TECHNOLOGY edge℠

Benefits and Challenges of High-Frequency Regulators

Application Note AN-1973

Stephen Ott, Technical Engineer
Marc Davis-Marsh, Applications Engineer

Introduction

Space constraints exist in many electronic designs. Beyond portable handsets, applications such as industrial instrumentation, point-of-sale terminals, and portable medical devices also have board space and height restrictions. Switching regulators with high switching frequency present an engineer working on a space-constrained design with an effective means to minimize solution size. National Semiconductor's newest high-frequency regulators offer a combination of high switching frequency and ease of use, thereby reducing solution size and complexity. Besides solution size, a well-designed high switching frequency regulator has the advantage of a faster transient response and reduced output voltage ripple.

There are a few considerations to keep in mind when using a high switching frequency regulator in a design. Careful layout must be considered to reduce EMI and improve the performance of the device. Also, the IC packaging selection and printed circuit board layout must be considered for dissipating heat in smaller spaces.

Design Made Easy

Power supply design is made easy for space-constrained applications by using the latest high switching frequency devices. Two time-consuming areas of power supply design are circuit design and layout.

The most difficult aspect of circuit design for a power supply is compensating the feedback loop. Design complexity is reduced dramatically by integrating the compensation network. This leads to savings in design time and a reduced bill of materials cost.

After the circuit has been finalized, the printed circuit board layout becomes the bottleneck. When selecting an IC to reduce prototyping time, it must feature internal compensation, few external components, and a smart pinout. National Semiconductor's high-frequency regulators such as the LM283x family, LM273x family, LM26420 and LM27341/42 meet these requirements.

Smaller Solution Size

Moving to a higher frequency reduces the total solution size by increasing the allowable cut-off frequency of the regulator's output filter. In other words, a smaller inductor in both physical size and inductance value as well as less input and output capacitance is required.

The inductor size is also determined by the amount of current ripple that is allowed in the switching regulator. For a given inductance, the ripple current decreases as the switching frequency increases. Therefore, a much smaller inductor can be used for maintaining the same amount of ripple current.

A good example of the solution footprint benefits of using high switching frequency regulators can be found in the LM2833 regulator. This is a 3A non-synchronous buck regulator switching at 3 MHz with an input range from 3V to 5.5V. It features very few external components, internal compensation for ease of use, and low RDS-ON for improved efficiency.

	LM2833Z	**LM2853**
Switching Frequency	3 MHz	550 kHz
Input Capacitor	22 µF	47 µF
Output Capacitor	22 µF	150 µF
Inductor (dimensions)	1 µH (5 x 5 x 2 mm)	4.7 µH (12 x 12 x 4.6 mm)
Total Component Area	57 mm^2	206 mm^2
Inductor Height	2 mm	5.7 mm

Table 1. Solution Comparison of LM2833Z vs. LM2853 for a 5V to 3.3V Conversion at 3A of Output Current

Referring to *Table 1*, the total component area and inductor height is drastically reduced when compared against the LM2853 regulator. The LM2853 is a synchronous buck regulator designed for high efficiency at low duty cycles.

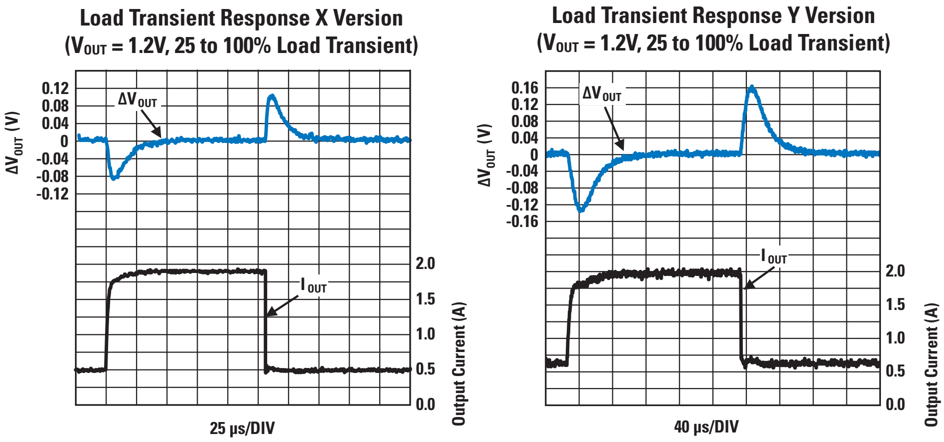

Figure 1. Transient Response of LM26420X (2.2 MHz) and LM26420Y (0.55 MHz)

