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Bodo´s Power Systems®

Electronics in Motion and Conversion

August 2017

Viewpoint 4
Wide Band Gap Semiconductors

Events 4

News 6-11

Blue Product of the Month 12
HiPak Modules in Chopper Configuration for 3300V and 4500V
ABB/Semiconductors

Market 14
PCIM Asia 2017 – Breaking New Ground
By Min XU, Bodo's Power Systems China

Cover Story 16-20
Side Wall Gate - Moving on from Trench
By Neil Markham, Hitachi Europe Ltd.

IGBTs 22-23
An Intelligent IGBT Module for Single-Ended Induction Heating Applications
By Wonjin Cho, Staff Application Engineer; Dino Ge, Marketing Manager; Bum-Seok Suh, Vice President of IPMs and IGBTs, Alpha and Omega Semiconductor, Inc.

IGBTs 24-28
Current Progress at Si IGBTs in the Voltage Range up to 1200V
By Dr.-Ing. Anton Mauder, Infineon Technologies AG

Automotive Power 30-33
Automotive PCB Properties and Design Considerations
By Dora Yang, PCBCart

Packaging 34-35
Choosing Among Ceramic Substrates for Power Circuits
By Olivier Mathieu, Product Innovation Manager, Rogers Corp., Power Electronics Solutions (PES)

Magnetics 36-38
Magnetics Design Part I
By Dr. Ray Ridley, Ridley Engineering Inc.

Measurement 40-49
Don't let your Digital Storage Oscilloscope betray you (Part 2)
By Dr.-Ing. Artur Seibt, Vienna

New Products 50-56

The Gallery

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Events

Thermal Management 2017
Denver CO, USA August 8-9
www.thermalnews.com/conferences

EPE ECCE 2017
Warsaw, Poland, September 11-14
www.epe2017.com

EV Tech Expo 2017
Novi MI, USA, September 12-14
www.evtechexpo.com

HusumWind 2017
Husum, Germany, September 12-15
www.husumwind.com

PCNS 2017
Brno, Czech Republic, September 12-15
www.passive-components.eu/pcns

Wide Band Gap Semiconductors

Wide Band Gap Semiconductors have been here for quite a while, but now Power Electronics is focused on these devices. They can reduce losses versus established silicon designs. GaN has traditionally been used in high frequency applications, but now GaN is reported with about a 1000 volts breakdown. SiC is capable of several kV – useful for even the traction systems of modern high speed trains.

In general, we are seeing a trend away from combustion-engine automobiles and towards electric vehicles. This is a mega change for the automobile industry. Moving away from combustion engines will cause industry changes of a similar nature to those in the history of steam locomotives. Electric and diesel took over and the old names in locomotive manufacturing disappeared. Now we see Elon Musk at Tesla overcoming the barriers of traditional automobiles by a clear focus on total electric cars.

While battery performance does continue to improve, wide band gap devices will help with lower losses. The goal is to a longer driving distance with one fully charged battery. Full- electric vehicles in our cities will do much to reduce pollution – high smog levels will disappear and health will improve in cities around the world. I remember a time, before catalytic converters became mandatory for combustion cars, when I looked down from the Griffin Observatory in Los Angeles to the Pacific Ocean. One could see clouds of smog and you hardly could imagine that the Ocean was there. Even my throat felt the pollution.

But that was about four decades ago, and as I visit California frequently, I notice the significant change today, and more will come through electric vehicles. Other countries, such as India and China, push ahead with EV's for similar reasons.

Our next meetings are conferences such as the EPE ECCE in Warsaw, Poland and the ECCE in Cincinnati, USA. These conferences focus on power semiconductors and their applications. Wide-band-gap devices are at the leading edge of new designs for reduced losses and improved efficiency.

This issue has the first article from Dr. Ridley. Over the coming year, Dr. Ridley will contribute to Bodo's Power a special series of articles on magnetics design, focusing on the basics of design, practical manufacturing aspects, and such advanced topics of proximity losses and modelling. To learn more, check out Dr. Ridley's video on magnetics at: **http://www.bit.ly/2rUZc4C**

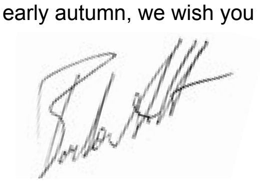
A wide range of additional information can be found in the papers and articles on Dr. Ridley's Power Supply Design Center at:
http://www.bit.ly/2rlcfha
We very much look forward to our collaboration.

Bodo's Power Systems reaches readers across the globe. If you are using any kind of tablet or smart phone, you will find all of our content on the new website www.eepower.com. If you speak the language, or just want to have a look, don't miss our Chinese version: www.bodospowerchina.com

My Green Power Tip for August:
Strawberries are at their best ! Eat them while you pick them in the fields. Some people, possibly with dental problems, turn them into a smoothie - save the energy of powering a smoothie maker - just pick and eat.

There is still time for a nice vacation during late summer and early autumn, we wish you well.

Best Regards



Roofing Ceremony in Neubiberg

Infineon Technologies AG celebrated the roofing ceremony for the expansion of the company's headquarter in Neubiberg. After the first groundbreaking at Campeon in July 2016, the building will be completed by the end of this year. Moving in will start early 2018. The building offers space for around 800 people and is directly linked to the positive development of Infineon during the last years. For CFO Domink Asam, the investment underpins the confidence in the Campeon site.

www.infineon.com

SFBAC IEEE PELS Wins three 2017 Best Chapter Awards

The SFBAC-PELS (combined Santa Clara Valley, San Francisco, and Oakland/East Bay - Power Electronics Society) is pleased to announce that it has been named a winner of the IEEE PELS Global Best Chapter Award, the IEEE Region 6 (Western US) Best Chapter Award, and the IEEE Santa Clara Valley Section Best Chapter Award. The IEEE Power Electronics Society Best Chapter Award was established in 2000 to recognize excellent service by a PELS Chapter – also joint with other societies – to its members and to the power electronics community. Criteria are substantial chapter accomplishments in fields such as: local service to PELS members; chapter meetings with technical, educational or networking contents, including meetings with invited distinguished lecturers from PELS; offering networking opportunities between local industry and academia, between students, young and senior engineers; power electronics related contribution to IEEE activities, such as establishment and promotion of IEEE milestones; essential local support of international IEEE PELS power electronics conferences; visibility e. g. related to high numbers of members and participants in chapter meetings, gain of new PELS members, public relations including website and publications; networking with local societies with a similar scope.

"We are delighted to win the unprecedented 'triple crown'", said Brian Zahnstecher, chair of the SFBAC-PELS chapter and Principal of the consulting firm PowerRox (www.powerrox.com). "The awards are recognition of the effort by the team of passionate power electronic professionals who revitalized the Bay Area chapter. In slightly more than a year since reestablishment of the chapter, we have organized and conducted 12 technical seminars, 2 workshops, and a webinar attended by hundreds of Bay Area power electronics professionals and students. We would like to thank IEEE and PELS for the awards and look forward to building on our success in the future."

pels IEEE POWER ELECTRONICS SOCIETY Powering a Sustainable Future

https://ewh.ieee.org/r6/scv/pels/index.html

PSMA Roadmap Charts Advances in Power Conversion Technologies

The Power Sources Manufacturers Association (PSMA) announces the availability of the 2017 edition of its The Power Technology Roadmap. The report, which forecasts the power technology and power delivery trends through 2021, includes a printed report along with a feature-rich USB memory drive containing recorded webinars with up-to-date explanations of the information contained in the final report. The recordings are extremely helpful in that they enable the listener to understand the context and the subtext of the report materials, as explained by the actual presenters. PSMA Regular and Associate member companies have been sent copies of the printed report and USB memory drive versions of 2017 edition as a benefit of their membership.

New to the PSMA Power Technology Roadmap report is a section titled: "Component Technologies." This section contains overviews of each component segment as applicable to power electronics. Component segments represented include Silicon IGBTs, MOSFETs, Silicon Carbide (SiC) devices, Gallium Nitride (GaN) devices and integrated circuits (ICs). For passive components, such as capacitors and magnetics, summaries from PSMA webinars related to these segments are also included.

www.psma.com/publications

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ML610Q772-B03: Microcontroller for MP

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www.rohm.com/eu

Leti and Fraunhofer Team up to Strengthen Microelectronics Innovation

Two leading European research institutes announced their new collaboration to develop innovative, next-generation microelectronics technologies to spur innovation in their countries and strengthen European strategic and economic sovereignty.

Leti, a research institute of CEA Tech in Grenoble, France, and the Berlin-based Fraunhofer Group for Microelectronics, Europe's largest R&D provider of smart systems, will initially focus on extending CMOS and More-than-Moore technologies to enable next-generation components for applications in the Internet of Things, augmented reality, automotive, health, aeronautics and other sectors, as well as systems to support French and German industries.

The agreement was signed today by Leti CEO Marie Semaria and Fraunhofer Group for Microelectronics Chairman Hubert Lakner during Leti Innovation Days, which are marking Leti's 50th anniversary.

"The ability to, one, develop key enabling technologies that overcome the formidable technical challenges that our leading technology companies will face, and, two, transfer them quickly to industry, is an essential focus for research institutes and industrials in France and Germany," Semaria said. "Building on our previous, successful collaborations, Leti and the Fraunhofer Group for Microelectronics will bring our complementary strengths to the task of keeping France and Germany's microelectronics industries in the forefront – and offer our innovations across Europe."

"Micro-/nanoelectronics and smart systems are key enabling technologies for the economic success of Europe, especially in France and

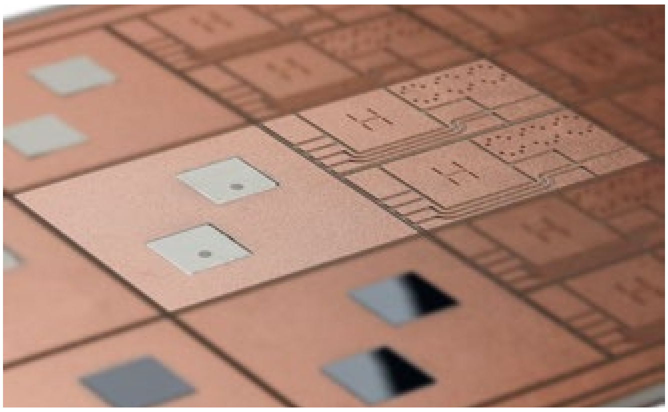
Germany. Thus, Europe can no longer afford to scatter its research competences. For the benefit of industry, joining forces will become more and more important, not only for industry but also for RTOs," Lakner explained. "The new cooperation agreement will be the starting point for a strategic research cooperation of the two countries in order to jointly support the upcoming EC initiative, Important Project of Common European Interest (IPCEI), on micro- and nanoelectronics."

www.leti-cea.com

www.mikroelektronik.fraunhofer.de

DCB+ Substrates with pre-applied Solder Simplify the Production Process

As an important part of its new add-ons and services portfolio for Direct Copper Bonded (DCB+) substrates, Heraeus Electronics is introducing DCB substrates with pre-applied solder pads, which reduce



the number of process steps for chip attachment by 50%. The printing and more importantly the residue cleaning process aren't required anymore, which were critical and time consuming. Furthermore, the DCB+ substrates with pre-applied solder substantially reduce solder splatters, thereby improving yield. Savings on facility investments and consumables are a further benefit of this innovation.

Beyond premium alumina DCBs, Heraeus is offering a comprehensive portfolio of additional features and services from the following four categories: properties, options, services, and processing. Customers can then benefit from more flexibility, customized solutions, and simplified production processes.

Heraeus is significantly expanding the range of services for DCB substrates and offers customers added value through custom substrates with special characteristics.

www.herae.us/pre-soldered_dcb

Hioki Establishes a Sales Subsidiary in Europe

Hioki E.E. Corporation has announced the establishment of a wholly-owned European subsidiary in Frankfurt am Main, Germany, and will begin operations in August 2017.

The company has identified the development of a global sales network as a top priority. To date, this approach has yielded results with the establishment of subsidiaries in the U.S., China, Singapore, South Korea, and India. As an extension of this effort, it will establish a subsidiary in Europe in order to pioneer new markets. The new company will enable Hioki to operate in closer proximity to major regional companies in sectors such as the automotive and aerospace industries so that it can deliver products, service, and support in a more timely manner. In addition to providing solutions that align with customer needs in markets that demand a high level of technological expertise, it will also work to bring the Hioki brand to these markets and expand its customer base.

"Globalization is one of Hioki's guiding policies, and we are on track with strengthening our presence in the international market. By enhancing the sales network, we will be able to increase the number of opportunities to communicate the value of Hioki products and services to potential customers and enable more users to experience the advanced technologies and quality offered by HIOKI," comments Hisashi Shimizu, Managing Director of Hioki Europe GmbH.

www.hioki.com

LpS 2017 Proudly Announces its Stellar Speakers and Event Program

LpS 2017 (LED Professional Symposium +Expo) are proud to reveal this year's event program, for what will be the greatest LpS to date. Joining over 1600 delegates and 100 exhibitors in Bregenz this year

will be global experts from industry and research, to focus on multiple lighting applications such as Human Centric Lighting, Transportation, Agricultural, Healthcare and many more.
These chosen specialists will be sharing their future visions, innovative technologies, trend insights and research findings in over 100 carefully selected lectures.
Highlights this year will include keynote lectures on the prominent trends Connected Lighting and Human Centric Lighting. Delegates will hear from the world's foremost expert in Solid-State Lighting, Fred Maxik, and industry trailblazer Jan Denneman, Vice President of Philips Lighting, who will be sharing his visions on "Connected Lighting – A Global View".
Additional sessions will also cover laser lighting, future markets & trends, Human Centric Lighting, light sources and modules, intelligent lighting, IoT and security, materials and components, system qualification and applications.

www.LpS2017.com

Alpha Celebrates 50 years in the Italian Market

Alpha Assembly Solutions, the world leader in the production of electronic soldering and bonding materials, last month celebrated its 50th Anniversary of the ALPHA® brand in Italy.
The bi-centenary was marked with a celebratory dinner at the Cannavacciuolo Café e Bistrot in Novara Martiri della Liberta, which was attended by both the current Alpha Italy team and also past employees who played a key role in establishing Alpha in the Italian market.
A commemorative silver plaque will be displayed within the entrance to the Alpha Assembly Solutions office in Italy. Alpha's VP of Sales for Europe, Fabio Taiana, commented, "This special evening was arranged to mark a great achievement for Alpha and recognize the hard work and dedication that the team has put in over the past 50 years to establish and maintain Alpha's position in the Italian market."
Alpha, a MacDermid Performance Solutions company, has become a leader in the Italian market for the supply of electronic assembly materials to key industries such as Consumer and Automotive Electronics. The Alpha Assembly Solutions team is now situated at the MacDermid Performance Solutions office in Trecate, Novara.

www.AlphaAssembly.com

The Rendezvous 100% Lighting

ForumLED Europe, the Congress / Expo entirely dedicated to LED technology, that will take place on the 13th & 14th December 2017 at the Cité Centre des Congrès, Lyon – France.
The Congress / Expo ForumLED Europe has for more than 8 years brought together the whole ecosystem of LED technology and has become the most important event on the subject in Europe. The exhibition will bring together professionals, manufacturers and users for LED technologies and LED lighting systems and equipment.
In 2017, the gathering of the leading exhibitions in France on the lighting market, ForumLED Europe, Full LED Expo and Forum LumiVille. With the combination and synergy of these events, we are introducing "Lighting Days" that will gather 3 international events in France dedicated to LED technologies, and indoor & outdoorlighting.

FORUMLED EUROPE

This meeting will be the place to meet lighting specialists and discover their products and innovative solutions in LED technologies, indoor LED lighting, outdoor lighting, public lighting or even smart lighting. This year's edition awaits more than 150 exhibitors and 3000 professionals & international visitors.

www.forumled.com

International Meeting Place for the PCB and EMS Industry

Digitalization is progressing and electronics is making its way into more and more areas of life. In this context, the functionality of the devices is essentially determined by the circuit board. At the PCB

& EMS Marketplace and on the highlight day “Sustainable EMS” in Hall B3, manufacturers of printed circuit boards and EMS providers will show concrete examples of how they are meeting increasing requirements in the automotive industry, medical technology, industrial electronics and mechanical engineering. productronica will take place on the grounds of Messe München from November 14 to 17, 2017. Sales of the printed circuit board industry in the DACH countries are increasing rapidly. Compared to the previous year, the value increased by 13.6 percent in March 2017. Overall, the first quarter total finished eight percent above the same period last year, as reported by the ZVEI association PCB and Electronic Systems. Sales and incoming orders achieved the highest absolute values in 15 years. Especially companies within the automotive industry regained jobs in the short term that had been lost to Asian companies. Local supply shortages in copper films were the cause.

http://productronica.com

Electric & Hybrid Vehicle Technology Expo

Based in Detroit, Michigan, America’s capital for electric-vehicle manufacturing, Electric & Hybrid Vehicle Technology Expo highlights advances right across the powertrain. From passenger and commercial vehicles to off-highway industrial vehicles, this manufacturing and engineering event showcases the latest innovations across a vast range of vehicles. Running concurrent to the exhibition is Electric & Hybrid Vehicle Technology Conference which attracts technical leaders and executives from global technology companies to reveal what is driving demand, shaping novel technologies and new innovations at the cutting edge. September 12-14, 2017

www.evtechexpo.com/visit/

HiPak Modules in Chopper Configuration for 3300V and 4500V

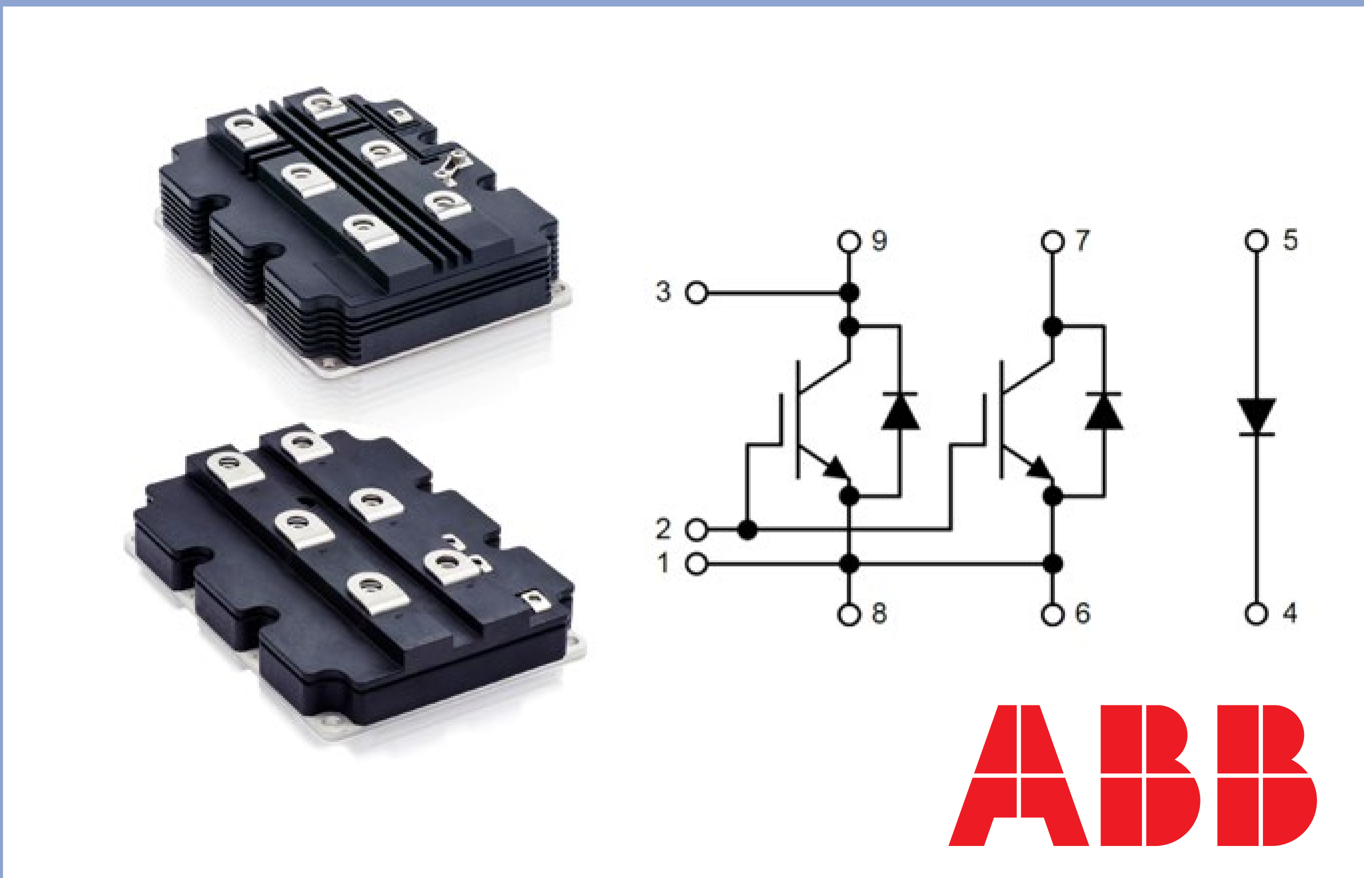


ABB introduces two new Chopper modules to its HiPak family. The products feature the well established reliability of the ABB HiPak power modules with highest load-cycling capability. The HiPak Chopper modules an IGBT with antiparallel free-wheeling diode and an additional separate diode to free-wheel the copper impedance or serve as a neutral point diode in three level inverters. These modules are an ideal solution for resistive voltage limiting Choppers or to simplify the built of three level converters.

