**TI Designs**

Cost-Effective Bias Power Supply With < 100-mW Standby and 75% Efficiency Reference Design

**Design Features**
- Designed for Wide Operating Input Range 90-V DC to 425-V DC or 85-V AC to 300-V AC
- Very-Low Standby Power of < 100 mW for No-Load Conditions
- Ultra-Simple Circuit With Low Cost Off-the-Shelf Components
- Tight Output Regulation of < ±1% on All Output Rails
- Robust Supply Protected for Output Over-Current, Short-Circuit and Output Overvoltage Conditions
- Inherent Open Loop or Loss of Feedback Detection in the Controller Shuts Off the Bipolar Junction Transistor (BJT) and Safeguards the System from Output Overvoltage
- Configurable for Output Voltage Requirements from 1.5 V to 15 V With Simple Resistor Change
- Efficiency of 75% at 125-V DC Input and 74% at 325-V DC Input and Full Load
- Small PCB Form Factor of 52 × 25 mm Offers Ease of Placement in High Power Density Applications
- Meets Requirements of Conducted Emissions Standard – EN55011 Class B

**Featured Applications**
- Refrigerators
- Washing Machines
- Kitchen Hoods
- Home Appliances
- Air Conditioners
- Vacuum Cleaners
- End Equipment With Bias Power Requirements

**Design Resources**

<table>
<thead>
<tr>
<th>TI Design Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIDA-00434</td>
<td>Tool Folder Containing Design Files</td>
</tr>
<tr>
<td>UCC28722</td>
<td>Product Folder</td>
</tr>
<tr>
<td>TLV1117</td>
<td>Product Folder</td>
</tr>
<tr>
<td>UA78L05A</td>
<td>Product Folder</td>
</tr>
</tbody>
</table>

**ASK Our E2E Experts**

WEBENCH® Calculator Tools
1 Introduction

Home appliance equipment such as refrigerators, air conditioners, dishwashers, and kitchen hoods use three-phase, pulse-width modulated (PWM) brushless DC electric motor drives (BLDC) or permanent magnet synchronous motor (PMSM) drives. These drives are typically fractional or low horsepower types with power ratings from 0.25 hp (186 W) to 2 hp (1,500 W). The motor drive circuits consist of an intelligent power module (IPM) or discrete insulated-gate bipolar transistors (IGBTs) with gate drivers for DC to AC conversion; a low-cost microcontroller for variable speed, torque control, or both; and current measurement and control feedback sensing circuits for closed loop control.

These systems require low watt power supplies to convert high voltage DC to the multiple low-voltage rails required to provide bias for control circuits. By default, these systems have a rectifier, and bulk capacitor that converts AC line input to DC bus, which, ultimately drives the three-phase electric motor. Also, these systems have electromagnetic interference (EMI) filters for reducing EMI and a 50-Hz DC choke to shape the line current and reduce harmonics. Hence, the bias power supply is a high voltage input DC-DC converter. Typically, these applications require a non-isolated power supply, as each of the circuits operate at the same potential.

This reference design is a simple buck regulator and is configured for appliances that require a non-isolated 2.4-W power supply. The design meets the key challenges of a bias power supply for appliances to provide safe and reliable power, while delivering a high performance, with low power consumption, and with a low Bill-of-Materials (BOM) cost.
## Key System Specifications

### Table 1. Key System Specifications

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SPECIFICATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input voltage</td>
<td>90- to 425-V DC or 85- to 300-V AC</td>
</tr>
<tr>
<td>Frequency</td>
<td>47 Hz to 52 Hz (for AC input)</td>
</tr>
<tr>
<td>Outputs</td>
<td>+12 V, 75 mA (200 mA when LDOs are not used)</td>
</tr>
<tr>
<td></td>
<td>+3.3V, 125 mA</td>
</tr>
<tr>
<td></td>
<td>+5.0V, 50 mA</td>
</tr>
<tr>
<td>Efficiency</td>
<td>&gt; 70%</td>
</tr>
<tr>
<td>Protections</td>
<td>Overload and short-circuit protection</td>
</tr>
<tr>
<td></td>
<td>Output overvoltage protection</td>
</tr>
<tr>
<td>Isolation</td>
<td>Non-isolated buck</td>
</tr>
<tr>
<td>Load and line regulation</td>
<td>&lt; ±1% on 3.3 V, 5 V, and 12 V</td>
</tr>
<tr>
<td>No load power</td>
<td>&lt; 100 mW</td>
</tr>
<tr>
<td>Board form factor and specs</td>
<td>30 × 25 mm (DC input)</td>
</tr>
<tr>
<td></td>
<td>52 × 25 mm (AC input)</td>
</tr>
<tr>
<td></td>
<td>PCB type: FR4, two-layer</td>
</tr>
<tr>
<td>Conducted emissions</td>
<td>In accordance with EN55011 - Class B</td>
</tr>
</tbody>
</table>
3 System Description

The reference design is a multiple output (12 V, 3.3 V, or 5 V), 2.4-W power supply that uses the UCC28722, a low-cost flyback controller. The design has a buck power stage that operates in discontinuous mode with valley switching to achieve reduced switching losses. The design can be used for converting a high voltage DC input with a wide range from 90- to 425-V DC, or converting an AC input ranging from 85- to 300-V AC, to standard power rails 12 V and 3.3 V or 5 V. As per the requirements of appliances, the design meets the requirements of high efficiency ( > 70%) and a low stand-by power of < 100 mW when the system is in idle mode.

The reference design offers the following key benefits:
- Works for a wide input range for both a DC input (90- to 425-V DC) or an AC input (85- to 300-V AC)
- Uses the lowest cost bipolar junction transistor (BJT) making the overall solution cheap
- Combination of frequency and peak current modulation causes high conversion efficiency
- Features a drum core inductor for the smallest form factor

The controller has an inherent safety feature that detects feedback for open loop or loss of feedback detection, during which the controller turns-off the BJT to safeguard the low-voltage system components from high voltage intrusion. In addition, the design offers protection for the output from short-circuit, overcurrent, and overvoltage conditions. The design can work down to low voltage inputs of 60-V DC with a reduced output current. Furthermore, the design can be configured to high wattage requirements with few component changes.

This design demonstrates the high performance DC-DC operation in a small form factor (30 mm × 25 mm), and provides flexibility for voltage settings through simple resistor changes. The board has component provisions for the rectifier, EMI filter, and bus capacitor to power directly from an AC input. This ability to power directly from an AC input provides flexibility for users to use the design as an independent bias power supply module. Using AC components, the form factor is 52 mm × 25 mm.

Various parameters of the design like regulation, efficiency, EMI signature, output ripple, startup, and switching stresses were tested and documented.
4 Block Diagram

Figure 1. Block Diagram of Bias Power Supply for Appliances

4.1 Highlighted Products and Key Benefits

The following are the highlighted products used in this reference design. Key features for selecting the devices for this reference design are elucidated below. Refer to the complete details of the highlighted devices in their respective product datasheets.

4.1.1 UCC28722

To achieve very-low power consumption, high performance, and optimized board space the UCC28722 is the preferred controller, as it offers a series of benefits to address the current and future increasing power requirements of bias supply in appliances.

The main value of the UCC28722 solution is a reduced total cost. The controller offers the advantage of driving a low-cost BJT power switch, providing flexibility to operate for high voltages (> 400-V DC) and to withstand higher voltage transients for AC input. Low start-up current, dynamically-controlled operating states and a tailored modulation profile support very-low, stand-by power without sacrificing start-up time or output transient response. Control algorithms in the UCC28722 family allow operating efficiencies to meet or exceed applicable standards. Discontinuous conduction mode (DCM) with valley switching is used to reduce switching losses. A combination of switching frequency and peak primary current amplitude modulation is used to keep conversion efficiency high across the full load and input voltage range.

The inherent protection features of the UCC28722 controller help improve the safety of the outputs for multiple protections such as overcurrent, short circuit, overvoltage, and open-loop detection without the requirement of external circuit components. These protection features help keep component stress levels in check across the operating range. The small SOT23-6 package of the controller and associated minimal component count help achieve a very-low form factor.

4.1.2 TLV1117

To meet the higher current (≥ 125 mA) requirements (for low output voltage applications), the TLV1117 is the preferred option, as it meets the key challenges of simple output capacitor requirements for stability, tight load, and line regulation as demanded by the power needs of the microcontroller.

