Application Note

NOVOSENSE

CAN Transceiver Node Calculation and Peripherals Circuit Reference Design

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ABSTRACT

As the control of various systems in cars is developing towards intelligence and automation, automotive electrical systems are becoming increasingly complex. Different OEMs and car manufacturers are defining different automotive bus standards to reduce the complexity of wire harness networks and electronic system failures, while also reducing overall vehicle costs. The CAN bus is most widely used in automotive buses, and adopting a suitable network topology and improving EMC performance is of great significance for CAN transceivers in complex automotive applications. The Novosense has launched multiple CAN transceivers that can meet different system applications. This application note mainly introduces the calculation of the number of nodes in the CAN network and the selection of peripheral circuit design for transceivers.

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1.Calculation of the number of CAN bus nodes

The maximum number of nodes supported by bus in a CAN network is an important parameter for measuring the performance of CAN transceivers. The factors that affect the number of CAN bus nodes can be considered from two aspects: the physical layer and the protocol layer of the CAN transceiver.

Firstly, in terms of the physical layer, the differential output voltage of the bus nodes determines whether the CAN bus level can be recognized normally and whether communication can proceed normally. This is mainly determined by the bus load resistance RL, which depends on the matching resistance of the bus terminals and the differential input resistance Rdif of each node. We can estimate the maximum number of nodes in a CAN network from the perspective of the physical layer as follows.

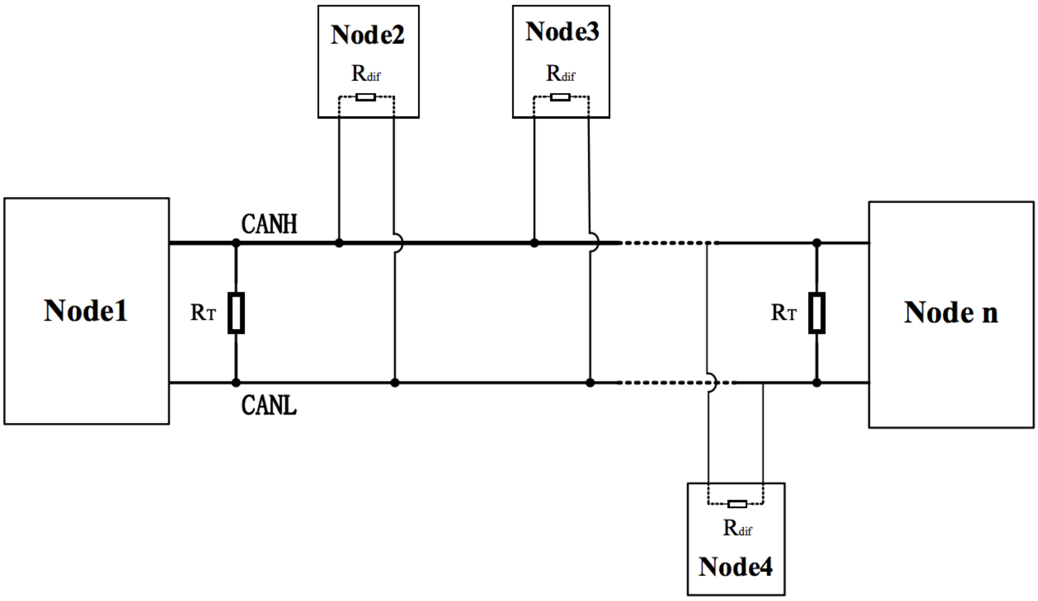

Figure1.1 Bus topology of CAN network with n nodes

The above figure shows the topology diagram of a bus network with n CAN nodes, where RT is the terminal matching resistor and Rdif is the bus differential input resistor of the CAN transceiver. A simple topology diagram can be obtained through circuit equivalence as follows:

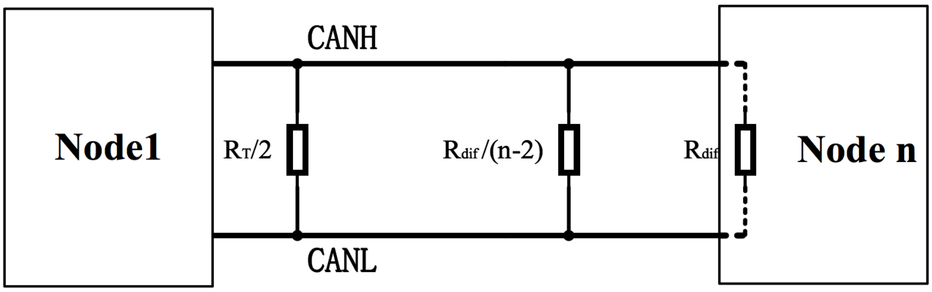

Figure1.2 Equivalent circuit diagram of CAN network with n nodes

As shown in the above figure, Node1 is used for signal transmission and Node n is used for signal reception. The equivalent resistance seen from Node 1 is:

$$R_L = \frac{R_T}{2} // [R_{dif}/(n-1)] \tag{1}$$

Simplifying equation (1) yields:

$$n = (\frac{1}{R_L} - \frac{2}{R_T})\, R_{dif} + 1 \tag{2}$$

R_T is the terminal matching resistor, where 120Ω is taken; Rdif is the differential input resistance, where 20kΩ is taken; The load resistance RL range is 45Ω~70Ω. When RL=45Ω, the maximum value of n is 112. So under these parameter conditions, a maximum of 112 CAN nodes can be supported in the CAN bus network.

From the perspective of protocol layer, as the number of nodes increases and the bus wire becomes longer, the parasitic parameter of the wire increases. In the case that local node sends and receives signals on its own, the increasing parasitic of bus may lead to more attenuation of the feedback signal and sampling errors in the CAN controller, resulting in abnormal communication; In the case of communication between two nodes that are far apart, the more intermediate nodes there are, the longer the wire, resulting in a longer signal propagation delay. After receiving the CAN signal from the sending node, the receiving node will respond within a frame (ACK), which may cause delayed response and communication failure. So when calculating the maximum number of supporting nodes on the CAN bus, the influence of wire parasitic and propagation delay should be considered. The specific requirement is that signal attenuation caused by large wire parasitic should not cause deviation in the sampling of CAN controller. Meanwhile, the propagation delay of the signal on the transmission path should be less than half of a bit time to ensure that the receiving node can respond timely and not cause communication failure.

2.CAN Bus peripheral circuit reference

In automotive applications, EMC has always been a widely concerned issue, and compared to traditional cars, the EMC problem of new energy vehicles is more prominent. Therefore, the EMC performance requirements for the bus interface chips are also relatively high. For achieving good EMC performance, in addition to chip design considerations, it is also crucial to improve the peripheral circuits of the chip in the system. This section will introduce some reference designs for the peripheral circuits of the CAN chip (as shown in Figure 2.1).

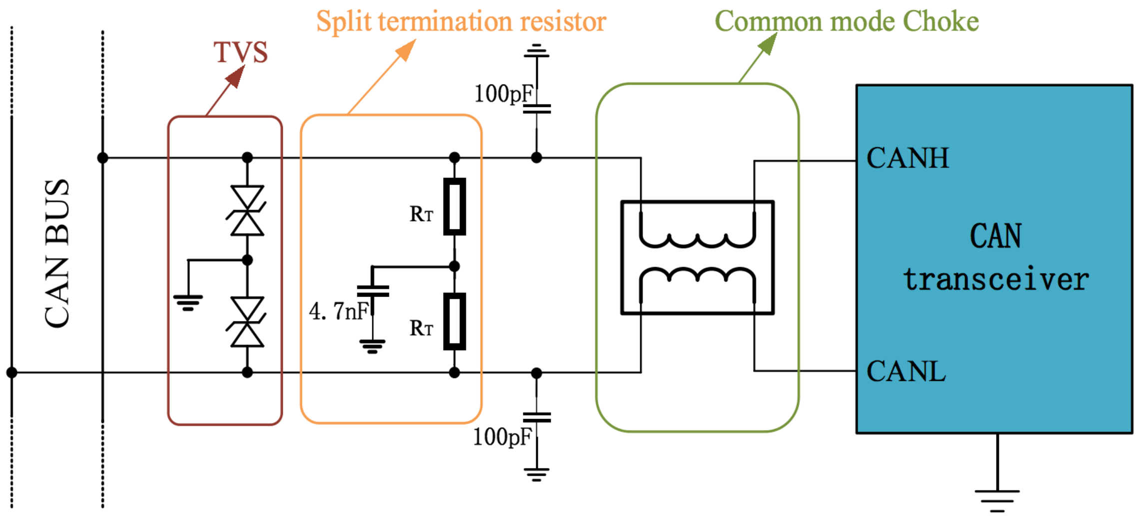

Figure 2.1 CAN bus peripheral circuit reference diagram

2.1.Common mode choke

The characteristic of common mode choke is that it exhibits higher impedance for common mode signals and lower impedance for differential mode signals, so it has a strong inhibitory effect on common mode noise interference. In the automotive CAN network, common mode choke is often used to improve the EMC performance of the system. In addition to filtering out the interference noise emitted by the system itself through the CAN bus and reducing its impact on other systems, it can also weaken the impact of interference noise generated by other systems on CAN bus communication.