The chopper modules are available as 4500V version with a current rating of 800A and 3300V with a current rating of 1000A. Both versions feature the highly rugged and low loss SPT+ chip technology that has proven its quality in numerous demanding applications such as in Traction, in T&D and in Renewables.

The modules can be ordered with the following part numbers:

- 4500V 800A Chopper: 5SNE 0800G450300
- 3300V 1000A Chopper: 5SNE 1000E330300

www.abb.com/semiconductors

PCIM Asia 2017 – Breaking New Ground

By Min XU, Bodo's Power Systems China

PCIM Asia 2017 returned to the Shanghai World Expo Exhibition & Convention Center, June 27 – 29. This was the 16th year for the show, including the largest exhibition for power electronics and a comprehensive conference program. PCIM Asia is now the definitive meeting place for the industry in China and Asia.
84(1) exhibiting companies occupied more than 7000 m² displaying the latest products and innovations to over 5600(2) trade visitors and media. The conference attracted over 352(3) participants offering a comprehensive English language conference program, which covers power electronics trends, especially in the area of smart grid and electric vehicles.
Having visited PCIM Asia for the past eight years, I've seen the growth of the industry and the exhibition from a regional event to now and increasingly global showcase featuring international and Chinese products with industry wide implications. Here are some of the most important highlights:

SiC Devices Are Center Stage at PCIM Asia
As the most advanced wide-band-gap semiconductor material, SiC has become increasingly important and in demand as its global industry chain increases. SiC device performs the best at high power, high frequency and low lose condition. At PCIM Asia this year, major leading exhibitors are showcasing their latest developments at SiC devices, including:

- Mitsubishi Electric showcased 15A/25A Full-SiC DIPIPM, 800A/1.2V Full-SiC MOSFET module, 100A~600A/1.2kV Hybrid-SiC high frequency IGBT and 1200A/1.7kV Hybrid-SiC HVIGBT.
- Infineon showcased their new advantage series IGBT, as well as full SiC module, which are going to be volume produced later this year.
- Fuji Electric showcased 1st Gen trench SiC module, covering from 25A~400A/1200V.
- Semikron showcased hybrid-SiC and All-SiC modules with SEMI-TOP package.
- Toshiba showcased All-SiC modules, including 400A/1700V 2in1, 600A/1200V 2in1 and 3300V 1in1.

China Domestic Players Are Globalizing
In recent years with the support of national and provincial Chinese organizations, China's SiC and GaN power device development has reached a breakthrough to international quality and specifications. Since 2000, many Chinese firms have applied for and received numerous patents for SiC and GaN power devices. Since 2010, the number of patent applications in this field has increased significantly. The number of patents for wide-band-gap materials and devices from China is 4th after Japan, US and Germany(4). Most of these patents applications are from research institutes, universities and companies less than ten years old.

At PCIM Asia this year,

- CRRC showcased 200A&300A/1200V All-SiC module with STD package, 500A/3300V hybrid-SiC IGBT module and discrete SiC devices.
- Microsilver showcased 300A/1200V All-SiC module with STD package, as well as 3-level I-type modules with NX package covering 200A~400A at 650V~1200V.
- CENGOL, founded in 2010 in Beijing, showcased 6A~40A/650V~1200V SiC SBD, MOSFET and 1200V full SiC power modules.
- BASiC semiconductor showcased 1200V, 1700V SiC JBS Diodes, 1200V SiC MOSFET and 10kV SiC PiN Diode.

PCIM Asia 2017 Exhibition Onsite (courtesy of PCIM Asia)

Outlook for the China Power Electronics Market
China is engaged in a national effort to revolutionize energy consumption and usage, which in turn will drive the power electronics device industry in China for the next 10 to 20 years. This is undoubtedly the start of the Chinese Golden age in power electronics. During the next 20 years, the industrial and commercial demands for power electronics devices will be great and competition will be intense. This will also foster greater investment in both incremental demand and energy-saving technology research that will foster rapid development of downstream industry production. By 2020, China's electrical power electronic device market is expected to exceed 500 billion RMB(5).

Looking forward to seeing you in Shanghai next year and keeping you informed through Bodo's Power Systems Magazine.

Follow Bodo's Power China WeChat by scanning QR code below.

www.bodospowerchina.com

Reference:
(1) Data from PCIM Asia 2017 organizer
(2) Data from PCIM Asia 2017 organizer
(3) Data from PCIM Asia 2017 organizer
(4) China Power Electronics Industry Development Blue Paper
(5) China Power Electronics Industry Development Blue Paper

Side Wall Gate - Moving on from Trench

A new Side Wall Gate Structure Shows Inspiring Performance Characteristics, Breaking Through the Trench Gate Ceiling. HITACHI Bridges the Performance Gap Between Silicon and Wide Band Gap Devices.

By Neil Markham, Hitachi Europe Ltd.

It is not news that the IGBT remains the backbone of the majority of inverter designs. Its bipolar structure enables handling of large powers and brings with it opportunities to improve efficiency targets of industrial, traction, T&D and automotive applications alike. Wide Band Gap devices, benefitting from a unipolar structure and all but eliminating recovery losses, dominate recent news. Hitachi is a firm advocate of this exciting technology, publishing academic papers and launching several new SiC high voltage products in the nHPD2 package. However, this does not necessarily mean that Silicon based technologies do not have a market.

Introduction

Dominating the power semiconductor market since its introduction, the IGBT has delivered evolutionary performance improvements but there has perhaps been little revolutionary progress. In the 1980s Planar gate IGBTs were the sole core silicon process technology, before the availability of Trench gate designs in the 1990s. Since this step change, Trench gate has fast been approaching performance saturation. SiC is positioned to take up the needs for continuous improvement, although not without its own challenges. Cost versus reliability is one simple example. Endeavouring to bridge the gap between Trench gate and SiC MOS designs, whilst conscious of both two key market forces, cost and reliability, HITACHI positions itself to launches first products based on a revolutionary technology: Side-Wall Gate (SWG).

Fundamental structure

The Side Wall Gate IGBT adopts a new structure of IGBT in which a thick oxide layer covers the majority of the gate surface, exposing less area to the floating p well and n- doped channel regions. This structure has a direct positive influence on reducing the Miller capacitance (Cres) which subsequently results in the trade-off relationship improvement between the diode reverse recovery (dv/dt) and combined turn_on and diode turn_off switching losses (Eon+Err), when compared to conventional IGBT structures. At the same time, the decreased Cres shows IGBT turn_off loss reductions.

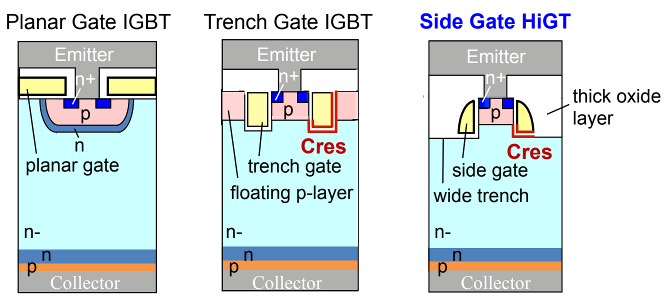


Figure 1: Schematic cross section of IGBT unit cell structure

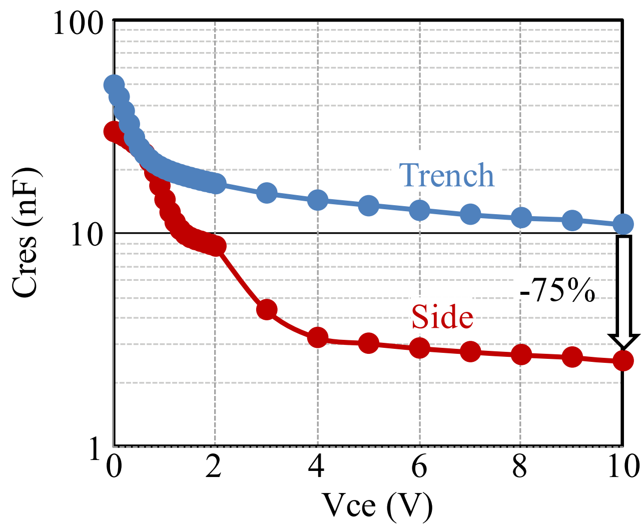


Figure 2: Side Wall Gate vs. Trench: Cres / Vce dependence*

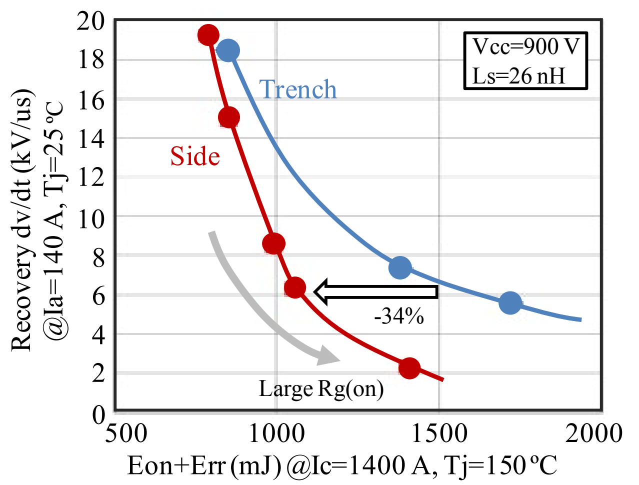


Figure 3: Diode recovery dv/dt vs. (Eon+Err) trade-off (1700V IGBT)*

Motivations

Whilst semiconductor device manufacturers can target and realise very fast switching solutions to reduce the system costs of expensive, large and heavy wound components in particular, not all applications are able to extract all that the data sheet promises to offer. For instance, in motor control, restrictions will be imposed by the motor insulation specification, which will likely force the inverter designer to reign in their ambitions to switch faster as dV/dt levels reach or surpass the motor's safe operating conditions. If forced to limit switching speed because of dV/dt limits, the performance benefit of a wide band gap module, for example MOS SiC, may be lost and the cost will abruptly become a critical gateway. In such instances, a bridging solution becomes of greater interest and a key motivation for HITACHI developing the Side Wall Gate device structure.

Let us consider 600V-1200V devices adopted in an inverter design. Switching frequency (fsw) is assumed to be relatively high, particularly if we benchmark against 6500V applications: kHz switching rather than Hz. As such, the reduction of switching losses will be most important due to the dominance of switching events versus static conduction. It is also vital to suppress the surge voltage during switching to provide a rugged system design with high reliability.

Now consider the Automotive sector, one market sector quickly adopting IGBT technology for traction drive, compelled to improve CO_2 emissions by EU6c standards. Several mandatory constraints are placed upon the OEMs: cost; size; reliability. Despite these, the driving experience must still deliver superior performance. WBG devices would be a logical starting basis for the drive inverter, but system costs may climb if switching frequency is limited to 12kHz by the electric motor. The challenge. To achieve improved switching loss characteristics without breaching the motor insulation limits. Considering this, the Side Wall Gate IGBT structure shows suitable promise, especially when battling the cost-performance quid pro quo. In a highly competitive price environment, high voltage SiC devices can sometimes be a victim of their own success, falling foul of commercial system demands, despite their inherent technical advantages. On the other-hand, based on a Silicon bulk wafer and existing manufacturing lines, Side Wall Gate aligns closely with traditional Planar and Trench manufacturing costs, supply chains and lead-times.

Side Wall Gate: Automotive 1200V IGBT

Figure 4 shows indicative simulation results of turn_off waveforms between a recent conventional Trench gate and the new Side Wall Gate (SWG).

SWG allows >30% faster turn_off, which is derived from the smaller Miller capacitance. On the other hand and importantly, despite the faster IGBT turn_off, the di/dt at which the peak voltage is reached shows the same level as the conventional device structure. Thus, the peak voltage is also the same level. Turn_off loss (Eoff) is in the region of 40% lower compared to the conventional Trench IGBT under same VCE(sat) as shown in Figure 4.

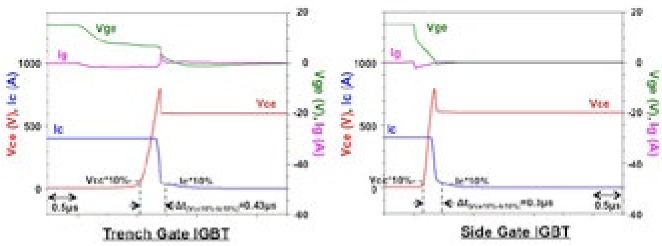


Figure 4: Simulated turn_off comparison

The turn_on waveform comparisons are given in Figure 5. SWG shows faster turn_on characteristics, in a similar manner to the turn_off. The peak current of SWG is even smaller than the conventional IGBT. Both the SWG IGBT and diode characteristic improvement enable this desirable characteristic – Eon reduction 12%.

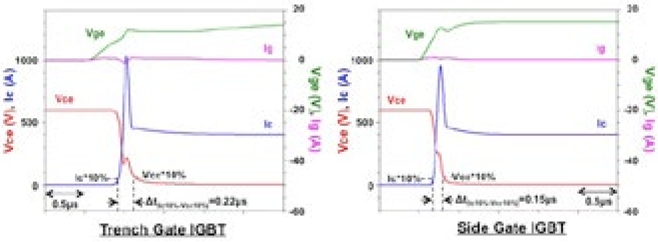


Figure 5: Simulated turn_on comparison

The counter arm diode reverse recovery is shown in Figure 6. Both peak current and tail current are smaller using SWG technology, culminating in a 9% improvement to the diode reverse recovery loss (Err). A reduction despite the diode VF being the same for both devices.

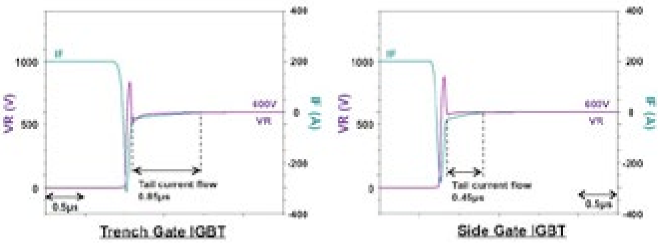


Figure 6: Simulated diode turn_off comparison

Module level investigation

In order to confirm the device level characteristics against the simulation data, SWG IGBTs were assembled into the HITACHI 98.5mm x 168mm pin-fin platform package shown in Figure 7. Results concur with the simulation modelling and measurement waveforms of IGBT turn_off, turn_on and diode reverse recovery are shown in Figure 8 respectively.

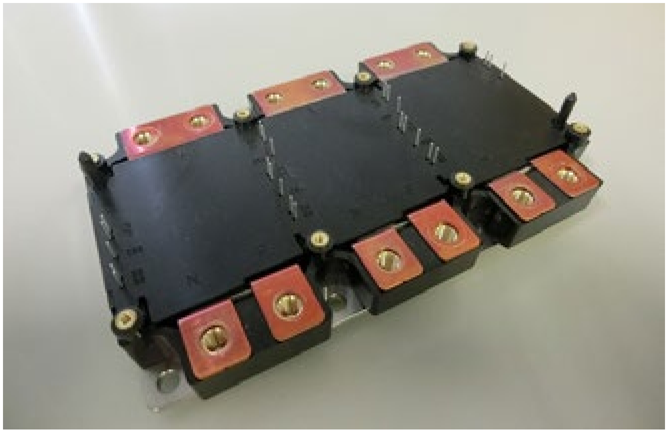


Figure 7: 400A/1200V 6-in-1 Test sample

Eoff of the new Side Wall Gate IGBT confirms a smaller power loss than that of the conventional IGBT. Similarly, Eon+Err is in line with the simulation data where a suitable Rg is applied.

Owing to the smaller Miller capacitance of the SWG design, the gate-emitter voltage becomes more stable with a lower Vge peak. This distinguishing feature, compared to a conventional Trench gate design, generates a 30% lower short circuit peak current.

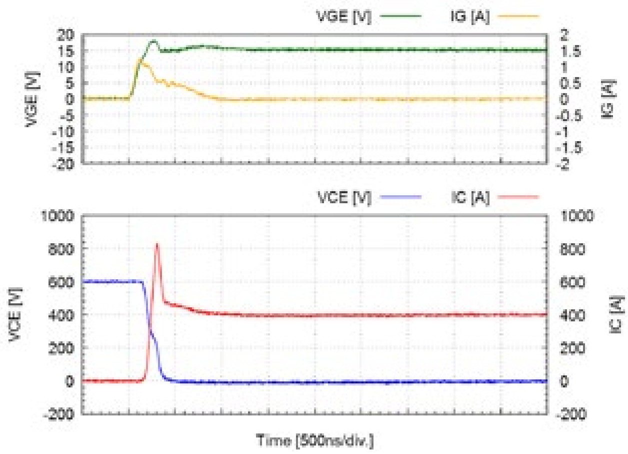


Figure 8a: Measured turn_on

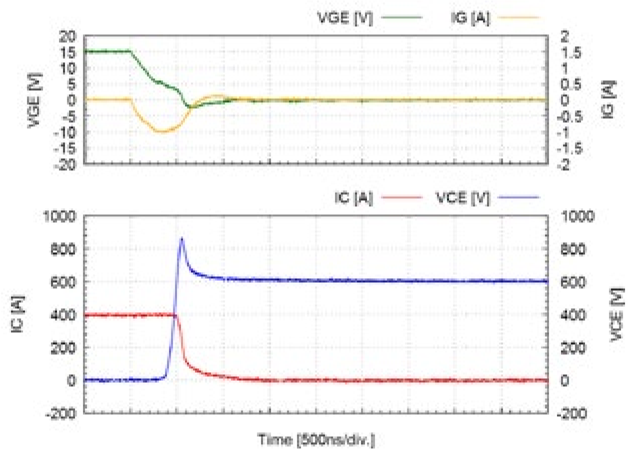


Figure 8b: Measured turn_off

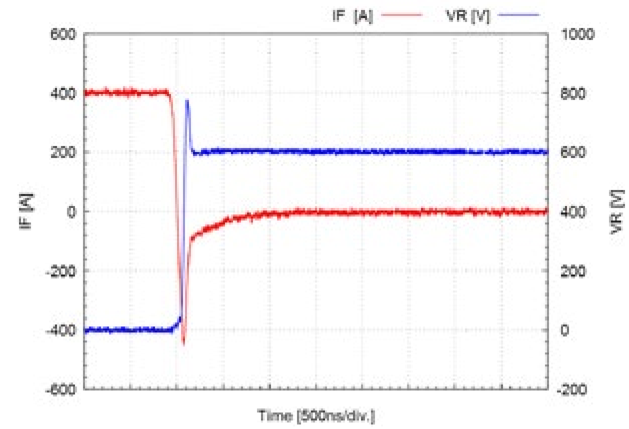


Figure 8c: Measured reverse recovery

Next steps
Following the first Side Wall Gate MBB400TX12A product release in Q4/2017 (3-phase pin-fin module rated 400A/1200V), the line-up will be expanded to reach the 6500V voltage class. Covering 600V to 6500V will bring the significant merits of Side Wall Gate, the first Silicon based technology leap for 20 years, to all traditional applications of module based IGBTs. Package platforms in pin-fin supported by future releases in both traditional HV-IHM and the new standard package platform nHPD2. MBN1000FH65G2 will be the flag-ship Side Wall Gate product rated 1000A 6500V and available for sampling.

