NMEA2000 relation to CAN and how Warwick Control can help

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Warwick Control

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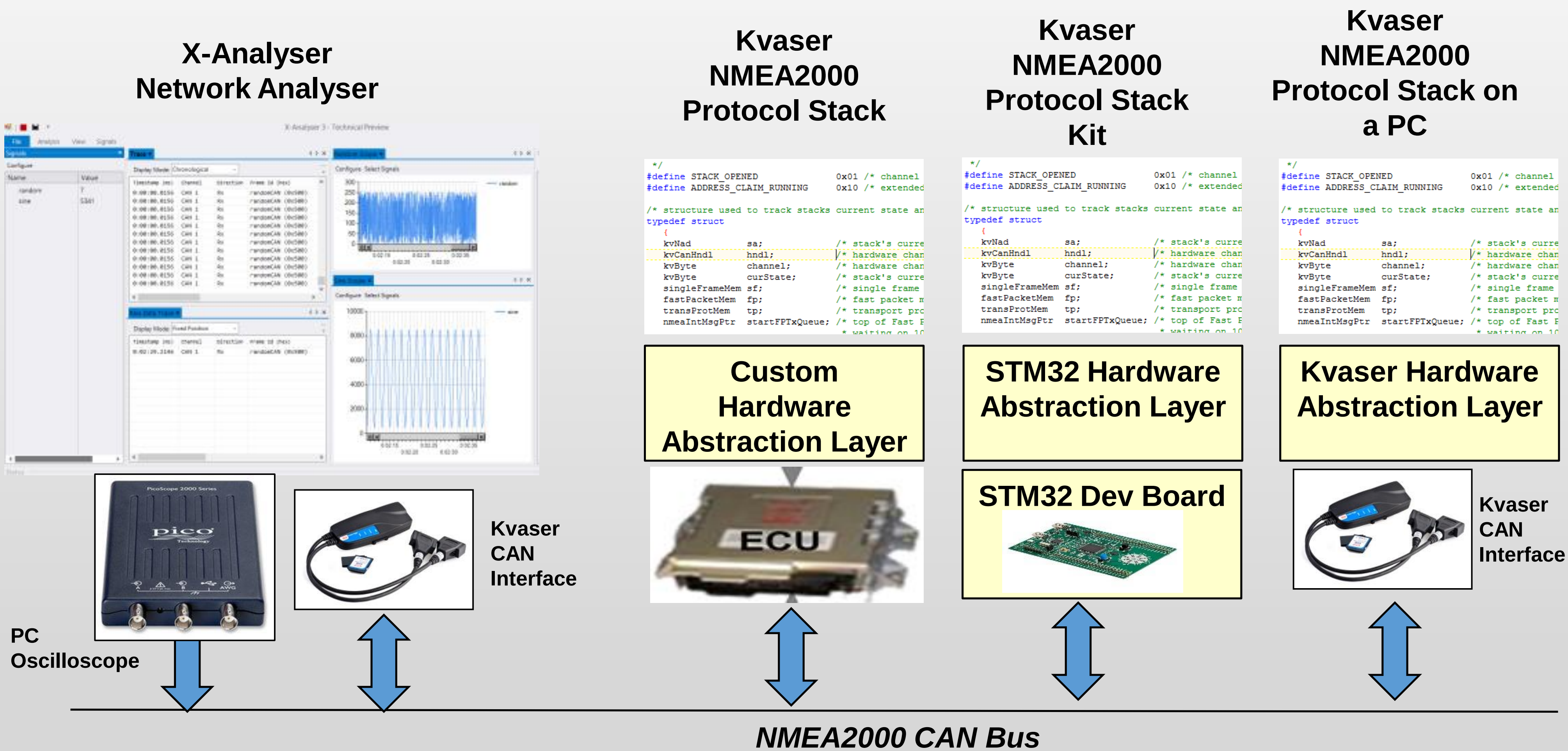
Company Profile

- Originally launched from the University of Warwick **CAN** group in 1999
  - CAN/control system research group – commencing 1991 included research in Automotive networks and Industrial Controls networks
  - Management buyout 2010 – company fully independent
- Target Technologies : Products and Services In:-
  - CAN Bus (inc. CANopen, J1939, **NMEA2000**), CAN-FD in vehicular and automation systems
  - Local Interconnect Network (LIN)
  - FlexRay for automotive and high integrity real-time systems
  - Ethernet
- Provider of products, solutions, consultancy and training
- Based in Warwick, UK
- Distributors worldwide for X-Analyser CAN/LIN analysis tool and J1939 & NMEA Software Stacks

Warwick Control NMEA2000/CAN Products



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Agenda for CAN/NMEA2000

Aim: How CAN relates to NMEA2000 and how shown in X-Analyser

- Brief history of CAN
- Applications of CAN
- Technical review of CAN and NMEA2000 based on 3 Layer Model
  - Physical Layer
  - Data Link Layer
  - Application Layer
- Utilising X-Analyser for detailed analysis of the 3 Layers
  - Physical Layer – Troubleshooting a broken data bus
  - Data Link Layer – Viewing CAN message IDs and Data fields
  - Application Layer – Verifying real values of CAN data

The Rolling Computer System

With the major growth of electronics in cars, there is a need for

In-Vehicle Computer Networks

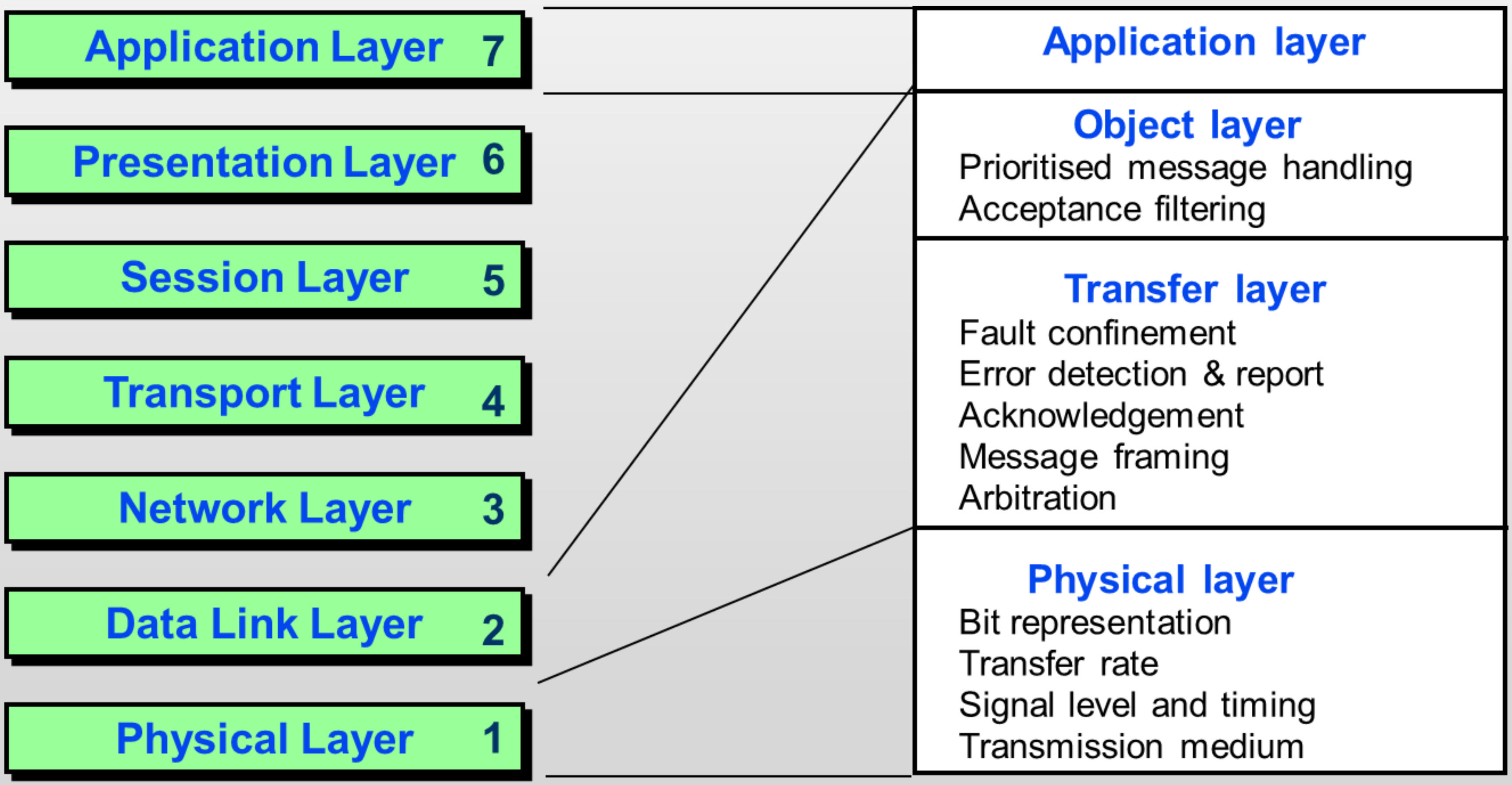
CAN – Controller Area Network

- Developed by Bosch in Europe at request of BMW and Mercedes
  - First definition in 1984
  - First Silicon in 1987
  - First use in car (S-Class Merc, BMW 8) in 1992
  - ISO 11898 in 1994
- Internal automobile communications
  - Reduce wiring bundles
  - Connect distributed controllers
- Robust
  - Tested against EMC
  - Powerful Error Detection/Confinement
- Penetrated in Industrial region
  - Low Cost
  - Other similar requirements as in automobile

CAN Applications

- Automotive Systems
- Truck and Bus (SAE J1939)
- Factory Automation (CANopen/ DeviceNet)
- Marine Electronics (e.g. NMEA 2000)
- Agricultural Equipment
- Construction Machinery
- Automation/Robotics
- Medical Systems
- Building Controls

Simple 3-layer CAN Model compared to the standard Computer Networks ISO-OSI 7-layer Model

