CAN transceiver choice for improved signal integrity

This article gives an introduction into the signal theory of the energy transmission via a CAN network. Then, some hints for achieving of an improved signal integrity and recommendations for further readings are given.

The complete article is published in theSeptember issue of the CAN Newsletter magazine 2020. This is just an excerpt.

Figure 1: Network topology with all possible stub-lines (see for lengths in Table 1) (Source: Kvaser)

Impedance analysis of a CAN network

Figure 1 shows a CAN network with a 9,6-m CAN-line (from point 16 to point 17) and possible stub-lines (points 1 to 15). The stub-lines can be selectively connected in order to execute diverse tests. The impedance check is done with the TDR (time domain reflectometer) tool connected at point 16. In the first test the impedance of a point-to-point connection (16 to 17) without stub-lines is analyzed.

Figure 2: Impedance of a point-to-point connection (16 to 17) (Source: Kvaser)

Figure 2 shows that the impedance value starts at 50 Ohm (standard impedance of most analyzing tools). The tool is connected with a 0,2-m, 50-Ohm coax cable via a 9-pin Dsub connector to the end of the CAT5 cable (point 16) with a characteristic impedance of 100 Ohm. Figure 2 also shows two impedance drops at the locations of possible connection points. These are caused by the small T-connectors without connected stub-lines. The cable ends at point 17 without a termination. Here, the impedance jumps to infinity. The signal delay from point 16 to point 17 lies in the range from 45 ns to 50 ns. The distance is calculated with an assumed wave speed of 4,7 ns/m (70 % of the light speed). With well-designed CAN-transceivers installed directly at the T-connector devices, it would be possible to achieve communication with bit-rates higher than 20 Mbit/s.

By adding of stub-lines to the T-connectors it is possible to see the changes in the impedance characteristics. Table 1 lists the lengths of the cable segments and the stub-lines, which can be connected.

Table 1: Lengths of the cable segments and the stub-lines, which can be connected (Source: Kvaser)

In the next test, only the short stub-lines at points 2, 8, 10, 14, and 15 are connected. The impedance characteristic for this case is shown in Figure 3. The impedance remains at 100 Ohm in the first cable segment (from point 16 to 1). At point 2 (1,3-m stub-line connected) the impedance drops to 60 Ohm. The measurement shows an impedance increase until the next section of the stub-lines connections, where the impedance drops to 40 Ohm. It should also be observed that at the cable end, the TDR measures a sloped (instead of a vertical) line to infinity. This means, that the star- topology prevents the TDR from measuring the correct impedance at the cable end. The impedance measurement using the TDR tool with all connected stub-lines delivers no meaningful results. A TDR tool is designed to find small impedance variations in a point-to-point connection. In a complex network topology it is necessary to use other tools to understand the limitations.

Scattering parameter analysis

If the impedance variation is too large, the high-speed data communication will be prevented. To understand the bit-rate limitation, it is necessary to check the frequency response and to estimate the possible analog bandwidth from that. This is achieved by measuring of the S12 parameters from the energy sender to the receiver. It is required to measure the parameters at several points in order to find out the worst-case frequency limits.

Figure 3: Impedance of the CAN-line with short stub-lines at points 2,8,10,14, and 15. (Source: Kvaser)

Figure 4: S12 tool measurement at frequencies 0 MHz to 100 MHz in a point-to-point connection (Source: Kvaser)

The first measurement is done on the 9,6-m point-to-point line. The S12 tool (energy source) connected at point 16 sends a signal with different frequencies, and the same tool measures how much of this energy reaches point 17.

The upper graph in Figure 4 shows the energy loss. The energy drop is 1dB to 2 dB for frequencies up to 45 MHz. From 45 MHz to 95 MHz, energy drops of up to 4 dB are measured. A 3-dB loss equates to a half of the input voltage. In this topology, a 2-V input would result in a 1-V output at 50 MHz.

The lower graph in Figure 4 shows the phase shift between points 16 and 17. At low frequency, the phase shift is zero and at 20 MHz it is 360°, which equates to one whole wavelength. The cycle time at 20 MHz is the inverse of this value, which is 50 ns. If 50 ns is divided by the length of the cable (ca. 10 m), one gets ca. 5 ns/m. At 100 MHz five full cycles between points 16 and 17 are elapsed.

Figure 5: S12 parameters measured at frequencies from 0 MHz to 100 MHz in a CAN network with stub-lines at points 2, 8, 10, 14, and 15. (Source: Kvaser)

Figure 6: The S12 parameters measured at frequencies from 0 to 100 MHz in a CAN network with all possible stub-lines connected. (Source: Kvaser)

In the next step the short stub-lines at points 2, 8, 10, 14, and 15 are connected. The upper graph in Figure 5 shows the energy loss in dB. At 20 MHz (cursor) the 3-dB level is achieved at which the signal voltage drops to 50 % of the transmitted level. This particular CAN network blocks all frequencies from 20 MHz to 75 MHz. The frequencies from 75 MHz to 100 MHz are 10 dB lower than the input level, but are not completely blocked. The phase diagram (lower graph) should not change very much, but when the signal level is low, there are increased measurement uncertainties. The next step is to install all possible stub-lines as shown in Figure 1 with the lengths given in Table 1.

Figure 6 shows the possible analog bandwidth between points 16 and 17. The 3-dB limit is reached at 4,2 MHz (see cursor 1). For frequencies above 4,2 MHz it is not possible to transfer energy from point 16 to point 17. If one repeats this measurement from point 16 to all other stub-line ends there will be similar but differing results. The connection from point 16 to 17 has the highest analog bandwidth of 4,2 MHz. The lowest analog bandwidth of 2,8 MHz was measured between point 16 and the end of the stub-line at point 2.

Relation between analog bandwidth and bit-rate

Data communication depends on the energy transfer over a transmission line. The analog bandwidth defines the highest sinus signal within a certain frequency that can transfer energy over the transmission line. A digital signal is similar to a square wave. A CAN-frame transmitted at 500 kbit/s is similar to a square signal with a frequency of 250 kHz. A cyclic signal can be transformed into the frequency spectrum by a Fourier transformation.

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