Reducing radiated EMI in DC-DC Switching converters

Abstract

Embedded electronic products that use DC/DC switching converters are major sources of EMI and often struggle to meet regulatory emission limits. This white paper focuses on reducing radiated EMI from switched DC/DC controllers used in low-power onboard applications, such as telecom, aerospace, and automotive systems. It evaluates methods for reducing EMI at the source without relying on additional measures such as shielding, PCB layout changes, or filtering. By analyzing the switching characteristics of the MOSFET, the key component in these converters, this paper proposes an improved approach for optimizing switching behaviour and demonstrates that radiated EMI can be reduced.

Introduction

DC/DC switching converters are among the most efficient methods for converting one DC voltage level to another. They are widely used in aerospace, commercial, industrial, and automotive applications because they offer high operating frequency, high efficiency, high power density, and low cost. Their power ratings range from a few milliwatts to hundreds of megawatts. This paper focuses on low-power DC/DC switching converters intended for onboard power applications, where they serve as a critical power source. Buck, boost, and buck-boost controllers are among the most commonly used converter topologies. A typical DC/DC converter consists of a switching controller, switching elements, and energy-storage components. The controller IC implements the converter logic, while one or more external high-current and/or high-voltage semiconductor switches handle the power switching. In most designs, these switches are MOSFETs and diodes, while inductors and capacitors are used as the primary energy-storage elements.

Problem statement

A recent trend in DC/DC switching converter design is to increase switching frequency to improve efficiency, reduce passive component size, and increase power density. However, this trend has made EMI a significant design challenge. Higher EMI reduces device electromagnetic compatibility (EMC) and can prevent products from meeting regulatory emission limits. Switching controllers generate two types of EMI: conducted EMI and radiated EMI.

In onboard applications, switching converters are an important source of EMI. The high dv/dt and di/dt transients that occur during MOSFET commutation are the primary sources of both conducted and radiated EMI in switching controllers. High dv/dt can create common-mode interference in power electronic circuits, while high di/dt can cause voltage and current overshoot and ringing. The ringing magnitude depends on the MOSFET switching speed and the parasitic inductances in the PCB layout and MOSFET package. Conducted EMI is commonly reduced using input filtering, while radiated EMI is addressed through shielding, optimized component placement, and PCB layout techniques. However, these methods alone may not be sufficient if the MOSFET switching speed is not optimized. Even well-designed systems that use filtering, shielding, optimized component placement, and careful PCB layout can still fail to meet regulatory radiated emission limits.

Proposed Solution

MOSFETs are widely used in switching converters because they offer high switching speed and low power loss. Their selection has a significant impact on the EMI performance of a DC/DC converter. In these converters, MOSFETs are typically hard-switched, with switching behaviour determined by the gate drivers in the controller IC and the device-level switching parameters of the MOSFETs. This white paper focuses on those MOSFET switching parameters during device selection. Fast MOSFET switching, combined with circuit parasitic inductances, increases EMI because of high dv/dt and di/dt at the converter switch node. High di/dt generates voltage spikes according to **V = L * (di/dt)**, where L is the self-inductance of the current loop and di/dt is the current transition rate. Reducing these spikes requires slowing the current transition rate, which in turn requires slower MOSFET switching. However, slower switching increases switching losses and reduces converter efficiency. Therefore, an appropriate trade-off must be established between EMI reduction and efficiency. The objective is to reduce radiated EMI by slowing MOSFET switching without compromising converter efficiency to an unacceptable level.

The rise time and fall time of the MOSFET switching is given by:

$$\mathbf{t_r = R_G * Q_{GD}/(V_{GS}-V_{gp})} \qquad \mathbf{(1)}$$

$t_f = R_G * Q_{GD}/(V_{gp})$ **(2)**

Equations (1) and (2) show that MOSFET turn-on and turn-off speeds depend on the gate-drive voltage (V_{GS}), gate resistance (R_G), gate plateau voltage (Vgp), and gate-drain charge (Q_{GD}). V_{GS} is set by the switching controller IC, while R_G, Vgp, and Q_{GD} are determined by the selected MOSFET. A common way to reduce switching speed is to add an external gate resistor, but this increases BOM cost and introduces additional resistor power dissipation. This white paper instead proposes using MOSFET gate charge to optimize switching speed. The following synchronous buck converter example illustrates how Q_{GD} affects MOSFET switching speed, power loss, and radiated EMI.

