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## Communication systems for vehicle electronics

### Presentation overview

- ❑ **Background**  
automotive electronics as an application area for real-time communication
- ❑ **Real time protocols**
  - LIN – Local Interconnection Network*
  - CAN – Controller Area Network*
  - TTCCAN, - Time Triggered CAN (based on “Controller Area Network”) (CAN)*
  - CAN FD – CAN with Flexible Data-rate*
  - FlexRay, based on BMW’ s “ByteFlight”*
- ❑ **Hybrid scheduling**  
combining static scheduling with fixed priority scheduling analysis



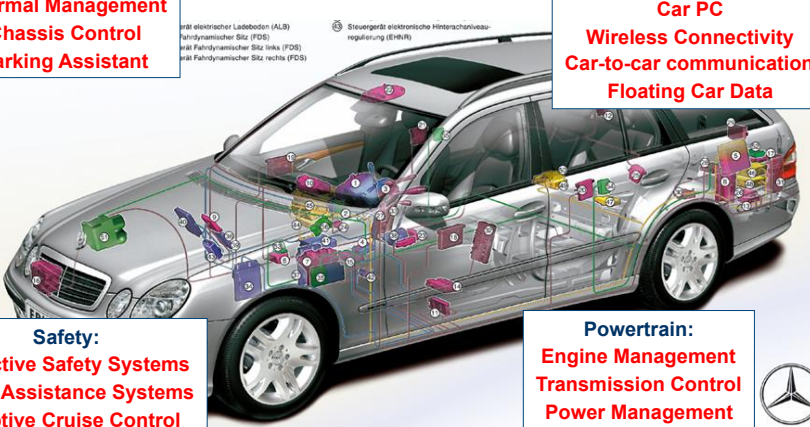
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## A premium passenger car is controlled and managed by 80+ Embedded Systems


**Comfort Electronics:**  
**Thermal Management**  
**Chassis Control**  
**Parking Assistant**

**Infotainment:**  
**Telematics Solutions**  
**Car PC**  
**Wireless Connectivity**  
**Car-to-car communication**  
**Floating Car Data**



**Safety:**  
**Predictive Safety Systems**  
**Driver Assistance Systems**  
**Adaptive Cruise Control**  
**Electric Power Steering**

**Powertrain:**  
**Engine Management**  
**Transmission Control**  
**Power Management**

  
 Courtesy of Daimler, Bosch

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### Virtual differentiation between variants

- All variants of a specific model are physically identical and differ only in their individual software configuration
- The various included physical components can be activated or deactivated by the software