Supplementing the first Side Wall Gate "A" series specifications for 600-1200V and "G2" series high voltage line-up (>1700V), follow on development activity has been presented on the academic circuit. Y. Takeuchi "A Novel Hybrid Power Module with Dual Side Gate HiGT and SiC-SBD" ISPSD 2017, shows the long-term future promise Side Wall Gate technology has to offer.

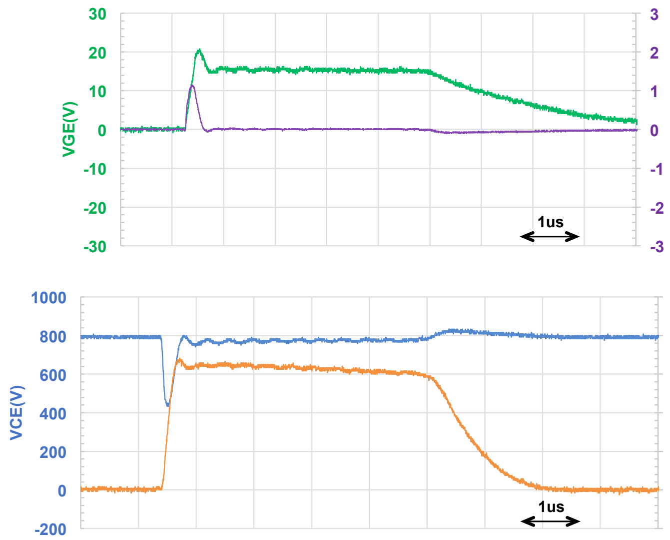


Figure 9: Type I short circuit waveform (VGE, 15V)

Conclusion
HITACHI has concluded the first phase of its strategy to bridge the large gap between the Silicon and Silicon Carbide cost-performance trade-off. Realising a low Cres cell structure, Side Wall Gate, enables higher frequency switching with 20% lower losses but avoiding increased stress to motor insulation. Based on traditional Silicon raw material, reliability is a known quantity and cost effective, particularly for larger volume applications including the Automotive traction powertrain against the higher performing but higher cost wide band gap devices.

Moving on from Trench? We are and we hope you will join us.

* Figure 2 and Figure 3 are derived from M. Shiraishi, et. al. "Side Gate HiGT with Low dv/dt Noise and Low Loss", ISPSD 2016.

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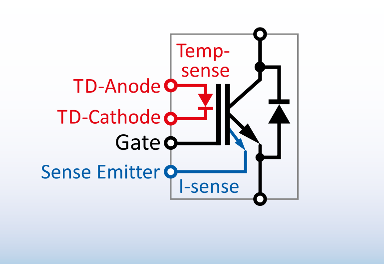
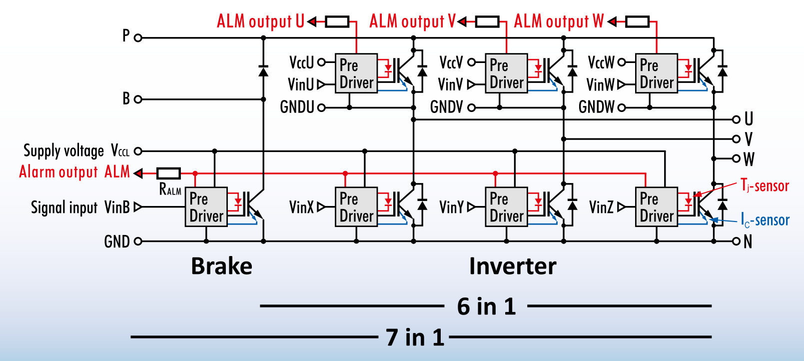
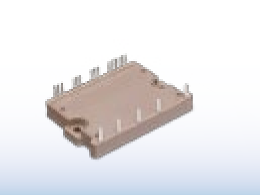
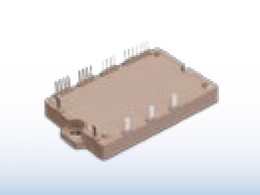
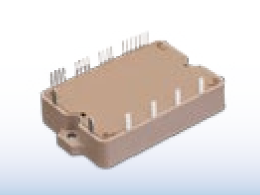
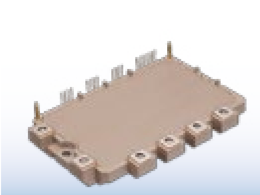
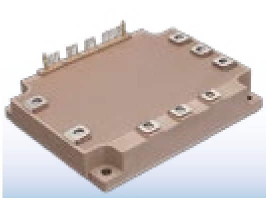


Inverter 6 in 1 and 7 in 1



6 in 1	6 in 1	6/7 in 1	6/7 in 1	6/7 in 1
				

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An Intelligent IGBT Module for Single-Ended Induction Heating Applications:

All-in-One Solution for Induction Cooking System

By Wonjin Cho, Staff Application Engineer, Dino Ge, Marketing Manager;
Bum-Seok Suh, Vice President of IPMs and IGBTs, Alpha and Omega Semiconductor, Inc.

Induction heating (IH) application has developed with requirements of higher efficiency, compactness, cost effectiveness, and reliability. Even with its simple structure, a single-ended IH system operates under high power conditions in domestic applications with various transient modes. Due to resonant operation, the IGBT suffers ~1 kV of blocking voltage and ~40 A of peak conduction current. As a consequence, the system requires robust protections for certain abnormal conditions such as surge input and high temperature. An intelligent IGBT module, so called IPM6, shown in Figure 1, provides multiple protective functions to meet market requirements and boost system reliability. The footprint of the package is same as that of the TO-247 standard package, which is popularly used in quasi-resonant IH applications.

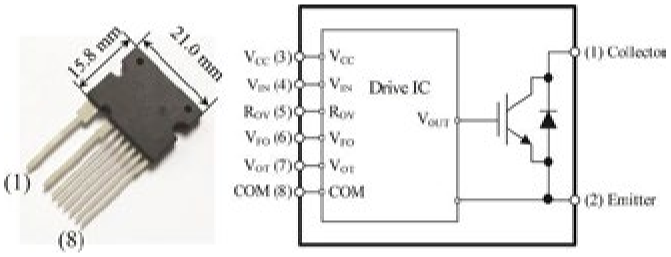

Figure 1: IPM6, Intelligent IGBT for single-ended induction heating applications.

Conventional Protective Functions in IPM6

IPM6 provides general protective functions which are used in motion control IPMs such as over-voltage lock-out (OVLO), under-voltage lock-out (UVLO), temperature monitoring and over-temperature (OT) protection. When the supply of the control IC exceeds trigger level of 22 V, the OVLO function blocks the input PWM signal so that the output signal stays in low state until OVLO is reset at 21 V. The UVLO function disables to output at 11 V and resets at 12 V. These OVLO and UVLO features are designed for conventional auxiliary voltage range of 15 to 18 V. OT protection is activated at the temperature of 120°C triggering the fault-out (FO) signal and is deactivated when the temperature decreases to 85°C releasing the FO signal.

Temperature of the control IC is represented as voltage value at the VOT pin of the IPM6 as shown in Figure 2. The monitored voltage has the range between 0 to 5 V for the temperature during normal operation, which is compatible with the sensing input range of the conventional 5 V micro controller. OT protection level is 130°C with reset level of 100°C. With OT protection, fault out signal is activated to indicate abnormal working condition.

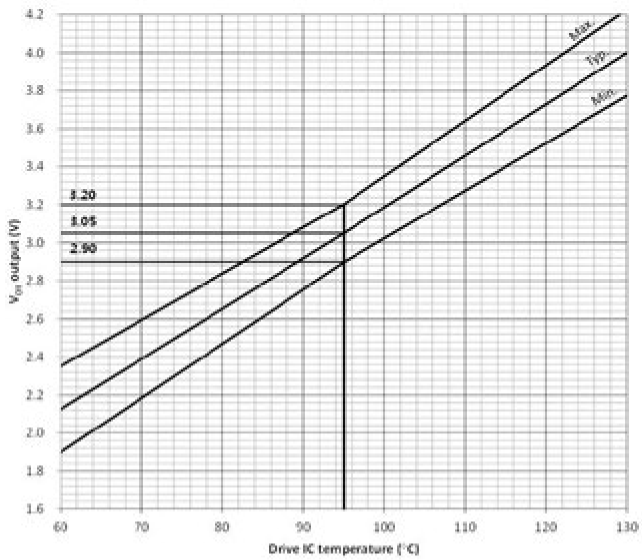

Figure 2: Temperature monitoring characteristic

Soft-Start Function

Practical single-ended IH systems start their operation by load detection control. Single or multiple pulses turn on the IGBT at the start-up, and corresponding current or voltage responses are fed back to the micro controller. During load detection, the single-ended IH inverter inevitably suffers high inrush current because of the empty resonant capacitor. Once the resonant capacitor is charged, single-ended IH inverter operates in zero-voltage switching (ZVS) turn-on. Thus the inrush current at the first turn-on has the most severe level in overall operation. IPM6 has built-in soft start logic, which is implemented by independent gate driver to limit inrush current. Soft-start function mitigates the peak of inrush current by ~70% as shown in Figure 3, and is disabled until the system restarts from halted operation.

Abnormal Turn-On Disable (ATOD) Function

During the normal operation of single-ended IH system, the IGBT voltage reaches ~1 kV during off-state. If the IGBT is unexpectedly turned on due to noise signal, it suffers severe hard switching which can be a problem for efficiency and reliability. ATOD function maintains the minimum turn-off duration for 10 μs by blocking input signal from the turn-off edge so that the designated turn-off period is guaranteed. The ATOD function is implemented by internal timing logic of the built-in control IC.

Hard Turn-On Disable (HTOD) Function
HTOD function is designed to prohibit excessively hard turn-on switching of the IGBT in abnormal system conditions like AC supply swell and malfunctional control cases. The HTOD function is implemented by the fast comparator to block any input signals when the sensed voltage of the IGBT is greater than ~450 V. Desired protective level of the IGBT can be adjusted by the conversion ratio of external sensing resistors.

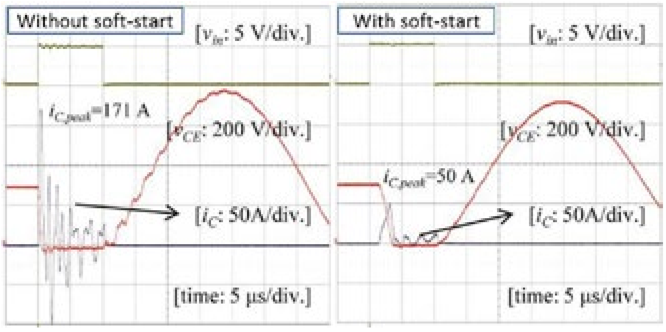

Figure 3: Soft-start function

Maximum Duty Cycle Disable (MDCD) Function
The peak conduction current level is proportional to turn-on duration of the IGBT in single-ended IH system. Because the conduction current is converted to the resonant voltage, the longer turn-on duration increases IGBT voltage higher during the resonance. With the conventional switching frequency range of 20 to 30 kHz of single-ended IH system, the designated turn-on duration range is 17 to 25 µs at the half duty cycle. IPM6 limits maximum turn-on duration at 37 µs to prevent excessively long turn-on and corresponding high voltage at the IGBT.

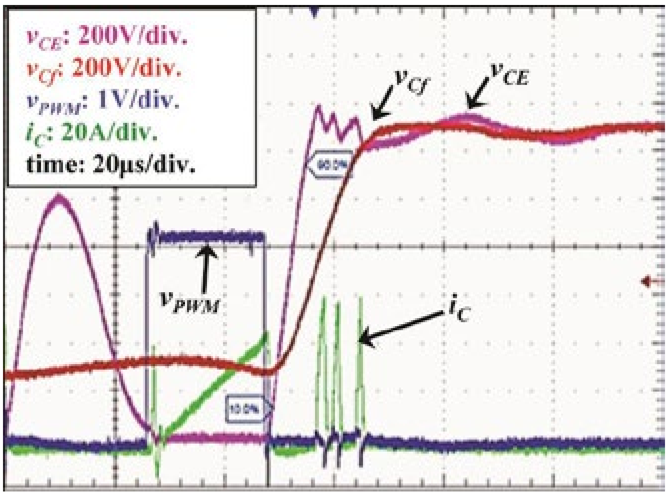

Figure 4: OVCP function

Over-Voltage Clamping Protection (OVCP) Function
If an excessive abnormal voltages such as from lightening surge or voltage swell are applied to ac input line of IH system, IGBT voltage can be increased by several hundred volts even though surge absorbing circuit suppresses those excessive inputs. IGBT voltage rating is chosen to have blocking margin for such abnormal cases but the increased voltage can even exceed the dynamic breakdown voltage of the IGBT. The purpose of the OVCP function is to consume the resonant current that is converted to the resonant voltage by partially turning on the IGBT. Partially turned-on IGBT does not experience severe short circuit current because the current channel between IGBT collector and emitter is limited by the gate voltage of ~8 V. Once the resonant current is consumed by IGBT, the resonant capacitor is not charged even discharged, so that IGBT voltage does not increase over the destructive level. The clamping level is determined by hysteresis band, defined by set and reset level, which can be controlled by the external sensing resistance ratio. Once IGBT voltage is settled in the reset level, OVCP function finishes its operation. In this case, the remaining current may charge the resonant capacitor again increasing the IGBT voltage, and then OVCP function is triggered again. The OVCP function can repeatedly work until IGBT voltage is permanently settled down as shown in Figure 4. The peak voltage of the IGBT is limited by ~1.4 kV which is below the dynamic breakdown voltage of the IGBT.

In summary, the new intelligent IGBT module, IPM6, is designed for single-ended induction heating applications about 2 kW. Besides conventional protective functions, designated functions for IH application surely give benefits in system reliability and create a completely new outlook for system designers enabling a far more optimum performance of the resonant converter and cost effectiveness as well.

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Current Progress at Si IGBTs in the Voltage Range up to 1200V

In recent years the basic features introduced at the turn of the millennium for IGBTs such as trench gate cell and field stop layers could be enhanced. Progress in the manufacturing processes enabled reduced cell pitch for trench IGBTs leading to significant lower on-state losses and improved switching behaviour. At the same time boundary conditions from the applications became clearer visible as hurdles for the further improvement even of silicon-based power switches and for reducing losses.

By Dr.-Ing. Anton Mauder, Infineon Technologies AG

1. Preface

For the user, the question for the best suited power switch for an application always stays important. This question will be considered here from a technical perspective in the light of new levels of development of Si IGBTs. In the focus are rated blocking voltages from 600V to 750V. The properties of these components may be extrapolated at least partly to higher voltage classes depending on the target application.

1.1 The "Ideal" Power Switch

The losses occurring in the operation are an essential aspect for power switches. Therefore, the losses in conduction and blocking mode should be minimized. The switching losses, however, are determined by the overlap in time of voltage and current at the switch and therefore by the allowed switching transients in the application [1]. The losses for driving high voltage devices are much smaller than the switching losses on the power side and will be neglected here.

Figure 1 illustrates the idealized hard turn-off and turn-on of a power switch, where parasitic elements were not taken into account. If boundary conditions of the application limit the switching transients for voltage and current (dv/dt, di/dt) the ideal switch for an application thus possesses minimum achievable switching losses. The minimum switching losses may be easily estimated from the integral of the product of voltage and current at the switch.

The ideal switch for an application therefore has only these losses in operation which are determined by the allowed switching transients. So, a further reduction of switching losses is only possible to that extent the application may accept steeper switching transients. These limitations apply independently from the type of the power semiconductor switch and are valid for all base materials as silicon or wide bandgap materials.

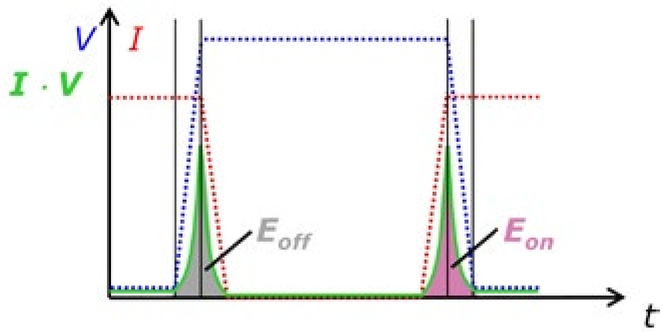

Figure 1: Schematic, idealized turn-off and turn-on neglecting parasitic elements.

1.2 Real IGBTs

In the blocking voltage range above 600V IGBTs are used as power switches for decades. Significant innovations have been introduced shortly before the turn of the Millennium which influenced the development of IGBTs – the combination of trench gate cells and vertical optimization using field stop layers at IGBTs. These innovations enabled to considerably reduce switching and conduction losses.

In power semiconductors, the chip area required in an application and thus the cost of the semiconductor devices are predefined by the power dissipation in operation. A larger chip area improves the heat flow from chip to ambient assuming otherwise same thermal boundary conditions in the setup.

Cost reduction for the semiconductor switch through a smaller chip area is possible only via reducing the losses in the switch.

The development of current power semiconductors has progressed so far that often no longer the semiconductors but the application limits the switching transients and thus dominates the switching losses. The development therefore has one focus on the reduction of on-state losses.

2. Reducing Losses of IGBTs

At IGBTs the on-state properties are improved by flooding a low doped zone needed to support the blocking voltage with electrons and holes. At the transition from on-state to blocking operation removal of this excess charge causes switching losses. The conduction losses could be reduced by introducing cells with trench gates. Optimizing the vertical structure (mainly field stop layers in combination with weak emitters at the collector side) helped to reduce both conduction and switching losses. Trench field stop IGBTs are dominant in the power semiconductor market today and have replaced older generations (punch-through- or non-punch through IGBTs) in most applications.

2.1 Reducing on-state Losses

Enhancements in the manufacturing processes allowed fine structures also for power transistors and thus trench cells with smaller cell pitches and narrow mesas in between the gate areas. It is possible to

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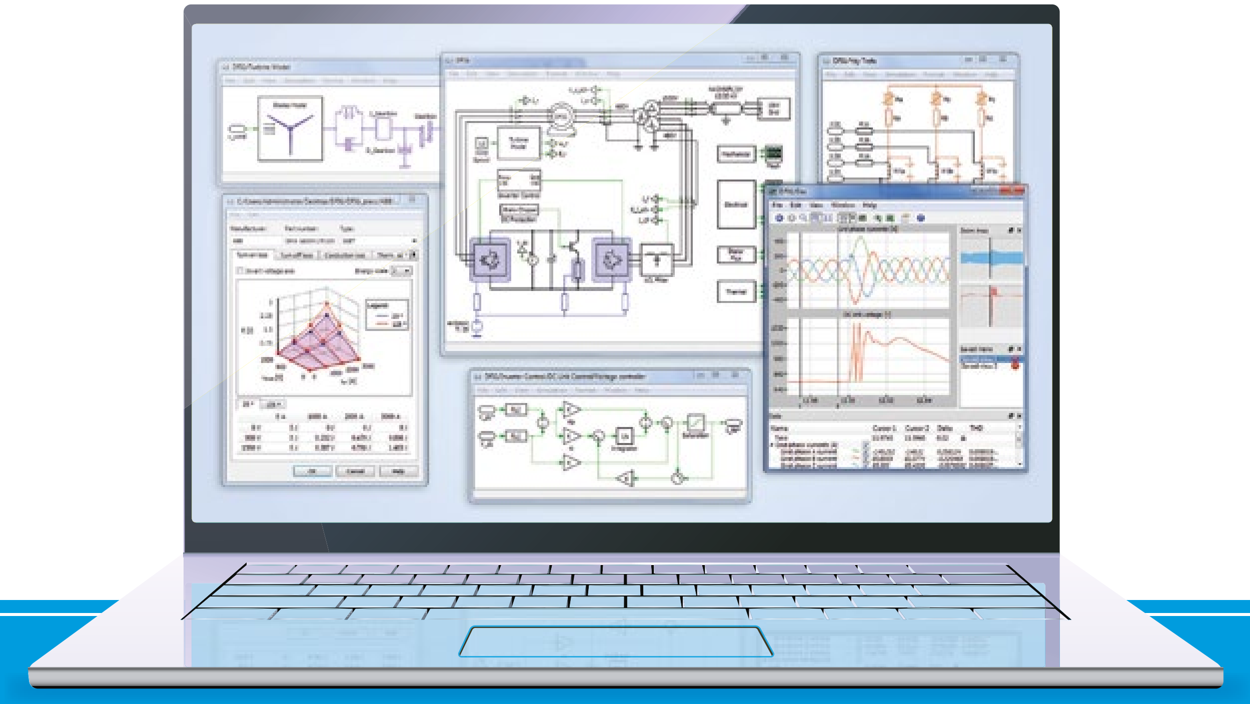

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further increase the carrier concentration below the emitter electrode compared to conventional trench cells (Figure 2) by constraining the flow of holes of the excess charge through the p-body to the emitter electrode. The strong carrier storage below the emitter electrode leads to a significant increase in the electrical conductivity in the drift zone and thus improves the forward voltage [2] when compared to a classical IGBT with trench cells (Figure 3). Particularly noteworthy is that the nominal voltage of the IGBTs with narrow mesas in Figure 3 with 750V is even 100V higher than that of the classic trench-field stop IGBT consulted for comparison.

