Application Note

Controller to Converter – Design Considerations for 24V and 48V Systems

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ABSTRACT

This application note provides a high-level comparison between Texas Instruments' switching buck controllers and buck converters best suited for 24V, 36V, and 48V systems. These high-voltage rails typically require wider input voltage devices to provide safe voltage margins and handle voltage transients up to 65V or 80V. This report discusses design considerations and tradeoffs between buck controller and buck converter designs for higher current applications, highlighting the value proposition of each device along with a side-by-side comparison of electrical performance, PCB design size, and design considerations. Texas Instrument's new 80V 8A Buck converter LM70880-Q1 can be used as an example comparison against similar high-voltage controllers, LM5148-Q1, LM5149-Q1, and LM5146-Q1.

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1 Introduction

The use of higher voltage rails and inputs is an increasing trend across markets such as:

- 48V Automotive systems - Hybrid electric vehicles (HEV) and on board charging
- 48V Enterprise and Communications - Data-centers and remote radio units
- 24V rails in Industrial - Factory automation, robotics and building automation

Large voltage transients are a common challenge in these applications requiring some 24V rail applications to use devices rated for 65V. Similarly, 48V automotive systems need to handle cold-crank voltage transients in the range of 65V to 80V. Typically for Wide-Vin, high output current designs, a buck controller with external MOSFETs is a standard choice.

New innovations in IC design, packaging and manufacturing allow for the creation of power dense, high current, high-voltage converters. These devices also have the ability to multi-phase allowing them to reach output currents that typically a controller solution could only achieve. Converter based designs offer many benefits over classical controller designs but also share some tradeoffs that can be highlighted in this report. Below is a high-level bullet point list of each device's value proposition and summarized in Table 1-1.

Buck controller designs feature a PWM controller IC that control external MOSFETs. These designs require good and careful layout design to minimize large parasitic loops created between the controller IC, MOSFETs and key passives such as the input and output capacitors and the inductor. With good design considerations a buck controller design provides the following value proposition:

- More design flexibility and optimization to design specifications
- More component optimization for efficiency and thermal performance
- Can achieve the lowest bill-of-material (BoM) cost

Buck converters feature a controller with one or more integrated power FETs. Some of the design challenges of a controller design are greatly mitigated with a converter. For example, with integrated FETs critical parasitic loops are minimized resulting in lower EMI designs to pass stringent EMI requirements easier. A buck converter design provides the following value proposition:

- Component integration simplifies component sourcing, reduces customer BoM and enables smaller design sizes
- Greatly reduces time and cost to market by reducing power-stage design time
- Minimized parasitic loops result in lower EMI emissions allowing for smaller and lower cost EMI filters

Table 1-1. Summary of Controller and Converter Highlights

	Controller	Converter
Design Difficulty	Moderate-Tough (More component selection and more layout design considerations)	**Easy**
Design Size	Medium (Requires 2 large external FETs)	**Small**
EMI	Medium (Large parasitic loops)	**Low**
Design Flexibility	**More (Component optimization)**	Less
Total BoM Cost	$$$-$	$$-$
Thermals	**Can be optimized for better performance**	Good

2 Efficiency and Thermals Comparison

Controllers are a standard design for high current and high ambient temperature applications due to their ability to use low resistance MOSFETs and have more PCB surface area for thermal dissipation. Converters, although offering less flexibility, can achieve comparable thermal performance through a combination of large thermal DAP (die attach paddle), integrated low-resistance FET and good IC design as shown in the following images.

Efficiency curves and thermal data were generated from each devices' respective EVM. LM5148-Q1 utilizes the same EVM as LM5149-Q1 named LM5149-Q1EVM-400 and share the same efficiency and thermal performance. LM70880QEVM was adjusted to use the same 6.8µH inductor as the LM5149-Q1EVM-400. Both devices were tested under similar conditions and LM5149 EVM utilizes MOSFETs with an RDSon values of 19.5mΩ and 8.8mΩ.

