# Convergence of Bandwidth, Robustness and Energy Saving challenges on CAN Physical Layer

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**Industry is facing antagonist trends, one requiring more bandwidth for higher data exchange at lower cost, and the other trend requiring better energy efficiency. CAN is at the heart of the equation and multiple innovations are considered to tackle both trends individually and together, with at the end, a convergence of requirements and constraints at the Physical Layer side.**

**This article describes CAN Flexible Data Physical layer technical challenges, potential use case scenario to support it, including the boundary conditions linked to robustness performance requirements, and the savings offered at the network side versus alternative solutions. In parallel, to optimize energy usage, the selective wake up of systems connected to CAN is growing adoption inside Automotive industry, and can highly benefit other markets**

**Each individual innovation contributes to keep and reinforce usage of CAN, improving efficiency or increasing connectivity, now combined together, new challenges need also to be considered.**

In vehicle Network communications standards have provided a major step forward in the proliferation of automotive electronics across platforms. Since its creation in the 80's the Controller Area Network (CAN) has permanently been adapted to tackle the challenges of industry in terms of bandwidth, of robustness and of energy savings.

Various markets adopted the CAN topology. Initially developed to support Automotive, with a large acceptance in all 5 domains of a car (Powertrain, Chassis, Safety, Body and Infotainment) CAN is now adopted in many other domains (Heavy vehicles - J1939-based solutions, Agriculture machinery - ISO 11783, also known as Isobus, Aviation systems - Arinc 825/6, Mobile equipments, Medical, and growing interest in factory automation applications with CANopen EN50325-4 and CANopen safety EN 50325-5).

With up to 2 billion nodes at the horizon 2015 (80% on the Automotive market and the rest on Industrial market according) CAN is part of the largest industry Network standard and still continue to raise interest for cost effective and robustness requirements.

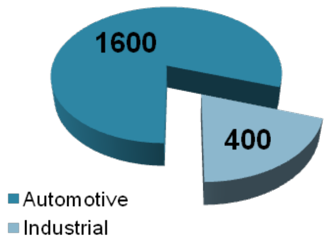



*Figure 1: CAN Market segmentation in M# (2015)*

CAN benefits are multiple; used as a inter system communication thanks to the differential topology, reducing sensitivity to noise, it can be utilized as a plug and play solution, with flexible bandwidth. Moreover, thanks to industry rules of acceptance and interoperability conformance test (electrical and from EMC/ESD stand point), the Physical Layer have significantly improved the immunity to external disturbances and self protection to system stresses. This new evolution of protection makes CAN usage simpler, faster and stronger.

Such standardization processes has been instrumental to make this bus a fast growing market, reducing the overall cost of ownership of the physical layer solution.

Now, to support evolution of industry trends in terms of faster communication exchanges, and also lowering the needs of energy utilization at the network level new standards emerged.

CAN partial networking (ISO11898-6) allows selective wake up, where ECU wake up frame is stored and checked inside the Physical Layer. Second one concerns the needs for improved bandwidth, where CAN Flexible Data allows faster baud rate and higher data quantity during transmission.

Increasing bandwidth at the network level is a way to delay the transition to higher baud rate networks, and at lower cost (versus FlexRay or Ethernet), provide intermediate system solutions that satisfy increased data communication exchange.

Such evolution requires adaptation of the physical layer to support each market needs, but also the combination of both that requires compromised architectures to maintain robustness performance.

**Challenge of CAN HS Physical Layer and Bandwidth improvement**

Most automotive CAN usage is today at 500kb/s. Only some rare applications operate at 1Mb/s, but they suffer of severe technical restrictions, such as network length and number of nodes which. CAN FD allows the increase of the bit rate in the CAN frame data section, as well as the extension of the number of transmitted data bytes, while keeping the beginning of the CAN frame (ID, DLC) at the same baud rate as today, mostly 500kb/s. This overall contributes to an increase of the CAN protocol efficiency, while keeping existing CAN networks topology (length, stubs, termination concept).

When announced, the CAN FD protocol and specification claim possible the usage of existing CAN transceiver, despite Fast Data operation up to 8Mb/s. However deeper analysis of the requirements, environment and specifications that the ECU and mainly CAN transceiver device should meet in their final application environment (like EMC) leads to the conclusion that at least some optimization of the CAN transceiver is mandatory, with eventually a significant change in the concept or design of the transceiver, for full compliance and usage of the FD specification.

