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Application Note 9015

July, 2000

A180W, 100KHz Forward Converter Using QFET

by I.S. Yang

Introduction

The inherent performance advantage of power MOSFETs makes their use very attractive in switched mode power supplies. The fundamental advantage of the power MOSFET is the operation at fast switching speeds and high frequencies. Higher operating frequency allows further reduction in the size of the filter and magnetic components. The recent introduction of Fairchild Semiconductor's QFET power MOSFETs provide a significant improvement in the reliability of switching power supplies. This application note illustrates ways in which QFET power MOSFETs may be used in switched mode power supplies. It describes a 100KHz, 180W simple off-line power supply with three regulated DC voltages.

Description of the SMPS

The power supply employs a single ended forward topology. (see Figure 3) The targeted performance figures for the supply are as follows:

Input voltage: 220V AC
Output Voltage and current: V_{O1} = +5V/20A
V_{O2} = +12V/6A
V_{O3} = -12V/0.8A
Full load efficiency: 75% (79% at half load)
Switching frequency: 100KHz
Output Regulation: 5% (1/2 full load to full load)

The control circuit is implemented by the use of the current-mode controller IC, KA3842 which is very popular in controlling power supplies. A single 800V/7A rated power QFET in a TO-220 package is used as the main switching device. The performance of a power supply is dependent on various factors such as layout and transformer construction etc. Because of this the above performance data should be regarded as a guide to what may be achieved.
The stated purpose of this application note is not to offer an optimum design but to provide some guidelines on using QFETs for switched mode power supplies.

Basic Circuit Description

In order to take full advantage of the characteristics of the power MOSFET, it is necessary to review the basic circuit concepts of single ended forward converter. The basic schematic for the operation of a single ended forward converter is shown in Figure 1. The operating waveforms describe the idealized voltage and current across the MOSFET. When the MOSFET turns on, the current is transferred from the primary DC power source through the secondary transformer to the output circuit. During the MOSFET's off period, the magnetizing energy in the primary transformer winding is discharged into the clamp and reset circuits. There are two main techniques, RCD type and reset winding, to properly clamp and reset the forward converter's primary transformer to prevent a potential saturation problem. In this application note a RCD type clamp circuit is used. According to the different values of RCD components, the clamp voltage is developed variably in the primary winding. Usually, high voltage with twice the input DC voltage is used to obtain the maximum 50% duty ratio for resetting the transformer flux during the MOSFET's off period at low input DC voltage and full load. That means the peak voltage of twice the primary DC voltage is developed across the MOSFET during the off period. For a nominal line of 220V AC, the peak voltage could reach to at least 660V. This is the reason for a minimum voltage rating of at least 800V.

Simple equations for selecting power MOSFET are as follows:

$$BV_{dss} \geq V_{in(max)} \frac{1}{1 - D_{max}} + \begin{Bmatrix} \text{leakage} \\ \text{inductance} \\ \text{spike} \end{Bmatrix}$$

$$I_{d(max)} \geq \frac{1.2 P_o}{\eta V_{in(min)} D_{(max)}}$$

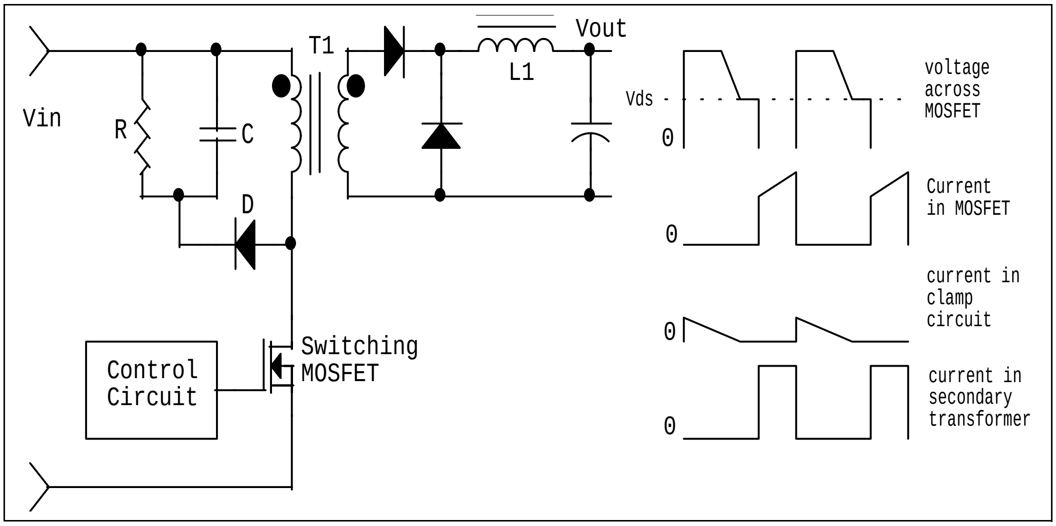


Figure 1. Basic Circuit and Idealized Waveforms

Input Voltage / Output Power	220V AC line	110V AC line
150W	FQP6N70	FQP6N50, FQP6N60
250W	FQP6N80, FQP7N80	FQP9N50, FQP12N60
300W	FQP7N80, FQP6N90	FQP12N60

