White Paper

Using CAN Bus Serial Communications in Space Flight Applications

Introduction

The controller area network (CAN) protocol is a proven, highly reliable communication system for harsh environments and has been used in automotive and industrial applications for over 30 years. The CAN two-wire bus multi-master/multi-drop topology makes it easy to add additional functionality to a system while significantly reducing the number of wires associated with wire intensive point-to-point topologies. The space community is well aware of the CAN protocol's many benefits and advantages, and the need for it to replace traditional spacecraft bus architectures.

This article examines the use of CAN bus in space flight applications. We will discuss the basics of the CAN serial communications protocol, advantages of using CAN for satellite communications and the special requirements needed by a radiation tolerant CAN transceiver.

The European Space Agency (ESA) is leading the development effort to get the hardware, firmware and software in place to implement CAN for on-board spacecraft communications and control systems. The ECSS-E-ST-50-15C (May 1, 2015) document was created by ESA to standardize the CAN communication protocol. It extends the definition of the ISO 11898-1/-2:2003 CAN protocol and specifies the parameters for serial communication and hardware connection to meet spacecraft requirements.

CAN Protocol Basics

Figure 1 shows a block diagram of a typical CAN bus network. It consists of two differential signal lines designated as CANH and CANL. Electronic control unit (ECU) devices connect to the differential data lines and communicate with each other over the differential bus. 120Ω termination resistors are used at the ends of the bus to suppress any electrical signal reflections.

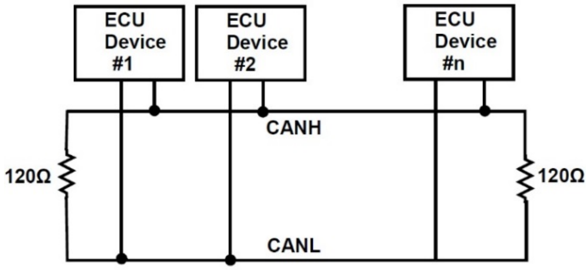

Figure 1. Block Diagram of a CAN Bus Network

A typical ECU consists of a CAN transceiver, CAN controller/embedded microprocessor (µP), clock source, analog-to-digital converter (ADC) and/or digital-to-analog converter (DAC), transducer, signal conditioning circuitry, sensor and actuator (see Figure 2).

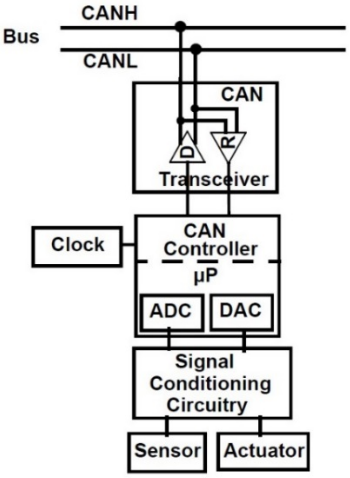

Figure 2. Block Diagram of an ECU Device

To communicate on the bus, every ECU must have a CAN controller, µP or digital signal processor (DSP) and a CAN transceiver that conforms to the ISO 11898-1/-2:2003 standards. ECUs are smart devices and each ECU has the ability to transmit a CAN data packet onto the bus and receive broadcasted data packets.

Each ECU's CAN controller filters the received data packet coming from the CAN transceiver to determine if it should take any action. The CAN controller also executes the data transmission. It puts the digital data into the proper CAN format and when it determines the bus is idle, the controller initiates the serial data stream transmission to the input of the CAN transceiver. The CAN transceiver responds to the serial data stream at its input by driving the signal lines with the proper differential signals, representing either a logic 0 (dominant bit) or a logic 1 (recessive bit).

The CAN controller conforms to the data layer specifications in ISO 11898-1, while the CAN transceiver conforms to the electrical specifications in ISO 11898-1/-2. It is ISO 11898-2 that states the electrical specifications and signal requirements for driving the bus with data rates up to 1Mbps.

CAN Transceiver Differential Signal

The CAN transceiver consists of a driver and a receiver. The driver takes a digital serial data stream from the CAN controller and drives the bus lines with the appropriate differential signal levels. The CAN differential signaling is unique among protocols. Figure 3 shows a representation of the signals and the levels applied at the CANH and CANL bus lines by the CAN transceiver whenever a recessive bit (logic 1) or a dominant bit (logic 0) is at the CAN transceiver's digital (D) input.

