Technical Article

Four Design Tips to Obtain 2MHz Switching Frequency

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Designers must meet many electromagnetic compatibility (EMC) requirements for automotive applications, and choosing the right switching frequency (fsw) for the power supply is important to meet these requirements. Most designers select an fsw outside the medium-wave AM broadcast band – typically 400kHz or 2MHz, where electromagnetic interference (EMI) must be limited. The 2MHz option is desirable for many reasons, so in this post, I'll provide some key considerations when trying to operate at 2MHz using TI's new TPS54116-Q1 DDR memory power solution as an example.

The first and most important consideration when operating at a 2MHz fsw is the minimum on-time of the converter. In a buck converter, when the high-side MOSFET turns on, it must stay on for a minimum on-time before it can turn off. With peak current-mode control, the minimum on-time is usually limited by the blanking time of the current-sense signal. The highest minimum on-time of a converter usually occurs at the minimum load condition and there are three reasons for this.

1. There are DC drops in the circuit at heavier loads, increasing the operating on-time.
2. The rise time and fall time at the switching node. During the dead times (the time between when the low-side MOSFET turns off to when the high-side MOSFET turns on and between when the high-side MOSFET turns off and the low-side MOSFET turns on), the current through the inductor charges and discharges any parasitic capacitance at the switching node. At light loads there is less current in the inductor, so the capacitance charges and discharges more slowly, causing longer rise and fall times at the switching node. These longer rise and fall times cause the effective pulse width at the switching node to increase.
3. Low-to-high dead time. When the low-side MOSFET turns off and before the high-side MOSFET turns on again, the current through the inductor charges the voltage at the switching node until the body diode of the high-side MOSFET clamps the switching-node voltage. As a result, the switching node is high during the low-side MOSFET off-to-high-side MOSFET on dead time. Since the switching node is high during this time period, the low-to-high dead time adds to the effective minimum pulse width. In Figure 1, you can see that although the on-time is the same, the pulse width is larger.