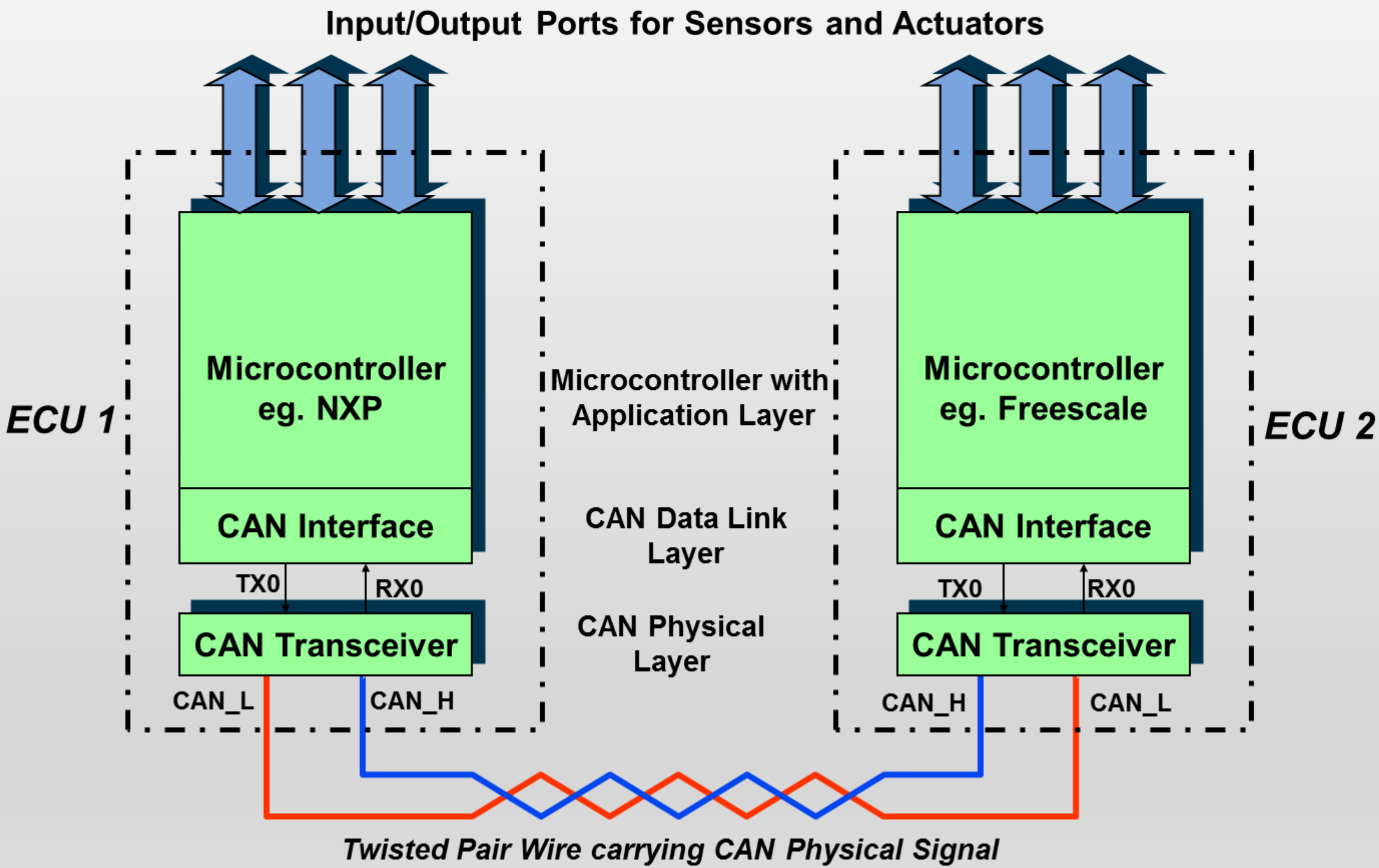


ISO-OSI 7 layer model

CAN layered architecture
ISO-11898

OSI = Open Systems Interconnection

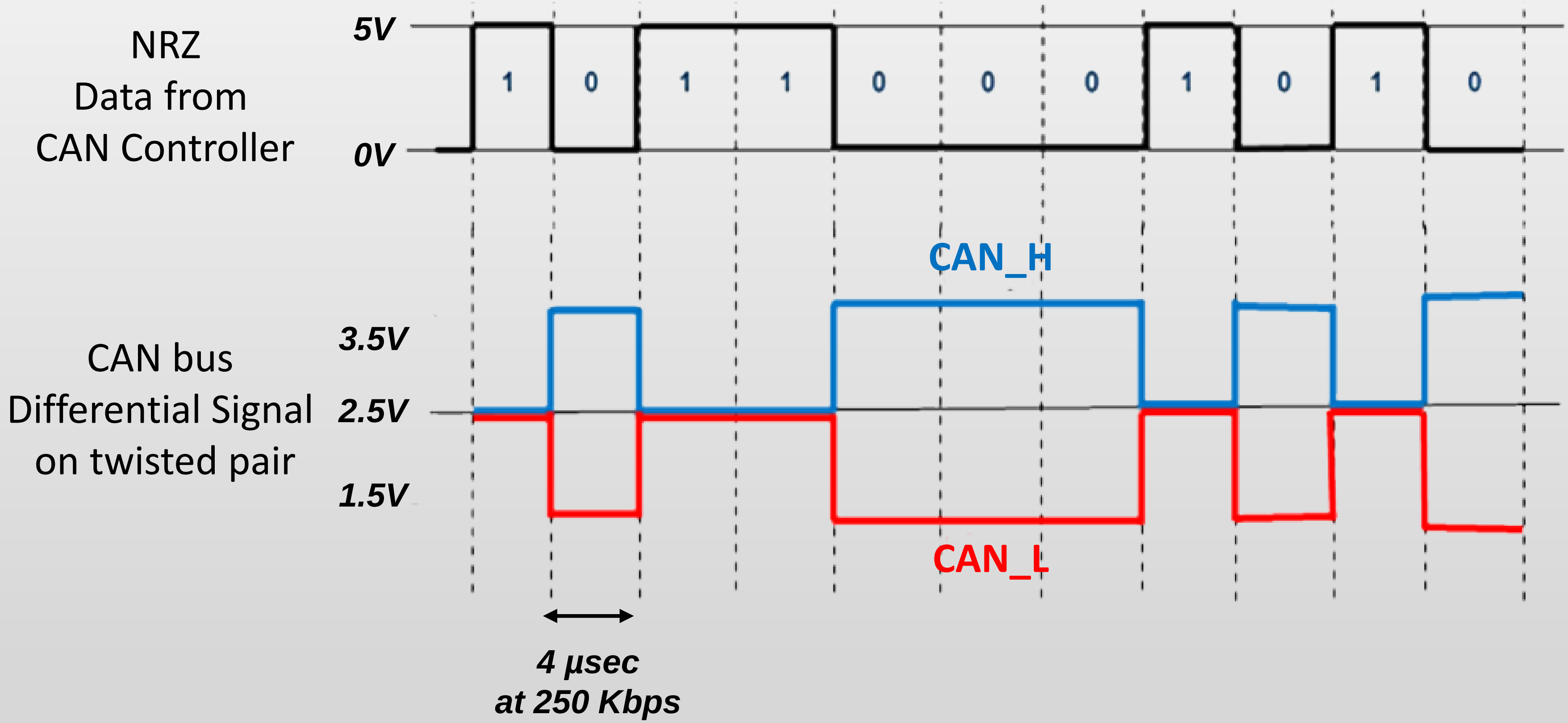
Typical CAN ECU Configuration



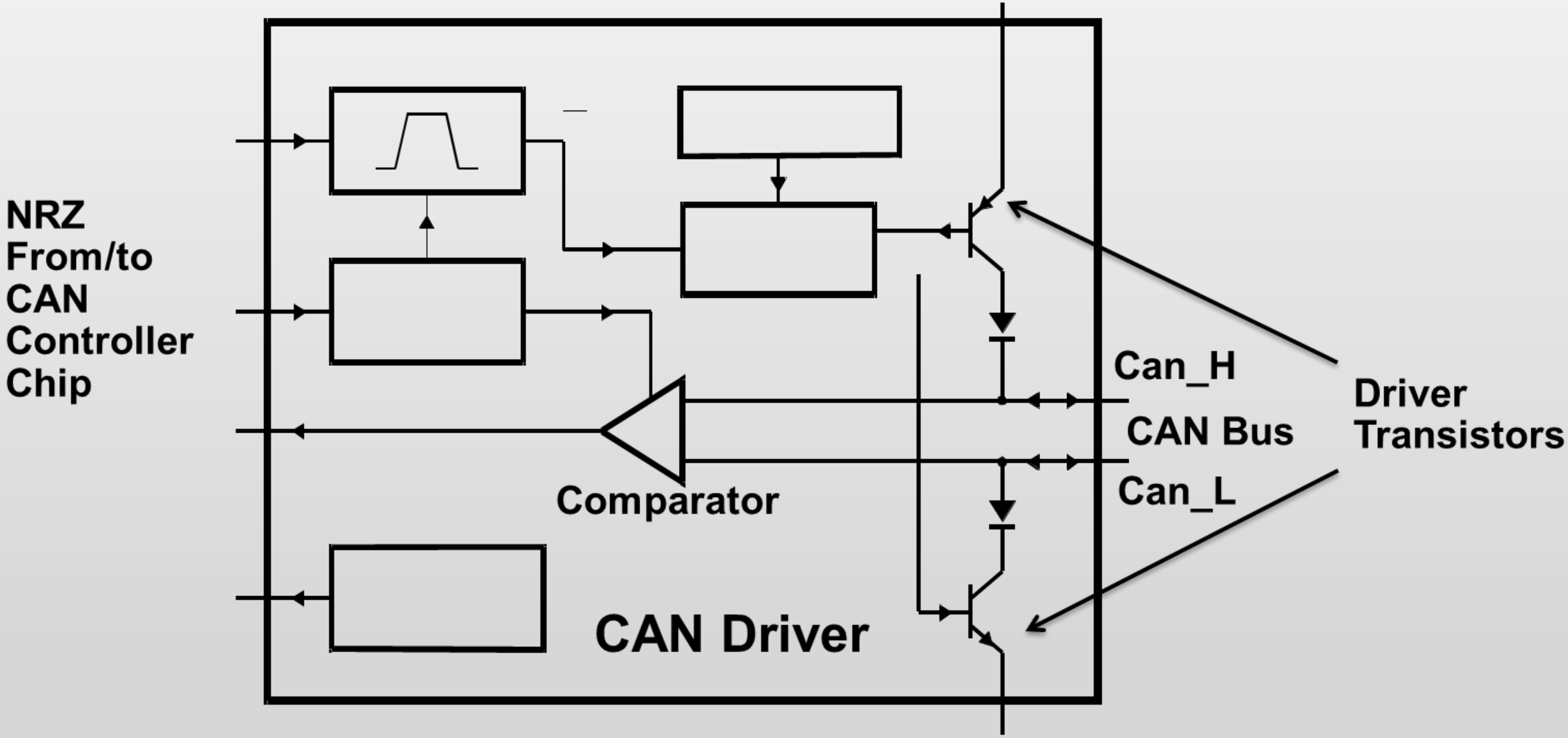
Aspects of the Physical Layer

- Transmission medium – Shielded twisted pair for NMEA2000. Typically unshielded for automotive
- Bit representation – Non-Return to Zero (NRZ)
- Transfer rate – up to 1Mbps. Typically 250 Kbps for NMEA and J1939. Typically 500 Kbps for automotive.
- Signal level and timing:
  - Differential pair modulating 1 V each around 2.5 V.
  - 4 µsec.
- Terminator - A 120 Ω terminator must be connected at each end of the CAN bus between CAN_H and CAN_L.