The TLV1117 device offers the following key benefits:

- Flexible output voltage option: 1.5 V, 1.8 V, 2.5 V, 3.3 V, 5 V, and adjustable-output voltage options
- Can drive heavy load demands with an output current up to 800 mA
- Ensures predictable performance with specified dropout voltage at multiple current levels
  - 0.2% line regulation maximum
  - 0.4% load regulation maximum
4.1.3 UA78L05A

For lower current requirements (≤ 50 mA), using a low component count is key, along with selecting an LDO that offers the most protection features. The UA78L05A regulator is the best fit with the right combination of performance and protection for low current requirements.

The UA78L05 offers the following key benefits:

- Simple package
- Output current up to 100 mA
- No external components
- Internal thermal-overload protection
- Internal short circuit current limiting
5 System Design Theory

The reference design is a non-isolated buck regulator operating in discontinuous mode, implemented using the UCC28722 controller, and specifically tailored for the needs of home appliance applications. This design serves as a simple and superior alternative to existing power supplies with integrated MOSFET technology. This design is intended for a wide range of input voltages between 90- to 425-V DC or 85- to 300-V AC. The system efficiency is over 75% with a 125-V DC input and 74% with a 325-V DC input under full load conditions.

Low EMI, high efficiency, low component count, and compact size are the main focus of this design for targeted applications.

5.1 Basic Principle of Buck Topology

Figure 2 shows a simplified schematic of the buck power stage with a drive circuit block included. The power switch, Q, is an NPN bipolar transistor. The diode, D, is usually called the freewheeling diode. The inductor, L, and capacitor, C, make up the output filter. \( R_{ESR} \) represents the capacitor ESR and \( R_L \) represents the inductor DC resistance. The resistor, \( R_{LOAD} \), represents the load seen by the power stage output.

![Figure 2. Buck Power Stage Schematic](image)

During normal operation of the buck power stage, Q is repeatedly switched on and off with the on and off times governed by the control circuit. This switching action causes a train of pulses at the junction of Q, D, and L, which is filtered by the L/C output filter to produce a DC output voltage, \( V_{OUT} \).

A power stage can operate in continuous or discontinuous inductor current mode. Continuous inductor current mode is characterized by current flowing continuously in the inductor during the entire switching cycle in steady-state operation. Discontinuous inductor current mode is characterized by the inductor current being zero for a portion of the switching cycle. The discontinuous inductor current mode starts at zero, reaches a peak value, and returns to zero during each switching cycle. A power stage operating in only one mode over its expected operating conditions is very desirable, because the power stage frequency response changes significantly between the two modes of operation.

5.2 Buck Steady-State Discontinuous Conduction Mode Analysis

The following is a description of steady-state operation in the discontinuous conduction mode, as the UCC28722 only operates in this mode. Figure 3 shows that a power stage operating in discontinuous conduction mode has three unique states during each switching cycle. The ON state is when Q is ON and D is OFF. The OFF state is when Q is OFF and D is ON. The IDLE state is when both Q and D are OFF.

A simple linear circuit can represent each of the three states where the switches in the circuit are replaced by their equivalent circuits during each state. Figure 3 shows the circuit diagram for each of the three states.

The duration of the ON state is \( T_{ON} = D_{ON} \times T_S \) where \( D_{ON} \) is the duty cycle, set by the control circuit, and expressed as a ratio of the switch ON time to the time of one complete switching cycle, \( T_S \). The duration of the OFF state is \( T_{OFF} = D_{OFF} \times T_S \). The IDLE time is the remainder of the switching cycle and is given as \( T_S - T_{ON} - T_{OFF} = D_{IDLE} \times T_S \). Figure 4 shows these times with waveforms.
The main result of this section is a derivation of the voltage conversion relationship for the discontinuous conduction mode buck power stage. In addition, the DC resistance of the output inductor, the output diode forward voltage drop, and the power BJT $V_{CE}$ drop are all assumed to be small enough to omit in analysis.

Referring to Figure 2, during the ON state, the voltage applied to the right-hand side of $L$ is simply the output voltage, $V_{OUT}$. The inductor current, $I_L$, flows from the input source, $V_{IN}$, through $Q$ and to the output capacitor $C$ and load resistor $R_{LOAD}$ combination. During the ON state, the voltage applied across the inductor is constant and equal to $V_{IN} - V_{OUT}$. Considering the polarity convention for the current, the inductor current ($I_L$), increases as a result of the applied voltage. Also, because the applied voltage is essentially constant, the inductor current increases linearly. Figure 4 shows this increase in inductor current during $T_{ON}$.

![Figure 3. Buck Power Stages in Discontinuous Mode](image-url)
The amount that the inductor current increases can be calculated by using a version of the familiar relationship:

\[ V_L = L \times \frac{dI_L}{dt} \]  

and

\[ \Delta I_L = \frac{V_L}{L} \times \Delta t \]  

The inductor current increase during the ON state is given by:

\[ \Delta I_{L(+)} = \frac{V_{IN} - V_{OUT}}{L} \times T_{ON} = \frac{V_{IN} - V_{OUT}}{L} \times D_{ON} \times T_S = I_{PK} \]  

The ripple current magnitude, \( \Delta I_{L(+)} \), is also the peak inductor current, \( I_{PK} \).

Referring to Figure 3, when Q is OFF, it presents high impedance from its collector to emitter. Therefore, because the current flowing in the inductor L cannot change instantaneously, the current shifts from Q to D. Due to the decreasing inductor current, the voltage across the inductor reverses polarity until rectifier D becomes forward-biased and turns ON. The voltage on the left-hand side of L becomes zero if the user neglects the forward voltage drop of diode D and the drop across the DC resistance of the inductor. The voltage applied to the right-hand side of L is still the output voltage, \( V_{OUT} \). The inductor current, \( I_L \), now flows from ground through diode D and to the output capacitor C and load resistor \( R_{LOAD} \) combination. During the OFF state, the magnitude of the voltage applied across the inductor is constant and equal to \( V_{OUT} \). Maintaining the polarity convention, this applied voltage is negative (or opposite in polarity from the applied voltage during the ON time). Hence, the inductor current decreases during the OFF time. Also, because the applied voltage is essentially constant, the inductor current decreases linearly. Figure 4 shows this decrease in inductor current during \( T_{OFF} \).

The inductor current decrease during the OFF state is given by:

\[ \Delta I_{L(-)} = \frac{V_{OUT}}{L} \times T_{OFF} \]  

This quantity, \( \Delta I_{L(-)} \), is also referred to as the inductor ripple current.

In steady-state conditions, the current increase, \( \Delta I_{L(+)} \), during the ON time and the current decrease during the OFF time, \( \Delta I_{L(-)} \), must be equal; otherwise, the inductor current would have a net increase or decrease from cycle-to-cycle, which does not constitute a steady-state condition. Therefore, Equation 3 and Equation 4 can be solved for \( V_{OUT} \) to obtain the first of two equations to use to solve for the voltage conversion ratio:

\[ V_{OUT} = \left( \frac{T_{ON}}{T_{ON} + T_{OFF}} \right) \times V_{IN} = V_{IN} \times \left( \frac{D_{ON}}{D_{ON} + D_{OFF}} \right) \]  

Now calculate the output current (the output voltage \( V_{OUT} \) divided by the output load \( R_{LOAD} \), which is the average of the inductor current:

\[ I_{OUT} = I_{L_{AVG}} = \frac{V_{OUT}}{R_{LOAD}} = \left( \frac{I_{PK}}{2} \right) \times \left( \frac{D_{ON} \times T_S + D_{OFF} \times T_S}{T_S} \right) \]  

Now substitute the relationship for \( I_{PK} \) into the previous Equation 6 to obtain:

\[ I_{OUT} = \left( V_{IN} - V_{OUT} \right) \times \left( \frac{D_{ON} \times T_S}{2 \times L} \right) \times \left( D_{ON} + D_{OFF} \right) \]

Now there are two equations to use: the one just derived for the output current and the one for the output voltage (above), both in terms of \( V_{IN} \), \( D_{ON} \), and \( D_{OFF} \). Now solve each equation for \( D_{OFF} \) and set the two equations equal to each other. Using the resulting equation, an expression for the output voltage, \( V_{OUT} \), can be derived.
The discontinuous conduction mode buck voltage conversion relationship is given by:

\[
V_{\text{OUT}} = V_{\text{IN}} \times \frac{2}{1 + \frac{2 \times K}{D_{\text{ON}}}}
\]

\[\text{(8)}\]

In the above Equation 8:

\[
K = \frac{2 \times L}{R_{\text{LOAD}} \times T_S}
\]

\[\text{(9)}\]

Figure 4. Discontinuous Mode Power Stage Buck Waveforms
5.3 **Circuit Component Design**

This section explains the design process and component selection a designer must follow to complete a buck switch mode power supply (SMPS) using the UCC28722 controller.

