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POWER MODULES

A 6in1 IGBT Module Performance Evaluation Platform

THE EUROPEAN JOURNAL
FOR POWER ELECTRONICS
AND TECHNOLOGY

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COVER STORY

A 6in1 IGBT Module Performance Evaluation Platform

Achieving good loss performance by high switching speed at low gate resistance is trading-off with the system's EMI behaviour. An evaluation platform has been developed to characterize 6in1 IGBT modules and to determine their dv/dt versus turn-on loss as function of the gate resistance. A chart indicating the trade-off between turn-on switching loss versus dv/dt parameterized as a function of the sum of internal and external gate resistance of a 150A/1200V 6in1 IGBT module will be presented in this article. The investigation on a 6in1 IGBT module equipped with newly tested chipset and a new FwDi has shown a superior switching loss versus dv/dt performance than previous generations of IGBT modules. Improving this trade-off leads to better performing drives or in turn to a potential cost advantage due to a reduction of the EMI filter. Full story on page 30.

Cover page supplied by Mitsubishi Electric Europe

Light or Shade in 2012?

While 2010 was a strong year for (power) semiconductors due to the recovery from the downturn in 2009 global semiconductor revenue in 2011 now is expected to rise by 1.2 percent compared to 2010, according to a recently revised market outlook by IHS iSuppli.

The electronics supply chain impact from the Japan disaster earlier this year played a notable role in influencing quarterly growth in the second and third quarters. The combined revenue collapse of many major Japanese semiconductor companies that suffered damage to their facilities in the disaster pulled the semiconductor market down by at least 2.5 percentage points in the second quarter and resulted in an overall market decline during that period. In terms of application markets, the strongest increases in semiconductor demand in 2011 is coming from the automotive electronics, industrial electronics and wireless equipment segments.

According to Infineon's CEO Peter Bauer the market trends in the fields of energy efficiency and mobility are intact. An exact forecast for the 2012 fiscal year is difficult at present. The macroeconomic constellation is a playing field for statisticians and forecasters. Development in the European Economic Area remains uncertain. The economy in the USA is recovering only slowly. The global economic unrest is impacting even China, through its exports and self-imposed restraint, although not to such a great extent. Infineon's forecast assumes that there will be an acceptable solution to the debt problem in Europe and that - following a correction phase until the middle of next year - the overall economy will display greater momentum.

His position is supported by market researchers such as iSuppli. They forecast weak economic conditions to persist into 2012 as worldwide GDP growth is projected to remain flat at 3.0 percent compared to 2011. The weak economy will continue to depress consumer spending, the foremost driver of electronics and semiconductor market demand. As a result, IHS forecasts 2012 semiconductor revenue growth will amount to an anemic 3.2 percent. A return to stronger growth will not begin until 2013. Despite the current slowdown in power management semiconductors, revenue expansion overall will be positive for the next five years, with growth to average around 7.2 percent during the period. Among the most promising markets will be that for inverters, anticipated to grow from $4.2 billion in 2010 to $7.5 billion in 2015. The need for efficient inverters will be supplied by various markets, including automotive, solar and wind turbines, motor controls in appliances and manufacturing automation.

For Germany the ZVEI section Electronic Components and Systems (semiconductors, passives, PCBs, electro-mechanics) forecasts a 2011 growth of 7 percent up to Euro 18 billion in Germany. For 2012 a further increase of 5 percent up to Euro 19 billion is expected. This slowed growth is mainly due to inventory adjustments. Over-proportional growth is expected for automotive and industrial electronics. And after the historical downturn in the year 2009 the electrical drives now can look at two good years with 17 percent market growth. The level of top year 2008 will be missed in 2011 by just two percent, the Electrical Drives section within ZVEI expect a turnover of around Euro 10.4 billion. On top of that figure are inverters for variable speed drives, these devices will see an increase of 35 percent, 17 percent higher than in the top year 2008. In terms of 2011 production three-phase AC motors in Germany have an estimated share of 35 percent or Euro 2.8 billion, followed by inverters with a share of 24 percent or production value of Euro 1.97 billion. These figures indicate that energy-saving drives are more and more in use. Roughly 60 percent of industrial electrical power consumption is related to electrical drives. The installed drives base in Germany is estimated to about 35 million, which can be substituted completely by energy-saving IE2/IE3 motors. In half of these applications an inverter for speed control is recommended. This could lead to a total energy saving potential of annually 38 billion kW/h. Also from the year 2014 the EU Commission will judge electrical drives on their energy efficiency in the application only, and from then on a new era will begin for the electrical drives and machinery industry. Energy efficiency will become the dominant criterion. All this will lead to a huge market opportunity for power electronics not only in Germany, but also in Europe and elsewhere. 2012 can come!

Thus I wish all readers all the best for the remaining weeks in 2011 and a good jump into 2012!

Achim Scharf
PEE Editor

Cloudy Outlook for Semiconductors Globally until 2013

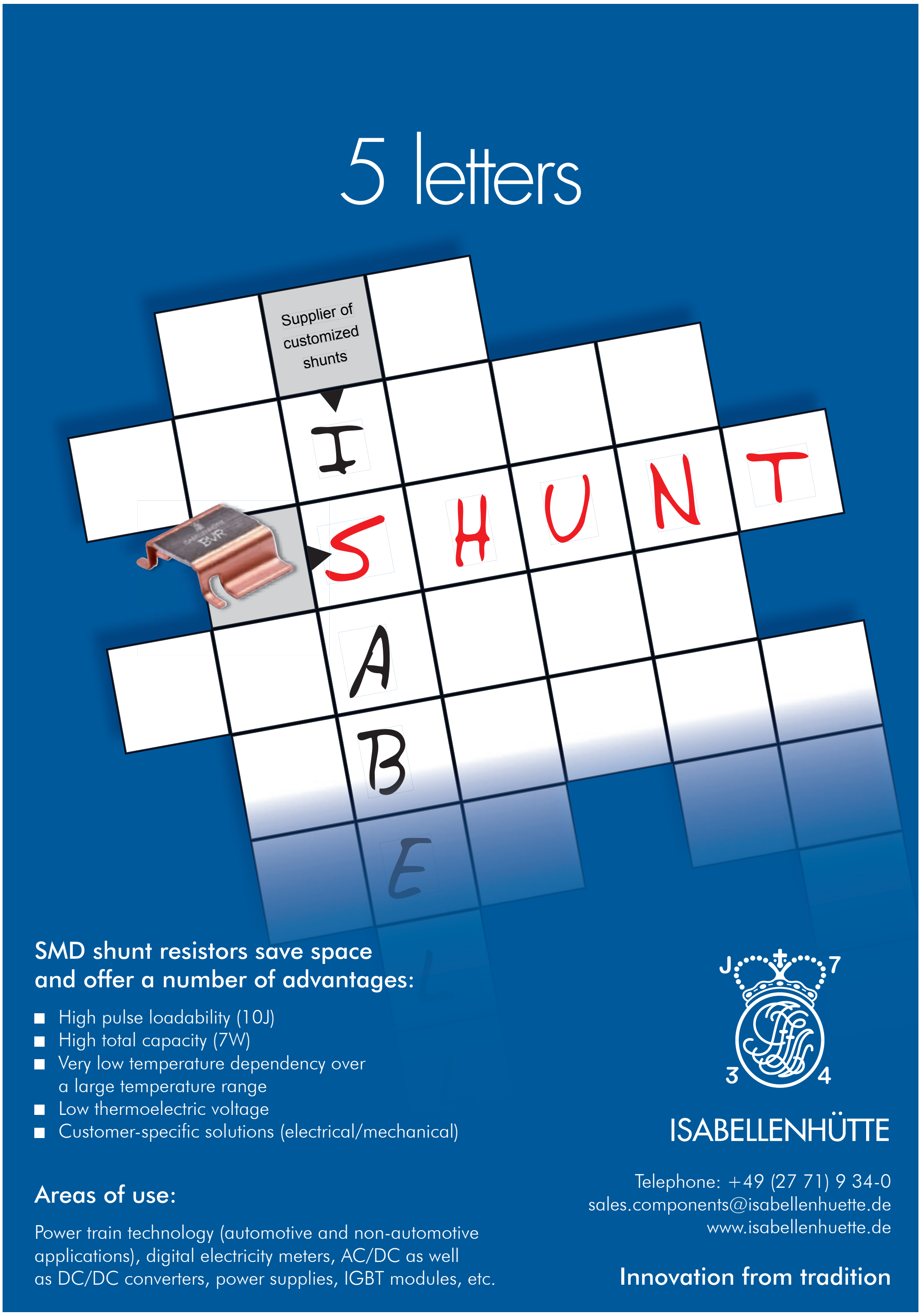
Global semiconductor revenue in 2011 now is expected to rise by 1.2 percent compared to 2010, according to a recently revised market outlook by his iSuppli.

While third-quarter revenue increased, conditions have been worsening in the last three months of the year. Revenue is projected to decline by 2 percent sequentially in the fourth quarter. Many major semiconductor suppliers are projecting fourth-quarter revenue declines that average in the high single digits. However, a number of major semiconductor suppliers-such as Intel, Samsung, Renesas, Qualcomm and Advanced Micro Devices-have projected solid growth in the fourth quarter that will limit the overall market decline. In order for the full year of 2011 to wind up in negative territory, overall semiconductor revenue would have to fall by 7 percent or more in the fourth quarter.

The electronics supply chain impact from the Japan disaster earlier this year played a notable role in influencing quarterly growth in the second and third quarters. The combined revenue collapse of many major Japanese semiconductor companies that suffered damage to their facilities in the disaster pulled the semiconductor market down by at least 2.5 percentage points in the second quarter and resulted in an overall market decline during that period. The rebound experienced in the third quarter by these same companies as they moved with aggressive recovery efforts added more than 2 percent to the growth to the market, pushing it comfortably above a 3 percent increase for the overall market in the third quarter. The Thailand flooding catastrophe is forecast to reduce hard disk drive (HDD) shipments by 30 percent in the fourth quarter. This will cause PC shipments to fall short of expectations, indirectly exerting a negative impact on the semiconductor market in the first quarter of 2012. Limitations in PC production are expected to hit in the first quarter of 2012 when HDD inventories will be depleted, and full production levels will not be restored as drive manufacturers continue to recover from the damage from the flood.

In terms of application markets, the strongest increases in semiconductor demand in 2011 is coming from the automotive electronics, industrial electronics and wireless equipment segments, with growth in chip demand ranging between 7.3 percent and 9.1 percent.

Weak economic conditions are forecast to persist into 2012 as



worldwide GDP growth is projected to remain flat at 3.0 percent compared to 2011. The weak economy will continue to depress consumer spending, the foremost driver of electronics and semiconductor market demand. As a result, IHS forecasts 2012 semiconductor revenue growth will amount to an anemic 3.2 percent. A return to stronger growth will not begin until 2013.

Better Outlook for Industrial Electronics

"While much attention is heaped on sexier semiconductor markets such as a wireless, computers and consumer electronics, the industrial segment actually outgrew all these areas in 2010," noted industrial electronics analyst Jacobo Carrasco Heres. "In fact, industrial electronics in 2010 was the second-fastest growing semiconductor market after automotive. Dallas-based Texas Instruments managed to lead in this area last year partly because of its robust footprint worldwide and its broad participation in virtually every industrial electronics market segment-from automation to medical, to energy and military. The company also benefitted from its strong product offerings in analog, microcontrollers and digital signal processing. And the acquisition of National Semiconductor in the third quarter this year is expected to further reinforce TI's hold on the pinnacle when rankings are reassessed at the end of 2011."

Industrial electronics spans a variety of application fields in an extremely broad range, including such disparate areas as manufacturing and process automation, test and measurement, medical electronics, building and home control, energy generation and distribution, and military and civil aerospace. Semiconductors counted as part of the industrial electronics umbrella include discretes, optical, sensors and actuators, and microcontrollers, as well as integrated circuits in the analog, microcomponents, logic and memory sectors. Revenue for semiconductors used in the industrial electronics market grew an impressive 35 percent in 2010. And while the market was clearly in retreat during the second half of this year, positive growth is still projected for all of 2011, with brisk double-digit expansion anticipated until 2017.The leading five companies in the industrial electronics semiconductor arena in 2010 had revenues ranging between $1 billion and $2 billion, and the Top 10 suppliers enjoyed combined revenues of $11.45 billion-roughly 42 percent of a market worth $27.46 billion.

Occupying the No. 2 slot in 2010 after TI was Italian-French entity STMicroelectronics, with $1.59 billion in industrial electronics semiconductor revenue and a 5.8 percent market share. While TI ranked highly in several segments, it failed to nab the top spot in any single submarket. In comparison, STMicroelectronics held the top spot in areas such as manufacturing process and automation, and was also No. 1 in the medical arena.

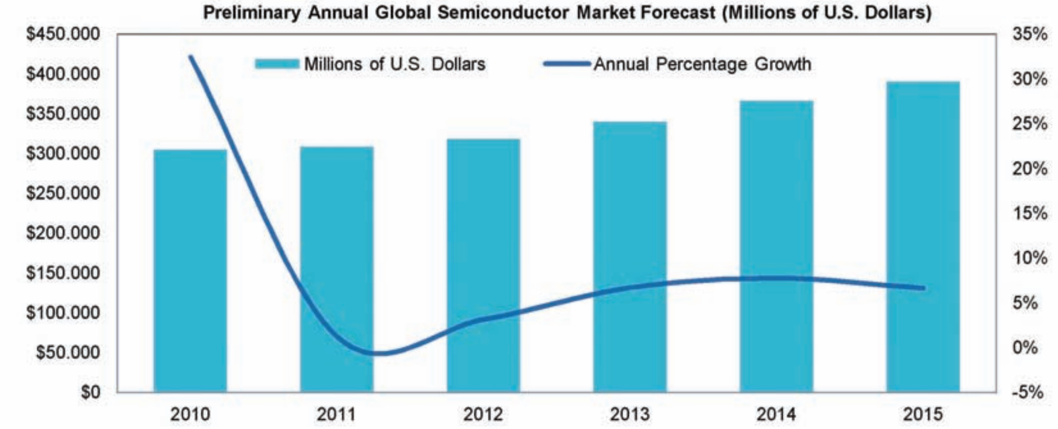
Third place last year went to German firm Infineon Technologies, with $1.42 billion in revenue and 5.2 percent of the market. Infineon was the top supplier in the energy segment.

Power Management Semiconductors Market Growth Slows in 2011

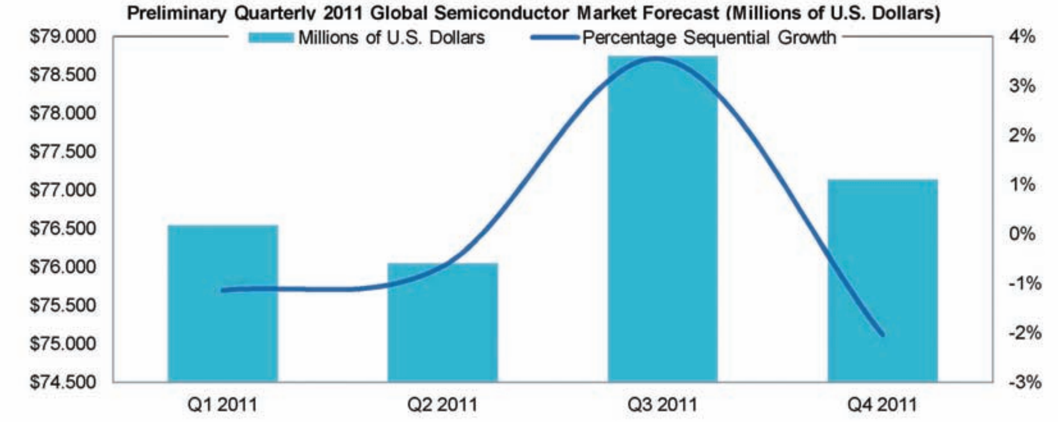
The market in 2011 for power management semiconductors will grow more slowly than expected, stymied by a general slowdown in consumer spending and the disruption caused by the March Japanese earthquake.

Revenue in 2011 from power management semiconductors is expected to reach $33.1 billion, up

Preliminary Annual Global Semiconductor Market Forecast (Millions of U.S. Dollars)



Preliminary Quarterly 2011 Global Semiconductor Market Forecast (Millions of U.S. Dollars)

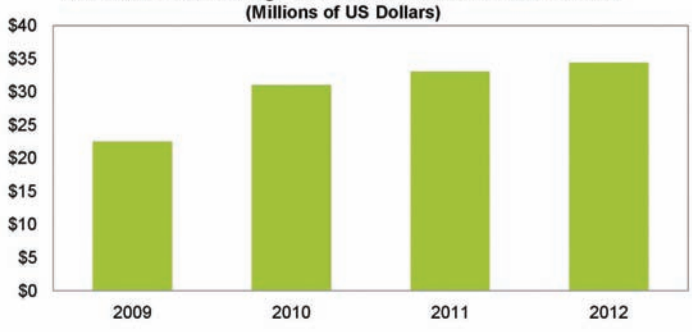


Top 10 Industrial Electronics Semiconductor Companies in 2010

Rank	Company	Revenue in US Dollars	Market Share (%)
1	Texas Instruments	$1.788	6,5%
2	STMicroelectronics	$1.592	5,8%
3	Infineon Technologies	$1.418	5,2%
4	Intel	$1.205	4,4%
5	Analog Devices	$1.188	4,3%
6	Renesas	$952	3,5%
7	Toshiba	$948	3,5%
8	NXP Semiconductors	$845	3,1%
9	Maxim Integrated Products	$779	2,8%
10	Mitsubishi	$753	2,7%

Source: IHS iSuppli Research, November 2011

Worldwide Power Management Semiconductor Revenue Forecast (Millions of US Dollars)



6.7 percent from $31.0 billion in 2010-much slower growth compared to the market's astounding 37.8 percent rebound last year. The market will rise a slight 3.9 percent next year to a projected $34.4 billion.

"Soon after the Japanese quake at the tail end of the first quarter, power management suffered a deceleration as manufacturing was halted in several areas of the country, home to many semiconductor plants and operations," said analyst Marijana Vukicevic. "The Japanese situation righted itself by September, but by then the industry was feeling yet another constraint-the decline in consumer spending that started in the middle of the year, a situation not likely to improve until after the first half of 2012." Already, a tightening in consumer expenditures has slowed revenue expansion in the power management sector during the third quarter to just 2.3 percent from the earlier quarter, compared to an 8.8 percent increase during the same time last year. Growth in the fourth quarter is not expected to improve, in light of projections showing curtailed demand for popular consumer electronic items like wireless handsets and mobile computing devices-two big drivers of the power management semiconductor space.

The biggest performers for the next five years

Despite the current slowdown in power management semiconductors, revenue expansion overall will be positive for the next five years, with growth to average around 7.2 percent during the period.

Among the most promising markets will be that for inverters, anticipated to grow from $4.2 billion in 2010 to $7.5 billion in 2015. The need for efficient inverters-devices that convert direct current to alternating current-will be supplied by various markets, including automotive, solar and wind turbines, motor controls in appliances and manufacturing automation.

Other areas that will drive power management in the next five years will be mobile; communications; energy and public infrastructure improvement; and the markets for new as well as alternative forms of energy-such as hybrid and electric vehicles, wind and solar energy, and grid upgrades affecting equipment like smart meters. Of particular interest will be the submarket for microinverters designed specifically for 200-watt solar applications-projected to be one of the highest-growth segments in the entire power management space.

In terms of device segments, the strongest growth will take place in media tablets, with power management semiconductors expected to post a compound annual growth rate (CAGR) of 63.3 percent, trailed by the server market at a distant second with a 12.0 percent CAGR. Other significant device segments will be building and home control, notebooks, enterprise voice networks, mobile infrastructure and medical electronics. For all these areas, low-voltage metal-oxide-semiconductor field-effect transistors (MOSFET) represent the main growth opportunity, followed by high-voltage MOSFETs and switching regulators.

