# dsPIC33A Digital Power Starter Kit 4 User Guide

## Introduction

This chapter introduces the dsPIC33A Digital Power Starter Kit (DPSK) and provides an overview of its features. The topics covered include:

- Overview
- Kit Contents
- Components
- Powering the Board
- Electrical Specifications
- Hardware Description
- Starter Kit Functionality and Features
- dsPIC33A Digital Power Starter Kit System Diagram

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# 1. Overview

The dsPIC33A Digital Power Starter Kit is intended to introduce and demonstrate the capabilities and features of Microchip's SMPS device families. The starter kit features an on-board dsPIC33AK512MPS506 Digital Signal Controller (DSC) device, SMPS power stages, resistive loads, an LCD display and a USB/UART bridge. It also includes a programmer/debugger, which eliminates the need for any additional hardware. The software for the demonstration application that is preprogrammed into the on-board dsPIC33A Digital Signal Controller (DSC) is available for download from MPLAB® Discover.

# 2. Kit Contents

The dsPIC33A Digital Power Starter Kit contains the following:

- dsPIC33A Digital Power Starter Kit Board
- 9V Power Supply
- USB-C Cable

**Note:** If you are missing any part of the kit, contact a Microchip sales office for assistance.

# 3. Components

## 3.1. Top and Bottom View

The top and bottom assemblies of the board are shown in Figure 3-1 and Figure 3-2.

Table 3-1 and Table 3-2 provide descriptions of the components.

**Figure 3-1.** dsPIC33A Digital Power Starter Kit (Top View)

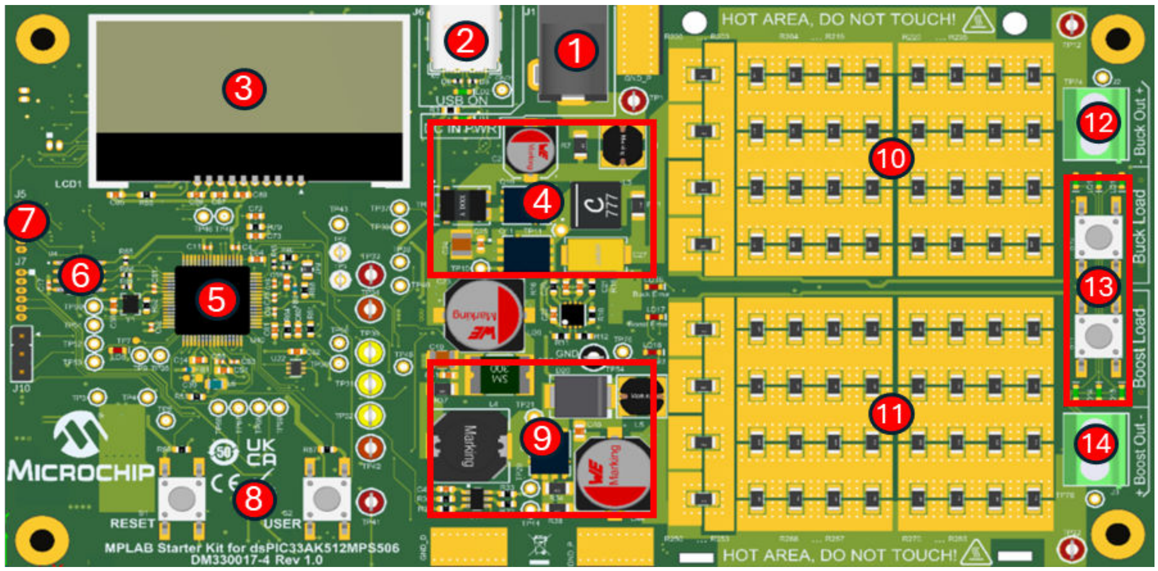



**Table 3-1.** dsPIC33A Digital Power Starter Kit Components (Top View)

| Number | Description |
|---|---|
| 1 | DC Power Input |
| 2 | USB-C Connector |
| 3 | 2x16 Character LCD |
| 4 | Buck Converter Stage |
| 5 | dsPIC33A Digital Signal Controller (DSC) |
| 6 | Trust Anchor Device |
| 7 | Programming Connection for dsPIC® DSC |
| 8 | User and Reset Push Buttons |
| 9 | Boost Converter Stage |
| 10 | Buck Load |
| 11 | Boost Load |
| 12 | Buck Converter Output |
| 13 | Push Buttons for Controlling Resistive Loads |
| 14 | Boost Converter Output |

**Figure 3-2.** dsPIC33A Digital Power Starter Kit (Bottom View)

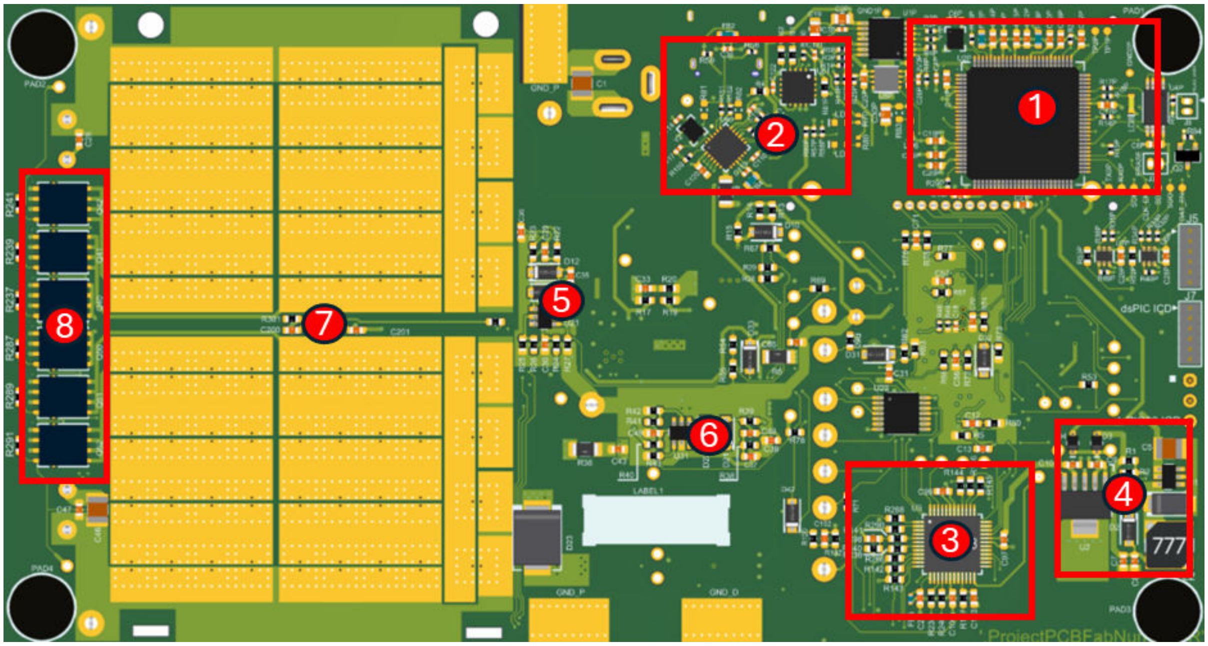


**Table 3-2.** dsPIC33A Digital Power Starter Kit Components (Bottom View)

| Number | Description |
|---|---|
| 1 | PICkit™ On-Board (PKOB) Programmer/Debugger Circuit |
| 2 | USB/UART Hub and Bridge |
| 3 | dsPIC33CK256MP305 Load/Protection Microcontroller |
| 4 | Auxiliary Power Supply |
| 5 | Buck Output Current Sense |
| 6 | Boost Input Current Sense |
| 7 | Temperature Sensor |
| 8 | Buck/Boost Load Control Switches |

# 4. Powering the Board

The dsPIC33A Digital Power Starter Kit is designed to be a self-contained power supply. The on-board power stages are:

- One Asynchronous Boost Converter Power Stage
- One Synchronous Buck Converter Power Stage

To power the board, use connectors J1 and/or J6 as follows:

- The +9V power connector (J1) supplies power to the dsPIC33A Digital Power Starter Kit, including the power stages and auxiliary power supply. Therefore, all building blocks on the board are powered by applying a voltage greater than 6V at this input. Once voltage is provided to this connector, power conversion starts immediately.
- The USB-C connector (J6) supplies power to the auxiliary supply and provides a connection to the USB/UART bridge and PKOB (programmer/debugger). This enables communication with, as well as programming and debugging of, the microcontrollers on the board without powering the buck/boost converters.

**Note:** Powering the board via a USB connector using a +5V supply only (without USB communication connections), such as wall chargers or USB power banks, is currently not supported.

When using a power supply with non-communication ports, the USB PICkit™ On-Board 4 (PKOB4) debugger/programmer will hold the target device in reset.

# 5. Electrical Specifications

The following tables outline the safe operating conditions for the buck and boost converters.

**Table 5-1.** DC Input Rating (J1)

| Parameter | Minimum | Typical | Maximum | Unit |
|---|---|---|---|---|
| Voltage | 6 | 9 | 13.8 | V |
| Current | - | 0.9 | - | A |

**Table 5-2.** Buck Converter Electrical Specifications

| Parameter | Minimum | Typical | Maximum | Unit |
|---|---|---|---|---|
| Output Voltage | 1[(1)] | 3.3 | 5[(1)] | V |
| Output Voltage Ripple | - | - | 40 | mV(pk-pk) |
| Output Current | - | 1 | 2 | A |
| Load Regulation: 3.3V<br>IOUT = 0.1 – 1.0A, VIN = 9V | - | 13 | - | mV/A |
| Switching Frequency | - | 500 | - | kHz |
| Output Power | - | 3.3[(2)] | 7.6[(3)] | W |

**Notes:**

1. Requires reprogramming of the dsPIC33A microcontroller.
2. Maximum power of on-board resistive loads should not exceed 3.3W.
3. Achieved with an external load.

**Table 5-3.** Boost Converter Electrical Specifications

| Parameter | Minimum | Typical | Maximum | Unit |
|---|---|---|---|---|
| Output Voltage | 10[(1,4)] | 15 | 20[(1)] | V |
| Output Voltage Ripple | - | 10 | - | mV(pk-pk) |
| Output Current | - | 0.2 | 0.4 | A |
| Load Regulation: 15V<br>IOUT = 0.03 – 0.2A, VIN = 9V | - | 4 | - | mV/A |
| Switching Frequency | - | 500 | - | kHz |
| Output Power | - | 3[(2)] | 6[(3)] | W |

**Notes:**

1. Requires reprogramming of the dsPIC33A microcontroller.
2. Maximum power of on-board resistive loads should not exceed 3.3W.
3. Achieved with an external load.
4. Output voltage must be greater than input voltage.

# 6. Hardware Description

Topics covered in this section include:

- Signal Configuration
- Board Connectors
- Indicators and Human Interfaces
- Test Points

## 6.1. Signal Configuration

Table 6-1 provides a complete list of the dsPIC33A DSC connections and a brief functional description of the pins used in the dsPIC33A Digital Power Starter Kit.

**Table 6-1.** dsPIC33A Configuration Details

| dsPIC33A DPSK | Pin Number | Pin Name | Description/Function |
|---|---|---|---|
| Unused | 1,7,9,24,27,28 | - | - |
| RA7_BUCK_VFB | 2 | RA7 | Analog – buck voltage feedback |
| RA1_DACOUT1 | 3 | RA1 | Analog – DAC output voltage test point |
| GND_D | 4,18,25,37,47,57 | VSS | Digital ground |
| +3.3V | 5,19,26,38,48,58 | VDD | Positive supply for microcontroller |
| RA11_VIN_MEAS | 6 | RA11 | Analog – input voltage feedback |
| RA9_UREF | 8 | RA9 | Analog – UREF/DAC output voltage test point |
| GND_A | 10 | AVSS | Analog ground |
| +3.3V_A | 11 | AVDD | Analog supply for microcontroller |
| RA2_VBODE_OUT | 12 | RA2 | Analog – injection circuit output feedback |
| RA3_VBODE_IN- | 13 | RA3 | Analog – injection circuit negative input |
| RA4_VBODE_IN+ | 14 | RA4 | Analog – injection circuit positive input |
| RA5_BOOST_VFB | 15 | RA5 | Analog – boost voltage feedback |
| RA6_TEMP_SNS | 16 | RA6 | Analog – PCB temperature sensor |
| RB5_BUCK_IFB_CT | 17 | RB5 | Analog – buck CT current feedback |
| RB0_BOOST_IFB_RES | 20 | RB0 | Analog – boost low-side current feedback |
| RB1_OA2- | 21 | RB1 | Analog – boost low-side current negative op amp input |
| RB2_OA2+ | 22 | RB2 | Analog – boost low-side current positive op amp Input |
| RB8_BOOST_IFB_AMP | 23 | RB8 | Analog – boost high-side current feedback |
| LCD_COM | 29, 30, 45, 46, 50 | | Digital LCD communication lines |
| RB10_BUCK_IFB_AMP | 31 | RB10 | Analog – buck output current feedback |
| RB11_DSP_GPIO3 | 32 | RB11 | Digital – general purpose test point |
| RC8_DSP_GPIO4 | 33 | RC8 | Digital – general purpose test point |
| RC9_TA_RESET | 34 | RC9 | Digital – reset line trust anchor device |
| RC6_TA_CLOCK | 35 | RC6 | Digital – clock line trust anchor device |
| RC7_TA_DATA | 36 | RC7 | Digital – data line trust anchor device |
| RC0_DSP_GPIO5 | 39 | RC0 | Digital – general purpose test point |
| RC1_CLKI | 40 | RC1 | Digital – clock input |
| RC2_PGC3_Target | 41 | RC2 | Digital – programming clock signal |

**Table 6-1.** dsPIC33A Configuration Details (continued)

| dsPIC33A DPSK | Pin Number | Pin Name | Description/Function |
|---|---|---|---|
| RC5_PGD3_Target | 42 | RC5 | Digital – programming data signal |
| CONSOLE_UART_TX | 43 | RC3 | Digital – UART comms console |
| CONSOLE_UART_RX | 44 | RC4 | Digital – UART comms console |
| RD0_PWM2H_BOOST | 49 | RD0 | Digital – boost converter PWM drive signal |
| RD2_PWM1H_Buck | 51 | RD2 | Digital – buck converter PWM drive signal |
| RD3_PWM1L_Buck | 52 | RD3 | Digital – buck converter PWM drive signal |
| Buck Switcher | 53, 54, 55, 56 | - | Microcontroller internal buck switcher |
| RD5_DSP_GPIO1 | 59 | RD5 | Digital – general purpose test point |
| RD6_SW_USER | 60 | RD6 | Digital – general purpose switch input |
| RD4_DSP_GPIO2 | 61 | RD4 | Digital – general purpose test point |
| dsPIC33_UART_TX | 62 | RD7 | Digital – UART comms inter-processor |
| dsPIC33_UART_RX | 63 | RD8 | Digital – UART comms inter-processor |
| SW_RESET | 64 | MCLR | Master clear (reset) input |

## 6.2. Board Connectors

Table 6-2 describes the hardware connections available on the dsPIC33A Digital Power Starter Kit.

