# (R) SAE Electric Vehicle Conductive Charge Coupler

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Prepared by the SAE EV Charging Systems Committee

Forward - Since the energy stored in a battery provides the power for an electric vehicle(EV), an EV requires a method of charging the battery on a regular basis. Conductive charging is a method for connecting the electric power supply network to the EV for the purpose of transferring energy to charge the battery and operate other vehicle electrical systems, establishing a reliable equipment grounding path, and exchanging control information between the EV and the supply equipment. This document describes the functional and performance requirements for proper operation and the physical interface for a conductive charging system. This document contains 24 pages, including this page, and should not be used as a design tool if any of the pages are missing.

Note: This SAE Recommended Practice is intended as a guide toward standard practice and is subject to change to keep pace with experience and technical advances

Table of Contents



1. Scope - This SAE Recommended Practice covers the general physical, electrical, and performance requirements for the electric vehicle conductive charge system and coupler for use in North America. The intent of this document is to define a common electric vehicle conductive charging system architecture including operational requirements and the functional and dimensional requirements for the vehicle inlet and mating connector.

2. References

2.1 Applicable Publications - The following publications form a part of this specification to the extent specified herein. The latest issue of SAE and other applicable publications shall apply.

2.1.1 SAE Publications – Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096

SAE J55-5: Performance Levels and Methods of Measurement of Magnetic and Electric Field Strength from Electric Vehicles, Broadband, 9 kHz to 30 MHz

SAE J551-11: Vehicle Electromagnetic Immunity – Off Vehicle sources
SAE J551-15: Vehicle electromagnetic immunity – Electrostatic discharge (ESD)
SAE J1211 – Recommended Environmental Practices for Electronic Equipment Design
SAE J1742 – Connections for High Voltage On-board Vehicle Electrical Wiring Harness
SAE J1850 – Class B Data Communication Network Messages
SAE J2178 – Class B Data communication Network Messages – Network Management Strategies
SAE J2293 – Energy Transfer System for Electric Vehicle

2.1.2 Underwriters Laboratories, Inc. Publications – Available from Underwriters Laboratories, Inc., Corporate offices, 333 Pfingsten Road, Northbrook, IL 60062-2096. Phone (708) 272-8800

UL 50 – Standard for Enclosures for Electrical Equipment
UL 94 – Tests for Flammability of Plastic Materials for Parts in Devices and Appliances
UL 746A – Standard for Polymeric Materials – Short Term Property Evaluations
UL 840 – Insulation Coordination including Clearance and Creepage Distances for Electrical Equipment
UL 1439 – Determination of Sharpness of Edges on Equipment
UL 2202 – EV Charging System Equipment
UL 2231 – Personnel Protection Systems for EV Charging Circuits
UL2251 – Plugs, Receptacles, and Couplers for Electric Vehicles

2.1.3 National Fire Protection Association Publication – Available from The National Fire Protection Association, Batterymarch Park, Quincy, MA 02269

National Electrical Code, NFPA 70 – Article 625

2.1.4 Canadian Standards Association – Available from  Canadian Standards Association, 170 Rexdale Boulevard, Rexdale, Ontario, Canada M9W 1R3

Canadian Electrical Code – Part 1, Section 86

2.1.5 Federal Communication Commission Publications – Available from The Superintendent of Documents, U. S. Government Printing Office, Mail Stop SSOP, Washington, D.C. 20402-9320

CFR 47- Code of Federal Regulations - Title 47, Parts 15A, 15B, and 18C
CFR 40 - Code of Federal Regulations – Title 40, Part 600, Subchapter Q

2.2 Related Publications - The following publications are provide for information purposes only and are not a required part of this document

2.2.1 SAE Publications – Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096

SAE J1773 – SAE Electric Vehicle Inductively Coupled Charging

2.2.2 International Electrotechnical Commission Publications – Available from the International Electrotechnical Commission, 3, Rue de Varembe / CH-1211, Geneva 20, Switzerland

Note: IEC Publications are also available from The American National Standards Institute, 11 West 42nd Street, New York, NY 10036-8002

IEC 61851-1 Electric Vehicle Conductive Charging System – Part 1: General Requirements
IEC 61851-2.1 Electric Vehicle Conductive Charging System – Part 2.1: Electric Vehicle Requirements for Connection to an AC / DC supply

IEC 61851-2.2 Electric Vehicle Conductive Charging System – Part 2.2: AC electric vehicle charging station
IEC 61851-2.3 Electric Vehicle Conductive Charging System – Part 2.3: DC electric vehicle charging station

## 3. Definitions

3.1 Charger – An electrical device that converts alternating current energy to regulated direct current for replenishing the energy of an energy storage device (i.e. battery) and may also provide energy for operating other vehicle electrical systems.

3.2 Conductive – Having the ability to transmit electricity through a physical path (conductor).

3.3 Connector – A conductive device that by insertion into a vehicle inlet establishes an electrical connection to the electric vehicle for the purpose of transferring energy and exchanging information. This is part of the coupler.

3.4 Coupler – A mating vehicle inlet and connector set.

3.5 Electric vehicle (EV) – An automotive type vehicle, intended for highway use, primarily powered by an electric motor that draws from a rechargeable energy storage device. For the purpose of this document the definition in the United States Code of Federal Regulations – Title 40, Part 600, Subchapter Q is used. Specifically, an automobile means:

a. Any four wheeled vehicle propelled by a combustion engine using on-board fuel or by an electric motor drawing current from a rechargeable storage battery or other portable energy devices (rechargeable using energy from a source off the vehicle such as residential electric service)
b. Which is manufactured primarily for use on public streets, roads, and highways
c. Which is rated not more that 3855.6 kg (8500 lbs.), which has a curb weight of not more than 2721.6 kg (6000 lbs.), and which has a basic frontal area of not more than 4.18 square meters (45 square feet).

3.6 Enclosure – The case or housing into which the contacts and insulators are assembled

3.7 Insulator – The portion of a coupler that provides for the separation, support, sealing, and protection of the contacts.

3.8 Contact – A conductive element in a connector that mates with a corresponding element in the vehicle inlet to provide an electrical path.

3.9 AC Level 1 charging – A method that allows an EV to be connected to the most common grounded electrical receptacle (NEMA 5-15R). The vehicle shall be fitted with an on-board charger capable of accepting energy from the existing alternating current (a.c.) supply network. The maximum power supplied for AC Level 1 charging shall conform to the values in Table 1.

3.10 AC Level 2 charging – A method that utilizes dedicated a.c. EV supply equipment in either private or public locations. The vehicle shall be fitted with an on-board charger capable of accepting energy from alternating current electric vehicle supply equipment. The maximum power supplied for AC Level 2 charging shall conform to the values in Table 1.

3.11 DC charging – A method that utilizes dedicated direct current (d.c.) EV supply equipment to provide energy from an appropriate off-board charger to the EV in either private or public locations. The range of charger ratings encompassed shall conform to the values shown in Table 1.

3.12 Off-board charger – A charger located off of the vehicle

3.13 On-board charger – A charger located on the vehicle

3.14 Equipment ground (grounding conductor) – A conductor used to connect the non-current carrying metal parts of the EV supply equipment to the system grounding conductor, the grounding electrode conductor, or both at the service equipment.

3.15 Chassis ground – The conductor used to connect the non-current carrying metal parts of the vehicle high voltage system to the equipment ground.

3.16 Control pilot – The primary control conductor that is connected to the equipment ground through control circuitry on the vehicle and performs the following functions:

a. verifies that the vehicle is present and connected
b. permits energization/de-energization of the supply
c. transmits supply equipment current rating to the vehicle
d. monitors the presence of the equipment ground
e. establishes vehicle ventilation requirements.

3.17 Vehicle inlet – The device on the electric vehicle into which the connector is inserted for the purpose of transferring energy and exchanging information. This is part of the coupler.

3.18 Electric Vehicle Supply Equipment (EVSE) – The conductors, including the ungrounded, grounded, and equipment grounding conductors, the electric vehicle connectors, attachment plugs, and all other fittings, devices, power outlets, or apparatuses installed specifically for the purpose of delivering energy from the premises wiring to the electric vehicle.

3.19 EV Charging System – The equipment required to condition and transfer energy from the constant frequency, constant voltage supply network to the direct current, variable voltage EV traction battery bus for the purpose of charging the battery and/or operating vehicle electrical systems while connected.

4. General Conductive Charging System Description - In the most fundamental sense, there are 3 functions, 2 electrical and 1 mechanical, that must be performed to allow charging of the EV battery from the electric supply network. The electric supply network transmits alternating current electrical energy at various nominal voltages(rms) and a frequency of 60 Hz. The EV battery is a direct current device that operates at a varying voltage depending on the nominal battery voltage, state-of-charge, and charge/discharge rate. The first electrical function converts the alternating current to direct current and is commonly referred to as rectification. The second electrical function is the supply voltage must be controlled or regulated at a voltage level that permits a managed charge rate based on the battery charge acceptance characteristics – i.e. voltage, capacity, electrochemistry, and other parameters. The combination of these two functions is the embodiment of a charger. The mechanical function is the physical coupling or connecting of the EV to the EVSE and is performed by the user. The conductive charging system consists of a charger and a coupler. The conductive system architecture is suitable for use with both on-board and off-board chargers with electrical ratings as specified in Table 1 and as shown in FIGURE 1.

TABLE 1 – CHARGE METHOD ELECTRICAL RATINGS (North America)

| Charge Method | Nominal Supply Voltage(Volts) | Maximum Current (Amps-continuous) | Branch Circuit Breaker rating (Amps) |
|---|---|---|---|
| AC Level 1 | 120 vac, 1-phase | 12 A | 15 A (minimum) |

| | | | |
|---|---|---|---|
| AC Level 2 | 208 to 240 vac, 1-phase | 32 A | 40 A |
| DC Charging | 600 vdc maximum | 400 A maximum | As required |

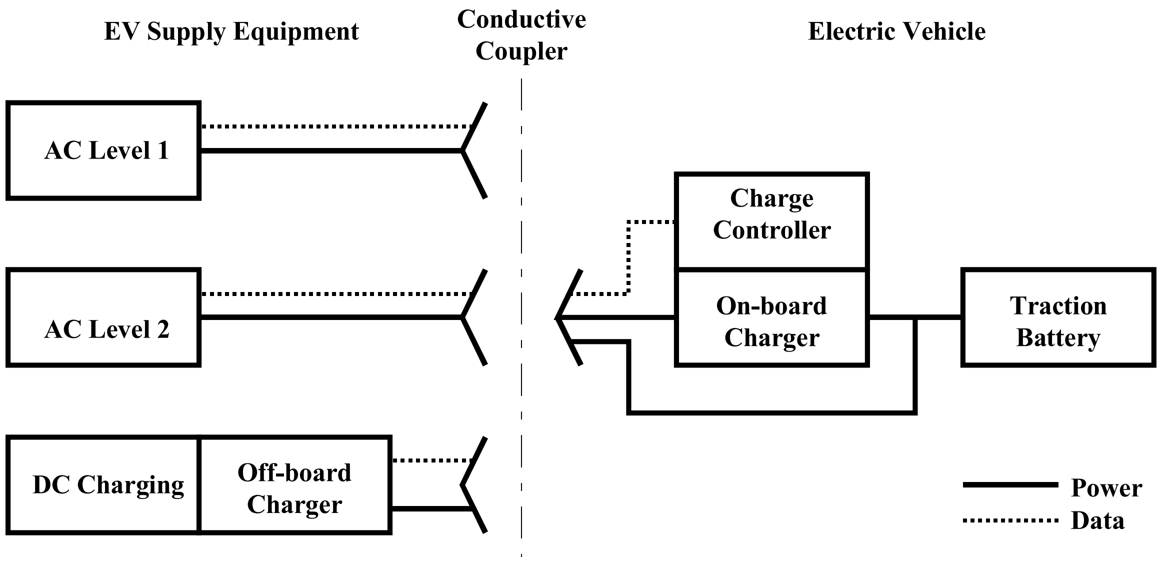



FIGURE 1 – CONDUCTIVE EV CHARGING SYSTEM ARCHITECTURE

4.1 Interface Functions - The conductive coupler consists of a connector/vehicle inlet set with electromechanical contacts imbedded in an insulator and contained within a housing for each of the mating parts. The contacts provide a physical connection at the vehicle interface for the power conductors, equipment grounding conductor, control pilot conductor, and under certain conditions serial data conductors between the EV and EVSE. The interface consists of 9 possible contacts that perform the interface functions as shown in FIGURE 2 and specified in TABLE 2.