With respect to EMC, the radiated or conducted emission depends of the signal integrity and wave shape of the CAN signals. However the fundamental frequency derived from the CAN transmission baud rate (i.e 500kb/s) and the harmonics are visible throughout the spectrum.

In case of increase of the baud rate or usage of the CAN FD, some bits are transmitted at higher baud rate, and this lead to a “shift” of the harmonics to the higher frequency of the spectrum.

EMC requirement has very low emission expectation at these frequencies, and the current transceivers operating in CAN FD, will not meet these requirements, without external filtering component or intrinsic design improvement.

The figure below show the spectrum of a typical CAN interface at 500kb/s and 2Mb/s, without any external filter. The frequency “shift” due to the operation in CAN FD at 2Mb/s is clearly visible.

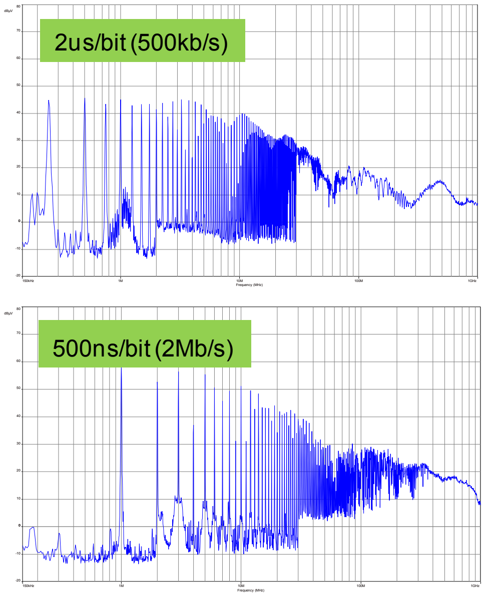



*Figure 2: Comparison of CAN emission at 500kps and 2Mbps*

In order to remain inside the EMC level targeted by car maker, optimization of the CAN driver is required, to allow operation in CAN FD at 2MB/s in a first step, and at high baud rate in future.

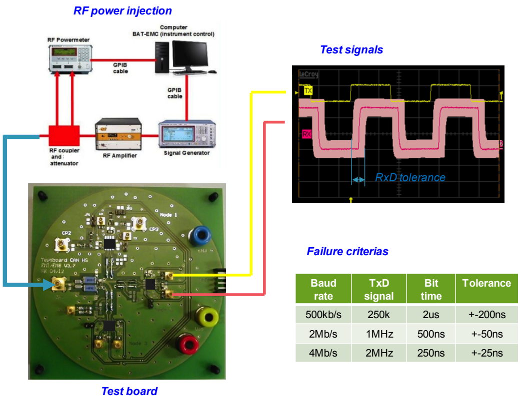
## CAN Robustness

A significant evolution of physical layer performance has been its self protection against system level stresses, with or without external protection component. Various specifications should be considered during the definition of a CAN Physical Layer.
To face these challenges a large range of innovations have been developed in (EME, EMI, ESD) using leading mixed signal and power technology SMARTMOS™ 8MV to manage the robustness improvements and support compliance to standards without need of external choke protections.

*Design for Immunity:*
The CAN network behaves like an antenna absorbing electromagnetic noise, generated by load switching such as motors, solenoids, relays or from external sources. During CAN communication the signal integrity must not be disturbed when electromagnetic noise is applied. This is known as Electromagnetic Immunity (EMI). There are two primary EMI tests used to simulate and validate the robustness of physical layers: these are the Direct Power Injection method (IEC62132-4) and Bulk Current Injection (ISO11452-4).

Under external EMC aggressions, the signal transmitted and received from / to the MCU TxD and RxD terminals should have limited jitter. With bit rate increase, the bit duration is reduced and consequently the acceptable jitter is reduced, requiring superior performance for the CAN transceiver.

