Application Note

AN- EVALQRC-ICE2QR4765

12W5V Evaluation Board with Quasi-Resonant CoolSET® ICE2QR4765

Power Management & Supply

Never stop thinking.

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Title

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Page	Subjects (major changes since last revision)
13	Revise typo

12W5V Evaluation Board with Quasi-Resonant CooLSET® ICE2QR4765
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1 Content

This application note is a description of 12W switching mode power supply evaluation board designed in a quasi resonant flyback converter topology using ICE2QR4765 Quasi-resonant CoolSET®.The target application of ICE2QR4765 are for set-top box, portable game controller, DVD player, netbook adapter and auxiliary power supply for LCD TV, etc. With the CoolMOS® integrated in this IC, it greatly simplifies the design and layout of the PCB. Due to valley switching, the turn on voltage is reduced and this offers higher conversion efficiency comparing to hard-switching flyback converter. With the DCM mode control, the reverse recovery problem of secondary rectify diode is relieved. And for its natural frequency jittering with line voltage, the EMI performance is better. Infineon's digital frequency reduction technology enables a quasi-resonant operation till very low load. As a result, the system efficiency, over the entire load range, is significantly improved compared to conventional free running quasi resonant converter implemented with only maximum switching frequency limitation at light load. In addition, numerous adjustable protection functions have been implemented in ICE2QR4765 to protect the system and customize the IC for the chosen application. In case of failure modes, like open control-loop/over load, output overvoltage, and transformer short winding, the device switches into **Auto Restart Mode** or **Latch-off Mode**. By means of the cycle-by-cycle peak current limitation plus foldback point correction, the dimension of the transformer and current rating of the secondary diode can both be optimized.Thus, a cost effective solution can be easily achieved.

2 Evaluation Board

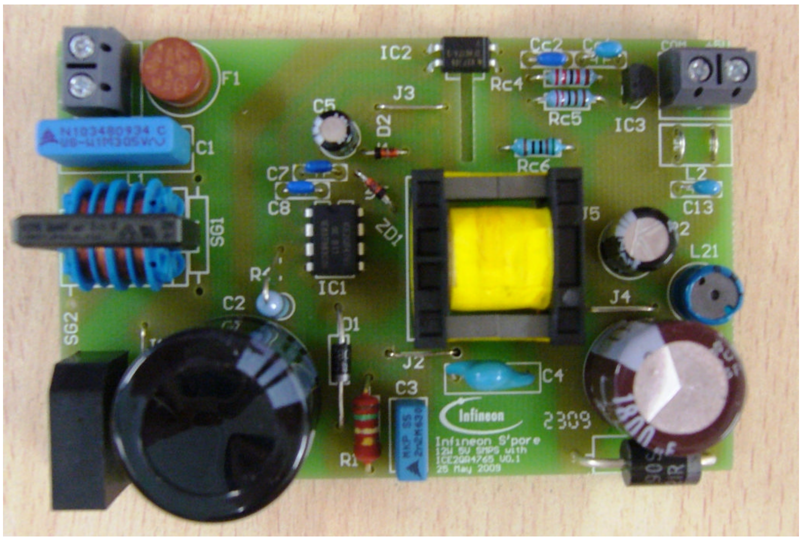

Figure 1-EVALQR-12W-ICE2QR4765

3 List of Features

650V avalanche rugged CoolMOS® with built in **depletion startup cell**
Quasi-resonant operation
Digital frequency reduction with decreasing load
Cycle-by-cycle peak current limitation with **foldback point correction**
Built-in **digital soft-start**
Direct current sensing with internal **Leading Edge Blanking Time**
VCC under voltage protection: **IC stop operation, recover with softstart**
VCC over voltage protection: **IC stop operation, recover with softstart**
Openloop/Overload protection: **Auto Restart**
Output overvoltage protection: **Latch-off with adjustable threshold**
Short-winding protection: **Latch-off**
Over temperature protection: **Autorestart**

4 Technical Specifications

Input voltage	**85Vac~265Vac**
Input frequency	**50Hz, 60Hz**
Output voltage and current	**5V 2.4A**
Output power	**12W**
Efficiency	**>78% at full load**
Standby power	**<100mW@no load**
Minimum switching frequency at full load, minimum input voltage	**65kHz**

5 Circuit Description

5.1 Mains Input and Rectification

The AC line input side comprises the input fuse F1 as overcurrent protection. The X2 Capacitors C1 and Choke L1 form a main filter to minimize the feedback of RFI into the main supply. After the bridge rectifier BR1, together with a smoothing capacitor C2, provide a voltage of 70VDC to 380 VDC depending on mains input voltage.

5.2 Integrated MOSFET and PWM Control

ICE2QR4765 is comprised of a power MOSFET and the quasi-resonant controller; this integrated solution greatly simplifies the circuit layout and reduces the cost of PCB manufacturing. The PWM switch-on is determined by the zero-crossing input signal and the value of the up/down counter. The PWM switch-off is determined by the feedback signal V_{FB} and the current sensing signal V_{CS}. ICE2QR4765 also performs all necessary protection functions in flyback converters. Details about the information mentioned above are illustrated in the product datasheet.

5.3 Snubber Network

A snubber network R1, C3 and D1 dissipate the energy of the leakage inductance and suppress ringing on the SMPS transformer.

5.4 Output Stage

On the secondary side, 5V output, the power is coupled out via a schottky diode D21. The capacitors C21 provides energy buffering followed by the L-C filters L21 and C22 to reduce the output ripple and prevent interference between SMPS switching frequency and line frequency considerably. Storage capacitors C21 is designed to have an internal resistance (ESR) as small as possible. This is to minimize the output voltage ripple caused by the triangular current.

