TI Designs

Level 1 and Level 2 Electric Vehicle Service Equipment (EVSE) Reference Design

Design Overview

This verified TI Design provides an overview on how to implement J1772-compliant level 1 and level 2 electric vehicle service equipment (EVSE). The design showcases safe failure modes using TI's peripheral drivers along with integrated fault checking. The design has a configurable power delivery control and implements self-metering to ensure maximum power delivery to the electric vehicle (EV). The design also includes a highly accurate energy meter for dollar-per-kWh based billing models.

Design Resources

TIDA-00637	Tool Folder Containing Design Files
OPA171	Product Folder
UCC28910	Product Folder
TPS62063	Product Folder
LM7322	Product Folder
TPL7407L	Product Folder
MSP430F6736	Product Folder

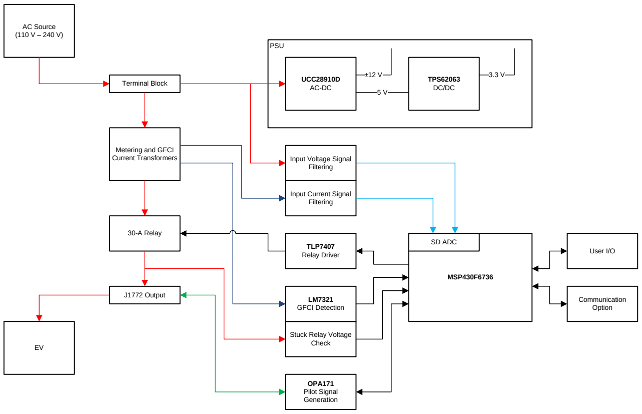
ASK Our E2E Experts

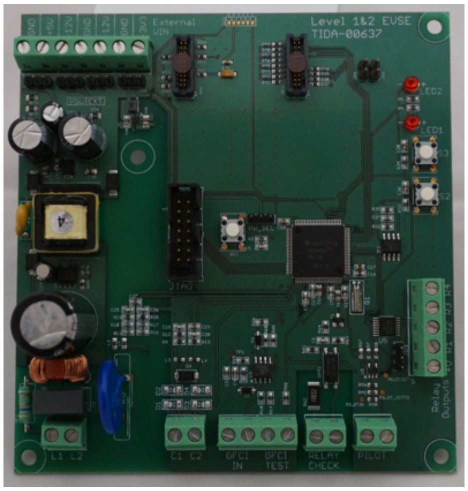
Design Features

- Full Implementation of J1772-Compliant Service Equipment
- High Current Relay Drivers for Support of High Current Contactors
- Standardized Pilot Wire Signaling Protocol
- Integrated Utility Meter Grade Energy Measurement
- GFCI Fault Detection and Protection
- Option for Communication Daughter Card Add-in

Featured Applications

- Level 1 and Level 2 Electric Vehicle Service Equipment (EVSE)





An IMPORTANT NOTICE at the end of this TI reference design addresses authorized use, intellectual property matters and other important disclaimers and information.

Copyright © 2016, Texas Instruments Incorporated

1 System Description

Electric vehicles have been around for over a century, but have had limited market success until recently. Modern advances in battery technology drive efficiency and market forces have accelerated the demand and deployment rates of electric vehicles that can compete with traditional internal combustion vehicles. Many vehicle owners now have a requirement of plugging and unplugging a very high power device to their home electricity system on a regular basis.

Traditional international combustion vehicles also benefit from a broad network of gas stations for rapid energy delivery to the vehicle and range extension. While the technology is improving, electric vehicles still suffer from slow energy delivery rates, which require vehicles to be stationary for long periods of time to recharge. The slow energy delivery systems behind electric vehicles also highlight the shortcomings of the gas station model.

The slow rate of charging is the result of using low battery charge currents to avoid damage (a problem that is constantly being improved), as well as the energy capacity of the local grid connection. Adding a high power connection can create issues in regards to safety and reliability. Public charge stations are able to tap into much higher current connections available in commercial buildings; however, these stations must be able to charge all varieties of electric vehicles (EVs) on the road to be resourceful.

Such problems are being mitigated through Electric Vehicle Service Equipment (EVSE), which controls the power flow into an electric vehicle. Many vehicle manufacturers have adopted the J1772 SAE standard for AC electrical connections to a vehicle. The same specifications also translate into international localizations, with only differing form factors.

The standard design of EV charging systems on the market at the time of this writing have the AC-DC converter for the battery charge system integrated into the vehicle, so only AC power is required. External DC-DC and charge circuitry is enabled on some vehicles, but this configuration is outside the scope of this design. To facilitate the power delivery to the vehicle, the EVSE sits between a stable grid connection and the vehicle, as Figure 1 shows.

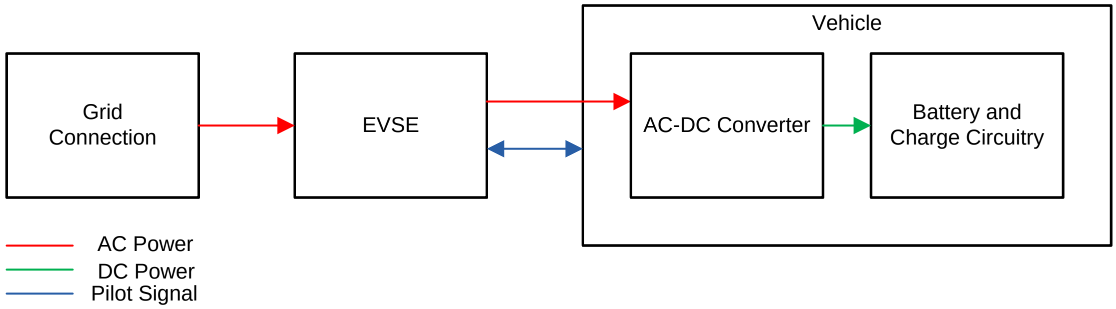


Figure 1. EVSE Position in Power Flow

The core of the EVSE operation for AC power delivery) is communication with the vehicle over a single-line pilot wire. This EVSE operation is based on level 1 and level 2 devices, for which Table 1 describes the differences. This single-line pilot wire enables negotiation with the vehicle for power status, available power, and charge state. In addition, the EVSE must be able to control AC power delivery to the plug itself (up to 240-V AC and 80 A in some cases) to necessitate robust relay or contactor driving. Additional functionality is often included such as ground-fault circuit interrupter (GFCI) protection and energy measurement.

Table 1. Level 1 and Level 2 Charging Standards

LEVEL	DEFINITION	ENERGY RATING
Level 1	Alternating current energy to the onboard charger of the vehicle; from the most common U.S. grounded household receptacle, commonly referred to as a 120-V outlet.	120-V AC; 16 A (= 1.92 kW)
Level 2	Alternating current energy to the onboard charger of the vehicle; 208 V to 240-V, single phase. The maximum current specified is 32 A (continuous) with a branch circuit breaker rated at 40 A.	208- to 240-V AC; 12 A to 80 A (= 2.5 kW to 19.2 kW)

Copyright © 2016, Texas Instruments Incorporated

This implementation of an EVSE contains a basic set of features, which are expandable to enable additional usage scenarios. The primary functionality includes:

- Level 1 and level 2 operation (120 V to 240 V)
- Power delivery up to 30 A (expandable with larger relays)
- Pilot signal wire communication support
- GFCI monitoring
- Latched relay detection
- Energy metering

1.1 Microcontroller Selection

Texas Instrument's (TI) MSP430™ family of microcontrollers (MCUs) offers a wide range of devices that can be used to fulfill the requirements of an EVSE. The MSP430F6736 microcontroller has been specifically chosen for this application because of its integrated delta sigma (Δ∑) converters, which can be leveraged to integrate power metrology. In addition, the device features a powerful 16-bit reduced instruction set computing (RISC) CPU, 16-bit registers, and constant generators that contribute to maximum code efficiency. The MSP430F6736 has a highly accurate timer module which can be used to generate the specific pulse width modulation (PWM) and duty cycles required of the pilot wire carrier generation, a successive approximation register (SAR) analog-to-digital converter (ADC) to read the response of the vehicle on the pilot wire, an interruptible general purpose input/output (GPIO) pin for rapid response to GFCI events, and several universal serial communication interface (USCI) modules to enable feature-rich communication in the future. For designs that only require a subset of these features, these MCUs also provide a simple, code-compatible path to devices with reduced flash, RAM, and feature sets.

Figure 2 shows a functional block diagram of the MPS430F673x.

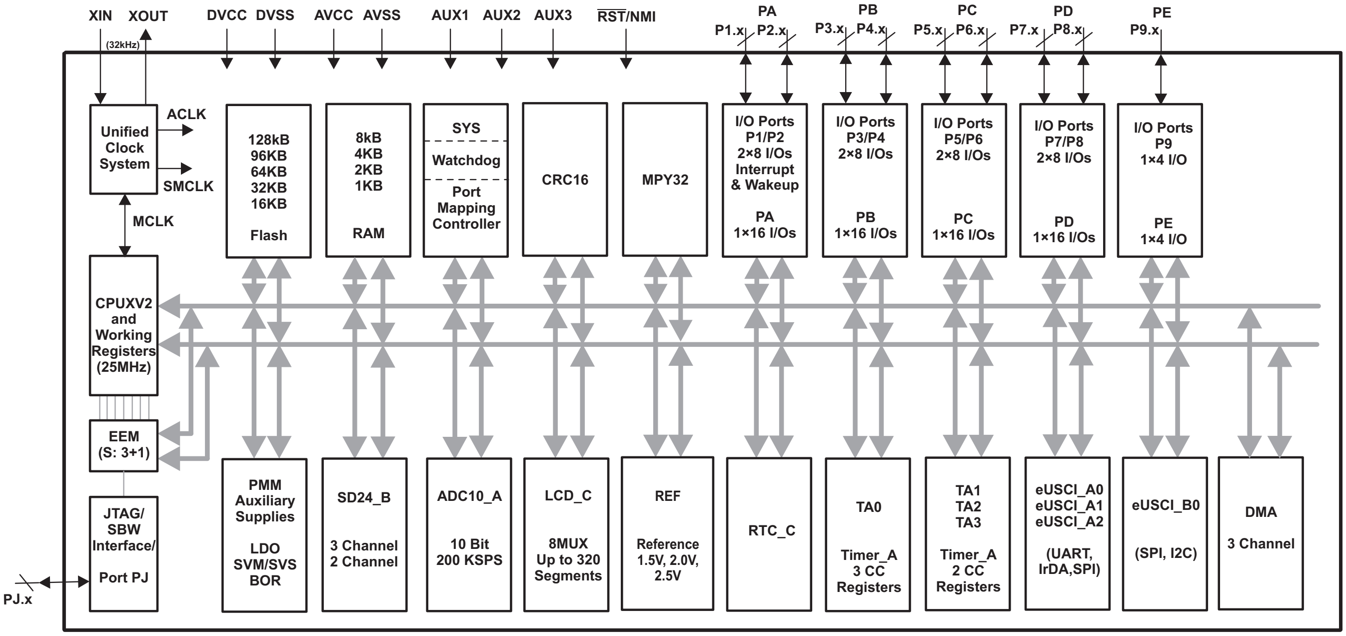


Figure 2. Functional Block Diagram, MSP430F673x

Copyright © 2016, Texas Instruments Incorporated

1.2 Power Management

A J1772 compliant EVSE (detailed further in Section 4.1) requires a ±12-V DC power supply, in addition to the power required for normal system ICs, such as the MCU. To simplify this design to focus on more application specific functionality, a preexisting design from the TI PowerLab™ reference design library was chosen. An AC-DC design with ±12-V outputs was chosen for simplicity, with the additional outputs providing a bonus for the rest of the application. The PMP10299 device fit all of the core requirements. The device is based around the UCC28910 PSR controller, has ±12- and 5-V outputs, and has been designed with automotive quality in mind.

The extra 5-V rail can be used to power the MCU and other ICs on the board, as well as potentially drive relays. Having 12- and 5-V outputs allows for a wide range of relay selection, which Section 4.3 covers in further detail.

A TPS62063 buck converter is used to bring the 5-V rail down to the 3.3 V required by most of the design. This converter has an input range of 2.7 V to 6 V, which makes it ideal for bringing down a pre-regulated 5-V rail to a system voltage of 3.3 V.

1.3 Pilot Signal Interface

The pilot signal interface, which Section 3 covers in further detail, requires a 1-kHz, ±12-V PWM signal to be transmitted down the length of the charger cable to the vehicle. The duty cycle communicates the power capability of the EVSE to the vehicle. The EV returns its current state by placing a load on the line, which causes a voltage drop. To facilitate this, the design requires an amplifier with a wide dual-rail voltage input and sufficient drive strength to facilitate the various line impedances. This design has selected the OPA171 amplifier based on its input range characteristics (up to ±18 V) and ability to handle various line impedance changes, even non-resistive changes in the event of cable parasitics.

1.4 GFCI Fault Detection

GFCI faults occur when the current flows through a path other than the primary conductors, usually as a result of a grounding fault. By passing both conductors through a ring-type current transformer, the net current measured normally equals zero. The current transformer (CT) must be rated for the full ampacity of the line in the event of massive current instability, but must be sensitive to even a small amount of leakage. The burden resistor on the transformer has a voltage correlated to the measured current, so a GFCI event would have a very low differential voltage, but potentially experience rapid increases.

The standard method of measuring current is to use a one-second window of measurement in an electricity metering (e-meter) solution, on which the EVSE-core MCU in Section 1.1 is based. This is too slow of a response rate for proper GFCI fault detection. A specific GFCI detection circuit has been built, which triggers an interruptible pin on the MCU during an event. The design requires a rapid transmission to VCC with minimal input voltage. A simple inverting integrator architecture with the LM7322 accomplishes this transmission and a second stage is used to ensure a solid rail voltage for the MCU to detect.

