UQM TECHNOLOGIES INC.
CAN Manual
Version 4.08 January 2011
Referring to firmware versions 4.08 and above

CAN COMMUNICATION SUMMARY

This brief description should be used in conjunction with the User's Manual.

All the information in this document is preliminary and is subject to change.

Note: Throughout this documentation a positive current is defined as current flowing into the inverter. A negative current is defined as current flowing out of the inverter.

Note: DBC files containing the message and signal formats for all CAN modes can be found in the installation directory for the UQM Motor Controller Diagnostic Software, defaulted to C:\Program Files\UQM Technologies\Motor Controller v4.08.

Note: All signals listed as "Reserved" in this document may be used for factory testing purposes, and may contain non-zero, varying values.

1. OVERVIEW

The CAN system is capable of three modes of operation:

- Torque control with speed limits
- Speed control with torque limits
- Voltage control with current limits

All three modes are commanded through the *Universal Command.*

Note: In order for the user to switch between these three control modes on the fly, the system must be configured to accept commands of all three types; refer to section 'Dynamically Switching Control Modes' (Section 2c) for details on enabling this feature.

The CAN protocols are based on the SAE J1939-21 specification, adding a user-selectable option for either 29-bit or 11-bit identifiers. Please refer to this document for more detailed information. This protocol specifies the following:

- Protocol Data Unit (PDU format) for all proprietary messages is 239 (0xEF)
- Priority 0 is the highest priority and 7 is the lowest

The 29-bit identifier consists of the following fields:

	Priority	**0**	**0**	**PDU Format (PF)**	**PDU Specific (PS)**	**Source Address (SA)**
Bit 31-29	*Bit 28-26*	*25*	*24*	*Bits 23-16*	*Bits 15-8*	*Bits 7-0*

The Parameter Group Number (PGN) for the CAN messages can be calculated using the formula:

$$(256_{10} * PF) + PS$$

For the proprietary PDU format of 239, the PDU specific is the same as the Destination Address (DA) (i.e. address of the intended message recipient node). Hence, the PGN should be configured as:
$61184_{10} + 218_{10} = 0xEF00_{16} + 0x00DA_{16}$

This protocol differs slightly in the case of 11-bit identifiers:

- The Source Address specifies the address of the UQM controller only – it does not change, regardless of whether the message is incoming or outgoing.
- The Message Direction bit is set to a 1 for outgoing messages sent by the UQM controller, and a 0 for incoming messages received by the UQM controller.
- Priority 0 is the highest priority and 7 is the lowest

The 11-bit identifier consists of the following fields:

Source Address (SA)	*Message Direction*	Priority
Bits 10-4	*Bit 3*	*Bits 2-0*

The CAN communication is configurable to any one of the following baud rates: 125 Kbps, 250 Kbps, 500 Kbps, and 1 Mbps. Appendix 3 lists the detailed CAN parameters.

The endianness of all CAN messages defaults to little endian, although this can be changed to big endian through the UQM Motor Controller Diagnostic Software, outlined below. Note that this only acts on the 16-bit values defined in the Appendix – the location and layout of 8-bit and lower values remain unchanged regardless of endianness.

The master controller of the user's system controller is configurable to any J1939 CAN network address of 0-255 when using 29-bit identifiers, and is ignored when using 11-bit identifiers. The UQM system CAN network address is configurable to any address J1939 CAN network address of 0-255 when using 29-bit identifiers, and 0-127 when using 11-bit identifiers.

The UQM Motor Controller Diagnostic Software allows the user to program each UQM controller to a different CAN address, baud rate, and command type. See the User Manual, or perform the following steps:

1. Select *Actio*ns → *System Configuration* → *Edit Current* from the UQM Diagnostic Software menu
2. Select the *Control* tab in the System Configuration dialog (Refer to Figure 1.1)
3. Select the *CANbus Control* radio button
4. Select the *CANbus Settings* tab in the System Configuration dialog (Refer to Figure 1.2)
5. Select the Drive Mode (described in Section 1)
6. Enable the *Transmit CAN messages* option
7. Enable individual messages to be transmitted (described in Section 2)
8. Select identifier *Style* (29-bit or 11-bit – defaults to 29-bit).
9. Select *Byte Order* (Little Endian or Big Endian – defaults to Little Endian).
10. Enter desired *Master Address* and *UQM Address* if using 29-bit identifiers, or only desired *UQM Address* when using 11-bit identifiers.
11. Select desired CAN baud rate and message transmission rate

Note: Each UQM system on the same CANbus must have a unique CAN network address. For more detailed information on UQM CAN messages see the Appendix located at the end of this document.

