CONTROL
TECHNOLOGIES UK

A MACHINE BUILDER'S GUIDE TO CAN-BUS

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WHITE PAPER - CT002 VERSION 3 - 30TH NOVEMBER 2018

CAN-bus offers many advantages for machine builders, including constructors of mobile machinery. This white paper outlines what machine builders need to know about CAN-bus, presents a four-step guide to implementing a CAN-bus system, and provides tips to help ensure the success of each project.

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INTRODUCTION TO CAN-BUS

If you are new to the subject, the following is a very brief introduction. CAN (Controller Area Network) is a serial communications bus for bidirectional transmission of control system data. Connections between control units and input/output devices are typically made using a two-wire, twisted-pair cable that enables data rates of up to 1 Mb/s to be achieved, depending on the bus length. CAN-bus benefits from guaranteed latency, excellent error detection, cost-effective hardware and efficient installation.

Originally developed in the 1980s to simplify and reduce wiring in automotive applications, the CAN-bus protocol has proven to be beneficial for a wide variety of industries including static and mobile machinery. CAN is described in a four-part international standard ISO 11898; in addition, various higher-layer protocols have been standardised for particular industries and types of application.

For a more in-depth introduction to CAN-bus and the pros and cons, see this article Getting started with CAN-bus.

APPLICATIONS FOR CAN-BUS IN MACHINERY

'Machinery' is a very broad term yet, at the same time, CAN-bus is extremely versatile. Machinery applications for which CAN-bus is suitable range from weighing systems, passenger lifts and factory automation, through to packaging machinery, off-highway vehicles and industrial robots. Such machinery may incorporate almost any control and sensing technologies such as servo drives, high-speed analogue and digital sensors, fluid power systems and safety-related control systems.

WHAT DOES CAN-BUS OFFER FOR MACHINE BUILDERS?

CAN-bus is a multi-master protocol, so it lends itself particularly well to decentralised control systems, which are becoming increasingly popular today. Furthermore, machines can be electrically noisy environments due to the presence of electric motors and switchgear, but this is not a problem for CAN-bus because it can achieve robust and reliable communications while still delivering high performance and near-real-time feedback for deterministic control systems. CAN-bus systems are straightforward to modify or expand, which provides scope for upgrades as well as future-proofing. These technical characteristics, coupled with the low cost of CAN-bus hardware, make the protocol highly attractive for machinery.

For machine builders operating in multiple geographical regions, CAN-bus also offers an advantage over some other communications protocols in that it is truly international; in contrast, some commonly encountered communications fieldbuses tend to be favoured more in Europe, while others are popular in Asia, and North American users have different preferences again.

FIRST, WRITE A FUNCTIONAL SPECIFICATION

Before you can implement a CAN-bus project, first you need to know what it is that you are trying to achieve. A functional specification (or functional requirements specification, FRS) defines what the CAN-bus must do and is always important, but even more so if you might use a contractor for all or part of the CAN-bus project. The requirements specification might also be expanded to become more of a CAN-bus project specification that includes information about team members, roles and responsibilities, deadlines, future-proofing, areas that might alter as the project evolves, and other 'soft' issues that will help in developing a CAN-bus system that meets all of the needs.

The requirements specification will list 'things that the system shall do' as well as standards with which it might comply, standards against which it will be tested, any restrictions on hardware selection (for example, a machine builder or end user might have a preference for controllers from a particular supplier), flow diagrams to show how functions are related, external communications (perhaps with other fieldbuses or remotely via telematics), inputs, outputs and key processes (which may be presented as algorithms, formulae, descriptions, etc).