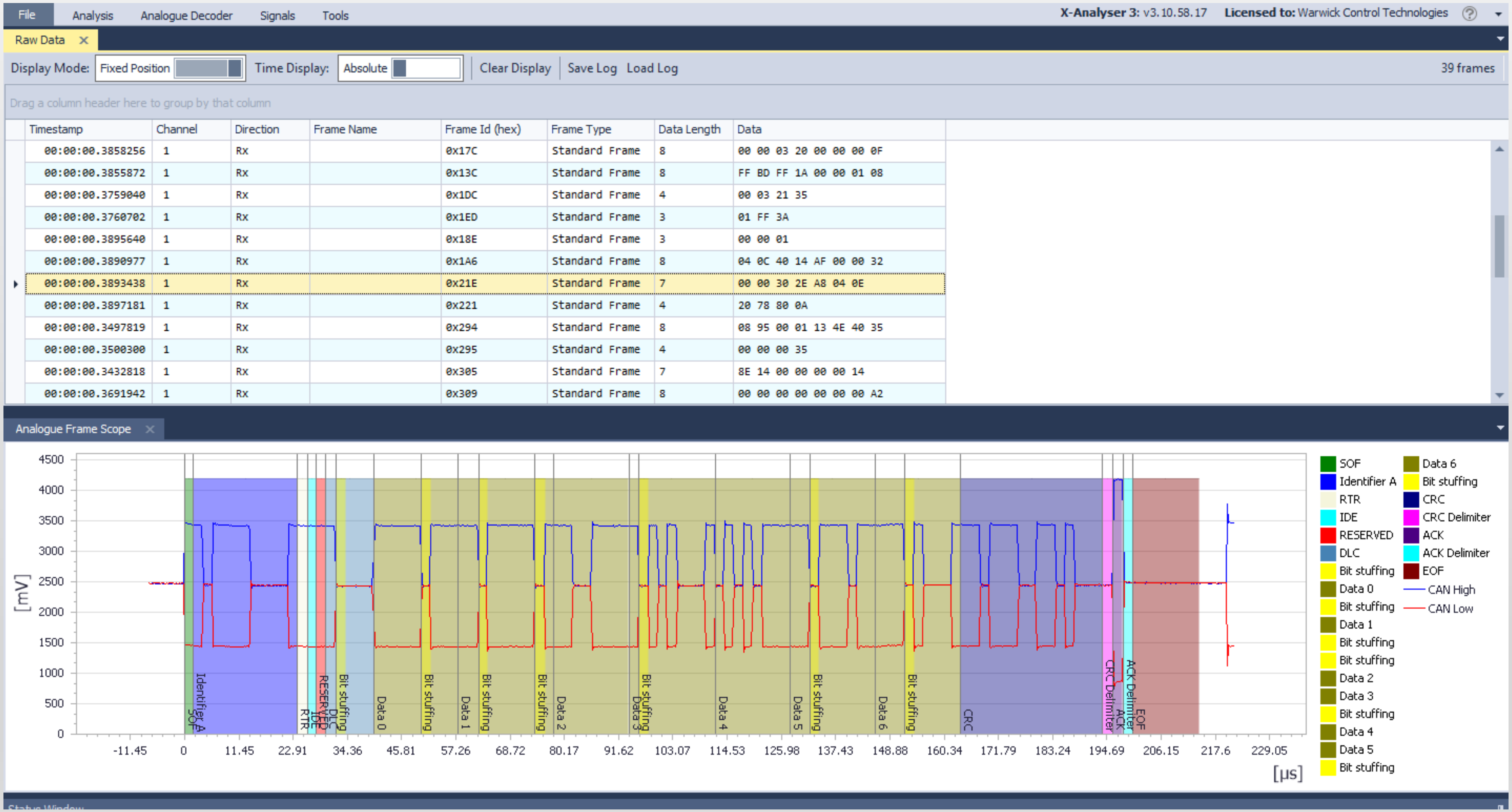
Example CAN Driver output



The CAN Transceiver



X-Analyser - Datalink and Physical Layers
- click on CAN message to its CAN_H and CAN_L



Timestamp	Channel	Direction	Frame Name	Frame Id (hex)	Frame Type	Data Length	Data
00:00:00.3858256	1	Rx		0x17C	Standard Frame	8	00 00 03 20 00 00 00 0F
00:00:00.3855872	1	Rx		0x13C	Standard Frame	8	FF BD FF 1A 00 00 01 08
00:00:00.3759040	1	Rx		0x1DC	Standard Frame	4	00 03 21 35
00:00:00.3760702	1	Rx		0x1ED	Standard Frame	3	01 FF 3A
00:00:00.3895640	1	Rx		0x18E	Standard Frame	3	00 00 01
00:00:00.3890977	1	Rx		0x1A6	Standard Frame	8	04 0C 40 14 AF 00 00 32
00:00:00.3893438	1	Rx		0x21E	Standard Frame	7	00 00 30 2E A8 04 0E
00:00:00.3897181	1	Rx		0x221	Standard Frame	4	20 78 80 0A
00:00:00.3497819	1	Rx		0x294	Standard Frame	8	08 95 00 01 13 4E 40 35
00:00:00.3500300	1	Rx		0x295	Standard Frame	4	00 00 00 35
00:00:00.3432818	1	Rx		0x305	Standard Frame	7	8E 14 00 00 00 00 14
00:00:00.3691942	1	Rx		0x309	Standard Frame	8	00 00 00 00 00 00 00 A2

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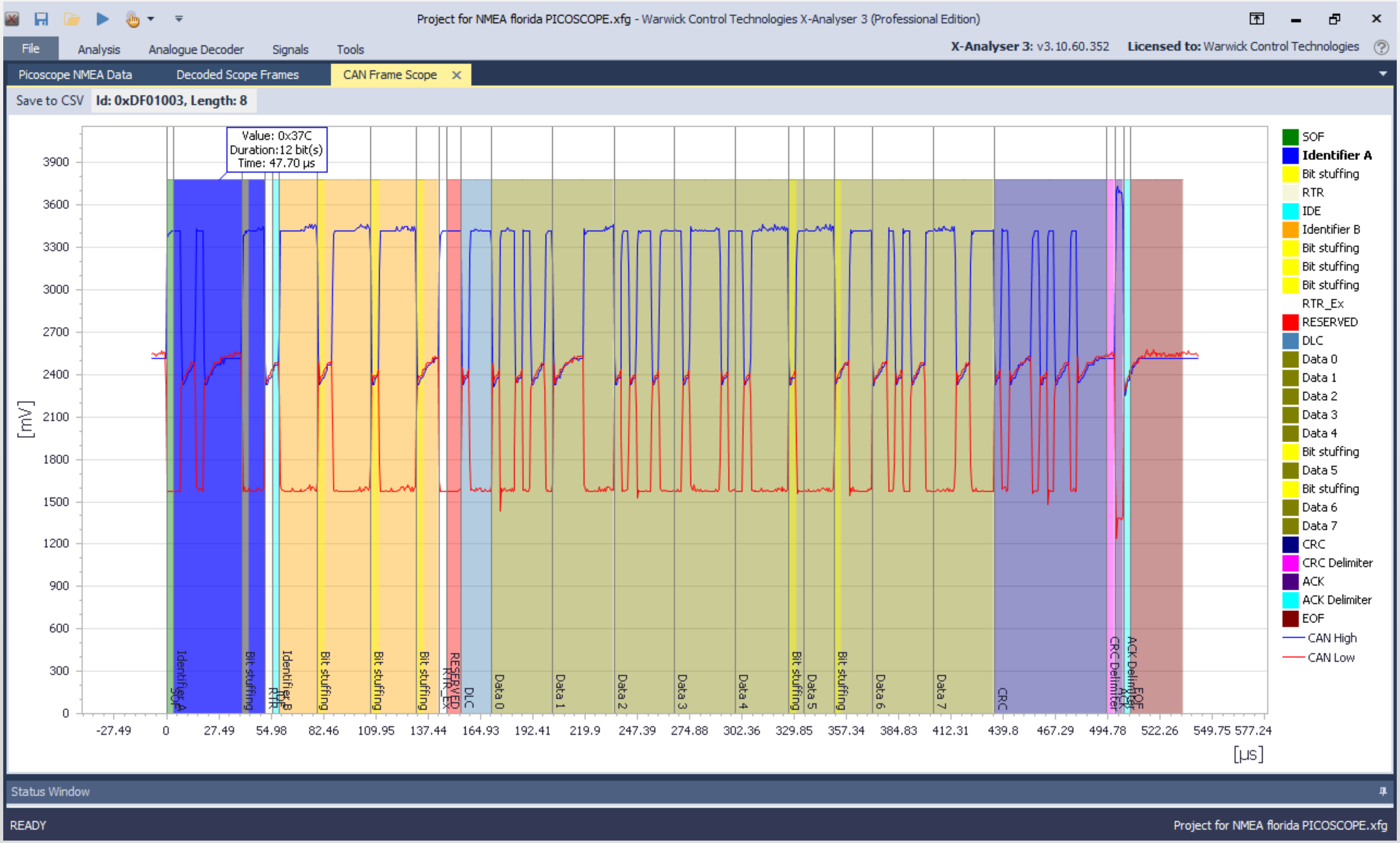
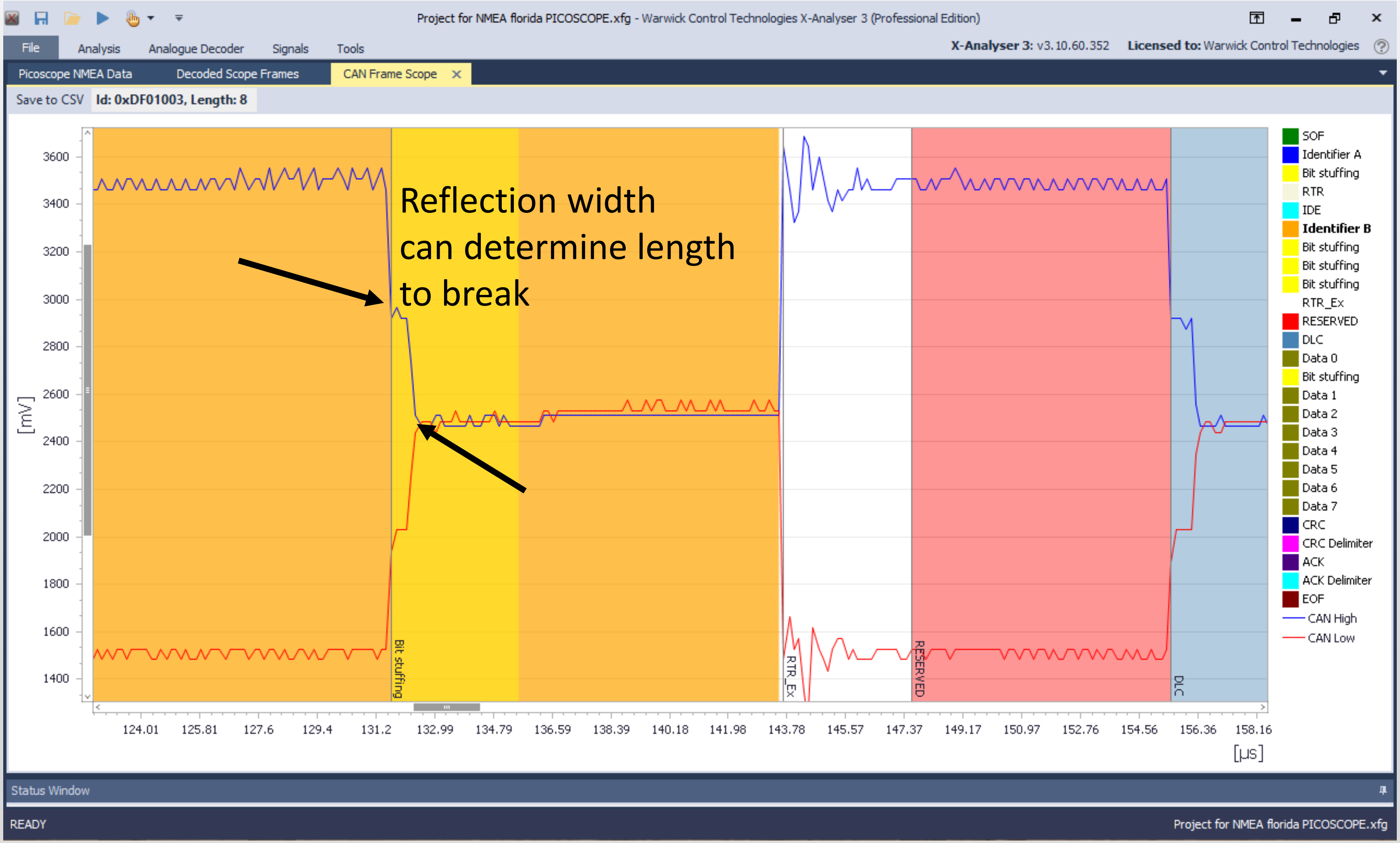
Utilising X-Analyser for the Physical Layer



