1 Startup

The startup waveform is shown in Figure 1. The input voltage is set at 12.0V, with no load on the 1.2V output.

Channel C1: input voltage
            2V/div, 2ms/div

Channel C2: output voltage
            500mV/div, 2ms/div

Figure 1
2 Shutdown

The shutdown waveform is shown in Figure 2. The input voltage is set at 12.0V with a 20.0A load on the 1.2V output.

Channel C1: **input voltage**
2V/div, 500us/div

Channel C2: **output voltage**
500mV/div, 500us/div

![Figure 2](image-url)
3 Efficiency

The efficiency is shown in Figure 3.

The measurements were done with two different inductors:

- **SER2009-601ML** 0.740mOhm max. 41A rms 49A sat
- **SER1408-501ME** 0.55mOhm max. 38A rms 30A sat

![Figure 3](image-url)
4 Load regulation

The load regulation of the 1.2V output is shown in Figure 4.

![Figure 4](image-url)
5 Output ripple voltage

The output ripple voltage at 20.0A load and 12.0V input voltage is shown in Figure 5.

Channel C1: switching node
10V/div, 1us/div

Channel C2: output voltage
20mV/div, 1us/div, AC coupled

Figure 5

Due to high noise from the switching node and the low ESR of the output capacitors it is very difficult to measure the exact output ripple.
The output ripple is approximately 5mV peak-peak.
6  Load transients

The response to a load step and a load dump at an input voltage of 12.0V is shown in Figure 6 and Figure 7.

Channel C2:  **output voltage**, -15mV undershoot
20mV/div, 50us/div, AC coupled

Channel C1:  **load current**, load step 10.0A to 20.0A
10A/div, 50us/div

![Figure 6](image-url)
Channel C2: **output voltage**, 10mV overshoot
20mV/div, 50us/div, AC coupled

Channel C1: **load current**, load dump 20.0A to 10.0A
10A/div, 50us/div

Figure 7
7 Frequency response

Figure 8 shows the loop response of the 1.2V output with 12.0V input and a 20.0A load.

67 deg phase margin @ crossover frequency 27.0 kHz
8 Miscellaneous waveforms

The drain-source voltage on the switching node is shown in Figure 9. The image was captured with a 12.0V input and a 25.0A load.

Channel C2: **drain-source voltage**, -1.2V minimum voltage, 26.5V maximum voltage
5V/div, 50ns/div

![Figure 9](image-url)

Figure 9
9 Thermal measurement

Figure 10 shows the circuit at an ambient temperature of 21 °C with an input voltage of 12.0V and a load of 20.0A. The measurement was done with two different inductors.

![Figure 10](image)

<table>
<thead>
<tr>
<th>Label</th>
<th>Temperature</th>
<th>Emissivity</th>
<th>Background</th>
</tr>
</thead>
<tbody>
<tr>
<td>SER2009-601M</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L1</td>
<td>54.1 °C</td>
<td>0.95</td>
<td>21.0 °C</td>
</tr>
<tr>
<td>R5</td>
<td>66.1 °C</td>
<td>0.95</td>
<td>21.0 °C</td>
</tr>
<tr>
<td>Q2</td>
<td>63.1 °C</td>
<td>0.95</td>
<td>21.0 °C</td>
</tr>
<tr>
<td>Q6</td>
<td>61.7 °C</td>
<td>0.95</td>
<td>21.0 °C</td>
</tr>
<tr>
<td>Q5</td>
<td>60.9 °C</td>
<td>0.95</td>
<td>21.0 °C</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Label</th>
<th>Temperature</th>
<th>Emissivity</th>
<th>Background</th>
</tr>
</thead>
<tbody>
<tr>
<td>SER1408-501ME</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L1</td>
<td>59.1 °C</td>
<td>0.95</td>
<td>21.0 °C</td>
</tr>
<tr>
<td>R5</td>
<td>66.8 °C</td>
<td>0.95</td>
<td>21.0 °C</td>
</tr>
<tr>
<td>Q6</td>
<td>61.9 °C</td>
<td>0.95</td>
<td>21.0 °C</td>
</tr>
<tr>
<td>Q5</td>
<td>60.9 °C</td>
<td>0.95</td>
<td>21.0 °C</td>
</tr>
<tr>
<td>Q2</td>
<td>63.3 °C</td>
<td>0.95</td>
<td>21.0 °C</td>
</tr>
</tbody>
</table>
10 Additional measurements & analysis

10.1 Low side schottky diode

Often an additional schottky diode is placed in parallel to the low side MOSFET to reduce the overshoot (diode is conducting when high side FET was switched off and the low side FET is not yet conducting).

Figure 11 shows clearly that an additional diode has no influence. The drain-source voltage of the low side FET is exactly the same.

