

HIGH SPEED COMMUNICATIONS IN RAIL TRACTION APPLICATIONS

There is a growing number of applications on board trains today that require higher speed electronic communications than ever before. Internet access, on board entertainment (video), real time positioning systems, cctv and safety critical systems are all driving the need for communication rates to increase into the high Megabit or even Gigabit per second levels. At these data rates, the length and characteristics of the cable, the connectors used to link the cable and the impedance characteristics of the electronic transceivers all need to be carefully considered and designed to ensure error free reliable communications. Sabritec has developed an enviable expertise in designing and manufacturing connectors to suit these demanding requirements.

Why has the data rate become important in the selection of cables and connectors?

When the time for a single piece (bit) of information is short compared to the time it takes this signal to travel the length of the carriage, care must be taken in the matching of components to help ensure all the signal energy is correctly received at its intended destination. For example, if we consider the average length of a carriage to be say 20m and that the average train may have 5 carriages then the length of train is 100m. The speed an electrical signal travels along a cable in general is approximately 1m in every 5ns and therefore it will take 500ns for the signal to travel the whole length of the train. Even if the data rate of the communication system is modest at 100 Mbps then it can still transmit 50 bits of information before the first bit reaches the far end. But what happens when this first bit of information reaches the far end?

Impedance matching

When a signal is injected into a long cable, the signal “assumes” that the cable is infinitely long. It sees an impedance, known as the “characteristic impedance”, at the beginning of the cable and establishes a voltage across this and injects energy into the cable. However the signals behaviour is also determined by what the conditions are at the end of the cable and therefore as it takes time to reach the end, the signal may need to be modified once it knows what is there.

Of course the only way to do this is if the signal is reflected back to the start to correct the “assumption”. If we consider the following extreme cases:

a. Open Circuit

Where the end of the cable is left unconnected, for example if a connector has not been mated, then the signal will see an open circuit or infinite impedance at this point. As there is nothing to absorb the energy injected at the start of the cable, all the energy must be reflected back to the start. This will result in the signal being reflected back with the same positive voltage as was transmitted. Therefore at the far end the signal will actually be twice the voltage that was expected (figure 1).

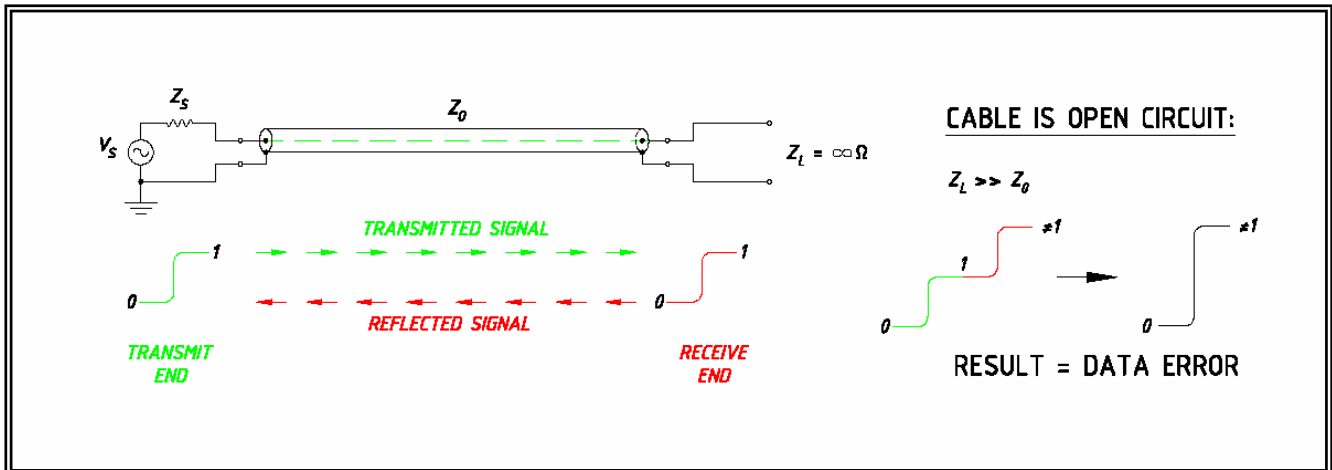


Figure 1

b. Short Circuit

Where the cable has been shorted together, for example a conductive protective cap has been fitted that shorts all the pins of the connector together, the signal will see a short circuit at this point. As there is no impedance to sustain the voltage of the signal, a signal is reflected back to the start of the cable that will cancel the original voltage out. Thus a negative voltage signals is reflected back and at the far end the signal will be of zero volts (figure 2).