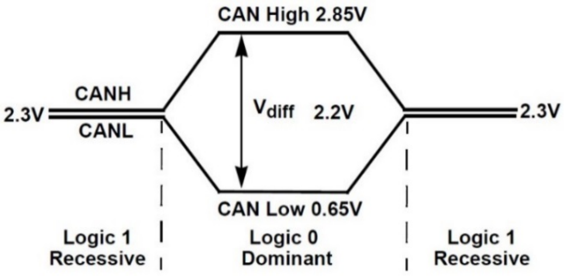

Figure 3. Schematic of CAN Differential Signal Levels

During a recessive bus time (logic 1) both CANH and CANL are driven to a 2.3V level and have a differential voltage (CANH - CANL) of approximately 0.2mV. All ECU receivers on the bus will read this 0.2mV differential voltage as a logic 1 and output a HIGH logic level from the R output of the CAN transceiver to the CAN controller receive buffer.

During a dominant bus time (logic 0), CANH is driven to 2.85V and CANL is driven to 0.65V. This creates a dominant differential voltage of 2.2V. All ECU receivers on the bus will read this 2.2V differential voltage as a logic 0 and output a LOW logic level from the R output of the CAN transceiver to the CAN controller receive buffer.

CAN Standard Data Frame and Frame Formatting

CAN devices send data across the CAN bus network in packets called frames, or messages. The CAN controller is responsible for putting the data packet into the proper format for transmission. It is also responsible for taking a received packet and filtering it to retrieve the sent data message. Figure 4 shows the standard CAN frame format.

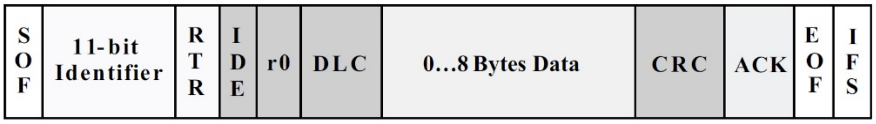

Figure 4. Standard CAN Frame Format

The definitions of the Figure 4 bit fields are:

- **SOF**: The single dominant start of frame (SOF) bit marks the start of a message.
- **Identifier**: The standard CAN 11-bit identifier establishes the priority of the message. The lower the binary value, the higher its priority.
- **RTR:** The single remote transmission request (RTR) bit is dominant when information is required from another node. All nodes receive the request, but the identifier determines the specific node. The responding data is also received by all nodes and is used by any interested node. This ensures all system data is uniform.
- **IDE**: A dominant single identifier extension (IDE) bit means that a standard CAN identifier with no extension is being transmitted.
- **r0:** Reserved (r0) bit is for possible use by a future standard amendment.
- **DLC**: The 4-bit data length code (DLC) contains the number of data bytes that will follow in the transmitted message.
- **Data**: Up to 64 bits of application data may be transmitted.
- **CRC**: The 16-bit (15 bits plus delimiter) cyclic redundancy check (CRC) contains the checksum (number of bits transmitted) of the preceding application data for error detection.
- **ACK:** Every node receiving an accurate message overwrites this recessive bit in the original message with a dominate bit, indicating an error-free message has been sent. Should a receiving node detect an error and leave this bit recessive, it discards the message and the sending node repeats the message after re-arbitration. In this way, each node acknowledges (ACK) its data integrity. ACK is 2 bits, one is the acknowledgment bit and the second is a delimiter.
- **EOF:** This end-of-frame (EOF), 7-bit field marks the end of a CAN frame (message) and disables bit-stuffing, indicating a stuffing error when dominant. When 5 bits of the same logic level occur in succession during normal operation, a bit of the opposite logic level is stuffed into the data.
- **IFS**: This 7-bit inter-frame space (IFS) contains the time required by the controller to move a correctly received frame to its proper position in a message buffer area.

Bus Contention Handling Is Built into the Protocol

The CAN bus is a serial, multi-master, broadcast bus where each transceiver’s bus driver is internally connected to its receiver, and then to every other receiver on the transmission line. Consequently, only one

ECU node can transmit data at a time. The CAN protocol provides for an automatic bit arbitration scheme so that in the event two or more ECUs attempt to simultaneously transmit, the content of the messages determines their priority. This is accomplished by using dominant and recessive bits.

CAN messages are prefaced by a string of bits called the message identifier number which are unique to each ECU. The clever part is that each CAN controller checks the bit as it is attempting to transmit against the bit it is receiving. If two or more ECUs attempt to transmit their message identifier numbers at the same time, the first node attempting a recessive bit transmission will see that the bus remains dominant and will cease its transmission. It will wait until the other ECU is finished before re-attempting transmission. This message priority is established by the bit patterns in the message identifier number, and arbitration occurs automatically, without loss of data, and without increasing bus latency.

