The CAN (controller area network) serial bus has already been deployed in numerous aviation applications. Extensive activities in CAN standard working committees such as ARINC 825 and ARINC 812 indicate that aircraft manufacturers, suppliers and airlines are increasingly relying on CAN systems in future aircraft programs. To meet the stringent requirements for robustness, reliability and long service life, there is an increasing demand for efficient measurement and test methods, which also cover the CAN physical transmission layer.

Although the CAN bus was originally developed for automobiles, properties such as its robustness, reliable time behavior and good cost/benefit ratio have quickly lead to its deployment in numerous other sectors and applications. Aviation poses many challenges for robust CAN communication, including long cables, extreme environmental conditions (heat, cold and moisture), stringent lightning protection requirements and long service life. While commercial vehicles are expected to have a bus length of no more than 40m, according to SAE J1939 a bus cable on a large airliner such as an Airbus A380 can be 200m or longer. A further challenge is the long service life of aircraft, of at least 30 years. Electrical installation is typically subject to gradual deterioration of its electrical parameters. Corrosion- and wear-induced aging quickly leave their mark, in particular on plug-in connections.

CAN is currently used in aircraft for systems such as environmental control, doors, galleys, smoke detection, potable water and de-icing. Due to the specific challenges in aviation and the long service life, adequate electrical reserves must be included in the design and layout of networks, to counteract the expected aging phenomena. However, the fact that a new system passes logical function tests says nothing about the quality and robustness of the physical communication. Such information can only be obtained by testing and measuring the CAN physical layer.

**THE CAN PHYSICAL LAYER**

The CAN protocol recommended for civil aviation is standardized in ARINC 825. Even in the CAN 2.0A/B standards originally published by Bosch, only the tasks of layer 2 (datalink layer) of the ISO/OSI layer model have a binding definition. In practice the physical parameters actually used depend heavily on the system developer and the specific conditions. This relates in particular to the bus length and the bit rate, which are related in that the longer the bus cable, the greater the signal propagation delay. ARINC 825 supports data transmission rates of 83.333kbps, 125kbps, 250kbps, 500kbps, and 1,000kbps. High-speed CAN buses use a twisted-pair cable and operate with a differential voltage of 0-2V. The bus cable is implemented in a line topology and requires termination at both ends with a terminating resistor. Bus nodes are connected using short stubs.

On a CAN bus, each sender expects bit-synchronous acknowledgments from one or more receivers. This is one of the reasons for the great robustness...
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of CAN. The instantaneous bus access method is also based on a (bit-synchronous) synchronization of the high-low signal state. All bus drivers are equipped with open-collector outputs, and a switched-through (low-resistance) output always prevails, because it pulls the high signal generated via pull-up resistors to low state. Low is thus always dominant and high is recessive.

**PHYSICAL LAYER ERRORS**

Each CAN bit is subdivided into multiple phases and the developer specifies a uniform sampling point – a kind of common denominator for the bus nodes. Physical layer problems in CAN networks are often caused by phase errors due to oscillator tolerances, bit asymmetries caused by transceiver delays and wire delays. Depending on the specifications of the physical layer components, the optimum for this time window can be shifted slightly forward or backward. Usually the aircraft manufacturer is responsible for specifying the bit timing as part of the physical specification of its CAN networks. It should therefore be checked that the bit timings are correctly configured in the individual CAN controllers for each bus node.

Physical layer errors can be caused by overly long bus cables, too many or too long stubs or a faulty termination. Due to cable lengths of 200m, signal propagation delays play an increasingly important role in aviation CAN networks. The position of the bit diverges with increasing cable length, making it more and more difficult to find a robust sampling point for all bus nodes; the use of a lower bit rate should help. An alternative approach is to divide the system into two faster separate networks.

The network stubs for each node can also cause ripple effects such as reflections. They occur at cable ends and transition points, including junctions and plug-in connections, and superimpose interference voltages on the CAN bus signal. As a rule of thumb the sum of all stubs should not exceed 10% of the total cable length. Finally, electromagnetic compatibility problems must always be considered if the bus cable is installed near sources of interference, such as strong electric motors and converters.

**SYNCHRONOUS ANALYSIS**

Developing a robust CAN network and detecting potential communication errors before they occur requires the synchronous analysis of both physical and logical CAN layers. Developers need bit-accurate insights into signal variations in the physical layers.

“DEVELOPING A ROBUST CAN NETWORK AND DETECTING POTENTIAL COMMUNICATION ERRORS BEFORE THEY OCCUR REQUIRES THE SYNCHRONOUS ANALYSIS OF BOTH PHYSICAL AND LOGICAL CAN LAYERS. DEVELOPERS NEED BIT-ACCURATE INSIGHTS INTO SIGNAL VARIATIONS IN THE PHYSICAL LAYERS”
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When an error event passes through the bit mask, it indicates a possible violation of the physical specification and/or the system reserve. CANoe.Scope displays violated bit masks in red, while untouched masks are displayed in green (Figure top, next page).

TROUBLESHOOTING AND ROBUSTNESS

Such oscilloscope analysis functions provide developers and test engineers with a fast and targeted analysis of the CAN physical layer. As a test strategy, Vector recommends individual testing of all Line Replaceable Units (LRU) to begin with, in order to filter out possible problem candidates. The location of identified errors can be narrowed down in subsequent steps and actions taken to eliminate them.

For sporadically occurring errors, endurance tests on the same frames or identifiers are useful. If a network is operating error-free, there is still a desire to know whether it is just barely functioning or if sufficient system reserves are still available. This can be determined using stricter violation criteria. The position and shape of the bit masks are changed incrementally until the first errors occur again. The LRUs responsible for the violations would be the first to fail in regular operation and represent potential error sources. Test reports of documented errors or exported data can easily be exchanged between aircraft.
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A further typical test strategy involves stressing the CAN network with artificial physical and logical errors. A suitable method is to use the CANstressDR hardware module (Right opening page).

Vector has been a CAN pioneer from the outset and can look back on 25 years of experience in the automotive, commercial vehicle, agricultural engineering, aviation and marine sectors. Its hardware and software solutions are supplemented by numerous training courses on subjects such as design, analysis, and testing of CAN systems and other networks such as CAN FD, AFDX and Ethernet. With the free e-learning module ‘Introduction to CAN (including CAN FD)’, interested parties can introduce themselves to CAN communication technology.

CONCLUSION AND OUTLOOK
Due to the several hundred CAN systems in current and future aircraft generations, manufacturers and suppliers alike are increasingly dependent on the availability of powerful analysis and test tools. Bit-accurate and time-synchronous analysis of logical and physical events on CAN buses with the described oscilloscope solution not only speeds up primary troubleshooting, but also enables the development of automated test tools capable of quickly performing routine production tests on every aircraft according to defined manufacturer specifications. Vector also plans to extend its oscilloscope solution with innovative measurement and analysis functions for checking CAN cables and terminations. Since the CAN cables in aircraft are often very long and difficult to access, the goal is to pinpoint the location of a damaged or broken cable to minimize troubleshooting costs.

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