5.3.1 **Power Budget**

The design has 12 V as a main rail and 3.3 V or 5 V are derived outputs from the 12-V power rail using linear regulators.

The key power requirements of typical targeted applications, such as motor drives in home appliances, are:

- Power for an IGBT/MOSFET gate driver: $V_{OUT} = 12 \text{ V} / 75 \text{ mA}$
- Power for a microcontroller and interface: $V_{OUT1} = 3.3 \text{ V} / 125 \text{ mA}$ or $5 \text{ V} / 50 \text{ mA}$

As the microcontroller and interface power derives from a 12-V bus through a linear regulator, the total maximum current on 12 V is 200 mA.

The total maximum output power requirement is:

$$P_{OUT} = V_{OUT} \times I_{OUT}$$

$$P_{OUT} = 12 \times 0.2 = 2.4 \text{ W} \tag{10}$$

The converter is designed for 2.4 W of maximum power.

For calculation of components, minimum targeted efficiency is considered as $\eta = 70\%$

$$P_{IN} = \left( \frac{P_{OUT}}{\eta} \right) = \frac{2.4}{0.7} = 3.43 \text{ W} \tag{11}$$

5.3.2 **Calculate Peak and RMS Currents**

During startup period, the converter remains in constant current mode charging the output capacitor until it comes into voltage loop or output regulation. This constant current must be more than the output current required to charge the output capacitor at full load. Figure 5 shows the inductor current and the output current of the converter for the UCC28722 controller in buck discontinuous mode.

![Discontinuous Current Waveform in UCC28722](image)

Use Equation 6 for the calculation of output current in constant current (CC) mode.

Substitute

- Average output current $I_{OUT} = I_{OCC}$
- $D_{ON} = T_{ON} / T$ is ignored as $T_{ON} \ll T_{OFF}$, $T_{ON}$ is very small due to the large differential between $V_{INDC}$ and $V_{OUT}$
- $D_{OFF} = T_{OFF} / T = D_{MAGCC}$
The UCC28722 controller achieves constant-current regulation by maintaining a maximum demagnetizing duty cycle ($D_{\text{MAGCC}}$) of 42.5%, at the maximum inductor current setting. This value is fixed internally to the controller and is based on the UCC28722 control logic.

\[ I_{\text{OCC}} = 10\% \text{ more than } I_{\text{OUT}} = I_{\text{OCC}} = 1.1 \times I_{\text{OUT}} = 1.1 \times 0.2 = 0.22 \text{ A} \]

\[ D_{\text{MAGCC}} = 0.425 \]

So,

\[ I_{\text{PK}} = 2 \times \frac{0.22 \text{ A}}{0.425} = 1.035 \text{ A} \]

The root mean square (RMS) current ($I_{\text{LRMS}}$) through the Inductor is determined by:

\[ I_{\text{LRMS}} = I_{\text{PK}} \times \sqrt{\frac{D_{\text{MAGCC}}}{3}} \]

\[ I_{\text{LRMS}} = 1.035 \times \sqrt{\frac{0.425}{3}} = 0.39 \text{ A} \]

The RMS current ($I_{\text{PRMS}}$) through the switching transistor Q, as well as the current sense resistor, is calculated by:

\[ I_{\text{PRMS}} = I_{\text{PK}} \times \sqrt{\frac{D_{\text{MAX}}}{3}} \]

The $D_{\text{MAX}}$ is the maximum duty cycle of operation = $V_{\text{OUT}} / V_{\text{INDC.MIN}} = 12 \text{ V} / 90 \text{ V} = 0.133$

\[ I_{\text{PRMS}} = 1.035 \times \sqrt{\frac{0.133}{3}} = 0.22 \text{ A} \]
5.3.3 **Output Inductor Selection**

The output inductor can be calculated by using Equation 3 as seen in the following Equation 17:

\[
L_2 = \frac{(V_{\text{INDC\_MAX}} - V_{\text{OUT}})}{I_{\text{PK}}} \times t_{\text{ON\_MIN}}
\]  

(17)

\(T_{\text{ON\_MIN}}\) is the minimum ON time of the MOSFET when operating at the maximum DC input.

The UCC28722 controller has an internal leading-edge blanking time of approximately 300 ns at the current sensing input to eliminate sensitivity to the turn-on current spike. A worst-case scenario of minimum on-time occurs at the maximum input voltage and light or no load condition, and this should be > 300 ns. With margins added, the minimum on-time should be greater than 500 ns.

To meet the minimum blanking time criteria at the minimum load, \(T_{\text{ON\_MIN}}\) is selected as 1.0 μs, with the maximum input voltage and maximum load conditions of the converter under consideration. So,

\[
L_2 = \frac{(425 \text{ V} - 12 \text{ V})}{1.035 \text{ A}} \times 1 \mu\text{s} = 399 \mu\text{H}
\]  

(18)

A standard value of 470 μH is chosen.

5.3.4 **Current Sense Resistor**

During the constant current mode, the voltage drop across the current sense resistor \(R_1\) is maintained at 0.78 V. \(R_1\) is calculated using Equation 18:

\[
R_1 = \frac{0.78}{I_{\text{PK}}} = \frac{0.78}{1.035} = 0.753 \Omega
\]  

(19)

A 0.75-Ω resistor was selected for this design.

The following calculation is the power dissipation in the current sense resistor:

\[
P_{\text{LOSS\_CS}} = I_{\text{PRMS}}^2 \times R_1 = 36 \text{ mW}
\]  

(20)

5.3.5 **Switching Frequency of Operation**

The user can estimate the switching frequency during the exit from CC to CV mode during the start-up phase. Using Equation 4 and substituting \(\Delta I_{\text{L(-)}} = I_{\text{PK}}\) and reorganizing the equation, \(T_{\text{OFF}}\) is given by:

\[
T_{\text{OFF}} = \frac{I_{\text{PK}}}{V_{\text{OUT}}} \times L_2
\]  

\[
T_{\text{OFF}} = \frac{1.035}{12} \times 470 \mu\text{H} = 40.54 \mu\text{s}
\]  

(21)

The switching frequency, \(f_{\text{SW}}\), is given by the following Equation 22.

\[
f_{\text{SW}} = \frac{1}{T_{\text{SW}}} = \frac{D_{\text{MAGCC}}}{T_{\text{OFF}}}
\]

\[
f_{\text{SW}} = \frac{0.425}{40.54 \mu\text{s}} = 10.5 \text{ kHz}
\]  

(22)
5.3.6 Output Capacitor Selection

In switching power supply power stages, the function of output capacitance is to store energy. The energy is stored in the capacitor electric field due to the voltage applied. Thus, qualitatively, the function of a capacitor is to maintain a constant voltage.

For discontinuous inductor current mode, the amount of capacitance required is a function of inductor current ripple ($\Delta I_L$), output current ($I_{OUT}$), switching frequency ($f_{SW}$), and output voltage ripple ($\Delta V_{OUT}$). Use the following Equation 23 assuming all of the output voltage ripple is due to the capacitors capacitance.

$$C_{OUT} \geq I_{OUT} \times \left(1 - \frac{I_{OUT}}{\Delta I_L}\right)^2 \times f_{SW} \times \Delta V_{OUT}$$

(23)

$\Delta I_L$ is the inductor ripple current defined as per Equation 3.

