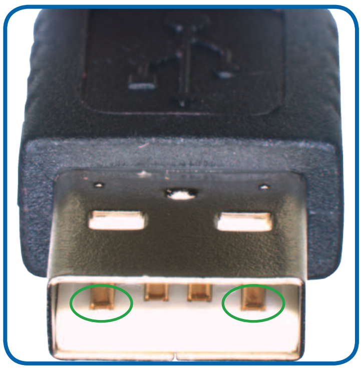
White Paper

First-Mate-Last-Break grounding contacts in the automotive industry

A chance to reduce the number of failures in electronics



List of failures, causes and solutions

July 2011

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ZVEI – German Electrical and Electronic Manufacturers‘ Association e.V.
Electronic Components and Systems (ECS) Division
PCB and Electronic Systems (PCB ES) Division
Lyoner Straße 9, 60528 Frankfurt am Main, Germany
Phone: +49 (0)69 6302 - 276
Fax: +49 (0)69 6302 - 407
E-mail: zvei-be@zvei.org
www.zvei.org/ecs

Download (free of charge):
www.zvei.org/first-mate-last-break

ZVEI contact person:
Dr. Stefan Gutschling
E-mail: gutschling@zvei.org

Technical contact:
Chairman of the working group
Christoph Thienel
Robert BOSCH GmbH
Engineering Integrated Circuits - Quality (AE/EIQ)
PO 1342, 72703 Reutlingen, Germany
E-mail: Christoph.Thienel@de.bosch.com

Photos:
Franz Binder GmbH & Co. Elektrische Bauelemente KG
FCI Automotive Deutschland GmbH
HARTING KGaA
Lumberg Holding GmbH & Co. KG
Robert BOSCH GmbH
Zollner Elektronik AG
ZVEI e.V.

Layout/cover photo:
Patricia Lutz, ZVEI e.V.

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MEMBERS OF WORKING COMMITTEE / AGREEING COMPANIES

Members of the working committee for the development of the White Paper:

Analog Devices GmbH

Automotive Lighting Reutlingen GmbH

Brose Fahrzeugteile GmbH & Co. KG

Delphi Deutschland GmbH

FCI Automotive Deutschland GmbH

Franz Binder GmbH & Co. Elektrische Bauelemente KG

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Webasto AG

Yazaki Europe Limited

Zollner Elektronik AG

The following companies also agree to the contents of the White Paper:

Continental Automotive, Division Interior

KOSTAL Kontakt Systeme GmbH

NXP Semiconductors Germany GmbH

Contents

Terms and definitions

Terms and abbreviations used in vehicle wiring

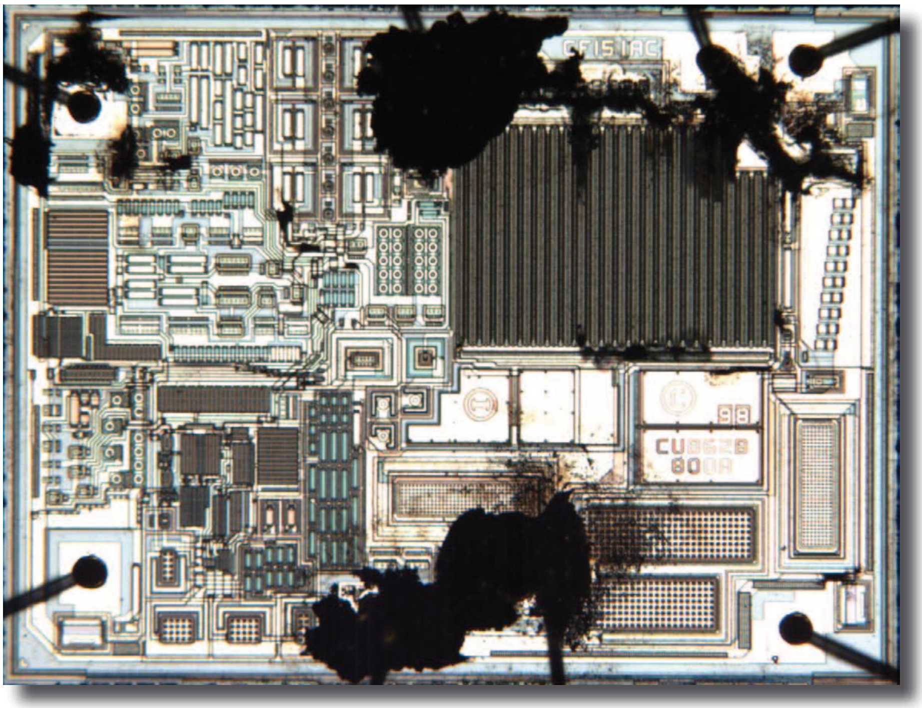
CAN bus	Data lines in the vehicle to allow electronic components to communicate with each other
FMLB	FMLB stands for First-Mate-Last-Break and refers to contacts designed to connect first and open last.
LIN bus	Data lines in the vehicle to allow electronic components to communicate with each other
Terminal 15	Battery voltage supplied from terminal 30 via ignition switch on
Terminal 30	Permanent voltage supply from battery
Terminal 31	Ground point (negative pole; normally the vehicle body)
Transceiver	Electronic circuit for sending and receiving data

Further abbreviations used in failure analysis:

ECU	Electronic Control Unit
EOS	Electrical Overstress
ESD	Electrostatic Discharge
Hot Plugging	Plugging or unplugging under voltage

Preface

When plugging/unplugging electronic control unit (ECU) connectors under voltage (hot plugging), semiconductors can be destroyed by electrical overstress (EOS).



Semiconductor destroyed by hot plugging

Investigations conducted by Bosch revealed that a high percentage of these semiconductor failures in vehicle ECUs can be prevented by using FMLB contacts.

FMLB stands for First-Mate-Last-Break and refers to contacts designed to connect first and open last.

The purpose of this White Paper is to introduce the subject of „First-Mate-Last-Break contacts in the automotive industry“, providing the reader with information on the relevant subjects regarding the design and introduction of connectors with FMLB contacts.

Several leading suppliers (Tier 1 and Tier 2) have given their expert opinion on this issue with the intention of providing an overview as well as general solution proposals.

The introduction of FMLB contacts as additional electronic protection is an important prerequisite on the way to achieving the zero defect target in the automotive industry.

1 Description of Hot Plugging

Hot plugging refers to the plugging and unplugging of contacts connected in a vehicle or sub-system (such as doors, etc.) while electrical voltage is applied.

This situation is **systematic** for the production, operation, maintenance and tuning of vehicles, irrespective of whether conducted deliberately or unknowingly. It is valid for IGNITION ON as well as IGNITION OFF.

In sub-systems, hot plugging mainly occurs during test, control and adjustment situations.

Typical examples are:

- Installation and test of the antenna
- Cockpit installation
- Retrofitting of components, (e.g. sunroof or auxiliary heating)
- Motor test operation on test stand
- Motor assembly
- Testing of headlights after assembly
- Installation and testing of doors

1.1 Ignition ON

When manufacturing or repairing vehicles, components are added or removed from the on-board network: **hot plugging**

1.2 Ignition OFF

There is a general **misunderstanding** that, after the ignition has been switched off, each connection can be plugged or unplugged without damaging the electronics since no voltage is supplied to the vehicle components.

However, the vehicle network continues to supply many components despite IGNITION OFF. Control units that are supplied from terminal 30 are still under voltage (even in standby mode) in the IGNITION OFF state.

