

SAE J1772

SAE J1772 (IEC Type 1), also known as a "J plug", is a North American standard for electrical connectors for electric vehicles maintained by the SAE International and has the formal title "SAE Surface Vehicle Recommended Practice J1772, SAE Electric Vehicle Conductive Charge Coupler".^[1] It covers the general physical, electrical, communication protocol, and performance requirements for the electric vehicle conductive charge system and coupler. The intent 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.

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History

SAE J1772



SAE J1772-2009 electric vehicle connector.

Type	Automotive power connector
Production history	
Manufacturer	Yazaki and others
Produced	2009
General specifications	
Pins	5

The main stimulus for the development of SAE J1772 came from the California Air Resources Board. Formerly electric vehicles like the General Motors EV1 had used inductive charger couplers. These were ruled out in favor of conductive coupling to supply electricity for recharging with the California Air Resources Board settling upon the SAE J1772-2001 standard^[2] as the charging interface for electric vehicles in California in June 2001.^[3] Avcon manufactured a rectangular connector compliant with that SAE J1772 REV NOV 2001 specification that was capable of delivering up to 6.6 kW of electrical power.^[4] (Photos and description of this old-revision rectangular "AVCon connector" and "AVCon inlet" are at ^[5])

The CARB regulation of 2001 mandated the usage of SAE J1772-2001 beginning with the 2006 model year. Later requirements asked for higher currents to be used than the Avcon connector could provide. This process led to the proposal of a new round connector design by Yazaki which allows for an increased power delivery of up to 19.2 kW delivered via single phase 120–240 V AC at up to 80 amperes. In 2008 the CARB published a draft amendment to section 1962.2 Title 13 that mandated the usage of the oncoming SAE J1772 standard beginning with the 2010 model year.^[6] this was approved in 2012.^[7]

The Yazaki plug that was built to the new SAE J1772 plug standard successfully completed certification at UL. The standard specification was subsequently voted upon by the SAE committee in July 2009.^[8] On January 14, 2010 the SAE J1772 REV 2009 was adopted by the SAE Motor Vehicle Council.^[9] The companies participating in or supporting the revised 2009 standard include Smart, Chrysler, GM, Ford, Toyota, Honda, Nissan, and Tesla.

The SAE J1772-2009 connector specification has been added to the international IEC 62196-2 standard ("Part 2: Dimensional compatibility and interchangeability requirements for a.c. pin and contact-tube accessories") with voting on the final specification to close in May 2011.^[10] The SAE J1772 connector is considered a "Type 1" implementation providing a single phase coupler.^[11]

Vehicle equipment

The SAE J1772-2009 was adopted by the car manufacturers of post-2000 electric vehicles like the third generation of the Chevrolet Volt and Nissan Leaf as the early models. The connector became standard equipment on the US-market due to the availability of charging stations with that plug type in the nation's electric vehicle network (with the help of funding such as ChargePoint America program drawing grants from provisions of the American Recovery and Reinvestment Act).

The European versions were equipped with a SAE J1772-2009 inlet as well until the automotive industry settled on the IEC Type 2 "Mennekes" connector as the standard inlet - since all IEC connectors use the same SAE J1772 signaling protocol the car manufacturers are selling cars with either a SAE J1772-2009 inlet or an IEC Type 2 inlet depending on the market. There are also (passive) adapters available that can convert J1772-2009 to IEC Type 2 and vice versa. The only difference is that most European versions have an on-board charger that can take advantage of three-phase electric power with higher voltage and current limits even for the same basic electric vehicle model (such as Chevrolet Volt / Opel Ampera).



The older Avcon connector, featured here on a Ford Ranger EV

Combined Charging System (CCS)

SAE is developing a Combined Charging System with a *Combo Coupler* variant of the J1772-2009 connector with additional pins to accommodate fast DC charging at 200–450 volts DC and up to 90 kW. This will also use Power Line Carrier technology to communicate between the vehicle, off-board charger, and smart grid.^[12] Seven car makers (Audi, BMW, Daimler, Ford, General Motors, Hyundai, Porsche, Volvo and Volkswagen) had agreed to introduce the "Combined Charging System" in mid-2012.^[13] The first vehicles using the SAE Combo plug were the BMW i3 released in late 2013, and the Chevrolet Spark EV released in 2014.^[14] In Europe, the combo coupler is based on the Type 2 (VDE) AC charging connector maintaining full compatibility with the SAE specification for DC charging and the GreenPHY PLC protocol.^[15]

Properties

Connector

The J1772-2009 connector is designed for single phase electrical systems with 120 V or 240 V such as those used in North America and Japan. The round 43 millimetres (1.7 in) diameter connector has five pins, with three different pin sizes (starting with the largest), for each of:

- AC line 1 and line 2
- Ground pin
- Proximity detection, and control pilot

Proximity detection

Prevents movement of the car while connected to the charger.