Copyright © 2016, Texas Instruments Incorporated

2 Block Diagram

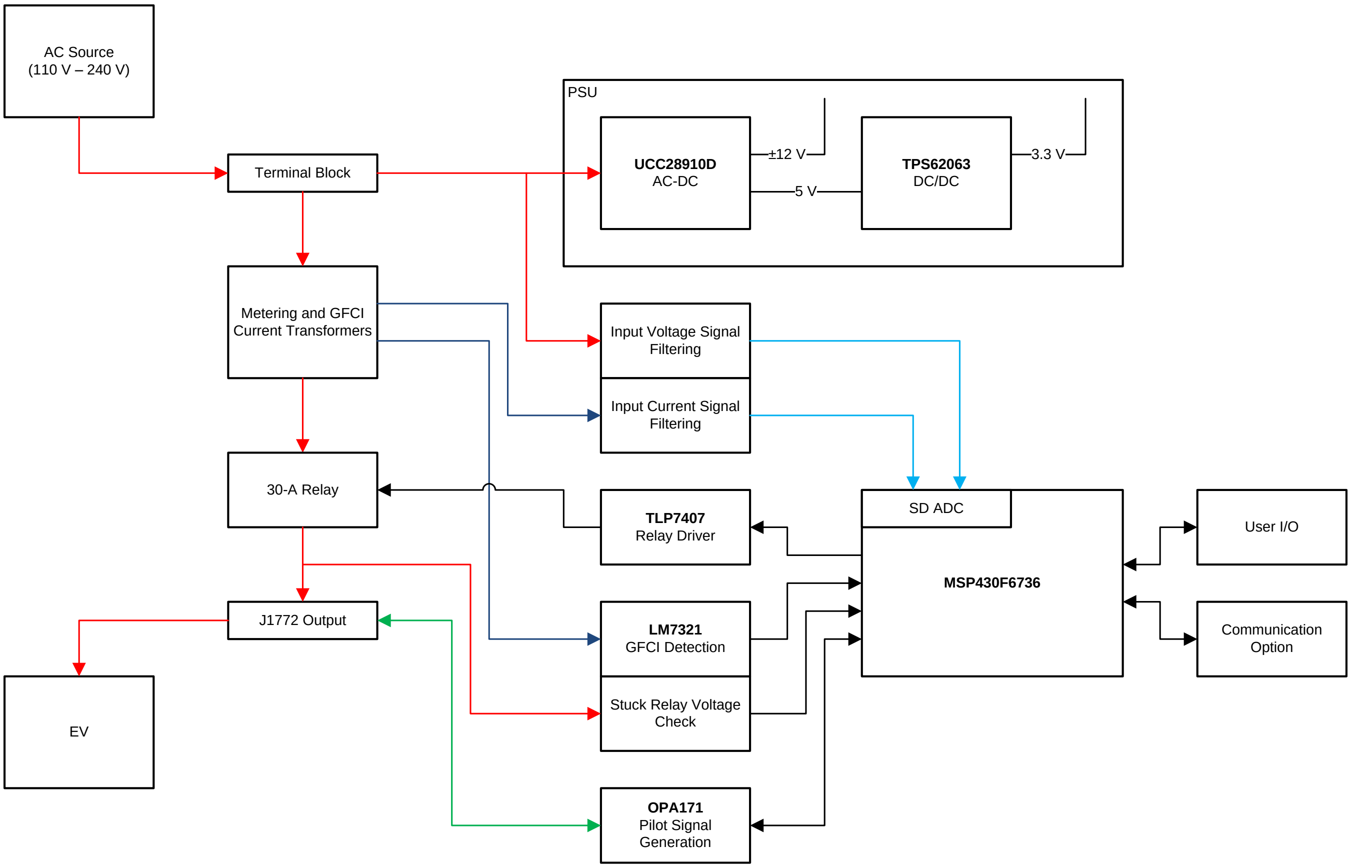


Figure 3. TIDA-006637 Block Diagram

Copyright © 2016, Texas Instruments Incorporated

3 Highlighted Products

The TIDA-00637 reference design features the following devices:

- MSP430F6736: Mixed-signal microcontroller (MCU)
- UCC28910D: 700-V flyback switcher with a constant-voltage constant-current and primary-side control
- TPS62063: 3-MHz, 1.6-A step-down converter
- OPA171: 36-V, low-power, rail-to-rail output (RRO), general purpose operational amplifier (op amp)
- LM7322: High output current and unlimited cap load ±15-V op amp
- TPL7407: 40-V, 7-channel NMOS array, low-side driver

For more information on each of these devices, see the respective product folders at www.ti.com.

3.1 MSP430F6736

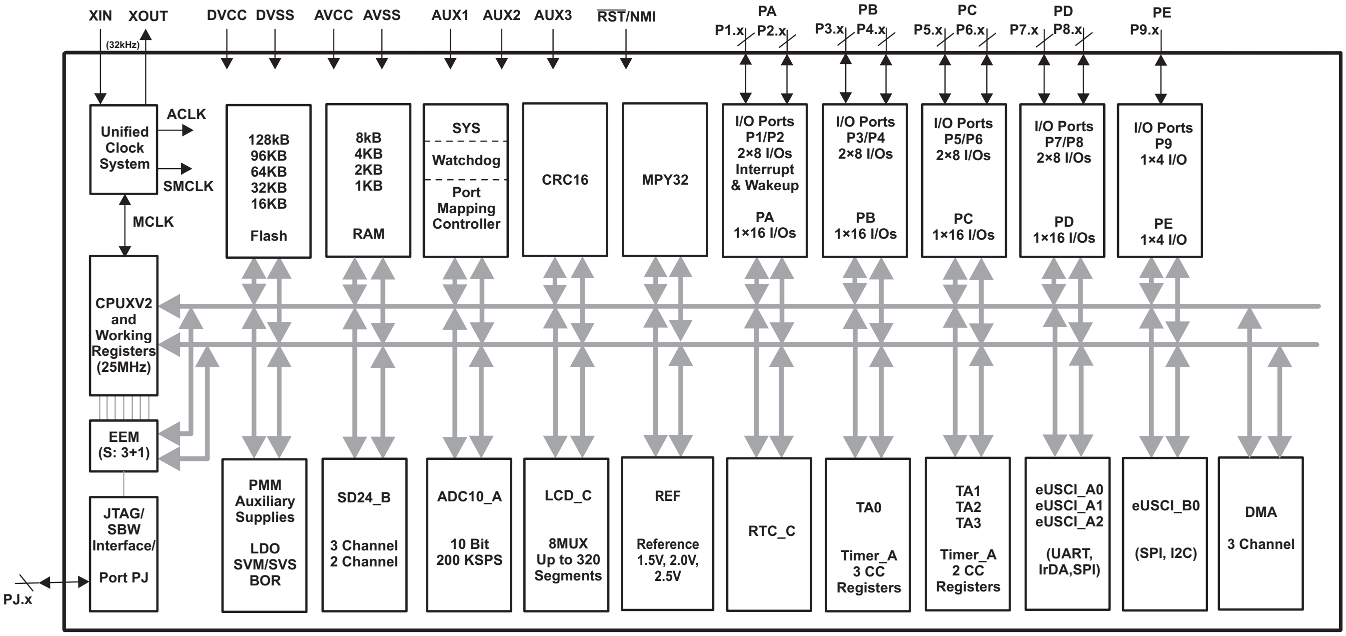


Figure 4. MSP430F6736 Functional Diagram

- Low supply voltage range: 3.6 V down to 1.8 V
- Ultralow power consumption
  - Active mode (AM):
    All system clocks active
    265 µA/MHz at 8 MHz, 3.0 V, flash program execution (typical)
    140 µA/MHz at 8 MHz, 3.0 V, RAM program execution (typical)
  - Standby mode (LPM3):
    Real-time clock with crystal, watchdog, and supply supervisor operational, full RAM retention, fast wake-up:
    1.7 µA at 2.2 V, 2.5 µA at 3.0 V (typical)
  - Off mode (LPM4):
    Full RAM retention, supply supervisor operational, fast wake-up:
    1.6 µA at 3.0 V (typical)
  - Shutdown RTC mode (LPM3.5):
    Shutdown mode, active real-time clock (RTC) with crystal:
    1.24 µA at 3.0 V (typical)
  - Shutdown mode (LPM4.5):
    78 µA at 3.0 V (typical)

Copyright © 2016, Texas Instruments Incorporated

- Wake-up from standby mode in 3 µs (typical)
- 16-bit RISC architecture, extended memory, up to 25-MHz system clock
- Flexible power management system
  - Fully integrated LDO with programmable regulated core supply voltage
  - Supply voltage supervision, monitoring, and brownout
  - System operation from up to two auxiliary power supplies
- Unified clock system
  - Frequency-locked loop (FLL) control loop for frequency stabilization
  - Low-power low-frequency internal clock source (VLO)
  - Low-frequency trimmed internal reference source (REFO)
  - 32-kHz crystals (XT1)
- One 16-bit timer with three capture and compare registers
- Three 16-bit timers with two capture and compare registers each
- Enhanced universal serial communication interfaces
  - eUSCI_A0, eUSCI_A1, and eUSCI_A2: enhanced universal asynchronous receiver/transmitter (UART) supports auto-baudrate detection, IrDA encoder and decoder, synchronous SPI
  - eUSCI_B0: I^2C with multi-slave addressing, synchronous SPI
- Password-protected RTC with crystal offset calibration and temperature compensation
- Separate voltage supply for backup subsystem
  - 32-kHz low-frequency oscillator (XT1)
  - Real-time clock
  - Backup memory (4 bits x 16 bits)
- Three 24-bit $\Delta\sum$ ADCs with differential PGA inputs
- Integrated liquid-crystal display (LCD) driver with contrast control for up to 320 segments in 8-mux mode
- Hardware multiplier supports 32-bit operations
- 10-bit 200-kSPS A-D converter
  - Internal reference
  - Sample-and-hold, auto-scan feature
  - Up to six external channels, two internal channels, including temperature sensor
- Three-channel internal DMA
- Serial onboard programming, no external programming voltage required
- Available in 100-pin and 80-pin LQFP packages

Copyright © 2016, Texas Instruments Incorporated

3.2 UCC28910D

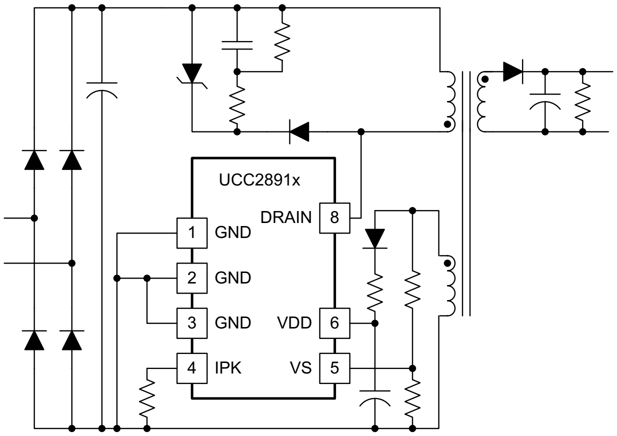


Figure 5. UCC28910D Simplified Schematic

- Constant-voltage (CV) and constant-current (CC) output regulation without optical-coupler
- ±5% output voltage regulation accuracy
- ±5% output current regulation with AC line and primary inductance tolerance compensation
- 700-V start-up and smart power management enables < 30-mW standby power
- 115-kHz maximum switching frequency design for high-power density
- Valley switching and frequency dithering to ease electromagnetic interference (EMI) compliance
- Thermal shut down
- Low line and output overvoltage protection

3.3 TPS62063

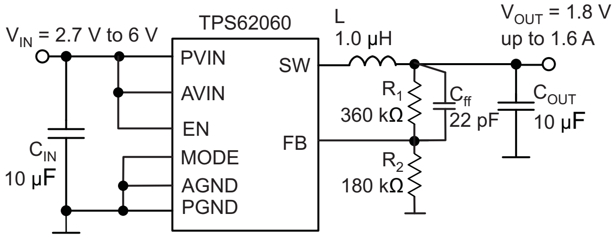


Figure 6. TPS62063 Typical Schematic

- 3-MHz switching frequency
- V_{IN} range from 2.7 V to 6 V
- 1.6-A output current
- Up to 97% efficiency
- Power save mode and 3-MHz fixed PWM mode
- Output voltage accuracy in PWM mode ±1.5%
- Output discharge function
- Typical 18-µA quiescent current
- 100% duty cycle for lowest dropout
- Voltage positioning
- Clock dithering
- Supports maximum 1-mm height solutions
- Available in a 2 mm × 2 mm × 0.75 mm WSON

Copyright © 2016, Texas Instruments Incorporated

3.4 OPA171

- Supply range: 2.7 V to 36 V, ±1.35 V to ±18 V
- Low noise: 14 nV/√Hz
- Low offset drift: ±0.3 µV/°C (typical)
- RFI filtered inputs
- Input range includes the negative supply
- Input range operates to positive supply
- Rail-to-rail output (RRO)
- Gain bandwidth: 3 MHz
- Low quiescent current: 475 µA per amplifier
- High common-mode rejection: 120 dB (typical)
- Low-input bias current: 8 pA

3.5 LM7322

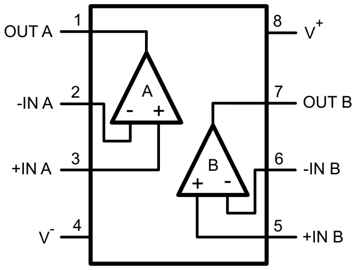


Figure 7. LM7322 Package Layout

- (V_S = ±15, T_A = 25°C, typical values unless specified)
- Wide supply voltage range 2.5 V to 32 V
- Output current +65 mA or –100 mA
- Gain bandwidth product 20 MHz
- Slew rate 18 V/µs
- Capacitive load tolerance unlimited
- Input common-mode voltage 0.3 V beyond rails
- Input voltage noise 15 nV/√Hz
- Input current noise 1.3 pA/√Hz
- Supply current and channel 1.1 mA
- Distortion THD+Noise –86 dB
- Temperature range –40°C to 125°C
- Tested at –40°C, 25°C and 125°C at 2.7 V, ±5 V, and ±15 V
- LM732xx are automotive grade products that are AEC-Q100 grade 1 qualified

Copyright © 2016, Texas Instruments Incorporated

3.6 TPL7407

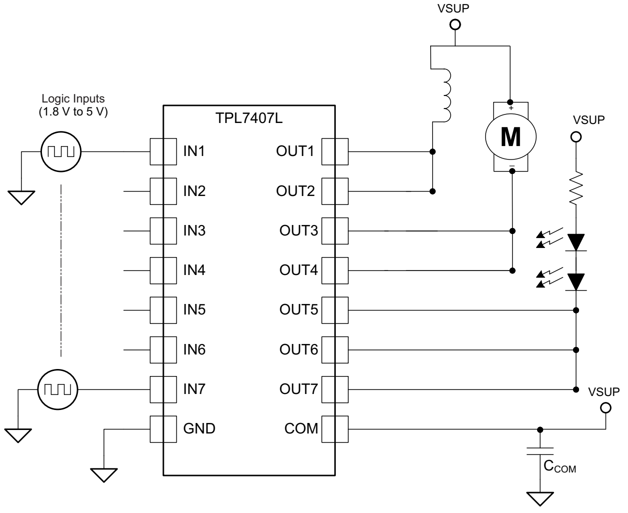


Figure 8. TPL7404 Sample Application Schematic

- 600-mA rated drain current (per channel)
- CMOS pin-to-pin improvement of 7-channel Darlington array (for example, ULN2003A)
- Power efficient (very low V_{OL})
  - Less than four times lower V_{OL} at 100 mA than Darlington array
- Very low output leakage < 10 nA per channel
- Extended ambient temperature range: T_A = –40°C to 125°C
- High-voltage outputs 40 V
- Compatible with 1.8- to 5.0-V MCUs and logic interface
- Internal free-wheeling diodes for inductive kick-back protection
- Input pulldown resistors allows tri-stating the input driver
- Input RC-snubber to eliminate spurious operation in noisy environments
- Inductive load driver applications
- Electrostatic discharge (ESD) protection exceeds JESD 22
  - 2-kV HBM, 500-V CDM

Copyright © 2016, Texas Instruments Incorporated

4 System Design Theory

4.1 Pilot Signal Interface

The pilot signal is the key method in which a J1772 compliant EVSE communicates with a vehicle. The pilot signal is based on a 1-kHz, ±12-V PWM signal that is transmitted to a vehicle over the charge chord. The vehicle can then respond by placing various loads on the line, affecting its voltage, which the EVSE measures.