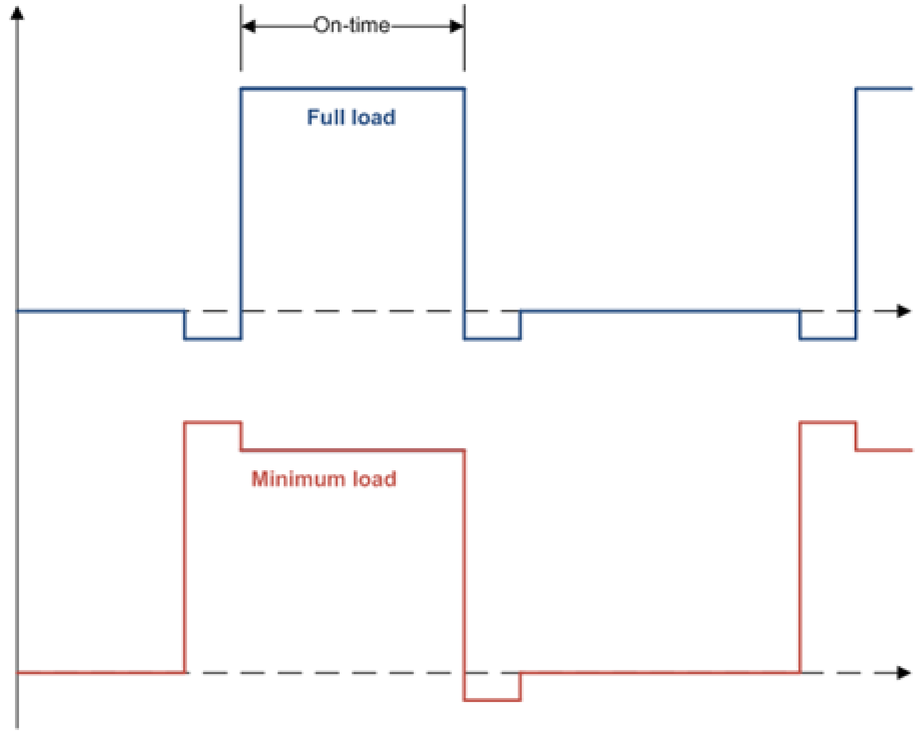

Figure 1. Pulse-width at Full Load vs. No Load

The second consideration when trying to operate at 2MHz is the minimum input voltage (V_{IN}) to output voltage (V_{OUT}) conversion ratio. This is related to the minimum on-time of the converter because this ratio sets the on-time at which the converter needs to operate. For example, if a converter has a minimum on-time of 100ns and operates at 2MHz, using Figure 2 the minimum conversion ratio (D_{min}) it can support is 20%. If a given V_{IN}-to-V_{OUT} ratio requires an on-time less than the minimum on-time, most converters enter a pulse-skip mode to keep the output voltage regulated. When pulse-skipping, the fsw varies and can cause noise in frequencies where noise needs to be limited.

$$D_{min} = ton_{min} \times f_{SW}$$

Figure 2. Equation 1

In automotive applications where the power supply connects to a battery, the on-time must support conversion from a typical V_{IN} range of 6V to 18V. Using Figure 3 with an 18V maximum input and 20% conversion ratio, the minimum output voltage is 3.6V. When directly connected to the battery, large voltage spikes can occur (such as during load dump) that exceed this typical range. Depending on the requirements of the application, the converter may or may not be allowed to pulse-skip during input voltage spikes.

$$Vout_{min} = D_{min} \times Vin_{max}$$

Figure 2. Equation 2

A regulator connected to a 3.3V or 5V rail can more easily operate at 2MHz. For example, the TPS54116-Q1 has a maximum minimum on-time of 125ns, so at 2MHz the minimum duty cycle is 25%. The minimum output voltage supportable from a 3.3V input is 0.825V; from a 5V rail it is 1.25V. A full analysis for the minimum output voltage in a given application should also include the tolerance on V_{IN} and fsw.

The third consideration when trying to operate at 2MHz is AC loss in the inductor. AC loss increases with fsw so it needs to be considered when choosing an inductor for 2MHz. Some inductors use a core material designed for lower AC losses to give better efficiency at higher frequencies. Most inductor vendors provide a tool to estimate AC loss in their inductors.

The fourth consideration when trying to operate at 2MHz is the tradeoff between size and efficiency. When selecting the fsw for a DC/DC converter, you must make a trade-off between size and efficiency. The inductor size and some converter losses increase with fsw. Comparing 400 kHz to 2MHz specifically, a 2MHz design will use 5x smaller inductance but have a 5x larger switching loss. A 5x smaller inductance means a smaller inductor size.

The two main losses in a converter related to fsw are switching loss in the high-side MOSFET and dead-time losses. Figure 4 is a basic estimate of these loses, which you can use to further analyze the effect of increased loss with higher fsw. For example, with a 5V input, 4A load, 3ns rise time, 2ns fall time, 0.7V body-diode drop and 20ns dead time, the estimated power loss is 325 mW at 2MHz and 65mW at 400kHz.

$$P(f_{SW}) = \frac{1}{2} \times Vin \times Iout \times (t_{rise} + t_{fall}) \times f_{SW} + Vbody \times Iout \times (t_{dead}lh + t_{dead}hl) \times f_{SW}$$

Figure 2. Equation 3

Extra power losses cause a higher operating junction temperature. Using Figure 5 with $R_{\theta JA}$ = 35°C/W from the TPS54116-Q1EVM-830, the integrated circuit's junction temperature will increase by only about 9°C. The thermal performance can vary with different PCB layouts.

$$T_{rise} = R_{\theta JA} \times (P(2MHz) - P(400kHz))$$

Figure 2. Equation 4

Just because the data sheet has 2MHz on the front page does not mean that 2MHz is achievable across all operating conditions. Switching at 2MHz has its advantages and disadvantages, and there's always a trade-off between the size of your DC/DC converter solutions and efficiency. Order the TPS54116-Q1EVM-830 evaluation module and start your 2MHz design in WEBENCH® Power Designer now.

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