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400 Commonwealth Drive, Warrendale, PA 15096-0001

SURFACE VEHICLE RECOMMENDED PRACTICE

Submitted for recognition as an American National Standard

SAE J1773

Issued 1995-01

ELECTRIC VEHICLE INDUCTIVE CHARGE COUPLING RECOMMENDED PRACTICE

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

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1. Scope—This SAE Recommended Practice covers the minimal physical, electrical, and performance requirements for the electric vehicle inductive charge coupling in the United States. The intent of the Recommended Practice is to define a common electric vehicle inductive charging inlet and its mating coupler. Application and compatibility requirements for the coupler and vehicle inlet are stated herein.

1.1 Inductive Charging—Since the energy stored in batteries provides the "fuel" that powers most electric vehicles (EVs), EVs will need a method of charging their batteries on a regular basis. Inductive charging is a method of transferring power from a charger to the battery of an electric vehicle) magnetically rather than by direct electrical contact. Unlike traditional conductive battery charging systems, there are no current carrying metal contacts between the inductive charger and the EV. Inductive charging technology is used today in appliances like electric toothbrushes and shavers (although at much lower power levels).

2. References

2.1 Applicable Documents—The following publications form a part of this specification to the extent specified herein. These documents are intended as a baseline to be used until SAE can develop a Standard(s) that encompasses applicable sections of the documents listed.

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

SAE J551—Performance Levels and Methods of Measurement of Electromagnetic Radiation from Vehicles and Devices (30 Hz to 1,000 MHz)
SAE J1211—Recommended Environmental Practices for Electronic Equipment Design
SAE J1742—Connections for High Voltage On-Board Road Vehicle Electrical Wiring Harness
SAE J1850—Class B Data Communication Network Interface

2.1.2 NFPA PUBLICATION—Available from The National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.

National Electric Code, NFPA 70-1996, Article 625 (as adopted)

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

FCC Code of Regulation, Title 47 (Includes Parts 15A, 15B, 18), Document # 869-019-00180-8

2.1.4 GENERAL MOTORS—Available from Global Documents Inc., 7730 Carondelet Ave. #607, Clayton, MO 63105, 1-800-854-7179.

GM9100P

NOTE—Available to public and to be used as starting place for Electromagnetic Interference (EMI) issues. Will be replaced when an industry recognized standard (SAE....) has developed comprehensive EMI guidelines.

2.1.5 UNDERWRITERS LABORATORY (UL)—Available from Underwriters Laboratories Inc., 333 Pfingsten Road Northbrook, IL 60062-2096

UL-583—Electric Battery Powered Industrial Trucks
UL-1564—Industral Battery Chargers
UL-94—Test for Flammability of Plastics Material
UL-1439—Standard for the Determination of Sharp Edges
UL-2202—Outline of Investigation for Electric Vehicle (EV) Charging System Equipment
UL-640—Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment

2.2 Related Publications—The following publications are provided for information purposes only and are not a required part of this document.

2.2.1 INTERNATIONAL ELECTROTECHNICAL COMMISSION (IEC)—Available from IEC, 3, Rue de Varembe, CH-1211, Geneva 20, Switzerland

NOTE—IEC Publications also available from American National Standards Institute, 11 West 42nd Street, New York, NY 10036-8002.

IEC555—Disturbances Caused by Equipment Connected to the Public Low Voltage Supply System
IEC529—Degrees of protection provided by enclosures. (Code) IP55
IEC801-2—Part 2—Electrostatic Discharge Requirements

2.2.2 JAPANESE STANDARDS ASSOCIATION—Available from Japanese Standards Association, 1-24, Akaska 4 Minatoku, Tokyo 107, Japan.

JIS D 0203—Methods of Moisture, Rain, and Spray Test for Automotive Parts
JIS C 0704—Insulation Test for Control Gear

2.3 Definitions

2.3.1 CHARGE COUPLING—The charge coupling is composed of two primary components; the vehicle inlet and the coupler. It is a take-apart transformer operating between 80 kHz and 300 kHz. Figure 1 shows the typical inductive charge coupling.

2.3.2 COUPLER—The device connected to the electric vehicle supply equipment that transfers power to the electric vehicle for charging the energy storage system and permits the exchange of information between the electric vehicle and the electric vehicle's supply equipment. The coupler contains the primary coil of the take-apart transformer, an antenna for communications, a magnet for connection check, and provisions for locking the coupler in the vehicle to prevent tampering. It is a part of the charge coupling.

2.3.3 CHARGER—A system which converts utility power to high frequency AC at the battery voltage with the current dictated by the vehicle.

2.3.4 ELECTRIC VEHICLE (EV)—An automotive type vehicle, intended for highway use, primarily powered by an electric motor that draws energy from a chargeable power storage device.

2.3.5 INDUCTIVE CHARGING SYSTEM—A charging system which converts low frequency utility power to high frequency, transfers power across a take-apart transformer, and rectifies that power into DC voltage to the batteries.

2.3.6 CHARGING CONTROL SYSTEM—The control system is based on an off-board charger which is controlled by the on-board battery controller and a charge interface consisting of power and communication transfer between the vehicle and the charger. Figure 2 shows a typical charge control diagram.

2.3.7 INDUCTIVE COUPLING STANDARD ZONE—The zone where the coupler inductively transfers power and communication signals across to the vehicle inlet.

2.3.8 INTERMATABILITY—The ability for a coupler to be inserted into a vehicle inlet to form a charge coupling.

2.3.9 LEVEL 1 CHARGING—This charging method allows an EV to be charged by the most popular grounded receptacle. Level 1 AC supply specification is:

120 VAC Nominal, 60 Hz, 15A, 1-phase

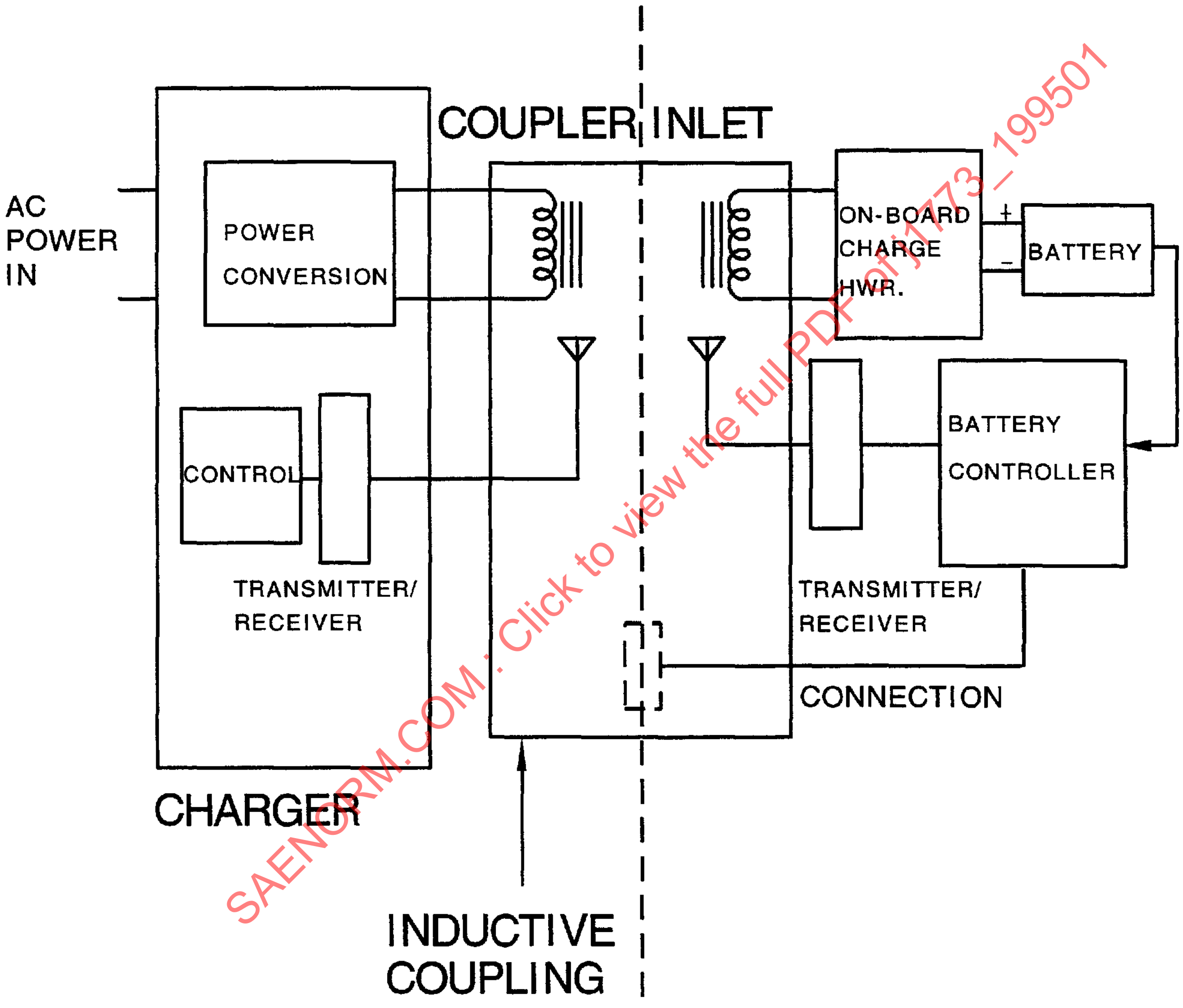

FIGURE 1—TYPICAL INDUCTIVE LEVEL 1,2,3 CHARGING

2.3.10 LEVEL 2 CHARGING—This charging method utilized dedicated EV charging equipment in both private and public locations. Level 2 AC supply specification is:

208 and 240 VAC Nominal, 60 Hz, 40A, 1-phase

2.3.11 LEVEL 3 CHARGING—This charging method allows EVs to be charged at commercial "fast" charge facilities. Level 3 AC supply specification is:

25 kW - 160 kW
208-600 VAC Nominal, 60 Hz, 3-phase

2.3.12 VEHICLE INLET—The device on the electric vehicle that makes up the secondary of the take-apart transformer into which the coupler is inserted to facilitate charging. It is a part of the charge coupling.

3. General System Description

3.1 Component Function and Responsibility—The basic principle behind inductive charging is that the two halves of the inductive coupling interface are the primary and secondary sides of a take-apart 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 like 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 60 Hz utility power to high frequency AC power (hundreds of kHz). The higher frequency is necessary to reduce the size and weight of the on-vehicle portion of the transformer. The vehicle inlet is the power inlet on the vehicle which receives the high frequency AC from the charger. The AC 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 a low power RF communications link between the vehicle inlet and the charger (the charger's RF 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.

3.2 Power and Communications Flow—The following steps correspond with the diagram in Figure 2, and describe the closed loop charging system.

1. Vehicle charge controller determines desired current into batteries. **
2. Vehicle charge controller transmits charger output power request to charger via RF communications interface. **
3. Charger controls input current from utility based on charger output power request from vehicle charge controller. **
4. Charger converts 60 Hz utility power to high frequency AC (HFAC) charger power.
5. HFAC charge power is magnetically coupled from the coupler (primary) to the vehicle inlet (secondary).
6. HFAC charge power is rectified / filtered to DC to charge the vehicle batteries.
   Process repeats until the vehicle charge controller determines the batteries are fully charged. **

   Note: Items with ** indicate control loop.

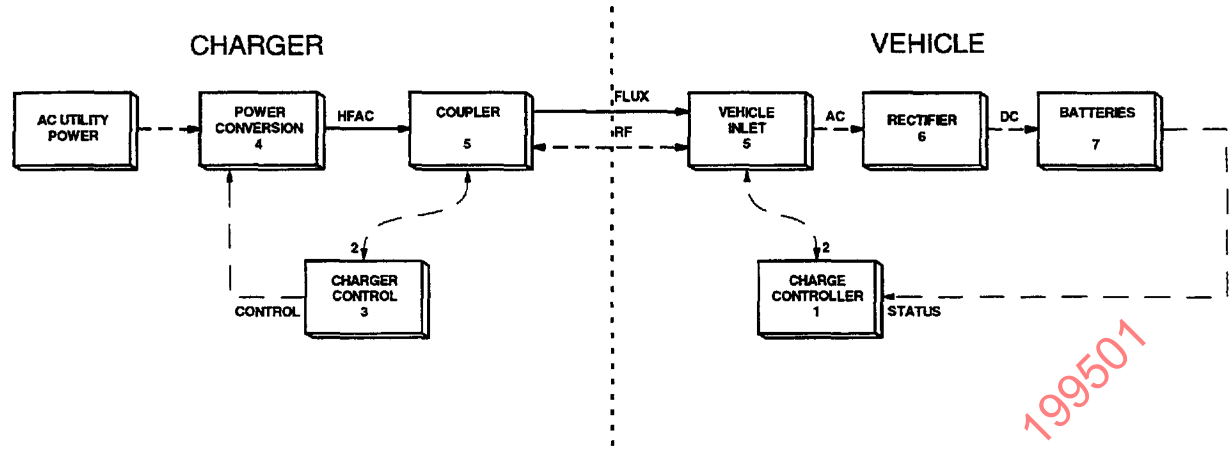

FIGURE 2—INDUCTIVE CHARGING CONTROL SYSTEM DIAGRAM

4. ***Interface Requirements***—This section provides a description of only the interface requirements between the vehicle and the off-board charger. The interface area is limited to those items that cross the boundary between the coupler and the vehicle inlet. An illustration of this interface area is provided in Figure 3. Please refer to the section 'Application Requirements' for methods of achieving these interface requirements.

4.1 System Considerations

4.1.1 VEHICLE INLET—The vehicle inlet shall be available in compatible physical configurations as defined in this specification. It will allow charging at Level 1, 2, or 3. The number of turns in the secondary of the vehicle inlet is dependent on the battery voltage of the vehicle. The vehicle inlet will also provide media for signal, control, safety, and communication.

4.1.2 COUPLER—The coupler shall have attributes for each of the charging levels as defined in this document. The primary for each of the couplers shall be sized to carry the current capacity for the level of charging for which they have been designed. The coupler will also provide media for signal, control, safety, and communication.

Power and Communications Symbolic Schematic - Level 1,2,3
1. High Frequency AC Power transfer
2. Radio Frequency Communication Link