**Table 6-2.** Hardware Connections

| Label | Hardware Element Description |
|---|---|
| J1 | 9V power supply barrel connector |
| J2 | Terminal block for buck converter output; can be used for external load. |
| J3 | Terminal block for boost converter output; can be used for external load. |
| J5 | Unpopulated header for an external programmer/debugger targeting the dsPIC33A device. |
| J6 | USB-C connector for communication and programming/debugging. |
| J7 | Unpopulated header for an external programmer/debugger targeting the dsPIC33C device (load/protection controller). |
| J10 | Unpopulated header for access to inter-processor communication (UART). |

## 6.3. Indicators and Human Interfaces

Table 6-3 describes the user interfaces available on the dsPIC33A Digital Power Starter Kit.

**Table 6-3.** Indicators and Human Interfaces

| Label | Hardware Element Description |
|---|---|
| LCD1 | User-programmable LCD display |
| LD1, LD2 | Power-on status LEDs, indicate 9V power and USB power |
| LD5 | User-programmable LED |
| LD10, LD11, LD12 | Buck converter load LEDs |
| LD13, LD14, LD15 | Boost converter load LEDs |
| LD16, LD17, LD18 | Buck, boost, and thermal error LEDs |
| S1 | dsPIC® device reset push button |
| S2 | User push button |

**Table 6-3.** Indicators and Human Interfaces (continued)

| Label | Hardware Element Description |
|---|---|
| S10 | Buck load control push button |
| S11 | Boost load control push button |

## 6.4. Test Points

Table 6-4 describes the test points that are available on the dsPIC33A Digital Power Starter Kit.

**Note:** The table lists several critical and useful test points. Consult the schematics in Appendix A. Board Layout and Schematics for additional test point information.

**Table 6-4.** Test Points

| Test Point | Description |
|---|---|
| TP1 | +9V DPSK board input voltage (red) |
| TP2, TP5 | Dedicated loop injection (white) |
| TP9, TP35 | dsPIC33A DAC output voltages |
| TP11 | Buck converter switch node |
| TP12 | Buck converter output voltage (red) |
| TP21 | Boost converter switch node |
| TP22 | Boost converter output voltage (red) |
| TP30, TP31, TP32 | Buck (low, high), and boost PWM drive signals (yellow) |
| TP33, TP34 | Buck converter loop injection (red, orange) |
| TP36 | Buck voltage feedback |
| TP38 | Buck CT current feedback |
| TP40 | Buck output current feedback |
| TP41, TP42 | Boost converter loop injection (red, orange) |
| TP43 | Boost voltage feedback |
| TP46 | Boost high-side current feedback |
| TP49 | Boost low-side current feedback |
| TP50, TP51, TP53, TP53 | General-purpose I/O |

# 7. Starter Kit Functionality and Features

The dsPIC33A Digital Power Starter Kit is a Switch Mode Power Supply (SMPS) board that consists of one independent DC/DC synchronous buck converter, one independent DC/DC boost converter, independent resistive loads, protection circuitry, a USB/UART converter/bridge and on-board programmer/debugger circuitry.

Both power stages are controlled by the dsPIC33A device. The loads and protection circuitry are controlled by an auxiliary dsPIC33C microcontroller. Inter-processor communication using UART allows for the exchange of information such as load temperature, load status and protection status. These messages can be adapted or extended by the user.

## 7.1. Buck Converter

The buck converter stage is rated for a maximum of 7.6W. However, the maximum on-board configurable resistive load is 3.3W. The output voltage and output current should remain within their Safe Operating Area (SOA). The output voltage of the buck converter (Buck_Out) can be programmed, but the default programmed voltage is set to 3.3V. The hardware gain, *1k/(1k + 1k + 20)*, of the voltage feedback from Buck_Out is provided by the resistor divider network, R62 and R63. Additionally, a 20 Ohm resistor, R60, for Bode plot measurements, is also in series with the feedback network. The hardware gain of the current feedback is provided by the current transformer (T1) with a turns ratio of 1:100 and burden resistor R14. Series resistor R29 and pull-up resistor R28 inject a voltage offset of approximately 250mV. In total, this voltage will have a gain of 1V/Amp with a DC offset of 250mV.

Figure 7-1 shows the load configuration. The load consists of three parallel resistor networks, with each network having its own equivalent resistance. Therefore, each network will draw a different current and dissipate a different amount of power at different output voltages. The board is supplied with a preprogrammed 3.3V at the buck output, providing a 3.3W load through the on-board load resistors. The power dissipation causes a 40°C ΔT on the board.

Load control and converter protections are handled by the dsPIC33C microcontroller. The available load options are: 0% (no load), 10%, 50% and 100% load (1A max). Briefly press the push button, Buck Load (No. 13 in Figure 3-1), to increase the load. In addition, the LEDs (LD10, LD11 and LD12) will turn on to indicate the load status. Once the level reaches 100%, pressing the button again will reset it to 0%, effectively turning off the load. All LEDs will be off, and the process can start from the beginning.

A long press (2 seconds) of the buck load switch will change to Load Stepping mode. The load step generator operates at 100 Hz with a 50% duty cycle. The supported load step schemes are:

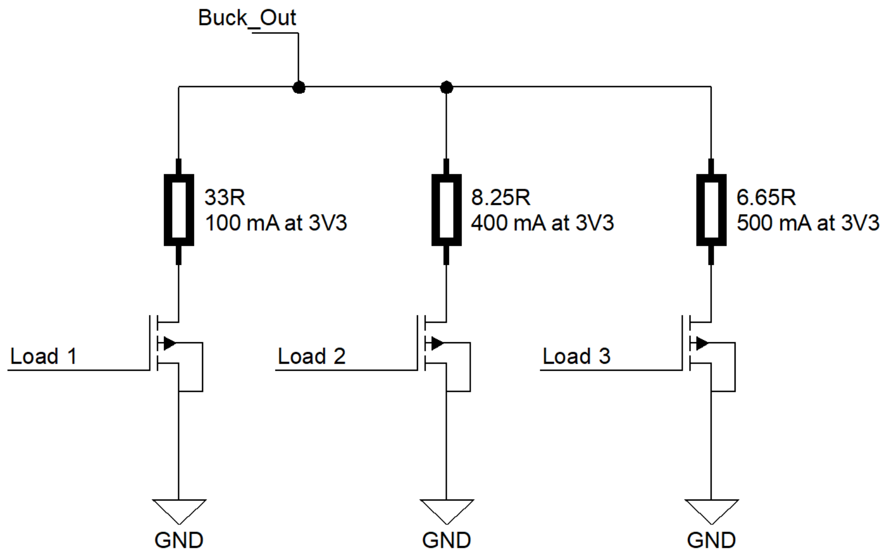
10% → 50%

50% → 100%

10% → 100%

Press and hold the buck load switch again to return back to static load conditions. Leaving on-board load enabled for extended durations may cause thermal shutdown.

**Figure 7-1.** Buck Converter: On-Board Resistive Load Configuration Option




## 7.2. Boost Converter

The boost converter stage is rated for a maximum power of 6W. However, the maximum on-board configurable resistive load is 3W. The output voltage and output current should remain within the Safe Operating Area (SOA) to avoid damage to the board. The output voltage of the boost converter (Boost_Out) can be programmed, but the default programmed voltage is 15V. The hardware gain, *1k/(1k + 6.98k + 20)*, of the voltage feedback from Boost_Out is provided by the resistor divider network of R72 and R73. Additionally, a 20 Ohm resistor, R71, for Bode plot measurements is also in series with the feedback network. The hardware gain of the current feedback is provided by the current sense resistors, R34 and R35, and an internal op amp gain of four. In total, this voltage will have an offset voltage of 1V and a gain of 1V/A.

Figure 7-2 shows the boost load configuration. The load consists of three parallel resistor networks, with each network having its own equivalent resistance. Therefore, each network will draw a different current and dissipate a different amount of power at different output voltages. The board is supplied with a preprogrammed 15V at the boost output, providing a 3W load through the on-board load resistors. The power dissipation causes a 40°C ΔT on the board.

Load control and converter protections are handled by the dsPIC33C microcontroller. The available load options are: 0% (no load), 15%, 50% and 100% load (200mA max). Briefly press the push button, Boost Load (No. 13 in Figure 3-1), to increase the load. In addition, the LEDs (LD13, LD14 and LD15) will turn on to indicate the load status. Once the level reaches 100%, pressing the button again will reset it to 0%; effectively, turning off the load. All LEDs will be off, and the process can start from the beginning.

A long press (2 seconds) of the Boost Load switch will switch to Load Stepping mode. The load step generator operates at 100 Hz with a 50% duty cycle. The supported load step schemes are:

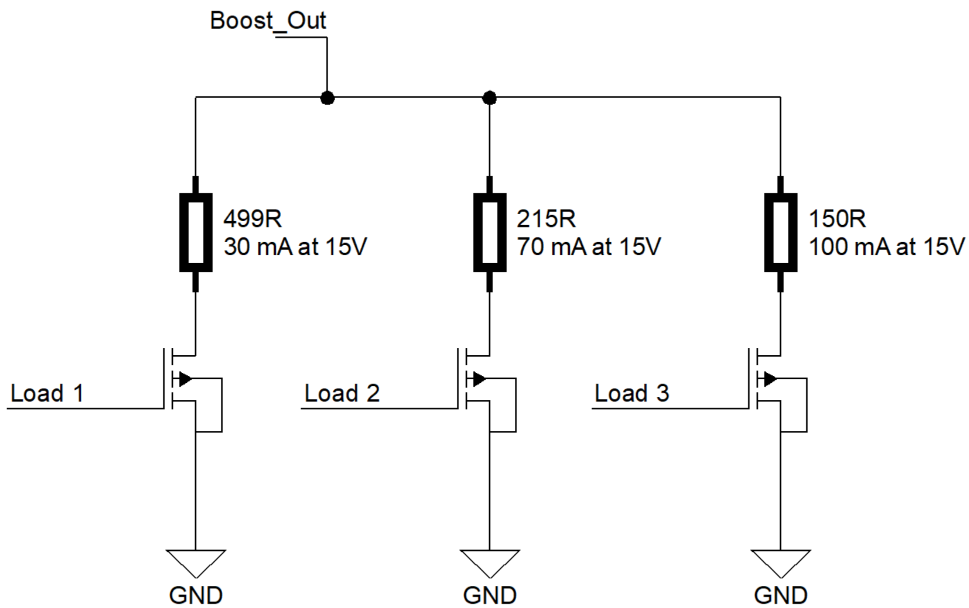
15% → 50%

50% → 100%

15% → 100%

Press and hold the Boost Load switch again to return to static load conditions. Leaving the on-board load enabled for extended durations may cause thermal shutdown.

**Figure 7-2.** Boost Converter: On-Board Resistive Load Configuration Option




## 7.3. Human Machine Interface

The Digital Power Starter Kit includes an on-board 2x16 LCD character display. This display is used to show relevant system data, such as voltages, currents, temperature, internal load settings and converter status (enabled/disabled). Pressing the push button labeled "USER" (No. 8 in Figure 3-1) transitions from one information page to another.

Press and hold the USER switch (2 seconds) to return to the previous page. The RESET switch, located next to the USER switch, can be used to force the dsPIC33A to go through a reset routine.

For UART communication, a USB/UART hub and bridge are on board, hard-wired to the dsPIC33A device (No.2 in Figure 3-2). Using a terminal emulator such as Tera term or HyperTerminal, real-time data from the microcontroller can be displayed. The default application does not include this feature.

In addition to the console interface, the Digital Power Starter Kit includes inter-processor communication through a separate UART channel. This channel is used for exchanging pertinent information about the system. Additional data can be appended and shared between microcontrollers, or even expanded and accessed through header J10.

## 7.4. Thermal Protections

The starter kit includes an on-board temperature sensor located between the buck/boost converter's resistive loads. This sensor enables temperature protection limits, leading to a high-temperature fail-safe shutdown. In conditions of excess heating, the loads will be permanently switched off until the board temperature drops to the safe operating temperature (65°C).