Examples (list not complete)

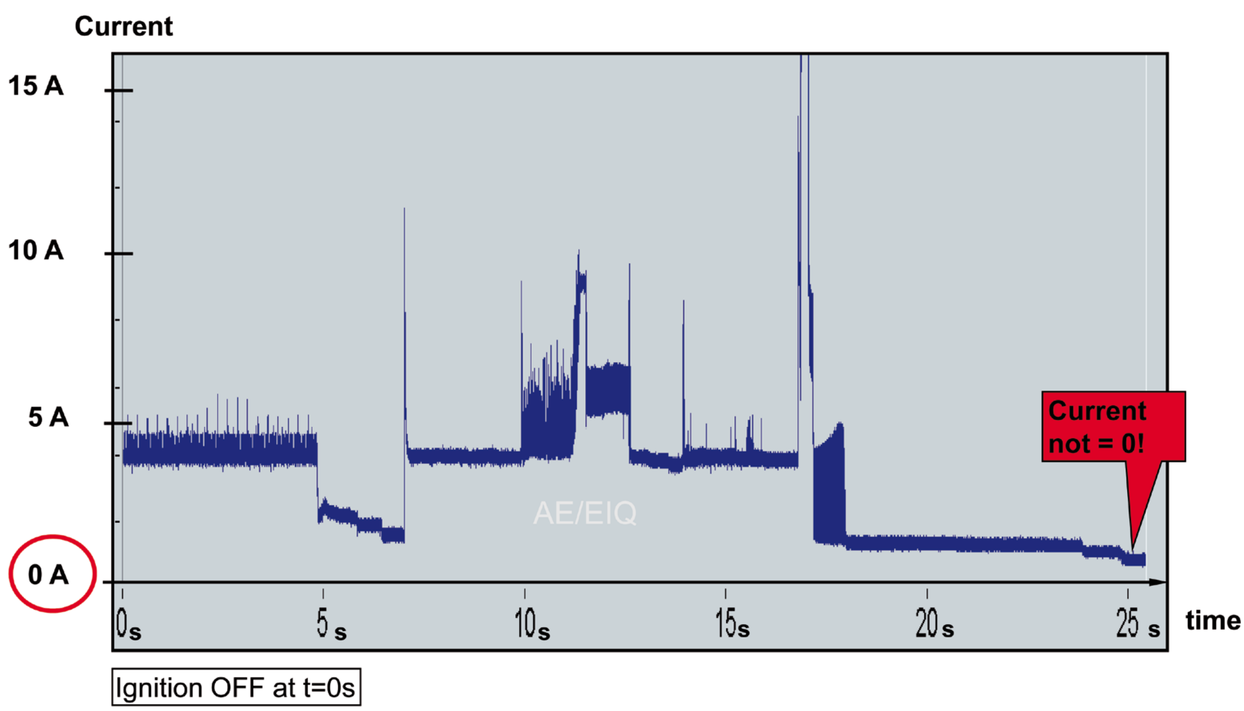
- Airbag in standby mode
- Coming home (headlights continue lighting)
- Window regulator
- Parking braking system
- Hands-free car kit
- Gateway
- Interior air ventilation
- Interior control system
- KIT mechanism in trunk (USA; allows opening of the trunk from the inside)
- Control of run-on operation of air conditioning and cooling fan
- Navigation system
- Radio
- Rear mirror (fold-in)

- Auxiliary heating
- ECUs update recorded errors
- Conducting throttle valve tests
- Clock
- Access systems

After switching-off the ignition, high currents still run through the vehicle network for several minutes. Each connection plugged or unplugged during this time can lead to non-defined equalizing currents occurring in the vehicle network. These equalizing currents can pre-damage or permanently destroy electronic components: **hot plugging** (more details are provided in Section 2 „Failures resulting from Hot Plugging“)

The following example of current measured in the battery grounding cable of a modern vehicle illustrates this situation.

Current flows through the system for several minutes, ranging between 100 mA to several amperes, single peaks even higher.



Current flowing through vehicle network does not reach zero for some time after the ignition has been switched off.

This means that **hot plugging is systematic in a vehicle.**

2 Failures resulting from Hot Plugging

In modern vehicles, many ECUs are linked with each other via data buses. In the event of **hot plugging**, for example, equalizing currents run via the bus in ECUs which are not part of the connection and damage them.

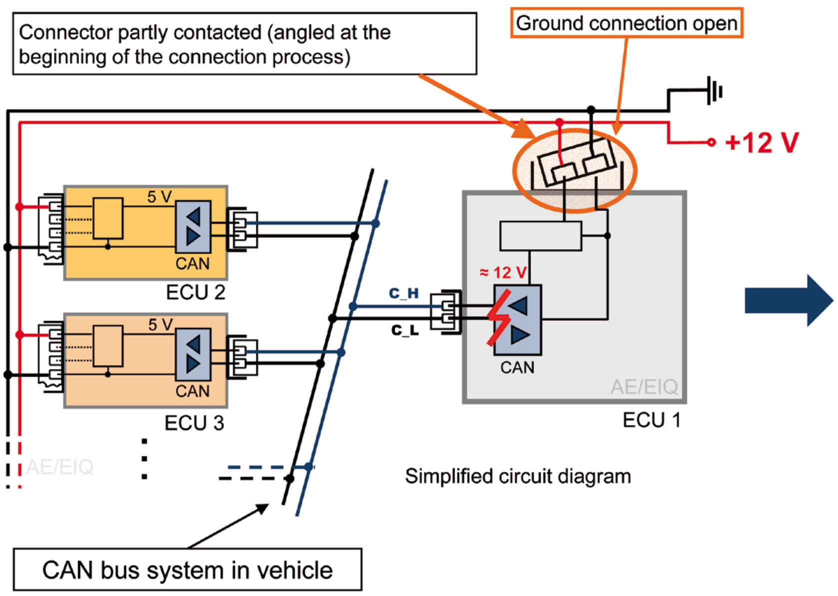
In general, this interaction prevents an appropriate failure analysis and identification of the real failure cause of the destroyed devices.

The following examples of real-life failures have been provided by well-known companies.

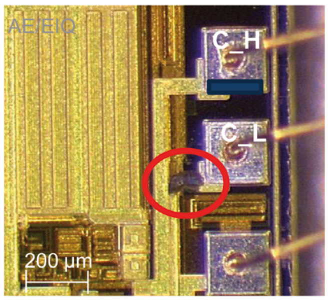
2.1 Example CAN bus

Mechanical description

When plugging a device under voltage (**hot plugging**), it may happen that the ground contact mates last if the plug is inserted at an angle into the socket connector. Since there is no ground connection for a short time, equalizing currents occur that damage the semi-conductors.



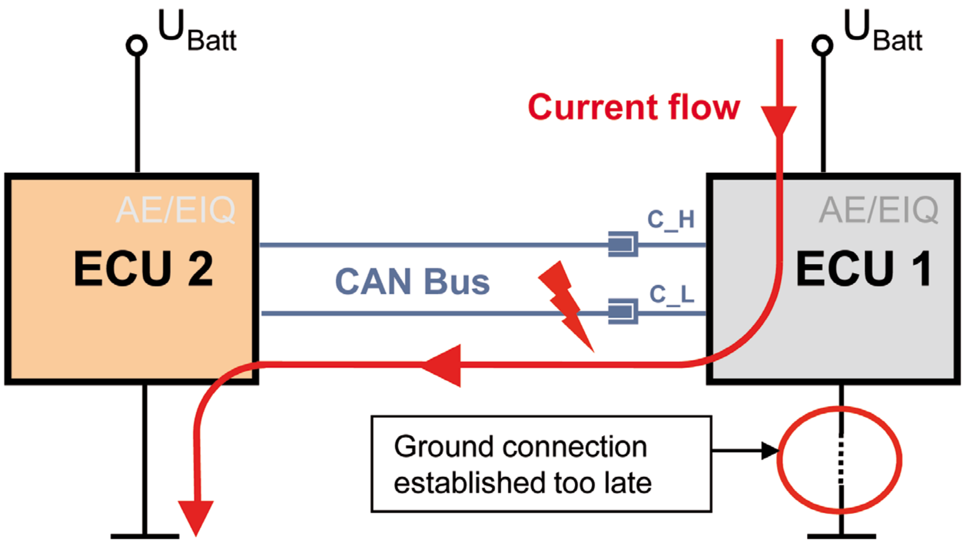
Simplified circuit diagram



Close-up of ASIC chip surface: molten metal strip conductor in the area of the CAN transceiver