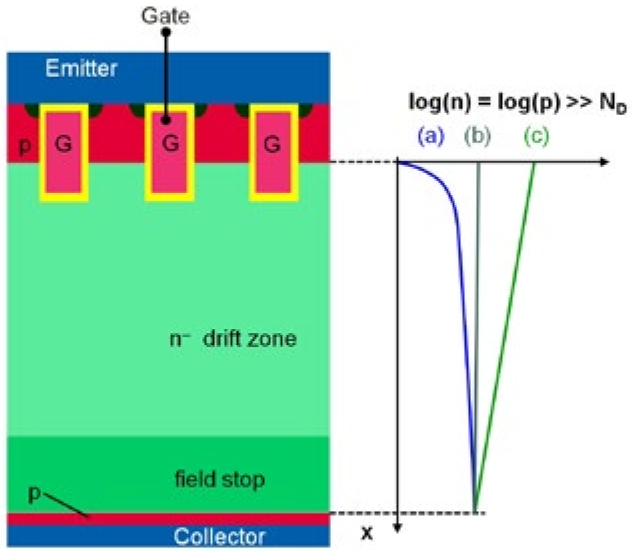

Figure 2: Vertical structure and carrier distribution at an IGBT with narrow mesas (c) compared to IGBTs with planar cells (a) and classical trench cells (b).

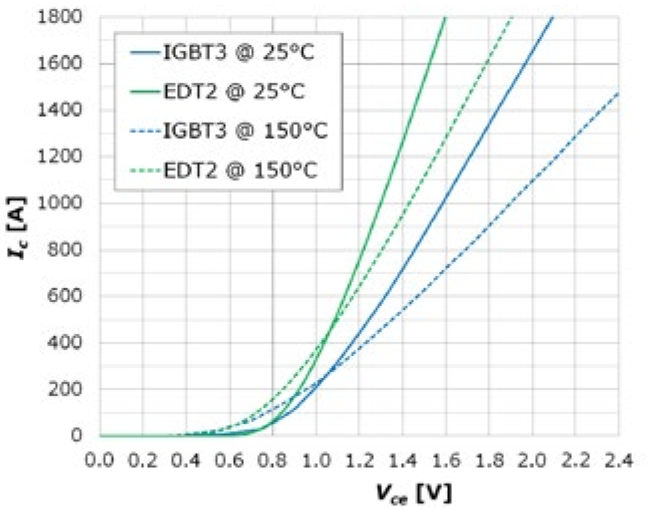

Figure 3: Comparison of the on-state voltage drop of an IGBT with narrow mesas (EDT2) and a conventional trench field stop IGBT (IGBT3).

The carrier gradient leads to an electron diffusion current through the drift zone which contributes to the total current. Thus the necessary portion of drift current and therefore the voltage drop in the drift zone are reduced [3]. The fine structures of the trench cells can be used, for example, to adjust the capacitances between collector and gate or the adjustment of the ratio of the collector-gate - and collector-emitter capacitances. Already [2] introduced a way of not connecting individual semiconductor regions between trench gates or to realize regions at the gates without source doping. In this way, the transconductance of the IGBT or its short circuit saturation current, for example, can be adjusted to the needs of the application [5].

2.2 Reducing turn-off Losses

At turning-off of an IGBT the electrons and holes must be removed from the flooded drift zone in order to build up a space charge area (SCA) in the depleted, low doped drift region. The electric field in the space charge area enables blocking of the applied voltage.

In Figure 4 the conditions in an IGBT with narrow mesas are schematically shown at an arbitrary time during turn-off. The excess charge in the drift region is already partially removed, with the holes being removed through the space charge area to the p-body regions and finally to the emitter electrode. The positive charge of the holes travelling through the electric field in the space charge area causes switching losses.

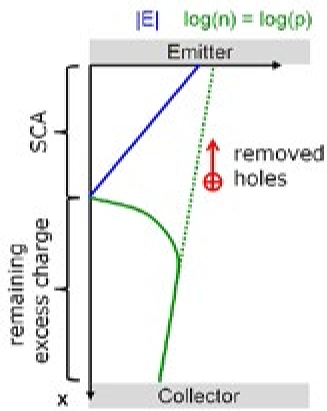

Figure 4: Schematic view during turn-off: removal of the remaining excess charge after on-state operation and building up the electric field / space charge area (SCA) to support the blocking voltage.

From Figure 4 it can be seen that IGBTs with narrow mesas remove the high hole concentration under the emitter electrode a blocking. The switching losses of IGBTs with narrow mesas in comparison to a conventional trench-field stop IGBT rise only slightly or not at all despite the significantly improved on-state properties. In any case, a more favorable operating point between conduction and switching losses will be found.

The electrons of the excess charge flow to the collector electrode at the rear side through the remaining, highly conductive remaining excess charge. Their charge is removed via an area that is practically free of electric field so that they contribute only indirectly to the turn-off losses because they cause additional injection of holes from the rear side emitter.

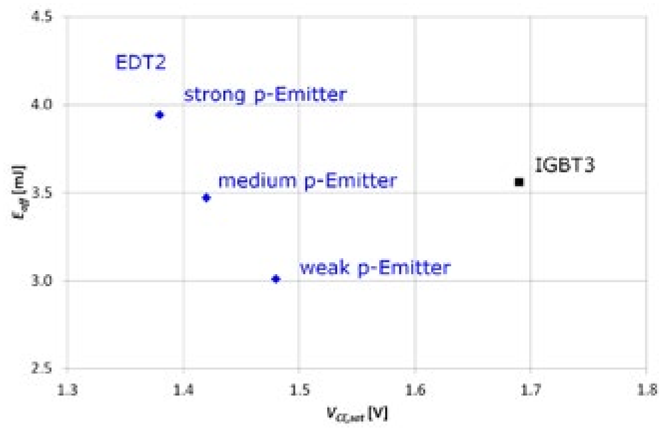

Figure 5: Turn-off losses and on-state voltage at an IGBT with narrow mesas (EDT2) compared to a conventional IGBT (IGBT3) [2]

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The relationship between on-state and turn-off losses is exemplarily shown in Figure 5, in which of course also at the conventional IGBT the ratio between on-state and switching losses can be varied, albeit at a less favorable area.

In [4] different paths of optimization for finely structured IGBT cells are shown in combination with variations in the vertical concept and especially with a targeted, well-adjusted p-emitter on the rear side of the IGBT.

From Figure 4 it appears that weaker p-emitters result in a lower attachment point for the excess charge density on the collector side end of the drift zone and thus lower turn-off losses, because when switching off, fewer holes need to take the lossy way through the SCA.

In this way, the concept allows to adjust IGBTs with narrow mesas for a wide variety of target applications, ranging from the classical drive applications, resonant topologies up to fast switching applications, which are today mainly addressed by MOSFETs.

For chip versions with low density of the excess charge in front of the collector electrode, switching losses can be achieved that can compete even with older generations of superjunction MOSFET under comparable operating conditions.

During turn-off of an IGBT, the slope of the current must be limited because in combination with stray inductances in the setup a peak overvoltage is generated. This voltage peak must not exceed the allowed blocking voltage limit of the IGBT in use. The current slope during turn-off is related to the excess charge density in front of the collector, and thus with the p-emitter. As shown in Figure 5 with the two more extreme designs, the turn-off loss between the weak and the strong p-emitter configuration is increased by approximately 1/3 while the forward voltage drops at the same current only by approximately 0.1V. Therefore, it is particularly advantageous for IGBTs with narrow mesas when their circuit surrounding, mainly the DC link, the IGBT package and the wiring, has particularly low stray inductances. During turn-off steeper current transients may be acceptable allowing the choice of an IGBT with narrow mesas having lower p-emitter efficiency and thus lower overall losses.

All IGBTs which exhibit a maximum of excess charge density below the emitter electrode on the front side of the chip have a slightly increased turn-off delay time while the high carrier density below the emitter electrode is reduced. During this turn-off delay time no significant losses occur because the voltage at the terminals of the IGBT is still near its saturation voltage. Future components which are closer to the limits for IGBTs described in [3] for physical reasons will have further increased turn-off delay times due to the distribution of the excess charge carrier density.

2.3 Turn-on Behavior

During hard turn-on in many cases other requirements of the circuit and application define the maximum slope in the change of load current at the IGBT (di_C/dt).
Among these are in particular the fulfillment of electromagnetic compatibility (EMC) regulations and avoiding excessive voltage peaks due to the current slope in combination with parasitic inductances elsewhere. Using the IGBT, for example, in a bridge circuit, too high diC/dt may also lead to a snap-off of the corresponding free-wheeling diode. Also the voltage drop during turn-on (dv_{CE}/dt) must not exceed limits defined by the application.

The turn-on behavior of IGBTs therefore in many cases is slowed down using gate resistors. The slower transients in di_C/dt and subsequent dv_{CE}/dt according to the collector gate feedback capacitance results in increased turn-on losses.

Switched mode power supplies, which allow for fast current and voltage transients and where low switching losses are important, current IGBTs are combined with SiC Schottky diodes. This avoids a part of the switching losses caused by the stored charge of bipolar diodes.

3. Summary and Outlook

In recent years, the on-state characteristic of IGBTs could be improved by use of modern semiconductor processing technology. In any cases, the on-state performance of modern silicon devices is still far from the physical limits or dimensioning rules for the application as published previously [3]. Several generations of IGBT devices will follow with further optimized on-state and switching properties.

For many hard switching applications, limits are given for the permissible current and voltage rise and fall rates during switching. As a consequence, minimum possible switching losses are defined.

Already state-of-the-art silicon devices in many cases show faster switching than present applications allow – or could be designed for applications allowing significantly faster switching.

The switching properties of current IGBTs with narrow mesas can be adjusted specifically on a wide variety of applications. In variants for low switching losses, they can replace conventional or even slower switching superjunction MOSFETs in some applications. Even in design variants adjusted on prescribed current rise/fall rates, they provide a significant reduction in the conduction and switching losses compared to classic trench-field stop IGBTs.

Acknowledgement
The author thanks at this point F. Wolter, C. Jäger and A. Vellei (for IGBTs), P. Türkes (regarding simulation) and F. J. Niedernostheide for good discussions and friendly support.

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Automotive PCB Properties and Design Considerations

Electronic elements have been playing an increasingly active role in automotives. At present, a top-level vehicle possibly contains more than 200 electronic control units some of which are sensors and processors applied in car cockpit. It can be concluded that the value of electronic products serving for automotives lies in dynamical system, body and chassis and majority of them are concerned with digital power.

By Dora Yang, PCBCart

Application of electronic systems in automotives aims to increase auto performance, covering three aspects: environmental improvement, security enhancement and convenience and comfort.

- Environment improvement refers to fuel saving, tail gas reduction, fuel transformation from gasoline, natural gas, bio-fuel to hybrid power and pure power. Electric vehicles, thus, have become a strategic direction for automotive industry.
- Security enhancement lies in traffic accident reduction, ranging from air bag, radar monitoring, stereo camera, infrared monitoring and automatic avoidance to autonomous driving. Currently, autonomous vehicles are attracting majority attention and invest from the globe.
- Convenience and comfort is generally rooted in audio, video display, air-conditioner, computer, mobile communication, internet, navigation and electronic toll collection for considerations of convenience and humanization.

As backbone of electronic devices, PCBs (Printed Circuit Boards) applied for automotives have to meet the requirement listed above as well.

Fundamental Requirement for Automotive PCBs

- Quality Assurance Requirement

A basic demand of long-term quality assurance for manufacturers or distributors lies in a sound quality management system, that is, ISO9001 from international perspective. Owing to particularity of automotive industry, three leading automotive manufacturers from North America co-established a quality management system in 1994 uniquely for automotive industry, that is, QS9000. At the beginning of 21st century, a new quality administration system was published by world automotive manufacturers based on regulations of ISO9001, that is, ISO/TS16949.

As technical regulations for automotive industry around the globe, ISO/TS16949 integrates special requirement for automotive industry and focuses on defects prevention, quality fluctuation and waste reduction in the supply chain of automotive components.

Therefore, the first certificate automotive PCB manufacturers have to achieve is ISO/TS16949 prior to their genuine entry into auto market.

- Basic Requirement on Performance

a) High reliability

Automotive reliability mainly comes in two aspects: one hand is service life during which control units and electronic components are able to normally work whereas the other hand is environmental resistance which allows automotive control units and electronic components to excellently behave in extreme environment.

The average service life of automotives is from 10 to 12 years during which only components or vulnerable parts can be replaced. In other words, electronic system and PCBs have to feature such service year as that of automotives.

Vehicles tend to be affected by climate and environment in the process of application, ranging from freezing cold, extreme heat and long-term shining and rain. Apart from those, they have to suffer from environmental changes led by heat generated due to working electronic components and systems. So do automotive electronic systems and PCBs. Automotive electronic systems have to defeat the following harshness in the environment including temperature, humidity, rain, acid smoke, vibration, electromagnetic interference (EMI) and current surge.

b) Light weight and miniaturization

Light weight and miniaturization are beneficial to fuel saving, which results from light weight and miniaturization of each component and circuit board. For example, the area of automotive-applied ECU (Electronic Control Unit) was 1,200cm^3 at the beginning of 21st century while that has been shrinked by four times at least. Light weight and miniaturization of PCBs derive from density improvement, area reduction, thinness and multiple layers.

Performance Properties of Automotive PCBs

- Multiple Types

As combinations of mechanical and electronic devices, modern vehicle technologies integrate both ancient and traditional techniques and up-to-date scientific technologies. Different parts in modern vehicles depend on electronic devices with different functions, leading to applications of PCBs with different missions.

Based on distinction in terms of substrate material of PCBs for automotives, they can be classified into two categories: inorganic ceramic-based PCBs and organic resin-based PCBs. The leading property of ceramic-based PCBs is high heat resistance and excellent dimensional stability, applicable for engine system in highly-thermal environment. Nevertheless, ceramic-based PCBs feature bad manufacturability, leading to a high cost of circuit boards. With the development of newly-developed resin substrate with increased heat resistance, resin-based PCBs are mostly applied in majority of modern vehicles.

One general rule is followed: PCBs using substrate materials with different performances are applied in different sections of a vehicle, responsible for implementation of different functions. The following table demonstrates PCB type compatible with part of vehicle devices or instrument.

Vehicle Devices	PCB Type
Speedometer; air conditioner	Single/double-layer PCB Single/double-layer flexible PCB
Car stereo; monitor	Double-layer PCB Multi-layer PCB Flexible PCB
Automotive communication devices; wireless location appliances; security control system	Multi-layer PCB HDI PCB FPCB
Engine system; power transmission control system	Metal-core PCB Rigid-flex PCB
Vehicle power controller; navigation device	Embedded PCB

Table1: PCB Type Compatible with Vehicle Devices or Instrument

- Reliability Requirement on PCBs at Different Sections of Vehicles

As a type of transportation tool concerning public security, automotives belong to a range of products with high reliability. Apart from ordinary dimensions, appearance and performance requirement on mechanics and electronics, a series of tests concerning reliability have to be implemented on them.

a) Thermal Cycling Test (TCT)
Five levels are set in accordance with different sections of a vehicle. Thermal cycling temperature for PCBs located at different sections of a vehicle can be summarized in Table 2 below.

Vehicle Section	Level	Low Temperature	High Temperature
Within vehicle body	A	-40℃	+85℃
Vehicle chassis below	B	-40℃	+125℃
Above engine	C	-40℃	+145℃
Transmission parts	D	-40℃	+155℃
Within engine	E	-40℃	+165℃

Table 2: Thermal Cycling Temperature of PCBs at Different Sections of a Vehicle

b) Thermal Shock Test (TST)
It's quite normal that automotive PCBs are applied in extreme heat environment, which is especially challenging for heavy copper PCBs since they have to suffer from both external heat and heat resulting from their own bodies. Thus, higher requirement is called for heat resistance of automotive PCBs.

To take part in thermal shock test, automotive PCBs have to be immersed in solder paste with a high temperature of 260°C or 288°C for 10 seconds three times, after which qualified PCBs feature no issues such as lamination, bumps or copper crack. Nowadays, lead-free soldering has been used in PCB assembly with a relatively high soldering temperature, which adds more necessity to thermal shock test.

c) Temperature-Humidity Bias (THB) Test
Automotive PCBs have to go through numerous and dynamic surroundings including rainy days and humid environment, which makes it necessary to carry out THB test that is also capable of inspecting PCB CAF (Conductive Anodic Filament) mobility. CAF just occurs in the following situations: between adjacent vias on circuit board, adjacent vias and wires, adjacent wires and adjacent layers. Insulativity in those situations decreases or even leads to shortcuts. Insulation resistance should be determined by distance between vias, wires and layers.

Manufacturing Features of Automotive PCBs

- High-frequency PCBs

Similar with military radar, as near-field radar, automotive anti-collision or predictive emergency braking system depends on PCBs to transmit microwave high-frequency signals. Thus, substrate materials with low dielectric loss are suggested, with PTFE (polytetrafluoroethylene) normally applied. Different from ordinary FR-4 as substrate materials, PTFE or similar high-frequency materials calls for distinct manufacturability naturally. For example, special drilling speed is required in the process of via drilling.

- Heavy copper PCBs

Vehicles tend to generate more heat due to their high electronic density and power. With the number of hybrid power and all-electric vehicles rising, more advancing power transmission systems are demanded, which also calls for more electronic functions. It thus means higher demand for heat dissipation capability and larger current. To achieve that, the thickness of copper in PCB should be increased or copper leads and metal are embedded in multi-layer PCBs.

It's easy to fabricate heavy copper double-layer PCBs while it's quite difficult to fabricate heavy copper multi-layer PCBs. The key point lies in heavy copper graphics etching and heavy copper gap filling.

Inner circuit of heavy copper multi-layer PCBs is heavy copper. Afterwards, graphics transferring requires heavy film with extremely high corrosion resistance. Etching time should be long enough and etching device and technical condition should stay in an optimal state in order to ensure excellent circuits of heavy copper.

Because there's a huge difference between inner conductor and insulator substrate material surface and ordinary multi-layer PCB stack up fails to make resin fully filled in, causing the generation of cavities, thin prepreg is then suggested containing a high amount of resin. Some multi-layer PCBs contain inner circuit with different copper thickness so that different prepreg can be used for areas with large distinction and small distinction.

- Component embedment

Embedded component PCBs were first applied in cell phones to increase assembly density and reduce product's overall size, which is essentially important for other electronic products as well. That's why embedment technology is used in automotive electronic devices.

Based on component embedment methods, there're many embedded PCB manufacturing options:

1. Groove is milled first then SMDs are assembled through wave soldering or conductive paste.
2. Thin-film SMDs are first assembled on inner circuits through wave soldering.
3. Thick-film components are printed on ceramic base.
4. SMDs are assembled through wave soldering and then resin is used for packaging. This type of embedded PCBs is more compatible with demands of vehicles such as heat resistance, humidity resistance and anti-shock, with high reliability.

- HDI technology

Similar with smart phones or tablet computers in terms of functions of entertainment and communication, vehicles call for HDI PCBs as well. As a result, microvia drilling, electroplating and interconnection technologies have to be applied in automotive PCBs.

Automotive PCB Design Considerations

- Inductor orientations

When two inductors (or even two PCB wires) come close to each other, inductance will be generated. Magnetic field created by current in one circuit (Circuit A) will afterwards cause drive of current in the other circuit (Circuit B). This process is similar with mutual effect between transformer primary and secondary collars. When two currents interact with each other through magnetic field, generated voltage is determined by mutual inductance (LM):

$$Y_B = L_M \frac{dL_A}{dt}$$

In this formula, Y_B is the error voltage input to Circuit B while L_A is the current through Circuit A. L_M is quite sensitive to circuit spacing, inductance loop area and loop direction.

