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## ABSTRACT

Network Interface Cards (NIC) are crucial for business continuity and reliable communications by connecting physical layer circuitry with data link layer standards, such as wired Ethernet or wireless networking. The performance of the NIC card directly affects the data transfer rate of the overall network. Texas Instruments (TI) provides performance power management solutions for use in NICs enabling low noise, high efficiency, reduced external components and good thermal management when powering the NIC's network processors, memory, and other circuitry.

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## 1 Suggested DC/DC Converters

**Table 1-1** highlights the latest point-of-load DC/DC converters with integrated MOSFETs, linear regulators and power modules applicable to powering NICs; however, they are designed to accommodate the requirements for a wide range of markets. These devices are designed to achieve fast transient response, low output voltage ripple, high efficiency, good thermal performance, and high output voltage accuracy. Notice that different control architectures are suggested in the table below.

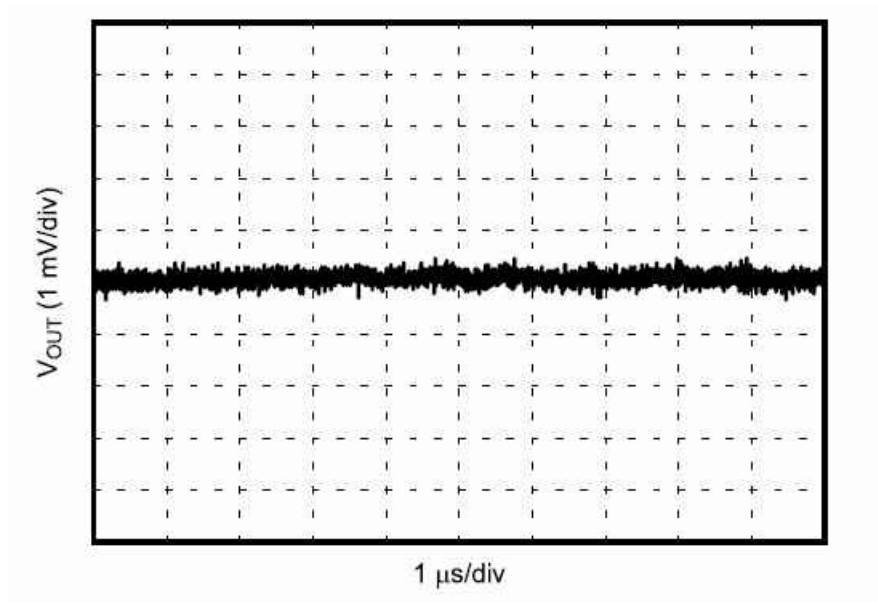
Fixed-frequency control architectures provide a predictable switching frequency and can be synchronized to an external clock. Current mode or voltage mode control is desirable in noise-sensitive applications that use data converters and high-speed analog circuits. On the other hand, devices implementing constant on-time control deliver a faster transient response than voltage or current mode control to quickly changing load profiles, since there is no internal clock to control the switching frequency. Several devices feature PMBus or I<sup>2</sup>C with adaptive voltage scaling and margining. Devices integrating PMBus or I<sup>2</sup>C with telemetry report voltage, current, and temperature information to a host.