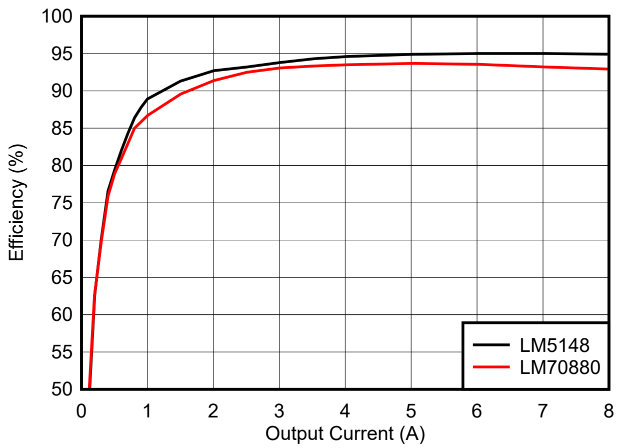


Figure 2-1. Controller vs. Converter Efficiency Comparison (VIN = 24V; VOUT = 5V) 0A to 8A

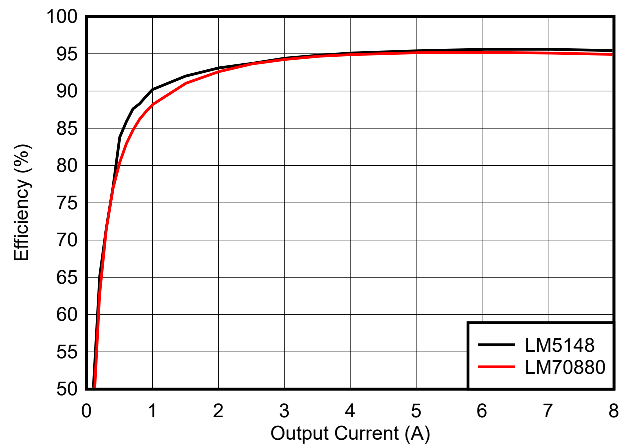


Figure 2-2. Controller vs. Converter Efficiency Comparison (VIN = 48V; VOUT = 12V) 0A to 8A

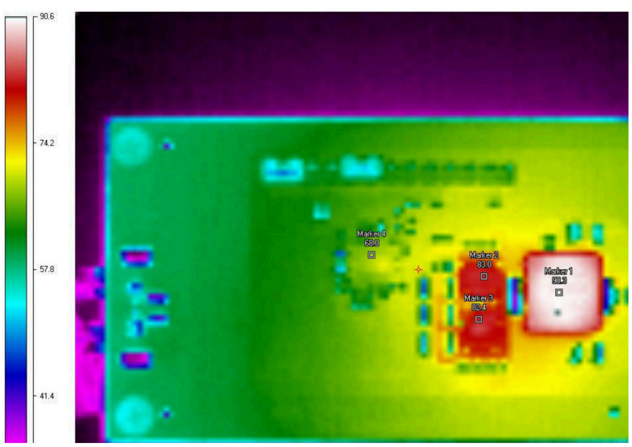


Figure 2-3. Controller Thermals (VIN = 48V; VOUT = 12V 8A)

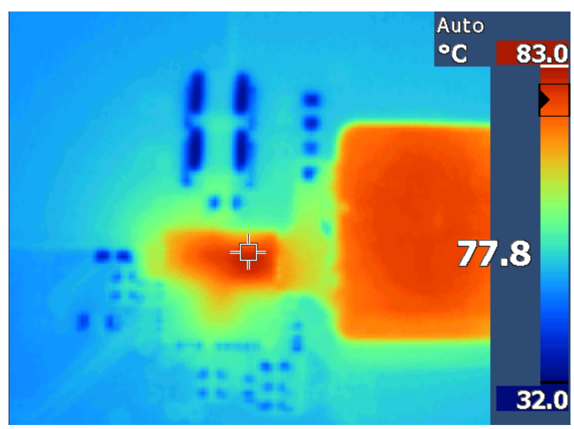


Figure 2-4. Converter Thermals (VIN = 48V; VOUT = 12V 8A)

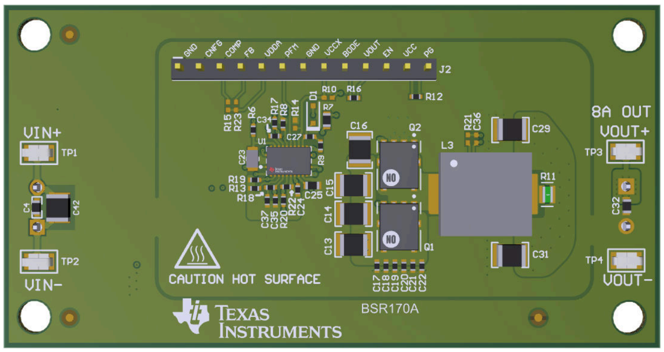
The converter design has the added benefit of easy performance characterization. A controller design requires greater simulation, calculations and design trials. Controller designs must consider the different specifications and performance per controller IC and per MOSFET chosen for the design.