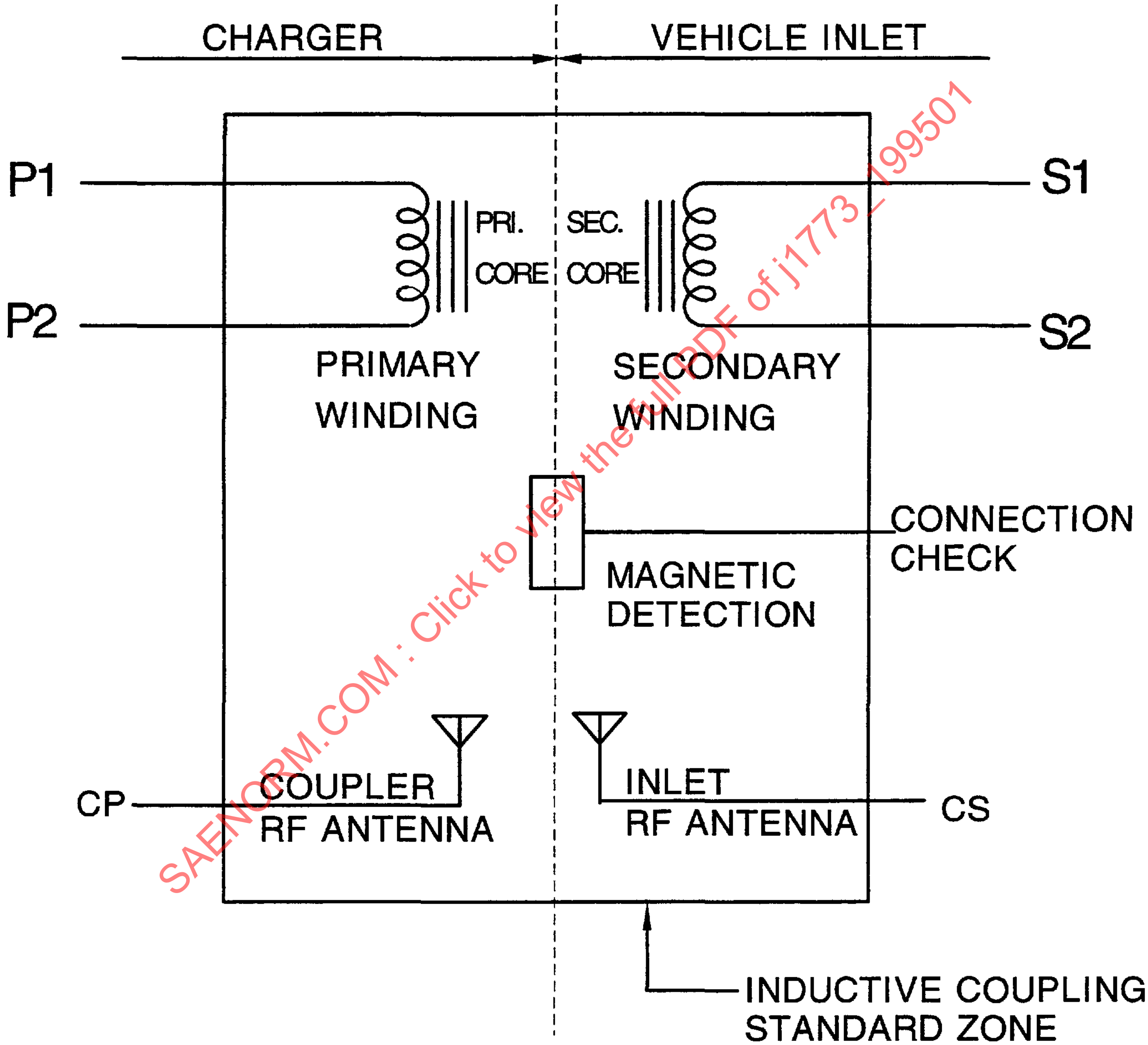

FIGURE 3—STANDARD EV INDUCTIVE COUPLING

4.1.3 PHYSICAL INTERFACE—The physical interface which mates with the vehicle inlet shall be identical for all three couplers. Figure 4 shows the common inlet for three charging levels. Inductive charge coupling shall be used for power transfer. Charge coupling represents a unique set of circumstances, all of which shall be considered in the system design process.

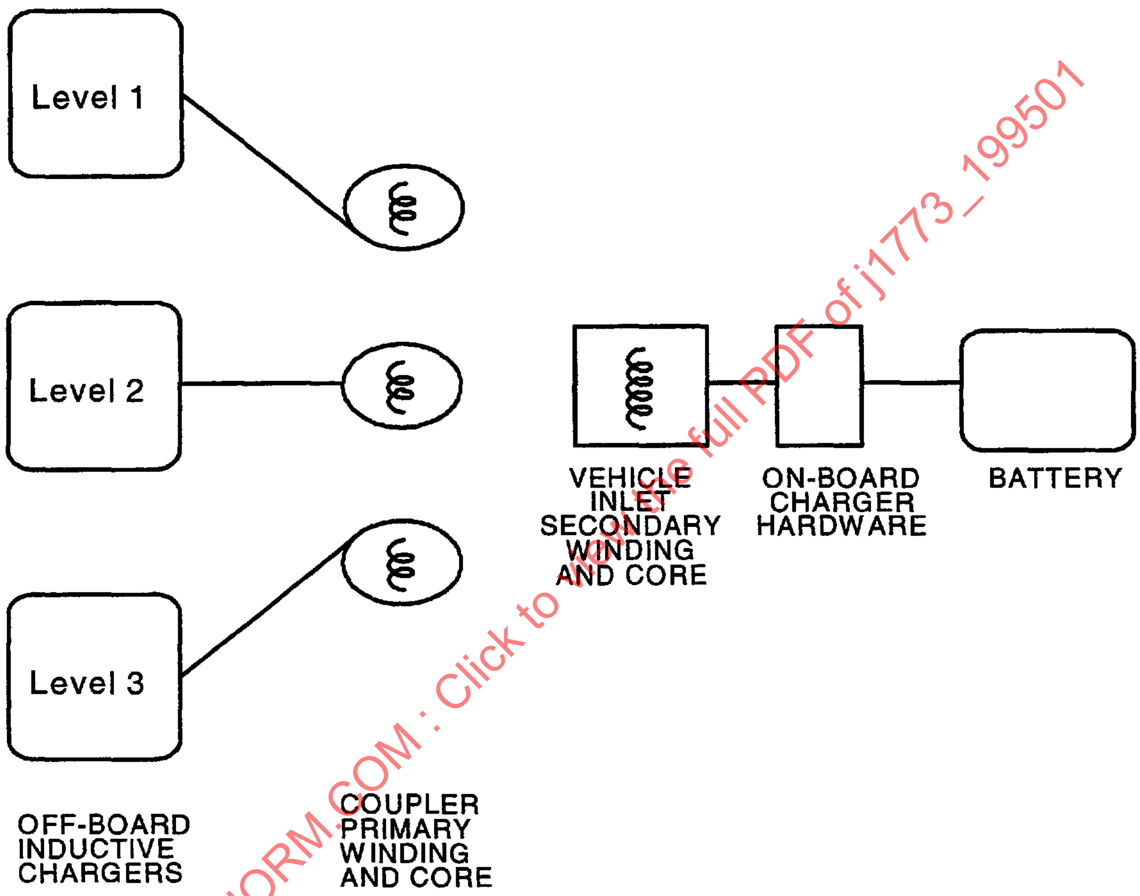

FIGURE 4—EV CHARGING LEVELS—INDUCTIVE COUPLING

4.1.4 INTERMATABILITY—Since the vehicle inlet will not always use the same coupler. all couplers and inlets shall be intermatable. The coupler and vehicle inlet may not be operating as a matched set.

4.2 Physical Characteristics

4.2.1 VEHICLE INLET—The vehicle inlet shall provide a means for alignment of the coupler during insertion. Refer to Figure 5.

The vehicle inlet shall conform to standard dimensions. Refer to Figure 5.

The vehicle inlet shall be provided with a connection presence switch. This may include a magnetic switch. Refer to Figure 5 for location.

The vehicle inlet shall be provided with an antenna to transmit and receive charge control data. Refer to Figure 5 for antenna location/s.

The vehicle inlet shall be provided with EMI tactile fingers to ensure compliance with Electromagnetic Compatibility (EMC) requirements. Refer to Figure 5 for proper location

The vehicle inlet secondary cores shall conform to standard dimensions to ensure proper coupling. Refer to Figure 6.