Due to adaptive gate drive the dead-time is already optimized by the controller.

**C2:** Schottky diode MBRS340A placed  
**M2:** no diode placed

![Figure 11](image_url)
10.2 Voltage on switching node and on pin SW

The maximum voltage on pin SW is 27V. To reduce this voltage either a resistor can be placed between pin SW and the switching node or the overshoot on the switching node has to be reduced (snubber, gate resistors e.g.). Already the inductance of the trace between the switching node and pin SW reduces the voltage on pin SW of the controller as Figure 12 shows. The voltage can be reduced either by placing a resistor between pin SW and the switching node. In this configuration no resistor is necessary.

Peak voltage on switching node: 26.5V  
Peak voltage on pin SW: 24.4V (no resistor between switching node and pin SW)
The pictures below show the influence of a resistor between the switching node and pin SW on the maximum voltage.

No resistor placed: 24.4V peak
3.3R placed: 22.5V peak

Care has to be taken if this resistor is placed inside or outside the bootstrap circuit of the high side FET! If it is located inside the bootstrap circuit it has also an influence on the switching behavior of the high side FET.
10.3 Gate Resistors

To reduce the overshoot on the switching node resistors can be placed in the gate lines. This reduces the switching frequency and thus the overshoot.

The measurements show that too high gate resistors lead to problems. If they are too high, the adaptive gate drive doesn’t work properly which leads to cross conduction.

8.0V input voltage, 1.2V @ 10.0A load

<table>
<thead>
<tr>
<th>R1 - high side</th>
<th>R8 - low side</th>
<th>Vpeak - sw. node</th>
<th>Input current</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0R</td>
<td>0.0R</td>
<td>17.2V</td>
<td>1.648A</td>
</tr>
<tr>
<td>1.0R</td>
<td>1.0R</td>
<td>15.5V</td>
<td>1.643A</td>
</tr>
<tr>
<td>2.2R</td>
<td>2.2R</td>
<td>15.2V</td>
<td>1.655A</td>
</tr>
<tr>
<td>3.3R</td>
<td>3.3R</td>
<td>15.3V</td>
<td>1.736A</td>
</tr>
</tbody>
</table>

A 1.0R resistor shows the best balance between peak voltage and input current. If the resistors are too high, the input current is increasing (cross conduction) and the converter doesn’t start up sometimes due to overcurrent.
10.4 Snubber circuit

A snubber placed in parallel to the low side FET reduces the overshoot. The influence is depending on the resistance and the capacitance.

The measurements were done at 8.0V input voltage and 1.2V output voltage with no load.

<table>
<thead>
<tr>
<th>R5 - snubber</th>
<th>C29 - snubber</th>
<th>Vpeak - sw. node</th>
<th>Input current</th>
</tr>
</thead>
<tbody>
<tr>
<td>open</td>
<td>open</td>
<td>14.5V</td>
<td>33mA</td>
</tr>
<tr>
<td>2.2R</td>
<td>3.3nF</td>
<td>13.9V</td>
<td>38mA</td>
</tr>
<tr>
<td>1.0R</td>
<td>3.3nF</td>
<td>13.6V</td>
<td>37mA</td>
</tr>
<tr>
<td>1.0R</td>
<td>10nF</td>
<td>12.4V</td>
<td>52mA</td>
</tr>
<tr>
<td>1.0R</td>
<td>4.7nF</td>
<td>13.0V</td>
<td>41mA</td>
</tr>
</tbody>
</table>

The resistor has to be pretty low to achieve a significant influence. By varying the capacitance the overshoot is reduced. It has to be taken care to burn not too much energy in the resistor!

10.5 Conclusion

- An additional schottky diode parallel to the low side FET has no influence and is thus unnecessary.
- A resistor between the switching node and pin SW reduces effective the voltage on pin SW if the switching node voltage is close to the maximum of 27V.
- Gate resistors can be used to reduce the overshoot. But too high values lead to cross conduction. A good value is 1.0R for NexFETs but it depends highly on the gate charge.
- Also a snubber circuit reduces the overshoot. The resistor has to be pretty low, around 1.0R. The capacitors depends on the overshoot (1..10nF)
For Feasibility Evaluation Only, in Laboratory/Development Environments. The EVM is not a complete product. It is intended solely for use for preliminary feasibility evaluation in laboratory / development environments by technically qualified electronics experts who are familiar with the dangers and application risks associated with handling electrical / mechanical components, systems and subsystems. It should not be used as all or part of a production unit.

