Automotive Communication Network Trends

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Automotive Application Engineer
Gary Miller

Product Marketing Manager
  - 32-bit Automotive Body

Previous experience
  - Hardware
    - EMC engineer on McDonnell Douglas F-15
    - Analog and digital design for visual flight simulation
  - Software
    - Ford -> Visteon: PowerTrain software
    - 13+ years automotive experience
    - Low level drivers and operating systems
  - Two patents

BSEE from University of Michigan
Renesas Technology & Solution Portfolio

Microcontrollers
No.1 Market Share Worldwide

Advanced and Proven Technologies

System LSIs

Analog & Power

Extensive, High-quality Portfolio
Microcontroller and Microprocessor Line-up

2010

**1200 DMIPS, Superscalar**
- Automotive & Industrial, 65nm
- 600µA/MHz, 1.5µA standby

**500 DMIPS, Low Power**
- Automotive & Industrial, 90nm
- 600µA/MHz, 1.5µA standby

**165 DMIPS, FPU, DSC**
- Industrial, 90nm
- 500µA/MHz, 1.6µA deep standby

**25 DMIPS, Low Power**
- Industrial & Automotive, 150nm
- 190µA/MHz, 0.3µA standby

**10 DMIPS, Capacitive Touch**
- Industrial & Automotive, 130nm
- 350µA/MHz, 1µA standby

2012

**1200 DMIPS, Performance**
- Automotive, 40nm
- 500µA/MHz, 35µA deep standby

**165 DMIPS, FPU, DSC**
- Industrial, 40nm
- 200µA/MHz, 0.3µA deep standby

**44 DMIPS, True Low Power**
- Industrial & Automotive, 130nm
- 144µA/MHz, 0.2µA standby
‘Enabling The Smart Society’

Challenge:
“Automotive communication protocols are changing rapidly. The communication environment is growing quickly as users want access to more information available in-vehicle. Bandwidth requirements are dramatically increasing because of new functionality, more interaction between modules, and bandwidth-hungry signals such as video.”

Solution:
“This class will discuss the Automotive trends and how Renesas understands the requirements to meet future demands.”
Agenda

- Terminology & Concepts
- Automotive Networks – Today & Tomorrow
- Security in Automotive
- Energy Efficiency Trends
- Summary
Terminology & Concepts
Bus Access

- **Single Master – Multiple Slaves Configuration**
  - Master node controls bus access
    - Establishes timing
    - Initiates all communications
  - Slave node(s) react to the master node
    - Cannot initiate communications

- **Peer-to-Peer / Multi-Master**
  - Any node can initiate communications
  - Requires means to control access to the bus
    - Token Passing
    - Time Division Multiplexing (TDM)
      - Agreed, assigned time to transmit
    - “Arbitrated” Access
      - CSMA variants
Arbitrated Access: CSMA

- **CS** = **C**arrier **S**ense — Nodes wait for period without bus activity (IDLE time) before initiating communication

- **MA** = **M**ultiple **A**ccess — Every node has an opportunity to initiate communication

- **CSMA-CD** = CSMA with **C**ollision **D**etection
  - Stop communicating when collision is detected
    - Try again from the start
  - IEEE 802.3 Ethernet (Half-Duplex Operation)

- **CSMA-CA** = CSMA with **C**ollision **A**voidance
  - Divide channel *somewhat* equally among all nodes
  - IEEE 802.11 WiFi (not possible to listen while sending)

- **CSMA-CR** = CSMA with **C**ollision **R**esolution
  - Resolve collision situations as they happen
  - Highest priority message remains intact: sent without delay or retry
  - All lower priority messages must retry in next IDLE time
CSMA-CR: Non-Destructive Bitwise Arbitration

- Dominant Bus State:
  - Any node attempts to drive the bus to its dominant state
  - bus = dominant

- Recessive Bus State:
  - Bus assumes recessive state if **no** nodes are driving bus to dominant state

- Dominant “wins” over recessive

- Typical Implementation - CAN transceiver
  - Active (transistor) drive to dominant state
  - Passive (resistor) pull to recessive state

- Non-Destructive Bitwise Arbitration
  - Node stops transmitting when it loses arb
  - Loses arbitration: RX’d bit NOT EQUAL TX
  - Field in the message header defines message priority
Event Driven vs. Time Driven

