Computer systems for railway applications

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More and more electronic systems are being built into trains, the underground, streetcars and buses. If you talk about the overall railway engineering market, you don’t only mean vehicles – in which areas and applications can one find these computers and which functions do they take over? And why are they so different to the office PC or the one at home?

Common studies like that of the SCI Verkehr roughly divide the railway market into vehicles, system technology and infrastructure. While the overall market has a volume of 143 billion euros (according to UNIFE 2012 for 2011), about 60% of the business amounts to vehicles, just over 30% to infrastructure and less than 10% to system technology. The term infrastructure includes the track system and electrification where no computers are needed. System technology comprises traffic management and train protection as well as information technology, including passenger information, passenger safety and fare management.

In all areas computers are of vital importance. What’s obvious in passenger information, which is customer-oriented to meet the usual convenience and standard of living, has to be clarified for traffic management and train protection. Ever increasing speeds with more and more dense traffic on the track and finally the harmonization of rail networks across countries (ERTMS, CRTMS, PTC) as well as the increase in safety and economic efficiency would be impossible to achieve without powerful computers on the wayside and in the railway control center or in the central control room. This makes system technology the smallest but fastest growing segment of the railway market – not just in Asia, with a market share of over 30%, but also in Western Europe (in second place with almost 30%) and North America/NAFTA (third place with nearly 20%).

Let’s go back to the vehicles, which take up almost two thirds of the global market volume. The average annual growth rates depend on the vehicle type and country (and new acquisition or maintenance) and are between 0 and 4%. The biggest driving force behind this lies in equipping the vehicles with computers for train protection and control. Of course, the computers on board the vehicles fulfill many other tasks, too. These include the control of vital functions (e.g. drive, brake, power supply, tilting technology), safety management (doors, light, etc), and convenience functions (heating, air conditioning, etc) inside the vehicle.

If you compare a computer inside a rail vehicle or in train protection with computers in other embedded applications, you will see two striking differences. On one hand, electronics for a railway-compliant control have to meet more severe requirements with respect to robustness, reliability and availability, and demand corresponding precautions and thorough knowledge in design, production, qualification and product care. The EN 50155 standard defines rules regarding different environmental impacts. The operating temperature is divided into two classes. Tx prescribes that the computer can be operated between -40°C and +70°C, for example, and for 10 minutes even up to +85°C. The electronics in the system must be coated by a special varnish for protection against humidity or condensation. It may also be necessary to protect the housing against splashing water. The standard also prescribes shock and vibration tests over a specific frequency range. In addition to common EMC inspections, the behaviour in case of overvoltage is tested. Failure-free operation of electronics must be guaranteed even with supply voltages between 70% and 125% of the nominal voltage. The basic material for printed circuit boards is defined with regard to flammability. Solder connections or other connections with insulation displacement are subject to the respective standards, and so on.

Depending on the application, only parts of the EN 50155 standard need be observed, or else all of its provisions. The European DIN EN 50155 standard (German VDE 0115, international IEC 571-x) „Railway applications - Electronic equipment used on rolling stock“ is issued by the European organization for electro-technical standardization, CENELEC, and was first published in 1995. It is very de-
tailed and refers to approximately 50 other standards, many of which need to be observed in addition. EN 50155 demands operation of electronic equipment in trains for 20 years with the already-mentioned requirements – without regular periodical maintenance.

The second main difference relates to applications that also require the safety of the electronic systems. A safe system is a system with a defined error behaviour. Fail-safe systems are switched off in case of an error, they have a safe state – a train, for example, would stop. Fault-tolerant systems have to continue operation correctly when part of the system fails – an absolute must, e.g. in a railway control center. This is achieved through redundant computer architectures and permanent testing of all components. The reliability required according to so-called SIL levels (SIL = safety integrity level) has a scale of SIL 1 to SIL 4 and is defined by the frequency of use. They are defined in IEC 61508 (Functional safety of electrical/electronic/programmable electronic safety-related systems). Additionally, the following standards are relevant for the design of railway-compliant computers:

