Bus Systems

Commercial Vehicle Bus Systems

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Commercial Vehicle Bus Systems

Learning objectives

- Understand commercial vehicle networks
- Understand physical properties and possible failures of ISOBUS
- Understand the ISOBUS Protocol
  - Understand the mapping of ISOBUS to CAN
  - Understand the encoding of larger ISOBUS messages to CAN bus frames

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Commercial vehicle networks

- Up to now: Automotive networks
  - Configured and assembled by automotive OEM
  - Usually immutable

- Commercial vehicles
  - Combine main unit (e.g. tractor) and implements
  - Implements are provided by 3rd party manufracurers
  - Require access to internal and safety relevant communication

- Examples
  - Perception head that conctrols tractor movements
  - Implement control from multi-purpose unit in driver cabin

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Commercial vehicle networks

- Require standardized application level protocols that enables communication between devices from different manufacturers
- 3rd party network devices are added and removed by end users
- ISOBUS is a high level network that has been built on CAN to enable the coupling of tractors and 3rd party implements
  - Standardize the method and format of transfer of data between sensors, actuators, control elements, and information-storage and -display units.
  - Open system interconnect (OSI) for electronic systems used by agricultural and forestry equipment.
- Conformity between implements and control units are regularly assessed during ‚plug fests' – here, all connections between tractor ECUs and implements are tested

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- ISOBUS (ISO 11783)
  - Realizes ISO/OSI Layer 7
    - Re-uses CAN Bus (Layer 1 & 2)
  - Based on CAN Bus extended frames
  - Connects tractor control units and implement control units
  - Standardization enables use of common hardware terminals
    - Maintains flexibility with respect to implement configuration and control needs
    - Without clobbering the driver cabin with individual controls for every supported implement device
  - Conforming implements may be controlled via the same terminal unit

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- ISOBUS Defines
  - Connectors & Cables
    - Standardized physical wiring
    - Prevents defects e.g. when unplugging was forgotten when detaching implement
  - Application level communication
    - Mapping of Application level Communication to CAN Bus frames
  - Virtual Terminal
    - Standardized was to provide implement specific configuration and controlling
    - Visualized on common hardware terminal
    - Functionality is provided by implement (cf. Web-Browser vs. Web-Server)
  - Device Addressing scheme
    - Address management and address aquisition

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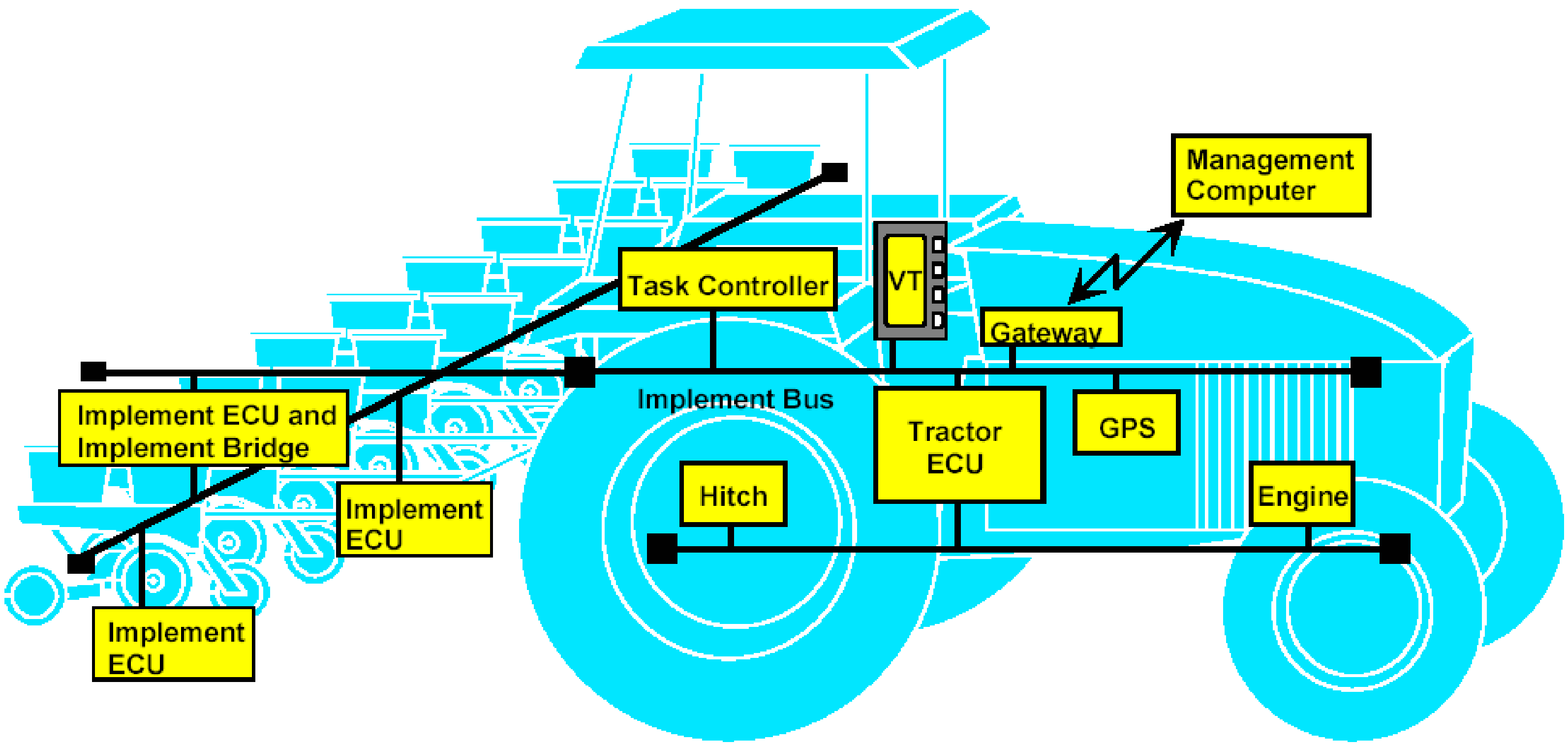
- ISOBUS Gateway
  - Tractor ECU provides gateway between proprietary tractor network and ISOBUS
    - Tractor network shall be ISOBUS compliant, but is not required to be
  - Virtual terminal is virtual user interface of implement