**Table 1-1. Suggested Point-of-Load Converters**

I <sub>OUT</sub> Range	Constant On-Time Control	Fixed Frequency Control	PMBus / I <sup>2</sup> C without Telemetry	PMBus / I <sup>2</sup> C with Telemetry	Power Module with Integrated Inductor
<b>Switch Mode Power Supplies</b>					
≤ 2 A	<a href="#">TPS62148</a>	<a href="#">TPS62912</a>	N/A	N/A	<a href="#">TPS82120</a>
2 A – 3 A	<a href="#">TPS62135</a>	<a href="#">TPS62913</a>	N/A	N/A	<a href="#">TPS82130</a>
3 A – 6 A	<a href="#">TPS54J061</a>	<a href="#">TPS543620</a>	<a href="#">TPS542A50</a>	<a href="#">TPS546A24A</a>	<a href="#">TPSM84624</a>
6 A – 10 A	<a href="#">TPS54JA20</a>	<a href="#">TPS54A24</a>	<a href="#">TPS542A50</a>	<a href="#">TPS546A24A</a>	<a href="#">LMZ31710</a>
10 A – 15 A	<a href="#">TPS548A29</a>	<a href="#">TPS542A52</a>	<a href="#">TPS542A50</a>	<a href="#">TPS546B24A</a>	<a href="#">TPSM41615</a>
15 A - 20 A	<a href="#">TPS548B28</a>	<a href="#">TPS543B20</a>	<a href="#">TPS549B22</a>	<a href="#">TPS546B24A</a>	<a href="#">TPSM41625</a>
20 A – 25 A	<a href="#">TPS548B22</a>	<a href="#">TPS543B20</a>	<a href="#">TPS549B22</a>	<a href="#">TPS546D24A</a>	<a href="#">TPSM41625</a>
25 A – 40 A	<a href="#">TPS548D22</a>	<a href="#">TPS543C20A</a>	<a href="#">TPS549D22</a>	<a href="#">TPS546D24A</a>	<a href="#">TPSM846C24</a>
<b>Low Drop Out Regulators</b>					
I <sub>OUT</sub>	Device	Description			
1.5-A	<a href="#">TPS74801</a>	Linear Regulator with PG and Enable			
2-A	<a href="#">TPS7A52</a>	High-Accuracy (0.5%), Low-Noise (4.4 μVRMS), LDO Voltage Regulator with 65 mV Dropout			
3-A	<a href="#">TPS7A53</a>	High-Accuracy (0.5%), Low-Noise (4.4 μVRMS), LDO Voltage Regulator with 110 mV Dropout			
4-A	<a href="#">TPS7A54</a>	High-Accuracy (0.5%), Low-Noise (4.4 μVRMS), LDO Voltage Regulator with 175 mV Dropout			

## 2 Low Ripple Noise

Several Ethernet controllers on the market integrate SERDES, PLLs and I/O ports on-chip that require low voltage ripple noise levels. The traditional method for achieving low output voltage ripple noise is to use a DC/DC converter followed by a low-dropout regulator (LDO) such as the TPS7A52, TPS7A53 or TPS7A54. This family of LDOs supports output currents up to 4-A with a low dropout voltage as low as 65 mV. As the output current increases, a linear regulator becomes less feasible due to added cost, board space, and power loss. Besides a linear regulator, another method to achieve low noise along with a switching DC/DC converter is to implement a second-stage L-C filter following the DC/DC converter. Every DC/DC converter generates an output voltage ripple at its switching frequency. Ethernet controllers with integrated noise-sensitive circuitry need low voltage ripple to minimize frequency spurs in the spectrum, which typically varies with switching frequency, inductor value, output capacitance, and equivalent series inductance and resistance. Low-ripple buck converters such as the 2-A TPS62912 and 3-A TPS62913 leverage an external ferrite-bead filter by integrating the compensation to accommodate the ferrite-bead. Using the inductance of the ferrite-bead along with an additional output capacitor removes the high frequency components of the output voltage ripple and achieves less than 10  $\mu\text{V}_{\text{rms}}$  ripple. [Figure 2-1](#) shows the output voltage ripple with an input voltage of 12 V, an output voltage of 1.2 V, and output current of 1-A.



**Figure 2-1. TPS62913 Output Voltage Ripple After the Second-stage L-C Filter**

### 3 Voltage Regulation Accuracy

As the semiconductor process technology advances, processors require tighter voltage accuracy and lower operating voltages. The processor data sheet specifies the voltage tolerance as either a percentage or as a value in mV, which includes DC, AC and ripple variations over the entire operating temperature range. Designers also consider the tolerance of the resistor divider used by the DC/DC converter, the routing and trace losses of the circuit board, and the variations of the application, like the input voltage variations, temperature swings, and fast changes in the load.