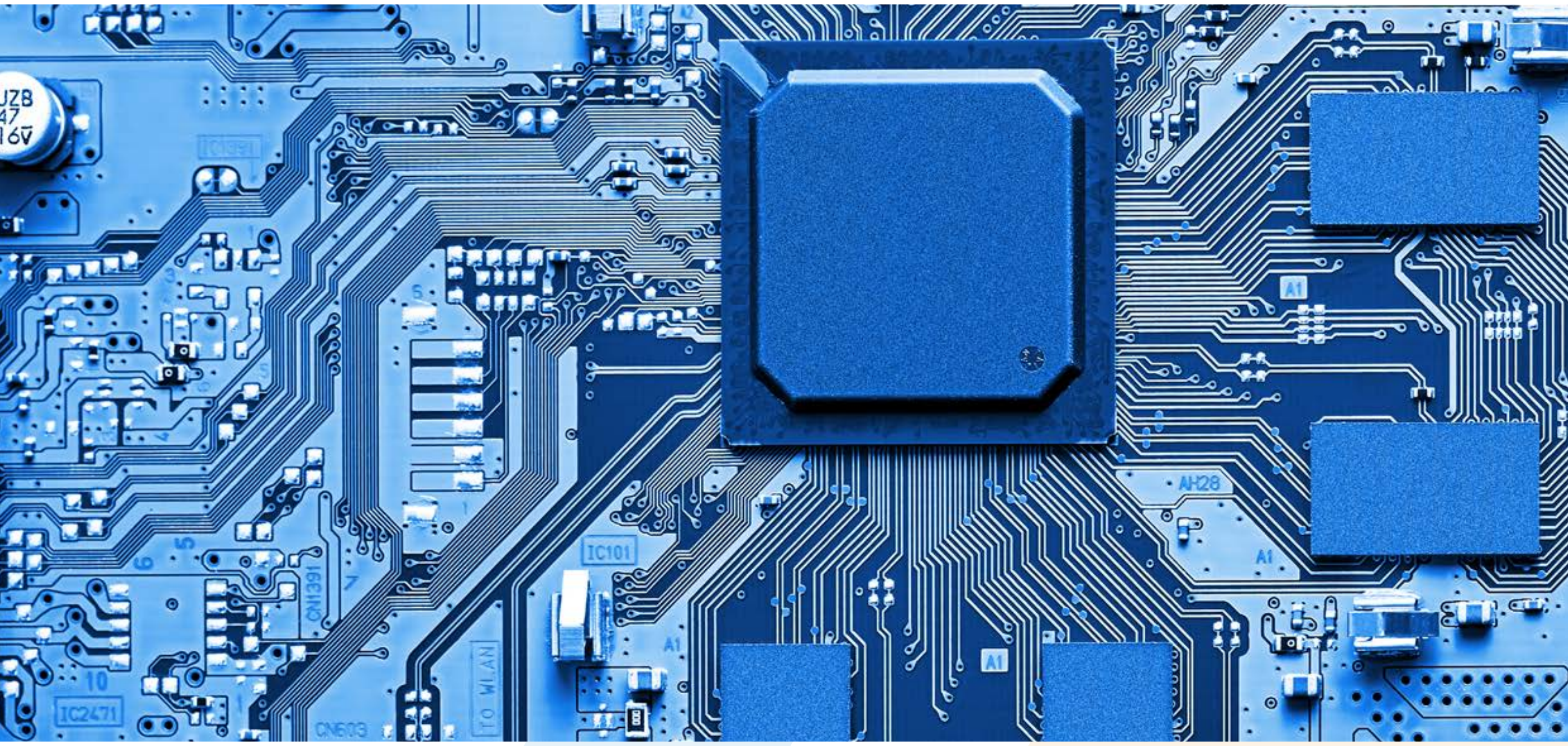
With a functional specification prepared, the CAN-bus project can now commence in earnest. We will now present a four-step process for implementing CAN-bus systems.

STEP 1

SPECIFY AND DESIGN THE CAN-BUS SYSTEM

The functional specification will greatly assist in preparing the specification for the CAN-bus system itself, which covers many aspects including but not limited to the following:

- **CAN NETWORK:** CAN 1.0, CAN 2.0A, CAN 2.0B, CAN FD or a hybrid.
- **HIGHER-LAYER PROTOCOL(S):** CANopen, DeviceNet, ISO Bus, ISO-TP, SAE J1939, etc or a mix of these.
- **DESIGN STANDARDS:** Usually ISO 11898 but there could be other international or industry standards as well.
- **TEST STANDARDS:** eg ISO 16845.
- **PHYSICAL LIMITS:** The cable lengths, as this may influence the maximum data rate.



