

**International Meeting on Powerline Communication  
for - but not limited to - Automotive  
Tuesday, 4 November 2008  
University of Pavia**

# **POWERLINE PROTOCOLS**

Review, evaluation and tests  
for automotive applications

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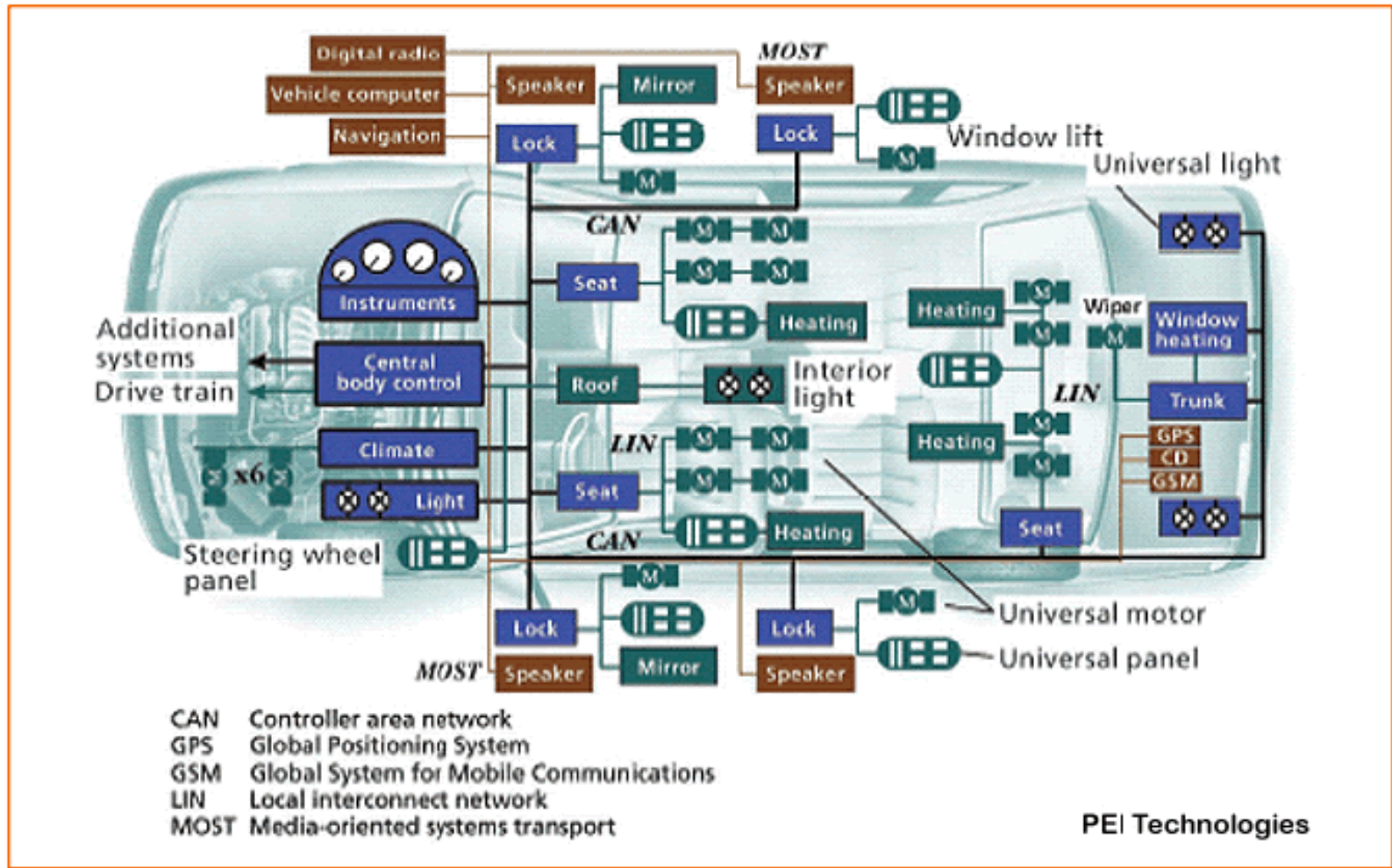
*University of Pavia*

*Robotics Laboratory and Department of Electrical Engineering*

# Summary

1. The cabling burden
2. Powerline communication principle
3. Performance and regulation
4. Powerline over DC Bus
5. The Car Channel characterization
6. PLC Protocols
7. PLC for automotive solutions
8. Experimental setup and testing
9. Open issues and evolution

# Powerline for data exchange in the vehicle



The cabling burden ...

# Powerline for data exchange in the vehicle

## The cabling burden ... [1,2]

- a more difficult design to account for hand made required assembly;
- cost multiplication because of the large scale production;
- electric bundle increase and related problems when passing through dashboard and instrumentation panels;
- The increased cost and complexity of cable connectors;
- more complex diagnostics and maintenance
- reduced benefit cost ratio, for any new device requiring an extra wiring;
- car weight increase and reduced efficiency;
- increased problems related to ECM (both immunity and emission

**... then choose the Powerline...**

# Powerline for data exchange in the vehicle

... then choose the Powerline...

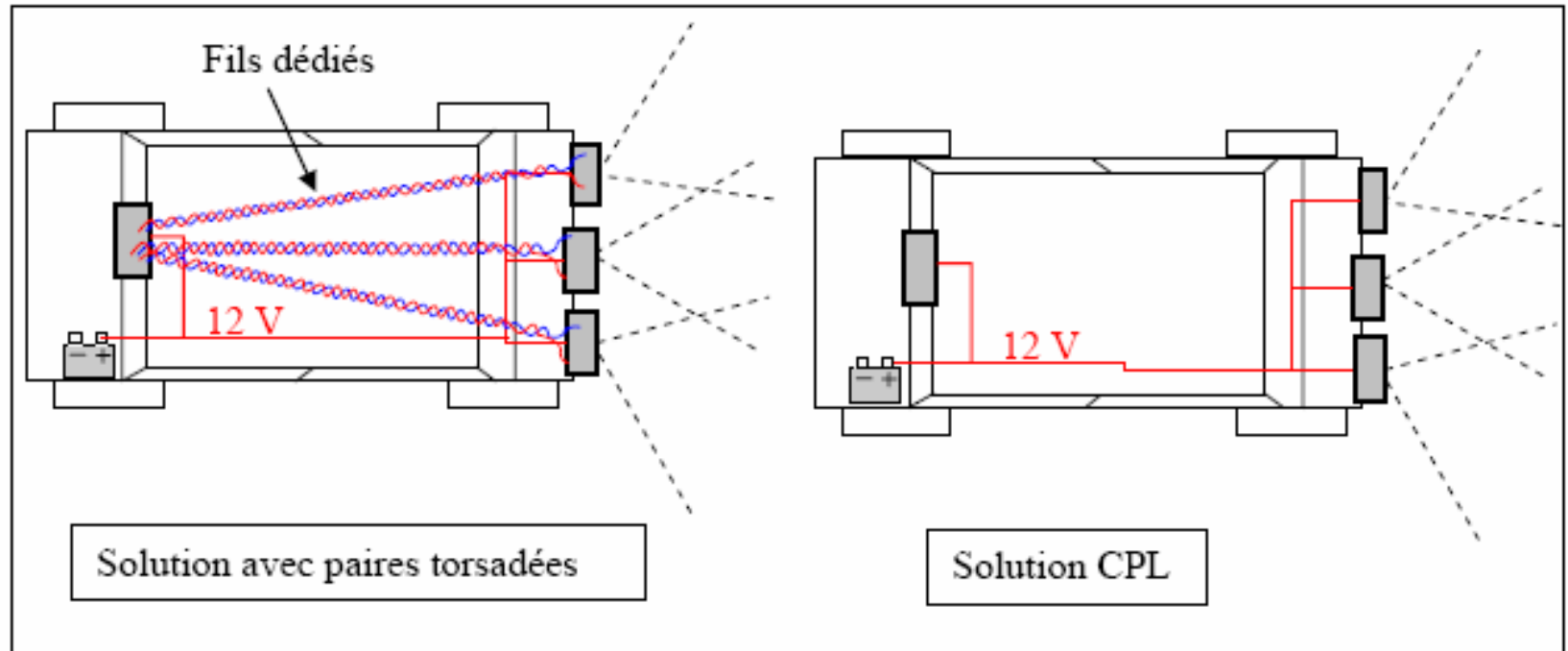


Figure 1.2 : Présentation d'un système de caméras de recul avec technologie CPL

Cable reduction by using PLC instead of dedicated twin pairs (or coax cables) for operating Backup cameras

# Powerline communication applications so far ...

The idea of using the power cable to communicate arises because of **POWER UTILITIES** requirements to interconnect and control **faraway** units:

- **communication over high and medium voltage AC cables**
- **reduced bitrate requirements (1,2 – 38,4 kbps / 4kHz Band, speech and SCADA networks)**

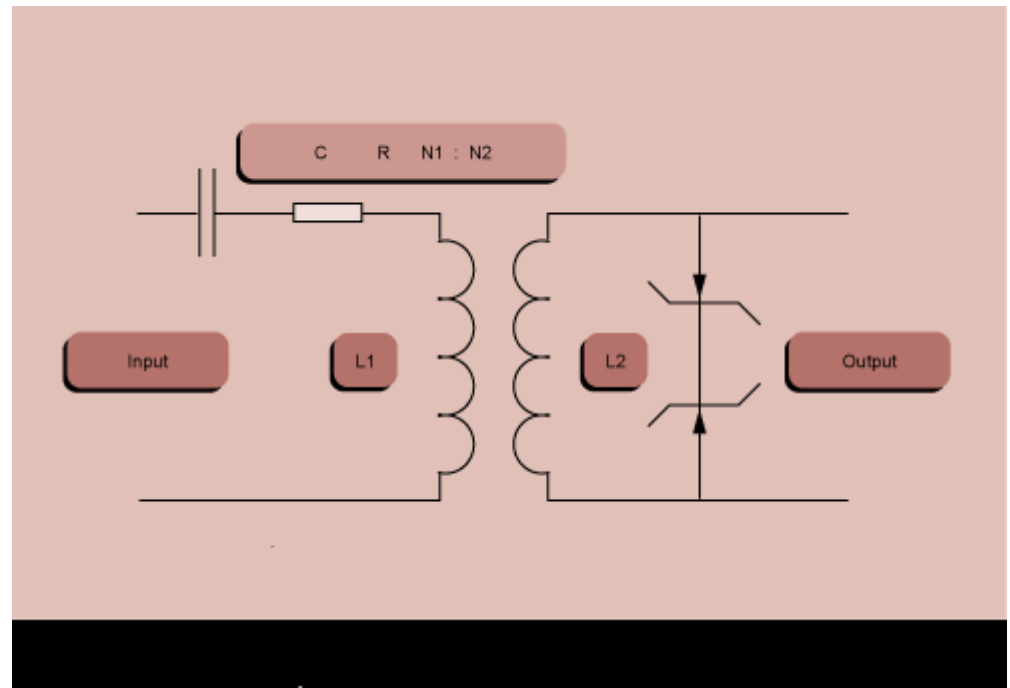
When coming to low voltage, the powerline seems useful for domestic meter reading, electric load management and **HOME AUTOMATION** diffusion, by also providing substantial cable reduction when compared to wired dedicated transmission:

- **communication over low voltage AC cables (110-240 V, 50-60 Hz)**
- **variable bitrate requirements (from on-off control to audio-video signals )**

# Powerline communication principles

The (digital) signal to be transmitted is modulated over the power line, by a proper **coupler** device, at an higher frequency in a given range; it is propagated over the power network; it can be decoupled and decoded in a different node of the network as long as a proper device (node) is provided.