- EN 50126 (Railway Applications - the specification and demonstration of transport)
- EN 50126 (Railway Applications - Software for railway control and protection system)
- EN 50126 (Railway Applications - Safety related electronic systems for signaling)

Last but not least, a company needs to qualify as a supplier for the railway market also from a commercial point of view. The IRIS (International Railway Industry Standard) standard is the best example of what is demanded here. IRIS is a quality management system built on ISO 9001 but requires very detailed documentation of the procedures and processes using key figures in order to guarantee a high quality of the entire supply chain inside the railway industry. IRIS processes include risk management, knowledge management or obsolescence management, among others. Long-term availability is extremely important in the railway market, because the vehicles have to pass complex acceptance tests before first operation and are then in use for several decades. The most significant IRIS procedures include RAMS (Reliability – Availability – Maintainability – Safety) and FAI (First Article Inspection). And finally all 12 knock-out criteria of IRIS, one of them being design validation, must be fulfilled during a certification audit, without exception.

How such a railway-compliant computer is built up obviously depends on its job. Still, many functions have to be specially designed for the specific application, but with consistent product planning and the electronics supplier road map, more and more computers can at least be partially built up of standard components. This saves time and costs. Due to its modularity, maintainability and robustness the CompactPCI bus system, based on the Eurocard format, proved itself in the area of 19” solutions. Initially based on the parallel PCI bus, at present there are further developments with CompactPCI PlusIO and CompactPCI Serial that possess serial interface architecture. This means PCI Express, SATA, USB and Ethernet on the bus backplane.

CompactPCI systems are ideal for application in passenger information as content servers or multimedia access units and in passenger and train surveillance for the recording and management of camera data, or for ticketing. They can be combined with diagnosis, maintenance and service functions. One or several CPU cards in the same system can take over different control jobs and can exchange results. In terms of processor architecture, the most up-to-date Intel platforms are available – currently the Core i7 (first and second generation) or types of the Intel Atom family, and also backwards-compatible CPU board models down to

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Figure 2. Evaluation model of IRIS.
Pentium M. Thanks to individually designed heat sinks, power-saving versions permit to do without active ventilation in the system, where necessary. Under even more severe conditions, the single assemblies are packaged into CCA frames and housed by conduction cooling enclosures that are even protected against splashing water (IP67). In standard 19” enclosures that are less protected, still the option remains of coating the whole electronics against humidity and condensation but also against dust – this should be taken into consideration already in the development phase.

In environments prone to shock and vibration you should completely do without connectors, if possible. Ideally, all components are permanently soldered on the board – even the CPU and main memory. The 2mm CompactPCI system connectors linking to the bus backplane (including the new AirMax connectors for CompactPCI Serial) are sufficiently robust. At the computer front, you should abstain from usual types like RJ45 and use D-Sub, Lemo or M12 connectors instead. The latter are now also available for Gigabit Ethernet. For antennas on wireless I/O cards, you can use SMA connectors.

Infotainment computers especially depend on loads of flexible interfaces to other computer units on board the train and to the outer world. CompactPCI (Serial) systems offer another plus here: you can simply plug up to 7 (8) peripheral slot cards (and more using bridges) into the system, for any desired I/O function and with hot swap support. These may be additional UART, USB and Ethernet Interfaces, multimedia connections for several screens and audio on/off, field bus connections from CAN bus up to railway-specific MVB and WTB or switches and gateways between the train bus, wagon bus and higher-level Ethernet communication. CompactPCI carriers for PCI Express MiniCards and combined SIM card slots can cover the whole world of HF requirements – WLAN, UMTS, GPS, GSM, HSDPA, LTE – up to the railway-specific GSM-Rail.

The use of standard mezzanine cards can make design even more modular – two M-Modules or one PMC or XMC or PC/104 can be plugged on a CompactPCI carrier in single Eurocard format. The choice of mezzanine boards of different manufacturers is huge, and especially with M-Modules there are myriads of analog and binary I/O and instrumentation and motion functions. CompactPCI boards with an individually programmable FPGA and a broad spectrum of IP cores are an additional alternative to implement an application by using almost only standard components.

