

Simplify CAN bus implementations with chokeless transceivers



Maxwell Robertson
Applications Manager
Industrial Interface group
Texas Instruments

Chokeless CAN transceivers allow system designers to reduce size, cost, and complexity of CAN bus implementations while meeting stringent automotive EMC requirements.

With the density of electronics in automobiles increasing each year, it is important to ensure that in-vehicle networks maintain a high level of performance with respect to electromagnetic compatibility (EMC). This ensures that various sub-systems will continue to function as intended when integrated into a larger solution and operated in a typical (noisy) environment. Although there are many different in-vehicle networking standards and a variety of different EMC requirements from automotive original equipment manufacturers (OEMs), this paper focuses on a topic that has proved to be particularly challenging: radio frequency (RF) emissions from a controller area network (CAN) bus.

CAN uses balanced, differential signaling in order to send binary data at baud rates of up to 1 Mbps (or higher, if the “flexible data rate” variant is used). Ideally, using differential signaling prevents the external coupling of any noise. Since each half of the differential pair (referred to as CANH and CANL) vary symmetrically, noise contributions of each will destructively interfere. However, no CAN transceiver is perfectly ideal, and small asymmetries between the CANH and CANL signals can give rise to a differential signal that is not perfectly balanced. When this occurs, the common-mode component of the CAN signal (the average of both CANH and CANL) will no longer be a constant DC value. Instead, it will exhibit data-dependent noise.

Two primary types of imbalance can lead to this noise. One is a mismatch between the steady-state common-mode voltage levels that occur during the dominant (driven) and recessive (high-impedance) states. Another is a difference in the timing between CANH and CANL signals as they transition between these two states.

The steady-state mismatch results in a noise pattern that resembles a scaled version of the CAN data itself. This noise pattern is broad in its frequency content, appearing as a series of evenly-spaced discrete spectral lines that extend down to very low frequencies. The timing mismatch results in a noise pattern consisting of short pulses or disturbances that occur whenever there is an edge transition in the data. This noise pattern tends to have spectral content primarily at higher frequencies.

The waveform in **Figure 1** shows an example of the common-mode noise that can be observed on the output of a typical CAN transceiver. In this image, the black trace (Channel 1) shows CANH, the purple trace (Channel 2) shows CANL, and the green trace (math function) is the sum of CANH and CANL. This summation gives a waveform whose value is equal to twice the common-mode voltage at a given point in time.

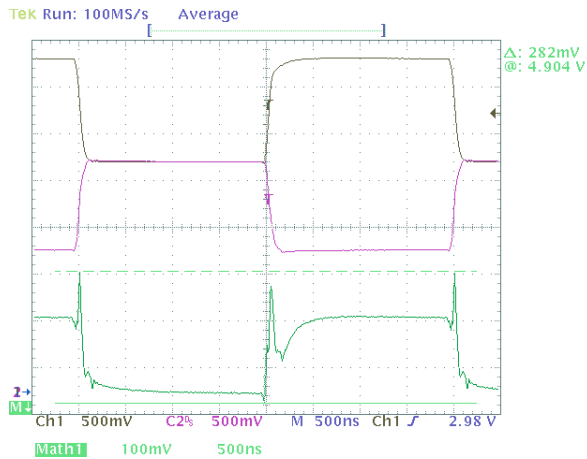


Figure 1: Typical CAN transceiver CANH/CANL outputs and common-mode noise

The common-mode waveform shows both types of noise: high-frequency noise corresponding to dominant-to-recessive/recessive-to-dominant transitions, and low-frequency noise corresponding to mismatched dominant and recessive common modes.

Since the common-mode portion of the signal can couple (through radiated or conducted paths) onto other components in a system (or to external systems), this common-mode noise directly impacts emissions performance. The conducted emissions of this device, which are measured per Engineering Services for Industrial Electrical Engineering/ Electronics (IBEE) Zwickau methodology, are plotted along with a common automotive original equipment manufacturer (OEM) limit line in **Figure 2**.