Considering $\Delta V_{OUT} = 1.5\%$ of $V_{OUT} = 0.015 \times 12 = 0.18$ V

$$C_{OUT} \geq 0.2 \times 0.135 \times 10.5 \text{ kHz} \times 0.18 \text{ V} = 69 \mu\text{F}$$

(24)

$$I_{OUT\_RMS} = \sqrt{\left(I_{PK} \times \sqrt{\frac{D_{MAG}}{3}}\right)^2 - \left(I_{OUT}\right)^2} = 0.33 \text{ A}$$

(25)

In many practical designs, to obtain the required ESR, the designer must select a capacitor with much more capacitance than what is required. The ESR required to limit the ripple $\Delta V_{OUT}$ is:

$$ESR \leq \frac{\Delta V_{OUT}}{I_{PK}} = \frac{0.18}{1.035} = 0.174 \Omega$$

(26)

So, 220 $\mu$F, 25 V with an impedance of 0.13 $\Omega$ is chosen for this design.

5.3.7 Bipolar Junction Transistor Selection

The bipolar junction transistor is selected based on three main specifications:

- Minimum current gain: $h_{FE}$
- $V_{CE\_SUS}$ breakdown
- Current rating

The current gain required is calculated by the following Equation 27:

$$h_{FE} = \frac{I_{PK}}{I_{DRS}}$$

(27)

where

- $I_{PK}$ is the peak current in constant current mode
- $I_{DRS}$ is the source current of the drive = 37 mA (as per UCC28722 specifications)

$$h_{FE} = \frac{1.035}{37 \text{ mA}} = 27.9$$

(28)

The current rating of the BJT must be > $1.5 \times I_{PK} = 1.55$ A

The voltage rating of the BJT must be > $1.1 \times V_{INDC\_MAX} = 467.5$ V

The KSC5026MOS, BJT is chosen for Q1 which satisfies all of the above three criteria.
5.3.8 Freewheeling Diode and $V_{dd}$ Diode Selection

Select D2, a fast rectifier diode with $PIV > 1.25 \times V_{\text{INDC\_MAX}} = 1.25 \times 425 = 531.3 \text{ V}$, and a forward current $IF > 1.5 \times I_{\text{OUT}} = 1.5 \times 0.2 \text{ A} = 0.3 \text{ A}$.

So a 1-A, 1000-V US13-M diode is chosen for the application.

The worst-case voltage across the $V_{dd}$ diode D3 is the maximum input voltage 425-V DC, so TI recommends a 1-A, 600-V rated component, considering a safety margin of 20%. The CGRM4005-G rectifier diode is chosen for this application. This device also offers the advantage of a small package.

5.3.9 Capacitance on $V_{dd}$ Pin

The capacitance on $V_{dd}$ must supply the device operating current until the output of the converter reaches the target minimum operating voltage in constant-current regulation. At this time, the output voltage can sustain the voltage to the UCC28722 controller. The total output current available to the load and to charge the output capacitors is the constant-current regulation target, $I_{OCC}$.

Figure 6 shows the timing diagram illustrating the startup of the UCC28722 controller.

The following Equation 29 is used to calculate the value of capacitance required at the $V_{dd}$ pin:

$$C_{DD} = \frac{I_{\text{DRS\_MAX}} \times \left(\frac{V_{\text{OUT}}}{V_{\text{INDC\_MIN}}} + I_{\text{RUN}}\right) \times (C_{\text{OUT}} \times V_{\text{OUT}})}{(V_{\text{DD\_ON}} - V_{\text{DD\_OFF}}) \times I_{\text{OCC}}}$$

where

- Typical IC run current $I_{\text{RUN}} = 2.65 \text{ mA}$
- Average Maximum Drive current $I_{\text{DRV\_MAX}} = 37 \text{ mA}$
- Typical $V_{dd}$ turn-on threshold $V_{\text{DD\_ON}} = 21 \text{ V}$
- Typical $V_{dd}$ turn-off threshold $V_{\text{DD\_OFF}} = 8.0 \text{ V}$

$$C_{DD} = \frac{37 \text{ mA} \times \left(\frac{12}{90} + 2 \text{ mA}\right) \times (220 \mu\text{F} \times 12)}{(12 - 8 - 1) \times 0.22} = 7.6 \mu\text{F}$$

So a standard value of 10 uF is chosen.

Figure 6. Timing Diagram of Startup Sequence in UCC28722
5.3.10 Startup Resistors and Startup Time

An external resistor connected from the bulk capacitor voltage to the $V_{DD}$ pin charges the $V_{DD}$ capacitor. The amount of startup current that is available to charge the $V_{DD}$ capacitor depends on the value of this external startup resistor. Smaller values supply more current and decrease startup time, but at the expense of increasing standby power and decreasing efficiency, particularly at high input voltage and light loading.

When $V_{DD}$ reaches the 21-V undervoltage lock-out (UVLO) turn-on threshold, the controller is enabled and the converter starts switching. The initial three cycles are limited to $I_{PP \_MIN}$. After the initial three cycles at minimum $I_{PP \_MIN}$, the controller responds to the condition dictated by the control law. The converter remains in discontinuous mode during the charging of the output capacitor or capacitors, maintaining a constant output current until the output voltage is in regulation.

Once the $V_{DD}$ capacitor is known, there is a tradeoff to be made between the startup time and overall standby input power to the converter. A faster startup time requires a smaller startup resistance, which results in a higher standby input power.

$$R_{STARTUP} = \frac{V_{INDC \_MIN}}{\left( \frac{V_{DD \_ON}}{t_{STR}} \times C_{DD} \right) + \left( I_{START} \right)}$$

(31)

where
- $I_{START}$ is the startup current of UCC28722
- $V_{DD \_ON}$ is the UVLO turn on threshold
- $t_{STR}$ is the time in which the power supply should be stable at desired output voltage
- $C_{DD}$ is the capacitance value at $V_{DD}$ pin

$$R_{STARTUP} = \frac{90}{\left( \frac{21}{3 \text{ s} \times 10 \text{ } \mu \text{F}} \right) + 1.5 \mu \text{A}} = 1.26 \text{ M} \Omega$$

(32)

To optimize the “no load power”, a higher value of 2.25-MΩ resistor is chosen. The resistance is split into three equal values: $R_2 = R_3 = R_4 = 750 \text{ k} \Omega$.

The actual start-up time may vary based on the tolerances of resistors and capacitors used.

5.3.11 Feedback Resistors

The VS pin divider resistors $R_5$ and $R_6$ determine the output voltage regulation point of the buck converter. The high-side divider resistor ($R_6$) determines the line voltage at which the controller enables continuous operation. $R_5$ is initially determined based on the desired input voltage operating threshold.

$$R_{PULLUP} = R_5 = \frac{V_{INDC \_MIN}}{I_{VSL \_RUN}}$$

(33)

where
- $V_{INDC \_MIN}$ is the minimum DC voltage to enable the turning-on of the controller (run)
- $I_{VSL \_RUN}$ is the run-threshold for the current pulled out of the VS pin during the switch ON time = 225 µA

$$R_{PULLUP} = R_5 = \frac{90 \text{ V}}{225 \mu \text{A}} = 400 \text{ k} \Omega$$

(34)

To keep the impedance at the VS pin low, TI suggests a resistance of ≤ 150 kΩ so as to avoid the effect of switching noise. A standard value of 100 kΩ is chosen.
The low-side VS pin resistor $R_6$ is selected based on the desired $V_{OUT}$ ($= 12$ V) regulation voltage:

$$R_{PULLDN} = R_6 = \frac{R_5 \times V_{VSR}}{V_{OUT} + V_F - V_{VSR}}$$  \hspace{1cm} (35)

where

- $V_F$ is the free-wheeling diode forward drop at near-zero current = 0.7 V
- $V_{VSR}$ is the CV-regulating level at the VS input (as per the datasheet) = 4.05 V

$$R_{PULLDN} = R_6 = \frac{100 \text{ k} \Omega \times 4.05}{12 \text{ V} + 0.7 - 4.05} = 46.8 \text{ k} \Omega$$  \hspace{1cm} (36)

A standard value of 47 kΩ is chosen.

### 5.4 Post Regulators for 5 V or 3.3 V

For the targeted applications, as previously mentioned, a 5-V or 3.3-V rail is required for powering the microcontroller and its peripherals. For low-end applications, the use of 5 V is more common and requires a current of 20 mA to 50 mA, whereas high-end applications with more peripherals require a 3.3-V microcontroller with an approximate current of 125 mA.