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- ISOBUS Gateway - Terminal
  - Standardized hardware terminal realized virtual terminal inputs/outputs
  - ISO 11783 part 6

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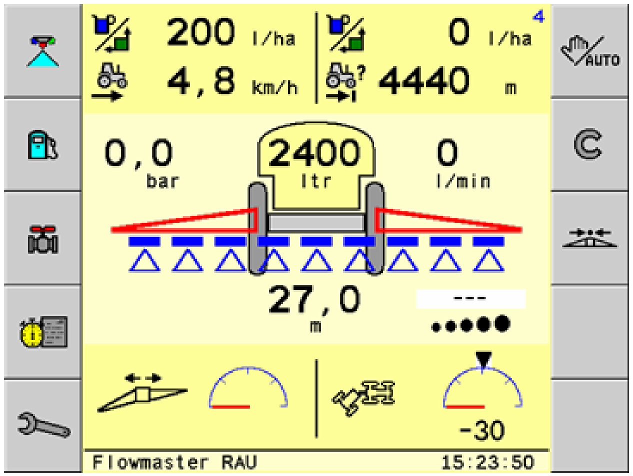
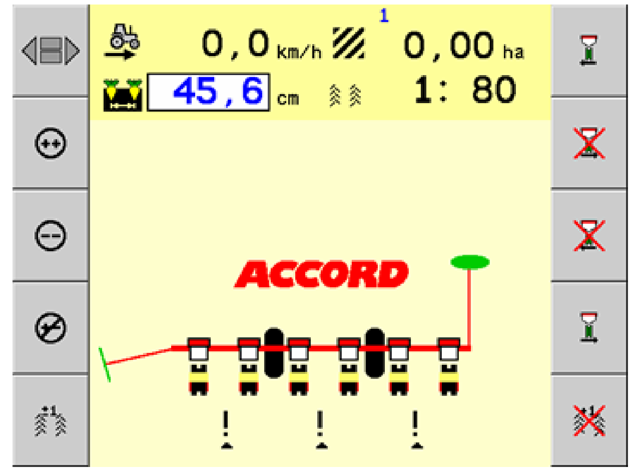
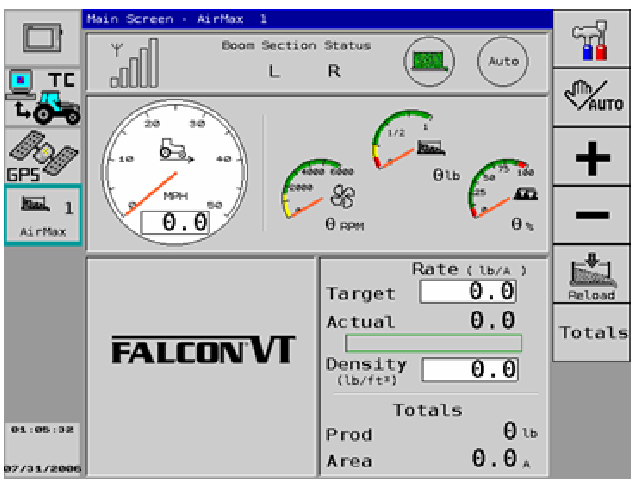
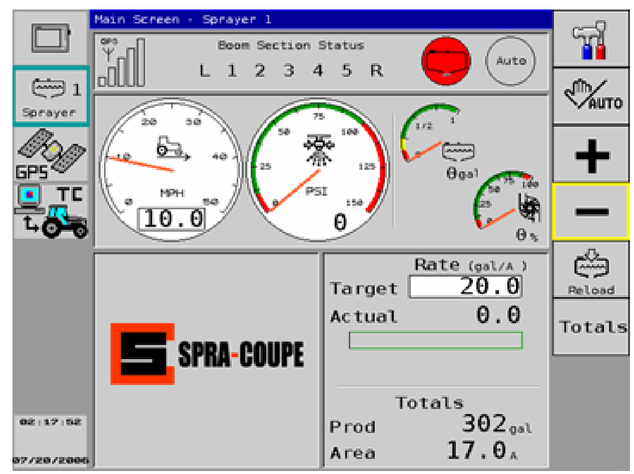
- ISOBUS Gateway – Virtual Terminal Examples









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ISOBUS – Physical Layer

- CAN Specifications
  - Transmission speed: 250 kBit/s, Bit-time is 4µs
  - Synchronize on recessive to dominant edge only.
  - Use a single sample point
  - Sample time is to be 80 % ± 3 % of the bit time, referenced to the start of the bit time.
  - Electrical limitations limit ISOBUS to 30 nodes per segment

- Connector specifications
  - Twisted quad cable.
  - CAN_H and CAN_L carry differential communications signals
  - TBC_PWR and TBC_RTN provide power for the terminating bias circuits (TBCs) on the bus segments