5.5 Feedback Loop

For feedback, the output is sensed by the voltage divider of Rc1 and Rc3 and compared to TL431 internal reference voltage. Cc1, Cc2 and Rc4 comprise the compensation network. The output voltage of TL431 is converted to the current signal via optocoupler IC2 and two resistors Rc5 and Rc6 for regulation control.

6 Circuit Operation

6.1 Startup Operation

Since there is a built-in startup cell in the ICE2QR4765, there is no need for external start up resistor, which can improve standby performance significantly.
When VCC reaches the turn on voltage threshold 18V, the IC begins with a soft start. The soft-start implemented in ICE2QR4765 is a digital time-based function. The preset soft-start time is 12ms with 4 steps. If not limited by other functions, the peak voltageon CS pin will increase step by step from 0.32V to 1V finally. After IC turns on, the Vcc voltage is supplied by auxiliary windings of the transformer.

6.2 Normal Mode Operation

The secondary output voltage is built up after startup. The secondary regulation control is adopted with TL431 and optocoupler. The compensation network Cc1, Cc2 and Rc4 constitute the external circuitry of the error amplifier of TL431. This circuitry allows the feedback to be precisely controlled with respect to dynamically varying load conditions, therefore providing stable control.

6.3 Primary side peak current control

The MOSFET drain source current is sensed via external resistor R4 and R4A. Since ICE2QR4765 is a current mode controller, it would have a cycle-by-cycle primary current and feedback voltage control which can make sure the maximum power of the converter is controlled in every switching cycle.

6.4 Digital Frequency Reduction

During normal operation, the switching frequency for ICE2QR4765 is digitally reduced with decreasing load. At light load, the MOSFET will be turned on not at the first minimum drain-source voltage time, but on the n_{th}. The counter is in range of 1 to 7, which depends on feedback voltage in a time-base. The feedback voltage decreases when the output power requirement decreases, and vice versa. Therefore, the counter is set by monitoring voltage V_{FB}. The counter will be increased with low V_{FB} and decreased with high V_{FB}. The thresholds are preset inside the IC.

6.5 Burst Mode Operation

At light load condition, the SMPS enters into Active Burst Mode. At this stage, the controller is always active but the Vcc must be kept above the switch off threshold. During active burst mode, the efficiency increase significantly and at the same time it supports low ripple on V_{out} and fast response on load jump.

For determination of entering Active Burst Mode operation, three conditions apply:

.the feedback voltage is lower than the threshold of V_{FBEB}(1.25V). Accordingly, the peak current sense voltage across the shunt resistor is 0.18;

.the up/down counter is 7;

.and a certain blanking time (t_{BEB}).

Once all of these conditions are fulfilled, the Active Burst Mode flip-flop is set and the controller enters Active Burst Mode operation. This multi-condition determination for entering Active Burst Mode operation prevents mistriggering of entering Active Burst Mode operation, so that the controller enters Active Burst Mode operation only when the output power is really low during the preset blanking time.

During active burst mode, the maximum current sense voltage is reduced from 1V to 0.34V so as to reduce the conduction loss and the audible noise. At the burst mode, the FB voltage is changing like a sawtooth between 3.0 and 3.6V.

The feedback voltage immediately increases if there is a high load jump. This is observed by one comparator. As the current limit is 34% during Active Burst Mode a certain load is needed so that feedback voltage can exceed VLB (4.5V). After leaving active busrt mode, maximum current can now be provided to stabilize V_O.

In addition, the up/down counter will be set to 1 immediately after leaving Active Burst Mode. This is helpful to decrease the output voltage undershoot

7 Protection Features

7.1 Vcc under voltage and over voltage protection

During normal operation, the VCC voltage is continuously monitored. When the Vcc voltage falls below the under voltage lock out level (VCCoff) or the Vcc voltage increases up to VCCovp, the IC will enter into autorestart mode.

7.2 Foldback point protection

For a quasi-resonant flyback converter, the maximum possible output power is increased when a constant current limit value is used for all the mains input voltage range. This is usually not desired as this will increase additional cost on transformer and output diode in case of output over power conditions.
The internal fold back protection is implemented to adjust the V_{CS} voltage limit according to the bus voltage. Here, the input line voltage is sensed using the current flowing out of **ZC** pin, during the MOSFET on-time. As the result, the maximum current limit will be lower at high input voltage and the maximum output power can be well limited versus the input voltage.

7.3 Open loop/over load protection

In case of open control loop, feedback voltage is pulled up with internally block. After a fixed blanking time 30ms, the IC enters into auto restart mode. In case of secondary short-circuit or overload, regulation voltage V_{FB} will also be pulled up, same protection is applied and IC will auto restart.

7.4 Adjustable output overvoltage protection

During off-time of the power switch, the voltage at the zero-crossing pin ZC is monitored for output overvoltage detection. If the voltage is higher than the preset threshold 3.7V for a preset period 100µs, the IC is latched off.

7.5 Short winding protection

The source current of the MOSFET is sensed via two shunt resistors R5 and R5A in parallel. If the voltage at the current sensing pin is higher than the preset threshold V_{CSSW} of 1.68V during the on-time of the power switch, the IC is latched off. This constitutes a short winding protection. To avoid an accidental latch off, a spike blanking time of 190ns is integrated in the output of internal comparator.

7.6 Auto restart for over temperature protection

The IC has a built-in over temperature protection function. When the controller’s temperature reaches 140 °C, the IC will shut down switch and enters into autorestart. This can protect power MOSFET from overheated.