The figure below is a simplified view of an EMC test principle, consisting in applying RF disturbance via coupling capacitor while the transceiver is actively driving the bus. The transceiver RxD signal are the monitored and compared to signal template, which is the typical signal with some allowed voltage and timing deviation (jitter). This jitter is becoming smaller to accommodated CAN FD operation.




| Baud rate | TxD signal | Bit time | Tolerance |
|---|---|---|---|
| 500kb/s | 250k | 2us | +-200ns |
| 2Mb/s | 1MHz | 500ns | +-50ns |
| 4Mb/s | 2MHz | 250ns | +-25ns |

*Figure 3: Simplified EMC test set up and acceptance criteria*

At the Physical Layer side it results in a complete design for EMC flow that include an accurate design and layout guide lines, an extensive simulation on block level and top cell level, and models that include process and temperature variations inside EMC simulation runs, to ensure a certain margin versus the specification. As a consequence, these design improvements lead to a CAN signal Integrity that support signal injection up to 39dBm.
With CAN FD use case, independent of any EMC constraints, some propagation delays should also be optimized in order to allow operation at higher baud rate. This

evolution of Physical Layer design has an impact on Immunity as the absolute jitter window is becoming smaller. Sensitivity to noise is therefore enhanced and the design is requiring higher immunity solutions. Below figure is showing the latest performance of Freescale CAN High Speed Physical Layer against DPI injection with a 2Mb/s use case.

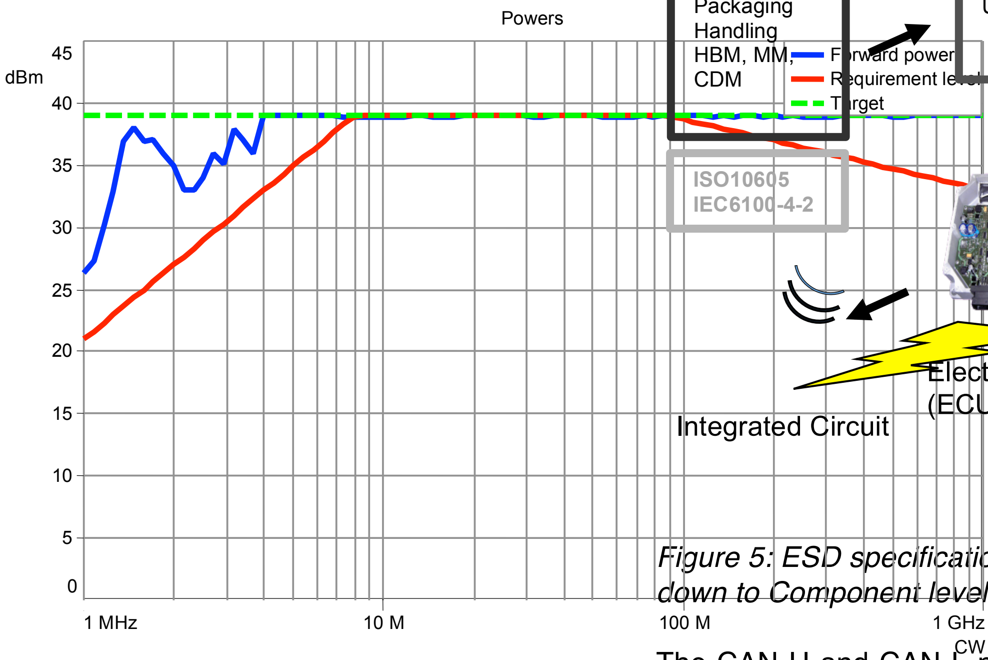



*Figure 4: Direct Power Injection CAN with choke, @ 2Mb/s*

*Improving system reliability with high ESD performance:*

The Physical Layers are specifically designed to withstand the most severe ESD standards defined at the IC level and at the system level. It passes the ESD tests specified in the AEC Q-100 document: Human Body Model (HBM) +-10kV, Machine Model (MM) +-200V and Charged Device model (CDM) +-750V. In addition the Physical Layer are optimized to pass system level stress defined in ISO 10605:2008 [2], IEC 61000-4-2:2008 [3], HMM (Human Metal Model) [4].

An ESD GUN is used to reproduce the impact of an electrostatic discharge when a human being is handling an electronic system sub-assembly or touching the car/equipment structure. Standards used to tests the Physical Layers are the ISO10605:2008, EN 61000-4-2:2008 specifications with IC powered and unpowered. All these standards have to be considered during the development phase of the integrated circuit because the setup variations for each standard lead to different stress characteristics.