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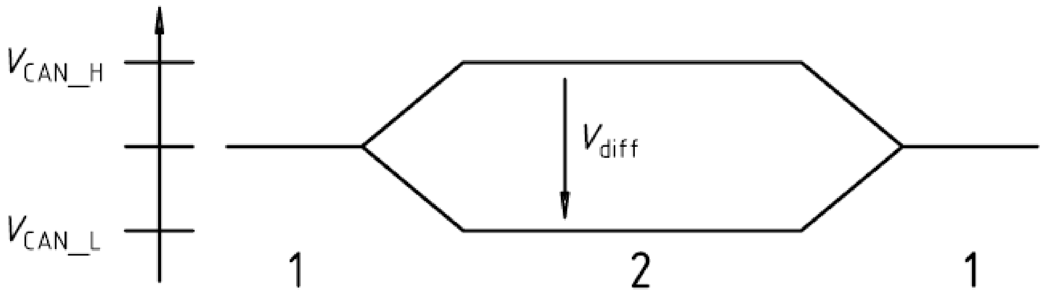
ISOBUS – Physical Layer

- Differential transmission
  - Bits are detected based on V_{diff} voltage only
  - Terminating bias circuits generate mean voltage level that represent recessive bus states
  - Provides termination that prevents reflections



Key

1 Recessive

2 Dominant

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ISOBUS – Physical line failures

- Case 1: CAN_H interrupted between “first” or “last” ECU and a TBC (loss of termination)
  - Data communications shall be able to continue between all nodes.
  - Fault indication shall be provided by the ECU.
  - There could be a reduction in the signal-to-noise ratio or an increase in electromagnetic emissions, or both.

- Case 2: CAN_H shorted to ECU_PWR
  - Data communications shall be able to continue between all nodes. Fault indication shall be provided by the ECU.
  - There could be a reduction in the signal-to-noise ratio and an increase in electromagnetic emissions. (The system will be operating single-ended, since this will normally be recognized as a fault by the bus transceiver.)

- Case 3: CAN_L shorted to GND
  - Data communications shall be able to continue between all nodes, because the bus voltages will be within the allowed common mode voltage range.
  - Fault indication shall be provided by the ECU.
  - The signal-to-noise ratio will be reduced and electromagnetic emissions could increase. Electromagnetic immunity will decrease. (The system will be operating single-ended, since this will normally be recognized as a fault by the bus transceiver.)

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ISOBUS – Physical line failures

- Case 4: CAN_H shorted to GND
  - Data communications shall be able to continue between nodes.
  - Fault indication shall be provided by the ECU.
  - The signal-to-noise ratio will be reduced and electromagnetic emissions could increase. Electromagnetic immunity will decrease. Fault indication shall be provided by the ECU. (The system will be operating single ended, since this will normally be recognized as a fault by the bus transceiver.)

- Case 5: CAN_H interrupted
  - Data communications shall be able to continue between nodes on each side of the interruption, even though it might not be possible to maintain communications between nodes across the interruption.
  - Fault indication shall be provided by the ECU.
  - There could be a reduction in the signal-to-noise ratio between nodes on opposite sides of the interruption.

- Case 6: CAN_L interrupted
  - Data communications shall be able to continue between nodes on each side of the interruption, even though it might not be possible to maintain communications between nodes across the interruption.
  - Fault indication shall be provided by the ECU.
  - There could be a reduction in the signal-to-noise ratio between nodes on opposite sides of the interruption.

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ISOBUS – Physical line failures

- Case 7: CAN_L shorted to ECU_PWR
  - Data communications shall be able to continue between all nodes.
  - Fault indication shall be provided by the ECU.
  - There could be a reduction in the signal-to-noise ratio because the system will be operating single-ended.

- Case 8: TBC_PWR shorted to GND
  - Data communications shall be able to continue between all nodes.
  - Fault indication shall be provided by the ECU.
  - There could be a reduction in the signal-to-noise ratio as the system will be operating with only one TBC and incorrect signal levels.

- Case 9: CAN_L opened to a single ECU
  - Data communications shall be able to continue between all nodes.
  - Fault indication shall be provided by the ECU.
  - There could be a reduction in the signal-to-noise ratio, as this node will be transmitting single-ended.
  - Receiver time constants will be important in this fault condition. The receivers will need to be able to switch to single-ended receive without bit loss when this ECU begins transmitting.

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ISOBUS – Physical line failures

- Case 10: CAN_H opened to a single ECU
  - Data communications shall be able to continue between nodes.
  - Fault indication shall be provided by the ECU.
  - There could be a reduction in the signal-to-noise ratio as this node will be transmitting single-ended. Receiver time constants will be important in this fault condition. The receivers will need to be able to switch to single-ended receive without bit loss when this ECU begins transmitting.

- Case 11: CAN_H shorted to CAN-L
  - Data communications will not be possible.

- Case 12: TBC_PWR interrupted between “supply-end” and “far-end” terminators
  - Data communications shall be able to continue between all nodes.
  - Fault indication shall be provided by the ECU.
  - There could be a reduction in the signal-to-noise ratio, since the signal lines will be loaded to ground by the TBC, which will be unpowered.

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ISOBUS – Physical line failures

- Case 13: Both bus signal lines interrupted at same location
  - Data communications between nodes on opposite sides of an interruption will not be possible.
  - Data communications between nodes on the same side of an interruption shall be able to continue, but may do so with reduced signal-to-noise ratio.
  - Fault indication shall be provided by the ECU.

- Case 14: TBC_RTN interrupted between “supply-end” and “far-end” TBCs
  - Data communications between nodes will not be possible.
  - Fault indication shall be provided by the ECU.

- Case 15: CAN_L interrupted between “first” or “last” ECU and TBCs
  - Data communications shall be able to continue between nodes.
  - Fault indication shall be provided by the ECU.
  - There could be a reduction in the signal-to-noise ratio or an increase in electromagnetic emissions, or both. (The swing on CAN_H will be essentially twice that on CAN_L, thereby allowing continued operation.)