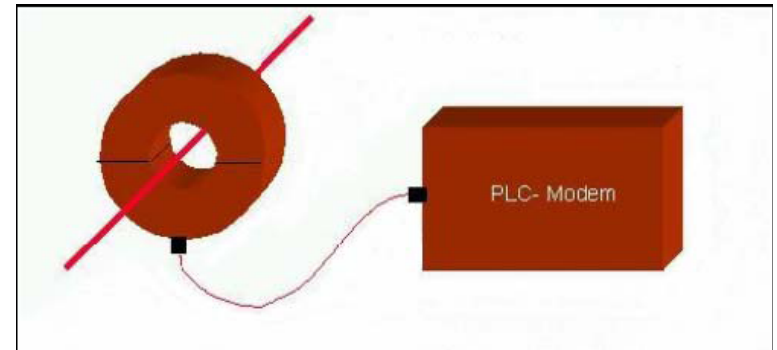
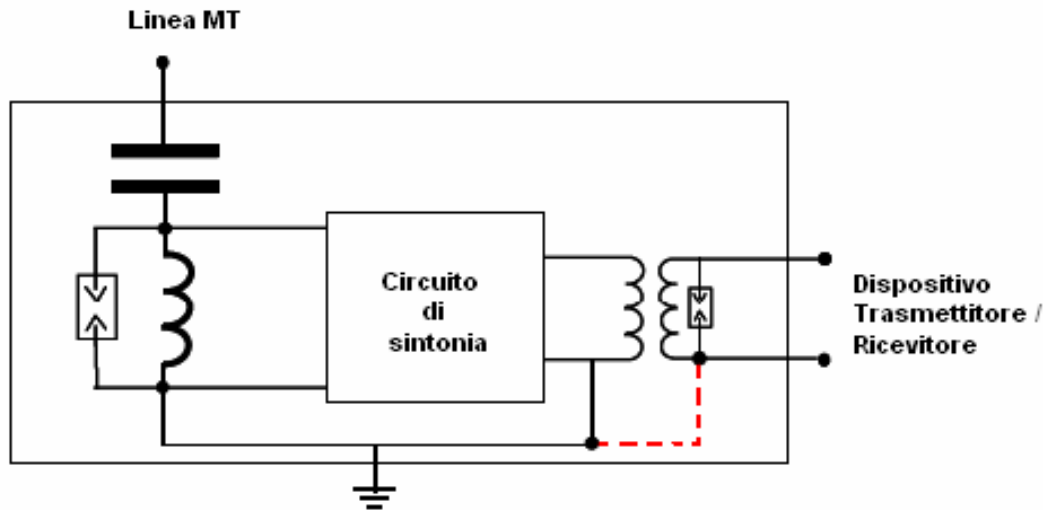
**A coupling transformer with high pass characteristic for AC coupling**



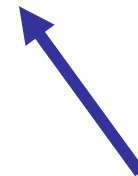
# Powerline communication couplers

## Couplers for power networks

Medium voltage capacitor coupler



Inductive coupler based PLC-Modem

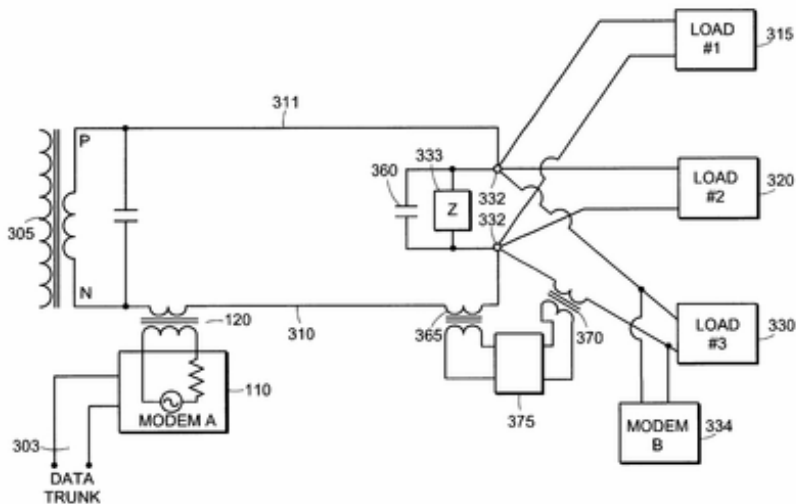
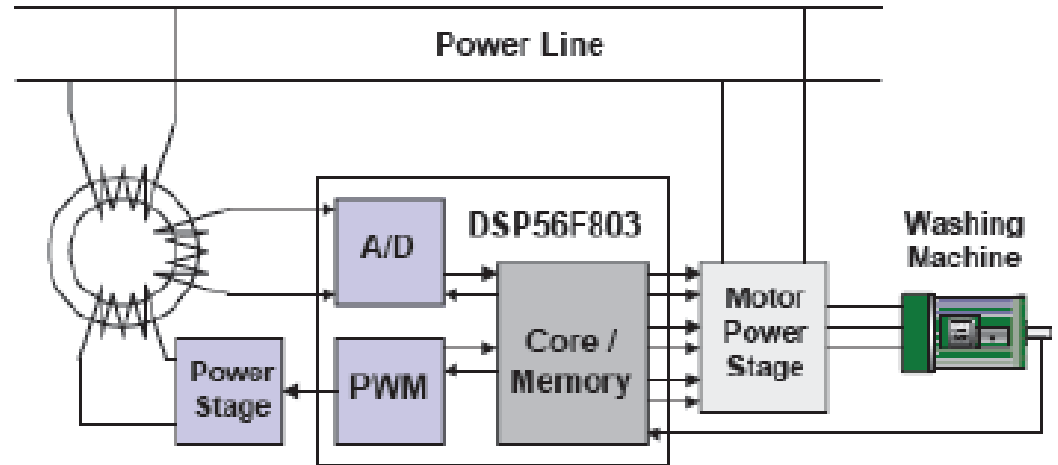




# Powerline communication couplers

## Couplers for home automation / Broadband

Coupler to a washing machine



High speed PL Modems with 10Base-T, USB connectors

# Powerline communication couplers

## Couplers for DC powerline

For DC power line carriers, coupling can be accomplished simply by using a series capacitor.

An ideal capacitor would block the dc power voltage, and pass high frequencies perfectly for a wide range of terminating impedance values.

The -3dB (half-power) cutoff point  $f_{LF}$  would be

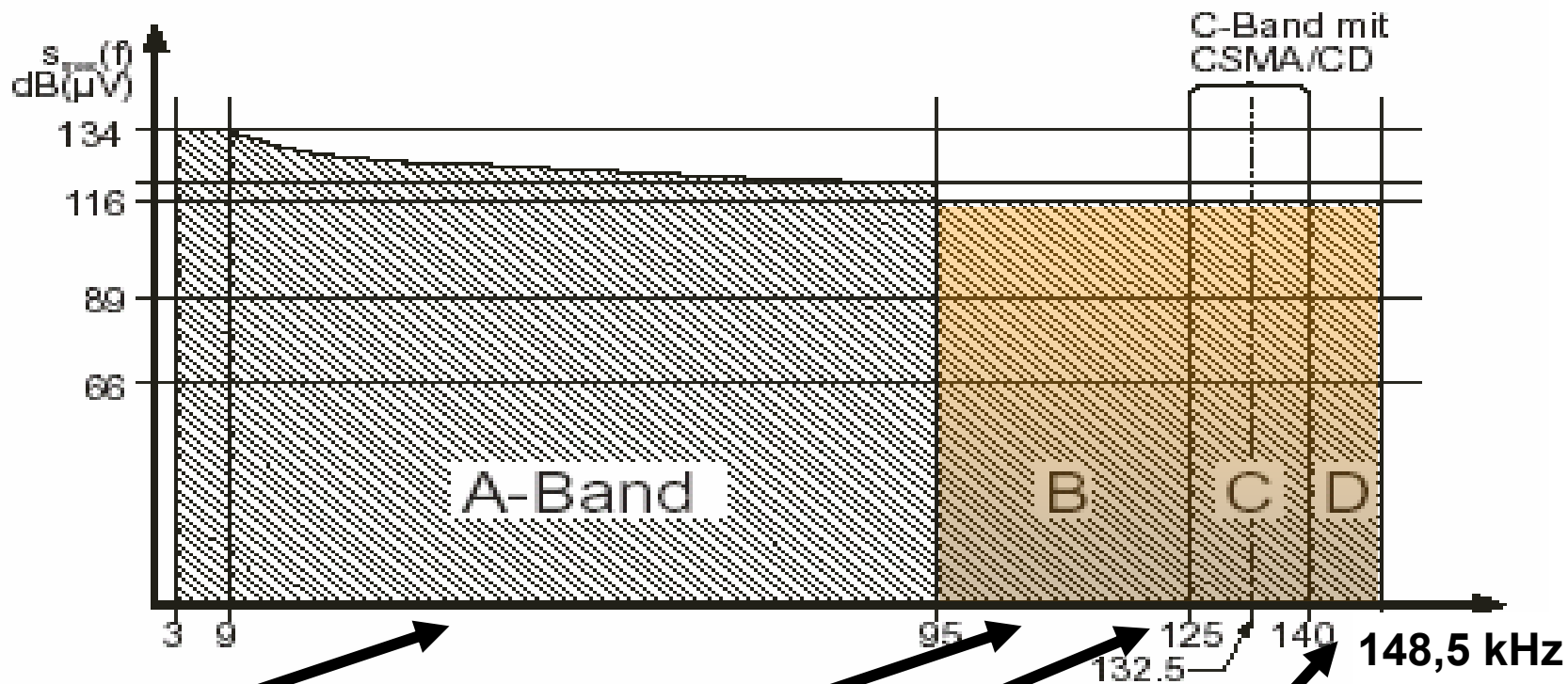
$$f_{LF} = \frac{1}{2\pi RC}$$

The suitability of a certain coupling capacitor depends on the impedance of the load into which it terminates.