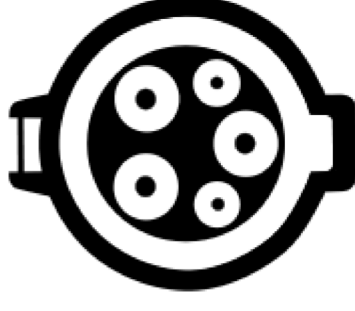
Control pilot

Communication line used to coordinate charging level between the car and the charger as well as other information.

A 1 kHz square wave at ± 12 volts generated by the electric vehicle supply equipment (EVSE; i.e., the charging station) on the control pilot to detect the presence of the vehicle, communicate the maximum allowable charging current, and control charging.^[16]

The connector is designed to withstand 10,000 mating cycles (a connection and a disconnection) and exposure to the elements. With 1 mating cycle per day, the connector's lifespan should exceed 27 years.

Charging



Type 1 "J1772" (Japan/US) slow AC connector

The J1772 standard defines two charging levels:[9]

	Voltage	Phase	Peak current	Power
AC Level 1	120 V	Single phase	16 A	1.92 kW
AC Level 2	208 V ^[17]	Leg to leg of a 208Y/120V 3-phase	48 A	9.98 kW
AC Level 2	240 V	Split phase	30 A 32 A (2001) 80 A (2009)	7.20 kW 7.68 kW 19.20 kW

The SAE J1772 committee has also proposed a DC connector based on the SAE J1772-2009 AC connector shape with additional DC and ground pins to support charging at 200–450 V DC and 80 A (36 kW) for **DC Level 1** and up to 200 A (90 kW) for **DC Level 2**^[18] after evaluating the J1772-2009 connector against other designs including the JARI/TEPCO connector used by the CHAdeMO DC fast charge protocol.^[19] The SAE **DC Level 3** charging levels have not been determined, but the standard as it exists as of 2009 has the potential to charge at 200–600 V DC at a maximum of 400 A (240 kW).

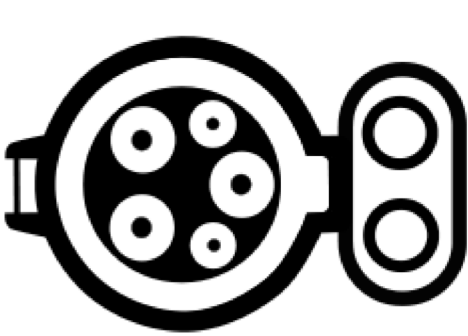
For example, a 240 kW charger that charges a plug-in vehicle, such as the BMW i3 with range extender that gets 100 miles per 21.7 kWh (155 MPGe, 217 Wh per mile), would get approximately 18 miles of range per minute that a driver spends charging throughout the life of the car. To put this into perspective, the Ford Taurus FWD 3.5L, which the EPA compares as an average new gasoline only car, gets 23 MPG, meaning that a gasoline pump that pumps at 7 gallons per minute gives 161 miles of range per every minute that a driver spends pumping gas throughout the life of the car.^[20]

Safety

The J1772 standard includes several levels of shock protection, ensuring the safety of charging even in wet conditions. Physically, the connection pins are isolated on the interior of the connector when mated, ensuring no physical access to those pins. When not mated, J1772 connectors have no power voltages at the pins,^[21] and charging power does not flow until commanded by the vehicle.^[19]

The power pins are of the first-make, last-break variety. If the plug is in the charging port of the vehicle and charging, and it is removed, the control pilot and proximity detection pin will break first causing the power relay in the charging station to open, cutting all current flow to the J1772 plug. This prevents any arcing on the power pins, prolonging their lifespan. The proximity detection pin is also connected to a switch that is triggered upon pressing the physical disconnect button when removing the connector from the vehicle. This causes the resistance to change on the proximity pin which commands the vehicle's onboard charger to stop drawing current immediately before the connector is pulled out.

Signaling



Type 1 CCS slow AC and fast DC connector

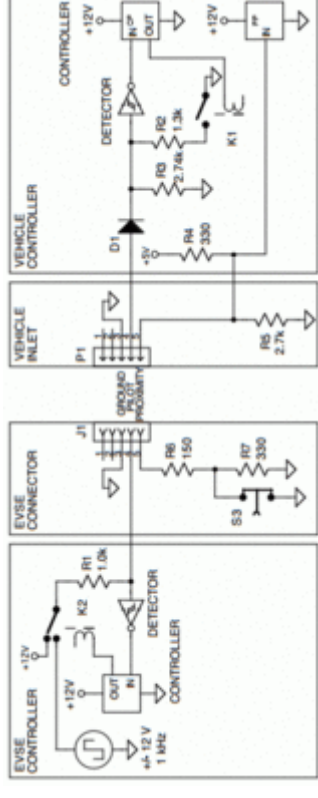
The signaling protocol has been designed so that^[19]