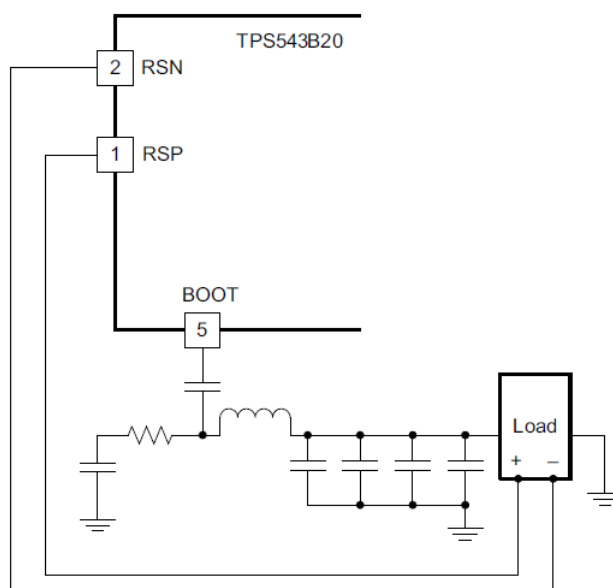
Check the feedback voltage accuracy of the DC/DC converter in the data sheet rather than the front page. [Table 3-1](#) shows the regulated feedback voltage, or the internal voltage reference specification of the TPS548A29, which is a 2.7 V to 16 V, 15-A converter, and shows that the reference accuracy is  $\pm 6$  mV or  $\pm 1\%$  over the full temperature range. The total output voltage accuracy is improved by choosing tighter tolerance resistors. If more headroom is needed, designers can choose 0.1% or 0.5% resistors, even though they may cost a little bit more. The additional headroom allows a total  $\pm 3\%$  or  $\pm 5\%$  output voltage variation to be met with less bulk and bypass capacitance. <sup>1</sup>

**Table 3-1. Internal Voltage Reference of the TPS548A29**

Parameter	Test Condition	Minimum	TYP	Maximum	Unit
Internal Voltage Reference	$T_J = -40^\circ\text{C to } 125^\circ\text{C}, V_{CC} = 3\text{ V}$	594	600	606	mV
	$T_J = 0^\circ\text{C to } 85^\circ\text{C}, V_{CC} = 3\text{ V}$	597	600	603	mV

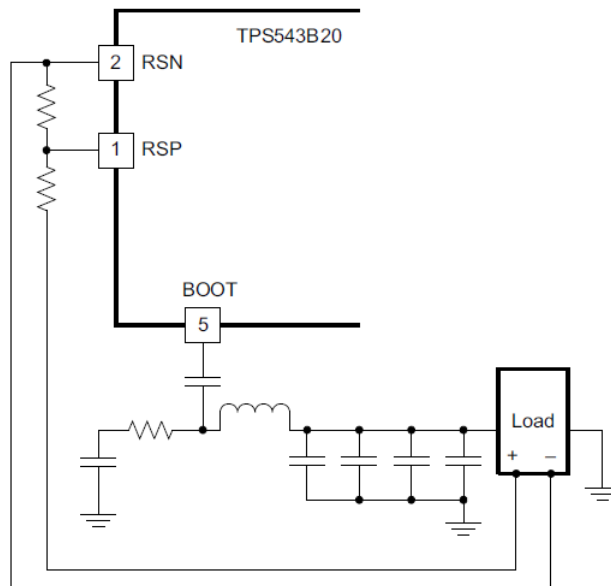
Layout constraints, connectors, and board density requirements affect the total output voltage accuracy. A remote sense feature of a DC/DC converter compensates for voltage drops from long trace lines to accommodate processors needing high accuracy output voltage. This feature is especially useful when routing higher currents since the voltage drop can be a large portion of the overall DC error.

[Figure 3-1](#) shows the TPS543B20 using the remote sense feature with voltage feedback resistors used to program the output voltage. [Figure 3-2](#) shows the TPS543B20 using the remote sense feature without voltage feedback resistors when the VSEL pin selects the reference voltage. The RSP and RSN pins are extremely high-impedance input terminals of a true differential remote sense amplifier.



