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Connecting Trains: The Promise of On-board Ethernet Networks

How to use Ethernet to increase on-board network functionality and lower costs

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ABSTRACT

In the rail transportation industry, sensors, on-board processing and other electronic systems have become more prevalent. As a result, bandwidth requirements for the technologies that connect equipment within a railcar – and that connect rail vehicles together – have been growing consistently.

This trend has put strain on the existing Train Communication Network (TCN) standard for data communication, and is contributing to reduced functionality and increased costs for rail operators. Recently, train manufacturers and system integrators have been making greater use of Ethernet technology to supplement TCN, with the ultimate goal of replacing the legacy technology entirely with an Ethernet standard.

For train manufacturers and system integrators looking to capitalize on the benefits of Ethernet train networks, there are three key steps to follow:

- Defining a network performance requirement
- Selecting the corresponding transmission hardware and Ethernet protocol
- Choosing the cabling most suitable to the application, such as copper or optical fiber.

However, applying Ethernet-based networks within the harsh on-board train environment poses technical challenges in terms of network configuration and component performance – the solutions to which include using the most qualified, high performance interconnects, capable of delivering a fault tolerant network that adheres to the unique topology of the train, even under severe mechanical and elemental stresses.

This white paper is a reference guide to help manufacturers navigate the process of implementing Ethernet train networks based on their own unique requirements and desired applications.

INTRODUCTION

While Ethernet and conventional TCN coexist in on-board applications today, Ethernet will increasingly replace TCN, resulting in a full integration of all the intelligent on-board devices and systems into one Ethernet network.

The leading train manufacturers are moving towards a "full Ethernet train," where the network carries all data types needed for control, security and passenger information; for example, data from surveillance cameras, passenger announcements, data to control the operation of the train and coaches, including doors, propulsion and lighting, etc.

The TCN standard for data communication (IEC 61375-1) on rail vehicles is a hierarchical combination of two fieldbus systems: a wire train bus (WTB), which connects the equipment within a vehicle, and a multifunction vehicle bus (MVB), which connects the vehicles.

Despite certain advantages to the WTB/MVB fieldbus (see sidebar), the high bandwidth requirements of components and systems used increasingly in rail vehicles exceed what any fieldbus can provide. Consequently, switched Ethernet IEEE 802.3 is being introduced progressively more into rolling stock.

At present, Ethernet is used predominantly for on-board video surveillance and information or entertainment systems, while most other disparate systems typically function off separate TCN fieldbus interconnection networks. However, some manufacturers have begun adopting Ethernet for train control data management functions too.

Ethernet will ultimately replace conventional TCN fieldbus technology entirely thanks to the increased functionality and reduced costs the protocol offers. This is because Ethernet products are common and available off-the-shelf, even for high data transmission and bandwidth applications, while rail-specific network equipment is highly customized and comes with high maintenance and replacement costs.

In order to respond to the bandwidth-intensive requirements of new data management systems – and capitalize on their benefits – manufacturers should be familiarizing themselves with the challenges in implementing on-board Ethernet networks, including how to build fault tolerant, low-latency and standards-compliant architectures.

Doing so, and ensuring a smooth and cost-effective transition to integrated, high-speed train networks, will require reliable interconnects with modern contact configurations capable of bridging between the legacy TCN data standard and modern, high-speed Ethernet.

WTB/MVB FIELDBUS ADVANTAGES:

- Extreme Reliability and Robustness
- No Message Collision
- Very Low Resource Requirements
- Low-Cost Implementation
- Designed for Real-Time Applications
- Very Short Error Recovery Time

WTB/MVB FIELDBUS DISADVANTAGES:

- Limited network length (depending on baud rate)
- Limited baud rate of one Mbit/sec
- Limited bandwidth

ETHERNET NETWORK ADVANTAGES:

- Speed (one GBit/sec and greater)
- Unlimited network length
- Robustness/reliability through use of established hardware components (RJ-45, M12 connectors, Switches, etc.)
- Increased system performance

MINI CASE STUDY:
How ITT Veam Connectors Support Train-based Ethernet

A major high-speed Italian rail network operator implemented a unique approach to implementing a high-speed train Ethernet network. Borrowing directly from state-of-the-art data center design, they created a sophisticated train Ethernet network architecture that overcame topology constraints to achieve a high level of fault tolerance.