4.1.1 J1772 Duty Cycle

The duty cycle of the pilot signals communicates the limit of current the EVSE is capable of supplying to the vehicle; the vehicle can then use up to that amount of current for its charging circuitry. This current rating is primarily determined by the electromechanical components in the EVSE, such as conductors, relays, contactors, and the service connection.

The relationship between duty cycle and current is defined by two different equations depending on the current range specified; for a 6- to 51-A service, Equation 1 is:

$$\text{Duty Cycle} = \frac{\text{Amps}}{0.6} \tag{1}$$

For a higher service in the 51- to 80-A range, Equation 2 is:

$$\text{Duty Cycle} = \left(\frac{\text{Amps}}{2.5}\right) + 64 \tag{2}$$

To demonstrate this relationship further, Table 2 shows some of the common service ratings.

Table 2. Pilot Wire Example Duty Cycles

AMPS	DUTY CYCLE
5	8.3%
15	25%
30	50%
40	66.6%
65	90%
80	96%

In this design, the PWM is generated by a timer module on the MSP430 MCU. The current rating can typically be set as a permanent value in the firmware because it is so tightly coupled to the external hardware.

Advanced EVSEs with a human machine interface (HMI) can enable the current to be derated if the service line is unable to provide enough current with a stable voltage. A significant voltage drop as a result of wire loss is possible in these high current applications.

Copyright © 2016, Texas Instruments Incorporated

4.1.2 Pilot Signal States

The EVSE connection and negotiation occurs through various states of the PWM signal and load resistances of the vehicle. Table 3 highlights these states:

Table 3. Pilot Signal State Parameters

STATE	PILOT HIGH VOLTAGE	PILOT LOW VOLTAGE	FREQUENCY	RESISTANCE	DESCRIPTION
State A	12 V	N/A	DC	N/A	Not connected
State B	9 V	–12 V	1 kHz	2.74 kΩ	EV connected, ready to charge
State C	6 V	–12 V	1 kHz	882 Ω	EV charging
State D	3 V	–12 V	1 kHz	246 Ω	EV charging, ventilation required
State E	0 V	0 V	N/A	—	Error
State F	N/A	–12 V	N/A	—	Unknown error

States A, B, and C are the core functionality and define the normal operation. An EVSE typically performs several self-tests upon initially powering on and then enters State A. When ready, the normal connection process follows several steps.

1. The EVSE puts 12 V on the pilot wire. This transmission signals the vehicle when the plug has been connected.
2. When the plug has been connected, the vehicle places a 2.74-kΩ load on the pilot line, which drops the voltage to 9 V.
3. The EVSE moves to State B, where it enables the PWM, which signals the vehicle how much current it can draw. The EVSE also closes the relays, providing power to the vehicle.
4. The vehicle starts to draw power and switches to the 822-Ω load, which drops the voltage to 6 V, signaling the EVSE that charging has started.
5. Most vehicles continue to pull low amounts of power in state C, even when fully charged, so the charging process is ended by unplugging the cable, which returns the voltage to 12 V. The EVSE measures this process and closes the relays and returns to State A.

Additional error handling such as missing diodes in the vehicle or an improper connection can be detected and handled by the EVSE by cutting the power, as well.

4.1.3 Pilot Signal Circuit

The pilot signal is required to travel down several meters of cable and through a load resistance. The pilot signal is also a bipolar ±12-V signal, which requires special consideration.

To accommodate these parameters, an amplifier with a wide input range and reasonable power output has been selected. The OPA171 has a voltage rating of ±18 V and a current rating of 475 mA, making it suitable for the application. In addition, while most EVSEs do not require an automotive qualification, a Q1-rated variant of the OPA171 exists if this feature is desired.

The amplification circuit is a simple rail-to-rail output configuration of the OPA171 device, with the MCU I/O driving the positive input. The output of the pilot amplifier is also fed into a simple voltage divider so that the MCU can measure the voltage during operation and detect the load resistance of the vehicle. Figure 9 shows the full schematic of this subsystem.

Copyright © 2016, Texas Instruments Incorporated

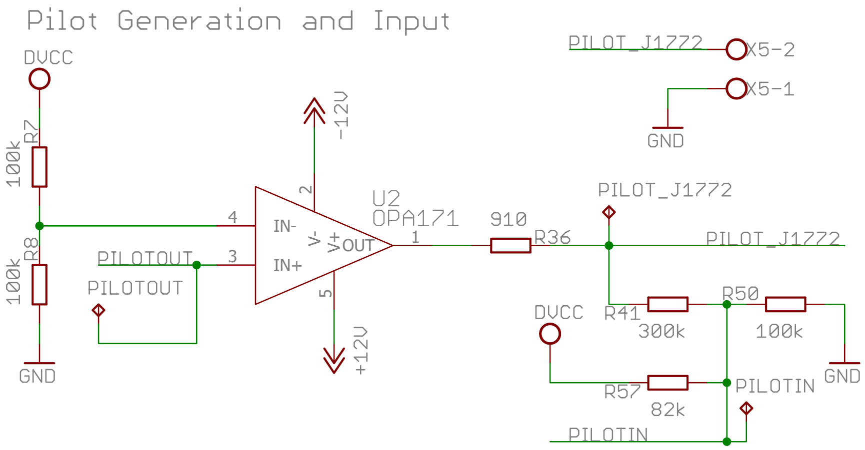
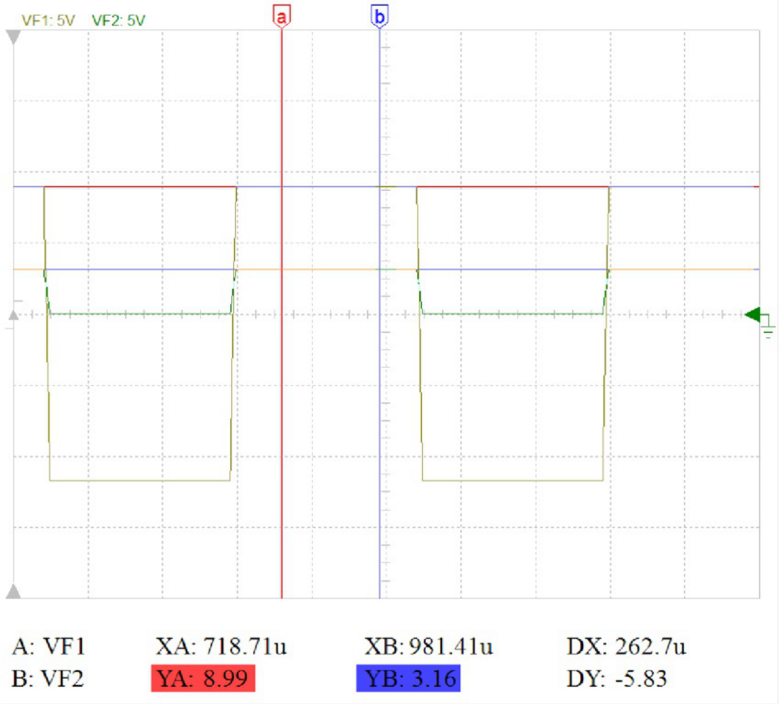


Figure 9. Pilot Signal Generation and Input

To validate the architecture, the design has been tested in the TINA-TI™ software from TI, which is a spice-based simulation tool. The resistor load states of the EVSE have also been included in these tests to simulate the response to the state changes. The simulation files are included in the design download packages. Figure 10 shows an example result of the simulation for a State B condition.



A: VF1 XA: 718.71u XB: 981.41u DX: 262.7u
B: VF2 YA: 8.99 YB: 3.16 DY: -5.83

Figure 10. Pilot Signal TINA Simulation

This capture has a 5-V per division Y-axis. VF1 is the line out channel and VF2 is the MCU ADC channel. The user can observe here that marker A (on VF1) is measuring 8.99 V and marker B (on VF2) is measuring 3.16 V. In addition, VF1 shows that the –12-V side is still intact and that VF2 does not drop below 0 V, which could damage the MCU). The pilot output is correct for the application and the MCU can easily measure the incoming signal.

Copyright © 2016, Texas Instruments Incorporated

4.2 GFCI Fault Detection and Test

A critical element of any electrical system that is to be used in potentially adverse environments is a ground-fault circuit interrupter (GFCI) subsystem. Because the typical areas to use an EVSE are garages or outdoor environments, the potential for electric shock as a result of water ingress is present. A GFCI detects unbalanced current through the primary conductors. If the current through these primary conductors is not balanced, then it must be flowing somewhere else, which indicates a fault somewhere else. The whole system must respond immediately by cutting power to the load.

The TIDA-00637 design takes advantage of the intrinsic design properties of a donut current transformer. The donut CT typically has the conductor feed through it and acts as the primary side of the transformer. In some applications, the conductor is looped through the CT several times, essentially multiplying the current through the CT. To create a GFCI detection CT, the designer can pass both conductors through the CT. The current passing in both directions cancels out and reads as 0 A under normal operating conditions. If current flows somewhere else in the system, the current through the CT is non-zero and results in a reading on the output. Any non-zero reading indicates a fault.

Because this is a safety system, self-test functionality is also a core requirement. The same CT can be easily modified to support this self-test functionality by integrating several loops of a small conductor around the donut. To reiterate, even a small amount of current taking multiple loops through the CT is multiplied and detectable.

For the EVSE design, the self-test signal is generated through an I/O on the MCU; however, to respond quickly to a GFCI event, consider using an interruptible I/O for input, rather than an ADC reading. Because the output of the CT is an AC signal, it must be filtered and latched to VCC before an I/O can read it. To accommodate this process, the circuit in Figure 11 has been implemented.

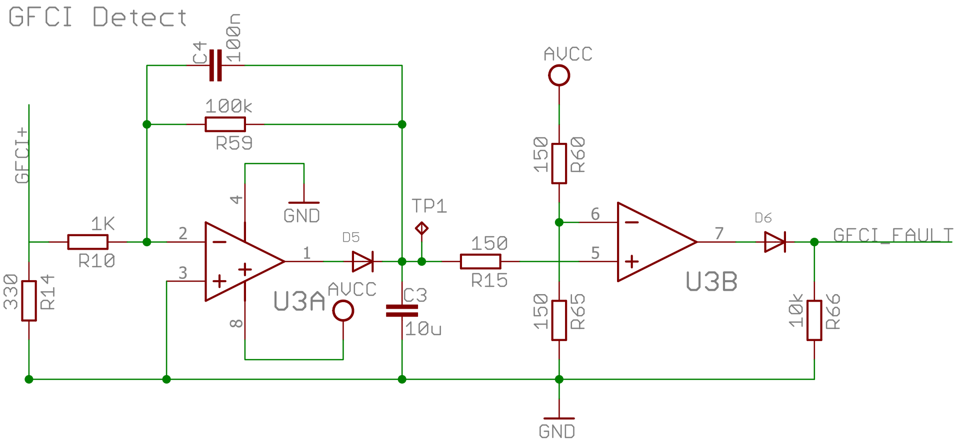


Figure 11. GFCI Detection

R14 acts as a burden resistor to the CT. An op amp in an inverting integrator configuration saturates quickly when an AC signal on the input is present. A discharge path also enables the system to reset itself and not become stuck in a GFCI fault case after a self-test. A second op amp, which rails to the MCU I/O voltage quickly, is used to convert the discharge path to a clean input to the MCU and boost any low-level signals that may self-attenuate too quickly.

The LM7322 op amp is able to tolerate the larger capacitive load of the configuration and fits well in this architecture.

To validate operation of the design prior to implementation, the TINA-TI software was used to generate a simulation using the actual selected silicon. The simulation file used is available for download in the design files. The capture results in Figure 12 demonstrate the rapid response nature of the filter configuration and that the sharp edge of the fault signal is easily detectable by the MCU. The input signal level has been tested down to 15 mV. To provide some noise immunity, the input signal level does not trigger below this level.

Copyright © 2016, Texas Instruments Incorporated

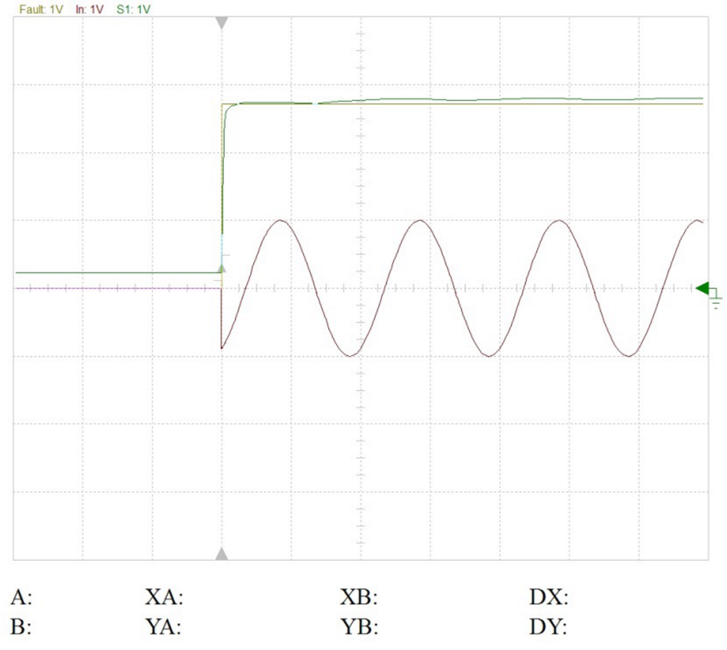


Figure 12. GFCI Detection Simulation

4.3 Relay Drive and Latch Detect

The primary functionality of the EVSE is the reliable control of large currents directed toward an electric vehicle at the mains voltage. In a normal use case, the relay must be held closed for several hours to fully charge a vehicle; however, the relays cannot be latching because of safety concerns. If something fails in the control system, the relays must fail open. These high current relays can typically draw 10s to 100s of milliamps as an inductive load, requiring specific drive architectures.