**Variant 1**  
Motor configuration A  
Entertainment configuration A

**Variant 2**  
Motor configuration B  
Entertainment configuration F

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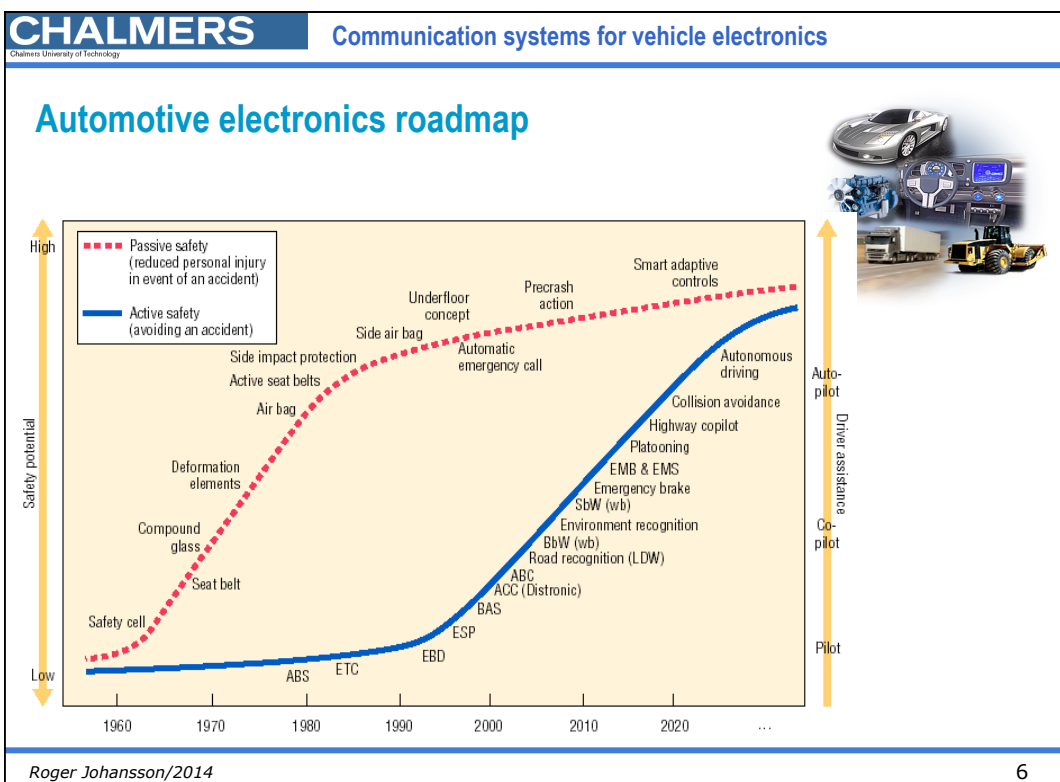
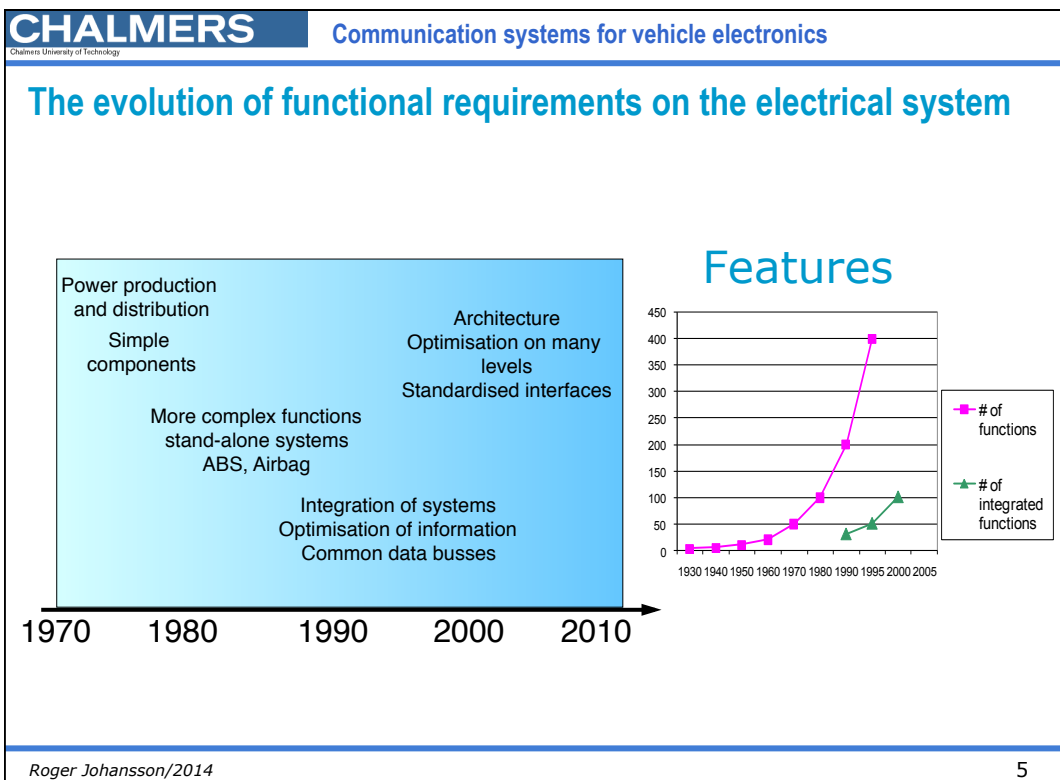
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### Example of the electrical system complexity 1927-1997

