Texas Instruments

# Quasi-Resonant Flyback Converter Universal Off-Line Input 65-W Evaluation Module

## User's Guide

March 2007

Power Supply MAN

SLUU263A

# *Quasi-Resonant Flyback Converter Universal Off-Line Input 65-W Evaluation Module*

# *User's Guide*

Literature Number: SLUU263A
October 2006–Revised March 2007

TEXAS INSTRUMENTS

# Quasi-Resonant Flyback Converter Universal Off-Line Input 65-W EVM

The UCC28600 evaluation module, (UCC28600EVM-65 W), is a 65-W off-line quasi-resonant flyback converter providing an 18-V regulated output at 3.6 A of load current, operating from a universal ac input between 85 $V_{AC}$ and 265 $V_{AC}$ with a frequency range of 47 Hz to 63 Hz. The EVM uses the UCC28600 quasi-resonant flyback green-mode controller which integrates built-in state of the art energy saving features with high-level protection features to provide cost effective solutions for energy efficient power supplies.

## 1 Description

The UCC28600EVM-65 W highlights the many benefits of using the UCC28600 quasi-resonant flyback green-mode controller and can also serve as a close-to-final product reference design. Low system parts count and multifunction pins in this green-mode controller provide a cost-effective solution while meeting stringent world-wide energy efficiency requirements. This user's guide provides the schematic, component list, and assembly drawing for a single-sided PCB application, artwork, and test set up necessary to evaluate the UCC28600 controller in a typical off-line converter application. The EVM is designed for either dual output or single output. At present, only single output (OUT1) is available.

The UCC28600EVM-65 W features:

- Regulated 18-V and 65-W dc output
- Universal off-line input voltage 85 $V_{AC}$ to 265 $V_{AC}$
- Meets EPA Energy Star® efficiency requirements and standby power requirements
- Power turn-on time less than 3 seconds
- Input power less than 1-W at 0.5-W output
- Prebias load turn-on with prebias voltage from 0% to 95% of output rated voltage
- Cycle-by-cycle power limit
- Output over-voltage protection
- Embedded over-temperature protection
- Regulation down to zero output current
- Single-sided board layout

## 2 Operating Guidelines

The operating guidelines for the EVM are provided with reference to the schematic in Figure 1. The set up is shown in Figure 2 for load operation, and Figure 3 for standby mode operation. Equipment set up is described followed by EVM operation.

**CAUTION**

Proper precautions must be taken when working with the EVM. High voltage levels and temperature higher than 60 C are present on the EVM when it is powered on.

The large bulk capacitor across the bridge diodes and the output capacitor bank must be completely discharged before the EVM can be handled. Serious injury can occur if proper safety precautions are not followed.

It is important to maintain the ambient temperature around the EVM to below 45C during operation.

## 2.1 Test Setup and Schematic Drawing Diagrams

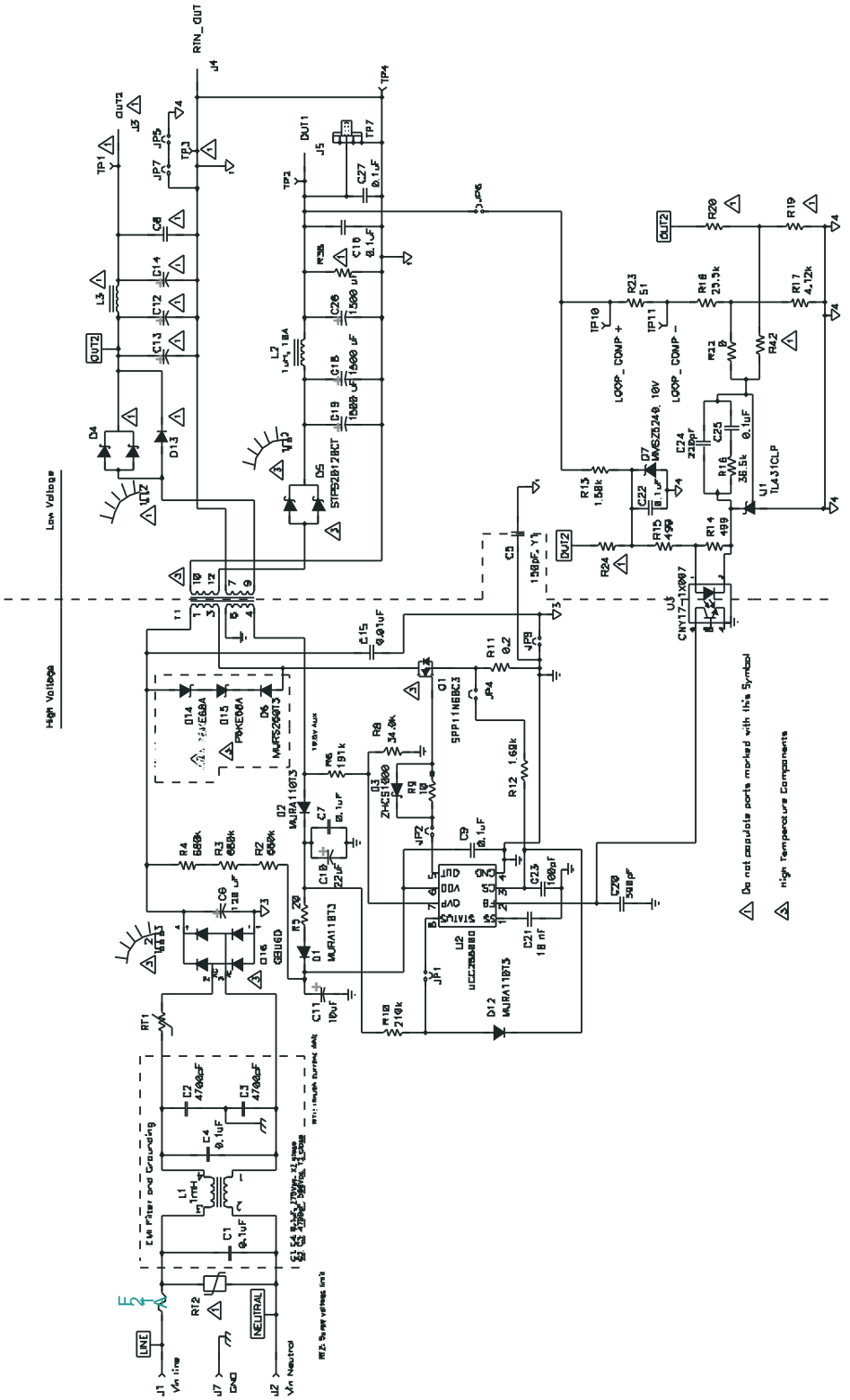
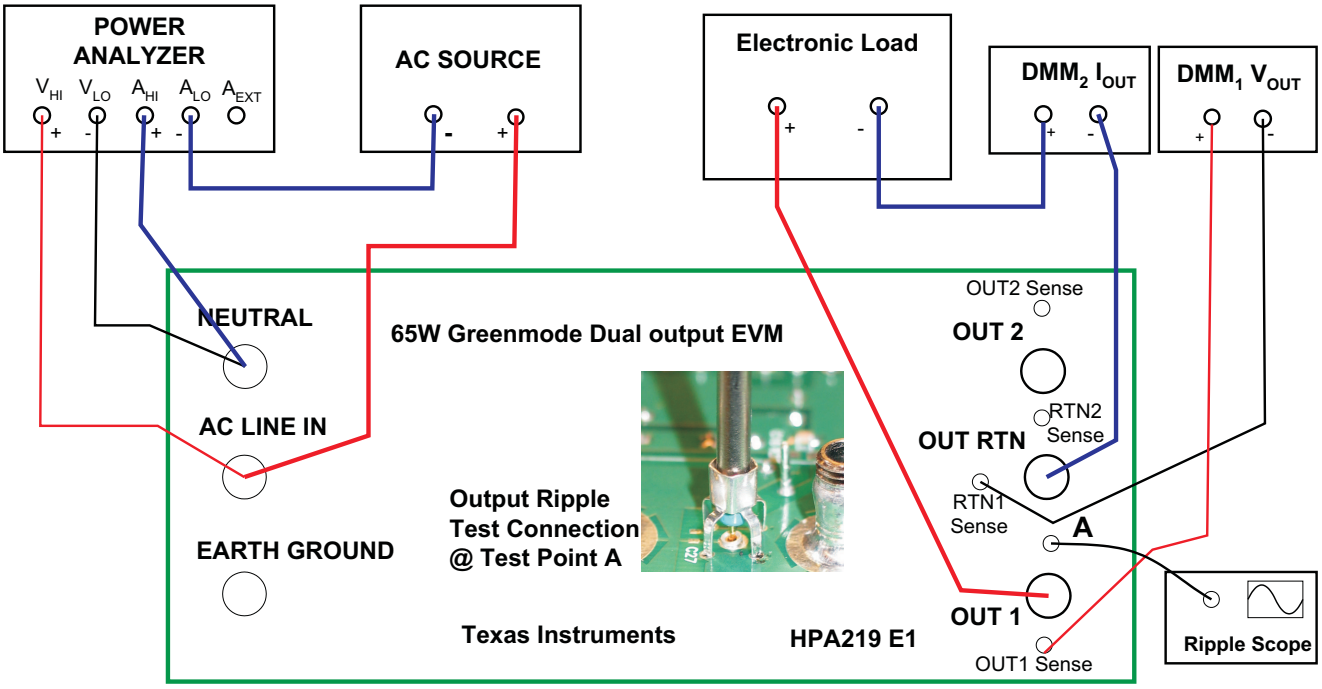


