



SURFACE VEHICLE RECOMMENDED PRACTICE

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SAE Electric Vehicle Inductively Coupled Charging

RATIONALE

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Foreword—This is a Recommended Practice and in no manner should be interpreted as a standard of the SAE. This proposal should not be interpreted as an endorsement of inductive charging by the SAE. This document contains 44 pages, including this page, and should not be used as a design tool if any of the pages are missing. Portions of this document may be revised to keep pace with experience and technological advances.

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- 1. Scope**—This SAE Recommended Practice establishes the minimum interface compatibility requirements for electric vehicle (EV) inductively coupled charging for North America.

This part of the specification is applicable to manually connected inductive charging for Levels 1 and 2 power transfer. Requirements for Level 3 compatibility are contained in Appendix B. Recommended software interface messaging requirements are contained in Appendix A.

This type of inductively coupled charging is generally intended for transferring power at frequencies significantly higher than power line frequencies. This part of the specification is not applicable to inductive coupling schemes that employ automatic connection methods or that are intended for transferring power at power line frequencies.

- 1.1 General Inductive Charging System Description**—The basic principle behind inductive charging is that the two halves of the inductive coupling interface are the primary and secondary of a two-part transformer. When the charge coupler (i.e., the primary) is inserted in the vehicle inlet (i.e., the secondary), power can be transferred magnetically with complete electrical isolation just as it occurs in a standard transformer. The number of turns (windings) on the secondary is “matched” to the vehicle’s battery pack voltage so that the same charger can charge any vehicle.

The charger converts utility power to high frequency AC (HFAC) power (130 kHz to 360 kHz). The high frequency operation is utilized to reduce the size and mass of the on-vehicle portion of the transformer. The vehicle inlet is the power inlet on the vehicle which receives the HFAC from the charger. The HFAC is converted into DC to charge the batteries. An on-vehicle charge controller continuously monitors the state of the batteries during charging and controls the charger output power level via an IR communications link between the vehicle inlet and the charger (the charger’s communications interface is physically imbedded in the charge coupler). The charge controller signals the charger to stop charging when it determines that the batteries are completely charged or a fault is detected during the charging process.

The following steps correspond with the diagram in Figure 1, and describe the closed-loop charging system.

- a. Vehicle charge controller determines desired current into batteries. **
- b. Vehicle charge controller transmits charger output power request to charger via an IR communications interface. **
- c. Charger controls input current from utility based on charger output power request from vehicle charge controller. **
- d. Charger converts 60 Hz utility power to HFAC power.
- e. HFAC power is magnetically coupled from the coupler (primary) to the vehicle inlet (secondary).
- f. HFAC power is rectified/filtered to DC to charge the vehicle batteries.
- g. Process repeats until the vehicle charge controller determines the batteries are fully charged. **

NOTE—Items with ** indicate control loop.

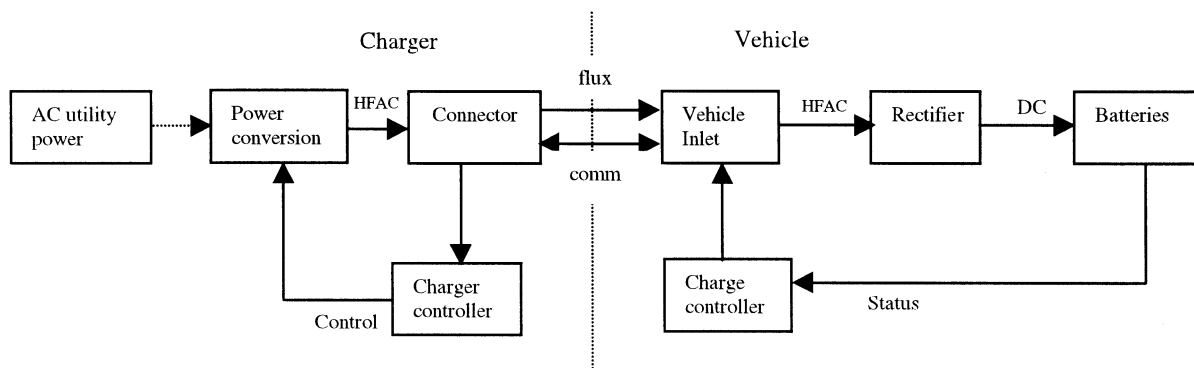


FIGURE 1—TYPICAL CLOSED-LOOP CHARGING SYSTEM.