ECU 2 is installed in vehicle and ECU 1 is being added

Circuit diagram of the situation described above



Simplified circuit diagram

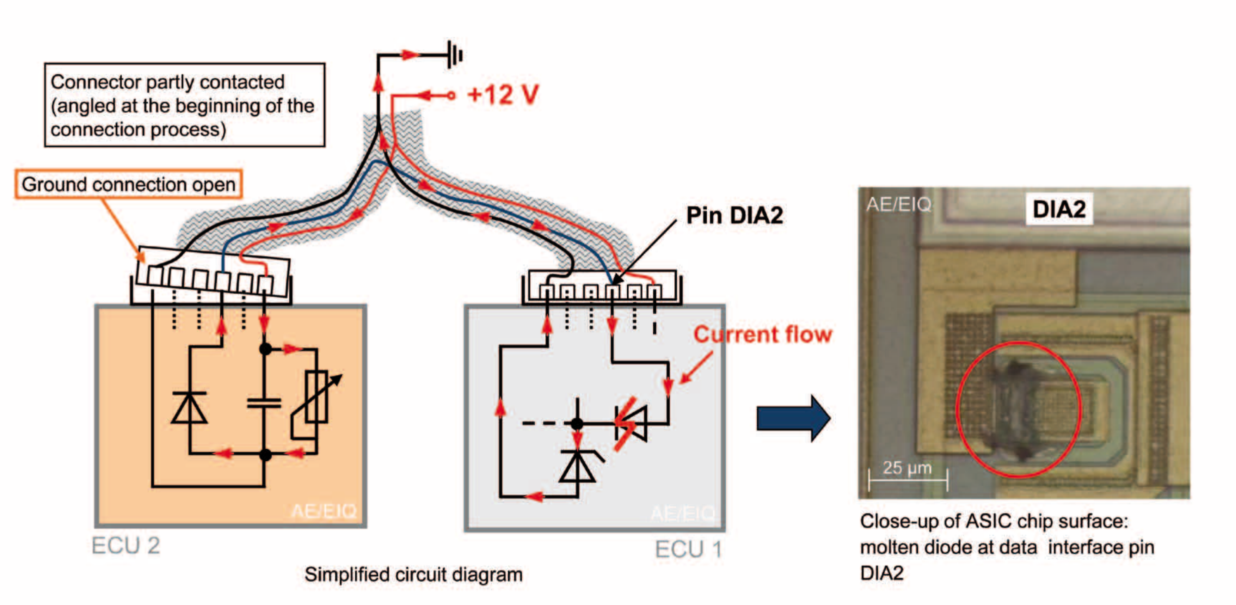
This failure mechanism may potentially affect all electronic components linked via communication buses.

It is extremely difficult to analyze the failure since the affected ECUs are supplied by different competitors. If ECU 2 is not damaged, it is difficult to explain the electrical overstress in ECU 1.

2.2 Example diagnostic line

Mechanical description

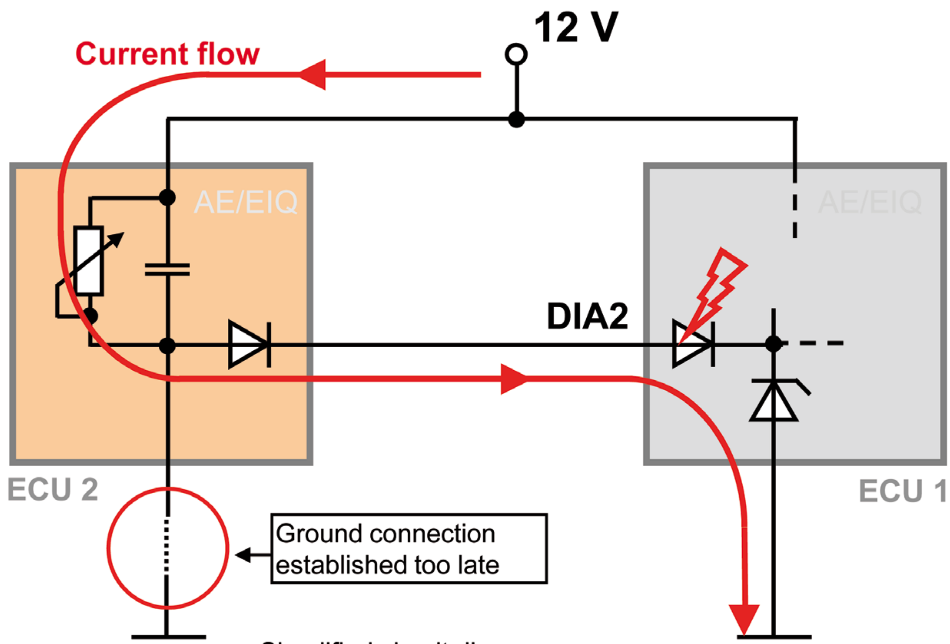
Illustration of the damage incurred to ECU 1 in the course of plugging ECU2 due to missing ground connection during **hot plugging**.



Close-up of ASIC chip surface: molten diode at data interface pin DIA2

ECU 1 is installed in vehicle and ECU 2 is being added

Electrical description

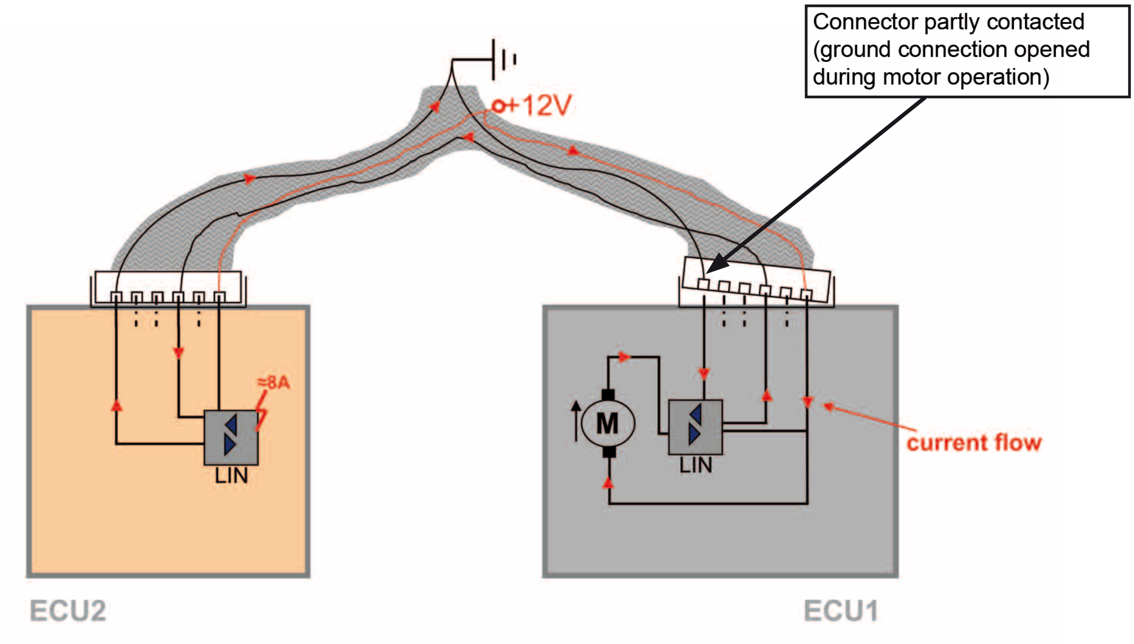


Simplified circuit diagram

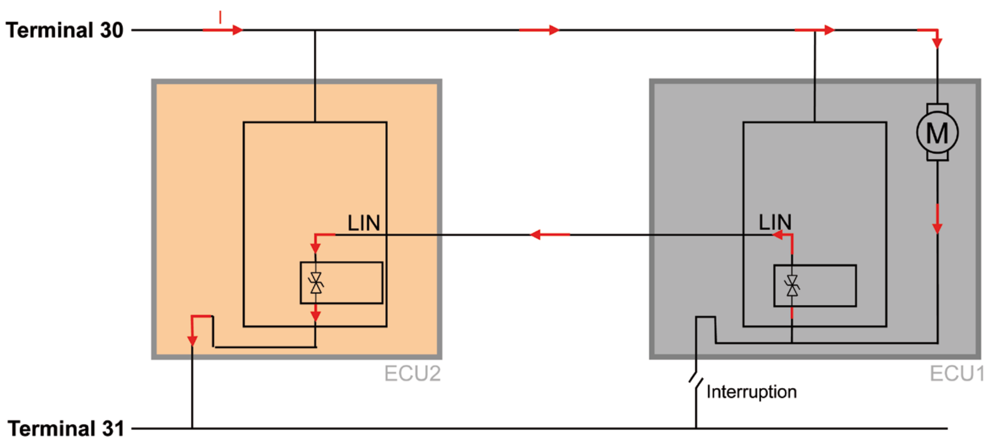
To prevent damages occurring, the ground connection must be established in time.