# Performance and regulation

Low frequencies regulation. Max bitrate 1 Mbps

Europe - Standard CENELEC - EN 50065-1



**A** – Power utilities

**B** – Home automation

**C** – Home automation protocols

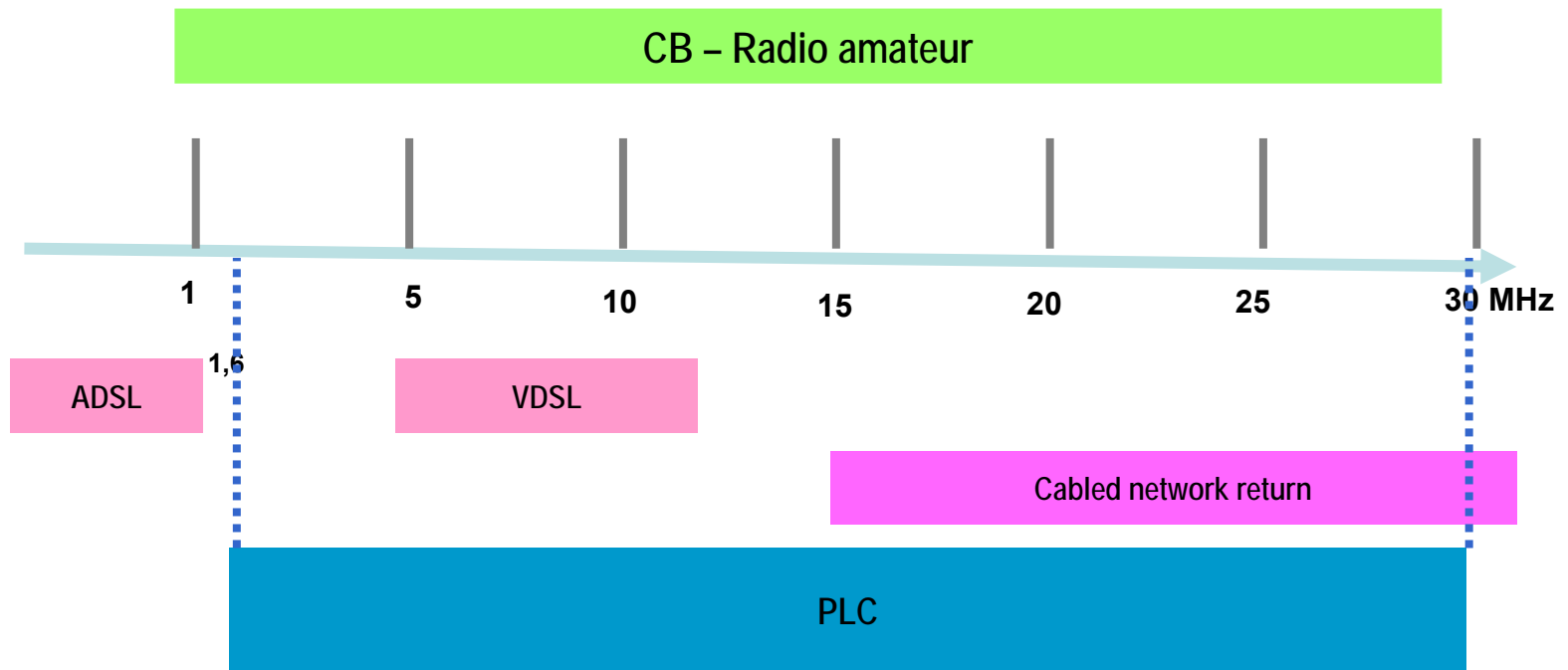
**D** – Home automation. Alarms and security

# Performance and regulation

Higher frequencies not yet regulated.

Bitrate up 10 Mbps and over

Work in progress: CENELEC SC205A WG10  
up to 30 MHz



# Performance and modulation techniques

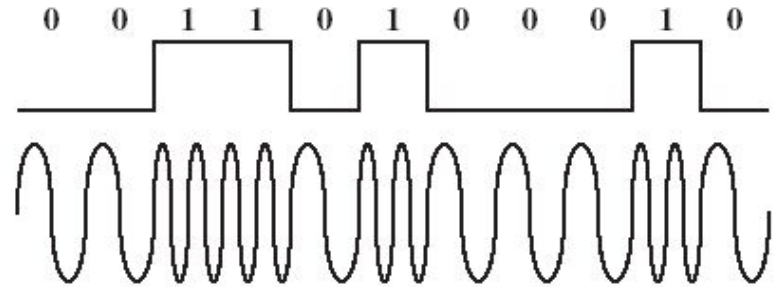
## FSK (Frequency Shift Keying)

### FSK advantages:

- low cost and easy to be implemented;

### FSK disadvantages at high bitrate:

- relevant Inter Symbol Interference;
- sensitive to narrow band noise;
- complex equalization at the receiver



(b) Frequency-shift keying

## Spread spectrum

A larger frequency band available allows for modulation techniques able to improve bitrate, efficiency and reliability.

With **Spread spectrum** techniques more than one carrier frequency is used at a time.

- **DSSS - Direct Sequence Spread Spectrum**

- **Frequency Hopping**

- **OFDM (Orthogonal Frequency Division Multiplexing)**

# Performance and modulation techniques

## OFDM

N orthogonal sub-carriers are phase and amplitude modulated.  
The total required band is the sum of the sub-carrier frequencies.

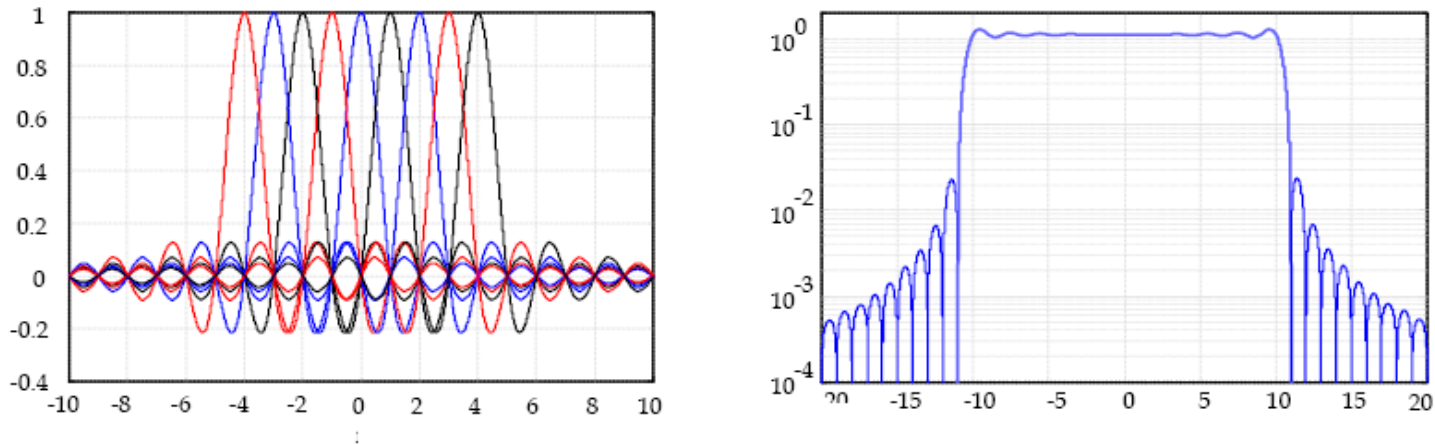


Figura 13 - Densità spettrale di potenza di un segnale OFDM per ciascuna portante e globale

### OFDM Advantages:

- high spectral efficiency and robust to narrow band interferences;
- flexible and adaptive (each subcarrier can be independently modulated)
- easy to synchronize

### OFDM Disadvantages:

- high peak power and emission
- not yet standardized in the high frequencies range

It can also be implemented in the low frequency range (Project Prime - Iberdrola [

# The channel characterization [2]

Differences and similarity between channel transfer function in domestic lines and car lines.

## **Multipath**

Non/flat frequency spectrum with a number of notches, making it difficult to operate over large spectrum band (unless a spread spectrum technique is used)

## **Impulsive noise**

Due to connected nonlinear devices and motor drives

## **Topology**

In a house: 3-4 wires grouped in a cable merging in the distribution board; transmitting mostly electric energy.

In a car: 3-50 wires confined in a limited space close to the chassis, working as a ground; transmitting electric energy and different protocol signal among car units.

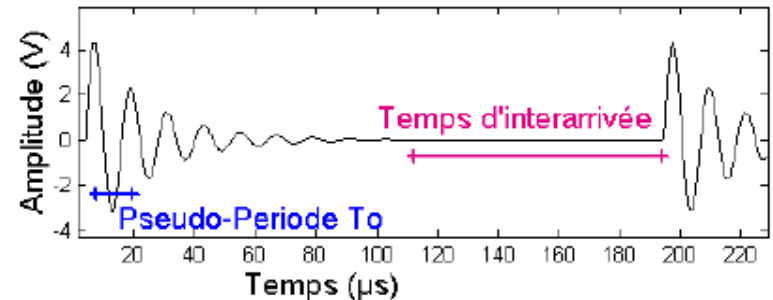
# The channel characterization

**Background noise** - Superposition of different, time variable (minutes, hours), noise sources, depending e.g. on the vehicle state, partially damped by the common metal body of the car. Coloured, not white noise, more relevant in low frequencies. **Relatively low spectral density.**

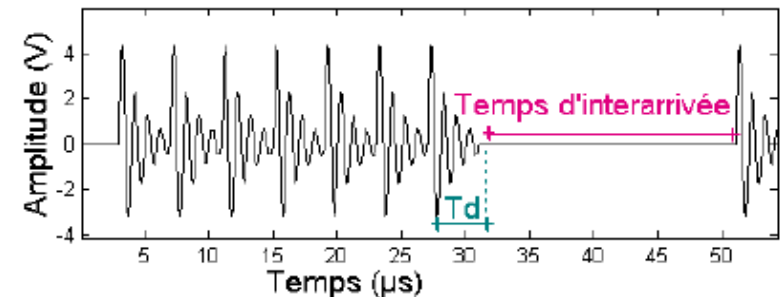
**Narrow band noise** - Mostly related to the wiring captation of radio broadcasting. Sinusoidal, amplitude modulated signals, also depending on the geographical location.