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ISOBUS – Physical line failures

- Case 16: Battery supply interrupted before reaching TBCs
  - Data communications between nodes will not be possible. Fault indication shall be provided by the ECU.
- Case 17: Ground interrupted before reaching TBCs
  - Data communications between nodes will not be possible. Fault indication shall be provided by the ECU.
- Case 18: Both CAN_H and CAN_L open to an ECU (loss of bus segment)
  - If a node becomes disconnected from its bus segment, the remaining nodes shall be able to continue communications.
- Case 19: Node power loss
  - If a node loses power, or is in a low-voltage condition, the remaining nodes shall be able to continue communications.

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ISOBUS – Physical line failures

- Case 20: Node ground loss
  - If a node loses ground, the remaining nodes shall be able to continue communications.
- Case 21: Loss of one TBC
  - Data communications shall be able to continue between all nodes.
  - Fault detection by any ECU will probably not be possible.
  - There could be a reduction in the signal-to-noise ratio and an increase in electromagnetic emissions because the media will no longer be terminated properly.
  - If both TBCs are disconnected, communications will most likely fail.
- Case 22: CAN_H shorted to TBC_PWR
  - Data communications shall be able to continue between all nodes. Fault indication shall be provided by the ECU.
  - There could be a reduction in the signal-to-noise ratio and an increase in electromagnetic emissions. (The system will be operating single-ended, since this will normally be recognized as a fault by the bus transceiver.)

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ISOBUS – Physical line failures

- Case 23: CAN_L shorted to TBC_PWR
  - Data communications shall be able to continue between all nodes. Fault indication shall be provided by the ECU.
  - There could be a reduction in the signal-to-noise ratio and an increase in electromagnetic emissions. (The system will be operating single-ended, since this will normally be recognized as a fault by the bus transceiver.)

- Case 24: Topology parameter violations (i.e. bus or stub length, node spacing)
  - Data communications via the bus might be possible, but with a reduction in the signal-to-noise ratio and possible loss of arbitration.

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ISOBUS – Physical line failures

- Possible threats
  - Loss of performance (SNR ratio, reflections, emissions)
  - Loss of individual stations
  - Loss of communication (in rare cases)

  - ECUs need to provide fault indication

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- ISOBUS – Control functions - Names
  - Control functions are executed within ECUs
    - Each ECU realizes at least one control function
    - Has at least one NAME assigned
  - Each control function has a NAME
    - 8 Byte Field that describes the control function
    - NAMEs need to be unique
    - Used to assign numerical address that enables access conflict resolution
  - Working set
    - Group of NAMEs (control functions) that belong together
    - Deploed to the same or to different ECUs
      - Enables shared control loops

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- Structure of the NAME field

Field	Definition	No. of bits	Byte no.	Byte ordering [a]
Self-configurable address	Indicates whether an ECU is self-configurable (1) or not (0); needs always to be known and set to the appropriate value	1	8	Bit 8: Self-configurable address
Industry group	Defined and assigned by ISO, identifies NAMEs associated with industries (e.g. agricultural equipment)	3		Bit 7 to bit 5: Industry group (most significant at bit 7)
Device class instance	Indicates occurrence of a particular device class in a connected network; definition depends on industry group field contents (see Figure 1)	4		Bit 4 to bit 1: Device class instance (most significant at bit 4) [b]
Device class	Defined and assigned by ISO, provides a common NAME for a group of functions within a connected network; when combined with an industry group can be correlated to a common NAME, e.g. “planter” with “agricultural equipment”	7	7	Bit 8 to bit 2: Device class (most significant at bit 8)
Reserved	Reserved for future definition by ISO	1		Bit 1: Reserved
Function	Defined and assigned by ISO: when value between 0 and 127, independent of any other field for definition; when > 127 and < 254, definition depends on device class; when combined with industry group and device class, can be correlated to a common NAME for specific hardware, though not implying any specific capabilities	8	6	Bit 8 to bit 1: Function (most significant at bit 8)

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- Structure of the NAME field

Function instance	Indicates specific occurrence of a function on a particular device system of a network [a]	5	5	Bit 8 to bit 4: Function instance (most significant at bit 8)
ECU instance	Indicates which of a group of ECUs associated with a given function is referenced [c]	3		Bit 3 to bit 1: ECU (most significant at bit 3)
Manufacturer code	Assigned by committee (see ISO 11783-1), indicates manufacturer of ECU for which the NAME is being referenced; independent of any other NAME field	11	4	Bit 8 to bit 1: Most significant 8 bits of manufacturer code (most significant at bit 8)
			3	Bit 8 to bit 6: Least significant 3 bits of manufacturer code (most significant at bit 8)
Identity number	Assigned by the ECU manufacturer, necessary where the NAME is not unique (i.e. two identical NAMEs on the same network)	21		Bit 5 to bit 1: Most significant 5 bits of identity number (most significant at bit 5)
			2	Bit 8 to bit 1: Second byte of identity number code (most significant at bit 8)
			1	Bit 8 to bit 1: Least significant byte of identity number (most significant at bit 8) [c]