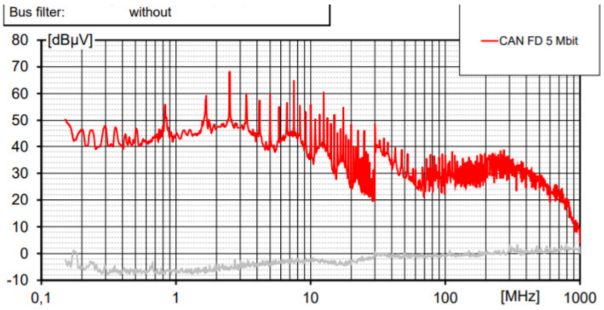

Figure 2.2 CAN FD=5Mbps EMI results without CMC

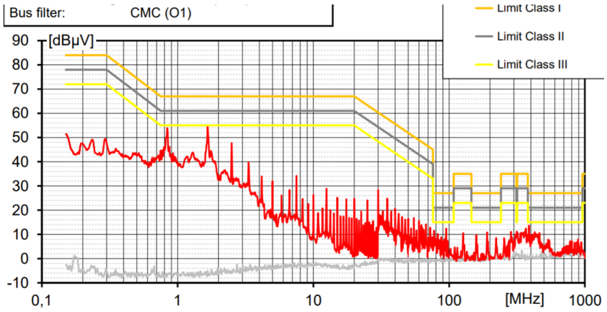

Figure 2.3 CAN FD=5Mbps EMI results with CMC

The above figures show the EMI test results of the NOVOSENSE CAN transceiver, with and without common mode choke (CMC) on the bus. The comparison shows that CMC has a strong inhibitory effect on electromagnetic interference emitted through the CAN bus.

When selecting CMC, we need to pay attention to characteristics such as inductance value, leakage inductance, DC resistance, and mode conversion characteristics.

- Inductance value

We need to consider the suppression of common mode noise when selecting the inductance value of CMC. At the common mode noise frequency of the CAN bus, CMC should have the highest possible inductance value, which is manifested as high impedance to suppress the propagation of common mode noise. A small inductance value will have poor suppression effect on common mode noise, while a large inductance value will have size and cost limitations. It is recommended to use a 51uH inductance CMC for 500kbps CAN communication, and a 100uH inductance CMC for 2Mbps CAN FD communication.

- Leakage inductance

Leakage inductance, also known as differential mode inductance, has a certain inhibitory effect on differential mode signals. A large leakage inductance may cause the CAN signal to ring, affecting the normal communication of the CAN bus. And a certain leakage inductance can also suppress the differential current in the CAN bus and improve the EMI performance of the system. Therefore, the impact of leakage inductance should be comprehensively considered. As long as there is no significant ringing on the bus signal that interferes with normal bus communication, appropriate leakage inductance is beneficial.

- DC resistance

The larger the DC resistance of the common mode choke, the greater the loss of the bus signal and the lower the transmission efficiency. After determining the inductance value of the common mode inductance, the CMC with the smallest possible DC resistance should be selected.

- Mode conversion characteristics

The mode conversion characteristics of common mode choke reflect the symmetry of the upper and lower coils of the inductor, which is reflected by the S_{sd12}/S_{ds21} parameters. The larger the parameter difference between S_{sd12}/S_{ds21}, the greater the mode conversion characteristics, indicating a greater asymmetry between the upper and lower coils of the CMC. This will introduce new common mode noise during CAN communication, reducing the EMI filtering performance of the CMC. So we should choose CMC with two parameters that are relatively close, S_{sd12}/S_{ds21}.
The impedance frequency characteristic curve of DLW32SH101XF2 is shown in Figure 2.4. Overall, CMC has a high common mode impedance to suppress common mode noise. In the frequency band of CAN bus communication, CMC has a high common mode impedance Zc and a small differential mode impedance Z_d, ensuring the suppression of common mode noise without affecting the normal communication.