2.3 Example window regulator

Mechanical description



Electrical description

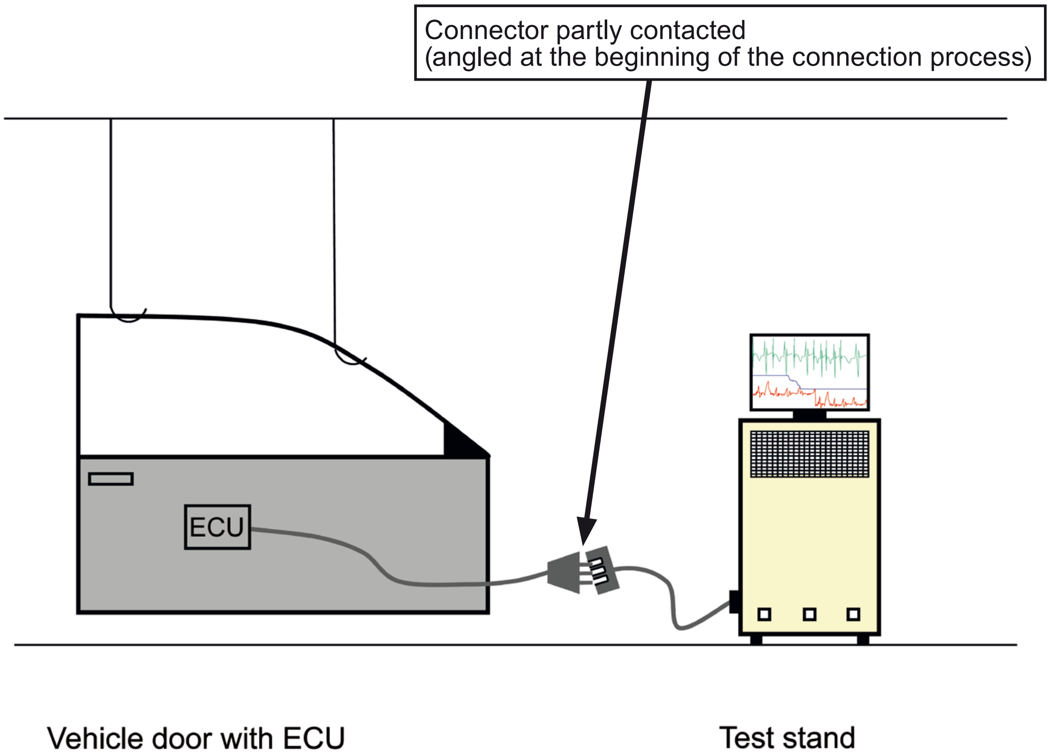


The ground cable is interrupted during motor operation (**hot plugging**). The resulting mutual induction voltage induces a potential shift in ECU 1.

This ground offset is transferred to ECU 2 via the LIN bus and this can destroy its semiconductors.

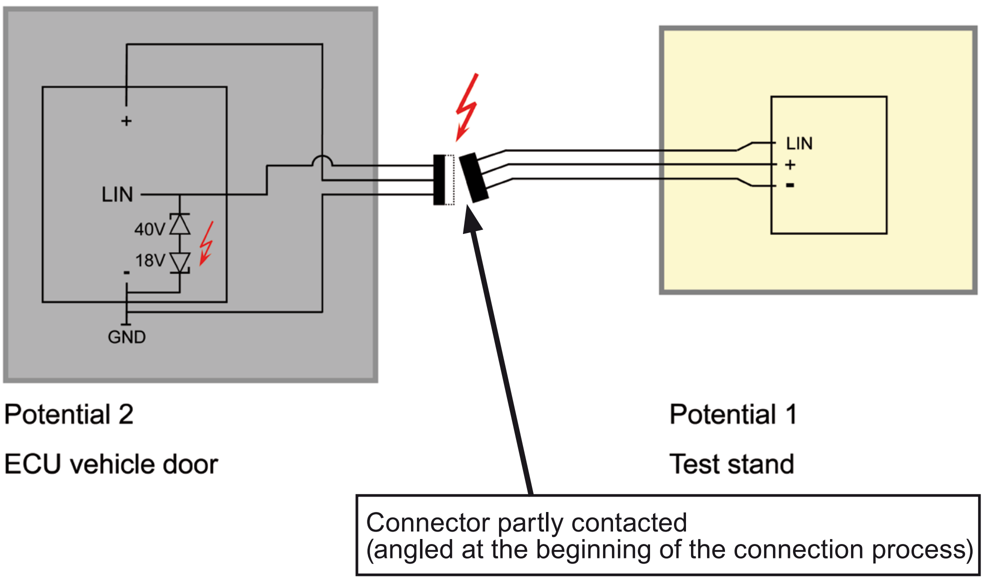
2.4 Example door assembly

Mechanical description



During the assembly and testing of a vehicle door, the semiconductors in the ECU may be destroyed due to **hot plugging** and a missing FMLB ground contact.

Electrical description



The reason for this is the voltage difference of the ground potentials between the door and test equipment. Due to the different ground potentials, equalizing currents run between the door electronics and the test equipment.

In the example, the equalizing current flows through the LIN transceiver if the LIN connection is established before the ground connection. The current passing through the LIN transceiver can damage or destroy it.

In general, the following applies:

An increasing level of integration, less package space and higher performance specifications require increasingly smaller structures for semiconductors, leading to lower EOS limits.

NOTE:

Improved ESD protection does not prevent or reduce EOS damage

3 Remedial actions connector systems

3.1 Plug-in/out sequence for one or several connectors (power, signal)

3.1.1 Single connector on an electronic vehicle component or wire harness

During plugging it must be ensured that the ground pin is engaged first and removed last during unplugging (First-Mate-Last-Break).

3.1.2 Several connectors on the electronic vehicle component

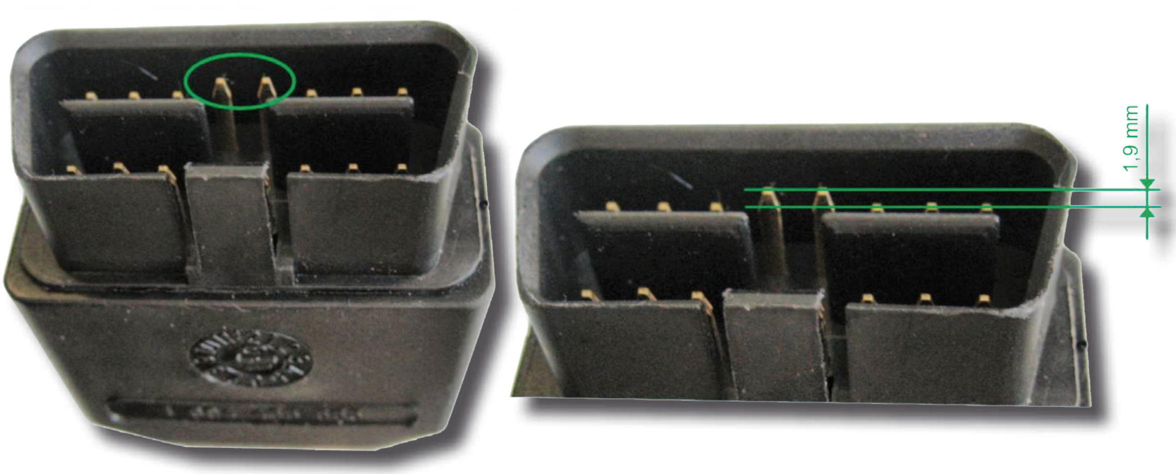
For each connector and each connection process, ground connections must be established before the data lines and disconnected in reverse order.

3.2 Connector systems used for vehicle production, operation, maintenance, repair and tuning

3.2.1 On Board Diagnostics II

The OBD-II connector is exemplary since it is fitted with FMLB ground pins to ensure safe connections with IGNITION ON and OFF. It is the only standardized and generally implemented connector in the automotive sector that has been specifically designed for **hot plugging**.

For more information, see ISO 15031-3.