- **NUMBER OF NODES:** Most CAN-bus networks can support up to 64 nodes but the actual figure may be higher or lower, depending on whether high-speed or low-speed CAN is used, and the performance of the CAN transceivers.
- **DATA RATES:** Data rates may be limited if cable runs are long, but otherwise the data rate will be determined by the response time needed for the application.

- **TOPOLOGY:** Linear (popular for high-speed networks), star (useful if the loss of a node must be tolerated or if the network is likely to be modified) or ring (best for high reliability and fault tolerance, particularly if a dual-ring configuration is specified). Another option is a hybrid linear/star, linear/ring or star/ring topology, the latter being popular for automotive systems.
- **ENVIRONMENTAL FACTORS:** Ingress protection, shock/vibration levels, operating temperatures, electromagnetic interference, etc (NB these may vary in different areas of the network or even for individual sensors, actuators or controllers).
- **CABLING:** Wire size, type, insulation, twists per unit length, etc.
- **TERMINATIONS:** High-speed linear buses should be terminated with 120Ω resistors whereas low-speed (fault-tolerant) networks should have each node terminated by a fraction of the overall resistance, which should be approximately 100Ω but not less than 100Ω.
- **CONNECTORS:** There is no single type of connector for CAN-bus networks so the system designer needs to specify this, though there are some recommendations (eg CiA (CAN in Automation) has published CiA 303-1, which recommends CANopen cabling and connector pin assignments).
- **HARDWARE:** Controllers, CAN-compatible HMI(s), CAN-compatible inputs and outputs, CAN interfaces for non-compatible inputs/outputs, etc.

As the design develops, use can be made of software-based simulators; the 'digital prototype' can be tested and, where necessary, modified to reduce the risk of problems occurring once the hardware is purchased and installed. For some aspects of the system, or later in the project, it may also be prudent to run the simulation with actual controller hardware or I/O devices – known as hardware-in-the-loop (HIL) simulation or testing.

STEP 2

BUILD AND IMPLEMENT THE CAN-BUS SYSTEM

Depending on the nature of the project, the CAN-bus system may be built directly on the machine or a rig could be constructed on a benchtop or an aluminium framework for assembling the controllers and some or all of the inputs and outputs. If a rig is built, then ideally the hardware and cabling should be laid out in a manner that will be representative of the built machine, including correct cable lengths, power cables and electrical equipment that might generate electromagnetic interference (EMI). CAN-bus is a robust and reliable protocol, and CAN-bus systems are often capable of coping with a degree of 'abuse' – such as faulty shielding or incorrect terminations – but the greatest long-term reliability will be achieved if adequate precautions are taken when building the network into the final machine. If a benchtop simulation is being built, care should be taken not to inadvertently avoid faults that might be present on the final machine.

IMPLEMENTATION

- Use high-quality cable and connectors
- Thorough labelling pays dividends
- Correct termination is essential

Provided the CAN-bus system has been correctly designed, the chances are that the biggest problems with the build and implementation will relate to poor wiring practices. It is essential that connectors are high-quality items that are suitable for the intended purpose and will therefore withstand shock, vibration and the ingress of dirt and moisture. While labelling will not have a direct impact on reliability, thorough labelling of cable harnesses and connectors will make assembly easier and quicker, and fewer errors will be made. After the machine has been put into operation, the labelling will also simplify maintenance and help to reduce downtime.

Another common error in the build phase of CAN-bus projects is incorrect terminations. As stated above, high-speed linear buses should be terminated with 120Ω resistors and low-speed (fault-tolerant) networks should have each node terminated by a fraction of the overall resistance, which should be approximately 100Ω but not less than 100Ω. Errors in terminations, or a failure to understand the requirements, often lead to CAN-bus faults.

STEP 3

TESTING THE CAN-BUS SYSTEM

As mentioned above, ideally an amount of testing will have been completed during the development phase by means of software-based simulations and/or hardware-in-the-loop testing.

