# Industrial Fiber Optics in Train Transportation Systems

## White Paper

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### Background

Trains are one of the most popular transportation systems in the world. They provide a high-speed and low cost method of transporting large amounts of people and goods with low CO2 emissions. A train can be a combination of one or more locomotives and attached railroad cars or a self-propelled multiple unit. A modern train is usually powered by grid electricity or by diesel locomotives. Trains have become more sophisticated with advanced systems that automatically control and monitor train operation. These integrated systems give passengers and freight a smooth and safe ride. This whitepaper discusses how modern train system design ensures reliable operation of the train power source, propulsion system and coach control systems.

### Train Propulsion System

Electricity and diesel powered trains are the most common modern trains. The main difference between these two train types is how the train is powered. Whether the primary energy source is grid electricity or diesel fuel powered generators, the power conversion process from energy source to propulsion power for the traction motor and to auxiliary electric power generation for onboard electrical systems is very similar. The process of converting grid and diesel energy sources to useable power is shown in Figures 1 and 2.

The power generated from the diesel generator or electrical grid is usually not directly suitable for the traction motor and the onboard electrical systems. It has to be converted into the correct voltage and frequency. As shown in Figures 1 and 2, the power conversion process involves devices like DC-links and converters.

Plastic optical fiber (POF) and Hard Clad Silica (HCS) is often used as the transmission medium to control the switching of power semiconductors—IGBTs, IGCTs, and GTOs —in the converters that create the right frequency and voltage for the electrical drive motors and electrical system. Fiber cable can also be used for sending and receiving monitoring signals for voltage and current protection at DC-links and converters.

In electricity powered trains, the power grid voltage has to be transferred down to a lower voltage by a transformer. Circuit breakers protect the grid and train in case of any malfunction of the electrical system. Since the distance between the train control unit and converter can be far, glass optical fiber is a much better solution than copper cable as it has long distance transmission capability and is EMI tolerant.

Since the power subsystems and power converters operate at high voltages and currents, their control and communication lines must be galvanically isolated and immune to the electromagnetic fields generated by the converter. Isolation

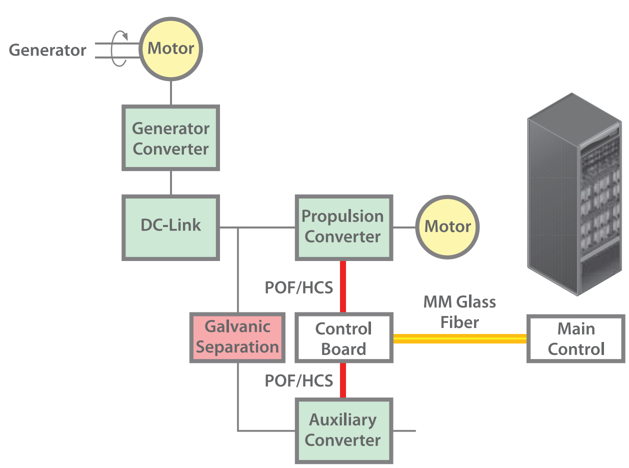


**Figure 1. Diesel powered train propulsion and auxiliary electricity converter**

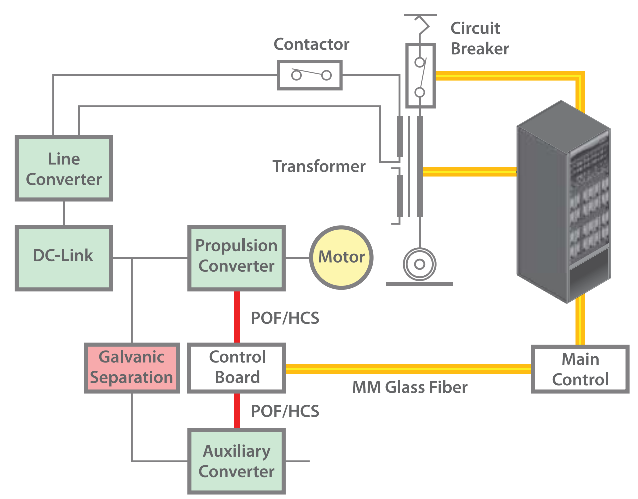


**Figure 2. Electricity powered train propulsion and auxiliary electricity converter**

and electromagnetic interference (EMI) immunity are important characteristics that ensure reliable, safe and stable train operation. In order to achieve isolation and EMI immunity, fiber optics technology is used because it offers both galvanic isolation and near perfect immunity to electromagnetic interference.