Temperature threshold levels are as follows:

- 65°C: Warning; LD18 (overheat) is permanently on
- 75°C: LD18 (overheat) is blinking

Considering the physical dimensions, ambient temperature, power dissipation and protection threshold of the board, there are two possible combinations for continuous loading:

1. A single power stage running at full power, 3.3W maximum
2. Both power stages running at 50% load each

Running both power stages at 100% load would result in 6.3W of power dissipation. This will cause the board to reach an overtemperature condition after a short period of time (within several minutes).

## 7.5. Hardware Protections

The on-board protection circuitry continuously monitors the currents and voltages of the Buck and Boost converters. This is handled by an external dsPIC33C microcontroller and its advanced peripherals. The microcontroller's trip levels are programmable, but the default setpoints are as follows:

- 3A Buck converter current
- 4V Buck converter output voltage
- 1.6A Boost converter current
- 18V Boost converter output voltage

In the event of a converter fault, the dsPIC33C immediately shuts down the gate drive signal (latched) and flags the shutdown event through the inter-processor communication. The current fault timeout duration is set to 1 second, after which the gate drive will be released and the converter may attempt a restart event.

## 7.6. Programmer/Debugger

The dsPIC33A Digital Power Starter Kit includes an on-board programmer/debugger circuit that provides connectivity via USB. This circuit is hard-wired to the dsPIC® DSC device to provide ICSP™ debugging/programming capability.

**Table 7-1.** Programmer/Debugger Components

| Component | Label | Description |
|---|---|---|
| On-Board Programmer/ Debugger | N/A | Controls the programming/debugging operations of the target dsPIC33A DSC (No.1 in Figure 3-2). |
| dsPIC33A External Programmer Header | J5 | 6-pin inline 1.27mm connector for external programmer/debugger to the dsPIC33A device. |
| Programmer/Debugger USB Connector | J6 | Provides power to the programmer/debugger and bidirectional communication between the host PC and the dsPIC33A device. |
| dsPIC33C External Programmer Header | J7 | 6-pin inline 1.27mm connector for external programmer/debugger to the dsPIC33C device. |

# 8. dsPIC33A Digital Power Starter Kit System Diagram

The dsPIC33A Digital Power Starter Kit provides closed-loop peak current mode control using a 2-pole, 2-zero (2P2Z) 32-bit fixed-point compensator, implemented in software, to maintain the desired load step response and converter stability criteria. The dsPIC33A device provides all necessary components, such as memory, peripherals (ADC, DAC, PWM, Comparators), and general-purpose I/Os, eliminating the need to perform these functions with external circuitry.

dsPIC33 DSC SMPS devices are specifically designed to provide low-cost and efficient control for a wide range of power supply topologies. The specialized peripherals facilitate closed-loop feedback control of switch mode power supplies, providing communication for remote monitoring and supervisory control.

The dsPIC33A family of devices offers the following features:

- Ultra-fast interrupt response time with interrupt priority logic and dedicated register contexts
- Multiple high-speed ADCs with configurable channel settings
- High-resolution PWM generators, specially designed to support different power topologies
- High-speed analog comparators for control loop implementation and system protections
- On-chip system communications (I2C/SPI/UART)
- Internal PDM DAC slope compensation
- On-chip Fast RC (FRC) oscillator for lower system cost, with backup FRC monitoring
- Floating-point unit coprocessor for fast, complex math

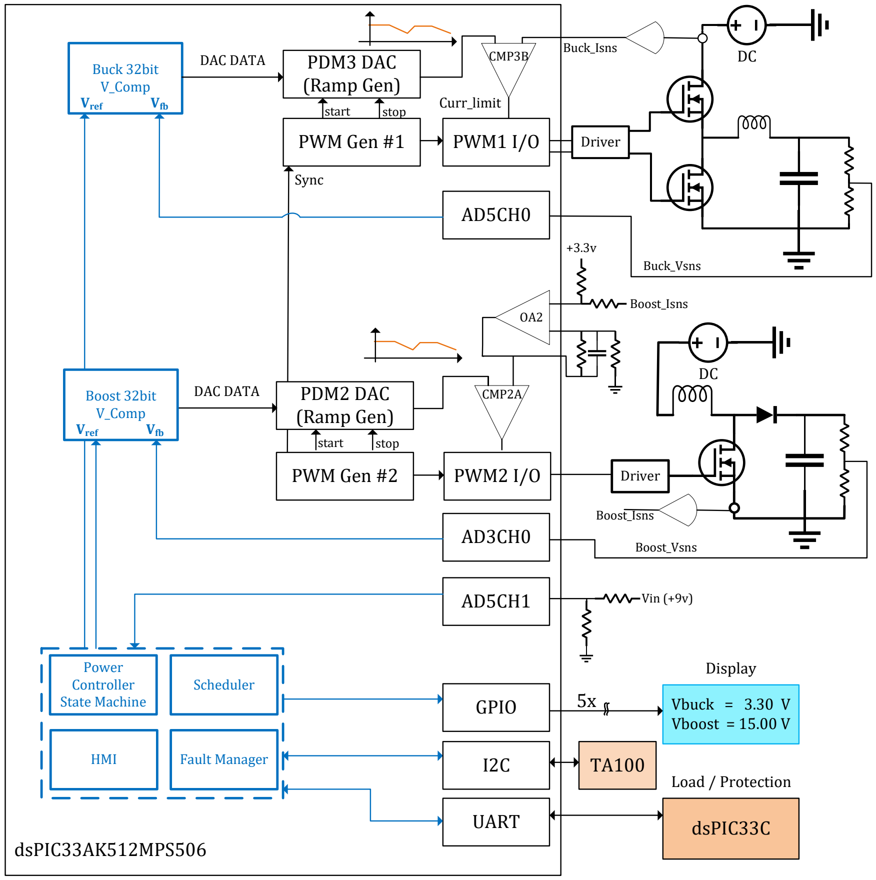
**Note:** Both buck and boost converters operate in Peak Current mode control (by default), but they can also be reprogrammed to operate in Average Current mode or Voltage mode control; this requires only minor firmware changes.

Figure 8-1 illustrates a high-level block diagram of the dsPIC33A interfacing with the power converters. Each converter's output voltage is sampled by the low-latency ADC, and the result is passed to the 2P2Z controller. The 2P2Z is an IIR recursive filter that computes the target output based on the previous output and error signals. This filter is developed in assembly language, taking advantage of the 72-bit accumulators and MAC instructions for fast multiplication and addition calculations.

The output of the controller is the PDM DAC reference voltage. This reference voltage is fed to an analog comparator and compared against the current sense feedback signal. When the feedback signal exceeds the DAC reference voltage, the comparator output becomes active and, through a PWM PCI (PWM Control Inputs) event, shuts down the PWM active on-time, thus achieving Peak Current mode control.

Each PWM generator consists of separate triggers to sample the output voltage through the ADC module and to start/stop the PDM DAC Slope mode. The output voltage is sampled every other PWM cycle (250kHz), while the PDM DAC triggers occur every cycle. The DAC start slope trigger occurs early in the duty cycle window, while the DAC stop trigger occurs at around 80% of the duty cycle to allow enough time to transition back to the static setpoint. The writeback to the DAC register occurs with the trigger stop event. The boost converter includes an additional trigger to synchronize the buck converters' start-of-cycle (with a 50% phase shift).

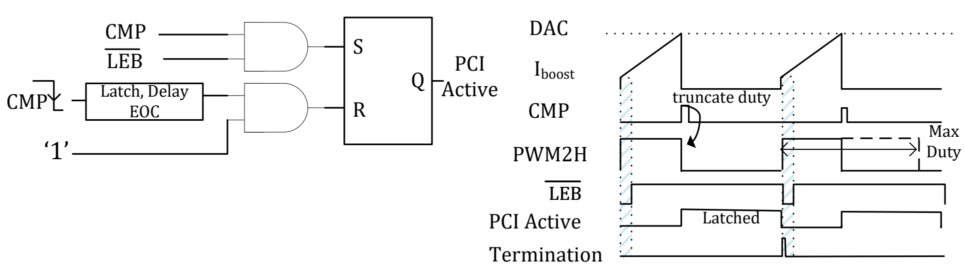
**Figure 8-1.** dsPIC33A Digital Power Starter Kit System Diagram




Configuring the PCI logic for cycle-by-cycle control is straightforward for the boost converter, as the low-side shunt current always returns to zero before the next switching cycle. For the boost converter, the PCI acceptance mode is selected as Reset-Dominated Latched mode, where the qualified terminator is simply the comparator falling edge in Auto-Termination mode. The comparator input is qualified with inverse LEB, which is triggered by the PWM rising edge. This will mask any noise when switching on the low-side MOSFET. The PWM module configures the current limit event to drive the PWM2H pin active low when the current limit PCI event is active.

Figure 8-2 shows the PCI configuration for the boost converter. Note that the programmed duty cycle is set to around 80% of the period, but the actual on-time is controlled by the current limit.

**Figure 8-2.** Boost PCI Current-Limit Configuration




The buck converter, on the other hand, requires a more complicated PCI configuration, as the low-side MOSFET needs to be OFF for certain periods during light load operation when the system enters Burst mode. With just a cycle-by-cycle current limit configuration, the CMP output may still be active at the start of the cycle, preventing the high-side switch from turning on. Due to the complementary PWM behavior, the low-side FET will continue to switch ON at almost 100% duty cycles. This switching will eventually lead to a build-up of current and trip the protection circuitry.

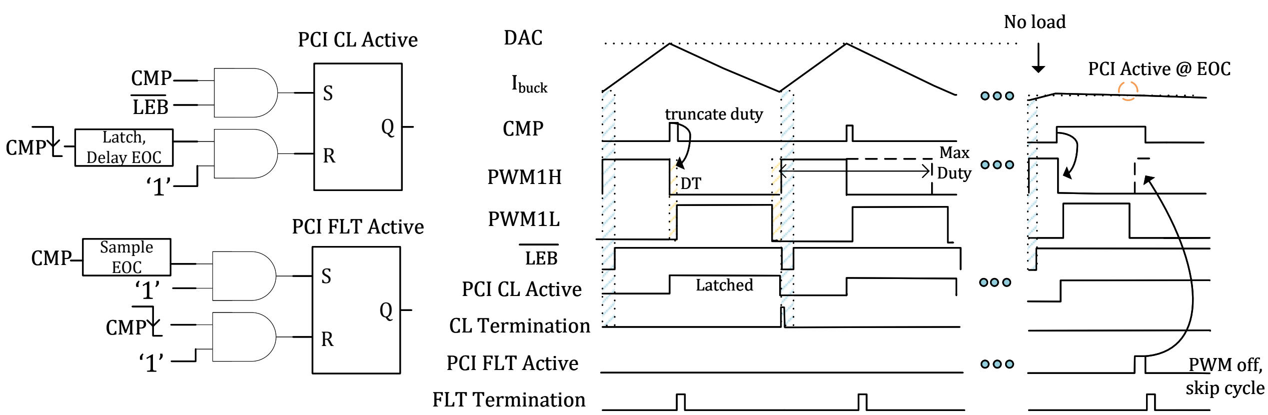
The buck converter PCI configuration includes a current limit PCI event that manages cycle-by-cycle control for CCM operation, but also adds a fault PCI event to override both PWM outputs to low when the buck current doesn't reset to zero within the same PWM period. The fault PCI event takes priority over the current-limit PCI.

The buck current limit PCI is configured just as in the boost converter, with reset-dominated latched-mode PCI with auto-termination. The only difference is the current limit data (0b01), which drives the low-side switch ON after truncating the on-time of the high-side switch. Dead time is automatically inserted between the falling edge of PWM1H and the rising edge of PWM1L.

The fault limit PCI is configured in Reset-Dominated Latched mode, but the fault limit will sample the PCI input (comparator output) at the end of the PWM cycle. If the PCI signal is active (with no qualifier), the fault limit PCI will be active and prevent the PWM from turning ON for the next switching cycle. The falling edge of the comparator will reset the flip-flop and disable the fault event.

Figure 8-3 shows the PCI configuration for the buck converter. Note that fault PCI has a higher priority then current limit PCI and prevents turn-on of both MOSFETs under a no-load condition. Also, the programmed duty cycle is set to around 80% of the period, but the actual on-time is controlled by the current limit.

**Figure 8-3.** Buck PCI Configuration



# 9. dsPIC33C Digital Power Starter Kit System Diagram

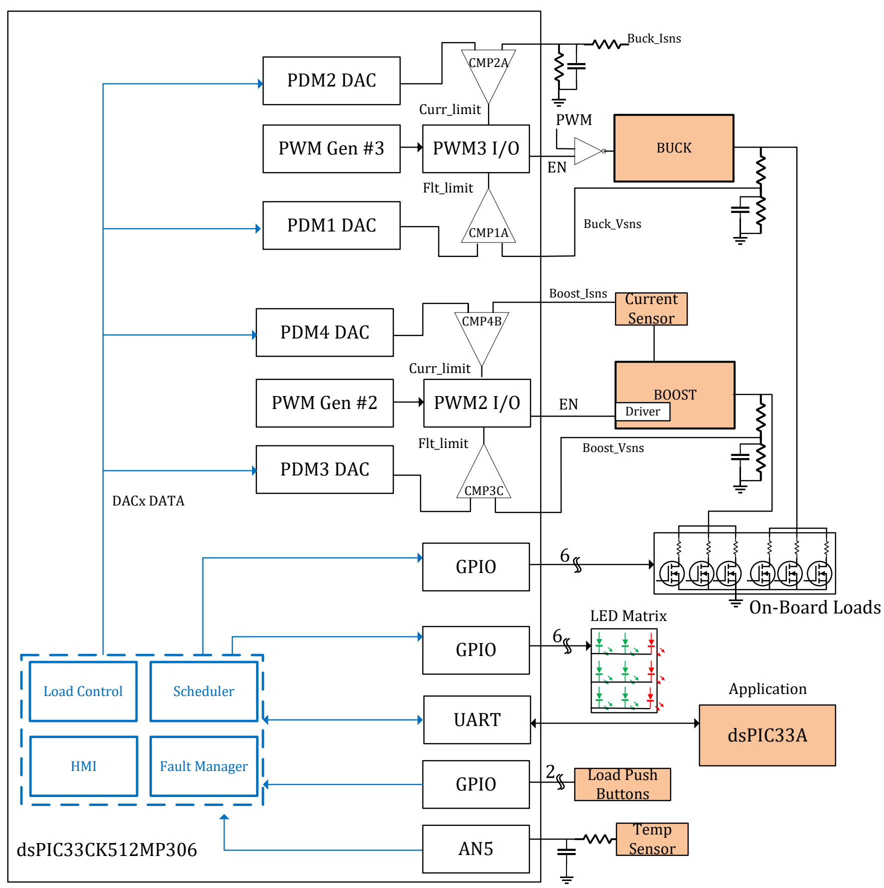
For load control and system protection, the Digital Power Starter Kit includes an auxiliary dsPIC33C microcontroller. The unique features of this device help reduce system costs by integrating protection features, load control, and communications into a single microcontroller.