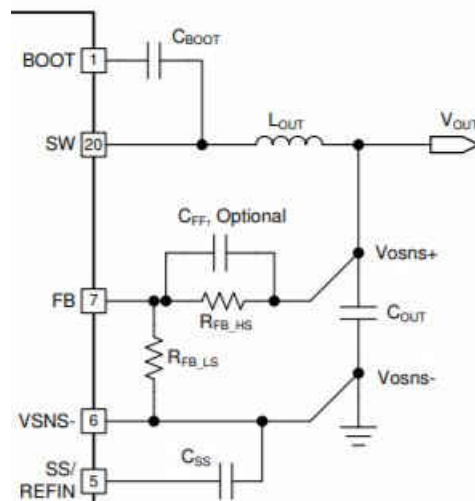
**Figure 3-1. TPS543B20 Remote Sense Without Feedback Resistors**

<sup>1</sup> [Power Tip #18](#): The output-voltage accuracy of the regulator may not be as bad as perceived.



**Figure 3-2. TPS543B20 Remote Sense With Feedback Resistors**

The TPS548A29 also offers a differential remote sense function through the FB and VSNS– pins. Connecting the FB voltage divider resistors to the remote location allows output voltage sensing at a remote location. The ground connection of the remote sensing signal is connected to the VSNS– pin, and the VOUT connection of the remote sensing signal is connected to the feedback resistor divider with the lower feedback resistor,  $R_{FB\_LS}$  terminated at the VSNS– pin. To maintain a stable output voltage and minimize the ripple, the remote sensing lines should stay away from any noise sources such as inductor and switch nodes, or high frequency clock lines. It is recommended to shield the pair of remote sensing lines with ground planes above and below.



**Figure 3-3. TPS548A29 Differential Remote Sense Implementation**

## 4 High Efficiency and Thermal Performance

NICs employ a circuit board with many PCB layers, depending on the form factor constraints. Since the NIC is designed to be used in tight spaces, consider the thermal environment and available airflow when selecting DC/DC converters. The ambient temperature inside a rack server, for example, is typically between 65°C and 70°C since forced airflow is usually available. Higher circuit board temperatures translate to lower reliability, and higher current DC/DC converters contribute to the overall thermal budget.

Figure 4-1 shows the safe operating curve and Figure 4-2 shows the efficiency plot of TPS548A29. The TPS548A29 DC/DC converter in a 3x4mm QFN package safely delivers 15-A and 1 V output with the ambient temperature of 81°C, without airflow. At 15-A and 1 V output, the total efficiency is about 86% at 800 kHz, which translates to the entire solution dissipating less than 2.5 W and the IC dissipating about 1.7 W, knowing the junction-to-ambient thermal resistance  $R\theta_{JA}$  is 26.6° C/W for the evaluation board measured.

The TPS548A29 measured junction-to-ambient thermal resistance of 26.6° C/W is based on a 4-layer, 2-oz Cu per layer and a 2.75 inch by 3 inch board size, which demonstrates low thermal resistance. However, many thermal metrics exist for semiconductor packages, which range from  $R\theta_{JA}$  to  $R\psi_{JT}$ . Often, designers misapply these thermal metrics when trying to estimate the junction temperatures in their systems. Ultimately, thermal performance depends on the circuit-board layout rather than using standard JEDEC-referenced thermal numbers.<sup>2</sup>