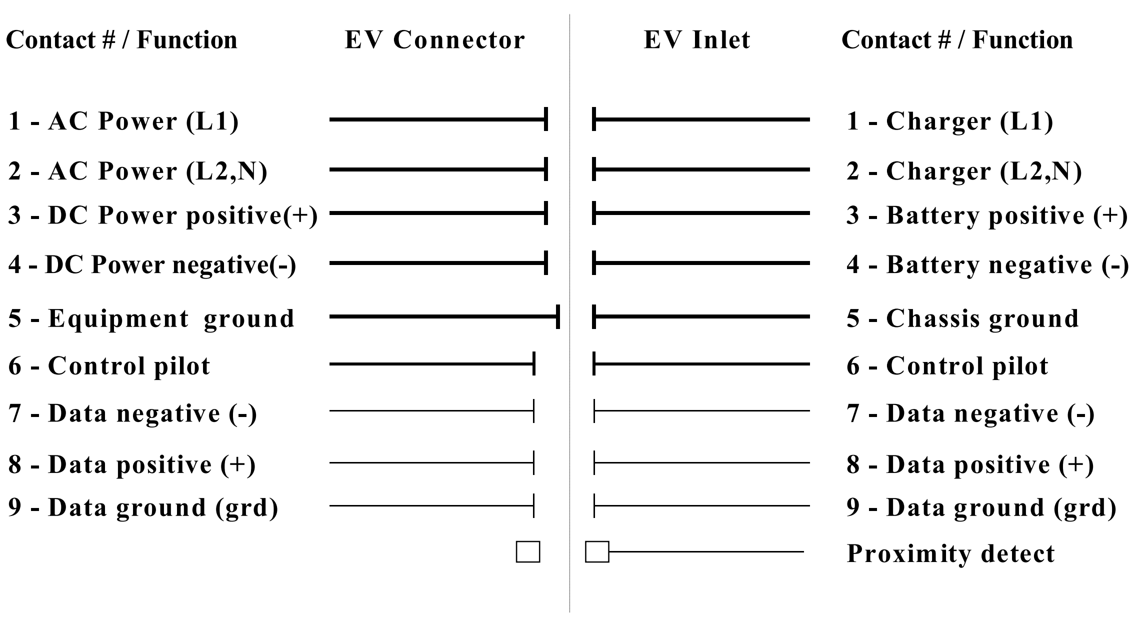


FIGURE 2 – CONDUCTIVE COUPLER CONTACT INTERFACE FUNCTIONS

TABLE 2 – CONDUCTIVE COUPLER CONTACT FUNCTIONS

| Contact # | Connector Function | Vehicle Inlet Function | Description |
|---|---|---|---|
| 1 | AC Power (L1) | Charger 1 | Power for AC Level 1 and 2 |
| 2 | AC Power (L2,N) | Charger 2 | Power for AC Level 1 and 2 |
| 3 | DC Power positive(+) | Battery positive(+) | Power for DC charging |
| 4 | DC Power negative(-) | Battery negative(-) | Power for DC charging |
| 5 | Equipment ground | Chassis ground | Connect EVSE equipment grounding conductor to EV chassis ground during charging |
| 6 | Control pilot | Control pilot | Primary control conductor (operation described in Section 5) |
| 7 | Data negative(-) | Data negative(-) | Negative serial data conductor (SAE J1850 Type 2 only) |
| 8 | Data positive(+) | Data positive(+) | Positive serial data conductor (SAE J1850 Type 1 and 2) |
| 9 | Data ground | Data ground | Serial data ground conductor (SAE J1850 Type 1 and 2) |

4.2 AC Level 2 Charging - The primary method of EV charging that extends a.c. power from the electric supply to an on-board charger from dedicated EVSE as shown in FIGURE 3. The electrical ratings are similar to large household appliances and specified in TABLE 1. AC Level 2 may be utilized at home, workplace, and public charging facilities.

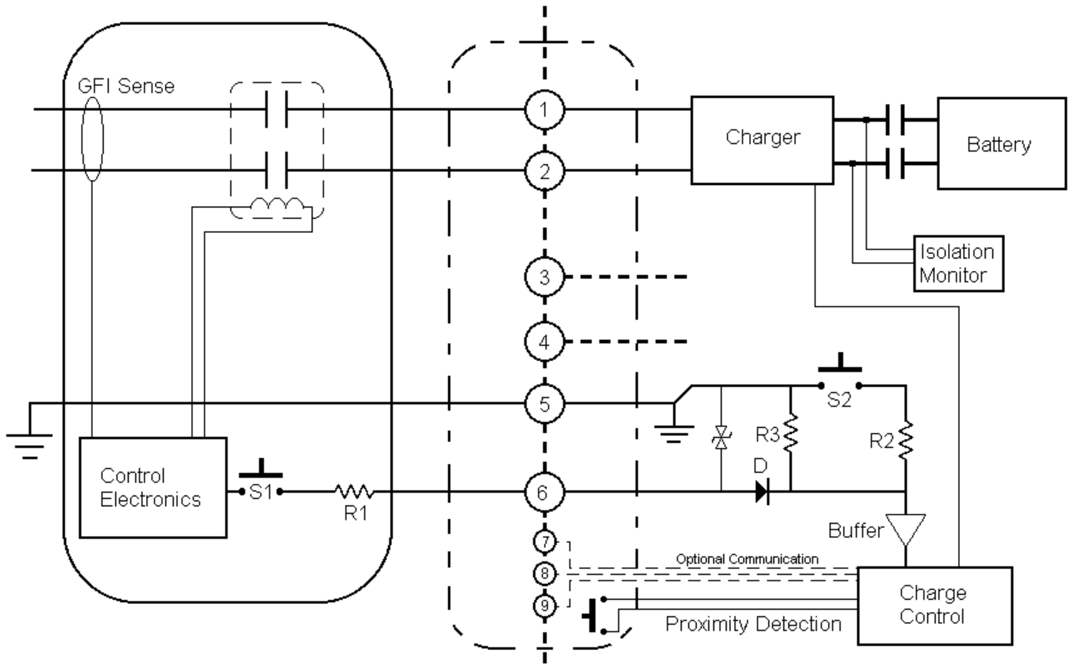



FIGURE 3 – AC LEVEL 2 SYSTEM CONFIGURATION

4.3 AC Level 1 Charging - A method of EV charging that extends a.c. power from the electric supply to an on-board charger from the most common grounded electrical receptacle using an appropriate cord set as shown in FIGURE 4 at the electrical ratings specified in TABLE 1. AC level 1 allows connection to existing electrical receptacles in compliance with the National Electrical Code.

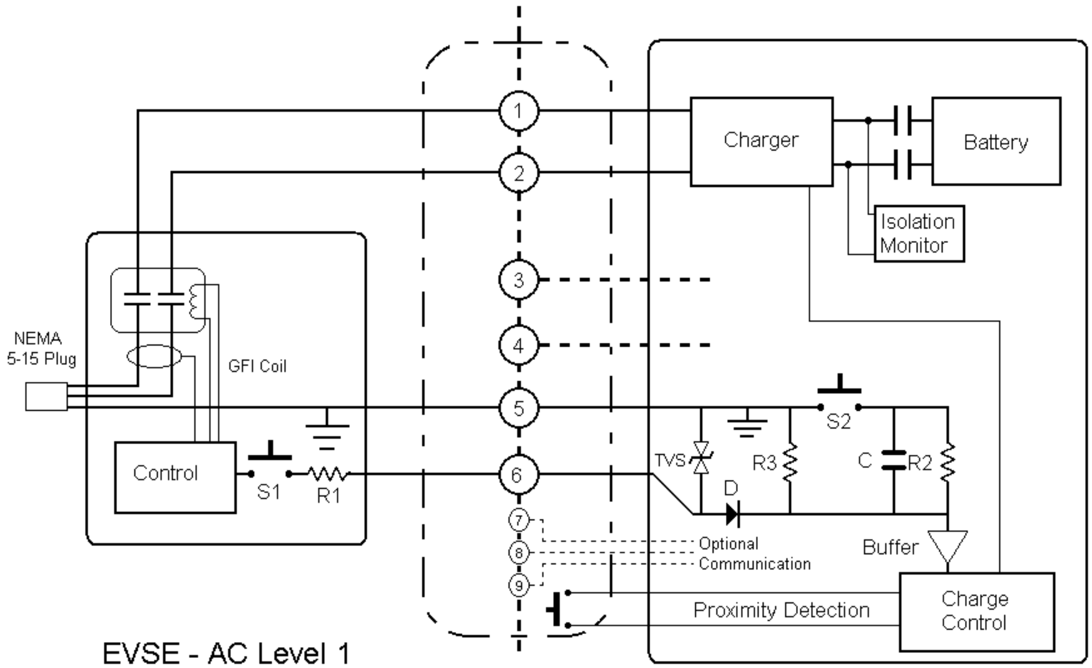



FIGURE 4 – AC LEVEL 1 SYSTEM CONFIGURATION

4.4 DC Charging - The conductive charging system architecture provides a method to provide energy from an appropriate off-board charger as shown in FIGURE 5 to the EV in either private or public locations. The power available for DC Charging can vary from power levels similar to AC Level 1 and 2 to very high power levels that may be capable of replenishing more than ½ of the capacity of the EV battery in as few as 10 minutes. The electrical ratings for DC Charging are specified in TABLE 1.

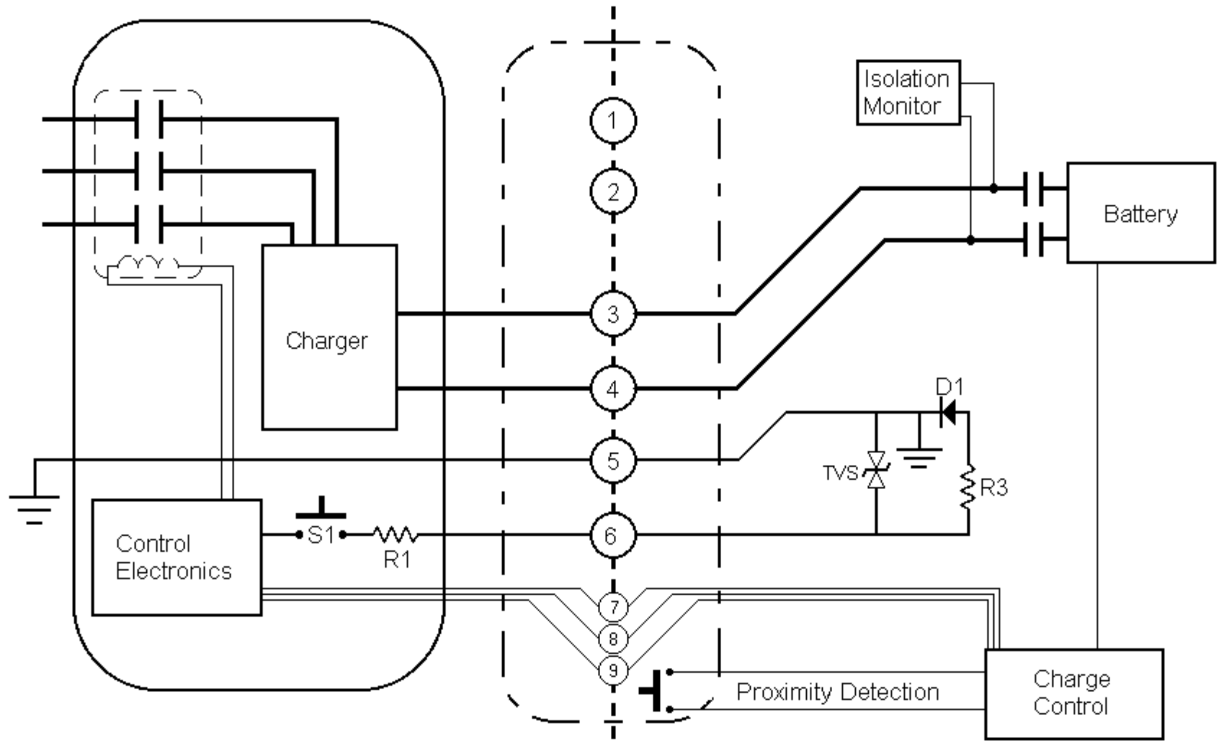



FIGURE 5 – DC CHARGING SYSTEM CONFIGURATION

5. Control and Data - The control pilot circuit is the primary control means to ensure proper operation when connecting an EV to the EVSE. This section describes the functions and sequencing of events for this circuit based on the recommended typical implementation or equivalent circuit parameters. Additional data exchange between the EV and EVSE, using SAE J1850, is mandatory for DC Charging control.