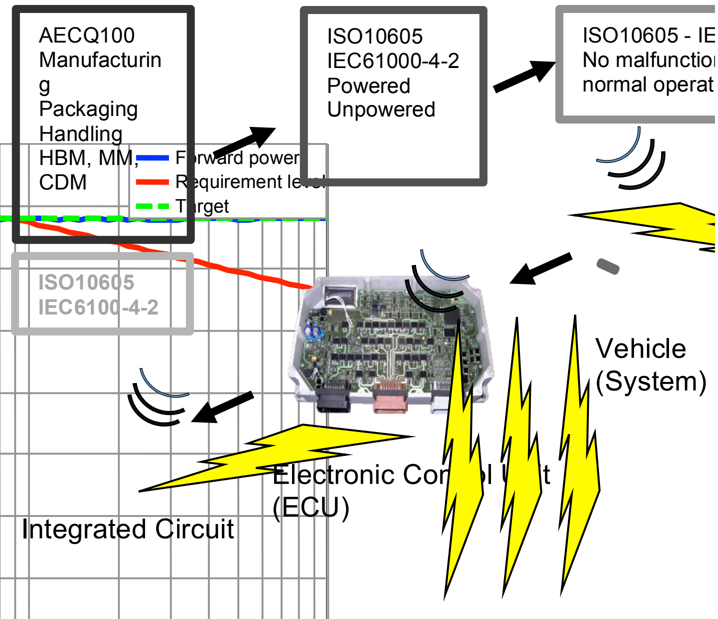



*Figure 5: ESD specification from System down to Component level*

The CAN H and CAN L pins are designed to be strongly immune against system level stress directly applied at the pin level with and without external protections. To achieve such high performance (up to 25kV), the SEED [6] approach (System Efficient ESD Design promotes an IC/OEM co-design methodology of on-board and on-chip ESD protections to achieve system –level ESD) is been used. As an example the ESD performance of latest Freescale CAN High Speed Physical Layer is summarized in the table below.

*Table 1: ESD performances summary*

| Specification | ISO 10605 device unpowered | ISO 10605 device powered |
|---|---|---|
| Device performance | +-8kV | +-8kV |
| **Specification** | **IEC61004 Device unpowered** | **CAN conformance** |
| Device performance | +-8kV | +-8kV |

The combination of high ESD and DPI performance is a challenge of energy absorption without compromising CAN communication. As presented in the above table, latest CAN Physical Layer are designed to pass all component and system ESD stress, while insensitive to external EMI parasitic stress, with or without need of external component like choke, and within a optimum die area. All of these innovations constitute the foundation of design for reliability of the Physical Layer integration inside more

integrated devices (SBC, ASSPs, ASICs…) where CAN Physical Layer is integrated. The combination of these constraints is the foundation of IC architecture to allow a successful final acceptance.

**CAN & Energy Efficiency**

Current consumption and energy saving can be managed at the system level, thanks to evolution and innovations on CAN standards. The over system current consumption can be reduced and optimized via the disabling and the activation into reduced power mode of selected ECU when unused in the vehicle. Of course theses ECU should resume operation when necessary.

As an illustration, the operation of 2 ECUs, car parking assistance and electrical parking brake, can be analyzed. These ECUs are not required and necessary while the car is running above a certain speed, let say some tens of km/h. These ECU can set themselves in reduce consumption mode, as they have access to the vehicle speed though CAN network and CAN messages. When the speed is greater than a pre determined threshold, these ECUs can set themselves in a reduced operating mode, by disabling or turning OFF power of components on the board like MCU, load driver etc. Only a minimum set of ICs will remain active to monitor CAN bus traffic and detect specific CAN message or part of CAN message, that will indicate to theses UCEs that they should resume operation, by enabling and powering up the disabled ICs.

This contributes to the overall electrical consumption reduction and optimization of the car.

Such operation is possible by implementing CAN message detection inside the CAN transceiver connected to the CAN bus. This is called CAN partial networking or CAN selective wake up.

The challenge is to be able to decode incoming CAN frame with extremely low consumption (target less than 500uA) for the complete partial networking function inside a CAN physical layer, with minimum cost, which excludes usage of accurate oscillator component like crystal or resonator. As a reminder, CAN controller inside MCU uses very accurate clock, derivate from crystal, having accuracy and deviation which is measured in ppm. Obviously, such clock accuracy is by far not achievable in silicon.

However, CAN message reception and decoding only require a clock in the “per cent” range. So the integration of CAN message is becoming achievable thanks to very innovative techniques and solutions that can be implemented inside mix signal silicon technologies, used for CAN transceiver functions.