The use of CompactPCI systems for passenger surveillance has another benefit. The new CompactPCI Serial standard in particular allows especially easy configuration of complex SATA RAID or NAS systems for the recording of camera data. Modern processors support up to 8 SATA channels that can be used to control 8 robust, hot-pluggable hard-disk shuttles via a standard bus backplane.

Even for safe computers in applications ranging from train control, train protection and control technology to driverless operation in ATO systems, CompactPCI and CompactPCI Serial are ideal platforms. Sub-computers on separate backplanes, each with an identical set-up of a CPU board, I/O functions and a PSU of their own, are built into the same rack or distributed over several racks to be connected as redundant, complete systems that monitor each other. They communicate via Ethernet, for example. You call this a 1oo2 (1-out-of-2) architecture, and if not only safety but also availability is demanded, a 2oo3 or 2oo4 etc architecture. The main memory in systems like these is typically protected using ECC. Another simple method is to use reflective memory assemblies in the system. You can also certify individual computer boards up to SIL 3 and SIL 4 which have a triple-redundant processor and main memory and are equipped with onboard voters and other safety-relevant features like BITE (Built-In Test Equipment). Due to lockstep architecture, the (also safe) operating system only “sees” one CPU. This reduces software overhead.

As many (CompactPCI) systems used in railway applications don’t necessarily need powerful graphics, and as Windows is not the most favorable operating system to choose at least for safe computers, CPU boards with PowerPC...
processors are also used in many cases. With less than one watt of power dissipation, some types of the PowerQUICC II and III families are very power saving, while the high-performance types of the QorIQ family offer up to eight processor cores. Even combinations of Intel-based host CPUs with PowerPC based slave CPUs inside the same system are common, for example for diagnosis and maintenance functions in different applications. A slave CPU connected via Ethernet could act as a diagnosis buffer. The PowerPC card running the VxWorks real-time operating system needs well under two seconds to boot and is ready for operation long before the Intel host is.

No matter whether you deal with a CompactPCI (Serial) or another type of embedded system – the top priorities are always compact and robust design, and standard conformity. Computer-On-Modules (COMs) also allow setting up small systems in a very flexible and inexpensive way. While the COM as a standard component already implements the entire computer architecture, carrier boards tailored to the specific application can be designed within short time. COM standards like ESMexpress and ESMini are enclosed by an aluminum case that is connected to the housing wall to transfer the heat. They have been designed for fanless conductive-cooling systems right from the beginning. Based on this, standard systems such as box computers are also available. They can be used to control different vehicle functions, and special enclosure models can also be protected against splashing water (IP67).

Intelligent display computers for passenger information systems (PIS) and driver cabin systems are ideally set up with conduction cooling features, too, and are then available for applications up to the Tx temperature range (−40°C to +70°C in continuous operation and 10 minutes up to +85°C). Like CompactPCI systems, box and display computers should have railway-compliant networks and phone connections for wireless communication, in addition to the usual computer interfaces – for instance to transfer service data to the control center or to receive traffic information.

Finally, Ethernet switches make communication inside the vehicle work and distribute relevant information to different computer systems. They are currently being used mainly for data-intensive newer equipment such as information and content servers, CCTV video surveillance cameras, web access and wireless services like GPS or GSM. Other subsystems still more or less communicate via standardized fieldbuses like WTB/MVB, CAN bus, Profinet or WorldFIP. However, some manufacturers have already taken the first step and have established Ethernet IP as an information bus beside WTB as the train bus and MVB, CAN etc as the vehicle bus. Ethernet switches can be found as assemblies in CompactPCI systems and are used as plug-in components for 19" systems and as compact, independent devices with IP67 protection.

The train as a modern transportation system is getting computerized to a growing extent. Computer systems for railway applications have to be able to include all current PC functions and have all the up-to-date technology. But not only that: robustness, safety and long-term availability are also demanded in this market. Possessing the relevant know-how and the necessary key competences is important for the manufacturers of these kinds of computers. That’s how the worldwide renaissance of rail traffic can have permanent success – and why not, as the future number 1 traffic carrier?