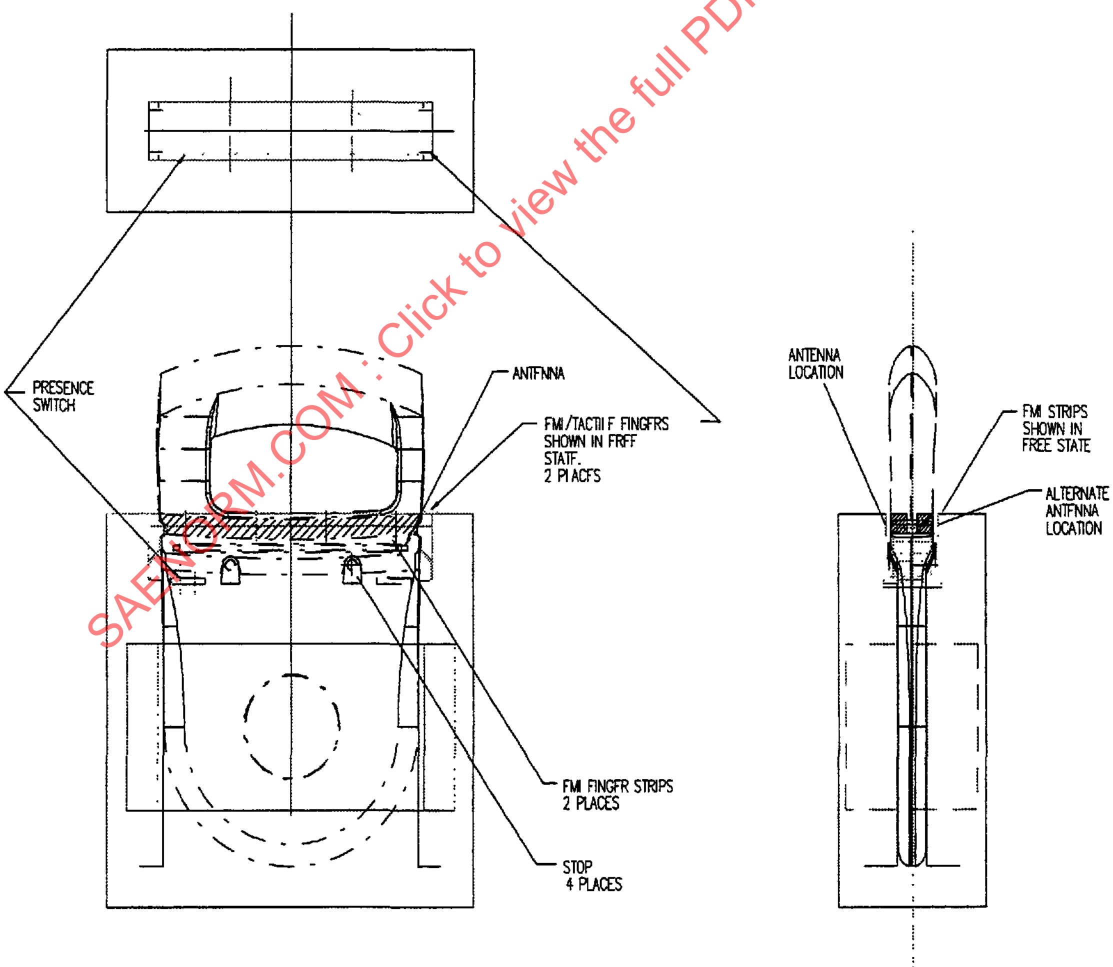

FIGURE 5A—PHYSICAL DIMENSIONS OF VEHICLE INLET

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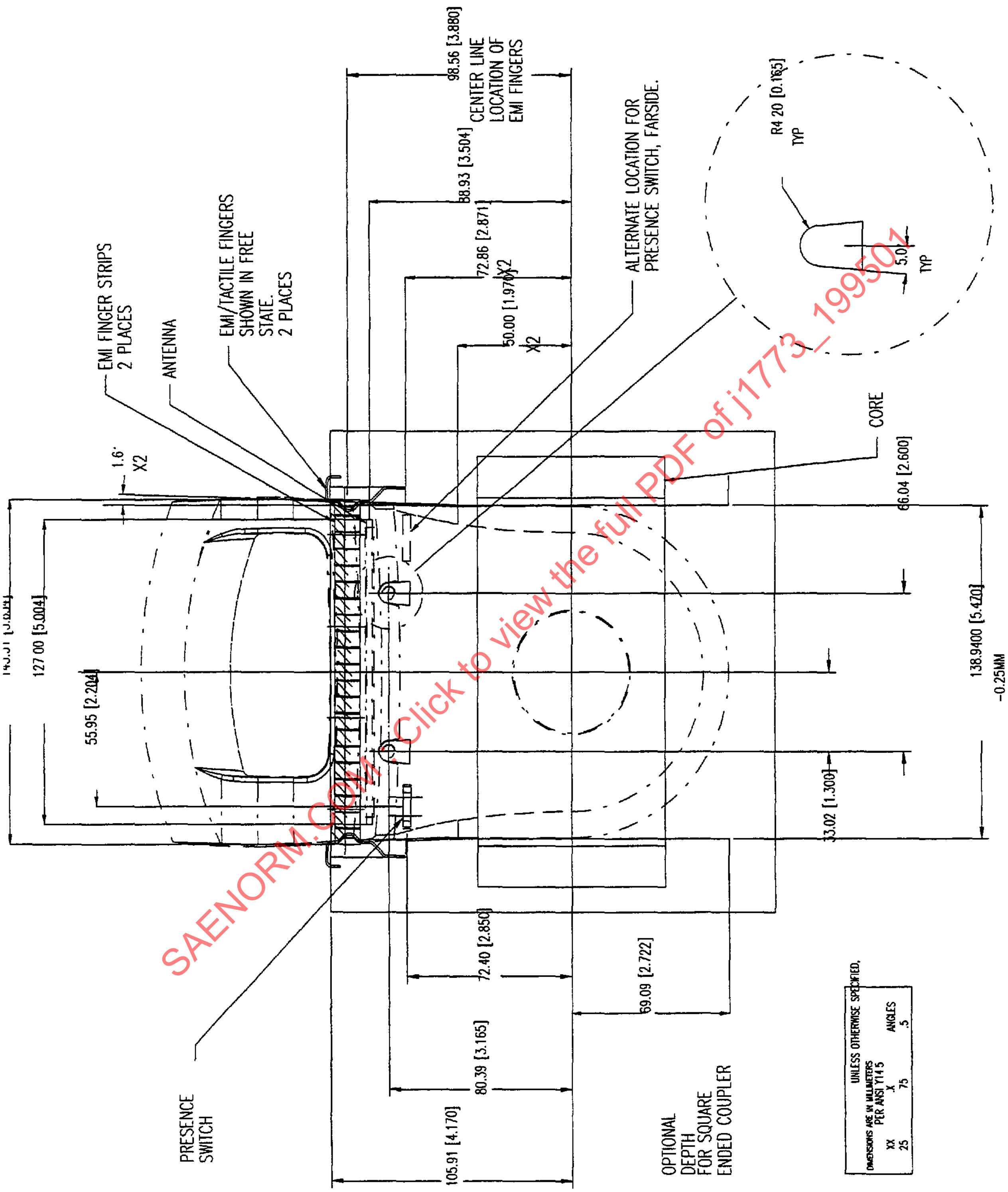


