# AN-REF-10W ADAPTER

## 10W 5V Adapter Reference Board with ICE2QS03G & IPU60R950C6

AN-PS0080

Application Note AN-REF-10W ADAPTER
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Power Management & Multimarket

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Last Trademarks Update 2011-11-11

## Revision History

**Major changes since previous revision**

| Date | Version | Changed By | Change Description |
|---|---|---|---|
| 20 Feb 2014 | 1.1 | Kyaw Zin Min | Update to new format |
| | | | |
| | | | |
| | | | |

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# Table of Contents

# 1 Abstract

This application note is an engineering report of a very small form factor reference design for universal input 10.5W 5V USB adapter. The adapter is using IFX **ICE2QS03G**, a second generation current mode control quasi-resonant flyback topology controller and IFX **IPU60R950C6**, a sixth generation of high voltage power CoolMOS™. The distinguishing features of this reference design are very small form factor, best in class low standby power, high efficiency, good EMI performance without using input common mode choke, very tight maximum input power control between low and high line and variious modes of protection for high reliable system.

# 2 Evaluation Board Photos

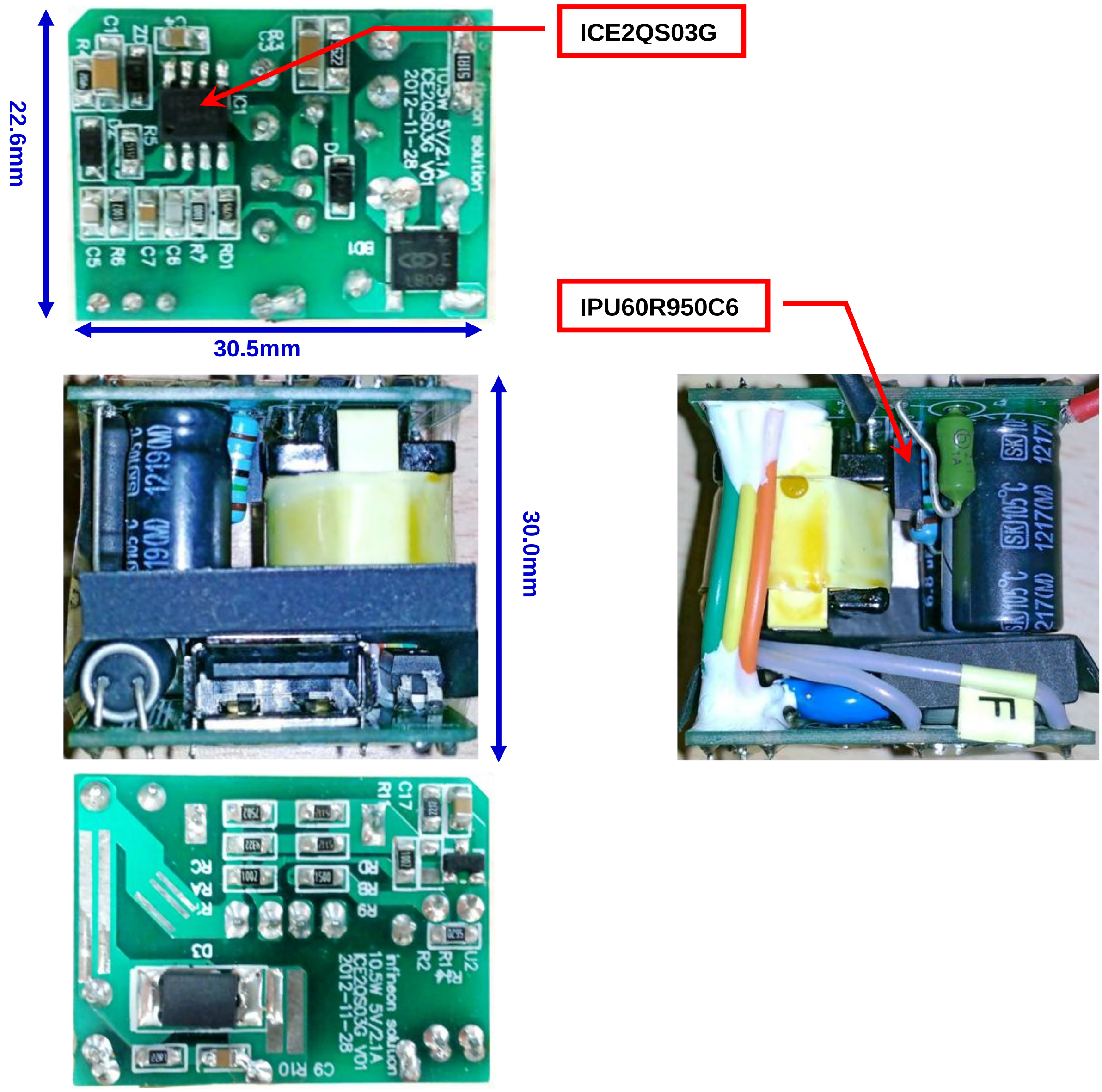



Figure 1 – REF-ICE2QS03G & IPU60R950C6 10W ADAPTER (Dimensions LxWxH: 30.5x22.6x30 $mm^3$)

This document contains the list of features, the power supply specification, schematic, bill of material and the transformer construction documentation. Typical operating characteristics such as performance curve and scope waveforms are showed at the rear of the report.

# 3 List of Features of ICE2QS03G

| |
|---|
| Quasi resonant operation till very low load |
| Active burst mode operation at light/no load for low standby input power (< 50mW) |
| Digital frequency reduction with decreasing load |
| HV startup cell with constant charging current |
| Built-in digital soft-start |
| Foldback correction and cycle-by-cycle peak current limitation |
| Auto restart mode for VCC Overvoltage protection |
| Auto restart mode for VCC Undervoltage protection |
| Auto restart mode for openloop/overload protection |
| Auto restart mode for Over temperature protection |
| Latch-off mode for adjustable output overvoltage protection |

# 4 Technical Specifications for Reference Board

| | |
|---|---|
| Input voltage | 90Vac~264Vac |
| Input frequency | 50/60Hz |
| Input Standby Power | < 50mW @ no load |
| Maximum input power(Peak Power) for full input range | < ±5% of input power |
| Output voltage | 5V |
| Output current | 2.1A |
| Output power | 10.5W |
| Active mode average efficiency(25%,50%,75% & 100%load) | >78% at full load |
| Minimum switching frequency at full load and minimum input voltage | 40kHz |

# 5 Circuit Description

## 5.1 Mains Input Rectification and Filtering

The AC line input side comprises the input fuse F1 as overcurrent protection. A rectified DC voltage (127V ~ 373V) is obtained through a bridge rectifier BR1 and a pi filter C1, L1, R13 and C2. The pi filer also attenuates the differential mode conducted EMI.