5.1 Control Pilot Circuit – A typical control pilot circuit is shown in Figure 6.

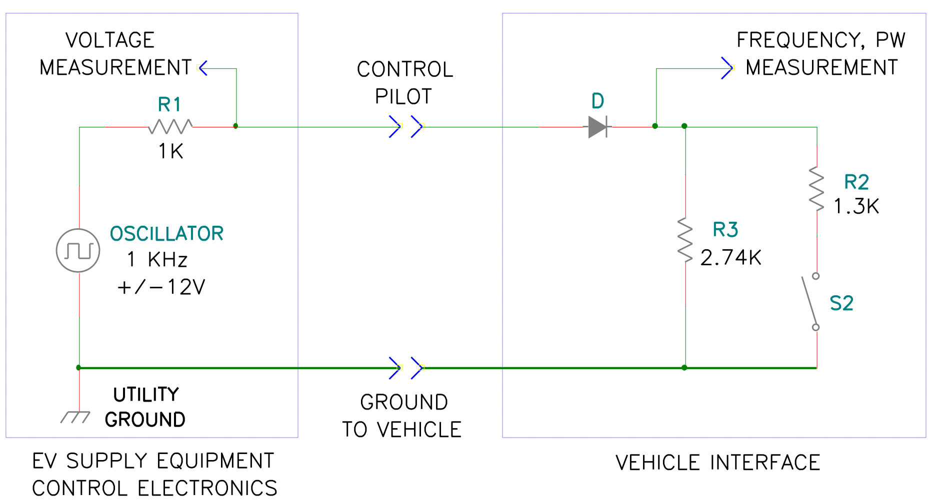



FIGURE 6 – TYPICAL CONTROL PILOT CIRCUIT

5.2 Control Pilot Circuit – The equivalent control pilot circuit and vehicle states are shown in FIGURE 7 and defined in TABLE 3, TABLE 4, and TABLE 5

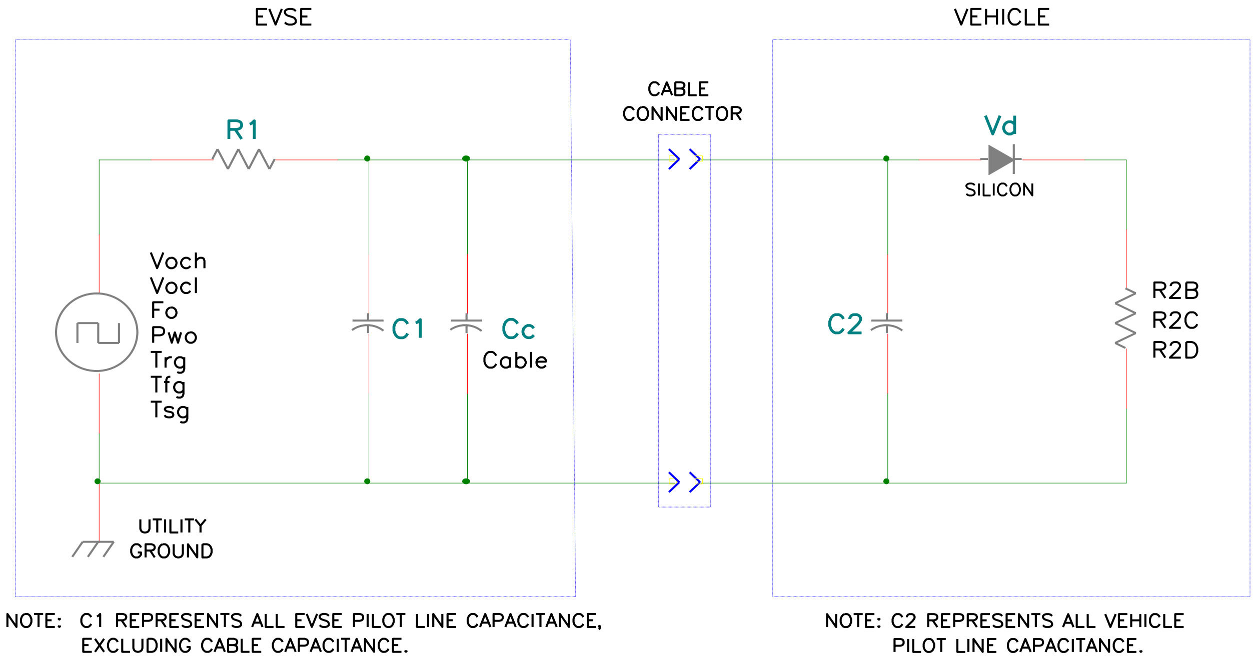



FIGURE 7 – CONTROL PILOT EQUIVALENT CIRCUIT

TABLE 3 – DEFINITION OF VEHICLE STATES

| Vehicle state designation | Voltage ( vdc nominal) | Description of vehicle state |
|---|---|---|
| State A | 12.0 ( a ) | Vehicle not connected |
| State B | 9.0 ( b ) | Vehicle connected / not ready to accept energy |
| State C | 6.0 ( b ) | Vehicle connected / ready to accept energy / indoor charging area ventilation not required |
| State D | 3.0 ( b ) | Vehicle connected / ready to accept energy / indoor charging area ventilation required |
| State E | 0 | EVSE disconnected, utility power not available, or other EVSE problem |
| State F | -12.0 ( a ) | EVSE not available, or other EVSE problem |

Notes:
a ) static voltage
b ) positive portion of 1 KHz square wave, measured after transition has fully settled

TABLE 4 – EVSE CONTROL PILOT CIRCUIT PARAMETERS (See Figure 7)

| Parameter ( a ) | Symbol | Units | Nominal value | Maximum value | Minimum value |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| **Generator** | | | | | |
| voltage high, open circuit | Voch | Volts | 12.00 | 12.60 | 11.40 |
| voltage low, open circuit | Vocl | Volts | -12.00 | -12.60 | -11.40 |
| Frequency | Fo | Hertz | 1000 | 1050 | 950 |
| pulse width ( d ) | Pwo | Microsec | Per Figure 8 | Nom, + 25 usec | Nom, - 25 usec |
| rise time ( b ) | Trg | Microsec | n.a. | 2 | n.a. |
| fall time ( b ) | Tfg | Microsec | n.a. | 2 | n.a. |
| settling time ( c ) | Tsg | microsec | n.a. | 3 | n.a. |
| **Output Components** | | | | | |
| equivalent source resistance | R1 | Ohms | 1000 | 1030 ( f ) | 970 ( f ) |
| total equivalent EVSE capacitance, w/o cable | C1 | Picofarads | n.a. | n.a. | 300 ( e ) |
| total equivalent EVSE capacitance, including cable | C1 + Cc | Picofarads | n.a. | 3100 | n.a. |

Notes :

a.) Tolerances to be maintained over the environmental conditions and useful life as specified by the manufacturer
b.) 10% to 90% of complete negative-to-positive transition or 90% to 10% of complete positive-to-negative transition. Generator rise/fall times longer than 2 usec may affect Pilot Line rise/fall times defined by source resistance and line capacitance.
c.) to 95% of steady state value, measured from start of transition
d.) measured at 50% points of complete negative-to-positive or positive-to-negative transitions.
e.) guarantees rise time slow enough to remove transmission line effects from cable
f.) Maximum and minimum resistor values are +/- 3% about nominal.

TABLE 5 – EV CONTROL PILOT CIRCUIT PARAMETERS (See Figure 7)

| Parameter ( a ) | Symbol | Units | Nominal value | Maximum value | Minimum value |
|---|---|---|---|---|---|
| Equivalent load resistance – State B | R2B | Ohms | 2740 | 2822 ( e ) | 2658 ( e ) |
| Equivalent load resistance – State C ( b ) | R2C | Ohms | 882 | 908 ( e ) | 856 ( e ) |
| Equivalent load resistance – State D ( c ) | R2D | Ohms | 246 | 253 ( e ) | 239 ( e ) |
| Total equivalent | C2 | picofarads | n.a. | 2,400 | n.a. |

capacitance

| | | | | | |
|---|---|---|---|---|---|
| Equivalent diode voltage drop ( d ) | Vd | Volts | 0.70 | 0.85 | 0.55 |

Notes:

a.) Tolerances to be maintained over the environmental conditions and useful life as specified by the manufacturer
b.) Vehicles not requiring ventilation for indoor charging areas
c.) Vehicles requiring ventilation for indoor charging areas
d.) Silicon small signal diode, -40 C to 85 C, forward current 2.75 to 10.0 ma
e.) Maximum and minimum resistor values are +/- 3% about nominal

TABLE 6 – EVSE and EV Response Time Specifications

| | Initial Condition (a) (b) (c) | New Condition | EVSE Response Time | EV Response Time | Specification or Condition |
|---|---|---|---|---|---|
| 1 | State = x<br>OSC = off | State = x<br>OSC = on | no maximum | | delay until pilot oscillator will be turned on by EVSE |
| 2 | State = x<br>OSC = x | State = A<br>OSC = x | 100 ms maximum | | delay from disconnect until the contactor opens and terminates AC energy transfer |
| 3 | State = x<br>OSC = x | State = E or<br>State = F<br>OSC = x | | 5 seconds maximum | delay until EV opens battery isolation contactor |
| 4 | State = x<br>OSC = on | State = A<br>OSC = off | 2 seconds maximum | | delay until oscillator turned off after EV is disconnected |
| 5 | State = B<br>OSC = on | State = C or<br>State = D<br>OSC = on | 3 seconds maximum | | delay until contactor closes and initiates AC energy transfer in response to S2 closed |
| 6 | State = C or<br>State = D<br>OSC = on | State = B<br>OSC = on | 3 seconds maximum | | delay until contactor opens and terminates AC energy transfer in response to S2 opened |
| 7 | State = x<br>OSC = x | State = A or<br>State = E or<br>State = F<br>OSC = x | | 3 seconds maximum | in response to an invalid pilot the EV enters a safe mode and if necessary opens S2 and terminates the AC energy transfer |
| 8 | State = x<br>OSC = x | State = E or<br>State = F<br>OSC = x | 3 seconds maximum | | delay from EVSE setting invalid pilot until termination of AC energy transfer |
| 9 | State = B or<br>State = C or<br>State = D<br>OSC = on | invalid pilot frequency | | 3 seconds maximum | in response to an invalid pilot frequency the EV enters a safe mode and if necessary opens S2 and terminates the AC energy transfer |
| 10 | State = x<br>OSC = x | external signal to EVSE | 10 seconds maximum | | delay from external load management signal until EVSE modifies pilot signal state or other required response |
| 11 | State = C or | change in | | 5 seconds | EV modifies maximum current draw |

| | | | | | |
|---|---|---|---|---|---|
| | State = D<br>OSC = on | pilot duty cycle | | maximum | for on-board battery charger in response to pilot signal duty cycle modification |

Notes:

a.) Current State from table 3 defining pilot voltage and vehicle state
b.) OSC = off for pilot oscillator turned off, OSC = on for pilot oscillator turned on
c.) x for state or oscillator indicates any condition or unknown condition