FIGURE 5B—VEHICLE INLET CONTINUED DETAIL SHEET

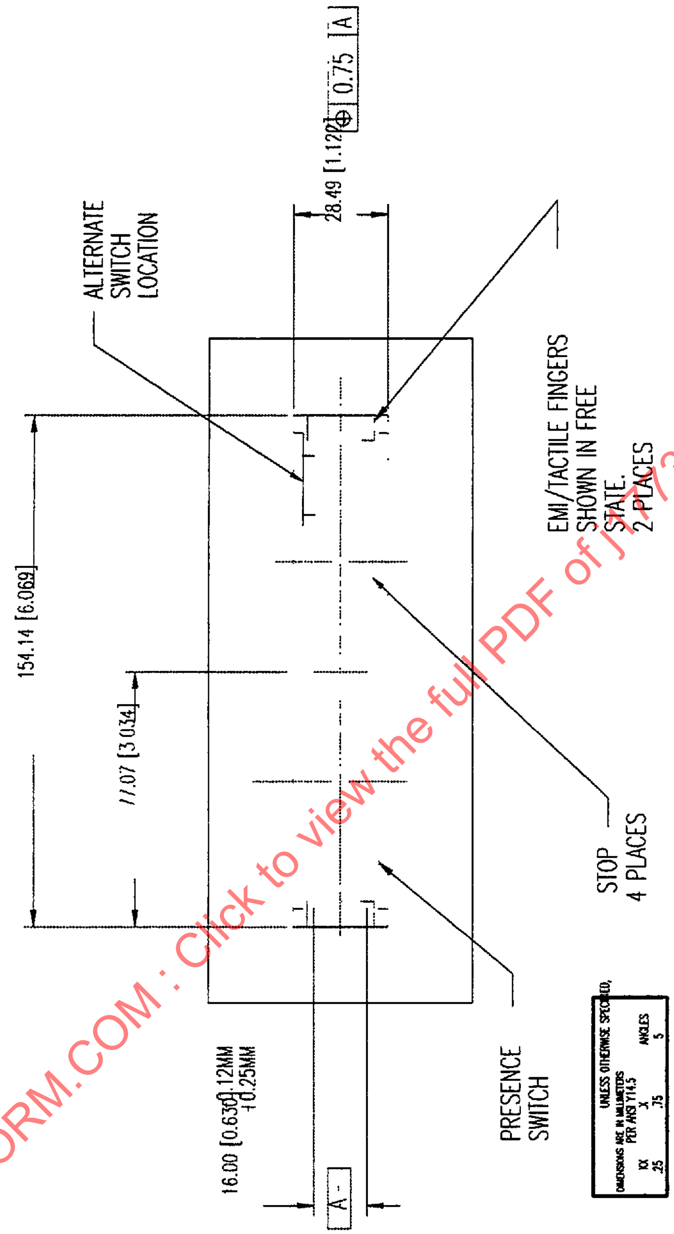


FIGURE 5C—VEHICLE INLET CONTINUED DETAIL SHEET

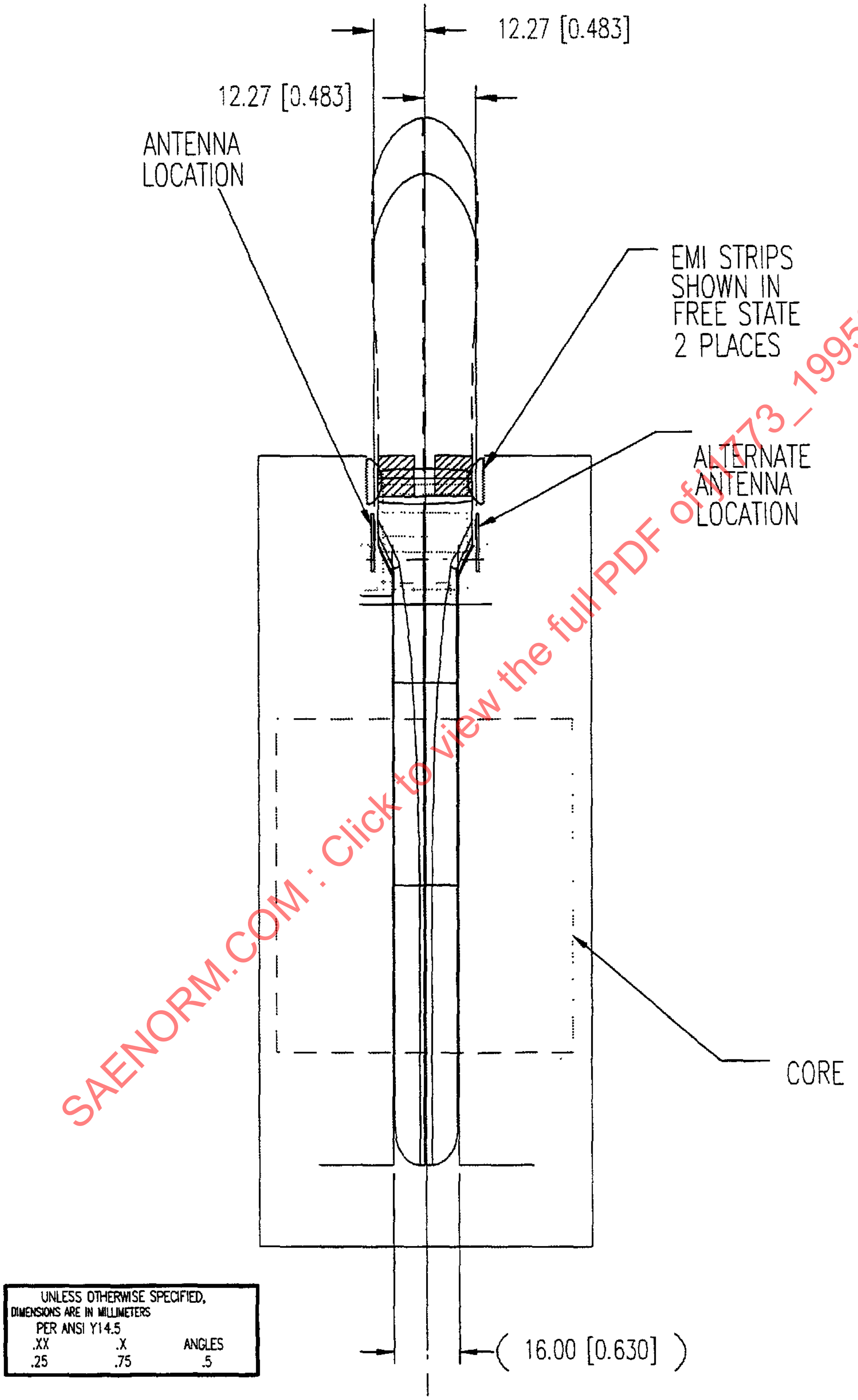


FIGURE 5D—VEHICLE INLET CONTINUED DETAIL SHEET

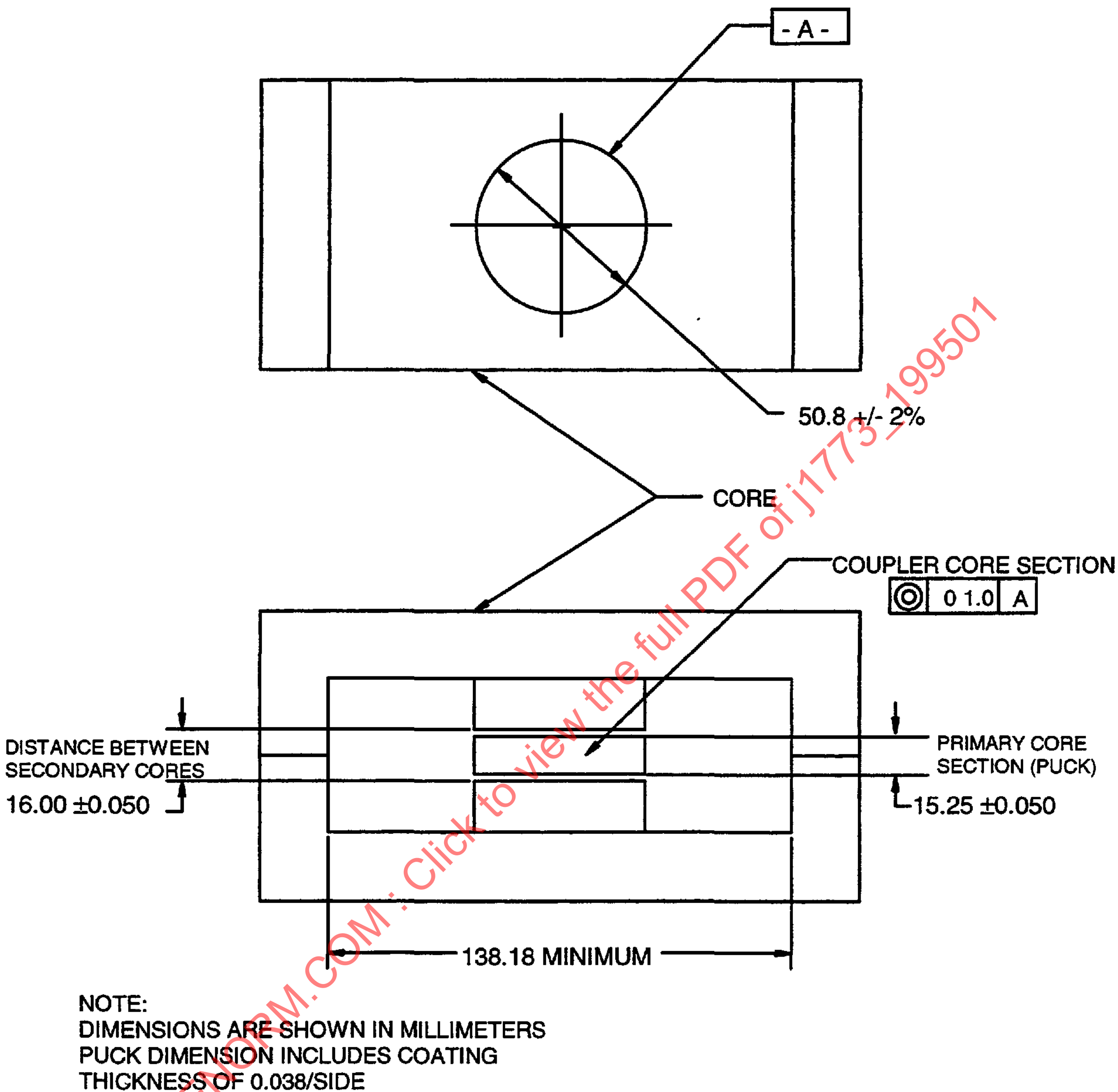


FIGURE 6—CRITICAL VEHICLE INLET CORE DIMENSIONS

4.2.2 COUPLER—The coupler shall be provided with an EMI shield contact zone area to ensure compliance with EMC requirements. Refer to Figure 7 for proper location.