This network approach also comprised a highly specialized cabling scheme for train vehicles, adopting fully shielded twisted-pair cables and connectors that provide Class F channel performance (see Ethernet and Cabling standards, pages 7-10), well in excess of the bandwidth requirements of Gigabit Ethernet.

Prior to this project, ITT had already developed an extension of its Veam FRCIR fiber optic connector series to cover data communication applications, by combining the historical reliability and robustness of the series' mechanical and sealing characteristics, with M12 contacts for WTB (2-pole contact) and for MVB and Ethernet 100 Mbit per second applications (4-pole contact).

The 4-pole M12 contacts had already been adopted by a few leading European train manufacturers, including the one developing Italy's high-speed rail program, but the network requirements for the high-speed project were much higher and unique in the market in several respects. ITT was engaged to design a new contact, able to support Ethernet one Gbit per second transmission requirements, and pass Class F Ethernet channel performance.

ITT developed prototypes of 8-pole M12 contacts and supplied them to the customer for testing and qualification. The solution fully met the desired performance level, proving to be the highest in the market for the specific application. It also proved to be a cost-effective, small-footprint solution, as ITT combined multiple M12 contacts in the same connector body, thereby mixing WTB/MVB fieldbus and Ethernet services.

ITT VEAM CIR M12 CONNECTOR FEATURES:

- FRCIR reliability and high mechanical and sealing performance
- Small footprint compared to rectangular solutions
- High performance, tested up to FA Class channel requirements
- Flexibility in configuration, including combination of multiple lines – Ethernet and WTB/MVB fieldbus– within the same connector
- ITT value-add capabilities including harnesses and test reports (see page 11 for an example)
- Installed on latest generation Italian high-speed train with highest transmission performance currently in use within the rolling stock market

IMPLEMENTING ETHERNET:
Defining Requirements

Applying Ethernet-based technology in the harsh on-board environment presents some technical challenges, both in terms of network configuration and component performance.

The main challenges with respect to train network requirements are related to fault tolerance (i.e. a network resilient to the failure of one or more of its components), topology due to train architecture and response time, or network latency – the time it takes for a packet to travel along a network path from sender to receiver.

The data cabling and connectors deployed in the network must satisfy very strict railway fire and smoke standards and meet rigorous mechanical and environmental requirements, primarily to do with vibration, sealing and temperature. This is especially true for vehicle-to-vehicle interconnects, which are subjected to higher mechanical stresses and exposed to a wide range of weather and climate.

The first step a train manufacturer or operator must take is to define the performance requirement for their Ethernet network – in terms of megabits or gigabits per second – a specification that will depend upon the bandwidth requirements of desired on-board systems.

The second step is to define a corresponding Ethernet application, to establish the right network transmission hardware and protocol. The appropriate Ethernet class for the application will be based on the network performance requirements, as well as key variables like train topology (particularly length) which have a bearing on the required channel length(s) for the network.

The third consideration is cabling. The two main standards in use today include twisted pair copper cabling and optical glass fiber, each of which offer unique characteristics suited to different applications. The Ethernet and cabling standards section on pages 7-10 explains the relationship between Ethernet class, application, data rate, the number of pairs/fibers needed, maximum bandwidth, cable construction and channel length requirements.

COPPER OR FIBRE?

Interconnection for both WTB and MVB can be achieved with an electric twisted pair copper cable or an optical glass fiber. The standard connection within most modern WTB train control systems is typically an 18-pin UIC 558 connector using a shielded twisted pair cable. For MVB interconnection however, there is no single international connector standard for the vehicle bus inside a coach, locomotive or train set.

A Train Communication Network based on Ethernet technology has been standardized with IEC 61375-2-5 (Ethernet Train Backbone, ETB, representing the WTB) and IEC 61375-3-4 (Ethernet Consist Network, ECN, representing the MVB).