## 5.2 PWM Control and switching MOSFET

The PWM pulse is generated by the Quasi Resonant PWM current-mode Controller **ICE2QS03G** and this PWM pulse drives the high power CoolMOS™, **IPU60R950C6 (C6)** which designed according to the revolutionary Superjunction (SJ) principle. The CoolMOS™ C6 provides all benefits of a fast switching SJ MOSFET while not sacrificing ease of use. It achieves extremely low conduction and switching losses and can make switching applications more efficient, more compact, lighter and cooler. 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 VFB and the current sensing signal VCS. **ICE2QS03G** 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 R3, C3 and D1 dissipate the energy of the leakage inductance and suppress ringing on the SMPS transformer. Due to the resonant capacitor (MOSFET's drain source capacitance), the overshoot is relatively smaller than fixed frequency flyback converter. Thus the snubber resistor can be used with a larger one which will reduce the snubber loss.

## 5.4 Output Stage

On the secondary side, 5V output, the power is coupled out via a schottky diode D3. The capacitors C8 and C10 provide energy buffering to reduce the output ripple and prevent interference between SMPS switching frequency and line frequency considerably. Storage capacitors C8 and C10 are 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 R1, R2 and R12 and compared to TL431 internal reference voltage. C17 and R11 comprise the compensation network. The output voltage of TL431 is converted to the current signal via optocoupler U1 and two resistors R9 and R14 for regulation control.

# 6 Circuit Operation

## 6.1 Startup Operation

Since there is a built-in startup cell in the **ICE2QS03G**, 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 **ICE2QS03G** is a digital time-based function. The preset soft-start time is 12ms with 4 steps. If not limited by other functions, the peak voltage on 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 C17 and R11 constitutes 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 R8 and buffer network R7, C6. Since ICE2QS03G 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 **ICE2QS03G** is digitally reduced with decreasing load. At light load, the CoolMOS™ **IPU60R950C6** will be turned on not at the first minimum drain-source voltage time, but on the nth. 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:

1. The feedback voltage is lower than the threshold of $V_{FBEB}$(1.25V). Accordingly, the peak current sense voltage across the shunt resistor is 0.1667;

2. The up/down counter is 7;

3. And a certain blanking time ($t_{BEB}$=24ms).

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 mis-triggering 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 burst 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 over voltage and under voltage protection

During normal operation, the Vcc voltage is continuously monitored. When the Vcc voltage increases up to $V_{VCCOVP}$ or Vcc voltage falls below the under voltage lock out level $V_{VCCoff}$, 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 foldback protection is implemented to adjust the VCS 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 Over load/Open loop protection

In case of open control loop, feedback voltage is pulled up with internally block. After a fixed blanking time, 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 external resistor R8. 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