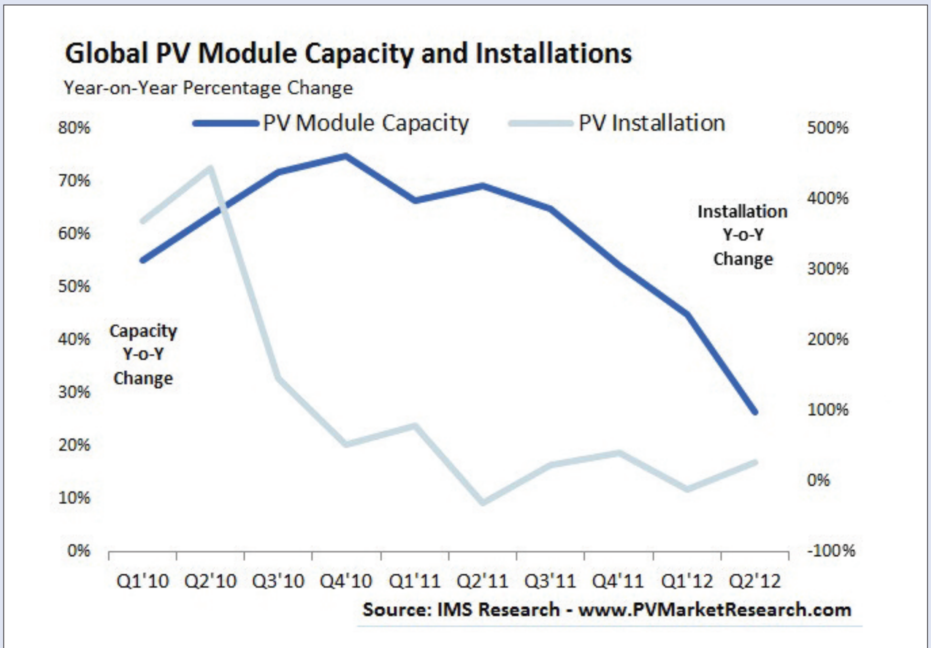
As consumer demand returns after 2014, the higher levels in ensuing expenditures will have a positive effect on power management semiconductors, resulting in improved revenue growth at a projected 8.7 percent by that time.

www.ihs.com

PV Manufacturing Equipment Revenues to Halve in 2012

The market for PV manufacturing equipment will more than halve in 2012 according to the latest quarterly-updated report from IMS Research. Significant decreases in the "new" manufacturing capacity required and limited demand for upgrade or replacement of existing capacity will result in a projected market decline of over 55 percent in revenues in 2012 from 2011.

In recent years, makers of PV products have invested heavily in new manufacturing equipment and additional capacity in an effort to increase their market share and establish themselves as a credible volume-supplier. Whilst this has fueled the recent boom in the PV equipment market, it has also caused the significant over-capacity for device manufacture that now exists.



"IMS Research estimates that the PV manufacturing equipment market, after a record year in 2011 ($12.8 billion revenues), will be worth just over $5.7 billion in 2012. Massive over-capacity, coupled with a reduction in demand, has led manufacturers either to postpone or, where possible, cancel orders for new manufacturing equipment, at least in the short term", analyst Tim Dawson commented. "Longer term, although a return to growth is inevitable for 2013, a strong V-shaped recovery has not been forecast. The PV manufacturing equipment market will instead steadily recover; as companies look to invest once again in new equipment to remain competitive, improve their production processes, increase cell efficiencies, and reduce the cost per watt associated with the ultimate end product."

tim.dawson@imsresearch.com

Renewable Electricity is the Cheapest Energy Source for Europe by 2050

On the basis of calculations for 36 countries in Europe and Northern Africa the German Advisory Council on the Environment (SRU) concludes that an energy supply completely based upon renewable sources by 2050 is achievable at average costs of 65 €/MWh.

"Renewable electricity will become the cheapest source of energy throughout Europe", says the lead author of the report, Prof. Olav Hohmeyer. The calculated costs are significantly lower than the pessimistic assumptions of the draft EU Energy Road Map 2050.

The SRU launches the scenario assume a cost-optimized mix of renewable energy sources and a high level of national self-sufficiency. Wind power is for most European countries the cheapest technology, in the Mediterranean region high shares of solar power can also be expected. A completely renewable electricity system, that guarantees security of supply at every moment throughout the year, is achievable at system costs of 65 €/MWh including the cost for grid expansion and storage. In countries with comparatively greater renewable potentials costs can even be lower. The pump storage potential in Norway is sufficient to function as the "green battery" of Europe.

The Commission results are at a level considerably above the calculations for a 100 percent renewables based scenario calulated by DLR (German Aerospace Center) on the basis of the ReMix-Model for the SRU. The European Commission has calculated overall cost including tax at a level of 199 €/MWh, the SRU estimated a level without tax at 65 €/MWh. The figures are not directly comparable - but the orders of magnitude diverge significantly. "The European Commission systematically underestimates the low cost potential of renewable energies for a truly sustainable power system", commented Hohmeyer at a presentation of the results in the House of Commons in London in November. The cost pessimism of the European Commission is scientifically not well grounded." Exaggerated cost estimates may undermine political acceptance for further expansion of renewable energy in the EU. "

In his special report, the SRU emphasizes that a supportive European framework is pivotal for a national energy transition towards renewable energies. The SRU recommends that the EU formulates ambitious binding targets for renewable energy for the year 2030 and that the future European electricity grid systematically has to match the needs of growing shares of renewable sources in the electricity mix. However, the SRU considers the harmonization of support schemes not appropriate, as the conditions in member states are too different.

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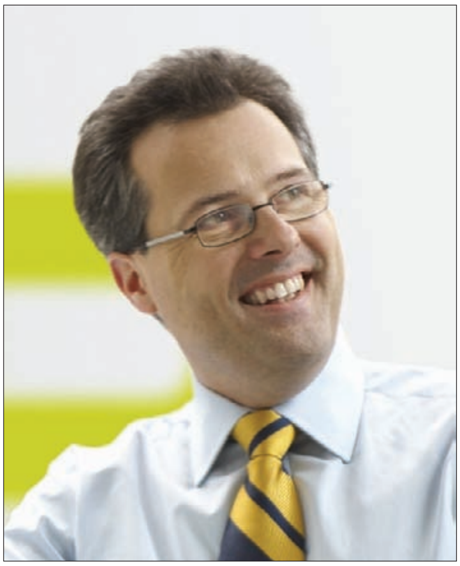
Good Prospects for Electronic Components in Recovering Markets



"Automotive electronics is the strongest end-user segment in Germany, it consists to a quarter of power semiconductors", said Kurt Sievers, Head of ZVEI section Electronic Components and Systems, at Productronica

"In 2011 inverters for variable speed drives will see a market increase of 35 percent in Germany", said Günter Baumüller, Head of the Electrical Drives section within ZVEI, at SPS-Drives

According to Central Association of the German Electrical and Electronics Industry (ZVEI) market statistics presented in November at Productronica/Munich and SPS-Drives/Nuremberg the German Electrical Industry has surpassed the 2009 downturn and is looking forward to a high single-digit growth in 2012.

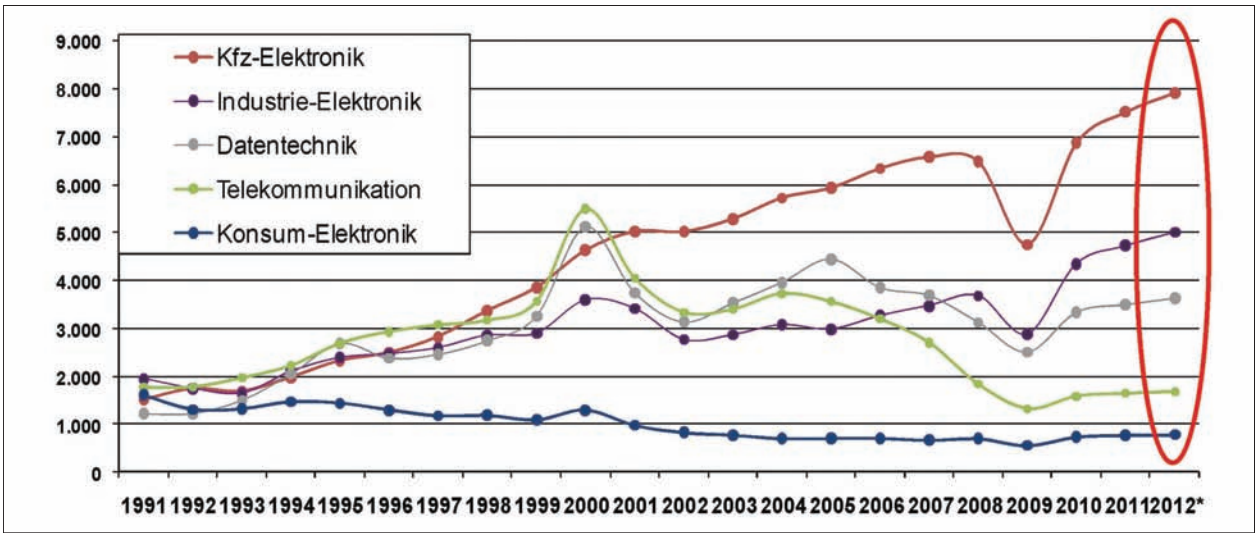
The ZVEI section Electronic Components and Systems (semiconductors, passives, PCBs, electro-mechanics) forecasts a 2011 growth of seven percent up to Euro 18 billion in Germany. For 2012 a further increase of five percent up to Euro 19 billion is expected. This slowed growth is mainly due to inventory adjustments. Over proportional growth is expected for automotive and industrial electronics. "This is due to the strong position of automotive and automation industries in Germany", said Kurt Sievers, Head of this ZVEI section. "Automotive electronics consists to a quarter of power semiconductors, a quarter of micro-controllers and another quarter of sensors. Highest growth so far is expected in start/stop systems".

For Europe ZVEI forecasts an increase of six percent up to $ 66 billion in 2011 (2012: 4 % - $ 70 billion), globally an increase of four percent up to $ 475 billion.

"After the historical downturn in the year 2009 the electrical drives now can look at two good years with 17 percent market growth. The level of top year 2008 will be missed in 2011 by just two percent, we expect a turnover of around Euro 10.4 billion", said Günter Baumüller, Head of the Electrical Drives section within ZVEI. "On top of that figure are inverters for variable speed drives, these devices will see an increase of 35 percent, 17 percent higher than in the top year 2008. In terms of 2011 production three-phase AC motors in Germany have an estimated share of 35 percent or Euro 2.8 billion, followed by inverters with a share of 24 percent or production value of Euro 1.97 billion. These figures indicate that energy-saving drives are more and more in use, certainly a result of the industry's efforts to educate our customers about the benefits of variable speed drives".

Roughly 60 percent of industrial electrical power consumption is related to electrical drives. The installed drives base in Germany is estimated to about 35 million, which can be substituted completely by energy-saving IE2/IE3 motors. In half of these applications an inverter for speed control is recommended. This could lead to a total energy saving potential of annually 38 billion kW/h. "But in face of the common motor retrofit rate of around four percent per year it would take 25 years for a complete modernisation, what is far too long. Thus the EU Commission will judge electrical drives beginning in the year 2014 on their energy efficiency in the application only, and from then on a new era will begin for the electrical drives and machinery industry. Energy efficiency will become the dominant criterion", Baumüller expects. And that development will lead to huge market opportunities not only in Germany. **AS**

www.zvei.org



Development of end-user industries for electronic components in Germany (€ billion)

Batteries Recognized as Core Technology

Though the outlook on the global semiconductor market for the next year is more or less cloudy the leading fair on electronics production, Productronica 2011 from November 15-18 in Munich, reported a substantial rise in the number of visitors. 38,500 visitors from more than 80 countries represent an increase of around 34 percent compared with the previous show. This proves that the industry has greatly recovered in the last two years and is back to the level in 2007. Also the number of exhibitors increased to 1,234 (2009: 1,106).

In addition to Germany, the countries with the highest number of visitors included Italy, Austria, the Czech Republic and Switzerland. Compared with previous events, there was a pronounced increase in the number of visitors from Israel, Poland, Hungary and the Russian Federation. "Productronica once again confirmed its leading position as the world's leading trade fair for the global electronics production industry. Following the weak event in 2009 caused by the economic crisis, we held intensive discussions with the industry. The cooperation with our commercial and industrial partners and representatives is now bearing fruit: the highlight themes, the special show 'Battery manufacturing and power electronics' and the PCB Community Area were magnets for both new visitor groups and exhibitor target groups," commented Norbert Bargmann, Deputy CEO of Messe München.

"Electromobility will create a new market which we will influence", said Rainer Kurtz, Managing Director of ERSA, Chairman of the Technical Advisory Board for productronica and Chairman of the Productronic Association in the German Engineering Federation (VDMA). "According to market researchers for the power modules in hybrid and pure electric vehicles a growth of 30 percent annually is forecasted, a main driver for power electronics".

The show "Battery manufacturing and power electronics" has been organised in close cooperation with the Productronic Association in the VDMA, RWTH Aachen University, the Fraunhofer Institute for Production Technology and leading companies. The complete battery production environment - from coating of the electrode material through to the finished module - has been presented for the first time as part of a trade fair event. High-performance batteries for electric cars or renewable energies differ a great deal from batteries for laptops or mobile phones, e.g. in terms of their reliability, service life, but also size. This alone calls for massive advances in production, the key topic of productronica. Solution of the biggest challenge, i.e. to reduce costs, requires close cooperation between manufacturers, suppliers, mechanical engineering companies and research institutes.

Dr. Eric Maiser, Managing Director of VDMA Productronic and Head of the Industry Group for Battery Production in the VDMA E-Motive Forum, regards mechanical engineering as a key factor in reducing costs: "Roadmaps for high-performance batteries have so far contained no mechanical

Li-Ion battery production was highlighted on a dedicated booth at productronica 2011

engineering solutions. Our Industry Group comprising mechanical engineering companies, manufacturers and researchers has started work in order to change this situation. Mechanical engineering companies can score points on the road to large-scale production, especially with the experiences from related industries such as electronics and photovoltaic production: productronica is therefore the best place to demonstrate and combine these skills. During the special show and in the Innovation Forum programme we showed how the industry is now structured and what will be required in the production of high-performance batteries in the future. We need to have substantial progress since 1 kilogram of petrol is equivalent to 60 kilograms of Li-Ion battery."

According to Prof. Dr. Achim Kampker from RWTH Aachen University, the pooling of know-how is also the right approach: "In cooperation with a close competence network of industry and research, the machine tool laboratory of RWTH Aachen University is working on the design of Lithium-Ion battery production. The focal point of this work is the continuous development of the entire process chain from coating of the electrodes through to the finished battery pack.

In May this year three of Germany s federal ministries launched a joint initiative to promote research and development in the field of energy storage technologies. The "Energy Storage Funding Initiative" is backed by the Federal Ministry of Economics and Technology, the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety and the Federal Ministry of Education and Research. In an initial phase through to 2014 the three ministries will provide a total of up to Euro 200 million to be made available to research projects for

"One kilogram of petrol is equivalent to 60 kilograms of Li-Ion battery, therefore we need substantial progress", said Eric Maiser, Head of Battery Production VDMA E-Motive Forum

the development of a broad range of storage technologies for electricity, heat and other forms of energy. This year also the Federal Government adopted the new National Electromobility Development Plan, which aims to double allocated funding for e-mobility research to a sum of Euro 1 billion by 2013. The creation of new production facilities for batteries and energy storage devices is expected to generate Euro 4.8 billion of new business in the engineering sector by 2020.

Thus designed as an independent event, Energy Storage will take place next from November 13-16, 2012 at the New Munich Trade Fair Center. An annual conference is also being planned, to accompany the trade show. Leading figures in the industry, in research and politics will be debating and exploring all the latest developments and solutions at this forum. Productronica 2013 will be held in Munich from 12 to 15 November.

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Rapid Progress in Power Electronics

The Applied Power Electronics Conference and Exhibition (APEC) to be held from February 5-9 in Orlando/Florida again turns out to be a successful event with around 170 exhibitors. Main topics are Wide Bandgap Semiconductors, efficient switching topologies, and applications such as renewable power sources including smart grids.

APEC was initially sponsored only by the IEEE Power Electronics Council and then the Power Electronics Society (PELS). In 1989, the IEEE Industry Applications Society (IAS) Annual Meeting was overwhelmed with paper submissions. Looking for a way for more IAS members to publish at a conference, the IAS approached PELS about co-sponsoring APEC. Both PELS and IAS thought this was a better idea than starting another power electronics conference. APEC '90 was then sponsored by both the Power Electronics Society and the Industry Applications Society.

At APEC '90, the fledgling Power Sources Manufacturers Association (PSMA) approached APEC. The PSMA had been sponsoring its own conference, the Power Electronics Conference (PEC) with modest success. The PSMA proposed that APEC and PEC merge. There were some complications but a deal was struck. The PSMA would drop the PEC and join with PELS and the IAS in sponsoring APEC.

As the PSMA was a non-IEEE organization, it was felt that a written sponsorship agreement was needed. Bob White volunteered and with guidance from Dr. Thomas G. Wilson, Sr., drafted the Sponsor's Agreement on the Continuing Operation of the Applied Power Electronics Conference (the Sponsor's Agreement or Operating Agreement). This agreement was completed in September, 1991. APEC has been sponsored by PELS, IAS and the PSMA ever since. The conference has enjoyed a growing success throughout the years with more than thousand delegates in 2011.

APEC is now considered to be one of the leading conference for practicing power electronics professionals. The APEC program addresses a broad range of topics in the use, design, manufacture and marketing of all kinds of power electronics equipment.

An important part of the APEC program is the Exposition. It has grown from about 30 exhibitors in 36 booths in 1991 to more than 165 exhibitors filling 260 booths today.

www.apec-conf.org

Tuesday Feb 7th, 2012 08:30-12:00	T01 DC-DC Converters: Applications Chr: Jim Marinos, Fariborz Musavi Track: DC-DC Converters	T02 Special Topics on Solar Energy Harvesting Chr: Robert Balog Track: Renewable Energy Systems	T03 Inverter Control Chr: Tobias Geyer, Fang Luo Track: Motor Drives and Inverters	T04 Silicon Devices Chr: Chuck Mullett, Carl Blake Track: Devices and Components	T05 Rectifer & Inverter Modeling & Control Chr: Zach Pan Track: Modeling, Simulation, and Control	T06 Grid Connected Inverter Applications in Renewable Energy Systems Chr: Yi Huang, Hui Li Track: Power Electronics for Utility Interface	T07 AC-DC Converters I Chr: Dustin Becker, Chris Jones Track: AC-DC Converters
Wednesday Feb 8th, 2012 08:30-10:15	T08 DC-DC Converters: Magnetics Chr: Stephen Carlsen, Jim Marinos Track: DC-DC Converters	T09 Misc. Technologies for Renewable Energy Systems Chr: Alexis Kwasinski Track: Renewable Energy Systems	T10 Converter Topology II Chr: Jinjun Liu, Fang Zheng Peng Track: Motor Drives and Inverters	T11 Power Supply on Chip Magnetics Chr: Charles Sullivan, Matthew Wilkowski Track: Devices and Components	T12 Modeling, Simulation & Control of Storage Units Chr: Omer Onar, Ali Davoudi Track: Modeling, Simulation, and Control	T13 EMI Chr: Berker Bilgin, Jonathan Kimball Track: System Integration	T14 Packaging & Nanotechnology Chr: Ernie Parker, Chuck Mullett Track: Packaging and Nanotechnology
Wednesday Feb 8th, 2012 14:00-17:30	T15 DC-DC Converters: Bidirectional Chr: Chris Mi, Peyman Asadi Track: DC-DC Converters	T16 Applications of Power Electronics in Renewable Energy Harvesting I Chr: Morgan Kiani, Juan Carlos Balda Track: Renewable Energy Systems	T17 Electric Machines & Drives Chr: Steve Pekarek, Kent Wanner Track: Motor Drives and Inverters	T18 Power Electronics Applications I Chr: Miaosen Shen, Seon-Hwan Hwang Track: Power Electronics Applications	T19 DC-DC Control Chr: Hamid Behjati, Jaber Abu Qahouq Track: Modeling, Simulation, and Control	T20 Inverter Control for Key Issues Solution Chr: Liming Liu, Guijia Su Track: Power Electronics for Utility Interface	T21 AC-DC Converters II Chr: Gerry Moschopoulos Track: AC-DC Converters
Thursday Feb 9th, 2012 08:30-11:30	T22 DC-DC Converters: Modeling Chr: Chris Mi, Peyman Asadi Track: DC-DC Converters	T23 Applications of Power Electronics in Renewable Energy Harvesting II Chr: Babak Fahimi, Art Barnes Track: Renewable Energy Systems	T24 Motor Drives & Inverters I Chr: Hamid Toliyat, Robert Shaw Track: Motor Drives and Inverters	T25 Lighting I Chr: Cahit Gezgin Track: Power Electronics Applications	T26 Magnetics Chr: Ed Herbert, Matthew Wilkowski Track: Devices and Components	T27 AC-DC Converter Topologies & Control Chr: Jin Wang, Yaosuo Xue Track: Power Electronics for Utility Interface	T28 DC-DC Converters: Control(s) Chr: Jim Spangler, Amir Rahimi Track: DC-DC Converters
Thursday Feb 9th, 2012 14:00-17:30	T29 DC-DC Converters: High Performance Chr: Arnold Alderman Track: DC-DC Converters	T30 Lighting II Chr: Berker Bilgin, Donald Boughton Track: Power Electronics Applications	T31 Converter Topology I Chr: Jin Wang, Bill Wu Track: Motor Drives and Inverters	T32 Power Electronics Applications II Chr: Jim Marinos, Omer Onar Track: Power Electronics Applications	T33 Gan and SiC Devices & Applications Chr: Carl Blake, Doug Hopkins Track: Devices and Components	T34 Misc. Modeling, Simulation & Control Chr: Omer Onar Track: Modeling, Simulation, and Control	T35 Vehicular Electronics I Chr: Alireza Khaligh, Jim Spangler Track: Vehicular Electronics

APEC 2012 lecture session schedule

PCIM 2012 Extends its Reach

PCIM
EUROPE

International Exhibition and Conference
for Power Electronics, Intelligent Motion,
Power Quality
Nuremberg, 8 - 10 May 2012

PCIM Europe 2012 will be held at Nuremberg Fairgrounds from 8 - 10 May 2012. PCIM 2011 attracted more than 730 conference delegates, 6600 exhibition visitors and 298 exhibitors with additionally 67 represented companies. Next year's event looks promising so far.