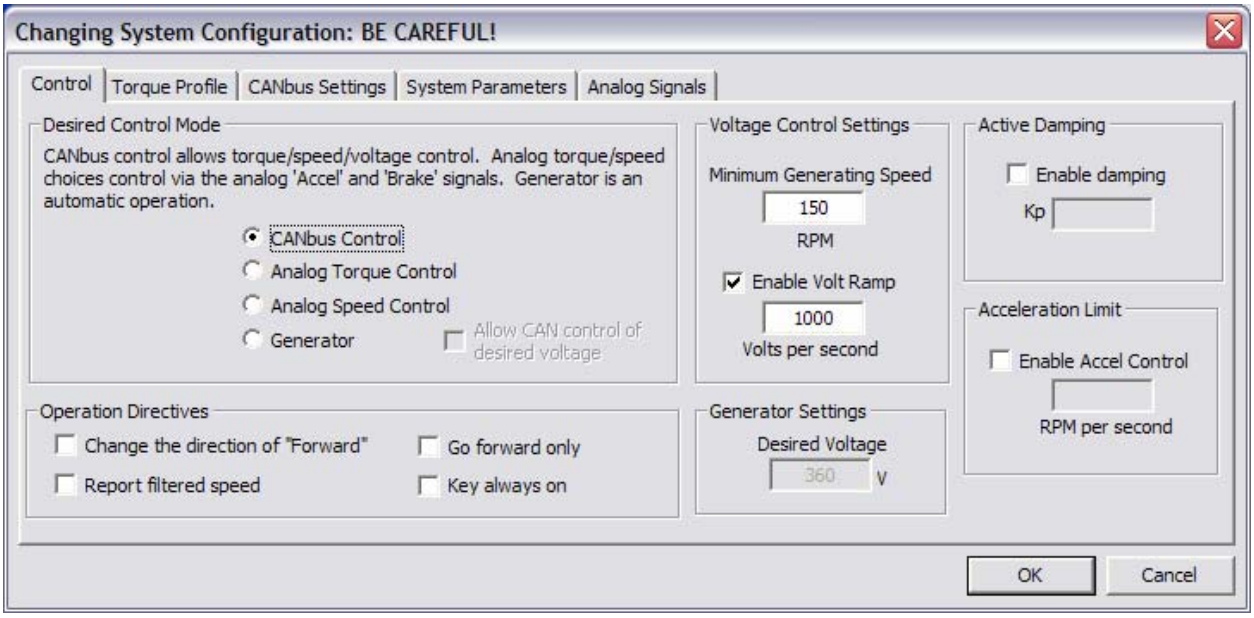

Figure 1.1 – System Configuration *Control* Tab

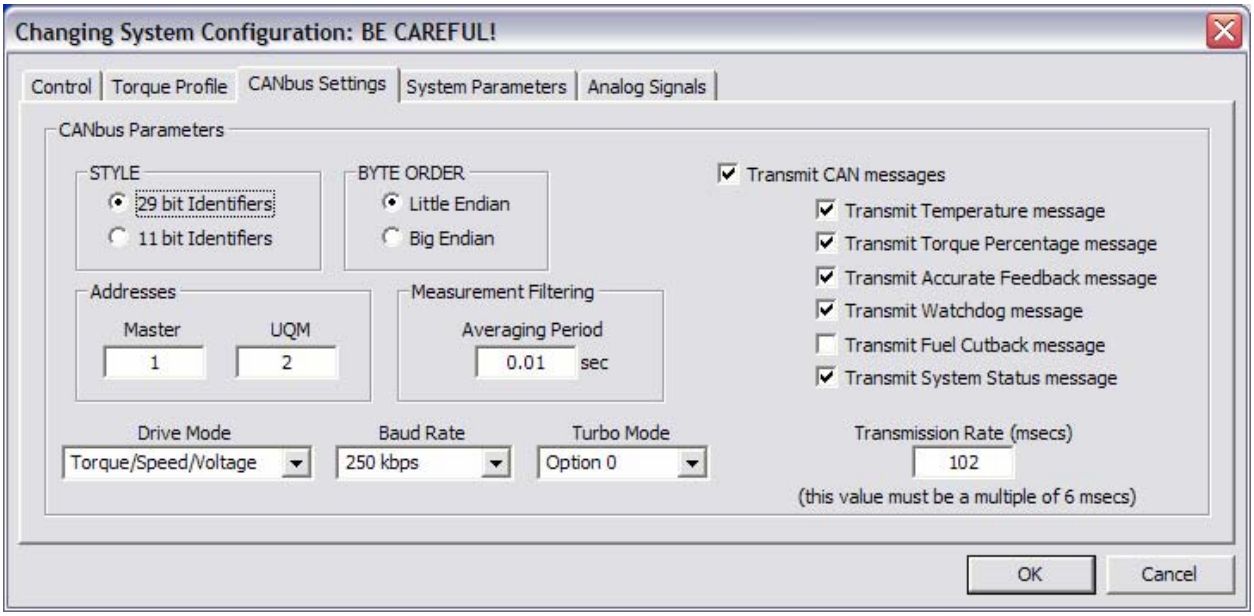

Figure 1.2 – System Configuration *CANbus* Tab

2. CAN COMMAND MESSAGES

A single message packet is used for receiving control commands from the system controller. This is called the *Universal Command.* The address assignment protocol is shown by the following examples.

If using 29-bit identifiers:

Assume the UQM's CAN address has been specified to 10 (0x0A) and the system controller is 1 (0x01). After specifying the CAN address, the hardware calculates a corresponding XTD identifier using a J1939 convention of [RXNODE], [TXNODE] → In this case the final 2 bytes in the XTD identifier are [$0A01_{16}$].

Identifier "0x14EF*rrss*" where *rr* is the receiving node address and *ss* is the sending node address.

Therefore, in this example the complete command identifier is: **"**0x14EF0A01**"**, where the CAN address on the UQM system was set to 10 (0x0A).

Bits 28, 27, and 26 of the identifier indicate the priority of this message (Bit 0 = LSB, Bit 2 = MSB). The above example shows a binary 101_2 or priority 5.

If using 11-bit identifiers:

Assume the UQM's CAN address has been specified to 10 (0x0A). Following the convention outlined on Page 2 of this document, the Universal Command would be as follows:

Identifier "*0xrrp*" where *rr* represents the UQM address, and *p* represents the direction and priority bits.

Therefore, in this example the complete command identifier is: **"**0x0A5**"**, where the CAN address on the UQM system was set to 10 (0x0A), the direction bit is zero (incoming to the UQM controller), and the priority (Bit 0 = LSB, Bit 2 = MSB) is a binary 101_2, or priority 5.

2 a) Universal Command

The CAN software is capable of receiving three command modes through the *Universal Command* whose first byte is the command byte:

- Torque Control with Speed Limits
- Speed Control with Torque Limits
- Voltage Control with Current Limits

The priority of this message is 5 (Priority 5 Identifier "0x14EF*rrss*" for 29-bit identifiers, or Identifier "0x*rr*5" for 11-bit identifiers). The message contains 8 bytes: the first byte is the command byte and the second byte contains control bits. The last 6 bytes contain the requested value and desired limits.

Torque Control Command [0x01]
The byte following the command byte contains control bits. It is used to send an enable command (bit 4, where the LSB is bit 0) and direction control (bit 3, where the LSB is bit 0). If bit 4 is set to zero, the system is considered as disabled and will control to zero torque. If bit 4 of this byte is set to one, then the system is considered as enabled and ready to control to the requested torque.

Note: The enable bit is coupled with the analog enable bit. You need both the CAN enable bit and the analog enable bit to be ON in order to request an enable of the system.

Bit 3 of the byte following the command byte is the direction bit. If bit 3 is set to 1, the motor will go in the forward direction. If it is set to 0, the motor will go in the opposite direction. This bit is coupled with the direction bit in the configuration menu. In the configuration menu, the user is allowed to define whether '1' defines a clockwise rotation of the motor or a counter clockwise rotation. To change the direction of rotation, follow these steps:

1. Select *Actio*ns → *System Configuration* → *Edit Current* from the inverter diagnostic software menu
2. Select the *Control* tab in the System Configuration dialog (refer to Figure 1.1)
3. Toggle the *Change Direction of "Forward"* selection

Bits 6 and 7 of the control byte can be used to set the Turbo Mode option. For more information on Turbo Mode options, see Section 2b of this document.