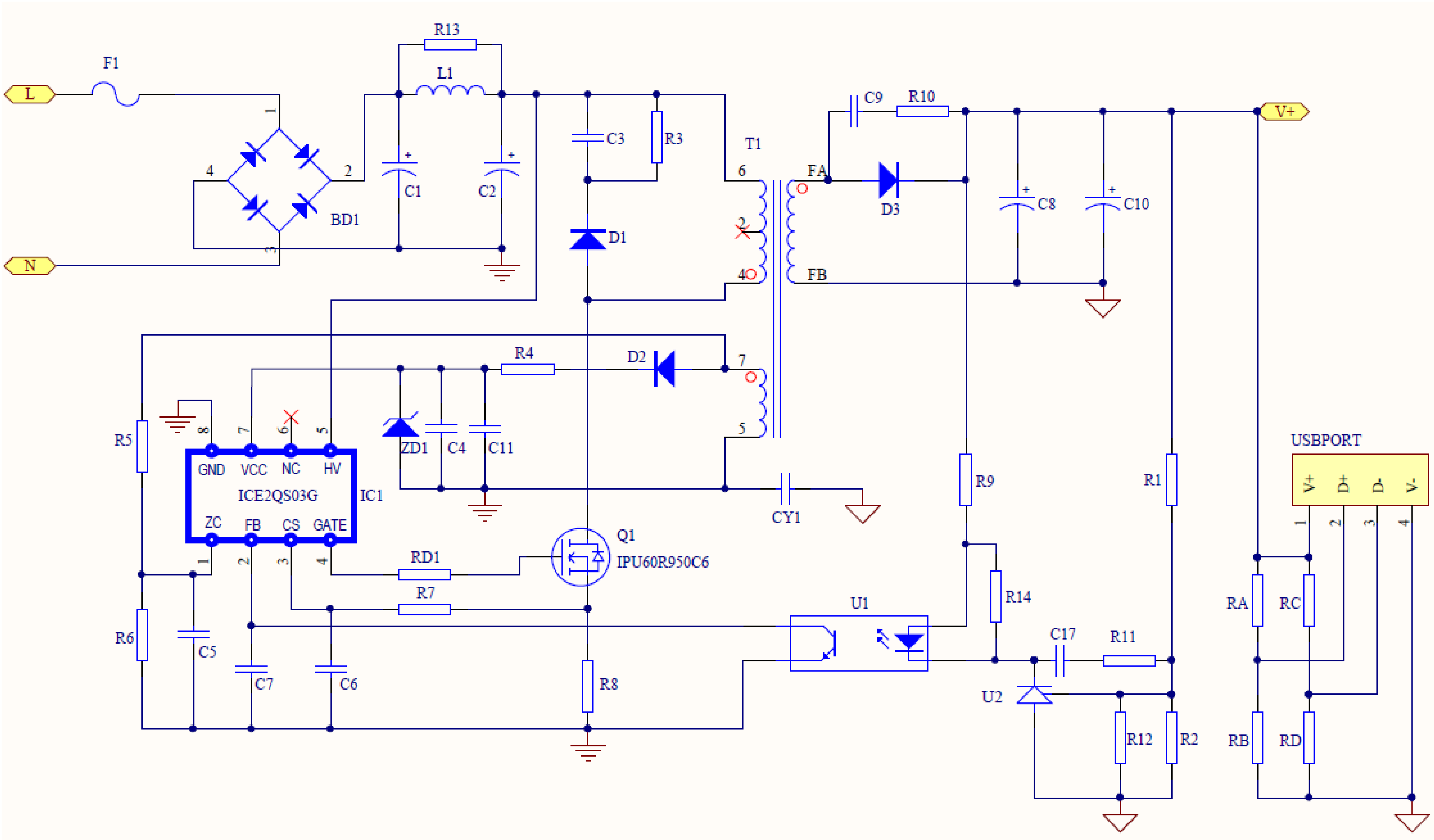



Figure 2 – Schematics

## 8.1 1st PCB artwork (top)

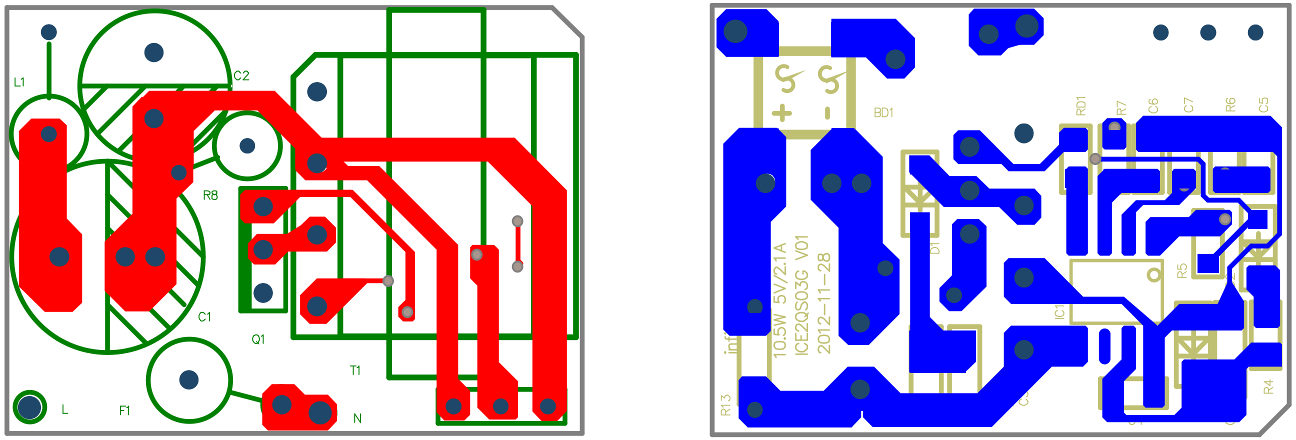



Figure 3 – View from component side (left) and solder side (right)

## 8.2 2nd PCB artwork (bottom)

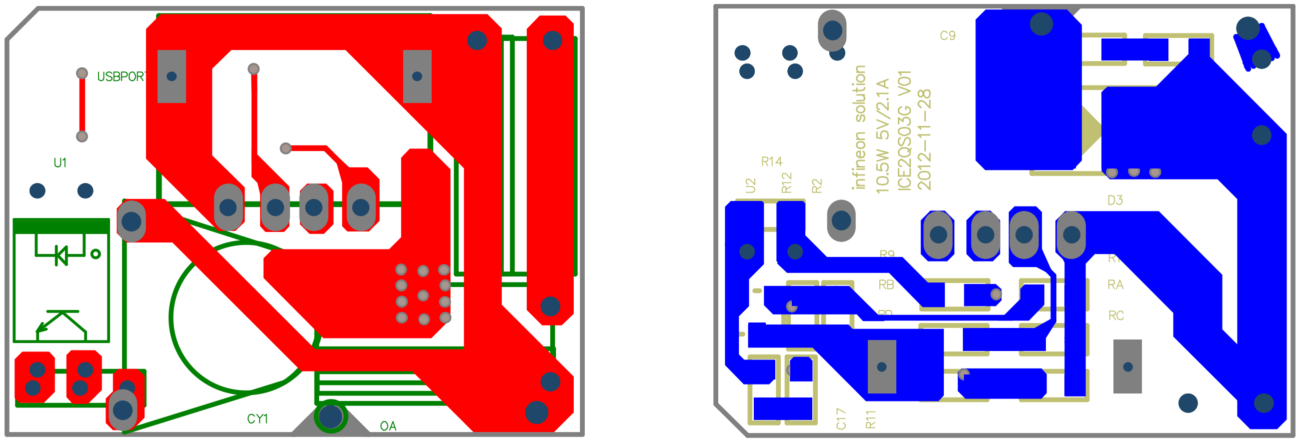



Figure 4 – View from component side (left) and solder side (right)

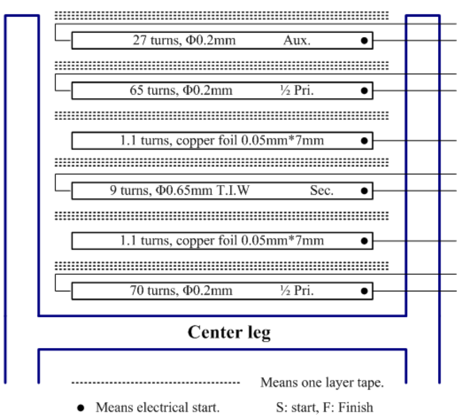
# 9 Component List

| Items | Designator | Part Value | Q'ty | Manufacturer |
|---|---|---|---|---|
| 1 | BD1 | B10S/0.5A, 1000V (bridge rectifier) | 1 | |
| 2 | C1 | 15uF/400V/105℃ | 1 | |
| 3 | C10 | 820uF/6.3V | 1 | |
| 4 | C11 | 10uF/25V/X7R | 1 | Murata |
| 5 | C17 | 100nF/X7R | 1 | |
| 6 | C2 | 6.8uF/400V/105℃ | 1 | |
| 7 | C3 | 4.7nF/630V/X7R | 1 | |
| 8 | C4 | 2.2uF/25V/X7R | 1 | Murata |
| 9 | C5 | 68pF/50V/NP0 | 1 | Murata |
| 10 | C6 | 100pF/50V/NP0 | 1 | Murata |
| 11 | C7 | 1nF/50V/X7R | 1 | Murata |
| 12 | C8 | 820uF/6.3V | 1 | |
| 13 | C9 | 1nF/50V/X7R | 1 | |
| 14 | CY1 | 2.2nF/250Vac | 1 | |
| 15 | D1 | F1J-600V/1A/1.25V | 1 | |
| 16 | D2 | BAV21W | 1 | |
| 17 | D3 | SBR10U45SP5-45V/10.0A/0.42V | 1 | |
| 18 | F1 | T1A/250V | 1 | |
| 19 | IC1 | ICE2QS03G | 1 | Infineon |
| 20 | L1 | 0.9mH/0.1A/φ0.12 | 1 | |
| 21 | Q1 | N MOS-IPU60R950C6 | 1 | Infineon |
| 22 | R1 | 10K/0805,±1% | 1 | |
| 23 | R10 | 22.1R/0805,±5% | 1 | |
| 24 | R11 | 22.1K/0805,±5% | 1 | |
| 25 | R12 | N.A | 1 | |
| 26 | R13 | 51.1R/1206, ±1% | 1 | |
| 27 | R14 | 562R/0805, ±1% | 1 | |
| 28 | R2 | 10K/0805,±1% | 1 | |
| 29 | R3 | 56.2K/1206, ±1% | 1 | |
| 30 | R4 | 4R02/0805, ±5% | 1 | |
| 31 | R5 | 51.1K/0805, ±1% | 1 | |
| 32 | R6 | 10K/0805,±1% | 1 | |
| 33 | R7 | 100R/0805, ±1% | 1 | |
| 34 | R8 | 1.5R/0.5W, ±1% | 1 | |
| 35 | R9 | 150R/0805,±5% | 1 | |
| 36 | RA | 43.2K/0805, ±1% | 1 | |
| 37 | RB | 51.1K/0805, ±1% | 1 | |
| 38 | RC | 75K/0805, ±1% | 1 | |
| 39 | RD | 51.1K/0805, ±1% | 1 | |
| 40 | RD1 | 47.5R/0805, ±1% | 1 | |
| 41 | T1 | 750341723 (EE19) | 1 | Wurth Electronics Midcom |
| 42 | U1 | SFH617A-3 | 1 | |
| 43 | U2 | TL431 | 1 | |
| 44 | USBPORT | 6Pin-USB,90℃ | 1 | |
| 45 | ZD1 | MMSZ22T1G | 1 | |
| 46 | L | 37MM-UL1007 22#-red | 1 | |
| 47 | N | 37MM-UL1007 22#-black | 1 | |

