NMEA2000 relation to CAN and how Warwick Control can help

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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



NMEA2000 CAN Bus



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

nnection ISO-110

Typical CAN ECU Configuration



Twisted Pair Wire carrying CAN Physical Signal



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

	file Analysis Ar	nalogue Decode	er Signals	Tools					X-Analyser 3: v3.10.58.17	Licensed to: Warwick Control Technologies 📀 👻
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	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		
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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_0 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



Scenario for Demonstration – The Network



NMEA 2000 devices, e.g.

- Fuel Level Display
- GPS
- Water Speed Sensor



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





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

						X-Analyser 3				V-23	
File Analysis View	Signals									Licensed to: Anthony Williams	
Real Time Playback	Raw Dat	a Trace × Scope							♦ ▷ × Object Trans	nitter ×	
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	29572	0:04:06.7660	CAN 1	Rx	0x430	Std. Frame	7	AE 08 7B 00 00 00 60		CAN Data	
	29573	0.01.00.7050	CAN 1	Rx	0×201	Std. Frame		00 00 7D 00 27 10 00 7D			
	29574	0:04:06.7850	CAN 1	Rx	0×420	Std. Frame	8	FF 00 00 75 42 00 00 00		Field	
Signals	29575	0:04:06.7850	CAN 1	Rx	0x620	Std. Frame	8	00 20 02 25 00 00 00 02	Statistics		
Configure	29576	0:04:06.7870	CAN 1	Rx	0x430	Std. Frame	7	AE 08 7B 00 00 00 60	Statistics Kvaser Leaf Light v2 Rx Frames 56702	Kvaser Leaf Light v2 0	
Name Value Units	29577	0:04:06.8050	CAN 1	Rx	0×201	Std. Frame	8	00 00 7D 00 27 10 00 7D	Rx Frames	56702	
	29578	0:04:06.8060	CAN 1	Rx	0x430	Std. Frame	7	AE 08 7B 00 00 00 60	Tx Frames	0	
	29579	0:04:06.8250	CAN 1	Rx	0×201	Std. Frame	8	00 00 7D 00 27 10 00 7D	Error Frames	0	
	29580	0:04:06.8270	CAN 1	Rx	0,150	Std. Frame	7	AE 08 7B 00 00 00 60	Bus State	Online	
	29581	0:04:06.8450	CAN 1	Rx	0x201	Std. Frame	8	00 00 7D 00 27 10 00 7D	Bus Load	3.07%	
CAN	29582	0:04:06.8470	1 100	Rx	0x430	Std. Frame	7	AE 08 7A 00 00 00 60	Max Bus Loa	d 3.14%	
CAN_	29583	0:04:06.8650	CAN 1	Rx	0x201	Std. Frame	8	00 00 7D 00 27 10 00 7D	Rx Frames/s	119.94	
Identifier	29584	0:04:06.8680	CAN 1	Rx	0x430	Std. Frame	7	AE 08 7B 00 00 00 60	Tx Frames/s	0.00	
	29585	0:04:06.8850	CAN 1	Rx	0x201	Std. Frame	8	00 00 7D 00 27 10 00 7D	Lost Frames	0	
	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		s Statistics	
	29588	0:04:06.8880	CAN 1	Rx	0x430	Std. Frame	7	AE 08 7B 00 00 00 60		5 0101131103	
tatus									•	Bus Load	
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Info 15	5:02:56	Analysis started a	t 15/01/2014 15	02:56						Eramo Count	
Info 15	5:06:42	Analysis stopped	at 15/01/2014 15	5:06:42, analy	sis ran for 3m, 46s, 650ms				•		
Info 15	5:21:49	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



CONTROL TECHNOLOGIES

CAN Data Link Layer

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

🛛 🗔 🍺 🕨 🖶 🖛 🖛 Project for NMEA florida PICOSCOPE.xfg - Warwick Control Technologies X-Analyser 3 (Professional Edition) Ť ÷P. x _ X-Analyser 3: v3.10.60.352 Licensed to: Warwick Control Technologies Analysis Analogue Decoder Signals Tools Picoscope NMEA Data Decoded Scope Frames 🗙 CAN Frame Scope Clear Display Save Log Load Log Display Mode: Fixed Position Time Display: Absolute 14 frames Frame Id (hex) Timestamp Channel Direction 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 8 95 FØ FF FF FF FF FF FF Ext. Frame 00.00:04:18.9212659 Analogue TxReq 8 0x09E50302 Ext. Ename 00 00 00 FF FF FF FF FF 00.00:04:18.9556456 Analogue TxRea 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

Status Windo

READY

Project for NMEA florida PICOSCOPE.xfg



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)
 - \rightarrow 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



- 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

Intel Length (16 bits) Byte Physical Bit 7 0 1 2 3 5 6 23 24 31 39 40 47 48 55 56 63 7 8 15 16 32 Isb msb 2 15 14 13 12 11 10 9 6 3 1 40 55 56 0 15 8 23 24 39 32 47 48 63 7 12 ... 16 31 Bit Index Bit Progression from start bit:Bitwise Left, Bytewise Right Start bit (24) **Motorola Forward** 0 1 7 2 3 4 5 6 23 24 31 32 39 40 47 48 15 16 55 56 63 msb lsb 15 14 13 12 11 10 9 7 6 5 3 8 4 2 1 ... 40 55 48 63 0 15 8 23 24 39 ... 32 47 ... --- 56 7 ... 12 ... 1631 ...

