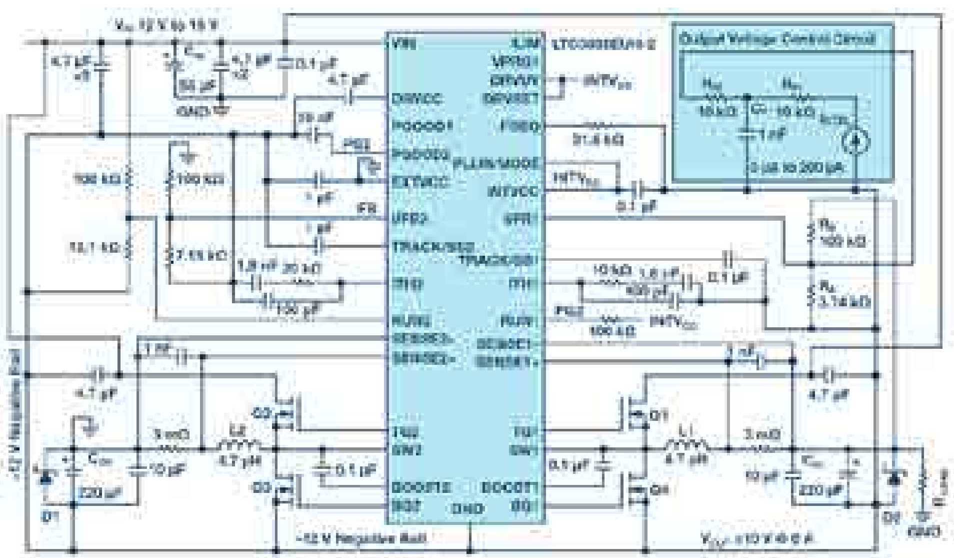


Figure 1: Electrical schematic of the two terminal, bipolar, adjustable power supply.

There are controllers that are specifically designed to implement the bipolar supply function, such as the LT8714, a bipolar output synchronous controller. Nevertheless, for many automotive and industrial manufacturers, testing and qualifying a specialized IC requires some investment in time and money. By contrast, many manufacturers already have prequalified step-down (buck) converters and controllers, as they are used in countless automotive and industrial applications. This article shows how to use a buck converter to produce a bipolar PS when a dedicated bipolar supply IC is not an option.

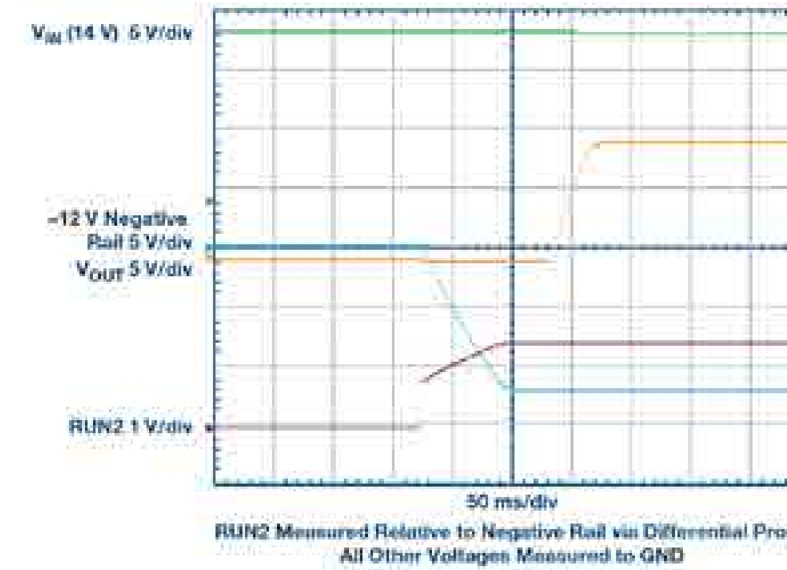


Figure 2: Start-up waveforms into resistive load

Circuit Description and Functionality

Figure 1 shows a buck converter-based solution for a bipolar (two-quadrant) adjustable power supply. The input voltage range is 12 V to 15 V; the output is any voltage in the ±10 V range, adjusted by the control block, that supports loads up to 6 A. The dual output step-down controller IC is the central component to this design. One output, connected per buck-boost topology, generates a stable –12 V (that is, the –12 V negative rail in Figure 1, with its power train comprising L2, Q2, Q3, and output filter CO2).

The –12 V rail serves as ground for the second channel with the controller's ground pins connected to the –12 V rail as well. Overall, this is a step-down buck converter, where the input voltage is the difference between –12 V and VIN. The output is adjustable and can be either positive or negative relative to GND. Note the output is always positive relative to the –12 V rail and includes a power train comprising L1, Q1, Q4, and CO1. The feedback resistor divider RB–RA sets the maximum output voltage. The value of this divider is adjusted by the output voltage control circuit, which can regulate the output down to the minimum output voltage (negative output) by injecting current into RA. The application start-up characteristics are set by the termination of the RUN and TRACK/SS pins.

Both outputs function in forced continuous conduction mode. In the output control circuit, the 0 μA to 200 μA current source, ICTRL, is connected to the negative rail as tested in the lab, but it can be referenced to the GND as well. The low-pass filter RF1–CF reduces fast output transients. To reduce the cost and size of the converter, output filters are formed using relatively inexpensive polarized capacitors. The optional diodes D1 and D2 prevent developing the reverse voltage across these capacitors, especially at startup. There is no need for the diodes if only ceramic capacitors are used.

Converter Testing and Evaluation

This solution was tested and evaluated based on the LTC3892 and evaluation kits DC1998A and DC2493A. The converter performed well in a number of tests, including line and load regulation, transient response, and output short. **Figure 2** shows startup to a 6 A load, with a +10 V output. The linearity of the function between the control current and output voltage is shown in **Figure 3**. As control current increases from

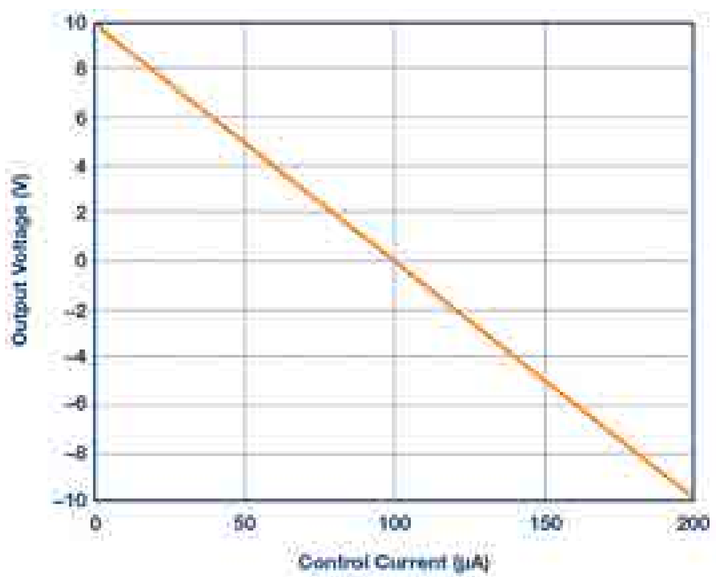


Figure 3: VOUT as a function of control current ICTRL. As ICTRL increases from 0 A to 200 μA, the output voltage drops from +10 V to –10 V

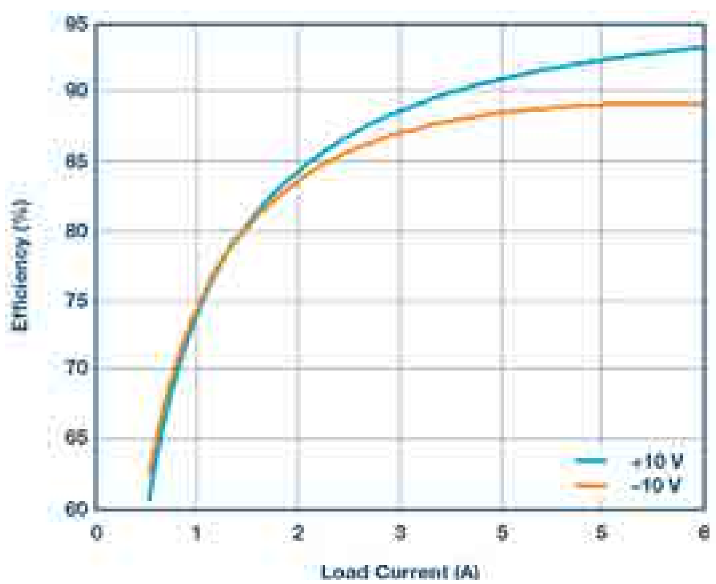


Figure 4: Efficiency curves for positive and negative output

0 μA to 200 μA, the output voltage decreases from +10 V to –10 V. **Figure 4** shows the efficiency curves.

An LTspice® model of the bipolar, two terminal power supply was developed to simplify adoption of this approach, allowing designers to analyze and simulate the circuit described above, introduce changes, view waveforms, and study component stress.

Essential Formulas and Expressions Describing this Topology

This approach is based on the negative rail, VNEG, generated by the buck-boost section of the design.

$$V_{NEG} = V_{OUT} + V_{OUT} \times K_m$$

Where VOUT is the absolute value of maximum output voltage and Km is a coefficient ranging from 0.1 to 0.3. Km limits the minimum duty cycle of the step-down converter. VNEG also sets the minimum value of VIN:

$$V_{IN} \geq |V_{NEG}|$$
$$V_{BUCK} = |V_{NEG}| + V_{IN}$$

Where VBUCK is the input voltage for the step-down section and thus presents the maximum voltage stress on the converter's semiconductors:

$$V_{BUCK(MAX)} = |V_{NEG}| + V_{OUT}$$
$$V_{BUCK(MIN)} = |V_{NEG}| - V_{OUT}$$

VBUCK(MAX) and VBUCK(MIN) are the maximum and minimum voltages of the step-down section of this topology, respectively. The maximum and minimum duty cycles and inductor current of the step-down section can be described by the following expressions, where IOUT is output current:

$$D_{BUCK(MAX)} = V_{BUCK(MAX)}/V_{BUCK}$$
$$D_{BUCK(MIN)} = V_{BUCK(MIN)}/V_{BUCK}$$
$$I_{L(BUCK)} = I_{OUT} + \Delta I_1$$

The duty cycle of the buck-boost section of the PS:

$$D_{BB} = |V_{NEG}|/(V_{IN} + |V_{NEG}|)$$

The input power of the step-down section and, correspondingly, output power of the buck-boost:

$$P_{OUT(BB)} = (V_{OUT} \times I_{OUT})/\eta$$

The converter power and input current.

$$I_{OUT(BB)} = P_{OUT(BB)}/|V_{NEG}|$$
$$I_{L(BB)} = I_{OUT(BB)}/(1 - D_{BB}) + \Delta I_2$$

The output voltage changes are executed by injecting current into the feedback resistor divider of the step-down section. Setting up the output voltage control is illustrated in the output voltage control circuit section of Figure 1.

If RB is given, then

$$P_{BB} = P_{OUT(BB)}/\eta$$
$$I_{BB} = P_{BB}/V_{IN}$$

where VFB is the feedback pin voltage.

When the current source ICTRL injects zero current into RA, the output voltage of the buck converter is the maximum positive value (VBUCK(MAX)) relative to the negative rail and maximum output voltage (+ VOUT) relative to GND. To produce a negative output voltage to the load (relative to GND), the output voltage is reduced to its minimum value, VBUCK(MIN), relative to the negative output voltage (–VOUT), by injecting ΔI into resistor RA of the buck's voltage divider.

Numerical Example

By using the previous equations, we can calculate voltage stress, current through the power train components, and the parameters of the control circuit for the bipolar power supply. For instance, the following calculations are for a supply generating ±10 V at 6 A from a 14 V input voltage.

If Km is 0.2, then VNEG = –12 V. Verifying conditions of minimum input voltage VIN ≥ | VNEG |. The voltage stress on the semiconductor's VBUCK is 26 V.

The maximum voltage of the step-down section is VBUCK(MAX) = 22 V, relative to negative rail, setting the output voltage +10 V relative to GND. The minimum voltage, VBUCK(MIN) = 2 V, corresponds to the output voltage of –10 V relative to GND. These maximum and minimum voltages correspond to the maximum and minimum duty cycles, DBUCK(MAX) = 0.846, DBUCK(MIN) = 0.077, and DBB = 0.462.

Power can be calculated by assuming an efficiency of 90%, producing POUT(BB) = 66.67 W, IOUT(BB) = 5.56 A, IL(BB) = 10.37 A, and PBB = 74.074 W.

For an output voltage of +10 V (as per Figure 1), the control circuit current, ΔI, is 0 μA, whereas for an output voltage of –10 V, ΔI = 200 μA.

Conclusion

This article presents a design for bipolar, two terminal power supplies. The approach discussed here is based on step-down converter topology, which is a staple of modern power electronics, and thus available in a variety of forms, from simple controllers with external components to complete modules. Employment of step-down topology gives the designer flexibility and an option to use prequalified parts, which saves time and cost.

Victor Khasiev is a senior applications engineer at Analog Devices. Victor has extensive experience in power electronics both in ac-to-dc and dc-to-dc conversion. He holds two patents and wrote multiple articles. These articles relate to using ADI semiconductors in automotive and industrial applications. They cover step-up, step-down, SEPIC, positive-to-negative, negative-to-negative, flyback, forward converters, and bidirectional backup supplies. His patents are about efficient power factor correction solutions and advanced gate drivers. Victor enjoys supporting ADI customers by answering questions about ADI products, troubleshooting, and participating in testing final systems, as well as by designing and verifying power supplies schematics and the layout of printed circuit boards.

Analog Devices
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Pick a Plug 'n' Play Linearizer for Your 5G RF Power Amplifier

Everything is linear if plotted on a log-log scale with a fat magic marker

By: Thomas Maudoux & Michael Jackson, Maxim Integrated

'Mar's Law' presents a tongue-in-cheek perspective on how data measurements can sometimes be manipulated to fit a more linear profile than is the reality. However, there are no such shortcuts to achieving high linearity for a power amplifier (PA), which is at the heart of mobile cellular communication infrastructure. The unfolding deployment of 5G or 5th generation cellular mobile communications (**Figure 1**) will place further demands on the performance of these amplifiers.