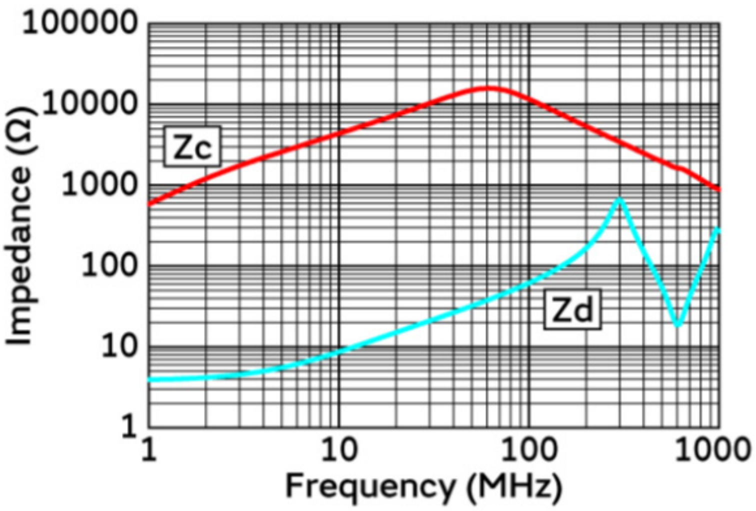

Figure2.4 CMC Impedance-frequency characteristic curve

During normal communication of the CAN network, if there is an abnormal fault on the bus, such as a short circuit to BAT or VCC, due to the CMC, a transient voltage near or exceeding the bus withstand voltage may be generated on the bus. For the NOVOSENSE series CAN transceivers, the transient overvoltage generated by bus short circuits on the CMC meets the opening conditions of the ESD protection circuit inside the chip bus pins. The overvoltage energy generated by the CMC on the bus will be completely released through the internal ESD protection circuit, without causing any damage to the chip.

2.2.Terminal Split resistors

In a CAN network with multiple nodes, communicating normally through the CANH and CANL pins of various CAN transceivers connected by the bus. Usually, a resistor is connected in parallel on the bus of the head and end nodes, and the resistance value is generally consistent with the characteristic impedance of the bus. The main functions of this resistor are as follows:

- Matching bus characteristic impedance to prevent signal reflection and ensure signal transmission quality

The characteristic impedance of the CAN bus is generally 120 Ω, while the differential input resistance of the CAN transceiver under recessive is several tens of kΩ. After the signal from the transmitting node is transmitted to the receiving node through the bus, it will generate signal reflection, causing the bus signal to ring and resulting in error codes. After connecting a resistor in parallel with the bus characteristic impedance at the receiving end, it can absorb the excess energy of the signal reaching the receiving end, avoid ringing, and ensure the transmission quality of the signal.

- The load resistance of the bus is within the range of 45 Ω to 70 Ω, improving the anti-interference performance of the bus

Because the input differential resistance value of the CAN transceiver is tens of kΩ, under recessive mode, some slight external interference may generate a dominant differential voltage through a resistance of tens of k Ω, changing the bus state. Therefore, it is necessary to parallel a resistor with a smaller resistance value at the bus to absorb some external interference. Meanwhile, considering the bus output voltage range of the CAN transceiver, the parallel resistance value should make the external equivalent load resistance of this node between 45 Ω and 70 Ω.

- Accelerate the falling edge of the bus signal to ensure that the bus quickly switches to recessive

The process of bus switching can also be seen as a process of charging and discharging capacitors. Without parallel terminal resistors, the parasitic capacitance of the bus is only discharged through the internal resistance of the CAN transceiver when switching from dominant to recessive. The process is slow and lead to slow signal dropping. In some fast communication networks, it will affect the normal communication of CAN. By paralleling a matching resistor with a smaller resistance value on the CAN bus, the discharge process can be accelerated, the falling edge of the bus signal can be accelerated, and the bus can quickly switch from dominant to recessive. As shown in Figures 2.5 and 2.6, the CAN bus waveforms are obtained without terminal resistors and with terminal matching resistors added respectively.