- **Event Driven**
  - Medium used only when necessary
  - Point when medium is accessible depends on current load
    - Unknown delay between when medium access is requested and when it is actually accessed
  - Time of message arrival is unknown
  - Medium might be overloaded

- **Time Driven**
  - Point in time when medium is accessible is defined / guaranteed
  - Bandwidth utilization is known (duration of how long the medium is used)
  - Time of arrival is defined / guaranteed
  - Time Driven = Deterministic
    - Mostly used for safety critical programs
TDMA: Time Division Multiple Access

- Share the bus
  - Dividing into different time slots
  - Transmit in rapid succession each using its own time slot

- Wireless
  - Slots assigned on demand in dynamic TDMA
  - 2G cellular systems based on TDMA

- Wired consumer
  - HSLAN over existing home wiring
  - power lines, phone lines and coaxial cables

- Automotive
  - FlexRay
Physical Media: Signal Formats

- **Non Return to Zero (NRZ)**
  - Logical Bit value:
    - bus **state during** the bit time
  - “1” = a specific bus state (e.g. low voltage)
  - “0” = a different specific bus state (e.g. high voltage)
  - Cannot extract clock, not inherently self-synchronizing

- **Manchester**
  - Logical Bit value:
    - **direction of transition** in the middle of the bit time
  - At least one transition during each data bit
    - Self clocking – clock can be recovered
    - More bandwidth required, more EMI

- **Bi-phase (Differential Manchester)**
  - Logical Bit value:
    - **presence / absence of transition** in middle of bit time
  - At least one transition every bit
Physical Media: Bit Stuffing

- NRZ Signaling Problem
  - How to maintain synchronization when a long string of the same bit value is transmitted?

- Solution: Bit Stuffing
  - 1 inverse polarity bit added ("stuffed") after "n" identical bits
  - Forces a transition edge:
    - Synchronization
    - Escape reserved code words such as frame sync sequence

- Drawbacks
  - Results in variable data rate
  - Reduces bus efficiency
Topology

- **Ring**
  - Data travels around one direction
  - Each device acts as a repeater
  - Keeps the signal strong as it travels

- **Star**
  - Each network host is connected to a central hub
  - All traffic passes through the central hub
  - Hub acts as a signal repeater

- **Bus**
  - Each node is connected to a single cable
  - Data travels in both directions to all nodes
  - If node address does not match intended address for the data, node ignores data
Automotive Networks – Today & Tomorrow
Automotive Networks Today

Data Rate (bps)

0.5 1 2.5 5

Relative Communication Cost Per Node

Multiplexing

Distributed Control

Multi-Media

LIN
• Master-Slave
• Low cost I/O Interface

CAN
• Multi-Master/CSMA-CR
• Distributed Data

FlexRay
• Multi-Master/Hybrid-TDMA
• Fault Tolerant

MOST
• Timing Master/TDMA
• Designed for multimedia & infotainment

# LIN / CAN / FlexRay Comparison

<table>
<thead>
<tr>
<th>Feature</th>
<th>LIN</th>
<th>CAN</th>
<th>FlexRay</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Features</strong></td>
<td>Scalable, Deterministic, Slave Autobaud Detection (lower accuracy clock for slaves)</td>
<td>Scalable, Event-Driven</td>
<td>Time-Driven, Deterministic, Redundant, Fault-Tolerant, Global Time Base</td>
</tr>
<tr>
<td><strong>Medium Access Control</strong></td>
<td>Single Master</td>
<td>Multi-Master CSMA-CR</td>
<td>Multi-Master Hybrid TDMA</td>
</tr>
<tr>
<td><strong>Bit Coding</strong></td>
<td>NRZ</td>
<td>NRZ w/ bit stuffing</td>
<td>NRZ</td>
</tr>
<tr>
<td><strong>Nodes</strong></td>
<td>1 master, up to 15 slaves</td>
<td>4 – 20, depending on distance / topology</td>
<td>4 – 22, depending on distance / topology</td>
</tr>
<tr>
<td><strong>Topology</strong></td>
<td>Bus</td>
<td>Bus</td>
<td>Star or Bus</td>
</tr>
<tr>
<td><strong>Typical Bus Speed</strong></td>
<td>Low: up to 20Kbps</td>
<td>33Kbps to 500Kbps typical</td>
<td>2.5Mbps to 10Mbps</td>
</tr>
<tr>
<td><strong>Data &amp; Frame Size</strong></td>
<td>1 - 8 bytes payload 44 bits overhead</td>
<td>0 – 8 bytes payload 47 bits overhead (std ID) 67 bits overhead (ext ID)</td>
<td>0 – 254 bytes payload 64 bits overhead</td>
</tr>
<tr>
<td><strong>Bus Utilization Efficiency</strong></td>
<td>1 byte payload: 15% 8 byte payload: 52%</td>
<td>1 byte payload: 15% (std) 8 byte payload: 58% (std) 1 byte payload: 11% (ext) 8 byte payload: 49% (ext)</td>
<td>8 byte payload: 50% 254 byte payload: 97%</td>
</tr>
<tr>
<td><strong>Physical Media</strong></td>
<td>Single wire, 12V</td>
<td>Single or dual wire, 5V</td>
<td>Twisted pair, optical option</td>
</tr>
<tr>
<td><strong>MCU Support</strong></td>
<td>Standard UART or UART w/ extensions</td>
<td>CAN Peripheral</td>
<td>FlexRay Peripheral</td>
</tr>
<tr>
<td><strong>Applications</strong></td>
<td>Sensor / actuator interface to a master ECU (doors, mirrors, windows, motors, ...)</td>
<td>Sharing data between ECU’s</td>
<td>High speed data sharing, distributed control, safety critical systems</td>
</tr>
</tbody>
</table>
Drivers of Change...