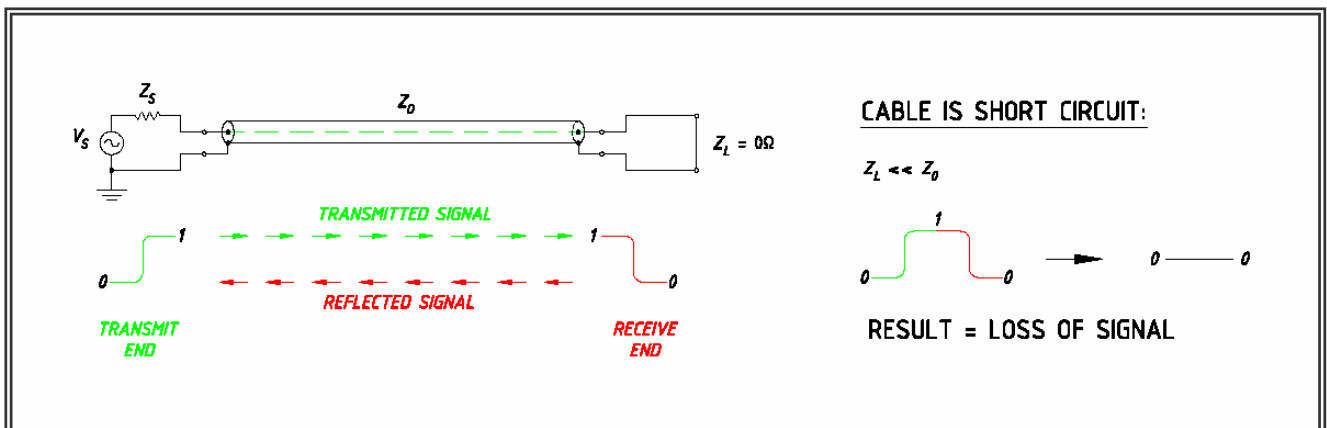


Figure 2

c. Matched Circuit

Of course in real applications the cable is not of infinite length but fortunately we can fool the signal into believing it is. If a resistor is placed at the far end of the cable that has exactly the same value of impedance as the characteristic impedance of the cable then the signal will be completely absorbed by this impedance and no energy will be reflected back. Of course the output impedance of the transmitter circuit and the input impedance of the receiver circuit should also be of the same value as the cable and the connectors to maximise energy transfer and optimise signal integrity. This ideal case is called a matched system (figure 3).