There are four analog comparators, each with their own DAC reference. If any of the four monitored signals exceeds its respective DAC reference voltage, the comparator output becomes active. These comparator outputs are directly tied to the PWM current limit and fault limit PCI events, automatically latching the PWM signal “OFF”, which in turn shuts down the drive signals to the buck/boost converters.

A fault event is communicated via UART to the dsPIC33A controller to disable or reset the power controller state machine. After the fault signal is removed, a short one-second timer is initiated before removing the fault signal and allowing the application to resume power operations.

Figure 9-1 illustrates a high-level block diagram for the auxiliary microcontroller for system protection and load control.

**Figure 9-1.** dsPIC33C Digital Power Starter Kit System Diagram



# 10. Appendix A. Board Layout and Schematics

This appendix contains the board layouts and schematics for the dsPIC33A Digital Power Starter Kit.

## 10.1. Assembly Drawings

**Figure 10-1.** dsPIC33A Digital Power Starter Kit Layout (Top)

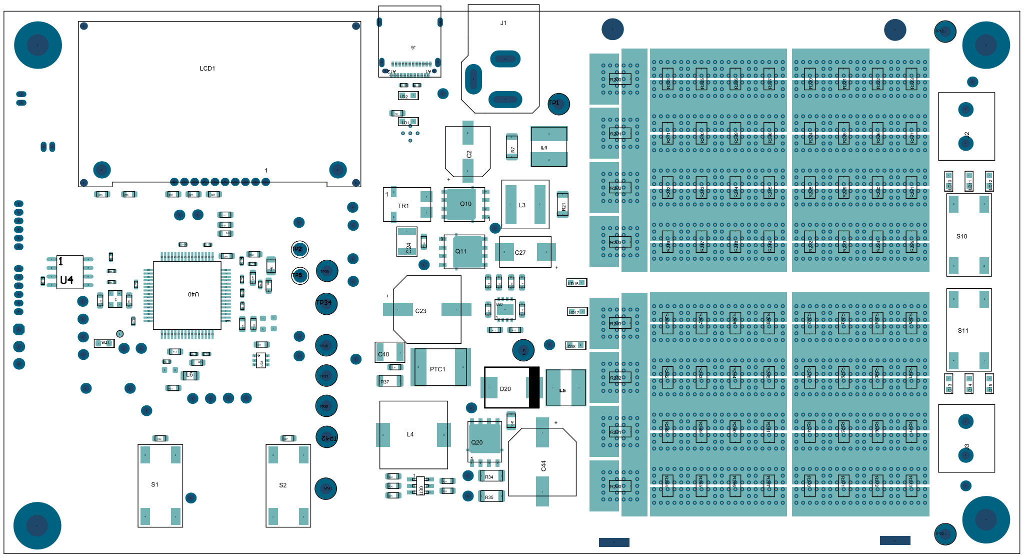
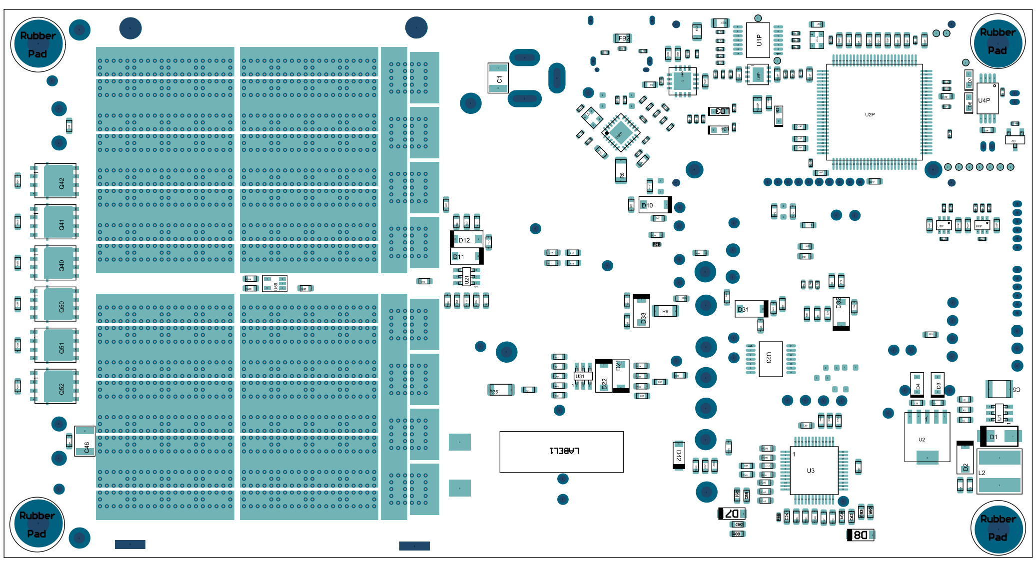


