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Application Note 9013

July, 2000

Reducing Switching Losses with QFET in a Step-up Converter

by B.C. Lim

Introduction

Efficiency is a critical factor in designing a switching mode power supply. With the increasing emphasis on efficiency, designers are concentrating on selecting MOSFETs with low switching losses. As frequencies increase, switching losses of the MOSFETs play a much greater role in the overall system losses.
Fairchild Semiconductor now offers a family of QFETs, the new power MOSFETs, which feature low on-resistance ($R_{DS(on)}$), and gate charge (Qg) characteristics to achieve lower switching and drive losses.
This application note describes a device which is effective in reducing system losses in a 70W step-up converter. This step-up converter is usually used in a C-Monitor.

Basic operation of a step-up converter

The step-up converter accepts a DC voltage input and provides a regulated output voltage which must be greater than the input voltage. The basic circuit configuration of a step-up converter is shown in Figure 1. When switch (Q1) is turned on, the supply voltage V_i is applied across inductor (L). The diode (D) is reverse biased by voltage Vo. Energy is transferred from the input supply voltage to the inductor. When switch (Q1) is turned off, the energy stored in the inductor (L) induces a voltage such that the diode conducts and delivers the energy to the output load (R) and the output capacitor (C). In addition to the energy stored in the inductor, additional energy is transferred from the input directly to the output during the diode conduction time.

By Volt-second balancing of the two switching periods on the inductor as follows:

$$V_i \cdot DT_s = (V_o - V_i) \cdot (1 - D)T_s \ldots\ldots(1)$$

Therefore:

$$V_o = \frac{1}{1-D}V_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Controlling the duty cycle regulates the output voltage. Since the duty cycle is smaller than “1”, the output voltage is always greater than the input voltage.
The inductor voltage:

$$v_L = L\frac{di}{dt} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

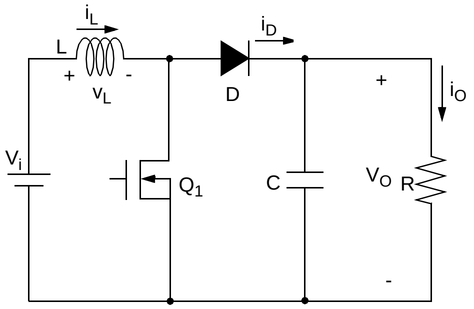


Figure 1. Basic circuit of a Step-up converter

Thus, when Q1 is turned on, the change in inductor current, Δi_L, is calculated as follows:

$$\Delta i_L = \frac{V_i}{L} D T_s \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

The average value of the inductor current, i_{av}, is:

$$i_{av} = \frac{1}{2}\Delta i_L + i_v = \frac{V_i}{2L} D T_s + i_v \ldots\ldots\ldots\ldots(5)$$

The current averaged over a complete switching cycle is equal to the output current because the average current in the output capacitor must be equal to zero. Because i_o is equal to $i_{av,}$ therefore:

$$i_v = i_o - \frac{V_i}{2L} D T_s \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

Being at the boundary between the continuous and the discontinuous mode the inductor current goes to zero at the end of the off period.

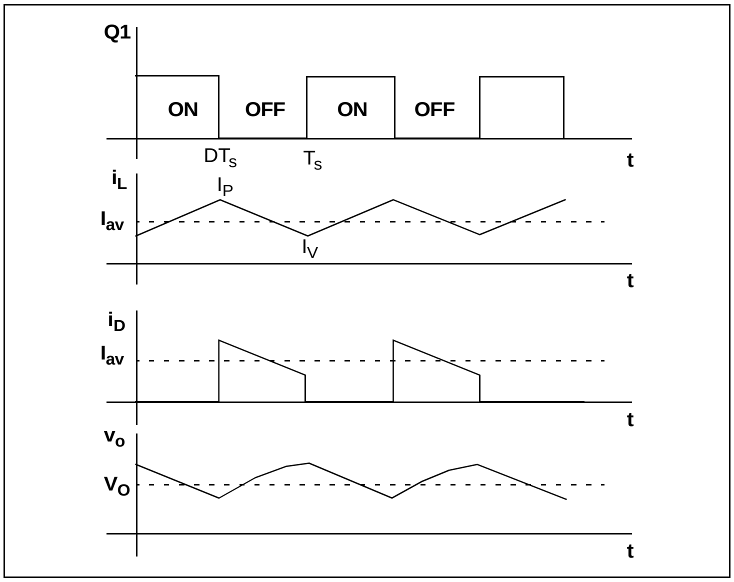


Figure 2. Waveform of each part

In continuous mode:

$$i_o > \frac{V_i}{2L} DT_s \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