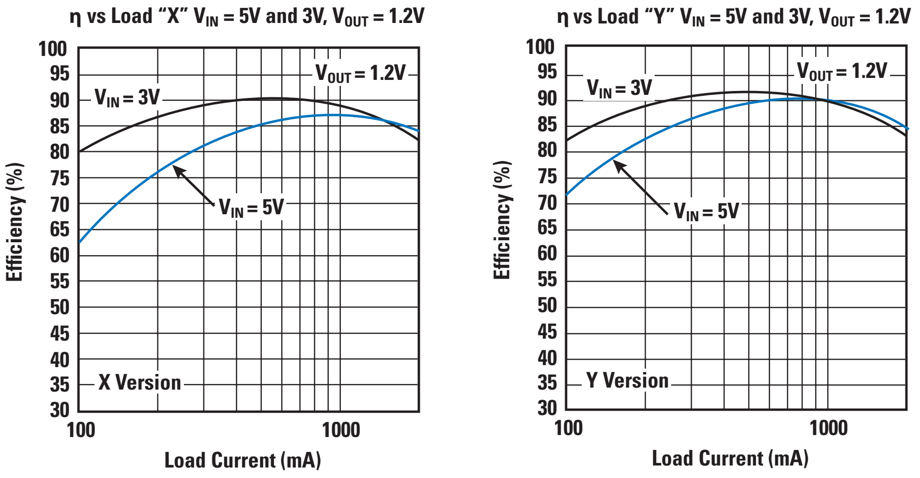

Figure 2. Efficiency Comparison of LM26420X (2.2 MHz) and LM26420Y (0.55 MHz)

Excellent Load Transient Response

High switching frequency regulators offer advantages beyond a smaller total solution size. The main performance advantage of using a high switching frequency regulator is the improved load transient response. The load transient response is better at higher switching frequencies because the bandwidth of the controller can be increased.

Highlighted in ***Figure 1***, the LM26420X (2.2 MHz) has a 30% improvement in load transient response when compared to the LM26420Y (0.55 MHz).

Improved Efficiency

One of the tradeoffs with higher switching frequency is lower efficiency. Using the latest process technology, the efficiency of new high switching frequency regulators has been improved. This result is primarily due to lower conduction and switching losses in the MOSFETs.

Conduction and switching losses have been reduced by improving the figure of merit (FOM) of the power transistor, which translates to lower channel resistance and less gate charge to drive the gate.

New design methodologies have also enabled regulator designs to have faster switching edges which lower the switching losses during MOSFET transitions.

The transition from non-synchronous to synchronous rectification drastically improves efficiency since the low-side switch is a MOSFET instead of a Schottky diode. This is extremely useful for low duty cycle applications.

Highlighted in ***Figure 2***, the LM26420 is offered in a 0.55 MHz and 2.2 MHz switching frequency option. Converting from an input voltage of 5V to an output voltage of 1.2V at 2A at approximately four times the switching frequency, the peak efficiency is only 3% less for the 2.2 MHz frequency option at 87%.

Electro-Magnetic Interference (EMI) Mitigation

Electro-magnetic interference can be problematic when operating at high switching frequencies. EMI from a switcher is proportional to the square of the switching frequency, thus if the switching frequency doubles, the EMI can increase fourfold. This can be mitigated by paying close attention to the printed circuit board layout and component selection.

When designing a printed circuit board for high switching frequencies it is critical to follow these rules. First, identify the high di/dt loop paths and minimize their area. This area is greatly reduced by including a ground plane on the second layer of the printed circuit board. Second, minimize parasitic inductance whenever possible. For example, do not use thermal reliefs in the capacitor pads. Lastly, keep the switch node traces as short as possible. Minimizing the capacitance of the switch node will reduce common-mode noise. The switch node is the common connection in many topologies where the MOSFET, the rectifier, and the inductor meet. Remember, the regulator's radiation resistance is proportional to the square of the length of the current path; reducing the current loop's length by two decreases the EMI by a factor of four.

$$R = 20\pi^2 \left(\frac{\ell}{\lambda}\right)^2$$

Equation 1. Radiation Resistance of a Dipole Antenna

More energy is transmitted as EMI as the radiation resistance increases. Notice in ***Equation 1***, the relationship to wavelength and the antenna length.

Highlighted in ***Figure 3*** are the current paths for a buck regulator. Blue indicates the current path during the switching off-time. Green indicates the current path during the switching on-time. The high di/dt path is highlighted in red, and this is the path the current takes as it transitions from blue to green and vice versa. Fast switching currents are present on these red paths, and are the most likely places to cause EMI.