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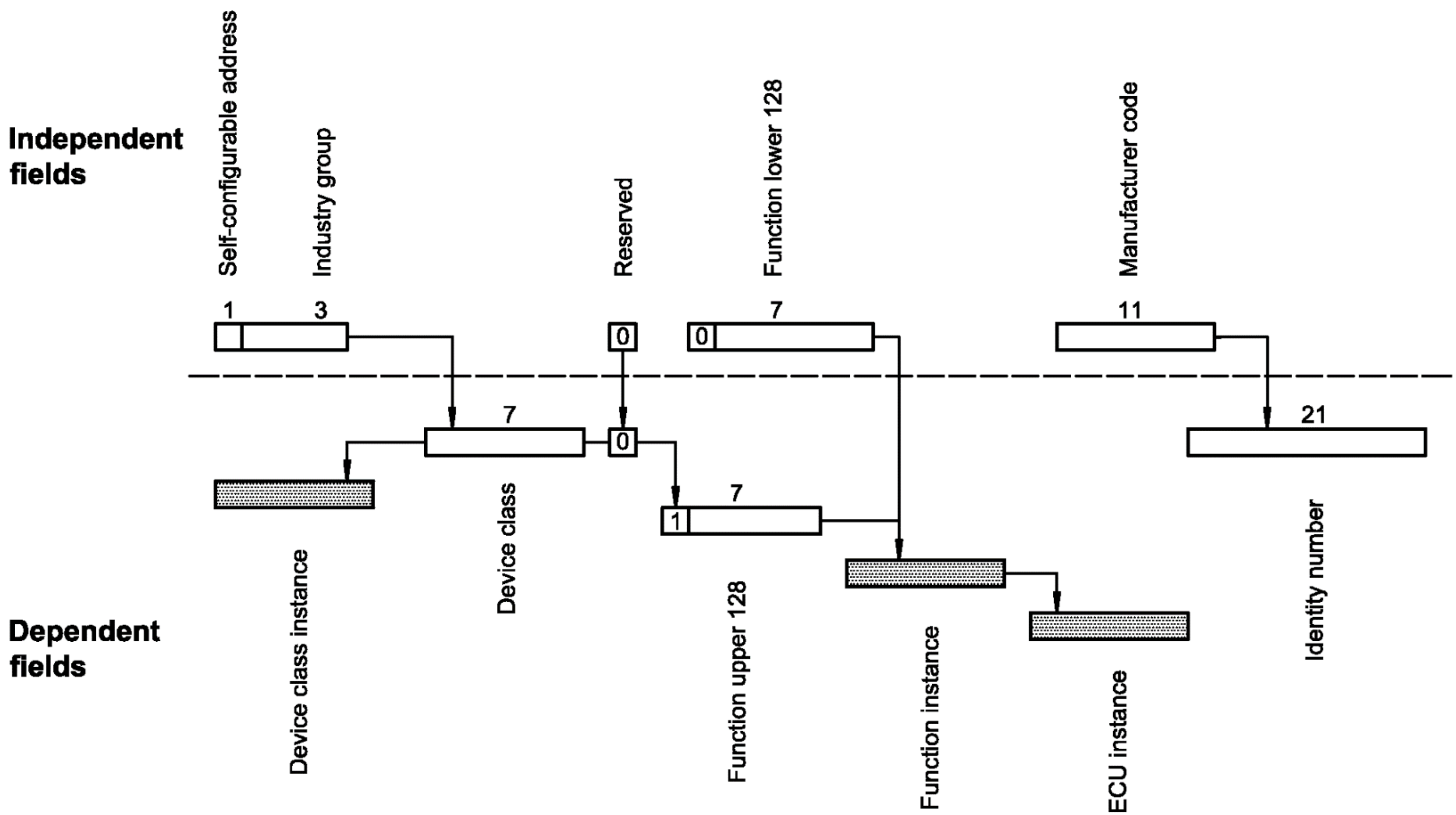
- ISOBUS –Name Field



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- ISOBUS – Names
  - Names must be unique
    - Manufacturer Code
    - IDs must be uniquely assigned by manufacturer
    - Instances should be re-assignable in case that multiple ECUs with same function are connected

- Names are used to claim addresses
  - Address: Temporal ID of a ECU or Function (8 Bits)
  - Addresses are claimed based on Name
    - Lower numerical value is higher priority
  - Nodes may be able to self-configure addresses or rely on preconfigured addresses
    - Address configuration/claiming is done during system startup or after connecting an implement

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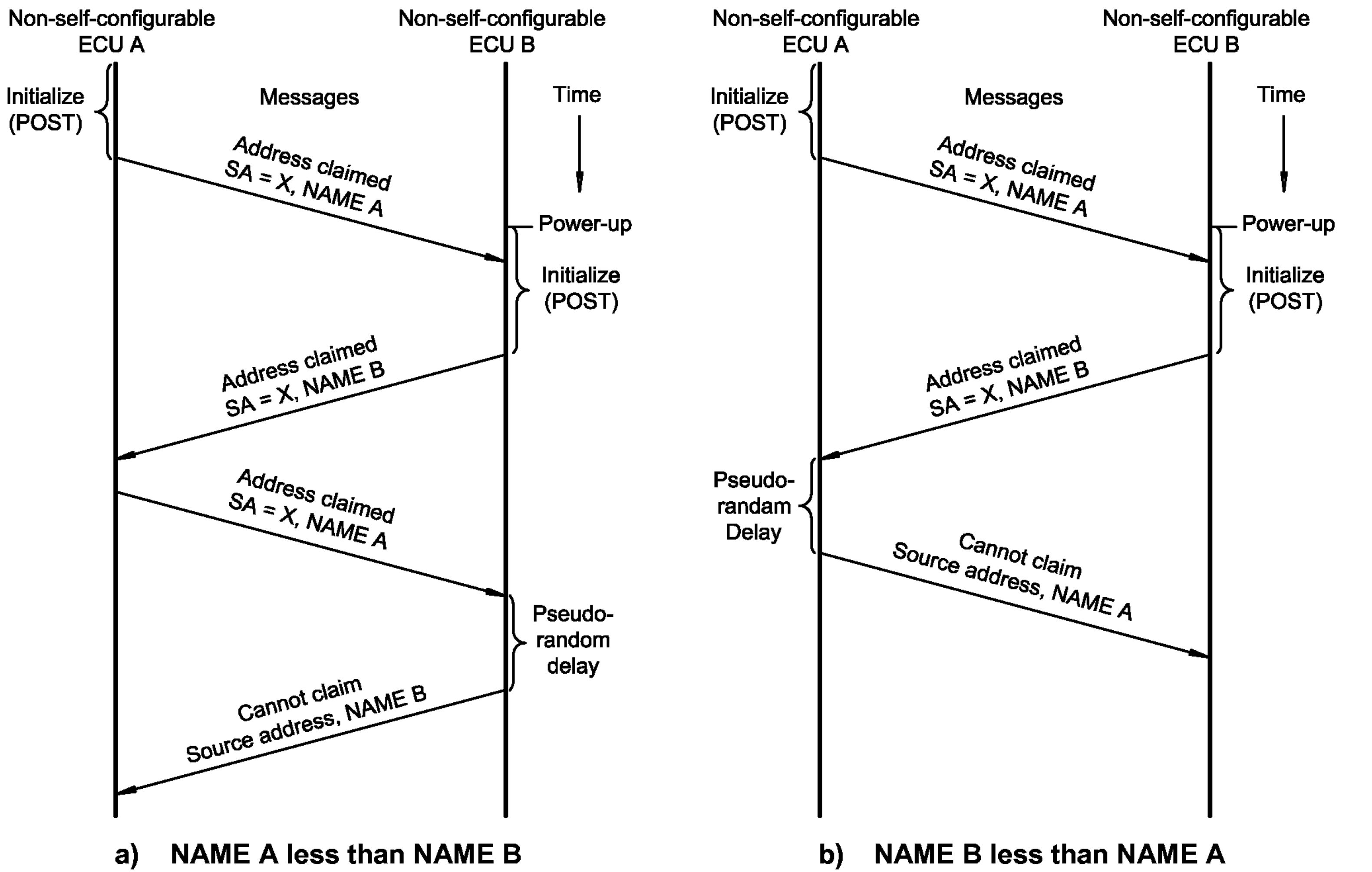