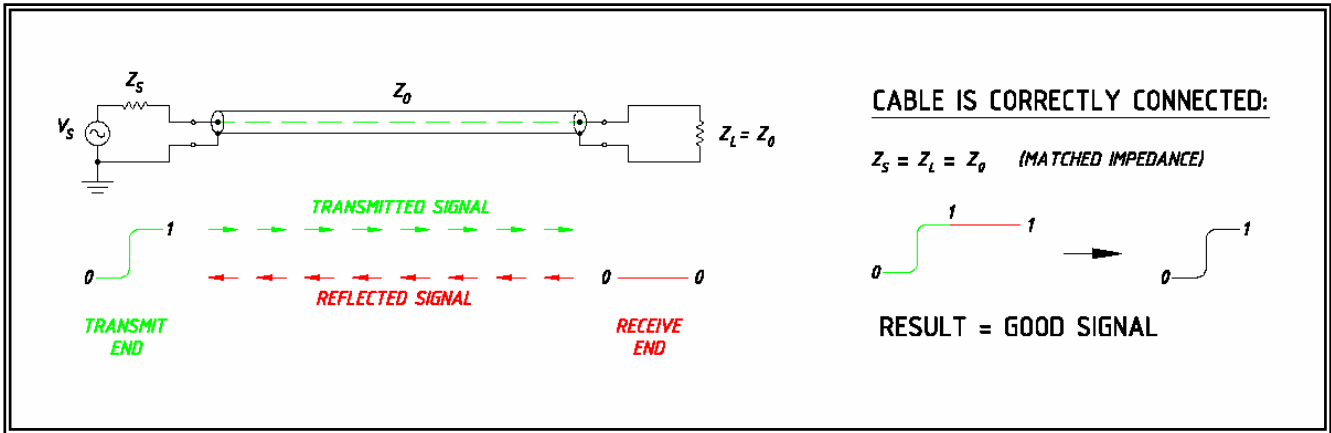


Figure 3

d. Real Application

In real applications, for example between carriages, cables are often connected together using connectors and these connectors can introduce a variation in the characteristic impedance that the signal experiences during its transmission from one end of the train to the other. Depending on whether the characteristic impedance of the connector is higher or lower than that of the cable, positive or negative reflections will arise whenever a connector occurs, both in the forward and in the reflected directions. This means that the signal can become very distorted effecting the clarity of signal and increasing the bit error rate (figure 4). It is of vital importance therefore that the connector is designed to match the application and the communications protocol that is being used.

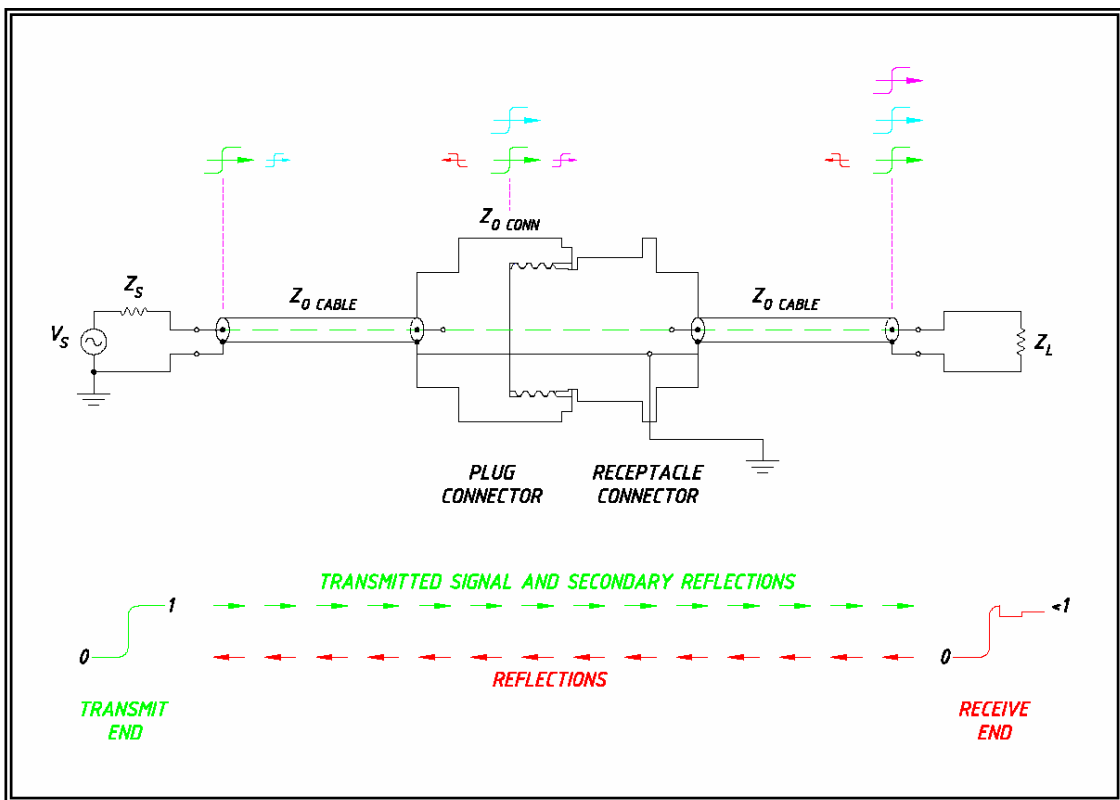


Figure 4

Communication Protocols

There exist many different communications protocols, each with a defined data rate, Characteristic Impedance and specifications for bit error rate and signal integrity. A list of some common protocols is shown in table 1. The design of both the cable and the connector is often performed specifically to suit one of these protocols. The issue arises however of how can the designer be sure that he has selected the best components for his application?