Year	No. of fuses	No. of meters of electric wires
1927	4	30
1944	5	50
1956	7	83
1966	9	183
1975	16	283
1982	27	575
1997	54	1200

Wiring diagram, Volvo ÖV4 ("Jacob") 1927

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### Multiplex Networks

Conventional system

Control units

Network

Module

Identifier Data Command Control

rpm

Engine Control

Automatic Transmission

Driver Information

Central Module

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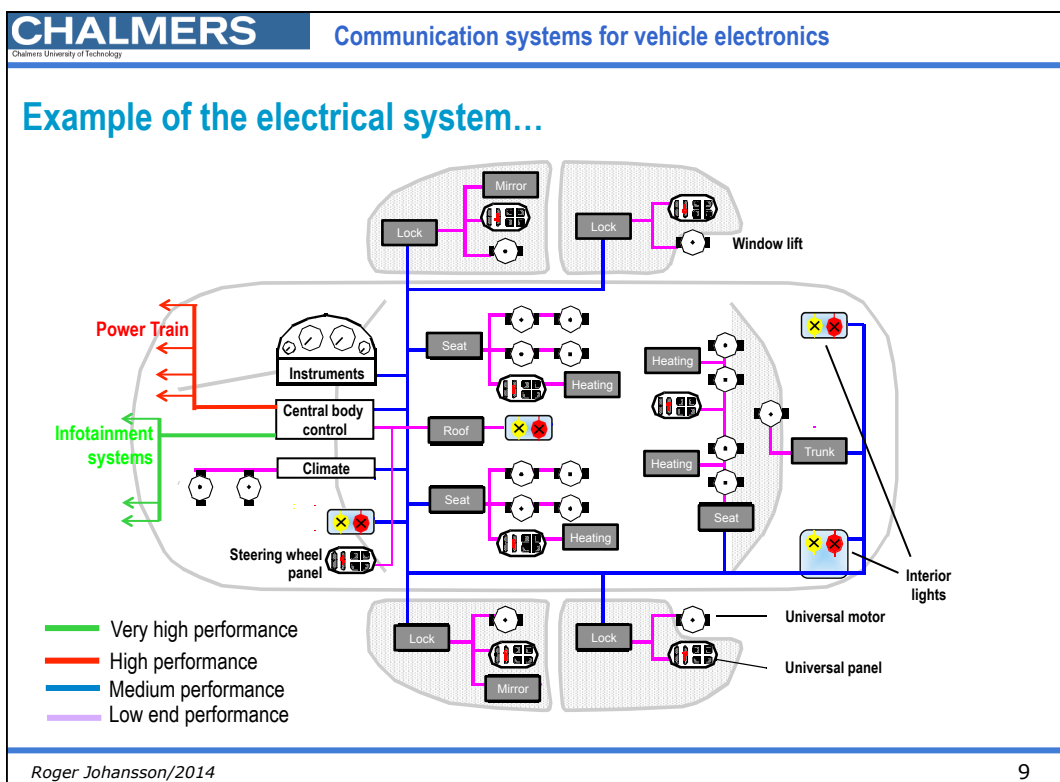
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### Evolution of protocols

1985 1990 1995 2000 2005 2010

VAN J1850 CAN CAN 2.0 LIN TTP/C TTCAN MOST Byteflight FlexRay CAN FD


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### The LIN protocol, started in 1998

LIN Local Interconnection network  
predecessor: VOLCANO Lite



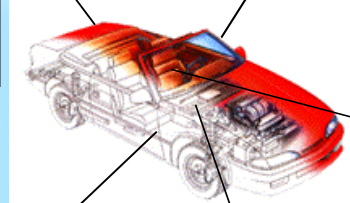
Cooperation between partners:  
Freescale, VOLVO CAR, BMW, AUDI, Volkswagen, Daimler-Chrysler  
Mentor Graphics (former: Volcano Communication Technology)

Objectives:  
Low cost, modest performance and safety requirements, flexible system architecture

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## LIN target applications



**Roof:**  
(high amount of wiring)  
Rain Sensor, Light Sensor,  
Light Control, Sun Roof ...  
(Rain Sensor needs to be  
interrogated every 10-20ms)

**Steering Wheel:**  
(very many controls are going to be  
positioned on the steering wheel)  
Cruise Control, Wiper,  
Turning Light, ...  
Optional: Climate Control, Radio,  
Telephone, etc.