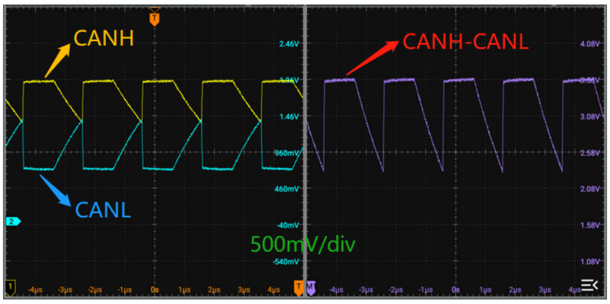

Figure2.5 CAN bus waveform without terminal resistor

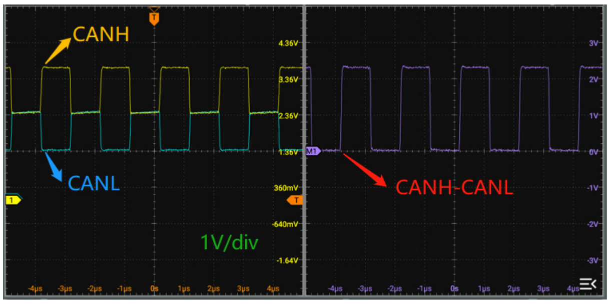

Figure2.6 CAN bus waveform with 60Ω terminal resistor

As shown in above figures, without terminal resistors, when the bus switches from dominant to recessive, the level drops slowly and occupies almost the entire recessive bit time (rate=1Mbps), which can lead to abnormal CAN communication;
In the case of adding terminal matching resistors, the level drops quickly and the bus waveform is ideal.
To further improve the EMC performance of CAN transceivers, it is recommended to divide the matching resistor of a single terminal into two split resistors, and connect them to GND through capacitors at intermediate nodes, as shown in Figure

2.1. This connection method can provide additional paths for common mode interference on the bus, further reducing the impact of common mode noise on the bus, and also forming an RC low-pass filter to filter out some high-frequency noise interference. For some intermediate nodes in the CAN network, this termination resistor method can also be used to further improve the signal quality of the intermediate nodes, as shown in Figure 2.7.

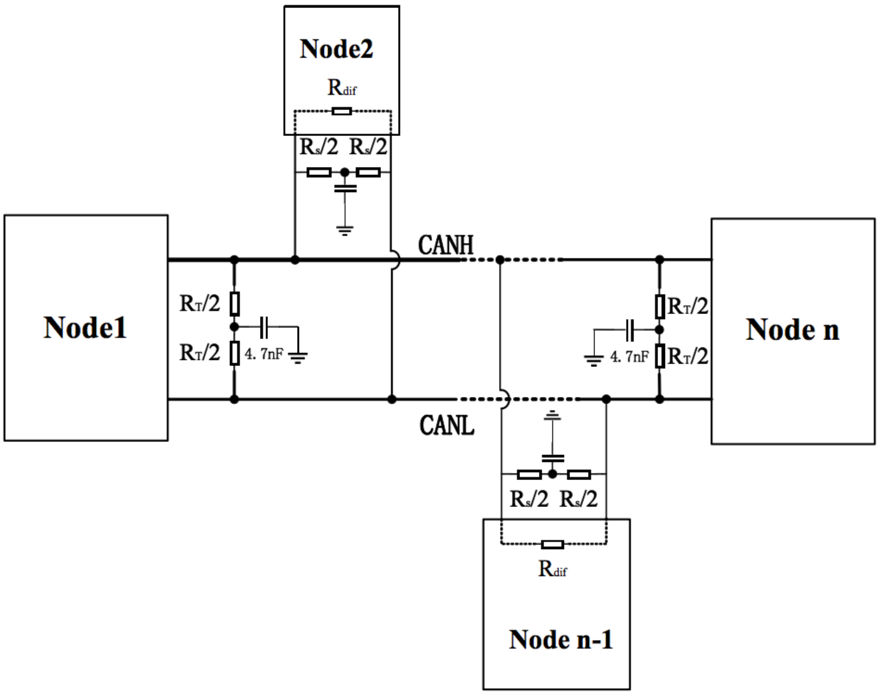

Figure2.7 split resistors at the terminals of each node in the CAN bus network diagram

As shown in the above figure, the terminal resistance value of the intermediate nodes should make the bus resistance of the entire CAN network is between 45 Ω and 70 Ω. For example, in an 11 nodes CAN network, R_T is set to 124 Ω. If the equivalent resistance value of the bus load is set to 50 Ω, according to the following formula:

$$\frac{1}{62}+\frac{1}{R_S/9}=\frac{1}{50}$$

It can be approximately calculated that the RS is about 2.3k Ω, so the $R_S/2$ is 1.15k Ω. Meanwhile, in order to maintain the symmetry of the CANH and CANL paths and avoid generating new common mode noise, resistors with high accuracy should be selected.