8 Circuit diagram

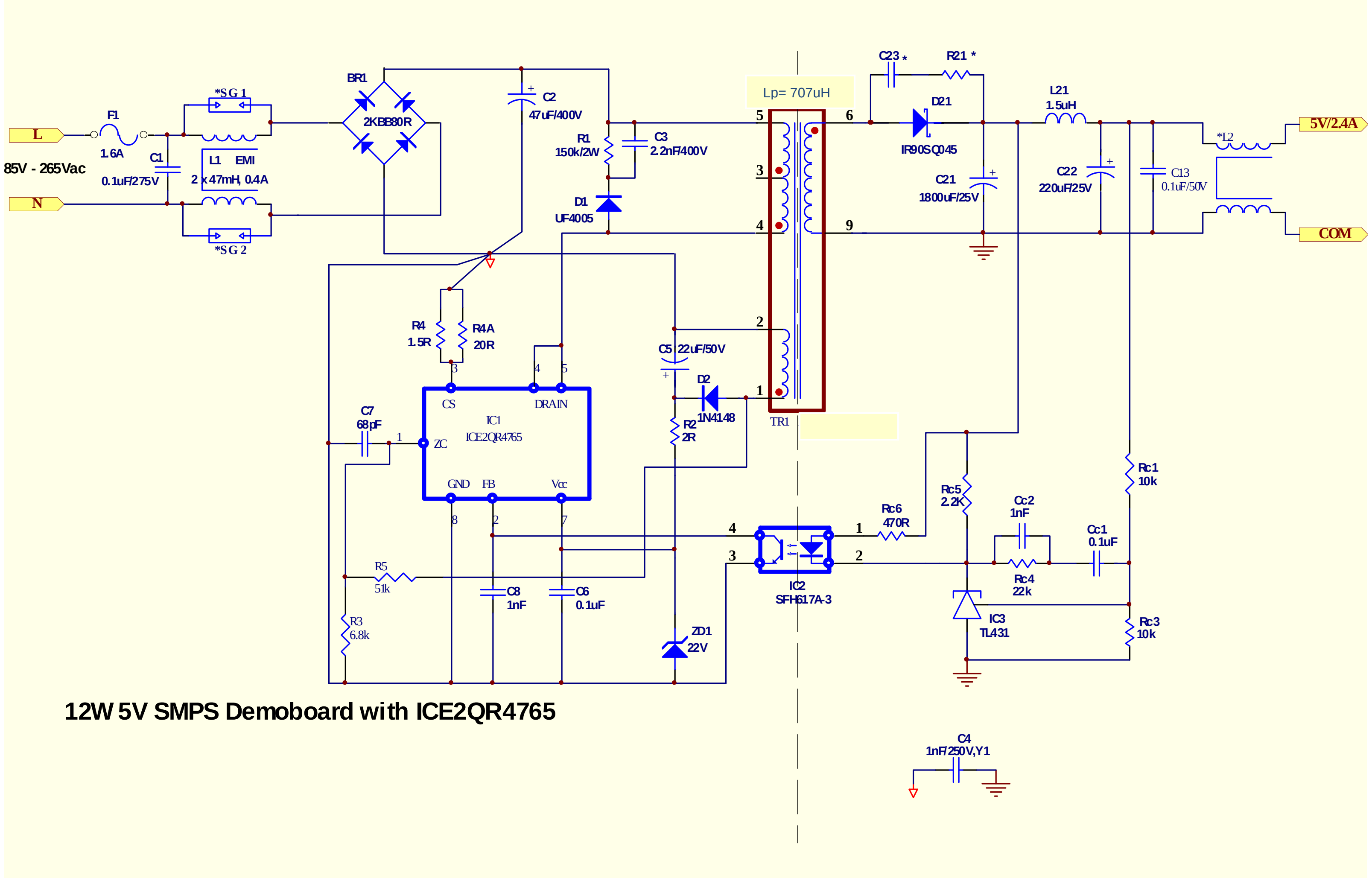

Figure 2 – Schematics

8.1 PCB Top overlayer

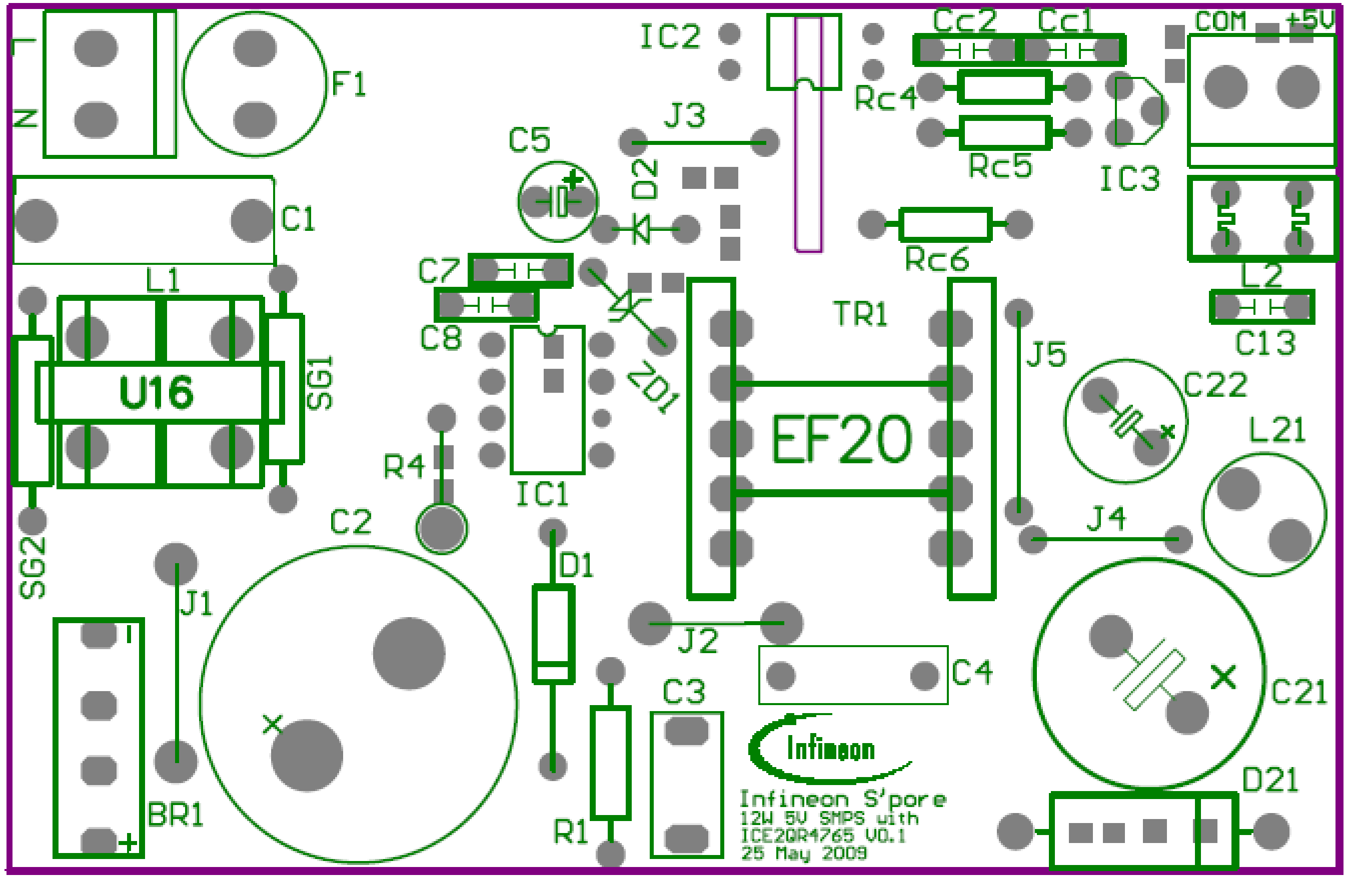

Figure 3 –Component Legend – View from topside

8.2 PCB Bottom Layer

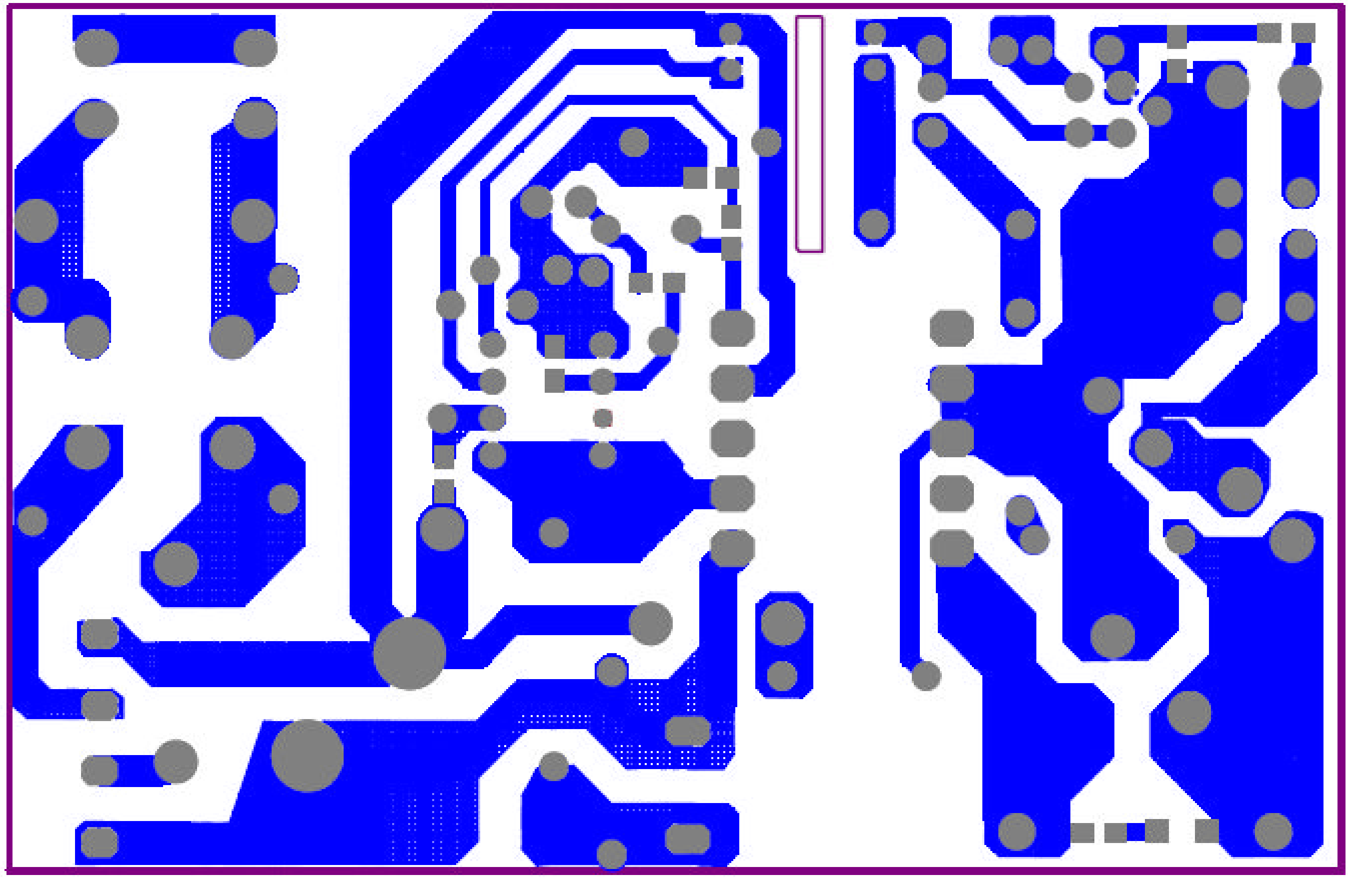

Figure 4 Solder side copper – View from bottom side

9 Component List

Items	Designator	Part Type	Part No.	Manufacturer
1	BR1	2KBB80R		
2	C1	0.1uF/305V	B32922C3104K000	Epcos
3	C13	0.1uF/50V	RPER71H104K2K1A03B	Murata
4	C2	47uF/400V	B43504A9476M	Epcos
5	C21	1800uF/25V		
6	C22	220uF/25V		
7	C3	2.2nF/630V		
8	C4	1nF/250V,Y1	DE1E3KX102MA4BL01	Murata
9	C5	22uF/50V	B41851A6226M000	Epcos
10	C6	0.1uF, SMD		
11	C7	68pF		
12	C8	1nF		
13	Cc1	0.1uF	RPER71H104K2K1A03B	Murata
14	Cc2	1nF		