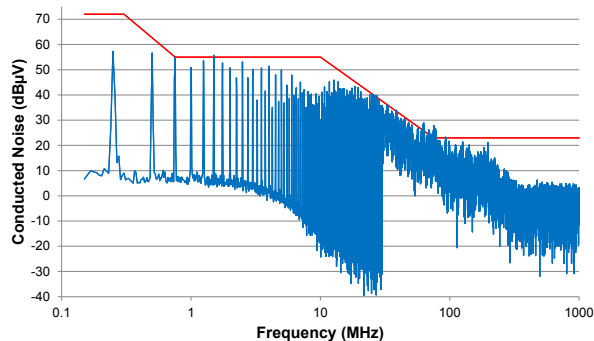


Figure 2: Conducted emissions of a typical CAN transceiver

The transceiver's output emissions exceed the OEM requirements in both low-frequency and high-frequency regions. In order to lower the emissions to a satisfactory level, some external filtering must be used.

The most commonly-used filter component in CAN buses is a common-mode choke (as shown in **Figure 3**). A common-mode choke is constructed out of two coils of wire that share a common core. The direction of each coil's windings is arranged such that common-mode currents (that is, currents flowing in the same direction through each coil) have magnetic fluxes that share the same polarity. This allows for the choke to act as an inductor for common-mode signals, giving an impedance that increases with increasing frequency. Conversely, differential-mode currents (that is, currents flowing in opposite directions through each coil) will have their magnetic fluxes interact with opposite polarities. For a balanced waveform like a CAN signal, the opposing magnetic fluxes from each coil will be equal in magnitude and therefore no net flux will accumulate in the core. This results in the choke acting as a short circuit for the CAN signals.

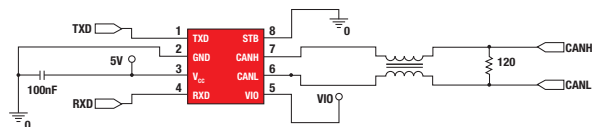


Figure 3: Common mode choke schematic

This technique can be very effective in reducing the emissions of a CAN bus. For example, when the above device that was shown to be failing emissions requirements was re-tested with a 51- μ H common-mode choke the performance improved significantly (**Figure 4**).

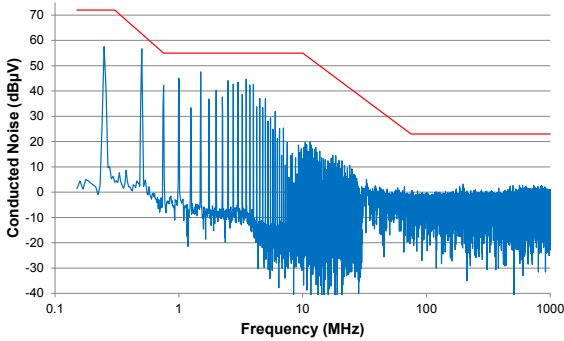


Figure 4: Conducted emissions of typical CAN transceiver (with common-mode choke)

However, there are several drawbacks to the addition of a common-mode choke. An obvious disadvantage to using a common-mode choke is the extra area required on the printed circuit board and additional cost incurred in the bill of materials. Beyond that, though, there are some more subtle effects on the CAN bus that should be considered. Since the choke coils introduce some series inductance, resonances can be created when this inductance is combined with the parasitic capacitance of the CAN network. Despite reducing the common-mode noise in most frequency bands, these resonances cause the amount of noise to increase at the resonant frequency. This effect can be observed in the common-mode noise waveform shown in **Figure 5**.

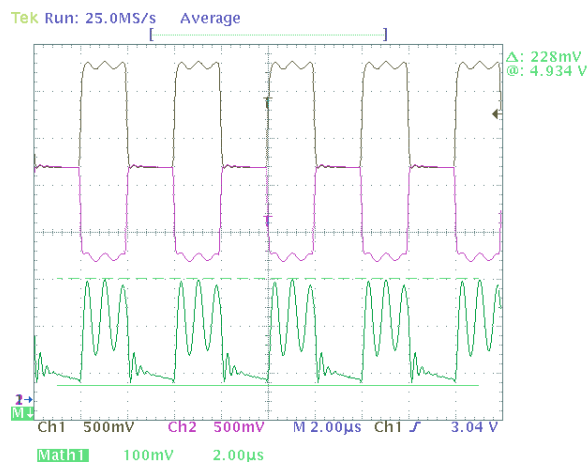


Figure 5: Common-mode noise resulting from choke inductance

This narrow-band noise can be particularly difficult to manage. It tends to be strong in amplitude, and its frequency can vary from system to system due to variation in the choke inductance and bus capacitance. Note that the inductance value of a common-mode choke is typically specified with wide tolerance ranges (such as $-30\%/+50\%$ from nominal). Similarly, the bus capacitance of a CAN network will vary based on the type and length of cabling being used, the number of nodes on the network, and the design of each node.