As mentioned, a controller design offers increased flexibility such as MOSFET optimization. MOSFETs with lower resistance specifications can yield higher efficiency and better thermals at the expense of increased cost. External MOSFET also sometimes have wider operating temperatures up to 175C° while converters are specified up to 150C°.

A growing amount of application designs require higher voltage conversions and higher output power. Thermals can be a common challenge amongst these designs and have to be managed with a variety of designs. Controller and converter based designs both require good layout and thermal mitigation techniques to work well in high ambient temperature environments.

3 Design Size Comparison

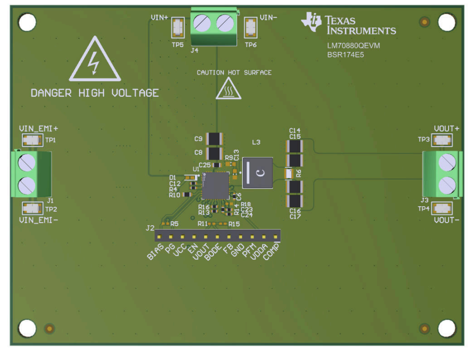
External FETs contribute a large amount of space on a controller design, particularly because each FET requires its own package. 80V MOSFETs typically are 5mm x 6mm in size and some 60V MOSFETs can be 3mm x 3mm. MOSFETs alone can contribute to more than 20% of a controller's total design size. Converters enable compact and power dense designs as shown between the two EVMs in Figure 3-1 and Figure 3-2



Note

Approximately 720mm^2 design size

Figure 3-1. Controller EVM Design Size (LM5149-Q1)



Note

Approximately 540mm^2 design size

Figure 3-2. Converter EVM Design Size (LM70880-Q1)

Saving space in the power-stage allows for either direct PCB cost savings or increases space available for other critical components. This alone can be worth the efficiency or BoM cost tradeoff of a converter design.

4 EMI and EMI Filter Comparison

Power stage designs require extra attention to detail to avoid unsafe electromagnetic interference across noise sensitive circuitry especially in applications that have EMI requirements such as CISPR 32 and CISPR 25. While newer controller designs have EMI reduction features such as Dual Random Spread Spectrum (DRSS) and Active EMI Filtering (AEF) like found in LM5149-Q1, the layout of a power design is critical for EMI performance. High parasitic loops that are formed in between key components such as the controller, FET, input and output capacitors as shown in Figure 4-1, minimizing these loops with good layout improve EMI performance. See *Improve High-Current DC/DC Regulator EMI Performance for Free with Optimized Power Stage Layout*, application note.