15	D1	UF4005	UF4005	Vishay
16	D2	1N4148		
17	D21	IR90SQ045		
18	F1	1.6A/250Vac		
19	IC1	ICE2QR4765	ICE2QR4765	Infineon
20	IC2	SFH617A-3		
21	IC3	TL431		
22	L1	2 x 47mH, 0.4A	B82731R2401A30	Epcos
23	L2	Jumper		
24	L21	1.5uH		
25	R1	150k/2W		
26	R2	2R, SMD		
27	R3	6.8k, SMD		
28	R4	1.5R		
29	R4A	20R, SMD		
30	R5	51k, SMD		
31	Rc1	10k, SMD		
32	Rc3	10k, SMD		
33	Rc4	22k		
34	Rc5	2.2K		
35	Rc6	470R		
36	TR1	Lp=707uH	EF20/10/6, N87	Epcos
37	ZD1	22V zenor diode		

Table 1– Component List

10 Transformer Construction

Core and material: EF20/10/6, EPCOS N87
Bobbin: Horizontal Version
Primary Inductance, Lp=707μH, measured between pin 5 and pin 4 (Gapped to Inductance)

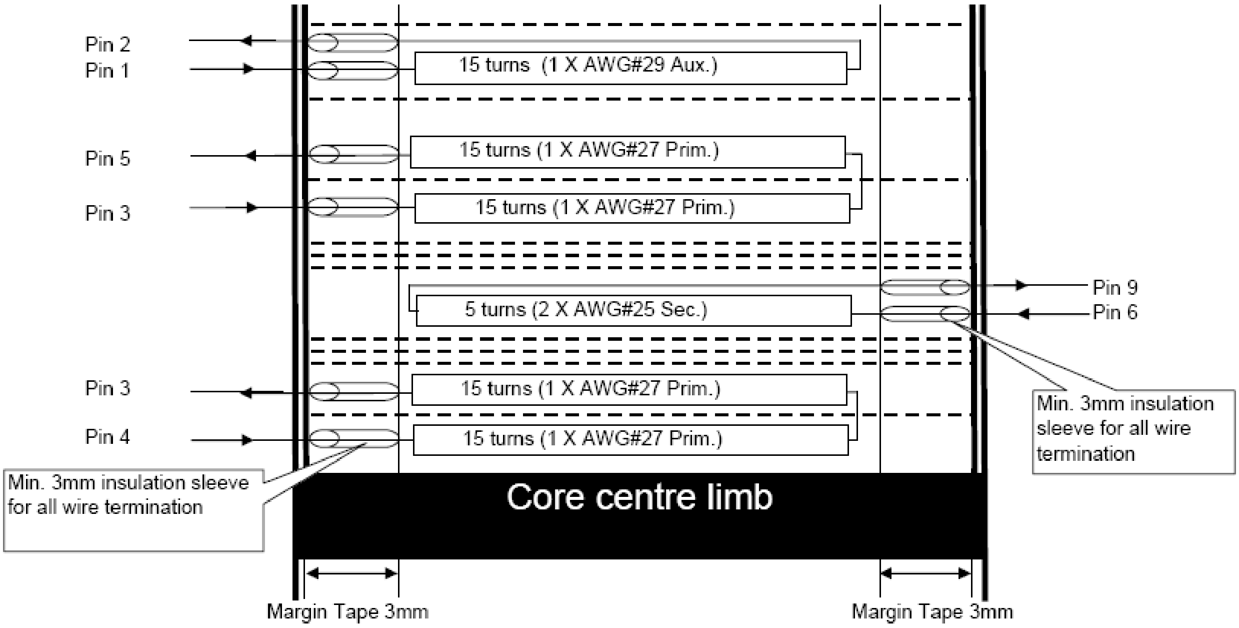

Figure 5 – Transformer structure