Because of the amount of time that a relay requires to remain powered, an efficient drive solution is preferred to the typical Darlington array, or even discrete transistor configuration. For this reason, the TPL7404L low-side driver has been selected to drive the relays in the design. The TPL7404L offers high-efficiency, integrated diode protection for inductive loads and has a wide-voltage output capability to match most electromechanical relays. The design defaults to a 5-V output but an external voltage can be used depending on the relay configuration.

The relay configuration used for design testing contains a two-stage approach. The first relay is controlled by the EVSE board through a 12-V signal from the TPL7404L device. This relay switches a 120-V signal into a much larger relay that is capable of supporting the large currents required of the EVSE. Many large contactors or high-amp relays are 120 V, so this configuration is not uncommon. This configuration also reduces power supply requirements because a lower current is required to drive a smaller first relay. Figure 13 shows a simple diagram of the relay configuration.

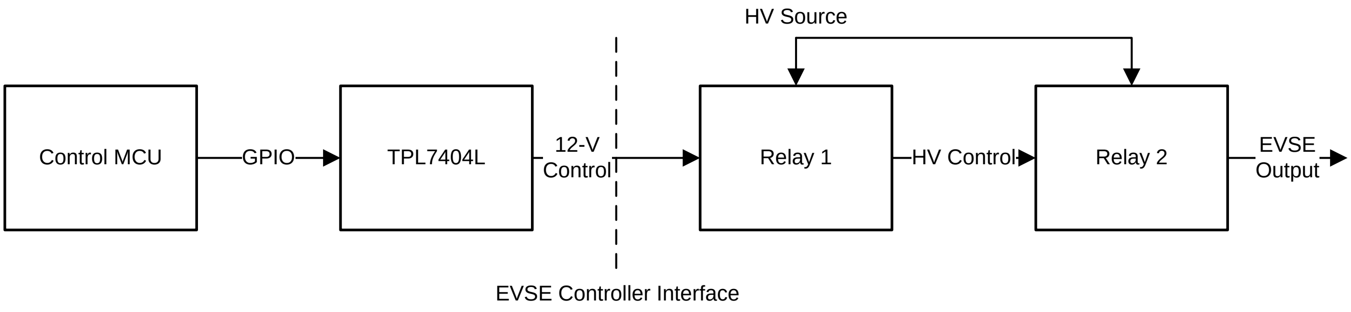


Figure 13. Relay Configuration

Copyright © 2016, Texas Instruments Incorporated

For safety reasons, detecting the output voltage of the primary relay is critical. On high voltage relays, the contacts can experience arcing and become fused together, providing power to the plug even when the system is not powering it. Checking that the operation completed correctly is important and should be done every time the relay is opened. To implement this check, an ADC can be used with a voltage divider, which is the same process used in the energy metering; however, the user can construct a simpler solution from an AC input optocoupler. The output from this is a GPIO-level DC signal that is high when voltage is present and can be fed directly into the MCU.

4.4 Energy Metering

The energy measurement section of this hardware design has been emulated from TI's existing portfolio of residential e-meter designs, specifically, the class 0.2 single-phase e-meter (TIDM-SINGLEPHASEMETER). This design offers a high-accuracy energy measurement through the MSP430F6736 MCU. The MCU is fully programmable and has also been adopted to run the software controlling the EVSE system. For more information about the metering solution, refer to the associated reference design (TIDM-SINGLEPHASEMETER).

Copyright © 2016, Texas Instruments Incorporated

5 Getting Started

5.1 Hardware Overview

The control system for the TIDA-00637 EVSE reference design is fully implemented in a single PCB. All schematic, layer prints, bill of materials, and other design materials are available in the reference design folder. Figure 14 shows the top view of the board.

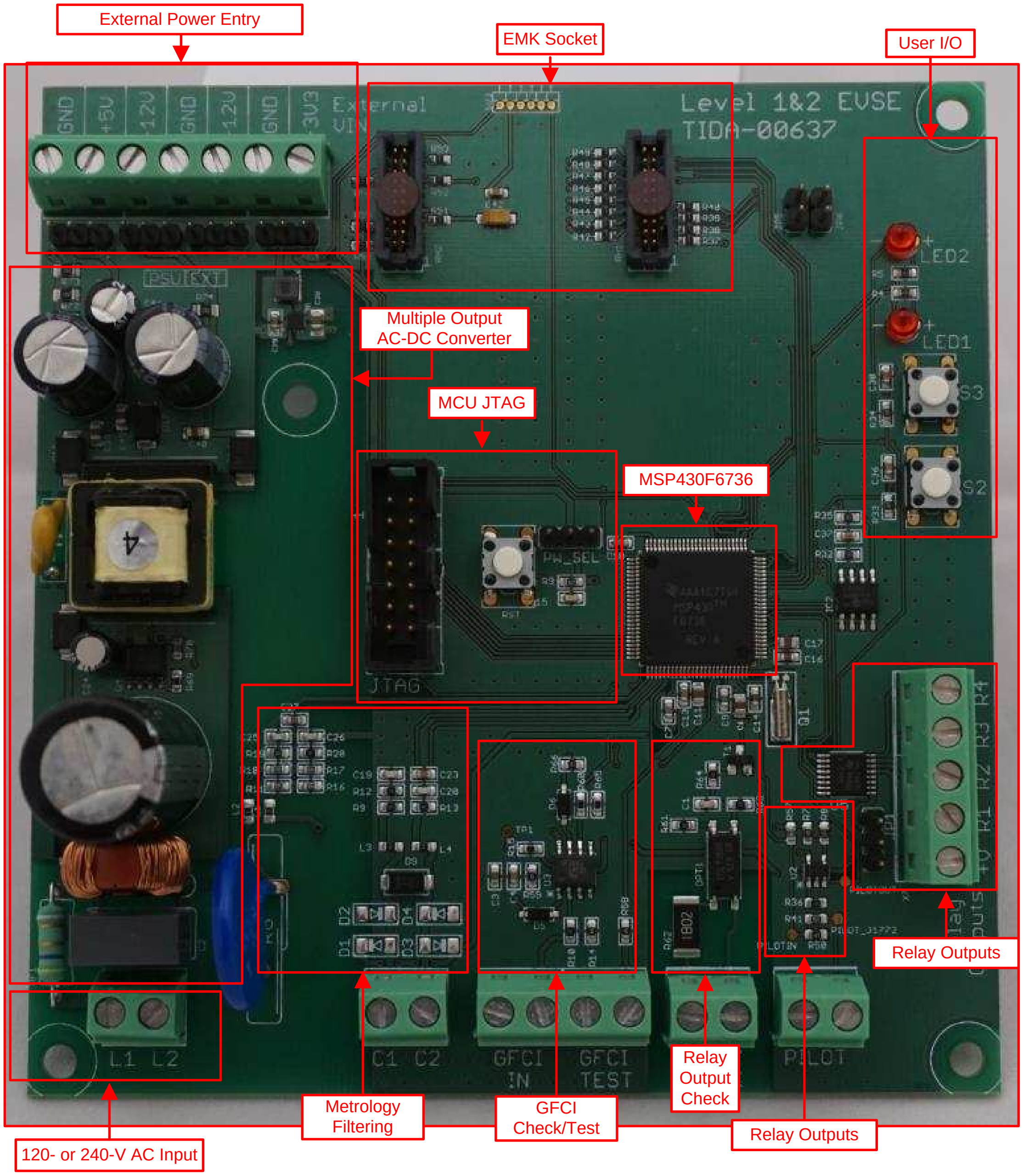


Figure 14. Top View of EVSE PCB

Copyright © 2016, Texas Instruments Incorporated

The EVSE has the following functional blocks:

- External power entry – Several screw terminals are available to evaluate alternative power options with the PCB. The system requires at least ±12 V and 3.3 V to operate, with an optional 5-V input available. Each input has a jumper option to enable selection between the internal and external power.
- EMK socket – A standard TI EMK socket has been provided to enable the easy addition of wireless cards produced by TI. In addition, is the board provides a second, dedicated communication power for EZ-RF boards or other UART compatible devices.
- User I/O - Two onboard buttons and two light-emitting diodes (LEDs) are have been provided on board to provide a simple user interface with the system. By default, the buttons to do not have mapped functions, and the LEDs signal error states for the GFCI and pilot line systems.
- MSP430F6736 – The F6736 series MSP430 is the MCU used to control the EVSE.
- MCU JTAG – A standard MSP430 14-pin JTAG connector is available for programing the device. A power selection jumper (to enable the MCU to be powered from the MSPFET) and reset push button have also been included.
- Multiple output AC-DC converter – The onboard AC-DC converter is capable of producing ±12 V and 5 V from a 120- or 240-V AC input. A small footprint DC-DC converter produces the 3.3-V rail from the 5-V output. All of these rails can be bypassed and powered externally through the external power entry block.
- 120- to 240-V AC input – The AC power entry terminal supports a wide input voltage and feeds both the onboard power supply as well as the metrology section of the system.
- Metrology filtering – The signal filtering for the energy metering is based on TI's class 0.2 single-phase e-meter (TIDM-SINGLEPHASEMETER). The design is a simple passive filter for both the AC voltage and a current transformer input through the terminal blocks. An external 0.05% CT is required to meet the high accuracy specification with the appropriate burden resistor tuning. **Section 5.2** provides additional information on the functionality of this hardware.
- GFCI check and GFCI test – Filtering for the GFCI input signal and the test signal output is supplied here. **Section 5.3** provides additional information on the hardware connections and setup.
- Relay output check – The AC output of the relay can be fed back into the EVSE for monitoring. This enables a quick check of the relay functionality.
- Pilot interface – A screw terminal is available here to make a connection between the pilot signal to the amplification and filtering block. **Section 5.4** provides additional information on the functionality of this hardware.
- Relay outputs – Output capability is provided for up to four discrete relay signals. An onboard jumper is available to select between using the onboard power supply to drive the relay and TPL7407 or using an external voltage. **Section 5.5** provides additional information on the functionality of this hardware.

5.2 Mains Power and Metrology

The power entry block on the TIDA-00637 reference design serves to both power the system and provide a signal to the metrology filters to be measured by the MCU. On a single-phase feeder, the terminal assignment is: Live → L1 and Neutral → L2. On a split-phase connection, the terminal connection does not have a specific polarity. In both cases, a ground connection is required, but only for the pilot wire signal, as **Section 5.4** details.

To measure the current that the vehicle is drawing, the terminal block labeled C1 and C2 is used to input the current output of a current transformer. The system has an integrated 13-Ω burden resistor and a 2000:1 ratio CT is typically used to give accurate metrology measurements up to 100 A with a 2000:1 dynamic range. If a lower ceiling on the current range is required, a CT with a lower current rating can be used, but the burden resistor must be chosen to match and the software must be updated with the new ranging information. The class 0.2 single-phase e-meter design provides additional information on choosing a CT (TIDM-SINGLEPHASEMETER).

Copyright © 2016, Texas Instruments Incorporated

5.3 GFCI

The GFCI system on the TIDA-00637 reference design uses a donut CT that is capable of feeding both primary conductors through it to act as the primary side of the transformer. Any current that feeds through a conductor in this style of CT is divided down by the transformer and fed into the terminal block labeled “GFCI IN”. The system has an onboard burden resistor, which makes a CT with an integrated resistor unnecessary. The onboard burden is oversized to amplify the output voltage to the sense filter, which is acceptable because the design does not use this signal for measurement, only detection.

The “GFCI TEST” output terminals are designed to output current through another conductor that also passes through the donut CT. Because the MCU is only capable of outputting about 10 mA, the user can create a GFCI test element by wrapping a length of small conductor through the CT several times to amplify the current that is detected in a test condition. Figure 15 shows a typical GFCI CT configuration with the two 240-V primary conductors, the GFCI test signal coil, and the GFCI signal output to the system.

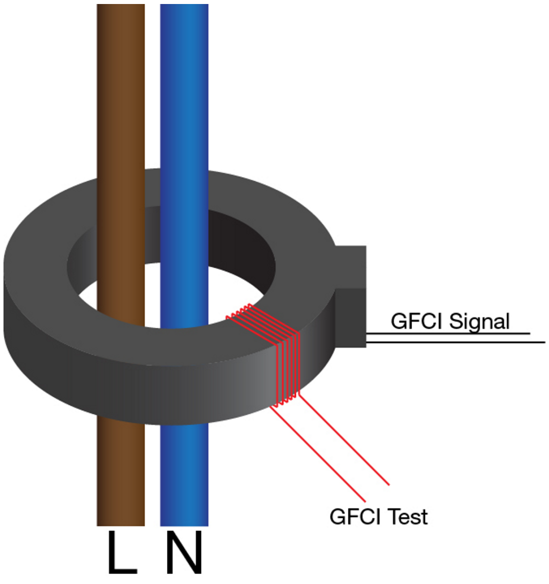


Figure 15. GFCI CT Configuration

5.4 Pilot Wire

The fourth and smaller wire on a standard J1772 cable is the pilot line. This line can be electrically connected directly to the right side of the “PILOT” terminal block on the EVSE system design. The EV interacts with the pilot signal by placing a resistance between the pilot pin and the ground connection on the cable. While the ground connection is not used for the power elements in this design, it is required as an electrical reference for the pilot signal. To set the ground connection to act as the electrical reference, the left connection of the “PILOT” terminal block must be connected to the earth ground on the EVSE cable.

Copyright © 2016, Texas Instruments Incorporated

5.5 Relays

The relay terminal block on the EVSE system design has output support for four relays, with a fifth terminal for a positive voltage output from the onboard supply, or external supply input. The four relay connectors have been set up to enable low-side switching of the relays without the requirement for external snubber diodes; however, having the diodes in place does not affect operation.

For normal connection of a relay using the onboard 12-V rail, the relay coil is connected between the +V port and the associated relay port on the terminal block, as Figure 16 shows.