Figure 1. 5th Generation Cellular Mobile Communication

In this design solution, we present the features and benefits that 5G telecommunications technology promises to bring and the associated demands that it will place on PA designs. We then review the most commonly used PA linearization techniques, assessing their suitability to meet these demands before presenting a low-power linearizer IC with the potential to greatly simplify PA designs while also reducing their power consumption in 5G applications.

Figure 1: 5th Generation Cellular Mobile Communication

5G Design Challenge

5G promises to offer several advantages over incumbent telecommunications technologies. It will provide higher data rates for more concurrent user, while also extending the battery life of mobile devices. To realise this, PAs must operate with the highest possible efficiency and at a higher bandwidth (up to 100MHz) than is currently required.

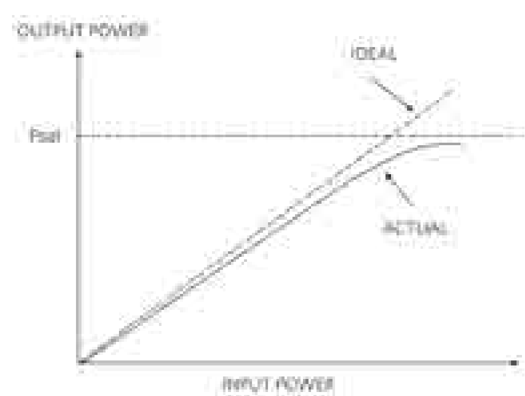

Figure 2: Relationship Between Output Power and Distortion

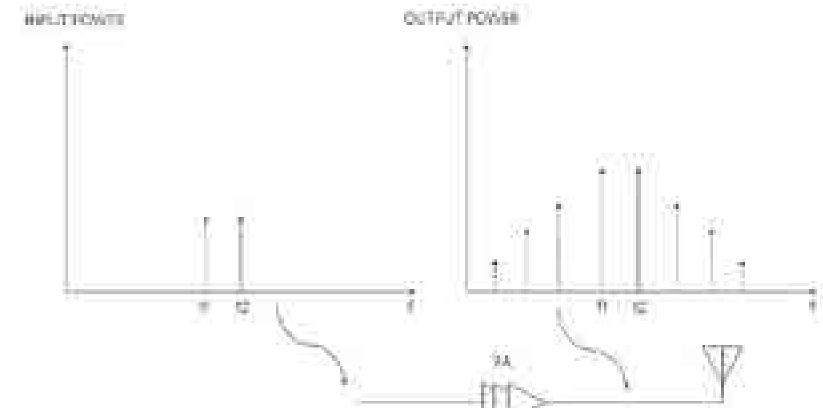

Figure 3: Intermodulation Terms Generated by PA

Amplifier Linearity

A perfectly linear PA should only generate an amplified version of a wanted input signal. In reality, such a PA does not exist. Instead, nonlinearity causes the output signal to be distorted, with the amount of distortion increasing as the amplifier approaches its saturation point (**Figure 2**)

For a multi-tone input signal, nonlinearity causes unwanted intermodulation frequencies to appear at the output of the PA (**Figure 3**).

Reducing PA distortion requires the use of some form of linearization technique. In the following sections, we discuss the operation and suitability of the most common linearization techniques, within the context of 5G.

Backoff

Limiting the maximum output power level so that the entire signal is within the linear region of the PA transfer curve is a technique commonly referred to as "backoff." A disadvantage of this relatively straightforward approach is that the amplifier's efficiency (the ability to convert DC supply power into RF energy) decreases as the PA operating point is further backed off from its saturation point The amount of backoff required to meet the signal peak-to-average ratio (PAR) required for some systems can reduce the efficiency of the PA to as low as 8%. This results in higher power consumption, higher cost of system implementation, and a much bigger heatsink. Therefore, backoff is not a suitable linearization approach to achieve acceptable efficiency in 5G applications.

Improving PA linearity without reducing efficiency requires a form of active linearization called "predistortion." With this technique, the amount of distortion caused by the inherent nonlinearity of the PA is "predicted" and its inverse is injected into signal path, reducing the magnitude of the unwanted tones, relative to the wanted signal at the amplifier output (**Figure 4**). This is specified as the adjacent channel leakage ratio (ACLR) and should be at least -50dBc.

Two commonly used types of active linearization are Digital

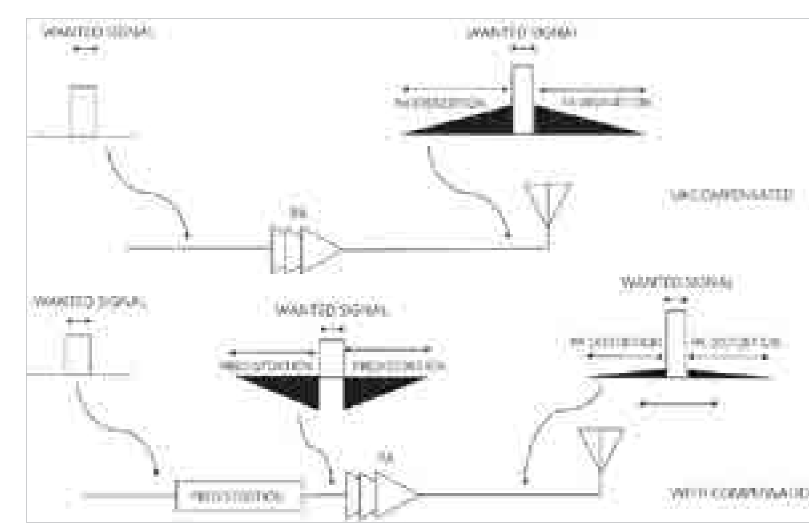

Figure 4: PA Output Characteristics with Predistortion Linearization

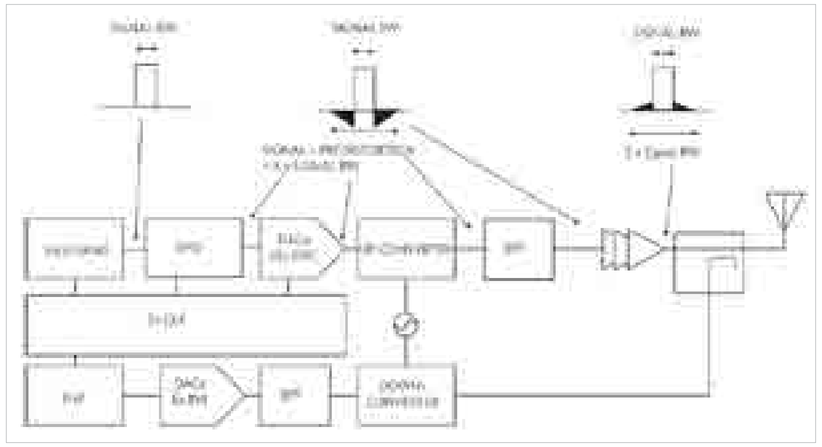
Figure 5: Digital Predistortion System Implementation

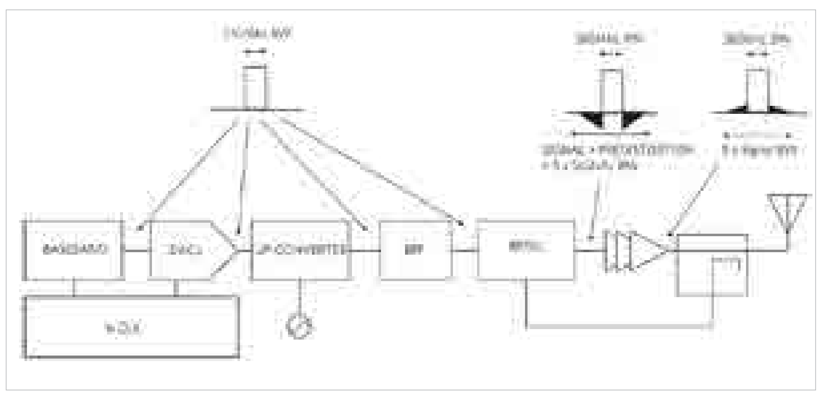
Figure 6: RF Predistortion System Implementation

Predistortion (DPD) and Radio frequency Power Amplifier Linearization (RFPAL).

DPD

As illustrated in **Figure 5**, digital predistortion (DPD) adds the predistortion correction signal to the desired signal at the earliest point in the signal chain, namely the digital baseband.

DPD systems can be implemented in several ways. While fully integrated versions (incorporating baseband, digital, and RF) are available, some solutions have a separate digital baseband with discrete RF. Yet another variation consists of an FPGA with an RF transceiver (and a DPD observation path). However, the requirement for the transceiver to work at a frequency of 5 times the input signal bandwidth greatly increases design complexity, footprint, and power consumption (5W typical), making DPD an unsuitable linearization technique to use in small, low-power applications.

RFPAL

Figure 6 below shows a high-level block diagram of a system using an alternative active linearization predistortion technique called radio frequency power amplifier linearization (RFPAL).

Using a standalone RF_{IN}/RF_{OUT} architecture and adaptive RF predistortion technology, this approach allows the correction signal to be injected only at the point it is needed, namely the PA's input. This means that the system can operate at a lower frequency (the input signal bandwidth) using a much simpler and smaller transmitter and baseband architecture, requiring less power than DPD systems. Until recently, the maximum linearized input-channel bandwidth using RFPAL was only 60MHz. **Figure 7** shows a new RFPAL IC which overcomes this limitation.

With an operating frequency range up to 3.8GHz, this part has a linearized input signal bandwidth of up to 100MHz. Consuming only 1280mW, it lowers power consumption by up to 70% compared to DPD solutions. **Figure 8** shows the measured ACLR and efficiency performance (five non-contiguous 20MHz LTE channels,10dB PAR) for a typical PA using this linearizer.

For an output power level of 37dBm, the efficiency of the PA is 23% at -50dB ACLR (an ACLR

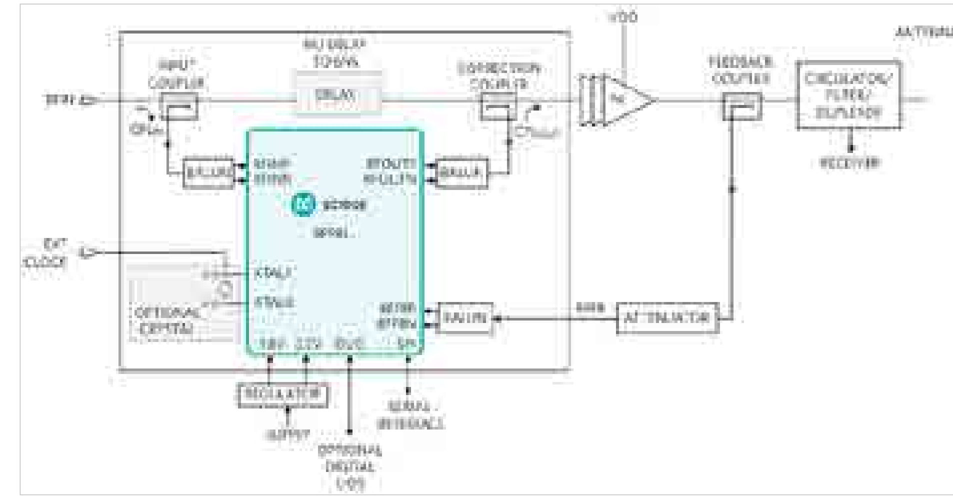
Figure 7: SC1905 RFPAL Typical Application Circuit

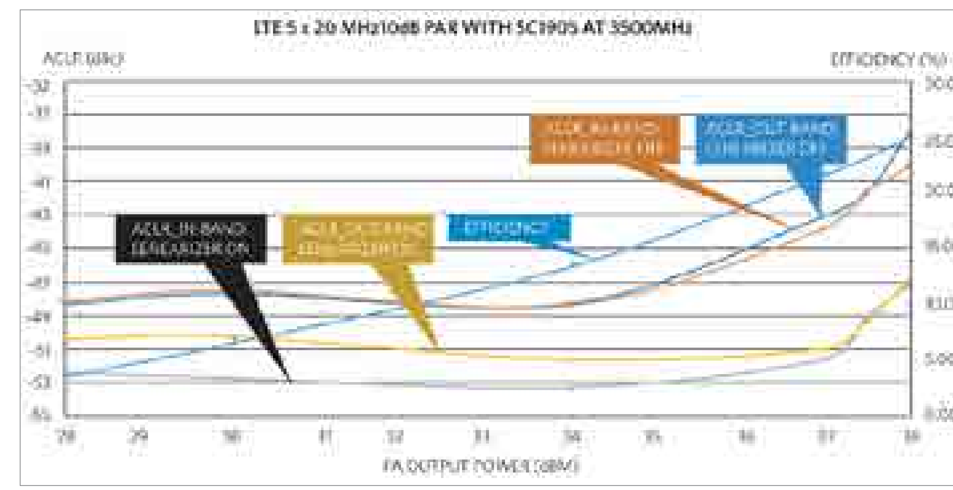

Figure 8: ACLR for PA Using SC1905 RFPAL

improvement of ~8dB without RFPAL). Additionally, since this RFPAL device has been evaluated with several popular PAs (including Class A, Class AB and Doherty) it effectively represents a "plug and play" solution, reducing design complexity, cycle duration, and risk. The IC is available in a 9mm x 9mm QFN package resulting in a total solution size (including power supply, heatsink, and enclosure) of only 6.5cm2. Additionally, the linearized PA signal can be upconverted using a mixer for applications up to 6GHz, if required.

Conclusion

5G telecommunications equipment will be required to operate at higher bandwidths and with greater efficiency than ever before. The linearity and efficiency of the PAs used will be key to meeting these requirements. In this design solution, we have considered some of the most common PA linearization techniques. We have shown that backoff is not suitable for use in 5G designs but using DPD as a form of active linearization improves overall linearity and efficiency. However, it is a highly complex technique, resulting in increased overall system power consumption and bigger solution size. We can conclude that a simpler, lower power form of linearization can be achieved using a small, plug and play RFPAL IC which increases PA efficiency for an input signal bandwidth up to 100MHz. It is suitable for use with PAs of different architectures (Class A/AB/Doherty), processes (GaAs, GaN, InGa), and frequencies (698MHz to 3.8GHz) across a range of applications. This makes it the best option for 5G wireless cellular infrastructure and other applications.