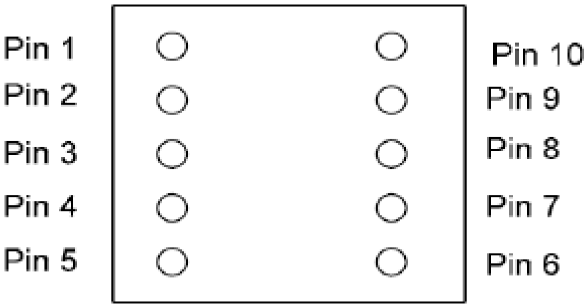

Figure 6 – Transformer complete – top view

Table 2 wire gauge used of the transformer windings

Start	Stop	No. of turns	Wire size	Layer
1	2	15	1XAWG#29	Auxiliary
3	5	30(15+15)	1XAWG#27	$^1/_2$ Primary
6	9	5	2XAWG#25	Secondary
4	3	30(15+15)	1XAWG#27	$^1/_2$ Primary

11 Test Results

11.1 Efficiency and standby performance

Input voltage(Vac)	Input power(W)	Vo(V)	Io(A)	Po(W)	Efficiency
115	3.7367	4.9983	0.6	2.99898	80.26%
115	7.5648	4.9978	1.2	5.99736	79.28%
115	11.3124	4.9973	1.8	8.99514	79.52%
115	15.2544	4.9966	2.4	11.99184	78.61%
230	3.7785	4.9983	0.6	2.99898	79.37%
230	7.4424	4.9979	1.2	5.99748	80.59%
230	11.1366	4.9975	1.8	8.9955	80.77%
230	14.7858	4.9971	2.4	11.99304	81.11%