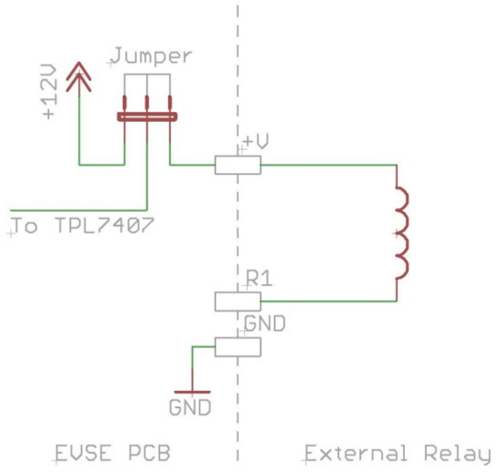


Figure 16. Normal Relay Connection

To use an external supply, the positive rail must connect to the +V port, ground to the GND port, and the relay to the associated control port, as Figure 17 shows.

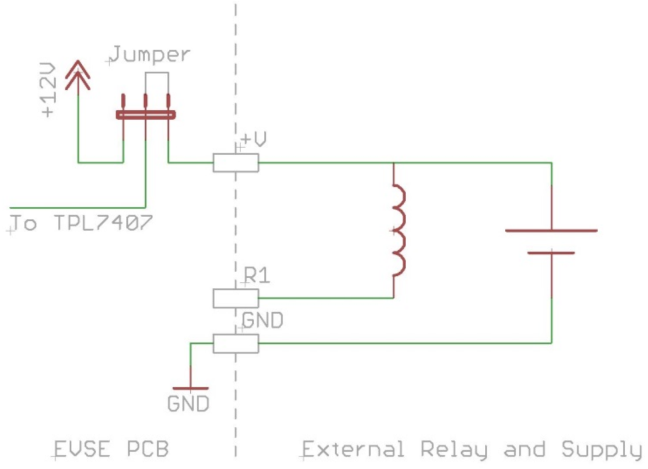


Figure 17. Relay with External Supply

In many cases, a relay able to switch the amount of current required for an EVSE requires a significant level of switching current to latch. Many high current relays or contacts mitigate this requirement by using line-level AC voltage on the coil. To control this style of relay or contactor, a smaller relay with a low-voltage control level can be switched by the EVSE, which in turn switches the line voltage to the high current control.

Copyright © 2016, Texas Instruments Incorporated

6 Getting Started Firmware

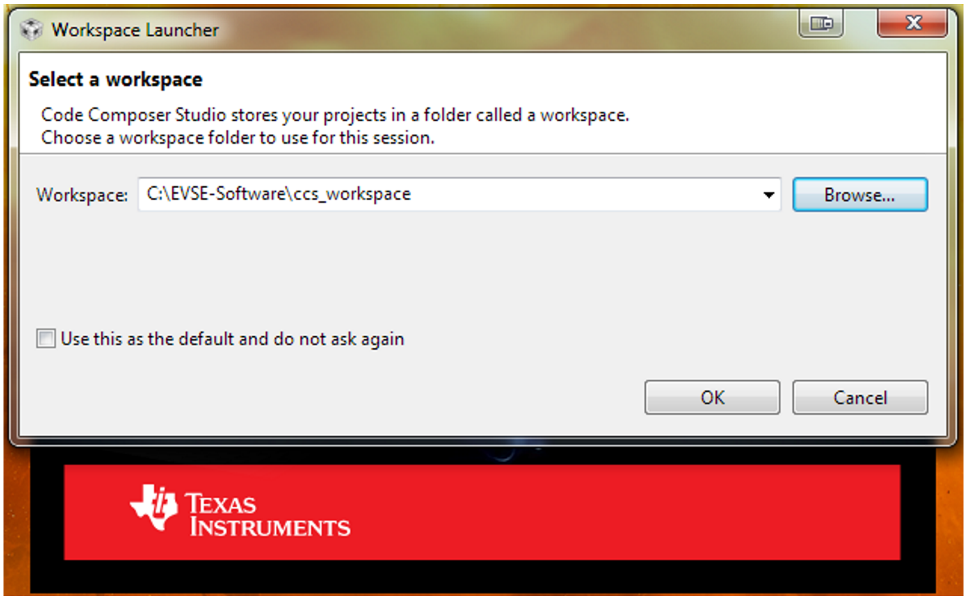
The software provided with this TI Design has been used to implement the basic structure of the J1772 signaling protocol and evaluate the functionality of design features. As such, the provided software is not production ready, but the basic principles can be leveraged to build a final application.

The software was built on top of the existing MSP430-Energy-Library. This library has been proven for use in electricity meters and provides an excellent framework on which to add the EVSE application state machine.

6.1 Workspace Setup

The software provided in this design requires the latest version of the Code Composer Studio™ (CCS) IDE from TI with the MSP430 plugins. This software can be obtained from: http://www.ti.com/tool/ccstudio.

When extracting the software, ensure that all of the directory structures remain unchanged. When opening CCS (or switching workspaces), select the “ccs_workspace” directory that was extracted from the archive. The following example in Figure 18 shows placement of the files in the *C:\EVSE-Software\ directory*.



Select a workspace

Code Composer Studio stores your projects in a folder called a workspace.
Choose a workspace folder to use for this session.

Workspace: C:\EVSE-Software\ccs_workspace

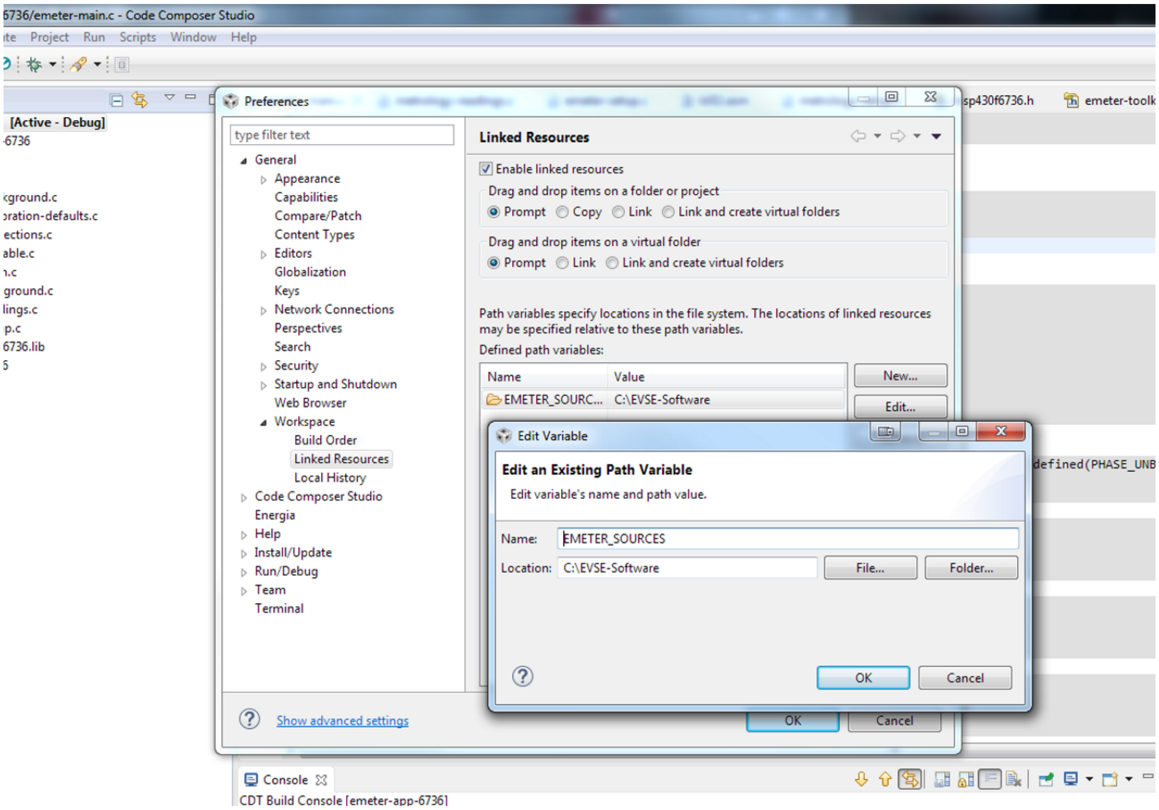
Figure 18. Opening CCS Workspace

Upon launching the workspace, three projects become visible:

- Emeter-app-6736—This workspace contains the application level code, including peripheral setup and foreground state machines
- Emeter-metrology-6736—This workspace is located one level below and has all of the metrology functionality. This functionality includes the ADC ISRs, metrology DSP calculations, and data access routines.
- Emeter-toolkit-6736—This workspace has many low-level functions that are used to accelerate processing for specific data types used in the metrology processing engine.

When opening the workspace for the first time, the user is required to set a global variable to reference files. Set this variable by navigating to *Window* → *Preferences* in the *File* menu on the task bar. When the preferences window appears, navigate through the sidebar to *General* → *Workspace* → *Linked Resources*. In the *Linked Resources* tab, edit the resource *EMETER_SOURCES* to be one directory above the *ccs_workspace* directory. In this example (Figure 19), that directory is *C:\EVSE-Software*.

Copyright © 2016, Texas Instruments Incorporated



Linked Resources

☑ Enable linked resources

Drag and drop items on a folder or project

● Prompt ○ Copy ○ Link ○ Link and create virtual folders

Drag and drop items on a virtual folder

● Prompt ○ Link ○ Link and create virtual folders

Path variables specify locations in the file system. The locations of linked resources may be specified relative to these path variables.

Defined path variables:

Name	Value
EMETER_SOURC...	C:\EVSE-Software

Edit Variable

Edit an Existing Path Variable

Edit variable's name and path value.

Name: EMETER_SOURCES

Location: C:\EVSE-Software

Figure 19. Changing EMETER_SOURCES Resource

The directory change can be tested by opening one of the C:\ drive files and recompiling the projects in the workspace.

When browsing the source code, major changes to the base library are flagged with the following comment block, which allows the user to quickly find and discern the core functionality:

```
/* --------------------------- */
/* EVSE Specific functionality */
/* --------------------------- */
```

The firmware can be flashed as is to evaluate functionality by initiating a debug of the *emeter-app-6736* project.

Any changes made to the individual projects must be propagated by recompiling the higher level projects because the *emeter-toolkit-6736* is used by *emeter-metrology-6736*, which, in turn, is used by *emeter-app-6736*.

6.2 Energy Measurement

The energy measurement functionality of the TIDA-00637 reference design is based on the MSP430-Energy-Library. Consult the documentation regarding the class 0.2 single-phase e-meter (TIDM-SINGLEPHASEMETER).

Copyright © 2016, Texas Instruments Incorporated

6.3 Hardware Specific Setup

All pins on the MSP430 device are set at the application launch based on the functionality defined in *emeter-template.h* file. The three core registers required to initialize a pin for each I/O module (PxDIR, PxSEL, and PxOUT) are defined here and applied in the system_setup() function. All clocking and power options have been left on the default settings, the same as defined in the base MSP430-Energy-Library.

Based on the reference design, the only additional setup required that is not covered by basic I/O settings is the pilot signal generation, GFCI interrupt, and ADC10 configuration.

6.3.1 Pilot Signal Setup

Because the pilot signal requires a steady 1-kHz PWM, the hardware has been designed to utilize a built-in timer module on the MSP430 device, known as TA2.1. The standard method of PWM generation on the MSP430 is to use one timer capture register to set the PWM frequency and another (with the appropriate output tied to a pin) as the PWM duty cycle.

The existing energy library clocking schema sets the SMCLK to match the MCLK at 25.16 MHz. Using an SMCLK with a divider of 25160 gives the appropriate timer frequency of 1 kHz. The PWM duty cycle can be set once and left alone because it is static through the operation of the EVSE (because it is based on the service connection and electromechanical design). Using Equation 1 and Equation 2, the user can determine the value for the TA2.1 trigger register as a percentage of 25160.

In the provided source code, the maximum current value is defined in a header; however, this value can be set programmatically if a variable value is required.

The initial state of the pilot wire is 12 V, or simply a high output from the timer module. The software sets up the timer and runs it at start-up, but does not output the signal. The signal output transpires in the application state machine when required.

6.3.2 GFCI Test Signal Setup

A simple I/O interrupt is required to enable the GFCI checking. On the MSP430 device, only ports one and two are capable of acting as interrupts. In the *emeter_setup()* function, the user must be sure to enable the P1.6 interrupt because the default register settings of the energy library do not allow implementing this setting.

6.3.3 ADC10 Configuration

All of the analog setup for the energy library occurs in the *emeter-metrology-6736* project, in the *metrology-setup.c* file. The energy library already has hooks in place to use the ADC10 device for energy measurement, which the user can repurpose to measure the pilot wire input. The SD24 interrupt for the metrology triggers at a 4-kHz rate, which is also sufficient for measuring the 1-kHz pilot signal.

The MSP430F6736 contains a port map feature that must be set to enable ADC10 input. This feature is unique to the MSP430F67xx family and not required if a different device has been selected.

The ADC10 has been configured with fairly standard settings, but has also been set to require an external trigger. This trigger has been set in the SD24 ISR so that the ADC10 samples as soon as it finishes with the background DSP process.

6.4 Application State Machine

The core functionality of the EVSE is primarily moving between different states of the J1772 pilot signal protocol. The simplest method of facilitating this movement is by implementing a simple state machine that has been built in the foreground of the energy library. The energy library has a function in the application layer that runs once per second (based on the number of SD24 samples collected), which provides the basis for the state machine. Figure 20 shows the basic layout of the implemented state machine.