To maintain low inductor peak current and good output ripple, it is recommended that Δi_L be about $0.3i_o$. Based on the above, Eq. (4) may be rewritten as follows:

$$L = \frac{V_i}{0.3i_{o,\,max}} \cdot DT_s \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

In this step-up converter the input voltage is 50V; max. output current is 0.6A (70W); max. turn on time is 7.3µs. Therefore,

$$L = \frac{50}{0.3 \times 0.6} \cdot 7.3 \times 10^{-6} = 2[mH]$$

While switch (Q1) is on, the output capacitor is discharged and the peak-peak voltage ripple Δv_o is given by

$$\Delta v_o = \frac{\Delta Q}{C} = \frac{i_o \cdot DT_S}{C} = \frac{V_o DT_s}{RC} = \frac{V_o D}{RCf} \ldots\ldots(9)$$

Rearranging Eq.(9):

$$C = \frac{DT_s}{R} \times \frac{V_o}{\Delta v_o} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(10)$$

Δv_o is 1.2V(1%); DT_S is 7.3µs; V_O is 120V. Thus, using Eq.(10) we obtain,

$$C = \frac{7.3}{200} \times \frac{120}{1.2} = 3.65[\mu F]$$

In this step-up converter we used a 500[uF] output capacitor for safe operation against the instantaneous variation of output load.

Main electrical characteristics of QFET

The trend in power supply design is focused on increasing efficiency by reducing loss. To obtain the high efficiency of a power system, it is important to select a switching device with low on-resistance ($R_{DS(on)}$) and gate charge (Qg) characteristics. Fairchild Semiconductor offers a family of QFET power MOSFETs that features on-resistance ratings which are lower than conventional devices by as much as 20 percent, balanced with gate charge characteristics that are reduced by 40 percent to achieve lower conduction and switching losses.

Device	Package	$R_{DS(on)}$ [Ω] typical	Qg [nC] typical	$R_{DS(on)}$ Improvement	Qg Improvement
FQP10N20	TO-220	0.28	13.5	16.2%	38.6%
Conventional Device	TO-220	0.334	22		

Table 1: Comparison of improved Rds(on) and Qg ratings

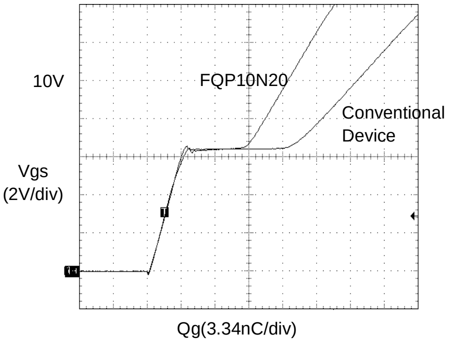


Figure 3. Gate Charge Comparison

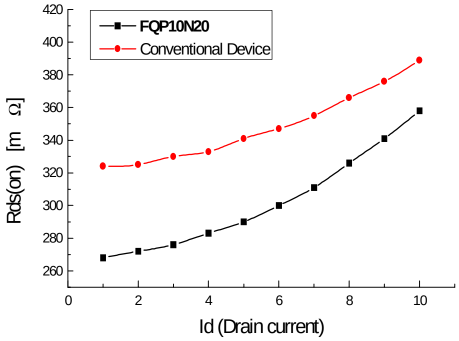
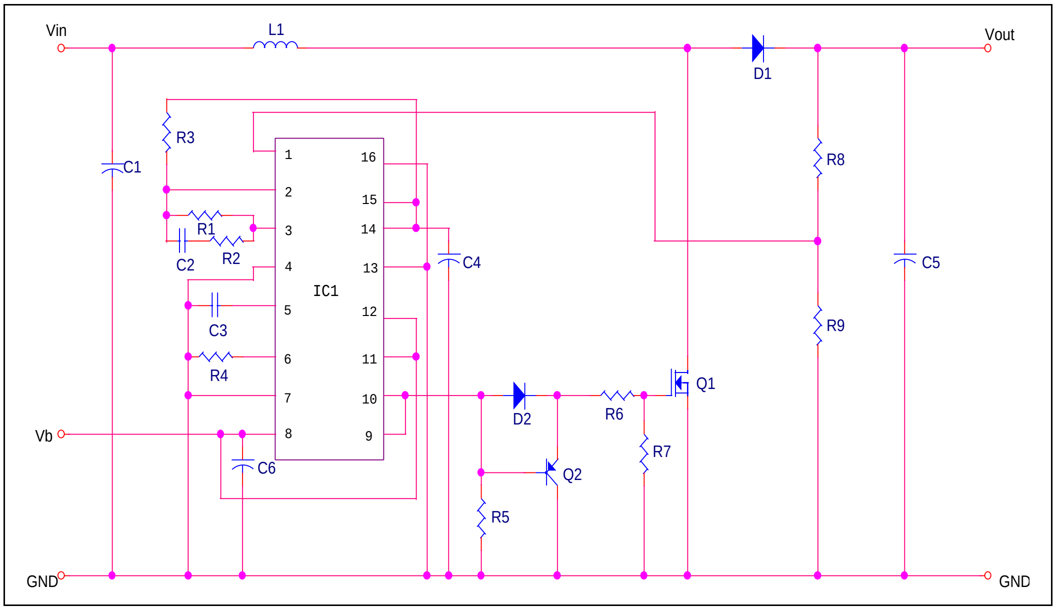