Table 3 – Efficiency vs. Load

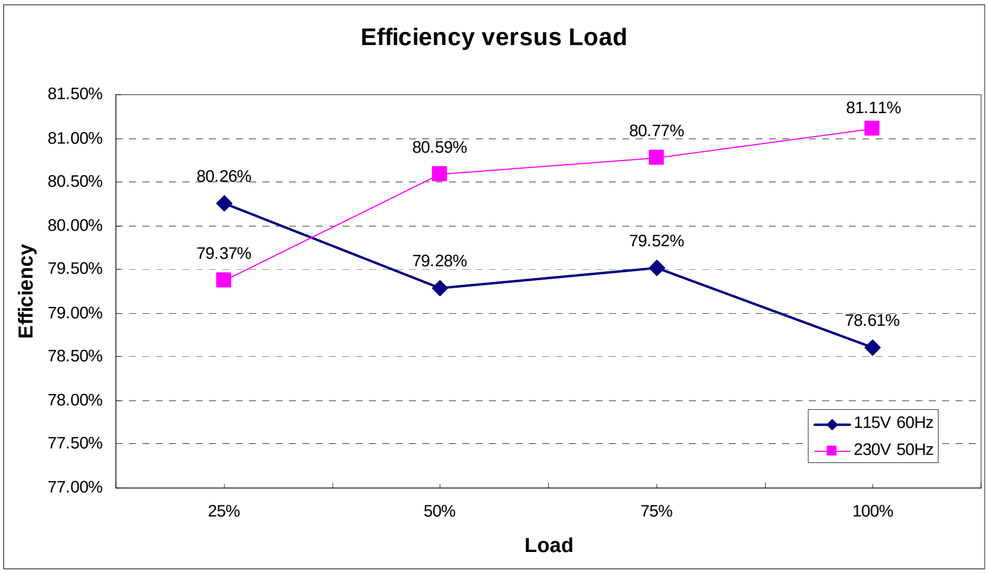

Figure 7 – Efficiency vs. AC line voltage

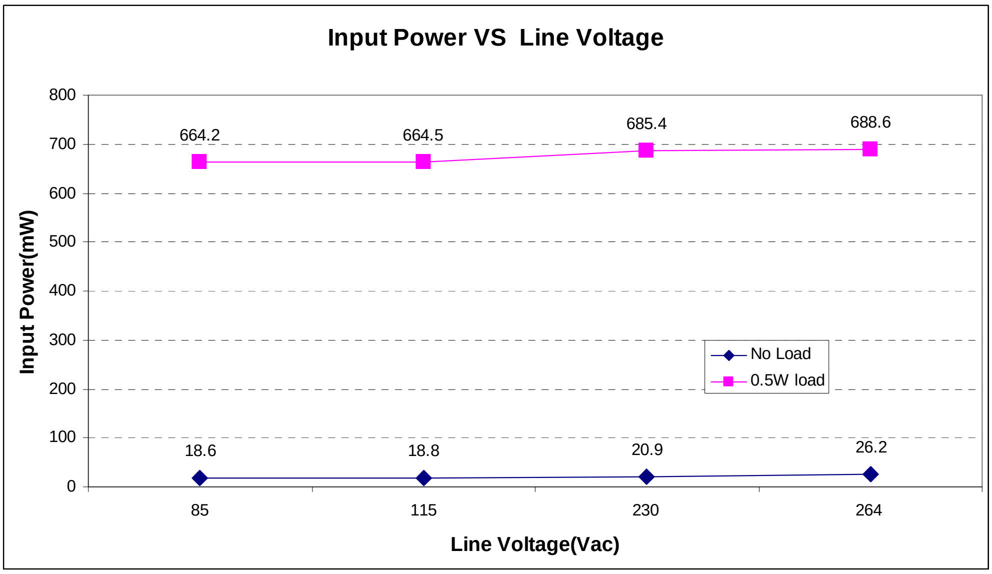

Figure 8 Standby input power vs AC line voltage

12 Waveform and scope plots

All waveform and scope were recorded with LeCroy 44Xi oscilloscope.

12.1 Startup @85Vac and 12W load

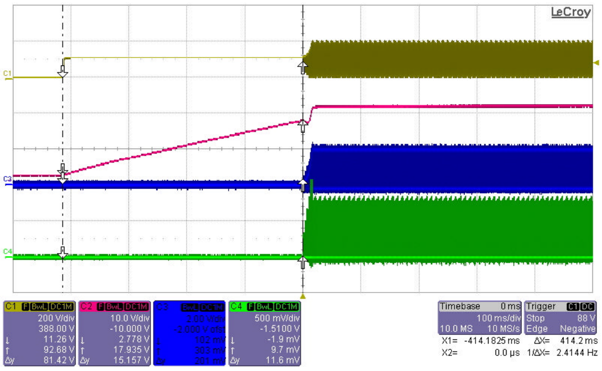

Figure 9 Constant charging VCC during startup

Ch1 Drain source voltage ; Ch2 VCC supply voltage ;

Ch3 Zero crossing voltage ; Ch4 Current sense voltage

Test condition: input 85Vac output 2.4A load

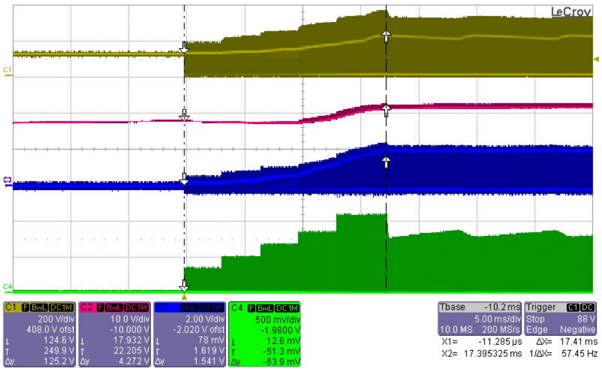

Figure 10 Softstart of current in 4 steps

Ch1 Drain source voltage ; Ch2 VCC supply voltage ;