Your Sole Responsibility and Risk. You acknowledge, represent and agree that:

1. You have unique knowledge concerning Federal, State and local regulatory requirements (including but not limited to Food and Drug Administration regulations, if applicable) which relate to your products and which relate to your use (and/or that of your employees, affiliates, contractors or designees) of the EVM for evaluation, testing and other purposes.
2. You have full and exclusive responsibility to assure the safety and compliance of your products with all such laws and other applicable regulatory requirements, and also to assure the safety of any activities to be conducted by you and/or your employees, affiliates, contractors or designees, using the EVM. Further, you are responsible to assure that any interfaces (electronic and/or mechanical) between the EVM and any human body are designed with suitable isolation and means to safely limit accessible leakage currents to minimize the risk of electrical shock hazard.
3. Since the EVM is not a completed product, it may not meet all applicable regulatory and safety compliance standards (such as UL, CSA, VDE, CE, RoHS and WEEE) which may normally be associated with similar items. You assume full responsibility to determine and/or assure compliance with any such standards and related certifications as may be applicable. You will employ reasonable safeguards to ensure that your use of the EVM will not result in any property damage, injury or death, even if the EVM should fail to perform as described or expected.

Certain Instructions. Exceeding the specified EVM ratings (including but not limited to input and output voltage, current, power, and environmental ranges) may cause property damage, personal injury or death. If there are questions concerning these ratings please contact a TI field representative prior to connecting interface electronics including input power and intended loads. Any loads applied outside of the specified output range may result in unintended and/or inaccurate operation and/or possible permanent damage to the EVM and/or interface electronics. Please consult the EVM User’s Guide prior to connecting any load to the EVM output. If there is uncertainty as to the load specification, please contact a TI field representative. During normal operation, some circuit components may have case temperatures greater than 60°C as long as the input and output ranges are maintained at nominal ambient operating temperature. These components include but are not limited to linear regulators, switching transistors, pass transistors, and current sense resistors which can be indentified using the EVM schematic located in the EVM User’s Guide. When placing measurement probes near these devices during normal operation, please be aware that these devices may be very warm to the touch.

Agreement to Defend, Indemnify and Hold Harmless. You agree to defend, indemnify and hold TI, its licensors and their representatives harmless from and against any and all claims, damages, losses, expenses, costs and liabilities (collectively, “Claims”) arising out of or in connection with any use of the EVM that is not in accordance with the terms of this agreement. This obligation shall apply whether Claims arise under the law of tort or contract or any other legal theory, and even if the EVM fails to perform as described or expected.

Safety-Critical or Life-Critical Applications. If you intend to evaluate TI components for possible use in safety-critical applications (such as life support) where a failure of the TI product would reasonably be expected to cause severe personal injury or death, such as devices which are classified as FDA Class III or similar classification, then you must specifically notify TI of such intent and enter into a separate Assurance and Indemnity Agreement.
## IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

TI assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using TI components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license from TI to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

TI products are not authorized for use in safety-critical applications (such as life support) where a failure of the TI product would reasonably be expected to cause severe personal injury or death, unless officers of the parties have executed an agreement specifically governing such use. Buyers represent that they have all necessary expertise in the safety and regulatory ramifications of their applications, and acknowledge and agree that they are solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI products are neither designed nor intended for use in military/aerospace applications or environments unless the TI products are specifically designated by TI as military-grade or "enhanced plastic." Only products designated by TI as military-grade meet military specifications. Buyers acknowledge and agree that any such use of TI products which TI has not designated as military-grade is solely at the Buyer's risk, and that they are solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI products are neither designed nor intended for use in automotive applications or environments unless the specific TI products are designated by TI as compliant with ISO/TS 16949 requirements. Buyers acknowledge and agree that, if they use any non-designated products in automotive applications, TI will not be responsible for meeting such requirements.

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

<table>
<thead>
<tr>
<th>Products</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Audio</td>
<td>Communications and Telecom</td>
</tr>
<tr>
<td>Amplifiers</td>
<td>Computers and Peripherals</td>
</tr>
<tr>
<td>Data Converters</td>
<td>Consumer Electronics</td>
</tr>
<tr>
<td>DLP® Products</td>
<td>Energy and Lighting</td>
</tr>
<tr>
<td>DSP</td>
<td>Industrial</td>
</tr>
<tr>
<td>Clocks and Timers</td>
<td>Medical</td>
</tr>
<tr>
<td>Interface</td>
<td>Security</td>
</tr>
<tr>
<td>Logic</td>
<td>Space, Avionics and Defense</td>
</tr>
<tr>
<td>Power Mgmt</td>
<td>Transportation and Automotive</td>
</tr>
<tr>
<td>Microcontrollers</td>
<td>Video and Imaging</td>
</tr>
<tr>
<td>RFID</td>
<td></td>
</tr>
<tr>
<td>OMAP Mobile Processors</td>
<td></td>
</tr>
<tr>
<td>Wireless Connectivity</td>
<td></td>
</tr>
</tbody>
</table>

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2011, Texas Instruments Incorporated