Following the control bits, bytes 3 & 4 contain the requested torque value. The range is -3212.8 to 3212.8 Nm with a 0.1 Nm delta. The actual range is dependent on the motor specification. Note that, even though torque requests can be made in 0.1 Nm increments, there is no guarantee that the control will react to these steps.

Following the requested torque value, bytes 5 & 6 contain the maximum speed allowed in the forward direction to achieve the desired torque, and bytes 7 & 8 contain the maximum speed allowed in the opposite direction to achieve the desired torque.

Note: The value in bytes 7 & 8 should be negative to allow the system to go into reverse – see Appendix Section 1.9.

The message details are listed in the Appendix in Section 2.3.

Speed Control Command [0x02]

The byte following the command is used to send an enable command. If bit 4 (where the LSB is bit 0) is set to zero, the system is considered as disabled and will control to zero torque. If bit 4 of this byte is set to one, then the system is considered as enabled and ready to control to the requested speed.

Note: The enable bit is coupled with the analog enable bit. You need both the CAN enable bit and the analog enable bit to be ON in order to request an enable of the system.

Bits 6 and 7 of the control byte can be used to set the Turbo Mode option. For more information on these options, see Section 2b of this document.

Following the control bits, bytes 3 & 4 contain the requested speed value. The range is -16064 to 16064 rpm with a 0.5 rpm delta. The actual range is dependent on the motor specification. Note that, even though speed requests can be made in 0.5 rpm increments, there is no guarantee that the control will react to these steps.

Following the requested speed value, bytes 5 & 6 contain the maximum motoring torque allowed to achieve the desired speed, and bytes 7 & 8 contain the maximum generating torque allowed to achieve the desired speed.

The message details are listed in the Appendix in Section 2.3.

Voltage Control Command [0x03]

Note: Voltage control requires that the controller's voltage bus **MUST** have a separate UQM capacitor box attached to it for safe control.

Voltage Control is always enabled, regardless of the CAN message or the analog enable line status. The enable bit is not utilized in Voltage Control, and will be ignored if sent. Note however, that if the speed is very slow (typically 200rpm or lower), then voltage control is not possible and the motor is controlled to a zero torque value until the speed goes above 200 rpm.

The Turbo Mode option is not active in voltage control. Voltage control always uses option 0. For more information on this option, see Section 2b of this document.

Following the control bits, bytes 3 & 4 contain the requested voltage value. The range is -3212.8 to 3212.8 V with a 0.1 V delta. The actual range is dependent on the motor specification. Note that, even though voltage requests can be made in 0.1 V increments, there is no guarantee that the control will react to these steps.

Following the requested voltage value, bytes 5 & 6 contain the maximum motoring current allowed to achieve the desired voltage, and bytes 7 & 8 contain the maximum generating current allowed to achieve the desired voltage.

The message details are listed in the Appendix in Section 2.3.

2 b) Turbo Mode Option Selection

Turbo mode was designed to maximize the power available at the highest possible efficiency. It dramatically lowers the IGBT switching loss, but in turn, creates harmonic content in the AC cables and electric machine, leading to engineering trade-offs. The primary tradeoff is efficiency versus audible noise. Lower speed transitions into Turbo mode will provide higher efficiency, but will create higher audible noise in the area of the transition. Higher speed transitions into Turbo mode will provide a quieter system, but with reduced efficiency at speeds leading up to the transition speed.

The following options give the user some control over these tradeoffs by changing the Turbo mode transition setpoints. These options are as follows:

Option 0: This is the default configuration, and with this option selected, the system will transition in and out of Turbo mode based upon the operating speed and voltage. There is a 200 RPM hysteresis band to this transition. Prior to V4.08 software, this was the only method available for switching in and out of Turbo mode. This option is included to provide backward compatibility for customers who want the exact same transitions that were standard in pre-V4.08 code. Datasheet information reflects operation in this mode.

Option 1: This will increase the speed range over which Turbo mode operates. The transition will occur at a lower speed compared to any of the other options. When compared to Option 0, the result will be higher system efficiency between the Option 1 and Option 0 transition speeds. The audible noise of the system will be higher between these speeds.

Option 2: This mode restricts the Turbo mode to a small range, transitioning at a higher speed than any of the other options. The efficiency leading up to the transition speed, therefore, will be lower than any of the other options. This will also be the quietest mode, with the lowest audible noise at speeds leading up to, and including, the transition speed.

These options are selectable in CAN and may be changed on the fly by the user:

Option 0 is selected with control bits 6 and 7 set to 00
Option 1 is selected with control bits 6 and 7 set to 01
Option 2 is selected with control bits 6 and 7 set to 10
Note: Control bits 6 and 7 set to 11 is RESERVED***

The default option is selectable in the System Configuration (See Figure 1.2). Sending a CAN command change will override this initial Turbo mode setting.

2 c) Dynamically Switching Control Modes

The user may switch between torque control, speed control, and voltage control modes dynamically by sending the appropriate CAN commands to the system. To enable this feature do the following:

1. Ensure CANbus control is enabled on the *Control* tab of the *System Configuration* dialog (Refer to Figure 1.1)
2. Set *Drive Mode* (on *CANbus Settings tab*) to *Torque / Speed / Voltage* (Refer to Figure 1.2)

Now the system will switch between these three control modes depending on the command mode of the *Universal Command* message it receives.

2 d) CAN Watchdog Commands

CAN Watchdog Commands [0xA5]
The priority of this message is 7 (Priority 7 Identifier "0x1CEF*rrss*" for 29-bit identifiers; identifier "0x*rr*7" for incoming (to UQM) 11-bit identifiers, or identifier "0x*rr*F" for outgoing (from UQM) 11-bit identifiers)

The CAN watchdog command is both received and transmitted by the UQM system – the sender and receiver addresses are swapped (29-bit identifiers) or the direction bit is flipped (11-bit identifiers) depending on whether the message has been received or transmitted. Bytes 1 & 8 should be used by the master controller to detect a watchdog error condition while bytes 1, 2 & 3 must be used by the master controller to prevent / clear an error condition.

Once communication has been established with the UQM controller, it is required that a valid command be received by it no slower than one transmission every 1 second. The valid commands that must be sent every second depend on the CAN drive mode (see note below) of the UQM controller. If the drive mode is set to *torque control mode* then only torque

commands are valid, if in *speed control mode* then only speed commands are valid, if in *voltage control mode* then only voltage commands are valid, and if in *automatic mode* then any of the three commands are valid. In addition, a *reset CAN watchdog timer* message is always valid irrespective of the CAN drive mode. If a valid CAN message is not received then the UQM system will issue a watchdog error condition, and the following will occur:

- If the controller is in Torque Control, the desired torque will be reduced to 0 Nm.
- If the controller is in Speed Control, the desired speed will be reduced to 0 rpm, and the motoring and regeneration torque limits will be reduced to 10% of the maximum.
- If the controller is in Voltage Control, it will maintain the currently requested voltage.