Due to the strong growth in floor space, PCIM Europe will in 2012 take place in two exhibition halls (11 and 12) for the first time. Visitor management concept as well as the integration of the PCIM Europe conference will connect both halls and thus provide the best possible visitor circulation. Besides well-known industry names like Infineon, Semikron, Mitsubishi, ABB, International Rectifier or Fairchild, medium-sized companies and young enterprises will exhibit at PCIM Europe. The amount of participating companies from the US and Asia is growing continuously. Registrations in general are well above those of 2011.

PCIM Europe 2012 will also increase its exhibition topics by energy storage. Energy storage and power electronics are, particularly within e-mobility, closely linked technologies. The integration of power storages into broad power electronic components and solutions is already well advanced. Main target groups of PCIM Europe and thus of the new Focus Area Energy Storage are engineers of user industries such as renewable energy recovery, e-mobility or smart grid.

Again the Best Paper Award (BPA) for the conference will be sponsored by Power Electronics Europe including a €1000 price and invitation to PCIM China 2013. PEE's Special Session **'High Frequency Switching Devices and Applications'** was another event at PCIM 2011 for supporting new technologies/applications attracting more than 120 conference delegates. Thus it was the major session on GaN/SiC technologies and devices. Next year's Special Session will cover power semiconductors for green applications.

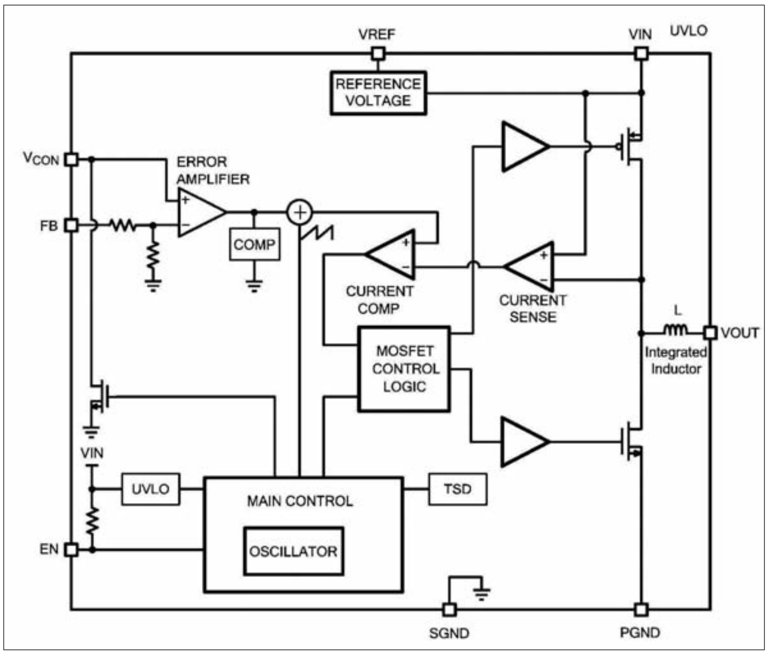
www.pcim.de

E-Mobility and energy storage will be one of the subjects of interest at PCIM 2012

Small Synchronous Regulators for Point-of-Load Power Conversions

Texas Instrument/National Semiconductor introduces power management integrated circuits for space-constrained point-of-load designs in industrial, communications and automotive applications. The National 1 A LMZ10501 and 650 mA LMZ10500 nano modules feature on-chip inductor. Used in conjunction with the WEBENCH online design tool, the products simplify and speed the design process.

The nano modules are offered in an 8-pin leadless surface mount package measuring 2.5 mm by 3 mm by 1.2 mm. The suggested retail price of the LMZ10501 is $1.80 and the LMZ10500 is $1.30 in 1,000-unit quantities.



LMZ10500 functional block diagram

LMZ10500 overview

The LMZ10500 is a synchronous Buck power module using a PFET for the high side switch and an NFET for the synchronous rectifier switch. A Low Temperature Co-fired Ceramic (LTCC) type 2.6 µH inductor with over 1.2A DC current rating and soft saturation profile for up to 2A is integrated into the package. This inductor allows for the 1.2 mm overall package height providing a compact solution with reduced EMI.

The LMZ10500 is capable of driving up to 650 mA load. Only an input and output capacitor, a small V_{CON} filter capacitor, and two resistors are required for basic operation. The nano module comes in 8-pin LLP footprint package with an integrated inductor. The LMZ10500 operates in fixed 2.0 MHz PWM mode. The output voltage is typically set by using a resistive divider between the built-in reference voltage V_{REF} and the control pin V_{CON}. The V_{CON} pin is the positive input to the error amplifier. The output voltage of the LMZ10500 can also be dynamically adjusted between 0.6V and 3.6V by driving the VCON pin externally. Internal current limit based softstart function, current overload protection, and thermal shutdown are also provided.

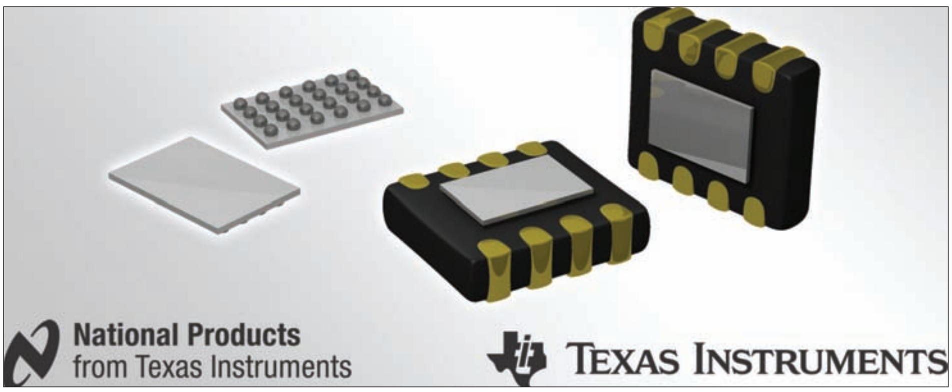
The output voltage is regulated by modulating the PFET switch on-time. The circuit generates a duty-cycle modulated rectangular signal. The rectangular signal is averaged using a low pass filter formed by the integrated inductor and an output capacitor. The output voltage is equal to the average of the duty-cycle modulated rectangular signal.

In PWM mode, the switching frequency is constant. The energy per cycle to the load is controlled by modulating the PFET on-time, which controls the peak inductor current. In current mode control architecture, the inductor current is compared with the slope compensated output of the error amplifier.

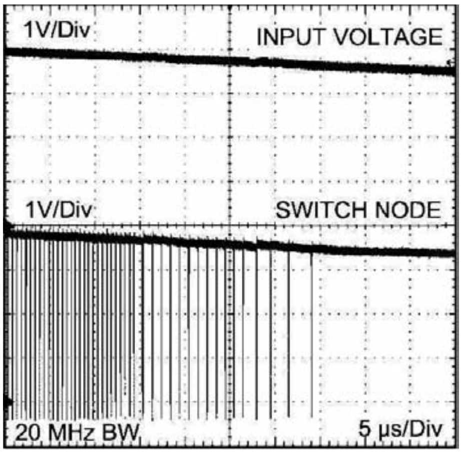
At the rising edge of the clock, the PFET is turned ON, ramping up the inductor current with a slope of (V_{IN} - V_{OUT})/L. The PFET is ON until the current signal equals the error signal. Then the PFET is turned OFF and NFET is turned ON, ramping down the inductor current with a slope of V_{OUT} /L. At the next rising edge of the clock, the cycle repeats. An increase of load pulls the output voltage down, resulting in an increase of the error signal. As the error signal goes up, the peak inductor current is increased, elevating the average inductor current and responding to the heavier load. To ensure stability, a slope compensation ramp is subtracted from the error signal and internal loop compensation is provided.

The LMZ10500 uses an internal NFET as a synchronous rectifier to minimize the switch voltage drop and increase efficiency. The NFET is designed to conduct through its intrinsic body diode during the built-in dead time between the PFET on-time and the NFET on-time. This eliminates the need for an external diode. The dead time between the PFET and NFET connection prevents shoot through current from V_{IN} to PGND during the switching transitions.

The LMZ10500 features a transition mode designed to extend the output regulation range to the minimum possible input voltage. As the input voltage decreases closer and closer to V_{OUT}, the off-time of the PFET gets smaller and smaller and the duty cycle eventually needs to reach 100 % to support theoutput voltage. The input voltage at which the duty cycle reaches 100 % is the edge of regulation. When the input voltage is lowered, such that the off-time of the PFET reduces to less than 35 ns, the LMZ10500 doubles the switching period to extend the off-time for that V_{IN} and maintain regulation. If V_{IN} is lowered even more, the off-time of the PFET will reach the 35 ns mark again. The frequency will then be reduced again,



Simple switcher nano modules now feature an integrated inductor



achieving less than 100 % duty cycle operation and maintaining regulation. As V_{IN} is lowered even more, the LMZ10500 will continue to scale down the frequency, aiming to maintain at least 35 ns off time. Eventually, as the input voltage decreases further, 100% duty cycle is reached.

Application considerations

The LMZ10500 provides a fixed 2.35 V_{REF} voltage output. As shown in the typical application circuit, a resistive divider formed by R_T and R_B sets the V_{CON} pin voltage level. The V_{OUT} voltage tracks V_{CON} and is

LEFT: High duty cycle operation and switching frequency reduction

governed by V_{OUT} = GAIN x V_{CON} (where GAIN is 2.5 V/V from V_{CON} to V_{FB}).

Each nano module is optimized to achieve high V_{OUT} accuracy. The output voltage as shown is a function of the V_{CON} voltage and the gain from V_{CON} to V_{FB}. The voltage at V_{CON} is derived from V_{REF}. Therefore the accuracy of the output voltage is a function of the V_{REF} x GAIN product as well as the tolerance of the R_T and R_B resistors.

The LMZ10500 is designed for use with low ESR multi-layer ceramic capacitors (MLCC) for its input and output filters. Using a 10 µF 0603 or 0805 with 6.3V or 10V rating ceramic input capacitor typically provides sufficient V_{IN} bypass. Use of multiple 4.7 µF or 2.2 µF capacitors can also be considered. Ceramic capacitors with X5R and X7R temperature characteristics are recommended for both input and output filters. These provide an optimal balance between small size, cost, reliability, and performance for space sensitive applications.

The DC voltage bias characteristics of the capacitors must be considered when selecting the DC voltage rating and case size of these components. The effective capacitance of an MLCC is typically reduced by the DC voltage bias applied across its terminals. For example, a typical 0805 case size X5R 6.3V 10 µF ceramic capacitor may only have 4.8 µF left in it when a 5.0V DC bias is applied. Similarly, a typical 0603 case size X5R 6.3V 10 µF ceramic capacitor may only have 2.4 µF at the same 5.0V DC. Smaller case size capacitors may have even larger percentage drop in value with DC bias. The optimum output capacitance value is application dependent.

Too small output capacitance can lead to instability due to lower loop phase margin. On the other hand, if the output capacitor is too large, it may prevent the output voltage from reaching the 0.375 V required voltage level at the end of the startup sequence. In such cases, the output short circuit protection can be engaged and the nano module will enter a hiccup mode.

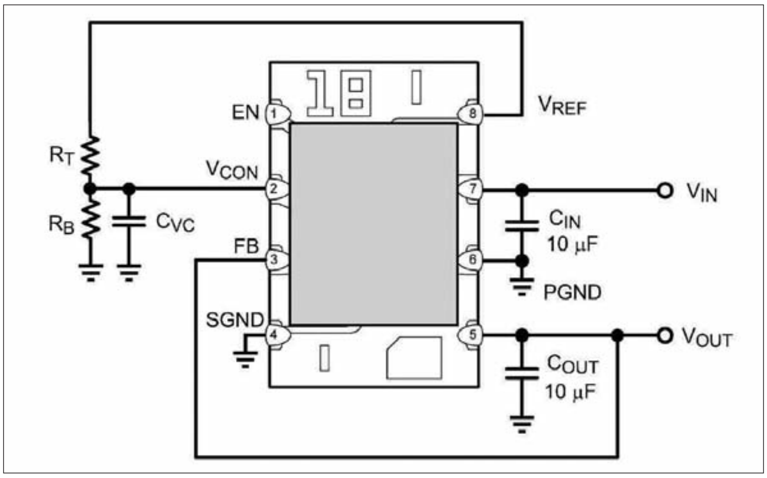
Use of multiple 4.7 µF or 2.2 µF output capacitors can be considered for reduced effective ESR and smaller output voltage ripple. In addition to the main output capacitor, small 0.1µF - 0.01µF parallel capacitors can be used to reduce high frequency noise.

The nano module package includes the LTCC inductor on the bottom and a micro SMD die mounted on top. The die has exposed edges and can be sensitive to ambient light. For applications with direct high intensity ambient red, infrared, LED, or natural light it is recommended to have the device shielded from the light source to avoid abnormal behavior.

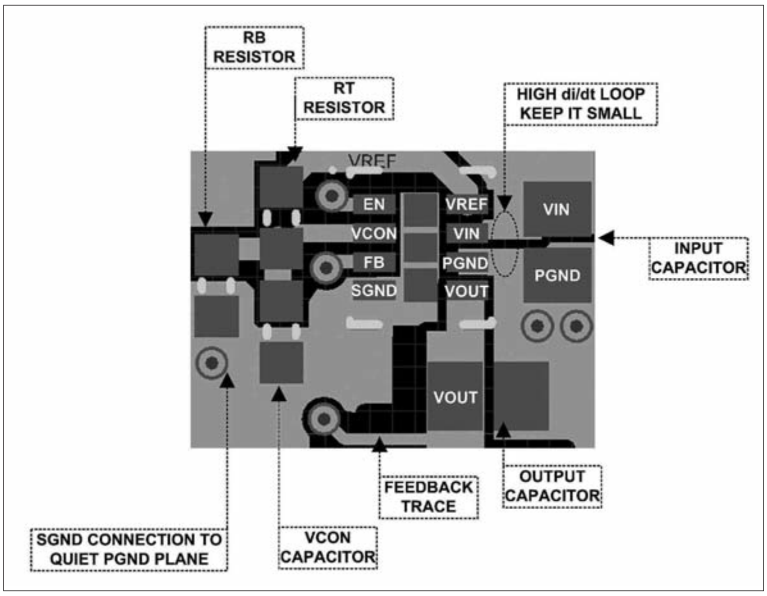
The board layout of any DC/DC switching converter is critical for the optimal performance of the design. Bad PCB layout design can disrupt the operation of an otherwise good schematic design. Even if the regulator still converts the voltage properly, the board layout can mean the difference between passing or failing EMI regulations. In a Buck converter, the most critical board layout path is between the input capacitor ground terminal and the synchronous rectifier ground. The loop formed by the input capacitor and the power FETs is a path for the high di/dt switching current during each switching period. This loop should always be kept as short as possible when laying out a board for any Buck converter.

The LMZ10500 integrates the inductor and simplifies the DC/DC converter board layout. An example layout is shown in the last figure. There are a few basic requirements to achieve a good LMZ10500 layout: 1) Place the input capacitor CIN as close as possible to the V_{IN} and PGND terminals. V_{IN} (pin 7) and PGND (pin 6) on the LMZ10500 are next to each other which makes the input capacitor placement simple. 2) Place the V_{CON} filter capacitor C_{VC} and the R_B R_T resistive divider as close as possible to the V_{CON} and SGND terminals. The C_{VC} capacitor (not R_B) should be the component closer to the V_{CON} pin. This allows for better bypass of the control voltage set at V_{CON}. 3) Run the feedback trace (from V_{OUT} to F_B) away from noise sources. 4) Connect SGND to a quiet GND plane. 5) Provide enough PCB area for proper heatsinking.

www.ti.com/nano-pr



LMZ10500 typical application circuit



Example top layer board layout

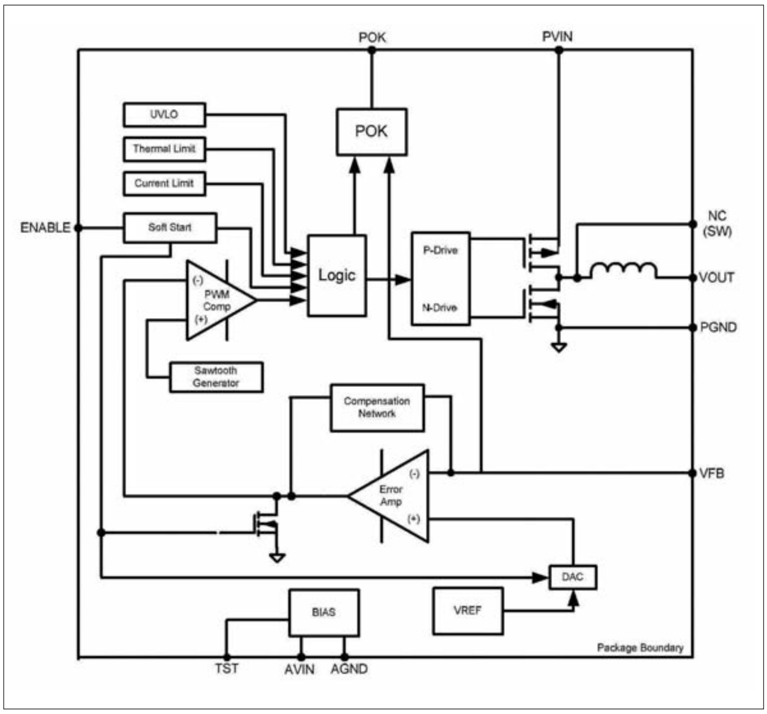
New Buck Converter Enables Embedded Power

The Enpirion EN5339 power system-on-a-chip (PowerSoC) integrates the controller, power MOSFETs, compensation network and inductor into one highly compact solution that significantly reduces the traditional engineering analysis and design effort associated with discrete DC/DC converter designs.

The so-called PowerSoC integrates two MOSFET (LDMOS - Laterally Diffused MOSFET) switches, all small-signal circuits, compensation, and the inductor in a 4 mm x 6 mm x 1.1 mm QFN package. Though the switching frequency of 3.5 MHz is relativley high efficiency is up to 95 %.

The EN5339 fits into a 55 mm_ solution area with a 1.1 mm profile, allowing for bottom-side PCB mounting. "Keeping up with the demands of embedded, industrial and storage applications, the EN5339 enables a 20 % solution footprint reduction and 40 % lower profile compared to previous Enpirion 3 A products", said Mark Cieri, Enpirion's director of marketing and business development. "Embedded have at least four point-of-load voltage rails. The EN5339's low profile enables highest-density computer-on-modules, densely stacked multi-board design and mounting on the backside of PCBs, which is often necessary. And typically only 3 to 6 external components are necessary".

PowerSoCs are specified, simulated, characterized, validated and manufacturing-tested as a complete power system. The EN5339 device is sampling now, with volume production by December 2011. The device is available for $1.88 at volumes of 1k units through distribution (Future Electronics, Mouser Electronics) or direct from Enpirion.



