Selecting the Switching Frequency in Automotive Applications

Introduction

This article will discuss the key factors in the energy conversion process, then analyze automotive applications at three switching frequency (f_{SW}) levels: 2MHz, 100kHz, and 500kHz.

Energy Conversion Process

In a buck circuit, the energy conversion process includes the input capacitance (C_{IN}), output capacitance (C_{OUT}), the energy stored in the inductor, and f_{SW}. f_{SW} can impact the following factors: device size, efficiency, temperature rise, and the minimum turn-on and minimum time-off times.

Device Size

The relationship between device size and f_{SW} can be determined using C_{IN}, C_{OUT}, and the energy stored in the inductor. As f_{SW} rises, less capacitance and inductance are required, which reduces device size. Figure 1 shows the required peripheral device parameters that can be obtained for 12V to 3.3V operating conditions at 2A.

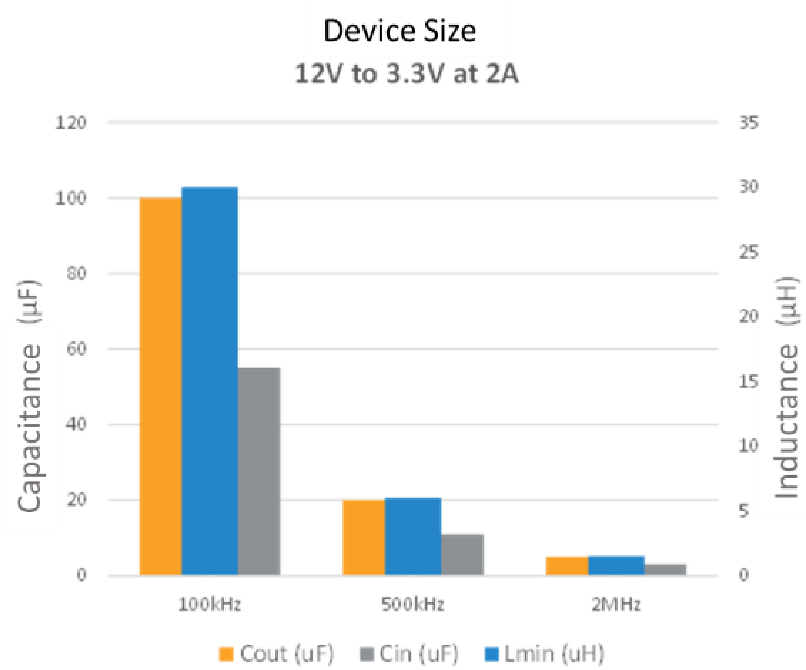

Figure 1: Required Peripheral Device Parameters

Switching Loss and Temperature Rise

Under the same operation conditions from Figure 1, the efficiency curves at different frequencies were obtained (see Figure 2). These parameters are useful because they allow designers to determine the device's temperature rise, where lower efficiency results in a higher temperature rise.