2. References

2.1 Applicable Publications—The following publications form a part of this document to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J551-2—Test Limits and Methods of Measurement of Radio Disturbance Characteristics of Vehicles, Motorboats, and Spark-Ignited Engine-Driven Devices

SAE J551-5—Performance levels and Methods of Measurement of Magnetic and Electric Field Strength from Electric Vehicles, Broadband, 9 kHz to 30 MHz

SAE 1211—Recommended Environmental Practices for Electronic Equipment Design

SAE J1850—Class B Data Communications Network Interface

SAE J2178—Class B Data Communication Network Messages

SAE J2293—Energy Transfer System for Electric Vehicles

2.1.2 FEDERAL COMMUNICATIONS COMMISSION (FCC)—Available from U.S. Government Printing Office, Superintendent of Documents, P.O. Box 371954, Pittsburgh, PA 15250-7954.

CFR 47—Code of Federal Regulations, Title 47, Parts 15B, 18C

CFR 40—Code of Federal Regulations, Title 40, Part 600, Subchapter Q

2.1.3 UNDERWRITERS LABORATORIES, INC.—Available from Underwriters Laboratories, Inc., 333 Pfingsten Road, Northbrook, IL 60062-2096.

UL 94—Tests for Flammability of Plastic Materials for Parts in Devices and Appliances

UL 2202—Electric Vehicle (EV) Charging System Equipment

2.2 Related Publications

2.2.1 NFPA PUBLICATION—Available from the National Fire Protective Association, Batterymarch Park, Quincy, MA 02269.

NFPA-70-1999—National Electric Code (NEC), - Article 625

2.2.2 CANADIAN ELECTRIC STANDARDS—Available from: Canadian Standards Association, 170 Rexdale Blvd., Rexdale, Ontario, Canada M9W 1R3

Canadian Electric Code*CEC Part 1, Section 86

3. Definitions

3.1 Electric Vehicle (EV)—An automotive type vehicle, intended for highway use, powered by an electric motor that draws current from an on-vehicle energy storage device, such as a battery, which is rechargeable from an off-vehicle source, such as residential or public electric service. For the purpose of this document the definition of automobile in the United States Code of Federal Regulations Title 40, Part 600 Subchapter Q is used. Specifically, an automobile means:

- Any four-wheeled vehicle propelled by a combustion engine using onboard 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),
- Which is manufactured primarily for use on public streets, roads, or highways,
- Which is rated at not more than 3855.6 kg (8500 lb) gross vehicle weight, which has a curb weight of not more than 2721.6 kg (6000 lb), and which has a basic vehicle frontal area of not more than 4.18 m² (45 ft²).