**Figure 10-2.** dsPIC33A Digital Power Starter Kit Layout (Bottom)



## 10.2. Schematics

**Figure 10-3.** Block Diagram

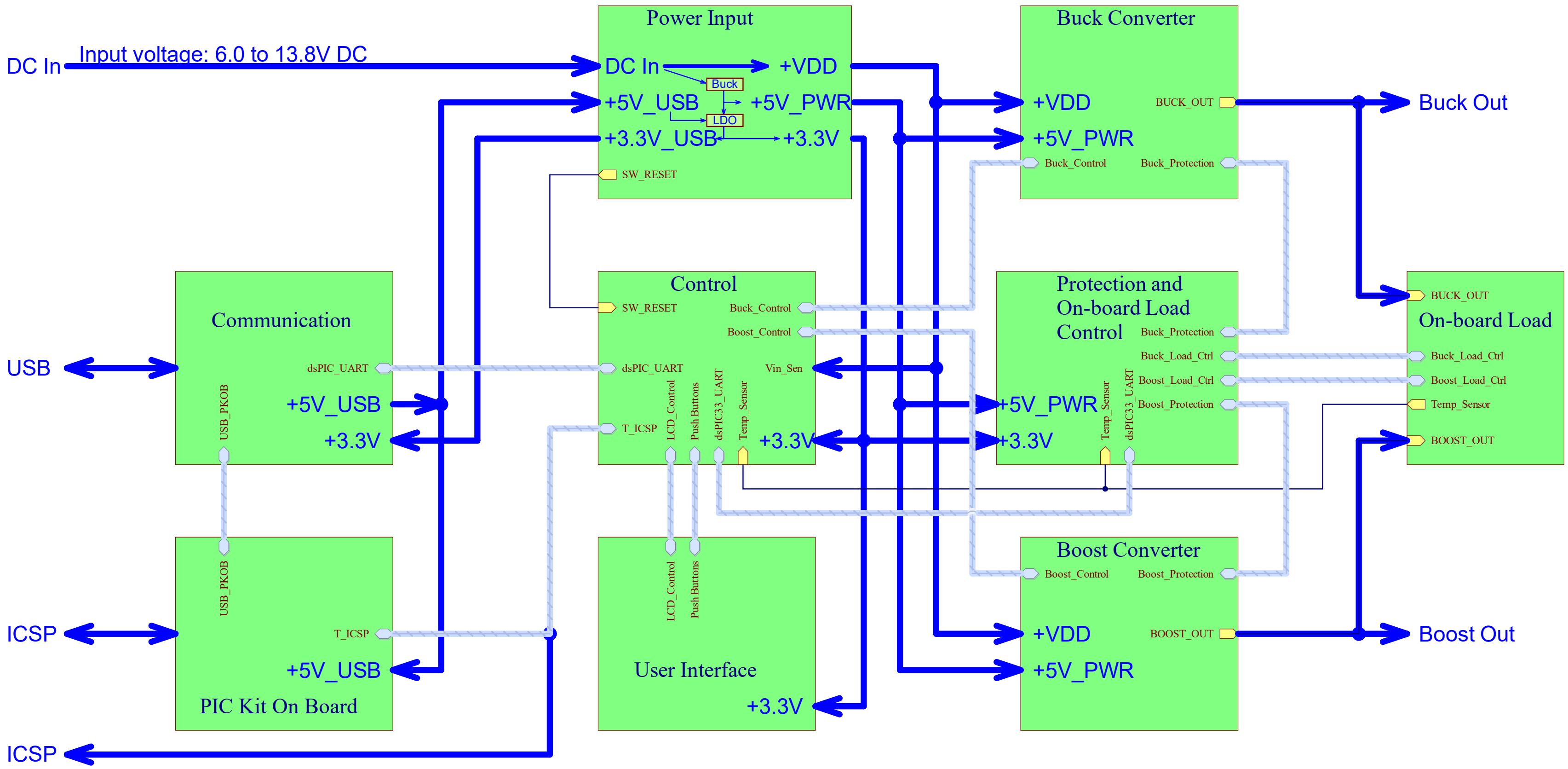


**Figure 10-4.** Power Input

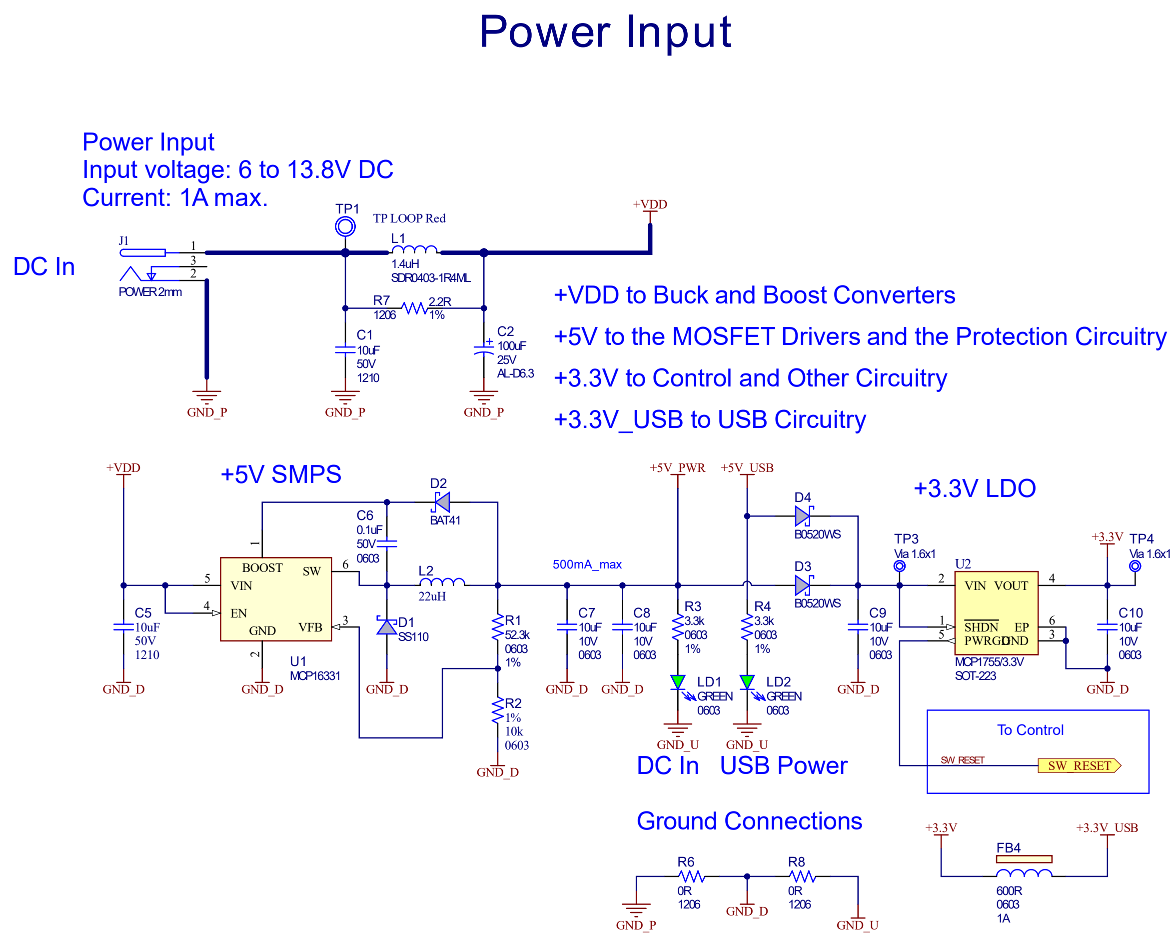


**Figure 10-5.** dsPIC33A DPSK Schematic - Buck Converter

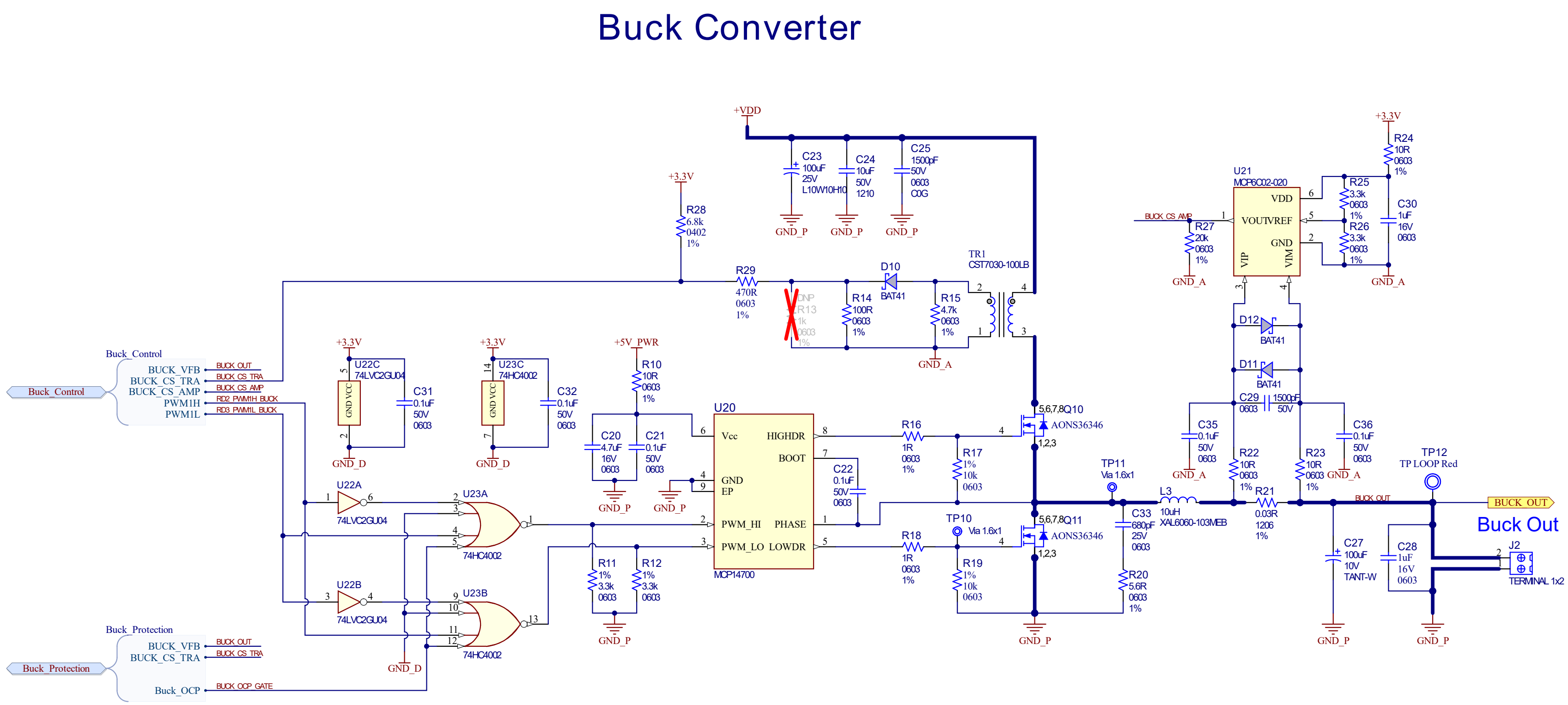


**Figure 10-6.** dsPIC33A DPSK Schematic - Boost Converter

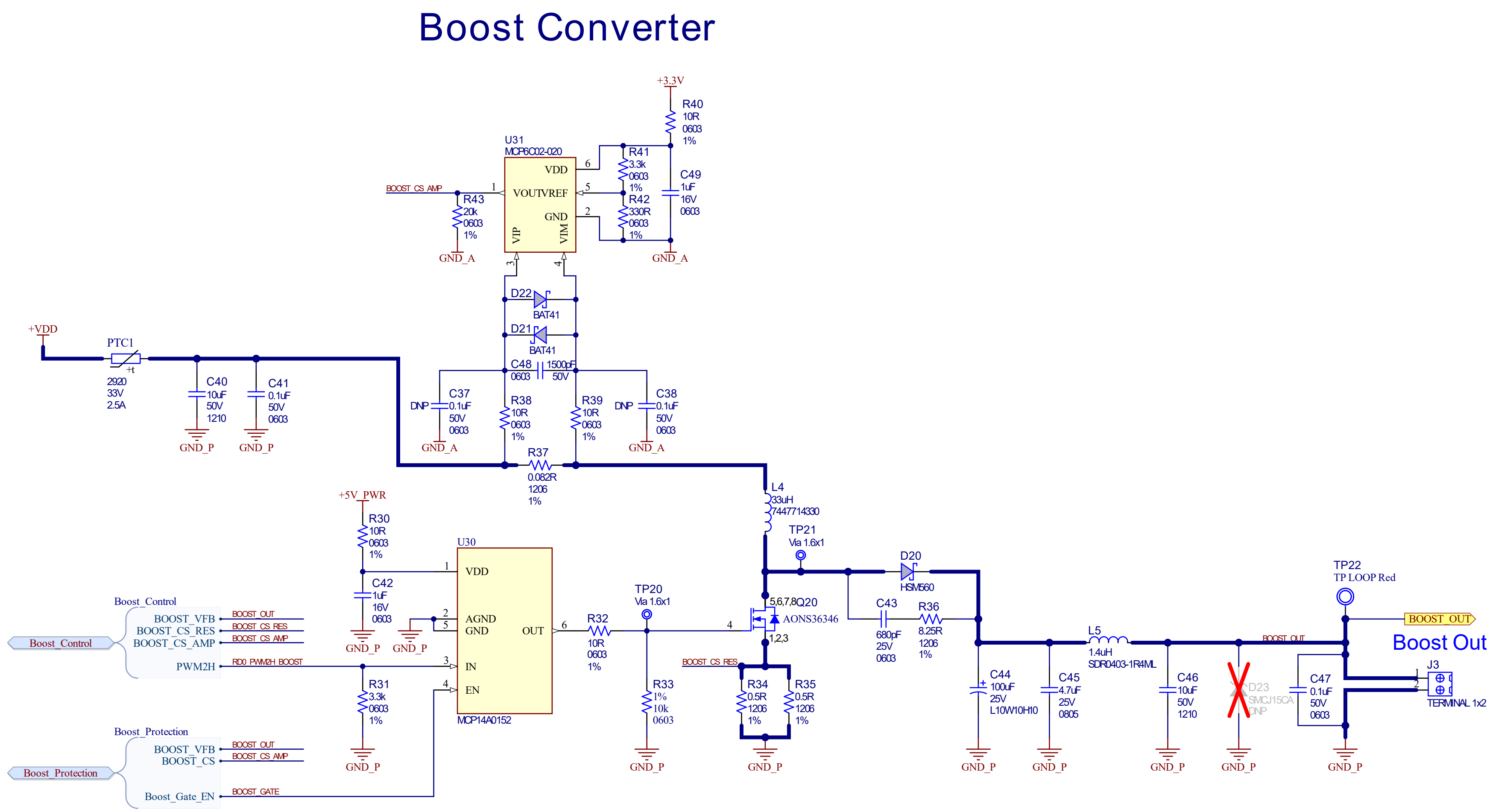


**Figure 10-7.** dsPIC33A DPSK Schematic - Control

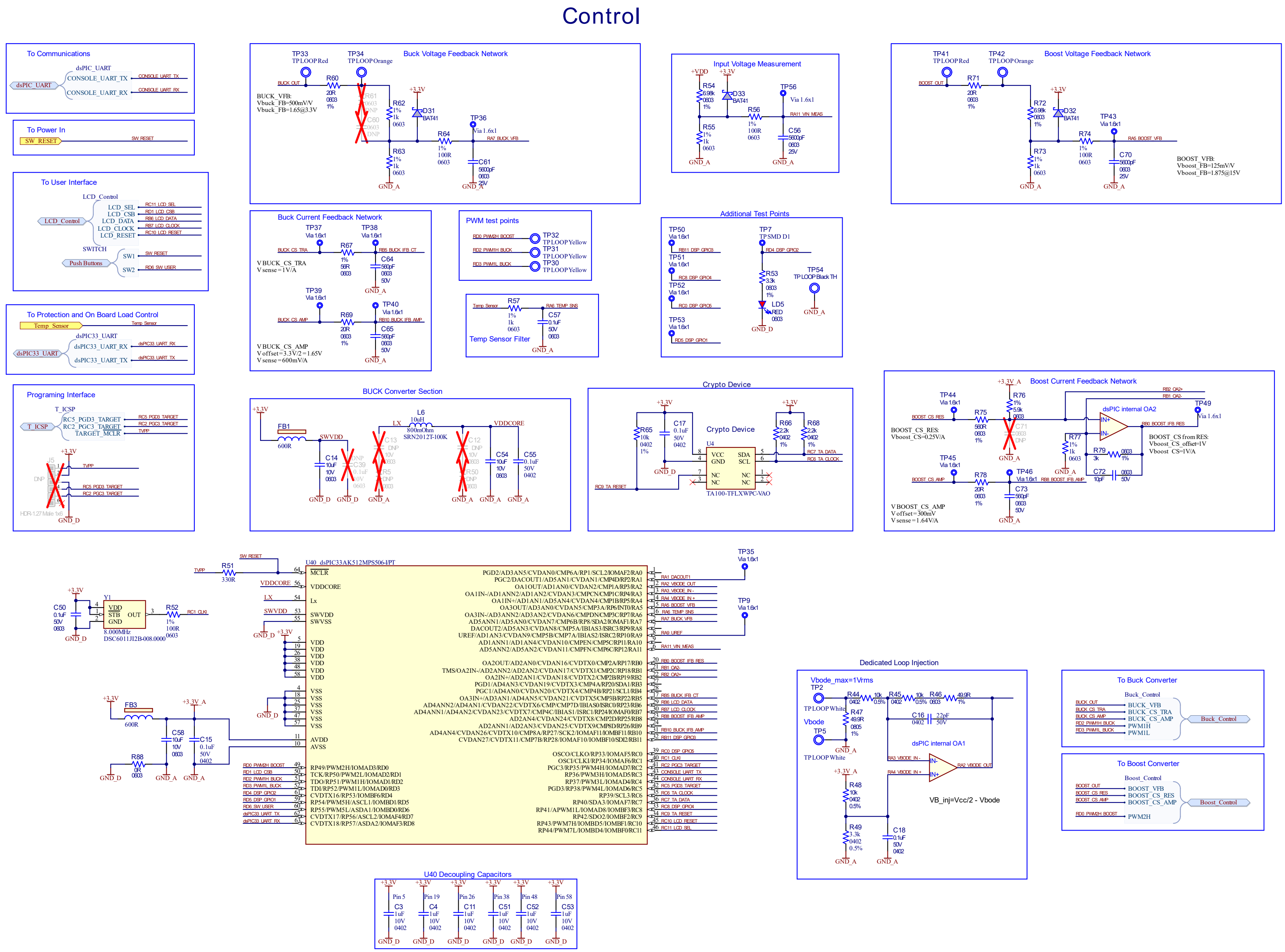


**Figure 10-8.** dsPIC33A DPSK Schematic - User Interface and LCD Control

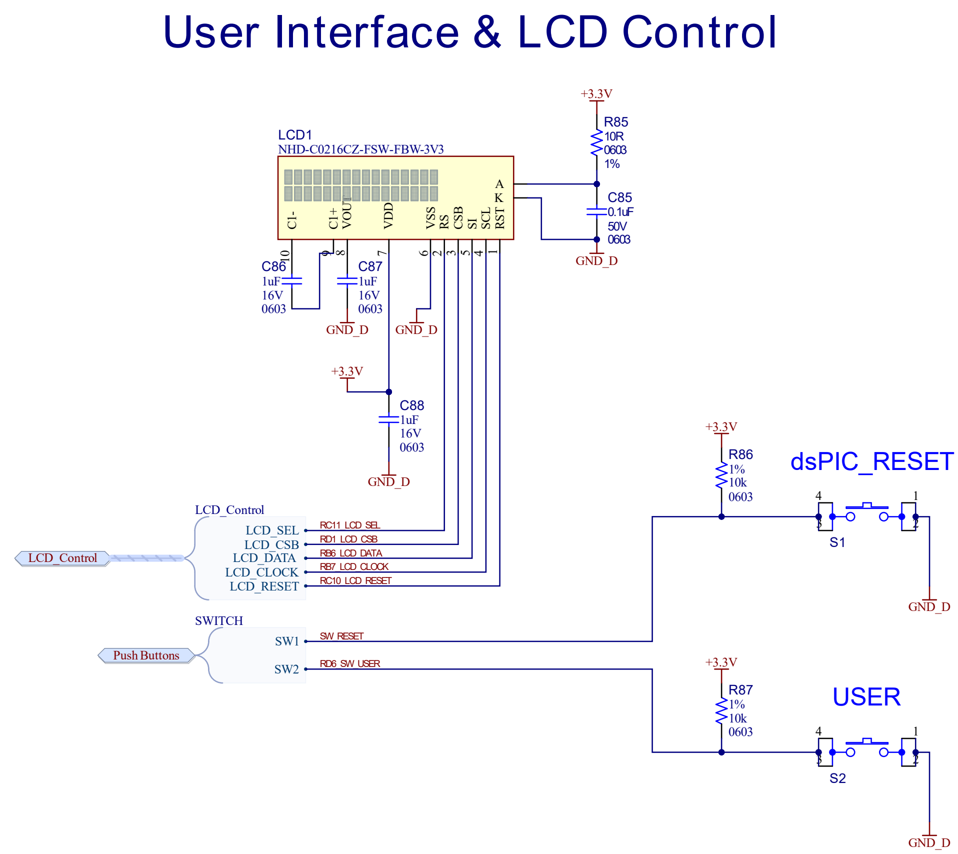