**Figure 1. EVM Schematic**




A Test point A may be found on the bottom side of the board.

**Figure 2. Test Setup for Operation with Load**

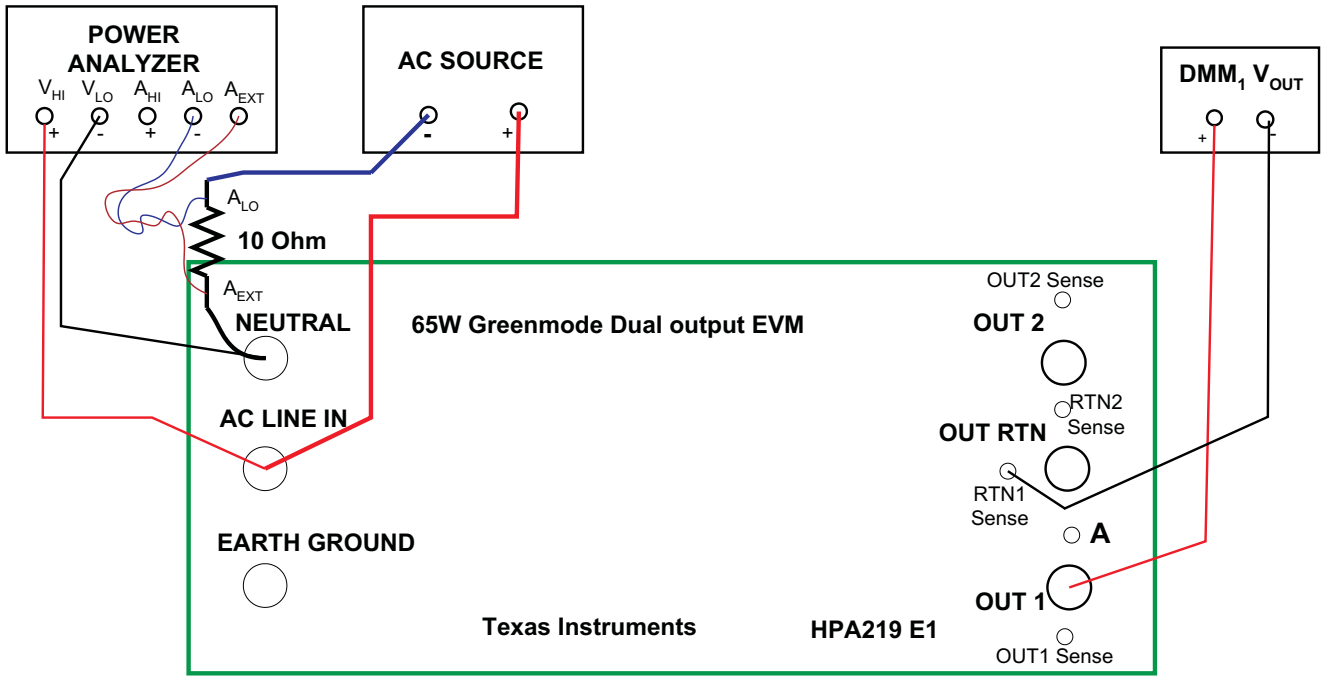



**Figure 3. Test Setup for Standby Mode Operation.**

## 2.2 Equipment Set up

### 2.2.1 Power Meter

The power meter shall be capable of measuring low input current, typically less than 5 mA, and a long averaging mode if low power standby mode input power measurements are to be taken. An example is the Voltech PM100 single phase power analyzer. To measure the intermittent bursts of current and power drawn from the line during no-load operation, requires the use of an external 10-Ω shunt resistor with 1% or better precision, low temperature coefficient and a typical current rating not less than 10 mA as shown in Figure 3.