# 10 Transformer Construction

Core and material: EE19, 3C90 (other equivalent ferrite)
Bobbin: EE19 Vertical Version
Primary Inductance: Lp=1.6mH (±10%), measured between pin 6 and pin 4
Manufacturer and part number: Wurth Electronics Midcom (750341723)

## Transformer structure:




| Start | End | No. of Turns | Wire size | Layer |
|---|---|---|---|---|
| 7 | 5 | 27 | Ø0.20mm | Auxiliary |
| 2 | 4 | 65 | Ø0.20mm | ½ Primary |
| 5 | x | 1.1 | 0.05mm*7mm Copper foil | Shielded |
| S | F | 9 | Ø0.65mm T.I.W | Secondary |
| 5 | x | 1.1 | 0.05mm*7mm Copper foil | Shielded |
| 6 | 2 | 70 | Ø0.20mm | ½ Primary |

Notes: The transformer has 2 shielded winding and 1 Faraday Shield. The Faraday Shield is 1 layer 0.05mm*7mm copper foil over the core and connected to Pin5.

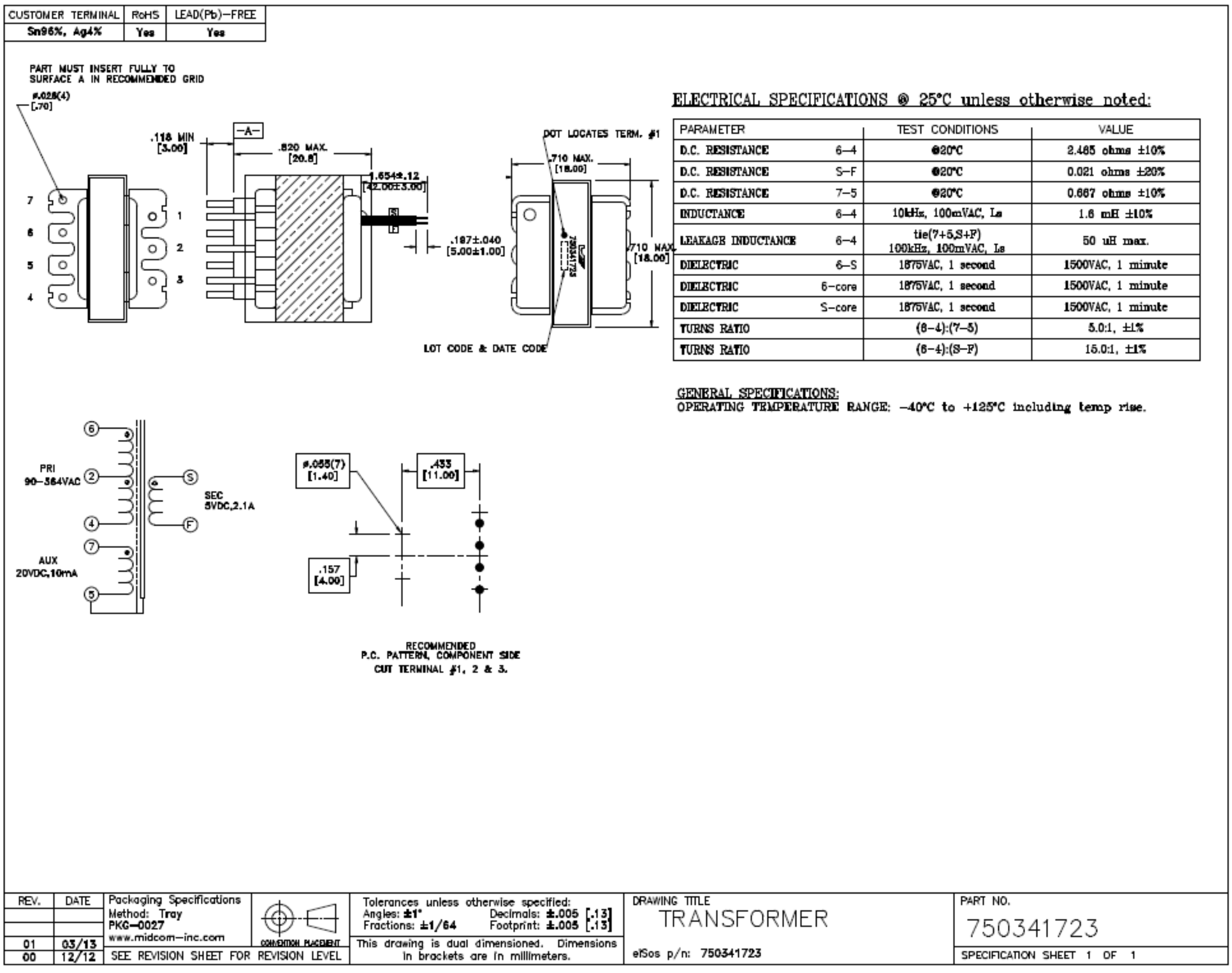



Figure 5 – Transformer structure

# 11 Test Results

## 11.1 Efficiency

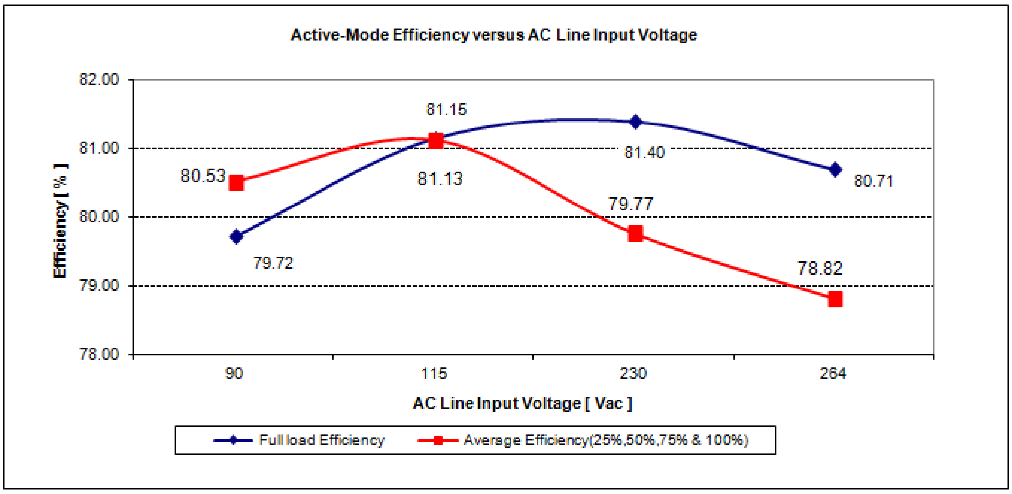



Figure 6 – Efficiency vs. AC line voltage

## 11.2 Input standby power

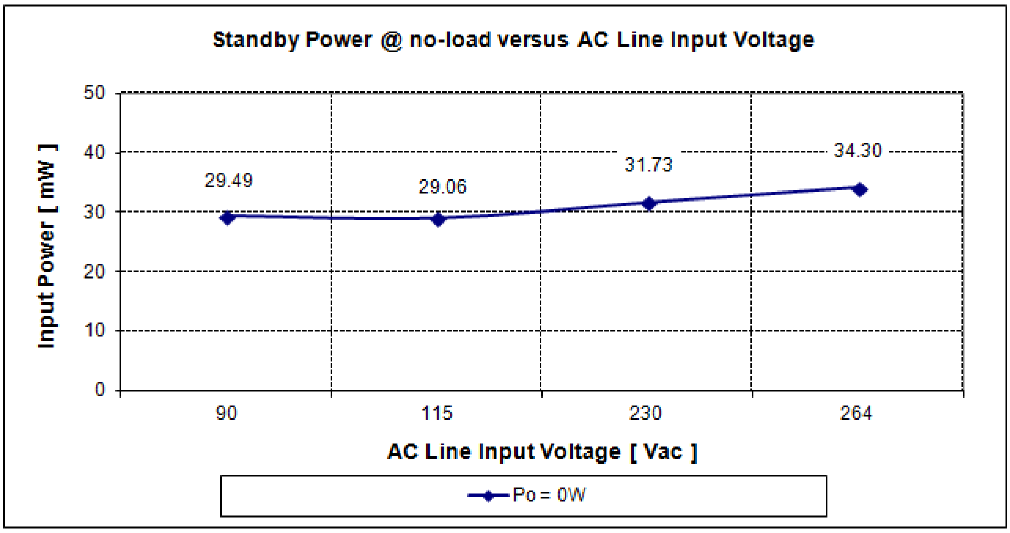