A *reset CAN watchdog timer* message should be sent to the UQM controller if the user wants to ensure a watchdog error condition does not happen and the user is not sending one of the other valid commands. To send a *reset CAN watchdog timer* message, byte 2 of the CAN Watchdog Command should be set to 0xA5.

If a watchdog error condition occurs, it is assumed that there is a problem with the physical CAN layer. Once a CAN watchdog error condition occurs, there are two ways to reset it. One method is to power down the high voltage bus, disconnect the 12V power supply, fix the physical CAN problem, and then reapply 12V and high voltage. If there is no physical CAN layer problem, then another method of resetting the watchdog is to send a 0x5A command in byte 3 of the CAN Watchdog Command after sending a valid drive command.

The message details are listed in the Appendix in Section 2.4.

Note: To set the CAN drive mode perform the following steps:

1. Select *Actions* → *System Configuration* → *Edit Current* from the inverter diagnostic software menu
2. Select the *CANbus Settings* tab in the System Configuration dialog
3. Select the desired drive mode from the *Drive Mode* dropdown menu.

3. CAN STATUS MESSAGES

Multiple identifier packets are used to send status messages from the UQM controller. These are detailed below. The address assignment protocol is shown by the following examples:

If using 29-bit identifiers:

Assume the UQM controller's CAN address has been specified to 10 (0x0A). The system controller is assigned address 1 (0x01). After specifying the CAN address, the hardware calculates a corresponding XTD identifier using a convention of ([RXNODE][TXNODE]). In this case the final 2 bytes in the XTD identifier are

[$010A_{16}$]. Note that this is reversed from the received packet described for received messages.

The seven transmitted messages are as follows:

- Priority 1 Identifier "0x04EF*rrss*", Accurate Feedback
- Priority 2 Identifier "0x08EF*rrss*", System Status Message
- Priority 3 Identifier "0x0CEF*rrss*", Emergency Fuel Cutback
- Priority 4 Identifier "0x10EF*rrss*", Reserved
- Priority 5 Identifier "0x14EF*rrss*", Limited Torque Percentage
- Priority 6 Identifier "0x18EF*rrss*", Drive Temperatures
- Priority 7 Identifier "0x1CEF*rrss*", CAN Watchdog Status

If using 11-bit identifiers:

Assume the UQM's CAN address has been specified to 10 (0x0A). Following the convention outlined on Page 2 of this document, the UQM address would be [$0x0A_{16}$]. Note that the direction bit will also be a 1 for messages transmitted by the UQM controller.

The seven transmitted messages are as follows:

- Priority 1 Identifier "0x*rr*9", Accurate Feedback
- Priority 2 Identifier "0x*rr*A", System Status Message
- Priority 3 Identifier "0x*rr*B", Emergency Fuel Cutback
- Priority 4 Identifier "0x*rr*C", Reserved
- Priority 5 Identifier "0x*rr*D", Limited Torque Percentage
- Priority 6 Identifier "0x*rr*E", Drive Temperatures
- Priority 7 Identifier "0x*rr*F", CAN Watchdog Status

If CAN transmission is enabled, these status commands will be sent at regular intervals once the controller is in normal operation.

In order to enable CAN transmission of these messages, perform the following steps:

1. Select *Actio*ns → *System Configuration* → *Edit Current* from the inverter diagnostic software menu
2. Select the *CANbus* tab in the System Configuration dialog (Refer to Figure 1.2)
3. Enable the *Transmit CAN messages* option
4. Enable the desired messages to be transmitted by the inverter.

3 a) Priority 1 Messages

Accurate Feedback Message

Priority 1 (Identifier "0x04EF*rrss*" for 29-bit identifiers, Identifier "0x*rr*9" for 11-bit identifiers).

This message provides the master controller with high-resolution measurements for torque, voltage, current, and speed. Note that, even though the measurements are reported at a high resolution, the actual resolution will be lower and the accuracy is typically 5% of Full Scale. Full Scale will depend on both the motor type and inverter type.

Bytes 1 & 2 contain the signed torque feedback. Its range is -3212.8 to 3212.8 Nm with a 0.1 Nm delta.

Bytes 3 & 4 contain the signed voltage feedback. Its range is -3212.8 to 3212.8 V with a 0.1 V delta.

Bytes 5 & 6 contain the signed current feedback. Its range is -3212.8 to 3212.8 A with a 0.1 A delta.

Bytes 7 & 8 contain the signed speed feedback. Its range is -16064.0 to 16064.0 A with a 0.5 RPM delta.

The message details are listed in the Appendix in Section 2.1.

3 b) Priority 2 Messages

System Status Message

Priority 2 (Identifier "0x08EF*rrss*" for 29-bit identifiers, Identifier "0x*rr*A" for 11-bit identifiers).

Bytes 1 and 2 contain the System Error. This will inform the user why the control is limiting the output power of the system.

Bytes 3 and 4 contain the System Error History. This is a latched version of the System Error word, showing what errors have occurred since the last startup.

Bytes 7 and 8 contain the system status bits. This will provide the user with additional messages indicating the current operational status of the system.

The message details are listed in the Appendix in Section 2.7.

3 c) Priority 3 Messages

Emergency Fuel Cutback (Derate/Shutdown) Message

Priority 3 (Identifier "0x0CEF*rrss*" for 29-bit identifiers, Identifier "0x*rr*B" for 11-bit identifiers).

This message is used to signal error conditions to the master controller and advise it to either reduce its power output demand from the system or shut it down completely depending on the severity of the problem. Typically the master also has control over an external device that is spinning the UQM system (i.e. internal combustion engine or ICE).

This message will work as described only if the system is in voltage control. It is assumed that as a voltage controller, the machine is spun externally as a generator. In this case, the generator system cannot self-limit without going out of voltage regulation. Instead of self-limiting and going out of regulation, the system will send a Derate/Shutdown message.