Copyright © 2016, Texas Instruments Incorporated

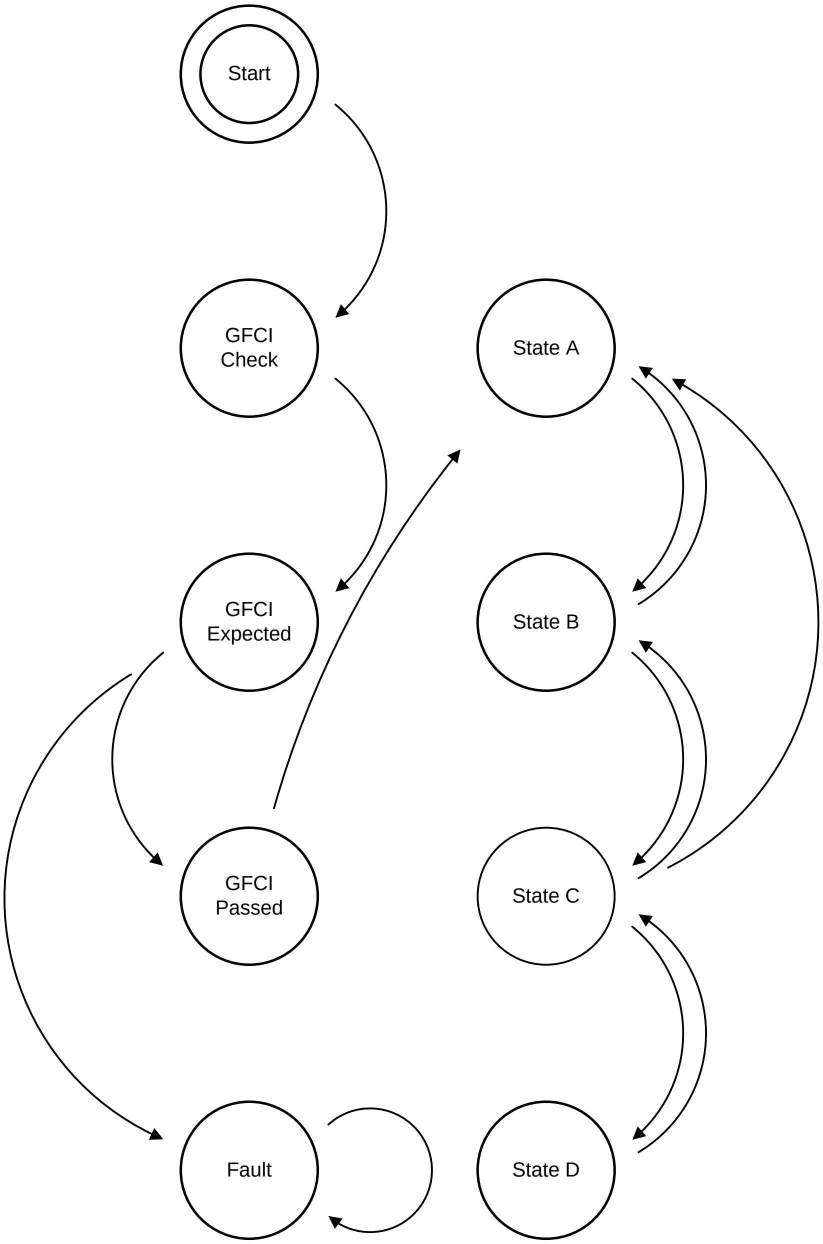


Figure 20. State Machine Overview

Copyright © 2016, Texas Instruments Incorporated

The following list outlines the process of the implemented state machine:

1. Start – State machine entry point. Any additional initialization can be put here.
2. GFCI Check – This state initializes a GFCI check by setting a flag for the ISR and outputting a pulse to the check coil. The pulse triggers the GFCI ISR, which does not trigger a fault if the check expected flag has been set.
3. GFCI Expected – Check that the GFCI test has been properly detected here. Trigger a GFCI Check fault and move to the fault state if necessary. If passed, move to the GFCI Passed state.
4. GFCI Passed – The pass state is a mostly empty state to facilitate any additional functionality that may be required to run before starting the J1772 signaling.
5. State A – To start the signaling, the pilot line is brought high at the beginning of State A. The only possible exit from here is to State B when the voltage drop on the pilot line has been signaled by the ADC10 ISR in the background. If a different voltage has been detected, this state can exit to the Fault state with a J1772 condition.
6. State B – State B enables the PWM output on the pilot line. From here, the only possible exit is to State C (indicating that the vehicle has changed to resistance to signal that it is ready to accept charge voltage), State A (indicating that the connector has been unplugged), or a J1772 fault condition that has been detected in the background.
7. State C – State C enables the charge voltage by closing the relay. Possible exits include State B (indicating that the vehicle has changed the resistance to signal that it is done charging), State A (indicating that the connector has been unplugged from the vehicle), State D (indicating that venting is required), or a J1772 fault condition that has been detected in the background.
8. State D – Indicates that venting is required. This state is implemented in software, but only returns to State C or to the fault condition.
9. Fault – The primary faults that can be triggered by the system are GFCI check failed, GFCI triggered, relay stuck, or a J1772 pilot signal fault. These faults are all critical and require a system restart to clear.

The primary mechanism for shifting between various states is the pilot wire measurement on the ADC10 module. When a voltage change has been measured, the foreground state machine detects this change and moves appropriately. This setup limits the response rate to 1 s because the foreground operates at 1 Hz, which is a sufficiently fast response rate for the application at hand.

Copyright © 2016, Texas Instruments Incorporated

7 Test Setup

To test the TIDA-00637 reference design, a fully functional EVSE was built using off-the-shelf electromechanical components. Selection of these components is generally inconsequential as long as they are rated for the full current used in the testing. Figure 21 shows a block diagram of the external component arrangement in the final system.

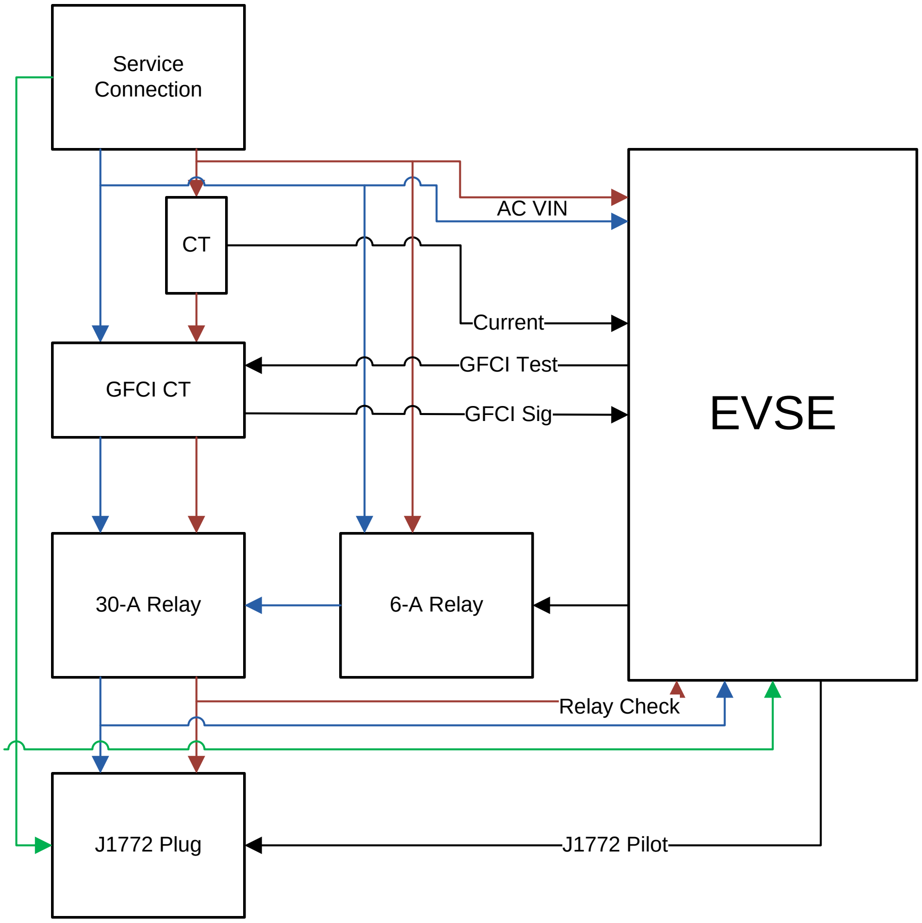


Figure 21. EVSE External Components

Copyright © 2016, Texas Instruments Incorporated

Figure 22 shows a test setup photo of the final system. The service input is limited to a mere 20-A circuit because of facility limitations.

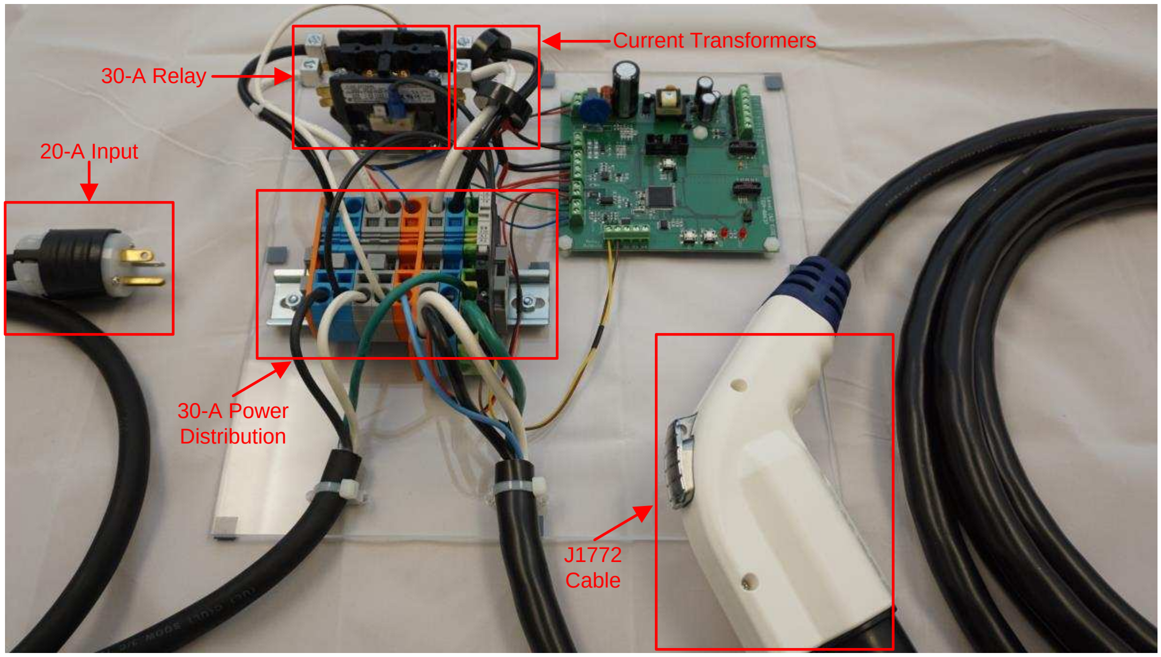


Figure 22. System as Tested

For bench testing, the vehicle can be simulated by a simple diode and resistor in series connected between the pilot line and earth ground on the J1772 plug for each state. The pilot line is monitored through an oscilloscope and onboard LEDs are used to indicate the current software state to ensure that each pilot state is properly detected and changed in the state machine.

To test the GFCI functionality and energy measurement, an MTE PSS 3.3C meter test station was used to accurately generate the current and voltage signals.

Copyright © 2016, Texas Instruments Incorporated

8 Test Data

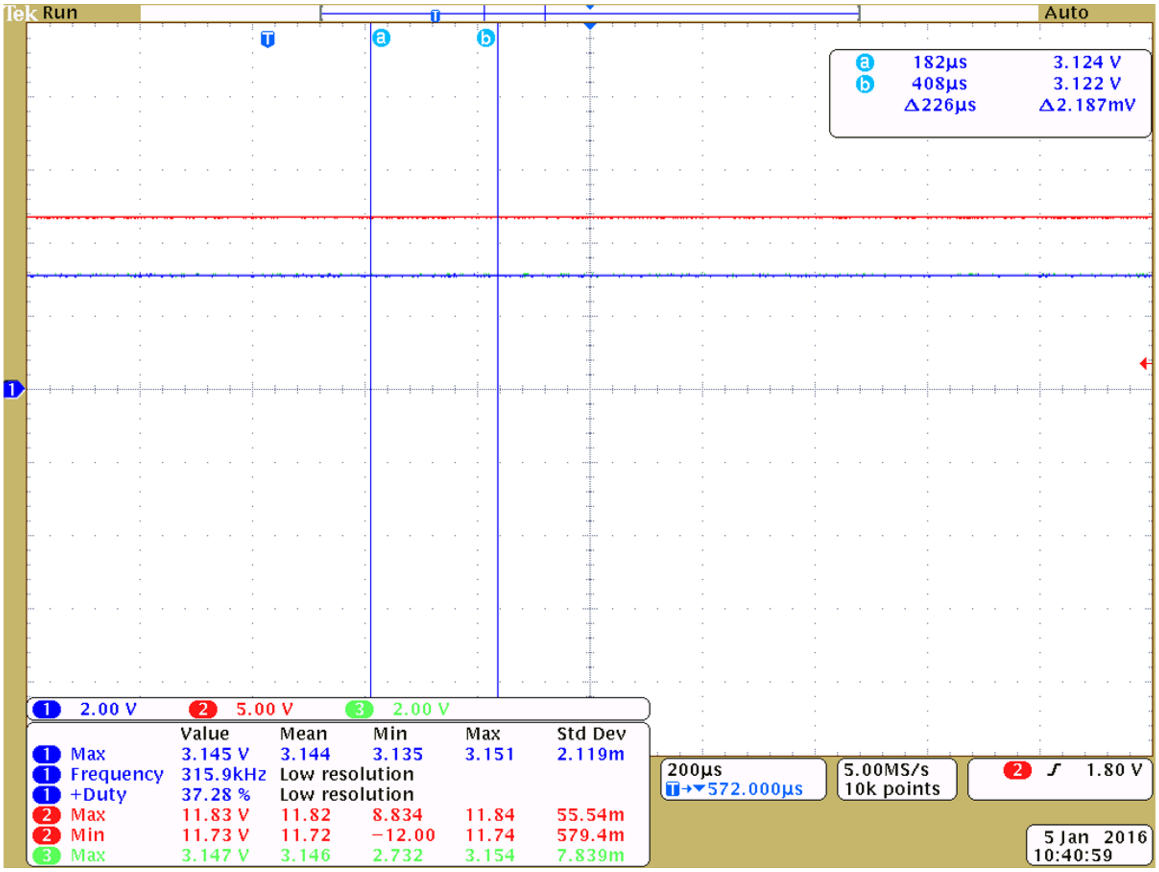
8.1 J1772 Pilot Signal

Oscilloscope plots of each state of the J1772 connection were obtained. The channel assignments are as follows:

1. MSP430 signal output
2. J1772 pilot signal
3. MSP430 signal input

The key measurements for the signal include the maximum and minimum voltages of each signal, the signal frequency, and the signal duty cycle.