As the distance between the control board and converters is usually short, POF or Hard Clad Silica (HCS) cables are often used. Fiber optic transmitters and receivers that support switching speeds from DC to 5 MBd or DC to 10 MBd are commonly used in this application. As shown in Table 1, the Avago Technologies Versatile Link product family offers the most cost effective and reliable solution to address this application.

The train central computer may be located further away from the control devices, so multimode glass fiber is selected to transmit and receive optical signal over the longer distance.

**Table 1. Common Avago fiber optic parts used in train propulsion, and control and monitoring systems**

| Parts | Data Rate | Link Distance |
|---|---|---|
| AFBR-1629Z & AFBR-2529Z | DC – 50MBd | 50m (POF) |
| HFBR-1528Z & HFBR-2528Z | DC – 10MBd | 40m (POF)<br>200m (HCS) |
| HFBR-1521ETZ & HFBR-2521ETZ | DC – 5MBd | 20m (POF) |
| HFBR-1522ETZ & HFBR-2522ETZ | DC – 1MBd | 43m (POF) |
| HFBR-1414Z & HFBR-2416Z | 20MBd | 2700m (MM) |
| HFBR-57E5APZ | 125MBd | 2000m (MM) |
| AFBR-5972Z | 125MBd | 50m (POF) |

## Train Communication Systems

In the past, there were many proprietary communication systems that were used within the train, and these systems were unfortunately not interoperable. The IEC 61375 Train Communication Network (TCN) standard was created to define communication architecture and protocols for trains. In general, the TCN defines a Wire Train Bus (WTB) and Multifunction Vehicles Bus (MVB). WTB connects the vehicles while MVB connects equipment in a vehicle or group of vehicles.

MVB operates over three media types: RS-485 for short distance; transformer-coupled twisted wire pairs for distances up to 200m; and optical glass fiber for long distance up to 2km. In this paper, we will only discuss MVB that uses optical glass fiber, which is commonly used in harsh and high electromagnetic interference environments. Optical glass fiber and POF is often the preferred media in a locomotive since it has high immunity to the electrical noise in the locomotive environment. Optical fiber connects the controller to devices and subsystems, such as power electronics, motor controllers, brakes, and radios. Figure 3 shows the general MVB layout in a locomotive.

As shown in Figure 4, MVB also connects equipment in a coach to control light, doors, air conditioning, and passenger displays. In order to increase network availability, MVB is backed up by a redundant line and devices transmit on both lines. If one line fails, the other line is available for communication.