Table 1: QFET Selection

QFETs appropriate for the respective power outputs are shown in Table 1. Fairchild Semiconductor's power MOSFET QFETs provide more useful characteristic ratings to the forward converter and other topologies by the reduction of on- resistance, gate charge, and improved reliability.

A RCD Type Clamp Circuit

Usually referred to as the RCD type (Resistor, Capacitor, and Diode), these clamp circuits are used to reset the main transformer to protect from potential saturation problems in this application. In Figure 1, the capacitor charges to the level of voltage of the diode to reset the primary transformer. Then the resistor dissipates the energy stored in the reservoir capacitor. These components develop varying clamp voltages by adjusting the value of the respective components. A high clamp voltage with an amplitude greater than twice the input voltage can deal with a maximum duty cycle beyond 50%. Because of this, the RCD type is particularly useful in a wide range of input supply designs. Clamp circuits have their advantages and disadvantages. The elimination of the reset winding is an obvious advantage in the reduction of transformer cost. The second advantage is that it is useful in a wide range of input power supplies. The main disadvantage of an RCD clamp circuit is the power loss from the resistor, resulting in the decrease of efficiency to some degree. The ground action of this simple clamp circuit is to reset the transformer at the end of the off period regardless of the level of the input voltage by adjusting the voltage across the capacitor with various values of three components. The simple process of acquiring an RCD network is as follows:

The energy stored in the primary transformer per one switching cycle is:

$$P_{ep} = \left[\frac{1}{2} \times L_{mag} \times I^2_{mag(pk)} + \frac{1}{2} \times L_s \times I^2_{L(pk)}\right] \times f$$

L_{mag}: the transformer magnetizing inductance
$I_{mag(pk)}$: the peak magnetizing current
L_S: the leakage inductance of the primary transformer
$I_{L(pk)}$: the peak current in the leakage inductance
f: the operating frequency

If the resistor dissipates the above energy, the main transformer is reset.

$$\frac{V_R^2}{R} = P_{ep}$$

V_R: the voltage across the resistor

These RCD type designs often need repetitive work with much of the development effort spent on designing the proper clamp network under all operating conditions. They are less likely to be at optimal efficiency at all lines and loads. Nevertheless, the RCD clamp circuit is very popular because it can make a system fairly efficient and cost-effective.

Designing the Transformer

After reviewing the core information offered by the various core manufacturers, it is obvious that the EER 3542 core adequately fits this application. The full height and width of the bobbin are needed for the required number of turns.

The following equations calculate the minimum number of turns needed by the primary transformer at the lowest DC bus voltage, which is 200V in this case, and the voltage per turn (V_{pt}):

$$V_{P(min)} = \frac{V_{in(min)} \times T_{on(max)}}{\Delta B \times A_e} = \frac{200\text{V} \times 5\mu\text{s}}{0.2\text{T} \times 109\text{mm}^2}$$

$$= 45 \text{ turns, approx. 50 turns}$$

$$V_{pt} = \frac{V_{in(min)}}{N} = \frac{200\text{V}}{50\text{T}} = 4\text{V/turn}$$

When the MOSFET is turned on, the voltage required at the secondary transformer to maintain the output voltage is:

$$V_{sec} = V_{diode} + V_{L(on)} + V_{out}$$

Where Vdiode is the output rectifier's forward voltage drop and $V_{L(on)}$ is the inductor voltage during the conduction time. As the output current is in continuous-mode operation, the relation between the secondary transformer voltage (Vsec) and output voltage is just equal to that of a Buck derived converter (see Figure 1):

$$V_{out} = D \times V_{sec} \qquad \text{D: Duty Ratio}$$

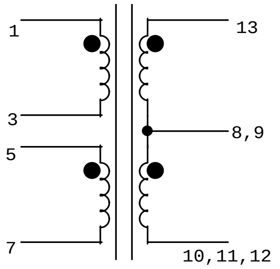
With a maximum duty cycle of 50%, Vsec is equal to 2Vout. Taking the voltage drop of Vdiode and $V_{L(on)}$ into consideration, the Vsec(5V) of the 5 V output stage can be then 12V and the Vsec(12V) of the 12V output stage is 26V with a little margin.