If a trial CAN-bus system has been assembled on a benchtop, then this should be tested thoroughly to minimise the likelihood of any problems being encountered when the system is installed on a machine for the first time.

A test specification should be prepared first, and this can draw on the contents of the functional specification – for each function, a number of tests can be specified. In addition to testing the functioning of every input, output and process for normal operation, tests can be conducted for proving the system in situations where operating parameters exceed the operating specification – though the necessity and severity of this type of testing will depend on the application.

Testing the functions (eg does a particular set of inputs result in the expected set of outputs?) is vital but it does not indicate whether, for example, the CAN-bus system is relying heavily on its built-in ability to resend data that is not received correctly first time. For this level of testing it can be helpful to have a PC loaded with relevant CAN-bus analysis software or, alternatively, a handheld analyser that typically has a screen, keypad and onboard software. This type of instrument can help in performing the following tests:

- Measure resistance between pins on CAN connectors
- Measure resistance of terminations
- Measure cable impedance
- Measure signal level
- Measure baud rate
- Measure bus load
- Monitor number of error frames per unit of time
- Identifier scan

TEST SPECIFICATION

- Refer back to the functional specification when preparing the test specification
- Decide how far to go if it is necessary to test beyond the system's normal operating parameters

A CAN-bus analyser can therefore provide a wealth of information that assists in checking the system and identifying faults.

STEP 4

DIAGNOSTIC DATA FROM THE CAN-BUS SYSTEM

Two types of diagnostic data will be of interest once the machine has been built, namely data relating to the CAN-bus system (eg baud rate, error rate, etc) and data relating to the physical I/O devices and controllers. The machine may have an HMI on which diagnostic data can be viewed, but it might also have a port into which a CAN-bus analyser and/or other device can be connected. A machine could also be equipped with Bluetooth for connecting diagnostic equipment wirelessly, or it might benefit from telematics, in which case the owner, supplier, maintenance contractor or other authorised personnel can view diagnostics remotely for faster troubleshooting and reduced downtime.

Data for the CAN-bus system can indicate degradations in overall performance, short circuits, open circuits and I/O devices that are starting to fail. It might also indicate if attempts have been made to carry out unauthorised modifications to the network.

Given the proliferation of sensors on modern machinery, the diagnostic data from these can prove invaluable. We are all familiar with the 'check engine' warning lamp on our cars' dashboards, and the subsequent trip to the garage to have the fault codes read – or you may have an OBD (on-board diagnostics) reader so you can plug it into the SAE J1962 diagnostic port on the car and read the codes yourself. Either way, the codes give an indication of the I/O devices that are generating the fault, and possibly also the nature of the fault, enabling mechanics to focus on the right area and perform a repair as quickly as possible. A CAN-bus system on a machine offers the same benefit of pinpointing the sources of errors so that they can be rectified swiftly and downtime minimised.

If the machine has telematics, faults can be diagnosed remotely and a local technician informed of what repairs are necessary.

CAN-bus controllers can be configured to store diagnostic data locally or transmit it elsewhere – potentially via WLAN, Bluetooth or a cellular connection. Some controllers have built-in GPS position-sensing capability and/or accelerometers, so this data can be logged simultaneously with the machine diagnostic data to give more insight into causes of failures.

However, one of the greatest advantages of having diagnostic data available is that a predictive maintenance regime can be implemented, whereby tell-tale signs of wearing or failing components can be identified automatically prior to a catastrophic failure. Replacement parts can be obtained and repairs scheduled for a convenient time so as to avoid unplanned downtime as well as the potential for failures that could have a knock-on effect resulting in more extensive damage to the machine.

SUMMARY OF CAN-BUS BENEFITS FOR MACHINE BUILDERS

Having seen how a CAN-bus system can be developed and implements on machinery, it is worth summarising the benefits for machine builders who are seeking cost savings and a technical edge over their competitors:

- Multi-master protocol suits decentralised control and modular machine architectures.
- Immunity to electrical noise (within reason).
- Wide availability of hardware.
- Relatively low-cost hardware.
- Robust and reliable communications.
- Straightforward to modify, upgrade or expand control system.
- Message prioritisation eliminates traffic congestion, hence entire network meets timing constraints.
- Error-checking at every node ensures freedom from errors.
- In most cases up to 64 nodes can be supported, and sometimes more are possible.
- Networks can operate over distances of up to 40m with data rates of 1 MB/s (5 km if data rates are reduced to 10 kB/s).
- Truly international, standardised protocol.
- Machine builders not tied to any particular controller type or manufacturer.