Figure 7 – Input standby power @ no load Vs. AC line input voltage ( measured by Yokogawa WT210 power meter - integration mode )

## 11.3 Line regulation

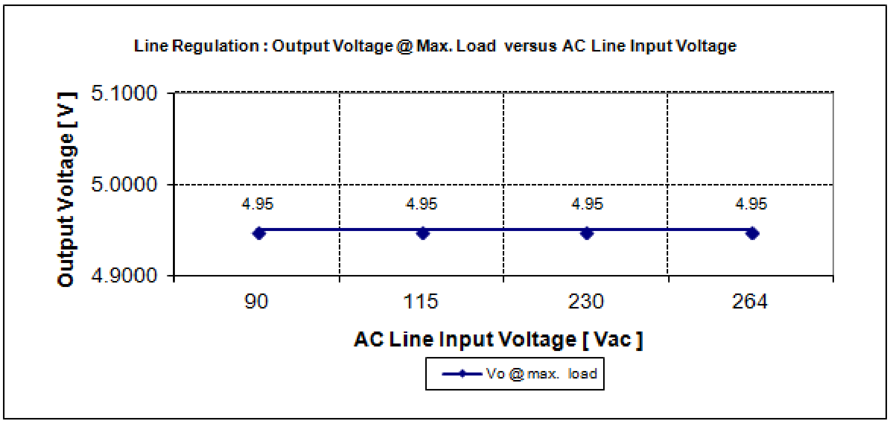



Figure 8 – Line regulation Vout @ full load vs. AC line input voltage

## 11.4 Load regulation

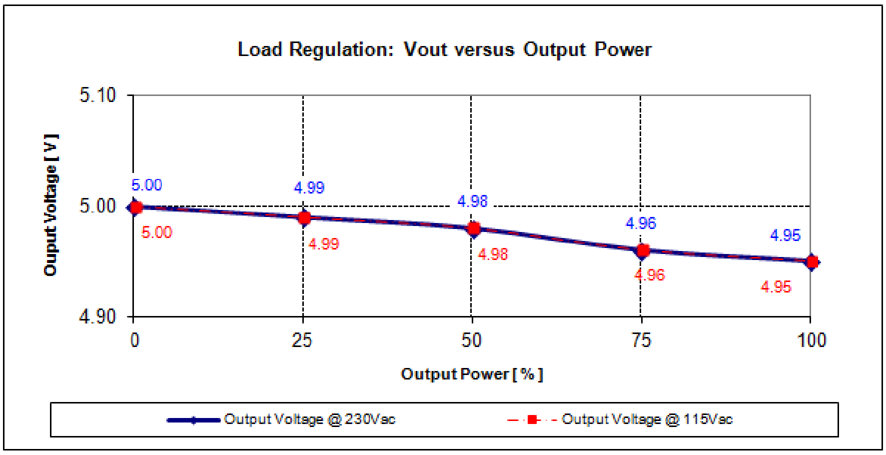



Figure 9 – Load regulation Vout vs. output power

## 11.5 Maximum input power between low and high line

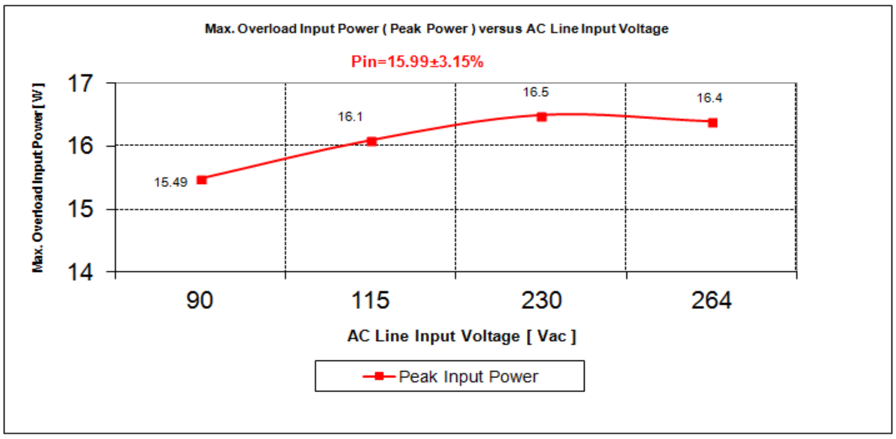



Figure 10 – Maximum input power ( before overload protection ) vs. AC line input voltage

## 11.6 EMI test results

The conducted EMI was measured by Schaffner (SMR4503) under test standard EN55022 or CISPR22 Class B. The demo board was set up at 10.5W with the input voltage at 115Vac and 230Vac. The Red curve(upper one) is the Quasi Peak data and the Green curve(lower one) is the Average data. Both of them can meet the regulations, pass conducted emissions EN55022 (CISPR 22) class B with > 6dB margin.