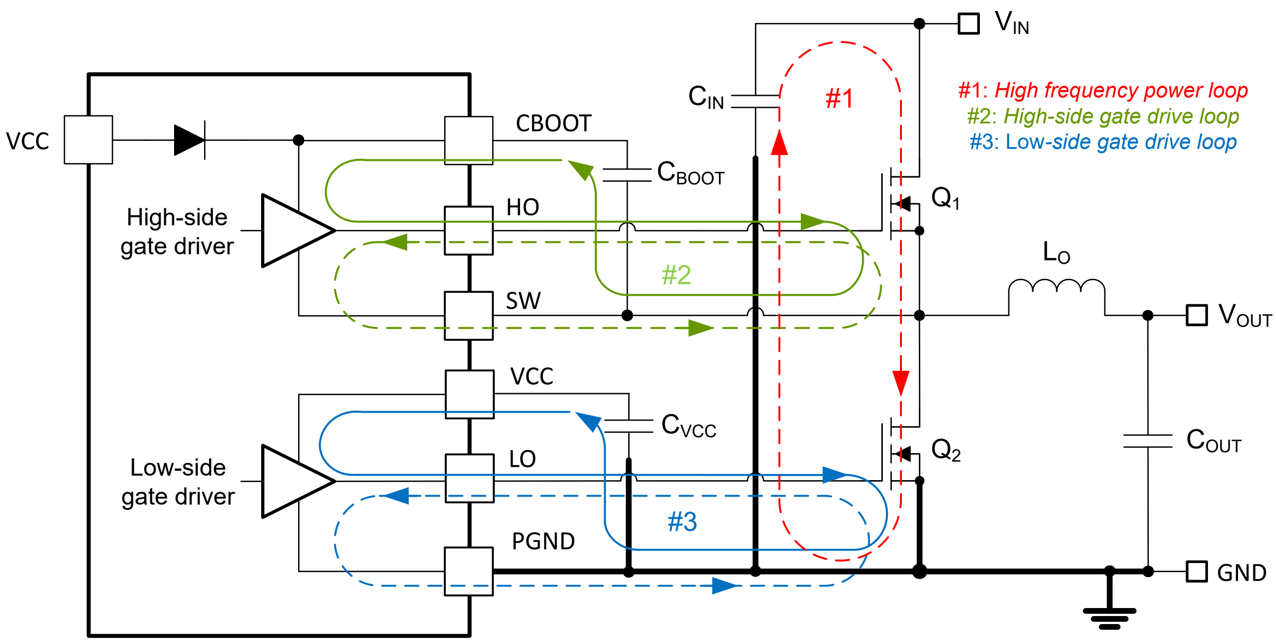
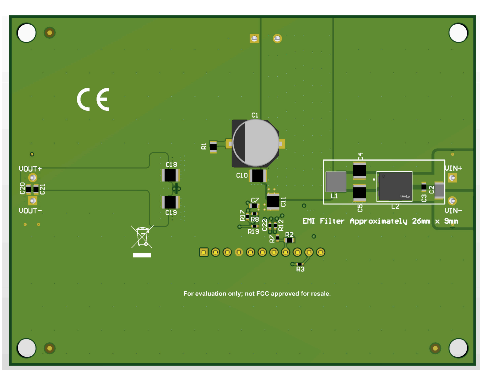


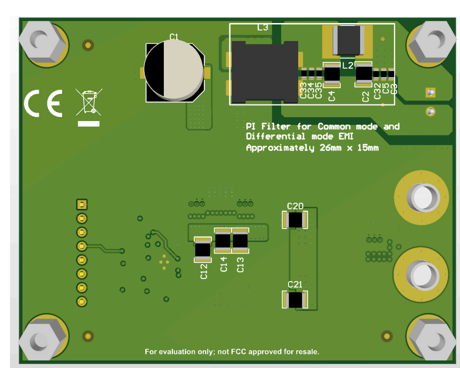
Figure 4-1. Parasitic Loops Formed in a Controller Design

A converter design provides the most minimal parasitic loop between controller and FET. This factor alone contributes highly to the EMI performance between a controller and converter design and can be seen in the EMI filter required for each design. Figure 4-2 showcases the EMI filter needed to pass CISPR25 Class 5, a stringent EMI specification for automotive applications, using a converter design with DRSS. Figure 4-3 and Figure 4-4 showcases the much larger filter and shielding required for a controller design with no EMI reduction features to pass the same EMI specification.



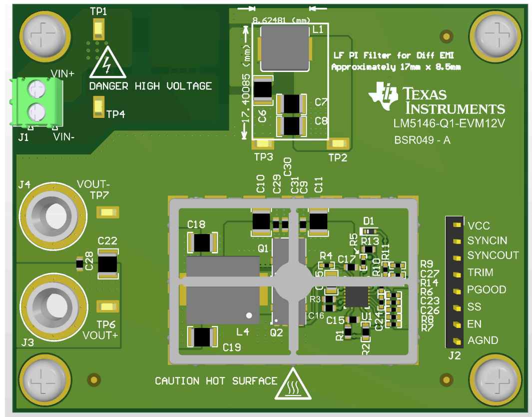
Note
EMI filter is highlighted is approximately 230mm²

Figure 4-2. LM70880-Q1 EVM EMI Filter



Note
Part of the EMI filter is highlighted and is approximately 390mm²

Figure 4-3. LM5146-Q1 EVM Front-End EMI Filter



Note

Part of the EMI filter is highlighted and is approximately 145mm²

Figure 4-4. LM5146-Q1 EVM Back-End EMI Filter

EMI filters can be a large contributor to design size and total cost but determining this can be a challenge. Sometimes a designer needs to complete their initial design and layout before being able to test their circuit's EMI performance and determine how much more EMI margin they require for their systems. This can be as simple as adding more passives to a filter such as input capacitors, ferrite beads or use larger filter inductors but it may also require additional design time to optimize circuit layout. A converter design will likely require the least amount of design work and EMI filter components required to pass EMI standards saving time, cost and design size.