The design has both options of 5-V and 3.3-V LDOs catering to the needs of both high-end and low-end applications. Maintaining tight tolerances on a 3.3-V or 5-V rail; protection features such as overcurrent, cost, and package size in mind, the UA78L05A device is chosen for a 5-V rail and the TLV1117 device is chosen for a 3.3-V rail.

The TLV1117 LDO is available in an adjustable output voltage variant and provides flexibility for various output settings from 1.5 V to 5 V through an external resistor change.

### 5.5 AC Input Stage Components

Components for AC Input are optional and are not required for the targeted applications previously mentioned as the system has an EMI filter, rectifier capacitor, and bulk capacitor as part of the inverter drive unit. The components RT1, RV1, D1, L1, C1, and C9 are only required when planning to use the design as a standalone bias supply powered from an AC input. The following sub-sections explain the selection of these components.

#### 5.5.1 Diode Rectifier Selection

As the input AC voltage can go up to 300-V AC, the DC voltage can reach voltage levels of up to 425-V DC. For these reasons, this design uses the 1000-V, 1-A diode 1N4007 for input rectification.

The forward voltage drop of the bridge rectifier diode, $V_{DA} = 1.0$ V.

The bridge rectifier average input current is:

$$I_{DA} = \left( \frac{2}{\sqrt{2}} \times \frac{P_{IN}}{V_{AC\_MIN}} \right)$$  \hspace{1cm} (37)

$$I_{DA} = \left( \frac{2.5 / 0.7}{2 \times \sqrt{2} \times 85} \right) = 44.8 \text{ mA}$$  \hspace{1cm} (38)

The estimated power dissipated in the bridge rectifier diode ($P_{DA}$) is:

$$P_{DA} = V_{DA} \times I_{DA} = 1 \times 0.045 = 45 \text{ mW}$$  \hspace{1cm} (39)
5.5.2 Input Capacitor Selection \((C_{IN} = C1)\) and DC Input Range

The capacitor \(C_{IN}\) is also known as the DC link capacitor, depending on the input voltage and input power. For a half-wave rectifier, the broad principle is to choose a capacitance between 4 \(\mu\)F to 6 \(\mu\)F per watt of output power for a universal AC input voltage range of 85- to 265-V AC or a working DC link greater than 400 V. Keeping the better quality of DC input voltage, cost, and size in mind, and maximum voltage of 300-V AC, \(C1 = 10 \mu\text{F}\) 450-V capacitor is chosen.

Having chosen the input capacitor, obtain the minimum DC input voltage (DC link capacitor voltage) by:

\[
V_{INDC\_MIN} = \sqrt{2 \times V_{AC\_MIN}^2 \times \frac{P_{IN} \times (1 - d_{CHG})}{C_{IN} \times f_{LINE\_MIN}}} 
\]

where

- \(d_{CHG}\) is the DC link capacitor duty ratio and is typically around 0.2

The DC link capacitor voltage simplifies to:

\[
V_{INDC\_MIN} = \sqrt{2 \times 85^2 \times \frac{3.43 \times (1 - 0.2)}{10 \mu\text{F} \times 47 \text{ Hz}}} = 92.8 \text{ V} 
\]

5.5.3 Filter Inductor (L1)

The filter inductor (L1) is used for EMI filtering. L1 and C9 form a differential filter attenuating the differential noise produced by the UCC28722-based converter. The recommended value for L1 is 2.2 mH to 4.7 mH and C9 is 47 nF to 100 nF.

A 4.7-mH inductor is chosen for this design to meet the requirements of class B level of conducted emissions norm EN55011.

5.5.4 Fusible Resistor (RT1)

To limit the inrush current during power and for safety, a 10-\(\Omega\) negative temperature co-efficient (NTC) resistor is placed at the input of this design. As the input current is very small, a 10-\(\Omega\), 3-W fusible resistor can be used as an alternative option to limit the inrush current.

When using the fusible resistor, the power loss in the fusible resistor is given by the following calculation:

\[
P_{LOSS\_FR} = \left(\frac{P_{OUT}}{\eta \times V_{AC\_MIN}}\right)^2 \times R_{FR} = 16.3 \text{ mW} 
\]
6 Getting Started Hardware

6.1 Test Conditions
When testing the input conditions of this design, set the input current limit to 0.2 A. The input supply \( V_{IN} \) must range from 90- to 425-V DC or 85- to 300-V AC.

When testing the output conditions of this design, use a variable resistive load, which varies from 0 mA to 200 mA.

6.2 Equipment Required
1. High-voltage DC source or isolated AC source
2. Digital oscilloscope
3. Multi-meters
4. Electronic load

6.3 Procedure
1. Connect input terminals (DC-Bus, RTN) of the reference board to the high voltage DC power source to test with the DC input, maintaining correct polarity.
2. Connect input terminals (L, N) of the reference board to the AC power source to test with the AC input.
3. Connect the output terminals (+12 V, 3.3 V, or 5 V) to the electronic load, maintaining the correct polarity.
4. Set and maintain a minimum load of about 2 mA.
5. Increase (gradually) the input voltage from 0- to 90-V DC.
6. Observe the startup conditions for the smooth switching waveforms.
7 Test Data

7.1 Standby Power
The standby power was noted at multiple DC input voltages with a 1.2-mA load on 12 V. Table 2 shows the results, which are in accordance with the target specifications.

Table 2. No Load Power Measurement

<table>
<thead>
<tr>
<th>DC INPUT (V-DC)</th>
<th>NO LOAD INPUT POWER (mW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>25</td>
</tr>
<tr>
<td>125</td>
<td>28</td>
</tr>
<tr>
<td>325</td>
<td>64</td>
</tr>
<tr>
<td>400</td>
<td>88</td>
</tr>
</tbody>
</table>

7.2 Efficiency and Regulation

7.2.1 Performance Data With DC Input
Note that the readings are taken with LDOs mounted on the board. The quiescent current ($I_Q$) consumed by the 5-V and 3.3-V LDO is not considered in $I_{OUT}$ readings. The $I_Q$ of LDOs add an approximate 5-mA current on a 12-V rail.

Table 3. Performance Data With DC Input

<table>
<thead>
<tr>
<th>$V_{INDC}$ (V)</th>
<th>$I_{INDC}$ (mA)</th>
<th>$P_{INDC}$ (W)</th>
<th>$V_{OUT}$ (V)</th>
<th>$I_{OUT}$ (mA)</th>
<th>$P_{OUT}$ (W)</th>
<th>POWER LOSS (W)</th>
<th>EFFICIENCY (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>56.00</td>
<td>3.360</td>
<td>12.34</td>
<td>204</td>
<td>2.517</td>
<td>0.84</td>
<td>74.92</td>
</tr>
<tr>
<td>70</td>
<td>48.00</td>
<td>3.360</td>
<td>12.35</td>
<td>204</td>
<td>2.519</td>
<td>0.84</td>
<td>74.98</td>
</tr>
<tr>
<td>80</td>
<td>42.04</td>
<td>3.363</td>
<td>12.35</td>
<td>204</td>
<td>2.520</td>
<td>0.84</td>
<td>74.92</td>
</tr>
<tr>
<td>90</td>
<td>37.34</td>
<td>3.361</td>
<td>12.35</td>
<td>204</td>
<td>2.520</td>
<td>0.84</td>
<td>74.99</td>
</tr>
<tr>
<td>125</td>
<td>26.76</td>
<td>3.345</td>
<td>12.36</td>
<td>204</td>
<td>2.520</td>
<td>0.82</td>
<td>75.35</td>
</tr>
<tr>
<td>150</td>
<td>22.29</td>
<td>3.344</td>
<td>12.36</td>
<td>204</td>
<td>2.521</td>
<td>0.82</td>
<td>75.39</td>
</tr>
<tr>
<td>175</td>
<td>19.10</td>
<td>3.343</td>
<td>12.36</td>
<td>204</td>
<td>2.521</td>
<td>0.82</td>
<td>75.42</td>
</tr>
<tr>
<td>200</td>
<td>16.73</td>
<td>3.346</td>
<td>12.36</td>
<td>204</td>
<td>2.521</td>
<td>0.82</td>
<td>75.36</td>
</tr>
<tr>
<td>225</td>
<td>14.90</td>
<td>3.353</td>
<td>12.36</td>
<td>204</td>
<td>2.521</td>
<td>0.83</td>
<td>75.21</td>
</tr>
<tr>
<td>250</td>
<td>13.46</td>
<td>3.365</td>
<td>12.36</td>
<td>204</td>
<td>2.522</td>
<td>0.84</td>
<td>74.94</td>
</tr>
<tr>
<td>275</td>
<td>12.29</td>
<td>3.380</td>
<td>12.36</td>
<td>204</td>
<td>2.522</td>
<td>0.86</td>
<td>74.63</td>
</tr>
<tr>
<td>300</td>
<td>11.31</td>
<td>3.393</td>
<td>12.37</td>
<td>204</td>
<td>2.523</td>
<td>0.87</td>
<td>74.35</td>
</tr>
<tr>
<td>325</td>
<td>10.49</td>
<td>3.409</td>
<td>12.37</td>
<td>204</td>
<td>2.523</td>
<td>0.89</td>
<td>74.01</td>
</tr>
<tr>
<td>350</td>
<td>9.80</td>
<td>3.430</td>
<td>12.37</td>
<td>204</td>
<td>2.523</td>
<td>0.91</td>
<td>73.57</td>
</tr>
<tr>
<td>375</td>
<td>9.21</td>
<td>3.454</td>
<td>12.37</td>
<td>204</td>
<td>2.523</td>
<td>0.93</td>
<td>73.06</td>
</tr>
<tr>
<td>400</td>
<td>8.69</td>
<td>3.476</td>
<td>12.37</td>
<td>204</td>
<td>2.523</td>
<td>0.95</td>
<td>72.60</td>
</tr>
<tr>
<td>425</td>
<td>8.25</td>
<td>3.506</td>
<td>12.37</td>
<td>204</td>
<td>2.523</td>
<td>0.98</td>
<td>71.97</td>
</tr>
</tbody>
</table>
7.2.2 Performance Data With AC Input