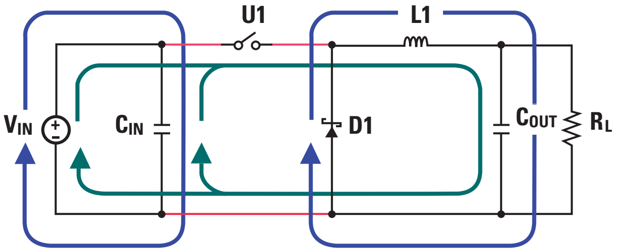

Figure 3. High-Current Paths of a Buck Regulator

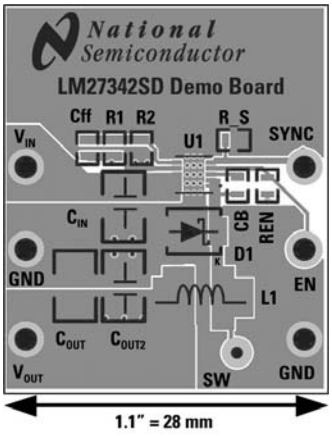

Figure 4. LM27342 Demo Board

A good example of a high frequency regulator layout is the LM27342 demo board. The LM27342 operates at a fixed 2 MHz switching frequency, and can synchronize to an external clock up to 2.35 MHz. EMI is decreased by minimizing the length of the switch node. Therefore, it should be kept as short as possible, and just wide enough to carry the current. The current loops are kept short with compact component placement and a ground plane on the second layer of the printed circuit board. To reduce EMI even further, right angles should not be used on the switch node because they cause discontinuities in the impedance. Referring to ***Figure 4***, the input capacitor (C_{IN}) should be kept as close as possible to the high-side switch (U1) and the catch diode (D1). EMI and noise is minimized by keeping these connections as close as possible.

Thermal Design Considerations

As the power density of a switching regulator increases, it becomes much more challenging to dissipate the heat. The best methods for dissipating the heat are using a package with an external die attached pad (DAP), using the correct amount of copper area for heatsinking, and using thermal vias to connect the package to additional ground layers.

The LM27342 regulator is packaged in an LLP-10 and an eMSOP-10 for customer flexibility. In this example, it is recommended to use at least eight thermal vias when using the LLP-10 or eMSOP-10 package. The diameter of the thermal via is also an important parameter to consider. Since the LLP is a light package, 8-mil thermal vias must be used to protect against solder wicking. Solder wicking is when solder wells up through the thermal vias causing the device to float. This can occur in the reflow process during manufacturing. When using a heavier package like the eMSOP package, 12-mil vias can be used while avoiding solder wicking.

The total copper area required can be determined by referring to the graph in ***Figure 5***. This is a typical graph of the Θ_{JA} which is the thermal impedance from the device to the ambient air. Multiplying Θ_{JA} by the power dissipated by the device will result in the temperature difference between the ambient air and the junction of the device. From ***Figure 5***, it is evident that an increased copper area attached to the DAP improves the thermal performance of the device. As the copper area increases beyond two square inches, the improvement of thermal performance from increased copper area decreases.

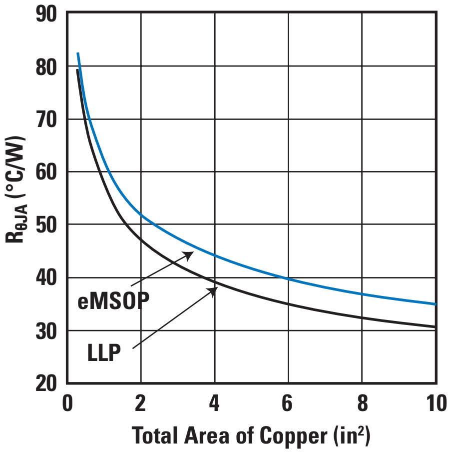

Figure 5. LLP-10 and eMSOP-10 θ_{JA} vs. Total Copper Area with No Airflow

Conclusion

Besides a smaller solution size, a high switching frequency regulator has the advantage of a faster transient response and reduced output voltage ripple. But, new design challenges exist that require careful layout of the printed circuit board to improve the performance of the device and effectively dissipate heat from a smaller space. By integrating the compensation network and reducing the number of external components, National Semiconductor's high switching frequency regulators reduce design complexity and save engineers valuable time while preserving valuable printed circuit board space.

National Semiconductor
2900 Semiconductor Drive
Santa Clara, CA 95051
1 800 272 9959

Mailing Address:
PO Box 58090
Santa Clara, CA 95052

For Additional Design Information

national.com/edge