Utilising X-Analyser for the Physical Layer checking
Reflections – missing terminator or severed bus

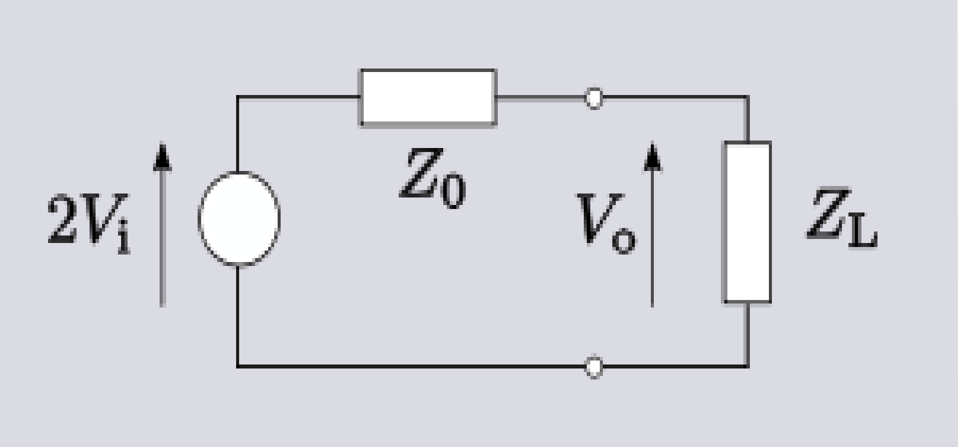


X-Analyser Benefits – Physical Layer

- CAN frame timing and triggering
  - Normal oscilloscopes
    - Tricky to set up triggering
    - Where do you trigger? On Start of Frame?
    - How do you ensure you get the CAN ID that you want?
  - X-Analyser
    - Just pick bit rate and grab a snapshot of bus activity
- Relate physical signals to a frame and therefore to a particular NMEA2000 device
- Save each frame as a Comma Separated Variable file
  - Can later import into Excel
- Normal TDR requires bus to be powered down so pulse can be injected

What is a Reflection on a CAN bus?

- Transmission line model
  - Z_O is the characteristic impedance of the CAN bus
  - Z_L is the load impedance (which is the terminator)



- Reflection
  - Happens when Z_L does not match Z_O due to
    - Terminator and cable tolerances
    - Bus cable breaks and shorts
  - Energy travels to the end of cable and is reflected back to transmitting device

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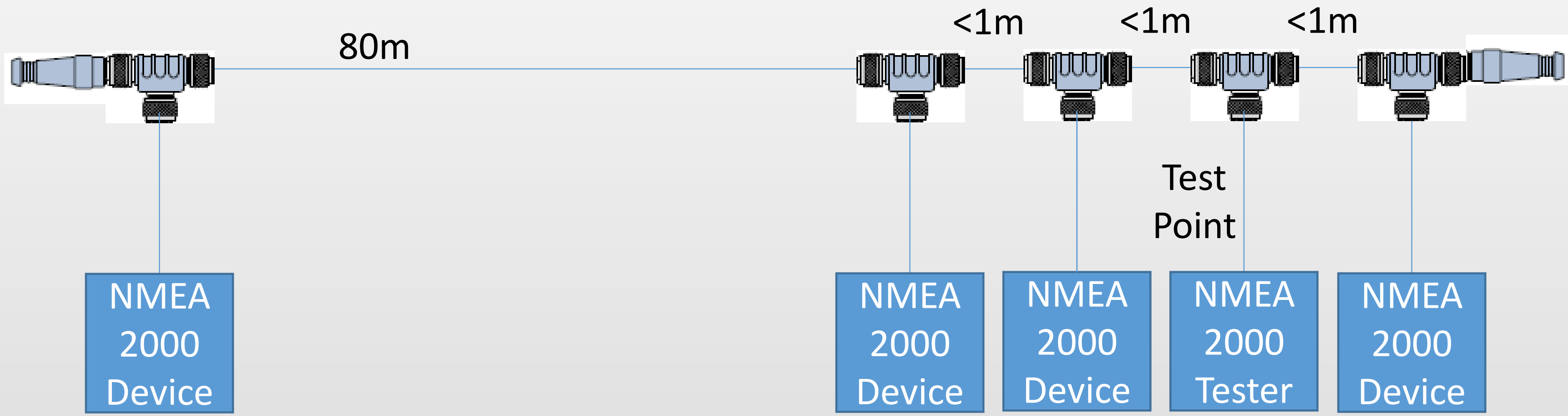
Scenario for Demonstration – The Network



NMEA 2000 devices, e.g.

- Fuel Level Display
- GPS
- Water Speed Sensor

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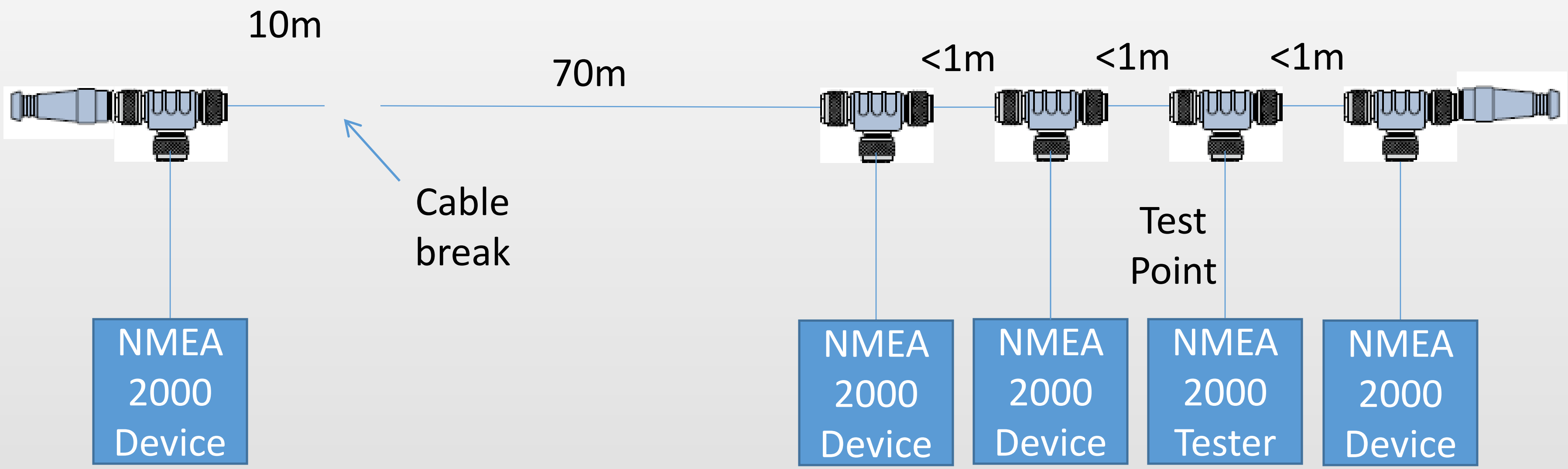
Scenario for Demonstration – Cable Break



70 metre break on 5ns/m cable

- Reflection approx. 700ns

Data Link Layer incorporates Two Sub-Groups

- Object Layer
  - Acceptance filtering
  - Prioritised message handling

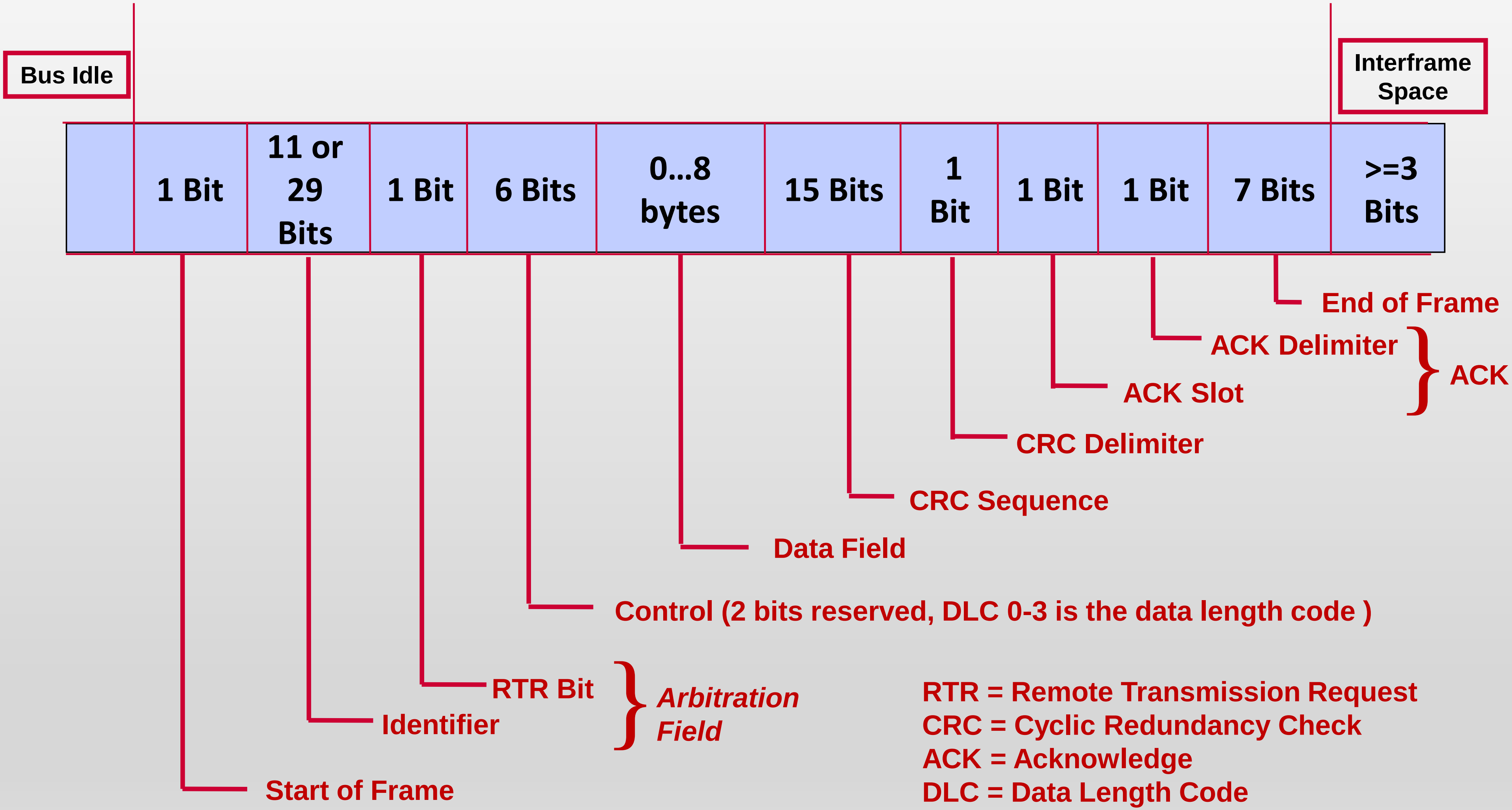
- Transfer Layer
  - Message framing
  - Bus Access and Arbitration
  - Acknowledgement
  - Error detection & report
  - Fault confinement