1.) The pilot signal oscillation indicates that the EVSE is ready to supply energy. Regardless of the state transition, there is no guarantee that the EVSE will be ready to supply AC energy within a minimum time period.
2.) The transition from any State to State A indicates the vehicle connector has been removed. For safety reasons, it is important to guarantee de-energization of the connector.
3.) The transition from any State to State E or State F is an indication that the connector has been removed or that the EVSE is not available. For safety reasons, it is important to guarantee the vehicle goes into a safe state.
4.) After a transition from any State to State A, the EVSE should turn off the oscillator. For the purpose of filtering and reasonable control response time, the EVSE will not respond immediately. The connector may be immediately reinserted into the vehicle, and the EV could see State C or State D with the oscillator turned on and no AC energy transfer for this maximum time before the oscillator is turned off.
5.) After the vehicle closes S2 in order to request AC energy transfer, the vehicle can expect the contactor to close within a specified time period.
6.) After the vehicle opens S2, in order to stop requesting AC energy transfer, it can expect the contactor to open within a specified time period.
7.) The vehicle must respond to the pilot signal voltages. In this case, the EVSE may be experiencing a power outage, ground fault, or other condition that requires termination of the AC energy transfer mode. The vehicle should respond by opening the S2 and entering a safe mode.
8.) If the EVSE is experiencing a condition that requires termination of the AC energy transfer mode, the EVSE must open the contactor in less than 3 seconds from setting the pilot signal to a non AC energy transfer state.
9.) The vehicle must respond to a pilot signal frequency that is significantly out of tolerance. The frequency of the EVSE oscillator is used to verify connection to a compatible EVSE and proper operation of the EVSE. If the frequency is incorrect, the vehicle should respond by opening the S2 and entering a safe mode. The recommended tolerance is ±10%, 1100Hz to 900Hz.
10.) It is common for EVSE equipment to support an input signal for the purpose of external load control. This input is used for various purposes including off peak charging support, utility load shedding, and building load management controllers. A maximum response time must be specified to guarantee universal compatibility with the external controlling equipment.
11.) The EVSE may modify the pilot signal pulse width at any time, commanding the EV to increase or decrease the maximum AC current draw. The vehicle must adhere to the maximum response time in order guarantee universal compatibility with the external controlling equipment. (see Table 6, specification 10)

5.3 Control Pilot Functions - The control pilot performs the following functions.

5.3.1 Verification of Vehicle Connection - The EVSE is able to determine that the connector is fully inserted into the vehicle inlet and properly connected to the EV by sensing resistance R3 as shown in FIGURES 3, 4, 5, and 6. The diode, D1, insures that an EV is actually connected and can be discriminated from other potential low impedance loads.

5.3.2 EVSE Ready to Supply Energy - The EVSE is able to indicate to the EV that it is ready to supply energy by turning on the oscillator and providing the square wave signal specified in Figure 8. In each of the states specified in Table 3, the EVSE may supply the pilot as a DC signal or as an oscillating signal. However, normally the oscillator is only turned on in State B, State C, or State D. Oscillation in other states should only be transitory as specified in Table 6.

5.3.3 EV Ready to Accept Energy - The EV indicates that it is ready to accept energy from the EVSE by closing switch S2, as shown in FIGURES 3, 4, 5, and 6, when the current profile on the control pilot oscillator is sensed. The EV may de-energize the EVSE at any time by opening switch S2.

5.3.4 Determination of Indoor Ventilation - The EVSE is able to determine if the EV requires indoor charging ventilation by sensing the voltage as specified in Table 3. If required, the EVSE will provide a signal to turn on the indoor charging area ventilation system according to NFPA 70 / NEC – Article 625.

5.3.5 EVSE Current Capacity - The EVSE provides the maximum available continuous current capacity, and by inference the rating of the protective circuit breaker, to the EV by modulating the pulse width as described in TABLE 4 and shown in FIGURE 8. The available line current is linearly proportional to the pulse width by the following equation:

**Ampacity = (0.6 amps x pulse width, in usec) / 10 usec**, **from 100 to 800 usec**.

As an example, a 200 usec pulse width would be (0.6 x 200)/10 = 12 amps. In this case, the vehicle must adjust its current draw to a maximum of 12 amps.

A pulse width of 900 usec, represents an off-board DC charger and requires that serial data communication be established with the EV before proceeding. The EVSE may accept an external signal to vary the pulse width for supply or premises power limitations. The EV shall use the pulse width to control the on-board charger input/output.

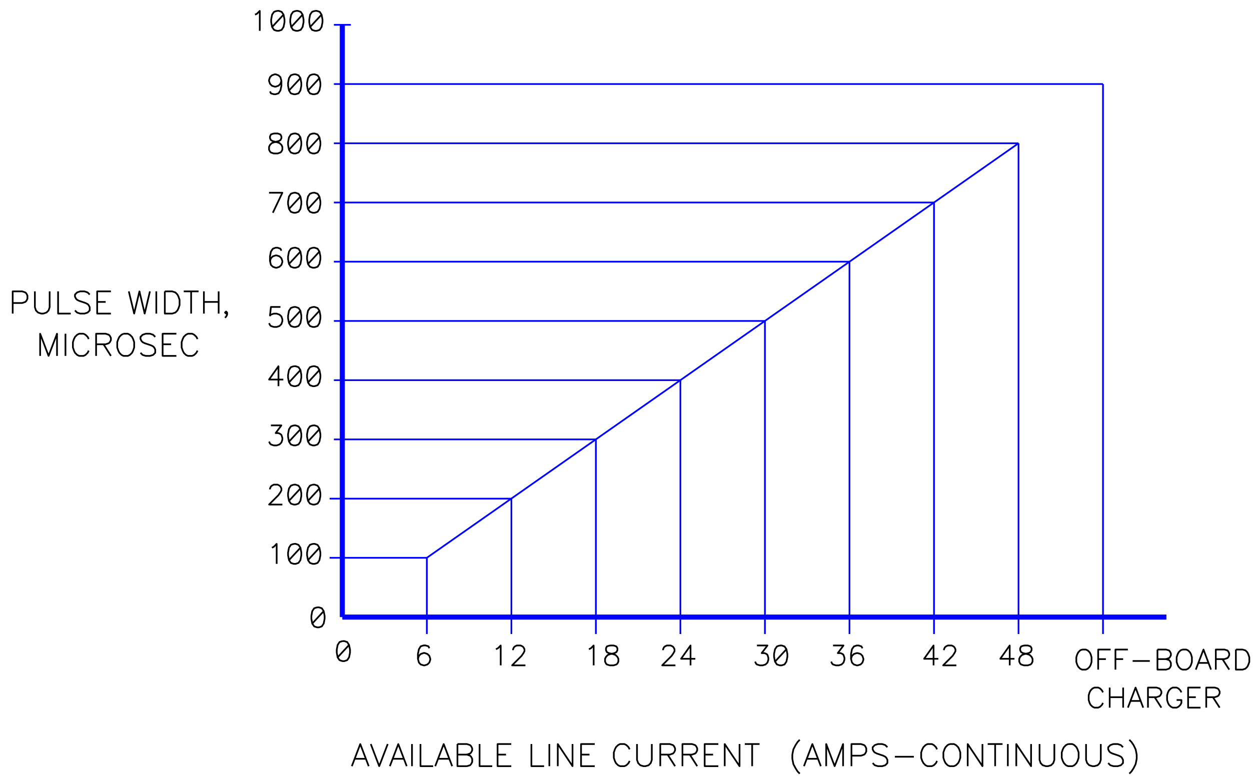



FIGURE 8 – EVSE CURRENT CAPACITY VS. CONTROL PILOT PULSE WIDTH

5.3.6 Verification of Equipment Grounding Continuity - The equipment grounding conductor provides a return path for the control pilot current to insure that the EVSE equipment ground is safely connected to the EV chassis ground during charging. Loss of this signal shall result in the automatic de-energization at the EVSE.

5.4 Proximity Detection - Upon initial insertion of the connector into the vehicle inlet and before any electrical contact is established, the coupler shall provide a means to detect the presence of the connector in the vehicle inlet at a point where damage to coupler, EV, or EVSE could occur if the EV were to be moved. The means shall provide a signal to activate the EV charge controller and engage the EV drive interlock system. One method to accomplish this is a permanent magnet in the connector and a corresponding hall effect switch in the vehicle inlet as specified in Section 8. Other functionally equivalent means to measure the presence of the connector's magnet shall be permitted at the discretion of the EV manufacturer.

5.5 Serial Data Transfer - Coupler contact numbers 7, 8, and 9 are provided to allow an exchange of serial data information between the EV and the EVSE based on SAE J1850, SAE J2178, and SAE J2293. The serial data link is mandatory for DC Charging to allow the vehicle to control the charge process. The serial data link is optional for AC Level 2 and AC Level 1 – i.e. for displaying charge related or other information to the user.

5.6 Typical Start Up Sequence - The charge process shall commence sequentially according to the following steps as the connector is inserted into the vehicle inlet:

1. The proximity detection means activates EV charge controller and drive interlock

2. Verification of EV connection is detected by EVSE, State B, the oscillator is turned off.
3. EVSE indicates that it is ready to supply energy by turning on the oscillator and supplying square wave pilot signal to the EV, State B.
4. EV indicates that it is ready to accept energy from the EVSE by closing switch S2 and providing vehicle ventilation information to the EVSE, State C or State D.
5. The EVSE determines that the equipment grounding conductor to the EV chassis ground is in place.
6. The EVSE determines that the EV pilot control circuitry is correctly configured by verifying the presence of the diode. The negative side of the pilot pulse must be within the range specified in Table 4.
7. The EVSE determines if indoor area ventilation is required or not. If indoor charging area ventilation is not required then proceed to the next step. If indoor charging area ventilation is required then 3 conditions can exist with corresponding EVSE responses. They are:

    a) Condition 1 – If the EVSE is listed for indoor charging of all vehicles, turn on the indoor area ventilation system and proceed to the next step.
    b) Condition 2 – If the EVSE is listed for outdoor charging of all vehicles, proceed to the next step
    c) Condition 3- If the EVSE is listed for vehicles not requiring indoor charging area ventilation, terminate the process and do not allow energization

8. The EV determines the nature of and available current from the EVSE according to 1 of the following 3 conditions by measuring the pulse width of the signal and proceeding as follows:

    a) If the pulse width is between 100 and 800 usec, establish the serial data link, if required, and proceed to the next step
    b) In the pulse width is 900 usec, indicating DC charging, the serial data link must be established before proceeding to the next step.
    c) If the serial data link cannot be established under the above circumstances, the process must be terminated and the fault condition displayed by the EVSE

9. The EVSE may now energize the system by closing the main power contactor and charging may commence at power levels up to rated maximum continuous current of the EVSE for continuous rated conditions, or up to the rating of the protective circuit breaker for non-continuous conditions, or up to the maximum rated current of the EVSE for DC charging as provided by the serial data link. A continuous load is defined as operating at a given level for more than 3 hours.
10. The above conditions shall be monitored continuously during the charge process. If any of the above conditions do not satisfy the specified requirements, the EVSE must terminate the charge process by opening the main contactor and turning off the pilot oscillator. The EVSE should also display the fault condition.
11. To terminate the charge process, turn the EVSE on/off switch to the off position and/or remove the connector from the vehicle inlet.

## 6. General EV Requirements

6.1 Electromagnetic Compatibility – During charging, the EV shall meet the requirements of CFR 47- Code of Federal Regulations - Title 47, Parts 15A, 15B, and 18C

6.2 Electromagnetic Emissions – During charging, the EV shall meet the requirements specified in SAE J551-5: Performance Levels and Methods of Measurement of Electromagnetic Radiation from Vehicles and Devices (30 Hz to 1 000 MHz)

6.3 Electromagnetic Immunity – The charging system shall be tested in accordance with SAE J511-11: Performance Levels and Methods of Measurement of Electromagnetic Radiation from Vehicles and Devices (30 Hz to 1 000 MHz) over the frequency range of 530 kHz to 1000 MHz. The test level shall be 50 V/m. As a minimum, the test shall be conducted at 90% of the maximum rated power and at the lowest power rating used during normal operation.