**Seat:**  
many Seat Position Motors,  
Occupancy Sensor,  
Control Panel

**Door/window/seat:**  
Mirror, Central ECU,  
Mirror, Switch, Window  
Lift,  
Seat Control Switch,  
Door Lock, etc.

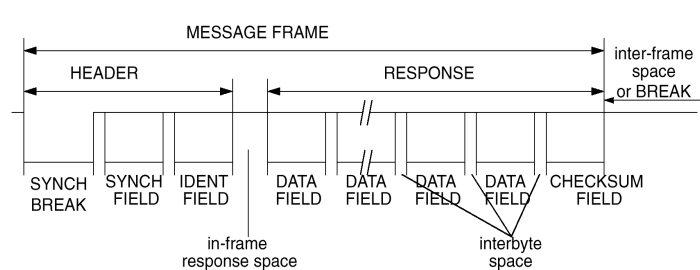
**Climate:**  
many Small Motors  
Control Panel

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## LIN protocol features

- Bus topology
- Master-slave protocol, no arbitration required
- UART protocol, 10 bits (uses "sync break" facility)
- 8 bits of data in a block
- 2-8 blocks of data per frame
- Single wire
- Maximum 20 kbits/s



MESSAGE FRAME

HEADER RESPONSE

inter-frame space or BREAK

SYNCH BREAK SYNCH FIELD IDENT FIELD DATA FIELD DATA FIELD DATA FIELD DATA FIELD CHECKSUM FIELD

in-frame response space interbyte space

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## LIN bus communication

The diagram illustrates the LIN bus communication protocol. At the top, a master control unit is shown with a 'polling' arrow pointing to a 'slave control unit' and another 'slave control unit'. The master control unit contains a 'master task' (red box) and a 'slave task' (green box). The slave control units also contain 'slave task' (green boxes). Below this, a waveform shows the signal structure over time. The waveform is divided into several fields: 'inter-frame spacing', 'synch', 'Identifier field', 'next synch field', '2 byte data', and '1 byte block parity'. The 'Master task' is shown as a red waveform, and the 'Slave Task' is shown as a blue waveform. The 'Slave Task' response includes 'Response spacing', '2 byte data', and '1 byte block parity'.

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## CAN – Controller Area Network

- Bus topology
- CSMA/CR (Carrier sense, Multiple Access/ Collision Resolution)
- Error detection capabilities
- Supports "atomic broadcast"
- 0-64 bytes of data per frame
- Twisted pair
- Maximum 1 Mbit/s

<b>ARB</b>	Arbitration (identifier)
<b>CTRL</b>	Control information
<b>DATA</b>	0-8 bytes
<b>CRC</b>	Checksum
<b>ACK</b>	Acknowledge
<b>EOF</b>	End of frame

← MESSAGE FRAME →

SOF	ARB	CTRL	DATA	CRC	ACK	EOF
-----	-----	------	------	-----	-----	-----

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### Bus collision detection

Idle bus (recessive level)

Bus transceivers  
 "Open collector"  
 Bus level:  
 Recessive (bit) "1"  
 Dominant (bit) "0"

+5V  
R

Bus level

Node A      Node B

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### Bus arbitration

Two nodes transmitting same level (1)

transmit 1  
receive 1

transmit 1  
receive 1

+5V  
R

Bus level

Node A      Node B

$I_R = 0$

$I_A = 0$        $I_B = 0$

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### Collision Resolution

transmit 0  
receive 0

transmit 1  
receive 0

+5V  
R  
 $I_R = I_A$

Bus level: 0V

Node A

Node B

0 1

$I_A$

1 0

$I_B = 0$

Node B aborts transmission since the received bit differs from the transmitted bit

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### Three messages collide...

Arbitration field (identifier with priority)  
 Nodes "own" specific message identifiers.