Note that the readings are taken with LDOs mounted on the board. The quiescent current consumed by the 5-V and 3.3-V LDO is not considered in \( I_{\text{OUT}} \) readings. The \( I_{\text{Q}} \) of LDOs add an approximate 5-mA current on a 12-V rail.

Table 4. Performance Data With AC Input

<table>
<thead>
<tr>
<th>( V_{\text{INAC}} ) (VAC)</th>
<th>( I_{\text{INAC}} ) (mA)</th>
<th>( P_{\text{INAC}} ) (W)</th>
<th>( V_{\text{OUT}} ) (V)</th>
<th>( I_{\text{OUT}} ) (mA)</th>
<th>( P_{\text{OUT}} ) (W)</th>
<th>POWER LOSS (W)</th>
<th>EFFICIENCY (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>85</td>
<td>95.600</td>
<td>3.670</td>
<td>12.35</td>
<td>0.200</td>
<td>2.47</td>
<td>1.20</td>
<td>67.3</td>
</tr>
<tr>
<td>100</td>
<td>80.980</td>
<td>3.571</td>
<td>12.36</td>
<td>0.200</td>
<td>2.47</td>
<td>1.10</td>
<td>69.2</td>
</tr>
<tr>
<td>125</td>
<td>67.230</td>
<td>3.485</td>
<td>12.36</td>
<td>0.200</td>
<td>2.47</td>
<td>1.01</td>
<td>70.9</td>
</tr>
<tr>
<td>150</td>
<td>58.940</td>
<td>3.452</td>
<td>12.36</td>
<td>0.200</td>
<td>2.47</td>
<td>0.98</td>
<td>71.6</td>
</tr>
<tr>
<td>175</td>
<td>52.890</td>
<td>3.445</td>
<td>12.36</td>
<td>0.200</td>
<td>2.47</td>
<td>0.97</td>
<td>71.8</td>
</tr>
<tr>
<td>200</td>
<td>48.470</td>
<td>3.452</td>
<td>12.37</td>
<td>0.200</td>
<td>2.47</td>
<td>0.98</td>
<td>71.6</td>
</tr>
<tr>
<td>230</td>
<td>44.240</td>
<td>3.475</td>
<td>12.37</td>
<td>0.200</td>
<td>2.47</td>
<td>1.00</td>
<td>71.2</td>
</tr>
<tr>
<td>251</td>
<td>41.760</td>
<td>3.500</td>
<td>12.37</td>
<td>0.200</td>
<td>2.47</td>
<td>1.03</td>
<td>70.7</td>
</tr>
<tr>
<td>274</td>
<td>39.610</td>
<td>3.525</td>
<td>12.37</td>
<td>0.200</td>
<td>2.47</td>
<td>1.05</td>
<td>70.2</td>
</tr>
</tbody>
</table>

7.2.3 Efficiency Curve

![Efficiency Versus DC Input Voltage (85- to 425-V DC)](image1)

![Efficiency Versus AC Input Voltage (85- to 275-V AC)](image2)

Figure 7. Efficiency Versus DC Input Voltage (85- to 425-V DC)

Figure 8. Efficiency Versus AC Input Voltage (85- to 275-V AC)
7.2.4 Efficiency Curve With Output Load Variation

![Efficiency Curve Diagram](image1)

**Figure 9. Efficiency Versus Output (12 V) Load Current**

7.2.5 Output Regulation (12 V)

![Output Regulation Diagram](image2)

**Figure 10. 12-V Output Voltage Variation Versus Output Load Current at 325-V DC**

**Figure 11. 12-V Output Voltage Variation Versus Input Voltage**

![Output Regulation Diagram](image3)

**Figure 12. 12-V Output Voltage Variation Versus Load Current**
7.3 Waveforms

7.3.1 Switching Node Waveforms

The waveform at the SW node was observed along with the collector current for 125-V DC and 325-V DC inputs and a 12-V output loaded to 200 mA.

![Figure 13. SW Node Voltage and Collector Current at $V_{\text{INDC}} = 125$-V DC, Full Load](image1)

![Figure 14. SW Node Voltage and Collector Current at $V_{\text{INDC}} = 125$-V DC, Full Load (Zoomed)](image2)

![Figure 15. SW Node Voltage and Collector Current at $V_{\text{INDC}} = 325$-V DC, Full Load](image3)

![Figure 16. SW Node Voltage and Collector Current at $V_{\text{INDC}} = 325$-V DC, Full Load (Zoomed)](image4)
7.3.1.1 **Output Ripple**

The ripple was observed at a 12-V output loaded to 200 mA at 125-V DC and 325-V DC.

**Figure 17. 12-V Output Ripple at $V_{INDC} = 125$-V DC, Full Load**

**Figure 18. 12-V Output Ripple at $V_{INDC} = 325$-V DC, Full Load**

7.3.2 **Turn-On Characteristics**

The 12-V output turn-on at 200 mA was recorded at 125-V DC and 325-V DC.

**Figure 19. 12-V Output Turn-On Waveform at $V_{INDC} = 125$-V DC, Full Load**

**Figure 20. 12-V Output Turn-On Waveform at $V_{INDC} = 325$-V DC, Full Load**
7.3.3 Transient Response

The transient load performance was observed at a 12-V output by switching the output load from 2 mA to 200 mA and vice versa with $V_{IN} = 325$-V DC.

Figure 21. 12-V Output Waveform at $V_{IN DC} = 325$-V DC, Load Transient from 2 mA to 200 mA

Figure 22. 12-V Output Waveform at $V_{IN DC} = 325$-V DC, Load Transient from 200 mA to 2 mA

7.3.4 Short Circuit Response

The short-circuit performance was observed using a load short with a 0.2-m wire length.

Figure 23. 12-V Output Waveform at $V_{IN DC} = 325$-V DC, Load Short, Auto-Retry, and Recovery
7.4 Conducted Emissions

Conducted emissions are generally more at full load currents, so this operating point was chosen for measuring the conducted EMI.

This test uses a 230-V AC input and 200-mA resistive load that is connected to a power supply unit (PSU) with short leads. In a pre-compliance test setup, the conducted emissions of the design comfortably met the EN55022 class B limits.

---

**Figure 24. Conducted Emissions as per EN55011 Class B**
7.5 Thermal Measurements

The thermal images were plotted at room temperature (25°C) and at full load conditions.