6.4 Electrostatic Discharge – During charging, the EV shall be tested in accordance with and meet the requirements of SAE J511-15: Performance Levels and Methods of Measurement of Electromagnetic Radiation from Vehicles and Devices (30 Hz to 1 000 MHz). The EV may also consider the requirements of IEC 61851-2.1 Electric Vehicle Conductive Charging System – Part 2.1: Electric Vehicle Requirements for Connection to an AC / DC supply

6.5 Environmental – The on-board EV charging system electronic components shall meet the requirements specified in SAE J1211 – Recommended Environmental Practices for Electronic Equipment Design

7. General EVSE Requirements

7.1 Installation Requirements – The EVSE shall meet the requirements specified in the National Electrical Code, NFPA 70 – Article 625 and Canadian Electrical Code – Part 1, Section 86

7.2 General Product Standards – The EVSE shall meet and be listed to the general product requirements specified in UL 2202 – EV Charging System Equipment

7.3 Personnel Protection System – The EVSE shall incorporate a listed system of personnel protection as specified in UL 2231 – Personnel Protection Systems for EV Charging Circuits

7.4 Conductor Cord Requirements – The conductor cord shall meet the requirements specified in the National Electrical Code, NFPA 70 – Articles 625 and Article 400 – Table 400-4, and UL 2202 – EV Charging System Equipment

7.5 Coupler Requirements – The EV coupler shall meet the requirements specified in the National Electrical Code, NFPA 70 – Articles 625, UL2251 – Plugs, Receptacles, and Couplers for Electric Vehicles, and Section 8 of this document

7.6 Electromagnetic Compatibility – During charging, the EVSE shall meet the requirements of CFR 47- Code of Federal Regulations - Title 47, Parts 15A, 15B, and 18C. See 6.1.

8. Coupler Requirements

8.1 Vehicle Inlet/ Connector Compatibility – The vehicle inlet designs shall be of a common physical configuration that is capable of accepting common connector physical configurations for AC Level 1, AC Level 2, and DC charging. Additionally, the physical requirements shall ensure compatibility of connectors and vehicle inlets manufactured by the same manufacturer at different points in time as well as different manufacturers of the mating connectors and vehicle inlets.

8.2 Ergonomic Requirements – The coupler shall comply with the following ergonomic requirements.

8.2.1 Ease of Use – During connection and disconnection, the human efforts required shall be within the physical capabilities of the general adult population and persons with limited or restricted capabilities

8.2.2 Indexing – During connection and disconnection, the insertion/removal of the connector and inlet shall be intuitively obvious and free of multiple orientations for AC Level 1, AC Level 2, and DC charging configurations.

8.2.3 Alignment – The vehicle inlet shall provide a lead-in feature for automatic alignment during insertion and removal of the connector

8.2.4 Tactile Feel – The coupler shall incorporate a means to provide tactile and/or audible feedback to the user when fully engaged

8.2.5 Latching – The coupler shall have a latching mechanism to prevent inadvertent or accidental decoupling. The latching mechanism should provide a means in the connector to open the control pilot conductor when disengaging from the vehicle inlet

8.2.6 Contact Visibility – The coupler contacts shall not be directly visible when decoupled per Section 8.5.8

8.3 Safety Requirements – The coupler shall comply with the following safety requirements

8.3.1 Isolation – The power contacts shall be electrically isolated from the electric supply and battery voltages when decoupled

8.3.2 Exposure of Contacts – When not connected the vehicle inlet and connector shall be designed to prevent direct contact with live parts according to UL2251.

8.3.3 Sharp Edges – The vehicle inlet and connector shall be free of sharp edges and potentially injurious protrusions per UL 1439: Determination of Sharpness of Edges on Equipment

8.3.4 Touch Temperature – the maximum external touch temperature of the coupler shall not be greater than 60 degrees C when the ambient temperature is 40 degrees C. the design process shall take into consideration material types as specified in UL2251: Plugs, Receptacles, and Couplers for Electric Vehicles

8.3.5 Hazardous Conditions – The coupler should be designed to avoid or mitigate potentially hazardous conditions – fire, electric shock, or personnel injury

8.3.6 Unauthorized Access – For unattended public access charging, the coupler should provide a means to engage a locking or latching mechanism to reduce the likelihood of tampering or unauthorized removal

8.4 Performance Requirements – The coupler shall comply with the following performance requirements

8.4.1 Design Life – The coupler shall be designed to a minimum of 10,000 cycles of mechanical operation. The coupler performance shall not be reduced by the environment conditions specified in Section 8.5 of this document.

8.4.2 Impact Resistance – The connector shall continue to function as intended after being dropped from a height of 1 m onto a concrete surface per UL2251: Plugs, Receptacles, and Couplers for Electric Vehicles

8.4.3 Vehicle Drive-over – The connector shall continue to function as intended or fail in a safe manner after being driven over by a vehicle as specified in UL2251: Plugs, Receptacles, and Couplers for Electric Vehicles

8.5 Environmental Requirements – The coupler  shall comply with the following environmental requirements

8.5.1 General Environmental Considerations – The vehicle inlet should meet the performance requirements specified in Section 8.4 under weather and environmental conditions specified by the individual automobile manufacturers.

8.5.2 Temperature Range – The coupler shall be designed to withstand continuous ambient temperatures in the range of –30 degrees C to +50 degrees C during operation when supplied with the EVSE or installed in the EV and continuous ambient temperatures in the range of –50 degrees C and +80 degrees C during shipping or storage when the components parts are assembled, supplied with the EVSE, or installed in the EV

8.5.3 Temperature Rise – The electrical contacts shall be designed for a maximum temperature rise of 50 degrees C above ambient at rated load. The wiring insulation shall be rated for 105 degrees C.  For couplers rated less than 200 A, the load is to be applied continuously. For connectors rated 200 A or greater, the load is to be applied for 20 minutes followed by a no-load period of 10 minutes and repeated until peak temperatures stabilize.

8.5.4 Insulation Resistance – The insulation resistance of the coupler between the power conductors and the EV chassis ground shall be a minimum of 10M Ohms at 500 volts DC.

8.5.5 Fluid Resistance – The coupler shall be unaffected by automotive lubricants, solvents, and fuels as specified in Section 4.4 Immersion and Splash of SAE J1211 – Recommended Environmental Practices for Electronic Equipment Design

8.5.6 Mechanical Requirements – The vehicle inlet shall be able to withstand the minimum automotive vibration conditions when tested to the following procedures and pass/fail criteria:

a. Vibration Test Procedure – A vehicle inlet as mounted on a test fixture shall be securely bolted to the table of the vibration test machine and subjected to vibration according to the following test parameters:
b. Frequency – Varied from 10 to 55 Hz and return to 10 Hz at a linear sweep period of 2 min./complete sweep cycle
c. Excursion – 1.0 + 0.1/- 0.0 mm peak to peak over the specified frequency range
d. Direction of Vibration – Vertical axis of the vehicle inlet as it is mounted on the vehicle
e. Test Duration – 60 + 1/- 0 minutes
f. Pass/fail criteria – After completion of the test, there shall be no observed rotation, displacement, cracking or rupture of parts of the device that could result in failure to operate as intended or cause to fail any of the other test requirements specified in this document. Cracking or rupture of the parts of the device that affect mounting shall constitute a failure

8.5.7 Sealing Requirements – The vehicle inlet and connector shall be sealed in a manner that the following requirements are met:

a. When de-coupled, the vehicle inlet shall have an effective sealing system for outdoor use to provide a degree of protection against corrosion, windblown dust and rain, splashing water, hose-directed water, and external ice formation per UL 50, type 3S: Standard for Enclosures for Electrical Equipment as specified in UL2251: Plugs, Receptacles, and Couplers for Electric Vehicles
b. When coupled, the vehicle inlet shall have an effective sealing system for outdoor use to provide a degree of protection against corrosion, windblown dust and rain, splashing water, hose-directed

water, and external ice formation per UL 50, type 3S: Standard for Enclosures for Electrical Equipment as specified in UL2251: Plugs, Receptacles, and Couplers for Electric Vehicles

c. The vehicle inlet shall provide for the egress of fluids

8.5.8 Shielding Requirements – The coupler shall meet the following shielding requirements:

a. In addition to an external door, the contacts of the vehicle inlet shall be shielded, physically and visually, when decoupled
b. The contacts of the connector shall be shielded, physically and visually, when decoupled
c. The shielding mechanism(s), shall operate automatically during decoupling
d. When decoupled, the shielding mechanism(s) should be designed to avoid or mitigate direct contact with conductive parts by reducing the likelihood of accidental or inadvertent touching
e. When decoupled, the shielding mechanism(s) should prevent the ingress of small particles, dirt, leaves, and other small objects from degrading the performance of the sealing system, obstructing electrical current flow, or diminishing coupler performance.

8.6 General Coupler Physical Description – The coupler interface shall be a single common configuration using pressure type contacts and shall be designed for interchangeability with devices of identical ratings and function.

8.6.1 Vehicle Inlet General requirements - There shall be a single vehicle inlet design with two configurations. The standard configuration shall be capable of AC Level 1 and AC Level 2 charging. The optional configuration shall be capable of AC Level 1, AC level 2, and DC Charging. The contact requirements shall be as specified in TABLE 6. The standard configuration shall not function with a connector suitable for DC Charging. The optional configuration shall function with all connector configurations.

TABLE 6 – VEHICLE INLET CONTACT REQUIREMENTS

| Contact # | Function | Standard – AC Level 1 and 2 | Optional – AC Level 1 and 2 , DC Charging |
|---|---|---|---|
| 1 | Charger 1 | X | X |
| 2 | Charger 2 | X | X |
| 3 | Battery positive | | X |
| 4 | Battery negative | | X |
| 5 | Chassis ground | X | X |
| 6 | Control pilot | X | X |
| 7 | Data negative | O | X |
| 8 | Data positive | O | X |
| 9 | Data ground | O | X |

Note: X = required, O = optional

8.6.2 Connector General Requirements – There shall be a single connector design with two configurations. The standard configuration shall be capable of AC Level 1 and AC Level 2 charging. The optional configuration shall be capable of DC Charging. The minimum contact requirements shall be as specified in TABLE 7. The connector shall be fitted with a cord corresponding to its intended usage and shall meet the requirements specified in the National Electrical Code, NFPA 70 – Articles 625 and Article 400 – Table 400-4.

TABLE 7 – CONNECTOR CONTACT REQUIREMENTS

| Contact # | Function | Standard – AC Level 1 | Optional – DC Charging |
|---|---|---|---|

| | | and 2 | |
|---|---|---|---|
| 1 | AC Power | X | O |
| 2 | AC Power | X | O |
| 3 | DC Power | | X |
| 4 | DC Power | | X |
| 5 | Equipment ground | X | X |
| 6 | Control pilot | X | X |
| 7 | Data negative | O | X |
| 8 | Data positive | O | X |
| 9 | Data ground | O | X |

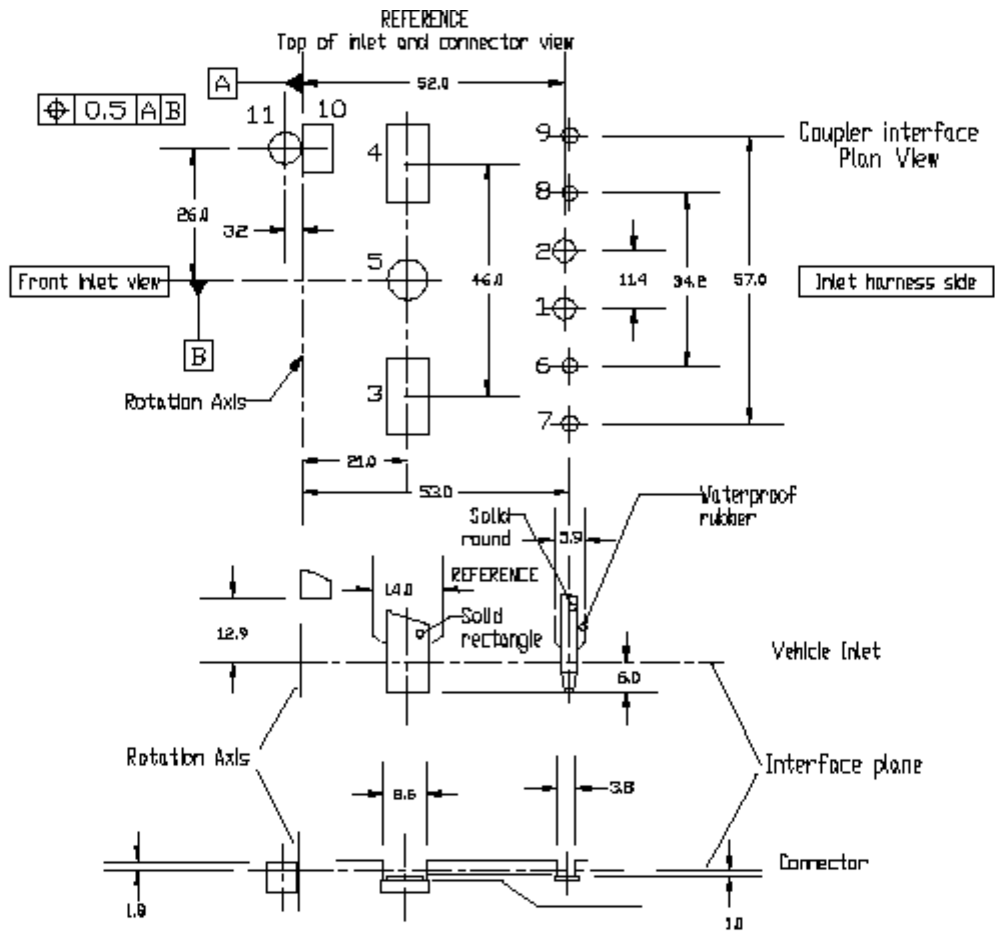
Note: X = required, O = optional

8.7 Dimensional Requirements – The coupler shall be designed to comply with the key dimensional requirements as specified in this section.