**EXAMPLE: Three nodes start simultaneously**

Node A transmits: \$257 (0010 0101 0111)  
 Node B transmits: \$360 (0011 0110 0000)  
 Node C transmits: \$25F (0010 0101 1111)

Bit number	SOF	1	2	3	4	5	6	7	8	9	10	11	12	13
Bus level	D	D	D	R	D	D	R	D	R	D	R	R	R	R
Node A			0	0	0	1	0	0	1	0	1	0	1	1
Node B	0	0	0	1	1	Aborts								
Node C	0	0	0	1	0	0	1	0	1	1	Aborts			

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### Standard/Extended CAN drawback....

- Protocol bus arbitration, acknowledge and error handling slow down bitrate ( maximum 1 Mbit/s)
- Solution: New CAN FD specification

### CAN Flexible Data-rate

Arbitration Field	Control Field	Data Field	CRC Field	Ack	EOF	Int.	Idle
SOF	IDE	RSL	4 bit DLC	1 1	7	3	
11 bit Identifier	1	0- 16* bytes	17* bit CRC				

Arbitration Field	Control Field	Data Field	CRC Field	Ack	EOF	Int.	Idle
SOF	IDE	RSL	4 bit DLC	1 1	7	3	
11 bit Base Identifier	18 bit Identifier Extension	0- 16* bytes	17* bit CRC				

CAN FD Arbitration Phase      CAN FD Data Phase      CAN FD Arbitration Phase

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### By-wire control

Hydraulic information carrier

Electronic information carrier

**Fly-By-Wire Controls**

The F-8 Digital Fly-By-Wire (DFBW) flight research project validated the principal concepts of all-electric flight control systems now used on nearly all modern high-performance aircraft and on military and civilian transports. The first flight of the 13-year project was on May 25, 1972.

Courtesy of Dryden Flight Research Center

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## Control system implementation strategies

**Local control**

- Local information processing
- Independent control objects

**Centralized global control**

- Local and central information processing
- Interconnected control objects

**Distributed global control**

- Local and distributed information processing
- Interconnected control objects

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## Non-functional requirements

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## Tradeoffs from Safety/Reliability requirements

The extremes from reliability requirements leads to safety requirements.

Safety requirements implies redundancy, (Fail-Operational, Fail-Safe, etc).

Safety requirements also demands predictability, we has to show, a priori, that the system will fulfill it's mission in every surrounding at every time.

**In a distributed environment, only time triggered protocols with redundant buses can provide this safety. Contemporary TTP's are:**

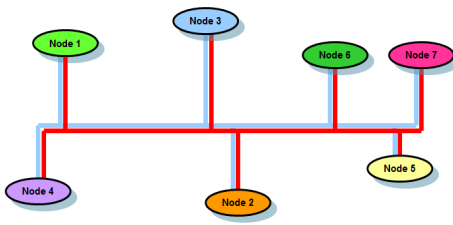
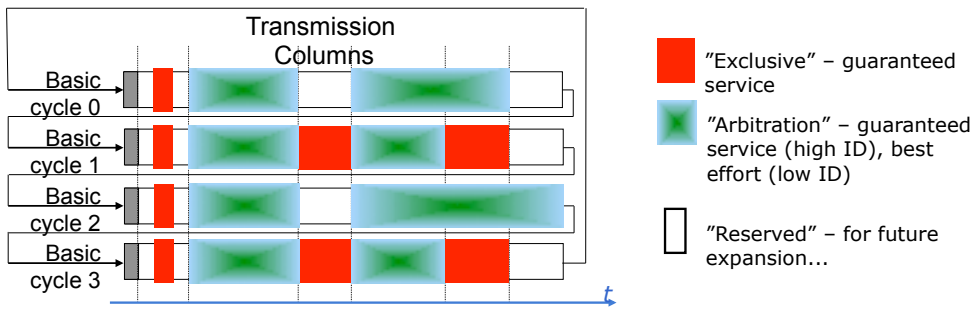
- TTCAN**, based on *Controller Area Network* (CAN) which is widely used in today's vehicular electronic systems.
- FlexRay**, based on BMW's "ByteFlight". Operational in contemporary automotive electronic systems.
- Time Triggered Ethernet**. TTEthernet expands classical Ethernet with services to meet time-critical, deterministic or safety-relevant conditions.

