White Paper

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

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Abstract

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 the automotive industry, and can highly benefit other markets requiring similar requirements such as the industrial market.

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.

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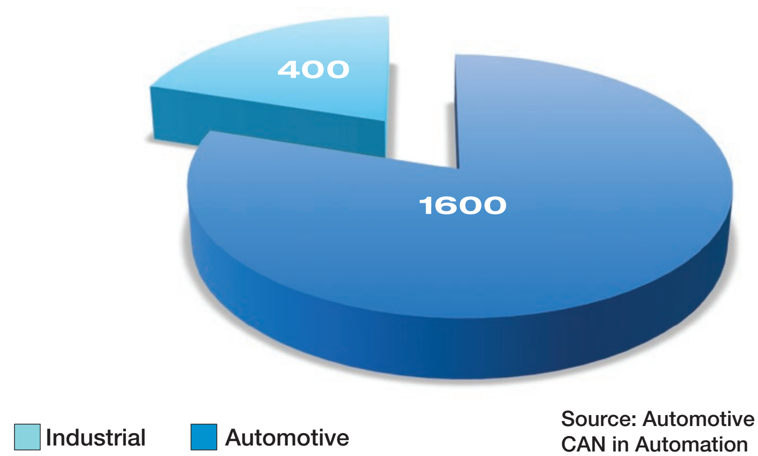
In vehicle network communications standards have provided a major step forward in the proliferation of automotive electronics across platforms. Since its creation in the 1980's the Controller Area Network (CAN) has permanently been adapted to tackle the challenges of industry in terms of bandwidth, of 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 equipment, 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 the industrial market accordingly) CAN is part of the largest industry network standard and still continues to raise interest for cost effective and robustness requirements.

CAN Market Segmentation in M# (2015)



Source: Automotive Analytics,
CAN in Automation

CAN benefits are multiple; used as an 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 has 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 have 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 need, but also the combination of both that requires compromised architectures to maintain robust performance.

Challenge of CAN High Speed Physical Layer and Bandwidth Improvement

Most automotive CAN usage is today at 500 kb/s. Only some rare applications operate at 1 Mb/s, but they suffer from 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 500 kb/s. This overall contributes to an increase of the CAN protocol efficiency, while keeping existing CAN network topology (length, stubs, termination concept).

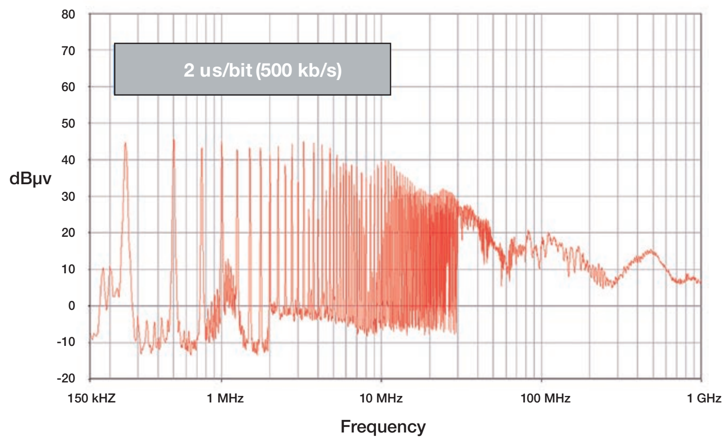
When announced, the CAN flexible data protocol and specification claim possible the usage of existing CAN transceivers, despite fast data operation up to 8 Mb/s. However deeper analysis of the requirements, environment and specifications that the ECU and mainly CAN transceiver device should meet in their 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 flexible data specification.

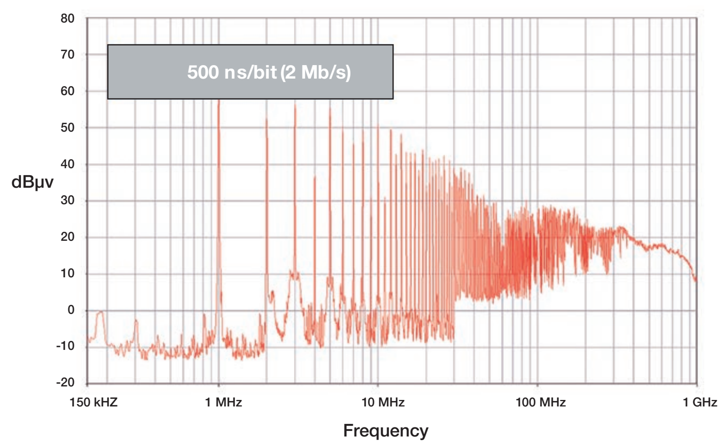
With respect to EMC, the radiated or conducted emission depends on the signal integrity and wave shape of the CAN signals. However the fundamental frequency derived from the CAN transmission baud rate (i.e., 500 kb/s) and the harmonics are visible throughout the spectrum.