Ch3 Zero crossing voltage ; Ch4 Current sense voltage

Test condition: input 85Vac output 2.4A load

12.2 Working at different zero crossing point

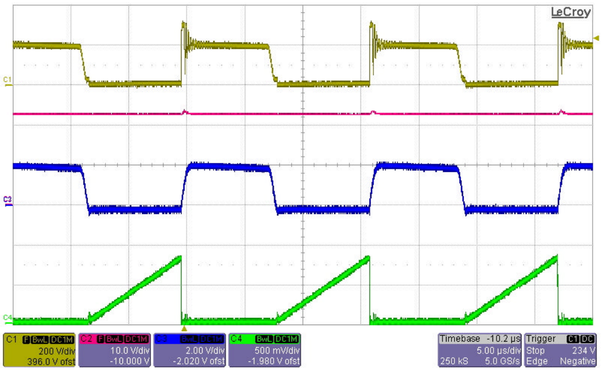

Figure 11 Working at first ZC point

Ch1 Drain source voltage ; Ch2 VCC supply voltage ;

Ch3 Zero crossing voltage ; Ch4 Current sense voltage

Test condition:5V/2.4A @85Vac

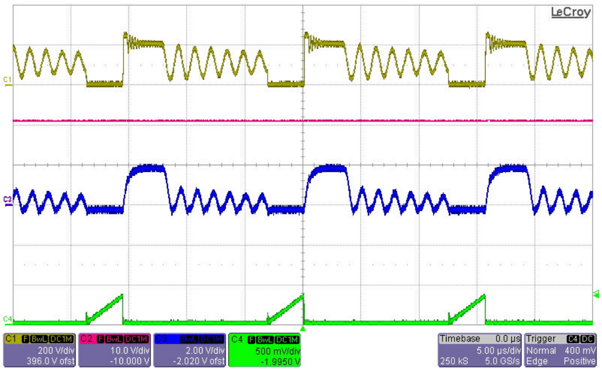

Figure 12 Working at 7th ZC point

Ch1 Drain source voltage ; Ch2 VCC supply voltage ;