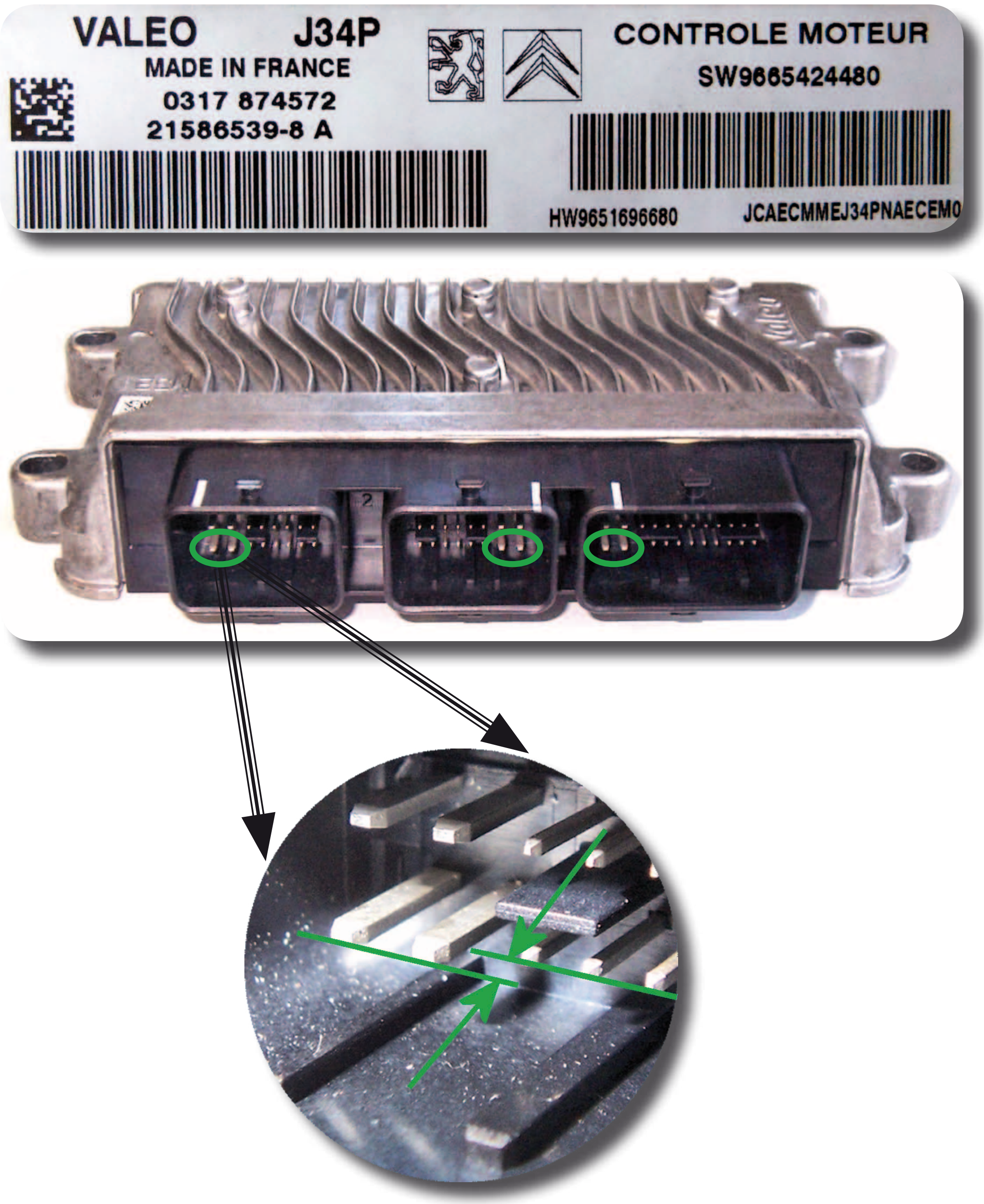
OBD-II connector with FMLB contacts

3.2.2 Other solutions in the automotive sector

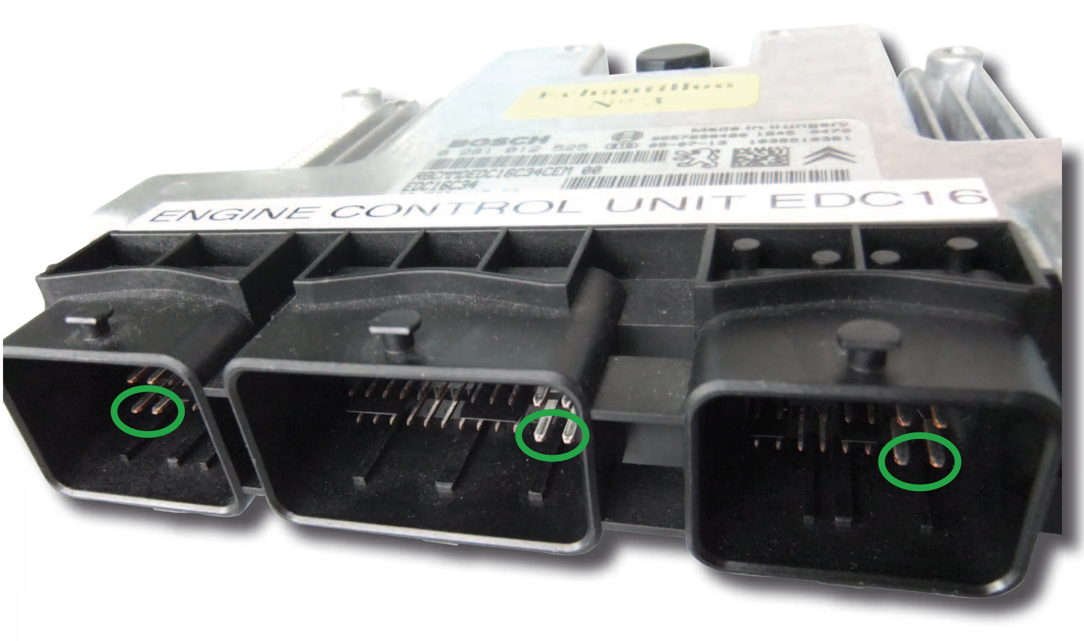
Infotainment features of modern vehicles are sometimes equipped with USB interfaces where different pin lengths are standard and are thus suitable for **hot plugging**.

It is extremely rare for **electronic control units** to be fitted with **FMLB contacts** for **hot plugging**.

Here are some examples:

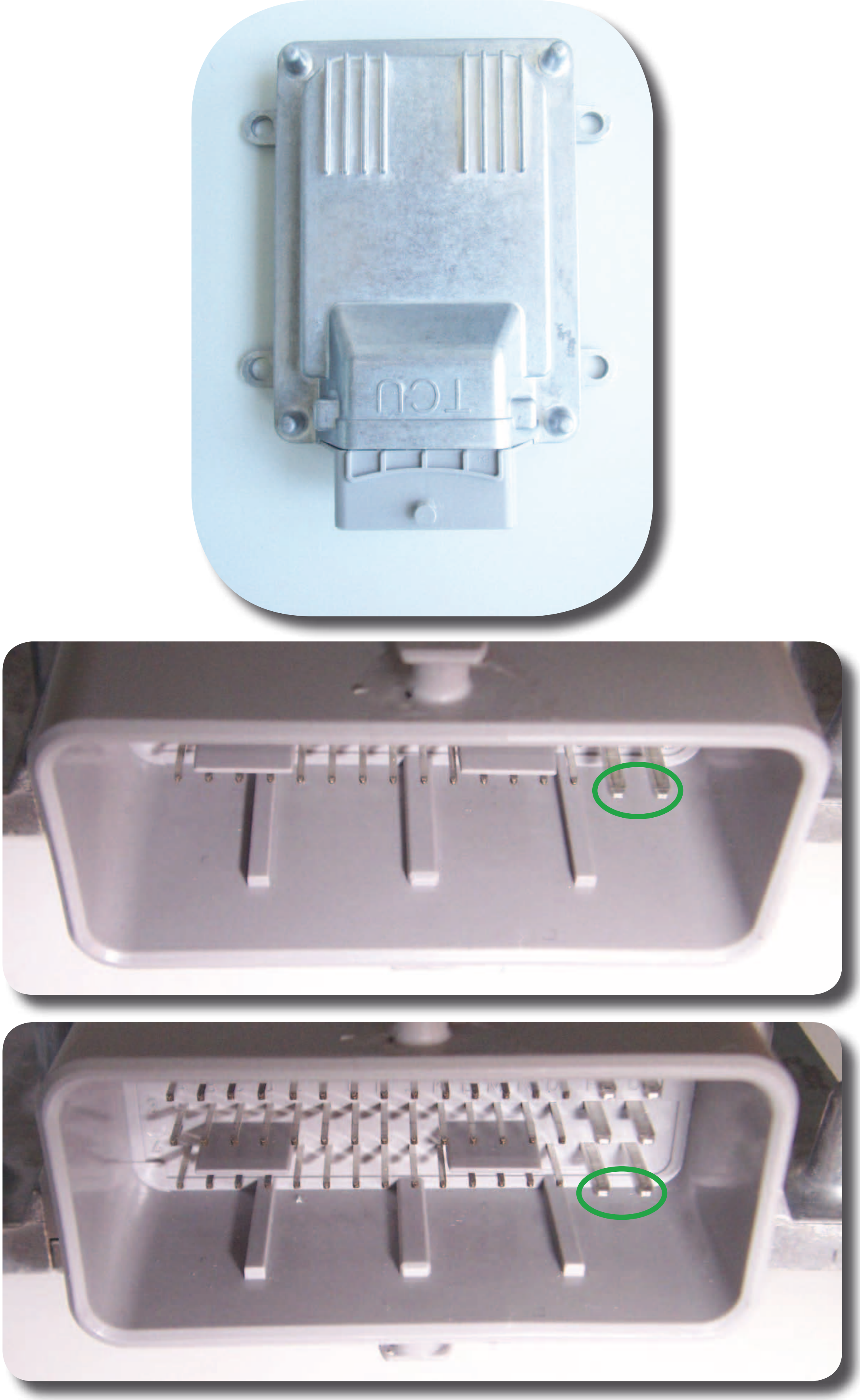


Valeo control unit J34P for Peugeot /Citroën with FMLB contacts



Bosch control unit EDC 16 for Peugeot/Citroën with FMLB contacts

Continental control unit with FMLB contacts



Control unit of a Chinese supplier with FMLB contacts

Conclusion

Apart from these positive examples, all other connector systems leave the flowing of equalizing currents to chance. This may lead, as illustrated in this paper, to electrical overstress and damage of electronic components in control units.