3.2 Inductive Coupling—A mating inductive vehicle inlet and inductive connector set. See Figure 2.

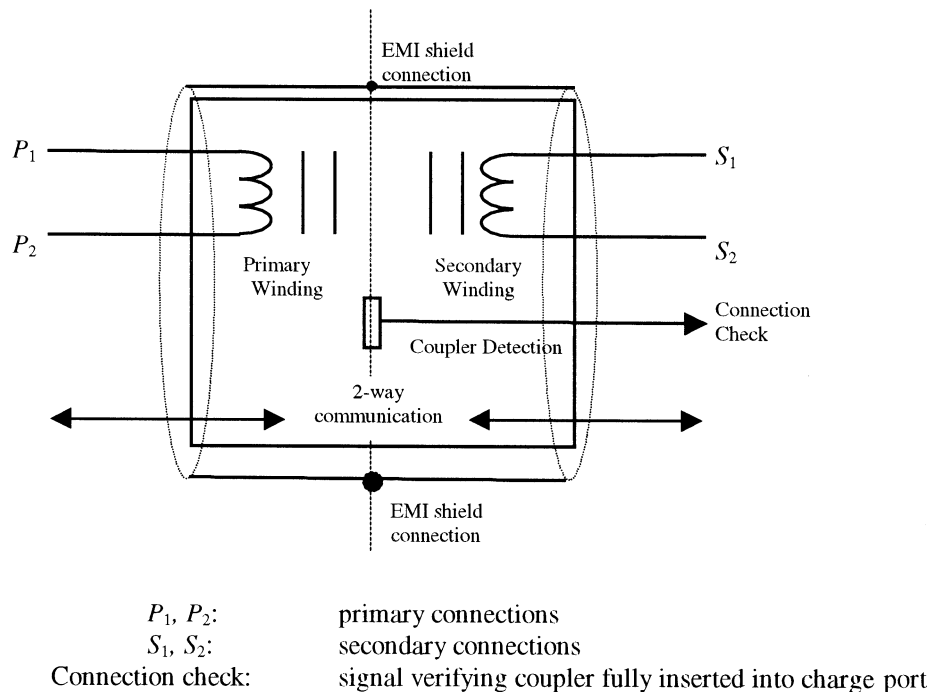


FIGURE 2—TYPICAL INDUCTIVE COUPLING.

3.3 Inductive Connector—The male part of the inductive coupling. The inductive connector is that part of an inductive charger, which is manually inserted into a mating inductive vehicle inlet. The inductive connector contains the primary windings, ferrite to complete the magnetic path, and a communications interface to the vehicle.

- 3.4 Inductive Vehicle Inlet**—The female part of the inductive coupling. The inductive vehicle inlet is that part of the electric vehicle, which mates with the inductive connector. The inductive vehicle inlet contains the secondary windings, ferrite to complete the magnetic path, and a communications interface to the charger.
- 3.5 Two-Part Transformer**—A transformer whose primary and secondary windings are located in separate devices designed to be physically separable from one another and which are galvanically isolated as in a double-wound transformer. Efficient energy transfer can occur when the two halves of the transformer are properly aligned.
- 3.6 Level 1 Charging**—A charging method that allows an electric vehicle to be charged by having its charger connected to the most common grounded receptacle (NEMA-5-15R). The maximum power supplied for Level 1 charging shall conform to the values shown in Table 1.

TABLE 1—CHARGE LEVEL SPECIFICATIONS (NORTH AMERICA)

Charge Method	Nominal Supply Voltage	Max Current (Amps-continuous)	Branch Circuit Breaker Rating (Amps)	Continuous Input Power (reference)
Level 1	120 VAC, 1-phase	12 A	15 A	1.44 kW
Level 2	208 to 240 VAC, 1-phase	32 A	40 A	6.66 to 7.68 kW
Level 3	208 to 600 VAC, 3-phase	400 A	As required	> 7.68 kW

- 3.7 Level 2 Charging**—A charging method that utilizes dedicated electric vehicle supply equipment in either private or public locations. The maximum power supplied for Level 2 charging shall conform to the values shown in Table 1.
- 3.8 Level 3 Charging**—A charging method that utilizes dedicated electric vehicle supply equipment in either private or public locations. The maximum power supplied for Level 3 charging shall conform to the values shown in Table 1.
- 4. Inductive Charging Interface Requirements**—The following paragraphs describe the technical requirements for the inductive interface.