### 2.2.2 AC Input Source

The input source shall be a variable ac sinusoidal source capable of supplying between 85 $V_{AC}$ and 265 $V_{AC}$ with frequency range of 47 Hz to 63 Hz and minimum 5-A peak current.

### 2.2.3 Multimeters

Multimeters are used to measure the output voltage (DMM1) and the output load current (DMM2).

### 2.2.4 Output Load

A programmable electronic load is recommended configurable for constant current mode and capable of sinking 0 $A_{DC}$ to 4 $A_{DC}$ at 18 $V_{DC}$. The output voltage can be monitored by connecting a dc voltmeter, DMM1 to sense pins shown in Figure 2 and Figure 3. A dc current meter, DMM2, may be inserted in series with the electronic load for accurate output current measurements.

### 2.2.5 Oscilloscope

Set the oscilloscope channel to ac coupling with 20-MHz bandwidth.

## 2.3 Operating EVM

The following steps are guidelines for power up and power down of the EVM.

1. An ESD workstation is recommended. Make sure that an ionizer is on before the EVM is removed from the protective packaging and power is applied to the EVM. Electrostatic smock and safety glasses should also be worn. Because voltages in excess of 400 V may be present on the EVM, do not connect the ground strap from the smock to the bench.
2. Power up.
   a. Prior to connecting the ac input source, limit the source current to 2.5 A maximum. Make sure the ac source is initially set between 85 $V_{RMS}$ and 265 $V_{RMS}$ and 47 Hz to 63 Hz prior to turning on. Connect the ac source to the EVM as shown in Figure 2 or Figure 3.
   b. Connect the power meter as shown in Figure 2 or Figure 3. If no-load input power measurements are to be made, set the power analyzer to long averaging and external shunt mode. Insert a shunt, such as a 10-Ω resistor as shown in Figure 3, in series with the NEUTRAL terminal of the EVM. Set the appropriate current scale on the power meter.
   c. Connect the current meter DMM2 as shown in Figure 2.
   d. Connect the volt meter DMM1 as shown in Figure 2 or Figure 3.
   e. For operation with a load, connect the electronic load to the EVM as shown in Figure 2. Set the load to constant current mode with initial value of 0 A.
   f. Turn on the ac source and observe that the output is regulating to 18 V.
   g. Vary the load between 0 A and 3.61 A.
3. Power down.
   a. Turn off the ac source.
   b. Discharge the output capacitor bank.
   c. Turn off the load.
   d. Using a volt meter, verify that the output capacitor bank and input bulk capacitor across the bridge diodes is near 0 V before handling the EVM.

# 3 EVM Typical Performance

**Table 1. 65W-EVM Performance Summary**

| PARAMETER | TEST CONDITION | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|
| **Input Characterihdrstics** | | | | | |
| Voltage range | $V_{IN}$ | 85 | | 265 | $V_{AC}$ |
| Frequency range | Sinusoidal source | 47 | | 63 | Hz |
| Input inrush current, peak | $V_{IN}$ = 115 $V_{AC}$ with 5-Ohm thermistor | | | 35 | A |
| Maximum Input current | $V_{IN}$ = 115 $V_{AC}$, $I_{OUT}$ = 3.61 A | | | 1.37 | $A_{RMS}$ |
| | $V_{IN}$ = 230 $V_{AC}$, $I_{OUT}$ = 3.61 A | | | 0.67 | |
| **Output Characteristics** | | | | | |
| Output voltage $V_O$ | 85 $V_{AC}$ < $V_{IN}$ < 265 $V_{AC}$, 0 A < $I_{OUT}$ < 3.61 A | 17.5 | 18 | 18.5 | $V_{DC}$ |
| Load current | 85 $V_{AC}$ < $V_{IN}$ < 265 $V_{AC}$ | 0 | | 3.61 | A |
| Continuous output power | 85 $V_{AC}$ < $V_{IN}$ < 265 $V_{AC}$ | | | 65 | W |
| Line regulation | 85 $V_{AC}$ < $V_{IN}$ < 265 $V_{AC}$, 0 A < $I_{OUT}$ < 3.61 A | | | 5 | mV |
| Load regulation | 85 $V_{AC}$ < $V_{IN}$ < 265 $V_{AC}$, 0 A < $I_{OUT}$ < 3.61 A | | | 5 | |
| Ripple (20 MHz BW) | 85 $V_{AC}$ < $V_{IN}$ < 265 $V_{AC}$, 0 A < $I_{OUT}$ < 3.61 A | | | 10 | $mV_{RMS}$ |
| Noise (20 MHz BW) | 85 $V_{AC}$ < $V_{IN}$ < 265 $V_{AC}$, 0 A < $I_{OUT}$ < 3.61 A | | | 75 | $mV_{pk-pk}$ |
| Start-up overshoot | 85 $V_{AC}$ < $V_{IN}$ < 265 $V_{AC}$, 0 A < $I_{OUT}$ < 3.61 A | | | 8% | % |
| Load transient deviation | 85 $V_{AC}$ < $V_{IN}$ < 265 $V_{AC}$, 0.361 A < $I_{OUT}$ < 3.61 A | | | 180 | mV |
| OVP limit | 85 $V_{AC}$ < $V_{IN}$ < 265 $V_{AC}$, 0 A < $I_{OUT}$ < 3.61 A | | 23 | 23.5 | $V_{DC}$ |
| Short circuit current | 85 $V_{AC}$ < $V_{IN}$ < 265 $V_{AC}$ | | 15 | | A |
| Max Power limit | 85 $V_{AC}$ < $V_{IN}$ < 265 $V_{AC}$ | | 90 | | W |
| $V_O$ pre-bias start range | 85 $V_{AC}$ < $V_{IN}$ < 265 $V_{AC}$, 0 A < $I_{OUT}$ < 3.61 A | 1% | | 95% | |
| **Control Characteristics** | | | | | |
| Bandwidth / phase margin | $V_{IN}$ = 115 $V_{AC}$, $I_{OUT}$ = 3.61 A | | 1.6 / 60 | | kHz/° |
| | $V_{IN}$ = 230 $V_{AC}$, $I_{OUT}$ = 3.61 A | | 2.4 / 70 | | |
| Turn-on time | $V_{IN}$ = 85 - 265 $V_{AC}$, IOUT: 0 - 3.61 A | | | 2.9 | s |
| **Efficiency** | | | | | |
| Peak | $V_{IN}$ = 230 $V_{AC}$, $I_{OUT}$ = 3.28 A | | 88.4% | | |
| Full load | $V_{IN}$ = 90 $V_{AC}$, $I_{OUT}$ = 3.61 A | | 86.0% | | |
| | $V_{IN}$ = 115 $V_{AC}$, $I_{OUT}$ = 3.61 A | | 87.0% | | |
| | $V_{IN}$ = 230 $V_{AC}$, $I_{OUT}$ = 3.61 A | | 88.0% | | |
| Energy star (EPA four points average) | $V_{IN}$ = 115 $V_{AC}$ | | 87.0% | | |
| | $V_{IN}$ = 230 $V_{AC}$ | | 88.0% | | |
| Standby power | $V_{IN}$ = 115 $V_{AC}$, $I_{OUT}$ = 0 A | | 150 | 200 | mW |
| | $V_{IN}$ = 230 $V_{AC}$, $I_{OUT}$ = 0 A | | 200 | 250 | |
| | $V_{IN}$ = 265 $V_{AC}$, $I_{OUT}$ = 0 A | | 220 | 270 | |
| Input power | $V_{IN}$ = 85 - 265 $V_{AC}$, load = 0.5 W | | | 0.85 | W |
| Operation temperature | Full load, natural convection cooling | | | 45 | C |