- User’s access to more information in vehicle
- Bandwidth requirements increasing
  - New functionality
  - More interaction between modules
  - Bandwidth-hungry signals such as video
- Requirements for safety and security on the bus
  - More safety related functions and security being emphasized
- Control signals using messaging to a remote actuator
- Diagnostics improvements requires more information
- Driver assistance
  - Vehicle to vehicle
  - Vehicle to infrastructure
- Autosar software architecture, separation of functions from hardware implementation
Automotive Networks Tomorrow

CAN with Flexible Data Rate (CAN FD)

- Higher bit rate possible once arbitration completed
  - After arbitration, only one node is transmitting...

- CAN FD controllers backward compatible (CAN 2.0 A/B)

Indicates bits sent at faster bit rate

CAN FD can be recognized as a recessive bit is sent where r0 is expected to be dominant
CAN with Flexible Data Rate (CAN FD)

- **CAN FD Proposal**
  - Increase bit rate after arbitration completes
    - Target: 2Mbps
  - Increase the data payload
    - From 8 bytes to 64 bytes / frame

- **OEM vision**
  - CAN 2.0 A/B still used
  - CAN FD where bandwidth increase needed
    - Programming

- **Concerns**
  - Requires revised / new ISO standard
  - Impacts CAN Protocol Controller: new design required
  - All nodes must have a CAN FD protocol controller
    - Minimum of Passive mode

Higher bit rates appear possible, but require HW/SW changes (protocol controller)

Industry acceptance / standardization needed
Automotive Ethernet

- High data rates – 10Mbps to 10+Gbps
  - 100Mbps over unshielded single twisted pair cable
  - Full duplex communication capability
  - Options allow data rate (and cost) to match application requirements

- Leverage widely available consumer / office / industrial infrastructure to reduce cost of ownership
  - Open standardization
  - Existing & proven hardware IP
  - Inexpensive & flexible cabling options
  - Proven TPC/IP protocol stack

- Flexible configuration
  - Supports different topologies
  - Easily add nodes
  - Virtually no limit on number of nodes

- Delivery not guaranteed
  - But if it is fast enough....
  - AVB Extension

- Interoperability with external networks
  - Easily connects to Internet and Cloud

Issue: Impact on cost-of-ownership by including stringent automotive requirements – reliability in extreme conditions (temperature, voltage…), EMC/EME, …
Ethernet AVB

- AVB (Audio Video Bridging) is developed for synchronized low latency A/V streaming transmission
  - Time critical data (e.g. multimedia) and non-time-critical data carried over same Ethernet network
  - Established common clock source among nodes

- Standards included in AVB
  - 802.1AS Timing and Synchronization
  - 802.1Qat Stream Reservation Protocol
  - 802.1Qav Forwarding and Queuing for Time-Sensitive Streams
  - 802.1BA Audio Video Bridging Systems
Future Network Electrical Architectures

- Ethernet / FlexRay / CAN
- Ethernet / MOST
- CAN

Vehicle Gateway

Diagnostic Connection
Future Network Electrical Architectures

Backbone (FlexRay / Ethernet)

- Powertrain / Chassis Gateway
  - Ethernet / FlexRay / CAN
    - Engine Control
    - Chassis Electronics
    - Steer-by-Wire
    - Brake-by-Wire

- Driver Information Gateway
  - Ethernet / MOST
    - Dashboard
    - Infotainment
    - Navigation
    - Headup Display

- Body Gateway
  - CAN
    - Comfort Electronics
    - Climate Control
    - Door Module
    - Roof Module
    - Lighting

Diagnostic Connection

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Security in Automotive
Security: *one of many* Automotive applications

Safety-relevant messages...