Another unintended consequence of the common-mode choke inductance is an increased risk of large transient voltages on the bus. Fault conditions such as a short to power supply, battery voltage, or system ground can cause abrupt changes in common-mode currents. This occurs both as the short-circuit connects/disconnects and as the CAN driver transitions between dominant and recessive states. When the current flowing through the choke inductance changes rapidly, a large voltage potential is created at the CAN terminals of the driver IC. In some cases this voltage may exceed the transient over-voltage handling capabilities of the CAN device and result in permanent damage.

In order to reduce emissions without facing the disadvantages associated with a common-mode choke, an alternate solution exists: reduce the common-mode noise output from the CAN driver. This may seem straightforward, but it requires careful design from the semiconductor manufacturer. The CANH and CANL voltage levels during recessive and dominant states need to be tightly controlled to make sure that the CAN bus waveform remains as balanced as possible.

Additionally, the transition times and timing skew between the CANH and CANL lines, as they transition between dominant and recessive states, need to be well-matched to limit the common-mode noise occurring in high frequency bands.

The transient waveform for TI's [TCAN1042-Q1](#) CAN transceiver is shown in **Figure 6**. The corresponding emissions plots are given in **Figure 7**.

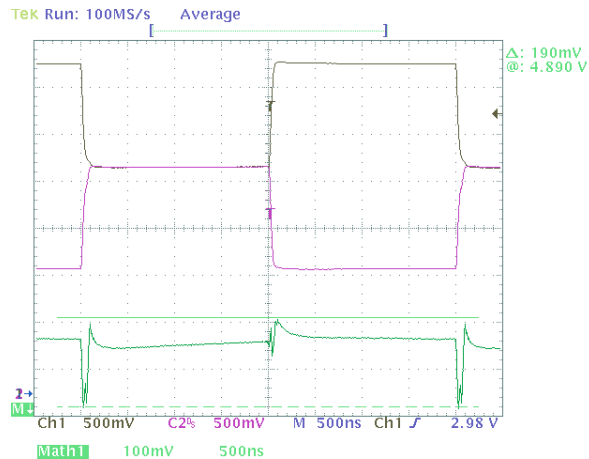


Figure 6: CANH/CANL outputs and common-mode noise

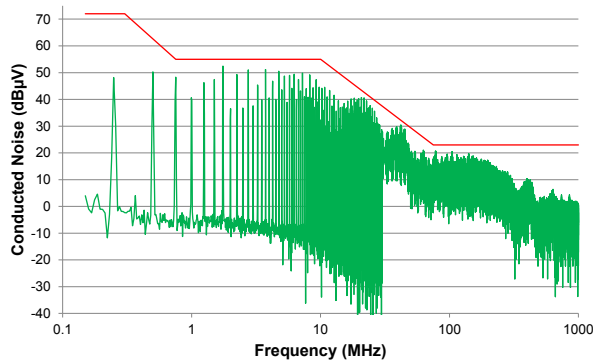


Figure 7: Conducted emissions of an automotive fault-protected CAN transceiver

The well-matched output stage of the [TCAN1042-Q1](#) gives rise to very low output common-mode noise. This results in emissions performance that is suitable to pass OEM requirements without the use of external common-mode filtering components like chokes.

Conclusion

Although common-mode chokes are widely used in the automotive industry today as a way to mitigate EMC concerns in CAN buses, new high-performing transceivers are rendering them unnecessary. Eliminating common-mode chokes allows for CAN bus implementations to be smaller and less expensive while avoiding issues like circuit resonances and inductive voltage spikes.

Additional information

Here's more information from TI about [CAN](#) bus transceivers.

[Download the TCAN1042-Q1 data sheet.](#)

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