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GaN in Space

GaN has many advantages over traditional semiconductor technology

By: Steve Taranovich, Eta Kappa Nu Member and an IEEE Life Senior Member

The commercial space sector led by Space X and Blue Origin, plus companies like Northrop Grumman and Boeing, have given new life and accelerated NASA's plans for the journey to Mars. The addition of the Artemis program, to establish a Moon base for the first leg of exploration and mining in the mid-2020s, will also be a gateway for the journey to Mars in the 2030s. NASA is now a spaceport with Space X, Blue Origin, and Boeing residing at Kennedy Space Center in Florida.

In this article, I would like to discuss an oft forgotten or little-noticed part of the spacecraft enabling travel into outer space---power management in the space vehicle. Wide bandgap semiconductors like gallium nitride (GaN), silicon carbide (SiC), as well as diamond, are looking to be the most promising materials for future electronic components since the discovery of silicon. These technologies, depending upon their design, offer huge advantages in terms of power capability (DC and microwave), radiation insensitivity, high temperature and high frequency operation, optical properties and even low noise capability. Therefore, wide bandgap components are strategically

Figure 1: Solar panels deployed on a satellite (Image courtesy of NASA)

important for the development of next generation space-borne systems.

I am particularly excited about wide bandgap semiconductors, especially enhancement mode gallium nitride, in this article as the power driver of choice for these critical power supplies in space. I will explain why GaN belongs in space-related power solutions and will be one of the most important elements in the power supply regarding SWaP: Size, Weight, and Power efficiency, the three most important elements in a space vehicle coupled, of course, with reliability (We can't pull off to the side of the road and call for help in the event of a malfunction in space).

Power sources are usually heavier than most other equipment onboard a spacecraft. GaN power devices can achieve the best efficiency as a power transistor as well as having the smallest size in a power management architecture since these power devices run at very high frequency which reduces the size of power magnetics (transformers and inductors that contain iron/metal cores that add weight) in the design architecture. Lighter weight also means less fuel consumption to escape Earth's gravitational pull upon launch; this equates to lower costs.
GaN also has EMI benefits because reduced parasitics lead to less energy stored and released in these parasitics during each switching cycle. The circuit architecture has a smaller footprint which will help designers improve loop inductance---which can act as a transmitting and receiving antenna on the board.

Primary power to spacecrafts and on the Moon's and Mars' surface: The MMRTG
A Multi-Mission Radioisotope Thermoelectric Generator now powers NASA's Mars 2020 Rover and also most previous Rovers on Mars. The MMRTG also provides the main power on many present and future spacecraft. This will be one of the primary sources of long-lasting power both aboard a spacecraft or on a planet/moon.

Another Primary Power Source: Solar Panels
The other primary power source would be the Sun, sending energy to a series of photelectric cells. Solar panels gather the Sun's energy and store it in batteries. This is a preferred way to power satellites. GaN excels here to take the solar panel output and to charge the batteries as well as converting those voltages in a Point of Load (PoL) converter to power instruments and other systems on the spacecraft. **See Figure 1**.

The International Space Station (ISS) uses nickel-hydrogen batteries to support its solar panels. Spirit, another older Mars rover, also uses batteries paired with Solar.

Mars Insight Lander
The Mars Insight Lander has 2 Solar Panels which are 7 feet in diameter. Their power is stored in two, 23 amp-hour, lithium batteries to power the space vehicle during the Martian night. GaN is also at home in this application.

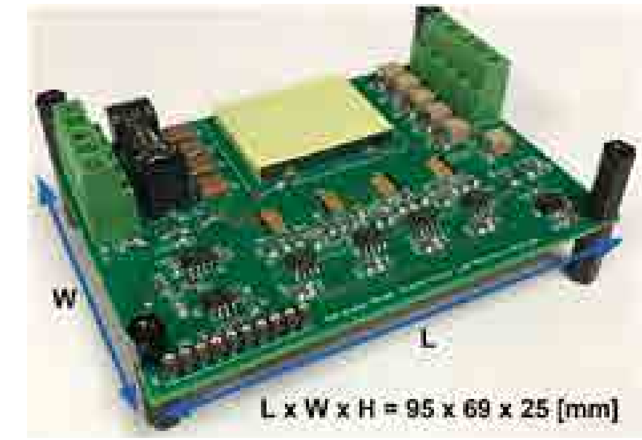

Figure 2: The prototype of a 400W DC/DC MPPT, Non-Inverting Buck Boost (NIBB) converter

A 500W Solar Power-based microgrid for Space
This design focuses upon four parameters that characterize Solar Power-based microgrids: battery voltage, PV Maximum Power, PV Maximum Power Point Voltage, and number of panels per string. In the end, the final optimization metric was the ratio of daily average deliverable power to total system mass (W/kg).

A series of different DC-DC micro-converters were investigated for this system including buck, boost, buck-boost, and non-inverting buck-boost (this topology proved the best candidate). **See Figure 2**. A Distributed Maximum Power Point Tracking (DMPPT) architecture could be used with a variety of power converters. eGaN® FETs from Efficient Power Conversion, or from their partner Freebird Semiconductor, were selected for the DC/DC converter switches in this design because of resilience to high radiation conditions as opposed to Si devices. High efficiency was also a reason to select GaN.

Power Conditioning
Power conditioning in a system is one of the most critical tasks to control in an optimum way so that the exchanges of power between the Solar generator or MMRTG, the battery and the loads is efficient. In order to achieve this, the power delivered to the loads has to remain within the voltage range that these loads can handle.

Proper sizing of the Solar Array must be a primary goal since the battery will need to be replenished during the time that the satellite equipment is being powered. Designers must ensure that the battery does not experience current- or voltage-related overcharging. The ability to disconnect some non-essential spacecraft functions, so as to avoid a battery full discharge, is critical to the safety of the spacecraft.

Distributed Power Architecture (DPA)

Driving modern high-speed digital processors, FPGAs and ASICs with a DPA could help system efficiency as well as dynamic response from negative effects of parasitic impedance. An Intermediate Bus Converter (IBC), with good transient response and followed by Point-of-Load (PoL) regulators, will help create a stable power architecture under various load fluctuations, especially with load voltages dropping below 1VDC with ever increasing current needs.

The Intermediate Bus Converter (IBC)

The IBC is usually the first conversion stage after an MMRTG or Solar Panel array and may be regulated or unregulated. The IBC is typically a DC/DC converter with a typical spacecraft power bus input of 28VDC. The designer will have to determine whether the IBC output source is regulated well enough, while also checking the PoL input range needs.

Point of Load (PoL) converter

Here is where GaN comes into play right at the load. There will typically be many of these PoLs with different output voltages that the loads would need and ultimately be directly driven by Space qualified GaN power transistors.

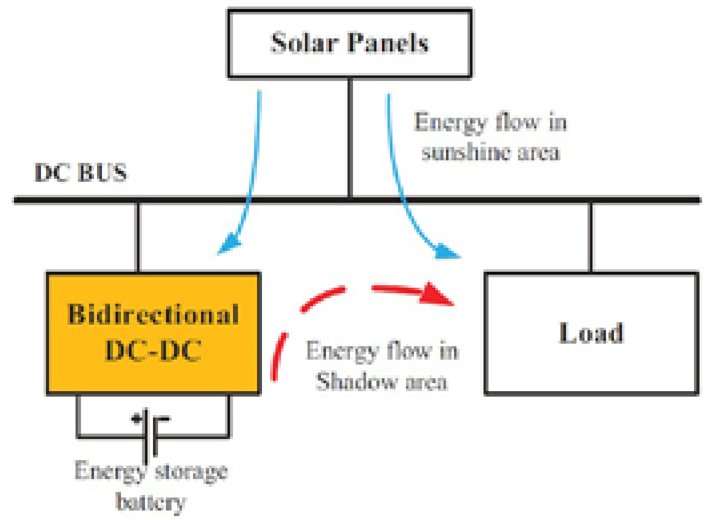

Figure 3: Solar Panels providing power to the Spacecraft load with an intermediate Bi-directional DC/DC converter for continuous power flow to the load at all times.

See how Data center power in 2019 demonstrates one such architecture on Earth; however, that architecture would also apply in Space.

eGaN Technology for Power Electronics enters the scene: Power needs in Space

Large Spacecraft

Power for larger spacecraft such as telecom satellites or the International Space Station (ISS) need tens of kW. GaN designs can easily handle this.

Satellites

Electrical loads in a satellite can vary widely, depending on which instruments/subsystems are running at a particular time.

The power system in a satellite must be protected against failures of the supplied units that could degrade it and even take it out of service, especially during short-circuits. This is a centralized distribution architecture and will have circuit breakers or fuses to eliminate uncontrolled current surges. Aboard a spacecraft, both fuses or electronic circuit breakers are commonly used.

Key areas in which GaN has typically been used in satellites is with RF and switching. The Space community has taken notice that the enhancement mode GaN FET now has the availability of integrated GaN FET driver modules (See Freebird section of this article)

Batteries are needed in satellites

Satellites will have orbits that may block the Sun behind the Earth, another planet, or Moon. For this reason, satellites and spacecraft need rechargeable secondary batteries to keep them powered. These batteries may be the sole power source available just after launcher separation and until the solar generators are deployed and properly pointed towards the Sun. A Bi-directional DC/DC topology has been proposed for such Space applications in **Figure 3**.

Weinberg's conventional topology by which a bi-directional topology is created with the addition of the switching device (GaN is perfect here) and a diode. This design has two working modes: boost (created with the Weinberg topology) and buck (designed as a conventional circuit). This design enables a smaller unit with higher energy density and low weight. **See Figure 4**.

Small Satellites and CubeSats

CubeSats typically only need a few watts of power.

Smallsats are a bit bigger and require a little more power, operate in Low Earth Orbit (LEO), and can deliver low-cost internet access around the world. These satellites have a 3 to 5 year lifetime. GaN is perfectly suited for these systems.

eGaN FETs provide the radiation tolerance, fast switching speeds, better efficiency, leading to smaller, lighter power supplies (smaller magnetics and reduced heat sink sizes or even elimination of heatsinks in many cases). Power supply designers have their choice of increasing the frequency to allow for smaller magnetics or increase efficiency or design a satisfactory balance of both. eGaN FETs

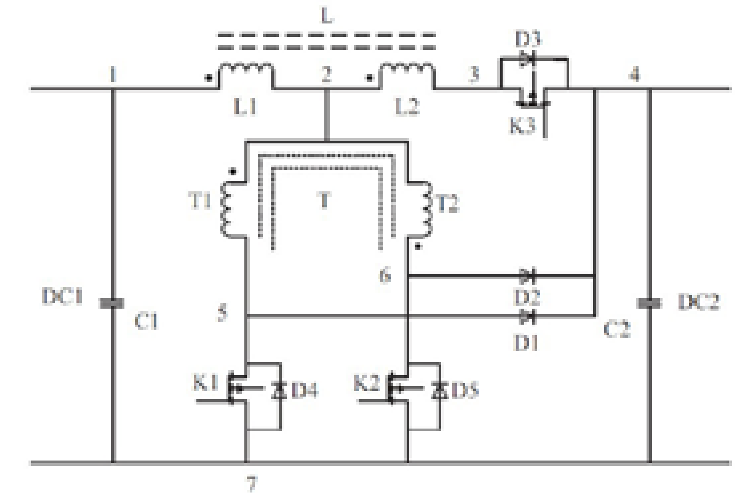

Figure 4: A bi-directional chopper circuit for the Weinberg converter.

Figure 5: Solar energy powers the Mars 2020 spacecraft during its 9 month journey to Mars, but while on the Mars surface, the MMRTG will be the prime source and heat pumps need to be used as well due to the extreme temperature conditions. (Image courtesy of NASA)

are also smaller than equivalent MOSFETs. Increasing the switching frequency also speeds up the feedback loop. Faster transient response can reduce capacitor sizes too.

Maximum gate voltage allowed is 6V, but is derated to 5.0V in satellite applications.

Rovers

Mars Rover 2020

Solar heating on Mars would be difficult for the electronics of the Rover since it would take a great deal of power. The mission is planned to last one Mars Year (about 687 Earth days), but as we have seen in the past, the Rovers usually go far beyond their planned missions.

The MMRTG, with a 14 year operational lifetime, supplies 110W of power (60W of that is for the Avionics on the journey to Mars) There are two rechargeable Lithium Ion backup batteries, each have an energy capability of 43 Ah.

The Rover's main onboard Power supply is essentially 22-36VDC in operation, a nominal 28VDC. GaN here would be an enormous benefit to lower weight, less wasted heat due to GaN's high efficiency, and smaller physical size in this type of power converter. **See Figure 6**.

Figure 6: Mars2020 Rover MMRTG power source circled in blue (Image courtesy of NASA)

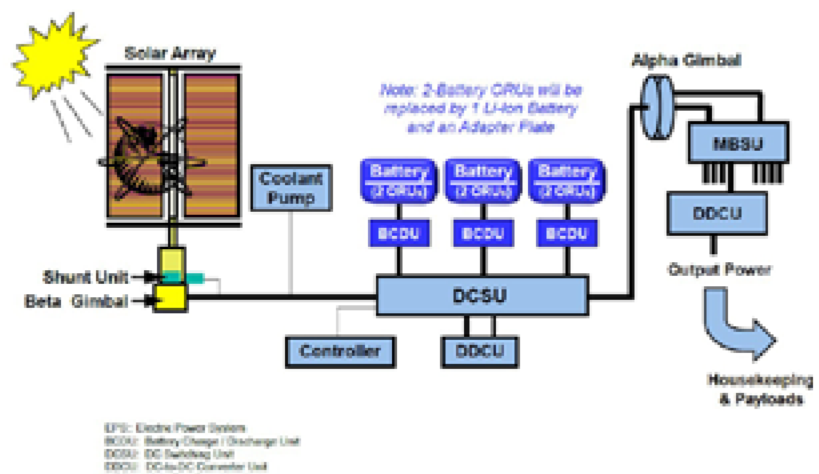

Figure 7: The ISS Electrical Power Channel (Image courtesy of NASA)

The European Space Agency (ESA)
The ESA realizes that power systems in space need power generation, conditioning, storage, distribution, and conversion. The ESA is investing heavily in GaN technology.