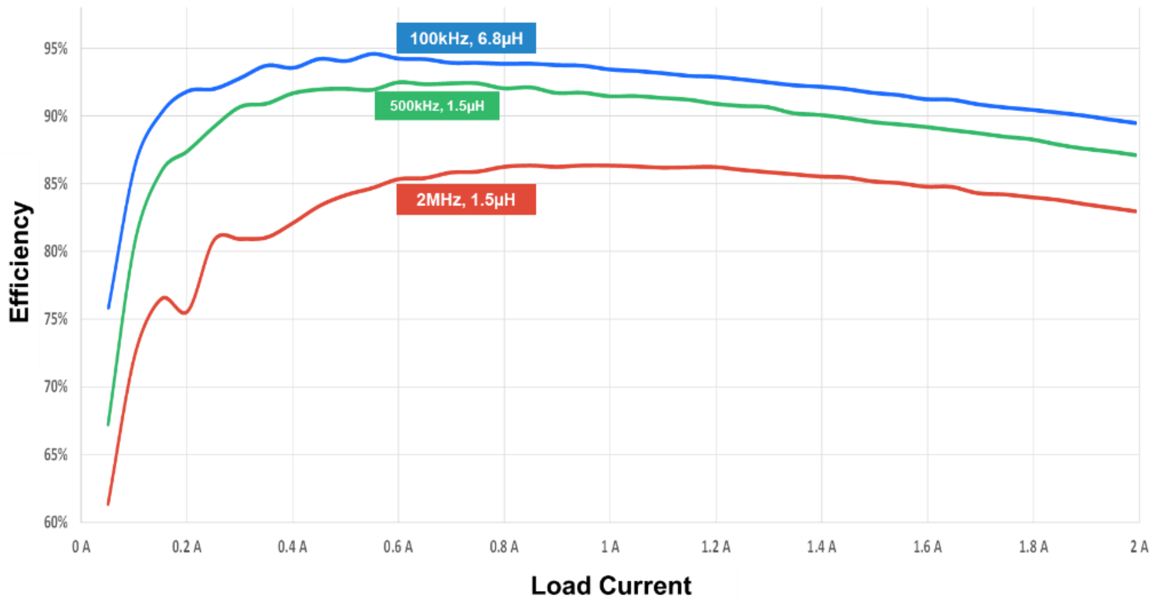

Figure 2: Efficiency Curves at Different Frequencies

Minimum On and Off Time Limit

If the input voltage (V_{IN}) increases, the chip's switching on time decreases. In this situation, decreasing f_{SW} can avoid triggering the device's minimum on time (t_{ON_MIN}). If V_{IN} decreases, the chip's switching off time decreases. In this situation, decreasing f_{SW} can avoid triggering the device's minimum off time (t_{OFF_MIN}).

Selecting the Switching Frequency

We will analyze performance at three different f_{SW} levels (100kHz, 500kHz, and 2MHz) to determine how these frequencies affect automotive applications. To accommodate varying f_{SW} levels, f_{SW} was set to be below 300kHz, between 300kHz and 530kHz, or above 1.8MHz.

The advantages and disadvantages of each f_{SW} level is described below:

1. 100kHz: Automotive applications can achieve excellent efficiency at this frequency with low switching loss. At 100kHz, application can achieve stable operation at an ambient temperature of 85°C with greatly reduced heat generation. However, this frequency is not recommended for space-constrained applications.
2. 500kHz: Most automotive USB charging and LED lighting applications operate at 500kHz because it optimizes the tradeoff between efficiency and solution size.
3. 2MHz: At 2MHz does not generate significant EMI in the AM frequency band. However, this frequency may exacerbate EMI in the high frequency band.

f_{SW} selection is important to manage EMI for DC/DC converters in automotive applications. Figure 3 shows a standard limit chart for CISPR25 Class 3 CE. The three f_{SW} levels (100kHz, 500kHz, and 2MHz) fall within these three intermittent regions.