**Impulsive noise** - Produced by the numerous electric systems on board. Can be divided into:

**single transient** or pulse



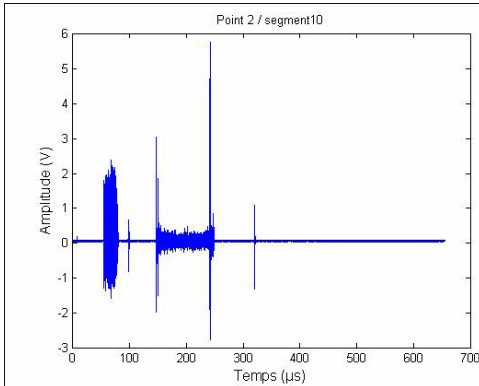
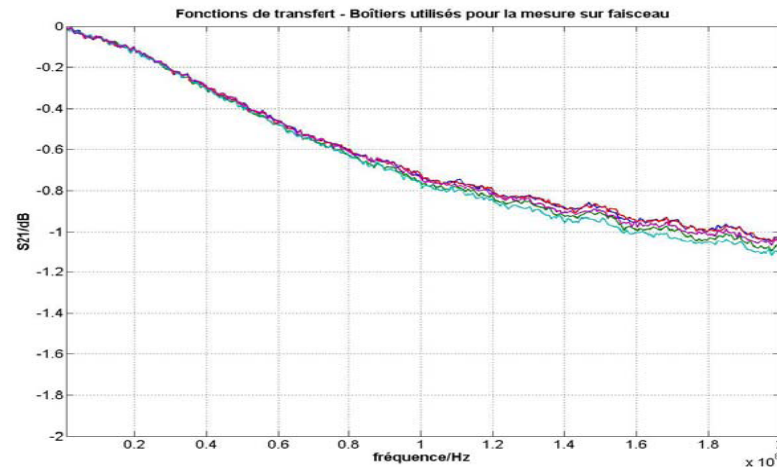
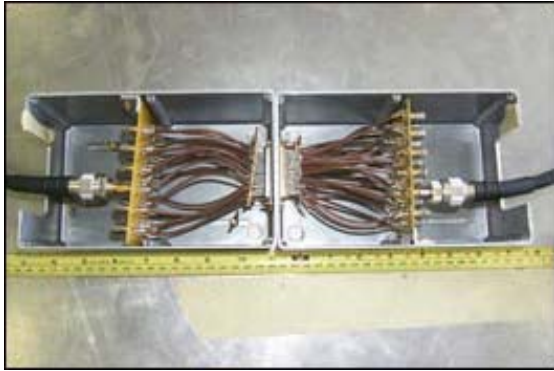
**burst** characterized by a succession of elementary pulses





# The channel characterization – Details: Marc Olivas Carrion, Thèse [2]

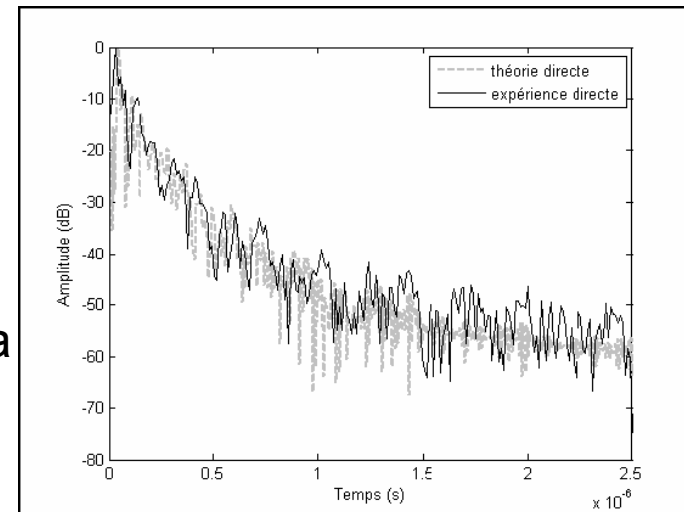
## Modélisation déterministe et de la fonction de transfert du canal



## Le Bruit impulsif sur le réseau électrique 12V des véhicules

### Caractérisation expérimentale du canal

Les résultats de l'analyse statistique ont montré que les paramètres de la modulation OFDM définis par la norme [HomePlug 1.0](#) étaient bien adaptés aux caractéristiques du canal de propagation sur le réseau électrique 12 V.



# PLC Protocols – HomePlug 1.0

*Born to serve the demand for sending digital voice, video and Internet data within the home, based on Powerline transmission*

HomePlug 1.0 was released in June 2001 by the HomePlug Alliance.

**Physical layer.** The OFDM used by HomePlug is specially tailored for powerline environments. It uses 84 equally spaced subcarriers in the frequency band between 4.5MHz and 21MHz. To overcome impulsive noise uses forward error correction (FEC), error detection, data interleaving, and automatic repeat request (ARQ).

**Medium Access Control** is modeled to work with IEEE 802.3 frame formats. This choice simplifies the integration with Ethernet frames.

**Frame format.** Long format (up to 160 OFDM symbols). Short format.

**Channel access mechanism.** Is a variant of the CSMA/CA scheme (Carrier sensing). In case of busy bus the new access is prioritized.

**Segmentation and Reassembly mechanism.**

**Quality of Service features.**

# PLC Protocols – HomePlug 1.0

## Performances

	Modulation	FEC	Physical Layer Throughput (Mbps)
DQPSK 3/4	DQPSK	3/4 Convolution Code and Reed-Solomon Code	13.78
DQPSK 1/2	DQPSK	1/2 Convolution Code and Reed-Solomon Code	9.19
DBPSK 1/2	DBPSK	Convolution Code and Reed-Solomon Code	4.59 Code and Reed-Solomon Code
ROBO	DBPSK	1/2 Convolution Code, Reed-Solomon Code and each bit is repeated four time	1.02

Physical Layer throughputs for various modulation and FEC choices

	HomePlug	10 Mbps Ethernet	IEEE 802.11b	HomePNA (2 Baud)	HomePNA (4 Baud)
Physical Layer	13.78	10	11	16	32
MAC Layer	8.2	9.8	7.48	14.6	26.9

Comparison of HomePlug with other (home automation) technologies

### Field Tests

- 77% of the power line links will support at least **5Mbps** of MAC throughput
- 98% of the power line links will support at least **1.5Mbps** MAC throughput.

# PLC Protocols – HomePlug AV

*HomePlug AV supports distribution data and multistream entertainment.*  
HomePlug AV was released in 2005 by the HomePlug Alliance.

**Physical layer.** Operates in the frequency range of 2 - 28 MHz and provides a **200 Mbps** physical channel rate and a 150 Mbps information rate. Long OFDM symbols with 917 usable carriers (tones) are used.

**Medium Access Control** provides

- a **connection-oriented** Contention Free (CF) service to support demanding AV and IP applications, based on periodic Time Division Multiple Access (TDMA);
- a **connectionless, prioritized service** based on CSMA/CA technology, applied to only traffic at the highest pending priority level.

Both features are accommodated by a **Central Coordinator** establishing a Beacon Period and a schedule.

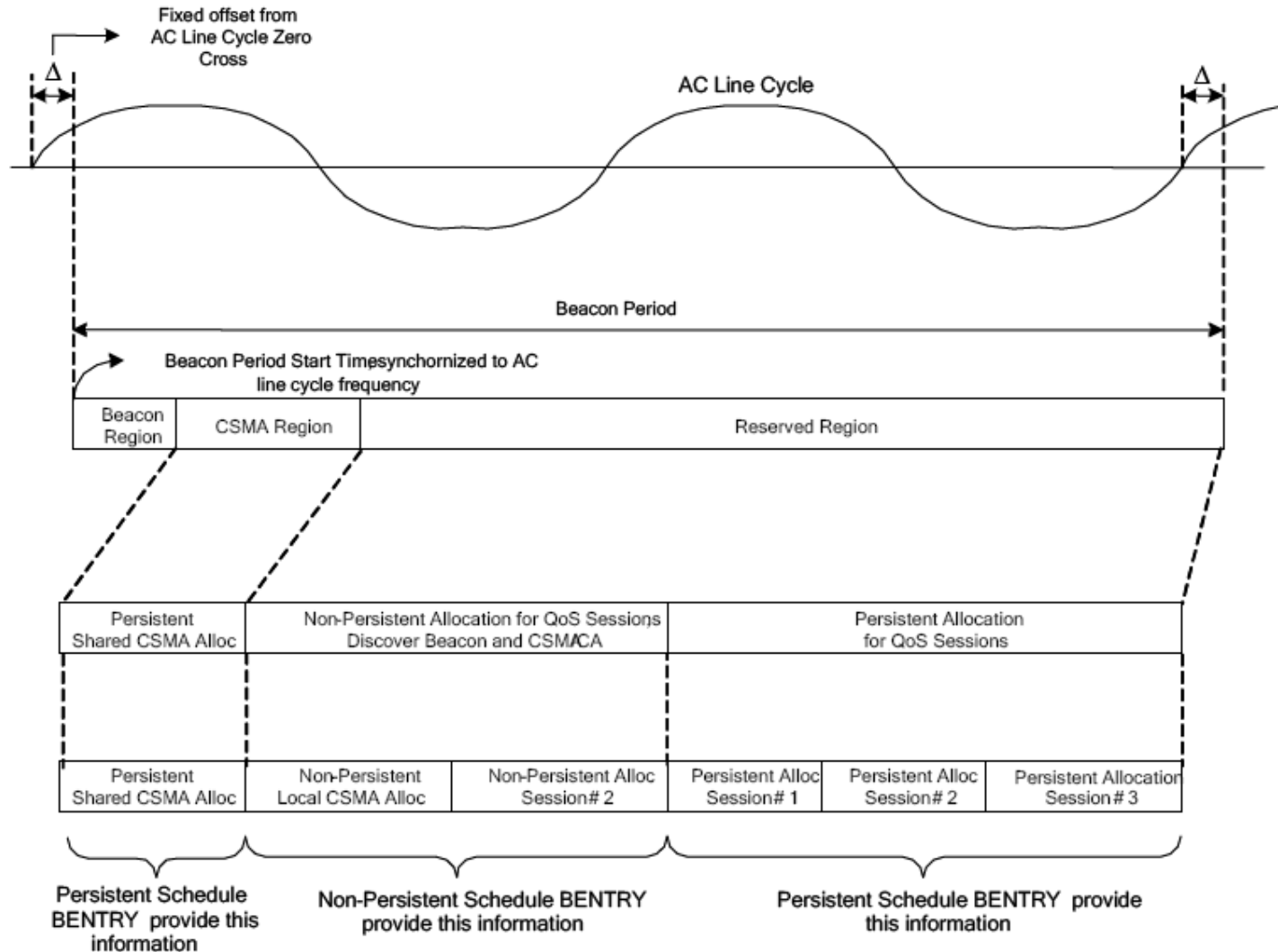
**Distributors in Europe**

**Devol AG – Germany**

**Intellon Corporation**

**ZyXEL**

# PLC Protocols – HomePlug AV

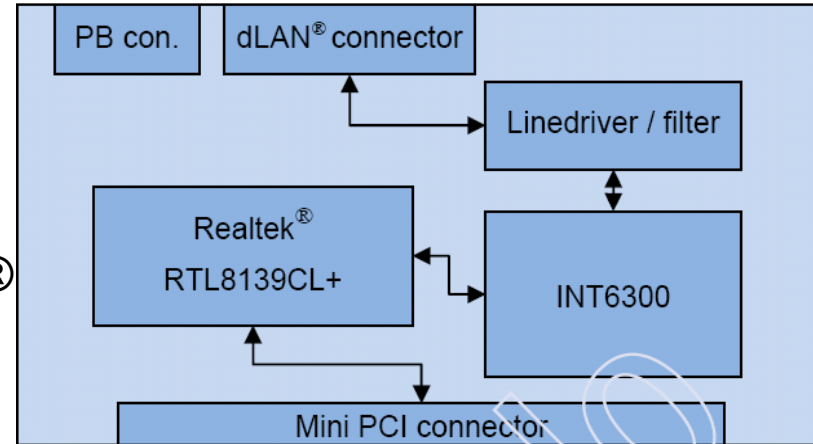


**Example of Beacon Period Structure**

# PLC Protocols – HomePlug Components

## Devolo® dLAN® 200 AVminiPCI

Is an integrated device for transmitting and receiving data over the powerline. Together with the dLAN® Coupling Device it holds all functions necessary for enabling HomePlug® AV network functionality on devices with one free Mini PCI Slot.