Global Support Technology Program (GSTP)
There is a focus upon high-voltage and high-switching speed DC/DC Converters based upon GaN technology for next generation power systems. The main goal of this activity is to develop high performance, space-compatible enhancement mode GaN power switching transistors while establishing a European industrial manufacturing route.

International Space Station (ISS) power
Energy from the Sun (solar power) is collected by the ISS solar arrays, and is roughly conditioned by the Sequential Shunt Unit (SSU), then tightly regulated by the Direct Current (DC) to DC Converter Unit (DDCU), and stored in Lithium Ion batteries.

Electric Power System (EPS) onboard the International Space Station (ISS) provides all the power vital for the continuous, reliable operation of the spacecraft. NASA Glenn Research Center's Space Operations Division is leading the sustaining engineering and subsystem integration of EPS hardware. Glenn also manages the integration of the EPS with ISS International Partners' elements.

The EPS consists of many hardware components called Orbital Replacement Units (ORU). Every different ORU is considered a subsystem of the entire EPS and astronauts can replace them upon failure either robotically or by Extra-Vehicular Activity (EVA). The components collectively provide power generation, power distribution and energy storage for the ISS.

DC-to-DC converter units supply the secondary power system at a constant 124.5 VDC, allowing the primary bus voltage to track the peak power point of the solar arrays. 200 V and 350 V eGaN FETs are perfect in this kind of design.

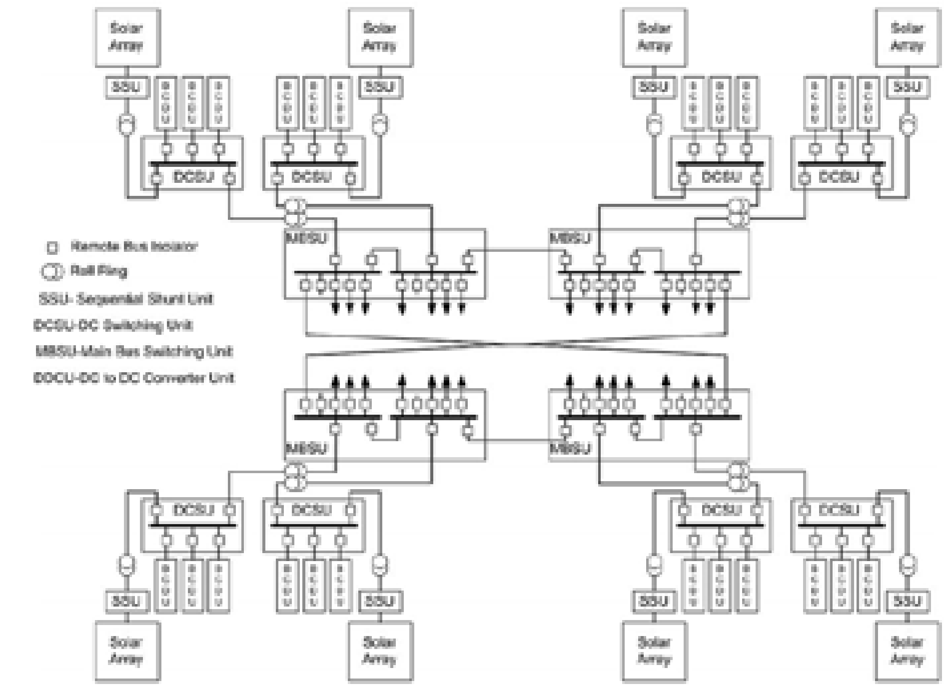

Figure 8: The Main Bus Switching Unit can be seen here. This unit had once malfunctioned on the ISS---all the more necessary for designers to learn lessons in improving and making designs in Space more robust (Image courtesy of NASA)

Starting in 2016, the nickel-hydrogen battery ORUs were being replaced by Lithium-ion (Li-ion) batteries. Each Li-ion battery weighs about 430 pounds, and each adapter plate weighs about 65 pounds, for a weight savings of over 200 lbs. as compared to Nickel-Hydrogen batteries.

Reliability
It has been more than nine years now that eGaN® devices have shown very high reliability in both laboratory testing and customer applications such as lidar for autonomous cars, 4G base stations, vehicle headlamps, and especially in satellites for this article. See eGaN FET Reliability for more details.

Radiation Hardness
I had the pleasure of interviewing Jim Larrauri Chief Strategy Officer who co-founded Freebird in 2015.

He told me that his company name was like a satellite, sometimes called 'a bird that is freed into space to provide a service'.

Back in 2016 Freebird took Efficient Power Conversion's (EPC's) commercial enhancement-mode GaN (eGaN) product and eliminated the variability that exists in the commercial eGaN and went on to develop that technology for Space.

They also take enhancement mode GaN and provide a package structure along with circuit structures, with patents held by Freebird Semiconductor, that puts them in a strategic position with their multi-function circuit pack in Freebird's modular part as drivers for the eGaN power transistors. It is the packaging in particular, that has been designed to help the end-user successfully transition from conventional silicon-based semiconductors into the high-reliability performance GaN arena. Part of Freebird's core strategy is to provide building-block solutions to make the implementation of eGaN HEMTs more successful, taking the guesswork out of the design process. These lower cost, easy to implement, modular solutions are used in space-borne and launch vehicle power systems. The modules provide the end-user with circuit flexibility integrated into a single module: from a half-bridge configuration to two "independent" low- and high-side switches, all incorporated and using "GaN-driving-GaN" technology.

Launch costs need to be reduced from about $200M to $250M per launch to a target like $50M, depending upon the specific launch vehicle and supplier, in order to be cost competitive for such launch vehicles as Delta or Atlas or even SpaceX low cost recovery units. Also, in the satellite industry, satellites can range in cost from $500M to $1B; these costs need to come down as well.

Nowadays there are also more large Low Earth Orbit (LEO) constellation satellite delivery systems for data transmissions. These systems have power budgets and need a technology to support these needs. eGaN devices were selected by Freebird over SiC because SiC does not have adequate baseline radiation hardness assurance capability built into it like eGaN does.

Enhancement-mode GaN is not natively Rad Hard; it has to be made Rad Hard. However, it is Radiation Tolerant in the technology sense due to its immunity to Total Ionizing Dose (TID). But from a Heavy Ion Single Event Effects (SEE) perspective you need to control and tweak the process with design to obtain the desired radiation hardness from the GaN.

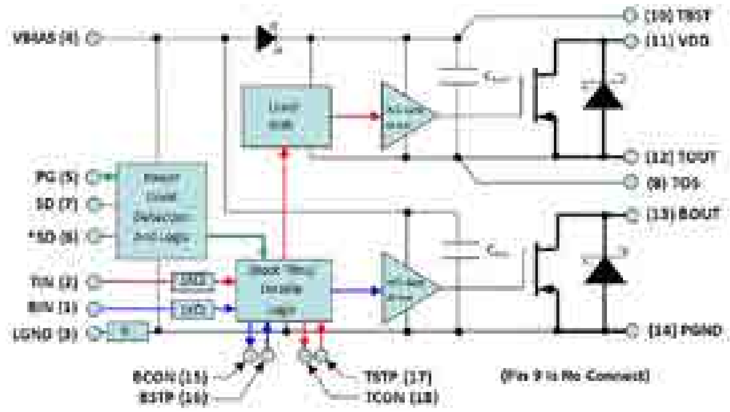

Figure 9: FBS-GAM02 10A/50V Multifunction Module block diagram composed of all eGaN devices except for diodes, capacitors, and resistors. No silicon-based switcher or monolithic ICs are employed inside these devices eliminating low-dose rate radiation effects, and more. (Image courtesy of Freebird Semiconductor)

Studies have been done for the many other supplier design processes for GaN, demonstrating at rated voltage, that they cannot pass the SEE requirements for the (Au) Gold Heavy Ion standard. There are other lesser heavy ions with which you can successfully bombard this technology in simulation of alternative space borne application environments, but only if you can pass the gold standard, and at rated voltage, have you achieved true rad hard product capability. Freebird Semiconductor uniquely performs 100% Radiation Hardness Assurance against MIL-STD-750, Method 1080 for (SEE) on "every wafer" of eGaN product supplied, conducted at a typical rated Au (15 MeV beam) with a linear energy transfer (LET (Si)) ~ 84.6 at Energy =2365 MeV & Range = 124μm with typical fluences of 3e5/1e7 as standards. As all of Freebirds modular products employ "GaN-driving-GaN" technology, this radiation hardness assurance pedigree is carried on through the entire product portfolio.

eGaN devices are High Mobility Electron Transistors (HEMT) which prove themselves to be excellent candidates for the radiation hardened market to replace Rad Hard MOSFETs in space. MOSFETs are the present incumbent supply base from military support programs down to small satellite systems. They all need Rad Hard MOSFETs. The pressing issues that need to be overcome is cost (there is essentially one major single source supplier with excellent products, along with a few secondary suppliers). MOSFETs however are an 'old' technology with large die sizes and a performance Figure of Merit (FoM= Rds(ON) * Ciss) that is much higher than that of eGaN FETs (lowering the Figure of Merit provides for better efficiencies).

The on-resistance of a Rad Hard MOSFET is much higher than an eGaN FET of the same die size. Freebird Rad Hard eGaN HEMT devices are majority carrier devices in which the channel conducts via a Two-Dimensional Electron Gas (2DEG) with a lateral channel current flow---there is NO charge storage in the channel. The eGaN switching speeds are determined solely by the R's and C's of the Gate and Drain nodes. Switching times can reach sub-nanosecond levels, so different thinking must be employed for both the design and PCB layout phases of development when using these high-performance devices.

The driving of a MOSFET or eGaN HEMT is highly in favor of eGaN with a 10x to 40x reduction in gate charge over the best Rad Hard MOSFET available.

GaN HEMT also wins in the size metric over MOSFETs. These devices can be mounted directly to a ceramic substrate (needing no external package), thus eliminating wire bonds. The elimination of wire bonds in our eGaN designs allows the true speed performance of the eGaN HEMTs to shine through, as wire bonds bring with them inductance, which can cause all manner of transient-related issues such as voltage overshoot and current ringing.

Doing business in the space community means being able to supply that market sector with a radiation hardness assured product each and every time. That is the initial roadblock to overcome for GaN technology use in space borne applications. Freebird, along with EPC, can state and prove that they can offer a radiation hardened version of EPC's design and process as a result of a proprietary sourcing agreement. GaN commercial products by themselves cannot claim and then provide that fact.

There are space community applications and programs such as evolving Internet needs across the globe nowadays that use large LEO constellations; Airbus OneWeb is one of these programs with their 900 satellites required in Space. There is also Maxar Technologies

(In one of the first steps of the NASA's Artemis lunar exploration plans, NASA announced in May 2019 the selection of Maxar Technologies, to develop and demonstrate power, propulsion and communications capabilities for NASA's lunar Gateway), Northrop Grumman, or Honeywell. These companies have satellite needs with one thing in common: A low-cost power delivery system. GaN is specifically used in these satellite systems now, just about across the board, in the Power Distribution Unit (PDU) within the satellite system. Each satellite company has their own PDU, Solar Array manufacturer, motor controller, etc. They all require efficient reliable power delivery.

Freebird supplies the basic power device building blocks to realize the PDU. These PDU systems can use discrete-packaged eGaN HEMTs or even the Freebird Die Adapter (FDA) devices which may then form the basic elements of the higher-level PDU. Freebird utilizes high reliability eGaN FET die and creates driver circuits for the eGaN power transistors. The result is a complete, fully-guaranteed Radiation Hardened power section. Designers can now have the radiation hardened building blocks to create their final PDU system using standard hardened products, not custom designed products.

Freebird DC/DC PoL Modular Converter Building Block

Freebird GAM Adapter series are modular building blocks containing high-reliability small signal eGaN FETs configured as high-speed gate drivers as well as high-powered eGaN power switches (i.e. GaN-driving-GaN) in surface mount package sizes ranging from 0.75" x 0.38" x 0.125: for a single gate driver, up to 1.00" x 0.75" x 0.125" for higher level functions. These larger modules can have low-side drivers, high-side drivers, as well as a complete multi-function module containing a half-bridge---the power stage for a Point of Load (PoL)as featured in the FBS-GAM02. **See Figure 9**.

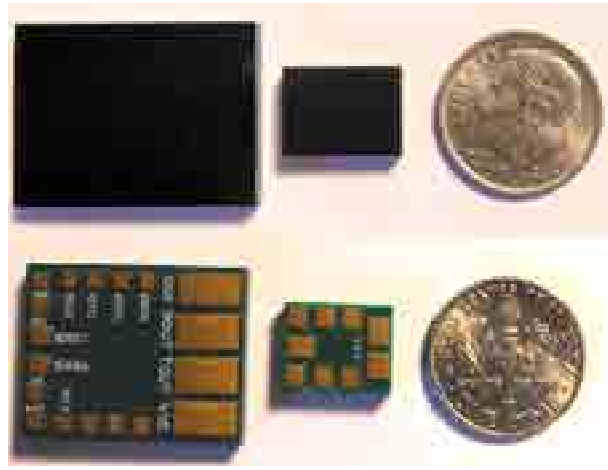

Figure 10: FBS-GAM02 10A/50V Multifunction Module (top) and FBS-GAM01-PSE eGaN HEMT Gate Driver (bottom) compared to US Dime. (Image courtesy of Freebird Semiconductor)

All FBS-GAM0X devices contain Freebird Semiconductors flight proven US Patent #10,122,274 B2 circuitry, pioneering eGaN driving eGaN technology building blocks from which users can create a wide variety of power supplies: Forward, Flyback, Boost, Full-bridge, Buck, Weinberg, Cuk, non-Isolated, Isolated on the Primary side or isolated on the Secondary side.