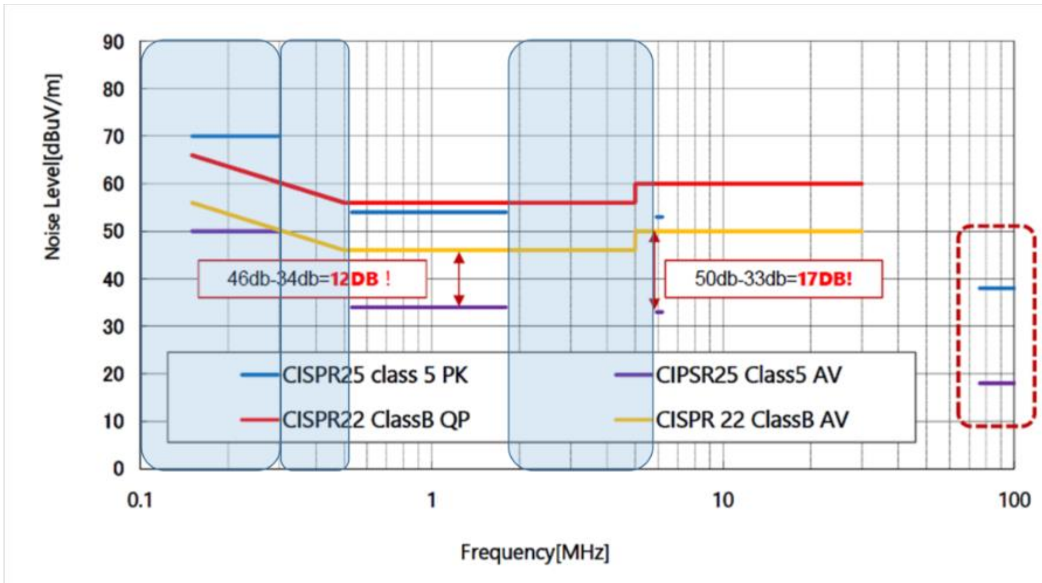

Figure 3: CISPR25 Class 3 CE Limit Standard Chart

The next step is to evaluate the three f_{SW} levels in different applications and select the required f_{SW} using three application examples: onboard camera sensors, onboard mobile charging devices, and autonomous driving controllers.

Onboard Camera Sensors

Figure 4 shows a diagram of an onboard camera sensor.

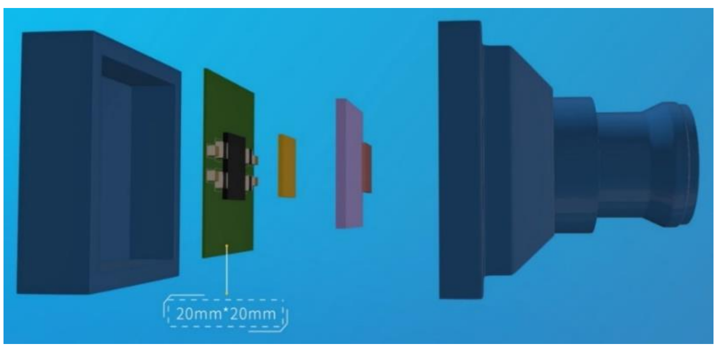

Figure 4: Onboard Camera Sensor

Onboard sensors are typically made to be as small as possible, which means the peripheral components (e.g. inductors and capacitors) should also be small. For switching power supplies, f_{SW} must be high to ensure that the inductors and capacitors can stay small. For space-constrained applications, setting f_{SW} to 2MHz is recommended because it mitigates EMI issues while minimizing heat generation and the camera's power consumption.

For a 12V input, the current is generally between 100mA and 200mA, leading to a relatively small conduction loss for the DC/DC converter. Therefore, even if f_{SW} increases, the higher switching loss does not produce a significant temperature rise for the power supply. At the same time, the camera module's overall power consumption is minimized. The power supply here is a highly integrated power management IC (PMIC) solution. These factors optimize the high-frequency dI/dt loop and improve EMI performance.

Setting f_{SW} to 2MHz ensures that a small solution can obtain excellent efficiency and EMI performance.

Onboard Mobile Charging Devices

Figure 5 shows onboard USB charging.

Figure 5: Onboard USB Charging

USB charging started from the original single-port USB Type-A, which was updated to the dual-port USB Type-A. Dual-port USB Type-C followed, leading up to the current USB Type-C power delivery (PD) ports. These charging devices have size requirements for the PCB board. Unlike camera modules though, the product is typically constrained at about 50mmx50mm.

If the PCB board size is also limited by the layout and device size, the 2MHz f_{SW} level is not an optimal solution. Consider a dual-port USB Type-C where each charging port can reach 5V at 3A. The total power reaches 30W, and even considering the 94% efficiency, there is still about 2W of heat on the PCB board. Testing in onboard automotive environments typically considers stable operation at 85°C.