# 4 EVM Typical Performance Curves

Soft Start Waveform

**Start-Up Output Voltage Waveform**

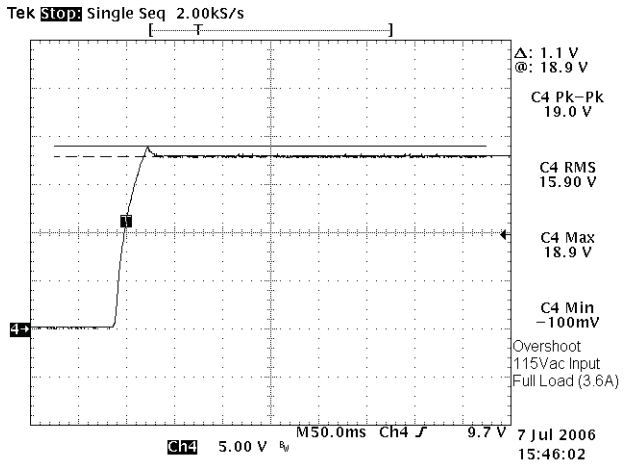



**Figure 4.**

Soft Start into Prebias Load

**Output Voltage Start into Prebias Load**

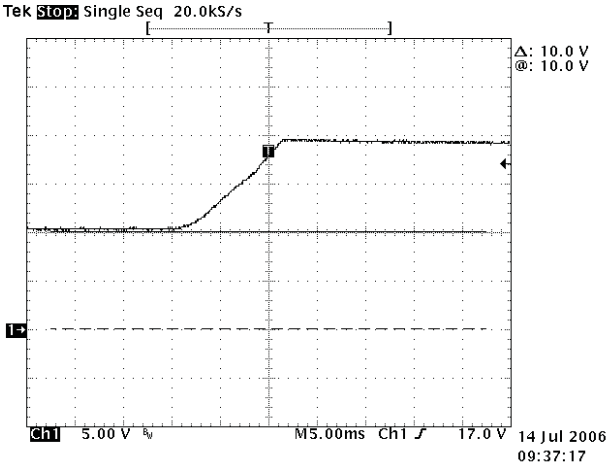



**Figure 5.**

Typical Turn-On Time

**Typical Turn-On Time**

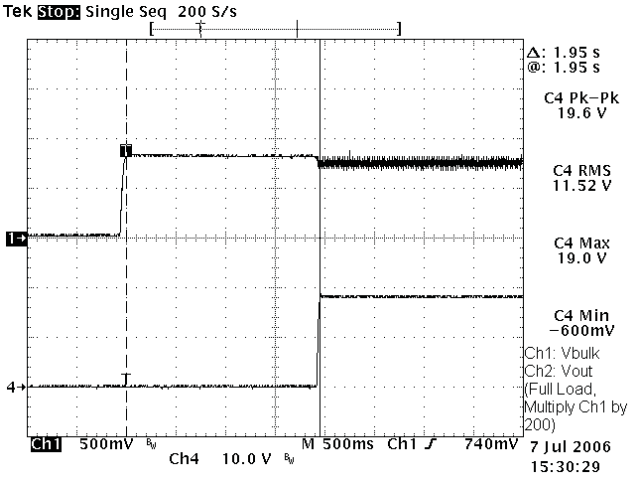



**Figure 6.**

Output Voltage Ripple

**Output Voltage Ripple and Noise**

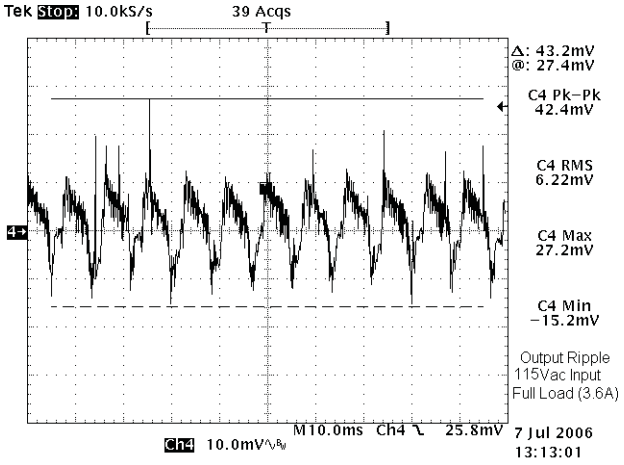



**Figure 7.**

Waveforms of Drain and Current Sensing Resistor Voltage at FFM

**Drain/Current Sensing Resistor Voltage at Frequency-Foldback Mode**

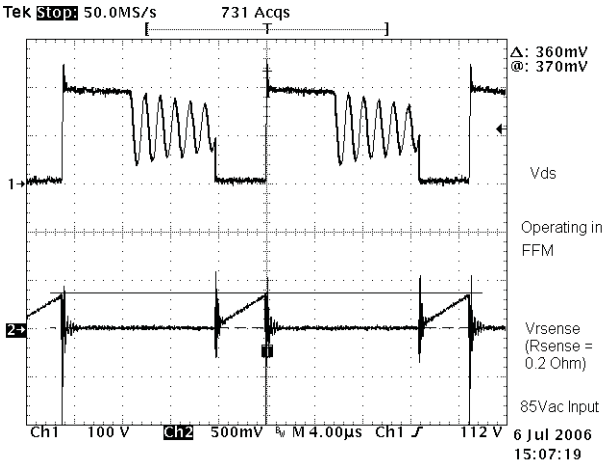