The main benefit of this arbitration scheme is that it allows CAN bus to operate as a subsystem without requiring a host computer to direct bus traffic. In contrast, most RS-485 systems are configured in a master-slave arrangement where the master node, under the control of a host processor, is used to coordinate data transmission. Because decision-making and control occurs higher up in the system hierarchy, latency times are increased. This is a significant issue on buses that have many nodes because in a master-slave arrangement, each node is serially polled to determine whether it needs servicing, whereas with CAN bus, a node can attempt to transmit as soon as its data is prepared. Moreover, in RS-485, a node's driver must be disabled because neither of its bits are in high impedance states to prevent it from tying up the bus. The host computer must direct the node controller to enable the driver stage before it can transmit, which adds latency. The CAN system of arbitration allows easy connection of multiple devices to the bus without any collision detection.

Common Mode Voltage

CAN buses may be used to drive long transmission lines in noisy industrial environments. Oftentimes the Earth provides the common ground for the whole transmission system. Consequently, there may be significant voltage differences between the local node grounds across the network. The difference in ground potential is usually called the "common mode" voltage when adjusted for the power supply. CAN buses, per ISO 11898-2, are expected to operate with ground differences of ±2V. That translates to a -2V to +7V common mode range for a 5V bus supply. The Intersil ISL7202xSEH family of CAN transceivers can operate over a common mode range of -7V to +12V.

Error Detection Is Built into the Protocol

There are four types of error flagging in the CAN protocol. Cyclic redundancy codes are computed for each message and transmitted as part of the message. The receiving ECU node also computes this code and detects an error if there is a mismatch. Additionally, formatting bits within the message must have certain values or the message will be discarded as erroneous. Stuffing bits are also inserted after five consecutive bits with the same value. Therefore, an error is raised if a receiver detects six or more identical bits in a row. Finally, a send-and-acknowledge scheme performs further error checking. When an ECU node receives a message, it must acknowledge its successful receipt by driving the bus low for a specific amount of time. The transmitting node will continue to transmit the message until it receives this acknowledgement or until a specified amount of time has passed. If a message is found to be in error, instead of acknowledging it, the ECU node that flagged the error will send an error message to all other nodes, including the original transmitter. This will abort transmission of the message and will alert all nodes that the message is erroneous.

Advantages of CAN Bus

Below is a list of the major features and benefits of the CAN protocol:

- The simple two-wire bus topology reduces wiring and saves space and cost by eliminating bulky wiring harnesses.

- The ISO 11898 standards for the CAN controller and CAN transceiver ensures ECUs built by different manufacturers will work together when put into a CAN network.
- An ECU device can communicate with multiple devices at the same time.
- High transceiver driver output current drives double terminated cables and long cables. Drives up to 120 devices at data rates up to 1Mbps.
- The CAN system of arbitration allows easy connection of multiple devices to the bus without any additional collision detection. Arbitration occurs automatically, without loss of data, and without increasing bus latency.
- Wide CMR of at least -2V to +7V. CAN allows networks to drive long cables in harsh environments where nodes may have large ground differences.
- Error detection is built into the protocol for reliable communications.

Advantages of Using CAN in Space Applications

The following outlines the advantages of employing a CAN bus communications network for data handling in space systems vs. the conventional MIL-STD-1553 and RS-485 point-to-point interface solutions. Figure 5 shows the comparison between the present conventional topology vs. the CAN two-wire broadcast topology. Several nodes can be added to a single bus. This significantly reduces system/cable costs while providing a cost-effective way to add functionality. According to ESA, a satellite's weight and mass can be reduced by 10% to 18%. Weight/mass is proportionate to overall satellite and launch costs:

- The CAN multi-master/multi-drop topology significantly reduces the amount of wiring and connectors.
- Replaces older, more costly communication protocols.
- CAN has lower power consumption vs. the conventional MIL-STD-1553 systems.
- Data prioritization and data contention is an advantage over other protocols.
- Adds several million dollars of functionality.
- CAN enables scalable bus architectures with increased reliability, observability and controllability.