4.1 Power Transfer

- 4.1.1 AVERAGE OUTPUT VOLTAGE RANGE**—The allowable range for the average voltage at the output of the secondary-side rectifier, V_O , of the vehicle inlet shall be from 10 V/turn to 107.5 V/turn.
- 4.1.2 MAXIMUM AVERAGE OUTPUT CURRENT AS A FUNCTION OF AVERAGE OUTPUT VOLTAGE**—The maximum value for the average current output, I_O , from the secondary-side rectifier shall be the lesser of (a) 100 A-turns, or (b) the current calculated by the division of 90% of the maximum Level 2 input power (7.68 kW) by the average output voltage, as shown in Figure 3, where 90% is the charger system efficiency.
- 4.1.3 POWER TRANSFER FREQUENCY RANGE**—The fundamental operating frequency for power transfer shall range from 130 kHz to 360 kHz for maximum continuous input power levels up to 7.68 kW.
- 4.1.4 MAXIMUM ALLOWABLE AVERAGE OUTPUT CURRENT VERSUS FREQUENCY**—The maximum average output current shall be 100 A-turns (e.g., 25 A for a four turn secondary) at the minimum frequency of 130 kHz. The allowable limit for the average output current, I_O , for an average output voltage range of 69.1 V/turn to 107.5 V/turn, is plotted as a function of the power transfer fundamental operating frequency in Figure 4 (lower curve).