Derate (recoverable conditions) is used for conditions where normal operation is expected to resume after reducing the speed to the generator or reducing the power out of the generator. The Derate conditions are:

a. Over temperature
b. Under voltage warning (below Minimum Battery Voltage)
c. Over voltage warning (above Maximum Battery Voltage)
d. Over positive/under negative bus current
e. Over leg current
f. Over speed alarm/warning
g. Over positive/under negative phase
h. Over maximum power

Shutdown (non-recoverable conditions) is used for conditions where normal operation is not expected to resume. The Shutdown conditions are:

a. Inverter fault or fault occurred
b. Over voltage alarm – voltage went above the maximum inverter voltage (400V on a D*x*_40_*xxx* controller and 450V on a D*x*_45_*xxx* controller). Sends both Derate and Shutdown messages. The Shutdown condition is latched and the system has to be reset to clear it.
c. Broken wire safety: leg current, bus current or +/-15V supply. Sends both Derate and Shutdown messages. The system has to be reset to clear it.
d. Controller Board was not calibrated.

To aid in debugging the system, the user should examine the system status of the System Status Message. This will help determine the source of the Derate or Shutdown message.

This message is sent every 500 ms periodically, but the system also transmits this message immediately if a change in the error condition occurs. Byte 1 is reserved, the LSB bit (bit 0) of byte 3 is the Derate status bit and bit 1 of byte 3 is the Shutdown status bit. To verify that the master controller is correctly responding to these messages, a test message is available and is described in Section 2.1.

The message details are listed in the Appendix in Section 2.6.

3 d) Priority 4 Messages

Reserved

Priority 4 (Identifier "0x10EFrrss" for 29-bit identifiers, Identifier "0xrrC" for 11-bit identifiers) are reserved for future use.

3 e) Priority 5 Messages

Limited Torque Percentage

Priority 5 (Identifier "0x14EF*rrss*" for 29-bit identifiers, Identifier "0x*rr*D" for 11-bit identifiers).

This status contains the maximum motoring and regen percentages allowed by the system at that instant. The system may be limiting the motoring (high bound) or regen (low bound) torque requested by the user for a variety of reasons.

Byte 1 is reserved. Byte 2 contains the High Bound Percentage, where 100% is no motoring limitations (full motoring torque and power are available) and 0% is complete limiting (no motoring torque and power are available). Byte 3 contains the Low Bound Percentage, where 100% is no regen limitations (full regen torque and power are available) and 0% is complete limiting (no regen torque and power are available). Byte 4 contains the Accel Analog Input voltage. Byte 5 contains the Brake Analog Input voltage. Byte 6 contains the Accel_2 Analog Input voltage.

Bytes 7 and 8 show the signed torque currently being desired by the UQM controller. The range of this message is from -3212.8 to 3212.8 Nm, with a 0.1 Nm delta – identical to the accurate feedback torque message. This value reflects the torque value the UQM controller is currently controlling to – any discrepancies between this value and the torque being requested by the user are caused by additional limiting within the UQM controller.

The message details are listed in the Appendix in Section 2.5.

3 f) Priority 6 Messages

Electric Drive Temperatures

Priority 6 (Identifier "0x18EF*rrss*" for 29-bit identifiers, Identifier "0x*rr*E" for 11-bit identifiers).

This message contains the current temperatures of the inverter, rotor and stator, as well as various temperatures and status bits related to the IGBT switching modules in the UQM controller.

Byte 2 contains the inverter heat sink temperature, ranging from –40 degrees C to 215 degrees C with an offset of 40 (i.e. 0x00 = -40 degrees C). Bytes 3 and 4 contain the current rotor and stator temperatures respectively, with the same scaling and offset as the inverter

temperature. Note that these three values will contain 0xFF when the sensor voltage (i.e. the HV supply) is invalid.

Byte 5 includes status bits about the IGBT temperature limit, outlined in the Appendix in Sections 1.20 and 1.21. Byte 6 contains the current calculated temperature of the IGBT modules, with an offset of 0 (i.e. 0x00 = 0 degrees C). Byte 7 contains the time in seconds until the IGBT temperature torque limit activates, or releases, depending on the current state.

The message details are listed in the Appendix in Section 2.2.

3 g) Priority 7 Messages

CAN Watchdog Commands

Priority 7 (Identifier "0x1CEF*rrss*" for 29-bit identifiers, Identifier "0x*rr*F" for 11-bit identifiers)

This message should be monitored constantly to detect whether the UQM hardware is transmitting a watchdog or CAN related error.

The CAN watchdog command is both received and transmitted by the UQM system (the sender and receiver addresses are swapped depending on whether the message has been received or transmitted). Bytes 1 & 8 should be used by the master controller to detect a watchdog error condition while bytes 1, 2 & 3 must be used by the master controller to prevent / clear an error condition.

Byte 8 sends the watchdog error to the host over CAN, which may be used by the host to detect a problem if the physical layer is intact. This will be sent every 0.5 seconds, if there is an error.

The message details are listed in the Appendix in Section 2.4.

3.1. Testing CAN Error Message Response

The inverter diagnostic software can be used to force the controller to transmit certain error messages over the CANbus; this feature can be useful while testing / debugging the response of a master controller to these error messages. (See following note).

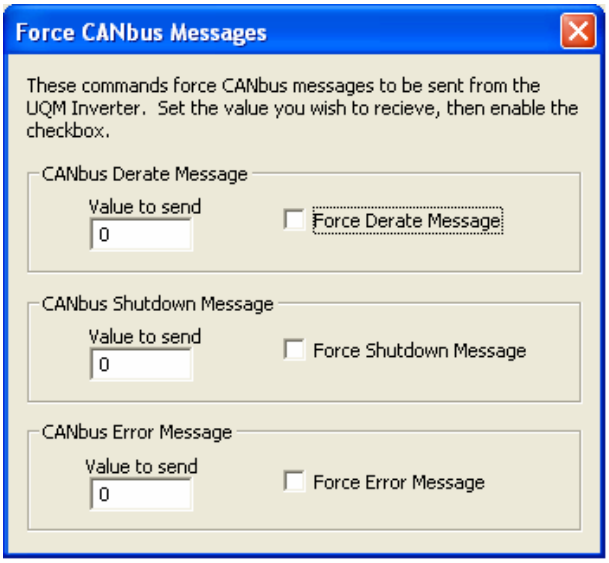

Figure 3.1 – CANbus Test Message Dialog

The following steps can be performed to force transmission of these error messages through the UQM Motor Controller Software:

1. Select *Actions* → *Show CAN Tests* from the inverter diagnostic software menu
2. In the dialog that pops up enter the value to be transmitted for a particular error message and select the accompanying *Force … Message* option (Refer to Figure 3.1)
3. Uncheck the appropriate *Force … Message* option to disable forced transmission of that message.

Note: The values for Shutdown and Derate error messages must be 0 or 1. The value for the CANbus error message must be in the range [0, 65535]. The CANbus error message will be transmitted in the *System Error* field of the *System Status Message*.