5 Other Design Considerations When Using Controllers and Converters

5.1 Power MOSFET Selection

While controller designs boast design flexibility this typically also means increased design complexity, one aspect of this is the MOSFET selection. The choice of MOSFETs has significant impact on a controller designs' performance and has various specifications that must be accounted for including:

- MOSFET on-state resistance or RDS(on), which dictates power loss and thermal performance
- Parasitic capacitances, which enable faster transition times and reduced switching losses
- Gate driver voltage, which Controller ICs vary in rating and determines if logic and or standard MOSFETs can be used

It takes a considerable amount of time and design effort to choose suitable Power MOSFETs. Table 5-1 is a typical table shown in data sheets that outline all the power losses that must be accounted for when selecting MOSFETs for a controller design. Converters skip this design process and have better characterizations of their performance.

Table 5-1. MOSFET Power Losses

Power Loss Mode	High-Side MOSFET	Low-Side MOSFET
MOSFET conduction	$P_{cond1} = D \cdot \left({I_{OUT}}^2 + \frac{\Delta I_L^2}{12} \right) \cdot R_{DS(on)1}$	$P_{cond2} = D' \cdot \left({I_{OUT}}^2 + \frac{\Delta I_L^2}{12} \right) \cdot R_{DS(on)2}$
MOSFET switching	$P_{sw1} = \frac{V_{IN} \cdot F_{SW}}{2} \left[\left(I_{OUT} - \frac{\Delta I_L}{2} \right) \cdot t_R + \left(I_{OUT} + \frac{\Delta I_L}{2} \right) \cdot t_F \right]$	Negligible
MOSFET gate drive	$P_{Gate1} = V_{CC} \cdot F_{SW} \cdot Q_{G1}$	$P_{Gate2} = V_{CC} \cdot F_{SW} \cdot Q_{G2}$
MOSFET output charge	$P_{Coss} = F_{SW} \cdot \left(V_{IN} \cdot Q_{oss2} + E_{oss1} - E_{oss2} \right)$	Negligible
Body diode conduction	N/A	$P_{cond_{BD}} = V_F \cdot F_{SW} \left[\left(I_{OUT} + \frac{\Delta I_L}{2} \right) \cdot t_{dt1} + \left(I_{OUT} - \frac{\Delta I_L}{2} \right) \cdot t_{dt2} \right]$
Body diode reverse recovery	$P_{RR} = V_{IN} \cdot F_{SW} \cdot Q_{RR2}$	

5.2 Feature Set

Controllers can offer a variety of features that aren't found in many converter designs. These features provide versatility and greater ease of use such as:

- Adjustable current limit, which allows for the use of one device to be used across designs and loads with minimal BoM adjustment.
- Internal or external compensation. While internal compensation is favored for design simplicity, external compensation can be considered when a customer wants to optimize their designs for load variation performance and stability or minimizing required output capacitance.
- Fixed Vout settings, reducing BoM for common outputs such as 3.3V, 5V and 12V

Some converters like LM70880-Q1 include these controller-like features, offering greater versatility for various applications.

5.3 Minimum On-Time for High Voltage Conversions

An important specification to consider in the device selection for a high voltage conversion design is the minimum on-time (Ton min). High voltage controllers typically have low Ton min allowing for designs such as 48Vin to 5Vout, 3.3Vout or lower.

Low Ton min is also important for designs requiring constant frequency switching to avoid interference with other frequency bands in your system. Frequency foldback occurs when the voltage conversion exceeds the minimum on-time specification at a certain switching frequency. This needs to be especially considered for systems that deal with voltage transients. LM5148-Q1 has a minimum on-time of around 50ns and LM70880-Q1 incorporates new IC innovation to offer an ultra-low minimum on-time of 25ns to handle a variety of high voltage conversion system challenges.

5.4 Power Inductor Consideration

A good power design practice is to use an output inductor with a saturation current rating higher than the maximum high side current limit specification of a regulator, this makes sure that the inductor does not saturate even during a soft-short condition on the output.