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- ISOBUS – Addresses
  - Nodes that get no address must not send any messages but cannot claim message
  - Reasons
    - Nodes cannot change pre-configured Address
    - No free addresses are available

- CAN Arbitration includes addresses
  - Collisions are avoided for nodes with addresses
  - Collisions could occur during address claiming phase
    - Conflict resolution based on pseudo random backoff delay
    - Unique NAME is used to seed backoff delay

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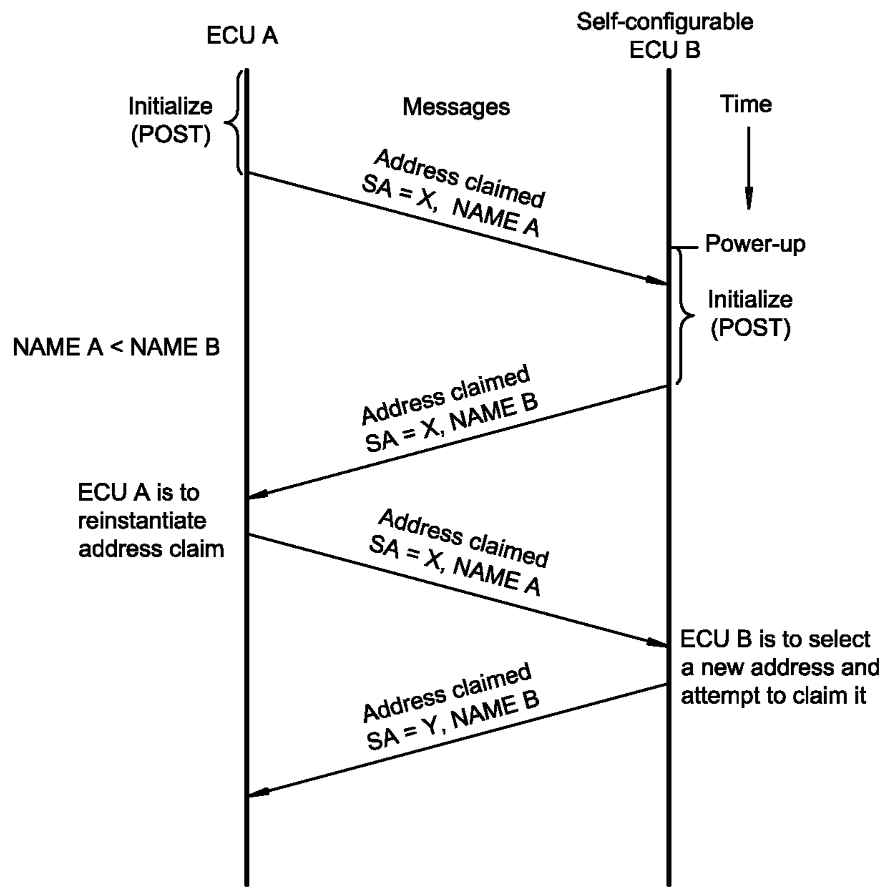

Figure 6 — Initialization of a non-configurable-address ECU (A) with NAME of higher priority than that of a self-configurable-address ECU (B)

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- ISOBUS - Communication
  - Broadcast communication transmits data on the network without directing it to a specific destination. This configuration permits any control function within an ECU to use the data without using additional request messages.
  - ISO 11783 also specifies that a specific destination address be included within the CAN identifier of the message when a message is directed to a particular control function.
    - The destination-specific message format is different from the broadcast message format.
  - Proprietary communication is also permitted in ISO 11783, using either destination-specific messages or broadcast message formats.