Considering the factors of power consumption and size, the 500kHz f_{SW} level is the most suitable f_{SW} option for onboard mobile device chargers.

Autonomous Driving Controllers

Figure 6 shows a 360-degree surround view electronic control unit (ECU).

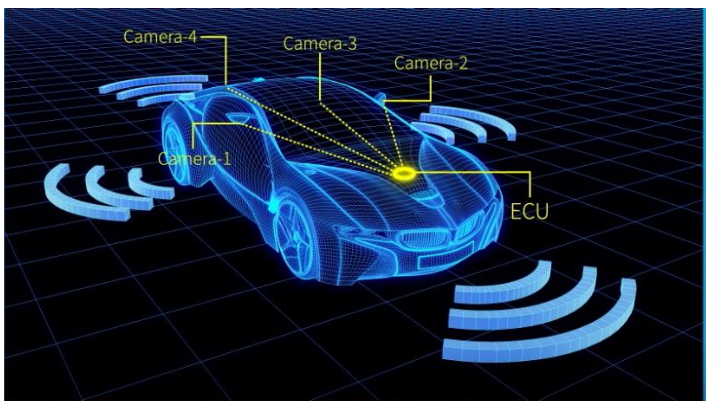

Figure 6: 360-Degree Surround View ECU

For autonomous driving controllers, the board area has more space. Compared to camera modules and USB charging, an autonomous driving controller has sufficient PCB layout area and space for heat dissipation. As a result, f_{SW} selection is not as strict, but the chip's t_{ON} and t_{OFF} limits must be considered.

For example, in a commercial vehicle, the battery system is 24V and the highest steady-state voltage reaches 32V. In a 360-degree surround view system, a 3.3V power supply is typically required, leading to a large voltage difference. If f_{SW} is set to 2MHz, the on time (t_{ON}) can be calculated with Equation (1):

$$T_{ON} = \frac{3.3V}{32V} \times \frac{1}{2.0MHz} \approx 51ns \quad (1)$$

Figure 7 shows the specifications of the MPQ4323-AEC1's minimum on time (t_{ON_MIN}). For this application, a lower frequency must be selected to avoid triggering t_{ON_MIN}.

Minimum on time	t_{ON_MIN}			65	80	ns
Minimum off time	t_{OFF_MIN}			50	70	ns

Figure 7: Minimum On Time Specifications

Occasionally, an 8V power rail is provided in the surround view system to act as the camera module's input power. Assuming a 12V battery system for passenger cars, it is often necessary to consider the 9V to 16V V_{IN} operating range with operating conditions at V_{IN} = 9V and V_{OUT} = 8V. If the 2MHz f_{SW} level is selected, the off time (t_{OFF}) can be calculated with Equation (2):

$$T_{OFF}=(1-\frac{8V}{9V})\times\frac{1}{2.0MHz}\approx 55.6ns \quad (2)$$

Figure 8 shows the specifications of the minimum off time (t_{OFF_MIN}). The maximum time is 70ns, meaning t_{OFF_MIN} would be triggered.

Minimum on time	t_{ON_MIN}			65	80	ns
Minimum off time	t_{OFF_MIN}			50	70	ns

Figure 8: Minimum Off Time Specifications

To ensure the chip's stable operation at a set f_{SW}, it is necessary to select the optimal f_{SW} based on specific V_{IN} and output voltage (V_{OUT}) conditions.

Conclusion

This article reviewed the overall energy conversion process and discussed the different characteristics of three f_{SW} levels (2MHz, 100kHz, and 500kHz). Using application examples with onboard sensors, onboard mobile charging devices, and autonomous driving controllers, we obtained the most suitable f_{SW} levels that achieve stable switching power supply performance.

For more information, refer to MPS's ADAS and Infotainment applications.