8.7.1 Interface Contact Spacing – The general contact sizes and spacing at the coupler interface shall comply with the dimensions as specified in TABLE 8 and shown in FIGURE 9.

TABLE 8 – CONTACT SIZE AND CURRENT RATING

| Contact # | Function | Size (mm) | Current rating (Amps) | Voltage rating | Dimension A(mm) | Dimension B(mm) |
|---|---|---|---|---|---|---|
| 1 | AC Power | 4.6 diameter | 40 A | 300 vac | 1.0 | 6.0 |
| 2 | AC Power | 4.6 diameter | 40 A | 300 vac | 1.0 | 6.0 |
| 3 | DC Power | 15.0 x 8.0 | 400 A | 600 vdc | 2.0 | 6.0 |
| 4 | DC Power | 15.0 x 8.0 | 400 A | 600 vdc | 2.0 | 6.0 |
| 5 | Equipment/chassis ground | 8.0 diameter | Fault rated | | 1.0 | 6.0 |
| 6 | Control pilot | 3.1 diameter | 15 A | 60 vdc | 1.0 | 5.0 |
| 7 | Data negative | 3.1 diameter | 15 A | 60 vdc | 1.0 | 6.0 |
| 8 | Data positive | 3.1 diameter | 15 A | 60 vdc | 1.0 | 6.0 |
| 9 | Data ground | 3.1 diameter | 15 A | 60 vdc | 1.0 | 6.0 |




| Pin Number | Designation | Size (mm) | Ampacity (A) | A±0.2 (mm) | B±0.2 (mm) | C±0.2 (mm) | D±0.2 (mm) | E±0.2 (mm) | F±0.2 (mm) | G±0.2 (mm) | H±0.2 (mm) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Low power AC (L,N) | ϕ 4.6 | 40 | – | – | 1 | 6 | – | 8.5 | – | 6.5 |
| 2 | Low power AC (L) | ϕ 4.6 | 40 | – | – | 1 | 6 | – | 8.5 | – | 6.5 |
| 3 | High Power | 15 x 8 | 400 | – | – | 2 | 6 | 13 | – | 11 | – |
| 4 | High Power | 15 x 8 | 400 | – | – | 2 | 6 | 13 | – | 11 | – |
| 5 | Equipt/Chassis ground | ϕ 8 | – | – | – | 1 | 6 | 13 | – | 11 | – |
| 6 | Control pilot | ϕ 3.1 | 15 | – | – | 1 | 5 | – | 6.8 | – | 52 |
| 7 | Communication (-) | ϕ 3.1 | 15 | – | – | 1 | 6 | – | 6.8 | – | 52 |
| 8 | Communication (+) | ϕ 3.1 | 15 | – | – | 1 | 6 | – | 6.8 | – | 52 |
| 9 | Communication (GRD) | ϕ 3.1 | 15 | – | – | 1 | 6 | – | 6.8 | – | 52 |
| 10 | Reed Switch * | 9 x 6 x20 | – | 12.9 | – | – | – | – | – | – | – |
| 11 | Magnetic Sensor * | ϕ 6 x 6.3 | Surf6000 Gauss 6.3!413 Gauss | – | 1.8 | – | – | – | – | – | – |

* Reed minimum attractive distance to magnet : 17mm

FIGURE 9 – CONTACT INTERFACE SPACING AND CONTROL DIMENSIONS

8.7.2 Connector Physical Dimensions – The connector shall comply with the key physical dimensions as shown in FIGURE 10.

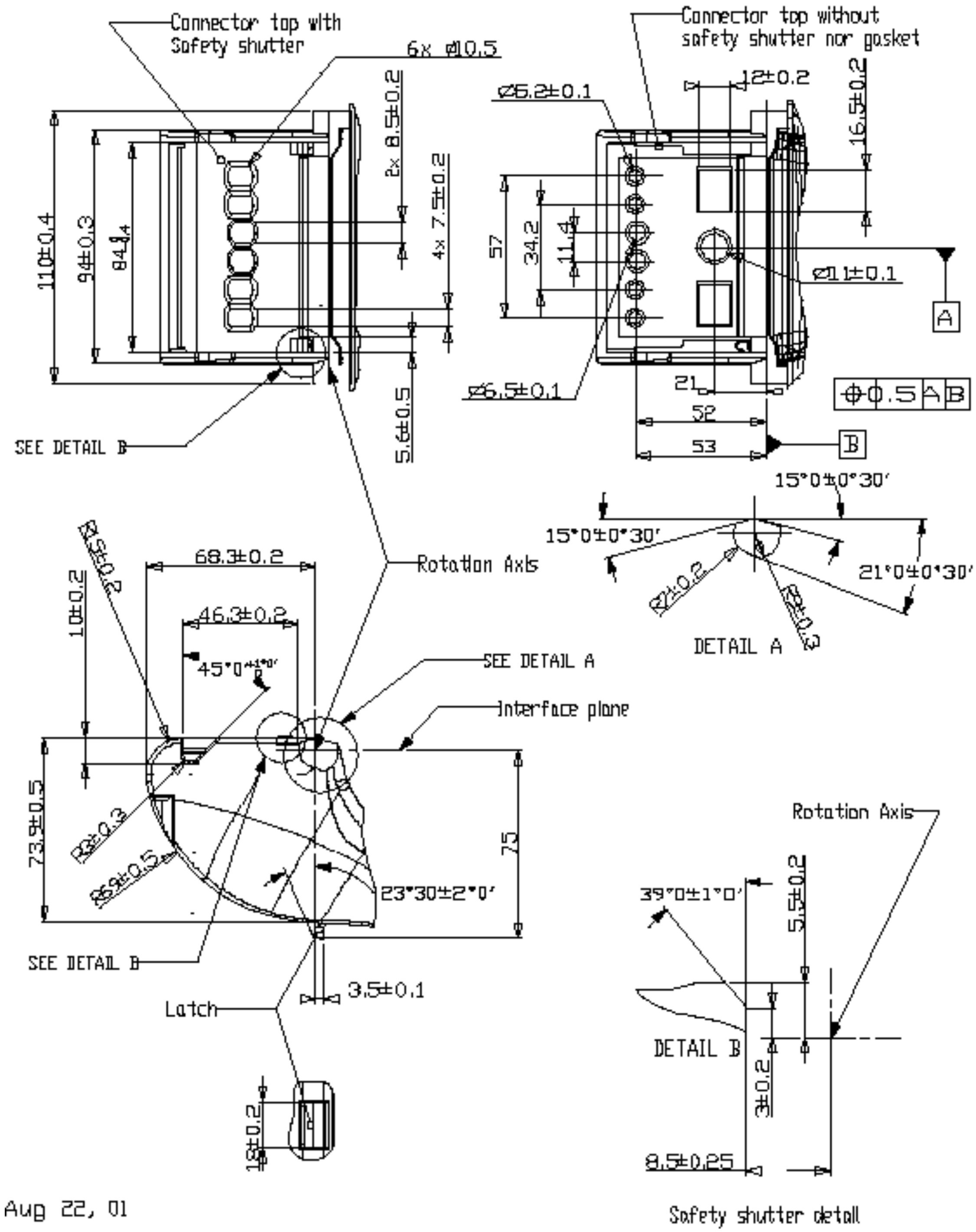



FIGURE 10 – CONNECTOR PHYSICAL CONTROL DIMENSIONS

8.7.3 Vehicle Inlet Physical Dimensions – The vehicle inlet shall comply with the key physical dimensions as shown in FIGURE 11.

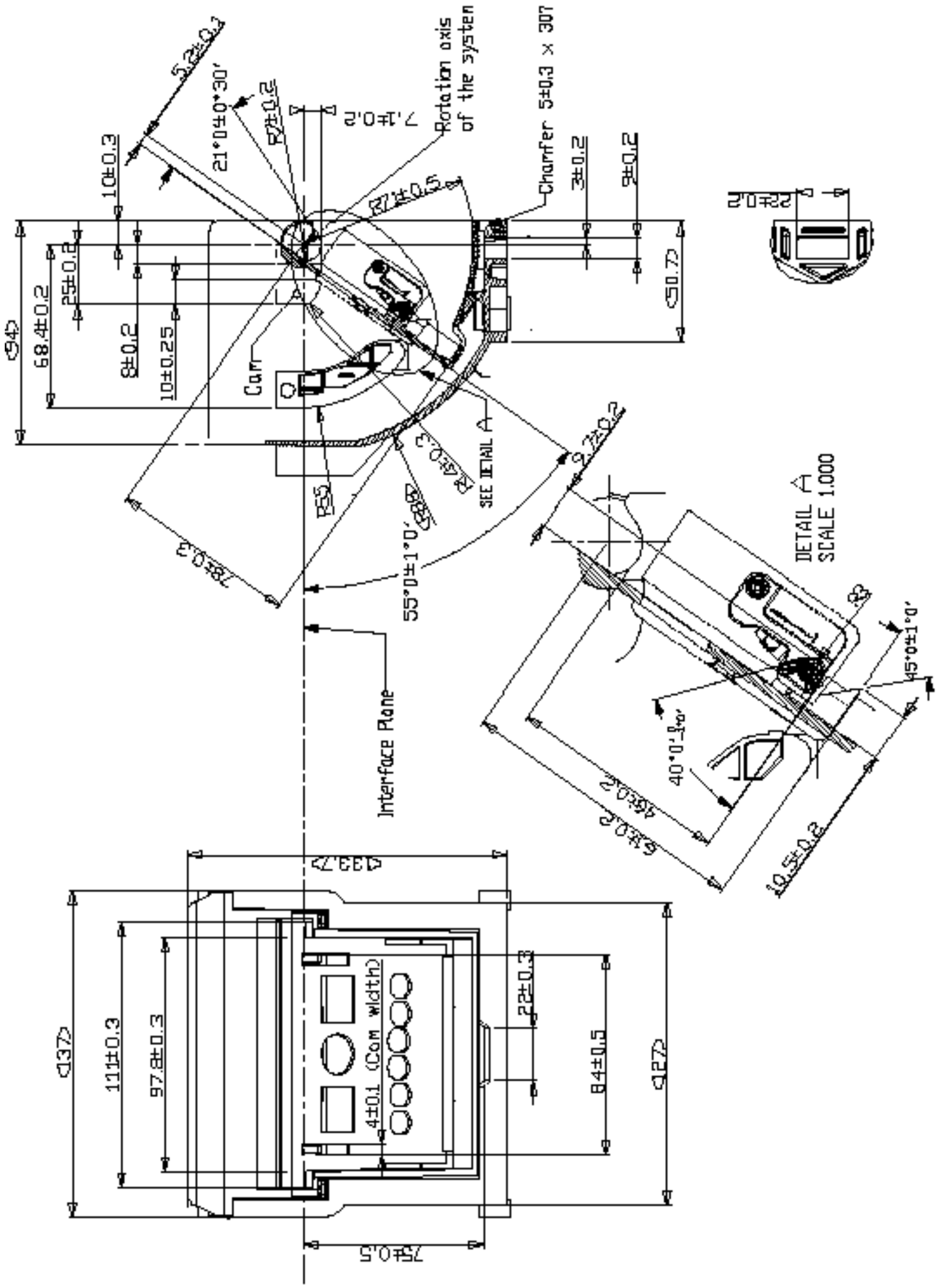



FIGURE 11 – VEHICLE INLET PHYSICAL CONTROL DIMENSIONS

8.7.4 Vehicle Inlet Access Zone – The vehicle inlet shall be installed in the vehicle to allow connector access when the cover door is opened as shown in FIGURE 12.