Communications Protocol	Applicable Standardization	Maximum Data Rate	Connector / Cabling	Characteristic Impedance, Z ₀
Ethernet: 10 Base-T	IEEE 802.3	10Mbit/s	2 x twisted pair - 100m max cable length	100Ω
Fast Ethernet: 100 Base-T	IEEE 802.3	100Mbit/s	2 x twisted pair - 100m max cable length	100Ω
Gigabit Ethernet: 1000 Base-T	IEEE 802.3	1000Mbit/s (1Gbit/s)	4 x twisted pair - 100m max cable length	100Ω
Firewire 400	IEEE 1394a	Variants of 100, 200 and 400Mbit/s	2 x twisted pair and power / ground lines - 4.5m max cable length	100Ω
Firewire 800	IEEE 1394b	Up to 3.2Mbit/s	2 x twisted pair and power /ground lines - 100m max cable length	110Ω
Fibre Channel	T11 technical committee of INCITS	Variants of: 1, 2, 4, 8 and 10Gbit/s	Fibre (10Km max), Coax (75m max) or Twisted pair (33 m max)	100Ω and 150Ω
USB 1.0 (Universal Serial Bus)	USB-IF (Implementers Forum)	12Mbit/s	2 x data lines twisted and 2 x power lines untwisted within shielded jacket - 5m max cable length	90Ω
USB 2.0		480Mbit/s		
USB 3.0		4.8Gbit/s		
S-ATA 1.0a	SATA-IO (International Organisation)	1.5Gbit/s	2 x shielded differential pairs and power / ground lines -1.5m max cable length	100Ω

Table 1

High Frequency Signal Simulation, Connector Modelling and Verification

During the design phase of its connectors, Sabritec will model the high frequency performance of the connector to ensure that the design achieves the characteristic impedance requirement of the communications protocol. This is a detailed and lengthy process as even the smallest feature on the connector can influence its high speed characteristics. Both mechanical dimensions and electrical properties of materials used are considered in the model and plots of characteristic impedance against frequency and S parameters showing reflection and transmission coefficients are developed to confirm the design aim is achievable.

Of course this modelling still needs to be verified and therefore using the latest Digital Signal Analysers, both the connector and the cable performance can be assessed again using S parameter plots or an Eye Diagram.

The Eye Diagram is a useful tool that enables all factors that effect the signal integrity to be assessed in an easy visual representation. The eye (figure 5) is generated by a pseudo random series of bits being transmitted through the connector (and cable assembly). The analyser builds up a picture of the transmission of these signals at a fixed point within the connector / cable assembly by displaying logic 0 and logic 1 voltage levels and also transitions from logic 0 to logic 1 and vice versa.

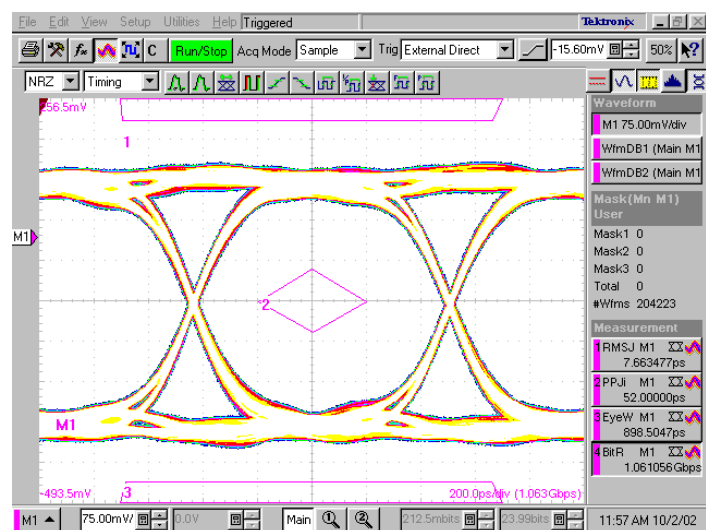


Figure 5

HIGH SPEED COMMUNICATION

This builds up a picture whose centre is the “eye”. The more open the “eye” the better the matching of all components within the system and the better the integrity of the signal. The “Eye” is determined by “no go” areas defined within the communications protocol and are shown in purple on figures 6 (bad eye) and 7 (good eye).