Object Layer

- Acceptance filtering
  - All nodes receive a CAN message
  - Decision to filter the message into the Microcontroller or discard it is made at the CAN controller

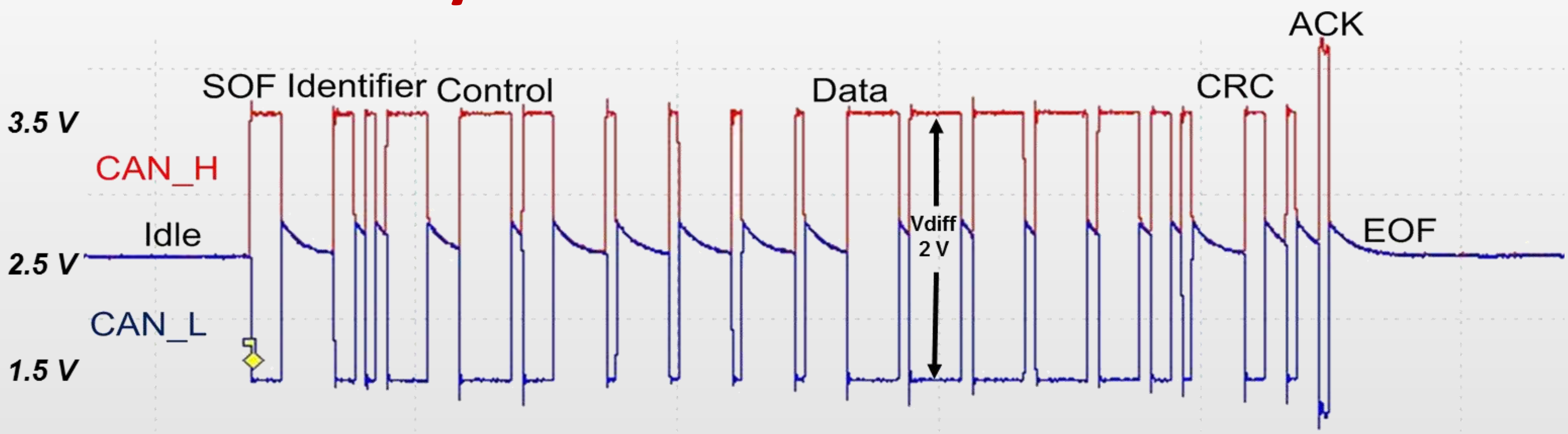
- Prioritised message handling
  - All CAN messages have its priority set by its identifier (CAN ID).
  - The lower the message CAN ID, the higher its priority.

Transfer Layer – CAN Frame Format



RTR = Remote Transmission Request
CRC = Cyclic Redundancy Check
ACK = Acknowledge
DLC = Data Length Code

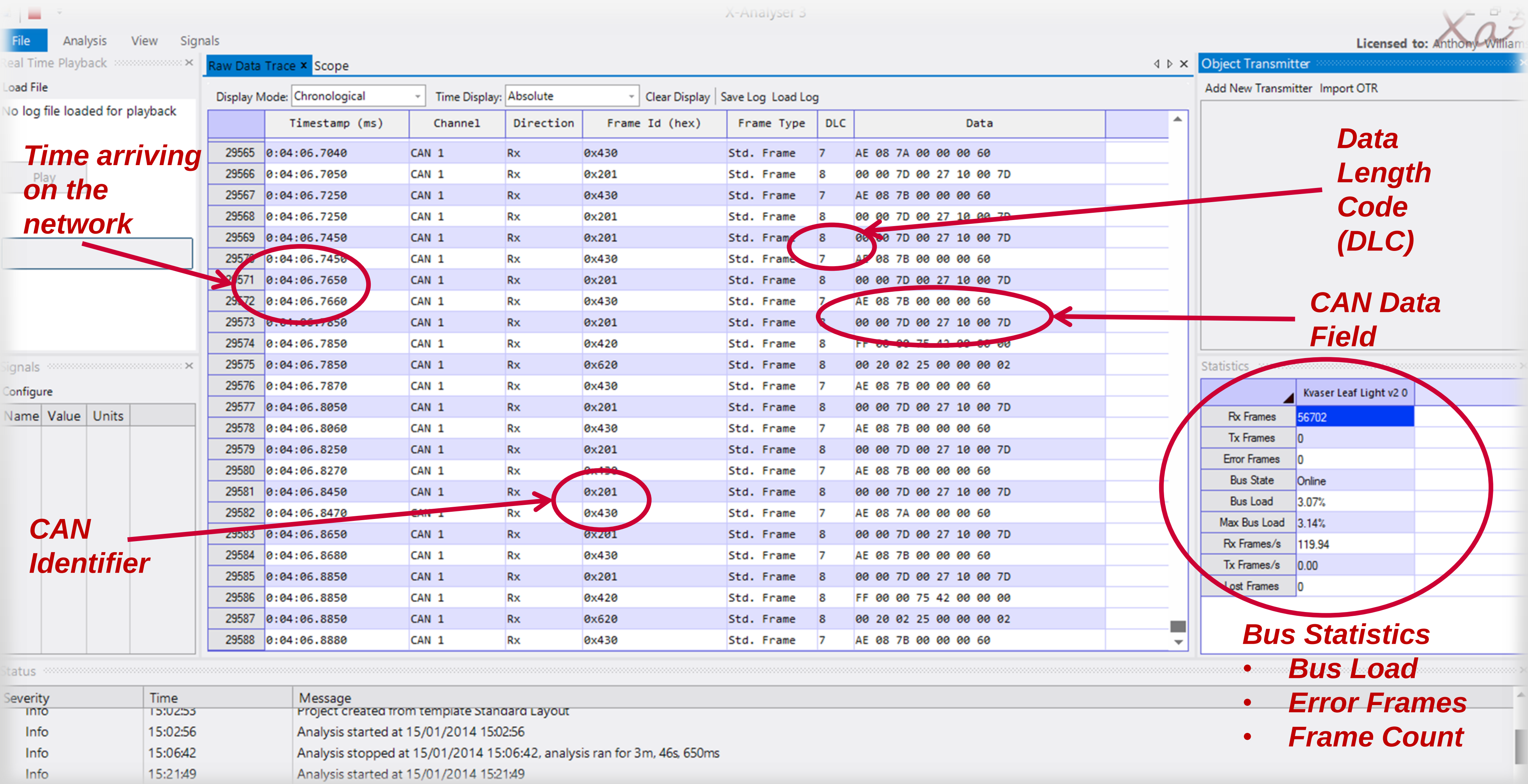
Physical CAN Frame Format



Start of Frame (SOF)
Arbitration Field
Identifier (ID)
Control Field
Data Field

Cylic Redundancy Check (CRC)
Acknowledge Slot
End of Frame
Interframe Space

Look at CAN frame on X-Analyser 3



	Timestamp (ms)	Channel	Direction	Frame Id (hex)	Frame Type	DLC	Data
29565	0:04:06.7040	CAN 1	Rx	0x430	Std. Frame	7	AE 08 7A 00 00 00 60
29566	0:04:06.7050	CAN 1	Rx	0x201	Std. Frame	8	00 00 7D 00 27 10 00 7D
29567	0:04:06.7250	CAN 1	Rx	0x430	Std. Frame	7	AE 08 7B 00 00 00 60
29568	0:04:06.7250	CAN 1	Rx	0x201	Std. Frame	8	00 00 7D 00 27 10 00 7D
29569	0:04:06.7450	CAN 1	Rx	0x201	Std. Frame	8	00 00 7D 00 27 10 00 7D
29570	0:04:06.7450	CAN 1	Rx	0x430	Std. Frame	7	AE 08 7B 00 00 00 60
29571	0:04:06.7650	CAN 1	Rx	0x201	Std. Frame	8	00 00 7D 00 27 10 00 7D
29572	0:04:06.7660	CAN 1	Rx	0x430	Std. Frame	7	AE 08 7B 00 00 00 60
29573	0:04:06.7850	CAN 1	Rx	0x201	Std. Frame	8	00 00 7D 00 27 10 00 7D
29574	0:04:06.7850	CAN 1	Rx	0x420	Std. Frame	8	FF 00 00 75 42 00 00 00
29575	0:04:06.7850	CAN 1	Rx	0x620	Std. Frame	8	00 20 02 25 00 00 00 02
29576	0:04:06.7870	CAN 1	Rx	0x430	Std. Frame	7	AE 08 7B 00 00 00 60
29577	0:04:06.8050	CAN 1	Rx	0x201	Std. Frame	8	00 00 7D 00 27 10 00 7D
29578	0:04:06.8060	CAN 1	Rx	0x430	Std. Frame	7	AE 08 7B 00 00 00 60
29579	0:04:06.8250	CAN 1	Rx	0x201	Std. Frame	8	00 00 7D 00 27 10 00 7D
29580	0:04:06.8270	CAN 1	Rx	0x430	Std. Frame	7	AE 08 7B 00 00 00 60
29581	0:04:06.8450	CAN 1	Rx	0x201	Std. Frame	8	00 00 7D 00 27 10 00 7D
29582	0:04:06.8470	CAN 1	Rx	0x430	Std. Frame	7	AE 08 7A 00 00 00 60
29583	0:04:06.8650	CAN 1	Rx	0x201	Std. Frame	8	00 00 7D 00 27 10 00 7D
29584	0:04:06.8680	CAN 1	Rx	0x430	Std. Frame	7	AE 08 7B 00 00 00 60
29585	0:04:06.8850	CAN 1	Rx	0x201	Std. Frame	8	00 00 7D 00 27 10 00 7D
29586	0:04:06.8850	CAN 1	Rx	0x420	Std. Frame	8	FF 00 00 75 42 00 00 00
29587	0:04:06.8850	CAN 1	Rx	0x620	Std. Frame	8	00 20 02 25 00 00 00 02
29588	0:04:06.8880	CAN 1	Rx	0x430	Std. Frame	7	AE 08 7B 00 00 00 60

	Kvaser Leaf Light v2 0
Rx Frames	56702
Tx Frames	0
Error Frames	0
Bus State	Online
Bus Load	3.07%
Max Bus Load	3.14%
Rx Frames/s	119.94
Tx Frames/s	0.00
Lost Frames	0

Severity	Time	Message
Info	15:02:53	Project created from template Standard Layout
Info	15:02:56	Analysis started at 15/01/2014 15:02:56
Info	15:06:42	Analysis stopped at 15/01/2014 15:06:42, analysis ran for 3m, 46s, 650ms
Info	15:21:49	Analysis started at 15/01/2014 15:21:49

Conventional Bus Access for Controller Area Network

(CAN) bus – Contention type data access.

Event Based

- Every node attempts to transmit packets of data when it wants to.
- Many times data is transferred at a periodic rate.