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- ISOBUS - Realization
  - ISOBUS is realized via CAN bus extended frames (ISO 11783)
  - Full strategy specified for CAN Bus extended frames only
  - CAN Bus Basic frames may be used together with ISOBUS frames but must obey restrictions as defined in ISO 11783-3
  - Arbitration works exactly as specified for CAN bus networks

- ISOBUS fields
  - SOF: Start of Frame (derived from CAN)
  - P# Message priority bits
  - R# Reserved Bit #n
  - SA# Source Address Bit #n
  - DP Data Page
  - PF# PDU Format Bit #n
  - PS# PDU Specific Bit #n
  - DLC Data length code (4 Bits – see CAN bus)

Bit No.	29 bit identifiers	
	CAN	ISO 11783
1	SOF	SOF *)
2	ID 28	P 3
3	ID 27	P 2
4	ID 26	P 1
5	ID 25	R 1
6	ID 24	DP
7	ID 23	PF 8
8	ID 22	PF 7
9	ID 21	PF 6
10	ID 20	PF 5
11	ID 19	PF 4
12	ID 18	PF 3
13	SRR (r)	SRR *)
14	IDE (r)	IDE *)
15	ID 17	PF 2
16	ID 16	PF 1
17	ID 15	PS 8
18	ID 14	PS 7
19	ID 13	PS 6
20	ID 12	PS 5
21	ID 11	PS 4
22	ID 10	PS 3
23	ID 9	PS 2
24	ID 8	PS 1
25	ID 7	SA 8
26	ID 6	SA 7
27	ID 5	SA 6
28	ID 4	SA 5
29	ID 3	SA 4
30	ID 2	SA 3
31	ID 1	SA 2
32	ID 0	SA 1
33	RTR (x)	RTR *)
34	r1	r1 *)
35	r0	r0 *)
36	DLC 4	DLC 4
37	DLC 3	DLC 3
38	DLC 2	DLC 2
39	DLC 1	DLC 1

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Each CAN Bus data frame encodes a single ISOBUS PDU

- Header format

P Priority	DP Data Page	PF PDU Format	PS PDU Specific	SA Source Address	DLC Data Length Code

The following fields are defined for a ISOBUS PDU:

- Priority (P) – 3 Bits (0-7)
  - Priority bits are used to optimize message latency for transmission onto the bus only.
  - They should be globally masked off by the receiver (ignored).
  - The priority of any message can be set from highest, 0 (0002), to lowest, 7 (1112).
  - The default for all control oriented messages is 3 (0112).
  - The default for all other informational, proprietary, request and NACK messages is 6 (1102).

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- Data Page (DP) – 1 Bits (0/1)
  - The data page bit sets an auxiliary page of Parameter Group descriptions.
  - Assignment of all Parameter Group Numbers available in page zero are complete (filled) before the page one assignments are made.
  - Each page contains 4096 Parameter Groups with a unique Number.

- PDU Format (PF) – 8 Bits (0-255)
  - The PDU Format is an 8-bit field that determines the PDU format and is one of the fields used to determine the Parameter Group Number assigned to the CAN data field.
  - Contains parameter group number
  - If the value of this field is below 240, the PS field contains a destination address.
  - If the value of this field is above or equal to 240, the PS field contains an extension of the Group Number; in this case, the message is broadcasted to all bus nodes.

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- PSU Specific Field (PS) – 8 Bits (0-255)
  - The PDU Specific field is an 8-bit field and its definition depends on the PDU format.
  - Depending on the PDU format value, it can be:
    - Destination Address (PF < 240)
    - Extension of Group Number (PF > 239)

- PS as Destination Address (DA)
  - This field defines the specific address to which the message is being sent. Any other controller should ignore this message. The global Destination Address (255) requires all controllers to listen and respond accordingly as message recipients.

- PS as Group Extension (GE):
  - When PF represents a number > 239, it indicates that the PS field is a Group Extension.
  - The Group Extension field, in conjunction with the four least significant bits of the PDU Format field, provide for 4096 Parameter Groups per data page.
  - These 4096 Parameter Groups are only available using the Group Extension Format PDU.
  - In addition, 240 Parameter Groups are provided in each data page for use only in the Destination Specific Format PDU.

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- Source Address Field (SA) – 8 Bits (0-255)
  - The Source Address field is 8 bits long.
  - There shall only be one controller on the network with a given source address.
  - Therefore, the source address field assures that the CAN identifier is unique, as required by CAN.