**Figure 10-9.** dsPIC33A DPSK Schematic - Protection and Load Control

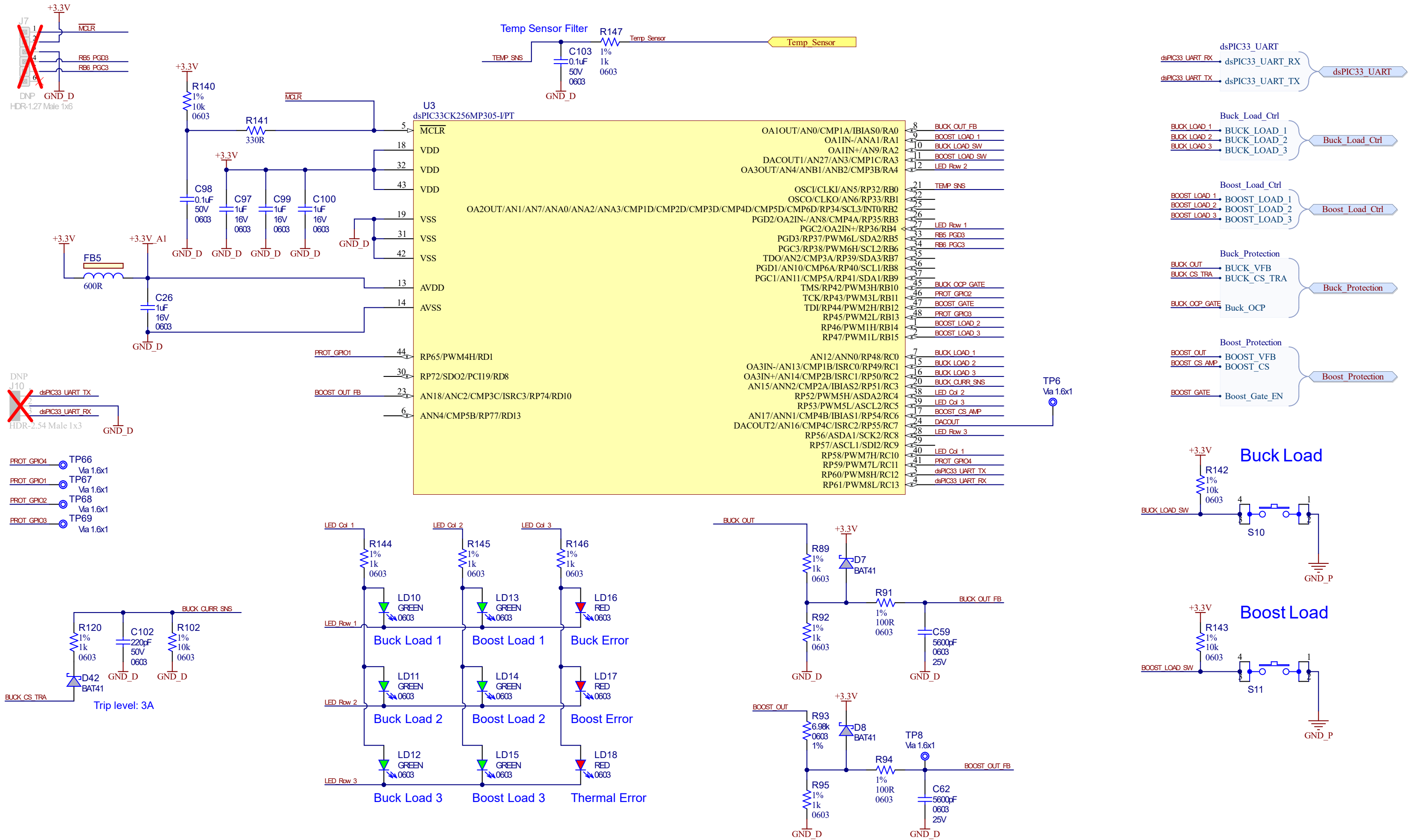


**Figure 10-10.** dsPIC33A DPSK Schematic - On-Board Load and Temperature Sensor

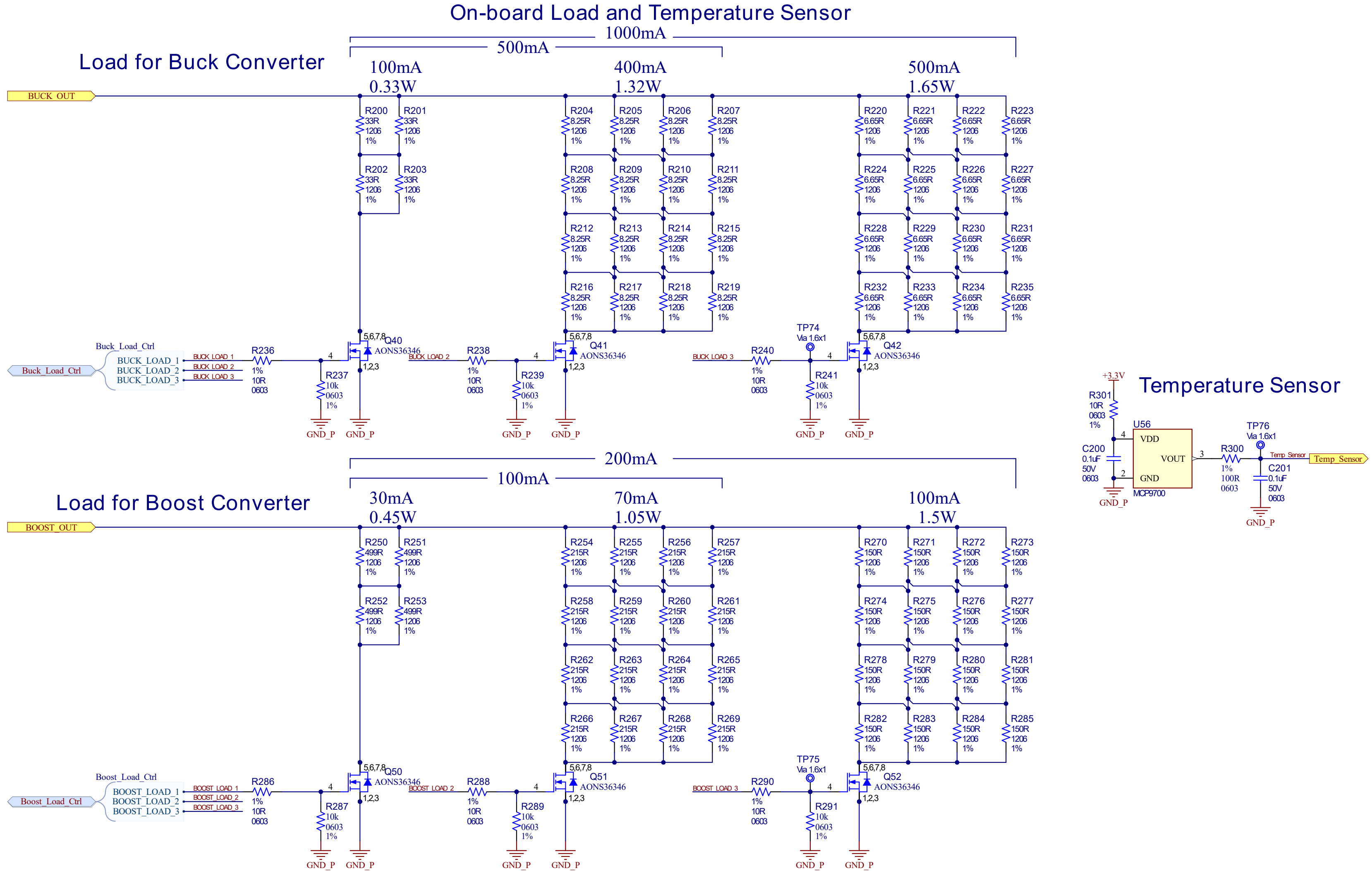
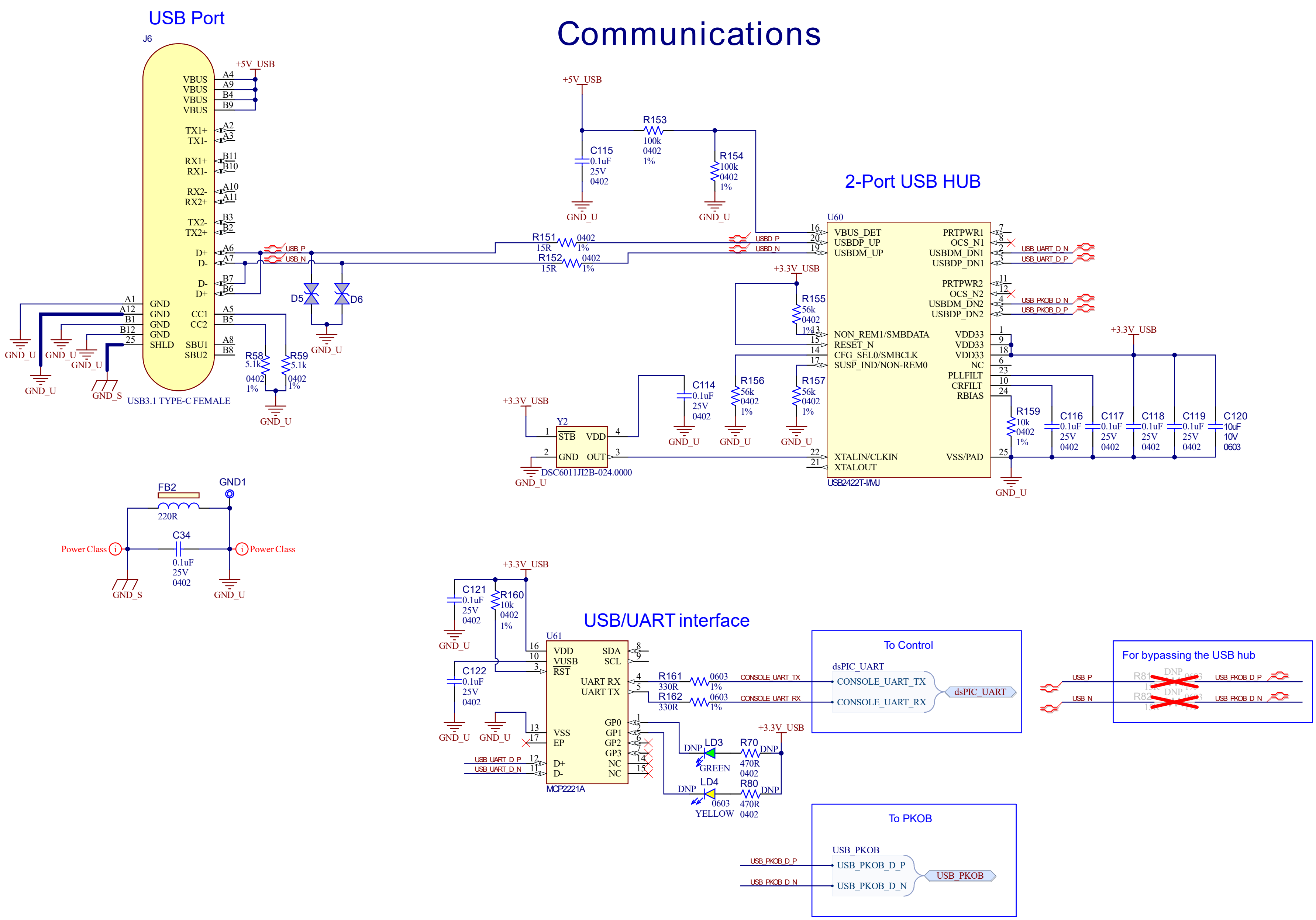


**Figure 10-11.** dsPIC33A DPSK Schematic - Communications



# 11. Appendix B. Bill of Materials

This appendix contains the Bill of Materials (BOM) for the dsPIC33A Digital Power Starter Kit.

## 11.1. Bill of Materials

The following table lists the Bill of Materials for the dsPIC33A Digital Power Starter Kit.