Arbitration

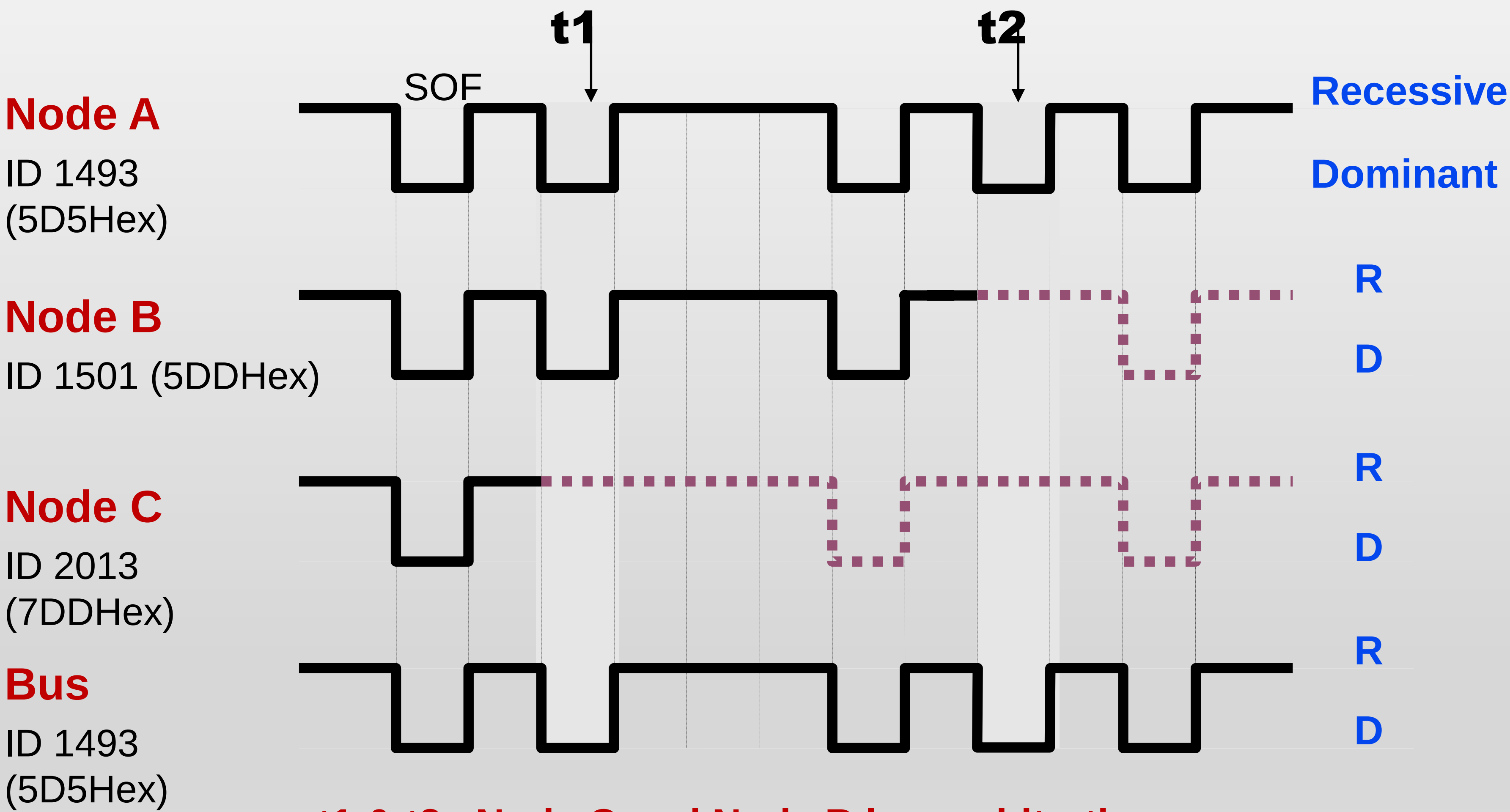
- Every node must contend for network access.
- The network is a virtual one wire bus.

Transfer Layer – Access and Arbitration CSMA/CD with Bitwise Arbitration

- CSMA/CD – Carrier Sense Multiple Access/Collision Detect
  - Multiple nodes sharing a virtual single wire (MA)
  - When a CAN node (ECU) is ready to transfer a CAN message, it senses if the bus is busy or not.

- Non-destructive Bit wise Arbitration
  - All CAN messages have its priority set by its identifier (CAN ID).
  - The lower the message CAN ID, the higher its priority.

Collision Detect + Bitwise Arbitration



t1 & t2 , Node C and Node B lose arbitration

Transfer Layer – Error Detection and Report

- Error conditions
  - CRC error – if the transmitter CRC and the receiver CRC do not match.
  - Bit error – While a node is transmitting, it is checking the data at its receiver in the CAN driver.
  - Stuff error – if a receiver sees 6 consecutive bits of the same polarity before the End of Frame.
- Error reporting
  - When a node detects an error it will transmit an Error Frame.
  - An Error Frame consists of six Dominant bits – this breaks the Bit Stuffing rule.
  - All nodes detect and ignore the last frame.
  - Transmitted message will attempt to re-transmit.

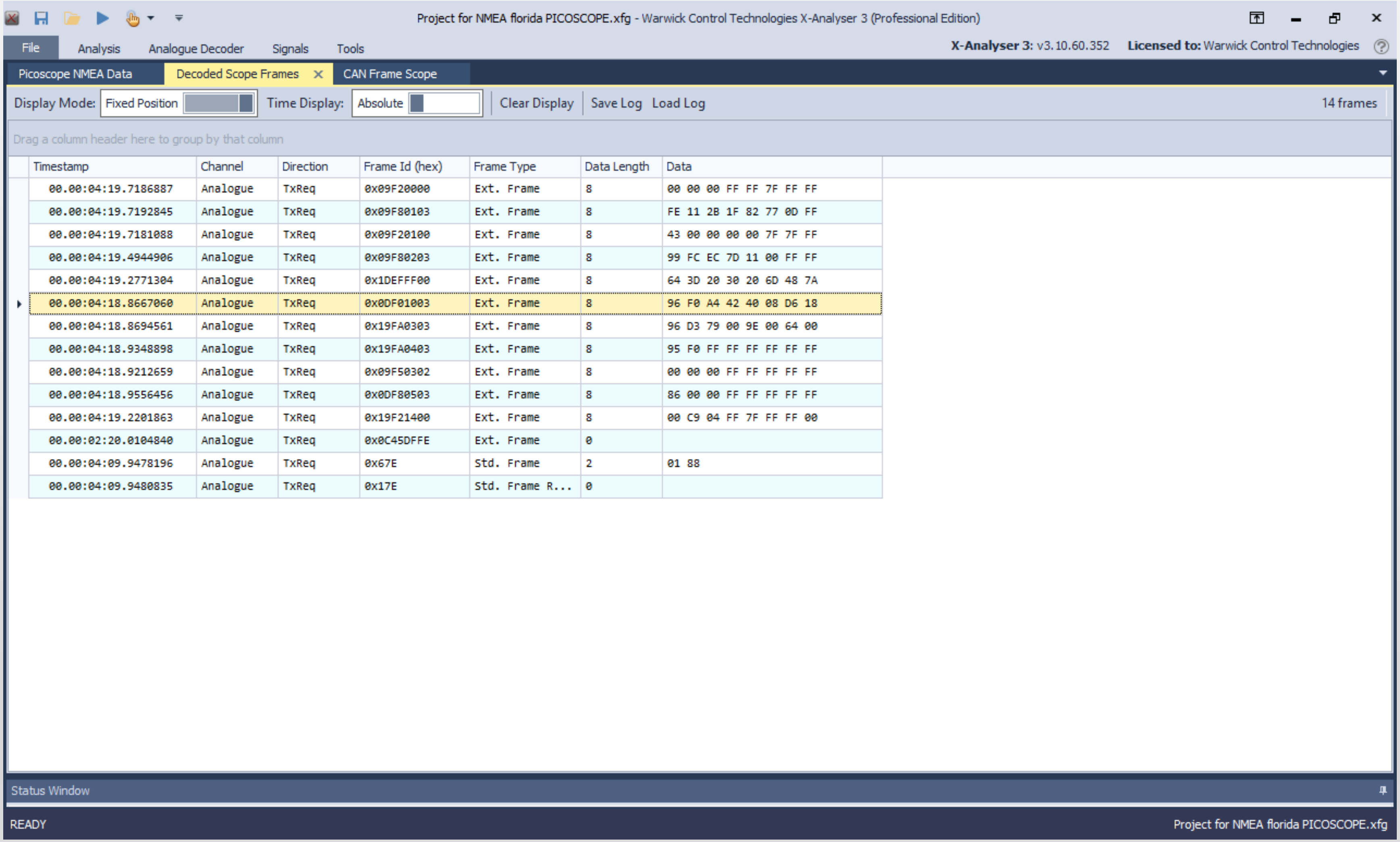
Transfer Layer – Fault Confinement

Error modes

- Error Active – Normal operating mode. When a node detects an error, it sends an Error Active frame of 6 Dominant bits.
- Error Passive – Intermediate operating mode. When a node detects an error, it sends an Error Active frame of 6 Recessive bits – no real effect on the bus.
- Bus Off – Node stops transmitting and removes itself from the CAN bus. Power must be cycled before it can return to the bus.

Transition between Error modes is determined by the CAN Controller's Error Counters.

Utilising X-Analyser for the Data Link Layer



Timestamp	Channel	Direction	Frame Id (hex)	Frame Type	Data Length	Data
00.00:04:19.7186887	Analogue	TxReq	0x09F20000	Ext. Frame	8	00 00 00 FF FF 7F FF FF
00.00:04:19.7192845	Analogue	TxReq	0x09F80103	Ext. Frame	8	FE 11 2B 1F 82 77 0D FF
00.00:04:19.7181088	Analogue	TxReq	0x09F20100	Ext. Frame	8	43 00 00 00 00 7F 7F FF
00.00:04:19.4944906	Analogue	TxReq	0x09F80203	Ext. Frame	8	99 FC EC 7D 11 00 FF FF
00.00:04:19.2771304	Analogue	TxReq	0x1DEFFF00	Ext. Frame	8	64 3D 20 30 20 6D 48 7A
00.00:04:18.8667060	Analogue	TxReq	0x0DF01003	Ext. Frame	8	96 F0 A4 42 40 08 D6 18
00.00:04:18.8694561	Analogue	TxReq	0x19FA0303	Ext. Frame	8	96 D3 79 00 9E 00 64 00
00.00:04:18.9348898	Analogue	TxReq	0x19FA0403	Ext. Frame	8	95 F0 FF FF FF FF FF FF
00.00:04:18.9212659	Analogue	TxReq	0x09F50302	Ext. Frame	8	00 00 00 FF FF FF FF FF
00.00:04:18.9556456	Analogue	TxReq	0x0DF80503	Ext. Frame	8	86 00 00 FF FF FF FF FF
00.00:04:19.2201863	Analogue	TxReq	0x19F21400	Ext. Frame	8	00 C9 04 FF 7F FF FF 00
00.00:02:20.0104840	Analogue	TxReq	0x0C45DFFE	Ext. Frame	0	
00.00:04:09.9478196	Analogue	TxReq	0x67E	Std. Frame	2	01 88
00.00:04:09.9480835	Analogue	TxReq	0x17E	Std. Frame R...	0	

Application Layer

- Application Layer is the embedded program within the ECU's Microcontroller.
- Rules to standardise a system's use of CAN message ID designation, e.g. Engine ECU, GPS, Water speed sensor, Radar
- Rules to standardise how the data is arranged in the CAN message, e.g. Engine Speed, Engine Temp, Water Speed, Longitude, Latitude, etc.
- Various Standards, e.g. NMEA2000, J1939, CANopen, etc.
- Automotive industry is "non-standard", i.e. every car manufacturer sets its own Proprietary Standard.

Application Layer also known as The CAN Higher Layer Protocol (HLP)

Common CAN HLPs

- Proprietary – as designated by each car manufacturer
- SAE J1939 – Originally for Truck and Bus industries. Utilised by many specialised vehicle industries. More Plug and Play rules.
- NMEA 2000 – Based on J1939 for the Marine Electronics industry. More Plug and Play rules.
- CANopen – Originally for automation industries. Utilised by many other industries, e.g. medical equipment, off-road vehicles, maritime electronics, railway applications or building automation.
- DeviceNet – Developed for automation and manufacturing industries. Popular in USA and Asia.