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## Time Triggered CAN

- Based on the CAN protocol
- Bus topology
- Media: twisted pair
- 1Mbit/s

Time is global and measured in *network time units* (NTU's)

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### Flexray

- Double channels, bus or star (even mixed).
- Media: twisted pair, fibre
- 10 Mbit/s for each channel

Redundant channel can be used for an alternative schedule

- "Static segment" (TTCAN "Exclusive") – guaranteed service
- "Dynamic segment" (TTCAN "Arbitration") – guaranteed service (high ID), "best effort" (low ID)

Max 64 nodes on a Flexray network.

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### Time Triggered Ethernet

- Classic Ethernet bus topology
- 1 Gbit for each channel

Compare with TTCAN "basic cycles"

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## Comparisons

All protocols targets real time applications.  
Provides for *time* AND *event* triggered paradigms.

All protocols are suitable for scheduling tools.  
Commercial production tools are available.

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CAN, many years experiences, a lot of existing applications.  
Implies migration of existing CAN applications into TTCAN and CAN FD.

Flexray is the automotive industries initiative.  
New hardware, promoted in for example "AUTOSAR".

TTEthernet.  
Proven technology with lots of existing hardware,

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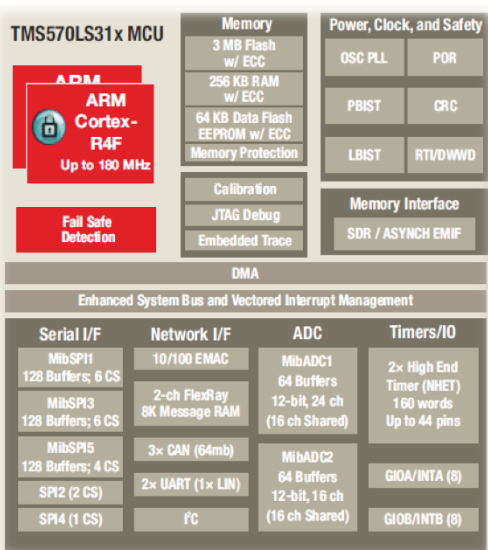
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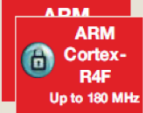

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## What to choose?



**TMS570LS31x MCU**

 <b>ARM Cortex-R4F</b> Up to 180 MHz	<b>Memory</b>		<b>Power, Clock, and Safety</b>	
	3 MB Flash w/ ECC		OSC PLL	POR
	256 KB RAM w/ ECC		PBIST	CRC
	64 KB Data Flash EEPROM w/ ECC Memory Protection		LBIST	RTI/DWWD
 <b>Fail Safe Detection</b>	Calibration		<b>Memory Interface</b>	
	JTAG Debug Embedded Trace		SDR / ASYNCH EMIF	
DMA				
Enhanced System Bus and Vectored Interrupt Management				
<b>Serial I/F</b>	<b>Network I/F</b>	<b>ADC</b>	<b>Timers/I/O</b>	
MibSPI1 128 Buffers; 6 CS	10/100 EMAC	MibADC1 64 Buffers 12-bit, 24 ch (16 ch Shared)	2x High End Timer (MHET) 160 words Up to 44 pins	
MibSPI3 128 Buffers; 6 CS	2-ch FlexRay 8K Message RAM	MibADC2 64 Buffers 12-bit, 16 ch (16 ch Shared)	GPIO/INTA (8)	
MibSPI5 128 Buffers; 4 CS	3x CAN (64mb)		GPIO/INTB (8)	
SPI2 (2 CS)	2x UART (1x LIN)			
SPI4 (1 CS)	FC			