As an example, some converters rated for 65V 8A have a maximum current limit greater than 17A whereas a controller can have a max current limit of approximately 12A for an 8A continuous output design. Higher current limits can restrict inductor choices and can require slightly larger or taller inductors versus what could be used with a device with tighter current limits. LM70880-Q1 shares the benefit of having tight current limits which can enable lower cost or smaller inductors.

6 Summary

This application note outlines the tradeoffs between controller and converter designs. New 65V and 80V converters integrate innovation on the fronts of packaging, FET technology, IC design and manufacturing. These new converters give power designers a new option in their tool belt that enable smaller, lower EMI and easy to design power-stages that are scalable to output currents only controllers could touch in the past. However, controllers won't be going away anytime soon with their design flexibility and optimization. As with all great challenges there are always multiple designs with tradeoffs.

The DC/DC converters and controllers in Table 6-1 are ideal for 24V systems and 48V systems across applications. For further design size reduction, greater ease of use and lower EMI, an integrated inductor module may be of interest such as TPSM365R6 and TPSM5601R5H.

Table 6-1. Suggested Step-Down Converters for High Voltage Systems

Device	Iout (A)	Input Voltage (V)	Package	Comment
LM5146-Q1	External FETs	5.5-100	4.5x3.5mm QFN	
LM5137-Q1	External FETs	4-80	6x6mm QFN	Dual Output
LM5190-Q1	External FETs	5-80	4.5x3.5mm QFN	Integrated CC/CV
LM5149-Q1	External FETs	3.5-80	5.5x3.5mm QFN	Single Output, Integrated AEF
LM5143A-Q1	External FETs	3.5-65	6x6mm QFN	Dual Output
LM70880-Q1	8	4.5-80	6x6mm QFN	
LM706A0-Q1	10	4.5-65	6x6mm QFN	
LM70660	6	4.5-65	6x6mm QFN	
LM65645-Q1	4.5	3-65	2.6x3.6mm WQFN	Ultra-low EMI, Ultra-low Iq
LMR51635	3.5	4.3-60	2.9x2.8mm SOT-23	Simple Switcher, Low Iq
LM5013-Q1	3.5	6-100	4.9x6mm HSOIC	Non-synchronous, Low Iq
LMR38025-Q1	2.5	4.2-80	3x3mm WSON	Simple Switcher, Low EMI
LMR38020-Q1	2	4.2-80	4.9x6mm HSOIC	Simple Switcher, Low EMI
LMR36520	2	4.2-65	4.9x6mm HSOIC	Simple Switcher, Low Iq
LMR36015-Q1	1.5	4.2-60	2x3mm QFN	Low EMI, Low Iq
LMR51610-Q1	1	4.5-65	2.9x2.8mm SOT-23	Simple Switcher, Low Iq
LM5164-Q1	1	6-100	4.9x6mm HSOIC	Low Iq
LM5169-Q1	0.65	6-120	4.9x6mm HSOIC	Low Iq
LMR36506-Q1	0.6	3-65	2x2mm QFN	Ultra-low Iq, Ultra-low EMI
LMR36503E-Q1	0.3	3-65V	2x2mm QFN	Ultra-low Iq, Ultra-low EMI, Extended Temperature
LMR36502	0.15	3-65V	2x2mm QFN	Ultra-low Iq, Ultra-low EMI
LMR36500	.05	3-65V	2x2mm QFN	Ultra-low Iq, Ultra-low EMI

7 References

- Texas Instruments, *LM5148-Q1 Automotive, 80V synchronous buck DC/DC controller with ultra-low IQ*, data sheet.
- Texas Instruments, *LM70880-Q1 Automotive, high-density, 4.5-V to 80-V input, 8-A low-EMI synchronous DC/DC step-down converter*, data sheet.
- Texas Instruments, *There are more ways than you think to reduce conducted EMI*, blog.
- Texas Instruments, *Automotive EMI Reduction Techniques, Applications and Solutions*, training video.
- Texas Instruments, *Understanding EMI and Mitigating Noise in DC/DC Converters*, training video.
- Texas Instruments, *Simple Success With Conducted EMI From DC-DC Converters*, application note.
- Texas Instruments, *Reduce Conducted EMI in Automotive Buck Converter Applications*, application note.

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