**Table 11-1.** dsPIC33A Digital Power Starter Kit Bill of Materials

| Designator | Description | Manufacturer | Manufacturer Part Number |
|---|---|---|---|
| C1, C5, C24, C40, C46 | CAP CER 10uF 50V 20% X7R SMD 1210 | TDK Corporation | C3225X7R1H106M250AC |
| C34, C114, C115, C116, C117, C118, C119, C121, C122 | CAP CER 0.1uF 25V 10% X7R SMD 0402 | TDK Corporation | C1005X7R1E104K050BB |
| C2 | CAP ALU 100uF 25V 20% SMD W6.6L6.6H7.7 | Wurth Elektronik | 865090445008 |
| C3, C4, C11, C51, C52, C53 | CAP CER 1uF 10V 10% X7S SMD 0402 | Murata Electronics® | GCM155C71A105KE38D |
| C6, C21, C22, C31, C32, C35, C36, C41, C47, C50, C57, C85, C98, C103, C200, C201 | CAP CER 0.1uF 50V 20% X7R SMD 0603 | TDK Corporation | C1608X7R1H104M |
| C7, C8, C9, C10, C14, C54, C58, C120 | CAP CER 10uF 10V 20% X5R SMD 0603 | Samsung Electro-Mechanics | CL10A106MP8NNNC |
| C20 | CAP CER 4.7uF 16V 10% X5R SMD 0603 | TDK Corporation | C1608X5R1C475K080AC |
| C15, C18, C55 | CAP CER 0.1uF 50V 10% X7R SMD 0402 | TDK Corporation | C1005X7R1H104K050BB |
| C16 | CAP HiQ 22pF 50V 5% NP0 1.95GHz SMD 0402 | Johanson Technology Inc. | 500R07S220JV4T |
| C17 | CAP CER 0.1uF 50V 10% X7R SMD 0402 AEC-Q200 | TDK Corporation | CGA2B3X7R1H104K050BB |
| C19 | CAP CER 47uF 10V 20% X5R 0805 | Taiyo Yuden | LMK212BBJ476MG-T |
| C23, C44 | CAP ALUM POLY 100UF 25V 20% SMD | Wurth Elektronik | 875075561005 |
| C25, C29, C48 | CAP CER 1500pF 50V 5% C0G SMD 0603 | Murata Electronics | GRM1885C1H152JA01D |
| C26, C28, C30, C42, C49, C86, C87, C88, C97, C99, C100 | CAP CER 1uF 16V 10% X5R SMD 0603 | Kyocera AVX | 0603YD105KAT2A |
| C27 | CAP TANT POLY 100uF 10V 20% 40mR SMD 2917 | KEMET | T520W107M010ATE040 |
| C33, C43 | CAP CER 680pF 25V 10% X7R 0603 | Wurth Elektronik | 885012206058 |
| C45 | CAP CER 4.7uF 25V 10% X5R SMD 0805 | Murata Electronics | GRM21BR61E475KA12L |
| C56, C59, C61, C62, C70 | CAP CER 5600pF 25V 5% C0G SMD 0603 | TDK Corporation | C1608C0G1E562J080AA |
| C64, C65, C73 | CAP CER 560pF 50V 5% C0G, NP0 SMD 0603 | KEMET | C0603C561J5GACTU |
| C72 | CAP CER 10pF 50V 0.5pF C0G SMD 0603 | TDK Corporation | C1608C0G1H100D |
| C102 | CAP CER 220pF 50V 5% NP0 SMD 0603 | KEMET | C0603C221J5GACTU |
| D1 | DIO SCTKY SS110 850mV 1A 100V DO-214AC_SMA | Micro Commercial Components | SS110-TP |

**Table 11-1.** dsPIC33A Digital Power Starter Kit Bill of Materials (continued)

| Designator | Description | Manufacturer | Manufacturer Part Number |
|---|---|---|---|
| D2, D7, D8, D10, D11, D12, D21, D22, D31, D32, D33, D42 | DIO SCTKY BAT41 1V 200mA 100V SOD-123 | STMicroelectronics | BAT41ZFILM |
| D3, D4 | DIO SCTKY B0520WS 430mV 500mA 20V SOD-323 | Diodes Incorporated® | B0520WS-7-F |
| D5, D6 | DIO TVS BIDIR PGB101 SMD 0402 | Littlefuse® Inc. | PGB1010402KR |
| D20 | DIO SCTKY HSM560JE3 650mV 5A 60V DO-214AB_SMC | Microchip Technology | HSM560JE3/TR13 |
| FB1, FB3, FB5 | FERRITE 600R@100MHz 0.23R 900mA SMD 0402 | Murata Electronics | BLM15PX601SN1D |
| FB2 | FERRITE 2A 220R SMD 0805 | Murata Electronics | BLM21PG221SN1D |
| FB4 | FERRITE 600R@100MHz 1A SMD 0603 | Bourns® Inc. | MH1608-601Y |
| J1 | CON POWER 2mm 5.5mm SWITCH TH R/A | Same Sky | PJ-002A |
| J2, J3 | CON TERMINAL 5mm 1x2 Female 12-26AWG 18A TH R/A | Phoenix Contact | 1935161 |
| J6 | CON USB3.1 TID TYPE-C Female SMD R/A | Amphenol Commercial Products | 12401610E4#2A |
| L1, L5 | INDUCTOR 1.4uH 3.3A 38mR SMD SDR0403 | Bourns Inc. | SDR0403-1R4ML |
| L2 | INDUCTOR 22uH 0.97A 20% SMD MSS6132 AEC-Q200 | Coilcraft | MSS6132T-223MLC |
| L3 | INDUCTOR 10uH 7A 20% SMD L6.56W6.36H6.1 | Coilcraft | XAL6060-103MEB |
| L4 | INDUCTOR 33uH 2.9A 20% SMD L10W10H5 | Wurth Elektronik | 7447714330 |
| L6 | Inductor 10uH 800 mOhms 560 mA 10% SMD 2mmx1.2mm | Bourns Inc. | SRN2012T-100K |
| LCD1 | LCD COG CHAR 2X16 WHT TRANSFL | Newhaven Display International | NHD-C0216CZ-FSW-FBW-3V3 |
| LD1, LD2, LD6, LD7, LD10, LD11, LD12, LD13, LD14, LD15 | DIO LED GREEN 2V 30mA 35mcd Clear SMD 0603 | Lite-On® Inc. | LTST-C190KGKT |
| LD5, LD16, LD17, LD18 | DIO LED RED 1.8V 40mA 10mcd Clear SMD 0603 | Lite-On Inc. | LTST-C190KRKT |
| LD8 | DIO LED YELLOW 2.1V 20mA 6mcd Clear SMD 0603 | Lite-On Inc. | LTST-C190YKT |
| PTC1 | RES FUSE RESETTABLE 1.25A 2.5A 33V PTC SMD 2920 | Littlefuse Inc. | SMDC125F/33-2 |
| Q2 | TRANS FET N-CH 2N7002NXBKR 60V 270mA 2.8R 0.4W SOT23-3 | Nexperia | 2N7002NXBKR |
| Q10, Q11, Q20, Q40, Q41, Q42, Q50, Q51, Q52 | AONS36346 MOSFET N-CH DFN 5X6 | Alpha & Omega Semiconductor Inc. | AONS36346 |
| R1 | RES TKF 52.3k 1% 1/10W SMD 0603 | Panasonic® - ECG | ERJ-3EKF5232 |
| R65, R84, R159, R160 | RES TKF 10k 1% 1/10W SMD 0402 | Panasonic - ECG | ERJ-2RKF1002X |
| R2, R17, R19, R33, R86, R87, R102, R140, R142, R143, R237, R239, R241, R287, R289, R291 | RES TKF 10k 1% 1/10W SMD 0603 | Vishay® Intertechnology, Inc. | CRCW060310K0FKEA |

**Table 11-1.** dsPIC33A Digital Power Starter Kit Bill of Materials (continued)

| Designator | Description | Manufacturer | Manufacturer Part Number |
|---|---|---|---|
| R3, R4, R11, R12, R25, R26, R31, R41, R53 | RES TKF 3.3k 1% 1/10W SMD 0603 | Panasonic - ECG | ERJ-3EKF3301V |
| R6, R8 | RES TKF 0R SMD 1206 | Yageo Corporation | RC1206JR-070RL |
| R7 | RES TKF 2.2R 1% 1/4W SMD 1206 | Yageo Corporation | RC1206FR-072R2L |
| R9, R153, R154 | RES TKF 100k 1% 1/10W SMD 0402 AEC-Q200 | Panasonic - ECG | ERJ-2RKF1003X |
| R10, R22, R23, R24, R30, R32, R38, R39, R40, R85, R236, R238, R240, R286, R288, R290, R301 | RES TKF 10R 1% 1/10W SMD 0603 | Stackpole Electronics Inc. | RMCF0603FT10R0 |
| R14, R52, R56, R64, R74, R91, R94, R300 | RES TKF 100R 1% 1/10W SMD 0603 | Panasonic - ECG | ERJ-3EKF1000V |
| R15 | RES TKF 4.7k 1% 1/10W SMD 0603 | Vishay Intertechnology, Inc. | CRCW06034K70FKEA |
| R16, R18 | RES TKF 1R 1% 1/10W SMD 0603 | Yageo Corporation | RC0603FR-071RL |
| R20 | RES TKF 5.6R 1/10W 1% SMD 0603 | Vishay Intertechnology, Inc. | CRCW06035R60FKEA |
| R21 | RES MS 0.03R 1% 1W SMD 1206 | Vishay Intertechnology, Inc. | WSLP1206R0300FEA |
| R27, R43 | RES TKF 20k 1% 1/10W SMD 0603 | Panasonic - ECG | ERJ-3EKF2002V |
| R28 | RES TKF 6.8K 1% 1/10W SMD 0402 AEC-Q200 | Panasonic - ECG | ERJ-2RKF6801X |
| R29 | RES TKF 470R 1% 1/10W SMD 0603 | Panasonic - ECG | ERJ-3EKF4700V |
| R34, R35 | RES TKF 0.5R 1% 1/2W SMD 1206 | Stackpole Electronics Inc. | CSR1206FKR500 |
| R36, R204, R205, R206, R207, R208, R209, R210, R211, R212, R213, R214, R215, R216, R217, R218, R219 | RES TKF 8.25R 1% 1/4W SMD 1206 | Vishay Intertechnology, Inc. | CRCW12068R25FKEA |
| R37 | RES MFO 0.082R 1% 3/4W SMD 1206 | SUSUMU® Co., Ltd. | KRL1632E-M-R082-F-T5 |
| R42, R51, R141, R161, R162 | RES TKF 330R 1% 1/10W SMD 0603 | Panasonic - ECG | ERJ-3EKF3300V |
| R44, R45, R48 | RES TF 10k 0.5% 1/16W SMD 0402 | SUSUMU Co., Ltd. | RR0510P-103-D |
| R46 | RES TKF 49.9R 1% 1/10W SMD 0603 | Panasonic - ECG | ERJ-3EKF49R9V |
| R47 | RES TKF 49.9R 1% 1/8W SMD 0805 | Panasonic - ECG | ERJ-6ENF49R9V |
| R49 | RES TKF 3.3k 0.5% 1/16W SMD 0402 | Panasonic - ECG | ERA-2AED332X |
| R54, R72, R93 | RES TKF 6.98K 1% 1/10W SMD 0603 AEC-Q200 | Panasonic - ECG | ERJ-3EKF6981V |
| R55, R57, R62, R63, R73, R77, R89, R92, R95, R120, R144, R145, R146, R147 | RES TKF 1k 1% 1/10W SMD 0603 | Panasonic - ECG | ERJ-3EKF1001V |
| R58, R59 | RES TKF 5.1k 1% 1/10W SMD 0402 | Panasonic - ECG | ERJ-2RKF5101X |

**Table 11-1.** dsPIC33A Digital Power Starter Kit Bill of Materials (continued)

| Designator | Description | Manufacturer | Manufacturer Part Number |
|---|---|---|---|
| R60, R69, R71, R78 | RES TKF 20R 1% 1/10W SMD 0603 | Panasonic - ECG | ERJ-3EKF20R0V |
| R66, R68 | RES TKF 2.2k 1% 1/10W SMD 0402 | Panasonic - ECG | ERJ-2RKF2201X |
| R67 | RES TKF 56R 1% 1/10W SMD 0603 | Panasonic - ECG | ERJ-3EKF56R0V |
| R75 | RES TKF 560R 1% 1/10W SMD 0603 | Yageo Corporation | RC0603FR-07560RL |
| R76 | RES TKF 5.9k 1% 1/10W SMD 0603 | Panasonic - ECG | ERJ-3EKF5901V |
| R79 | RES TKF 3k 1% 1/10W SMD 0603 | Panasonic - ECG | ERJ-3EKF3001V |
| R88 | RES TKF 0R 1/10W SMD 0603 | NIC Components Corp. | NRC06Z0TRF |
| R83 | RES TF 2.2k 1% 1/10W SMD 0603 AEC-Q200 | TE Connectivity | CRGCQ0603F2K2 |
| R151, R152 | RES TKF 15R 1% 1/10W SMD 0402 | Panasonic - ECG | ERJ-2RKF15R0X |
| R155, R156, R157 | RES TKF 56k 1% 1/16W SMD 0402 | ROHM Semiconductor | MCR01MZPF5602 |
| R200, R201, R202, R203 | RES TKF 33R 1% 1/4W SMD 1206 AEC-Q200 | Panasonic - ECG | ERJ-8ENF33R0V |
| R220, R221, R222, R223, R224, R225, R226, R227, R228, R229, R230, R231, R232, R233, R234, R235 | RES TKF 6.65R 1% 1/4W SMD 1206 | Yageo Corporation | RC1206FR-076R65L |
| R250, R251, R252, R253 | RES TKF 499R 1% 1/4W SMD 1206 AEC-Q200 | Panasonic - ECG | ERJ-8ENF4990V |
| R254, R255, R256, R257, R258, R259, R260, R261, R262, R263, R264, R265, R266, R267, R268, R269 | RES TKF 215R 1% 1/4W SMD 1206 AEC-Q200 | Panasonic - ECG | ERJ-8ENF2150V |
| R270, R271, R272, R273, R274, R275, R276, R277, R278, R279, R280, R281, R282, R283, R284, R285 | RES TKF 150R 1% 1/4W SMD 1206 AEC-Q200 | Panasonic - ECG | ERJ-8ENF1500V |
| S1, S2, S10, S11 | SWITCH TACT SPST 12V 50mA TL3301AF160QG SMD | E-Switch®, Inc. | TL3301AF160QG |
| TP1, TP12, TP22, TP33, TP41 | CON TP LOOP Red TH | Keystone Electronics®, Corp. | 5010 |
| TP2, TP5 | MISC, TEST POINT MULTI PURPOSE MINI WHITE | Keystone Electronics, Corp. | 5002 |
| TP30, TP31, TP32 | CON TP LOOP Yellow TH | Keystone Electronics, Corp. | 5014 |
| TP34, TP42 | CON TP LOOP Orange TH | Keystone Electronics, Corp. | 5013 |
| TP54 | CON TP LOOP Black TH | Keystone Electronics, Corp. | 5011 |
| TR1 | TRANS CURRENT 1:100 1MHz 20A SMD | Coilcraft | CST7030-100LB |
| U21, U31 | MCHP ANALOG CUR MEASURE MCP6C02-020 SOT-23-6 | Microchip Technology | MCP6C02-020 |
| U22 | IC LOGIC INV 2CH 74LVC2G04 SOT-363 | Nexperia | 74LVC2GU04GW,125 |
| U23 | IC LOGIC NOR 4IN 2CH 74HC4002 TSSOP-14 | Nexperia | 74HC4002PW,118 |