Figure 23 shows the EVSE pilot line in the unplugged State A; the pilot has an expected value of 12-V DC.



a	182µs	3.124 V
b	408µs	3.122 V
	Δ226µs	Δ2.187mV

1 2.00 V 2 5.00 V 3 2.00 V

	Value	Mean	Min	Max	Std Dev
1 Max	3.145 V	3.144	3.135	3.151	2.119m
1 Frequency	315.9kHz	Low resolution			
1 +Duty	37.28 %	Low resolution			
2 Max	11.83 V	11.82	8.834	11.84	55.54m
2 Min	11.73 V	11.72	−12.00	11.74	579.4m
3 Max	3.147 V	3.146	2.732	3.154	7.839m

200µs
T→▼572.000µs

5.00MS/s
10k points

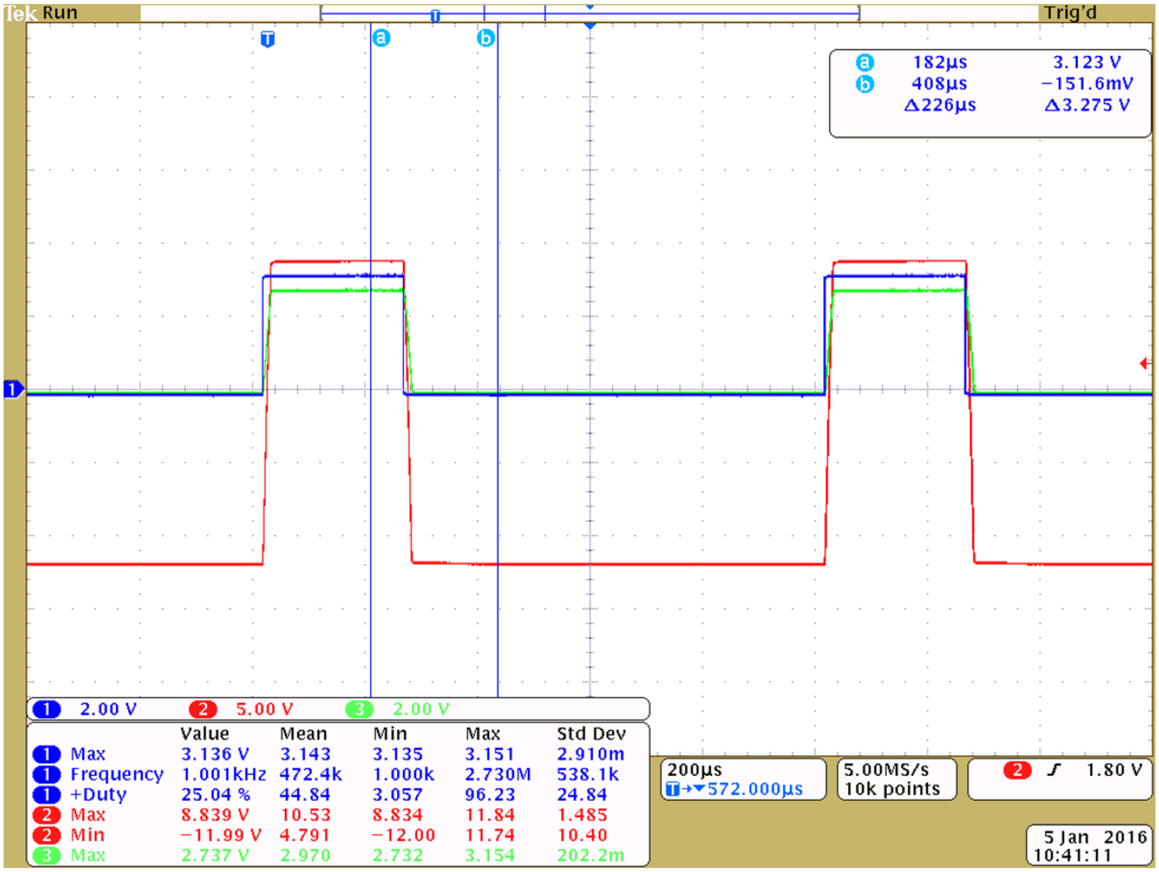
2 ʃ 1.80 V

5 Jan 2016
10:40:59

Figure 23. EVSE Pilot Wire—State A

Copyright © 2016, Texas Instruments Incorporated

Figure 24 shows the EVSE pilot in State B. This state occurs after plugging the EVSE into the EV. The vehicle detects the 12 V from State A and places a 2.74-kΩ resistor between the pilot and ground. The EVSE then detects the voltage drop and starts the PWM signal to the vehicle. The signal frequency here is 1.001 kHz with a PWM of 25% (equating to 15 A of available current). The pilot signal has also dropped to 8.84 V/–12 V (9 V/–12 V is ideal), resulting in a signal back to the MSP430 device at 2.737 V, which is within the expected range for detection.

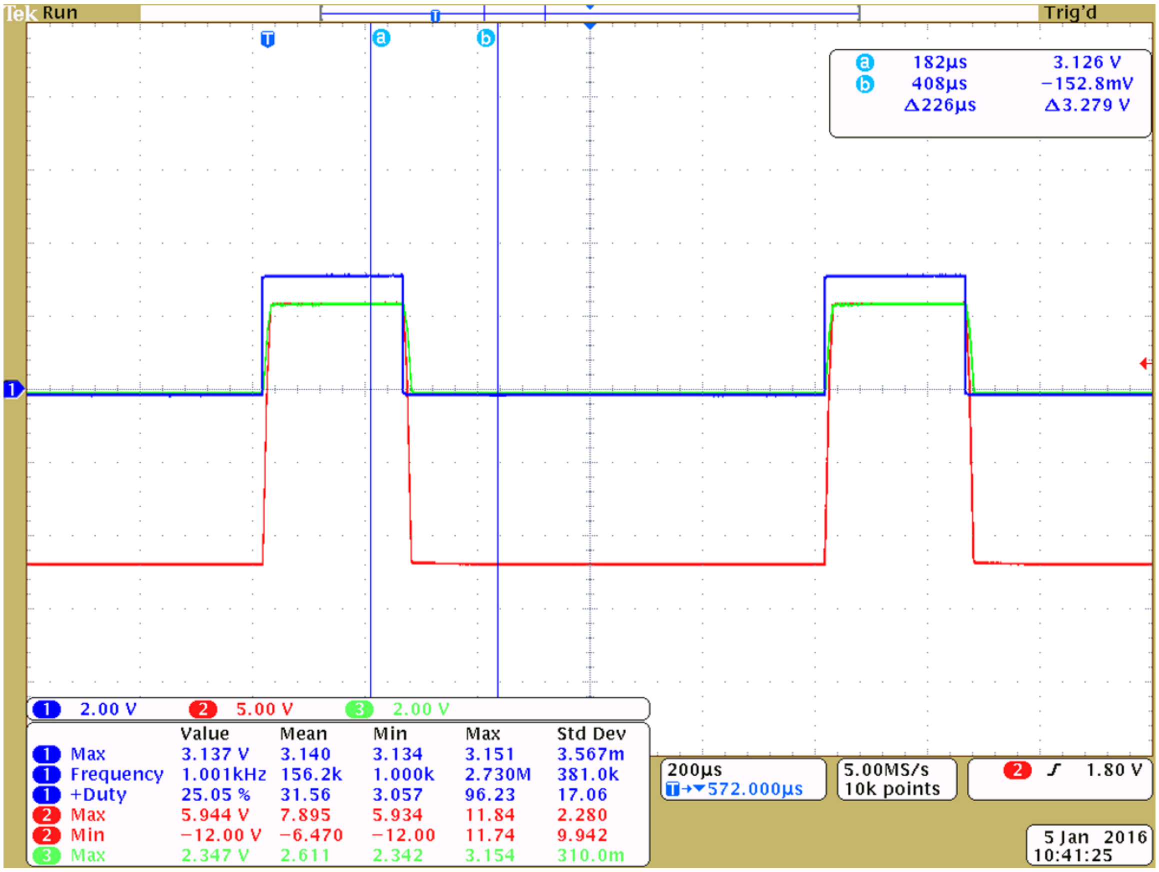


	Value	Mean	Min	Max	Std Dev
1 Max	3.136 V	3.143	3.135	3.151	2.910m
1 Frequency	1.001kHz	472.4k	1.000k	2.730M	538.1k
1 +Duty	25.04 %	44.84	3.057	96.23	24.84
2 Max	8.839 V	10.53	8.834	11.84	1.485
2 Min	−11.99 V	4.791	−12.00	11.74	10.40
3 Max	2.737 V	2.970	2.732	3.154	202.2m

Figure 24. EVSE Pilot Wire—State B

Copyright © 2016, Texas Instruments Incorporated

Figure 25 shows the EVSE pilot in State C. After the PWM signal is on the line, the vehicle switches to the 882-Ω resistor, which indicates to the EVSE that it is ready to receive the full AC voltage. The pilot signal itself is at 5.944 V/–12 V (6 V/–12 V is ideal). At this point, the software has also triggered the relay to close and provide power to the vehicle.



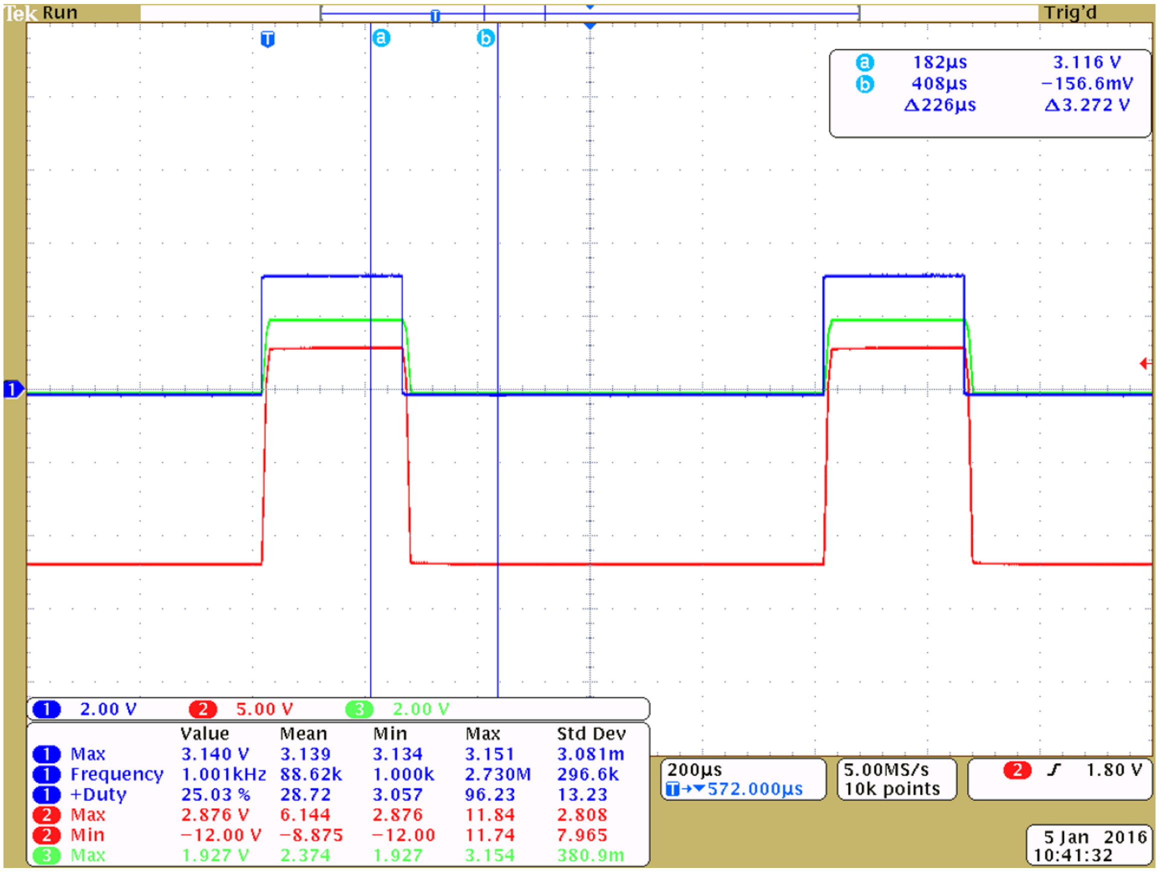
a	182µs	3.126 V
b	408µs	−152.8mV
	Δ226µs	Δ3.279 V

	Value	Mean	Min	Max	Std Dev
① Max	3.137 V	3.140	3.134	3.151	3.567m
① Frequency	1.001kHz	156.2k	1.000k	2.730M	381.0k
① +Duty	25.05 %	31.56	3.057	96.23	17.06
② Max	5.944 V	7.895	5.934	11.84	2.280
② Min	−12.00 V	−6.470	−12.00	11.74	9.942
③ Max	2.347 V	2.611	2.342	3.154	310.0m

Figure 25. EVSE Pilot Wire—State C

Copyright © 2016, Texas Instruments Incorporated

Figure 26 shows the EVSE pilot in State D. In this state the EV has indicated an error by applying a 246-Ω resistor. While the functionality for this state has not been implemented in the reference design, the state can still be detected. The resulting pilot voltage level of 2.87 V/–12 V (3 V/–12 V is ideal) is detected by the software, but the EVSE just returns to State C.



	Value	Mean	Min	Max	Std Dev
1 Max	3.140 V	3.139	3.134	3.151	3.081m
1 Frequency	1.001kHz	88.62k	1.000k	2.730M	296.6k
1 +Duty	25.03 %	28.72	3.057	96.23	13.23
2 Max	2.876 V	6.144	2.876	11.84	2.808
2 Min	−12.00 V	−8.875	−12.00	11.74	7.965
3 Max	1.927 V	2.374	1.927	3.154	380.9m

Figure 26. EVSE Pilot Wire—State D

Copyright © 2016, Texas Instruments Incorporated

8.2 GFCI Test Signal

The GFCI test signal is applied from the MCU I/O through the 330-Ω resistor through a multi-turn coil on the current transformer (see Figure 27). Using the background process running at 4 kHz in the software, the MCU was able to output a 2-kHz waveform for a short duration to excite the coil, which only passes AC current. Using this process, the system was able to trigger and detect an output pulse from the GFCI subsystem within 30 ms, which quickly validates the GFCI coil physical connection and operation in the circuit.