The coupler shall be provided with a means to engage a locking mechanism to prevent tampering or unauthorized removal during charging.

The coupler shall be provided with an antenna to transmit and receive charge control data. Refer to Figure 7 for antenna locations.

The coupler core section (puck) will conform to standard dimensions to ensure proper coupling of magnetic flux. Refer to Figure 8.

The coupler shall be provided with two magnets (for reversibility of the coupler) to engage the magnetic switches in the vehicle inlet. The strength of the magnets shall be 60 to 80 millitesla. Refer to Figure 7 for locations.

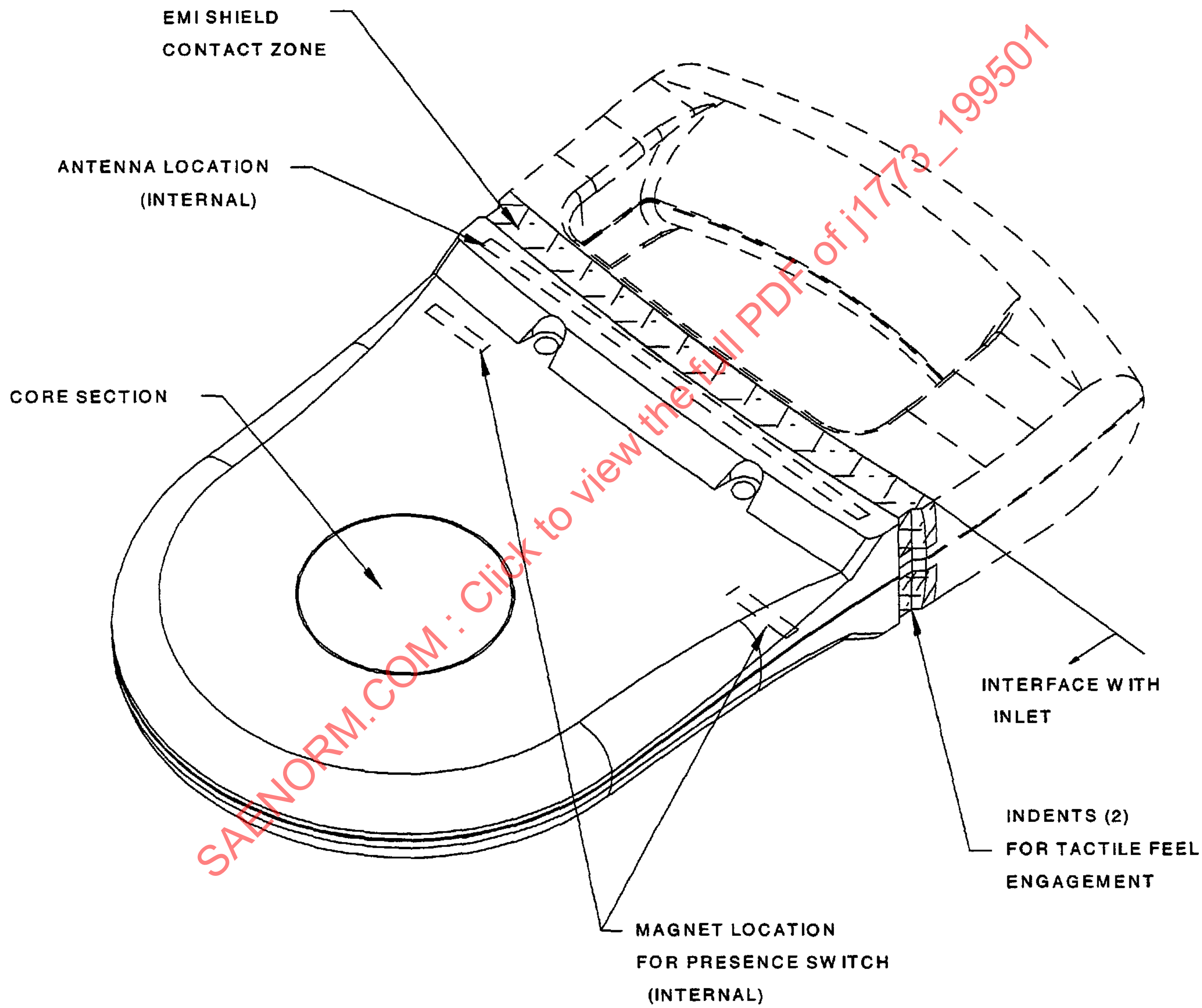


FIGURE 7—EV INDUCTIVE COUPLING TYPICAL CHARGING COUPLER FEATURES

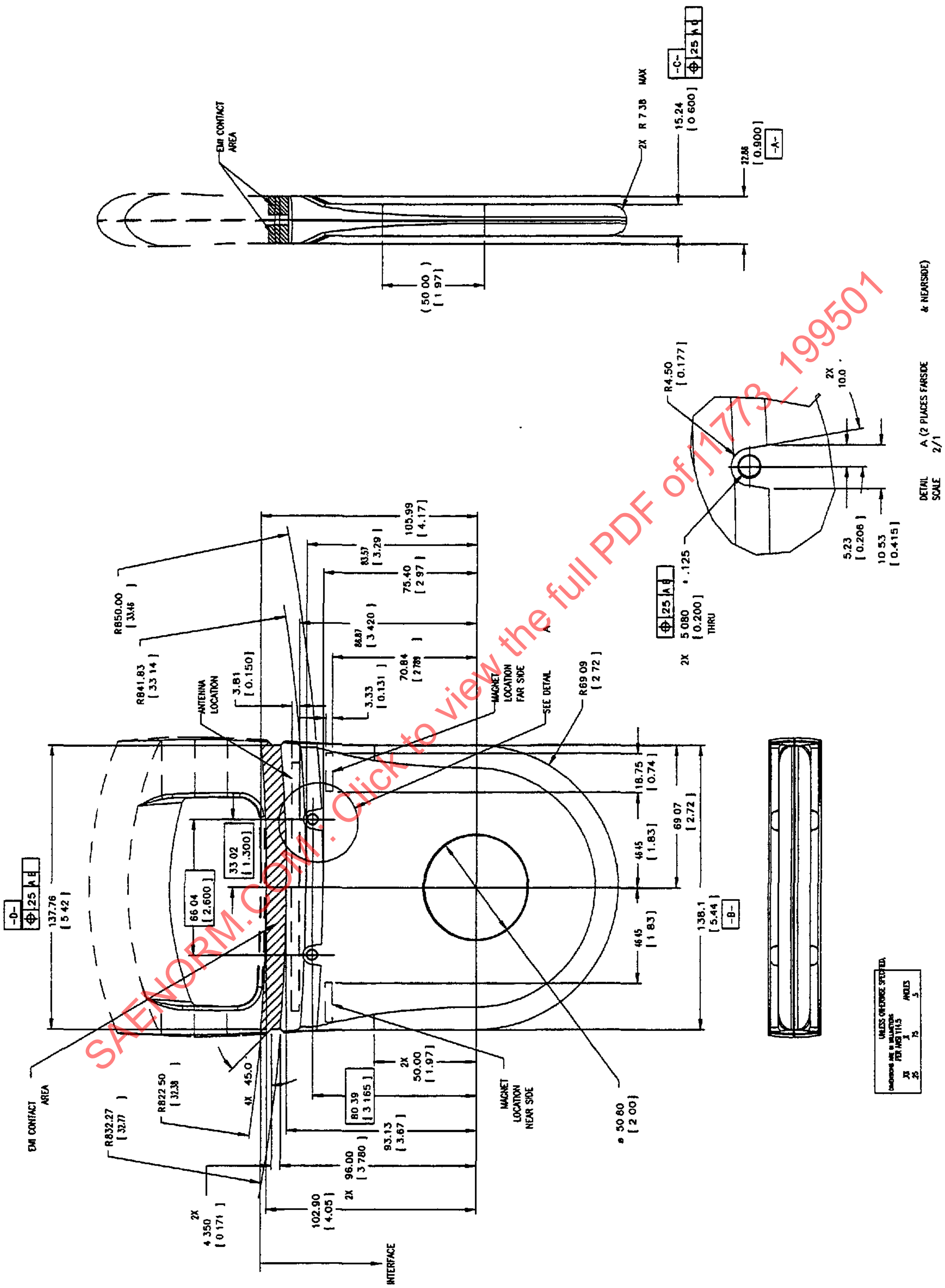


FIGURE 8A—PHYSICAL DIMENSIONS OF CHARGING COUPLER

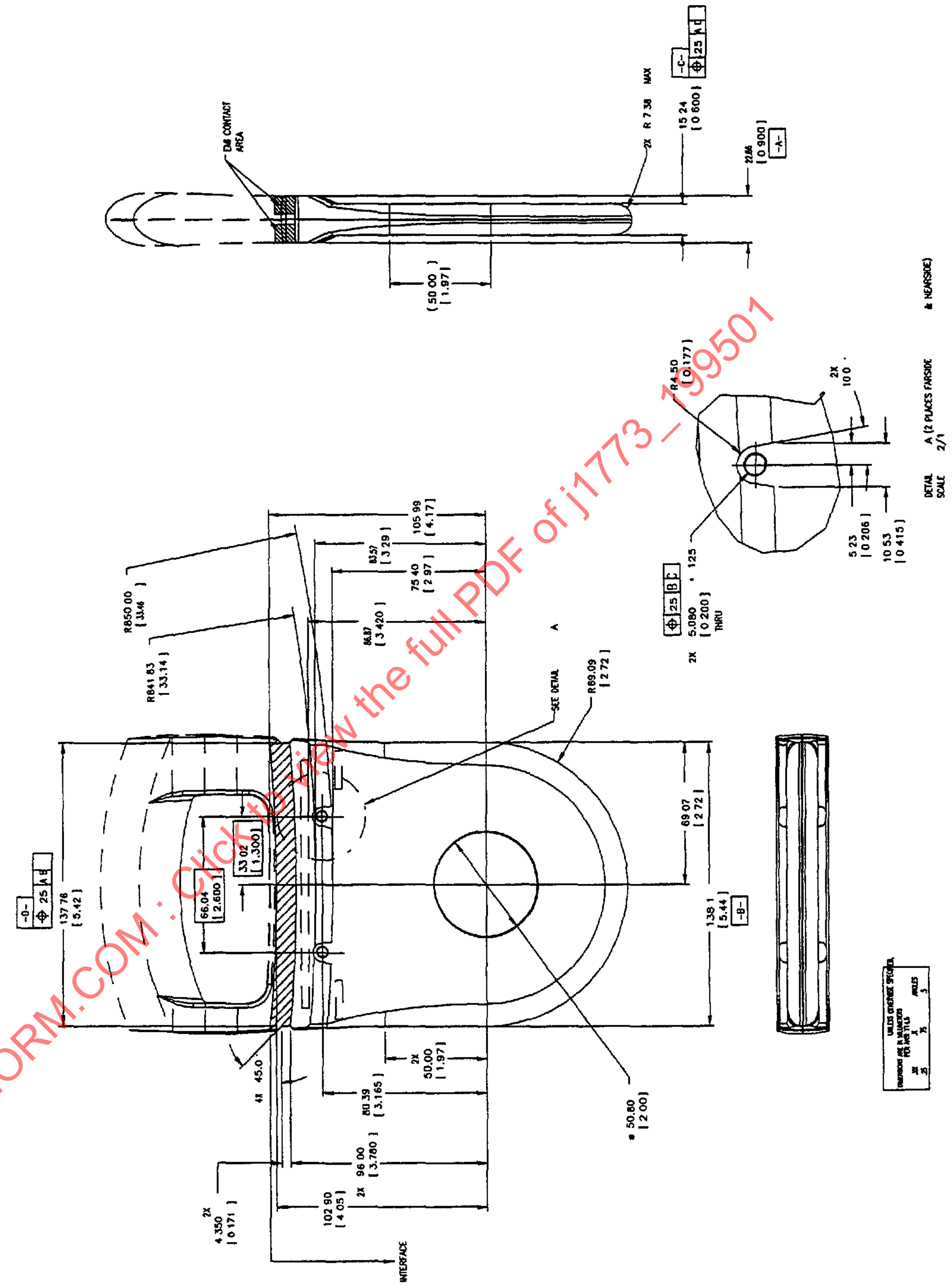


FIGURE 8B—CHARGING COUPLER CONTINUED DETAIL SHEET

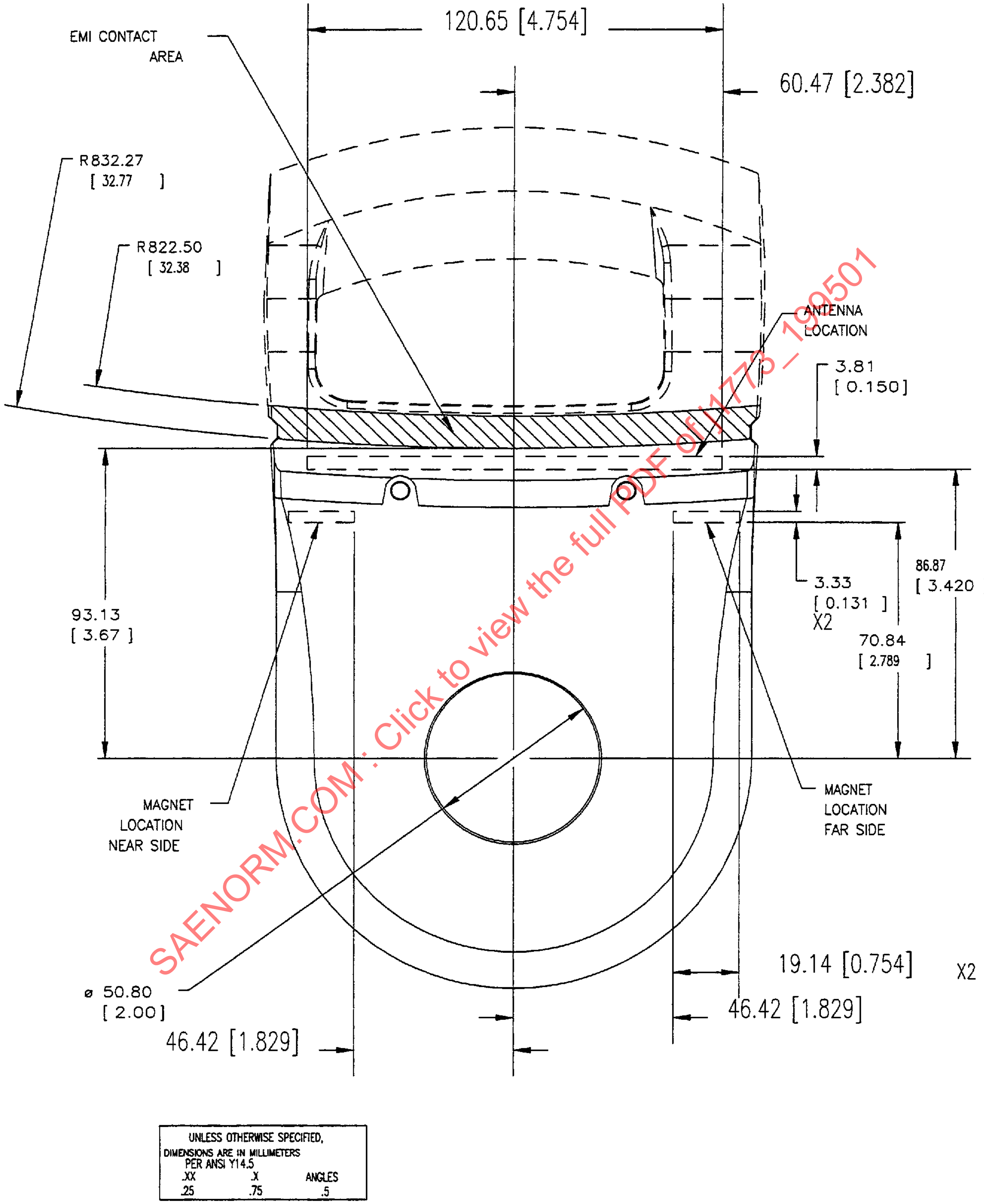
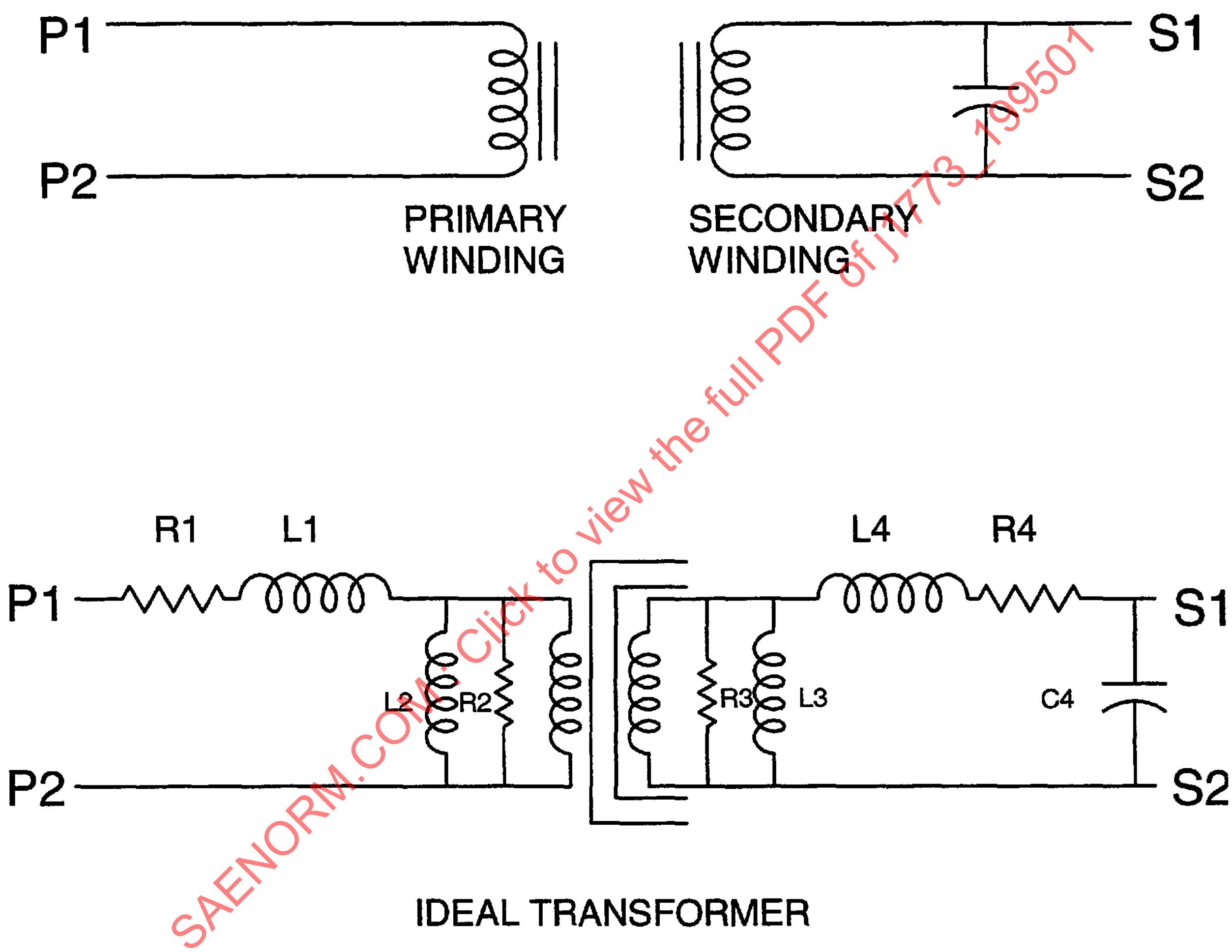


FIGURE 8C—CHARGING COUPLER CONTINUED DETAIL SHEET