Note: Setting the value of an error message to 0 but leaving the *Force … Message* option checked DOES NOT disable forced transmission of that message. This will cause the inverter to always report absence of an error condition and could potentially result in damage to the inverter and / or the entire system. This capability is intended for debug purposes only and its use is not recommended during regular operation.

4. CAN Status Message Transmission rate

If CAN transmission is enabled and transmission of drive state messages is allowed then this command sets the transmission rate of Accurate Feedback status messages. The System Status Message will also be sent at the same rate (See following note).

The following steps can be performed to program the transmission rate through the UQM Motor Controller Software:

1. Select *Actio*ns → *System Configuration* → *Edit Current* from the inverter diagnostic software menu
2. Select the *CANbus* tab in the System Configuration dialog (refer to Figure 1.2)
3. Enter the desired CAN message transmission rate (the rate MUST be a multiple of 6ms).

Note: According to the SAE J1939-21 CAN Data Link Layer specification, a proprietary CAN message using a PDU format of 239 may not be transmitted at a rate faster than 100 ms. Hence, even though the user has the capability of setting the transmission rate of Accurate Feedback message as low as 6.24 ms, any rate faster than 100 ms would be in violation of the specification.

General Guidelines

Messages should be sent constantly from the host to the UQM controller.

Once a valid CAN command is sent to the UQM unit, a valid CAN command must be sent every one-second or the system issues a watchdog error. A *CANbus Communication Error* message in the Status column (left side of main page) indicates this (see description below.) There are two methods to eliminate the CAN watchdog error:

1) Send a *Reset CAN Watchdog Error* command
2) Reset the power to the UQM system (both high voltage and 12 V)

The valid commands that must be sent every second are: *the Universal Command or the reset CAN watchdog timer*.

The UQM Motor Controller Diagnostic Software has an output in the Status column for CAN communication status.

If *No CANbus Communication* –	Inverter is in CAN control mode but hasn't received a valid CAN message yet.
If *CANbus Communication Error* –	CAN communication has ceased and inverter is disabled. To re-enable use one of the two methods mentioned above.

CAN configuration menu options

CANbus Control mode / Drive Mode	Disabled	Enabled
Speed Only	Listening to hardware inputs. CAN ignored.	Hardware inputs ignored. System in speed control, waiting for a CAN speed command message.
Torque Only		Hardware inputs ignored. System in closed loop torque control, waiting for a CAN torque command message.
Voltage Only		Hardware inputs ignored. System in voltage control, waiting for a CAN voltage command message. If speed < 200rpm, controlling to zero torque.
Torque/Speed/Voltage		Hardware inputs ignored. Switching to Voltage, Speed or Torque Control depending upon which CAN message is received

APPENDIX

UQM Proprietary Vehicle Application Layer

1 Parameter Definitions

1.1 ANALOG INPUT VOLTAGE

Use: Informational
Data Length: 1 byte
Resolution: 0.02 V/bit gain
Data Range: 0.00 to 5.00 V
Type: Status
Reference: 2.5

1.2 CONTROL BYTE

Turbo Mode Bits			Enable bit	Direction bit			
Bit 7	*Bit 6*	*Bit 5*	*Bit 4*	*Bit 3*	*Bit 2*	*Bit 1*	*Bit 0*

Use: Control
Data Length: 1 byte
Resolution: N/A
Data Range: All unused bits are reserved, set to 0
Type: Command
Reference: 2.3

1.2.1 Turbo Mode Bits

Use: Control
Data Length: Bits 7 and 6 in Control Byte (where LSB is bit 0)
Resolution: N/A
Data Range: 00 = Turbo mode operating based on speed only (option 0)
01 = Turbo mode operating range large (option 1)
10 = Turbo mode operating range small (option 2)
11 = Reserved
Type: Command
Reference: 2.3

1.2.2 Enable Bit

Use: Control
Data Length: bit 4 in Control Byte (where LSB is bit 0)
Resolution: N/A
Data Range: 1 is enabled, 0 is disabled
Type: Command
Reference: 2.3

1.2.3 Direction Bit

Use: Control
Data Length: bit 3 in Control Byte (where LSB is bit 0)
Resolution: N/A
Data Range: 1 is forward, 0 is reverse
Type: Command
Reference: 2.3

1.3 LIMITATION MOTORING

Use: Informational
Data Length: 1 byte
Resolution: 0.8%/bit gain, -100% offset
Data Range: -100% to 100%
Type: Status
Reference: 2.5

1.4 LIMITATION REGENERATION

Use: Informational
Data Length: 1 byte
Resolution: 0.8%/bit gain, -100% offset
Data Range: -100% to 100%
Type: Status
Reference: 2.5

1.5 RESET CAN WATCHDOG TIMER

Use: Control
Data Length: 1 byte
Resolution: N/A
Data Range: 0xA5
Type: Command
Reference: 2.4

1.6 RESET CAN WATCHDOG ERROR

Use: Control
Data Length: 1 byte
Resolution: N/A
Data Range: 0x5A
Type: Command
Reference: 2.4

1.7 SHUTDOWN DERATE BITS

						Shutdown bit	Derate bit
Bit 7	*Bit 6*	*Bit 5*	*Bit 4*	*Bit 3*	*Bit 2*	*Bit 1*	*Bit 0*

Use: Informational
Data Length: 1 byte
Type: Status
Bit: 7-2 Unused
1 Shutdown
Note: The microprocessor sets this bit to signal a serious error condition to the master controller that will require restarting of the system. (1 = Shutdown, 0 = No error)
0 Derate
Note: The microprocessor sets this bit to signal the master controller that an error has occurred due to which the master should reduce output demand, the system will still function but not at the rated limit. (1 = Derate, 0 = No error)
Reference: 2.6

1.8 SIGNED CURRENT

Use: Control/Informational
Data Length: 2 bytes
Byte Order: Little or Big Endian (user selectable)
Resolution: 0.1 A/bit gain, -3212.8 offset
Data Range: -3212.8 A to +3212.8 A
Type: Measured or Command
Reference: 2.1, 2.3

1.9 SIGNED SPEED

Use: Control/Informational
Data Length: 2 bytes
Byte Order: Little or Big Endian (user selectable)
Resolution: 0.50 rpm/bit gain, -16064 rpm offset
Data Range: -16064 rpm to +16064 rpm
Type: Measured or Command
Reference: 2.1, 2.3

1.10 SIGNED TORQUE

Use: Control/Informational
Data Length: 2 bytes
Byte Order: Little or Big Endian (user selectable)
Resolution: 0.1 Nm/bit gain, -3212.8 offset
Data Range: -3212.8 Nm to +3212.8 Nm
Type: Measured or Command
Reference: 2.1, 2.3