2.3.BUS capacitor

In addition to improving the EMC performance of the CAN transceiver by adding CMC to the bus pins and using split terminal resistors, adding a ground capacitor to CANH and CANL can also filter out some high-frequency noise on the bus, which can improve the EMC performance to a certain extent. The selection of capacitance needs to consider multiple factors comprehensively. If the capacitance is too large, it will cause bus signal attenuation, increase rise and fall time, shorten bit time, and affect normal communication; The cutoff frequency of the RC low-pass filter composed of the ground capacitor and the impedance of the signal source should be higher than the communication rate of the CAN bus to ensure normal communication. So it is necessary to comprehensively consider factors such as bus length, number of nodes, communication rate to choose the appropriate ground capacitance. It is generally recommended that for 2Mbps CAN FD communication, the ground capacitance should not exceed 100pF.

2.4.ESD protection diode

In automotive or industrial applications, for some systems with external connection interfaces, excessive charges accumulated during installation and maintenance can flow into modules through interface cables. The discharge energy is high enough and sometimes reach several tens of kV. The interface chip located at the interface end will be the first to be affected, damaged by the discharge energy, causing the system to malfunction. So protecting the interface transceiver from the impact of ESD is crucial for system applications. For CAN transceivers, although ESD protection circuits are designed inside the chip, limited by the chip size, the ESD protection capability of the bus end may be far from meeting the ESD impact in some environments. Therefore, it is necessary to use external ESD protection diodes to enhance the ESD protection capability of the system, and transient voltage suppression (TVS) diodes are commonly used for external ESD protection.

For the selection of TVS, in addition to considering their instantaneous response characteristics, which can quickly release large instantaneous energy, we should also pay attention to the following parameters:

- Reverse Stand-off Voltage (V_{RWM})

The reverse stand-off voltage parameter characterizes the maximum withstand voltage of a TVS transistor in a non-conducting state. Under normal operation of the CAN bus, the TVS should be in the cut-off state. When the CAN bus experiences abnormal overvoltage and reaches the TVS breakdown voltage, the TVS changes from a high resistance state to a low resistance state, releasing the instantaneous overcurrent caused by the abnormal overvoltage to the ground. So the reverse stand-off voltage of the TVS should be higher than the normal working voltage of the CAN bus. The reverse stand-off voltage of a general TVS should be higher than the common mode voltage operating range of the CAN transceiver bus.

- Breakdown Voltage (V_{BR})

V_{BR} characterizes the voltage at both ends of TVS when passing through a certain current. At this voltage, the TVS exhibits low impedance characteristic, and in general, VBR is slightly higher than V_{RWM}.

- Clamping Voltage (V_{CL})

V_{CL} characterizes the maximum clamping voltage of TVS under peak pulse current. In CAN system applications, the V_{CL} of the TVS should not exceed the absolute maximum rated voltage (AMR) of the bus, otherwise it may damage the CAN transceiver.

- Peak Pulse power (P_{PP})

The peak pulse power is the product of the peak pulse current and the clamping voltage. The larger the P_{PP}, the greater the transient surge current absorption capacity of TVS under the given maximum clamping voltage condition, and the better the ESD protection of TVS. So, under the selecting of fixed VCL, TVS with larger P_{PP} should be chosen.

- Capacitance (C_d)

C_d characterizes the parasitic capacitance of TVS at a certain frequency. Under the certain communication frequency of CAN bus, TVS with lower parasitic capacitance should be selected to avoid significant attenuation of bus signal.
The TVS should be placed at the external connection of the module for quickly releasing external energy to the ground.
The PCB routing of TVS should be as short as possible to reduce parasitic inductance and impedance effects. Parasitic inductance may cause an increase in V_{CL} voltage, while routing impedance will reduce the ability to release surge energy.

3.Revision History

Revision	Description	Author	Date
1.0	Initial version	Lele Zhang, Fuming Deng,	06/1/2024

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