IMPLEMENTING ETHERNET:
Connector Considerations

A high-performance, fault tolerant train Ethernet network is a scalable infrastructure able to transfer not only typical dedicated railway data (such as that for command, control and maintenance), but also new passenger multimedia services and IP telephony, even on existing fleets, without re-wiring coaches.

ITT Veam CIR M12 connectors

Once the performance requirements, Ethernet class, application and cabling standards have been defined, one of the most critical considerations is the interconnection of jumper cables between vehicles. Using reverse-bayonet circular connectors (such as ITT Veam's CIR/FRCIR), which have proven themselves reliable over decades of use in severe train environments, in combination with customizable M12-type contacts is an effective, economic and low-risk solution.

These connectors fulfill all requirements for standard TCN vehicle bus as well as high-speed data communication over Ethernet, making the steady, incremental transition to full Ethernet trains smooth and cost-effective.

In addition, these connectors are fully compliant with the latest state-of-the-art standards for fire and smoke behavior, and are generally regarded as the most robust solution for vehicle-to-vehicle interconnection, guaranteeing optimal sealing in addition to shock and vibration resistance required for rolling stock applications.

The latest iterations of these ITT Veam CIR M12 contacts have been tested in train network configurations up to Class FA performance (i.e. at maximum bandwidth of 1 GHz), the highest requirements in the global rail market as of 2016 (see Ethernet and Cabling Standards section, below). It is worth noting that this test only became possible in recent months, after advanced cable field testers, capable of measurement in the 1 GHz band and above, became available in the market. Details of a testing report can be seen on page 11.

Additional Information on Ethernet and Cabling Standards

Ethernet based technologies are defined by IEEE 802.1 and 802.3 standard families. In particular, the IEEE 802.3 group specifies the performance and versions for wired networks. There are no specific cabling standards for railcars, so industry players mainly refer to ISO/IEC11801 – information technology – generic cabling for customer premises specifications for transmission.

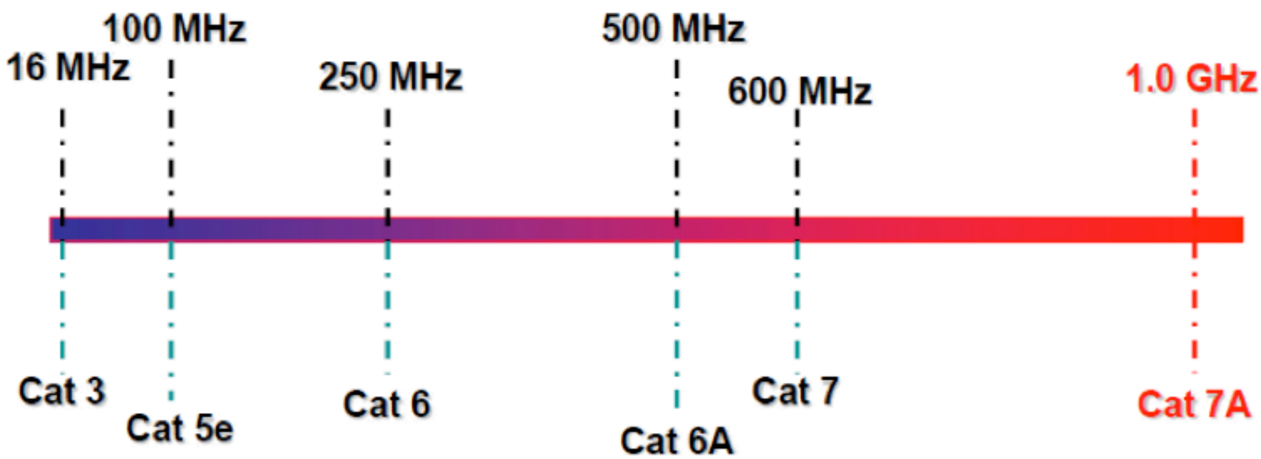
ISO/IEC 11801 specifies general-purpose telecommunication cabling systems (structured cabling) that are suitable for a wide range of applications, such as analog and ISDN telephony, various data communication standards, control systems, factory automation, etc. The standard covers both balanced copper cabling and optical fiber cabling.