Example of Solution

A synchronous buck converter is a DC/DC converter that steps down the input supply voltage to a lower output voltage for the load. It is a switched-mode power supply that typically uses two semiconductor switches—the high-side MOSFET Q1 and the low-side MOSFET Q2—along with at least one energy-storage element, such as a capacitor, an inductor, or both. In this converter, MOSFET switching produces high dv/dt and di/dt at the switch node (Vsw, shown in Figure 1), which is a major source of EMI.

External N-channel standard-level power MOSFETs are usually selected based on on-resistance (RDS(ON)), maximum drain-source voltage (VDSS), and maximum continuous drain current (ID). However, total gate charge (QG) should also be considered because it affects switching speed, power loss, and the EMI performance of the switching converter.

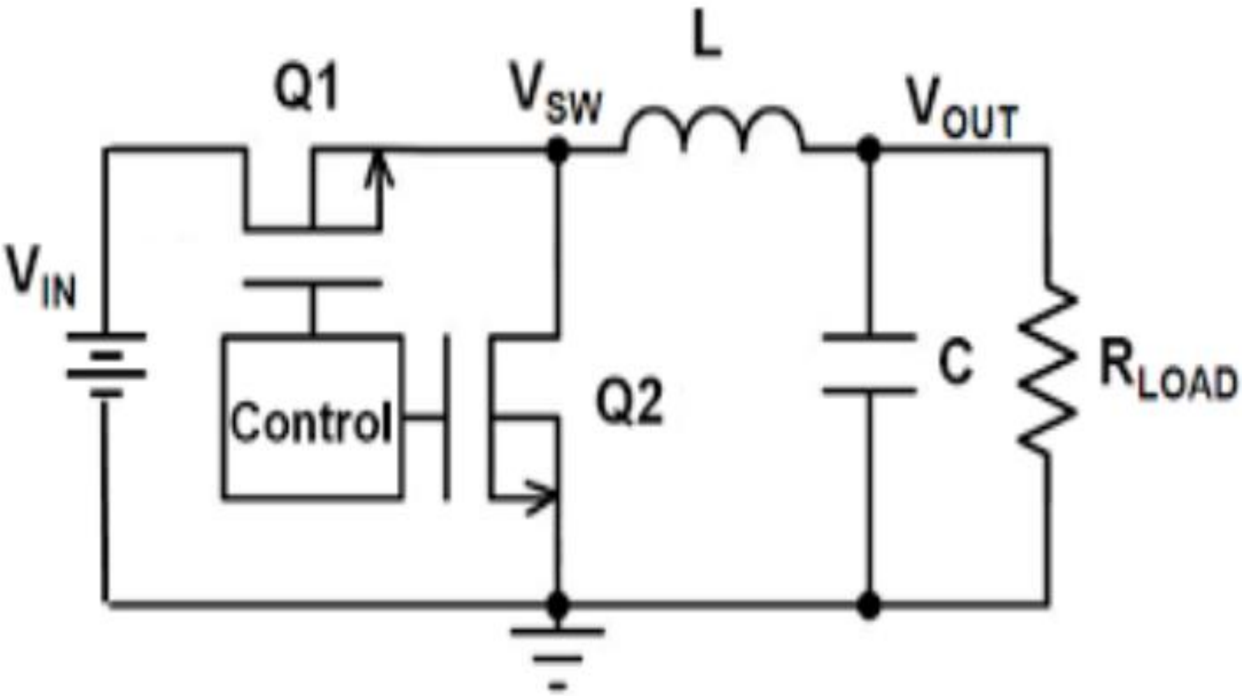

Figure 1: Synchronous Buck Converter architecture

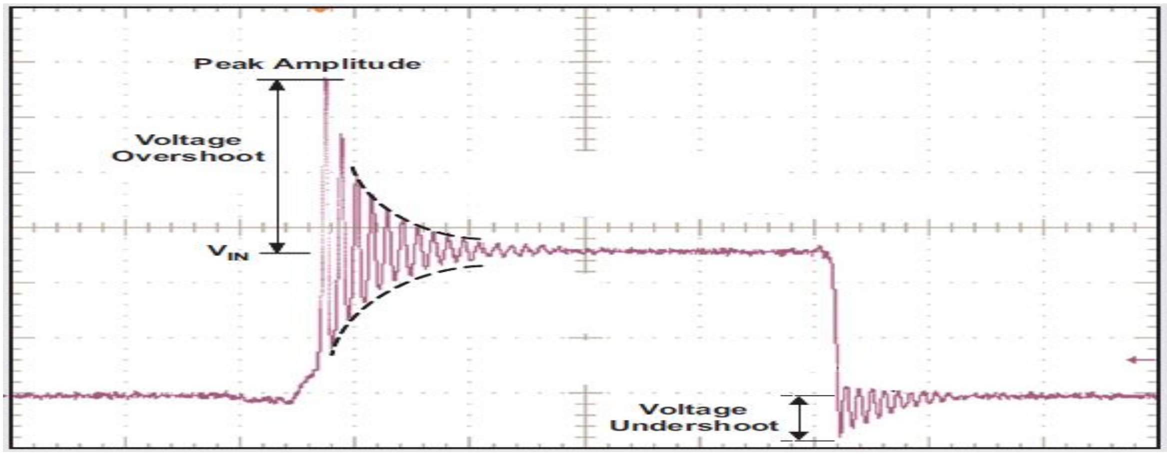

Figure 2: Overshoot and ringing in Switch node volatge (VSW)waveform

The following equations calculate MOSFET power loss and radiated EMI. For this analysis, only the high-side MOSFET (Q1) is considered. Its total power loss is the sum of conduction loss and switching loss, as defined below:

$P_{COND(H)} = I_{OUT}$^2 * (V_{OUT}/V_{IN}) * $R_{DS(ON)}$ **(3)**

$P_{SW(H)} = (V_{IN} * I_{OUT} *(tr+tf)*Fsw)/2$ (4)

$P_{TOTAL(H)} = P_{COND(H)} + P_{SW(H)}$ (5)

$P_{COND(H)}$ = Conduction Loss in High side MOSFET
$P_{SW(H)}$ = Switching Loss in High side MOSFET
V_{IN} = Input Voltage to the buck converter
V_{OUT} = Output Voltage of the buck converter
$R_{DS(ON)}$ = On resistance of MOSFET
I_{OUT} = Output Voltage of the buck converter
Fsw = Switching frequency of the buck converter

The following equation represents the electric field for differential-mode EMI. The radiated field is proportional to the square of frequency (f), loop area (A), and current (I), and is inversely proportional to the distance (r) between the radiating source and receiving antenna. Here, frequency is expressed in hertz, A in m², I in amperes, and r in meters.