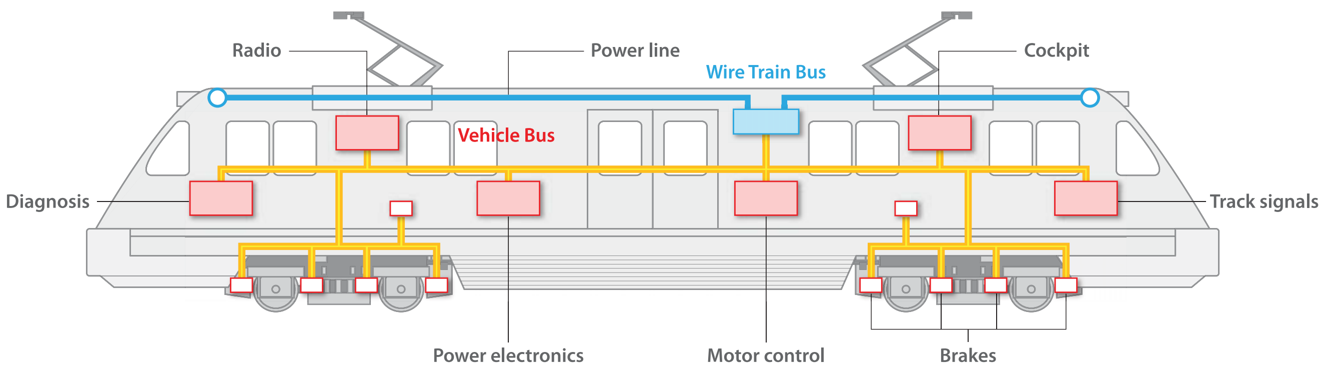


**Figure 3. MVB layout in a locomotive**

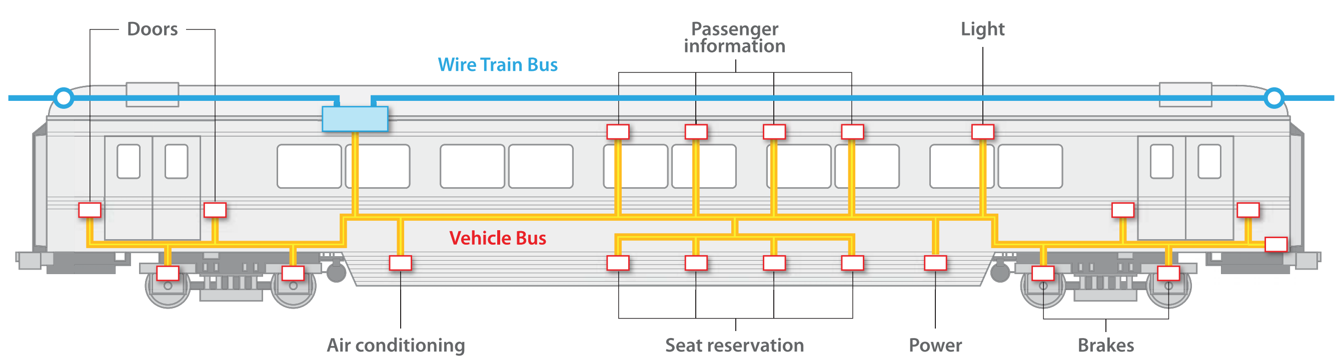


**Figure 4. MVB layout in a coach**

When MVB is implemented with optical fiber, a star coupler is used to restore the signal quality for connecting up to 4095 devices in one bus, as shown in Figure 5. MVB data rate is fixed at 1.5 Mbps, which can be easily handled by the Avago HFBR-1412Z transmitter and HFBR-2412Z receiver fiber optic components.

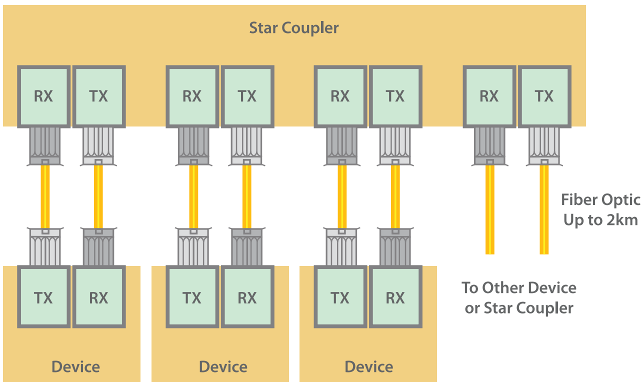


**Figure 5. Fiber optic configuration for MVB**

## Frequency Converters for Electric Grid Powered Trains

Power grid electricity is 3-phase AC at either 50 Hz or 60 Hz. This electricity is not suitable for powering trains that require single AC power at 16.7 Hz or 25 Hz at a lower voltage than the power grid line voltage. The electricity from the power grid lines has to be converted to the suitable voltage and frequency. In order to do that, equipment like power converters, transformers, circuit breakers are needed. Figure 6 shows one static frequency converter concept. Since this equipment operates with high to medium voltages, galvanic isolation between the controller and the equipment is necessary. For this, Avago offers a complete fiber optic portfolio to meet short link and medium to long link distance needs with products that transmit and receive data through POF and multimode glass fiber cable. Table 2 shows some of the Avago parts used in power generation and the distribution network.