The number of turns needed for +5V and +12V secondary by the V_{pt}:

$$N_{sec(5V)} = \frac{12}{V_{pt}} = 3 \ \text{turns}$$

$$N_{sec(17V)} = \frac{26}{V_{pt}} = 6.5 \ \text{turns, approx. 7 turns}$$

Four auxiliary windings generate the control IC operating voltage of +16V output. Considering the diode voltage drops, the minimum drop across the inductor is 16V. The physical winding of the transformer is important as the transformer's performance is affected by it. Figure 2 shows the power transformer used in this application.



Core: 3C8 Ferrite EER3542D
1→3: Primary Windings
50 turns AWG23 2 layers
5→7: Auxiliary Winding
4 turns AWG37
10, 11, 12→8, 9: Output (+5V)
3 turns Copper Plate
8, 9→13: Output(+12V)
7 turns 4 AWG35
(4 wires paralleled)

Figure 2. Power Transformer, T1

Performance

The efficiency of the power supply is 79% at half load, and 75% at full load condition (+5V/20A, +12V/6A, -12V/0.8A). The -12V output stage employs the negative fixed voltage regulator (KA7912) featuring output current in excess of 1A for precise output voltage, before the coupled filter inductor (see Figure 3). The power MOSFET QFET FQP7N80, used as the main switching device, offers improved characteristics featuring a smaller gate charge (Qg (max)= 52nC) and lower on-resistance (Rds(on)max=1.5) than a conventional MOSFET. By taking full advantage of singular well stripe technology, Fairchild Semiconductor's power QFET provides designers with highly effective performance systems. Figure 4(a) shows the waveforms of the gate-to-source [Vgs] and drain-to-source voltage [Vds] at half load condition, while figure 4(b) shows the waveforms at full load condition.

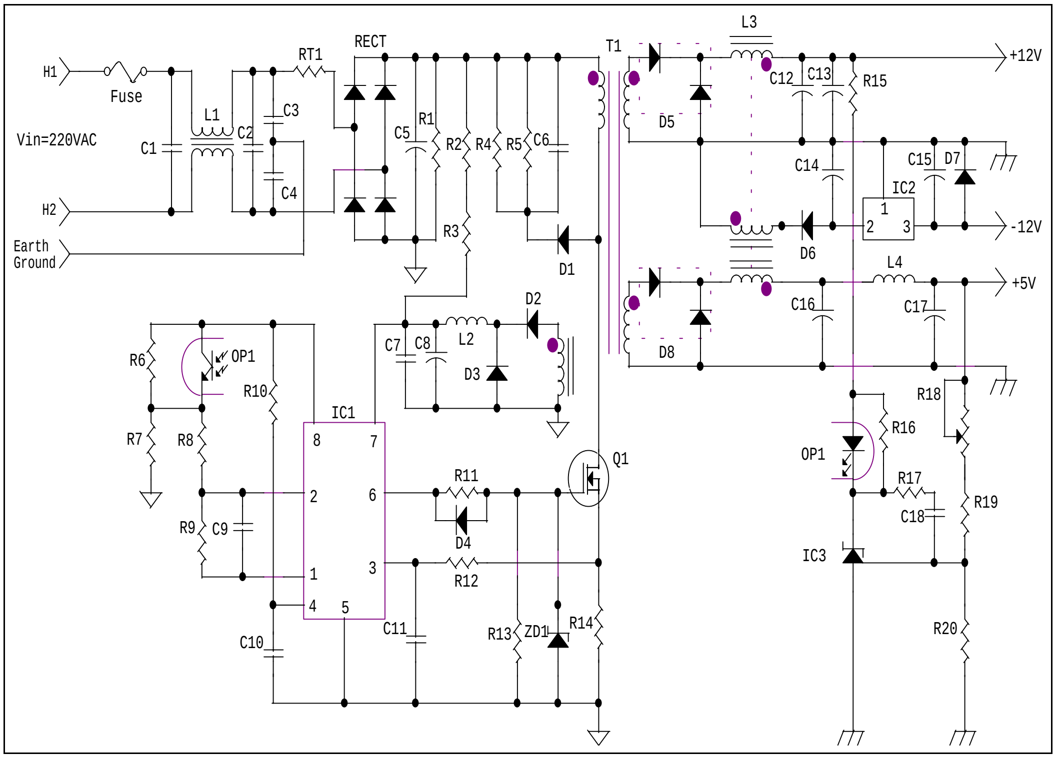
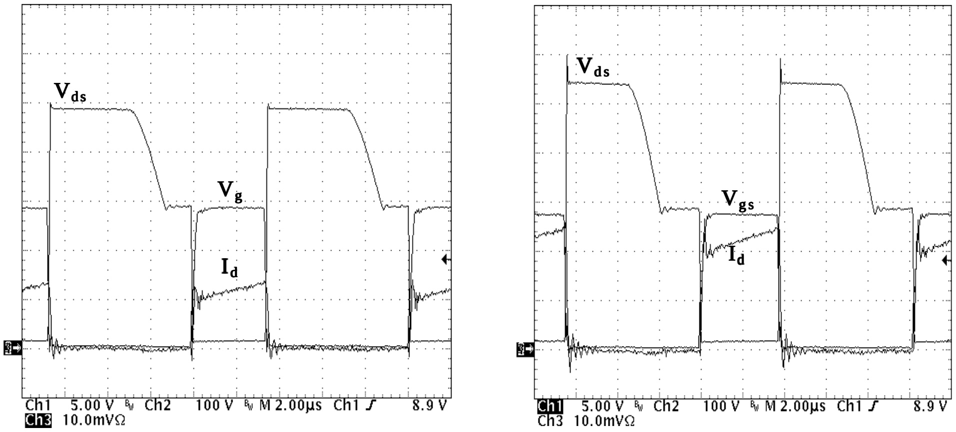