$E = (263e\text{^}{-16} \times f^2 \times A \times I) / r$ V/m (5)

Usually the highest frequency component with significant energy (the Band Width) is equal to 0.35 divided by the rise time of the switch node shown in Figure 1.

f = Band Width = $0.35 / t_r$ (6)

In the below table using the above equations we shall see that how two MOSFETs with different gate charges used in a buck converter shall have impact on the power losses and radiated EMI.

Let V_{IN} = 5V, V_{OUT} = 3.3V, I_{OUT} = 5A, Fsw = 400KHz, VGS = 7.4V, loop area(A) = 12mm^2, r = 1m

MOSFET 1	MOSFET 2
Q_{GD} = 8 nC	Q_{GD} = 25nC
$R_{DS(ON)}$ = 15mohm	$R_{DS(ON)}$ = 15mohm
Vgp = 3V	Vgp = 5.2V
R_G = 1.3ohm	R_G = 1.3ohm
t_r = 2.36 nS	t_r = 14.77ns
t_f = 3.46nS	t_f = 6.25ns
$P_{COND(H)}$ = 225mW	$P_{COND(H)}$ = 225mW
$P_{SW(H)}$ = 2.9mW	$P_{SW(H)}$ = 105mW
$P_{TOTAL(H)}$ = 227.9mW	$P_{TOTAL(H)}$ = 330mW
f(Band width) = 148.3MHz	f(Band width) = 23.7MHz
E = 34.7mV/m = 90.8dBuV/m	**E = 886uV/m = 58.95dBuV/m**

The table shows that, in a buck converter, selecting a MOSFET with higher gate charge can significantly reduce radiated EMI. However, the allowable MOSFET gate charge is limited by the selected switching controller IC. Therefore, when choosing a higher-gate-charge MOSFET, designers must ensure that its gate charge remains within the controller IC's maximum gate-drive capability.

This EMI reduction is achieved without changes to PCB layout, filtering, or shielding. The trade-off is an increase in power loss; however, for low-power applications up to 50 W, this increase is relatively small. The same approach can also be applied to boost and buck-boost converters because the MOSFET switching characteristics remain similar.

Conclusion

This white paper demonstrates how MOSFET gate charge can be used to optimize switching speed and reduce radiated EMI in switched DC/DC converters. The methods presented can help estimate radiated EMI caused by MOSFET switching during the design phase. This enables designers to select suitable MOSFETs and establish an effective trade-off between converter efficiency and radiated EMI performance.

References

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