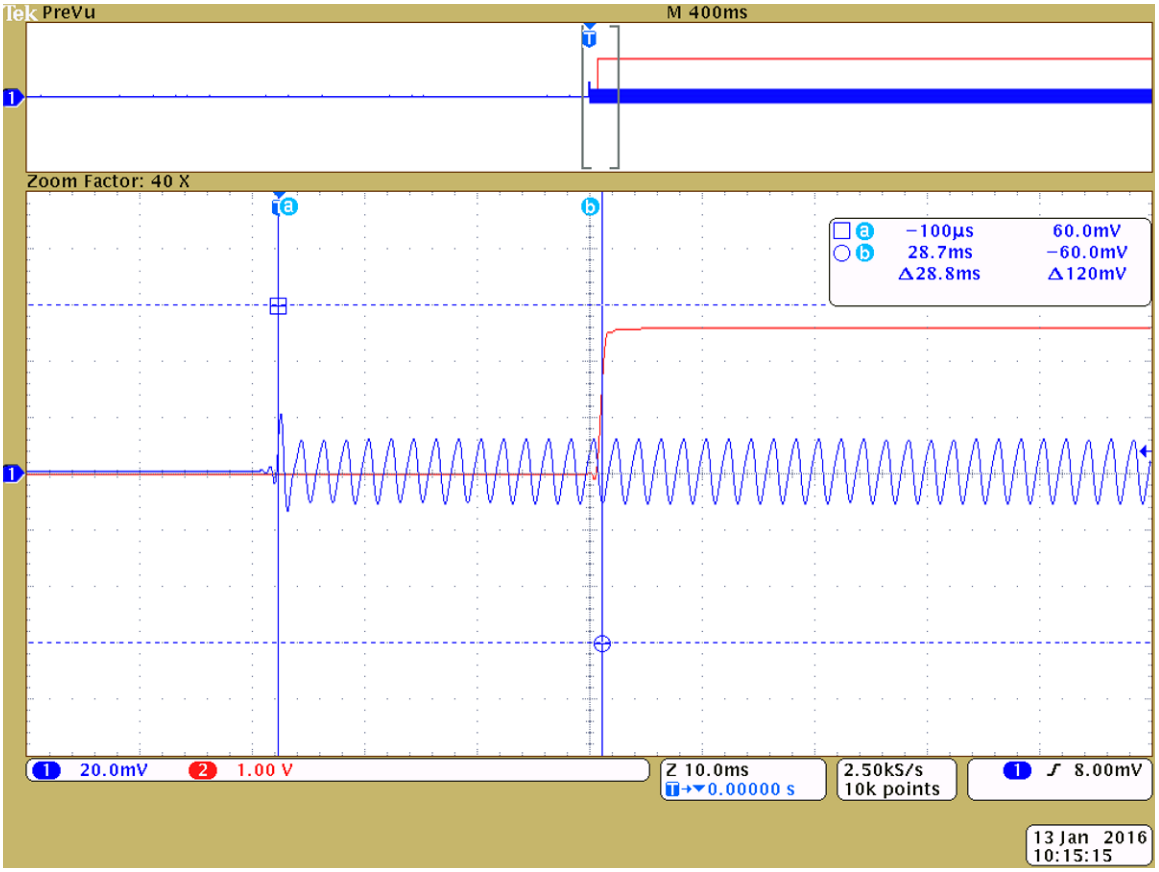


Figure 27. GFCI Test Signal

Copyright © 2016, Texas Instruments Incorporated

8.3 GFCI Fault Detection

The GFCI detection system must avoid false triggers below a specific level and ensure solid triggering above the trip level. In this design, the test cases for these levels are 10 mA and 15 mA respectively. To alter this range, the burden resistor and gain stages of the circuit can be changed accordingly.

For the no-trip portion, 10 mA was provided through the PTS3.3C test system through the 100:1 CT. Using the 330-Ω burden, the expected input voltage to the amplification and filtering is approximately 33 mV. Figure 28 shows an input signal amplitude (Channel 1) of 33.60 mV and no trip detected on the I/O line to the MSP430 (Channel 2).

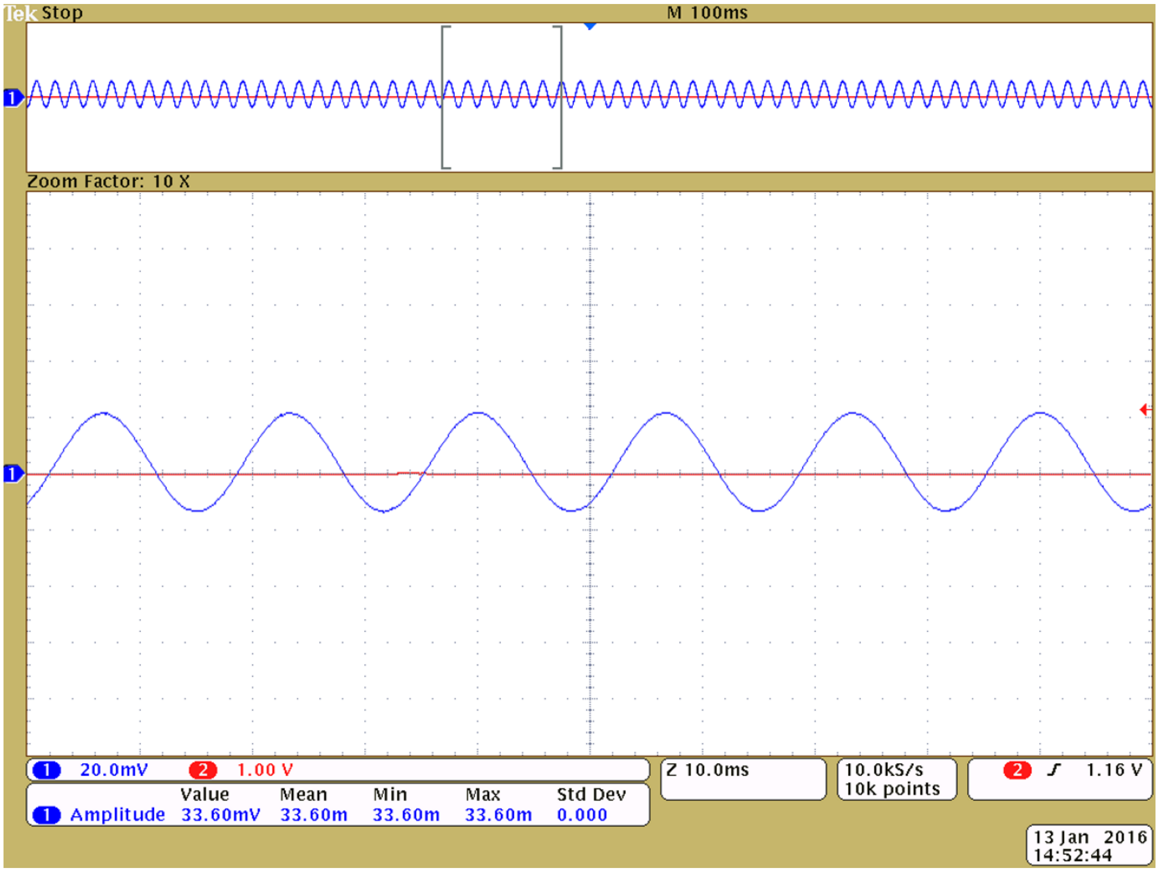
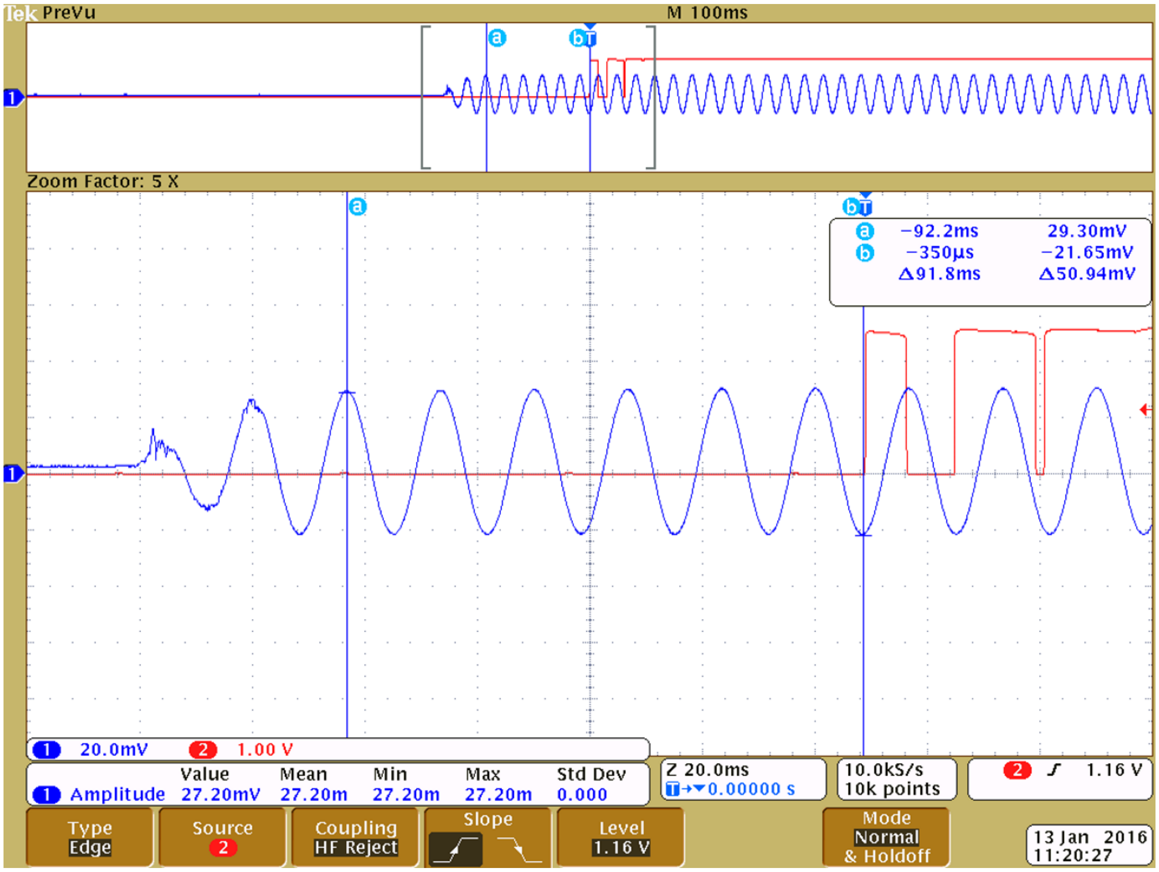


Figure 28. GFCI No Trip Detection

Copyright © 2016, Texas Instruments Incorporated

Using the PTS3.3C, a 15-mA AC source was latched through the CT. An input signal of approximately 50 mV is expected with the 100:1 CT and 330-Ω burden resistor, as well as a valid signal on the filter output. Figure 29 shows these results for the test case as expected. The system tripped within seven full-line cycles.



	Value	Mean	Min	Max	Std Dev
1 Amplitude	27.20mV	27.20m	27.20m	27.20m	0.000

Figure 29. GFCI Valid Trip

8.4 Energy Measurement

The energy measurement accuracy results for this reference design are identical to the results in the class 0.2 single-phase e-meter design. Reference this design for a full analysis of results (TIDM-SINGLEPHASEMETER).

8.5 Power Supply

For a full analysis of the power supply, upon which the TIDA-00637 design was based, visit the PMP10299.1 tool folder (PMP10299.1)

Copyright © 2016, Texas Instruments Incorporated

9 Design Files

9.1 Schematics

To download the schematics, see the design files at TIDA-00637.

9.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-00637.

9.3 Layout Prints

To download the layout prints, see the design files at TIDA-00637.

9.4 EagleCAD Project

To download the EagleCAD project files, see the design files at TIDA-00637.

10 Software Files

To download the software files, see the design files at TIDA-00637.

11 Terminology

CT— Current Transistor

EV— Electric vehicle

EVSE— Electric vehicle service equipment

GFCI— Ground-fault circuit interrupter

Plot line or plot wire—One-wire communication between an EVSE and an EV

12 References

1. Texas Instruments, *Class 0.2 Single-Phase E-meter*, (http://www.ti.com/tool/TIDM-SINGLEPHASEMETER)
2. Texas Instruments, *PMP10299 Test Results*, (TIDUAB3)

13 About the Author

BART BASILE is a systems architect in the Texas Instruments Grid Infrastructure Solutions Team, focusing on renewable energy and EV infrastructure. Bart works across multiple product families and technologies to leverage the best solutions possible for system level application design. Bart received his Bachelors of Science in Electronic Engineering from Texas A&M University.

Copyright © 2016, Texas Instruments Incorporated

IMPORTANT NOTICE FOR TI REFERENCE DESIGNS

Texas Instruments Incorporated ("TI") reference designs are solely intended to assist designers (“Buyers”) who are developing systems that incorporate TI semiconductor products (also referred to herein as “components”). Buyer understands and agrees that Buyer remains responsible for using its independent analysis, evaluation and judgment in designing Buyer’s systems and products.

TI reference designs have been created using standard laboratory conditions and engineering practices. **TI has not conducted any testing other than that specifically described in the published documentation for a particular reference design.** TI may make corrections, enhancements, improvements and other changes to its reference designs.

Buyers are authorized to use TI reference designs with the TI component(s) identified in each particular reference design and to modify the reference design in the development of their end products. HOWEVER, NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY OTHER TI INTELLECTUAL PROPERTY RIGHT, AND NO LICENSE TO ANY THIRD PARTY TECHNOLOGY OR INTELLECTUAL PROPERTY RIGHT, 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 components 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 such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

TI REFERENCE DESIGNS ARE PROVIDED "AS IS". TI MAKES NO WARRANTIES OR REPRESENTATIONS WITH REGARD TO THE REFERENCE DESIGNS OR USE OF THE REFERENCE DESIGNS, EXPRESS, IMPLIED OR STATUTORY, INCLUDING ACCURACY OR COMPLETENESS. TI DISCLAIMS ANY WARRANTY OF TITLE AND ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, QUIET ENJOYMENT, QUIET POSSESSION, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS WITH REGARD TO TI REFERENCE DESIGNS OR USE THEREOF. TI SHALL NOT BE LIABLE FOR AND SHALL NOT DEFEND OR INDEMNIFY BUYERS AGAINST ANY THIRD PARTY INFRINGEMENT CLAIM THAT RELATES TO OR IS BASED ON A COMBINATION OF COMPONENTS PROVIDED IN A TI REFERENCE DESIGN. IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, SPECIAL, INCIDENTAL, CONSEQUENTIAL OR INDIRECT DAMAGES, HOWEVER CAUSED, ON ANY THEORY OF LIABILITY AND WHETHER OR NOT TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES, ARISING IN ANY WAY OUT OF TI REFERENCE DESIGNS OR BUYER’S USE OF TI REFERENCE DESIGNS.

TI reserves the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products are sold subject to TI’s terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI’s terms and conditions of sale of semiconductor products. Testing and other quality control techniques for TI components are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

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

Reproduction of significant portions of TI information in TI data books, data sheets or reference designs is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards that anticipate dangerous failures, monitor failures and their consequences, lessen the likelihood of dangerous failures and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in Buyer’s safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI’s goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed an agreement specifically governing such use.

Only those TI components that TI has specifically designated as military grade or “enhanced plastic” are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components that have ***not*** been so designated is solely at Buyer's risk, and Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

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