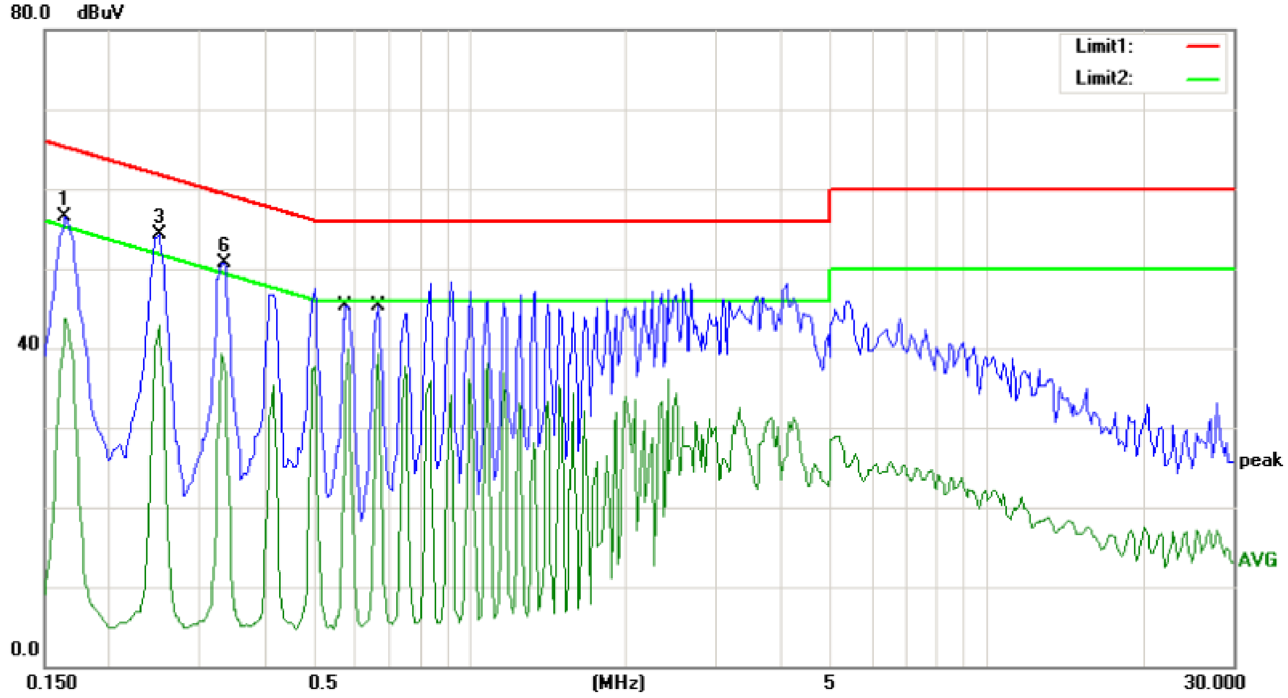



Figure 11 – 230V Line results

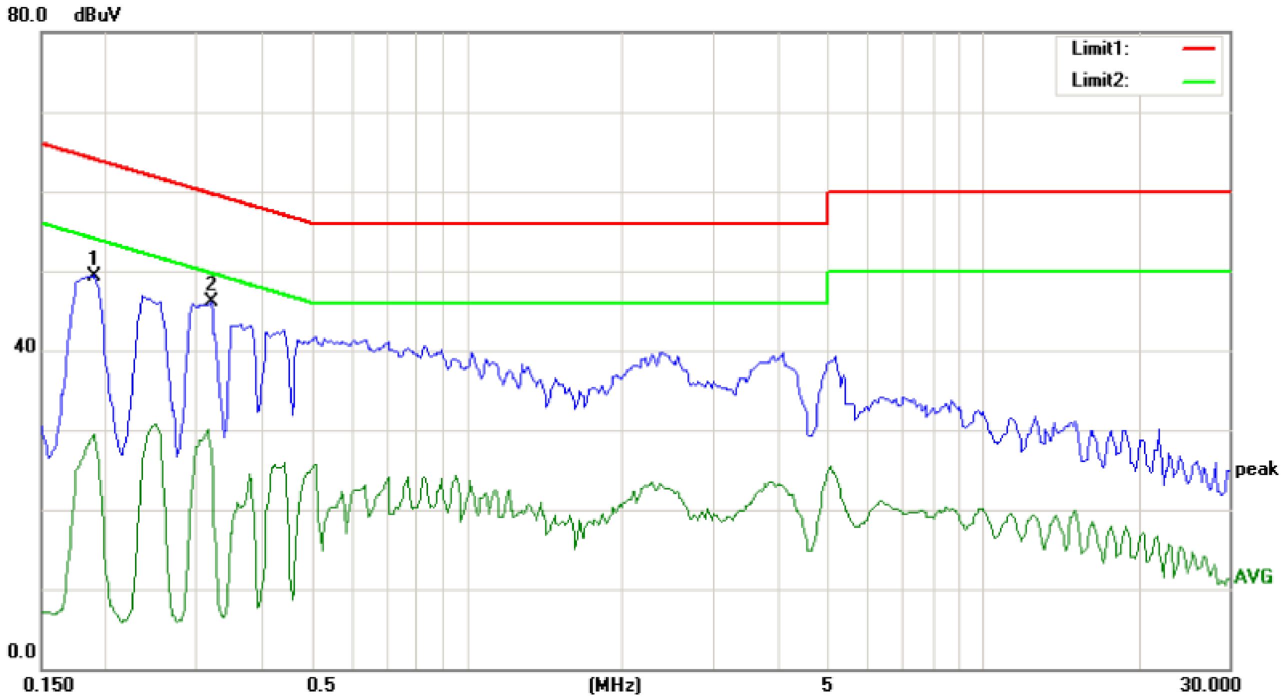



Figure 12 – 115V Line results

# 12 Waveforms and Scope Plots

## 12.1 Startup at Full Load

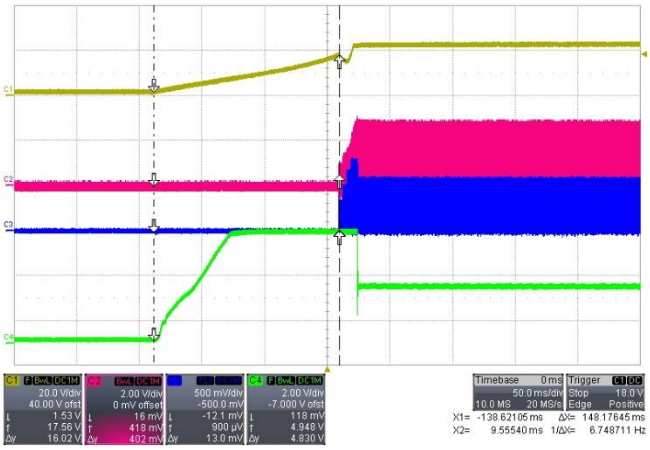


Figure 13 – Constant Charging $V_{CC}$ at Startup
CH1(Yellow) Supply Voltage, $V_{CC}$
CH2(Red) Zero Crossing Voltage, $V_{ZC}$
CH3(Blue) Current Sense Voltage, $V_{CS}$
CH4(Green) Feedback Voltage, $V_{FB}$

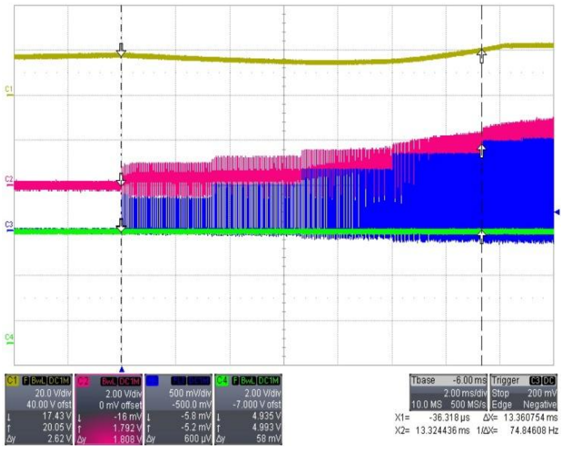


Figure 14 – Step Softstart
CH1(Yellow) Supply Voltage, $V_{CC}$
CH2(Red) Zero Crossing Voltage, $V_{ZC}$
CH3(Blue) Current Sense Voltage, $V_{CS}$
CH4(Green) Feedback Voltage, $V_{FB}$