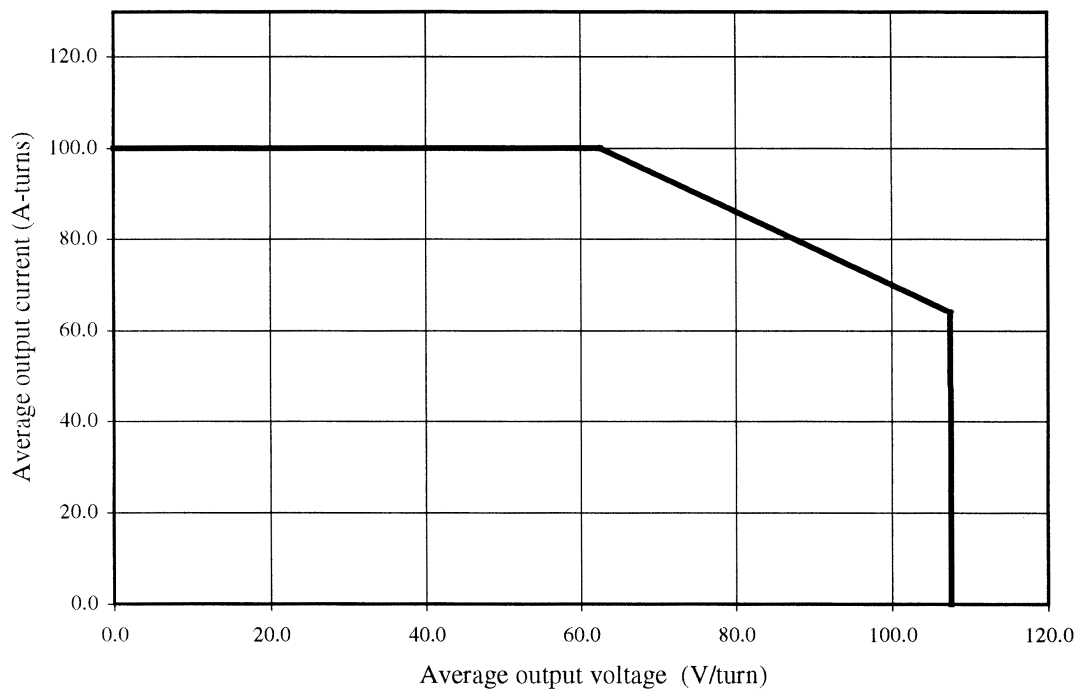


FIGURE 3—MAXIMUM AVERAGE OUTPUT CURRENT, I_O , AS A FUNCTION OF AVERAGE OUPUT VOLTAGE, V_O

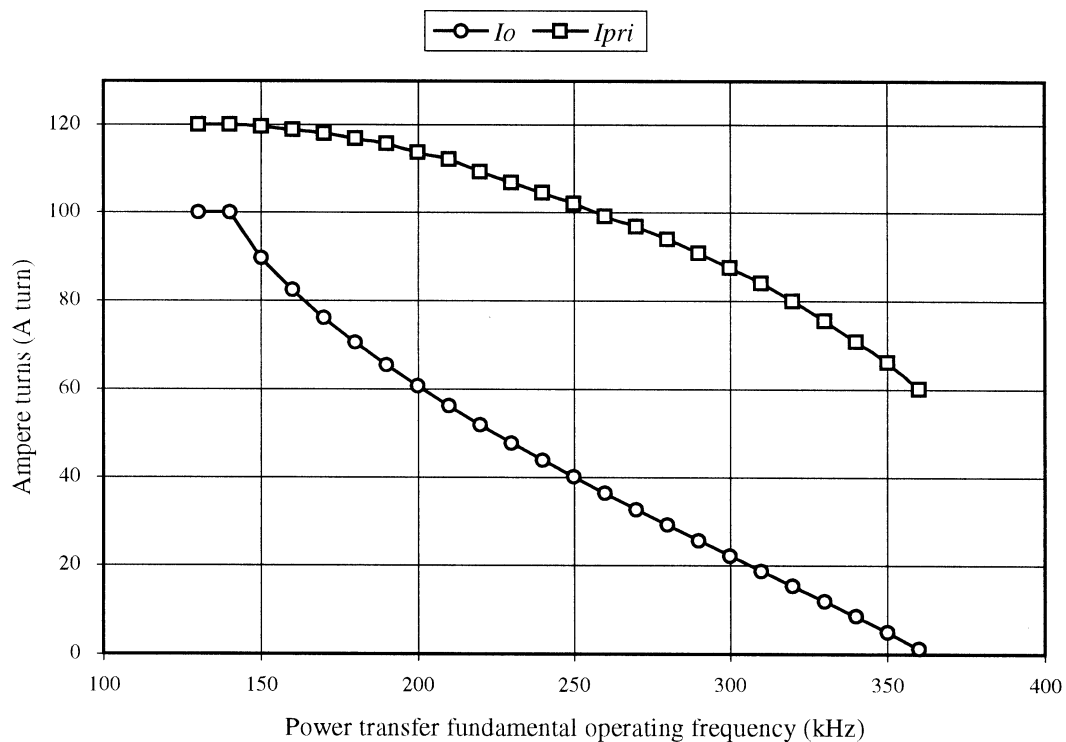


FIGURE 4—MAXIMUM ALLOWABLE INLET CURRENTS

4.1.5 MAXIMUM ALLOWABLE RMS INPUT CURRENT VERSUS FREQUENCY—The maximum allowable RMS primary current shall be 120 A-turns (e.g., 30 A for a four turn primary) at the minimum frequency of 130 kHz. The allowable limit for the RMS input current, I_{pri} , as a function of the power transfer fundamental operating frequency is shown by the upper curve in Figure 4.

4.1.6 EQUIVALENT CIRCUIT PARAMETERS AT CHARGE COUPLING INTERFACE—The inductive interface equivalent circuit diagram is shown in Figure 5. The interface parameters shall conform to the requirements of Table 2.