- supply equipment signals presence of AC input power
- vehicle detects plug via proximity circuit (thus the vehicle can prevent driving away while connected)
- control pilot functions begin
 - supply equipment detects plug-in electric vehicle
 - supply equipment indicates to plug-in electric vehicle (PEV) readiness to supply energy
 - PEV ventilation requirements are determined
 - supply equipment current capacity provided to PEV
- PEV commands energy flow
- PEV and supply equipment continuously monitor continuity of safety ground
- charge continues as determined by PEV
- charge may be interrupted by disconnecting the plug from the vehicle

The technical specification was described first in the 2001 version of SAE J1772 and subsequently the IEC 61851-1 and IEC TS 62763:2013. The charging station puts 12 V on the contact pilot (CP) and the proximity pilot (also, plug present; PP) measuring the voltage differences. This protocol doesn't require integrated circuits, which would be required for other charging protocols, making the SAE J1772 robust and operable through a temperature range of -40°C to $+85^{\circ}\text{C}$.

The charging station sends a 1 kHz square wave on the contact pilot that is connected back to the protected earth on the side of the vehicle by means of a resistor and a diode (voltage range $\pm 12.0 \pm 0.4$ V). The live wires of public charging stations are always dead if the CP-PE (protective earth) circuit is open, although the standard allows a charging current as in Mode 1 (maximum 16 A). If the circuit is closed then the charging station can also test the protective earth to be functional. The vehicle can request a charging state by setting a resistor; using 2.7 k Ω a Mode 3 compatible vehicle is announced (*vehicle detected*) which does not require charging. Switching to 880 Ω the vehicle is *ready* to be charged and switching to 240 Ω the vehicle requests *with ventilation* charging in which case charging power is only supplied if the area is ventilated (i.e., outdoors). The charging station can use the wave signal to describe the maximum current that is available from the charging station with the help of pulse width modulation: a 16% PWM is a 10 A maximum, a 25% PWM is a 16 A maximum, a 50% PWM is a 32 A maximum and a 90% PWM flags a fast charge option.^[22]

The pilot line circuitry examples in SAE J1772:2001 show that the current loop CP-PE is connected permanently via a 2.74 k Ω resistor making for a voltage drop to from +12 V to +9 V when a cable is hooked up to the charging station which activates the wave generator. The charging is activated by the car by adding parallel 1.3 k Ω resistor resulting in a voltage drop to +6 V or by adding a parallel 270 Ω resistor for a required ventilation resulting in a voltage drop to +3 V. Hence the charging station can react by only checking the voltage range present on the CP-PE loop.^[23] Note that the diode will only make for a voltage drop in the positive range; any negative voltage on the CP-PE loop will shut off the current as being considered a fatal error (like touching the pins).



J1772 signaling circuit

Base status	Charging status	Resistance, CP-PE	Resistance, R2	Voltage, CP-PE
Status A	Standby	Open, or ∞ Ω		+12 V
Status B	Vehicle detected	2740 Ω		+9±1 V
Status C	Ready (charging)	882 Ω	1300 Ω	+6±1 V
Status D	With ventilation	246 Ω	270 Ω	+3±1 V
Status E	No power (shut off)			0 V
Status F	Error			−12 V

The PWM duty cycle of the 1 kHz CP signal indicates the maximum allowed mains current. According to the SAE it includes socket outlet, cable and vehicle inlet. In the US, the definition of the *ampacity* (ampere capacity, or current capacity) is split for continuous and short term operation.^[22] The SAE defines the ampacity value to be derived by a formula based on the 1 ms full cycle (of the 1 kHz signal) with the maximum continuous ampere rating being 0.6 A per 10 μs (with the lowest 100 μs giving 6 A and the highest 800 μs giving 48 A).^[23]

PWM duty cycle indicating ampere capacity^[22]

PWM	SAE continuous	SAE short term
50%	30 A	36 A peak
40%	24 A	30 A peak
30%	18 A	22 A peak
25%	15 A	20 A peak
16%	9.6 A	
10%	6 A	

The pin, PP, is also named *plug present* as the SAE J1772 example pinout describes the switch, S3, as being mechanically linked to the connector latch release actuator. During charging, the EVSE side connects the PP-PE loop via S3 and a 150 Ω R6; when opening the release actuator a 330 Ω R7 is added in the PP-PE loop on the EVSE side which gives a voltage shift on the line to allow the electric vehicle to initiate a controlled shut off prior to actual disconnection of the charge power pins. However many low power adapter cables do not offer that locking actuator state detection on the PP pin.