**Figure 8.**

Waveforms of $V_{FB}$, $V_{OVP}$, $V_{CS}$ and $V_{GATE}$

**$V_{FB}$, $V_{OVP}$, $V_{CS}$ and $V_{GATE}$**

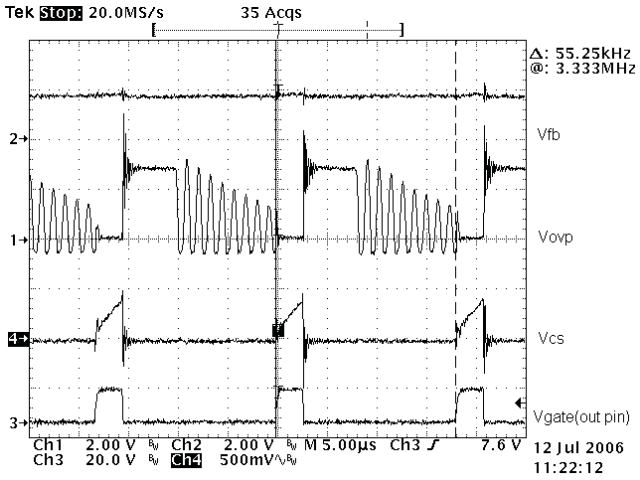



**Figure 9.**

**EFFICIENCY vs LOAD POWER**

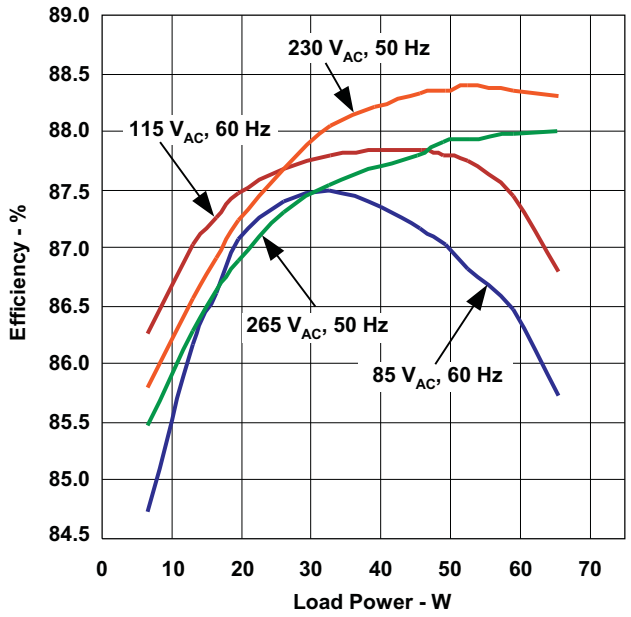



**Figure 10.**

**EFFICIENCY vs INPUT VOLTAGE AT FULL LOAD**

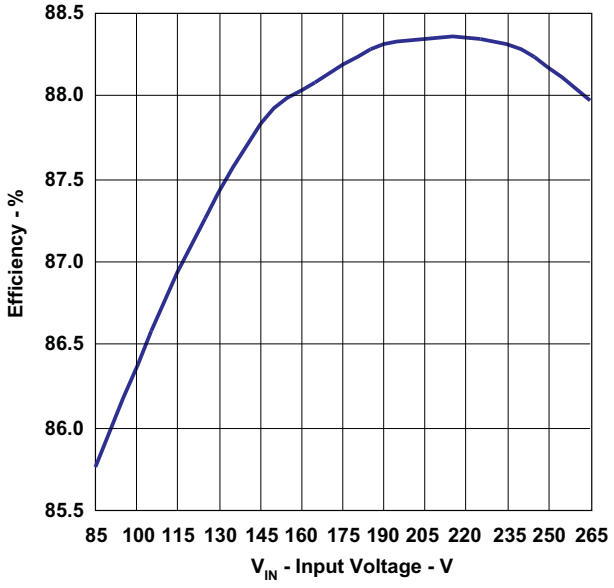



**Figure 11.**

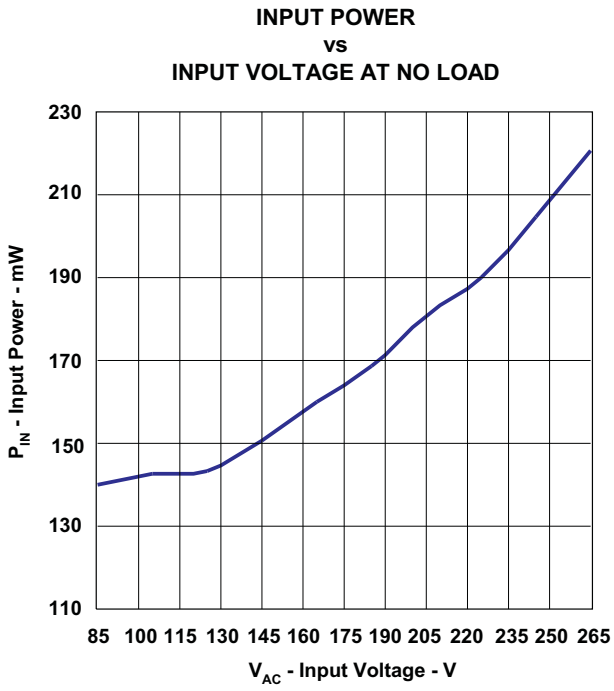



**Figure 12.**

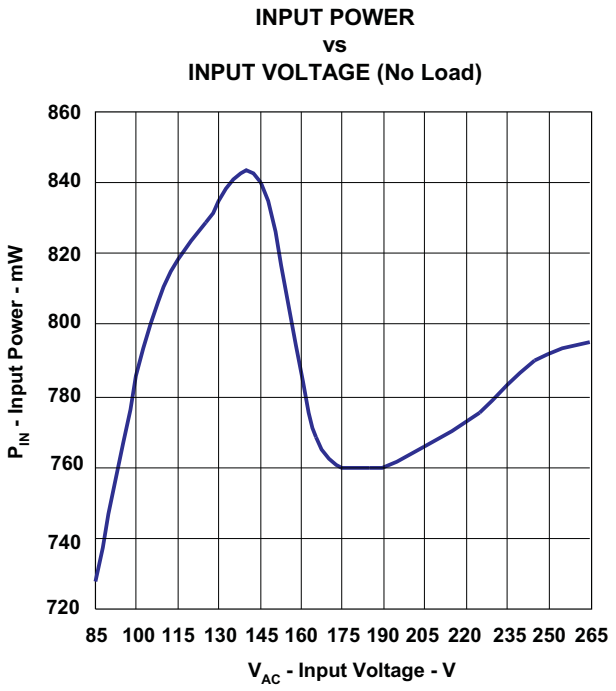



**Figure 13.**

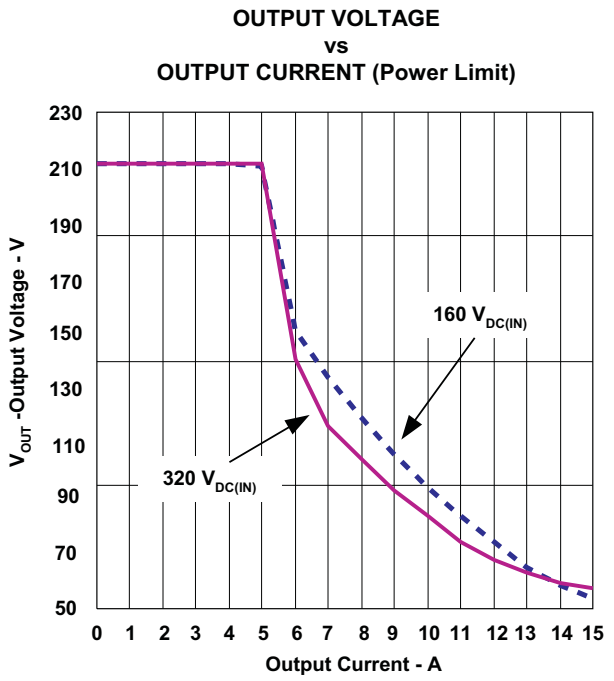



**Figure 14.**

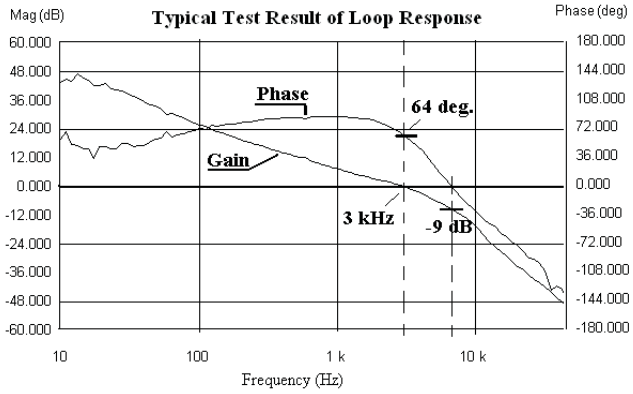



**Figure 15.**

## 16 EVM Assembly Drawing and Layout

Figure 16 and Figure 17 show the layout of the single-sided printed circuit board used for the EVM.