Figure 4. On-Resistance Comparison

Table 1 shows an example of the value for QFET (FQP10N20, 200V/10A), which is compared with a conventional MOSFET counterpart. Figure 3 shows the gate charge comparison graph between FQP10N20 and a conventional device. With the reduction of gate to drain capacitance (Miller capacitance), the total gate charge of a QFET (FQP10N20) is smaller than that of a conventional device by 40 percent. An advantage of this lower gate charge is reduced switching losses which improves efficiency in high frequency applications. Higher frequencies can also be employed, particularly to reduce the size of the inductor and heat sink. Figure 4 shows how $R_{DS(on)}$ varies under different drain current conditions. A QFET is lower than a conventional device by approximately 20 percent. A lower $R_{DS(on)}$ has the advantage of reducing conduction loss.



- Input voltage: DC 50V, output voltage: 120V ± 1%
- Maximum output load: 70W
- Switching frequency: 80KHz
- Efficiency: 90% @Full load

Figure 5. Step-up Converter

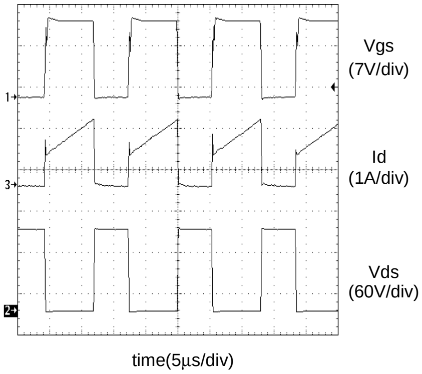


Figure 6. FQP10N20 Operating Waveform

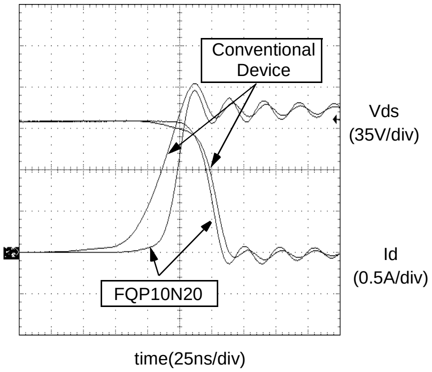


Figure 7. Switching off Waveform

The comparison of QFET & conventional MOSFET in step-up converter

Figure 5 shows a design of a 70W step-up converter having an 80kHz operating frequency, which is usually used in a C-Monitor. It accepts a DC 50 voltage input and provides a regulated DC 120 voltage output. In this circuit we used a KA7500B (Fairchild Semiconductor), which is a voltage mode PWM IC. Figure 6 shows the operating waveform when the QFET (FQP10N20) is used as the switching device under a 52W output load and 80KHz operating frequency. When 15 volts is applied between the gate and source, the MOSFET fully turns on, and the drain current flows. Simultaneously, the drain-source voltage falls close to the ground level.

Figure 7 shows the switching-off waveform that compares a QFET with a conventional device at the same operating conditions as that of Figure 6. As shown, the QFET is faster than the conventional device in the rising time of drain to source voltage and the falling time of drain current. As a result, QFETs can reduce power losses in a power supply, facilitating either a smaller heat sink or cooler operation. Figure 8 shows the switching-off loss associated with QFETs and conventional MOSFETs. The area of the waveform is proportional to the energy that is dissipated in the device during turn-off. The loss area of the QFET is much less than that of a conventional device.