P1901 powerline communication

In an updated standard due in 2012, SAE proposes to use power line communication, specifically IEEE 1901, between the vehicle, off-board charging station, and the smart grid, without requiring an additional pin; SAE and the IEEE Standards Association are sharing their draft standards related to the smart grid and vehicle electrification.^[24]

P1901 communication is compatible with other 802.x standards via the IEEE 1905 standard, allowing arbitrary IP-based communications with the vehicle, meter or distributor, and the building where chargers are located. P1905 includes wireless communications. In at least one implementation, communication between the off-board DC EVSE and PEV occurs on the pilot wire of the SAE J1772 connector via HomePlug Green PHY power line communication (PLC).^{[25][26][27]}

Compatible charging stations

In North America and Japan, the Chevrolet Volt,^[28] Nissan Leaf,^[29] Mitsubishi i-MiEV, Toyota Prius Plug-in Hybrid, Smart electric drive and Kia Soul EV all come with 120 V portable charging leads that couple a 120 V mains plug to the car's J1772 receptacle; in the countries where 220-230V domestic mains electricity is common, the portable EVSE leads commonly supplied with the vehicle can perform a level 2 charge from a domestic mains plug, albeit at a lower current than a dedicated high-current charging station.

Products compatible with SAE J1772-2009 include:

- AeroVironment home charging station for the Nissan Leaf^[30]
- BTCPower (Broadband TelCom Power), the first commercially available SAE DC Fast Charger in the United States^{[31][32]}
- Bosch Power Max home charging stations
- ClipperCreek products include CS-40,^[33] LCS-25^[34] and LCS-25p,^[35] HCS-40.^[36] The product with highest charging current is CS-100.^[37]
- ChargePoint CT4000 intelligent charger, cable management, driver services; CT500, CT2000], CT2100, and CT2020 families of ChargePoint Networked Charging Stations^[38]
- Eaton Pow-R-Station Family of Electric Vehicle Charging Stations^[39]
- ECOtality Blink home wall-mount and commercial stand-alone charging stations^{[40][41]}
- Electric Motor Werks JuiceBox Open Source 18 kW 75 A EVSE^[42]
- EVSEadapters EVSE240V16A] 240V 16A Portable Level 2 EVSE^[43]
- EvoCharge – Retractable Reel EVSE's designed to support Residential, Commercial and Industrial Markets.
- GE Wattstation available in 2011^[44]
- GoSmart Technologies ChargeSPOT line of charging stations
- GRIDbot's "UP" family of charging stations
- Hubbell PEP Stations^[45]
- Leviton home charging stations at a range of power levels, with separate pre-wire kit that allows one to plug into a NEMA 6 240 V receptacle^[46]
- Schneider Electric / Square D EVLink Charging Solutions for residential, commercial, and fleet charging solutions.
- Siemens VersiCharge for cost effective residential, semi-public, and fleet level 2 EV charging.
- SemaConnect ChargePro Charging Stations
- Shorepower Technologies ePump line of fully customizable EVSE; indoor and outdoor solutions for cars and trucks.
- TucsonEV - J1772 Adapter Boxes, J1772 Extension cords, Inlets and Plugs with and without cord, J1772 Compatible EVSE for 240 V/30 A, Zero Motorcycle to J1772 Adapter, Tesla UMC to J1772 conversion, 30A and 40A EV UL listed cord.
- Circontrol CircaLife product range includes EV charging infrastructure with post and wall mount units with J1772 standard^[47]

- OpenEVSE Project - Open Source Design for EVSE.
- eStation Level-2 Charger by Vega. Part of chargeNET network in Sri Lanka

Competing standards

The proposal of the Mennekes connector initiated by RWE and Daimler has been added as a "Type 2" implementation to IEC 62196 (IEC Type 2) providing a single and three phase coupler.^{[11][48]} The connector was specified in the VDE-AR-E 2623-2-2 standard - this connector specifies up to 63 A three-phase (at 400 V in Central Europe) which makes for a maximum of $63\text{ A} \times 400\text{ V} \times \sqrt{3} = 43.6\text{ kW}$. Additionally the IEC 62196-2 standard specifies a "Type 3" connector providing a single and three phase coupler with shutters.^[11] All plug types - including Type 1 (SAE), Type 2 (VDE) and Type 3 - share the same specifications for the pilot pin taken from the IEC 61851-1 standard.

Tokyo Electric Power Company has developed a specification solely for automotive high-voltage DC fast charging using the JARI DC connector, and formed the CHAdeMO (abbreviation of "CHArge de MOve", equivalent to "charge for moving") association with Japanese automakers Mitsubishi, Nissan and Subaru to promote it.^[49]

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External links

- SAE J1772 Committee (<http://www.sae.org/servlets/works/committees/committeeHome.do?comtID=TEVHYB3>)

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