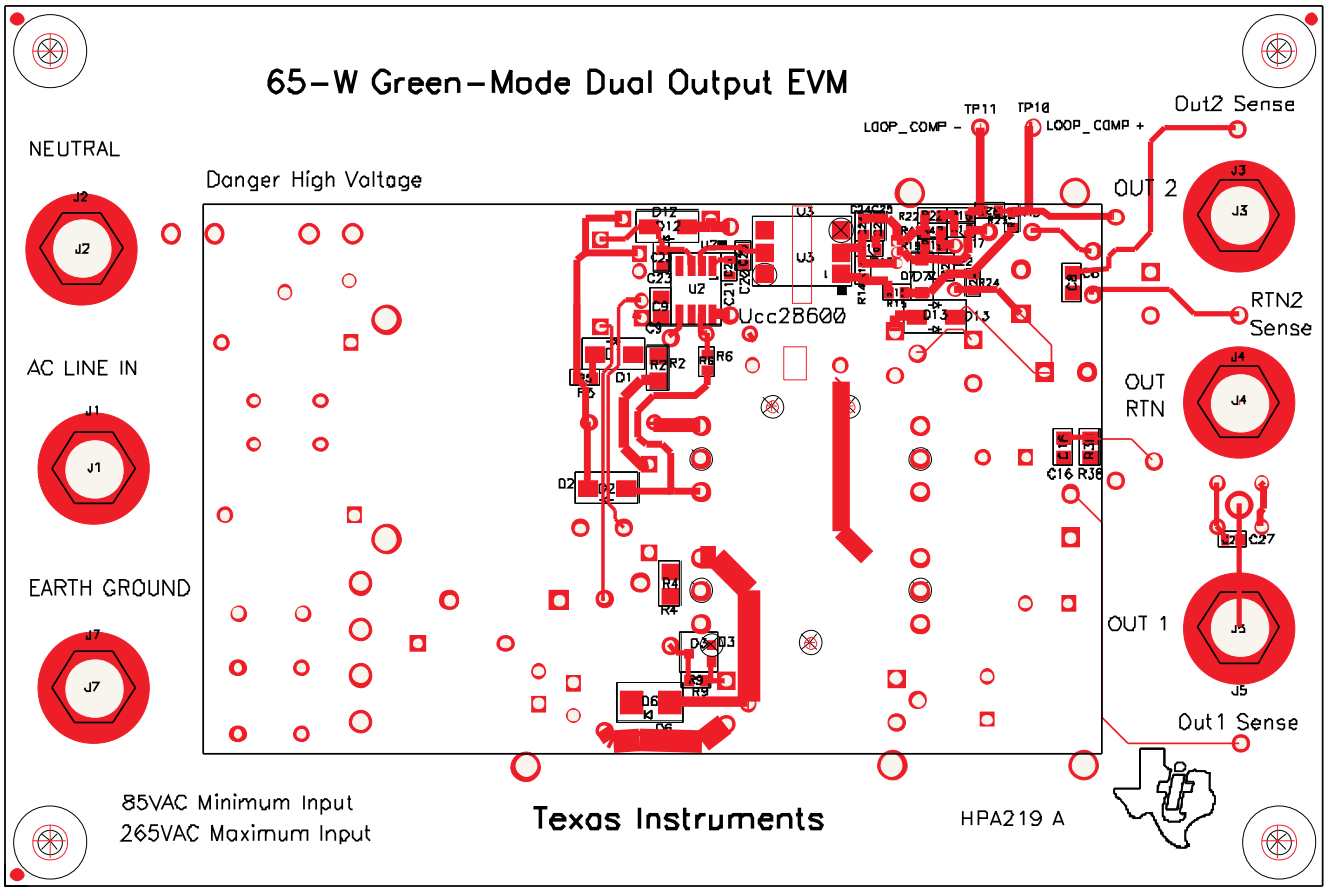



**Figure 16. Top View**

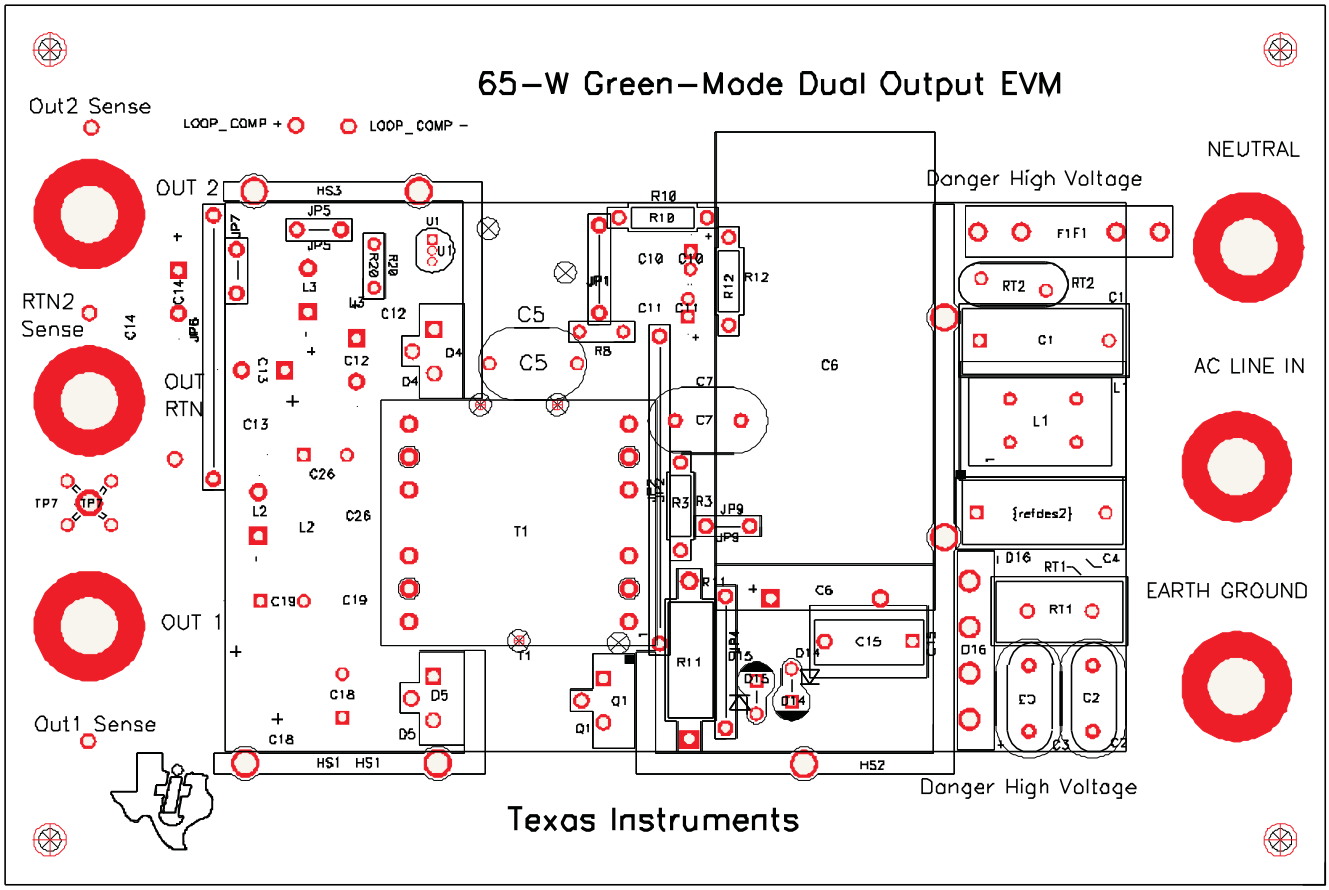



**Figure 17. Bottom View**

# 17 List of Materials

**Table 2. List of Materials**

| RefDes | Qty | Description | MFR | Part Number |
|---|---|---|---|---|
| C1 | 1 | Capacitor, film, 0.1 µF, 275 $V_{AC}$, 20% | Panasonic | ECQU2A104ML |
| C10 | 1 | Capacitor, aluminum, 22 µF, 50 V, 20% (FC series) | Panasonic | EEU-FC1H100 |
| C11 | 1 | Capacitor, aluminum, 10 µF, 50 V, 20% (FC series) | Panasonic | EEU-FC1H100 |
| C15 | 1 | Capacitor, polyester, 0.01 µF, 630 V, 10% | Panasonic - ECG | ECQ-E6103KF |
| C18, C19, C26 | 3 | Capacitor, aluminum, 1500 uF, 25 V, 20% | Panasonic | EEU-FC1E152 |
| C2, C3 | 2 | Y2 Capacitor, ceramic disc, 4700 pF, 250 V, 20% | Murata | DE2E3KY472M |
| C20 | 1 | Capacitor, ceramic, 390 pF, 50 V, X7R, 10% | Murata Electronics | GRM188R71H391KA01D |
| C21 | 1 | Capacitor, ceramic, 18 nF, 25 V, X7R, 10% | Panasonic - ECG | ECJ-1VB1E183K |
| C22, C25 | 2 | Capacitor, ceramic, 0.1 µF, 16 V, X7R, 10% | Kemet | C0603C104K4RACTU |
| C23 | 1 | Capacitor, ceramic, 100 pF, 100 V, C0G, 5% | Murata Electronics | GRM1885C2A101JA01D |
| C24 | 1 | Capacitor, ceramic, 220 pF, 100 V, C0G, 5% | Murata Electronics | GRM1885C2A221JA01D |
| C4 | 1 | Capacitor, film, 0.1 µF, 275 $V_{AC}$, 20% | Panasonic | ECQU2A104ML |
| C5 | 1 | Capacitor, ceramic disc, 150 pF, 4 kV, temp 15%, 20%, Y1 class | Panasonic | ECKANA151MB |
| C6 | 1 | Capacitor, aluminum, 120 µF, 400 V, 20% | Chemi-Con | ESMG401E121MN40SLL |
| C7 | 1 | Capacitor, ceramic disc, 0.1 µF, 50 V, X7R, 20% | BC Components | K104K15X7RF5TH5 |