## Devolo® dLAN® Coupling Device

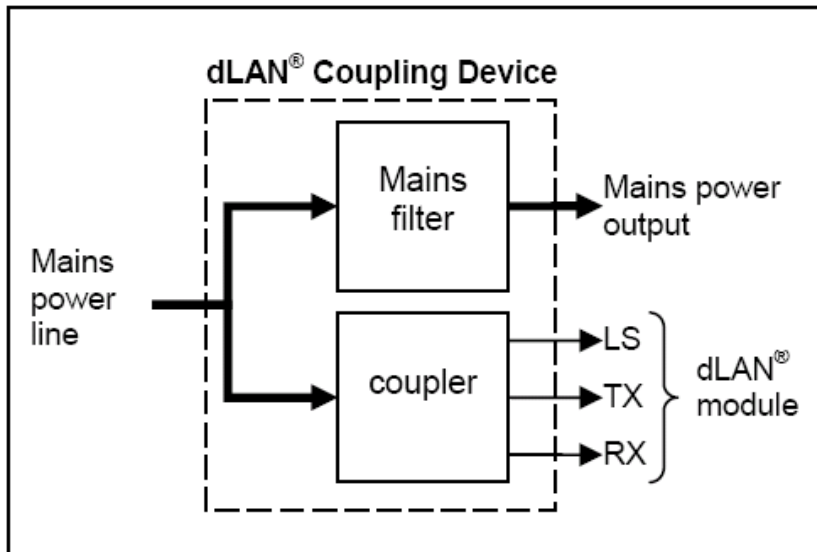


Fig. 1: Block diagram dLAN® Coupling Device

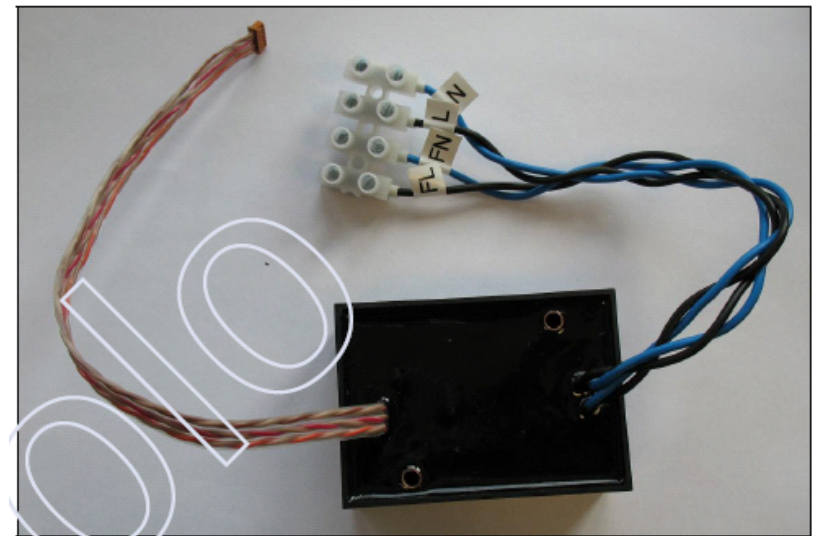


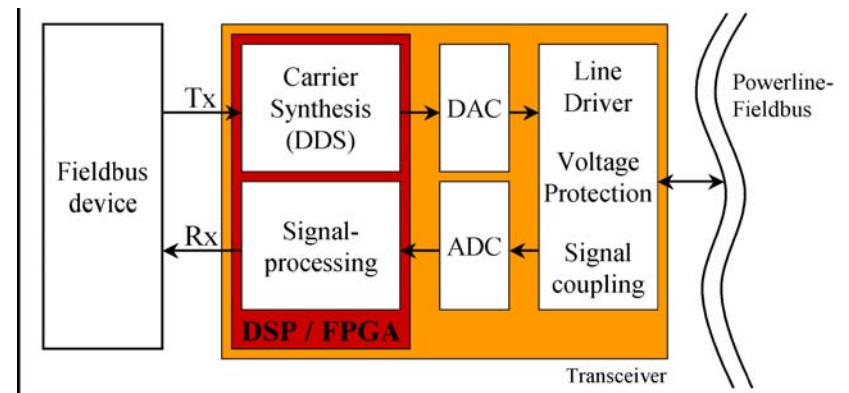
Fig. 3: The dLAN® Coupling Device

# PLC Protocols – CAN over Powerline

Requirements for a reliable transmission come from the CSMA procedure, which limits the total signal delay to complete the bitwise arbitration and acknowledge.

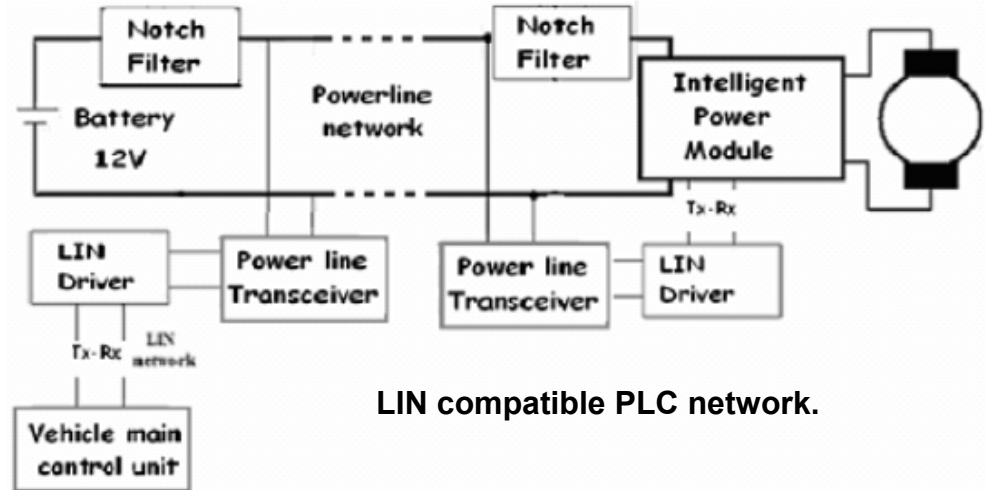
To achieve full compatibility for arbitrary networks at high noise immunity CAN must be implemented on PL by **carrier modulation** (2.2 MHz – 3.5 MHz according to CENELEC) together with a digital modulation. To obtain the 100% CSMA-conformity the possible modulation technique is restricted to the ASK (Amplitude Shift Keying) with 100% keying (On-Off-Keying).

A digital multi carrier transceiver has been proposed, but due to a number of limitation only bitrate up to 100 kBit/s are expected to be possible.  
[Beikirch, 3]

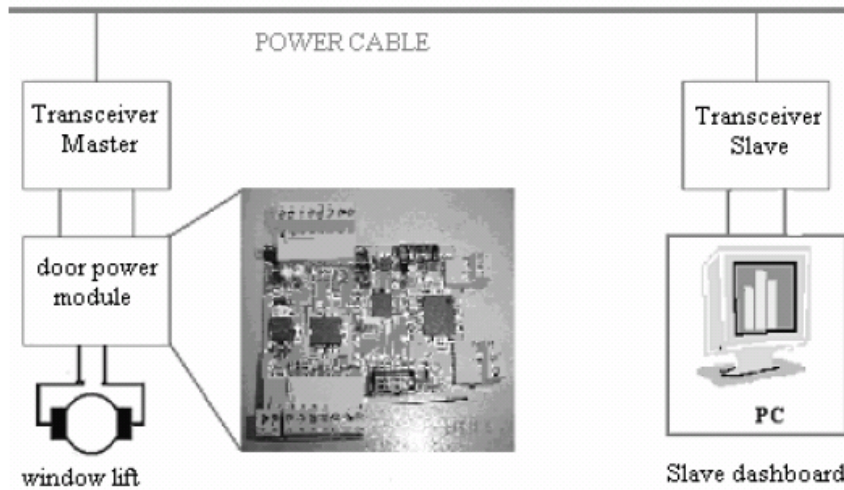


# PLC Protocols – LIN over Powerline [Testa, 4]

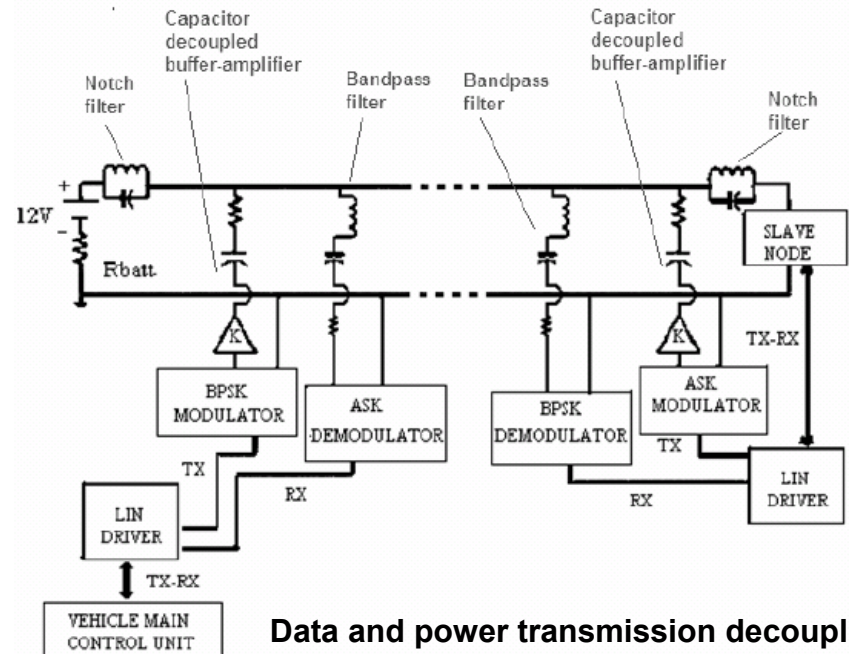
**The approach.** Suitable bi-directional interfaces (transceivers) allowing data exchange between a standard LIN network and a PLC network have been designed, rather than developing a specific protocol.