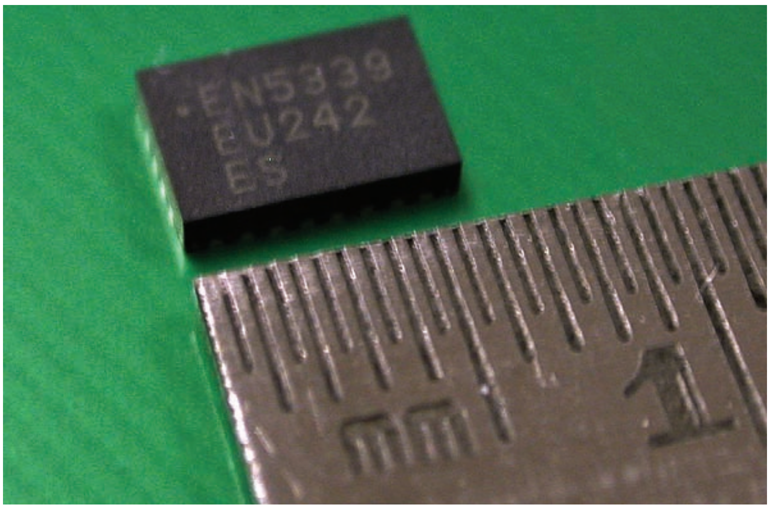
EN5339 functional block diagram

Functional description

The converter uses Type III voltage mode control to provide high noise immunity, low output impedance and good load transient response. No external compensation components are needed for most applications.

Power OK (POK) monitors the output voltage and signals if it is within ±10% of nominal. Protection features include under voltage lockout (UVLO), over-current protection, short circuit protection, and thermal overload protection.

The EN5339 provides an open drain output to indicate if the output voltage stays within 92 % to 111 % of the set value. Within this range, the POK output is allowed to be pulled high. Outside this range, POK remains low. However, during transitions such as power up, power down, and dynamic voltage scaling, the POK output will not change state until the transition is complete for enhanced noise immunity. The POK has 5 mA sink capability for events where it needs to feed a digital controller with standard CMOS inputs. When POK is pulled high, the pin leakage current is as low as 500 nA maximum over temperature. This allows a large pull up resistor such as 100 kΩ to be used for minimal current consumption in shutdown mode. The POK output can also be conveniently used as an ENABLE input of the next stage for power sequencing of multiple converters.



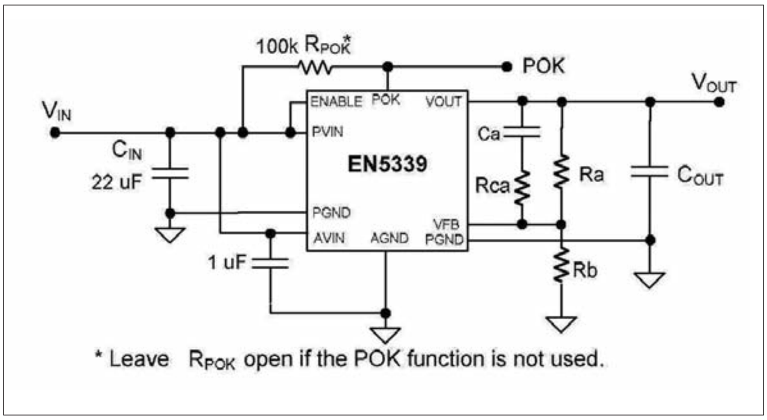
EN5339 package size

An internal compensation network is designed to provide stable operation over a wide range of operating conditions. To improve transient performance or reduce output voltage ripple with dynamic loads supplementary capacitance to the output can be added.

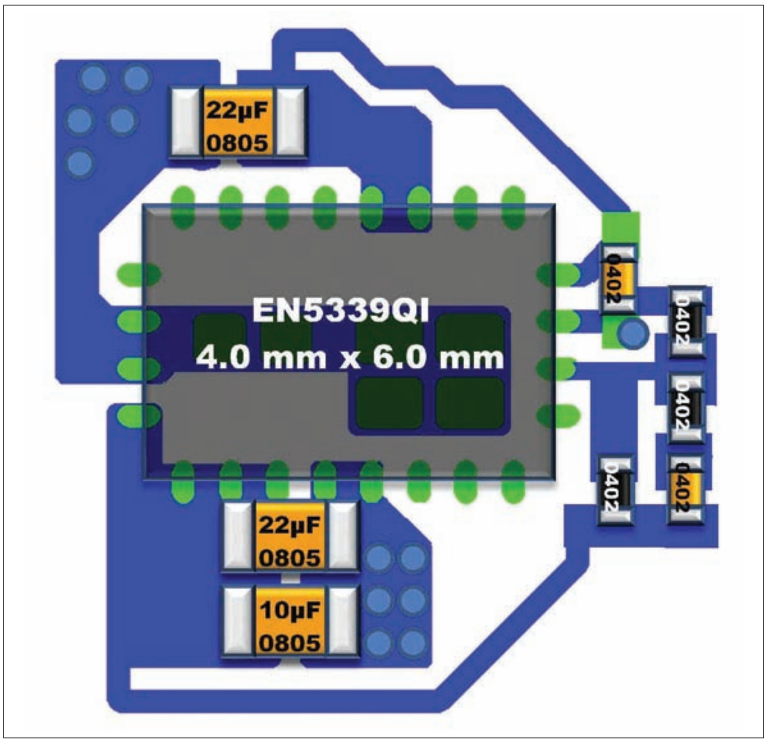
Excess bulk capacitance on the output can cause an over-current condition at startup. Since the slew rate varies with the output voltage setting, the maximum capacitance is a function of the VOUT setting. The maximum capacitance on the output power rail, including the output filter capacitors and all decoupling and bulk capacitors on the supply rail is given by $C_{OUT\_TOTAL\_MAX}$ [F] = $3.6x10^{-3}/V_{OUT}$.

Application considerations

The EN5339 uses a simple resistor divider network to program the output voltage. The recommended component values for the feedback network as a function of VIN, VOUT, and anticipated maximum



Typical application circuit with external resistor divider



Optimized layout recommendations

load current are shown in the table. It is recommended to use 1 % or better feedback resistors to ensure high accuracy. The value of resistor R_a is given in the table for the specific operating conditions. Based on that value, the value of the bottom resistor R_b is given as $R_b = R_a \times V_{ref} / V_{out} - V_{ref}$. V_{OUT} is the output voltage and V_{ref} is 0.6V nominally.

AVIN Filter Capacitor: A 1.0 µF, 10V, 0402 MLCC capacitor should be placed between the AVIN and AGND pins. This will provide high frequency bypass to ensure clean chip supply for optimal performance.

Input Filter Capacitor Selection: A single 22 µF, 0805 X5R MLCC capacitor is needed on PVIN for all applications. Connect between the PVIN and PGND pins. Make sure that the capacitor is placed as close to the pins of the EN5339QI as the application allows. Placement of this part is critical to ensure low conducted and radiated EMI. Low ESR MLCC capacitors with X5R or X7R or equivalent dielectric should be used for the input capacitors. Y5V or equivalent dielectrics lose too much capacitance with frequency, DC bias, and temperature. Therefore, they are not suitable for switch-mode DC/DC converter filtering, and must be avoided.

Layout recommendations

Input and output filter capacitors should be placed on the same side of the PCB, and as close to the EN5339 as possible. They should be connected to the device with very short and wide traces. Do not use thermal reliefs or spokes when connecting the capacitor pads to the respective nodes. The +V and GND traces between the capacitors and the EN5339 should be as close to each other as possible so that the gap between the two nodes is minimized, even under the capacitors.

The system ground plane should be the first layer immediately below the surface layer. This ground plane should be continuous and uninterrupted below the converter and the input/output capacitors.

The thermal pad underneath the component must be connected to the system ground plane through as many vias as possible. The drill diameter of the vias should be 0.33 mm, and the vias must have at least 1 oz. copper plating on the inside wall, making the finished hole size around 0.20-0.26 mm. Do not use thermal reliefs or spokes to connect the vias to the ground plane. This connection provides the path for heat dissipation from the converter.

Multiple small vias should be used to connect ground terminal of the input capacitor and output capacitors to the system ground plane. It is preferred to put these vias along the edge of the GND copper closest to the +V copper. These vias connect the input/output filter capacitors to the GND plane, and help reduce parasitic inductances in the input and output current loops.

AVIN is the power supply for the small-signal control circuits. It should be connected to the input voltage at a quiet point. In the optimized layout this connection is made at the input capacitor. Connect a 1µF capacitor from the AVIN pin to AGND.

The V_{out} sense point should be just after the last output filter capacitor. Keep the sense trace short in order to avoid noise coupling into the node.

Keep the R_A, C_A, R_B and R_1 close to the VFB pin. This pin is a high-impedance, sensitive node. Keep the trace to this pin as short as possible. Whenever possible, connect R_B directly to the AGND pin instead of going through the GND plane.

www.enpirion.com

VIN (V)	IOUT	VOUT	COUT	Ra (kΩ)	Ca (pF)	Rca (kΩ)
2.5 to 5.5	3A	0.9V	3x 22µF (0805)	344	18	0
		1V				
		1.2V				
		1.5V				
		1.8V				
		2.5V				
		2.85V		200	15	
		3.3V				

Low ripple recommended components

- **High reliability**
  by innovative solder material and ultrasonic welding
- **Improved thermal behaviour**
  by reduced thermal cross coupling and uniform temperature distribution
- **Low internal inductance**
  by parallel and closely arranged bus-bars

Package 2-Pack & Chopper	I_C	1200V E-type	1200V P-type Soft turn-off	1700V E-type
 89 x 172 mm	600A	●		
	650A			●
	900A	●	●	
 89 x 250 mm	1000A			●
	1400A		●	●

$T_{j,op}$ = 150°C $T_{j,max}$ = 175°C $V_{iso,\ 1min}$ = 4.0kv CTI > 600

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Isolated PFC Offline Regulator Needs No Opto

Linear Technology's new LT3798 is an isolated flyback controller with single stage active power factor correction (PFC). A power factor of greater than 0.97% is accomplished by actively modulating the input current eliminating the need for an extra switching power stage and associated components. In addition, no optoisolator or signal transformer is required for feedback since the output voltage is sensed from the primary-side flyback signal. Efficiencies greater than 86 % can be achieved with output power levels up to 100 W.

The LT3798 is a current mode switching controller IC designed specifically for generating a constant current/constant voltage supply in an isolated flyback topology. The special problem normally encountered in such circuits is that information relating to the output voltage and current on the isolated secondary side of the transformer must be communicated to the primary side in order to maintain regulation. This has been done with an optoisolator. The LT3798 uses a novel method of using the external MOSFETs peak current information from the sense resistor to calculate the output current of a flyback converter without the need of an optocoupler.

Active power factor correction is becoming a requirement for offline power supplies and the power levels are decreasing. A power factor of one is achieved if the current drawn is proportional to the input voltage. The LT3798 modulates the peak current limit with a scaled version of the input voltage. This technique can provide power factors of 0.97 or greater.

Operation priciple

The Block Diagram shows an overall view of the system. The external components are in a flyback topology configuration. The third winding senses the output voltage and also supplies power to the part in steady-state operation. The VIN pin supplies power to an internal LDO that generates 10 V at the INTV$_{CC}$ pin. The novel control circuitry consists of two error amplifiers, a minimum circuit, a multiplier, a transmission gate, a current comparator, a low output current oscillator and a master latch. The device also features a sample-and-hold to sample the output voltage from the third winding. A comparator is used to detect discontinuous conduction mode (DCM) with a capacitor connected to the third winding. A 1.9 A gate driver is also included.

The LT3798 is designed for both off-line and DC applications. The EN/UVLO and a resistor divider can be configured for a micropower hysteretic start-up. In the block diagram, R3 is used to stand off the high voltage supply voltage.

The internal LDO starts to supply current to the INTV$_{CC}$ when VIN is above 2.5V. The V_{IN} and INTV$_{CC}$ capacitors are charged by the current from R3. When V_{IN} exceeds the turn-on threshold and INTV$_{CC}$ is in regulation at 10 V, the device begins to switch. The V_{IN} hysteresis is set by the EN/UVLO resistor divider. The third winding provides power to V_{IN} when its voltage is higher than the V_{IN} voltage. A voltage shunt is provided for fault protection and can sink over 20 mA of current when V_{IN} is over 40 V.

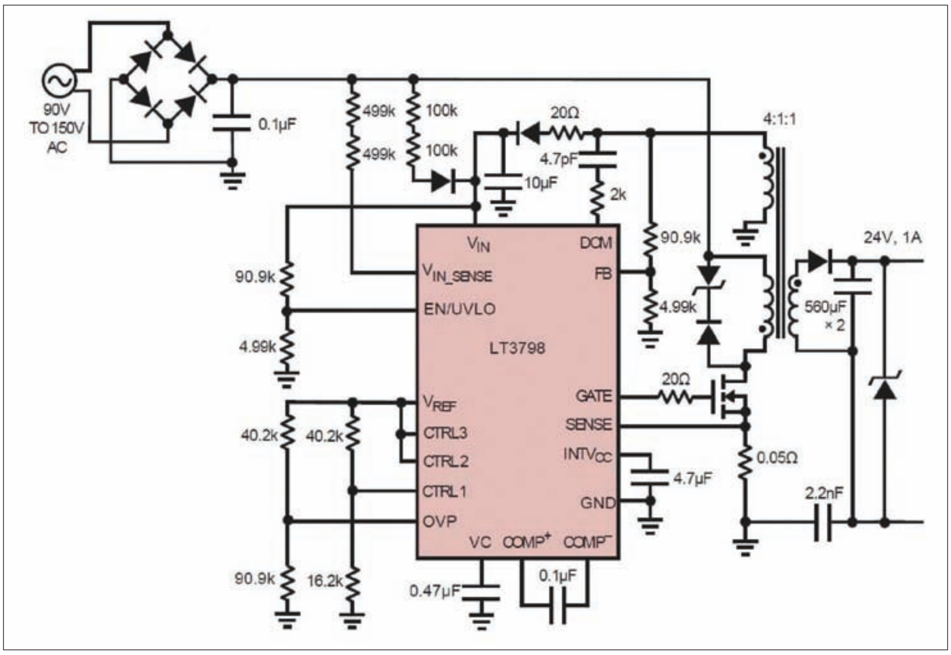
During a typical cycle, the gate driver turns the external MOSFET on and a current flows through the primary winding. This current increases at a rate proportional to the input voltage and inversely proportional to the magnetizing inductance of the transformer. The control loop determines the maximum current and the current comparator turns the switch off when the current level is reached.

When the switch turns off, the energy in the core of the transformer flows out the secondary winding through the output diode D1. This current decreases at a rate proportional to the output voltage. When the current decreases to zero, the output diode turns off and voltage across the secondary winding starts to oscillate from the parasitic capacitance and the magnetizing inductance of the transformer. Since all windings have the same voltage across them, the third winding rings too. The capacitor connected to the DCM pin, C1, trips the comparator A2, which serves as a dv/dt detector, when the ringing occurs. This timing information is used to calculate the output current. The dv/dt detector waits for the ringing waveform to reach its minimum value and then the switch turns back on.

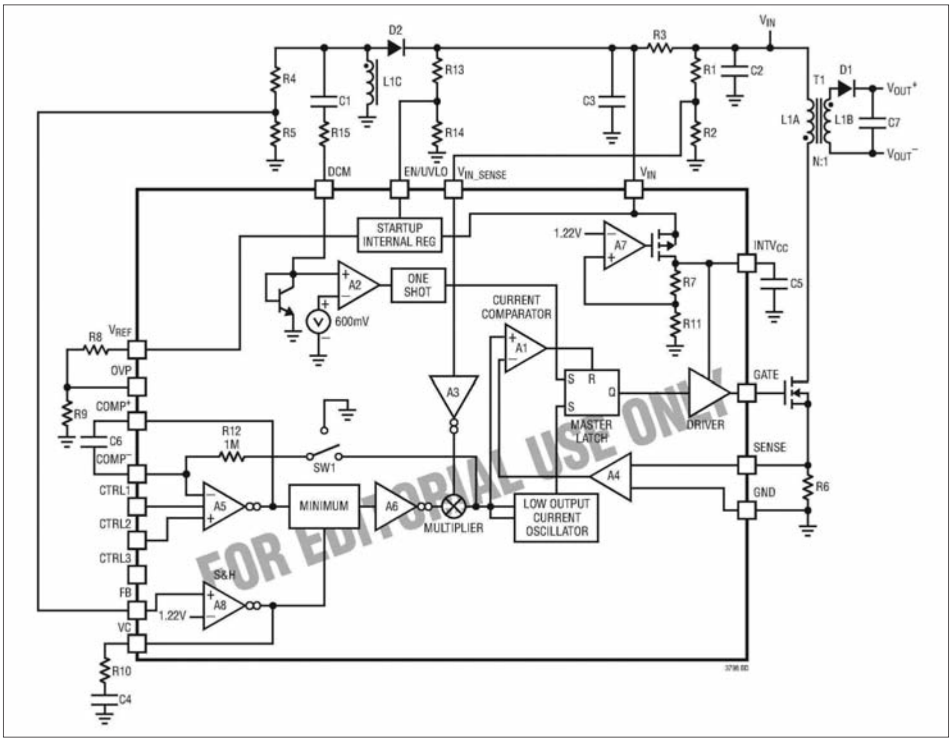
This switching behavior is similar to zero volt switching and minimizes the amount of energy lost when the switch is turned back on and improves efficiency as much as 5 %. Since operation is on the edge of continuous conduction mode and discontinuous conduction mode, the operating mode is called critical conduction mode (or boundary conduction mode).

Power factor correction

When the $V_{INSENSE}$ voltage is connected to a resistor divider of the supply voltage, the current limit is proportional to the supply voltage. The minimum of the two error amplifier outputs is multiplied with the $V_{INSENSE}$ pin voltage. If the LT3798 is configured with a fast control loop, slower changes from the $V_{INSENSE}$ pin would not interfere with the current limit or the output current. The COMP+ pin would adjust to the changes of the VINSENSE. The only way for the multiplier to function is to set the control loop to be an order of magnitude slower than the fundamental frequency of the VINSENSE signal. In an offline case, the fundamental frequency of the supply voltage is 100Hz (120Hz in the US), so the control loop unity gain frequency needs to be set less than approximately 10/12Hz. Without a large amount of energy storage on the secondary side, the output current will be affected by the supply voltage changes, but the DC component of the



Block diagram of the isolated flyback controller LT3798 with single stage active power factor correction



Typical application as 24W PFC (>0.97) bus converter

output current will be accurate. The active PFC provides smoother input current waveforms and PFC values up to 98 %.

Programming output voltage

The output voltage is set using a resistor divider from the third winding to the FB pin. From the block diagram, the resistors R4 and R5 form a resistor divider from the third winding. The FB also has an internal current source that compensates for the diode drop. This current source causes an offset in the output voltage that needs to be accounted for when setting the output voltage. The output voltage equation is:

$$V_{OUT} = V_{BG}\ (R4+R5)/(N_{ST} \cdot R5)-(V_F + (R4 \cdot I_{TC})/N_{ST})$$

where V_{BG} is the internal reference voltage, N_{ST} is the winding ratio between the secondary winding and the third winding, V_F is the forward drop of the output rectifying diode, and I_{TC} is the internal current source for the FB pin.

Programming output current

The maximum output current depends on the supply voltage and the output voltage in a flyback topology. With the $V_{INSENSE}$ pin connected to 100 µA current source and a DC supply voltage, the maximum output current is determined at the minimum supply voltage, and the maximum output voltage using the following equation:

$$I_{OUT(MAX)} = 2 \cdot (1- D) \cdot N / 42 \cdot R_{SENSE}$$

where $D = V_{OUT} \cdot N / (V_{OUT} \cdot N) + V_{IN}$

The maximum control voltage to achieve this maximum output current is 2V • (1-D). It is suggested to operate at 95 % of these values to give to give margin for the part's tolerances.