**Test Setting 1:**
- Input voltage 90-V AC
- Load on 12 V, 200 mA
- No load on 3.3 V and 5 V

**Test Setting 2:**
- Input voltage 90-V AC
- Load on 120% on 3.3 V (150 mA) and 5 V (60 mA) LDO
- No load on 12 V
- Power loss in 3.3-V regulator = \((12 \text{ V} – 3.3 \text{ V}) \times 0.15 \text{ A} = 1.305 \text{ W}\)
- Power loss in 5-V regulator = \((12 \text{ V} – 5 \text{ V}) \times 0.06 \text{ A} = 0.420 \text{ W}\)

**NOTE:** The temperature rise of LDO can be optimized or reduced by having a wider area to spread the heat.
8 Design Files

8.1 Schematics

To download the Schematics for each board, see the design files at: TIDA-00434.

*Note: For fixed output TLV1117, R8 = Open & R9= Short (0 ohm)

Figure 29. Bias Power Supply for Home Appliances Schematic
### 8.2 Bill of Materials

To download the bill of materials (BOM), see the design files at [TIDA-00434](https://www.ti.com).

#### Table 5. BOM

<table>
<thead>
<tr>
<th>QTY</th>
<th>REFERENCE</th>
<th>PART DESCRIPTION</th>
<th>MANUFACTURER</th>
<th>MANUFACTURER PART #</th>
<th>NOTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PCB</td>
<td>Printed Circuit Board</td>
<td>Any</td>
<td>TIDA-00434</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>3.3V, 5V, 12V, DC bus, L</td>
<td>Test Point, Miniature, Red, TH</td>
<td>Keystone</td>
<td>5000</td>
<td>Fitted</td>
</tr>
<tr>
<td>1</td>
<td>C1</td>
<td>CAP, AL, 10uF, 450V, +/-20%, 2.864788 ohm, TH</td>
<td>Panasonic</td>
<td>EEUED2W100</td>
<td>Fitted</td>
</tr>
<tr>
<td>1</td>
<td>C2</td>
<td>CAP, AL, 220 µF, 35 V, +/- 20%, 0.09 ohm, TH</td>
<td>Rubycon</td>
<td>25YXG220MEFC8X11.5</td>
<td>Fitted</td>
</tr>
<tr>
<td>1</td>
<td>C3, C8</td>
<td>CAP, CERM, 0.1 µF, 50 V, +/- 10%, X7R</td>
<td>AVX</td>
<td>06035C104KAT2A</td>
<td>Fitted</td>
</tr>
<tr>
<td>1</td>
<td>C4</td>
<td>CAP, CERM, 10 µF, 25 V, +/- 10%, X5R, 1206</td>
<td>Taiyo Yuden</td>
<td>TMK316BJ106KL-T</td>
<td>Fitted</td>
</tr>
<tr>
<td>1</td>
<td>C5</td>
<td>CAP, AL, 22 µF, 25 V, +/- 20%, TH</td>
<td>Nichicon</td>
<td>UPW1E220MDD6</td>
<td>Fitted</td>
</tr>
<tr>
<td>1</td>
<td>C6</td>
<td>CAP, AL, 100 µF, 25 V, +/- 20%, 0.23 ohm, TH</td>
<td>Nichicon</td>
<td>UPW1E101MED1TD</td>
<td>Fitted</td>
</tr>
<tr>
<td>1</td>
<td>C7</td>
<td>CAP, CERM, 1 µF, 25 V, +/- 10%, X5R, 0603</td>
<td>Murata</td>
<td>GRM188R61E105KA12D</td>
<td>Fitted</td>
</tr>
<tr>
<td>1</td>
<td>C9</td>
<td>CAP, Film, 0.1uF, 305V, +/-20%, TH</td>
<td>EPCOS Inc</td>
<td>B32921C3104M</td>
<td>Fitted</td>
</tr>
<tr>
<td>1</td>
<td>D1</td>
<td>Diode, P-N, 1000V, 1A, TH</td>
<td>Fairchild Semiconductor</td>
<td>B32921C3104M</td>
<td>Fitted</td>
</tr>
<tr>
<td>1</td>
<td>D2</td>
<td>Diode, Ultrafast, 1000V, 1A, SMA</td>
<td>Diodes Inc.</td>
<td>US1M-13-F</td>
<td>Fitted</td>
</tr>
<tr>
<td>1</td>
<td>D3</td>
<td>SMD General Purpose, 600 V, 1.0 A, SOD-123</td>
<td>Comchip Technology</td>
<td>CGRM4005-G</td>
<td>Fitted</td>
</tr>
<tr>
<td>1</td>
<td>D4</td>
<td>Diode, Schottky, 40 V, 1 A, SOD-123</td>
<td>Diodes Inc.</td>
<td>1N58194W-7-F</td>
<td>Fitted</td>
</tr>
<tr>
<td>3</td>
<td>GND, N, RTN</td>
<td>Test Point, Miniature, Black, TH</td>
<td>Keystone</td>
<td>5001</td>
<td>Fitted</td>
</tr>
<tr>
<td>1</td>
<td>L1</td>
<td>Inductor, Wirewound, Ferrite, 4.7mH, 0.15A, TH</td>
<td>Wurth Elektronik eiSos</td>
<td>744741472</td>
<td>Fitted</td>
</tr>
<tr>
<td>1</td>
<td>L2</td>
<td>Inductor, Wirewound, Ferrite, 470 µH, 1.15 A, 0.47 ohm, TH</td>
<td>Wurth Elektronik eiSos</td>
<td>7447480471</td>
<td>Fitted</td>
</tr>
<tr>
<td>1</td>
<td>Q1</td>
<td>Transistor, NPN, Vcc 80V, Vceo 60, Vbeo 7V, IC 3A</td>
<td>Fairchild</td>
<td>KSC5026MOS</td>
<td>Fitted</td>
</tr>
<tr>
<td>1</td>
<td>R1</td>
<td>RES, 0.75 ohm, 1%, 0.5W, 1206</td>
<td>Stackpole Electronics Inc</td>
<td>CSR1206FKR750</td>
<td>Fitted</td>
</tr>
<tr>
<td>3</td>
<td>R2, R3, R4</td>
<td>RES, 750 k, 1%, 0.25 W, 1206</td>
<td>Yageo America</td>
<td>RC1206FR-07750KL</td>
<td>Fitted</td>
</tr>
<tr>
<td>1</td>
<td>R5</td>
<td>RES, 100 k, 1%, 0.1 W, 0603</td>
<td>Vishay-Dale</td>
<td>CRCW0603100KFKEA</td>
<td>Fitted</td>
</tr>
<tr>
<td>1</td>
<td>R6</td>
<td>RES, 47 k, 5%, 0.1 W, 0603</td>
<td>Vishay-Dale</td>
<td>CRCW060347K0JNEA</td>
<td>Fitted</td>
</tr>
<tr>
<td>1</td>
<td>R7</td>
<td>RES, 47.5 k, 1%, 0.125 W, 0805</td>
<td>Vishay-Dale</td>
<td>CRCW080547K5FKEA</td>
<td>Fitted</td>
</tr>
<tr>
<td>1</td>
<td>R8</td>
<td>RES, 10.0 k, 1%, 0.1 W, 0603</td>
<td>Vishay-Dale</td>
<td>CRCW060310K0FKEA</td>
<td>Fitted</td>
</tr>
<tr>
<td>1</td>
<td>R9</td>
<td>RES, 16.9 k, 1%, 0.1 W, 0603</td>
<td>Vishay-Dale</td>
<td>CRCW060316K9FKEA</td>
<td>Fitted</td>
</tr>
<tr>
<td>1</td>
<td>RT1</td>
<td>Thermistor NTC, 10 ohm, 20%, Disc_11.5mmx6mm</td>
<td>EPCOS Inc</td>
<td>B57236S100M000</td>
<td>Fitted</td>
</tr>
<tr>
<td>1</td>
<td>RV1</td>
<td>Varistor, 300V, 1.75kA, 7MM Radial, TH</td>
<td>EPCOS Inc</td>
<td>B72207S2301K101</td>
<td>Fitted</td>
</tr>
<tr>
<td>1</td>
<td>U1</td>
<td>Constant-Voltage, Constant-Current Controller With Primary-Side Regulation, BJT Drive</td>
<td>Texas Instruments</td>
<td>UCC28722DBV</td>
<td>Fitted</td>
</tr>
<tr>
<td>1</td>
<td>U2</td>
<td>3-Terminal Positive Regulators, 3-pin TO-92</td>
<td>Texas Instruments</td>
<td>UA78L05ACP</td>
<td>Fitted</td>
</tr>
<tr>
<td>1</td>
<td>U3</td>
<td>Adjustable and fixed LDO voltage regulator</td>
<td>Texas Instruments</td>
<td>TLV1117CKVU</td>
<td>Fitted</td>
</tr>
</tbody>
</table>
8.3 **PCB Layout Recommendations**

A careful PCB layout is critical for proper operation of power electronics devices. As with all switching power supplies, attention to detail in the layout can save much time in troubleshooting later on. The following sub-sections specify the key guidelines to follow.