8.7.5 Contact Sequencing – During connection, the connector and vehicle inlet shall comply with the contact sequencing and events shown in FIGURE 13 and specified in TABLE 9. It should be noted that the equipment/chassis ground contact is first make/last break and the control pilot contact is last make/first break.

TABLE 9 – COUPLER INTERFACE CONTACT SEQUENCING EVENTS

| Sequencing event | AC Level 1 and 2<br>Angle A (degrees) | DC Charging<br>Angle A (degrees) |
|---|---|---|
| Insertion zone | 0 to –12 | 0 to –12 |
| Line-to-line connector/inlet | 0 | 0 |
| Equipment-chassis ground | 44.5 | 34.5 |
| Power | 49.5 | 43.0 |
| Data | 51.0 | 51.0 |
| Control pilot | 52.0 | 52.0 |
| Latch point | 55.0 | 55.0 |
| Over travel | 58.0 | 58.0 |

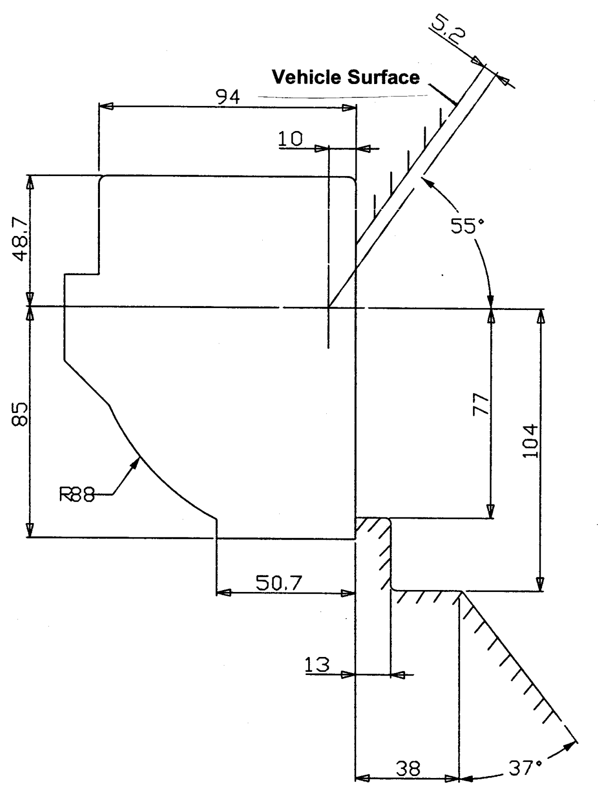



FIGURE 12 – VEHICLE INLET INTERFACE ACCESS ZONE

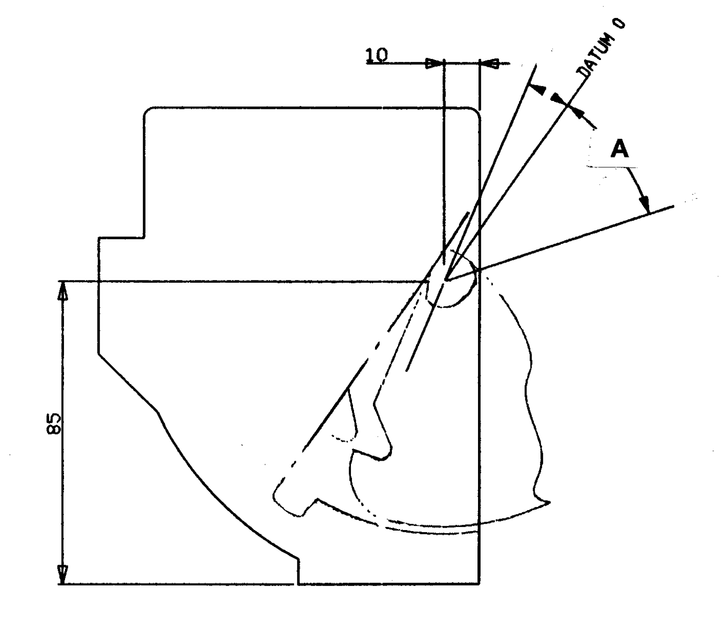


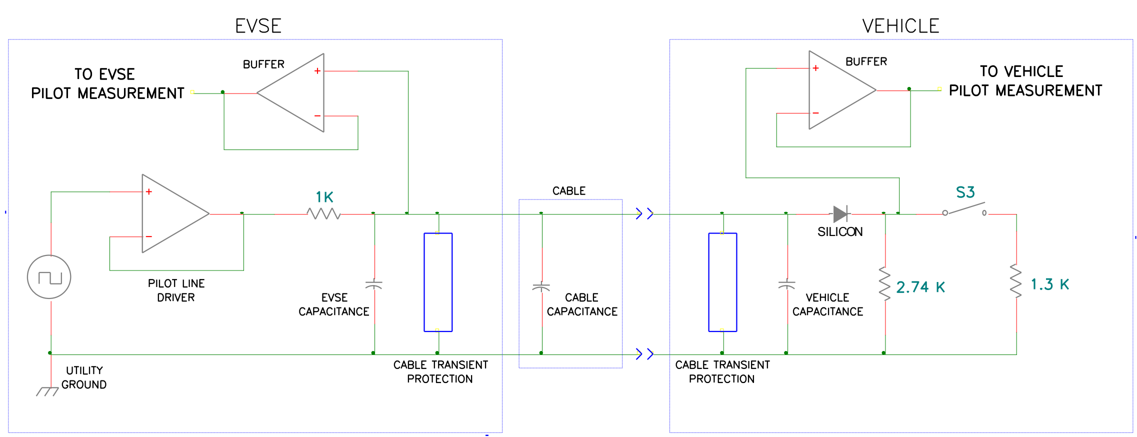

FIGURE 13 – COUPLER INTERFACE CONTACT SEQUENCING

## Appendix A - History EVSE/Vehicle Interface

The specifications for the Control Pilot system shown in Section 5 of SAE J1772 are purposely written to convey the most basic information needed to precisely define the system. However, the initial version of this system has been in use since 1997, and the experience gained by the industry may be of help to new manufacturers attempting to design equipment conforming to the SAE J1772 Standard. This Appendix is a compilation of that experience, focused on the interface circuitry between the EVSE and the Vehicle.

Typical circuitry presently in use by Charging Station and Vehicle Manufacturers, is shown in basic form in Figure 1 below. Actual schematics cannot be shown due to proprietary considerations.

**Figure 1. Typical Pilot Line Circuitry**




*Pilot Circuit Components*

1. The op-amp shown as a driver is only indicative of the function, and is not intended to imply that this is a Standard method of driving the Pilot line. The low output impedance of a typical op-amp makes the source resistance essentially the resistor itself. Although this may simplify the design, it does not mean that this is the only valid architecture. Other factors, such as susceptibility to cable transients, should also be considered in the design effort.

2. The two op-amps shown as buffers are meant to show a method of tapping off the Pilot line, for measurement purposes, in a manner that will not significantly effect the line waveform.

3. Switch S2 need not be a mechanical switch or relay. At least one vehicle manufacturer is successfully using an FET for this purpose.

4. The diode shown on the vehicle side is intended to be a common small signal silicon diode. Reverse voltage ratings of at least 100V are readily available and are recommended since this diode is exposed directly to cable transients.

5. The cable capacitance from the Pilot wire to the Ground wire will probably be around 25 pF per foot, and many cables are 15 to 20 feet long. If the EVSE's contactor closes when the line voltage is near a positive or negative peak, then the voltage on the contactor output can rise from 0 to 170 volts in just a few nanoseconds. This fast, high-voltage transition can easily be coupled through the capacitance of the cable. In addition, with the contactor closed during charging, any transients such as might be generated by nearby industrial equipment or lightning strikes can be coupled through. It is highly recommended that transient protection be installed on both the EVSE output and the vehicle input.

Basic Communication Sequence.

The most basic communication sequence between the EVSE and the Vehicle is presented below in terms of the nominal voltage levels involved.

1. The EVSE generates a static +12V, waiting for connection to the Vehicle.

2. Upon connection, assuming that switch S2 is open, the 2.74K resistor on the vehicle will pull the +12V down to +9V, as measured at the EVSE output. The EVSE will sense this and begin generating a +9V, -12V, 1 KHz square wave. Because of the diode on the Vehicle, the negative portion will be at –12V. Note that, for standard AC Level I and AC Level 2 charging, the negative portion will always remain at –12V. This purpose of this feature is safety, to allow the EVSE to distinguish between a vehicle and the straight resistance of a curious child's fingers.

3. If the Vehicle requires AC energy transfer, it will close switch S2. Most often, this will switch a 1.3K resistor in parallel with the 2.74K resistor, for an effective total resistance of 882 ohms. This value will pull the positive portion of the square wave down to +6V. The EVSE will interpret this as a request for AC power and close the contactor.

   If a 270 ohm resistor is switched in, the positive portion of the square wave will be pulled down to +3V, informing the EVSE that the vehicle's battery is a type that emits hazardous gasses during charging, and requires an exhaust fan in enclosed areas. Unless the EVSE is equipped to verify that such a fan is running, it must not close the contactor. In practice, very few auto manufacturers have put such batteries in their vehicles due to liability issues, and virtually all are using the 1.3K resistor value.

4. When the Vehicle no longer requires AC energy transfer, it will open S2 and the positive portion of the signal will go back up to +9V. The EVSE will open the contactor, removing power. The +9V, -12V square wave will remain until the cable is disconnected from the Vehicle, when it will again go back to the static +12V state.

Pilot Line Voltage Ranges

Table 1 is not intended to imply that the Control Pilot voltages must remain within the minimum and maximum voltages shown. Rather, given the voltages and component values, and their tolerances as specified in Section 5 of SAE J1772, it shows the range of voltages that will be obtained on the Pilot line output, over a –40 C to 85 C temperature range. This includes a tolerance of 3% for resistors on both the EVSE and the vehicle, and includes temperature affects on the small signal silicon diode. The table also assumes low-resistance Pilot Line and Ground connections through the cable and connections.

EVSE manufacturers must decide for themselves what voltage tolerances will be acceptable for each Pilot line state, keeping in mind that vehicle tolerances are also involved.

Table 1. Pilot Line Voltage Ranges

| | minimum | nominal | maximum |
|---:|:---:|:---:|:---:|
| Positive Voltage, State A | 11.40 | 12.00 | 12.60 |
| Positive Voltage, State B | 8.36 | 9.00 | 9.56 |
| Positive Voltage, State C | 5.48 | 6.00 | 6.49 |
| Positive Voltage, State D | 2.62 | 3.00 | 3.25 |
| Negative Voltage - States B, C, D, and F | -11.40 | -12.00 | -12.60 |

In the States B, C, and D, where a 1 KHz square wave is present with capacitance on the line, the voltages shown represent the fully-settled values (> 8RC) after a transition.

The +12V and –12V voltages will most likely be generated using generic 3-terminal regulators. The minimum and maximum voltages shown in Table 1 both indicate a 5% tolerance. However, in recent years the +12V regulators have become commonly and inexpensively available with tolerances of +/- 2% over line, load, and temperature variations. The –12V regulators are commonly available with +/- 4% tolerance. Use of these, or others that may have even tighter tolerance specifications, will give greater tolerance to other components, increasing the probability that system voltages will stay within the specifications over the life of the equipment.