Additional remarks

Connector systems that ensure FMLB are required for the **entire contact sequence in the process**.

Some examples are (list not complete):

- Test stations for programming („flashing") control units
- Any adaption of sub-processes at outsourcers
- Cable extensions connected to an interface, (e.g. for OBD-II if the test stand is too far away)

In addition to mechanical considerations, the required **current carrying capacity** of FMLB contacts must be defined. The leading part is only charged for a short time. A low current carrying capacity may thus be sufficient.

If the **leading connection is established at the control unit**, it can safely be assumed that the protection will hold. However, if the leading connection is established at the counter plug of the wire harness, control unit and vehicle are no longer protected if the compatible plug of the wire harness has no FMLB contact.

As an alternative to FMLB contacts, the electronics of control units may be safeguarded by additional protective measures under certain circumstances.

However, these also involve **various disadvantages**:

- Components cost money
- Components require package space
- Components require an operating voltage or the voltage drops
- Components reduce the overall reliability
- The circuit performance decreases, (e.g. CAN bus)

If a protective circuit is applied, this can normally not be specified in detail since the destroying pulses are not fully known.
Despite the great amount of time and effort required for a protective circuit, there is still a high risk of a circuit failure.

4 Introduction scenarios

4.1 Compatibility

The basic idea is not to change existing products. Automotive manufacturers are rather requested to demand that FMLB contacts be implemented in new products and contact interfaces in vehicles.

As far as costs are concerned, existing systems no longer have to be adapted, rather FMLB contacts can be included in the new design right from the start and thus ensure an optimal solution in terms of technology and cost.

4.2 Current discussions on changes to automotive wire harnesses and connector systems

At present, some changes are being investigated regarding the vehicle wire harness. This is a perfect time to introduce FMLB contacts on a wide scale.

Some examples of discussed changes:

- Increasing automation of wire harness production.
- In line with decreasing the copper cross-sectional area of cables, connectors can be changed.
- New interfaces are to be created in the wire harness to use components and aggregates from other vehicles or other manufacturers.
- Replacement of some cables by aluminum.
- Use of flat cables
- Introduction of new data bus systems (Ethernet)
- New products, e.g. LED headlights

4.3 Savings potential

Rough estimate for the global savings potential achieved by introducing connectors with FMLB contacts using the example of 2011:

Vehicles manufactured worldwide	70	million
Automotive semiconductors (ASIC, controller) manufactured worldwide	8.4	billion

Assuming that the application of FMLB contacts **will reduce the number of failures by 1 ppm** and that the cost of one failure amounts to **5,000 euros**, the following savings can be made:

Failures prevented (1 ppm of 8.4 billion semiconductors)	8,400	pieces
Overall cost per failure	5,000	euros
Overall cost of all failures	42,000,000	euros
Total saved per vehicle (42 million euros / 70 million)	**0.6**	**euros per vehicle**

Further savings potentials may be obtained from **standardizing** this new connector interface with FMLB contacts.

5 Summary

In many industry sectors, FMLB contacts already ensure safer connection processes today.

They establish a ground connection prior to connecting the signal and power lines and thus reliably protect man and electronics.

This is an advantage the automotive industry would also benefit from.

A large number of EOS failures currently occurring in semiconductors could to a great extent be prevented. This is particularly valid for large scale incidents.

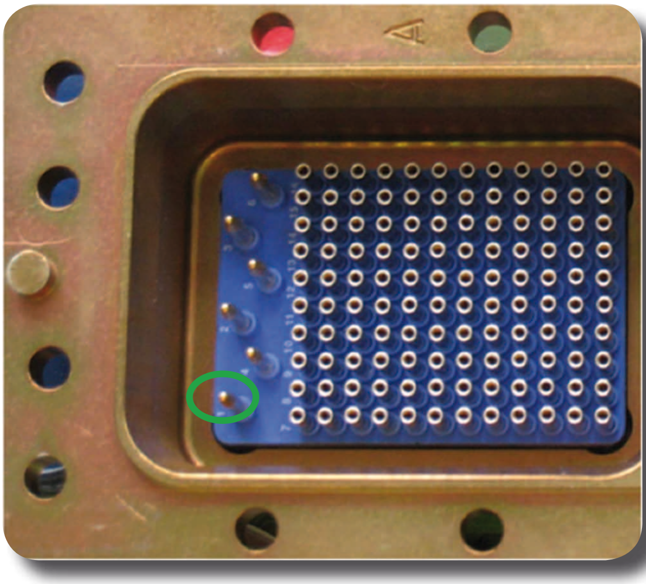
This measure would make a major contribution to achieving the zero defect target.

In view of the multitude of connector systems, the introduction of FMLB contacts must be initiated by the automotive manufacturers („top down“). All parties involved will need to make their own preliminary considerations and it will certainly require a special time frame.