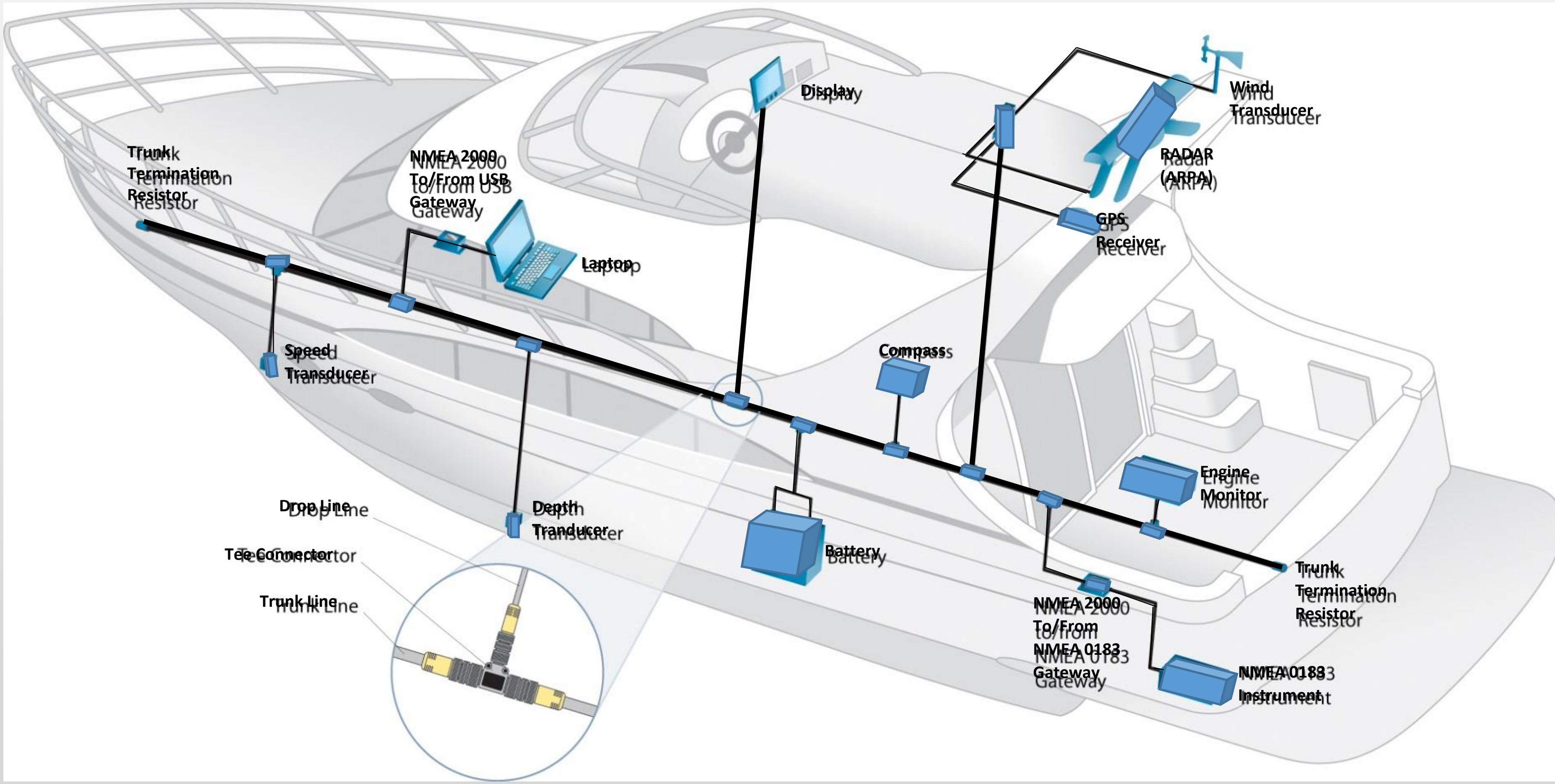
NMEA2000 PGN Database

- Properties of an application's CAN system:
  →Parameter Group Number (PGN)– CAN IDs (priority)
  →signals and fields within each PGN.
- Determined during the design of an ECU.
- This information is used to convert the "raw" CAN data to a "real world" values.
- Allows analysis/test tools to view the values of parameters within the CAN frame Data Field.

NMEA2000

- CAN extension of NMEA-0183
- 250k bits/second vs. 4.8k bits/second for NMEA 0183
- Based on J1939
- Specified and certified by US based National Marine Electronics Association
- Bus topology (e.g. CAN bus 120 ohm terminated)
- Certification to ensure conformance and trademark use

NMEA2000 Applications



Comparison with J1939

- Physical Layer number of nodes more dependant on Power Supply.
- Fast Packet Protocol
  - New feature specifically for NMEA2000
  - NMEA 2000 provides a faster means to stream up to 223 bytes of data as well as the J1939 Transport Protocol of the 1785 bytes.
- Application layer
  - Own application specific message defined
  - More Marine oriented rather than road transport
  - Data Page Set to logic 1 for NMEA2000 (set to 0 for J1939)

Parameter Group Number (PGN) in the 29 bit CAN ID

$$\underbrace{\text{PDU Format 8 bits} \quad \text{PDU Specific 8 bits}}_{\text{16 bits represent the PGN}}$$

Priority	Reserved	DP	PDU Format	PDU Specific	Source Address
3 bits	*1 bit*	*1 bit*	*8 bits*	*8 bits*	*8 bits*

- PDU – 16 bits effectively represents the PGN
  - Describes the content and purpose of the message, e.g.
    - 0xF004 – Electronic Engine Controller1
    - 0xF005 – Electronic Transmission Controller2

CAN ID Format for J1939/NMEA2000

- Priority (3 bits)
  - Used to prioritise messages by CAN arbitration
- Data Page (1 bit)
  - Extends the number of PGN that can be defined
  - J1939 set to Page 0, Page 1 for NMEA2000
- PDU (Protocol Data Unit) – (16 bits)
  - Describes message content
  - This is effectively J1939/NMEA2000 jargon for PGN
- Source Address (8 bits)
  - Unique address for an ECU

Signals

Engineering signals carried by CAN data field

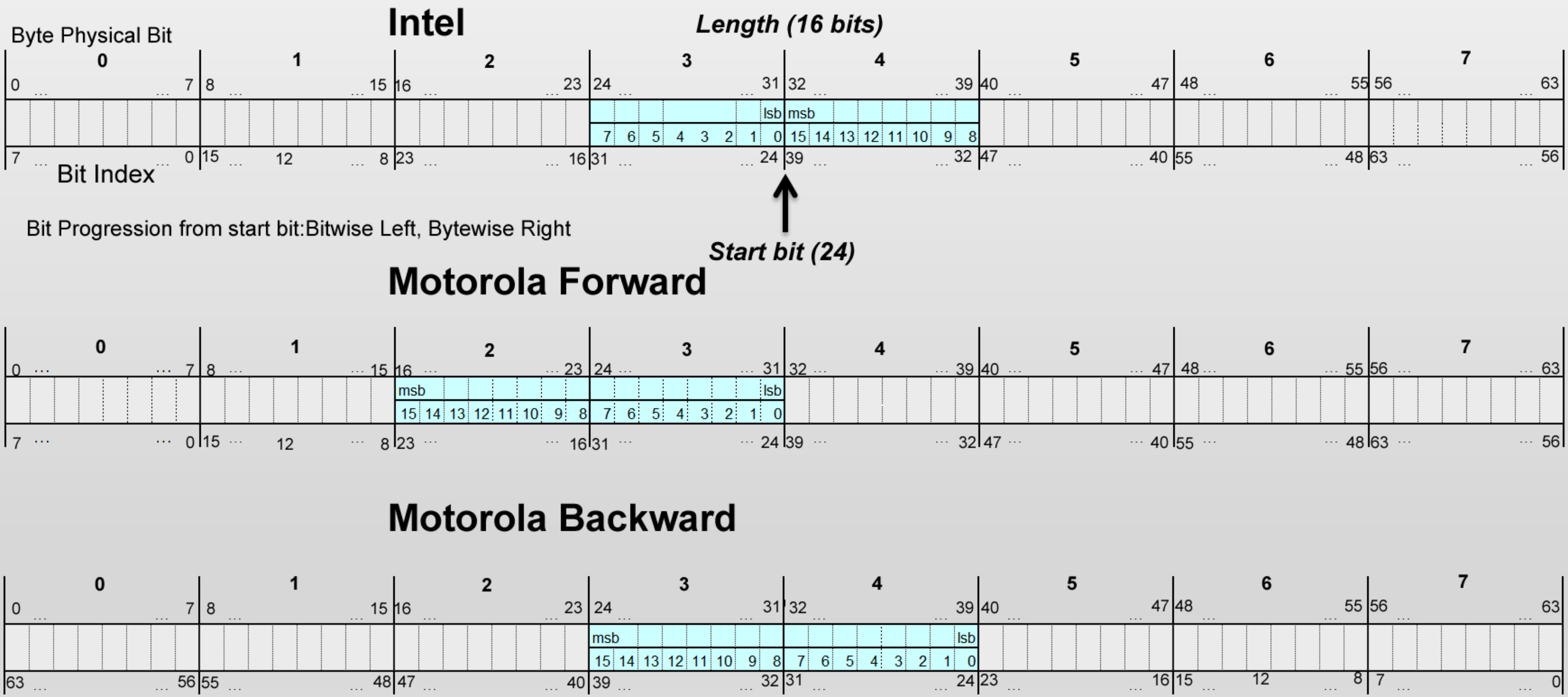
→Description even down to specific signals (e.g. Engine Speed)