IN ADDITION, CAN-BUS PROVIDES

BENEFITS FOR MACHINE BUYERS AND END USERS:

- Comprehensive bidirectional communications deliver excellent diagnostics and reduced downtime.
- Straightforward to add telematics and remote diagnostics, with associated benefits in terms of downtime reduction.
- Robust protocol results in high reliability and reduced downtime.
- Lower build cost due to reduced wiring.
- Future-proofing for modifications and upgrades that are highly likely to be required at some point in the machine's lifetime.
- Minimal wiring simplifies maintenance and repairs.

LIMITATIONS OF CAN-BUS FOR MACHINE BUILDERS

CAN-bus is a low-cost protocol that is widely used and easy-to-implement but, in common with other technologies and communications protocols, it cannot do everything. In the field of machine building, arguably the most significant limitation is the number of nodes that can be added to the network – usually a maximum of 64. While 64 nodes is likely to be more than enough for many machines, large and/or complex machines may require a greater number of nodes and an alternative communications protocol might prove better.

There is also a trade-off between data rate and bus length. A rate of 1MB/s for lengths of up to 40m is likely to be sufficient for most applications but some large machines might need higher data rates for very fast synchronisation of multiple axes, or large machines might need 1MB/s to be maintained over longer distances.

While not strictly a limitation of CAN-bus, the system architecture must be correctly specified, designed and implemented if the expected performance is to be achieved and maintained in the long term. Because CAN-bus is a robust and reliable protocol, sometimes a poorly designed or implemented system can initially operate as required, which gives a false sense of security. In such cases it may only take a small change to the machine or something else in the operating environment for the CAN-bus to be 'tipped over the edge' and become unreliable. See the section below for hints on successful implementation.

TIPS FOR SUCCESSFUL IMPLEMENTATION OF CAN-BUS SYSTEMS

Adhering to the following guidelines will help machine builders to achieve a CAN-bus system that meets the functional specification and continues to perform as intended for the lifetime of the machine:

- Do not assume that the functional specification is correct and complete – check it!
- Take time to specify the CAN-bus system so it meets the functional specification, then ensure that the system design and individual components meet all aspects of the specification.
- As the system is being developed, use simulations to check its operation.
- Where possible, use CAN-compatible I/O devices rather than standard devices and CAN interfaces, as the CAN-compatible devices will have better diagnostics.
- Specify and use good quality cabling and connectors, with sufficient labelling to avoid connection errors.

- During the installation, take care over shielding and grounding, and try to avoid inductive coupling by not running CAN-bus cables parallel to and close to power cables.
- If the operating environment is electrically noisy, consider using CAN-bus to fibre optic converters, as the optical signal in the fibre will be immune to electrical noise.
- Test the system rigorously; adhere to a detailed test specification and use a CAN analyser.
- Ensure cables are adequately supported so they do not suffer unduly from vibration and cannot be snagged by other objects.

CAN-BUS SYSTEMS FOR REAL-WORLD MACHINES

Control Technologies UK is a CAN-bus specialist with many years of real-world experience of machine control systems and other applications, helping companies to leverage greater functionality, efficiency and cost savings. Whether you are looking to save weight, cut build costs, enhance diagnostics, improve reliability, reduce downtime or you need support to improve the performance of an existing CAN-bus system, our team is available to provide advice and engineering. We work closely with leading manufacturers and technology partners, ensuring customers benefit from the most relevant solution to their CAN-bus challenges. Overall, we offer the most complete end-to-end service, extending your engineering capabilities without extending your overheads.

CONTACT US TO DISCUSS YOUR CAN-BUS AND CONTROL SYSTEM REQUIREMENTS.

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