LIN compatible PLC network.



Experimental LIN based power line network.



Data and power transmission decoupling.



# Powerline for automotive – What's going on

## Low bitrate (up to 2 Mbps)

- YAMAR (Israel) well established company. Solutions based on transmission over battery cables and CAN protocol
- Valeo (lower bitrate)
- Research Theses en France (Spread Spectrum over 4 MHz, up to 2 Mbps and CAN) [Degardin, 5]

## Higher bitrate

Experimental setup for broadband automotive. Operating benchmarking results at 1 Mbps (4-FSK) and 5 Mbps (2-FSK) [Van Rensburg, 6]

Research in Germany (BMW, Bosch)

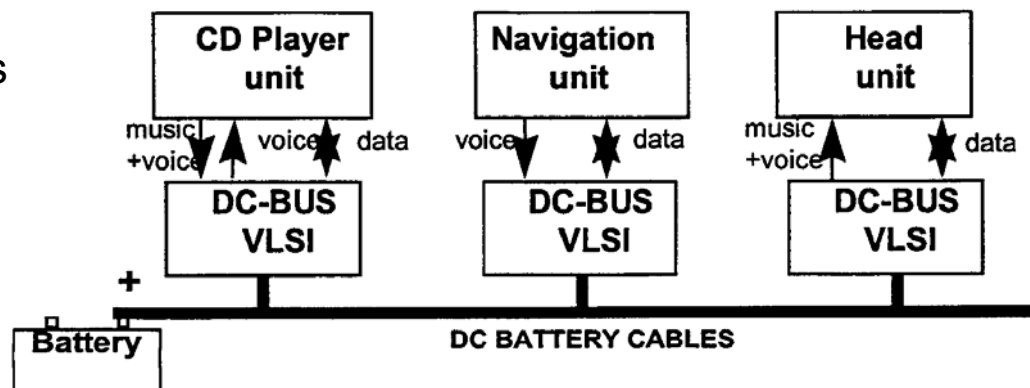
1. To work with the actual (not ideal) cable distribution to get high bitrate performance
2. To design a new cabling for the car to optimize even the transmission rate. [Dostert, 7]

# PLC Solutions for Automotive

## The Yamar proposal

Yamar Electronics Ltd. Offer devices reducing cabling by implementing digital communication over the battery DC-BUS (12, 24 or 42V) , with multiplex technology transfers.

**Low bitrate (10 Kbps)** solutions for implementing several interfaces to protocols such as CAN and J1850 was tested for several automotive applications, by using existing software for PLC.



**Medium speed PLC (250Kbps)** enabling use of digitized voice and Data communication (e.g. Internet, Navigation, Truck-Trailer) are *under test* by leading automotive companies.

**High speed (1.7Mbps) PLC** prototypes (e.g. link between CD Changer in the trunk and a Head Unit on the dashboard) are *under test*

# PLC Solutions for Automotive - The Yamar proposal

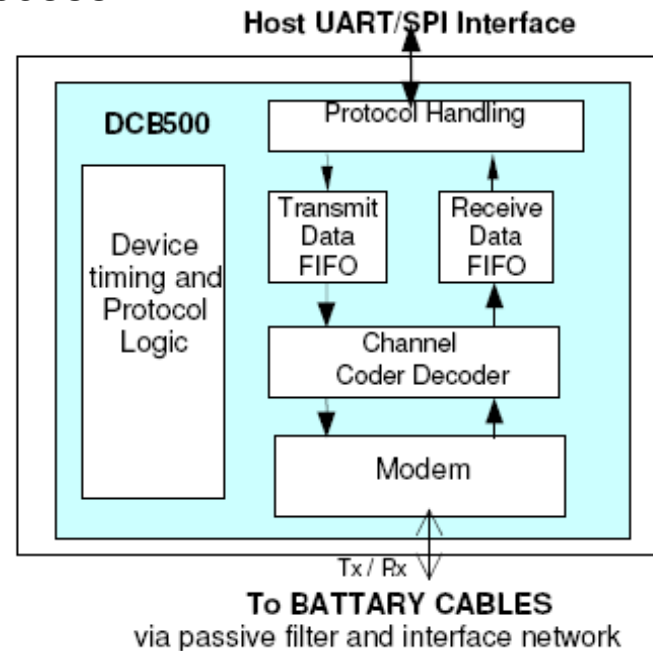
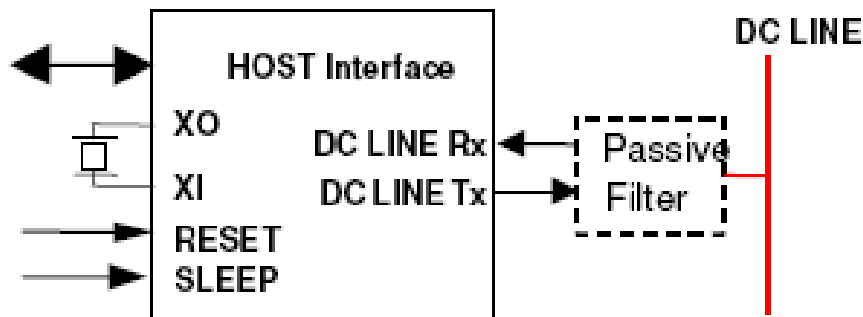
## Technology insight

By coupling through a capacitor to the powerline, it uses a DC-BUS™ technology for multiplex network communication.

It uses narrow band channels operable in various frequencies (channels) with center frequency selectable between 2 and 12MHz

Data entered from a sensor or other device such as CAN Controller is buffered in a Transmit FIFO, translated into packet message and coded by Error Correction Codes.

CSMA/CA technique is used for medium access



# PLC Solutions for Automotive - The Yamar proposal

## DCB500 – Transceiver

### Characteristics

**Data transfer rate:** 300 or 500 kbps

**Collision resolution:** Built in CSMA/CA

**Error correction codes:** Built in Forward Error Correction Code (ECC)

**Power save mode:** Built in Sleep moded.(Only 50 us to sense activity)

**Packet size:** User defined

**Interface:** UART or SPI

**Network** of up to 16 nodes.



# PLC Solutions for Automotive - The Yamar proposal

## DCAN250 Transceiver

Enables CAN-bus messages communication over vehicle's dedicated DC power-line

**Data transfer rate:** 250 kbps

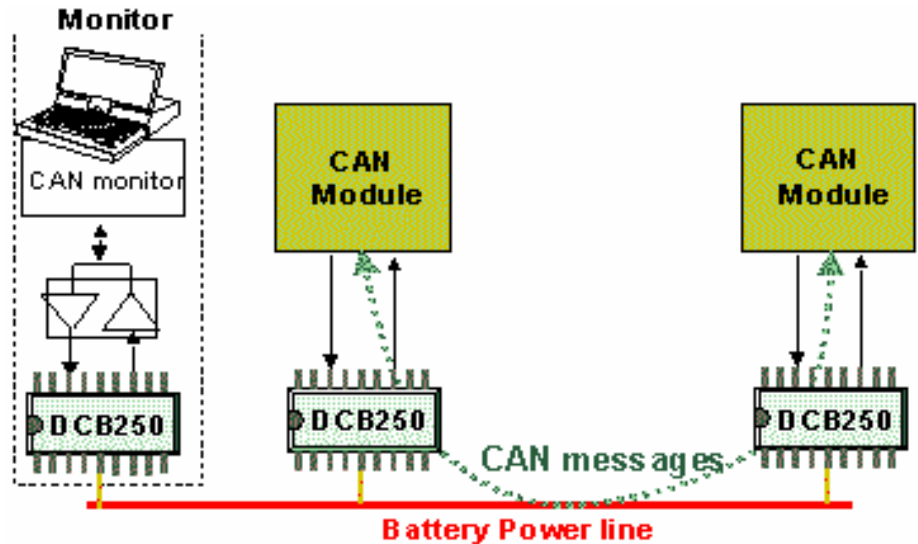
**Collision resolution:** Built in CSMA/CR

**Error correction codes:** Automatic Retransmit Requests and Retransmissions\*

**Power save mode:** Built in Sleep moded.(Only 50  $\mu$ s to sense activity)

**Packet size:** User defined

**Network** of up to 16 nodes.



DCB250 Device

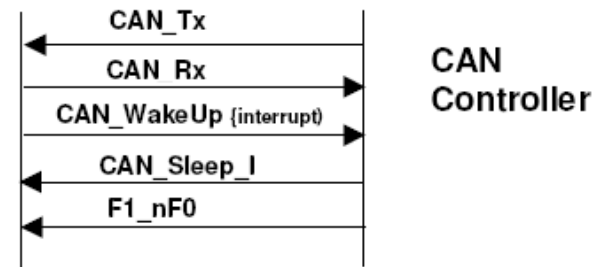


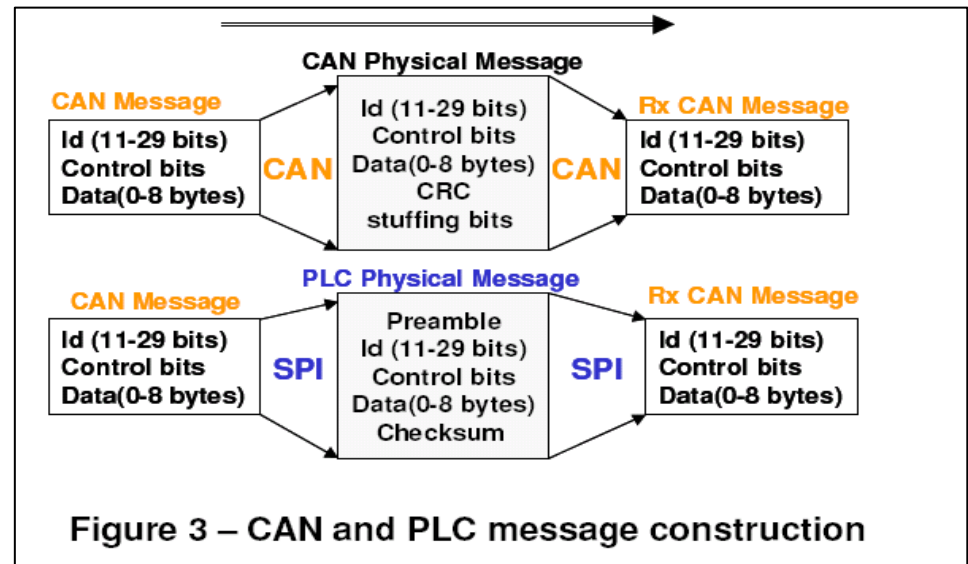
Figure 4.1 - CAN Interface signals

# PLC Solutions for Automotive - The Yamar proposal

## In summary

The PLC does not intend to compete with the existing CAN, LIN or Flexray networks. Yamar designed its PLC devices as an *alternative physical layer, using LIN / CAN protocols as an interface with ECUs* providing a convenient solution to customers.