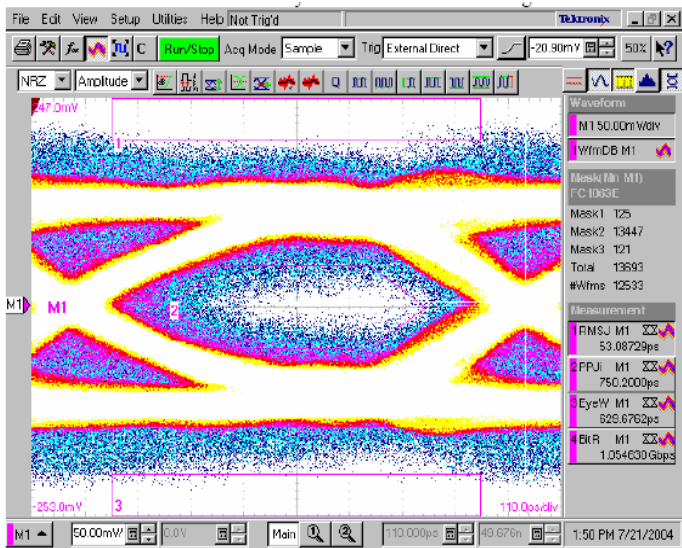


Figure 6

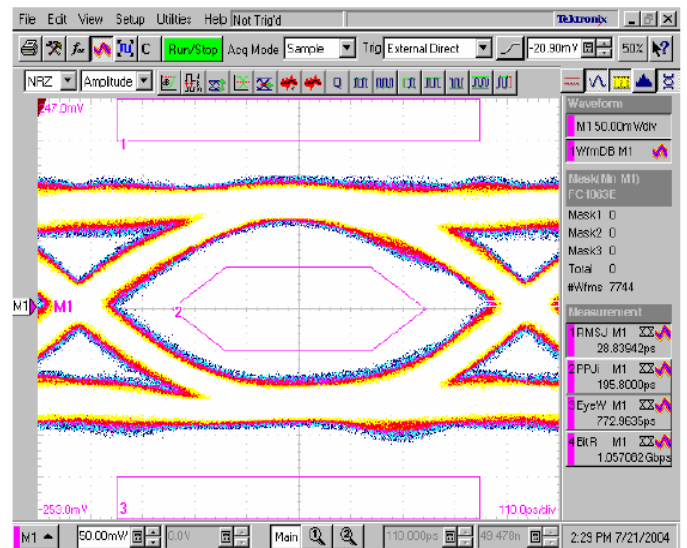
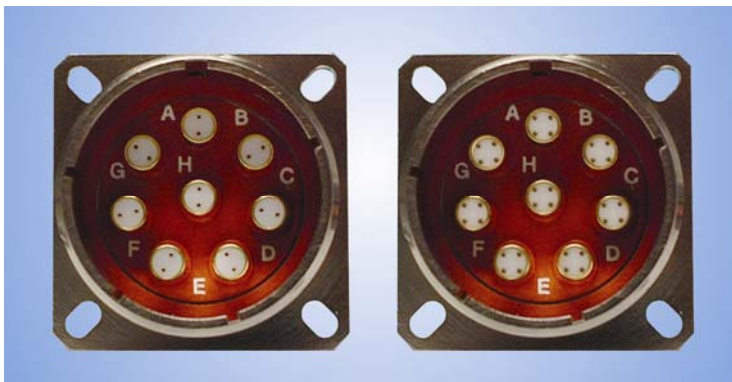


Figure 7

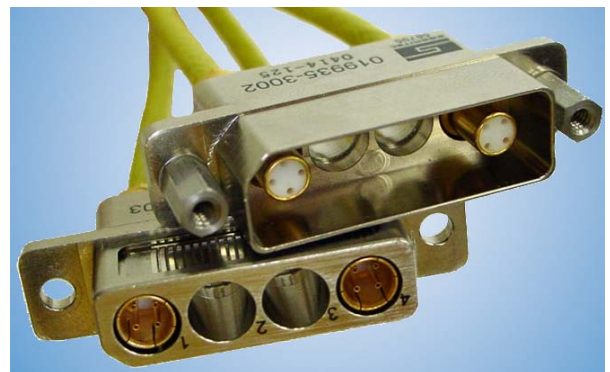
Sabritec Contacts and Connectors

Sabritec designs and manufactures a wide range of Coaxial, Triaxial, Twinax and Quadrax contacts and connectors all of which have been optimised to achieve a certain characteristic impedance requirement and to match a specific cable. Where necessary, a new design of contact can be readily performed to match a specific cable type not previously supported.

Sabritec contacts have been proven to perform up to frequencies of 40GHz with very low reflection coefficients (VSWR less than 1.25) and in excess of 3.5Gbps for digital communication systems.



twinax and quadrax contacts



D-Sub connectors with quadrax contacts