These solutions uses high precision analog function like low power accurate oscillators, low current differential receiver, low power voltage references and biasing circuitry, and are combined with digital CAN message decoder, in order to realize the incoming CAN message decoding. The incoming CAN message is then compared with preselected message and the transceiver wake up and allow the ECU to resume operation.

Here also the EMC challenges are presents, as the CAN frame should be properly decoded despite presence of RF disturbances and electrical transients on the vehicle. This becomes a real implementation challenge as the circuitry is operating with very low current, some tenth of uA, to achieve the overall 500uA consumption target.

The figure below shows a block diagram of a typical implementation of CAN partial networking function, in a market standard pin configuration. The blocks in grey are the one operating during the partial networking operation which in total require less than 500uA.

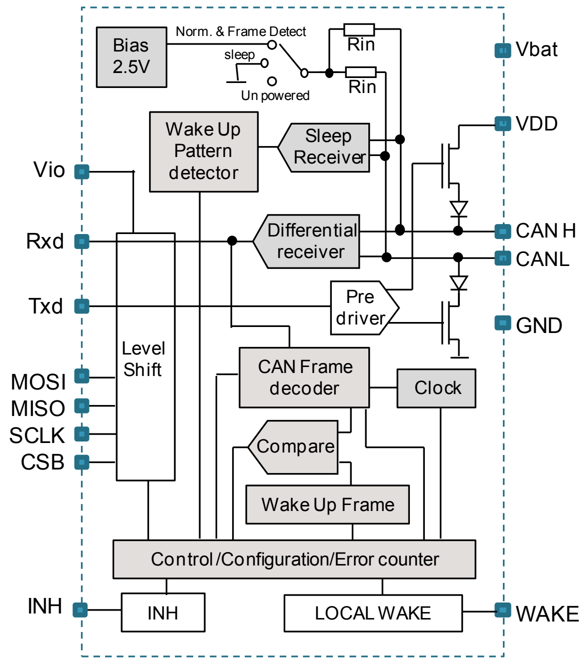



*Figure 5: Block diagram of a CAN transceiver with Partial Networking function.*

<u>Technical summary:</u>
The table below summarizes the main technical constraints and impact of the CAN FD on future evolution of CAN transceivers.

| Standard | XCVR mode | Operation | Impact |
|---|---|---|---|
| ISO 11898-2 | Transmit-Receive | Interface to the physical CAN bus | **FD active** Operation at x8 speed. Timing optimized. Proposal for **2Mb/s operation** Definition of EMC tests set up and failure criteria. |
| ISO 11898-5 | Low power mode | Wake up on any frame. | No impact. |
| ISO 11898-6 | SWU, frame detect (Partial Networking) | Wake up on a dedicated frame (ISO 11898-1).<br><br>Error manage-ment . | **FD passive** Evolutions of “Frame Decoding” & “Error Management” to ensure no error detected due CAN FD frame. Proper “End of frame” detection. |

For normal operation, as described in ISO 11898-2, the main impact is meeting the EMC specifications, which are not anticipated to be relaxed to accommodate CAN FD.

In partial networking operation, as described in ISO 11898-6, the CAN FD frames should not disturbed CAN incoming message detection, and for such the CAN PN transceiver should be “FD passive”. This is archived by proper detection of the CAN inter frame space, properly discriminated from fast data section.

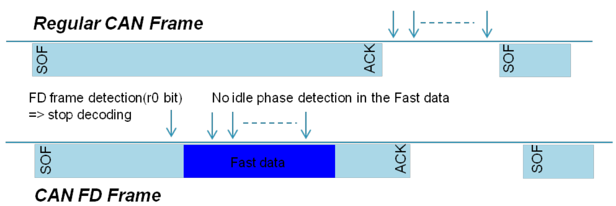



*Figure 6: Comparison of regular and FD frames*

## Antagonist integration of innovations

The right tradeoff between emission and Immunity, ESD robustness, low power consumption and higher baud rate on the CAN High Speed communications is achieved by a deep analysis of each physical phenomenon on the Analog IC, and also the right interaction each others.

Evolution of the market to reach higher baud rate has an influence on immunity and emission levels. This requirements need to be taken at the front end definition level in order to keep the same performance level with higher relative performance.

In addition, Partial Networking requires Analog transceivers structures that need lower power consumption, potentially less immune to external noise. Again, the alignment between noise model and design architecture is allowing Physical Layer to sustain same level of EMC performance while reducing the power consumption of the Physical Layer.

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