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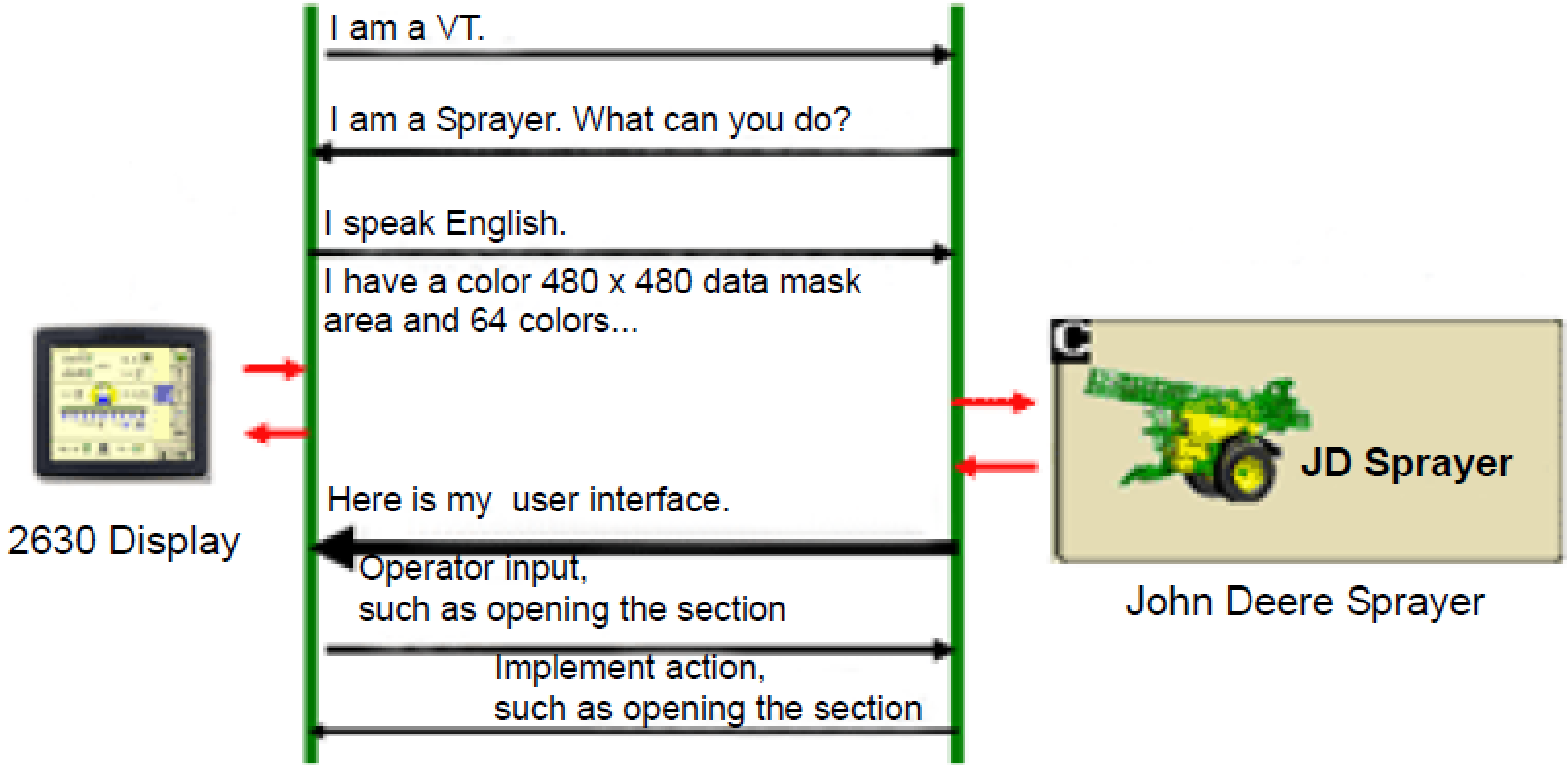
ISOBUS – Example Communication using ISOBUS frames



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ISOBUS – Encoding of Message Payload

- Smaller messages (0-8 Bytes payload)
  - When eight or less bytes of data are required for expressing a given Parameter Group, then all eight data bytes of the CAN data frame can be used.
  - Once the number of bytes of data associated with a Parameter Group Number is specified, it cannot be changed.

- Larger messages (9-1785 Bytes payload)
  - Communication is split into multiple CAN Data Frames (Multi-Packet transmission)
  - Those packets transmitted in separate message frames.
    - First byte of payload of each message frame contains sequence number
    - Leads to maximum message size: 255 * 7 Bytes = 1785 Bytes
  - At the destination, the individual message frames must be received, parsed, and the original message reassembled from the received packets.
  - Multi-Packet transmissions are framed by transport protocol frames

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- ISOBUS – Transport Protocol Frames

- Large Broadcast Messages
  - Broadcast Announce Message (BAM) frame type is used to inform all the nodes of the network that a large message is about to be broadcast.
  - The BAM message contains the Parameter Group Number of the large message to be broadcast; its size and the number of belonging message frames.
  - Controllers interested in the broadcast data are then required to allocate the resources necessary to receive and reassemble the message.
  - After the transmission of the BAM message, Data Transport messages passed from the originator of this message will contain the packetized broadcast data.
  - Each node must send only one concurrent large broadcast message at a time
  - Receivers must be ready to receive multiple concurrent large broadcast messages from different senders

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- ISOBUS – Transport Protocol Frames

- Transmission of large unicast Messages (1/2)

  - Request to Send
    - Transmission starts with Connection Mode: Request to Send message
    - The TP.CM_RTS message informs a controller that another controller on the network wishes to open a virtual connection with it.
    - It consists of a message with the source address field equal to that of the originating controller, destination address set to that of the intended recipient of a large message, and the remaining fields set appropriately for the Parameter Group Number being sent.

  - Clear to Send
    - The TP.CM_CTS message is used to respond to the Request To Send message.
    - It informs the peer controller that it is ready to receive a number of frames that make up a large message.

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- ISOBUS – Transport Protocol Frames

- Transmission of large unicast Messages (2/2)

  - End of Message ACK
    - The TP.CM_EndofMsgACK message is passed from the recipient of a large message to its originator indicating that the entire message was received and reassembled correctly.

  - Connection Abort
    - The TP.Conn_Abort message is used by either controller involved in a virtual connection to close the connection without completing the transfer of the message.
    - Upon receipt of a Connection Mode Request To Send message, a node must determine if there are sufficient resources available to deal with the message for which this connection is sought. If this is not possible, a Connection Abort message would be sent. It may also be sent in other situations to indicate the unavailability of the receiving controller.

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- ISOBUS
  - Application level coupling of tractor and 3rd implements
  - Dynamic couling at system runtime
  - Built based on CAN bus

- Technology
  - Uses CAN Bus arbitration scheme to avoid collissions
    - Uses CAN bus extended frames
    - Redefines meaning of most CAN fields but remains compatible to legacy CAN
    - Encodes sender ID into frame header to ensure unique frame IDs
  - Enables transmission of large unicast and broadcast frames
    - Necessary for transmission of user interfaces, object pools, and large generic data
    - Device IDs are dynamically assigned