When designing for power factor correction, the output current waveform is going to have a half sine wave squared shape and will no longer be able to provide the above currents. By taking the integral of a sine wave squared over half a cycle, the average output current is found to be half the value of the peak output current. In this case, the recommended maximum average output current is as follows:

$$I_{OUT(MAX)} = 2 \cdot (1 - D) \cdot N / (42 \cdot R_{SENSE}) \cdot 47.5\ \%$$

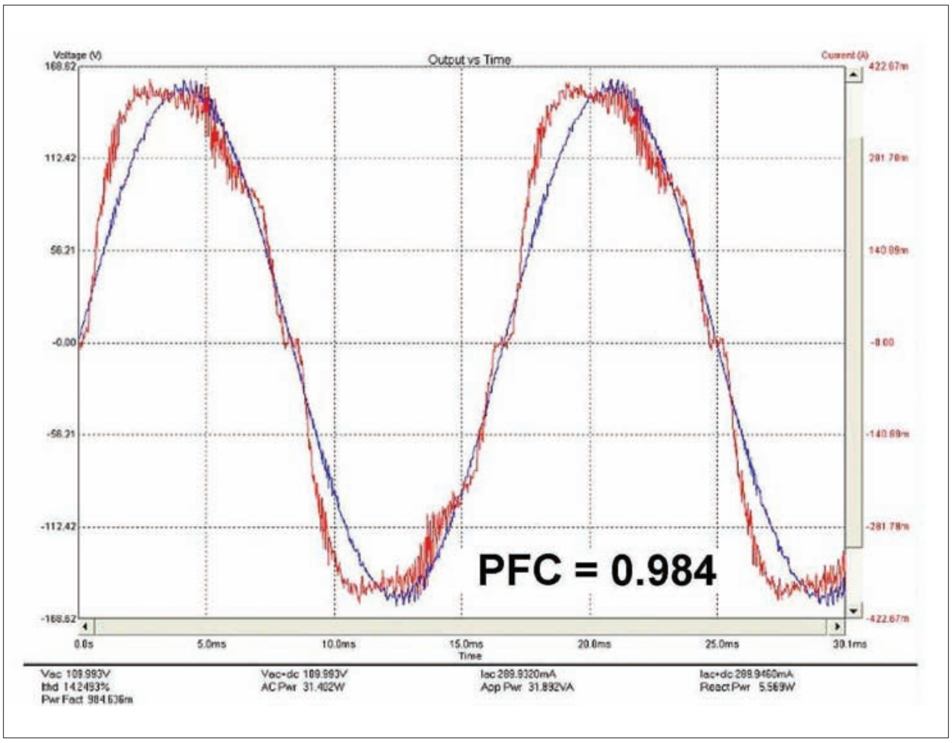
The maximum control voltage to achieve this maximum output current is (1-D) • 47.5%.

Winding turns ratio

Boundary mode operation gives a lot of freedom in selecting the turns ratio of the transformer. It is suggested to keep the duty cycle low, lower NPS, at the maximum input voltage since the duty cycle will increase when the AC waveform is decreases to zero volts. A higher NPS increases the output current while keeping the primary current limit constant. Although this seems to be a good idea, it comes at the expense of a higher RMS current for the secondary-side diode which might not be desirable because of the primary side MOSFET's superior performance as a switch. A higher NPS does reduce the voltage stress on the secondary-side diode while increasing the voltage stress on the primary-side MOSFET.

If switching frequency at full output load is kept constant, the amount of energy delivered per cycle by the transformer also stays constant regardless of the NPS. Therefore, the size of the transformer remains the same at practical NPS's. Adjusting the turns ratio is a good way to find an optimal MOSFET and diode for a given application.

Since the current on the secondary side of the transformer is inferred by the current sampled on the primary, the transformer turns ratio must be tightly controlled to ensure a consistent output current. A tolerance of ±5 % in turns ratio from transformer to transformer could result in a



Active power factor correction provides smooth input current waveforms (red) and power factor of 0.984 in this setup

variation of more than ±5 % in output regulation. Fortunately, most magnetic component manufacturers are capable of guaranteeing a turns ratio tolerance of 1 % or better. Linear Technology has worked with several leading magnetic component manufacturers to produce pre-designed flyback transformers for use with the LT3798.

The actual frequency will depend on V_{IN} and V_{OUT} conditions as well as load current. Nevertheless, its frequency range is from 30 kHz to 300 kHz.

MOSFET and diode selection

With a 1.9A gate driver, the LT3798 can drive most high voltage MOSFETs. A low gate charge MOSFET is recommended to maximize efficiency. In most applications, the $R_{DS(ON)}$ should be chosen to limit the temperature rise of the MOSFET. The drain of the MOSFET is stressed to V_{OUT} • NPS + V_{IN} during the time the MOSFET is off and the secondary diode is conducting current. But in most applications, the leakage inductance voltage spike exceeds this voltage.

The voltage of this stress is determined by the switch voltage clamp. Always check the switch waveform with an oscilloscope to make sure the leakage inductance voltage spike is below the breakdown voltage of the MOSFET. A transient voltage suppressor and diode are slower than the leakage inductance voltage spike, therefore causing a higher voltage than calculated.

The secondary diode stress may be as much as V_{OUT} + 2 • V_{IN}/NPS due to the anode of the diode ringing with the secondary leakage inductance. An RC snubber in parallel with the diode eliminates this ringing, so that the reverse voltage stress is limited to V_{OUT} + V_{IN}/NPS. With a high NPS and output current greater than 3 A, the IRMS through the diode can become very high and a low forward drop Schottky is recommended.

Universal input

The LT3798 operates over the universal input range of 90 to 265VAC. Output current regulation error may be minimized by using two application circuits for the wide input range: one optimized for 120VAC and another optimized for 220VAC.

The application of a 24 W PFC bus converter shows that the device's input voltage range is dependent on the choice of external components and it can operate over a 90VAC to 277VAC range, and can easily be scaled higher or lower. Furthermore, the LT3798 can be designed into high input voltage DC applications, making it well suited for industrial, EV/EHV automotive, mining and medical applications.

www.linear.com/product/LT3798

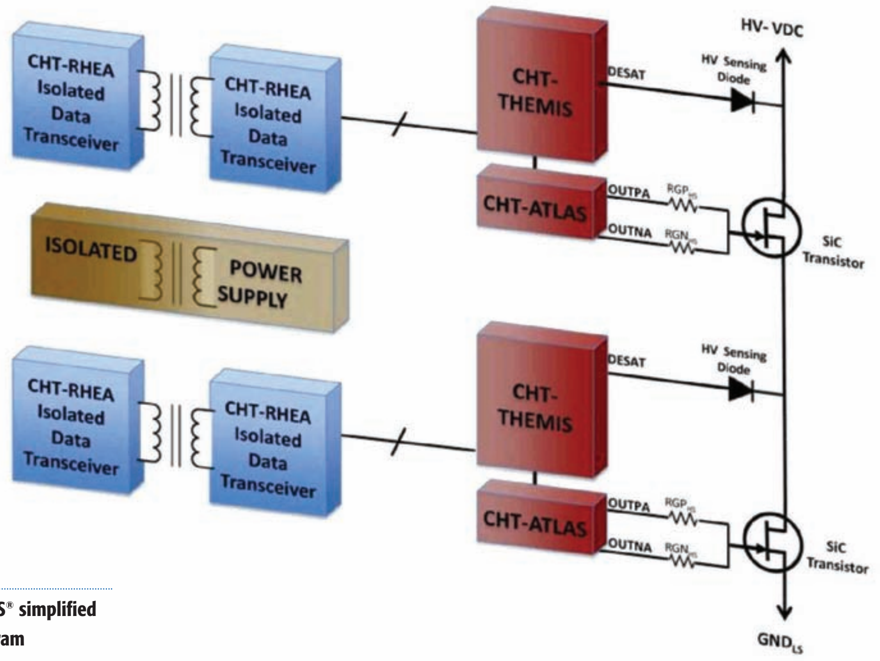
High-Temperature Driver for SiC and GaN

HADES from Belgium CISSOID has been designed to drive seamlessly Silicon Carbide (SiC) power transistors, which have low switching losses. The driver can switch them at high frequencies, which means smaller and lighter passive and magnetic components. Furthermore, thanks to its ability to sustain high temperatures, it can be located next to the power transistors which reduces parasitic capacitances and inductances, and that further improves the associated losses and delays in the system. The device has been designed for high dV/dt immunity (50 kV/_s) and junction temperatures up to 225°C. As an example, operation and performances were demonstrated in a 3 kW Buck DC/DC converter, driving SiC MOSFETs, at 175°C ambient and switching at 150 kHz, with rise times of less than 25 ns.

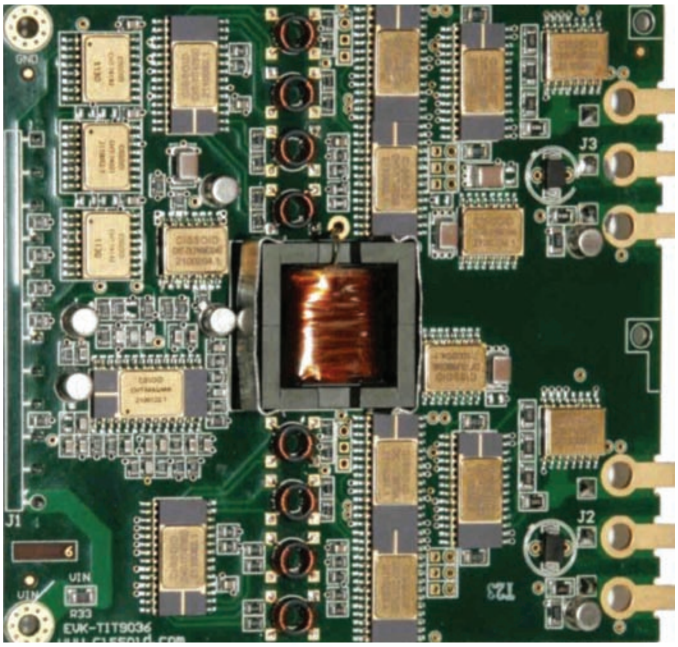
EVK-HADES is a dual-channel gate drive Reference Design dedicated to drive newest generation of wide bandgap power switch devices such as SiC and GaN (MOSFETs or JFETs).Other types of devices (BJTs, IGBTs) can be supported but may require some hardware adaptations. The Evaluation Board implements a turnkey gate driver solution that can be used immediately to implement a power converter or a motor drive, supporting a bus voltage up to 1200V and gate currents up to ±4A. The two channels can be con-trolled independently of each other or used in a half-bridge configuration.In the latter case, the EVK-HADES board in combination with power switches can form a com-plete 1-leg inverter solution for immediate evaluation.

The Reference Design is based on the chipset CHT-THEMIS / CHT-ATLAS and CHT-RHEA. The solution also includes an isolated power supply built with CHT-MAGMA PWM controller. For applications that require gate currents greater than ±4A, designers can modify the reference design and build their own board by adding up to 4 four additional CHT-ATLAS circuits per channel (high-side and low side) in order to source / sink up to +/-20A to the gate of the power switch devices.

The board is populated with CISSOID integrated circuits in ceramic package form (CSOIC28), guaranteed for -55°C to +225°C. The board is based on a polyimide PCB (rated 200°C). The passive components and the desaturation diode allow operation up to 175°C, with possible short excursions to 225°C for testing. The evaluation board is delivered with the complete electrical schematic, the bill of



EVK-HADES® simplified block diagram



ABOVE: Evaluation Board for SiC/GaN drivers

LEFT: Evaluation Board and 3 kW Buck DC/DC converter test setup

materials including active and passive components, and the Gerber files.

Electrical performance

EVK-HADES exhibits high-temperature operation, combining high efficiency and high frequency capabilities, making it ideal for high power density solutions such as power converter sub-systems and Intelligent Power Modules (IPMs). Double pulse switching tests were carried out with two SiC MOSFET CMF20120D from CREE. The power transistors were connected in a half-bridge and used to drive a clamped inductive load at 600 V/15 A/Ta=175°C. The same half-bridge has been tested in a 3 kW Buck DC/DC converter test board, which demonstrated power efficiencies in the range 97.0 % and 94.5 % for switching frequencies of 50 kHz and 150 kHz and running at 175°C (ambient) - the majority of the losses being dynamic losses within the MOSFET switches. All CISSOID's active components are guaranteed for normal operation over the full range -55°C to +225°C. The magnetic isolation of the power supply also sustains reliably high temperatures, as opposed to optocouplers. On-board protection functions include Under Voltage Lockout (UVLO) and Desaturation Detection that monitors the drain-to-source voltage of the power transistor to detect over-currents. The board also implements Active Miller Clamping function which prevents parasitic turn-on due to the Miller capacitor of the power switch. EVK-HADES is available priced at €7,500.

www.cissoid.com

GaN and SiC at IEDM

The IEEE International Electron Devices Meeting (IEDM) is the world's premier forum for the presentation of advances in microelectronic, nanoelectronic and bioelectronic devices. The 57th annual IEDM conference held from December 5-7 in Washington DC/USA emphasised circuit-device interaction, energy-harvesting and also power devices. The research will be transferred sooner or later into products. Thus we have prepared a summary of this power semiconductor session 26.

The 57th annual IEDM took place at the newly renovated Hilton Washington Hotel from December 5-7, 2011. "IEDM 2011 featured state-of-the-art results from major semiconductor manufacturers and research institutions around the globe, continuing our tradition of being the premier venue for the presentation of the highest quality electronic device research," said Patrick Fay, IEDM 2011 Publicity Chair and Professor in the Department of Electrical Engineering at the University of Notre Dame. "Progress in devices continues at a rapid pace, and was reflected in this year's technical program. For example, there were reports of 20 nanometer devices made with conventional Silicon, record speeds from promising new materials like gallium nitride, and significant advancements in memories."

Focus on power (SiC) MOSFETs and (GaN) Diodes

Session 26 entitled Quantum, Power, and Compound Semiconductor Devices - Power Devices and Applications was focused on GaN and SiC devices with one exception.

The first paper **NexFET Generation 2, New Way to Power** has been presented by Texas Instruments and the University of Central Florida. An integrated NexFET power module that meets the requirements on high-current density DC/DC converters has been developed. It is composed of a stacked-die package, Silicon power MOSFETs, and monolithically integrated components to avoid shoot-through. In a synchronous buck application over 90 % efficiency and low switch node ringing at output current of 25 A under 12 V input and 1.3 V output conditions at 1 MHz switching frequency can be achieved. At 2 MHz 88 % and at 3 MHz 85 % efficiency have been measured.

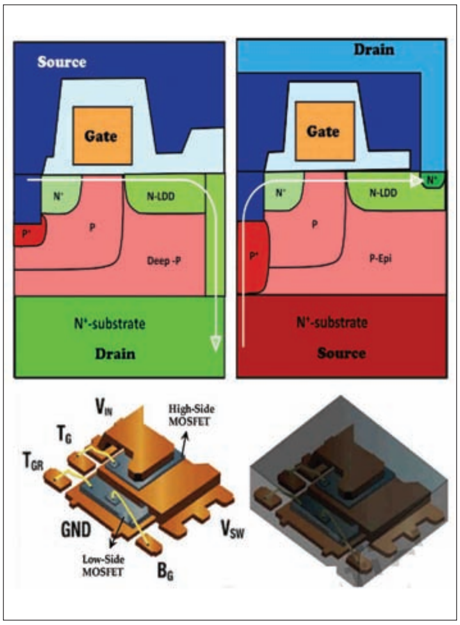
In order to maximize the performance of a typical synchronous Buck converter, the parasitic inductances and resistances in the power circuit formed by the two MOSFETs in the power stage need to be minimized. This is accomplished through an innovative packaging approach in the NexFET Power Block where the MOSFETs are actually stacked on a grounded lead frame with two copper clips.

The low-side die is attached to the main pad of the lead frame, providing the ground connection of the MOSFET pair. The low-side drain is connected to the outside through a thick copper clip that constitutes the device's switching node. On top of the thick copper clip the high-side MOSFET is soldered, which also uses a source down technology. Finally, another thick copper clip connects the high-side drain (input of the buck converter) to the device's external pins. The gate connections are made using Au wire bonds.

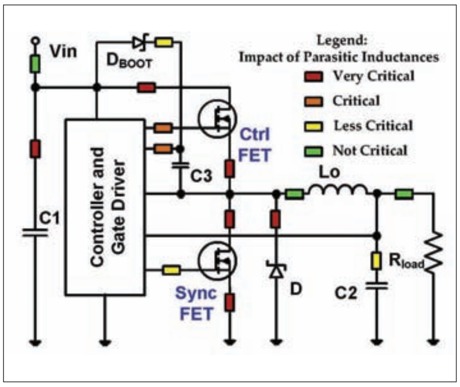
In the second paper Panasonic presented a **GaN-based Multi-Junction Diode with Reverse Leakage Current Using P-type Barrier Controlling Layer**. This GaN diode ensures high-voltage operation up to 600 V. The device consists of multi-junctions AlGaN/GaN with a p-GaN overlayer where the anode and cathode are formed on the sidewalls of the channels. The tunneling current which originates the leakage current can be reduced by controlling the the potential barrier at the anode sidewall by means of the depletion layer from the p-GaN. The fabricated diode exhibits forward current of 18 A at 1.5 V and small $R_{on}C$ of 70 pΩF which is according to the authors smaller than the 95 pΩF of commercially available SiC Schottky Barrier Diodes. The GaN diode shows high conversion efficiency of more than 98 % in a voltage boosting converter (400 V) in combination with a GaN Gate Injection Transistor (GIT).

The GaN diode is processed on a Silicon substrate with a total thickness of 5 μm ensuring 600 V breakdown voltage. The GIT has an on-resistance of 100 mΩ, this combination achieves an efficiency of 98 % in a boost converter switching at 100 kHz. This diode can be used also to replace Si FRD and SiC SBD in cost-effective Silicon structures.

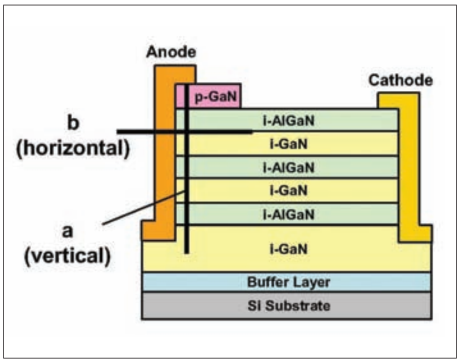
The third paper from Hitachi also covered diodes by introducing a **Photon-recycling GaN p-n Diodes Demonstrating Temperature-independent, Extremely Low**



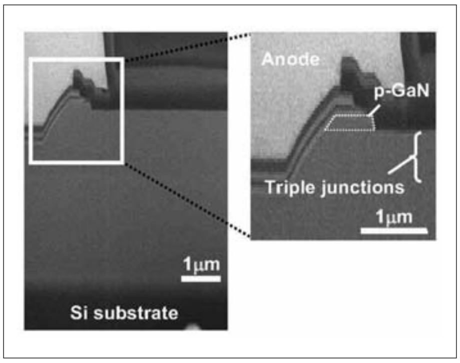
Cross section of Drain Down (left) and Source Down (right) NexFET Power MOSFETs and Power Block structure (bottom) Source: TI



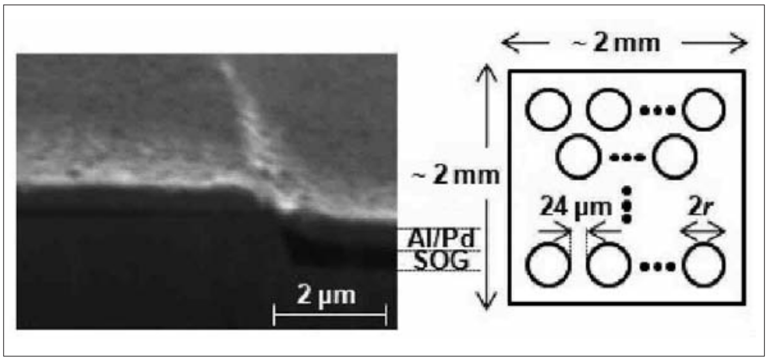
Schematic of synchronous buck converter with parasitic components Source: TI



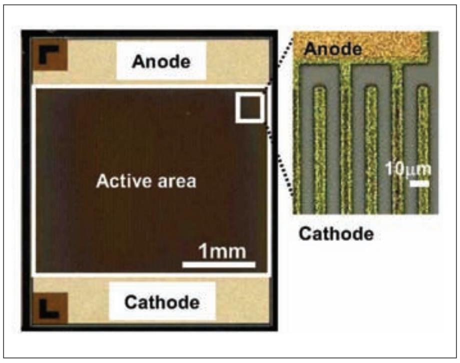
Cross section of GaN-based Multi-Junction Diode with reverse leakage current using p-type barrier controlling layer Source: Panasonic