Therefore, an optimal method to arrange all inductors in a circuit can be achieved through compact circuit layout and coupling balance reduction.

Distribution of mutual inductance is related with inductance alignment. Therefore, direction modification of Circuit B makes its current loop parallel to magnetic lines of Circuit A. To achieve that, inductors should be vertically arranged, which is beneficial to mutual inductance reduction.

Inductor layout rules for automotive PCBs:

a) Inductor space should be as large as possible;
b) Inductor alignment should be set as right angles so that crosstalk between them will be minimized.

- Lead coupling

Similar with inductor alignment affecting magnetic field coupling, if leads are close to each other, coupling will be affected as well and mutual inductance will be possibly generated. The leading issue in RF circuit lies in sensitive component layout such as input matching network, receiver's resonant channel and emitter's antenna matching network.

Return current path should be as close to main current path as possible with radiation field minimized, which is beneficial to current loop area reduction. Optimal low impedance path is normally grounding area under leads, that is, loop area is effectively limited in the area with dielectric thickness times lead length. If grounding area is split, however, loop area will be enlarged. For leads going across split area, return current will be forced to go across high impedance path, which greatly increases current loop area. This type of layout also makes circuit accessible to mutual inductance.

In a word, integrated grounding should be ensured under leads as much as possible since integrated mass area grounding is beneficial to circuit performance improvement.

- Grounding thru-hole

The main issue RF circuit has to solve usually lies in bad characteristic impedance of circuits, including electronic components and interconnection. Copper layer with low thickness is equivalent to inductance wire. Moreover, distributed capacitance can be formed by the combination between copper layer and adjacent leads. As leads go through thru holes, inductance and capacitance characteristics will be displayed as well.

Thru-hole capacitance mainly derives from capacitance between copper at thru-hole pad edge and bottom copper. Another element affecting thru-hole capacitance is cylinder of metal thru holes. Parasitic capacitance affects little since it usually just leads to low signal edge of high-speed digital signals.

The largest effect of thru holes is corresponding parasitic inductance aroused by interconnection. Because majority of metal thru holes feature the same dimension as that of integrated components in RF PCB design, a simple formula can be used to estimate the effect of thru hole.

$$L_{VIA}(\mathrm{nH})=5.08h[\ln\frac{4h}{d}+1]$$

In this formula, L_{VIA} is the integrated inductance of thru holes; h refers to via height with inch as unit; d refers to via diameter with inch as unit.

As a result, circuit layout should conform to the following principles:
a) Inductance module should be established for thru holes in sensitive area;
b) Filter or matching network depends on independent thru holes;
c) Thinner PCB copper will reduce the effect of thru hole parasitic inductance.

- Grounding and filling

Grounding or power plane defines a public reference voltage that supplies power to all components in the system through low impedance path. Based on that scheme, all the electric fields can be balanced with excellent shielding scheme generated.

Direct current always flows through low impedance path. Similarly, high-frequency current is also a path flowing through the lowest impedance at the first minute. Therefore, for standard PCB leads above ground plane, return current tries to flow into the grounding area rightly under leads. Afterwards, split grounding area arouses all kinds of noises, which further increases crosstalk through magnetic field coupling or current accumulation. As a result, ground integrity should be ensured as much as possible, or return current will drive crosstalk.

In addition, filling ground, also called protective wire, is usually applied for design of circuits containing areas where continuous ground is difficult to be arranged or that requires shielding sensitive circuits. Grounding thru holes can be positioned at terminals of wires or along the wires to increase shielding effect. Protective wires can't be mixed with leads designed to provide return current path, which will bring forward crosstalk.

When copper area isn't connected to ground or connected to ground at one terminal, its validity will be decreased. In some cases, parasitic capacitance will be generated with ambient impedance changed or potential path formed between circuits, which, thus, lead to bad effect. Simply speaking, if copper has to be arranged on the board, the same electroplating thickness should be maintained.

In the end, grounding area near antenna has to be taken into consideration. Any monopole regards grounding area, routing and thru hole as a section of system balance and non-ideal balanced routing will affect radiation efficiency and direction of antenna. Therefore, grounding area mustn't be directly placed right under monopole antenna of a circuit board.

To sum up, the following design principles should be conformed to in terms of grounding and filling:
a) Continuous grounding area with low impedance should be provided as much as possible;
b) Two terminals of filling wires should be connected to the ground with thru hole array applied;
c) Copper-coated lines have to be connected to the ground near circuit around which copper coatings aren't necessary. When it comes to circuit boards with multiple layers, a grounding thru hole should be arranged as signal lines are transferred from one side to the other.

In conclusion, automotive PCB design rules can be summarized into the following table:

Inductor layout	a. Inductor space should be as large as possible; b. Inductor alignment should be set as right angles;
Integrated grounding	a. Integrated grounding should be arranged under leads;
Thru holes	a. Inductance module should be set for thru holes in sensitive area; b. Filter or matching network depends on independent thru holes; c. Thinner PCB copper reduces the effect of thru hole parasitic inductance;
Grounding and filling	a. Continuous grounding area with low impedance should be provided; b. Connect terminals of filling wires to the ground with thru hole array applied; c. Copper-coated lines have to connected to the ground;

Table 3: Automotive PCB Design Rules

About the Author:

Dora, a technical engineer from PCBCart - China-based full turnkey PCB assembly service provider - constantly summing up the experience gained past work and sharing them on PCBCart's blog. Got any questions related to PCBs design, manufacturing or assembly for Dora?
Reach her on Twitter @dorayang0227.

Choosing Among Ceramic Substrates for Power Circuits

Designing modern power circuits starts with a choice of circuit material. This choice is critical for meeting performance goals. The material must often support dense circuits with high voltages, so high isolation is essential. As thermal management is also important for reliability, these circuit materials must also provide excellent thermal conductivity. Ceramic circuit materials can handle high voltages with high isolation and high thermal conductivity. However, ceramic materials have their differences, and knowing those differences can help ease the power circuit substrate selection process.

By Olivier Mathieu, Product Innovation Manager, Rogers Corp., Power Electronics Solutions (PES)

Ceramic Substrate Materials & EV/HEV Power Modules
Designing power circuits requires a substrate material suited to the application. New applications, such as power modules for electric vehicles (EVs) and hybrid electric vehicles (HEVs), call for higher voltage and power from smaller circuits, requiring circuit materials capable of providing high voltage isolation with efficient dissipation of heat from densely packed semiconductor devices such as IGBTs and MOSFETs.

Ceramic substrate materials have the properties needed, but not all ceramic substrates are made the same. Attachment of copper to ceramic, for example, can be done in different ways, including by direct bond copper (DBC) or active metal brazing (AMB) processes. Knowing how ceramic substrates compare can help when specifying one for an application that must handle high voltage with high isolation and efficient dissipation of heat.

The number of EVs and HEVs are increasing steadily worldwide, with improvements in energy storage systems and consequent increases in driving range. Power circuits for these vehicles are built around switching diodes - IGBTs, and MOSFETs - and are designed to handle DC voltages from about 400 to 750 V; in some cases the voltages in EVs and HEVs can reach as high as 900 to 1200 V. Because space is limited in an EV or HEV, power circuits and modules are generally built into tight spaces. Fortunately, ceramic substrate materials can meet the electrical and mechanical requirements of EV and HEV power modules as well as many other power electronic applications.

Ceramic substrates include copper layers for fabrication of circuit patterns, heat sinks, and other electronic structures. Ceramic materials include alumina (Al_2O_3), aluminum nitride (AlN), and silicon nitride (Si_3N_4). Copper is bonded to the ceramic material by different methods, depending on the type of material, with the DBC process used for alumina and AlN and the AMB process an effective means of joining copper to Si_3N_4. The DBC process, which is performed at temperatures of about +1065ºC, forms a bond as a result of melting and diffusion between the ceramic substrate and the copper. The AMB process, with a lower process temperature of about +800ºC, creates a high-temperature brazed joint between pure copper and the Si3N4 ceramic material.

Both DBC and AMB ceramic substrates have properties suited for the high-power densities in EV/HEV power modules. The high electrical conductivity of copper supports high current; the excellent dielectric properties of the ceramic substrates enable the high isolation needed for densely packed circuits in power modules (Figure 1). Understanding how mechanical attributes, such as copper thickness and ceramic thickness, relate to performance can help when attempting to optimize ceramic material parameters for electrical performance and effective thermal management.

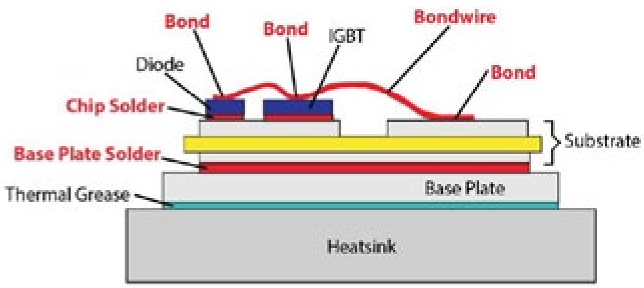


Figure 1
Structural details of an IGBT module
(Connections that are relevant to module lifetime are marked in red)

Figure 1: Direct bond copper (DBC) and active metal brazing (AMB) are two processes for joining conductive copper to ceramic dielectric substrate materials.

Handling High Voltages
As EVs and HEVs evolve and their supporting technologies (such as energy storage) improve, the number of such vehicles produced each year will continue to grow. The increased weights and higher-performance requirements of EVs and HEVs will require high-voltage inverters with higher current capacities. Diodes, IGBTs, and MOSFETs used as switching devices in vehicle power circuits are available from a number of suppliers. These semiconductors are rated for different operating voltages (VCES) and isolation voltages (VISOL), and the supporting power circuits and their substrate materials must provide the performance for reliable operation at the required voltage and power levels.

The isolation test voltage for power semiconductor devices is included in various standards and regulations for EVs and HEVs. It refers to a maximum voltage applied between the device terminals and the insulated module base plate without electrical breakdown occurring. For an active device mounted on a circuit substrate, the dielectric strength and thickness of the substrate material will impact the isolation voltage. Ceramic substrate materials provide high dielectric strength of greater than 20 kV/mm in favor of handling high-voltage circuits and devices.

The thickness of the ceramic substrate material will determine the isolation voltage possible for a particular circuit, with thicker materials supporting higher voltages. For example, a ceramic substrate with 0.38-mm thickness supports isolation voltages as high as 6 kV, while a 0.63-mm-thick ceramic substrate is capable of isolation voltage to about 13 kV. Thicker ceramic substrates enable thicker isolation voltages.

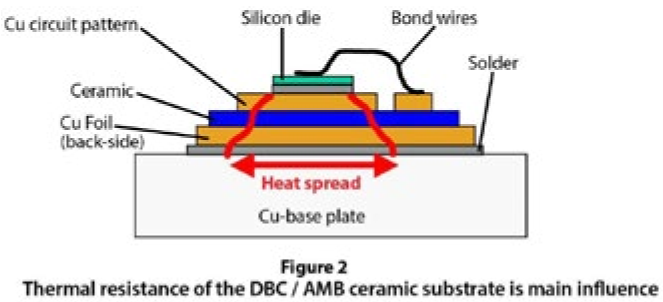


Figure 2: Affecting the thermal resistance of the DBC or AMB ceramic substrate.

Dealing with the Heat

The common design goals for EVs and HEVs of minimizing the size of electronic components has resulted in a trend towards smaller power modules at higher power levels, which invariably leads to thermal issues. Even the most efficient power semiconductors produce thermal energy as a byproduct of current flow through an active device, such as an IGBT or MOSFET. To ensure reliability and long operating lifetime, the heat must be removed, and this can be effectively accomplished through the use of circuit substrate materials with high thermal conductivity, such as ceramic substrates.

The amount of heat that must be managed for a given device will be a function of power produced by the device, with higher power levels producing more heat. DBC and AMB ceramic substrates have different thermal characteristics, such as thermal resistance (Rth) and thermal conductivity, which serve as guidelines for which material is better suited for which power levels. At +20°C, for example, the thermal conductivity of alumina (Al_2O_3) is 24 W/mK while that of silicon nitride (Si_3N_4) is 90 W/mK. But for AlN, the thermal conductivity is 170 W/mK, which makes it the clear-cut choice for extremely high-power, high-power-density circuits in which heat must be dissipated at any cost. When low thermal resistance is needed to dissipate large amounts of heat, this can also be accomplished by reducing the thickness of the ceramic substrate, increasing the area of the copper upon which the active device is mounted, and increasing the thickness of the copper layer (Figure 2).

Another material-related parameter to consider as part of a search for a power circuit substrate material for EVs and HEVs is the coefficient of thermal expansion (CTE), which describes how different materials expand and contract with temperature. Two materials physically joined with two different CTEs can suffer stress with large changes in temperature. Optimally, any mismatch in CTEs, such as those of a silicon IGBT or MOSFET and its circuit substrate, should be minimized to reduce thermally caused mechanical stress at the interface of the two different materials.

Fortunately, the low CTEs for ceramic substrates - 6.8 ppm/K for alumina, 2.5 ppm/K for silicon nitride, and 4.7 ppm/K for AlN - are compatible with the low CTE of silicon transistor die (about 2.6 ppm/K). By forming device lead frames combined of ceramic and copper, the CTE is lower than that of lead frames made of bare copper. The use of low-CTE ceramic helps to compensate for CTE mismatches between the silicon chip and the chip solder (with a CTE of about 22 ppm/K) used for die attachment.

Magnetics Design Part I

Standard or Custom?

By Dr. Ray Ridley, Ridley Engineering Inc.

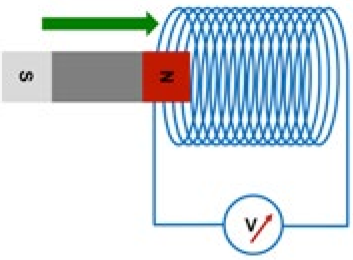
A brief history

Magnetics represent the most ancient of technologies used in modern electronics systems. Despite being with us for almost 200 years, it is still the most critical component in power supplies. Nothing has been able to replace magnetics in terms of performance, size, and cost.

Invention of the Transformer

In the early part of the 19th century, Faraday and Ampère were busy researching the interaction of magnetic fields with electric currents and voltages. There were two aspects of the interaction that led directly to the invention of the transformer. The first led to Faraday's Law of Induction which stated that a changing magnetic field would induce a voltage across a coil of wire, as shown in Figure 1. When the magnet is plunged into the coil, the voltmeter moves in one direction, and when it is pulled out of the coil, the voltmeter moves in the opposite direction.

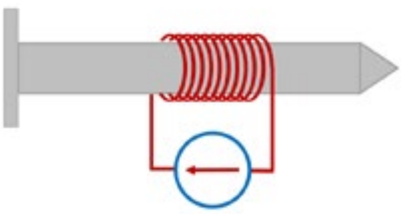
This coil and magnet experiment is something that most schools will illustrate to students at an early age.



$$\nabla \times E = -\frac{\partial B}{\partial t}$$

Figure 1: Faraday's Law of induction with Maxwell's Mathematical Formulation

Another experiment taught to children early in their education is the electromagnet. If you wrap turns of wire around an iron nail and pass current through the wire, the nail becomes magnetized and can pick up other iron objects.



$$\nabla \times H = J$$

Figure 2: Ampere's Circuital Law with Maxwell's Mathematical Notation

What is missing from early education is the link between these two laws, and how they can work together to make a useful electromagnetic device. If we put two windings on the iron nail, and apply a current to one of them, it will produce a magnetic field that increases as the current increases. This is a changing magnetic field, which then works with Faraday's Law of Induction to provide a voltage on the second winding (or current if the second coil is shorted). Hence, a current in one winding gives rise to a current in the other winding and the coupling mechanism is the changing magnetic field between the two.

Faraday recognized this connection, and built the first transformer in 1831. Rather than using a straight nail, he used a toroid of iron, which provided better coupling. With this he showed that a voltage or current in one winding induced a voltage or current in the other winding. This structure is not very different from modern magnetics designs – only the core material is changed.

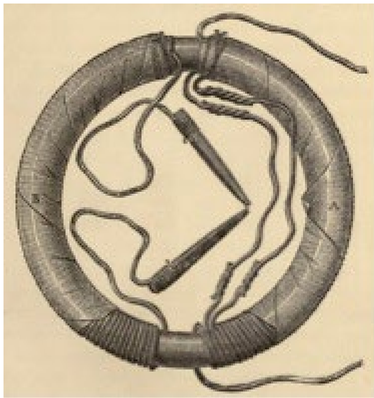


Figure 3: The first transformer, made by Faraday in 1831

Early experiments like these produced weak forces with the electromagnet, or small deflections of the voltmeter. They conceal how much power could be transmitted, the coupling speed, and the efficiency of the process. However, it did not take long for the early experiments to be turned into highly practical applications.

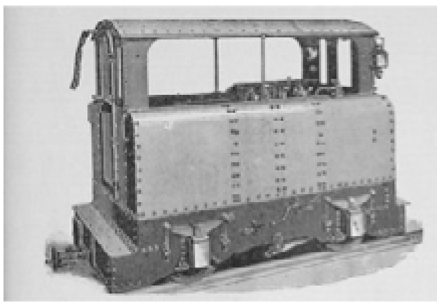


Figure 4: Application of transformer technology by the 1890s

Transformer Applications
Not long after Faraday's transformer, engineers were making motors, trains, and transformers at increasing power levels. Early trains appeared in the 1830s around the world, and by the 1890s, London started using electric trains in their underground system.

Transformers turned out to be highly efficient—well above 99%. There is almost no limit to the power level. Transformers exist today that can process over 1 GW of power. However, due to their longevity, transformers are often regarded as slow and low-tech when compared to modern electronics. Despite this misperception, they are still unsurpassed in performance in modern electronic power supplies.

High-Frequency Magnetics
Low frequency magnetics were extremely mature by the beginning of the 20th century. The advent of vacuum tubes created radio technology and suddenly catapulted electromagnetic devices into the multi-MHz range. And—they worked. That is because the electromagnetic effect moves not slowly, but at the speed of light, and there is no theoretical limit to the bandwidth of transformers.

We saw the invention of semiconductors in the 1960s, power mosfets in the 1980s, and wide band-gap devices in the 2000s. Transformers continue to reign supreme, much to the chagrin of many program managers and semiconductor companies. How can it be that a 200-year-old technology is still the best way to convert power? And, more importantly, how is it that my engineers don't seem to know how to design these things?

Standard Vs. Custom Inductors
In this high-technology age where electronics parts can be ordered and delivered overnight, inductors and transformers are a sticking point in power supply development. Most designs need custom magnetics parts that are not 'off-the-shelf' components. This is due to the extremely wide range of power electronics applications.

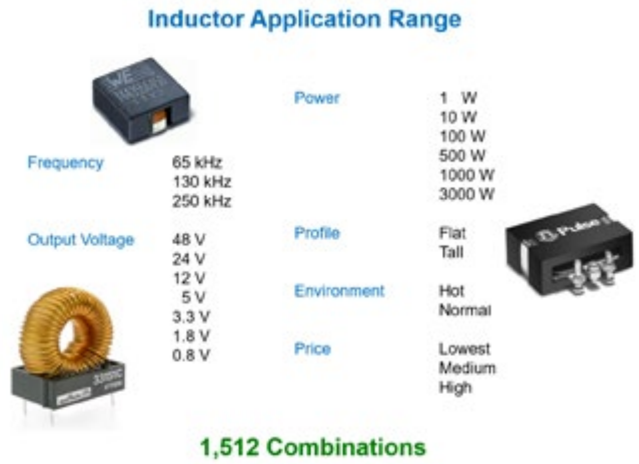


Figure 5: Inductor needs – several thousand standard inductors can meet most design requirements.

Figure 5 shows the variables involved in designing a power supply at power levels from 1 W to 3 kW. Three switching frequencies are considered, 65 kHz, 130 kHz and 250 kHz. This covers the majority of applications, although there are many other frequencies used. When all permutations are considered, we only really need about 1500 different types of inductors to cover most applications.

Not every engineer realizes that some off-the-shelf parts will suffice. For example, if a 134 uH part is needed and a part cannot be matched, sometimes the inductor value is not a critical design element. In that case, standard parts can result in good price and performance.