Ch3 Zero crossing voltage ; Ch4 Current sense voltage

Test condition:5V/0.5A @85Vac

12.3 Load transient response

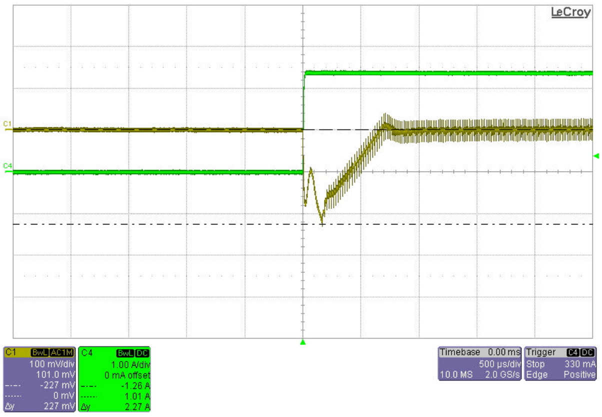

Figure 13 AC output ripple undershoot

Ch1 Output ripple voltage div 100mv

Ch4 Output current

Measured with decouple capacitor 0.1uF+10uF, scope bandwidth 20MHz

Test condition:0A to 2.4A

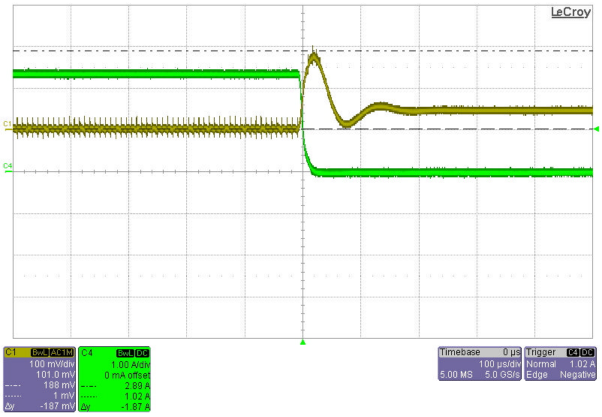

Figure 14 AC output ripple overshoot

Ch1 Output ripple voltage div 110mv

Ch4 Output current

Measured with decouple capacitor 0.1uF+10uF, scope bandwidth 20MHz

Test condition:2.4A to 0A

12.4 AC Output ripple during full load

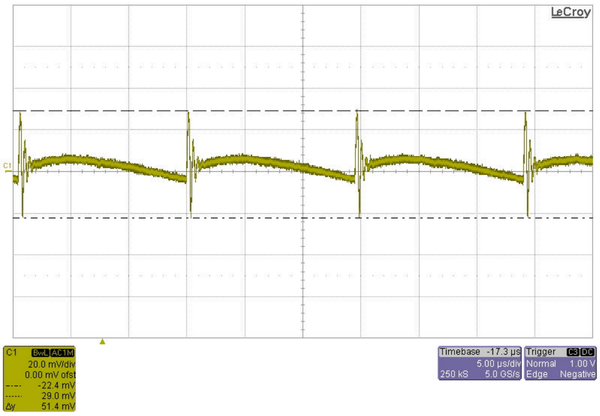

Figure 15 AC output ripple at 85 Vac input

Ch1 Output ripple voltage div 20mV

Measured with decouple capacitor 0.1uF+10uF, scope bandwidth 20MHz

Test condition: 85V 5V/2.4A

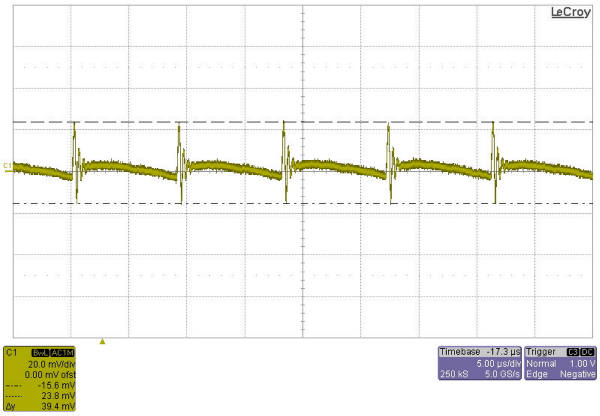

Figure 16 AC output ripple at 265 Vac input

Ch1 Output ripple voltage div 20mV

Measured with decouple capacitor 0.1uF+10uF, scope bandwidth 20MHz

Test condition: 265V 5V/2.4A

12.5 Burst mode operation

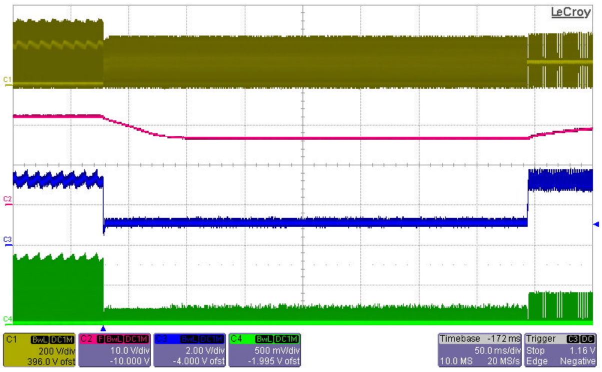

Figure 17 Entering burst mode

Ch1 Drain source voltage ; Ch2 Supply voltage VCC ;

Ch3 Feedback voltage Vfb ; Ch4 Current sense voltage

Test condition: load jump from 2.4A to 0.1A at 85Vac line

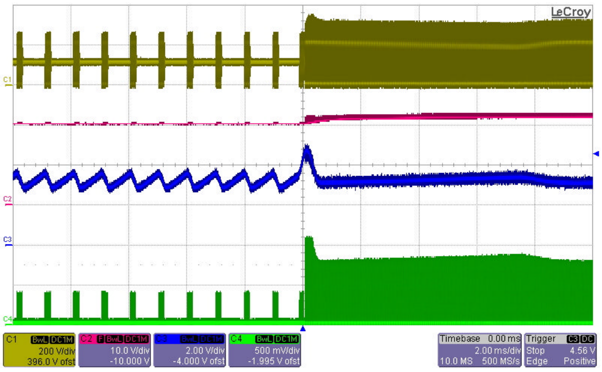

Figure 18 Leaving burst mode

Ch1 Drain source voltage ; Ch2 Supply voltage VCC ;

Ch3 Feedback voltage Vfb ; Ch4 Current sense voltage

Test condition: load jump from 0A to 2.4A at 85Vac line

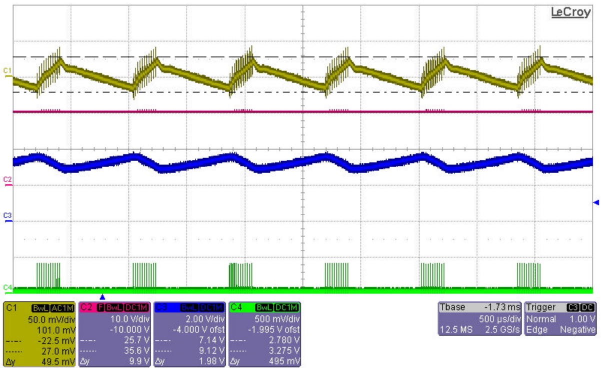

Figure 19 AC output ripple during 85Vac

Ch1 AC output ripple 50mV/ div; Ch2 Supply voltage VCC ;

Ch3 Feed back voltage Vfb ; Ch4 Current sense voltage

Measured with decouple capacitor 0.1uF+10uF, scope bandwidth 20MHz

Test condition : 85V ac line, 5V/0.1A

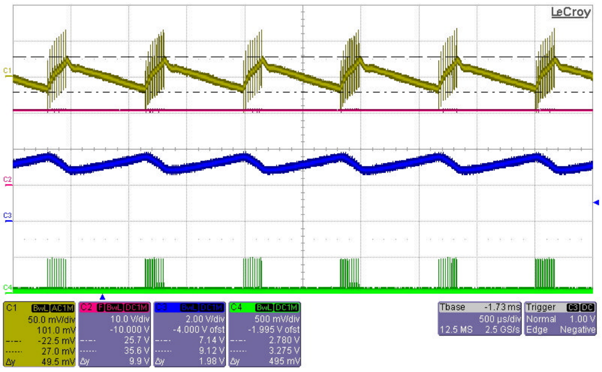

Figure 20 AC output ripple during 265V

Ch1 AC output ripple 50mV/ div; Ch2 Supply voltage VCC;

Ch3 Feed back voltage Vfb ; Ch4 Current sense voltage

Measured with decouple capacitor 0.1uF+10uF, scope bandwidth 20MHz

Test condition : 265V ac line, 5V/0.1A

13 References

[1] ICE2QR4765 datasheet Infineon Technologies AG,2009

[2] ICE2QRxx65/80x Quasi Resonance CoolSET Design Guide, Infineon Technologies, 2010. [AN-PS0053]

[3] Design tips for flyback converters using the Quasi-Resonant PWM controller ICE2QS01, Infineon Technologies, 2006. [ANPS0005]

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