Examples for such use is the DCB500 PLC transceiver used as a *redundant CAN communication network.*



Flexray may use PLC to extend its nodes for remote sensors / actuators. Since the actuators or sensors communicate with the Flexray every ~10mS. A low speed sub-bus will be sufficient to communicate with each of the sensors.

# PLC for automotive – Open issues

**Opportunity:** is the PLC solution attractive for car manufacturers?

**Performances and technology:** is the today technology able to meet the performance requirements?

**Research:** what are the crucial issues tyhat deserves further insight and research work? Reliability, Real Time operation, EMC.

**Lab experiments:** how can be defined a viable lab experience?

# Experiments: Summary and goal

- evaluate the issues related to PowerLine Communication (PLC) in the automotive domain
- define, implement and tune the experimental setup
- carry out measurements on communication performance under realistic conditions (EMI, etc.)
- assess the timing behavior of the communication



# Experimental setup

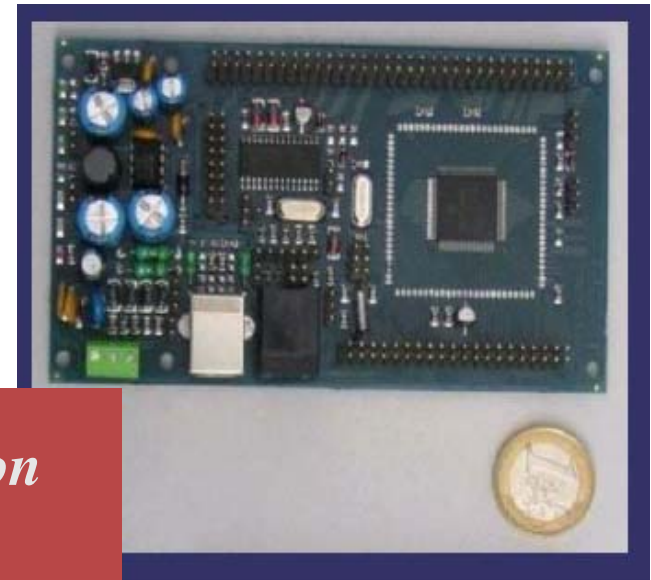
## hardware/software

- ✓ **FLEX Board** from Evidence SRL (based on the Microchip **dsPIC® DSC microcontroller dsPIC33FJ256MC710**)
- ✓ **DCB 500 Serial PLC Modem** transceiver from Yamar LTD
- ✓ **Ignition System** by Magneti Marelli
- ✓ **Erika Enterprise Real-time OS** from Evidence SRL

# Experimental setup

## TX/RX hosts

- FLEX Full and the onboard Microchip dsPIC® DSC come with:
  - ✓ real-time OS (**Erika Enterprise**)
  - ✓ **SPI interface** communication
  - ✓ high speed data transfer
  - ✓ general purpose **I/O**
  - ✓ **many others...**



*FLEX FULL Evaluation  
Board*

# Experimental setup

## DC-line interface

- DCB500 features:
  - ✓ communication over DC-line
  - ✓ bit rate up to 500 Kbit/s
  - ✓ SPI interface with host
  - ✓ built-in DC-line access scheme

**DCB 500  
transceiver**

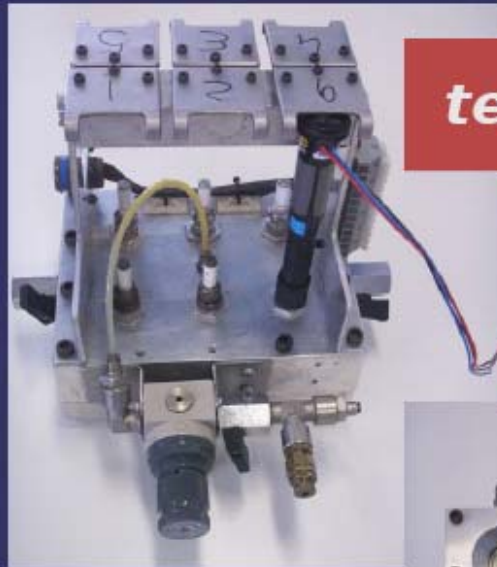


# Experimental setup ignition system

✓ generate **realistic EMI** on the DC-line



**Electronic  
Control Unit**



**test-bed**



**coil**



# Experiment roadmap

step 1

*ok*

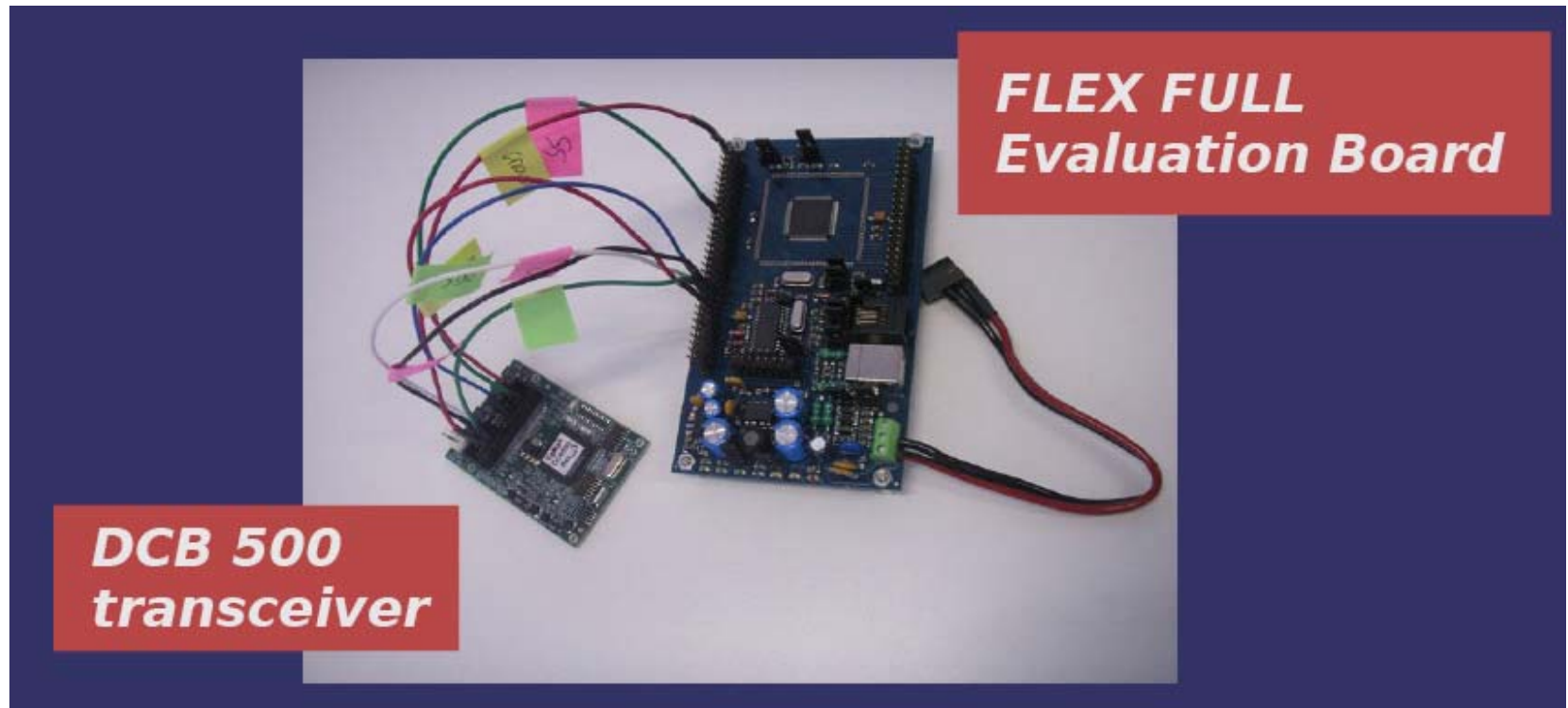
- DCB500 **functioning test**
  - ✓ **check** the correct operation of all devices
  - ✓ test the functionality using the **supplied software package**
  - ✓ **send simple messages** and test reception correctness (using UART at max speed of 115 Kbit/s)