... must be secured! (so that they can be trusted)
Security-enabled Automotive MCU

Master in the system: has unrestricted accesses to all MCU resources

New master in the system: controls a (small) set of specific but exclusive resources for security relevant tasks
Potential use Case: Encrypted CAN Messages

Application Domain

1. Main application loop
2. Process the message received
3. Prepare a message to send

Execution time

Secure Domain

1. Wait for a CAN message
2. Decrypt the mailbox
3. Encrypt the mailbox
4. Send the CAN message

Secret keys are never seen in the application domain
Potential use Case: Boot Loader Verification

Application Domain

- Initiate the application environment
- Initiate the communication stack
- Main application loop

Secure Domain

- Calculate H as the hash value of the boot loader memory
- Calculate H’ as the verification of the boot loader signature (prev. stored)

Flow:

- H’ == H?
  - Yes: Boot loader verification successful: prepare for next security service
  - No: Boot loader verification failed: break the application loop

Execution time

HW Reset

Enables systematic background check with no impact on application domain timings
Security in Automotive applications: Renesas’ value proposition

The next generation of Renesas Automotive devices integrates a scalable range of security peripherals to support existing and emerging security requirements on a broad range of automotive applications.

Security Peripherals for MCU with embedded Flash
- ICU-S
- ICU-M2
- ICU-M3

Security Peripherals for Flash-less SoC
- Crypto Engine

Renesas RH850
(low- to mid-end)
Low power
Low cost

Renesas RH850
(mid- to high-end)
Flexibility and performances

Renesas R-Car SoC
High-performance (stream ciphers)
Energy Efficiency Trends
Energy Efficient Automotive Networks

- Not all ECUs need to be used during the entire drive-cycle
  - Trade-off between:
    - Energy savings
    - ECU start-up time
  - Selectively set ECU’s into lower-power states
    - Pretended Networking
    - Partial Networking
Pretended Networking

- Local Power Saving Intelligence
  - Each ECU independently decides when to enter / exit a lower power mode
  - MCU in sleep / stop mode - can be woken up quickly

- No changes to Network Management layer
  - Compatible with other nodes not supporting this feature
  - Easy integration into existing networks

- Uses existing / standard transceivers

- Efficiently implemented in software using Renesas low power products
  - e.g. RH850/X1x

Varying power saving effect, but seamless compatibility with existing networks
Partial Networking

- Shutting-down & starting-up during normal bus communication
  - ECU’s or groups of ECU’s
  - Shuts down complete ECU (except transceiver)
    - MCU not powered
    - Increases wake-up time
  - Network master node(s) coordinate power saving intelligence
  - Changes Network Management Layer
    - Accommodate Partial Network Cluster (PNC)

- Requires special / new transceivers
  - “Selective Wake Up” transceivers

- ISO 11898-6
  - ISO 11898-5 had global wakeup
  - ISO 11898-6 has wakeup pattern or frame

Potentially large power saving effect, but at expense of changes to the network
Summary
Summary

- Automotive communication
  - Terminology & Concepts
  - What is used today

- Trends for tomorrow
  - Protocol changes
  - Security
  - Energy efficiency

- Renesas is ready “Enabling the Smart Society”
Questions?
‘Enabling The Smart Society’

- **Challenge:**
  “Automotive communication protocols are changing rapidly. The communication environment is growing quickly as users want access to more information available in-vehicle. Bandwidth requirements are dramatically increasing because of new functionality, more interaction between modules, and bandwidth-hungry signals such as video.”

- **Solution:**
  “This class will discuss the Automotive trends and how Renesas understands the requirements to meet future demands.”

- **Do you agree that we accomplished the above statement?**
Please Provide Your Feedback...

- Please utilize the ‘Guidebook’ application to leave feedback

or

- Ask me for the paper feedback form for you to use...