The GAM discrete and modular products may be used for many applications other than power supplies such as actuators, power switches, squib drivers, load dump switches, single-phase or three-phase motor drivers.

Today's space community works mainly in the digital arena regarding electronic circuitry. Every FPGA, every ASIC, every processor in use today are effectively digital. As such we can look at eGaN as a Digital Power, +5V logic-level driven front-end power transistor device!

Even though the space community is slow to change, eGaN devices have been proven compelling as a solid technology for space and they are gradually being considered and accepted. A large part of this acceptance is that fact that Freebird uses MIL-PRF-19500 as the baseline for its space level standard device qualification methodology for their eGaN discrete technology. MIL-PRF-19500 has a long history-within the high reliability industry to ensure effective screening and conformance qualifications for silicon semiconductor transistors including MOSFETS and IGBTs. As a testament to their efforts in the high-reliability, rad-hard space electronics arena Freebird has their eGaN HEMTs and modular devices presently successfully flying in space, accumulating valuable operational history for this technology! Their commercial space product is presently offered in their unique, proprietary epoxy over-molded GAM (GaN Adaptor Module) technology packaging (See **Figure 10**)

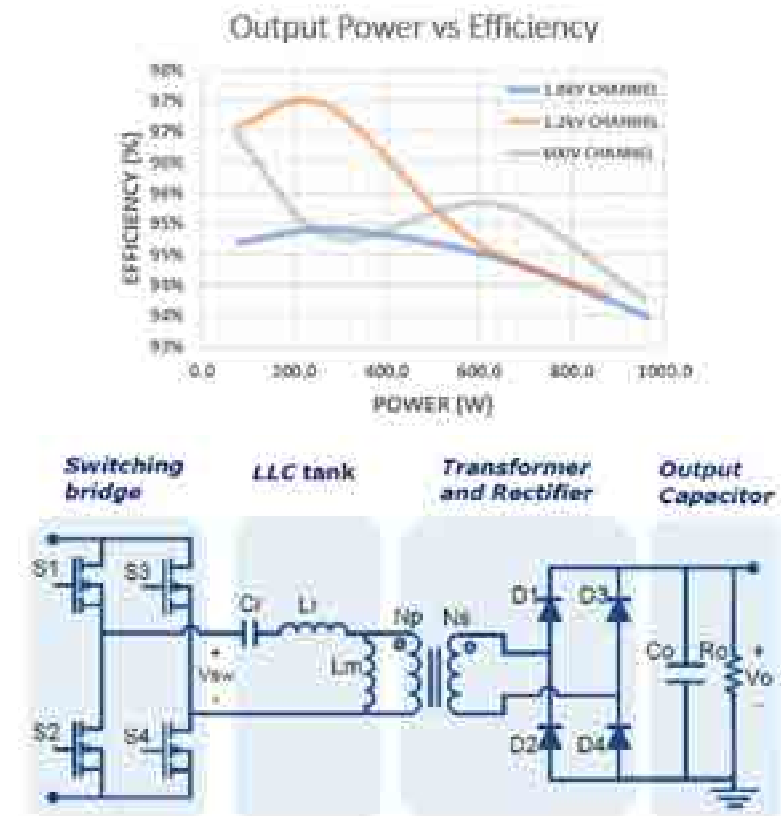

Figure 11a (top) and 11b (bottom): SET group 1-kW GaN-LLC Converter (Image Courtesy of Setgroup.us)

Many power supplies used in space applications are hard-switched architectures. Freebird's slowest commercial space eGaN multi-function modules are capable of running up to 500kHz (fully de-rated), and 1MHz (with power/thermal de-rating), with their independent drivers capable of speeds up to 3Mhz+ .

Further advancements, in the area of radiation-hardness-assured conversion products, are being developed by industry participants such as SET Group (working in partnership with NASA) whose founding partner Dr. Raul Chinga Alvarado provides the example of a high power, high-frequency, wide-range LLC resonant converter capability utilizing Freebird Semiconductor Rad Hard eGaN device technologies:

SET Group company specializes in the design and development of high-density power converters, leveraging state-of-the-art technology. SET group has achieved a module specific power of 15-20kW/kg as of 2019.

In 2017, SET group began work with NASA on the design, fabrication and demonstration of a gallium nitride (GaN)-based high-power, high-frequency, wide-range LLC resonant converter (GaN-LLC) capable of handling high-power and high-frequency operation. The GaN LLC converter operates at an input voltage of 95V - 150V and can output 600V – 1.8kV, specifically utilizing space-grade Freebird Semiconductor's GaN HEMT (rated up to 300 kRad) and uses a novel additive-manufactured thermal management solution.

The LLC topology provides high efficiency and also the advantage of handling a wide input voltage range. Together with Freebird Semiconductor devices and NASA, SET group has successfully developed a 1.25 kW GaN-LLC converter in a half-brick form factor (2.4in x 2.3in x 0.5in) with an input voltage of 70V – 150V and an output voltage of 200 – 600V. SET group is currently continuing to push the limits of DC-DC power conversion topologies by leveraging space-grade GaN devices from Freebird for new and existing space applications.

EPC (Efficient Power Conversion)
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Inside:

Powering Advanced Healthcare Devices... 32

Mobile Diagnostic Technology Can Deliver Hypertension Screening... 36

Power Requirements of Biosensor-Based Wearables... 40

Protecting Manufacturers Appliance Products from Cyberattacks... 43

Augmented Reality and the Internet of Things (IoT): Connecting to Circuit Protection... 47

Powering Advanced Healthcare Devices

Aging populations are pushing the demand for personalized, easy to use, and advanced healthcare devices, including wearables

By: Tony Armstrong, Analog Devices Inc.

The costs associated with keeping a patient in a hospital bed for a prolonged period are becoming economically unsustainable – both for the institution itself, and the patient. As a result, hospitals are looking for ways to reduce these cost burdens by getting the patient well and autonomous as soon as possible without compromising a complete recovery. One way of attaining this objective is to release the patient with remote monitoring and diagnostic devices so that they can return to their own homes. These remote patient monitoring functions typically include heart rate, blood pressure, breathing rate, sleep apnea, blood glucose levels and body temperature. Hence, this bolsters the premise that one of the current trends fueling the growth of portable and wireless medical instrumentation is outpatient care. As a consequence, many of these portable electronic monitoring systems must incorporate RF transmitters so that any data gathered from the patient monitoring systems can

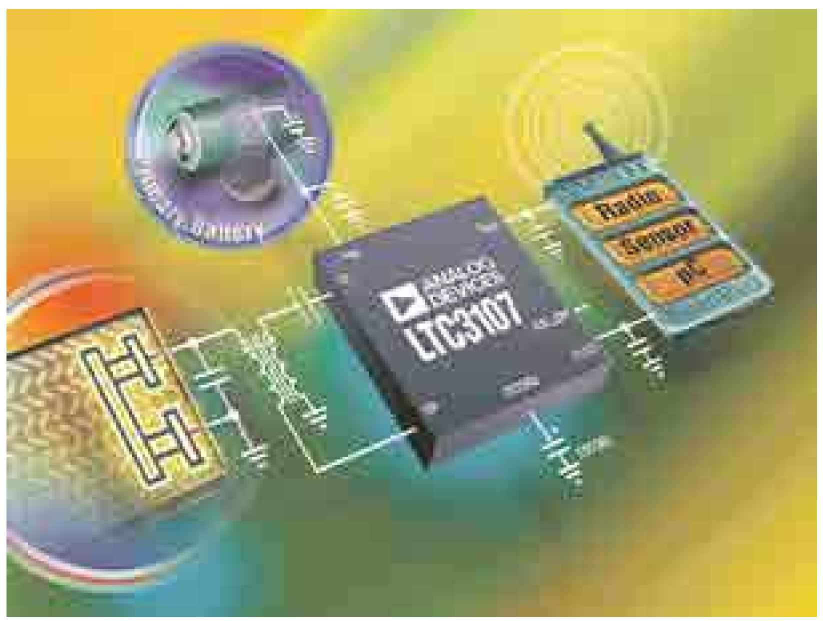

Figure 1: LTC3107 Harvesting Thermal Energy to Power a WSN and/or Charge a Battery

readily be sent directly back to a supervisory system within the hospital where it can be later reviewed and analyzed by the governing physician.

Low power precision components have enabled the rapid growth of portable and wireless medical instruments. However, unlike many other applications, these types of medical products typically have much higher standards for reliability, runtime and robustness. Much of this burden falls on the power system and its components. Medical products must operate properly and switch seamlessly between a variety of power sources such as an AC mains outlet, battery backup and even harvested ambient energy sources. Furthermore, great lengths must be taken to protect against, as well as tolerate various fault conditions, maximize operating time when powered from batteries and ensure that normal system operation is reliable whenever a valid power source is present.

Potential Solutions for Patient Monitoring Systems

It is reasonable to assume that the cost of supplying the appropriate medical instrumentation to the patient for home use is more than offset by the costs of keeping them in the hospital for these same purposes. Nevertheless, it is of paramount importance that the equipment used by the patient be not only reliable but patient proof! As a result, the manufactures and designers of these products must ensure that they can run seamlessly from multiple power sources (including backup sources) and have high reliability of the data collected from the patient, as well as 99.999% integrity of the wireless data transmission. This requires the system designers to ensure that the power management architecture to be used is not only robust and flexible, but also compact and efficient. In this manner, the needs of the hospital and those of the patient are mutually satisfied.

Fortunately, there are a number of analog companies, such as Analog Devices, that focus on bringing solutions to these problems by introducing innovative products. Since there are many applications in medical

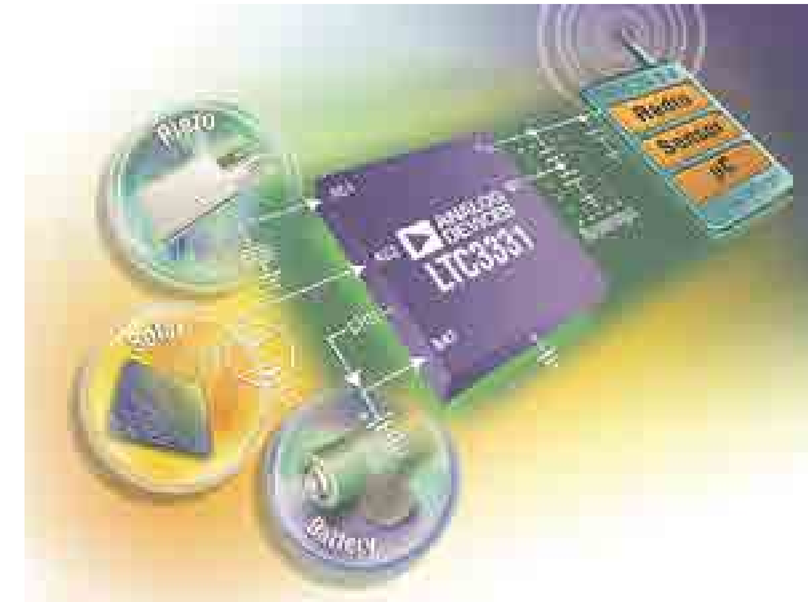

Figure 2: The LTC3331 Converts Multiple Energy Sources & Can Use a Primary Rechargeable Battery

electronic systems that require continuous power even when the mains supply is interrupted, a key requirement is low quiescent current to extend battery life. Accordingly, switching regulators with standby quiescent current less than 9 A are usually needed. In fact, some of the new systems that are run on a combination of a battery and energy harvesting as their main power sources, require their quiescent currents to be in the single digit micro-amps range, or in some case, even nano-amps. This is a necessary prerequisite for adoption in such "in-home use" patient medical electronic systems.

Although switching regulators generate more noise than linear regulators, their efficiency is far superior. Noise and EMI levels have proven to be manageable in many sensitive applications as long as the switcher behaves predictably. If a switching regulator switches at a constant frequency in normal mode, and the switching edges are clean and predictable with no overshoot or high frequency ringing, then EMI is minimized. A small package size and high operating frequency can provide a small tight layout, which minimizes EMI radiation. Furthermore, if the regulator can be used with low ESR ceramic capacitors, both input and output voltage ripple can be minimized, which are additional sources of noise in the system.

The number of power rails in today's feature-rich patient monitoring medical devices has increased while operating voltages have continued to decrease. Nevertheless, many of these systems still require 3V, 3.3V or 3.6V rails for powering low power sensors, memory, microcontroller cores, I/O and logic circuitry. Furthermore, since their operation is sometimes critical, many of them have a battery backup system should the main power supply to the unit fail.

Traditionally their voltage rails have been supplied by step-down switching regulators or low-dropout regulators. However, these types of ICs do not capitalize on the battery cell's full operating range, thereby shortening the device's potential battery run time. Therefore, when a buck-boost converter is used (it can step voltages up or step them down) it will allow the battery's full operating range to be utilized. This increases the operating margin and extends the battery run time as more of the battery's life is usable, especially as it nears the lower end of its discharge profile.

Energy Harvesting as a Power Source

Recently, there has been a great deal of innovation in the area of energy harvesting; especially using a human beings own body heat as a potential energy source to power electronic monitoring systems or recharge a battery that powers them. Such advances enable modification of the size and shape of medical electronics components so as to accommodate a milliwatt and/or microwatt power range. This means that many complex electronic systems and devices, such as wearable medical and autonomous devices, can now consume power in the range of less than 250μW.

Furthermore, wireless sensor networks with power levels in the range of μWs to 100mWs are routinely operated from battery power. However, due to the intrinsic limitations of battery power, such as the longevity of charge and where applicable, the need for periodic recharging, possibilities to use ambient energy sources such as heat or vibration for the periodic recharging of a "rechargeable" battery have presented themselves. That is, until now.

Analog Devices' Power by Linear Group has been manufacturing energy harvesting ICs for almost a decade; the first product introduced being the LTC3108 in December of 2009. The LTC3108 is an ultralow voltage DC/DC converter and power manager that is designed specifically to collect and dispense surplus energy, creating extremely low voltages from heat sources. This can be from hot to hotter or cold to colder, since all that is needed is a temperature gradient of 1°C or more.

Nevertheless, a more recent introduction is the LTC3107, a highly integrated DC/DC converter that is designed to extend the life of a primary battery in low power wireless systems by harvesting and managing surplus energy from extremely low input voltage sources such as TEGs (Thermoelectric Generators) and thermopiles.

