



2019 PSMA POWER TECHNOLOGY ROADMAP

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University Research 2019

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PSMA Power Technology Roadmap

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Roadmap Chair 1994

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Horizon Consultants Ltd.
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Purpose of the PSMA

The Power Sources Manufacturers Association (PSMA) is a not-for-profit organization incorporated in the state of California. As stated in the papers of incorporation, the purpose of the Association shall be to enhance the stature and reputation of its members and their products; improve their knowledge of technological and other developments related to power sources; and educate the electronics industry, academia, and government and industry agencies as to the importance of, and relevant applications for, all types of power sources and conversion devices.

PSMA Mission

The PSMA mission is to integrate the resources of the power sources industry to more effectively and profitably serve the needs of the power sources users, providers, and PSMA members.

The PSMA Power Technology Roadmap Report is devised and intended for technology assessment only and is without regard to any commercial considerations pertaining to individual products or equipment.

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its members, its committees, recent activities, other publications,
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Foreword

The 2019 Power Technology Roadmap reiterates the theme of Empowering the Electronics Industry. The power supply industry continues to emerge from the shadows to play a leading role in the next phase of electronics industry evolution. We hope that you will find plenty of evidence and indicators that underline this transition as you are perusing this edition of the PSMA PTR report. Like the previous PSMA PTR reports, this report is a result of the collaborative work by all-volunteer participants, who happen to be leading experts in their respective fields. As a result, this spectrum of valuable information brings different perspectives, but is tied together by common formats and templates that have been crystallized over time. This report is unlike any other in the power technology industry and we hope the readers benefit from its many insights.

This is the eleventh Power Technology Roadmap. The first report was in 1994. The next report came out in 1997 and the cycle has been repeated every three years up to the 2009 report. As the report's influence has grown, the frequency of the report also increased to provide our members, and the industry as a whole, more timely updates. As a result, this roadmap report is now a bi-annual effort, with editions published in 2009, 2011, 2013, 2015, 2017, and now 2019.

The Power Technology Roadmap is one of the primary benefits of your company's membership in PSMA. Please share this copy with others in your organization. Additional copies of this report, or any other PSMA publications, can be purchased at psma.com or by calling the PSMA office.

Non-members may also purchase copies of the report at psma.com or by calling the PSMA office.

Philosophy

Since its inception, the goal of the report is to review, comment, and capture power conversion technology and trends for the next two to five years. As the industry evolves, the emphasis of the report changes, while many of the tracked quantitative metrics are retained for the sake of consistency.

Traditional applications in computing, consumer, and telecommunications segments remain technology responsive; however, many emerging applications have power technologies at their core and are technology-driven. These include solar inverters, variable frequency drives, electric vehicles, and LED lighting systems, to name a few.

In technology-responsive applications, the end user is indifferent to the inherent features or other details of the power conversion technology embedded within the product or equipment. In technology-driven applications, the power conversion systems can be immediately differentiated through their technology advances. In all types of applications, the technology and differentiation is subject to cost constraints and regulatory environments. All face the continuing industry competitiveness that drives smaller size, higher efficiency, and better electrical performance; while continuing to drive technology down the cost curve.

These requirements result in severe technical challenges in the design, manufacture, and even in the selling, processes. These challenges push all of us to strive for new levels of excellence in our respective businesses. We need better materials, better components, better solutions, better aligned innovations from the academic research communities, and more effective ways to manufacture and deliver them. Our

interests are best served by taking a proactive stance – by anticipating these challenges and developing the technology required to meet them on or ahead of time.

It is in this spirit that the Power Sources Manufacturers Association (PSMA) has been conducting these Power Technology Roadmap activities since 1994. Leaders from the key groups – supply manufacturers, component suppliers, end users, academic institutions, and power industry experts contribute their views through a series of public webinar presentations. These are conducted throughout the year prior to publication, encouraging high levels of industry participation while gathering these important perspectives. The webinars cover a wide range of power conversion topics loosely grouped into Application Trends, Component Technologies, University Research in Power Electronics, and Power Supply and Converter Trends. This is combined with the work of volunteer working groups that analyze industry trends and ultimately produces the output that is this report.

What's New This Year

The PTR report always strives to provide multi-dimensional perspectives to the growth and evolution of power conversion technology. After starting out with predictions for four major product segments, Application Trends and Emerging Technologies commentaries were added in 2011 and 2013, respectively. In the 2017 edition, a new section on Component Technologies was added.