Figure 3. Circuit Diagram of a Forward Converter

As output load increases gradually, the MOSFET conduction time automatically increases from 33% at half load to 38% at full load under the action of a closed-loop regulator circuit, which maintains an essentially constant output voltage.



(a) Half Load Condition

$V_{ds(max)}$=510V, $I_{d(max)}$=1.3A, Duty=33%, f=100KHz

(b) Full load condition

$V_{ds(max)}$=600V, $I_{d(max)}$=2.4A, Duty=38%, f=100KHz

Figure 4. Waveforms of Drain Voltage and Current During Turn-on, 220VAC Line Input

Figure 4(b) shows that at even nominal line input voltage of 220V AC, the peak drain-to-source voltage of the MOSFET is at least 600V. The power QFET FQP7N80 is adequate for this switching condition.

Part	Value	Part	Value	Part	Value
Q1	FQP7N80	R16	10KΩ (1/4W)	C15	470µF (25V)
IC1	KA3842B	R17	1KΩ (1/4W)	C16	3300µF (10V)
IC2	KA7912	VR18	1KΩ (1/4W)	C17	3300µF (10V)
IC3	KA431	R19	2.2KΩ (1/4W)	C18	104
R1	220KΩ (1W)	R20	2.2KΩ (1/4W)	OP	PC817
R2	150KΩ (1W)	C1	0.47µF	T1	Transformer
R3	150KΩ (1W)	C2	0.22µF	L1	Line Filter
R4	150KΩ (1W)	C3	0.33µF	L2	3µH
R5	150KΩ (1W)	C4	0.33µF	L3	Coupled Inductor
R6	12KΩ (1/4W)	C5	220µF	L4	10µH
R7	2.7KΩ (1/4W)	C6	223	ZD1	1N4749
R8	100KΩ (1/4W)	C7	102	D1~3	1N4937
R9	100KΩ (1/4W)	C8	47µF	D4	1N4148
R10	7KΩ (1/4W)	C9	561	D5	FYPF1010DN(100V/10A)
R11	33Ω (1/4W)	C10	222	D6	FYAF3040DN(40V/30A)
R12	1KΩ(1/4W)	C11	471	D7	1N4937
R13	10KΩ(1/4W)	C12	2200µF (25V)	D8	FR304
R14	0.3Ω (1W)	C13	2200µF (25V)	Fuse	3A / 250VAC
R15	1KΩ(1/4W)	C14	470µF (25V)		

Summary

This application note describes ways in which the Fairchild Semiconductor power QFET may be used in switched mode power supplies. An illustration of this application is a 180W, 100kHz forward type power supply using a single 800V rated QFET (FQP7N80) to provide regulated three output voltages. Because the performance of a power supply of this type depends on various factors such as PCB layout, transformer construction, and switching device etc., the stated performance results have to be regarded as benchmarks and not absolutes. The other series of high voltage rated QFETs offered by Fairchild Semiconductor (700, 800, and 900V ratings) allows designers to improve the performance of a switched mode power supply by significantly reducing gate charge and on-resistance.

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2. Practical Switching Power Supply Design, Marty Brown, Academic Press, San Diego,CA.

3. Power Supply Cookbook, Marty Brown, Butterworth Heinemann, 1994

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