Example DLC 8, Start bit 24, Length 16

Motorola Backward





CAN Application Layer

Utilising X-Analyser for the Application Layer Viewing Signals

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File Analysis Analogue Decoder Sig	gnals Tools Transmitter	X-Analyse	r 3: v3.10.60.352 Licensed to: Warwick Control Technologies 📀						
Image: Save Project Image: Save Project New Project Image: Open Project Stop Show Project	Configuration Clear All Displays Acquisition Time (seconds) 10 1	Add Channel Channel Channel Options							
Project	Analysis	Channel Configuration	*						
Real Time Playback 🗖 🖪	× Kvaser NMEA Data × Scope Gauges		Object Transmitter 🗖 📮 🗙						
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	⊕ 00.00:00:44.85250 s Position, Rapid Update	1F801 Src/Dest: 03/FF Single Frame 8	97 13 2B 1F 3E						
Position	⊕ 00.00:00:44 0048887 System Time ■	1F010 Src/Dest: 03/FF Single Fram 8	DC F0 A4 42 44						
	→ → ↔ 00.00:00/44.9161639 GNSS DOPs	1FA03 Src/Dest: 03/FF Single Frame 8	DC D3 2C 01 E5						
	⊕ 00.00:0:44.2449402 GNSS Position Data	1F805 Src/Dest: 03/FF Fast Packet 47	D7 A4 42 30 C6						
	⊕ 00.00.00:44.7799096 COG & SOG, Rapid Update	1F802 Src/Dest: 03/FF Single Frame 8	DB FC 63 EF 12						
Sionals D. V	× 00.0:44.7471743 Engine Parameters, Dynamic	1F201 Src/Dest: 00/FF Fast Packet 26	00 88 13 FF FF Statistics						
Configure	00.00 00:44.5131542 PGN 126720 (1EF00)	1EF00 Src/Dest: 00/FF Single Frame 8	24 3D 20 30 20 Reset						
Name Value Units	s → 00.00:00:44.3660582 Battery Status	1F214 Src/Dest: 00/FF Single Frame 8	00 C9 04 FF 7F Kvaser Leaf Light v2 0						
Speed_Water_Referenced 3.45 m/s	⊕ 00.00:00:11.1355395 Speed, Water Referenced	1F503 Src/Dest: 02/FF Single Frame S	00 59 01 FF FF						
Latitude 52.2916759 deg	00.00:00:44.10 8775 GNSS Sats in View	1FA04 Src/Dest: 03/FF Fast Parket 147	D7 FD 0C 1B C2						
Fluid_Level 40 %	E 00.00:00:44.8947137 Eluid Level	1F211 Src/Dest: FE/FF Sigle Frame 8	00 10 27 00 00 Error Prames 1						
	00.00:00:24.0399886 PGN 0 (0.94)	00000 Src/Dect 00/00 Single Frame 4	00 08 00 00 Bus State Online						
Signals Panel	VN/ accord Niema	O DCN internet	Bus Load 3.99%						
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Status Window									
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Info 12:50:42	Channel CAN 1 is now mapped to interface Kvaser Leaf Linh	t v2 0							
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Info 12:53:54	Analysis stopped at 16/09/2016 12:53:54, analysis ran for 3s								
Info 12:54:51	Analysis started at 16/09/2016 12:54:51	Analysis started at 16/09/2016 12:54:51							
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Utilising X-Analyser for the Application Layer Converting Signals to Graphs/Scope

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File Analysis Analogue Decoder S	inals Tools X-Analyser 3: v3.10.60.352	Licensed to: Warwick Control Technologies
New Project Project Open Project Stop Show	Configuration Clear All Displays ► Start time limited analysis Acquisition Time (seconds) 10 • Analysis Channel Options	*
Real Time Playback 🗖 📮	X Kvaser NMEA Data Scope X Gauges	Object Transmitter 🗖 📮 🗙
Load File	Select Signals Export Zoom - Synchronise -	Fuel Level
No log file loaded for playback Play Position	Supervised water_Referenced::Speed_Water_Referenced	
Signals 🗖 🗖	× Time	Statistics 🗆 🛛 🗸 🗙
Name Value Unit Speed_Water_Referenced 3.35 m/s Latitude 52.2916692 deg Longitude -1.5894566 deg Fluid_Level 100 %	2 30 40 40 40 40 40 40 40 40 40 4	Reset Kvaser Leaf Light v2 0 Tx Frames 170 Error Frames 1 Bus State Online Bus Load 3.53% Max Bus Load 4.84% Px Frames/s 66.95
Status Window		д
Severity Time	Message	
Info 12:50:42 Info 12:53:51 Info 12:53:54 Info 12:54:51	Channel CAN 1 is now mapped to interface Kvaser Leaf Light v2 0 Analysis started at 16/09/2016 12:53:51 Analysis stopped at 16/09/2016 12:53:54, analysis ran for 3s, 632ms Analysis started at 16/09/2016 12:54:51	
RUNNING: 00:01:34		Project for NMEA florida KVASER.xfg



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

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Real Time Playback	₽ ₽	× Kvaser NMEA Data	a Scope <mark>Gauges X</mark>				•	Object Transmitter 🗖 🗭 🗸
Load File		Configure					Ŧ	Fuel Level
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Status Window								ą
Severity	Time	Message						
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RUNNING: 00:02:29								Project for NMEA florida KVASER.xfg



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