Beginning with this 2019 edition, a new section on University Research in Power Electronics is included. Major university research programs in power electronics were asked to provide a snapshot of their research priorities in the coming years and these inputs are presented and analyzed. It is hoped that by providing a window into the research priorities of major power electronics programs, we are able to provide an additional dimension.

One additional change has been made for the 2019 edition; the Emerging Technologies section was merged into the Application Trends and Component Technologies Sections.

Other than the above-mentioned changes, this year's roadmap follows the format of previous years' roadmaps and maintains the consistency of format and sections.

During this roadmap cycle, an effort was made to start the webinar presentations even earlier (from November 2017, instead of January start during the previous cycle) to accommodate a more diverse set of presentations. As a result, the number of webinars presented rose to a record level of 17 during this cycle. We continue to include the recorded webinars on the USB drives. The webinars add much to the presentation materials because the listener can hear and understand the context and the subtext of the original presentation in the speaker's voice. Including the recordings also allows us to capture the interesting and informative question and answer periods. We appreciate these interactive discussions and their contributions to how we understand our industry and the underlying power technologies. Sharing information and improving knowledge is, after all, the goal of PSMA.

We continue to use an online survey to gather trends data for four Power Supply & Converter architecture segments. This year, the survey tool was updated to be more professional, portable, and consistent across the segments. The effort resulted in fewer, more streamlined, more focused, questions for each segment.

PSMA Power Technology Roadmap

We also expanded the reach of the survey by developing a Chinese language version and leveraging the co-operation from China Power Supply Society (CPSS) to get broader feedback. The increased participation has helped provide a more accurate picture of where we are today and forecast changes to expect for the next five years. The editors of each segment continue to exercise their judgment to validate and/or filter the survey data to present a coherent picture.

While the roadmap report looks to the future for power technology trends, we should also be cognizant of what came before. It is not possible to include the content of all the previous roadmap reports, but recognizing the previous work and topics discussed shows the evolution of topics and trends. We provide a listing of the previous years' presentations and their authors in Appendix III.

The end result of all the webinars, surveys, and discussions is this report. It offers a consolidated view of the latest trends in the management, control, and delivery of state-of-the-art power conversion technologies. We hope you find it useful, thought provoking, and valuable.

Conor Quinn and Dhaval Dalal
Roadmap Chairs

Acknowledgements

The PSMA Power Technology Roadmap is a result of the collaborative work by volunteer participants.

We would first like to thank the webinar presenters, each of whom put many hours into the webinars. A large portion of the success of the PTR is due to their efforts in preparing the materials and their skills in delivering the information clearly and concisely. The willingness of all the presenters to answer all the questions posed by the audience brings additional value to the PTR effort.

Likewise, we thank the authors of the articles and summaries that bring together the Application Trends, Components Technologies, University Research in Power Electronics, and Power Supply & Converter Trends sections of the reports. All of these authors are industry experts who have taken time to articulate their views of the major trends and challenges in each vertical application segment and overarching technologies as they apply to power electronics.

Special thanks are warranted for the segment leaders whose efforts were essential to completing this report. Thank you to Brian Zahnstecher and Ed Massey (Ac-Dc Front-end Power Supply Segment); John Wiggernhorn and Stephen Oliver (External Ac-Dc Power Supply Segment); Ian Mazsa and Mark Scott (Isolated Dc-Dc Converter Segment); Jeff Nilles, Xin Zhang, and Arnold Alderman (Non-Isolated Dc-Dc Converter Segment); Ajay Hari and Upal Sengupta (Application Trends section); Bob White (University Research section); Vittorio Crisafulli and Tim McDonald (Component Technologies section).

The report was further enriched by the survey participants; power technologists, component experts, and academics. Their input provided the base for the quantitative power supply design trend tables and the summaries; an essential part of this report. The segment leaders provided additional interpretation and summary excerpts and insights that complement the presentations and the tabulated survey results.

Thanks also go to Jim Warrick of Beacon Technology Partners for help in development of the new survey tool. Laurie House helped edit the full report and kept things together during a chaotic race to the finish line. Aung Tu helped with many valuable tips based on his many years' experience and also stepped in to edit the video files.