8.3.1 **Power Stage Specific Guidelines**

The following are key guidelines for routing power stage components:

- Minimize the loop area and trace length of the power path circuits, which contain high-frequency switching currents. This minimization helps reduce EMI and improve the overall converter performance.
- Keep traces with high $dV/dt$ potential and high $di/dt$ capability away from or shielded from sensitive signal traces.
- Keep power ground and control ground separate. Tie them together (if they are electrically connected) in one point near the DC input return or output return of the given stage correspondingly.
- The width of PCB traces must be chosen based on an acceptable temperature rise at the rated current per the IPC-2152 standard, as well as acceptable DC and AC impedances. Also, the traces must be able to withstand the fault currents (such as a short-circuit current) before the activation of electronic protections such as a fuse or circuit breaker.
- The distances between various circuits must be determined according to the requirements of applicable standards, such as UL 60950-1.

8.3.2 **Controller Specific Guidelines**

The following are key guidelines for the routing of controller components and signal circuits:

- The optimum placement of a decoupling capacitor is closest to the VDD and GND terminals of the device. Take care to minimize the loop area formed by the bypass-capacitor connection and the GND terminal of the IC.
- The reference ground for the device, a low current signal ground (SGND), must be a copper plane or island.
- Locate all of the controller support components at specific signal pins (DRV, VDD, VS, and CS) close to their connection pin. Connect the other end of the component to the SGND with the shortest trace length.
- The trace routing for the voltage sensing and current sensing circuit components to the device must be as short as possible to reduce parasitic effects on the current limit and current/voltage monitoring accuracy. These traces must not have any coupling to switching signals on the board.
- The SGND plane must be connected to the high current ground (main power ground) at a single point. In the case of this design (buck topology), the SGND must be tied to the switching node plane.
8.4 Layer Prints

To download the layer prints for each board, see the design files at [TIDA-00434](https://www.ti.com).
8.5 Altium Project
To download the Altium project files for each board, see the design files at TIDA-00434.

8.6 Gerber Files
To download the Gerber files for each board, see the design files at TIDA-00434.

8.7 Assembly Drawings
To download the assembly drawings for each board, see the design files at TIDA-00434.

8.8 Software Files
To download the software files, see the design files at TIDA-00434.

8.9 Design Calculator
To download the design calculator spreadsheet file for this reference design, see the file at TIDA-00434.

9 References
1. Texas Instruments, Constant-Voltage, Constant-Current Controller With Primary-Side Regulation, BJT Drive, Datasheet, (SLUSBL7)
3. Texas Instruments, Exposing the inner behavior of a quasi-resonant flyback converter, TI Presentation, Topic 3; 2012, (SLIP302)
4. Texas Instruments, UCC28722/UCC28720 5W USB BJT Flyback Design Example, Application Report, (SLUA700)

10 About the Author
LATIF AMEER BABU is a Systems Engineer at Texas Instruments, where he is responsible for developing reference design solutions for the industrial segment. Latif brings to this role his extensive experience in power electronics, high frequency DC-DC converter, and analog circuit design. Latif earned his Master of Technology in Power Electronics & Power Systems from Indian Institute of Technology, Mumbai; IN. Latif is a member of the Institute of Electrical and Electronics Engineers (IEEE).
### Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

<table>
<thead>
<tr>
<th>Changes from Original (April 2015) to B Revision</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Changed title from Simple and Robust Bias Power Supply With Low Standby for Home Appliances to Cost-Effective Bias Power Supply With &lt; 100-mW Standby and 75% Efficiency Reference Design</td>
<td>1</td>
</tr>
</tbody>
</table>

---

Submit Documentation Feedback
IMPORTANT NOTICE FOR TI REFERENCE DESIGNS

Texas Instruments Incorporated (‘TI’) reference designs are solely intended to assist designers (‘Designer(s)’) who are developing systems that incorporate TI products. TI has not conducted any testing other than that specifically described in the published documentation for a particular reference design.

TI’s provision of reference designs and any other technical, applications or design advice, quality characterization, reliability data or other information or services does not expand or otherwise alter TI’s applicable published warranties or warranty disclaimers for TI products, and no additional obligations or liabilities arise from TI providing such reference designs or other items.

TI reserves the right to make corrections, enhancements, improvements and other changes to its reference designs and other items.

Designer understands and agrees that Designer remains responsible for using its independent analysis, evaluation and judgment in designing Designer’s systems and products, and has full and exclusive responsibility to assure the safety of its products and compliance of its products (and of all TI products used in or for such Designer’s products) with all applicable regulations, laws and other applicable requirements. Designer represents that, with respect to its applications, it has all the necessary expertise to create and implement safeguards that (1) anticipate dangerous consequences of failures, (2) monitor failures and their consequences, and (3) lessen the likelihood of failures that might cause harm and take appropriate actions. Designer agrees that prior to using or distributing any systems that include TI products, Designer will thoroughly test such systems and the functionality of such TI products as used in such systems. Designer may not use any TI products in life-critical medical equipment unless authorized officers of the parties have executed a special contract specifically governing such use. Life-critical medical equipment is medical equipment where failure of such equipment would cause serious bodily injury or death (e.g., life support, pacemakers, defibrillators, heart pumps, neurostimulators, and implantables). Such equipment includes, without limitation, all medical devices identified by the U.S. Food and Drug Administration as Class III devices and equivalent classifications outside the U.S.

Designers are authorized to use, copy and modify any individual TI reference design only in connection with the development of end products that include the TI product(s) identified in that reference design. HOWEVER, NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY OTHER TI INTELLECTUAL PROPERTY RIGHT, AND NO LICENSE TO ANY TECHNOLOGY OR INTELLECTUAL PROPERTY RIGHT OF TI OR ANY THIRD PARTY IS GRANTED HEREIN, including but not limited to any patent right, copyright, mask work right, or other 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 to use such products or services, or a warranty or endorsement thereof. Use of the reference design or other items described above 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.

TI REFERENCE DESIGNS AND OTHER ITEMS DESCRIBED ABOVE ARE PROVIDED “AS IS” AND WITH ALL FAULTS. TI DISCLAIMS ALL OTHER WARRANTIES OR REPRESENTATIONS, EXPRESS OR IMPLIED, REGARDING THE REFERENCE DESIGNS OR USE OF THE REFERENCE DESIGNS, INCLUDING BUT NOT LIMITED TO ACCURACY OR COMPLETENESS, TITLE, ANY EPIDEMIC FAILURE WARRANTY AND ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

TI SHALL NOT BE LIABLE FOR AND SHALL NOT DEFEND OR INDEMNIFY DESIGNERS AGAINST ANY CLAIM, INCLUDING BUT NOT LIMITED TO ANY INFRINGEMENT CLAIM THAT RELATES TO OR IS BASED ON ANY COMBINATION OF PRODUCTS AS DESCRIBED IN A TI REFERENCE DESIGN OR OTHERWISE. IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, DIRECT, SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF THE REFERENCE DESIGNS OR USE OF THE REFERENCE DESIGNS, AND REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

TI’s standard terms of sale for semiconductor products (http://www.ti.com/sc/docs/stdterms.htm) apply to the sale of packaged integrated circuit products. Additional terms may apply to the use or sale of other types of TI products and services. Designer will fully indemnify TI and its representatives against any damages, costs, losses, and/or liabilities arising out of Designer’s non-compliance with the terms and provisions of this Notice.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2016, Texas Instruments Incorporated