- Start bits within the data field
- Scaling and offset
- Bit length

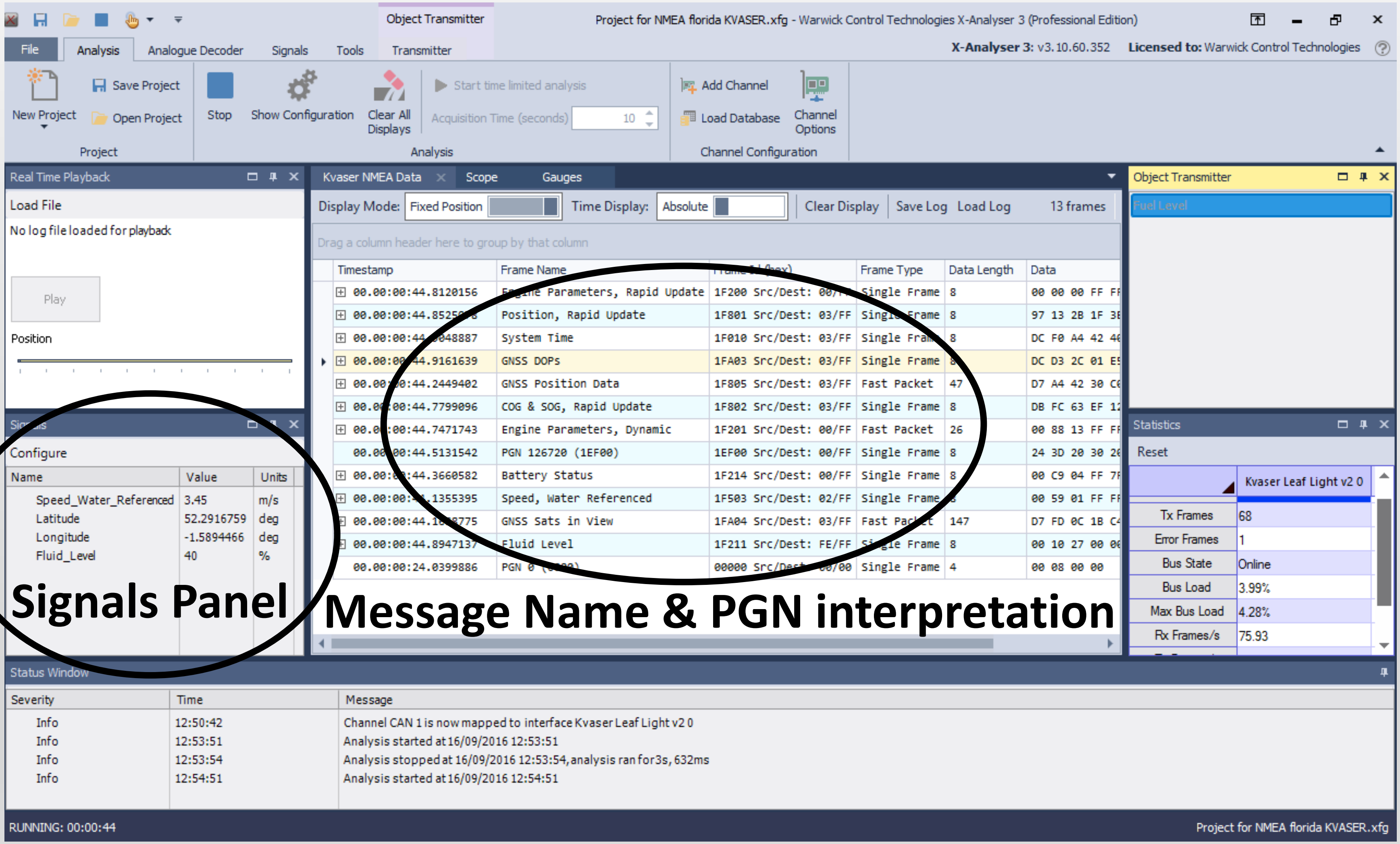
→Rules can be viewed in the NMEA2000 Specification and PGN database

NMEA2000/J1939 Signals use Intel Bit Format
Engine Speed Example

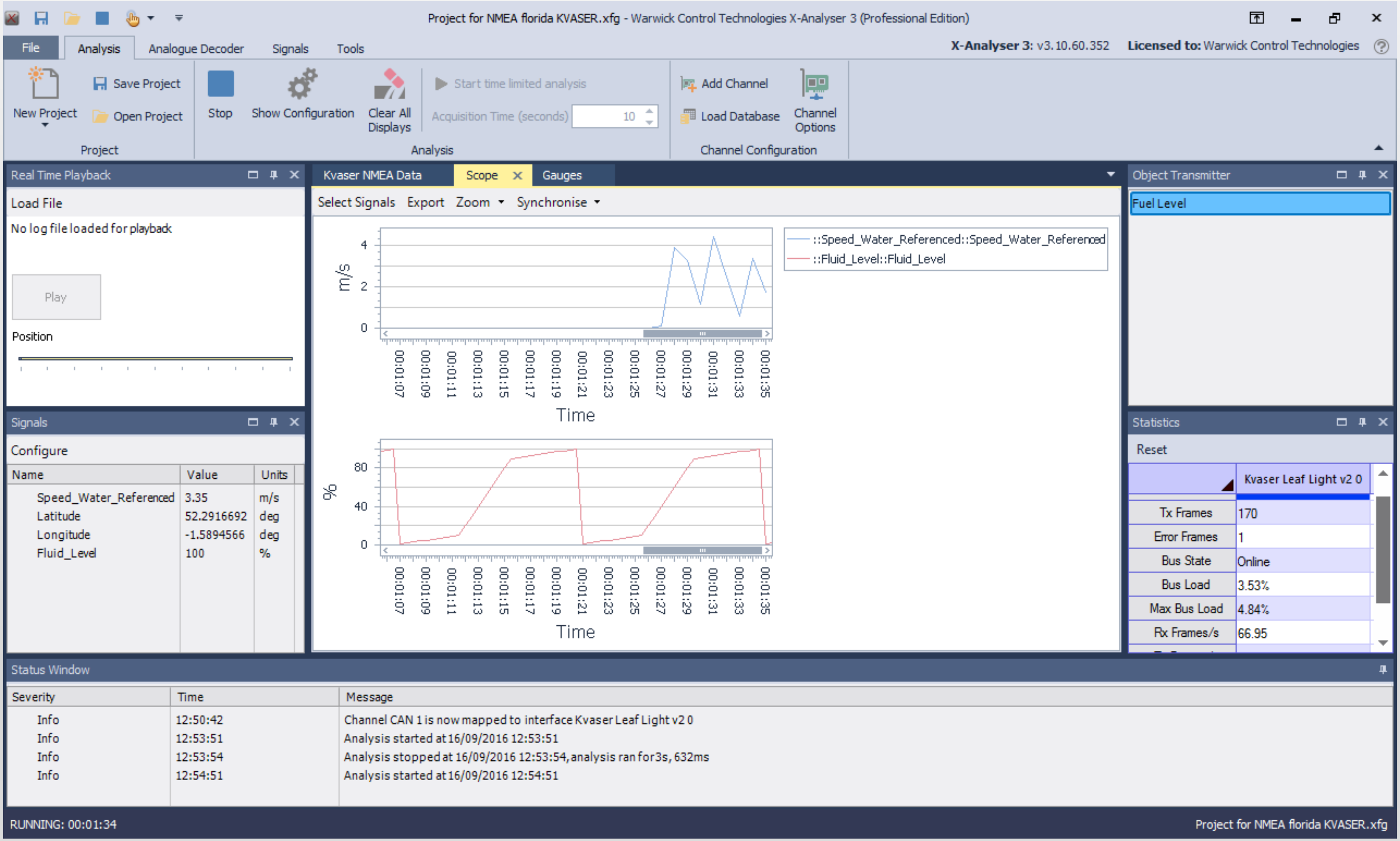
Example DLC 8, Start bit 24, Length 16



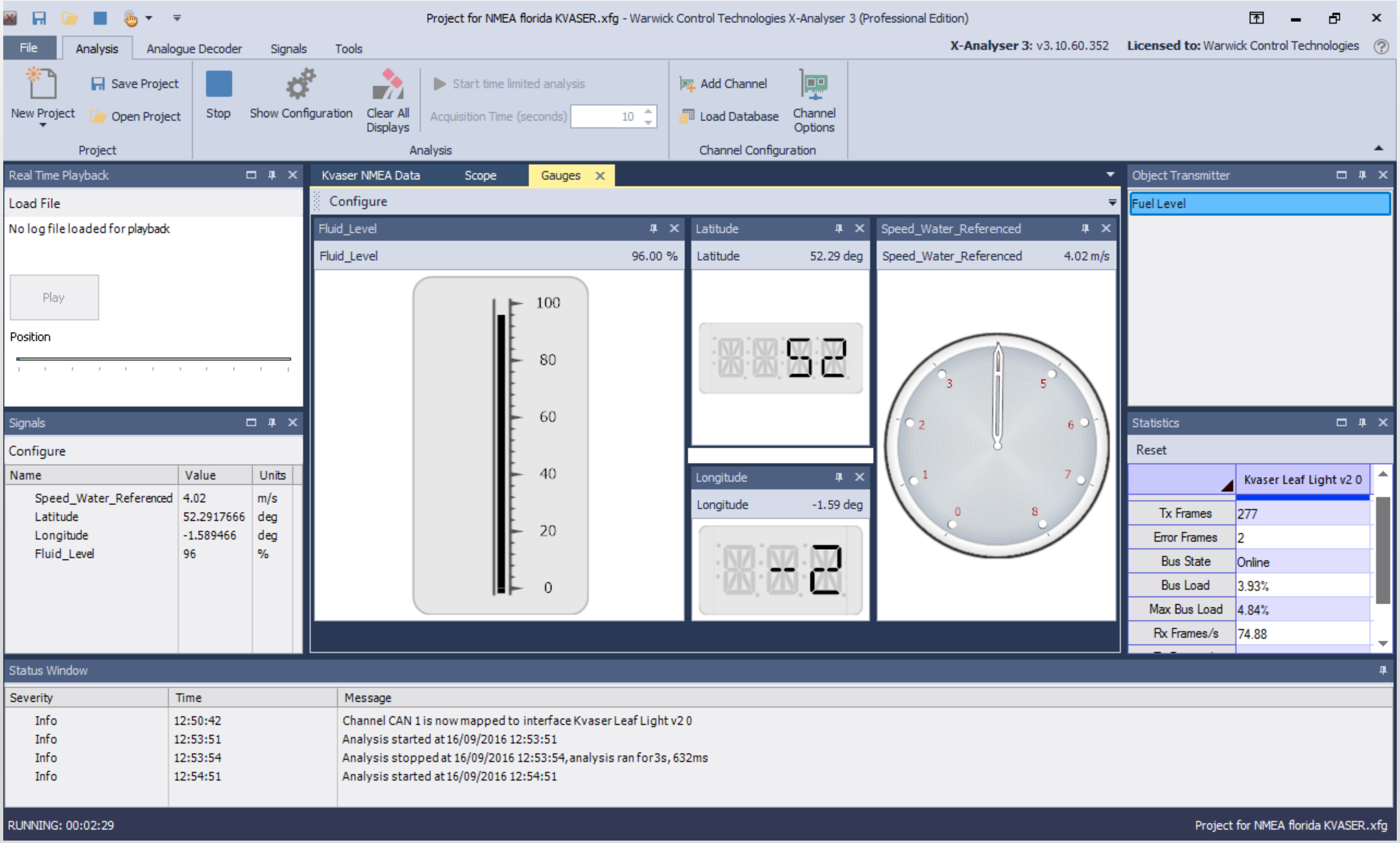
Utilising X-Analyser for the Application Layer Viewing Signals



Utilising X-Analyser for the Application Layer Converting Signals to Graphs/Scope



Utilising X-Analyser for the Application Layer Converting Signals to Gauges



X-Analyser CAN NMEA2000 J1939 CANopen
Latest Production Version

Aimed at high level users and developers, features for NMEA2000 include:

- CAN Identifier interpretation into PGN, Source Address, Pr. etc.
- CAN signals database for PGNs up to 8 bytes (database available to NMEA2000 members)
  - CAN map PGNs and SA to signal scope and gauge displays
- Interactive Generator (Input PGN, SA, Pr. etc. and send on the fly)
- Record and playback of network activity (Save logs in variety of different file formats inc. text & CSV)
- Bus load % statistics (minimum, maximum, current)
- Error frame monitoring
- Virtual network for playback on your desk (no interface required)
- Multiple network channel support
- Hardware interfaces available (M12, Deutsch and DSUB CAN interfaces)

* No transport protocol support currently – shown as a sequence of 8 byte frames

X-Analyser CAN NMEA2000 J1939 CANopen
Latest Beta Version

New features for NMEA2000 integrators:

- **Full Transport Protocol integrated including Fast Packet Protocol**
- **NMEA 2013 database integrated. Entertainment PGNs integrated (hard coded)**
- **PicoScope for physical layer analysis (inc. wire break detection)**

Words of Wisdom