## 12.2 Drain and $V_{CS}$ voltage at maximum load

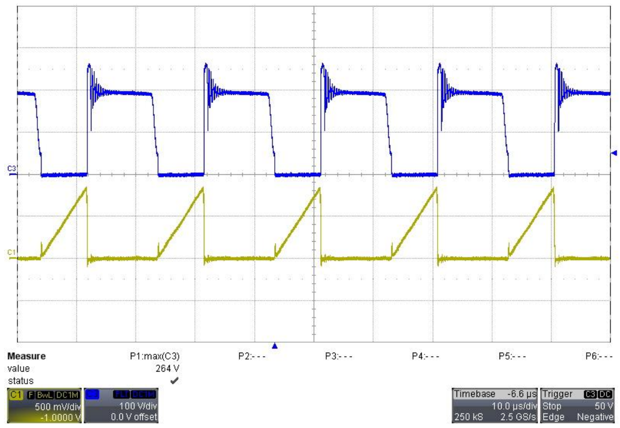


Figure 15 - Operation @ 90Vac and max. load
Ch1=Vcs(Yellow), Ch3=Vds(Blue)
Vin=90Vac, Iout=2.1A(full load)
Vds_max=264V

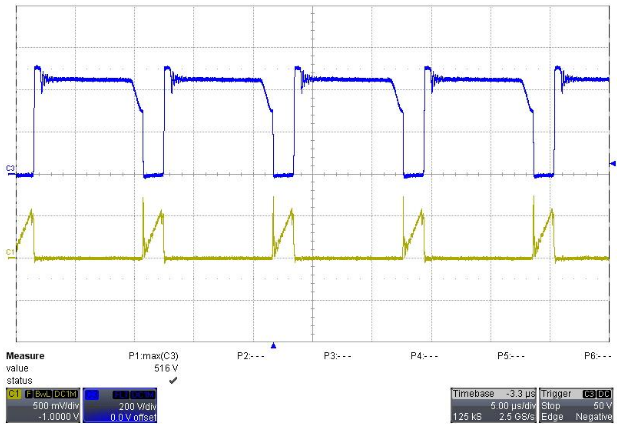


Figure 16 - Operation @ 264Vac and max. load
Ch1=Vcs(Yellow), Ch3=Vds(Blue)
Vin=264Vac, Iout=2.1A(full load)
Vds_max=516V

## 12.3 Zero Crossing Point during Normal Operation

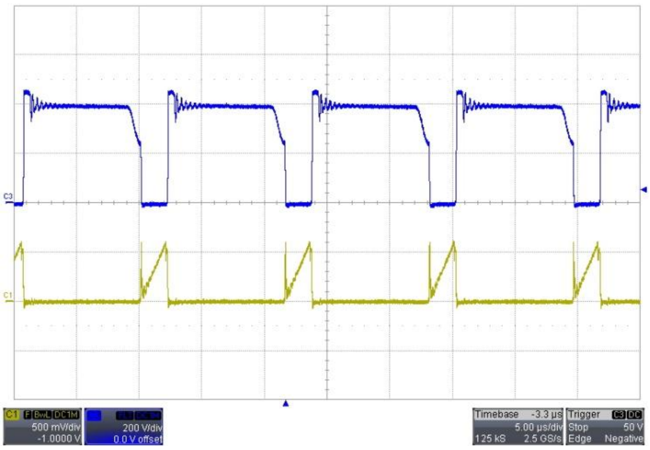


Figure 17 – Working at 1st ZC
CH1(Yellow) Current Sense Voltage, $V_{CS}$
CH3(Blue) MOSFET Dain-Source Voltage, $V_{DS}$

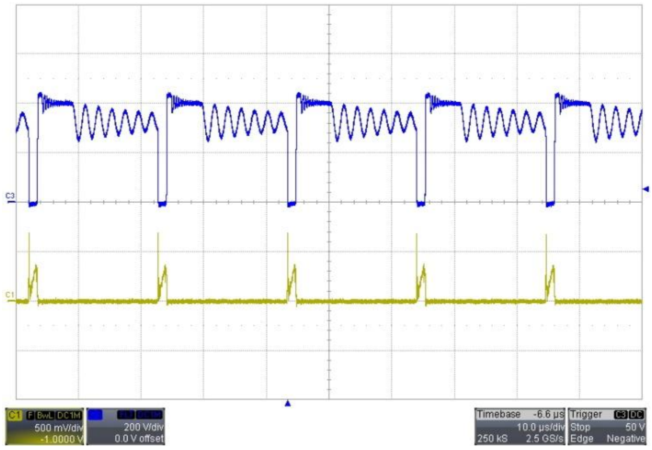


Figure 18 – Working at 7th ZC
CH1(Yellow) Current Sense Voltage, $V_{CS}$
CH2 MOSFET Dain-Source Voltage, $V_{DS}$

## 12.4 Load Transient Response

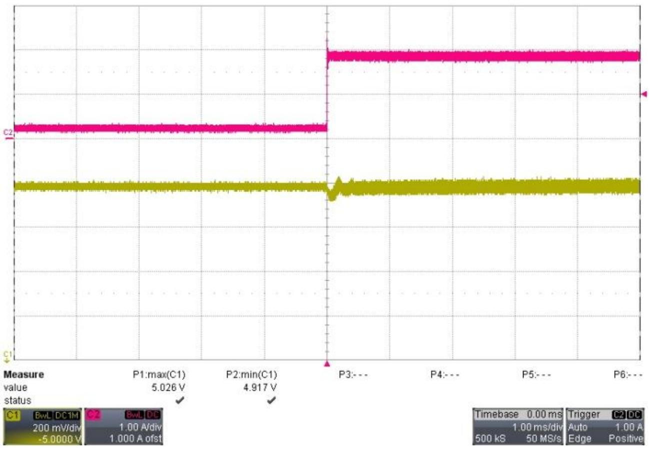


Figure 19 – AC Output Ripple Undershoot
10% → 100% load, 0.4A/us
$V_{O\_max}$=5.026V
$V_{O\_min}$=4.917V
$V_{ripple\_pk\_pk}$=109mV
CH1 Output Voltage, $V_o$
CH2 Output Current, $I_o$