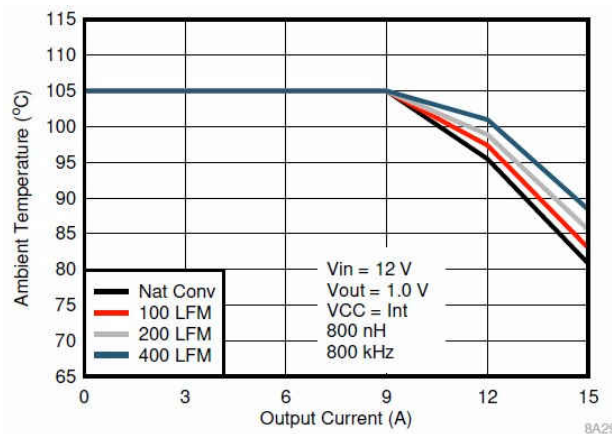


Figure 4-1. TPS548A29 SOA Curve

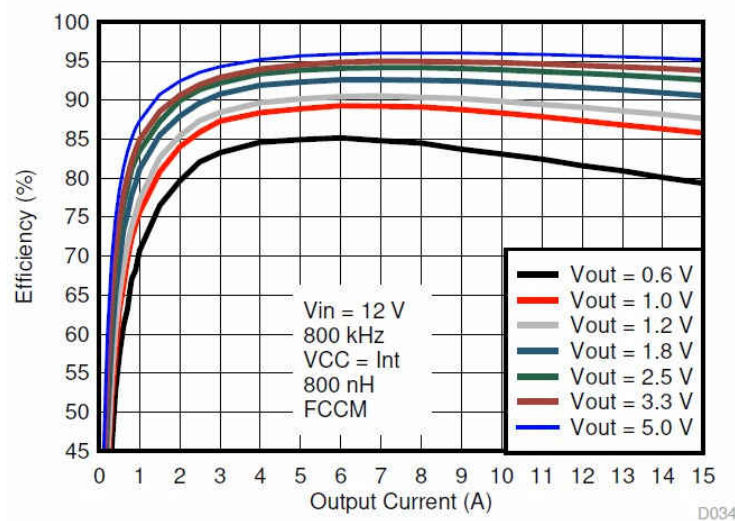


Figure 4-2. TPS548A29 Efficiency Curve

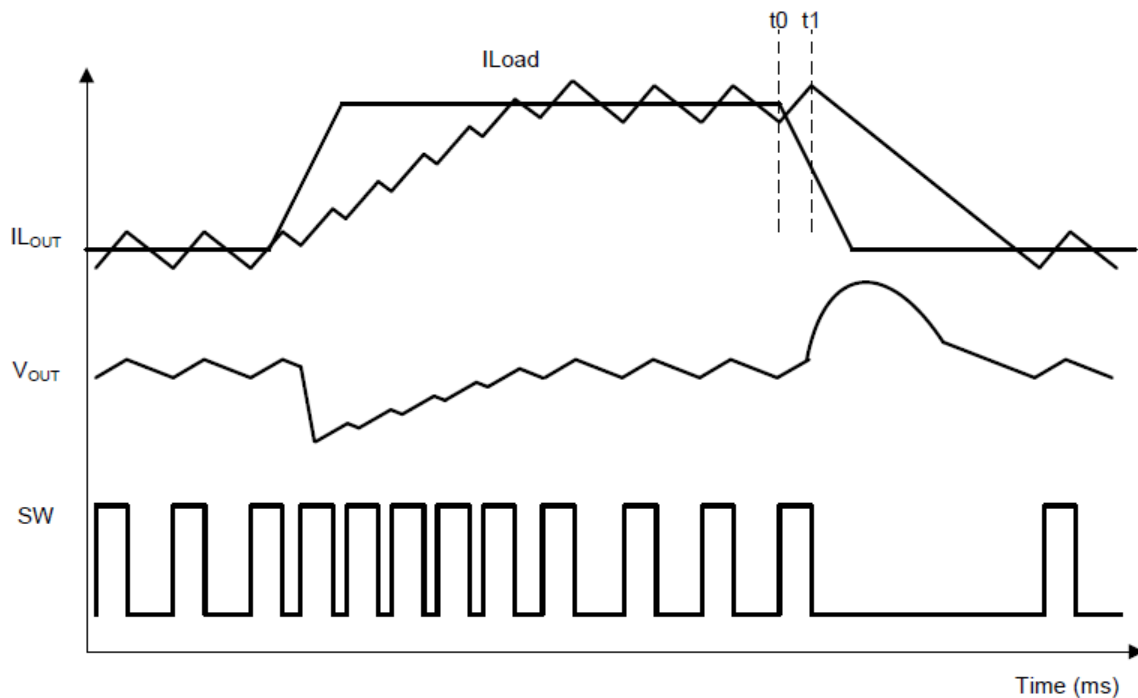
<sup>2</sup> Understanding the thermal-resistance specification of DC/DC converters with integrated power MOSFETs

## 5 Load Transient Response

Since the load profile can change dramatically in an enterprise rack server, it is important to consider AC transient performance. Choosing a DC/DC converter with a fast transient response using non-linear control techniques, such as constant on-time or D-CAP3™, allows a fast transient response with minimal output capacitance. A typical D-CAP3 converter design has three primary considerations for deciding the value of the output capacitance: transient (which includes load step and slew rate of the load step), output ripple, and stability. In applications where the load transient is stringent, the output capacitance is predominantly driven by the transient requirement.