In case of increase of the baud rate or usage of the CAN flexible data, some bits are transmitted at higher baud rate, and this leads 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 flexible data will not meet these requirements, without external filtering component or intrinsic design improvement. The figure below shows the spectrum of a typical CAN interface at 500 kb/s and 2 Mb/s, without any external filter. It is measured according to IEC61967 [8]. The frequency “shift” due to the operation in CAN flexible data at 2 Mb/s is clearly visible.

Comparison of CAN Emission at 500 kps and 2 Mbps on MC33901





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

CAN Robustness

A significant evolution of physical layer performance has been its self protection against system level stresses, with or without external protection components. 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 8 medium voltage to manage the robustness improvements and support compliance to standards without need of external choke protections.

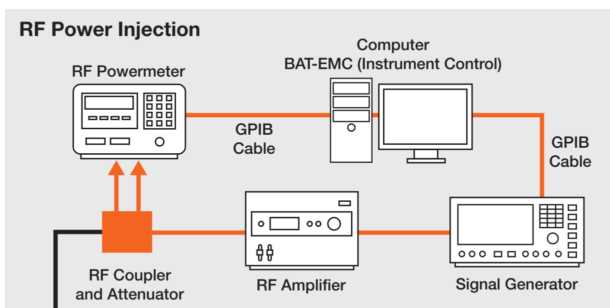
Design for Immunity:

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) [2].

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.

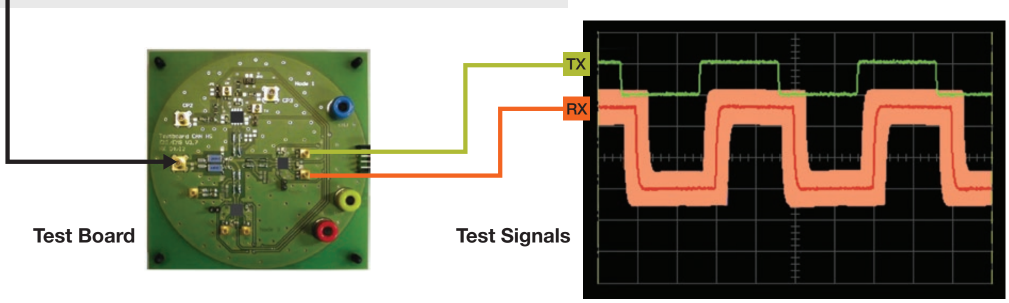
The figure below is a simplified view of an EMC test principle, consisting in applying RF disturbance via coupling capacitor while the transceiver is actively driving the bus. The transceiver RxD signal is monitored and compared to the signal template, which is the typical signal with some allowed voltage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

Simplified EMC Test Set Up and Acceptance Criteria



Failure Criterias

Baud Rate	TxD Signal	Bit Time	Tolerance
500 kb/s	250 k	2 us	±200 ns
2 Mb/s	1 MHz	500 ns	±50 ns
4 Mb/s	2 MHz	250 ns	±25 ns



At the physical layer side, it results in a complete design for EMC flow that includes 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 supports signal injection up to 39 dBm.

With CAN flexible data use case, independent of any EMC constraints, some propagation delays should also be optimized in order to allow operation at a 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. The figure below is showing the performance of Freescale's MC33901 CAN high speed physical layer passing DPI injection with a 2 Mb/s use case.