With the LTC3107, a point-of-load energy harvester requires little space, just enough room for the LTC3107's 3mm x 3mm DFN package and a few external components. By generating an output voltage that tracks that of the existing primary battery, the LTC3107 can be seamlessly adopted to bring the cost savings of free thermal energy harvesting to new and existing battery-powered designs. Furthermore, the LTC3107, along with a small source of thermal energy, can extend battery life, in some cases up to the shelf life of the battery, thereby reducing the recurring maintenance costs associated with battery replacement. The LTC3107 was designed to augment the battery or even supply the load entirely, depending on the load conditions and harvested energy available. Figure 1 illustrates how easily the LTC3107 can harvest thermal energy to power wireless senor nodes (WSNs), and seamlessly switch over to battery power is the ambient energy source is not available.

Moreover, the LTC3331 is a multi-functional ambient energy harvester that forms a complete regulating energy harvesting solution that delivers up to 50mA of continuous output current to extend battery life when harvestable energy is available, see Figure 2. It requires no supply current from the battery when providing regulated power to the load from harvested energy and only 950nA operating when powered from the battery under no-load conditions. The LTC3331 integrates a high voltage energy harvesting power supply, plus a synchronous buck-boost DC/DC converter powered from a rechargeable primary cell battery to create a single non-interruptible output for energy harvesting applications such as WSNs and internet-of-things (IoT) devices.

The LTC3331's energy harvesting power supply, consisting of a full-wave bridge rectifier accommodating AC or DC inputs and a high efficiency synchronous buck converter, harvests energy from piezoelectric (AC), solar (DC) or magnetic (AC) sources. A 10mA shunt enables simple charging of the battery with harvested energy while a low battery disconnect function protects the battery from deep discharge. The rechargeable battery powers a synchronous buck-boost converter that operates from 1.8V to 5.5V at its input and is used when harvested energy is not available to regulate the output whether the input is above, below or equal to the output. The LTC3331 battery charger has a very important power management feature that cannot be overlooked when dealing with micropower sources. The LTC3331 incorporates logical control of the battery charger such that it will only charge the battery when the energy harvested supply has excess energy. Without this logical function the energy harvested source would get stuck at startup at some non-optimal operating point and not be able to power the intended application through its startup. The LTC3331 automatically transitions to the battery when the harvesting source is no longer available. This has the added benefit of allowing the battery operated WSN to extend its operating life from 10 years to over 20 years if a suitable ambient energy power source is available at least half-of-the time, and even longer if the ambient energy source is more prevalent.

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Mobile Diagnostic Technology Can Deliver Hypertension Screening

Wearable technology is both being adopted & accepted by the medical community as the benefits of low cost diagnosis become apparent

By: Dr Chris Elliott FREng, Leman Micro Devices SA

With consumer wearables such as FitBits and the Apple Watch established in the market and consumers who have bought these devices now accustomed to seeing their own personalised health data such as heart rate displayed on their wrists (although not to standards of accuracy required by the medical profession), is the time now right for major disruption in the medical device market?

Figure 1: A Medical Diagnostic Technology-equipped smartphone Source: Leman Micro Devices SA

As evidenced by devices like the Apple Watch, all top tier smartphone companies have identified healthcare as the next major driver for the slowing handset market and have active healthcare groups. Researchers and analysts have also been showing a keen interest in the potential that consumer health wearables could bring to medical care, and multiple reports and papers have been published. The Rise of Consumer Health Wearables: Promises and Barriers (Piwek L, Ellis DA, Andrews S, Joinson A (2016), offered conclusions others have also arrived at: "Consumer wearables can provide patients with personalized health data, which could assist with self-diagnosis and behaviour change interventions. Crucially, that same report posed the question: "Will consumer wearable technology ever be adopted or accepted by the medical community?"

The answer to the latter is almost certainly yes – but a qualified yes. Medicine is a science, and only consumer devices that are able to deliver medically-accurate vital signs measurements will be trusted sufficiently by clinicians to be of use as a means of diagnosis and monitoring.

In addition, it's important to note that the term "consumer wearable technology" when looking at the potential of devices for personalised medical self-monitoring by individuals encompasses more than just smart watches - the playing field contains smart clothing (sensors built into clothing) and smartphones, so more accurately is Mobile Diagnostic Technology.

So what will drive the case for serious adoption of Mobile Diagnostic Technology (MDT), both by consumers themselves and the medical profession? As may be expected, it's about the benefits these devices can bring to healthcare:

- For consumers, the convenience and reassurance of easily monitoring their own health and of those that they care about - detecting unknown conditions and more easily managing those that have already been diagnosed

- For the medical profession, MDTs would provide a low-cost method of providing data to assist diagnosis and management of chronic conditions, and also enable such 21st century innovations as telehealth consultations, if, and only if, vital signs (blood pressure, respiration rate, temperature, heart rate, blood oxygen levels) can be measured with the same accuracy as current equipment used by the medical profession.

Let's not forget the importance of health economics. MDTs could deliver a paradigm shift not only to consumers and the medical profession but quantifiable benefits measured by these exacting and precise economic standards. Again, the essential criterion has to be the accuracy of mobile devices - measurements of vital signs to the standards of comparable legacy standalone devices used by medical professionals is the market driver.

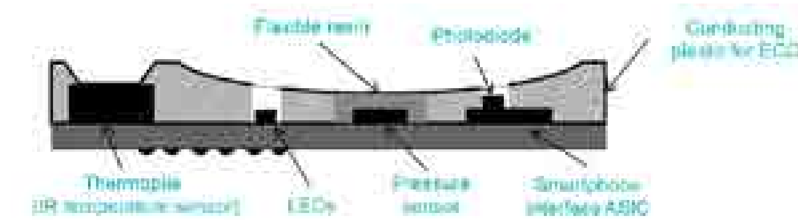

Figure 2: Sensor Block Diagram

Take the example of blood pressure measurements. Hypertension is one of the leading risk factors for cardiovascular disease, which leads to the top two causes of death in both high and low income countries. The World Health Organisation views it as the most important risk factor to be controlled and treated to lower mortality and morbidity. Awareness of the disease is greater in high income countries than middle and low income countries but there are considerable differences even in first-world countries.

High blood pressure is so important because around forty percent of the global adult population has this condition and a very significant proportion of these individuals are unaware of it. High blood pressure is one of the biggest risk factors for cardiovascular disease and stroke, but can be treated and managed reasonably simply once diagnosed. However at present, symptomless hypertensive individuals are only going to be picked up by opportunistic monitoring when they visit a doctor, population-wide programmes having been found impractical or too expensive.

The advent of MDT and particularly simple-to-use devices which enable self-measurement of the vital signs (blood pressure, blood oxygen, heart rate and others) will enable individuals to self-screen, detecting problems before symptoms appear and the condition becomes acute, or worse, causes a heart attack or stroke.

A report on a study carried out at the University of Lausanne, Switzerland (Evaluation of Potential Health Benefits and the Economic Impact of Mobile Diagnostic Technology: Case of Hypertension Screening in England. Wiesner, R. July 2015) sought to estimate the expected health benefits and costs of introducing MDT to screen a large population for high blood pressure and evaluate the economic implications and therefore cost effectiveness of this approach.

The main questions it posed were:

- How does the introduction of the MDT device in the general population affect early detection and treatment of hypertension?

- How does detection of hypertension in turn affect quantitative health outcomes (primarily for cardiovascular disease (CVD), CV-mortality and non-CV mortality) and costs on average for the whole health care system compared with the current common practice of detection at the primary care physician practice?

- What is the potential impact of the introduction of MDT smartphones on long-term health outcomes (coronary heart disease (CHD) and stroke risk) and costs, with and without early detection of hypertension?

The study devised a screening model for hypertension to assess potential health benefits and costs of introducing MDT smartphones into a larger population that is unaware of its blood pressure values. It is of course essential that the MDT is certified as medically-accurate and makes an absolute measure of blood pressure. Devices that track blood pressure after being calibrated by a conventional cuff do nothing to detect hypertension because the user will learn that from the cuff. The study compares self-screening using MDT with opportunistic base case screening by a GP and applied the model to the English population over two years from data taken from a representative sample of the Heath Survey for England (England was chosen because the integrated health service provides a large database).

The results were measured in two ways:

- The number Quality Adjusted Life Days (QALDs) that are gained (one QALD equals a day in perfect health, one day when suffering may be weighted to less than one QALD)
- The net cost of the treatment to achieve those benefits, including confirmation of the diagnosis, the treatment and the savings due to decreased cardiovascular risk.
Health economists often express the benefits and costs in discounted values because the majority of healthcare interventions cost money and produce outcomes over a period of years. Discounting is a method of taking the impact of time into account when valuing these costs and outcomes, whereby a future benefit or cost is considered to be less significant than an immediate one. This study computed both discounted and undiscounted values; for simplicity we have presented only the undiscounted values here.

The study found that using an MDT device (medically-accurate smartphone) was a cost-effective method of screening a large population for hypertension and improving health outcomes across both genders and in all age and gender subgroups (30, 40, 50, 60 and 70 years).

In terms of pure health benefits, the most QALDs were gained by male subgroups. Females also benefited, again more markedly in the younger age groups. The gender discrepancy is accounted for by differences in the incidence of hypertension and the differences in CHD and stroke risks between the two sexes, plus the differences in mortality (cardiovascular and non-cardiovascular): females have lower risks and consequently have lower benefits from hypertension screening and treatment).
MDT intervention is cost-effective when compared with conventional screening for males and females in all age groups, especially for males. The model showed an average gain of 104 QALDs for men and 68 QALDs for women, with an average cost per QALD of £0.32 and £1.53 respectively. This average cost per QALD gained was very significantly below the cost-effectiveness threshold of around £55 recommended in the UK, and significantly cheaper than current practice.

This masks the most striking effect, which is that the greatest benefit occurs to younger users, up to 178 QALD for males and 118 for females. In other words, the average young man who buys and uses an MDT will live at least 6 months longer. That is on average, for some there will be little gain but for others it will be much greater. If discounting is considered, the greatest benefit and most cost-effective treatment is for men on their 30s and 40s, because the benefits generally occur later in life so are more heavily discounted for younger people.

The study showed clear health benefits and the cost effectiveness of Medical Diagnostic Technology used to screen for hypertensive individuals in a population, as opposed to random and opportunistic screenings during a primary care visit. In terms of subgroups, there were significantly higher benefits and lower costs for males, while the highest health benefits were to be gained by younger individuals.

The Lausanne study found that screening with MDTs could significantly improve detection and treatment rates and concluded that MDT was cost-effective for all age and gender groups. The study also concluded that there is a large potential for a private-public partnership, where screening is provided through MDT-enabled smartphones and the healthcare system provides medical treatment. The same intervention transposed to different populations (other than the predominantly Caucasian, high income one studied) to one with a known and greater prevalence of hypertension (such as an Asian or African population) for example, would likely yield results showing an even greater incentive for the introduction of MDT.

If MDT devices to measure vital signs to medical accuracy are accessible, affordable to the majority, and widely adopted, they present a hitherto unavailable opportunity to tackle one of the world's leading causes of mortality and morbidity.

Looking at the future for MDTs, it is clear that the potential impact is huge and market disruption is inevitable. In the case of, for example, smartphones able to measure blood pressure and other vital signs to medical accuracy, the data gained from measurements on this scale is of great interest to many organisations in the healthcare eco system (telehealth providers, pharmaceutical companies, health insurers, healthcare research and others). Not only that - the ability to obtain such data from a smartphone will provide the smartphone companies incorporating this technology into next-gen handsets with the next compelling smartphone feature – after all, who can now imagine a smartphone without a camera?

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Power Requirements of Biosensor-Based Wearables

Extending Battery Life of Wristband Wearables for Patients in Need of Continuous Monitoring

By: Rakesh Sethi, Vice President, General Manager R&D, TDK U.S.A. Corporation

The medical field has introduced an increasing number of portable and wireless medical devices for in-home patient care as it witnesses broader adoption of tele-medicine. With the advent of increasingly miniaturized and powerful electronics, we foresee the adoption of adapted wireless wristband wearables for medical/wellness use cases to supplement traditional wireless portable devices.

Figure 1: Examples of wearable designs that can provide enhanced battery life via low-powered design.

Consider the following events that have occurred over the last decade:

Exponential rise of healthcare costs in the United States:

- Americans spend an average of ~$7 trillion annually on healthcare costs, equal to 27% of GDP.
- With all this spending, the United States ranks only 37th in worldwide quality of care
- There continue to be chronic issues with the high cost of tests, re-hospitalizations, and a sense of a lack of ownership.
- Like other developed nations, America is experiencing an increase in its aging population: 130 million Americans are now on Medicare and Medicaid.
- Today's Americans who are 65 years old are expected to live another 19 years (up from 15 years for prior generations of 65-year-olds).

And a shift towards digital and connected health:

- 75 million Americans have adopted tele-medicine.
- Today, there is only a 3% attach rate for wearables.

Modern wearable technologies offer the promise to quantify physical fitness and health. The state of a user's fitness may be judged by exogenous data such as posture, gait, reaction time, meal consumption time, sleep quality and cognitive overload. Most consumer-grade wearables can currently quantify a few of these parameters, but they are not designed to provide for meaningful correlations to be made to well-being. Companies in the electronic component industry are developing new technologies to provide a more comprehensive view of these parameters, along with relevant feedback and insights.