Today, a tight ripple requirement is becoming important in some high-end, high-performance application-specific integrated circuit (ASIC) and field-programmable gate array (FPGA) designs. The LC output power stage must be designed to meet the ripple criteria. For a D-CAP3-based design, there is a minimum capacitance requirement in terms of small signal stability. This requirement prevents subharmonic, multiple-pulsing behavior in all D-CAP modulators.

Figure 5-1 shows how D-CAP3 control mode works in a load transient case. The [Calculating Output Capacitance to Meet Transient and Ripple Requirements of an Integrated POL Converter Design Based on D-CAPx™ Modulators](#) application report shows how to design the output filter for a 1-V output to accommodate a  $\pm 10$  mV ripple requirement and a  $\pm 30$  mV transient voltage deviation using the D-CAP3 control mode.



**Figure 5-1. Load Transient Response of a D-CAP3 Converter**

The TPS543B20 converter features a new control mode called Advanced Current Mode (ACM), which is an internally compensated emulated peak-current-mode control, with a clock synchronizable, fixed-frequency modulator. The internal integrator and directly amplifying ramp tracking loop eliminate the need for external compensation over a wide range of frequencies. The TPS543B20 also features Asynchronous Pulse Injection (API) and body braking to improve transient performance by significantly reducing undershoot and overshoot, respectively, reducing the external capacitance requirement. When the API and body diode braking are activated, ACM delivers a similar transient performance as D-CAP3. [Figure 5-2](#) shows examples of output voltage undershoot and overshoot reduction with API and body braking.<sup>3</sup>

<sup>3</sup> Comparing internally-compensated advanced current mode (ACM) with D-CAP3™ control