This standard specifies generic installation and design topologies that are characterized by a "category" or "class" of transmission performance. It defines several link/channel classes and cabling categories of twisted-pair copper interconnects, which differ in the maximum frequency for which a certain channel performance is required:

- Class A: link/channel up to 100 kHz using Category 1 cable/connectors
- Class B: link/channel up to 1 MHz using Category 2 cable/connectors
- Class C: link/channel up to 16 MHz using Category 3 cable/connectors
- Class D: link/channel up to 100 MHz using Category 5e cable/connectors
- Class E: link/channel up to 250 MHz using Category 6 cable/connectors
- Class EA: link/channel up to 500 MHz using Category 6A cable/connectors
- Class F: link/channel up to 600 MHz using Category 7 cable/connectors
- Class FA: link/channel up to 1000 MHz using Category 7A cable/connectors

ISO/IEC 11801-Annex E, Acronyms for balanced cables, provides a system to specify the exact construction for both unshielded and shielded balanced twisted-pair cables. It uses three letters - U for unshielded, S for braided shielding, and F for foil shielding - to form a two-part abbreviation in the form of xx/xTP, where the first part specifies the type of overall cable shielding, and the second part specifies shielding for individual cable elements.

Common cable types include U/UTP (unshielded cable); U/FTP (individual pair shielding without the overall screen); F/UTP, S/UTP, or SF/UTP (overall screen without individual shielding); and F/FTP, S/FTP, or SF/FTP (overall screen with individual foil shielding).



ETHERNET STRUCTURED CABLING STANDARDS AND CORRESPONDING FREQUENCY RANGES

ISO/IEC 11801 also defines several classes of optical fiber interconnect:

OM1: Multimode fiber type 62.5 µm core; minimum modal bandwidth of 200 MHz·km at 850 nm

- OM2: Multimode fiber type 50 µm core; minimum modal bandwidth of 500 MHz·km at 850 nm
- OM3: Multimode fiber type 50 µm core; minimum modal bandwidth of 2000 MHz·km at 850 nm
- OM4: Multimode fiber type 50 µm core; minimum modal bandwidth of 4700 MHz·km at 850 nm
- OS1: Single-mode fiber type 1 db/km attenuation
- OS2: Single-mode fiber type 0.4 db/km attenuation

The cabling standards are subsequently referenced in applications standards, such as IEEE for Ethernet, as a minimum level of performance necessary to ensure application operation.

Table 1 below explains the correspondence between Ethernet applications and twisted-pair wiring systems.

Class	Ethernet applications	Maximum application data rate	Number of pairs needed	Maximum Bandwidth	Cable construction	Maximum Channel Length
C	10 Base-T	10 Mbps	2	16 MHz	Unshielded or Shielded	100 m
D	10 Base-T 100 Base-TX 1000 Base-T	10 Mbps 100 Mbps 1 Gbps	2 2 4	100 MHz	Unshielded or Shielded	100 m
E	10 Base-T 100 Base-TX 1000 Base-T	10 Mbps 100 Mbps 1 Gbps	2 2 4	250 MHz	Unshielded or Shielded	100 m
E_A	10 Base-T 100 Base-TX 1000 Base-T 10 GBase-T	10 Mbps 100 Mbps 1 Gbps 10 Gbps	2 2 4 4	500 MHz	Unshielded or Shielded	100 m
F	10 Base-T 100 Base-TX 1000 Base-T 10 GBase-T	10 Mbps 100 Mbps 1 Gbps 10 Gbps	2 2 4 4	600 MHz	Shielded Only	100 m
F_A	10 Base-T 100 Base-TX 1000 Base-T 10 GBase-T	10 Mbps 100 Mbps 1 Gbps 10 Gbps	2 2 4 4	1000 MHz	Shielded Only	100 m

Table 2 below explains the correspondence between Ethernet applications and fiber optic wiring systems