**Table 11-1.** dsPIC33A Digital Power Starter Kit Bill of Materials (continued)

| Designator | Description | Manufacturer | Manufacturer Part Number |
|---|---|---|---|
| U1 | MCHP ANALOG SWITCHER Buck 2 to 24V MCP16331T-E/CH SOT-23-6 | Microchip Technology | MCP16331T-E/CH |
| U2 | MCHP ANALOG LDO 3.3V MCP1755T-3302E/DC SOT-223-5 | Microchip Technology | MCP1755T-3302E/DC |
| U3 | MCHP MCU16-BIT 100MIPS 256k 64k dsPIC33CK256MP305-I/PT TQFP-48 | Microchip Technology | dsPIC33CK256MP305-I/PT |
| U4 | CryptoAutomotive™ TA100 SOIC-8 | Microchip Technology | TA100-TFLXWPC-VAO |
| U20 | MCHP ANALOG FET DRIVER Single-Non-Inverting MCP14700-E/MF | Microchip Technology | MCP14700-E/MF |
| U30 | MCHP ANALOG FET DRIVER Single-Non-Inverting MCP14A0152 6L SOT-23 | Microchip Technology | MCP14A0152T-E/CH |
| U40 | MCHP MCU 32-BIT 100MIPS 512k 64k dsPIC33AK512MPS506-I/PT TQFP-64 | Microchip Technology | dsPIC33AK512MPS506-I/PT |
| U56 | MCHP ANALOG TEMPERATURE SENSOR -40C to +150C MCP9700T-E/LT SC-70-5 | Microchip Technology | MCP9700T-E/LT |
| U60 | MCHP INTERFACE USB 2.0 HS 2 PORT HUB CTRLR QFN-24 | Microchip Technology | USB2422T-I/MJ |
| U61 | MCHP INTERFACE USB I2C/ UART MCP2221A-I/ML QFN-16 | Microchip Technology | MCP2221A-I/ML |
| Y1 | MCHP CLOCK OSCILLATOR SINGLE 8.000MHz DSC6011JI2B-008.0000 VDFN-4 | Microchip Technology | DSC6011JI2B-008.0000 |
| Y2 | MCHP OSC MEMS DSC6011JI2B-024.0000_2.5LX 2.0WX0.89H_LGA | Microchip Technology | DSC6011JI2B-024.0000 |

# 12. Appendix C. Program Operation

The dsPIC33A device is preprogrammed with closed-loop Peak Current Mode Control (PkCMC) application software that simultaneously regulates the output voltages of the two DC-DC converters while performing auxiliary tasks such as LCD writes, inter-processor communication, input voltage monitoring/protection and general service tasks (pushbuttons, LEDs, etc.).

This appendix highlights the building blocks of the PkCMC controller and the general code architecture used in the peak current mode application. This is intended to be informative and is not a comprehensive overview. For additional code examples supported by the hardware, search for DPSK4 on MPLAB Discover.

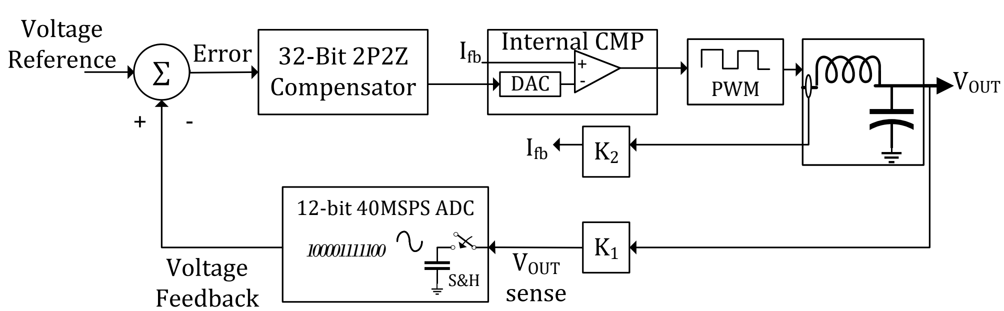
## 12.1. Closed-Loop Program Demonstration

Closed-loop control is performed by sampling the output voltage via the 12-bit 40MSPS Analog-to-Digital converter (ADC), calculating the error, and passing it into a 32-bit 2P2Z digital IIR compensator filter, which in turn sets the control output (a 12-bit DAC reference that sets the peak current threshold for the internal analog comparator). The cycle-by-cycle peak current limit truncates the on-time of the PWM module that drives the plant (buck/boost converter power stages). The high-level block diagram for PkCMC is shown in Figure 12-1.

The 2P2Z control scheme consists of the following parameters:

- Reference – desired digital set point for the output voltage
- Error – calculation of (Reference – Feedback). This is the value the compensator acts upon.
- System Plant – buck/boost converter being controlled
- Control Output – output voltage
- Feedback – measured output signal level

**Figure 12-1.** Peak Current Mode Control Loop Block Diagram

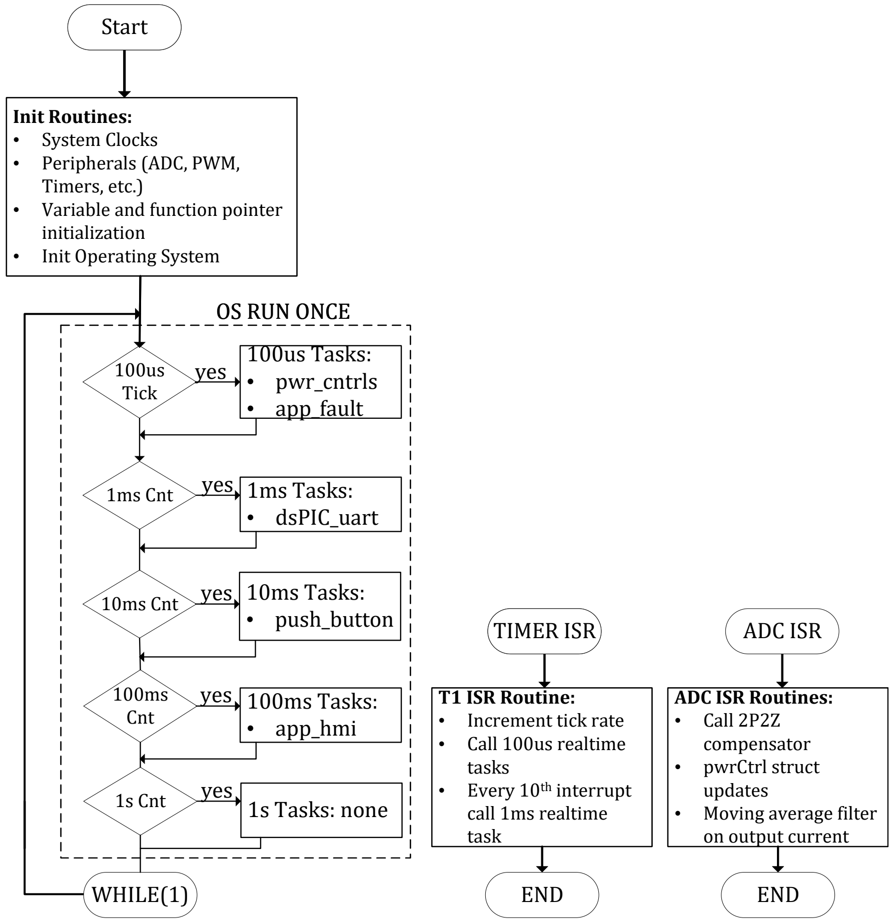



## 12.2. Code Architecture

A simple task scheduler-type operating system with 100us tick resolution is used to execute the periodic functions required for the application. Only soft-timed tasks (not interrupt-driven) are used for the application, with the exception that the 2P2Z controllers are executed in the ADC interrupts. The OS includes standard 1ms, 10ms, 100ms, and 1s task handlers. Many core modules include internal state machines, such as the power controllers and HMI components. These state machines may have their own initialization blocks that are not included in the system initialization.

See the program flow chart shown in Figure 12-2 for a breakdown of application tasks and the general program architecture.

**Figure 12-2.** FW Architecture and Flow Chart




### 12.2.1. System Initialization

When power is applied to the board, the program starts by configuring various system clocks and performing a clock switch to the external clock with the PLL executing at 200MHz. From here, power and communication peripherals are initialized (ADC, PWM, UART, CMP, etc.), global variables and function pointers are initialized (e.g., the controller structure) and finally, the operating scheduler is configured.

### 12.2.2. Fault Check

The program checks for any faults that might have occurred during program operation. The input voltage fault check is performed in the 100us task, while other faults are dispersed throughout the application. The faults include:

- Input Overvoltage/Undervoltage
- Buck/Boost Converter Overtemperature
- Buck/Boost Soft Start

If any of the listed faults occur, the corresponding fault will be shown on the LCD display. The corresponding PWM signals and loads are disabled until the fault condition has been cleared.

### 12.2.3. Timer ISR

A timer module is configured to interrupt the system every 100us. This is the tick rate resolution for the scheduler. A static counter is incremented and used to determine when to call OS tasks.

In this ISR, two real-time task rates can be called (100us and 1ms), although they are not used in this application. These should only be used for functions that must be called with limited jitter, but care should be taken not to overload the 100us task.

### 12.2.4. Task Handler

A task handler is used to call application functions at specific rates. The power controller and application fault handler are critical components and are required to be called at a high execution rate (i.e., 100us task), whereas communication can occur at a much slower, millisecond task rate. The task handler includes 100us, 1ms, 10ms, 100ms and 1s task handlers, as well as a background function. This application does not require code components to be called in the 1s and background tasks.

### 12.2.5. ADC ISR

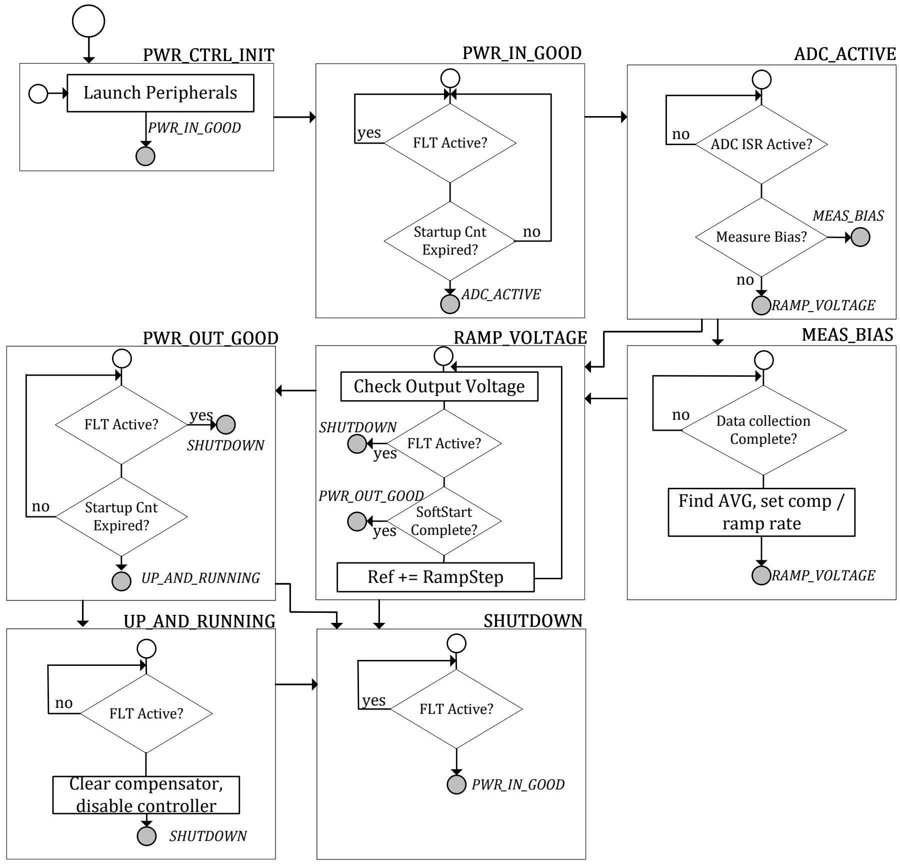
Each power stage utilizes an ADC interrupt to execute the power controller. The interrupts are triggered by the PWM converter every 4us and are out of phase with each other. Due to the very high execution rate, the 2P2Z controller is optimized in assembly and consumes only ~10% of the CPU utilization.

### 12.2.6. Power Controller State Machine

The power controller state machine consists of several different states to ensure the system is properly configured and starts up in the correct manner. Both the buck converter and the boost converter execute this state machine. The main difference is in the measure bias state, where the boost converter ramp rate starts from the measured output voltage (i.e. input voltage).

In the ramp voltage state, the compensator reference is increased until the desired output voltage setpoint is reached. With each step, new output voltage protections are set, and the output voltage measurement is checked to ensure that the soft start occurs as intended. See Figure 12-3 for more information on code execution for each state.

**Figure 12-3.** Power Controller State Machine



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