Standard Vs. Custom Transformers

Transformers can create a problem. One of the functions of a transformer is to change the voltage level, which is why the inductor variation count is not so high. Input voltage variation does not appear in figure 5. However, each voltage range will need a different transformer turns ratio, as you can see in figure 6. In addition, every topology needs a different transformer design to provide the proper circuit connections. Multiple outputs make the process even more variable.

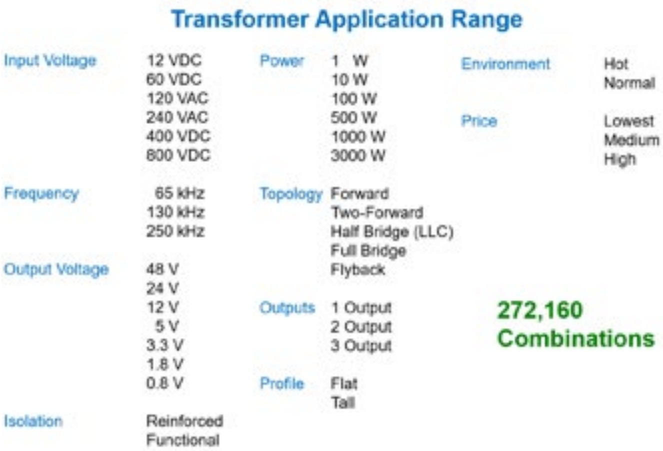


Figure 6: Transformer needs – several hundred thousand different transformers would be needed to meet most transformer needs

After all variations are considered, the industry needs about 272,000 different transformer designs. It is unreasonable to expect manufacturers to cover this wide range, so we resort to custom transformers.

A custom transformer may seem like a necessary evil in the development process, and a standard inductor will be used. Be cautioned that it is not always that straightforward. The objective of a designer is to maximize circuit performance, efficiency, size, and price. It is often easier to build a better inductor than buying standard parts, keeping in mind that there is a tradeoff in the price of development against the benefits of performance advantage.

Launching Magnetics Design

It is difficult to find a good and comprehensive guide for designing magnetics. Techniques and opinions vary on the subject in published works. Imagine the frustration of a newcomer to the industry, or a recent graduate. Most universities teach theory, but not real-world application. What we need is clarity and guidance.

To begin, know that there are low–cost parts available in abundance. Figure 7 shows the basics required to get started with magnetics prototyping—wire, foil, litz, bobbins, toroids, two-piece cores, and tape. The next step is deciding how to configure these basic elementary parts to get outstanding performance from your design. Thus, the series on magnetics design begins here to help being clarity to the process. Stay tuned for next month's article.

Figure 7: Parts needed for custom magnetics prototypes and manufacturing

Summary

Custom magnetics are an essential element of modern power supply design if you need isolation and high performance. Whether developing custom magnetics or working closely with a vendor, comprehension of the process is critical and worthy of time in the development schedule. Very few engineers are equipped to design magnetics, so we will begin unfolding the methodology in this series.

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[3] Learn about proximity losses and magnetics design in our hands-on workshops for power supply design www.ridleyengineering.com/workshops.html (The only hands-on magnetics seminar in the world.) http://www.ridleyengineering.com/workshops.html
[4] Join our LinkedIn group titled Power Supply Design Center. Noncommercial site with over 7400 helpful industry members with lots of theoretical and practical experience. http://www.linkedin.com/groups?&gid=4860717
[5] Join our new Facebook group titled Power Supply Design Center. Advanced in-depth discussion group for all topics related to power supply design. https://www.facebook.com/groups/ridleyengineering/

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Don’t let your Digital Storage Oscilloscope betray you

Caveat emptor = Let the buyer beware: The majority of low and medium-priced DSO’s in use and still on the market lack sufficient memory and are unfit for use in design and test of switching circuitry. Refrain from buying or using any DSO with less than 1 MB.

By Dr.-Ing. Artur Seibt, Vienna

Please note that the probe must be included because it has its own rise time. Some firms used to specify the scope rise time at the probe tip. Any bandwidth printed onto a probe is to be taken with a grain of salt, because it will depend on the scope used and the correct calibration of the probe.

Many modern wide band DSO’s use software tricks to “lift” the frequency response by manipulating the signal after the a/d conversion, dispensing with the undistorted pulse response.

► Although DSO’s have to show a Gaussian response they remain sampling scopes. If the actual bandwidth is determined by the sampling rate, the pulse response will not any more be Gaussian.

Any signal content above half the actual sampling frequency will be aliased. An analog scope is able to show signals far above its bandwidth, they are reduced in amplitude and rounded, but visible. This applies e.g. to wild oscillations of a circuit which will be obvious. DSO’s can not show anything above half the sampling frequency, i.e. only artefacts.

2.2 Artefacts, invalid digital data.

Whenever the sampling frequency is too low distortions and artefacts will crop up which mostly bear no resemblance to the signal. Only a low pass filter with sufficient damping at half the sampling frequency could avoid this. In principle, this would be possible if the sampling frequency were always constant, but DSO’s with small memories would require a low pass with variable cut-off frequency.

► While analog scopes do not distort signals at all, sampling scopes will show limitations and distortions due to the sampling process (see later).

DSO’s, however, will show the combined signal distortions of three processing steps: sampling, a/d conversion and d/a conversion.

► If a DSO displays artefacts it follows that all digital data derived are false, and so are all calculations based on such data! But how does one know that the display and the data are false? See later.

Note that the true rise time of 0.7 ns was shown eventually false by a whopping 6 orders of magnitude!
Magnificent progress!

2.3 Resolution and accuracy.

► Most manufacturers claim that their DSO’s could improve their resolution from the usual 8 to 11 bits. Yes, this is true. What the manufacturers do not say, however, is that the higher resolution is achieved by averaging which is identical to low pass filtering, and that the bandwidth will be knocked down to a fraction of the nominal, e.g. from 100 to 1 MHZ! The innocent user will not be aware that he is now measuring with only 1 MHz bandwidth! They also do not say that averaging is limited to signals which repeat with the same shape. There is never something for nothing.

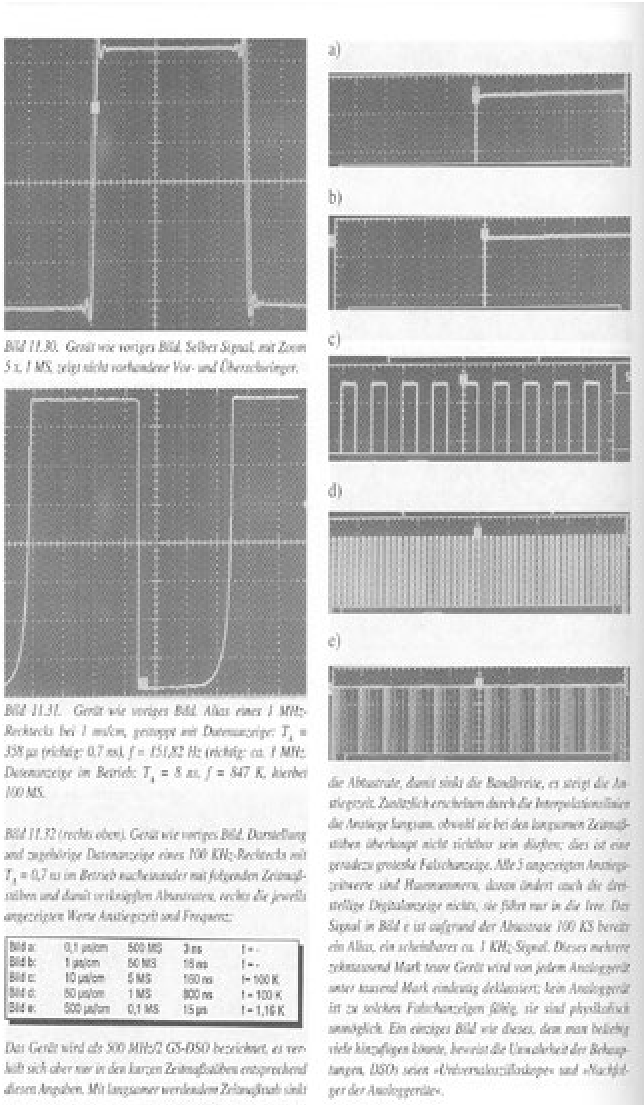

Figure 2.3: a to e show 5 screen photos of a 500 MHz DSO, the table below shows the digital display of the bandwidths, rise times and signal frequencies of a 100 KHz 0.7 ns rise time square wave at sweep speeds from 0.1 us/cm to 500 us/cm.

Except for a few very recent instruments with 12 bits with prices up to 40 K$ all DSO's have a maximum of 8 bits of vertical resolution; the stress is on the the word "max.", because the a/d converter range is seldomly fully used. It is "effective bits" which count.

It is customary to advertise impressive theoretical high dynamic ranges of digitized signals like the 16 bits of the cd which should yield 96 dB. It is not mentioned that the distortions rise to 100 % when the signal approaches zero, so the lower bits can not be used. In case of the cd the lower 10 bits are for the birds, so only 6 bits or 36 dB dynamic range are usable. This is the reason why the music is compressed into those upper bits. The "low noise" is due to the fact that cd players short the output for low values of signal. Any good record has a dynamic range of 60 dB, top tape recorders achieve up to 80 dB. With analog signal processing the resolution remains infinite until the signal disappears in the noise.

► With 8 bit DSO's the trace remains jittery which causes the user to believe that his measuring object was noisy. With CCD's this is still worse.

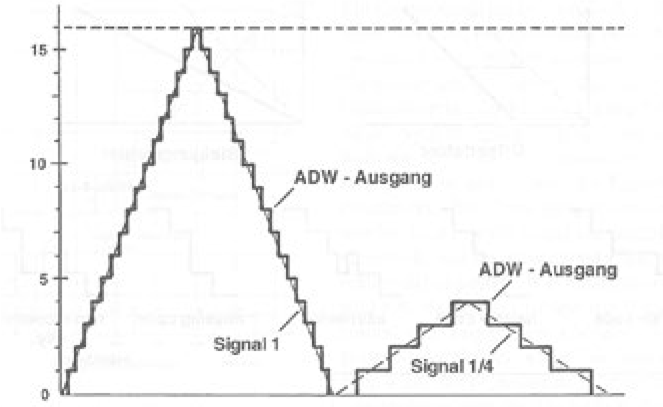

Figure 2.4: Digitized signals become the more distorted the smaller they become. Eventually, only the LSB will be switched on and off, i.e. there will be a rectangle, irrespective how the original signal looked like.

2.4 Reconstruction problems

There are many applications of the sampling technique where it is not necessary to reconstruct the waveform, e.g. if only the rms value of a signal is to be measured. However, with scopes reconstruction is the purpose. Just two sampling points per signal period (= Nyquist) give no hint to the waveform, any waveform may be drawn through these two points! From 10 points on a rough guess is possible, for a useful reconstruction many more points are required, a decent one needs about 100! This is just another way of expressing the need for a sampling frequency 5 to 10 higher than Nyquist or 10 to 20 times higher than the bandwidth. A single glimpse onto the screen of a sampling scope is enough to prove this.

Quotation Tektronix:

„For accurate reconstruction, using linear interpolation, the sample rate should be at least 10 times the highest frequency signal component!"

Quotation LeCroy:

"...with linear interpolation at least 10 points per cycle are necessary..." This statement pertains to the requirements of a barely acceptable reconstruction.

If linear interpolation were forbidden, DSO's would never have captured the market.

In the operating modes ETS and RS (see below) always sufficient points are gathered, however, in the operating mode RTS only the points which are obtained once are available, and this determines the performance of a DSO. The reason for the discrepancies in the manufacturers' wordings is their effort for years to sidestep Nyquist and their statements at that time they had a special method to get away with 2.5 times the sampling rate instead of 10 times. This applies to the sin x/ x reconstruction which, however, is only appropriate for sine waves. The amount of data captured is mostly too much for the display, e.g. a 2,000 x 2,000 pixel vector display, so the samples acquired are binned down to 2,000 pixels. Decimation binning means that e.g. only every 50th sample is taken, this means that also the bandwidth is divided by 50. In order to see fast events, the user must scroll through the memory and search.

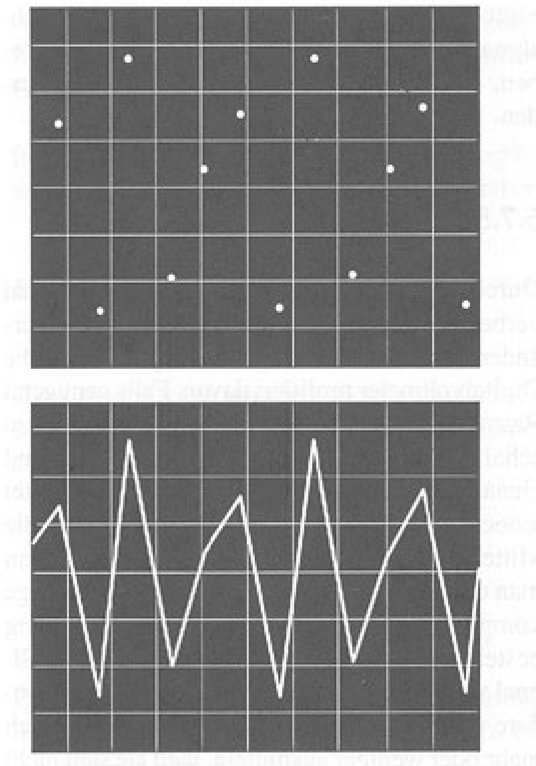

Figure 2.5: Reconstruction errors resp. distortions caused by linear interpolation if the number of points is insufficient. The top picture shows the sampling points of a sine as they are obtained by a single acquisition in the operating mode "Real Time Sampling". This display is entirely useless, inspite of this all DSO's draw interpolation lines through these points, the result is shown below and demonstrates how reliable DSO displays are if they are obtained from too few points! This display is just worthless and grossly misleading for the user.

2.5 Z - axis

► DSO displays are devoid of any information content within the trace, the trace is equally bright everywhere.

In analog scopes the trace is intensity-modulated by its speed, in other words those parts of the display where the trace is comparatively slow are brighter than those where its speed is higher. The display of a fast 1 KHz square wave, e.g., shows bright upper and lower parts while the transitions remain invisible. This is a very valuable information. A DSO will display the whole waveform equally bright which is false. Some newer extremely expensive DSO's try to simulate this behaviour of analog scopes.

2.6 Repetition rate, capture rate
Even the oldest analog scopes featured repetition rates of 100 KHz, the last ones of 400 KHz. In analog scopes, the signal is always on the screen, but during the retrace time the trace is blanked, so it is not visible. DSO's function entirely differently: after the signal was captured once, the DSO has to digitize and store it, the stored signal is mostly sampled again with a slow clock because the display can not accept the amount of information and d/a - converted. These processing steps take so much time, that the first and second DSO generations were only able to capture the signal at a rate below 100 Hz. In the time between the DSO remains blind to the signal, hence a DSO is least fit to detect rare events. These DSOs reacted so slowly that they could not even be used to adjust something, some needed minutes to fill the screen once. This so called capture rate was increased over the years slowly so some hundred Hz. Tektronix introduced the only true advancement when they incorporated the whole signal processing of an analog scope so they advanced the capture rate in their most expensive products to over 400 KHz, they call it "Digital Phosphor" DSO's are asleep for 99.9935 % of the time".

3. How to identify false displays
3.1 Use a Combiscope
The Combiscope was invented around 1993 by Philips NL, it consisted of an analog scope which also contained the electronics of a DSO. By pushing a front panel button the function could be switched between analog and digital. The instrument was a 200 MHz 4-channel scope which also featured a unique autocalibration function: by pushing a button the instrument performed an almost complete self-calibration, even including the adjustment of the input attenuators. After Philips sold this business to Fluke, the oscilloscopes were discontinued. Hameg Instruments D introduced a whole line of Combiscopes and also used the term, the top of the line model was the 200 MHz, 2-channel type 2008 which used the same 14 KV, extremely bright and sharp crt from Philips. Production was terminated around 2010. If such an instrument is still available second-hand it would be a good buy, the original price was only around 2,000 E.

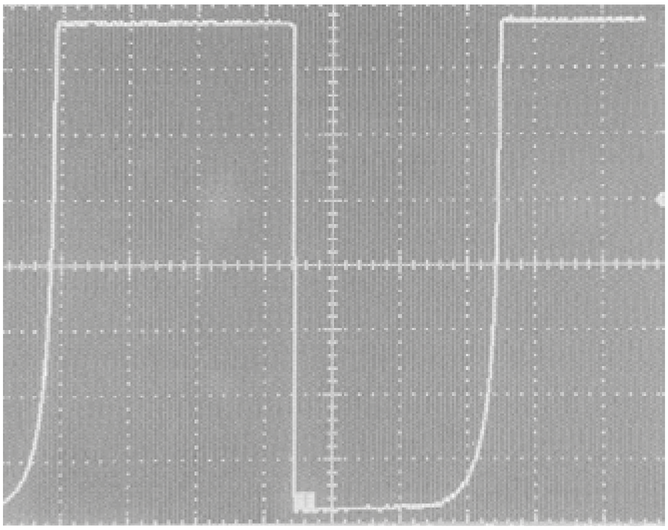

Figure 3.1: False stopped display of a 1 MHz square wave shown here as 151.82 Hz with a rise time of 358 us (correct: 0.7 ns). When running the frequency is shown as 847 KHz and the rise time as 8 ns. Actual sampling rate 100 MS/s

A 200 MHz Combiscope would not only be sufficient for most work on switching circuits, but it unites the best of both worlds. One would use it normally in the analog mode; the digital mode would only be needed if digitized signal data or signal storage were desired. The validity of the digital data can be verified any time by switching to the analog mode; in fact this is the only sound method.

A Combiscope must be more expensive than an analog scope, but this was not the main reason why no other firms ever offered some. They were afraid of the easiness with which the shortcomings of their DSO's and the superior quality of the analog display could be proven by just pushing a button...

3.2 Change the time base setting
According to the explanation above a DSO with an insufficient memory will have a different sampling rate and bandwidth in every lower time base position. Hence the false displays will be different in each position.

► Whenever one suspects a false display change the time base setting and watch the display.

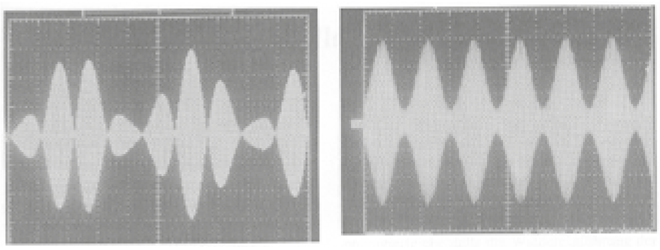

Figure 3.2: 500 MHz, 2 GS/s - DSO. 10 MHz sine wave, 80 % amplitude-modulated with 1 KHz. left 100 us/cm. Right 50 us/cm, 200 KS/s, best picture achievable, comes closest to the truth, but the waveforms inside the lobes are aliases

3.3 Watch the digital numerical displays
If e.g. a fast square wave is applied to the DSO, the rise time will be indicated on the screen. Switch the time base to slower positions and watch these numerical displays. Of course, the rise time of the signal does not change, hence the rise time display should not change either. But it will, and the rise time can be shown wrong by e.g. 6 orders of magnitude, see below. This is called progress.

3.4 Change the signal if possible
False displays will mostly change if e.g. the signal frequency is changed a bit, especially if the signal frequency and the sampling frequency happen to generate beat frequencies. Such false displays can look quite convincing, but their "frequency" may be off by orders of magnitude. 100 MHz can be shown as "1 KHz"!

3.5 Beware of modulated and similar signals
As will be explained in later chapters, the standard operating mode is ETS = Equivalent Time Sampling. In this mode a screen display is composed of a multitude of signal reocurrencies in the very same shape. In the case of modulated and similar signals, each following signal period has a different shape.

If a continuous sine wave is sampled at the Nyquist limit, it will appear as an amplitude-modulated sine.

3.6 Watch for steps
Watch whether the display shows steps: this is always a clear sign of insufficient resolution, there are too few points for a proper reconstruction, such displays are faulty, the data useless.