1.11 SIGNED DESIRED TORQUE

Use: Control/Informational
Data Length: 2 bytes
Byte Order: Little or Big Endian (user selectable)
Resolution: 0.1 Nm/bit gain, -3212.8 offset
Data Range: -3212.8 Nm to +3212.8 Nm
Type: Measured or Command
Reference: 2.5

1.12 SIGNED VOLTAGE

Use: Control/Informational
Data Length: 2 bytes
Byte Order: Little or Big Endian (user selectable)
Resolution: 0.1 V/bit gain, -3212.8 offset
Data Range: -3212.8 V to +3212.8 V
Type: Measured or Command
Reference: 2.1, 2.3

1.13 SYSTEM ERROR BYTE 1

Inverter over temperature	Motor over temperature	Rotor over temperature	Under voltage warning	Over phase advance	Over bus current	Over leg current	Not enabled
Bit 7	*Bit 6*	*Bit 5*	*Bit 4*	*Bit 3*	*Bit 2*	*Bit 1*	*Bit 0*

Use: Informational
Data Length: 1 byte
Type: Status
Bit: 7 Inverter Over Temperature / Open Sensor
6 Motor Over Temperature / Open Sensor
5 Rotor Over Temperature / Open Sensor
4 Under Voltage Warning
3 Over Phase Advance
2 Bus Over Current
1 Leg Over Current
0 Not Enabled
Reference: 2.7

1.14 SYSTEM ERROR BYTE 2

Inverter fault	Inverter fault occurred	Over power	ADC calibration problem	Over voltage alarm	Over speed alarm	Over voltage warning	Over/Under* speed warning
Bit 7	*Bit 6*	*Bit 5*	*Bit 4*	*Bit 3*	*Bit 2*	*Bit 1*	*Bit 0*

Use: Informational
Data Length: 1 byte
Type: Status
Bit: 7 Inverter Fault
6 Inverter Fault Occurred (Latched Inverter Fault)
5 Over Power (Only valid when system is in voltage control mode)
4 ADC calibration problem
3 Over Voltage Alarm
2 Over Speed Alarm
1 Over Voltage Warning
0 Over Speed Warning (* or Under Speed Warning when in Voltage Control)
Reference: 2.7

1.15 SYSTEM ERROR HISTORY BYTES 1 & 2

Use: Informational
Data Length: 2 bytes
Type: Status
Note: Latched version of System Error bytes
Reference: 2.7, 1.13, 1.14

1.16 SYSTEM STATUS BYTE 1

			Actively Damping	Motor Leg Order	System disabled in motion	CAN limits active	Force voltage control mode
Bit 7	*Bit 6*	*Bit 5*	*Bit 4*	*Bit 3*	*Bit 2*	*Bit 1*	*Bit 0*

Use: Informational
Data Length: 1 byte
Type: Status
Bit: 5-7 Reserved
4 System is actively damping
3 Motor Leg Order (1 is ABC, 0 is CBA)
2 System disabled but motor is in motion
1 CAN Limits in effect
0 Force Voltage Control Mode
Reference: 2.7

1.17 SYSTEM STATUS BYTE 2

Bad system configuration	Invalid 15V	Bad driver	Bad position signal	Error with leg current sensors	Stall conditions occurring	Forced open loop	Turbo mode
Bit 7	*Bit 6*	*Bit 5*	*Bit 4*	*Bit 3*	*Bit 2*	*Bit 1*	*Bit 0*

Use: Informational
Data Length: 2 bytes
Byte Order: Little or Big Endian (user selectable)
Type: Status
Bit: 7 Bad system configuration
6 Invalid 15V
5 Bad driver
4 Bad position signal
3 Error with leg current sensors
2 Stall conditions occurring
1 Forced open loop
0 Turbo mode
Reference: 2.7

1.18 TEMPERATURE INVERTER

Use: Informational
Data Length: 1 byte
Resolution: 1 ºC/bit gain, -40 ºC offset
Data Range: -40 ºC to +210 ºC
Type: Measured
Reference: 2.2

1.19 TEMPERATURE ROTOR

Use: Informational
Data Length: 1 byte
Resolution: 1 ºC/bit gain, -40 ºC offset
Data Range: -40 ºC to +210 ºC
Type: Measured
Reference: 2.2

1.20 TEMPERATURE STATOR

Use: Informational
Data Length: 1 byte
Resolution: 1 ºC/bit gain, -40 ºC offset
Data Range: -40 ºC to +210 ºC
Type: Measured
Reference: 2.2

1.21 WATCHDOG ERROR BIT

							Watchdog error
Bit 7	*Bit 6*	*Bit 5*	*Bit 4*	*Bit 3*	*Bit 2*	*Bit 1*	*Bit 0*

Use: Informational
Data Length: 1 byte
Type: Status
Bit: 7-1 Unused
0 Watchdog Error
Reference: 2.4
Note: After the microprocessor receives a CAN message, then it must receive another message within 1.0 seconds or it will issue this error message. (1= Error, 0 = No error)

1.22 OVER IGBT JUNCTION TEMPERATURE

							Over IGBT Junc. Temp.
Bit 7	*Bit 6*	*Bit 5*	*Bit 4*	*Bit 3*	*Bit 2*	*Bit 1*	*Bit 0*

Use: Informational
Data Length: Bit 0 of byte 5 (where LSB is bit 0)
Resolution: N/A
Data Range: 1 indicates over temperature, 0 indicates below temperature threshold
Type: Status
Reference: 2.2

1.23 IGBT JUNCTION TEMPERATURE LIMIT ACTIVE

						IGBT Junc. Temp. limit active	
Bit 7	*Bit 6*	*Bit 5*	*Bit 4*	*Bit 3*	*Bit 2*	*Bit 1*	*Bit 0*

Use: Informational
Data Length: Bit 1 of byte 5 (where LSB is bit 0)
Resolution: N/A
Data Range: 1 indicates system is limited due to over IGBT junction temperature, 0 indicates limiting is inactive
Type: Status
Reference: 2.2

1.24 IGBT JUNCTION TEMPERATURE

Use: Informational
Data Length: Byte 6
Resolution: 1 ºC/bit gain, 0 ºC offset
Data Range: 0 ºC to +250 ºC
Type: Measured
Reference: 2.2

1.25 IGBT JUNCTION TEMPERATURE LIMIT TIME

Use: Informational
Data Length: Byte 7
Resolution: 0.5 sec/bit gain, 0 sec offset
Data Range: 0 sec to +125 sec
Type: Measured
Reference: 2.2