Fiber Type	Ethernet applications	Maximum application data rate	Number of fibers needed	Maximum Channel Length
Multi-mode OM1	10 Base-SX 100 Base-FX 1000 Base-SX 1000 Base-FX 10 GBase-S	10 Mbps 100 Mbps 1 Gbps 1 Gbps 10 Gbps	2 2 2 2 2	300 m 2000 m 275 m 550 m 33 m
Multi-mode OM2	10 Base-SX 100 Base-FX 1000 Base-SX 1000 Base-FX 10 GBase-S	10 Mbps 100 Mbps 1 Gbps 1 Gbps 10 Gbps	2 2 2 2 2	300 m 2000 m 550 m 550 m 82 m
Multi-mode OM3	10 Base-SX 100 Base-FX 1000 Base-SX 1000 Base-FX 10 GBase-S 40 GBase-SR4 100 GBase-SR10	10 Mbps 100 Mbps 1 Gbps 1 Gbps 10 Gbps 40 Gbps 100 Gbps	2 2 2 2 2 2 2	300 m 2000 m 800 m 550 m 300 m 100 m 100 m
Multi-mode OM4	10 Base-SX 100 Base-FX 1000 Base-SX 1000 Base-FX 10 GBase-S 40 GBase-SR4 100 GBase-SR10	10 Mbps 100 Mbps 1 Gbps 1 Gbps 10 Gbps 40 Gbps 100 Gbps	2 2 2 2 2 2 2	300 m 2000 m 880 m 550 m 450 m 125 m 125 m
Single-mode OS1	1000 Base-LX 10 GBase-LX4 40 GBase-LR4 100 GBase-LR4	1 Gbps 10 Gbps 40 Gbps 100 Gbps	2 2 2 2	5000 m 10000 m 10000 m 10000 m
Single-mode OS2	1000 Base-LX 10 GBase-LX4 10 GBase-E 40 GBase-LR4 100 GBase-LR4	1 Gbps 10 Gbps 10 Gbps 40 Gbps 100 Gbps	2 2 2 2 2	5000 m 10000 m 40000 m 10000 m 10000 m

AN EXAMPLE OF AN ITT-GENERATED REPORT SHOWING RESULTS OF COPPER CABLED ETHERNET TRAIN NETWORK SUBJECTED TO RIGOROUS PERFORMANCE TESTING

Copper Certification Report

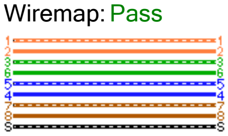
Cable Label: A-5

Overall Result:

Date & Time:	23/03/2016 08:57:15	Building:	Unspecified-Building
Limit Type:	ISO - Class FA Channel	Floor:	Unspecified-Floor
Cable Name:	CAT 7A FTP	Room:	Unspecified-Room
Connector Name:	CAT7A	Rack:	Unspecified-Rack
Site:	Itt Lainate	Panel:	Unspecified-Panel
Operator Name:	Izzo Stefano		

Local Ser. No.:	pw20302223	Remote Ser. No.:	pw20302224
Local Adapter:	Tera Channel	Remote Adapter:	Tera Channel
Local Calibration Date:	Mar 15 2016	Remote Calibration Date:	Mar 15 2016
Device Software:	7.1	Reporting Software:	Build_#294_7.1_2015-12-08_00-34-42

Wiremap: Pass

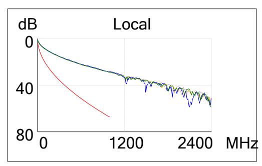


Wiremap: T568B

	Value	Limit	Margin
Length (m):	51,6		
Cable NVP:	82,0		
Propagation Delay (ns):	220,0	-	335,0
Delay Skew (ns):	5,0	30,0	25,0
Resistance (Ohms):	7,2	25,0	17,8

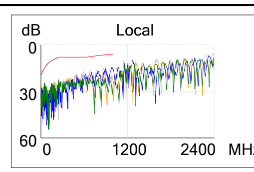
Insertion Loss: Pass

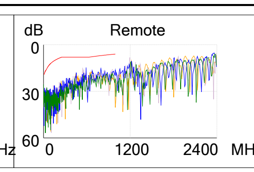
	Worst Margin:	Worst Value:
	Local:	Local:
Pair:	12	78
Value (dB):	1,8	29,1
Limit (dB):	4,0	67,4
Margin (dB):	2,2	38,3
Frequency (MHz):	3,85	996,00