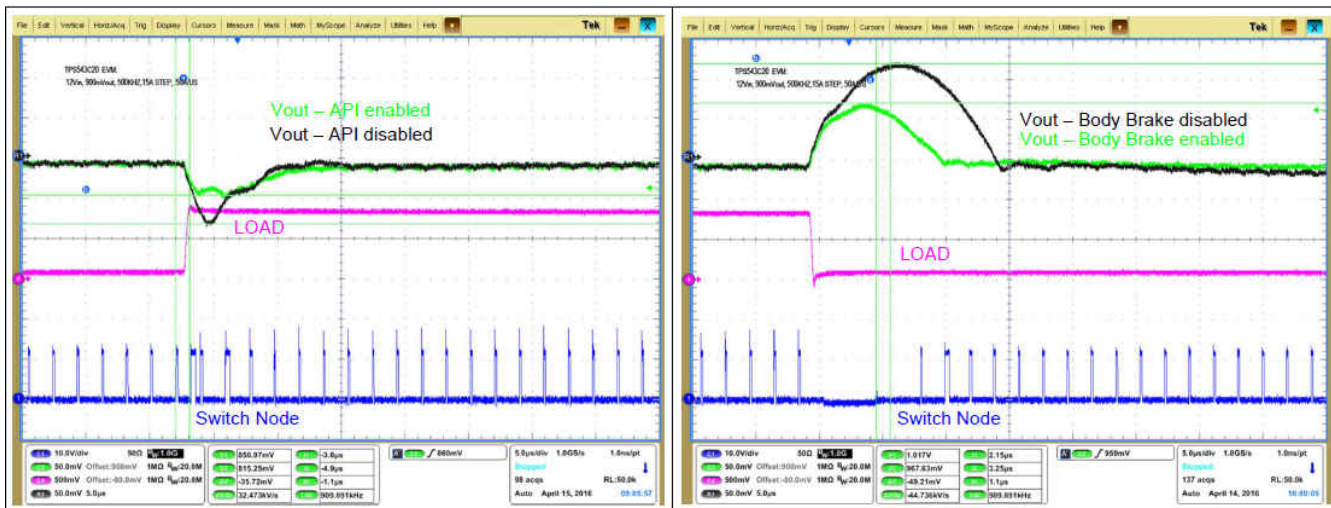


Figure 5-2. Asynchronous Pulse Injection and Body Braking



## 6 Linear Regulator with Adjustable Soft-Start

For low current rails, a linear regulator with a user-programmable soft-start minimizes stress on the input power source by reducing the capacitive inrush current on start-up, especially from highly capacitive loads or with processors requiring many bypass capacitors. The TPS74801 adjustable linear regulator provides a monotonic (non-negative slope) soft-start that is well-suited for powering many different types of processors. Figure 6-1 illustrates the start-up waveform showing the start-up times varying over several soft start capacitor values.

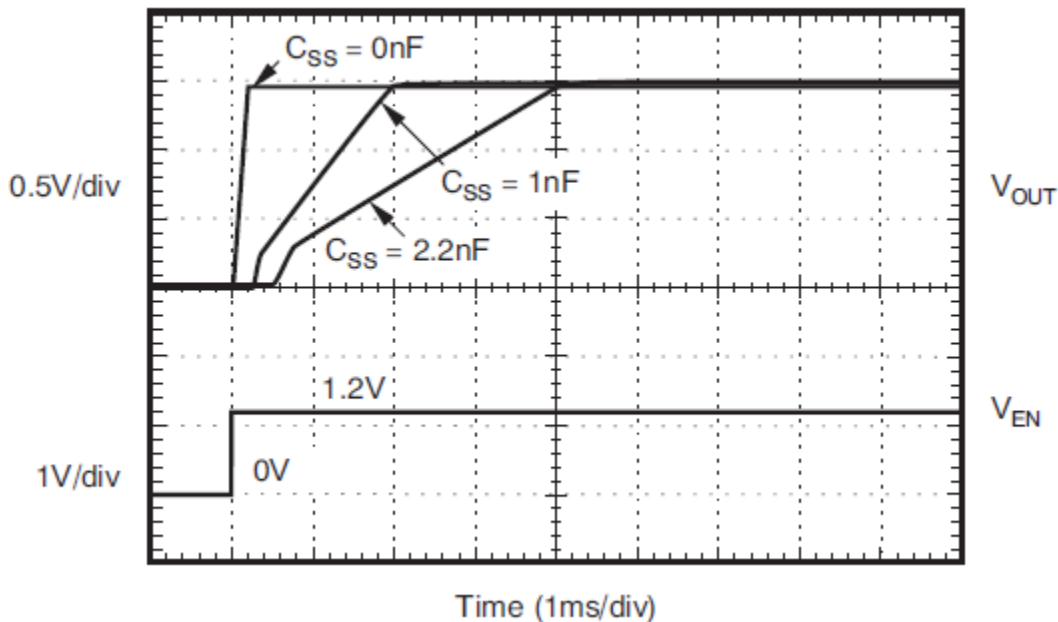


Figure 6-1. TPS74801 Start-up Waveforms

## 7 Conclusion

The performance of network interface cards benefits from DC/DC converters that offer improved output voltage accuracy, low output voltage ripple, fast transient response, reduced external component count, high efficiency and excellent thermal performance. TI offers high performance point-of-load solutions including DC/DC converters, power modules, and linear regulators to address these design requirements.

## 8 Additional Resources

- Texas Instruments, [How to Meet DC Voltage Accuracy and AC Load Transient Specification?](#) TI training video.
  - Texas Instruments, [Minimize Noise and Ripple with a Low-noise Buck Converter](#) blog.
  - Texas Instruments, [Accuracy-Enhanced Ramp-Generation Design for D-CAP3 Modulation](#) application report.
  - Texas Instruments, [Internally Compensated Advanced Current Mode](#), white paper.
  - Texas Instruments, [Control Mode Quick Reference Guide, Step-Down Non-Isolated DC/DC](#) selection guide.
- Texas Instruments, [TI Network Interface Card](#).

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