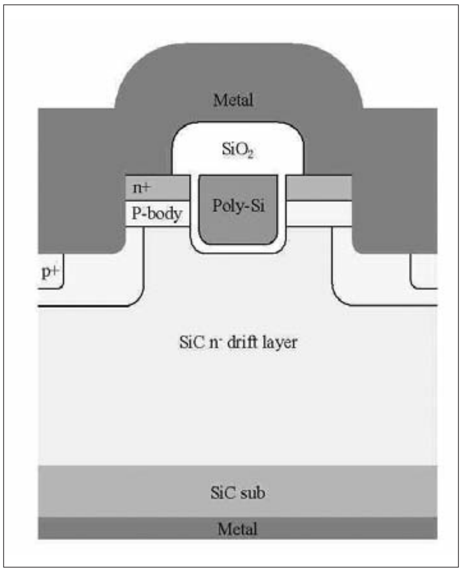
Cross sectional Scanning Electron Micrograph image of the Multi-Junction Diode Source: Panasonic



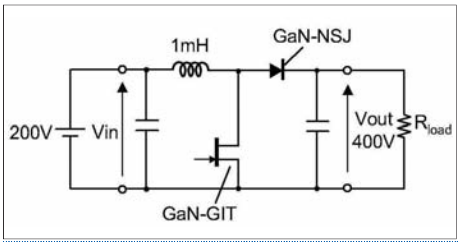
Scanning Electron Micrograph image of mesa structure in Hitachi's GaN p-n diode and schematic of proposed 100A chip (right) Source: Hitachi



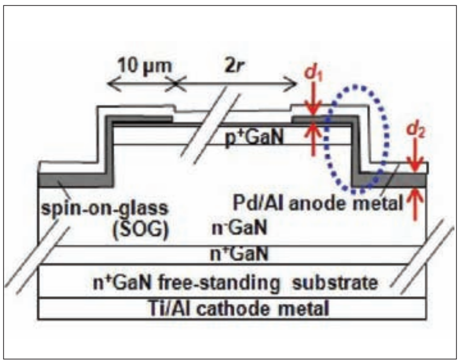
Chip photograph of the Multi-Junction Diode Source: Panasonic



Cross section of Rohm's SiC trench MOSFET with Source and Gate trench Source: Rohm



Boost converter using GaN Multi-Junction Diode and GIT Source: Panasonic



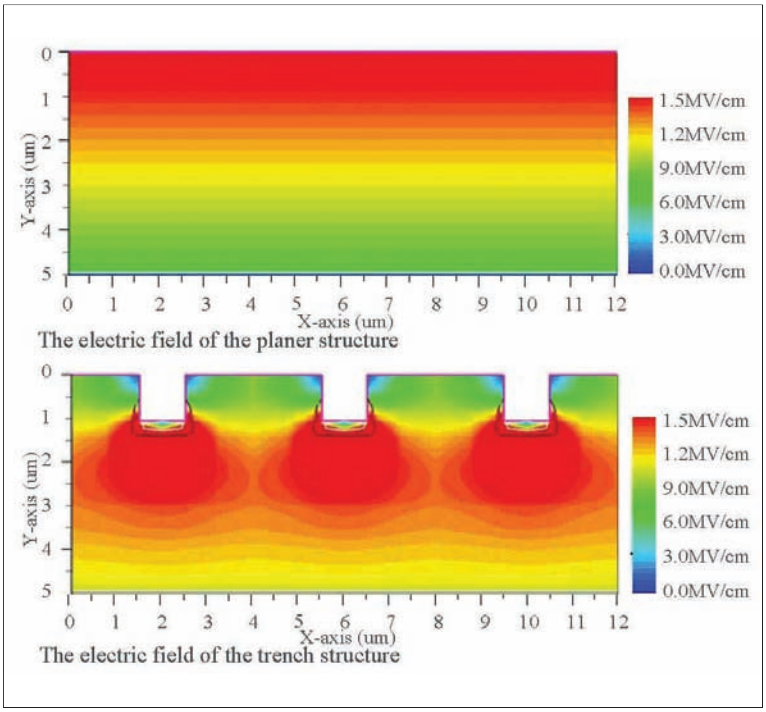
Cross section of Hitachi's GaN p-n diode with mesa-field-plate edge termination. The domain of the dotted ellipse is shown in the next image on the left Source: Hitachi

On-resistance. Gallium-nitride p-n diodes with 20-micron-radius anodes and breakdown voltages of 0.7-0.8 kV fabricated by utilizing self-absorption of recombination radiation demonstrated temperature-independent, extremely low on-resistance [i.e., 0.5 mΩcm^2 (273-373 K) at 5 V], which is a promising characteristic for power electronics applications such as fast, high-voltage freewheeling diodes.

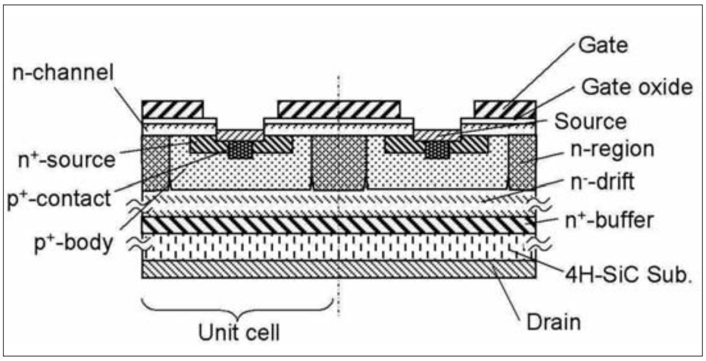
The photon-recycling effect has been used in GaAs lasers to increase intrinsic photoconduction through self-absorption of recombination radiation. The effect is applied to increase extrinsic photoconduction in magnesium-doped GaN. Current density is known to peak around the edge of an anode electrode in GaN p-n diodes, indicating that radiative recombination reaches maximum there.

GaN p-n diodes with a radius of 20-190 μm have been fabricated on epitaxial GaN substrates by inductively-coupled plasma dry etching. Titanium/aluminium and palladium/aluminium ohmic electrodes were formed by electron-beam depostion. The on-resistance of a 100A chip is around 0.7 mΩcm^2, which is approaching according to the authors the unipolar limit of 4H-SiC. Further reduction in on-resistance is expected by extending the use of photon recycling.

The fourth paper **Integrated Power Design Platform Based on Modeling Dynamic Behavior of GaN Devices** given by Panasonic presented an integrated design platform for power electronics applications. The dynamic behavior of whole systems and circuits can be simulated. In the platform, GaN current collapse is precisely modeled by using an



Electric field distribution at 600 V on the epi layer of planar Schottky (upper) and p-type region of the trench structure Source: Rohm



Cross section of Panasonic's SiC DioMOS with the thin channel layer Source: Panasonic

equivalent circuit. Simulated results reproduce more accurate behavior which cannot be reproduced by conventional simulators.

Rohm introduced **High Performance SiC Trench Devices with Ultra-low R_{on}.** SiC Schottky diodes reduce switching losses in high-voltage applications, but exhibit high forward voltage comparing to Silicon diodes. The reason is that SiC Schottky diodes need high barrier height to block the leakage current. Rohm has fabricated SiC Trench Schottky diodes with low barrier height, which can reduce the leakage current by reduction of the electric field on the Schottky interface. Thus the device exhibits improved performance, the threshold voltage is 0.45 V lower than that of a planar SiC Schottky diode. Also double trenches 790 V MOSFETs have been fabricated leading to lowest on-resistance (1.0 to 2.99 $m\Omega cm^2$ at 790/1720 V blocking voltage respectively).

Finally Panasonic presented a **Novel SiC Power MOSFET with Integrated Unipolar Internal Inverse MOS-Channel Diode.** This SiC DioMOS has two specific features: The growth of the SiC crystal defects caused by the continuous bipolar forward current of the internal p-n diode is completely eliminated because the diode current passes through the MOS channel region with low forward-voltage drop. The other is that the very small-size power modules are successfully designed because the external inverse diode chips paired with the transistor chips are not necessary.

The MOS channel of the SiC DioMOS is designed by well-controlled epitaxial growth of the n-channel layer and high doping in the p^+-body region. This design and the delta-doped channel-epitaxy technique allow the on-state current of the FET and the forward current of the internal inverse diode to pass through the same MOS channel in the opposite direction by lowering the potential barrier at the MOS interface. The forward-voltage of the SiC DioMOS was confirmed to be 0.4 V, meaning that the diode current passes through the MOS channel without bipolar current though the internal p-n diode. The SiC DioMOS exhibits both characteristics of the normally-off FET and the low forward-voltage drop diode. The channel diode switches like the SiC Schottky Barrier Diode, therefore it can be practically used as the inverse diode.

AS

A 6in1 IGBT Module Performance Evaluation Platform

Achieving good loss performance by high switching speed at low gate resistance is trading-off with the system's EMI behaviour. An evaluation platform has been developed to characterize 6in1 IGBT modules and to determine their dv/dt versus turn-on loss as function of the gate resistance. A chart indicating the trade-off between turn-on switching loss versus dv/dt parameterized as a function of the sum of internal and external gate resistance of a 150A/1200V 6in1 IGBT module will be presented in this article. **Marco Honsberg, Thomas Radke / Kazufumi Ishii, Jokou Manotobu, Mitsubishi Electric Europe / Japan**

Adjusting the EMI performance of a system is a complex task, because the influencing parameters are numerous and require a detailed investigation. Thus, changing a drive's or a UPS' power stage e.g. by upgrading a power semiconductor module is a time consuming task. The investigation carried out is limited to the gate driving and its linked trade-off between dv/dt and specifically the turn-on switching loss. Analyzing the dependency of the switching behaviour, especially the dv/dt as a function of the Gate resistor on one hand and on the other the loss of the IGBT being greatly influenced by the choice of gate driving conditions, a link between IGBT loss and potential EMI behavior can be established.

In the first step switching tests utilizing multi pulse generators were carried out under presumed worst case conditions. While switching loss is usually worst at high DC-link voltage paired with high collector current and high junction temperature of the device under test, the dv/dt behaviour in contrast to this is most severe at room temperature level and low currents. Applications like motor drives and UPS undergo all these different conditions during operation, e.g. from cold start to operation at high loads and corresponding high junction temperatures.

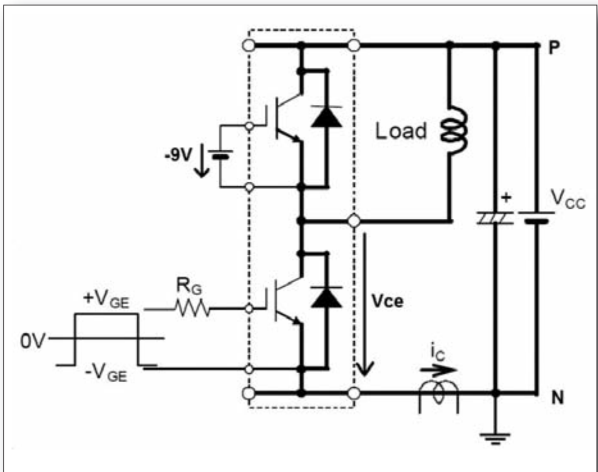


Figure 1: Test setup switching loss (E_{on})

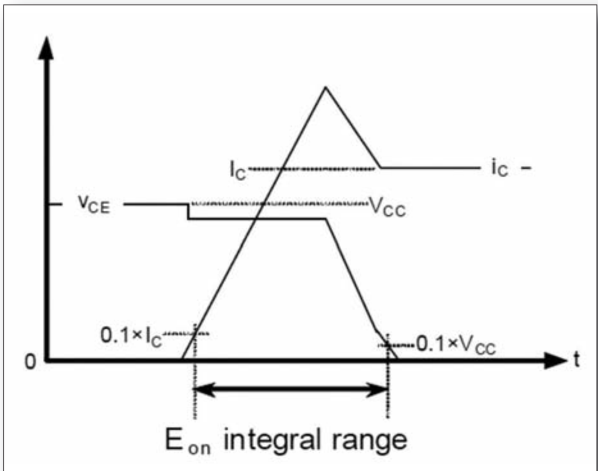


Figure 2: Integration range of switching loss

Test setup and parameter

All measurements to characterize the turn-on loss were carried out on a 150A/1200V 6in1 IGBT module. The measurement of the loss requires only one leg of the module. The test conditions were V_{CC}=600 V, I_C=150 A, V_{GE}=+15/-10 V, T_j=125°C. The test setup is shown in Figure 1

The measured switching energies are a result of the integrated instantaneous power loss within the time boundaries specified 10 % of the switched current and 10 % of the applied supply voltage V_{cc}. Figure 2 indicates these boundaries, whereas the equation below expresses the associated calculation.

$$E_{on} = \int_{t@Ic(t)=10\%Ic}^{t@Vce(t)=10\%Vcc} i_C(t)\cdot v_{CE}(t)\cdot dt$$

Dv/dt measurement

The acquisition of the dv/dt information is performed at a specification point where highest dv/dt values are expected, e.g. at low currents and comparatively cold temperatures. This worst case evaluation has been determined to be at 10 % of the rated IGBT current and a DC-link supply voltage of 600 VDC. In fact the RBSOA of the 6th generation CSTBT™ chipset would cover up to 850 V, but for the sake of many motor control applications being supplied without active front end the value of 600 VDC has been chosen. The entire driving conditions are I_C=15 A, V_{CC}=600 V, V_{GE}=15/-10 V, T_j=25°C.

The test circuit proposed in Figure 1 for

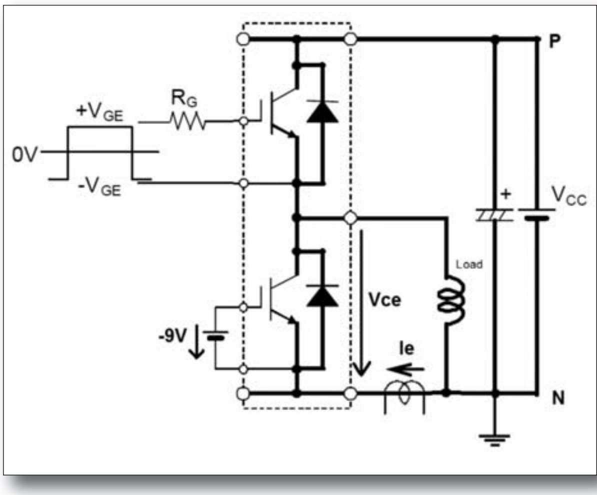


Figure 3: dv/dt test setup

the turn-on energy has been modified to keep the device under test "non floating". This modification of the test setup (Figure 3) allows keeping the oscilloscope on a stable and non floating potential.

Evaluation board design

These tests can be performed utilizing a dedicated evaluation board (EVB) as shown in Figure 4.

The 2-PCB solution reveals the construction of this evaluation board: An IGBT driver circuitry with integrated desaturation detection located on top of the IGBT module and the insulated DC/DC converter for each IGBT is employed on the second board on top of the gate driver board. Gate resistances can be selected over the entire recommended range of available IGBTs and the DC/DC converter covers the complete range of 6in1 IGBT modules utilizing 6th generation CSTBT considering switching frequencies of up to 20kHz. Safety insulation between control inputs and the IGBT output has been realized by optocoupler and a reinforced insulation of the DC/DC converter.

Design of the PCB

Furthermore the layout of this evaluation platform becomes rather critical because of space constraints affecting the achievable clearance and creepage distances. As shown in Figure 4 the evaluation board consists of two PCBs that are mounted on top of each other and that are interconnected by pinheaders. The PCB close to the IGBT module contains the electrical insulation of the input stage and gate drive circuit itself while the PCB on top of the gate drive circuitry contains the DC/DC converter supplying the gate drive circuits individually for each channel.

The estimated power consumption per channel is derived from the (comparatively small) amount of gate charge of the CSTBT at the specified gate voltage levels for turn-on and turn-off respectively and a presumed switching frequency range.

Computing the required gate drive stage power for the largest available module in a 6in1 configuration, e.g. a 150 A/1200 V device, at a maximum switching frequency of 15 kHz and considering a positive bias of 15 V and -8 V as negative bias, a power requirement of approximately 1 W per driver channel will be needed. In a conservative approach the DC/DC converter, realized in a push - pull topology, has been designed to deliver 1.5 W per IGBT driver channel.

Having mentioned before the difficulty to provide sufficient clearance and creepage distances it turns out that despite the limited surface area of the IGBT case structure and the complexity of the pin layout it is possible to reach approximately 5.5 mm of clearance and creepage on the IGBT driver board. The design of the DC/DC converter reveals more difficulties.

Having chosen considerably big EE-13.5 cores and mainly wired (THT) mounted components for the DC/DC converter's

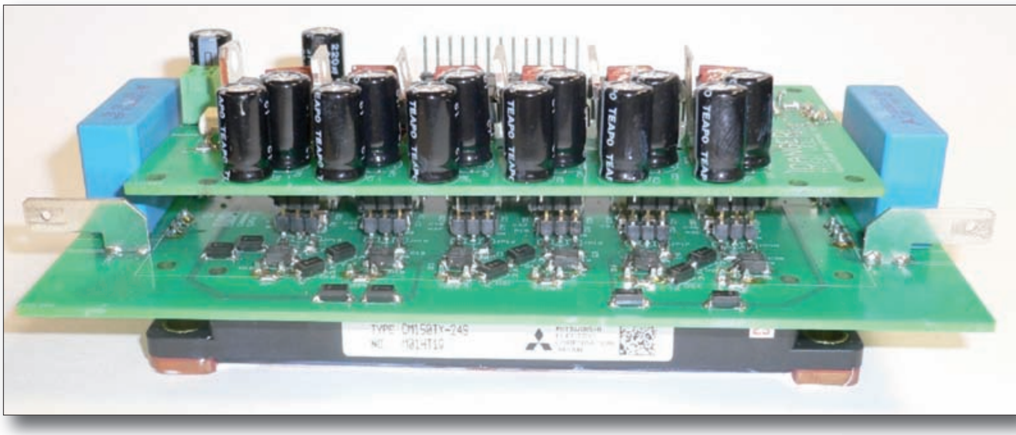


Figure 4: EVBNX6in1 and its two PCB solution (bottom: IGBT driver, top: DC/DC converter)

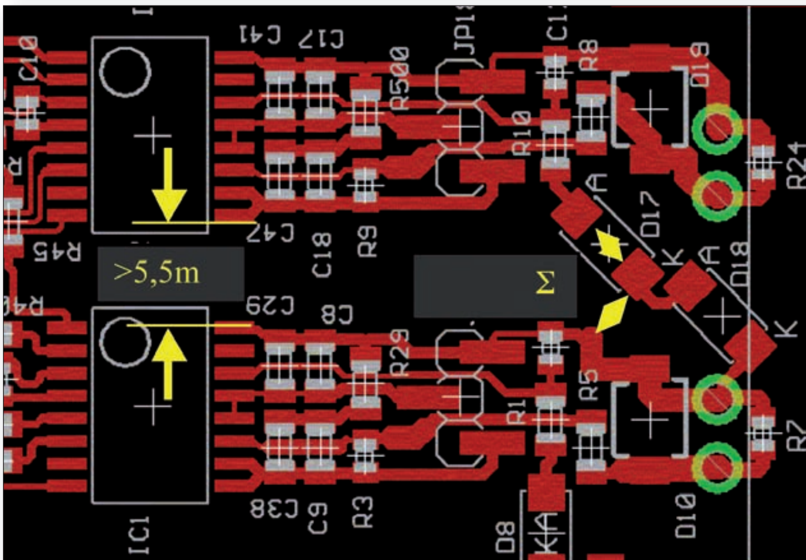


Figure 5: Two adjacent IGBT drivers on the driver board and the creepage distance

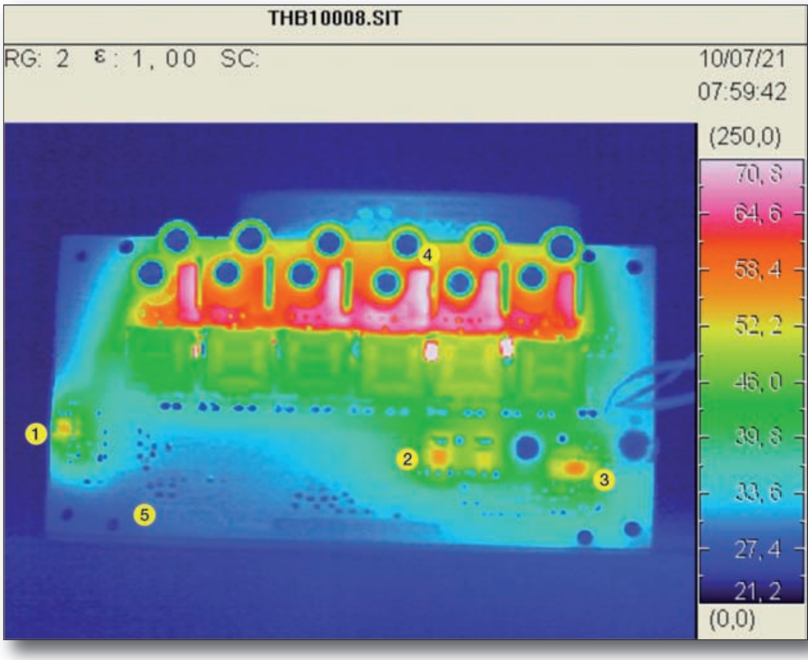


Figure 6: Thermal image of the DC-DC converter

first prototype the achievable clearance was limited to about 3.5 mm only. A next revision of this board is targeting to reach 5.5 mm or more clearance and creepage distance permitting the utilization of this platform at higher pollution degrees. Referring to the mentioned abundance of power of this SMPS design the clearance and creepage targets can be reached by adjusting the power of the SMPS and the selection of smaller ferrite core sizes as well as the utilization of surface mounted components for the stabilization of the positive and negative bias of the gate driver supply voltages.