Return Loss: Pass

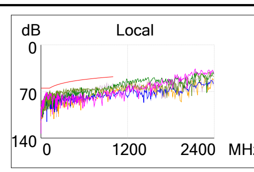
	Worst Margin:		Worst Value:	
	Local:	Remote:	Local:	Remote:
Pair:	45	45	45	45
Value (dB):	14,3	14,8	14,3	14,8
Limit (dB):	6,1	8,0	6,1	8,0
Margin (dB):	8,2	6,8	8,2	6,8
Frequency (MHz):	980,00	589,00	980,00	589,00

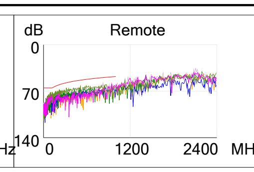




NEXT: Pass

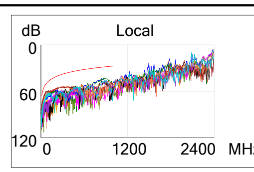
	Worst Margin:		Worst Value:	
	Local:	Remote:	Local:	Remote:
Pair:	36-78	36-78	12-45	12-45
Value (dB):	68,6	69,7	57,9	57,1
Limit (dB):	64,8	64,2	48,7	49,5
Margin (dB):	3,8	5,5	9,2	7,6
Frequency (MHz):	123,00	132,50	912,00	826,00

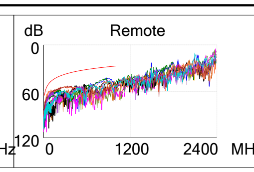




ACR-F: Pass

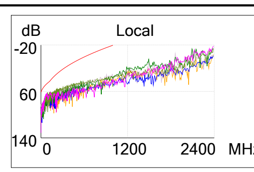
	Worst Margin:		Worst Value:	
	Local:	Remote:	Local:	Remote:
Pair:	78-36	36-78	45-12	45-12
Value (dB):	63,7	63,7	42,4	42,3
Limit (dB):	54,1	54,1	28,5	28,7
Margin (dB):	9,6	9,6	13,9	13,6
Frequency (MHz):	46,25	46,25	884,00	858,00

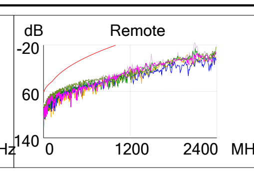




ACR-N: Pass

	Worst Margin:		Worst Value:	
	Local:	Remote:	Local:	Remote:
Pair:	36-78	36-78	12-45	12-45
Value (dB):	62,2	63,8	29,9	30,1
Limit (dB):	46,3	45,8	-19,2	-17,2
Margin (dB):	15,9	18,0	49,1	47,3
Frequency (MHz):	86,00	90,50	990,00	946,00





PS-NEXT: Pass · PS-ACRF: Pass · PS-ACRN: Pass

	PS-NEXT Worst Margin:		PS-NEXT Worst Value:		PS-ACRF Worst Margin:		PS-ACRF Worst Value:		PS-ACRN Worst Margin:		PS-ACRN Worst Value:	
	Local:	Remote:	Local:	Remote:	Local:	Remote:	Local:	Remote:	Local:	Remote:	Local:	Remote:
Pair:	78	78	45	45	36	78	45	45	78	78	45	45
Value (dB):	67,8	69,1	56,9	55,4	63,4	62,6	41,3	40,4	61,1	63,1	28,8	27,4
Limit (dB):	61,8	61,2	45,7	45,4	51,1	51,1	25,7	25,5	43,8	42,8	-22,1	-20,2
Margin (dB):	6,0	7,9	11,2	10,0	12,3	11,5	15,6	14,9	17,3	20,3	50,9	47,6
Frequency (MHz):	123,00	132,50	908,00	946,00	46,25	46,25	858,00	884,00	81,00	90,50	988,00	946,00

Network Compliance:10BASE-T, 100BASE-T, 1000BASE-T, 10GBASE-T

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Connect with the experts

ITT Interconnect Solutions' Veam brand is a world leader in the design and manufacture of highly engineered connector solutions for the rail market.

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