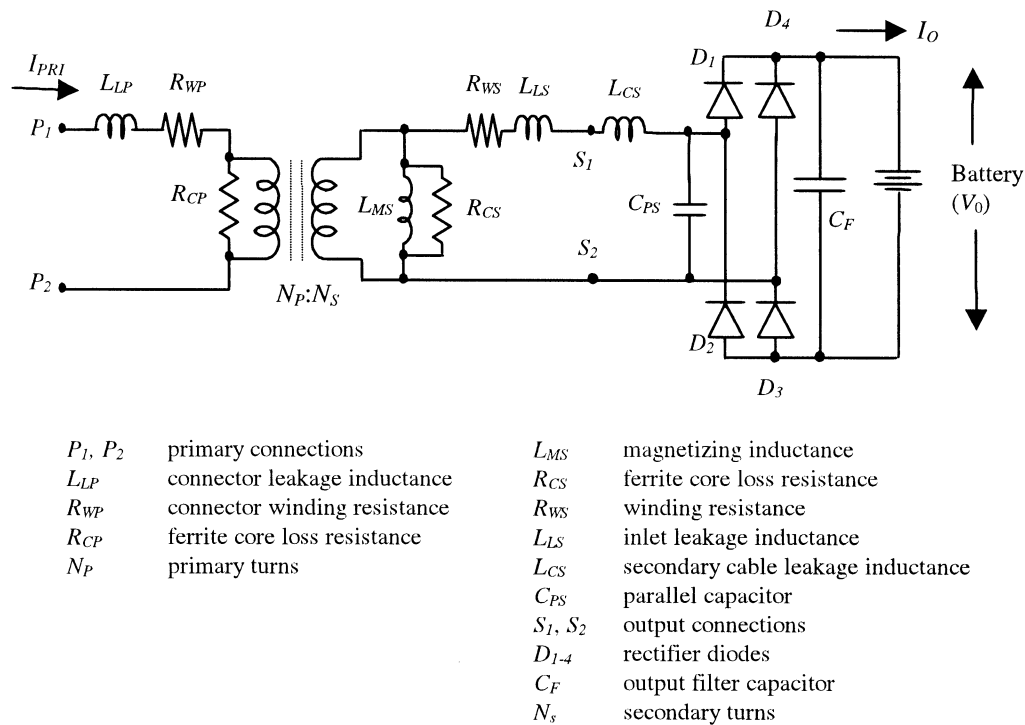


FIGURE 5—INDUCTIVE INTERFACE EQUIVALENT CIRCUIT

TABLE 2—ALLOWABLE RANGE OF EQUIVALENT CIRCUIT PARAMETERS
FOR A NORMALIZED TRANSFORMER
(SINGLE TURN PRIMARY AND SINGLE TURN SECONDARY)

Parameter	L_{MS}	$L_{LP} + L_{LS} + L_{CS}$	C_{PS}	R_{WP}	P_{RWP}	R_{CP}	P_{RCP}	R_{CS}	V_0	I_0	R_{WS}
(unit)	($\mu\text{H}/\text{turn}^2$)	($\mu\text{H}/\text{turn}^2$)	(nF turn ²)	(m Ω/turn^2)	(W)	(k Ω/turn^2)	(W)	(k Ω/turn^2)	(V/turn)	(A-turn)	(m Ω/turn^2)
Minimum	2.37		608						10	0	
Typical	2.63	0.031-0.219	640	0.625		2.5		0.125			0.938
Maximum	3.75	0.25	704		10		5		107.5	100	

4.2 Heat Transfer

- 4.2.1 **EXCESS INDUCTIVE CONNECTOR POWER DISSIPATION**—The inductive interface cooling system shall have the capability to dissipate 15 W maximum added to the interface by the inductive connector during charging.
- 4.2.2 **INDUCTIVE CONNECTOR TOUCH TEMPERATURE**—The maximum surface temperatures shall comply with UL 2202, Electric Vehicle (EV) Charging System Equipment.

4.3 **Communications**—The inductive charging interface shall contain an IR link between the vehicle and the charger. The communications interface physical layer shall be compatible with SAE J2293. Conformance to this requirement shall be determined by demonstrating the ability of the physical layer to pass SAE J1850-compliant messages across the inductive interface.

- 4.3.1 **IR COMMUNICATIONS METRICS**—See Table 3.