4.2.3 THERMAL—The vehicle inlet shall provide the cooling capacity to remove up to 4.5 W in the ferrite puck area and 6.5 W in the primary coil area, at 25 °C ambient air temperature.

4.3 Electrical

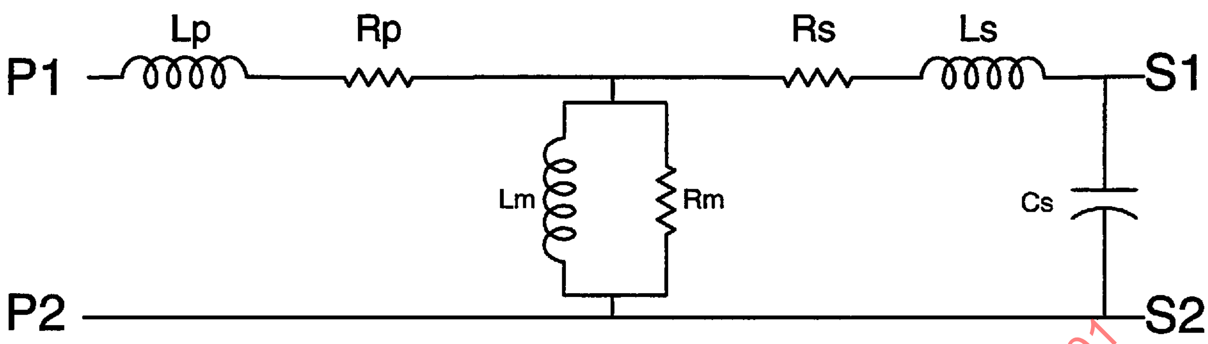
4.3.1 POWER TRANSFER—The charge coupling shall be capable of transferring high frequency AC power. Transformer equivalent circuit and values are shown in Figure 9.



	Max R1	Max L1	Min R2	±10% L2	Min R3	±10% L3	Max R4	Max L4	±5% C4
f min (100 kHz)	20 mW	0.8 mH	40 kW	2.0 mH	1.6 kW	45 mH	20 mW	0.8 mH	0.04 mf
f max (350 kHz)	35 mW	0.6 mH	140 kW	2.5 mH	5.6 kW	50 mH	35 mW	0.6 mH	0.04 mf

All figures are nominal, with the following assumptions: use of a sine wave, a resonant circuit, and a 4:4 turns ratio at 6.6 kW. Self resonant frequency (SRO) greater than 1.2 Mhz (does not apply to C4).

FIGURE 9—TRANSFORMER EQUIVALENT CIRCUIT



SIMPLIFIED EQUIVALENT TRANSFORMER

	Max RP	±10% Lp	Min Rm	±10% Lm	Max Rs	±10% Ls	Min Cs
f min (100 kHz)	20 mW	0.8 mH	1.6 kW	45 mH	20 mW	0.8 mH	0.02 mf
f max (350 kHz)	40 mW	0.5 mH	1.3 kW	55 mH	40 mW	0.5 mH	0.02 mf

All figures are nominal, with the following assumptions: use of a sine wave, a resonant circuit, and a 4:4 turns ratio at 6.6 kW. Self resonant frequency (SRO) greater than 1.2 Mhz (does not apply to Cs).

FIGURE 9—TRANSFORMER EQUIVALENT CIRCUIT (CONTINUED)

The Volts per turn in the secondary shall be 100 V/Turn. (operating range 50 to 101 V/Turn)

A low current magnetically-controlled switch shall provide a connection presence indication to the vehicle controller by completing a continuity path. Refer to Figure 3.

The maximum charging power for charge coupling shall be as follows:

a. Level 3—160 kW
b. Level 2—7.6 kW
c. Level 1—1.9 kW

The maximum charging voltage for the vehicle inlet for all charging levels shall be 475 V.

The maximum charging current for the vehicle inlet for all charging levels shall be 400 A.

The minimum charge coupling efficiency shall be 99.5%.

The insulation resistance between the power contacts and the vehicle chassis in the vehicle inlet shall be greater than 100 MΩ.

4.3.2 EMC—EMC requirements of the vehicle inlet under all power levels will meet radiated and conductive requirements of GM9100P and SAE J551. In case of conflict of coverage, GM9100P will govern.