**Hercules™  
MCU**  
TEXAS INSTRUMENTS

### Key features

- ARM Cortex-R4F core floating-point support
- Up to 180 MHz
- Lockstep safety features built-in simplify SIL-3/ASIL D applications
- Up to 3-MB Flash/256-KB RAM with ECC
- Memory protection units in CPU and DMA
- Multiple communication peripherals:
  - Ethernet, FlexRay, CAN, LIN, SPI
- Flexible timer module with up to 44 channels
- 12-bit analog/digital converter
- External memory interface

**Targeted transportation applications**


- Braking systems (ABS and ESC)
- Electric power steering (EPS)
- HEV/EV inverter systems
- Aerospace
- Railway control, communications and signaling
- Off-road vehicles

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## Combining time triggering with events: Example of Hybrid scheduling for TTCAN

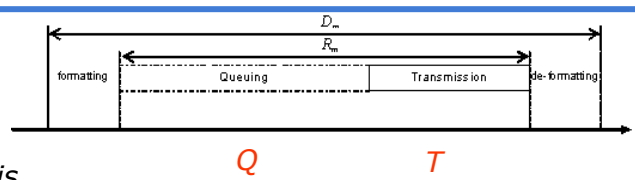


- **Hard real-time**, for minimal jitter with guaranteed response time.
- **Firm real-time**, for guaranteed response time, but can tolerate jitter.
- **Soft real-time**, for "best effort" messages.

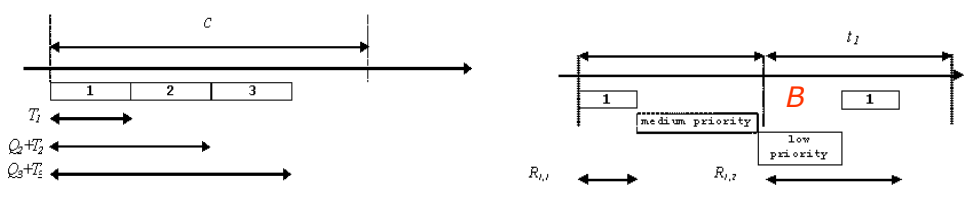
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## TTCAN detailed study



*Response time analysis*



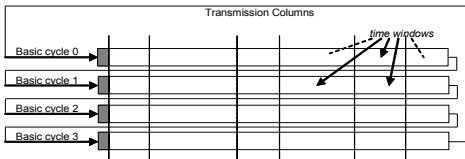
$$Q_i = \sum_{\forall R_j < R_i} \left\lceil \frac{Q_j}{t_j} \right\rceil T_j$$

$$R_i = B_i + T_i + Q_i$$

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## Time triggered messages $M^h$



After structuring:  
 $\mathbf{M} : \{M^h, M^r, M^s\}$ , assume that at least  $M^h$  is defined. We now construct a matrix cycle. Due to protocol constraints, the schedule has to fulfil:

$$\text{LCM}(M_p^h) = x 2^n$$

where:

- LCM is *least common multiple* period for the  $M^h$  message set;
- $x$  is the preferred length of a basic cycle within LCM;
- $n$  is the number of *basic cycles*.

Hardware constraints:

Hwc1:  $1 \leq x \leq 2^y$ , has to be consistent with a hardware register,  $y$  bits  
 Hwc2:  $0 \leq n \leq k$ , always a power of 2, constraint in hardware.  
 Hwc3: # of triggers  $\leq Tr$ , columns in the matrix cycle. Limited by the number of available trigger registers.

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## Multiple solutions satisfies the equation...

Choose a strategy:

**Strategy 1:**  
 Minimize number of *basic cycles*, requires a longer *basic cycle*, and more *triggers*.

**Strategy 2:**  
 Minimize length of *basic cycles*, increase probability of finding a feasible schedule for large message

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## Persuading the strategies...