| C16 | 1 | Capacitor, ceramic, 0.1 µF, 35 V, X5R, 10% | Murata Electronics | GRM21B1H104K |
| C9 | 1 | Capacitor, ceramic, 0.1 µF, 50 V, X7R | Murata Electronics | GRM21BR71H104KA01K |
| D1, D2, D12 | 3 | Diode, ultra fast rectifier, 1 A, 100 V | ON Semiconductor | MURA110T3 |
| D14, D15 | 2 | Diode,transient voltage suppressor, 68 V, 5 W | Vishay | P6KE68A |
| D16 | 1 | Diode, bridge rectifier, 6 A, 400 V | Vishay | GBU6G |
| D3 | 1 | Diode, Schottky, 1 A, 40 V | Central Semiconductor | ZHCS1000 |
| D5 | 1 | Diode, dual Schottky, 2 A x 10 A, 120 V | STMicroelectronics | STPS20120CT |
| D6 | 1 | Diode, ultra fast rectifier, 2 A, 600 V | ON Semiconductor | MURS260T3 |
| D7 | 1 | Diode, Zener, 500 mW, 10 V | ON Semiconductor | MMSZ5240BT1G |
| F1 | 1 | Fuse, axial, fast acting, 2 A, 250 V | Littelfuse | 0263002.M |
| L1 | 1 | Inductor, SMT, 1 mH, 3 A, 0.035 Ω, 30% | JW Miller | 7111JW |
| L2 | 1 | Inductor, 8RHB2 type, 10 A, 1 µH | JW Miller Magnetics | 6000-1R0M-RC |
| Q1 | 1 | MOSFET, cool MOS power N-channel, 650 V, 11 A, 380 mΩ, | Infineon Technologies | SPP11N60C3 |
| R10 | 1 | Resistor, metal film, 210 kΩ, 1/4 W, 1%, axial | Yageo America | MFR-25FBF-210K |
| R11 | 1 | Resistor, metal film, 0.2 Ω, 3 W, 5%, axial | KOA Speer Electronics | SPRX3CT52OR20F |
| R12 | 1 | Resistor, metal film, 1.69 kΩ, 1/4 W, 1%, axial | Yageo America | MFR-25FBF-1K69 |
| R13 | 1 | Resistor, chip, 1.50 kΩ, 1/10 W, 1%, 0603 | Yageo America | RC0603FR-071K5L |
| R14 | 1 | Resistor, chip, 499 Ω, 1/10 W, 1%, 0603 | Yageo America | RC0603FR-07215RL |