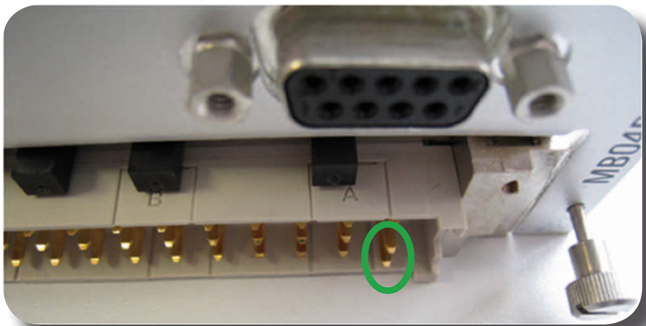
6 Appendix

Examples of connector systems with FMLB contacts

6.1 Aviation

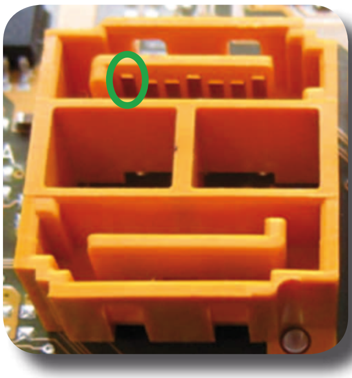


6.2 Railways

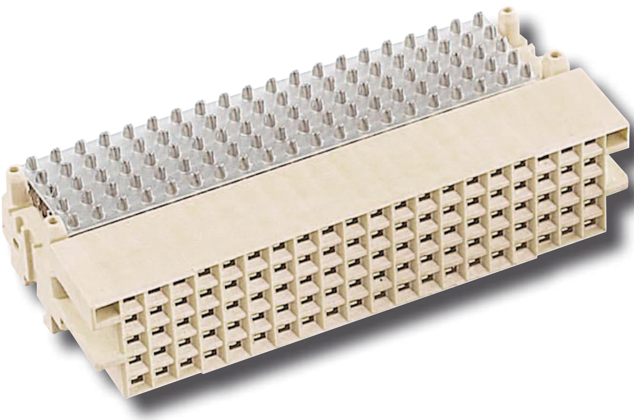


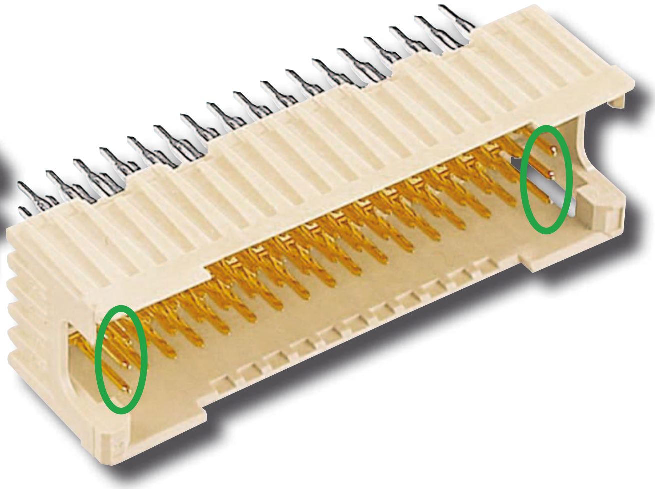
6.3 Domestic power supply

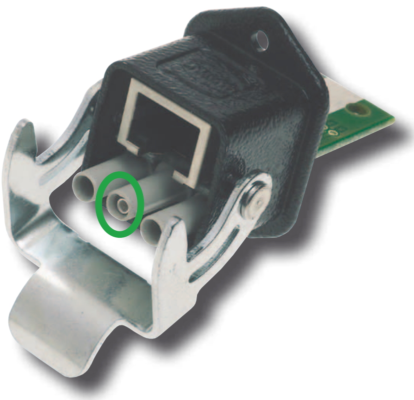
6.4 Personal computer



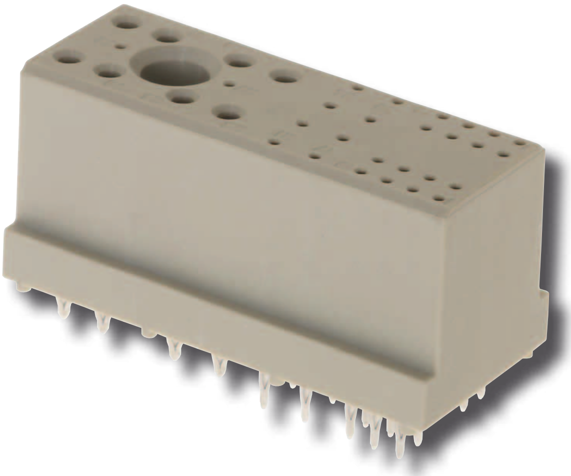
6.5 Telecommunication

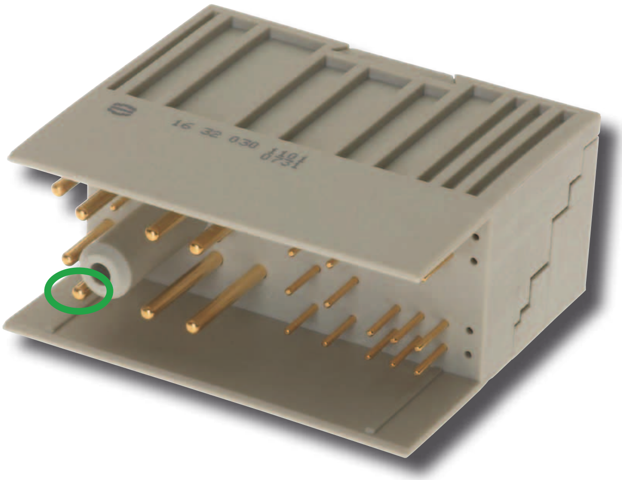


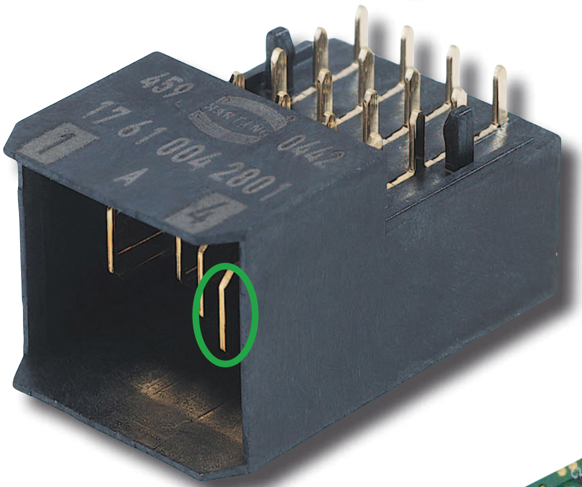


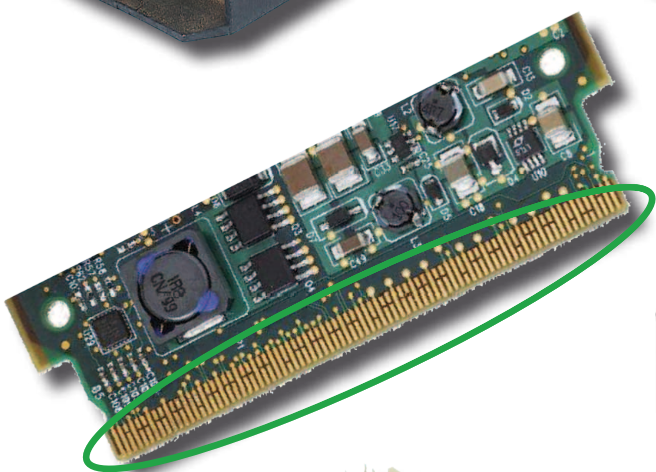


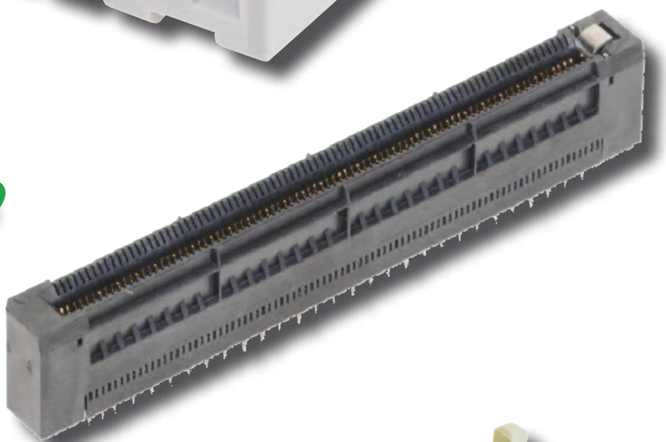
(6.5 Telecommunications continued)