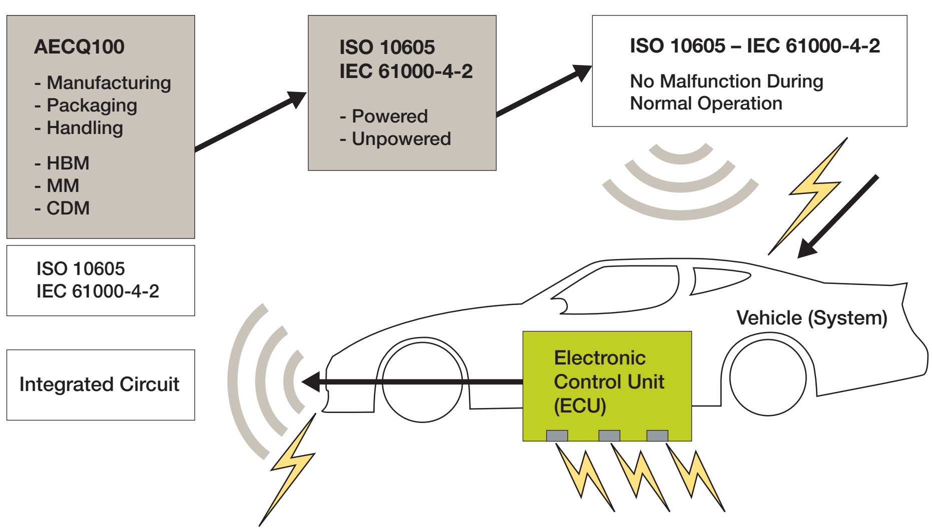
MC33901/MC34901 – Direct Power Injection CAN with Choke, at 2 Mb/s

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) +-10 kV, Machine Model (MM) +-200 V and Charged Device model (CDM) +-750 V. In addition the physical layer is optimized to pass system level stress defined in ISO10605:2008 [3], IEC61000-4-2:2008 [4], HMM (Human Metal Model) [5].

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.

ESD Specification from System Level 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 25 kV), the SEED [7] 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) has been used. As an example the ESD performance of Freescale's CAN high speed physical layer is summarized in the table below.

ESD Performance Summary

Specification	ISO 10605 device unpowered	ISO 10605 device powered
Device performance	±8 kV	±8 kV
Specification	**IEC61004 device unpowered**	**CAN conformance**
Device performance	±8 kV	±8 kV

The combination of high ESD and DPI performance is a challenge of energy absorption without compromising CAN communication. As presented in the above table, the 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 an optimum die area. All of these innovations constitute the foundation of design for reliability of the physical layer integration inside more integrated devices (system basis chip (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 the 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's say some tens of km/h. These ECUs 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 such as MCUs or load drivers. Only a minimum set of ICs will remain active to monitor CAN bus traffic and detect specific CAN messages or part of a CAN message, that will indicate to these ECUs 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 500 uA) for the complete partial networking function inside a CAN physical layer, with minimum cost, which excludes usage of accurate oscillator components such as crystal or a resonator. As a reminder, a CAN controller inside MCUs 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.

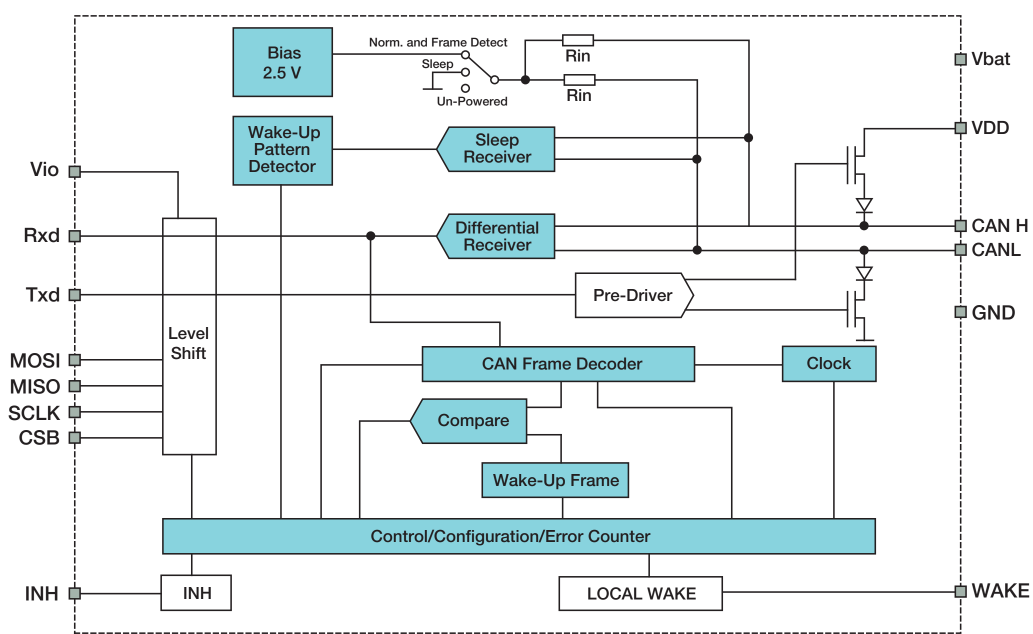
However, CAN message reception and decoding only require a clock in the “per cent” range. So the integration of CAN message is becoming achievable thanks to very innovative techniques and solutions that can be implemented inside mixed signal silicon technologies, used for CAN transceiver functions.