4. Analog oscilloscopes.
Briefly, an analog scope consists of a cathode ray tube with its high voltage supply (up to 24 KV) , a wideband vertical amplifier for the

signal and a time base which generates a saw tooth of variable speed which moves the trace from left to right. A delay line in the vertical delays the signal for some ten ns until the time base starts so the front of a pulse is visible which triggered the time base. It is the signal itself which deflects the trace in vertical direction. Analog scopes have a constant bandwidth and infinite resolution. Analog scopes were available in compact format and as plug-in instruments. Plug-ins can be exchanged like lenses in a camera; in addition to vertical amplifier and time base plug-ins there were sampling, spectrum analyzer, digital multimeter, counter, curve-tracer etc. plug-ins. This allowed to change the scope within minutes, the user got three instruments in one. Today, he has to buy separate instruments. In 1992 the production of the Tektronix 7000 series was terminated. The 7104 1 GHz type was the fastest analog scope ever. Since then some measuring tasks can not any more be fulfilled with scopes out of current production, e.g. there is no 10 uV/cm scope.

In second-hand shops they are still available at a fraction of the original prices. A first-class scope set for a SMPS or similar lab would consist of: 7904A 600 MHz mainframe + 2 x 7A26 200 MHz 2-channel verticals + 7B92A dual time base with 0.5 ns/cm. Passive 10:1 and 100:1 probes, a 50 MHz DC/AC current probe and FET probes would complete the set. With a 7L13 spectrum analyzer plug-in and a self-built LISN emi measurements can be made.

5. Sampling oscilloscopes (SOs)

► All DSOs are by nature also sampling oscilloscopes because any a/d conversion must be preceded by sampling the signal. DSO's can not be understood without understanding SO's.
In pure SO's sampling happens directly at the 50 ohm input, the amplitude samples are amplified and displayed on the screen with infinite resolution as in analog scopes. DSOs' inputs are identical to those of analog scopes, the signal is amplified and then sampled, a/d converted, stored. The stored data are binned or sampled again at a low rate, d/a converted and displayed.

Sampling is based on the stroboscopic principle, the first such apparatus was built in 1880 by Joubert. If the sampling frequency is the same or a multiple of the signal frequency, the difference frequency will be displayed which can be zero, in this case only horizontal lines will appear. This has an interesting consequence: the time scale can be extended to infinity.

The servo system was invented 1898 by Callender. In 1952 McQueen in GB presented the first random sampling scope which already contained nearly all features of today's instruments. In 1957 Sugarman built the first sampling scope capable of showing non-periodic signals. HP manufactured 1960 the first commercially available sampling scope (500 MHz, 10 mV/cm), 1962 the first 1 GHz scope followed, a two-channel unit with sampling probes, 1964 4 GHz and 1966 12.4 GHz scopes came in due course. Tektronix stayed behind until 1967 when the random sampling time base 3T2 appeared and 1, 4 and 14 GHz samplers.

Neither is the automatic measurement of signal parameters an invention of DSO manufacturers: also already in 1967 the Tektronix 567 and 568 measured automatically amplitude, time, time differences, frequency, rise, fall and delay times, averages etc., compared these with preset limits, displayed the values on digital displays with high accuracy and sent the data to external computers.

5.1 Principle

Sampling uses intermediate analog storage which is equivalent to pulse stretching, usually called sample and hold. This implies that energy is taken from the signal which will distort it more or less.

In practice, there are two methods:

- A switch beween signal source and hold capacitor is closed for a very short time.
- A switch between signal source and hold capacitor is normally closed so the voltage on the hold capacitor follows the signal; in the moment of sampling the switch will be opened, the capacitor holds the last signal value.

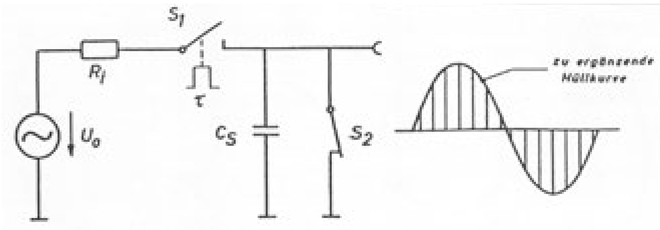

Figure 5.1: Simple sampling circuit with reset as they were used in the first sampling scopes

Figure 5.1 shows the basic circuit. A second switch S 2 resets the hold capacitor as soon as the sampled value has been processed.

Two basic properties of sampling are obvious:

- During sampling the signal is being averaged by the RC.
- The signal portions between the sample points are lost forever.

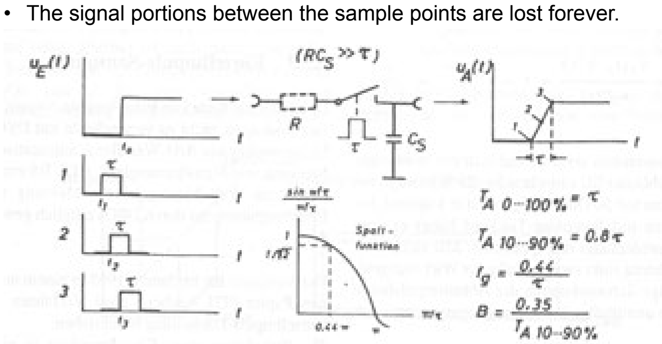

Figure 5.2: Influence of the width of the sampling pulses on the rise time and the waveform

If sampling is performed with a frequency very high with respect to the signal frequency a series of needle-shaped pulses is obtained as shown on the right, the envelope is the original signal waveform. Low pass filtering will delete the sampling frequency and its harmonics, so the signal's waveform is approximately regained. Without filtering the signal frequency band will be grouped around the sampling frequency and its harmonics. Sampling is hence a process very similar to mixing or modulation, these expressions mean about the same just like multiplication; this is easy to understand if one realizes that a mixer or modulator also is nothing else but a switch which passes the signal at a rate given by the oscillator (= sampling) frequency. This also explains the generation of beat frequencies (artefacts, ghosts, aliases). The purpose of mixing, e.g. in a radio, is a frequency transformation of the hf signal into a frequency range where amplification and filtering are easier (intermediate frequency).

In a SO the signal's waveform shall be preserved and later reconstructed.

Assumed the input circuit of a SO does not impair the bandwidth what then limits it? Figure 5.2 shows the influence of the width of the sampling pulses.

The sampling pulse of width 1 samples the input signal (front of an ideal square wave) at 3 times t1 to t3. During the closure of switch S1 the voltage across Cs assumes the average of the input voltage uE (t). The result uA (t) is a linear rise of duration τ for 0 to 100 %. As the rise time is defined from 10 to 90 % it follows:

$$tr = 0{,}8\ \tau$$

In case of a sine wave the well-known function:

$$\frac{\sin p f t}{p f t} \quad \text{with} \quad f_g = \frac{0{,}4}{t}$$

will be obtained.

Evidently the result will be zero if a whole signal period (or multiples) fits into the window, it is also evident that the result may become negative if the average is negative at the end of the sampling period. First-class samplers indeed do show this linear rise as in Figure 5.2 which does not at all convene with a Gaussian response. In spite of this the already known equation:

$$tr \times f_g = 0.35, \text{ because } 0.35 = 0.8 \times 0.44$$

also holds here.

► Even if there are no other influences, the limited width of the sampling pulses will limit the rise time to tr = 0.8 τ.

Figure 5.2 delivers another important parameter, this is the sampling efficiency. The charging of Cs is via Ri and follows an exponential. It depends hence of τ, Ri, Cs how many percent of the input voltage will remain on Cs. The efficiency is hence:

$$\eta = (u_A(t_e + \tau)) / (u_E(t_o)) = 1 - \exp(-\tau/R_iC_s) = \tau/RiCs$$

The efficiency of typical samplers is 3 to 25 %; if the input impedance is 50 ohms it is constant. The efficiency decreases with increasing bandwidth. Any fluctuations of the sampling pulse width will enter the output.

5.2 Equivalent-Time-Sampling (ETS), principle of the SO

As mentioned the SO is based on the stroboscopic principle. The frequency-to-time transformation is best understood by looking at the socalled information volume shown in Fig. 5.3. By the use of the stroboscopic method the shape of the volume is modified: it is compressed in the bandwidth axis and simultaneously extended in the time axis, the amplitude and volume remaining constant.

ETS and RS can only function if two preconditions are fulfilled:

- The signal must repeat itself until it has been reconstructed once.
- The signal shape must not change during the whole reconstruction time.

The sampling pulses are controlled in such a manner that only one sample is taken from consecutive signal periods, each sample is delayed by a fixed amount, such that, after completion of one sampling cycle, the same effect is obtained as if all samples had been taken from only one signal occurrence. Depending on the desired resolution, thousands or millions of signal repetitions will be necessary in order to reconstruct the signal once. Typically, SO's require 10 us for

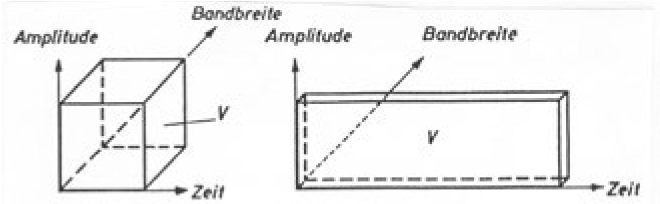

Figure 5.3: Volume representing the information content and how it is deformed by the stroboscopic sampling process (Bandbreite = bandwidth, Zeit = time)

one sampling cycle, the maximum "sampling frequency" is thus 100 KHz. If the signal frequency is higher cycles will be skipped.

► In ETS mode the Nyquist theorem does NOT apply! There is no correlation between the signal and sampling frequencies. Sampling along the signal waveform can also be done manually or from a plotter. Bandwidth is limited only by the analog input resp. the minimum sampling pulse width.

The delay of the sampling pulses from cycle to cycle requires a trigger signal which is derived from the same point of the signal; triggering allows a variable repetition rate, i.e. the signal need not be periodic.

The trigger pulses cause a socalled fast ramp to start. A second signal generated in the time base is a staircase which is increased one step by each trigger pulse and moves the display one step in X direction.

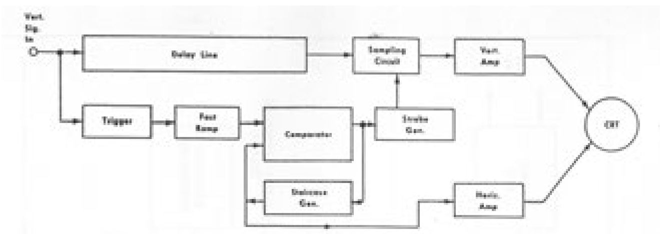

Figure 5.4: Basic block diagram of a SO in ETS mode

A comparator compares the instantaneous values of fast ramp and staircase, if it switches a sampling pulse is triggered in the vertical channel of the SO. This is the same procedure as in a stroboscope.

The important parameter is the time increment T by which the sampling pulses are delayed, it is called the equivalent time scale. Standard SO's cannot sample faster than each 10 us, i.e. that the individual samples on the screen are 10 us or more apart. If a screen display consists e.g. of 100 samples it takes 1 ms so fill it once. The real-time time scale would thus be 0.1 ms/cm, but this value is of no interest to the user. Only the "Equivalent Time Scale" is important and indicated on the front panel or the screen, this is the time scale related to the signal. As one does not read the time between two samples but from the raster the customary time scale is derived by taking the number of points per cm into account which are equivalent to the number of steps of the staircase per cm. If T = 1 ns, and if the SO is set to 10 points per cm the time scale will be 10 ns/cm.

The time scale is decreased by decreasing the height of the steps, this yields an arbitrary time stretching up to infinity, in this case the same point on the signal is sampled, so a horizontal line will appear on the screen according to the height of this point. This is a property of the stroboscopic method and does not constitute a particular performance. A SO or DSO is not better than another one because its time scale is faster. As with any scope a fast time scale makes only sense up to the point where its own rise time is well resolved.

Which are the requirements other parts of a SO have to fulfill in ETS mode? As the samples are acquired not faster than every 10 us, a rise time of the vertical amplifier of 2 us will be sufficient which is equivalent to a bandwidth of 170 KHz. The fastest real time scale was 0.1 ms/cm or 1 ms for a full screen in X direction. Both are very low requirements. How many signal periods are necessary to reconstruct the signal once depends on the desired quality. At 100 points per screen and 10 us it takes 1 ms; during this time the 1 GHz signal will produce 10-3 x 10+9 = 10+6 periods of which only 100 are used. If the quality is increased to 100 points/cm, i.e. 1,000 points per screen, 10+7 periods will be needed..

This is a vital viewpoint which should be approached also from another side. A SO has the same vertical resolution as an analog scope, i.e. infinite resolution; in practice the resolution is limited by the trace width and sharpness, far superior to any DSO. As the samples gained in ETS mode are identical to those which would be derived from a single signal cycle, 1,000 points per signal period (assumed one cycle would exactly fill the screen) would be equivalent to an apparent sampling frequency of 1,000 GHz if the signal frequency is 1 GHz!

► Because the normal operating mode of SO's and DSO's is ETS, manufacturers like to quote such fictitious figures in order to impress potential customers who tend to interpret these meaningless numbers as performance specifications.

100 points/cm are equal to 1 point/0.1 mm, even very good crt's have wider traces such that the display will already look like a continuous trace. A SO delivers vertically and horizontally a signal quality equivalent to that of an AO, and this is a marked difference to DSO's. There are no interpolations with resulting often gross distortions, and this is standard since 1960! As mentioned the signal can be sampled as slowly as desired, i.e. manually or controlled by a XY plotter. Screen shots are hence an old hat and no invention of DSO's, not to speak of the enormous difference in quality between an analog plot and a printout.

It should be stressed again that the ETS mode strictly requires that the signal must repeat with the same shape until the screen has been filled. In many practical applications this is not possible: examples are oscillating regulation loops, modulated signals, stochastic breakdowns of semiconductors etc. Such phenomena can only be captured in RTS mode.

5.3 Random Sampling

ETS suffers from the necessity of an analog delay line or a pretrigger if the pulse front shall be displayed, the same as in an analog scope. The horizontal system needs some time to start upon receipt of a trigger pulse. Delay lines with a bandwidth of 1 GHz were already incorporated in SO's in the 1960's, even two. Delay lines with shorter rise times are extremely bulky and heavy. In order to see the pulse front with faster samplers without a pre trigger, Tektronix brought 1967 the first commercial "Random Sampling" time base 3T2 onto the market.

In order to see the pulse front without a delay line, the time base must be started before receipt of the trigger. RS functions entirely differently from ETS: the sampling time base runs freely and triggers continuously samples in the vertical channel; there is hence no correlation between the signal and sampling frequencies, this is like in RTS mode. Which parts of the signals are thus “hit” by the samples is random. The purpose of a scope is to reconstruct the signal waveform vs. time. In order to realize this, it is necessary to know the exact time position of each sample relative to a fixed point in time (trigger) and to position that sample correctly on the screen.

The vertical channel is identical to that in ETS mode - with one marked difference: the loop gain must be exactly equal to one, because any sample is not correlated to the preceding one. If the loop gain differs from one, the signal cannot approach its correct waveform, but the result will be a broad, scattered “sky of stars”.

The horizontal channel is a very complicated structure. Its function is basically to predict the occurrence of the next triggering slope and to start the time base early enough so that the pulse front is visible.

The signal representation in RS mode is not so good as in the ETS mode because the samples do not follow in due order nor are they equally well distributed. Depending on the precision of the reoccurrence of the signal the samples are more or less statistically distributed and move back and forth within the waveform.

In RS mode the likelihood of steady pictures of artefacts is low.

5.4 Real-Time Sampling (RTS)
This operating mode is not common with SO’s because they lack a memory.

6. DSOs
6.1 Summary of advantages of DSO’s.

1. Storage of single events.
2. Unlimited storage time.
3. it is possible to store long signal sequences for a later inspection in detail. This is especially valuable when searching for problems and rarely reoccurring phenomena.
4. Capture of events before a trigger by continuously writing into the memory and stopping this upon receipt of a trigger. This not only important in order to see the pulse front which triggered; depending on the size of the memory a wide time span before the trigger can be inspected. However, due to the rather low capture rate of most DSO’s this is of doubtful value; only fast capturing DSO’s like the socalled DPO’s can use this fully.
5. Flicker-free display of very slow events. Analog storage scopes can also do this, but the display will disintegrate after some time because the stored charges will leak off.
6. All measurement results are available in digitized format and can be used for further digital processing within the scope or externally.

Despite their successful capturing of the whole market DSO’s are neither the successors of analog scopes nor are they “universal scopes”, also the claim that they “unite all advantages of analog and digital scopes” is objectively false. Reliable measurements of unknown signals can only be done with the most expensive DSO’s.

6.2 Operating modes ETS and RS
The operating modes ETS and RS are identical to those in SO’s, the only difference is the fact that each sample is a/d converted, stored, processed, d/a converted and displayed. Note that the highest bandwidth is obtained in these modes. With most DSO’s, especially low-cost models, the specified bandwidth is only achieved in these modes; what the manufacturers do not say is that these modes can only be used with repetitive signals!

6.3 Operating mode Real Time Sampling (RTS).
Even the oldest SO’s and DSO’s featured RTS. Of course, DSO’s can never show the signal in real time, they remain sampling instruments, i.e. they reconstruct the signal from samples, long after it disappeared.

Quite obviously it is again the purpose to lead potential customers astray by insinuating these “Real Time DSO’s” could show the signal in real time like analog scopes. This designation is false and misleading, the correct one is: Real Time Sampling Oscilloscope because it only describes an operating mode.

RTS means that all samples displayed are derived from a single capturing event. A DSO is characterized by its performance in RTS mode.

Which sampling rate is required for RTS? Shannon - Nyquist only ask for a rate twice as high as the highest frequency in the signal. It is not as simple as that, with DSO’s there are two criteria for the sampling rate:

- 1. Fulfilment of the Shannon-Nyquist requirement. Again it should be stressed that the “highest frequency in the signal” is not mixed up with the bandwidth. Compliance with this requirement only protects from aliases, this is not sufficient for a usable display. In mathematician’s language this is necessary, but not sufficient.
- 2. The sampling rate must be high enough to allow a usable reconstruction of an arbitrary non-sinusoidal signal. It is up to the user to determine what he considers acceptable resp. usable...

In ETS mode the resolution can be so high that the trace looks continuous, in RTS mode only the points are available which are obtained in one stroke. Assumed a 2 GS/s 200 MHz DSO would sample a 100 MHz square wave, this would yield 20 points or 2 per cm; one might suspect that these 20 points belong to a square wave, but the transitions would not be visible and the rise times could not be measured. A 200 MHz analog scope would show a rounded square wave continuous curve with infinite resolution, i.e., it is obvious that it is a square wave, no guesses necessary. If the DSO uses linear interpolation as usual, also a square wave would be shown, but the transitions would not be those of the square wave but those of the interpolation, i.e. unusable.

In order to display e.g. a 20 MHz signal with 100 points resolution, i.e. 1 point per mm, a sampling rate of 100 x 20 MHz = 2 GS/s is necessary. This example shows how fast seemingly impressive figures are deflated.

The erroneous perception Nyquist were good enough is one of the most severe misconceptions about DSO’s! The Nyquist theorem is not wrong, but pure theory, it is the most misunderstood theorem in electronics. It has caused many wrong decisions. Its application would require a socalled brick-wall low pass filter. Apart from the fact that this is not realizable it would create strong pulse distortions. As mentioned earlier, the factor of 2 would mean that, after sampling, there were only 2 points on the screen through which any arbitrary waveform could be drawn. In Nyquist there is the hidden assumption resp. pre-knowledge that the signal is a sine. The factor of 2 is to be taken as an absolute limit and not applicable in practice. The inverse of Nyquist is also seldomly understood: if a signal has been sampled with a given frequency, the reconstruction will definitely not contain any higher frequency than half the sampling frequency.

From the fact that a brick-wall filter is neither realizable nor tolerable in an oscilloscope it follows that "oversampling" is mandatory. This is just another way of looking at it. Oversampling allows to insert a filter with the gradual slope of the Gauss curve. As mentioned earlier, a minimum attenuation of - 50 dB at half the sampling frequency is necessary. The Gauss response is that far down at about 4 x the bandwidth. Hence the sampling frequency must be > 8 x bandwidth if there is no filter. The factor of 10:1 ensures some reserve. While an analog scope still shows signals far above its bandwidth, although attenuated and rounded, this is not the case with sampling scopes; a sampling system has a hard limit at half the sampling frequency! If there are signals above that limit, they will show up as artefacts.