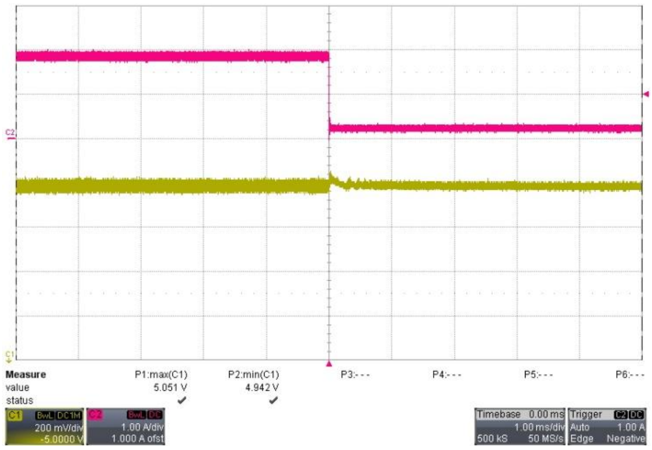


Figure 20 – AC Output Ripple Overshoot
100% → 10% load, 0.4A/us
$V_{O\_max}$=5.051V
$V_{O\_min}$=4.942V
$V_{ripple\_pk\_pk}$=109mV
CH1 Output Voltage, $V_o$
CH2 Output Current, $I_o$

## 12.5 Burst Mode Operation

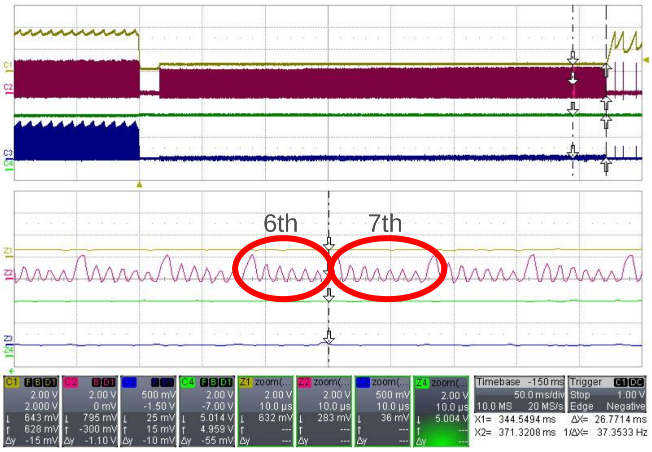



Figure 21 – Entering Burst Mode
CH1(Yellow) Feedback Voltage, $V_{FB}$
CH2(Red) Zero Crossing Voltage, $V_{ZC}$
CH3(Blue) Current Sense Voltage, $V_{CS}$
CH4(Green) Output Voltage, $V_O$
Condition: ZC=7, FB<1.25V, Blanking time = 26ms

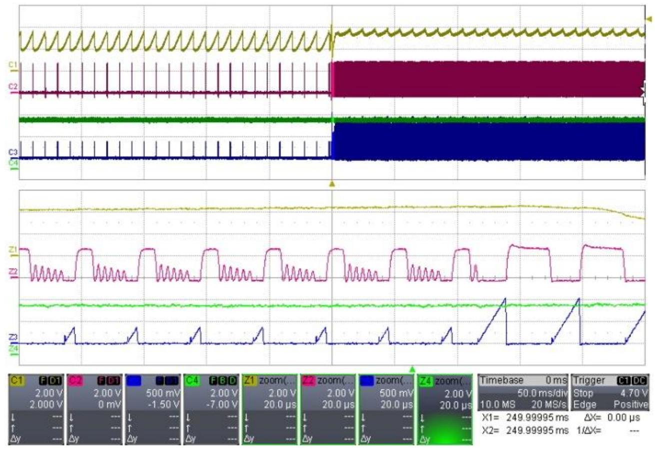


Figure 22 – Leaving Burst Mode
CH1(Yellow) Feedback Voltage, $V_{FB}$
CH2(Red) Zero Crossing Voltage, $V_{ZC}$
CH3(Blue) Current Sense Voltage, $V_{CS}$
CH4(Green) Output Voltage, $V_O$
Condition: $V_{FB}$>4.5V

## 12.6 Protection Mode

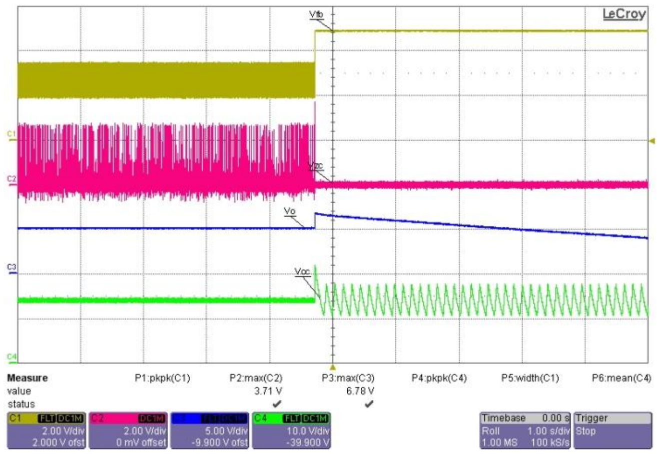



Figure 23 – Vout Over Voltage Protection
CH1(Yellow) Feedback Voltage, $V_{FB}$
CH2(Red) Zero Crossing Voltage, $V_{ZC}$
CH3(Blue) Output Voltage, $V_O$
CH4(Green) Supply Voltage, $V_{cc}$
Condition: $V_O$ >6.7V ($V_{ZC}$>3.7V)

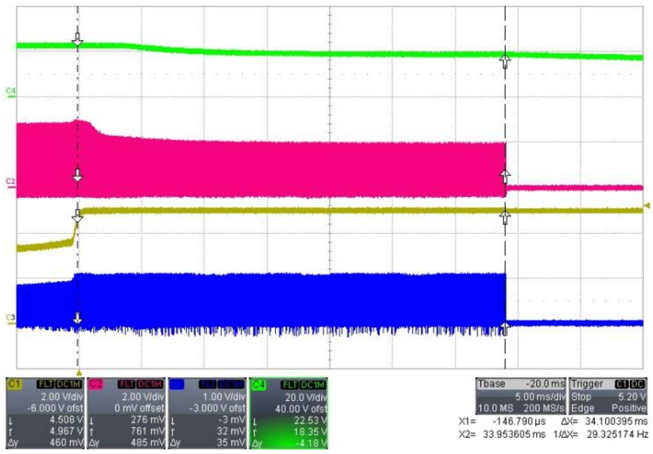


Figure 24 – Over Load/Open Loop Protection
CH1(Yellow) Feedback Voltage, $V_{FB}$
CH2(Red) Zero Crossing Voltage, $V_{ZC}$
CH3(Blue) Current Sense Voltage, $V_{CS}$
CH4(Green) Supply Voltage, $V_{cc}$
Condition: $V_{FB}$>4.5V for 30ms

# 13 References


[1] ICE2QS03G datasheet, Infineon Technologies AG

[2] IPU60R950C6 datasheet, 600V CoolMOS™ C6 Power Transistor

[3] Converter Design Using the Quasi-Resonant PWM Controller ICE2QS01, Infineon Technologies AG, 2006. [ANPS0003]

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

[5] Determine the switching frequency of Quasi-Resonant flyback converters designed with ICE2QS01, Infineon Technologies, 2006. [ANPS0004]

[6] ICE2QS03G design guide. [ANPS0027]

[7] 36W Evaluation Board with Quasi-Resonant PWM Controller ICE2QS03G, 2011. [AN-PS0040]

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