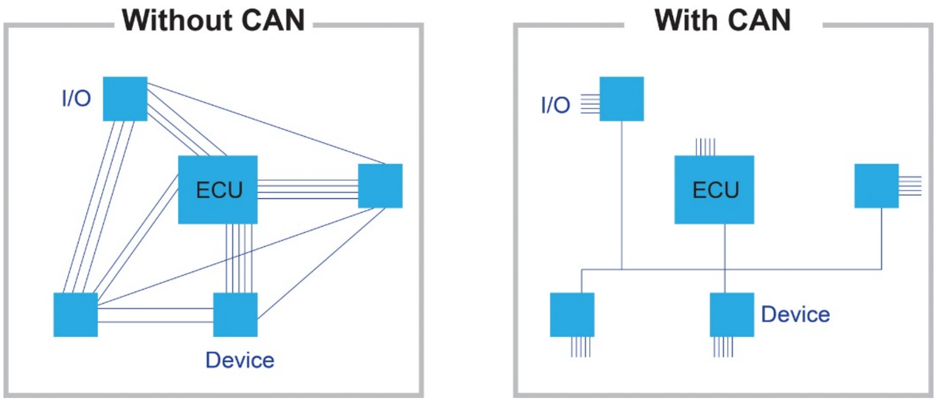

Figure 5. CAN Networks Significantly Reduce Wiring

Special Requirements of a Radiation Tolerant CAN Transceiver

The ECSS-E-ST-50-15C space standard for CAN bus extension protocol states: “This standard does not modify the basic CAN network specification and complies with ISO 11898-1/-2:2003. This standard does define protocol extensions needed to meet spacecraft specific requirements.” Therefore, CAN transceivers used in space applications must meet the key electrical specification of the ISO 11898-2 standard. In addition, they must be able to survive the harsh radiation environment encountered in space, and support system redundancy while meeting the space bus requirements for fault detection.

Radiation Tolerance

Space radiation effects on electronic devices are an important system design consideration. They can cause problems ranging from operational malfunctions to severe physical damage to the devices.

CMOS technology is preferred for space applications because of its high noise margins and low static power requirements. Scaling and integration are other advantages CMOS has over other semiconductor process technologies. However, CMOS is susceptive to two types of space radiation effects caused by electrons and protons trapped in the terrestrial magnetic field: total ionizing dose (TID) and single event effects (SEE). TID effects are the result of accumulated exposure to ionizing radiation. SEE are the result of a single high-energy particle that strikes the device.

The total dose radiation exposure is measured in rads. The term rad (radiation-absorbed dose) quantifies the total radiation exposure of a material. One rad(Si) is equal to 10×10^{-6} W of energy absorbed per gram of silicon. The total dose radiation threshold of a device is the minimum level of rad(Si) that will cause device failure. Typical commercial CMOS devices can survive around 5krads before physical damage occurs. However, SEE are significantly more hazardous to the satellite and can result in single event upset (SEU), single event transient (SET) or single event latch-up (SEL).

SEU effects are internal device memory bit changes (0 becomes 1 and vice versa) that can cause erroneous instruction execution and SET is a transient voltage pulse that can cause erroneous data transmission over a bus. SEU and SET effects are considered soft-errors and do not cause physical damage to the devices. In contrast, SEL effect is a hard-error, which leads to a high current-flow through the device. If not remedied quickly, latch-up can cause permanent damage.

TID testing on Intersil's ISL7202xSEH family of CAN transceivers was done to 75krad(Si) at 0.01rad(Si)/s under biased and grounded conditions and were followed by a biased anneal at 100°C for 168 hours as outlined in MIL-STD-883 Test Method 1019. No rejects to SMD parametric limits were encountered. These radiation tolerant devices have a low dose rate guarantee of 75krads.

SEE testing results:

- No SEL or single event burnout (SEB) for ions with LET ≤ 60 MeV•cm^2/mg with VCC ≤ 4.5V and CANH/CANL with ± 18V.
- No SET detected for LET ≤ 2.7 MeV•cm^2/mg (no bit errors at 1Mbps).
- Only single bit errors at 1Mbps and fast slew with LET = 20 MeV•cm^2/mg to a cross section of 4×10^{-7} cm^2.
- Only single bit errors at 1Mbps and fast slew with LET = 43 MeV•cm^2/mg to a cross section of 4×10^{-6} cm^2.

Bus Failure Detection

A space CAN transceiver must meet the "bus failure detection" requirements for space applications per Section 5.3.3 in ECSS-E-ST-50-15C (May 1, 2015). Intersil worked with ESA to develop the requirements outlined in Section 5.3.3, and the ISL7202xSEH CAN transceivers meet these requirements.

Redundancy and Cold Spare Capability

Reliability is an essential requirement in space applications and single point failures must be avoided. To achieve a high reliability communication system, an ECU node will use two CAN transceivers in parallel. One transceiver will be active while the other transceiver is cold spare in a powered down condition. The redundant cold spare transceiver is used if the active transceiver malfunctions. In a powered off state, the ISL7202xSEH CAN transceivers do not affect communications on the bus and present a high impedance between the bus and the system supply rail at >2MΩ (typical).

Conclusion

With the arrival of the QML-V qualified ISL7202xSEH radiation tolerant CAN bus transceivers, space communications engineers will now be able to implement a CAN bus network for spacecraft on-board communications and controls. A CAN bus system will allow engineers to replace older, more complex wiring communications architectures, such as MIL-STD-1553, with a CAN two-wire bus network. Reducing the number of wires and weight along with lower power consumption will result in major cost savings for spacecraft manufacturers.

Next Steps

- Learn more about the ISL7202xSEH
- Download the datasheet
- Get the TID report and SEE report
- Watch the video

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