These solutions use high precision analog functions such as low power accurate oscillators, low current differential receivers, low power voltage references and biasing circuitry, and are combined with digital CAN message decoders, 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 present, 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 500 uA 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 ones operating during the partial networking operation which in total require less than 500 uA.

Block Diagram of a CAN Transceiver with Partial Networking Function



The table below summarizes the main technical constraints and impact of the CAN flexible data on future evolution of CAN transceivers.

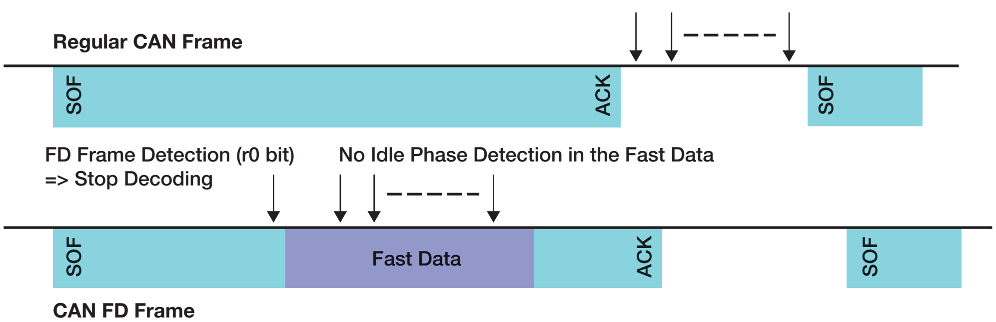
Technical Summary

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 **2 Mb/s operation.** Definition of EMC tests setup 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) Error management	**FD passive** evolutions of "frame decoding" and "error management" to ensure no error detected due CAN FD frame. Proper "end of frame" detection.

For normal operation, as described in ISO11898-2, the main impact is meeting the EMC specifications, which are not anticipated to be relaxed to accommodate CAN flexible data.

In partial networking operation, as described in ISO11898-6, the CAN flexible data frames should not disturb the CAN incoming message detection, and for such the CAN partial networking transceiver should be "flexible data passive". This is archived by proper detection of the CAN inter frame space and properly discriminated from the fast data section.

Comparison of Regular and Flexible Data 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.

Evolution of the market to reach higher baud rate has an influence on immunity and emission levels. These requirements are taken at the front end definition level in order to improve performance without compromising robustness.

This combination of high robustness, low quiescent current and performance under higher CAN flexible data baud rate requirements has been defined and implemented inside the Freescale MC33901 and MC34901 CAN physical layer stand alone devices. This new solution of Freescale CAN physical layers are offered in several options, addressing automotive (MC33901) and Industrial (MC34901) markets, with and without bus wake up options (W version or S version).

With respect to partial networking, the physical layer requires analog transceiver 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 the same level of EMC performance while reducing the power consumption of the physical layer.

References

[1] iCC (international CAN Conference), organised by CAN in Automation (more details on http://www.can-cia.org/index.php?id=1846)

[2] IEC62132-4 (Direct Power Injection method) and ISO11452-4 (Bulk Current Injection)

[3] 61000-4-2:2008 Electromagnetic compatibility (EMC) – Part 4-2: testing and measurement techniques – electrostatic discharge immunity test. Ed 2.0, 2008-12

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[5] ESD TR5.6-01-09 Human Metal Model (HMM), Working Group 5.6, Human Metal Model, ESD Association

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