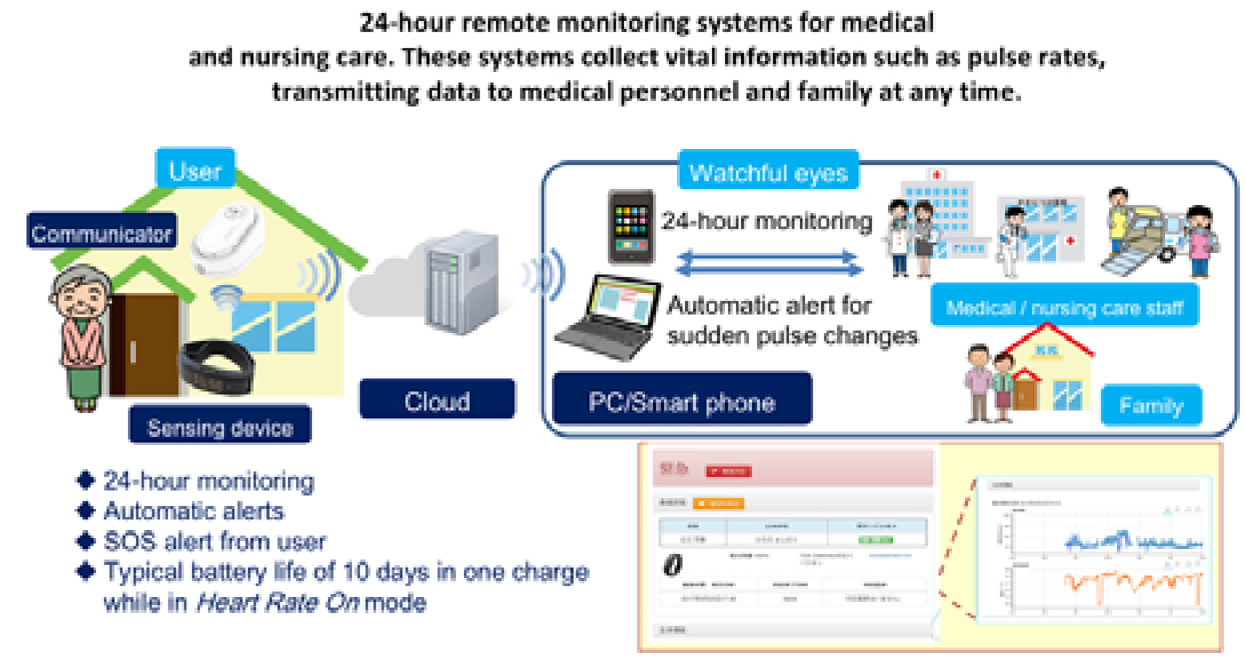

Figure 2: This holistic data may be used by researchers to develop correlations to activity, cognition, productivity and reduction of stress

For example, there is an opportunity for wearable devices to be designed to support medical researchers and medical device companies conducting comprehensive research aimed at disease prevention and diagnostics. The main goal of these development and testing efforts will be to provide the holistic integration of data analysis techniques and links to the healthcare providers, to ultimately improve the health and well-being of patients. These clinical studies that could rely on wristband wearables for collecting key data require the wearables to be extremely power-conscious. This will ensure that critical data is captured periodically without the necessity of recharging the devices during the course of the trials. Trials may last one to two weeks or longer, thereby requiring the wearables to provide uninterrupted data beyond what is the current, typical battery life for wearables operating in pulse detection mode.

Quantification of bio-signals: Major industry players including TDK are developing technologies designed to collect and evaluate bio-signals emerging from the human body that may aid in the early detection of cognitive decline which could lead to diseases such as dementia, Alzheimer's and related mental-health issues. For example, sensors are being developed to evaluate a mix of voice and heart rate data.

Quantification of risk factors leading to dementia and Alzheimer's: Most primary risk factors for the diagnosis of dementia are genetic, vascular, lifestyle-related and protective. Genetic factors may have several links to lifestyle conditions such as hypertension, diabetes, obesity and hyperlipidemia. Lifestyle factors include social isolation, physical inactivity, smoking and irregular sleep habits or patterns. Protective factors that are potentially within our control are physical exercise, leisure activities, diet and a rich social network. Several studies (for example, Lancet Neurol,

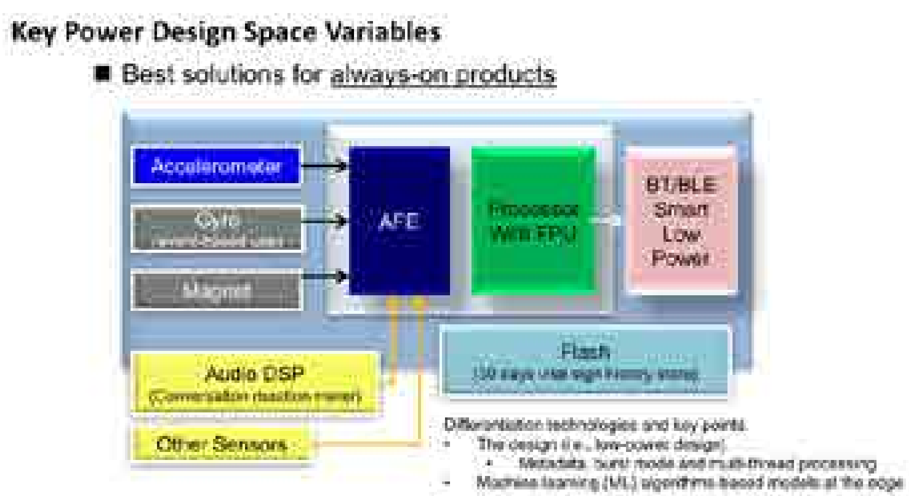

Figure 3: These components are key in a wristband wearable design with the desired always-on functionality

2014) have pointed to strong links between Alzheimer's and lower education levels, mid-life hypertension, obesity, depression and smoking. Increasing both physical activity and social interactions have been noted to support improved outcomes.

Researchers are seeking to collect, quantify and seamlessly transfer vital signs data into aggregated data stores for analysis to formulate wellness strategies.

Power design requirements for medical-use wearables

The current power design challenge of achieving a minimum two-week life span for 50mAh to 200mAh battery-based devices with pulse-measuring capability is daunting. Key differentiators for low-power design include the choice of sampling frequency of the MicroController Unit (MCU) (such as an ARM Cortex-M4), to include or not include a Floating Point Unit (FPU), and the operating temperature (10 to 40 degrees C). The ability of the MCU to process multiple data streams simultaneously is also important. Other key considerations are the optimization of MPU processing, bias and leak current time. Further design considerations that impact the ability to reduce power consumption in wearables include how much of computation is done at the edge vs the cloud. Furthermore, the communication payload design is modified such that an optimum packet of metadata is transferred to the host or the cloud. These design choices can lead to a significant reduction of power dissipation.

Conclusion

Scientists in R&D labs have considered the best designs for low-power devices for medical/wellness usage, and the wearables we are developing benefit from this innovation and rigorous testing. We have found the key factor in prolonging battery life for wearables is the choice of MCU and the achievement of a low-sampling rate at 20 hertz. Additionally, the balance between the amount of data to be processed at the edge versus on the host contributes to power dissipation improvement. For example, at its current stage of development, the TDK Silmee™ family of wearables has achieved a reliable operation for 10 to 14 days per charge. This lifespan supports medical researchers and medical device companies that are conducting comprehensive research aimed at disease prevention and diagnostics, opening up new possibilities for using wearables with advanced sensors that collect and evaluate human bio-signals that may aid in the early detection of cognitive decline that could lead to diseases such as dementia, Alzheimer's and related mental-health issues.

TDK USA Corporation
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Protecting Manufacturers Appliance Products From Cyberattacks

Most in-home appliances cannot be fixed once they are infected

By: Alan Grau, VP of IoT, Embedded Systems, Sectigo

Cyberattacks are on the rise worldwide. Most of the attacks that generate big press coverage are very dramatic and well-documented. We have all read about malware attacks, Denial of Service attacks, which shut down factories, governments and large international businesses - and even portions of the Internet - and ransomware attacks that hold small businesses hostage or take advantage of hospitals, local governments, schools, and other easy-to-infiltrate targets.

In addition, there are entire classes of lesser-known attacks on cars, planes, utilities, etc. One of the most classic is the StuxNet attack on Iran's uranium enrichment industry that took control of the rapidly spinning centrifuges themselves and caused them to essentially self destruct. Another well-documented attack is the Mirai botnet attack that took control of millions of "slave" devices, forcing them to send out more malware and packet flood attacks, crippling a variety of websites and Internet services.

Figure 1: Unless protected by the appropriate cyber security technologies, appliances – including refrigerators – can host and spread a wide range of malware and computer viruses

These kinds of botnet attacks are insidious and can also target any connected appliances and small IoT devices within a home or a business.

As they are not an obvious vector for cyberattack, the embedded electronics inside appliances present an easy path of entry. It's already been happening. According to Proofpoint and Business Insider, one of the first refrigerator incidents occurred in late 2013 when a refrigerator-based botnet was used to attack businesses.

Many manufacturers essentially

ignore these types of appliance botnet attacks because, in most cases, appliances infected with botnet malware don't really have much effect upon the appliance's day-to-day operation. In fact, if a "smart" refrigerator gets infected by a bot, the homeowner might not even notice anything wrong.

However, these connected-appliance based cyberattacks are not limited to just refrigerators – and they are rarely one-off incidents. Almost any type of appliance can be hacked and used to host a botnet that could attack online targets. According to Wired Magazine, a botnet of compromised water heaters, space heaters, air conditioners and other big power consuming home appliances, could suddenly turn on simultaneously, creating an immense power draw that could cripple the country's power grid.

A botnet attack can also impact the end user. What if the infected refrigerator decides to turn off and not turn back on? Without a way for the home user, or even a skilled refrigerator repairperson, to diagnose and cure a malware infection, all the food inside could go bad and the homeowner would be forced to replace their existing infected refrigerator with a new one. And, if the malware is still

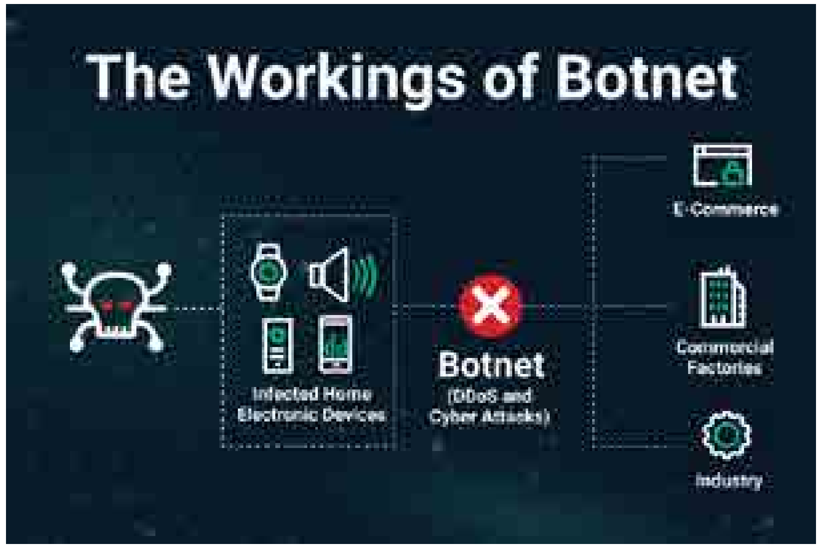

Figure 2: A bad actor or cyber criminal can send infected messages to a home or business network that target various appliances or machines. Once infected, that machine is under the control of the bad actor and can be used to send out thousands of infected messages to new targets worldwide

hiding inside the home's WiFi modem, central PC, or network, the minute the homeowner plugs in the new refrigerator, it would be infected and instantly compromised as well!

Why Can't the Homeowner Fix Their Infected Appliances?

There are two reasons that, once infected, most appliances cannot be disinfected by the end user in a home or a business.

First, there is no input/output connections or display screen to allow the home user to navigate inside the connected appliance's CPU. Most appliances have no connection for a keyboard or a mouse to enable the end to find and remove bad software, download new improved software or middleware, or to re-program the unit. Nor is there a connection for a display to enable the user to see and diagnose what is happening with their appliance or to review the appliance's software to find the infection.

Second, unlike most home or work PCs running on Windows, iOS or Linux, there is not enough memory and processing power to run a typical anti-virus or anti malware program. Instead of a big, hundreds of gigabytes in size operating system, most appliances run what is called an RTOS (Real Time Operating System), which is extremely small and actually resides inside the appliance's chips and processors.

What is a Bot?

Figure 3: It is critical that connected appliance and device manufacturers protect all the end nodes on the IoT, not just servers and network nodes

A bot, quite simply, is an infected computer. Many cyberattacks, like the Mirai malware and the Dyn attacks, infect a network of computers and computer devices, including "smart" connected devices such as home appliances, security cameras, baby monitors, air conditioning/heating controls, televisions, etc., and turn them all into compromised servers.

These compromised servers then act as nodes in an attack and together create a botnet. They can participate in a variety of coordinated attacks, infecting other devices and expanding the network of bots, or participating

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Models	Power (W)	Output (VDC)	Input (VDC)	Output (A)	Effizienz
THN 15-2411WI-A1	15	6	9–36	3	86 %
THN 15-4811WI-A1	15	6	18–75	3	87 %
THN 20-2411WI-A1	20	6	9–36	4	89 %
THN 20-4811WI-A1	20	6	18–75	4	89 %
THN 30-2411WI-A1	30	6	9–36	6	89 %
THN 30-4811WI-A1	30	6	18–75	6	90 %

CB Scheme UL 60950-1
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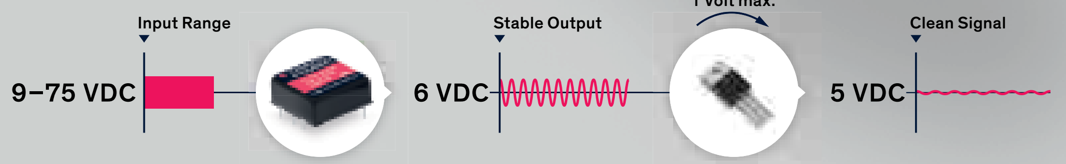

in Distributed Denial of Service (DDoS) attacks.

Without any apparent symptoms or notice, a criminally enhanced refrigerator could be generating and sending out thousands of attacks every minute. In addition to the homeowner never realizing what is going on, these attacks may be unstoppable until the machine itself is powered down or disconnected from the web.

Additionally, the infected refrigerator could spread malware from the kitchen to the home's "smart" TVs, to the home's computer networks, to other smart devices in the home, and even to connected smart phones. All of these computing targets could then be transformed into malicious bots that continue to attack other devices, further propagating the botnet or could all be instructed to send a flood of messages to a single target as part of an overwhelming DDOS attack.