Finally, the PTR webinars and this report could not have succeeded without the help of Joe and Lisa Horzepa of PSMA. Joe and Lisa did a great job arranging the meeting facilities, providing great feedback through the process, and managing the book printing and USB drive duplication process. We also thank the PSMA board of directors for their continued and steadfast support.

The PSMA Power Technology Roadmap remains a two-year effort. We hope that the many of the existing and new volunteers will continue to support or join this extremely rewarding effort.

Conor Quinn and Dhaval Dalal
Roadmap Chairs

Section I
Roadmap Overview

Roadmap Goal

The goal of the Power Technology Roadmap is to paint a comprehensive picture of the direction of the power technology in the next two to five years. While it provides selective metrics to project the technology evolution and trajectory in quantitative terms, it contains significantly more valuable and potent qualitative information in the pages written by many leading industry experts.

The member organizations will benefit by using the report as a companion to the readily available market reports – which may contain more specific market projections, but lack the “why and how” behind those projections. The report is also intended to act as a “call to action” for the member organizations in terms of addressing the gaps in the ecosystem identified in the report.

Roadmap Methodology

The PTR 2019 activities kicked-off in March of 2017 in Tampa, FL, at APEC 2017. During APEC, PSMA organizers held a kick-off meeting where interested members attended a meeting to review the scope of the report. There was also a lessons-learned analysis of the just released PTR 2017 report to facilitate learnings and improvements.

Like the previous roadmap, the report’s structure remains a three-dimension overview of:

- ❖ Application Trends and Emerging Technology (which may be used across many products and are enabled by many components)
- ❖ Components Technologies (power semiconductors, ICs, magnetic materials, etc.), and
- ❖ Power Supply and Converter products and technology (ac-dc front-end power supplies, external ac-dc supplies, isolated and non-isolated dc-dc converters)

The following provides a 3D visualization of the power technology roadmap structure. The power technology roadmap cube (“PTR Cube” below) shows how each of the technology, component, and application segments intersect and overlap, describing the dependency between multiple cross segments.

PSMA Power Technology Roadmap



The PTR Cube

Since the 2017 edition, the report includes a dedicated segment to address the component facet of the PTR cube. In earlier roadmaps, this facet was largely addressed through the webinar coverage.

An improved online survey was also commissioned for the 2019 edition and results were tabulated by the segment teams to forecast power supply and converter design trends.

To gather perspectives and data from a broad range of experts, a series of webinars was conducted between November 2017 and December 2018. The webinars covered a wide range of power conversion topics loosely grouped into Application Trends, Component Technologies, University Research, and Power Supply & Converter Trends. The presentations were from OEMs, suppliers, technologists, research labs, and academics. These presented snapshots of today's state-of-the-art in power conversion technology, synopses of end-customer expectations for the next few years, and perspectives on how component technology is changing.

In recent years, we have opened the webinars beyond PSMA membership to all interested parties, which has increased the participation level significantly. The webinars were generally an hour-long with a question-and-answer period that sometimes got extended with significant dialogue. This allowed the segment leaders to gain a more thorough understanding of the trends being discussed.

The webinars were recorded to allow the segment teams to review the presentations for estimating trends for each product. The recorded material is available as part of the electronic copy of this roadmap report. The webinar recordings add much to the presentation materials as the listener can hear and understand the context and the subtext of the original presentation in the speaker's voice.

For the second part of the roadmap effort, the core team and the volunteers divided into four segment teams. Each team is responsible for a different type of product (Power Supply and Converter technology), chosen as representatives of the overall market:

- ❖ Ac-Dc Front-End Power Supplies (200 W – 2000 W)
- ❖ External Ac-Dc Power Supplies (up to 150 W, with data specific to 27 W and 150 W)
- ❖ Isolated Dc-Dc Converters (with data specific to 100 W, regulated)
- ❖ Non-Isolated Dc-Dc Converters (sub-divided into standard, PSiP, and PwrSoC converters)

For each, the segment leaders made their best assessments of the technologies and metrics to track. A significant effort was made to streamline the survey questions (for both the online survey and the more detailed trends tables) to allow ease of data entry.

The online survey was created and sent out to the PSMA and CPSS mailing lists for responses. After the online survey closed, each segment team examined the results as they applied to their focused power supply design segment. Conference calls and questionnaires were used to gather inputs from other stake holders. The consolidated results were then captured in a series of defined tables, which formed the basis of the trend tables in Section VI of this report. These tables are a major part of this report and provide the essence of the workshop in a compact way.