The DC/DC converter's PCB contains additionally a circuitry to transfer the temperature information provided by the NTC incorporated in the IGBT module housing through a safety insulation barrier to the control pinheader on top of the PCB. Besides the evaluation of electrical performance the thermal performance of the DC/DC converter was analyzed.

Electrical and thermal evaluation

The DC/DC converter's and the driver stage's loss performance have been evaluated during the design stage by simulation. On the first prototype a thermal evaluation and verification has been carried out to prove previous theoretical results. The image of an IR camera observing the DC/DC converter under-(over-) load, e.g. 1.5 W per IGBT channel and all 6 channels operating is shown in Figure 6. The photo was taken after the thermal equilibrium was reached at an ambient temperature of 21°C. The entire surface has been painted black providing a uniform emission coefficient of 0.99 for the entire PCB and its mounted components.

Five reference points have been chosen for this analysis as shown in figure 5. While at thermal evaluation results of operation conditions at maximum load are most relevant, an electrical evaluation of a SMPS must also consider the complete load range, e.g. from 0 to 100 % (150 %) of load to prove sufficient stability of the supplied voltages. The thermal image discloses that multiple small transformers are used in parallel in this test design and, hence, also the balancing of the secondary voltages must be considered. The closed loop control of the SMPS delivered satisfying results with small and acceptable voltage variations over the entire load range. The quite inhomogeneous temperature of the PCB in Figure 6 however needs a deeper analysis.

In this thermal image reference point no. 5 is the point being far away from the heat sources and contains the information of the PCB's base temperature. The indicated hot spots are assigned to numbers from 1 to 5 and they correspond to the following stages of the DC/DC converter indicated in Table 1. The reference point with the highest temperature of 70.8°C is 49.8 K above the ambient temperature.

A further deeper analysis of the components having the highest case temperatures according to Figure 6 should be carried out. Considering the individual loss of those spotted components and calculating the internal temperature rise by utilizing the individual thermal resistance $R_{th(j-c)}$ of each component allows judging the safety of this design and its reliability. The highest junction temperature was found at reference point number 4, e.g. at the stabilization circuitry of the positive gate supply voltage. In this case the highest measured surface temperature matched indeed with the highest calculated junction temperature. The DC/DC converter solution provides even under approximately 1.5 times overload a thermally stable design and reveals margin that could be used to either make the design more compact or to increase the maximum permitted ambient temperature of the evaluation platform.

Test results

The compiled results of the turn-on loss (E_{on}) and the dv/dt tests are indicated in Figure 7. Dv/dt and E_{on} results are jointly shown in this figure having the gate resistor value as parameter.

Besides EMI the dv/dt is considered to have an impact on the ageing of windings, too. EMI besides the IGBT/FwDi and their switching speed as source is also influenced by propagation mechanisms such as capacitive coupling. An IGBT module upgrade implies that the EMI/EMC propagation is basically unchanged except the internal construction of the module.

Table 1: Test conditions of the dv/dt test

Ref.	Temperature	Component/stage
1	26.2°C	Linear regulator of the auxiliary supply to transfer the temperature information of the IGBT module's built-in NTC
2	59.1°C	MOSFET push pull power stage
3	61.3°C	Control IC of the SMPS
4	70.8°C	+15V linear regulator: positive bias to drive the IGBT
5	23.9°C	Coldest point on the PCB representing the PCB base temperature

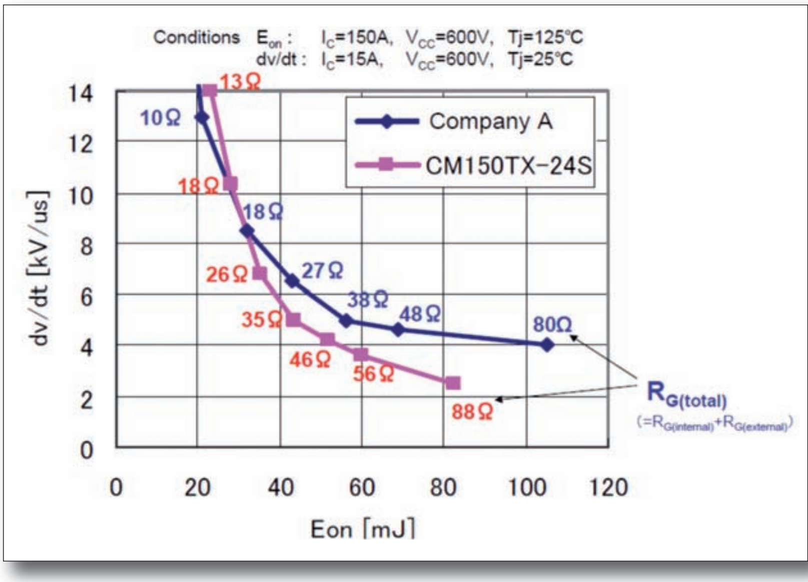


Figure 7: Trade-off between E_{on} and dv/dt as function of the turn-on Gate resistor (based on "ES" sample measurement)

The new suggested modules are all using Aluminium Nitride (AlN) as baseplate which allows reducing the coupling capacitance between traces and collector side of the chips to earth by increased thickness of the substrate compared with conventional Al_2O_3.

For reference the E_{on} vs. dv/dt results of an industrial standard module without this new 6th generation CSTBT and FwDi chipset has been depicted in Figure 7, too.

In comparison of these two different technologies the module with 6th generation chips offers a better trade-off between dv/dt and specific turn on loss. Hence, in turn a loss-wise better performing solution by a superior chipset maintains a certain dv/dt level of an industrial standard solution. The range of relevant dv/dt setups in inverters depend on the final application of the power stages. Applications with dedicated output filter operate at higher dv/dt levels compared with motor drive applications. Especially for motor drive applications typical dv/dt values can be observed at less than 8kV/µs and usually rather closer to 4kV/µs.

Conclusion

The investigation on a 6in1 IGBT module equipped with newly tested chipset and a new FwDi has shown a superior switching loss versus dv/dt performance than previous generations of IGBT modules. Improving this trade-off leads to better performing drives or in turn to a potential cost advantage due to a reduction of the EMI filter.

Literature

"A 6in1 IGBT module performance evaluation platform determining the trade-off between dv/dt and turn-on loss of different IGBT/Free-wheeling Diode chip setups", Mitsubishi Electric Europe B.V. and Mitsubishi Electric Corp. Japan, Proceedings EPE 2011 Birmingham/UK.

Simple and Highly Efficient Super Capacitor Charger

Super capacitors with high capacitive density are used in conjunction with batteries because super capacitors can charge and discharge continuously. Synchronous buck regulators can serve as a quick and simple charger to provide the adjustable fully charged voltage. **Marian Chang, Application Engineer, International Rectifier, El Segundo, USA**

Super capacitors are used as power failure backups without degrading like batteries [1]. As capacitor makers develop super capacitors with higher voltage capability, they need adjustable chargers that may not yet be readily available commercially. Synchronous buck regulators, in this case, can serve as a quick and simple charger to provide the adjustable fully charged voltage. However, general-purpose synchronous switch-mode converters are not suitable super capacitor chargers due to their high inrush current.

Typically, dedicated controller and discrete switches are combined to control the charging current and the final super capacitor voltage. These are excellent choices for charging a wide range of super capacitors with different charging current and fully charged voltage. These dedicated controllers usually have a wide input voltage range and adjustable output voltage and output current limit. However, the discrete solutions require many external components, including MOSFETs that are used as switches, and compensation components for conventional voltage mode regulation.

Integrated COT solution

In this paper, a simple integrated solution based on a constant-on-time (COT) SupIRBuck® is presented. The COT SupIRBuck is a family of general-purpose synchronous buck regulator that integrates constant on-time hysteretic controller and power MOSFETs to provide an easy-to-use and highly efficient DC/DC voltage regulation. The proposed application circuit senses the charging current and uses it to control the output voltage to prevent a high inrush current during the initial charging stage.

The advantages of using a COT SupIRBuck to charge super capacitors include: adjustable fully charged voltage, adjustable initial charging current, automatic power save mode when the super capacitor is fully charged, and minimal number of external components.

To address the high inrush current in a general-purpose synchronous buck converter, a resistor is placed in series with the super capacitor (C_{super}) to sense and feedback the charging current information to the converter. The proposed circuit is shown in Figure 1. IR3863 COT SupIRBuck® is used as an example here. This scheme can be applied to other synchronous buck converters.

Theory of operation

For applications where connecting the

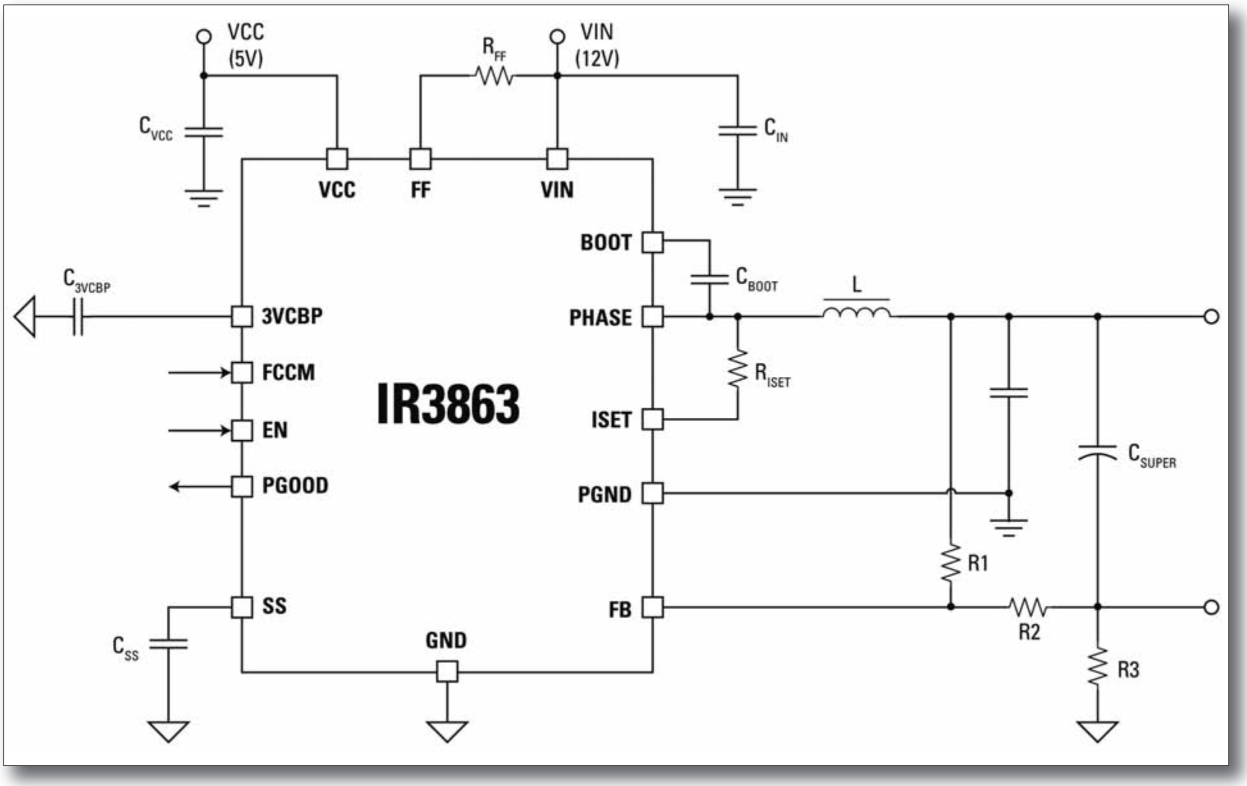


Figure 1: Proposed super capacitor charger circuit

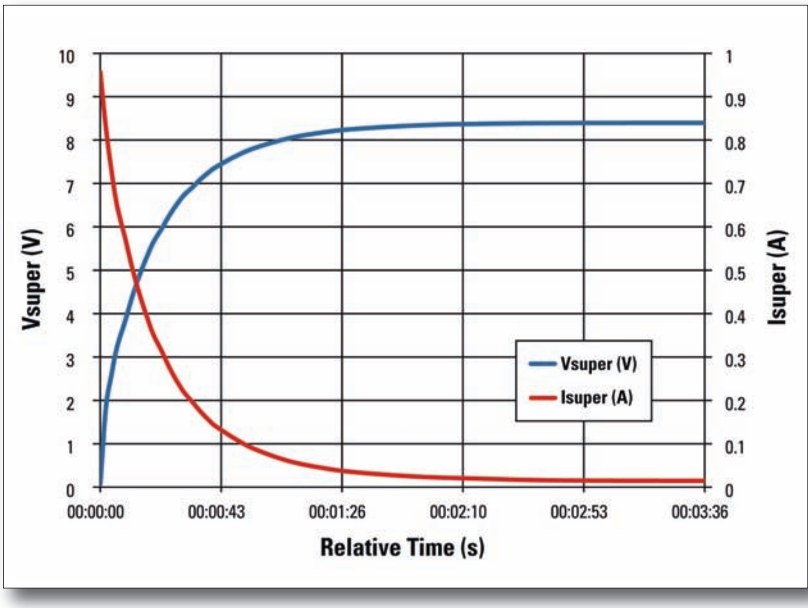


Figure 2: **Super capacitor I-V charging characteristic over time**

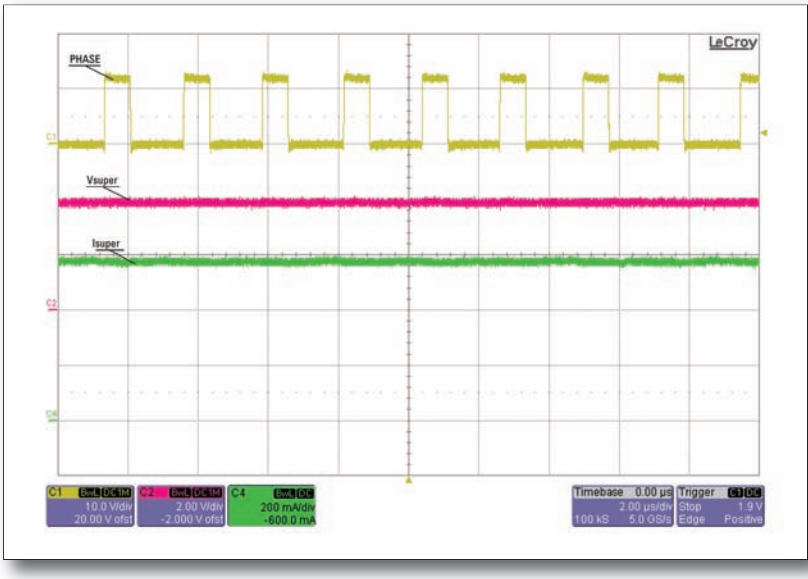


Figure 3: **Typical converter switch node waveform during the initial charging stage**

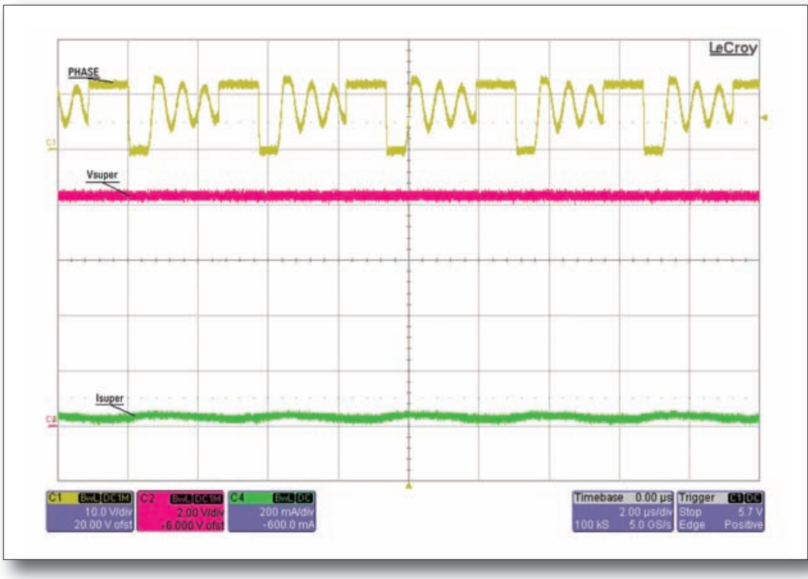


Figure 4: **Typical converter switch node waveform during the final charging stage**

negative terminal of C_{super} to the system ground is preferred, simply connect VIN and VCC ground to the negative terminal of C_{super}. In both cases, the sensing resistor, R3, in Figure 1 should be chosen to ensure that the inrush current stays below the maximum charging current specified for the super capacitor. For IR3863, the regulator reference voltage is 0.5 V; to limit the initial charging current to below 1 A, a 500 mΩ resistor is selected for R3. To set the fully charged voltage (V_{final}) of C_{super}, R1 and R2 are chosen according to the equation below:

R2 / (R1 + R2) x V_{final} = 0.5 V

During the initial charging stage, the voltage (V_{super}) across the super capacitor is zero, so the voltage across R2 is zero. The feedback node (FB) sees the voltage across R3. As current flows through C_{super} to charge it, this charging current information is sensed by R3 and fed back to the FB node to be regulated to the regulator reference voltage. The regulator reference voltage may also be programmed to ramp up from zero volts to the internally designed reference (which is 0.5V in this case for IR3863). The voltage ramp rate can be set through the choice of the soft-start capacitor (C_{ss}). During the initial charging stage, even though V_{super} is close to zero, IR3863 does not push out a high inrush current because the voltage across R3 satisfies the regulation condition.

As the controlled charging current flows to C_{super}, V_{super} increases such that the voltage fed back from the resistive divider composed of R1 and R2 increases. To regulate the FB voltage, the voltage across R3 needs to be reduced. IR3863 then reduces the charging current delivered to the super capacitor to accommodate the V_{super} increase. This process continues to reduce the charging current as V_{super} increases until the voltage across R3 becomes negligible, and the super capacitor is fully charged to the final super capacitor voltage defined by R1, R2, and the regulator reference voltage that FB is being compared to. The charging characteristic over time of this application circuit is shown in Figure 2.

Wide adjustable fully charged voltage range

Super capacitor chargers composed of synchronous buck converters have a wide adjustable fully charged voltage range and charging current limit. For example, with IR3863, the fully charged voltage can be programmed from 0.5 V to 12 V, and the charging current limit can be programmed up to 6 A. In this example design, the initial charging current is programmed to 1 A and the fully charged super capacitor voltage is programmed to 8.5 V.

In addition to having adjustable output voltage and charging current limit, the COT SupIRBuck family also features power save mode and fast transient response to V_{super} variations. By grounding the FCCM (forced continuous conduction mode) pin, IR3863 is allowed to operate in DCM (discontinuous conduction mode) when the charging current delivered to the super capacitor is below half of the inductor current ripple. This feature allows the converter to automatically enter a power saving mode when the super capacitor is fully charged. The switching frequency of IR3863 varies with load, so during the initial charging stage, converter operates in the CCM (continuous conduction mode) to quickly charge up V_{super} as shown in Figure 3. The converter also operates in the CCM when the super capacitor is discharged by its load to restore the super capacitor back to the specified fully charged voltage. Once V_{super} is in the proximity of the fully charged voltage, IR3863 operates in DCM to reduce the charging current and converter switching loss while maintaining the V_{super} voltage. A typical converter switch node waveform during this stage is shown in Figure 4.