TABLE 3—IR COMMUNICATIONS METRICS

	IR System Value
SAE J1850 Parameters	
Direction	bi-directional, half duplex
Baud Rate	10.4 kbits/s
Bit Encoding	VPW
Communication protocol between inlet and charger	encoded SAE J1850 (see Figure 6)
Communication Metrics	
Transmit Frequency	880 nm
Modulation Type	on-off keying
On/Off Power ratio	≥30 dBm
Max Duty Cycle	80% "Active" @ 4 kHz
Min Duty Cycle	0%
Max "Active" On Time	500 μs
SAE J1850 Metrics	
Max Node Voltage Offset	0.25 V
Network Time Constant	5.2 μs
Transceiver loading	1 unit load
Noise Rejection	≤8 μs
Steady-State Performance Metrics	
IR Radiant intensity measured	2.3 mW/Sr
Voltage Output	V_{ol} and V_{oh} per SAE J1850
Voltage Input	V_{il} and V_{ih} per SAE J1850
Transient Performance Metrics	
Transmitter Turn On Delay	1.0 μs ± 0.5 μs
Receiver Turn On Delay	7.0 μs ± 2.0 μs
Total System Delay	10.5 μs (max)

NOTE 1—The IR transmit power level shall be measured at the surface, on both sides of the inductive connector, directly above the transceiver interface.

NOTE 2—It is highly recommended that the communications interface be implemented as a dedicated link due to the potential for SAE J1850 bitwise arbitration problems when the interface is used in a multi-node communications system.

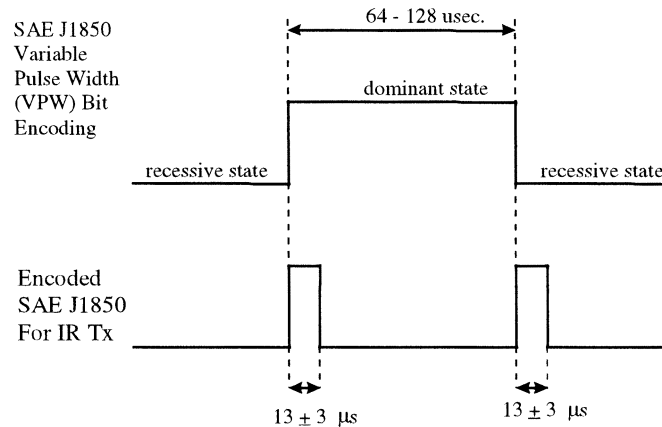


FIGURE 6—SAE J1850 ENCODING FOR IR TRANSMISSION

4.4 Physical Compatibility

4.4.1 INDUCTIVE CONNECTOR

4.4.1.1 *Critical Dimensions*—See Figures 7 and 8.

4.4.1.2 *Orientation*—The operation of the inductive connector shall be independent of the orientation when inserted into the vehicle inlet.

4.4.1.3 *Connection Present Magnet Location*—The inductive connector shall contain two magnets at the locations specified in Figure 8. These magnets may be used by the vehicle to detect the presence of the inductive connector when it is fully inserted into the vehicle inlet.

4.4.1.4 *Connection Present Magnet Strength*—The magnetic field strength of the coupler connection detection magnets shall be 60 millitesla minimum when measured at the surface of the connector directly above the magnet location.

4.4.1.5 *Tactile Feel Indents*—There shall be indents on both sides of the inductive connector at the locations specified in Figure 7. These indents may be used by the vehicle to provide positive tactile feedback to the user when the inductive connector is fully inserted into the vehicle inlet.

4.4.1.6 *EMI Shield Contact Zone Location*—There shall be a conductive contact area encircling the inductive connector as specified in Figure 7. This contact area shall be used to connect the charger ground to the vehicle chassis ground for purposes of EMI shielding when the inductive connector is fully inserted into the vehicle inlet.

4.4.1.7 *EMI Shield Contact Zone Impedance*—The resistance between the external surface of the EMI shield contact zone and charger ground shall be less than 0.5 Ω .

4.4.1.8 *IR Transceiver Interface Location*—The inductive connector may contain one IR transceiver interface at the locations specified in Figure 8 to meet the IR communications requirements. This transceiver interface shall be used for IR communications between the charger and vehicle inlet when the inductive connector is fully inserted into the vehicle inlet.