Protecting the Edge Is up to Manufacturers

So how do appliance manufacturers combat the threat of botnets? What can they do to prevent appliances and connected edge devices from becoming infected?

Unfortunately, as detailed above, end users and repair people really have no power to fix this problem. This means that it is up to device manufacturers to protect against these attacks.

Security needs to start at ground zero in the actual design process for the refrigerator itself, in the manufacturing plant, as well as in the supply lines and factories that furnish the various electronic components and control surfaces integrated into the appliances.

As most appliance manufacturers get their control sub-assemblies from a wide network of smaller manufacturers, sometimes with a worldwide supply chain, these suppliers need to make sure that the chips and sub-assemblies they use are secure from hacks.

Here are two critical security practices that should be implemented by appliance makers:

- **Secure Remote Updates and Alerts** – Validate that the firmware inside the device is authenticated and unmodified before permitting installation of any new firmware updates. Updates ensure the incoming software components have not been modified and are authenticated software download modules from the appliance manufacturer.
- **Embedded Firewall** with blacklist, whitelist and Stateful Packet Inspection (SPI) support – Protect appliances and edge devices from attacks by building firewall technology directly into the appliance. An embedded firewall can review incoming messages from the web or over the home network and, via a built in and regularly updated blacklist, reject any that are not previously approved. SPI filtering rejects packets that attempt to exploit weaknesses in the TCP protocol as part of denial of service attacks.

Most consumer and device manufacturers are familiar with the potential for attacks on smart devices like door locks, baby monitors, and home thermostats, but this risk awareness needs to expand to all types of connected systems – including appliances.

An infected refrigerator sending out malware is not just a funny story. Ensuring the security of these devices is necessary to protect home networks, slow the spread of malware, and even protect credit card numbers or other personal data stored in smart home devices.

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Augmented Reality and the IoT: Connecting to Circuit Protection

Circuit protection technologies and board layout strategies that promote safety, reliability and connectivity

By: James Colby, Manager of Business Development, Littelfuse, Inc.

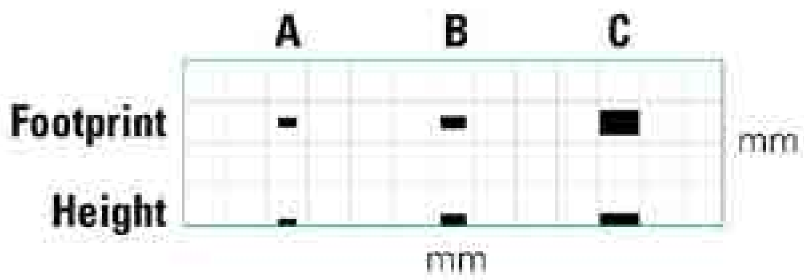
For those of us who wear glasses for vision correction, we are used to seeing the world through lenses. However, new technologies will allow a virtual world to be laid on top of the real world that we normally see. In other words, the lenses will become displays that allow us to see the "real" world that is augmented with overlaid information and images, creating an Augmented Reality (AR). An example would be the integration of navigation into the AR glasses to allow a user to walk through town with turn-by-turn instructions (visual or verbal) to help them easily get to their destination. Other examples include facial recognition, fitness tracking, first-person photos and videos, as well as health-sensing and travel applications (**Figure 1**).


Figure 1: Augmented Reality (AR) glasses displaying airline flight information

With the continued decrease in the size of microprocessors, and the inverse increase in computing power, it is now possible for the lenses to become displays that enhance the world that we see. And the forecast is bright indeed. There are forecasts that predict growth of about 150% between now and 2024. In order for there to be broad market acceptance, the products will have to deliver on the promise of the technology to enhance our perception of the world around us, and do so with quality and reliability throughout their functional lifetime.

The integration of these AR glasses into our lives as well as the broader IoT world demands advanced technology to protect the sensitive electronic components and circuits needed to maintain functionality and IoT connections. Since the glasses will be worn on our faces and next to the skin, they are constantly bombarded by static electricity generated by close interaction with the user. Without proper protection, the device's sensor circuits, battery-charging interfaces, buttons or data I/Os could be damaged by electrostatic discharge (ESD).

This article will discuss advanced circuit protection technologies and board layout strategies that safeguard wearable devices and their users. Applying these recommendations early in the design process will help today's circuit designers improve the performance, safety and reliability



	Form Factor	Footprint (mm)	Height (mm)	ESD Suppression Device (Product Examples)
A	01005 Flipchip	0.44 x 0.23	0.181	Discrete Diode (SP1020/SP1021-01WTG)
B	0201 Flipchip	0.62 x 0.32	0.275	Discrete Diode (SP1005-01WTG)
C	Flipchip	0.94 x 0.61	0.300	5 Channel uDFN Array (SP1012-05WTG)

Figure 2: As the sophisticated chipsets used in wearable devices get smaller and faster, the form factor and performance of the circuit protection devices must do the same

of their wearable technology designs and help build a more reliable IoT ecosystem.

Robust ESD Protection in a Small Form Factor

Providing adequate circuit protection for wearable devices has its own challenges caused by the need to continue shrinking the processors, memory, etc. that allow the AR glasses to have some much computing power. In the past, large diode structures and large package sizes (e.g., 0603 and 0402) were needed to achieve excellent ESD performance and low clamping voltages. However, with continued improvements in wafer fabrication processes and back-end assemblies, it is now possible to have very robust ESD protection in a small form factor. For example, a general purpose 01005 transient voltage suppression (TVS) diode from Littelfuse can withstand 30kV contact discharge (IEC 61000-4-2). It packs that robust ESD performance into a package with dimensions of only 0.4mm x 0.2mm! (See **Figure 2**.)

Why is robust ESD protection so important? While the test level used in the Human Body Model (HBM) specification for modern integrated circuits can reach 2,000V, most application designers ensure that their system meets at least Level 4 of the IEC 61000-4-2 test standard (8kV contact, 15kV air discharge). In many examples of portable devices and wearables, the contact discharge level has been raised to 15kV or 20kV, with some companies setting it as high as 30kV. This "mismatch" between what the processors can survive, and what they'll experience in the field, needs to be addressed with robust ESD suppression technologies like those offered by Littelfuse, to ensure long-term operation and reliability.

Selecting and applying modern ESD technologies can result in significant board area savings. For example, the most common discrete form factor for ESD Diodes is the SOD882 package, which has an outline of 1.0 mm x 0.6 mm. By moving to the 0201 form factor (0.6 mm x 0.3 mm), the designer can save approximately 70 percent in board area. Furthermore, moving to the 01005 outline yields a savings of over 85 percent compared to the SOD882 package. (See **Figure 3** and table in **Figure 2**.)

Despite the reduced form factor of wearables, today's ESD diodes are able to deliver outstanding performance without any reduction in ESD performance. In fact, discrete semiconductors with a small form factor can have the same level of ESD robustness (30kV contact discharge) and low clamping performance (dynamic resistance < 1 Ω) as their larger counterparts (e.g., SOD323 and SOD123). However, the small size of the component may present manufacturing challenges. At 0.4 mm x 0.2 mm, the 01005 package will require well-designed board treatments such as solder pads and thick stencils to ensure that the component does not slide or "tombstone" during the reflow solder process.

Figure 3: Products like the SP1020 from Littelfuse pack robust ESD protection in a very space efficient 01005 package; ideal for applications like AR Glasses where there is very little board space available

Selection and Configuration Factors for TVS Diodes

As previously discussed, today's ESD diodes offer a variety of performance benefits for Augmented Reality applications led by a small form factor. The following recommendations for the selection and configuration of ESD Diode technologies will help design engineers optimize their future circuit designs.

Choosing unidirectional or bidirectional diodes. ESD diodes are available in unidirectional or bidirectional configurations. Unidirectional diodes are typically used for DC circuits, including pushbuttons and keypads, as well as digital circuits. Bidirectional diodes are used in AC circuits, which may include any signal with a negative component greater than -0.7 V. These circuits include audio, analog video, legacy data ports and RF interfaces.

Whenever possible, design engineers should choose unidirectional diode configurations since the performance during negative-voltage ESD strikes is improved. During these strikes, the clamping voltage will be based on the forward bias of the diode, which is typically less than 1.0 V. A bidirectional diode configuration provides a clamping voltage during a negative strike that is based on the reverse breakdown voltage, which is higher than the forward bias of the unidirectional diode. Thus, the unidirectional configuration can dramatically reduce the stress on the system during negative transients.

Determine diode location. Most circuits do not require board-level ESD Diodes at each of the IC's pins. Rather, the designer should determine which pins have exposure to the outside of the application where user-generated ESD events are likely to occur. If the communication/control line can be touched by the user, it could become a pathway for ESD to enter the integrated circuit. Typical circuits include USB, audio, button/switch, RF antennas and other data buses. Incrementally adding these discrete devices will take up board space, so it is important to reduce their size to fit 0201 or 01005 outlines. For some wearable applications, there are also space-saving multi-channel arrays available.

Consider routing of "ESD" trace. To protect the IC's pins with an ESD Diode, there are several key considerations for trace routing—from I/O to ground. Unlike lightning transients, ESD does not unleash a large amount of current for a long duration of time. To effectively handle ESD, it is important to move the charge from the protected circuit to the ESD reference as quickly as possible. The length of the trace—from the I/O line to the ESD component and from the ESD component to ground—are the overriding factors, not the width of the trace to ground. The length of the trace should be kept as short as possible to limit parasitic inductance. This inductance would result in inductive overshoot, which is a brief voltage spike that can reach hundreds of volts if the

Figure 4: Low-capacitance bidirectional discrete TVS diode arrays, including the SP3022 Series, provide symmetrical ESD protection for high-speed data lines when AC signals are present. They are also designed for consumer electronics such as fitness bands, smart watches, smartphones, tablets and eReaders

stub trace is long enough. Recent package developments include µDFN outlines that fit directly over the data lanes to eliminate the need for stub traces entirely.

Understand HBM, Machine Model (MM) and Charged Device Model (CDM) definitions. HBM, MM and CDM are test models for characterizing the ESD robustness of the integrated circuits that run the portable device or wearable, including the processor, memory and ASIC. They are used by the semiconductor supplier to ensure the robustness of the circuits during manufacturing. The current trend is for suppliers to reduce the voltage test levels since it saves die space and because most suppliers adhere to excellent in-house ESD policies.

While strict ESD policies benefit the supplier, the application designer ends up with a chip that is very sensitive to application-level ESD, but must not be allowed to fail due to field-level or user-induced ESD. To succeed, the designer must select a board-level device that is robust enough to protect against intense electrical stresses yet offers low enough clamping to protect the highly sensitive integrated circuitry. When evaluating an ESD protection device, consider the following parameters:

1. Dynamic resistance: This value is a measurement of how well the diode will clamp and divert the ESD transient to ground. It helps determine how low the resistance of the diode will be after it switches on. The lower the dynamic resistance value, the better.

2. IEC 61000-4-2 rating: The ESD Diode supplier determines this value by increasing the ESD voltage until the diode fails, which characterizes the robustness of the diode. For this parameter, the higher the value, the better. A growing number of Littelfuse ESD Diodes can reach as high as 20kV and 30kV contact discharge, which far exceeds the highest level of the IEC 61000-4-2 (Level 4 = 8kV contact discharge).

Conclusion

The nascent market for Augmented Reality Glasses offers many interesting and useful opportunities for us as consumers. But, all those amazing capabilities will not be recognized if the glasses are not able to survive the daily bombardment of ESD transients generated by the wearer of the glasses. For this reason, it is more important than ever to consider ESD protection and proper board layout practices early in the design process to ensure that the application is reliable with a useful lifetime. Circuit protection devices like ESD Diodes are designed to be highly robust even with small form factors; preventing ESD damage to the AR headset and providing the user with years of reliable service. Designing in hardy protection for the sensitive integrated circuitry inside the wearable device is necessary to maintain the value proposition of the IoT ecosystem.

Littelfuse, Inc.
www.littelfuse.com

Defining the Internet of Things

By: Jason Lomberg, North America Editor, PSD

The Internet of Things (IoT) is really more of a concept than a tangible device – the IoT comprises billions of palpable objects, but no one will “switch it on” in the same way the ARPANET officially began in October of 1969. Of course, no one has to flip a switch because the IoT is already here (albeit in its infancy). So it’s worth asking – what’ll a mature IoT look like?

In a way, the IoT was inevitable. The Internet is about connection, so as widgets and portable devices – to say nothing of clothing, cars, TVs, and everything we interact with daily – get more sophisticated, they’re fated to join this burgeoning worldwide network. And as technology becomes more automated, it needs more sophisticated methods to communicate. Before long, everything literally communicates with everything, by design and by happenstance.

In its IoT primer, “The Internet of Things: Making sense of the next mega-trend,” Goldman Sachs noted that the IoT is emerging as the third wave in the development of the Internet, with 28 billion “things” connected by 2020.

And the industry largely reflects this linear rate of growth. Arker Trewin, Senior Director of Content and Communications at Aria Systems, mused that “The Internet of Things is big news because it ups the ante: ‘Reach out and touch somebody’ is becoming ‘reach out and touch everything’.”

Golden Sachs further likens the IoT to the industrial revolution, with business amounting to $2 trillion by next year.

But I think it’s more than the number of devices or dollars. The IoT is almost a state of being, a ubiquitous system that most of us won’t even think about, but we’ll interface with it constantly. It’ll become part of our daily routine, molding and shaping itself to accommodate millions of users.

I think Eric Schmidt, Chairman at Google, nailed this philosophical aspect:

“The Internet will disappear. There will be so many IP addresses, so many devices, sensors, things that you are wearing, things that you are interacting with, that you won’t even sense it. It will be part of your presence all the time. Imagine you walk into a room, and the room is dynamic. And with your permission and all of that, you are interacting with the things going on in the room.”

That is what the IoT will look like – more than a mere network, it’ll become an extension of us. We’ll be an integral part of the process, but it’ll persist on its own (with some help on the power side).

It’s an exciting time to be in this industry, and I’m thrilled to see the IoT evolve and become an indispensible part of our daily lives.

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