The dynamic range resp. the S/N ratio of an 8 bit a/d converter theoretically amounts to 256 : 1 or 50 (6n + 1.78) dB. In reality, assumed that another +- ½ LSB from other disturbances comes ontop of the +- ½ LSB, the SNR = 40 (6n - 7.8) dB, i.e. a whole bit is lost in the a/d conversion. Still another way of looking at it assumes that an antialiasing filter must attenuate at least - 59 dB, if all signal content should be lower than the rms value of the quantizing noise which is q/(2 x sqrt 3).

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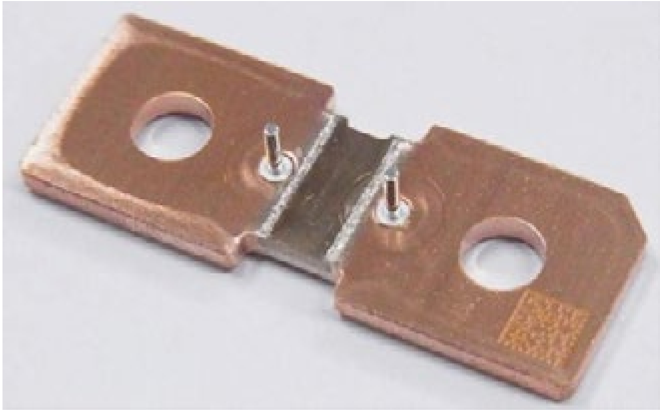
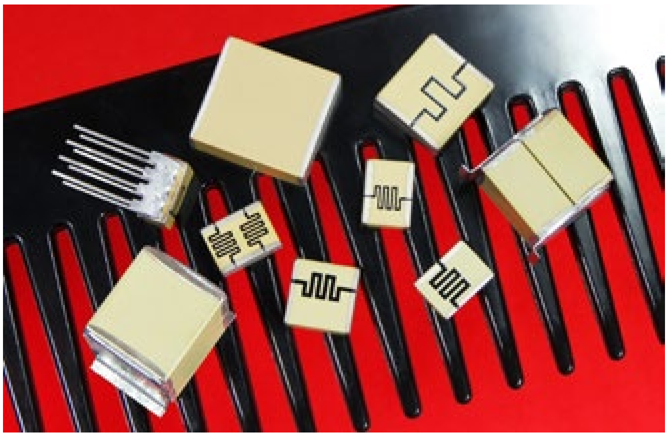
600 A – Large Current Shunt



The HS series from KOA is ideal for sensing currents up to 600 A. Constructed using a solid metal alloy resistance element with copper terminations the device provides superior corrosion and heat resistance and has excellent pulse resistance.
Product Features: Large current detection by ultra-low resistance of 100 µΩ; High accuracy sensing with dedicated detection terminals; High reliability by robust construction; Small size (40 mm x 15 mm) and high performance; 2D code marking for individual resistance information is possible; Custom specific shapes on request; EU-RoHS compliant; AEC-Q200 qualified

www.koaglobal.com/product/shunt

Pulse Discharge MLC Capacitors



Dedicated pulse discharge Multilayer Ceramic chip capacitors for munitions, ordinance, and oil field exploration and perforation are available from Knowles Capacitors brand, Novacap. These capacitors offer the exceptional reliability afforded by ceramic multilayer fabrication using advanced ceramic and electrode formulations, with thin, dense and precise dielectric layers to satisfy unique and difficult requirements with unsurpassed quality. Energy density exceeds that of conventional Class 1 materials and offers excellent short duration pulse delivery at temperatures to 200ºC.
These high temperature, high energy, capacitors are manufactured with a dielectric formulation designed for reliable operation under single or repetitive high energy, multiple pulse, firing into typical EFI and LEEFI circuits where resistive loads are in the 0.10 to 0.25 Ohm range. Discharge pulse width, which is typically less than 100 nanoseconds, will vary with load conditions which are influenced by inductive and resistive load components.

www.knowlescapacitors.com

Chip Fuses Low-Loss and Precise

SCHURTER offers a broad range of high-quality chip fuses, which were developed specially for low-loss and precise overcurrent protection in secondary circuitry. Six different types, available in chip dimensions from 0402 to 1206, offer compact and effective protection in the event of a fault.
The SCHURTER chip fuses are available in a number of different current ratings from 50 mA to 25 A at a rated voltage of up to 125 VAC/VDC. Depending on the version and voltage ratings, a breaking capacity of up to 600 A is reached. Thanks to these impressively high values and variety, these chip fuses can be used in a wide range of applications. Chip fuses are especially suitable for mobile and battery-operated devices in sensor technology and industrial electronics.

www.schurter.com

Dual-Sided Cooling Power MOSFETs

Toshiba America Electronic Components, Inc. has extended its range of U-MOS IX-H MOSFETs. The new 60V TPW1R306PL is an N-channel device in a DSOP Advance surface mount device (SMD) package that offers dual-sided cooling.

The enhanced thermal dissipation provided by dual-sided cooling can help to reduce device count and save space in applications with high component density, including: DC-DC converters, secondary-side circuits of AC-DC power supplies and motor drives in cordless home appliances and power tools.
The TPW1R306PL has an ultra-low typical on-resistance (@VGS =10V) of just 0.95mΩ and is offered in a very small form factor of 5x6mm. Maximum drain current and power dissipation are 100A and 170W, respectively. Additionally, the TPW1R306PL's top-of-package thermal resistance rating (Rth (ch-c) of 0.88k/W) is very low.
Toshiba's U-MOS IX-H process enables an exceptional performance trade-off between RDS(ON) and output capacitance/output charge, making typical QOSS just 77.5nC (@VDS=30V, f=1MHz). This allows designers to further improve system performance and efficiency by raising switching speeds and reducing switching losses.

www.toshiba.semicon-storage.com

Ionic Contamination Test for quantitative analysis

The ionic contamination test, also known as ROSE Test (Resistivity of Solvent Extract), is an extractive analysis technique offered in ZESTRON's Analytical Center, enabling the quantitative measurement of ionic contamination on an electronic board according to IPC-TM 650 2.3.25. Thus, initial risk evaluations conducted at an early stage can identify potential problems that may lead to future field failures. For a more precise analysis, ion chromatography is available which provides both quantitative and qualitative ionic contamination measurements.

www.zestron.com

Smart Power Switches with PROFET™+2 and High Current PROFET™

Car makers want in-vehicle electronic systems to provide a large number of energy-efficient functions in as little space as possible. Infineon Technologies AG supports this trend with its new power IC manufacturing technology SMART7. Infineon designed it specifically for automotive applications such as Body Control Modules or Power Distribution Centers. SMART7 power ICs drive, diagnose and protect loads in applications like heating, power distribution, air-conditioning, exterior and interior lighting, seat and mirror adjustment. They also provide a cost-effective and robust replacement of electromechanical relays and fuses. SMART7 is based on thin-wafer technology that reduces power losses and chip sizes.

Based on SMART7, Infineon now introduces the two high-side power switch families PROFET™+2 and High Current PROFET™. The SPOC™+2 multichannel SPI high-side power controllers will follow within a year.

www.infineon.com/switches

www.infineon.com/profet+2

EconoPIM™ 3 with Increased Current Rating of 150 A

Infineon Technologies AG is expanding the product portfolio of the IGBT modules with the EconoPIM™ 3 package. The current rating of the module is thereby increased from 100 A by 50 percent to 150 A. The new power modules serve the growing demand for higher power density within the same footprint. Typical applications are motor controls for drives in elevators, escalators, fans or pumps.

EconoPIM modules are characterized by a high integration of different functionalities. For example, each contains a three-phase rectifier, a brake chopper, a three-phase inverter and a NTC thermistor for temperature measurement. With a blocking voltage of 1200 V, the new EconoPIM 3 reaches a maximum current rating of 150 A – the highest current in the market for this design.
The housing is equipped with a base plate and corresponds to the industrial standard regarding dimensions. It can therefore easily be implemented as a drop-in replacement for already existing designs. When used in drives, the EconoPIM 3 therefore allows up to 30 percent more output power with the same footprint. The modules integrate the IGBT4 chip with Trenchstop™ technology, which is proven to have a high degree of robustness and reliability.

www.infineon.com/EconoPIM

350 Farad Super Capacitors Offer Low ESR, Low Cost

The newest series of super capacitors from Illinois Capacitor is the DGH Series, offering capacitance values up to 350 Farads. This series continues a supercapacitor trend of incremental improvements, while achieving lower costs. The DGH Series includes 21 different value/voltage combinations, ranging in capacitance from 0.5F (Farad) to 350F, with voltage ratings from 2.7 to 5.5WVDC. ESR varies by part, but is notably lower than capacitors with similar storage capabilities. Operating temperature ranges from -40 to +65°C for extended life performance in countless applications.

Like other IC super capacitors, DGH supercaps provide engineers with interesting new design options. With their massive energy storage, they have the ability to provide instantaneous bursts of power to smooth power interruptions, supplement batteries or even be used in place of batteries in certain applications. DGH supercaps do not degrade with each cycle. At 2.7 volts, operating life is rated at 10 years with 500,000 cycles. Applications for these super capacitors include: energy harvesting, mechanical actuators, transportation power, smart electric meters, pulse battery pack alternatives, memory backup, battery/capacitor hybrids, UPS systems, emergency lighting, LED power, solar lighting or anywhere that significant energy storage is needed.

www.illinoiscapacitor.com/products/DGH_series.aspx

High-Performance Low-Power Turnkey Pedometer Solution with Embedded Functionality

ROHM Group company Kionix, Inc., a leader in the design and manufacture of MEMS solutions, has added embedded functionality to its line of high-performance accelerometers. The KX126 tri-axis accelerometer integrates a step detector and step counter.
According to Nader Sadrzadeh, Kionix's CEO, "As the applications for sensors grow, we look for use cases that become widespread enough to warrant embedding algorithms and functionality directly into our sensors. Pedometry has crossed that threshold. The usefulness of detecting when someone is walking and then counting their steps goes beyond fitness tracking – it can be adapted to assess the mobility of recuperating patients and the elderly, assist in identifying location changes, improve logistics and employee efficiency in workplaces, and more."

The trend towards embedding functionality directly in a sensor has benefits that go beyond simply providing an easy to use, turnkey pedometer solution. It also extends battery life. Adds Sadrzadeh: "By optimizing the algorithm for low power and then embedding it into our sensor, we add less than 100nA compared to an accelerometer running without this function. This is a fraction of the power that would be consumed running a pedometer algorithm on an external MCU."

www.kionix.com

Low Impedance Aluminium Electrolytic Capacitors for High Frequency Applications

Components Bureau introduces the RH series of miniature aluminium electrolytic capacitors which is ideal for numerous power supply applications. Manufactured by AiSHi, the high-performance products are available in a wide number of capacitance values, with ripple currents as high as 1,430A (rms) at 105°C, 100kHz.

The series offers between 2,000 and 3,000 hours life at +105°C, with minimum operating temperatures down to -40°C. Multiple working voltages are available in the industry standard values of 160 to 450Vdc, with standard capacitance values from 0.47 to 470µF. The radial capacitors are available in a range of diameters, from 5 to 22mm, and case lengths of 11 to 60mm, depending on the working voltage selected.

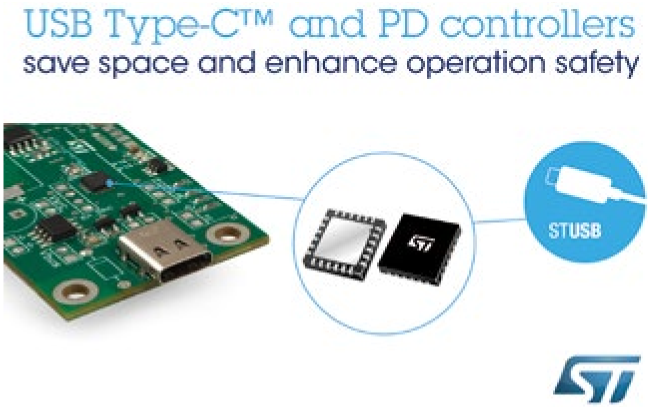
CE marked to meet the RoHS directive, the competitively priced RH series of aluminium electronic capacitors is available from Components Bureau now.

www.componentsbureau.com

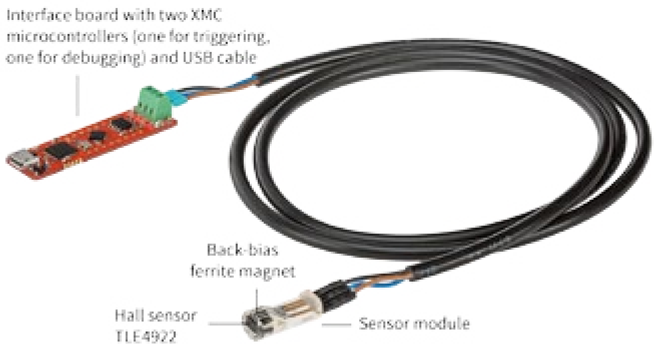
Robust USB Type-C™ Controllers with Internal Protection

STMicro's USB Type-C specifies reversible plug orientation and cable direction, which simplifies attaching and powering a wide range of devices. The Type-C connection also consolidates support for all USB features including 480Mbps USB 2.0 and 10Gbps USB 3.1 data exchange, power delivery from 5V/0.5A up to 20V/5.0A, managed active cables that extend connection distance, and alternate mode that even allows guest protocols such as HDMI or DisplayPort to use the same cable. Making things simpler for users requires more complex interface electronics to setup each connection correctly. In addition, the 20V maximum bus voltage (VBUS) for power delivery demands extra protection for low-voltage circuitry.

www.st.com/usbtypeC-pr



Sensor Designs with TLE4922 Sensor and "Speed Sensor 2Go" kit



Development kits for sensors from Infineon are significantly reducing design effort – and thereby development time and system costs. For reliable and fast measurement of speed, Infineon Technologies AG is offering the new Hall sensor TLE4922 as well as the "Speed Sensor 2Go" design kit that goes with it. The TLE4922 was developed for industrial and automotive applications, where fast and reliable measurement of speed is critical, such as speed detection of crankshafts and transmissions in two-wheelers and three-wheelers. Industrial applications are speed detection in production and building automation as well as the control of electric drives.

www.infineon.com/sensors

www.infineon.com/makers

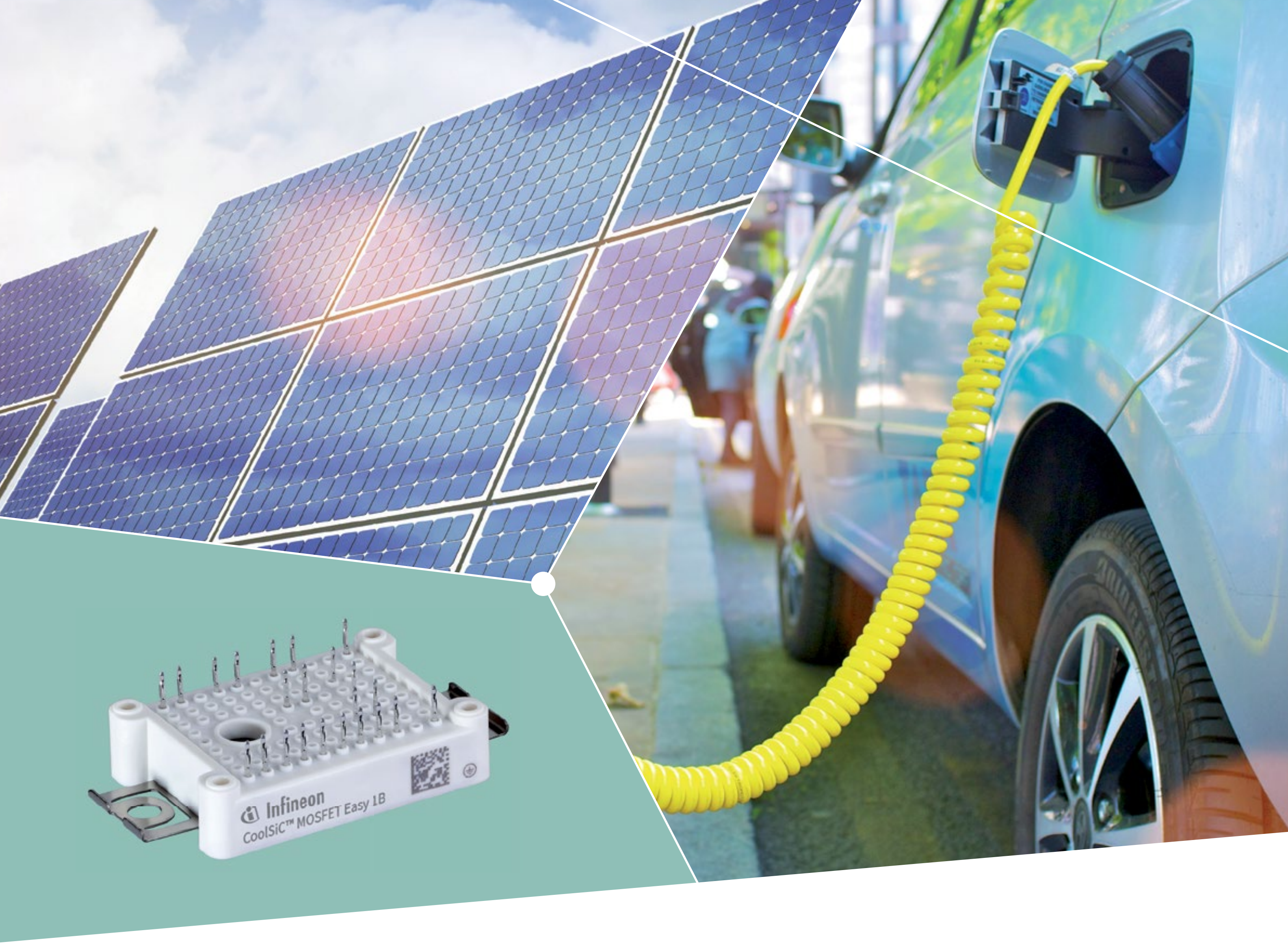
Boost Regulator Delivers Longest Battery Life and Smallest Solution Size

With the industry's highest efficiency and lowest quiescent current (IQ) of only 300nA, the MAX17222 nanoPower boost regulator from Maxim Integrated Products, Inc. (NASDAQ: MXIM) enables the longest battery life in the smallest form factor for wearable and consumer IoT designs. The 0.4V to 5.5V input, 1.8V to 5V output boost regulator with 500mA input current limit reduces solution size by up to 50% compared to similar products and offers 95% peak efficiency to minimize heat dissipation. These benefits are ideal for wearable devices which IDC forecasts will experience a compound annual growth rate (CAGR) of 18.4% in 2020. Designers of new wearable, health-monitoring, internet of things (IoT), mobile, and other connected devices are struggling to extend battery life for next-generation products, particularly with increasing functionality and performance in smaller form factors. Power solutions servicing this market require mastery of low quiescent current design techniques and high integration.

www.maximintegrated.com

Advertising Index

ABB Semiconductor	1+C3	Hitachi	15	Ridley	53
Cwieme Chicago	45	Husum Wind	39	Rohm	7
Danfoss	31	Infineon	C4	Semicon Taiwan	43
Dean Technology	23	ITPR	35	Semikron	9
Dr.-Ing. Seibt	49	LEM	5	SPS IPC Drivers	51
Eagtop	49	LpS2017	29	Teledyne LeCroy	47
electronic concepts	1	Malico	37	TDK Epcos	11
FTCap	35	Microchip	27	USCi	13
Fuji Electric Europe	21	Mitsubishi	19	Vincotech	17
GvA	C2	Plexim	25	Würth	3
Hioki	56	Productronica	55		



Power modules with CoolSiC™ MOSFET

Halfbridge and booster topology in Infineon's Easy 1B housing

Infineon CoolSiC™ MOSFETs have unique advantages

- Superior gate oxide reliability
- Threshold voltage, $V_{th} > 4$ V
- IGBT compatible driving (+15 V)
- Application oriented short-circuit robustness

SiC characteristics bring unbeatable performance

- Doubling power density
- Boosted efficiency
- Reduction of total system cost
- Smaller housing and design

CoolSiC™ – Revolution to rely on

Infineon CoolSiC™ semiconductor solutions are the next step towards an energy-smart world. Combining revolutionary SiC technology with extensive system understanding, best-in-class packaging, and manufacturing excellence, Infineon CoolSiC™ enables you to develop radical new product designs with best system cost-performance ratio.

www.infineon.com/CoolSiC

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