In the third part of the roadmap effort, the application and technology commentaries provide insight into key issues of the end applications and important technologies. Various industry leaders contributed articles on the general trends, key metrics, key market drivers, and challenges of each application segment. The following segments are covered:

Application Trends

- ❖ Automotive
- ❖ Battery Charging
- ❖ Cloud Computing
- ❖ Energy Harvesting
- ❖ Lighting
- ❖ Motor Control
- ❖ Renewable Energy / Grid Storage
- ❖ Safety and Compliance

Component Technologies

- ❖ Prismatic Aluminum Electrolytic Technology
- ❖ Magnetics
- ❖ LV MOSFETs
- ❖ Silicon SJ MOSFETs
- ❖ Isolated Gate Drivers
- ❖ SiC Diodes and MOSFETs
- ❖ GaN Devices and ICs
- ❖ Packaging in High Power
- ❖ Design Enablement

The Presentations

There are a total of seventeen presentations loosely grouped into the four technology categories around which this report is structured.

Application Trends

- ❖ Getting from 48 Volts in Emerging Server and Automotive Applications
- ❖ How to Drive Silicon Carbide MOSFETs
- ❖ Power Connections for Higher Loads and Hotter Environments
- ❖ SiC Penetrating Electric Vehicle Market; a 2018 Update
- ❖ Powering IoT Edge Devices –Ecosystem and Use Cases

Component Technologies

- ❖ From GaNSPEC DWG to JEDEC JC70.1: An update on industry qualification standards for Gallium Nitride power conversion devices
- ❖ Power Electronics Devices Technology and Market Status
- ❖ Monolithic GaN Device Integration Drives Efficiency, Density, and Reliability in Power Conversion
- ❖ Physically Based, Scalable SPICE Modeling Methodologies for Wide-Band Gap Technologies
- ❖ Advances in Low-profile Capacitor Technologies

University Research

- ❖ Power Electronics Continuing Education in the Age of Massive Online Courses
- ❖ Emerging Embedded Passive Technologies that Enable High Density 3D Power Packaging with Roadmap Projections
- ❖ Emerging Mixed-Signal Control and Hybrid Topological Solutions for Designing High Power Density Dc-Dc SMPS

Power Supply and Converter Trends

- ❖ Navigating the Present and Future Trajectories of Product Compliance Standards
- ❖ Worth of a Watt – its Capital Equivalent
- ❖ Systems Reliability Approach to Implement Digital Control in Power Systems
- ❖ Delivering the Inner Power of SoCs: the Value of Fully Integrated Voltage Regulators in SoCs

Summary of the Roadmap

Readers are encouraged to review the various sections of this report and draw their own conclusions. With such vast data and diverse commentaries, it is near impossible for editors to distill the report down to a single page summary.

Instead, we have tried to identify the cross-currents and common themes among different sections and tried to present those in a summary table below.

Webinar Cross Reference *

Webinar	Application Trends	Component Technologies	University Research	Power Supply and Converter Trends			
				Ac-Dc Front-End	Ac-Dc External	Dc-Dc Isolated	Dc-Dc Non-Isolated
Butler et al.		✓		✓	✓	✓	✓
Bock et al.	✓	✓		✓	✓	✓	✓
Erickson			✓				
Prodic	✓	✓	✓	✓	✓	✓	✓
Jacobs	✓			✓	✓	✓	✓
Martin et al.	✓	✓		✓			
Lin et al.	✓	✓		✓	✓	✓	✓
Lidow	✓	✓		✓	✓	✓	✓
Frank	✓	✓		✓	✓		
Kinzer et al.	✓	✓		✓	✓		
Victory		✓		✓	✓	✓	✓
Raj	✓	✓	✓			✓	✓
Copper	✓	✓		✓			
Laird	✓			✓	✓	✓	
Philips	✓	✓				✓	✓
Hayes et al.	✓					✓	✓
Lohrber et al.		✓		✓	✓	✓	✓

(*) Somewhat subjective. There may be other less obvious relationships today or relationships that will develop over time as technologies mature.

In summary, we would like to highlight that this roadmap is unique in terms of it being fully a volunteer effort. As you read through the pages, gather insights, and develop questions; what better way to extend the tradition than to contribute to the next edition of the roadmap through your active participation?