# Experiment roadmap

step 2

*ok*

- ✓ **physically connect** the ECU (FLEX board) to the DCB500 transceiver

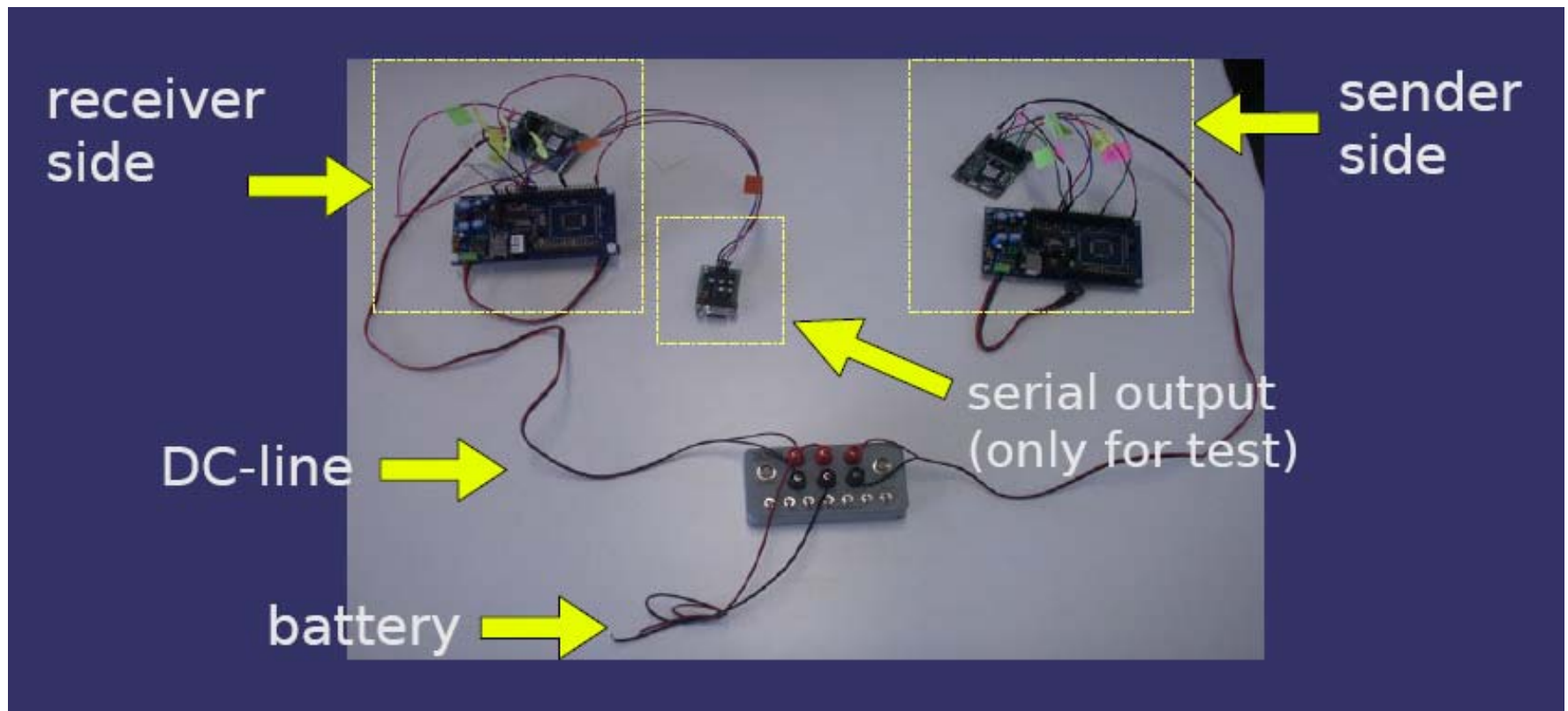


# Experiment roadmap

step 3

*ok*

- simple communication system using 2 ECUs, 2 DCB500 transceivers over the DC-line



# Experiment roadmap

step 4

*ongoing*

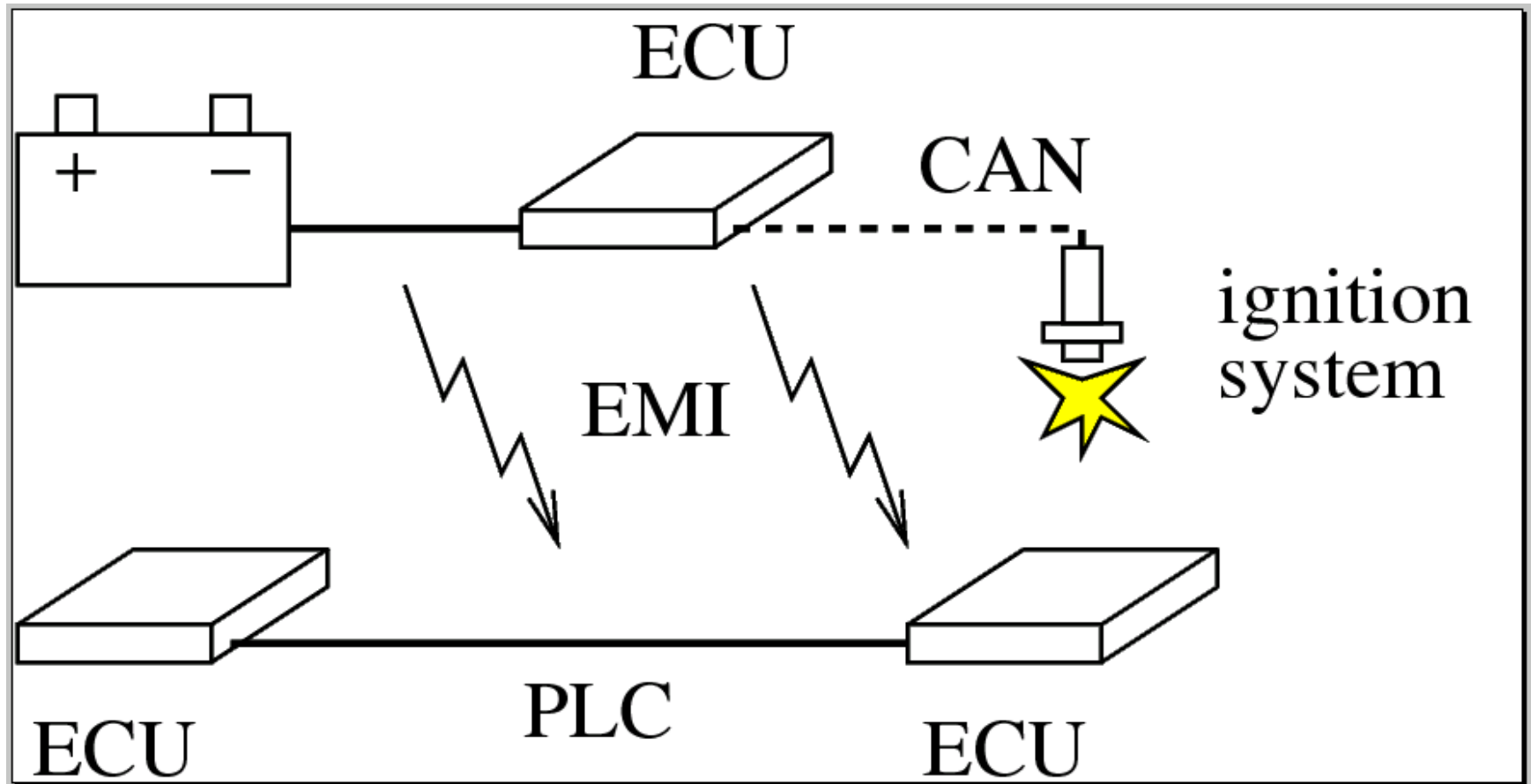
- interface ECUs (FLEX boards) with the DCB500 transceiver
- ✓ implement the high speed SPI interface (4 Mbit/s)
- ✓ communication protocol setup
- ✓ programming the test application



# Experiment roadmap

step 4

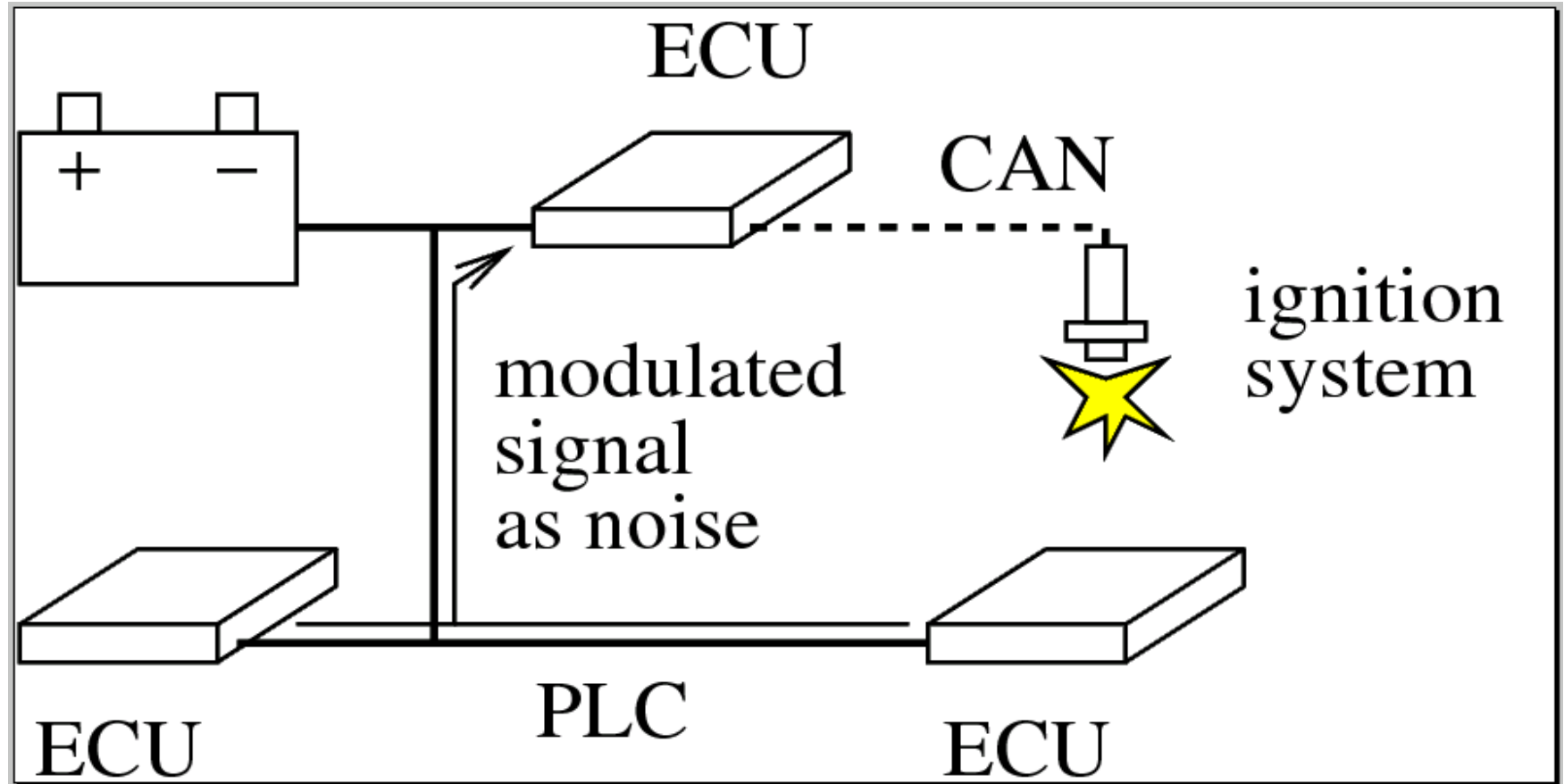
*ongoing*



# Experiment roadmap

step 4

*ongoing*



# Experiment roadmap

step 5

*to be done*

- using 2 ECUs, at the **max possible speed** without communication errors
  - ✓ throughput
  - ✓ response time
  - ✓ end to end latency
- introduce **source of noise** (i.e. ignition system, cell phones, etc.)
  - ✓ reevaluation the communication performance

# Conclusions

- ✓ some preliminary work done
- ✓ the main performance assessment to be done

future works and wishes

- ✓ what happens with many nodes connected?
- ✓ find people interested on the topic
- ✓ possibility of collaboration on funded projects

# ***Robotics Lab. research activities***

- **real-time operating systems (scheduling, power-aware, multi-core, etc.)**
- **real-time wired/wireless communication**
- **power-line communication systems**
- **embedded systems (Linux, etc.)**
- **autonomous robot navigation (mobile robots, manipulators, etc.)**
- **multi-robot co-ordination**
- **domotics**

# ***Electrical drives and automation lab***

- **electrical drives and machines control**
- **electrical drives, actuators and algorithms for industrial manipulators**
- **real-time control in industrial environment**
- **fieldbus protocols and application for industry**
- **fieldbus protocols and applications in domestic environment**

# REFERENCES

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