Previously, SAE J1772 specified the voltage range for each state, as shown in Table 2, below. Each state had a +/- 1V range, with 1V gaps between each range that were considered invalid voltages. This was intended to give each state a large tolerance leeway, and provide gaps between states for noise immunity.

Table 2. Original Pilot Voltage Specification (no longer required)

| | |
|---:|:---|
| | Invalid |
| | 13.0V |
| State A | 12.0V - nominal |
| | 11.0V |
| | Invalid |
| | 10.0V |
| State B | 9.0V - nominal |

| | |
|---|---|
| | 8.0V |
| | Invalid |
| | 7.0V |
| State C | 6.0V - nominal |
| | 5.0V |
| | Invalid |
| | 4.0V |
| State D | 3.0V - nominal |
| | 2.0V |
| | Invalid |

These voltage ranges are no longer part of the SAE 1772 Specification. EVSE manufacturers may still use these ranges, at their discretion, but they are no longer constrained to do so by the Standard. As shown in Table 1, in a properly functioning system where the voltages and component tolerances are within the Specification, the voltages obtained will be well within those in Table 2.

However, staying within the Specifications for the EVSE in Section 5 of SAE J1772, it will be left to the EVSE designer to decide the general architecture they will use and what voltage tolerances they will allow in their equipment for each state. At the other end of the cable, the Vehicle Manufacturers must be sure the equivalent resistances for each state fall within the Specifications.

The specifications for the EVSE in Table 4 of SAE J1772 can be used by the Vehicle Manufacturers to fully test their end of the system by simulating the EVSE part of the interface. The same is true for EVSE manufacturers, who can simulate the vehicle part of the interface. Values of all parameters can be adjusted over their specified range, and the robustness of the system can be determined before committing to the manufacture of a particular design.

## APPENDIX B - AC Level 3 Charging

B.1 Scope—This appendix is intended to provide guidance to accommodate vehicles using an on-board charging system capable of accepting current in excess of 48 A a.c.

B.1.1 System Description—The J1772 recommended conductive coupler provides for two sets of current-carrying conductors. Contacts 1 and 2 are designated for a.c. charging at 6 to 48 A line current; contacts 3 and 4 are designated for high-current charging at up to 400 A. DC Charging uses the high-current contacts exclusively while AC Level 2 and AC Level 1 charging use the low-current contacts exclusively. Improvements in onboard charging technology enable more powerful charging, but require more current than can be supplied by contacts 1 and 2. The high-power coupler contacts 3 and 4 may be used to supply AC Level 3 to compatible vehicles following the guidelines in this appendix.

Definition: AC Level 3 – A charging method that utilizes dedicated electric vehicle supply equipment in either private or public locations. The vehicle shall be fitted with an on-board charger capable of accepting energy from an a.c. supply network at a nominal voltage of 208 and 240 vac and a maximum current of 400 A.

Table B1 compares the characteristics of electric vehicle charging modes. Note that AC Level 3 charging shares most characteristics with AC Level 2 charging because the charger is located in the vehicle.

Table B1—CHARGING MODE CHARACTERISTICS

| EVSE Type | EVSE Input | EVSE Output | EVSE—Vehicle Control Method | Charger Location | Charger Location | Power Max. |
|---|---|---|---|---|---|---|
| AC Level 2 | 208-240 Vac | 208-240 Vac | J1772 Pilot | Vehicle | Vehicle | 11.5 kW |
| AC Level 3 | 208-240 Vac | 208-240 Vac | J1772 Pilot | Vehicle | Vehicle | 96 kW |
| DC Charging | 208-600 V | 0-600 Vdc | J1772 and J2293 | EVSE | EVSE | 240 kW |

B.2 Pilot Circuit—AC Level 3 charging interface is controlled by a pilot signal output from the Electric Vehicle Supply Equipment, similar to AC Level 2 charging. Characteristics of the EVSE are conveyed by the output (open circuit) voltage combination of the pilot signal. When plugged into an EVSE, a vehicle connects the pilot output to the supply ground through a resistor/diode combination, bringing the pilot test point voltages into the range of a valid response. If the EVSE detects a valid charge request, it adjusts the pilot duty cycle to convey the available a.c. line current, and then closes the appropriate contactor.

B2.1 Electric Vehicle Supply Equipment output parameters—Table A2 defines pilot signal characteristics for AC Level 2, AC Level 3, and DC Charging EVSE. Note that an AC Level 3 EVSE can operate as an AC Level 2 EVSE if AC Level 3 charging is not requested. The AC Level 3 pilot signal duty cycle range corresponds to the duty cycle range for AC Level 2 charging but not DC Charging. Permissible supply resistance (on pilot oscillator output) is the same for all EVSE.

Table B2—EVSE CONTROL PILOT PARAMETERS

| EVSE Type | Output OCV (-) | Output OCV (+) | Duty Cycle Min. | Duty Cycle Max. | Oscillator Hz | Supply Resistance |
|---|---|---|---|---|---|---|
| AC Level 2 | -12 Vdc | +12 Vdc | 10% | 80% | 1000 | 1000Ω |
| DC Charging | -12 Vdc | +12 Vdc | 90% | 90% | 1000 | 1000Ω |
| AC Level 3 | -9 Vdc* | +12 Vdc | 10% | 80% | 1000 | 1000Ω |

*EVSE supporting Level 2 and High-power AC may transition to –12 v for Level 2 mode

B.2.2 Vehicle response parameters—Electric vehicles respond to the pilot signal by applying a resistor/diode combination to complete the pilot circuit. The necessary equivalent resistance (diode plus resistor) values for valid responses are indicated in Table B3.

Table B3—VEHICLE CHARGE REQUEST PARAMETERS

| Charge Request | Pilot Voltage Test Point (-) | Pilot Voltage Test Point (+) | Vehicle Equiv. Resistance (-) | Vehicle Equiv. Resistance (+) |
|---|---|---|---|---|
| AC Level 2 | -12 Vdc | +6 Vdc* | ∞ | 1000Ω* |
| DC Charging | -12 Vdc | +9 Vdc | N/A | 3000Ω |
| AC Level 2 | -3 Vdc | +9 Vdc | 500Ω | 3000Ω |

*Confirmation is +3 v if ventilation is required, $R_{eq.}$ = 333Ω

B.2.3 EVSE response parameters—The EVSE continuously monitors the filtered test point voltages. Test point voltages specified in Table B4 constitute valid responses. While the power contactor is being opened or closed, the EVSE may be configured to lower pilot duty cycle (current limit) to reduce wear on the power contacts.

Table B4—EVSE RESPONSE PARAMETERS

| EVSE Type | Vehicle Present Test Point (-) | Vehicle Present Test Point (+) | Charge Request Test Point (-) | Charge Request Test Point (+) |
|---|---|---|---|---|
| AC Level 2 | -12vdc | +9vdc | -12vdc | +6vdc* |
| DC Charging | -12vdc | +9vdc | -12vdc | +9vdc |
| AC Level 3 | -9vdc | +9vdc | -3vdc | +9vdc |

*Test point is +3 v if ventilation is required

B.2.4 EVSE current limit function—AC Level 2 and AC Level 3 EVSE use the pilot signal duty cycle to communicate available line current to the vehicle charger. The equations for these scales are indicated Table B5. The AC Level 3 charging scale enables the EVSE to limit current between 0 and 400 A, while the AC Level 2 scale enables control between 6 and 48 A. Examples of duty-cycle to line-limit correspondence are shown in Table B6.

Table B5—CURRENT LIMIT EQUATION

| Charging Mode | Duty Cycle Range | Current Limit, AC amperes |
|---|---|---|
| AC Level 2 | 5% < duty cycle <80% | I = 60 X ( DUTY CYCLE) |
| AC Level 3 | 13% < duty cycle <80% | I = 600 X ( DUTY CYCLE) – 80 |
| AC Level 3 | If duty cycle < 13% | I = 0 |

Table B6—CURRENT LIMIT SCALE

| Control Pilot Duty Cycle | Current Limit ACLevel 2 (AC amps, cont.) | Current Limit ACLevel3 (AC amps, cont.) |
|---|---|---|
| 10% | 6 | 0 |
| 20% | 12 | 40 |
| 30% | 18 | 100 |
| 40% | 24 | 160 |
| 50% | 30 | 220 |
| 60% | 36 | 280 |
| 70% | 42 | 340 |
| 80% | 48 | 400 |
| 90% | 0—DC Charging Only | 0—DC Charging Only |

B.2.5 AC charging implementation—Vehicles and EVSE configured for AC Level 3 charging may also support AC Level 2 for greater compatibility. Figure B1 shows an EVSE/ vehicle implementation of AC Level 3 charging. Note that the EVSE and EV are both configured to support AC Level 2 charging. The vehicle's low and high current charge port contacts are wired together to permit the on-board charger to operate from either low or high power sources. The EVSE uses 2 separate contactors to preclude parallel current paths while charging AC Level 3 vehicles. Vehicles could also be configured for DC Charging with the addition of a serial data interface and contactors between the high power contacts and the on-board charger and battery pack.

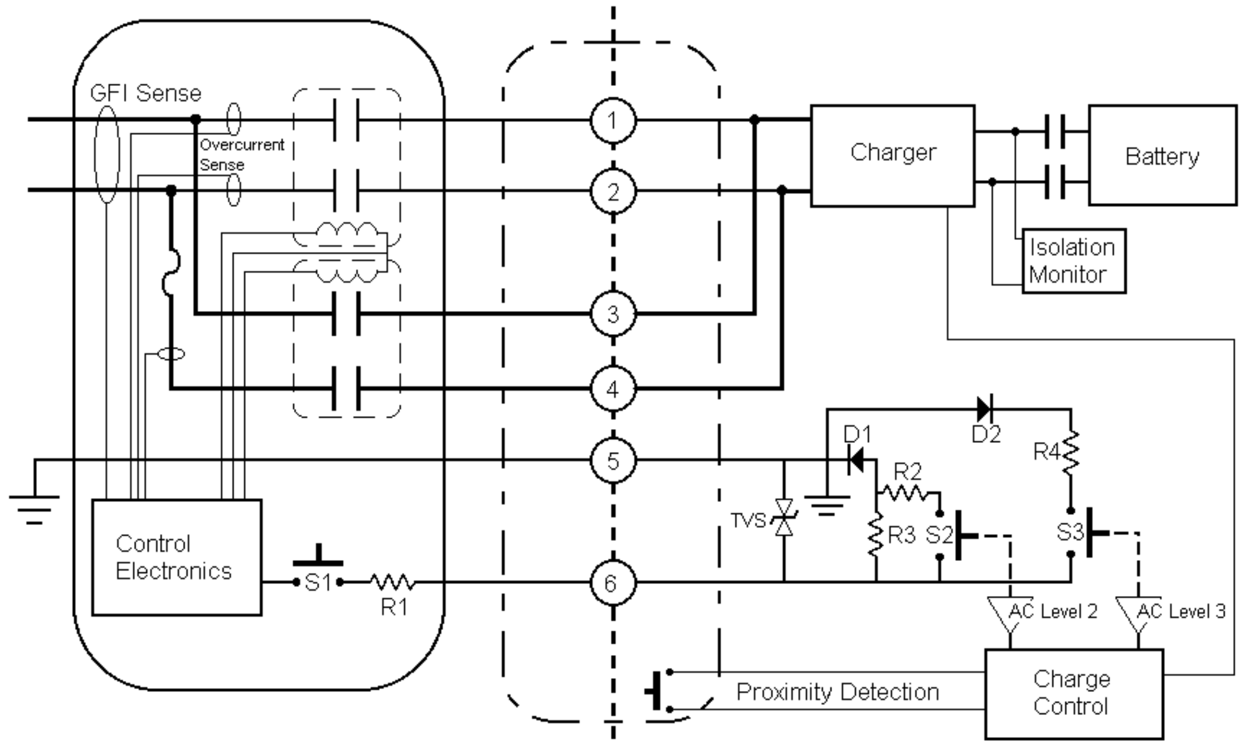



**Figure B1—AC LEVEL 3 AND AC LEVEL 2 SYSTEM CONFIGURATION**