2 Parameter Group Definitions

DA = Destination Address

2.1 ACCURATE FEEDBACK [0X04EF*RRSS OR* 0X*RR*9]

Signed Torque		Signed Voltage		Signed Current		Signed Speed	
Byte 1	*Byte 2*	*Byte 3*	*Byte 4*	*Byte 5*	*Byte 6*	*Byte 7*	*Byte 8*

Transmission repetition rate: Increments of 0.006 seconds, 0.102 seconds default, user adjustable
Data length: 8 bytes
Data page: 0
PDU format: 239
PDU specific: DA
Default priority: 1

Byte:			
	1,2	Signed Torque Feedback	1.10
	3,4	Signed Voltage Feedback	1.12
	5,6	Signed Current Feedback	1.8
	7,8	Signed Speed Feedback	1.9

2.2 ELECTRIC DRIVE TEMPERATURE [0X18EF*RRSS OR* 0X*RR*E]

	Inverter heat sink temp.	Estimated rotor temp.	Stator temp.	IGBT junction temp. status	IGBT junction temp.	IGBT junction temp. limit time	
Byte 1	*Byte 2*	*Byte 3*	*Byte 4*	*Byte 5*	*Byte 6*	*Byte 7*	*Byte 8*

Transmission repetition rate: 1 s
Data length: 8 bytes
Data page: 0
PDU format: 239
PDU specific: DA
Default priority: 6

Byte:			
	1	Reserved	
	2	Inverter Heat Sink Temperature	1.18
	3	Estimated Rotor Temperature	1.19
	4	Stator Temperature	1.20
	5	IGBT Junction Temperature Status Bits	0, 1.23
	6	IGBT Junction Temperature	1.24
	7	IGBT Junction Temperature Limit Time	1.25
	8	Reserved	

2.3 UNIVERSAL COMMAND [0X14EF*RRSS OR* 0X*RR*5]

Command	Control bits	Requested torque, speed or voltage		Maximum speed, torque or current limit		Minimum speed, torque or current limit	
Byte 1	*Byte 2*	*Byte 3*	*Byte 4*	*Byte 5*	*Byte 6*	*Byte 7*	*Byte 8*

Data length: 8 bytes
Data page: 0
PDU format: 239
PDU specific: DA
Default priority: 5

FOR TORQUE:

Byte:			
	1	Command 0x01	
	2	Control Bits	1.2.1, 1.2.3
	3,4	Requested Signed Torque	1.10
	5,6	Maximum Forward Speed Limit	1.9
	7,8	Maximum Reverse Speed Limit	1.9

FOR SPEED:

Byte:			
	1	Command 0x02	
	2	Control Bits	1.2.1
	3,4	Requested Signed Speed	1.9
	5,6	Maximum Torque Limit	1.10
	7,8	Minimum Torque Limit	1.10

FOR VOLTAGE:

Byte:			
	1	Command 0x03	
	2	Control Bits	Reserved
	3,4	Requested Signed Voltage	1.12
	5,6	Maximum Current Limit	1.8
	7,8	Minimum Current Limit	1.8

2.4 CAN WATCHDOG COMMANDS [0X1CEF*RRSS OR* 0X*RR*7/0X*RR*F]

0xA5	Reset watchdog timer	Reset CAN watchdog error					Watchdog error bit
Byte 1	*Byte 2*	*Byte 3*	*Byte 4*	*Byte 5*	*Byte 6*	*Byte 7*	*Byte 8*

Transmission repetition rate: 0.5 s
Data length: 8 bytes
Data page: 0
PDU format: 239
PDU specific: DA
Default priority: 7

Byte:			
	1	Command 0xA5	
	2	Reset Watchdog Timer	1.5
	3	Reset CAN Watchdog Error	1.6
	4-7	Reserved	
	8	Watchdog Error Bit	1.21

2.5 LIMITED TORQUE PERCENTAGE [0X14EFRRSS *OR* 0X*RR*D]

	High bound percentage	Low bound percentage	Accel analog input	Brake analog input	Accel2 analog input	Signed desired torque	
Byte 1	*Byte 2*	*Byte 3*	*Byte 4*	*Byte 5*	*Byte 6*	*Byte 7*	*Byte 8*

Transmission repetition rate: Same as Accurate Feedback
Data length: 8 bytes
Data page: 0
PDU format: 239
PDU specific: DA
Default priority: 5

Byte:			
	1	Reserved	
	2	High bound percentage	1.3
	3	Low bound percentage	1.4
	4	Accel Analog Input	1.1
	5	Brake Analog Input	1.1
	6	Accel_2 Analog Input	1.1
	7,8	Signed desired torque	1.11

2.6 EMERGENCY FUEL CUTBACK COMMAND [0X0CEFRRSS *OR* 0X*RR*B]

		Shutdown / Derate bits					
Byte 1	*Byte 2*	*Byte 3*	*Byte 4*	*Byte 5*	*Byte 6*	*Byte 7*	*Byte 8*

Transmission repetition rate: 0.5s periodically, and immediately if the error condition changes
Data length: 8 bytes
Data page: 0
PDU format: 239
PDU specific: DA
Default priority: 3

Byte:			
	1	Reserved	
	2	Reserved	
	3	Shutdown Derate Bits	1.7
	4-8	Reserved	

2.7 SYSTEM STATUS MESSAGE [0X08EFRRSS *OR* 0X*RR*A]

System error byte 1	System error byte 2	System error history byte 1	System error history byte 2			System status byte 1	System status byte 2
Byte 1	*Byte 2*	*Byte 3*	*Byte 4*	*Byte 5*	*Byte 6*	*Byte 7*	*Byte 8*

Transmission repetition rate: 0.5 s periodically, and immediately if the error condition changes
Data length: 8 bytes
Data page: 0
PDU format: 239
PDU specific: DA
Default priority: 2

Byte:			
	1,2	System Error	1.13, 1.14
	3,4	System Error History	1.15
	5,6	Reserved	
	7,8	System Status Bits	1.16, 1.17

2.8 RESERVED MESSAGE [0X10EFRRSS *OR* 0X*RR*C]

Transmission repetition rate: TBD
Data length: 8 bytes
Data page: 0
PDU format: 239
PDU specific: DA
Default priority: 4

Byte:		
	1-8	Reserved

3 DETAILED CAN PARAMETERS

Detailed CAN Parameters

Baud Rate	SBG	SJW	SAM	BRT	TSEG1	TSEG2
125 k	1	1	1	60	12	7
250 k	1	1	1	30	12	7
500 k	1	1	1	15	12	7
1000 k	1	1	1	10	11	3