**Table 2. Avago fiber optic components used in power generation and distribution**

| Parts | Data Rate | Link Distance |
|---|---|---|
| AFBR-1629Z & AFBR-2529Z | DC – 50MBd | 50m (POF) |
| HFBR-1528Z & HFBR-2528Z | DC – 10MBd | 40m (POF)<br>200m (HCS) |
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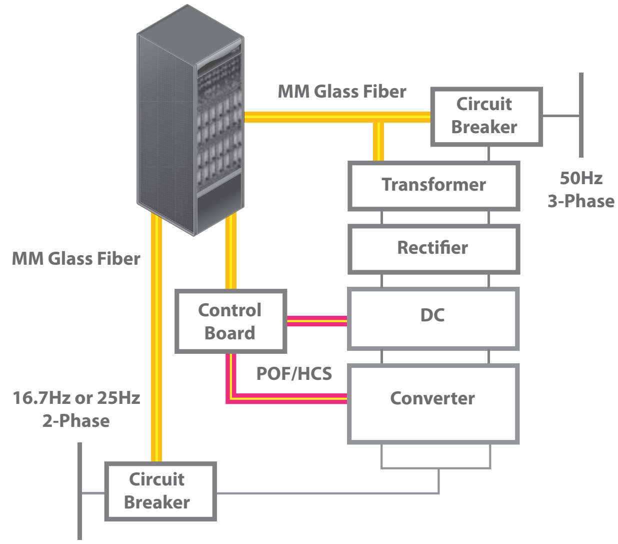


**Figure 6. Static frequency converter**

## Traction Power and Grid Power Quality

In electrical grid powered trains, single-phase power is taken from the 3-phase AC power grid line to supply the train's AC power line. This creates an unbalance in the grid which must be compensated.

One of the most common methods of balancing and restoring the power quality of the grid is to use Static Var Compensation (SVC). SVC utilizes Thyristor-Switched Capacitors (TSCs) and Thyristor-Controlled Reactor (TCR) to compensate the unbalanced load, as shown in Figure 7. TSC and TCR operate and switch on/off at high voltage and current. This creates very high electromagnetic fields that will induce electrical noise into nearby copper lines. Fiber optic cables are the best medium for sending control signals to the devices in SVC systems because they are immune to electromagnetic fields.

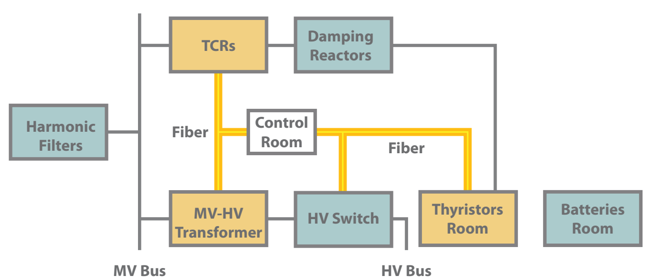


**Figure 7. Static Var Compensation (SVC) block diagram**

## Conclusion

In recent years in the face of rising energy prices, train popularity has increased due to their cost effective transportation of passengers and goods. With advances in train technology, automatic control and monitoring systems now ensure reliable operation and control passenger convenience systems.  Smooth and reliable train operation has resulted.

IEC 61375 defines standard train communication architecture and protocols that ensure interoperability among train equipment vendors. In this standard, optical fiber is used for long link distances and for applications in the electromagnetic filled environment that MVB operates.

Optical glass and plastic fiber is also used in other train system applications. For example, controlling and monitoring power distribution equipment like the transformer and circuit breaker, and turning on/off the IGBTs, IGCTs or GTOs of the propulsion and auxiliary converters and frequency converter.

The advantage of fiber optical cable over copper cable comes from its intrinsic immunity against electromagnetic interference and inherent galvanic isolation. Therefore, optical fiber is often chosen as the preferred medium to transmit and receive communication and control data. Avago Technologies provides a complete set of fiber optic solutions that address state-of-the-art train and locomotive applications.

## References


2. Schäfers, C.; Hans, G. "IEC 61375-1 and UIC 556 - International Standards for Train Communication." IEEE, 2000.

1. Bonsen, G.A. zur. "The Multifunction Vehicles Bus (MVB)." IEEE.





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