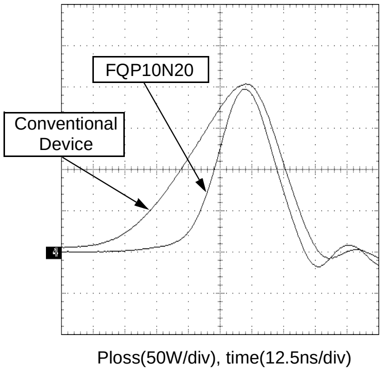


Figure 8. Switching off Loss Waveform

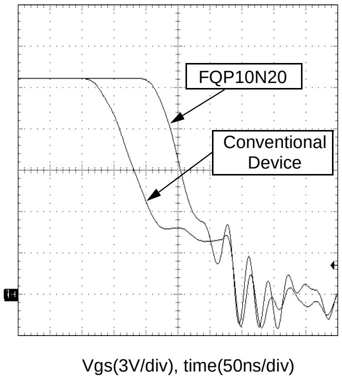


Figure 9. Vgs off Waveform

This is due to the low gate charge of the QFET. The difference in the switching loss between the two devices varies according to the value of the gate resistance (R6). Figure 9 shows the shape of a gate to source voltage waveform during turn-off. As shown, the falling time of a QFET is shorter than that of a conventional counterpart. This is also the result of a low gate charge. Figure 10 was generated from test data obtained from the step-up converter, which operated under different operating frequency conditions and with a 52W output load. As shown, the QFET provides 2~4% higher efficiency. The difference between the two devices becomes more noticeable as frequencies increase.

Summary

Selecting MOSFETs with optimum characteristics is the key to designing a high efficiency switching power supply. A power MOSFET’s contribution to converter losses is mostly due to conduction and switching losses. To improve efficiency, obtaining MOSFETs with low Rds(on) and Qg is important. Fairchild Semiconductor introduces the QFET family, the new power MOSFETs, to address these needs. QFETs offer low on-resistance and gate charge specifications to improve the efficiency of the power system and to reduce heat-sinking requirements. The QFET family allows the designer to dramatically reduce switching losses, especially in high frequency applications. The overall system cost can be further reduced by operating this QFET family at high frequencies.

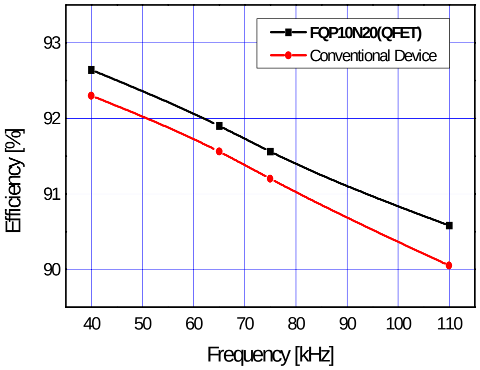
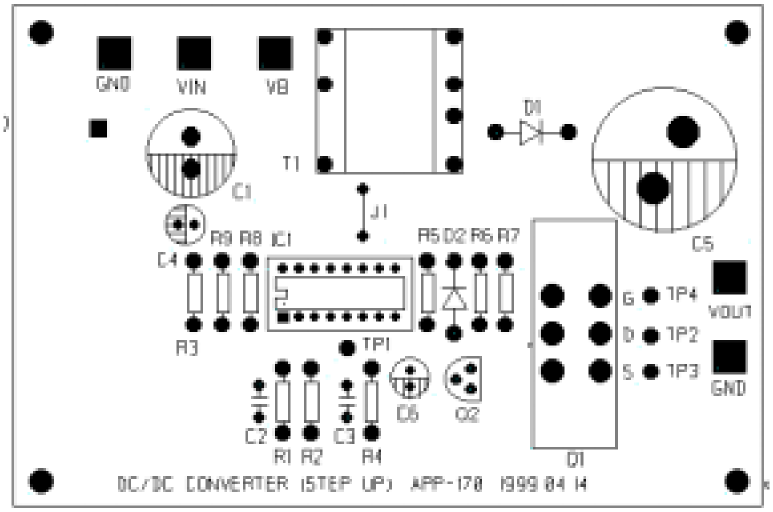


Figure 10. Efficiency Comparison Under Different Operating Frequency

Appendix

Circuit Board Layout



Parts List

Part	Specification
R1	1MΩ (1/4W)
R2	47KΩ(1/4W)
R3	5.1KΩ (1/4W)
R4	15KΩ (1/4W)
R5	1KΩ (1/4W)
R6	15Ω (1/4W)
R7	47KΩ (1/4W)
R8	27KΩ (1/4W)
R9	1.2KΩ (1/4W)
Q1	FQP10N20 (Fairchild)
Q2	KSA733-Y (Fairchild)

Part	Specification
C1	100µF (100V)
C2	0.1µF (104)
C3	0.001µF (102)
C4	0.1µF (104)
C5	500µF (200V)
C6	0.1µF (104)
D1	FE6D
D2	1N4148
L1	2mH
IC1	KA7500B (Fairchild)

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