Another advantage of using COT SupIRBuck converters as super capacitor charger is having minimal external components. The COT device family integrates the controller, driver and power MOSFETs in a low profile 4 mm x 5 mm or 5 mm x 6 mm QFN package. Unlike voltage-mode buck regulators, COT SupIRBuck converters do not require the usual PID compensation circuit thus further reduce the number of external components. In addition, COT SupIRBuck adjusts its on-time through feed-forward to compensate for input voltage changes, allowing stable operation over a wide input voltage range which typically impacts controller stability in conventional voltage-mode regulators.

Conclusion

With adjustable fully charged super capacitor voltage, adjustable initial charging current, automatic power save mode, and the ease to design with minimal number of external components, COT SupIRBuck can serve as a simple and highly efficient super capacitor charger with the current sensing circuitry presented.

Literature

[1] Supercapacitors, Illinois Capacitor Inc., www.illinoiscapacitor.com/pdf/Papers/supercapacitors.pdf

SupIRBuck Online Design Tool

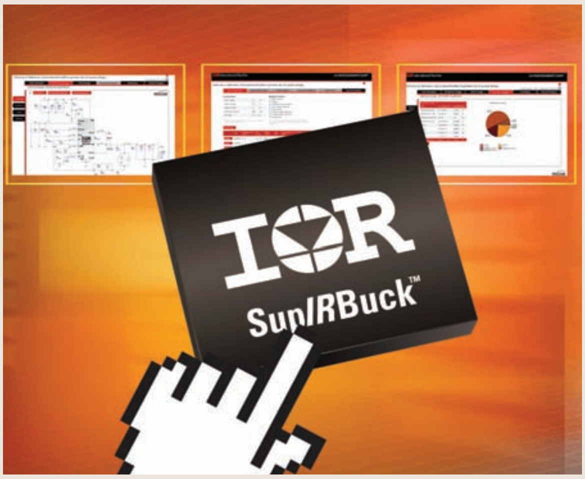
IR has expanded its online design tool for the SupIRBuck® family of integrated point-of-load voltage regulators to include new devices utilizing hysteretic constant on-time (COT) control designed to offer improved light load efficiency.

The web-based tool enables the rapid selection, electrical and thermal simulation and design optimization of over 15 SupIRBuck integrated voltage regulators. The expanded product line includes high-voltage (27 V) devices, current ratings up to 15 A and regulators in both 5 mm x 6 mm and 4 mm x 5 mm packages. Enhanced simulation capabilities now include the unique ability to compensate COT control devices using Aluminum Electrolytic capacitors for lower cost applications as well as all-ceramic capacitors for higher frequency applications.

Based on a designer's given input and output parameters, the SupIRBuck online tool selects suitable devices for a given application. Once basic requirements are entered, the tool allows the user to capture schematics, create a reference design along with associated bill of materials (BOM), view waveforms, and perform complex thermal and application analysis.

SupIRBuck voltage regulators integrate IR's snchronous buck control ICs and HEXFET trench MOSFETs in a compact Power QFN package, shrinking the silicon footprint compared to discrete solutions, and offering between 8 to 10 percent higher full-load efficiency than monolithic ICs.

http://mypower.irf.com/SupIRBuck



RIGHT: Online design tool for the SupIRBuck family of integrated POL voltage regulators

Bright LED Technology Thanks to Correct Resistors

LED technology is becoming an increasingly popular choice for lighting up the headlights of modern cars as well as their displays and cockpits. Special resistors are necessary to make the diodes work properly. LEDs challenge automotive suppliers: the rear part of the light unit leaves only little space for installation and the law requires a minimum brightness level. On top of that, LED chains must not emit different brightness levels and the technology has to withstand high temperatures up to 125°C. Consequently, resistors used in LED technology have to be very small, perform extremely well, be extraordinarily robust, highly stable and have a small tolerance. Isabellenhütte's VMK resistors have the required specifications: 1 W permanent power up to 110°C terminal temperature; constant current up to 10 A (10 mΩ); small size (1206; 3.2 mm x 1.6 mm); high pulse loadability (1 W); long-term stability (0.1 % drift in 2,000 h); reflow and IR soldering; TC < 20 ppm/K; AEC-Q200 certified.

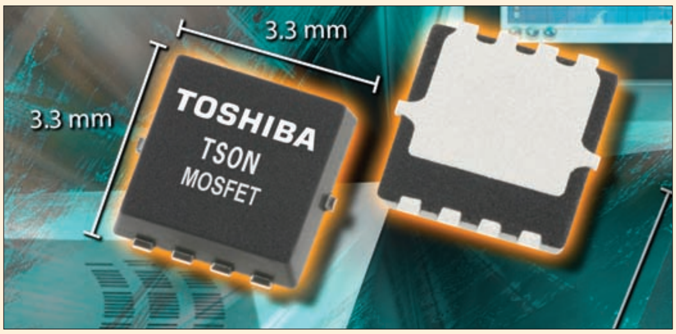
VLK resistors with long side termination are also used in LED technology. At a size of 0612 (3.25 mm length, 1.52 mm width), they also provide particularly high performance and use little space. The contacts on the long side make the component less susceptible to temperature and load cycles.

www.isabellenhuette.de

High-Current MOSFETs

Toshiba Electronics Europe (TEE) has extended its family of 30 V power MOSFETs with new devices that combine high-speed switching, high current ratings and compact package size. The latest devices in the TPCx family are suited for products that require synchronous rectification DC/DC conversion. Based on 7th generation UMOS VII-H semiconductor process, the power MOSFETs comprises nine devices in SOP-8 and the new TSON Advance package formats. The latter bridges the gap between industrial standard SOT23 and SOP8 package formats - at just 3.3 mm x 3.3 mm this package format delivers a 64 % smaller footprint than a SOP-8 device with an equivalent power rating. All of the new MOSFETs have a maximum V_{DSS} rating of 30 V and a maximum V_{GSS} rating of ±20V. Typical $R_{DS(ON)}$ values (V_{GS} = 10 V) range from 20 mΩ down to 6.0 mΩ. TPC806x-H and TPC822x-H devices are supplied in SOP-8 and dual Chip SOP-8 packages respectively. TPCC806x-H parts in the TSON advanced package achieve a power dissipation of 1.9 W, due to a metal base plate.

www.toshiba-components.com



1200V XPT IGBTs

IXYS expanded its XPT IGBT product line with the release of new discrete high-speed, high-gain 1200V products. The new devices feature high current ratings (105A - 160A, T_C=25°C) and are specifically optimized for applications that require hard-switching frequencies of up to 50 kHz. Developed using IXYS XPT design platform, these new devices feature excellent electrical characteristics which include low collector to emitter saturation voltages (3.0V), low typical current fall times (57ns), and low turn-off energy per pulse values (1.2mJ, T_J=25°C). In addition, these new IGBTs retain a positive temperature coefficient of its collector to emitter saturation voltage for ease of parallel configuration. The low gate charge characteristics of these new devices also aid in the reduction in gate drive power requirements of the device, thus allowing the implementation of simple and more economical gate drive solutions. Additional features include dynamic avalanche ratings and a square reverse bias safe operating area (RBSOA) rated up to the device's blocking voltage for enhanced system ruggedness. The new 1200V XPT devices are available with IXYS' Sonic-FRD anti-parallel ultra-fast diodes (i. e. IXYN82N120C3H1). The combination of XPT IGBT and Sonic-FRD result in an optimal match for reduced turn-off losses. Furthermore, the soft recovery characteristics of the Sonic-FRD co-packed diode allows the XPT IGBT to be switched on at very high di/dt's regardless of low current and temperature conditions.

www.ixys.com

Ultra-fast 1200 V IGBTs

International Rectifier offers a family of thin wafer Field-Stop Trench 1200 V IGBTs. These devices are further optimized for applications that do not require short-circuit capability such as UPS, solar inverters, and welding, and complement IR's products with 10 µs short circuit capability for motor drive applications. Covering a broad current range from 20 - 50 A as packaged devices and up to 150 A for die products, key performance benefits include wide square reverse bias safe operating area (RBSOA), positive $V_{CE(on)}$ temperature coefficient, and low $V_{CE(on)}$ to reduce power dissipation and achieve higher power density. In addition, devices are available with or without an internal ultra-fast soft recovery diode. Die products are also available with solderable front metal (SFM) for improved thermal performance, reliability and efficiency.

http://mypower.irf.com/IGBT

Current Transducer for Traction

LEM has announced the ITC series of transducers for galvanically-isolated, high-precision current measurements in rail-traction applications. The new transducer series (closed-loop fluxgate) comprises three models, ITC 1000-S, 2000-S and 4000-S, with corresponding nominal current measurement ratings of 1000, 2000 and 4000 A_{RMS}. LEM designed the ITC series for the rail-traction industry sector, reaching the Class 0.5R measurement accuracy when Class 1R is required by the prEN 50463 standard for on-board energy monitoring. The ITC series features linearity error of under 0.05% with offset currents of less than +/- 20µA. The rail-traction industry requires unprecedented accuracy necessary of course to maintain optimum control of traction motors, but mainly in energy metering to log energy usage for fiscal purposes, for example in billing power costs for trains that cross regional borders. The industry is working to a provisional ("pr") standard designated prEN 50463. Precise energy metering depends on accurate current and voltage measurements, and LEM has a complete offering for prEN 50463. Used together with highly-accurate voltage transducers such as the LEM DV series (available in Class 1R or Class 0.75R certified accuracy), and an energy meter such as LEM's EM4T, ITC-series current transducers bring the necessary class accuracy.

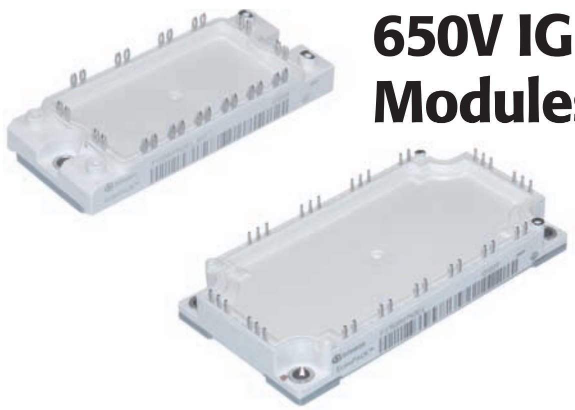
LEM offers the ITC series in either a one-piece housing (ITC 4000-S model), or a split construction (ITC 1000 and 2000-S models) with the measurement head in a case, and the measurement circuitry mounted remotely in a metal enclosure, to facilitate locating the measurement head in confined spaces such as the train roof space.

www.lem.com

Standby Power Regulations With One Chip

Fairchild's new FSB series of AC regulators help designers to meet the challenge of achieving less than 0.5 W power consumption in standby mode. The FSB series dramatically reduce standby and no-load power consumption, enabling conformance to all worldwide standby mode guidelines. The FSB series integrates advanced current-mode pulse width modulator (PWM) and an avalanche-rugged 700 V SenseFET in a single package allowing auxiliary power designs with higher standby energy efficiency, reduced size, improved reliability and a lower system cost than previous solutions. Integrated protection features include programmable cycle-by-cycle current limiting, internal open-loop protection, built-in brown-in and brown-out protection, high and low line compensation for constant power limit, over-temperature protection with hysteresis, under-voltage lockout and over-voltage protection. The FSB-series offers integrated MOSFETs with different current ratings to cover up to 35 W designs. The first product released in the lineup is the FSB127H with 2A internal MOSFET. It is available in an 8-pin dual-inline package.

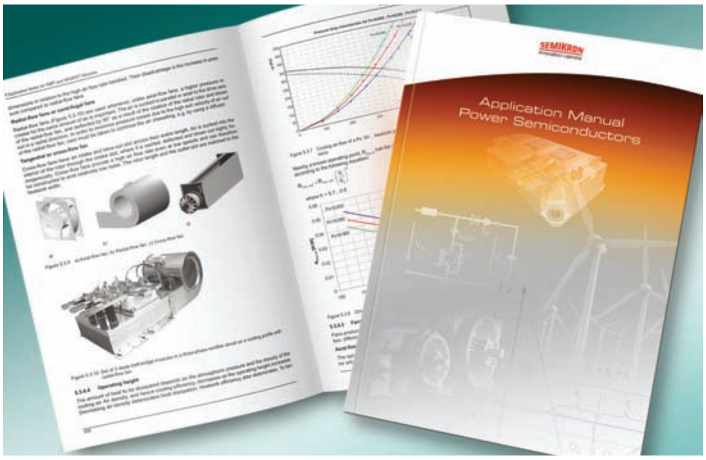
www.fairchildsemi.com



650V IGBT4 Modules

Infineon Technologies introduces a new series of PIM and six-pack modules featuring 650 V IGBT4 ranging from 50 A up to 200 A. The modules are available in EconoPIM and EconoPACK 2 and 3 housings. Relying on PressFIT technology, fast and solder-less assembly combined with highest reliability levels can be achieved. Solder pin versions are equally available. Performance and ease of design are the main benefit of these new products: 650 V blocking voltage allows for more safety margin during operation, and 10 µs short circuit robustness allows using a standard driver design at optimized cost. EconoPIM™ and EconoPACK™ 650 V IGBT4 modules complement existing 1200 V and 1700 V IGBT4 Econo solutions for drives inverters up to 690 V.

www.infineon.com



Power Semiconductor Application Manual

Semikron presents the English version of its Application Manual. The 464-page-long manual provides electronics experts with detailed information on the selection and use of IGBT, MOSFET, diode and thyristor components. The German version is already available.

The Application Manual contains detailed application-related information such as electrical configuration for key operating conditions, driver and protection elements for semiconductors, thermal dimensioning and cooling, tips on parallel and series connection, assembly tips for optimised power layouts with regard to parasitic elements, as well as notes to help users better understand datasheets and the requirements that arise from specific ambient conditions. Assembly and connection technologies which have a major impact on the properties of semiconductor modules and the limits in field applications are also described, as are reliability data, life cycle analyses and key test processes.

The German and English Application Manual is available for €9.90 under the ISBN No. 978-3-938843-56-7 (German) and under ISBN-Nr. 978-3-938843-66-6 (English) and via the Sindopower power electronics eCommerce portal.

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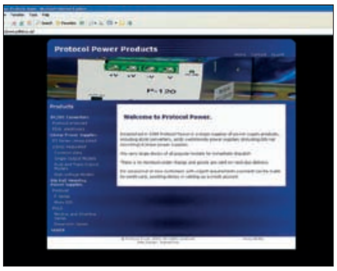

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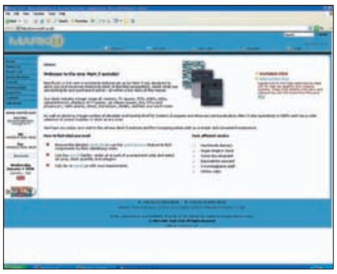

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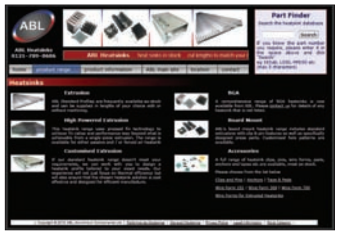

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Voltage References

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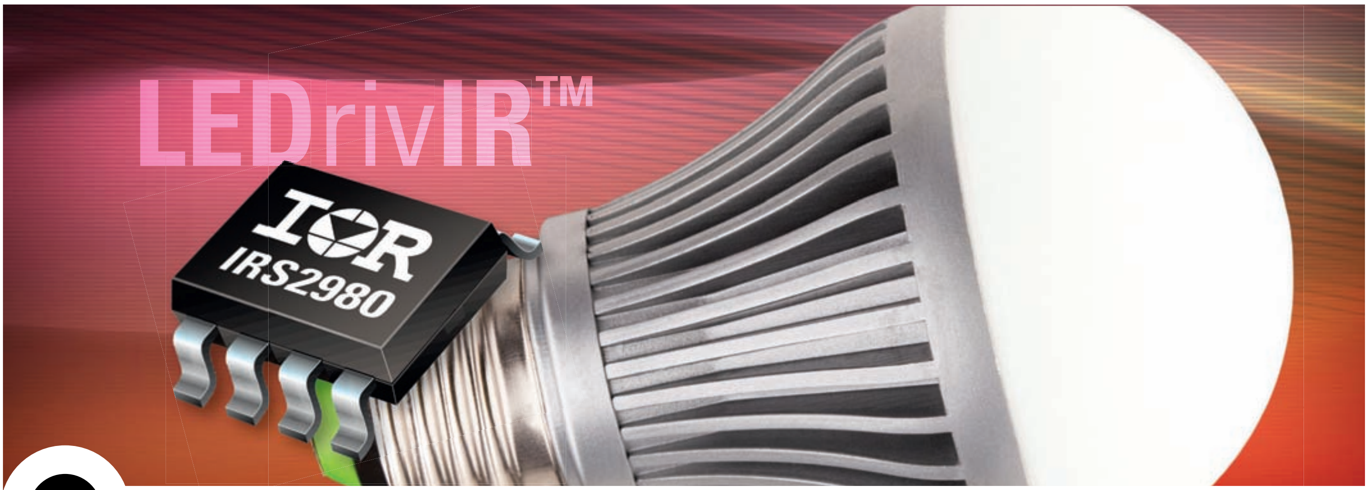
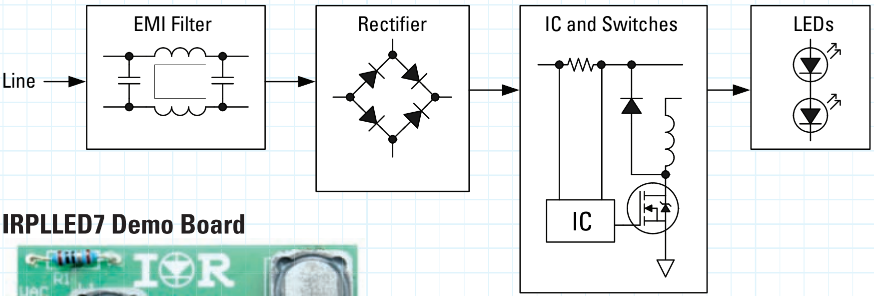


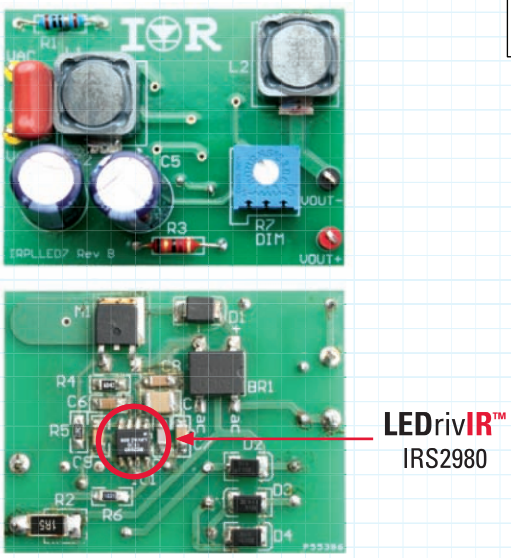
High-Voltage Buck Control ICs for Constant LED Current Regulation



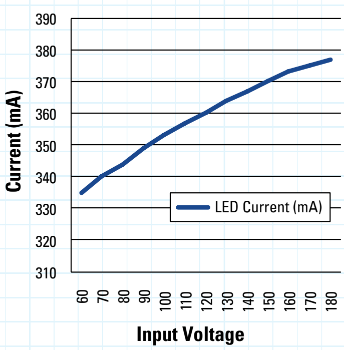
Features

- Internal high voltage regulator
- Hysteretic current control
- High side current sensing
- PWM dimming with analog or PWM control input
- Free running frequency with maximum limiting (150kHz)

IRPLLED7 Demo Board



LED Current vs Input Voltage



Benefits

- Low component count
- Off-line operation
- Very simple design
- Inherent stability
- Inherent short circuit protection

Specifications

- Input Voltage 70V to 250V (AC)
- Output Voltage 0V to 50V (DC)
- Regulated Output Current: 350mA
- Power Factor > 0.9
- Low component count
- Dimmable 0 to 100%
- Non-isolated Buck regulator

Part Number	Package	Voltage	Load Current Regulation	Startup Current	Frequency
IRS2980S	SO-8	600V	+/-5%	<250 µA	<150 kHz
IRS25401S	SO-8	200V	+/-5%	<500 µA	<500 kHz
IRS25411S	SO-8	600V	+/-5%	<500 µA	<500 kHz

For more information call +49 (0) 6102 884 311
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