Construct a schedule for the following set:

$M^h = (M1, M2, M3)$  with the following attributes (NTU):

$M1_p = 1000, M1_e = 168$   
 $M2_p = 2000, M2_e = 184$   
 $M3_p = 3000, M3_e = 216$

It's obvious that:  
 $LCM(M1, M2, M3) = 6000.$   
 and:  
 $6000 = x \cdot 2^n$

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## Strategy 1

Minimizing number of basic cycles yields:  $2^n = 1$ , so  $n = 0$  and  $x = 6000$ .  
 Hwc1 and Hwc2 are fulfilled.  
 Total numbers of *triggers* for  $N$  messages in one *basic cycle* is:

$$\sum_{i=1}^N \frac{LCM(M)}{M^i}$$

in this case:

$$\# \text{ of triggers} = \frac{6000}{1000} + \frac{6000}{2000} + \frac{6000}{3000} = 11$$

So, strategy 1, leads to a solution with:

- 1 *basic cycle* and 11 triggers.
- MATrix cycle length is 6000 NTU.

0	168	352	1000		2000	2168		3000	3352	4000	4168		5000	
$M_1$	$M_2$	$M_3$	$M_1$		$M_1$	$M_2$		$M_1$	$M_3$	$M_1$	$M_2$		$M_1$	

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### Strategy 2

$n = 0:$   
 $6000 = x 2^0 \quad \boxed{x} = 6000$   
(same as strategy 1)

$n = 1:$   
 $6000 = x 2^1 \quad \boxed{x} = 3000$

$n = 2:$   
 $6000 = x 2^2 \quad \boxed{x} = 1500$

$n = 3:$   
 $6000 = x 2^3 \quad \boxed{x} = 750$

$n = 4:$   
 $6000 = x 2^4 \quad \boxed{x} = 375$

$n = 5:$   
 $6000 = x 2^5 \quad \boxed{x} = 187.5$

Basic cycle	1 (at 0)	2 (at 375)	3 (at 750)	4 (at 1125)	5 (at 1500)	6 (at 1875)	7 (at 2250)	8 (at 2625)	9 (at 3000)	10 (at 3375)	11 (at 3750)	12 (at 4125)	13 (at 4500)	14 (at 4875)	15 (at 5250)	16 (at 5625)	Trigger Information	
1	0	168	352															
2						1000												
3																		
4																		
5																		
6																		
7																		
8																		
9																		
10																		
11																		
12																		
13																		
14																		
15																		
16																		
		$M_1$	$M_2$	$M_3$														3
1																		0
3										$M_1$								1
4																		0
5																		0
6																		2
7																		0
8																		0
9																		2
10																		0
11																		1
12																		2
13																		0
14																		35
15																		0
16																		0

Minimum Triggers

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### Strategy 2

Avoid this conflict with the requirement that:  
*a basic cycle shall be at least as long as the shortest period in the message set.*

Applying this restriction we get:  
 $n = 2, (x = 1500)$   
which yields a feasible schedule:

Basic cycle	1 (at 0)	2 (at 375)	3 (at 750)	4 (at 1125)	5 (at 1500)	6 (at 1875)	7 (at 2250)	8 (at 2625)	9 (at 3000)	10 (at 3375)	11 (at 3750)	12 (at 4125)	13 (at 4500)	14 (at 4875)	15 (at 5250)	16 (at 5625)	Trigger Information	
1	0	168	352															
2																		
3																		
4																		
1		$M_1$	$M_2$	$M_3$														4
2																		2
3																		4
4																		1

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## Verifying the events... ( $M^f$ )

Basic Cycle	Grey slots are supposed to be allocated for $M^h$						
	NTU-slots (Columns)						
1		q <sub>0</sub>					
2		q <sub>1</sub>				q <sub>2</sub>	
3		q <sub>3</sub>		q <sub>4</sub>			q <sub>5</sub>
...		...				...	...
$2^h$		q <sub>N-3</sub>				q <sub>N-2</sub>	q <sub>N-1</sub>

```

for each message m in Mf:
  for message m = 1 up to last_m
    for virtual message VMi = 1 up to last_VM
      if ( Qm + Tm ) falls within ( VMi,start , VMi,completion )
        Qm = VMi,completion
      else
        Qm = ∑∇j:Pm<Pj ⌈  $\frac{Q_m}{t_j}$  ⌉ Tj
      endif
    end
  end
end
end
end

```

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Thank you for your attention.

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