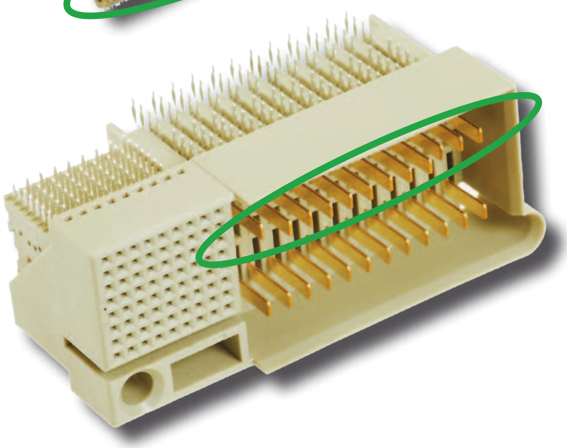


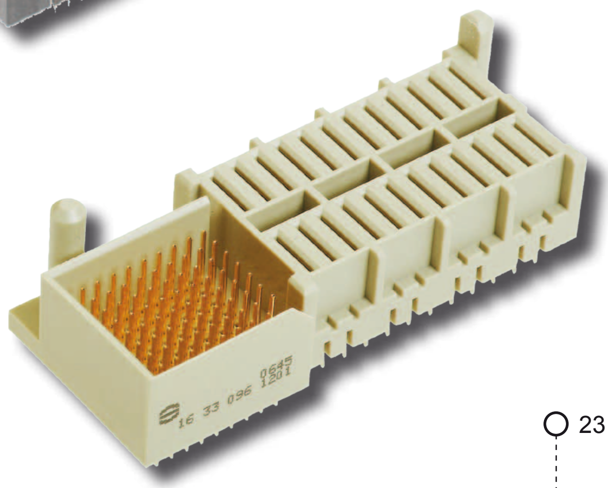






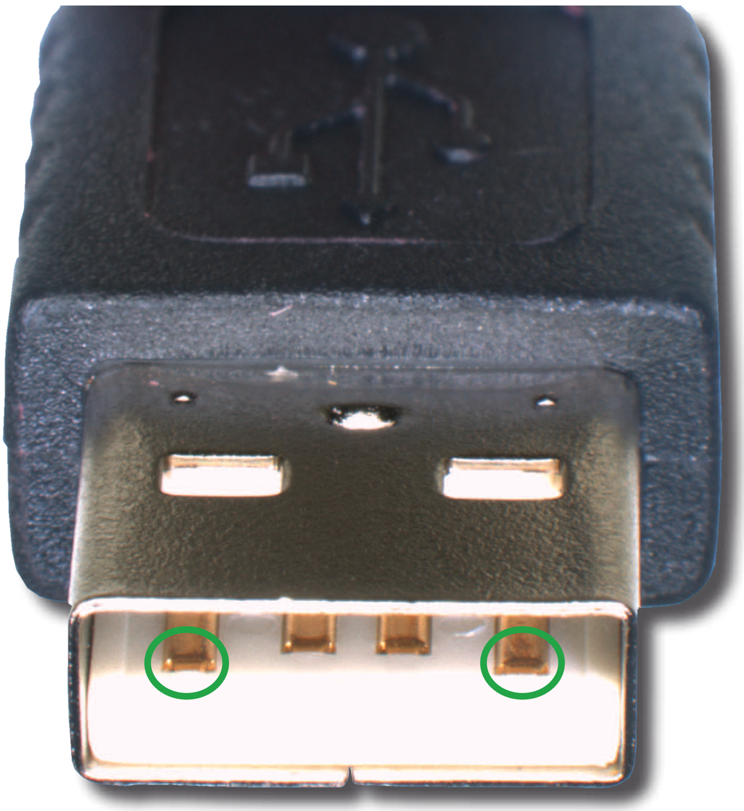




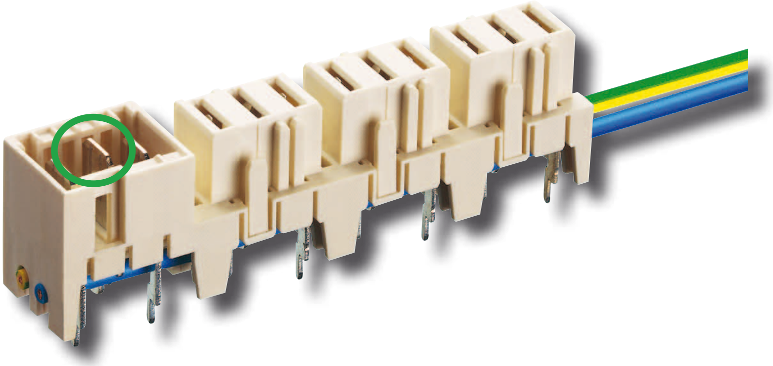


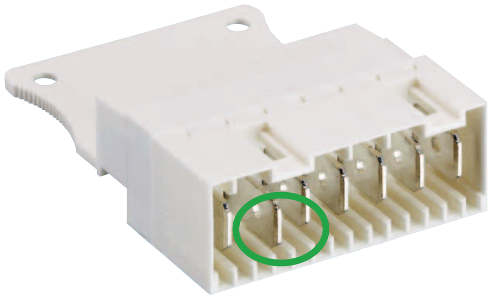
(6.5 Telecommunications continued)

6.6 USB 2.0 (Universal Serial Bus 2.0)

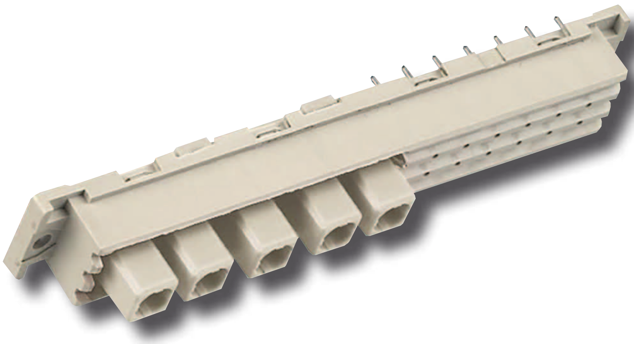


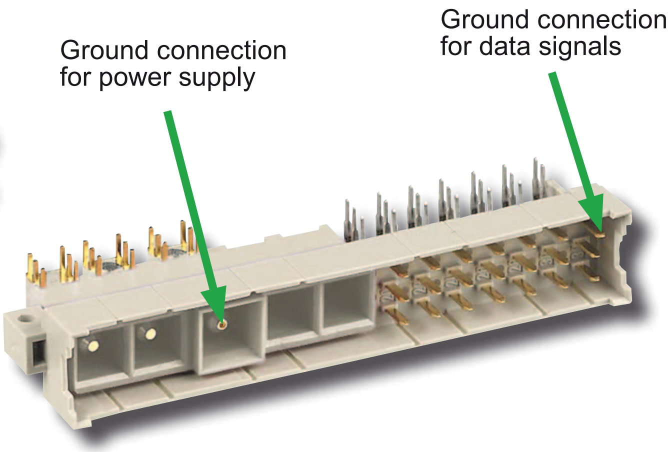
6.7 Home appliances

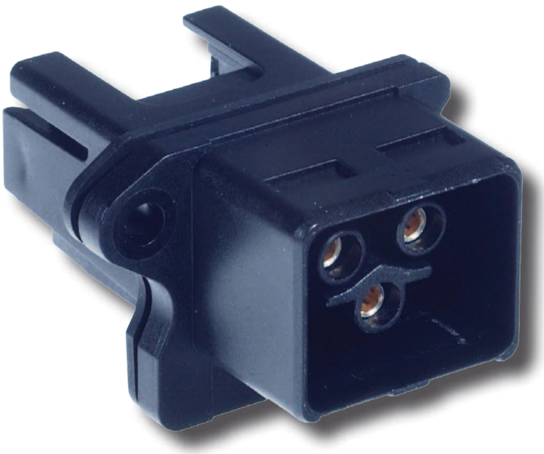




6.8 Industrial power supply

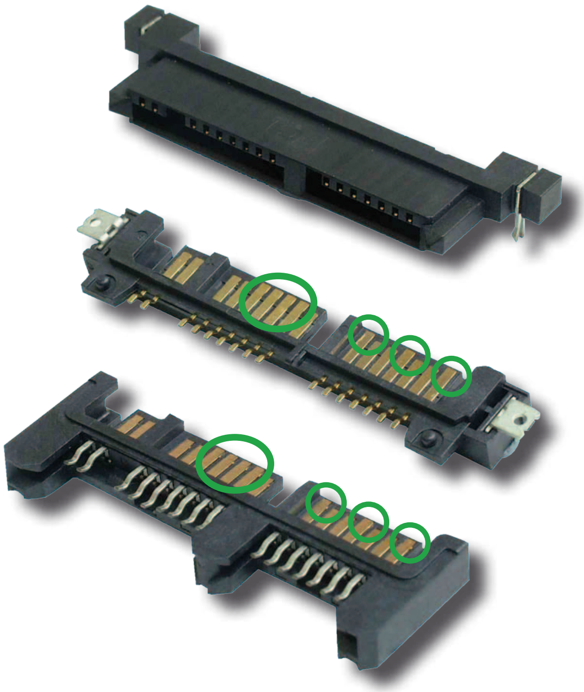




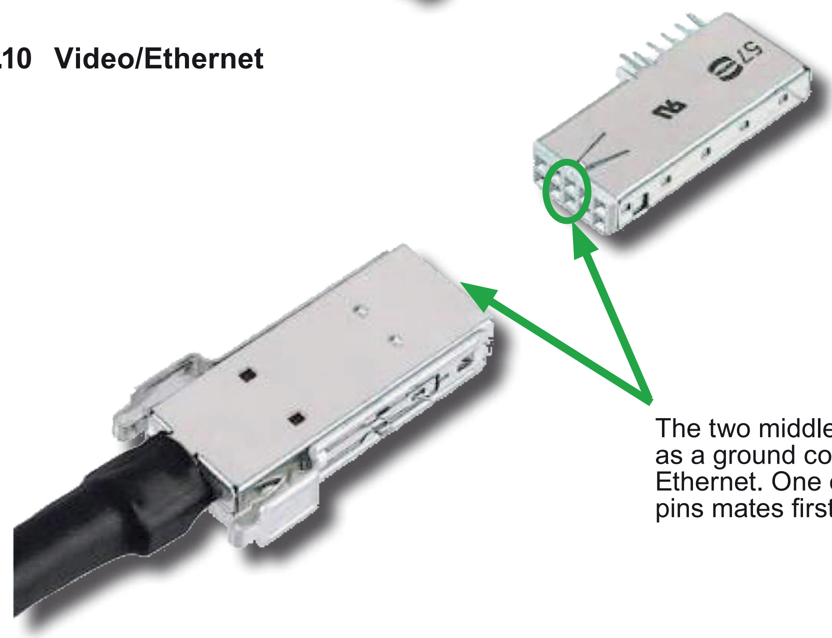


(6.8 Industrial power supply continued)

6.9 Data and consumer applications



6.10 Video/Ethernet



NOTES

ZVEI – German Electrical and Electronic Manufacturers‘ Association e.V.
Electronic Components and Systems (ECS) Division
PCB and Electronic Systems (PCB ES) Division
Lyoner Straße 9
60528 Frankfurt am Main, Germany
Phone: +49 (0)69 6302 - 276
Fax: +49 (0)69 6302 - 407
E-mail: zvei-be@zvei.org
www.zvei.org/ecs