**Table 2. List of Materials (continued)**

| RefDes | Qty | Description | MFR | Part Number |
|---|---|---|---|---|
| R15 | 1 | Resistor, chip, 499 Ω, 1/10 W, 1%, 0603 | Yageo America | RC0603FR-07215RL |
| R16 | 1 | Resistor, chip, 36.5 kΩ, 1/10 W, 1%, 0603 | Yageo America | RC0603FR-0736K5L |
| R17, R19 | 2 | Resistor, chip, 4.12 kΩ, 1/10 W, 1%, 0603 | Yageo America | RC0603FR-074K12L |
| R18 | 1 | Resistor, chip, 25.5 kΩ, 1/10 W, 1%, 0603 | Yageo America | RC0603FR-0725k5L |
| R2 | 1 | Resistor, chip, 680 kΩ, 1/4 W, 5%, 1206 | Panasonic - ECG | ERJ-8GEYJ684V |
| R20 | 1 | Resistor, metal film, 4.12 kΩ, 1/4 W, 5% | Yageo America | MFR-25FBF-4K12 |
| R22 | 1 | Resistor, chip, 0 Ω, 1/10 W, 1%, 0603 | Yageo America | RC0603FR-070000L |
| R23 | 1 | Resistor, chip, 50 Ω, 1/10 W, 1%, 0603 | Yageo America | RC0603FR-074k12L |
| R3 | | Resistor, metal film, 680 kΩ, 1/4 W, 1%, Axial | Yageo America | MFR-25FBF-680K |
| R4 | | Resistor, chip, 680 kΩ, 1/4 W, 5%, 1206 | Panasonic - ECG | ERJ-8GEYJ684V |
| R5 | 1 | Resistor, chip, 20 Ω, 1/10 W, 5%, 0603 | Panasonic - ECG | ERJ-3GEYJ200V |
| R6 | 1 | Resistor, chip, 210 kΩ, 1/10 W, 1%, 0603 | Rohm | MCR03EZPFX1603 |
| R8 | 1 | Resistor, Metal Film, 28.7 kΩ, 1/4 W, 5% | YAGEO | MFR-25FBF-28K7 |
| R9 | 1 | Resistor, chip, 10 Ω, 1/16 W, 1%, 0603 | Panasonic - ECG | ERJ-3EKF10R0V |
| RT1 | 1 | Thermistor, NTC, 5 Ω, 4.2 A | Epcos | B57235S0509M000 |
| T1 | 1 | XFMR, flyback | GCI | G065022LF |
| U1 | 1 | Adj. precision shunt | Texas Instruments | TL431CLP |
| U2 | 1 | Quasi-Resonant Flyback Green-Mode Controller | Texas Instruments | UCC28600D |
| U3 | 1 | Optocoupler, NPN with base | Vishay | CNY17-1X007 |

## 18 References

1. *UCC28600 8-pin quasi-resonant flyback green mode controller*, datasheet, TI literature Number SLUS646B, May 2006
2. *Test method for calculating the energy efficiency of single-voltage ac-dc and ac-ac power supplies*, California Energy Commission, August 11, 2004
3. *Standby and Low Power Measurements*, Voltech Notes, VPN 104-054/1
4. *Design Consideration for the UCC28600*, Application Note, TI literature Number SLUA399

## IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

TI assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using TI components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license from TI to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

TI products are not authorized for use in safety-critical applications (such as life support) where a failure of the TI product would reasonably be expected to cause severe personal injury or death, unless officers of the parties have executed an agreement specifically governing such use. Buyers represent that they have all necessary expertise in the safety and regulatory ramifications of their applications, and acknowledge and agree that they are solely responsible for all legal, regulatory and safety-related requirements concerning their products and any use of TI products in such safety-critical applications, notwithstanding any applications-related information or support that may be provided by TI. Further, Buyers must fully indemnify TI and its representatives against any damages arising out of the use of TI products in such safety-critical applications.

TI products are neither designed nor intended for use in military/aerospace applications or environments unless the TI products are specifically designated by TI as military-grade or "enhanced plastic." Only products designated by TI as military-grade meet military specifications. Buyers acknowledge and agree that any such use of TI products which TI has not designated as military-grade is solely at the Buyer's risk, and that they are solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI products are neither designed nor intended for use in automotive applications or environments unless the specific TI products are designated by TI as compliant with ISO/TS 16949 requirements. Buyers acknowledge and agree that, if they use any non-designated products in automotive applications, TI will not be responsible for any failure to meet such requirements.

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

| **Products** | | **Applications** | |
|---|---|---|---|
| Amplifiers | amplifier.ti.com | Audio | www.ti.com/audio |
| Data Converters | dataconverter.ti.com | Automotive | www.ti.com/automotive |
| DSP | dsp.ti.com | Broadband | www.ti.com/broadband |
| Interface | interface.ti.com | Digital Control | www.ti.com/digitalcontrol |
| Logic | logic.ti.com | Military | www.ti.com/military |
| Power Mgmt | power.ti.com | Optical Networking | www.ti.com/opticalnetwork |
| Microcontrollers | microcontroller.ti.com | Security | www.ti.com/security |
| RFID | www.ti-rfid.com | Telephony | www.ti.com/telephony |
| Low Power Wireless | www.ti.com/lpw | Video & Imaging | www.ti.com/video |
| | | Wireless | www.ti.com/wireless |

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2007, Texas Instruments Incorporated