New Generation of Multifunction Sensors Specially Designed for Rolling Stock Applications

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Summary

A new fire detection system for use on passenger trains, based on a multifunction point-type sensor, is described. The full development process of the new system is described, and all the choices made in order to make a railway specific product explained. The basic concepts of the system described are:

- full compliance to all the standards for safety-related electronics on rolling stocks,
- detection performances derived from existing standards for commercial buildings, with adaptation,
- multifunction sensors, capable to measure the smoke obscuration and the air temperature, and to control external devices, and also able to drive signal and power outputs,
- detection criteria delegated to a central supervisory unit, receiving the real-time information from the multifunction sensors over a safe and robust communication link, redundant CAN bus,
- commands to actuate the sensor's output sent selectively over the same communication link.

A comparison with other traditional fire detection systems is made, and examples of application and of installation are given, both for fixed and variable composition trains. Reference is made to several existing applications on trains in many countries, like Italy, Switzerland, Finland, Russia, China and Poland. A table is presented with field data from thousands units in operation, demonstrating an MTBF in excess of 20 millions-hour.

Keywords: **s**ensor, smoke, multifunction, railways, safety, standards

1. Background

When, more than ten year ago, we decided to extend our activity in electronic equipment for rolling stocks also to fire detection systems, the normative status was somewhat primitive, if not totally lacking. The rare applications of fire detection

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systems in rolling stocks were approached in a totally unregulated way, trying to adapt commercial smoke detectors for residential use to the rolling stocks environment, as exemplified by the following Fig. 1.

Fig. 1. Example of use of commercial sensors on rolling stocks

The picture shows that even in an high-level new train the solution was to modify battery-operated smoke sensors designed for household to operate on a dedicated local supply, on a coach level basis, with the standard 9 V supply derived from the train battery, and collecting the summarizing alarm to sound a buzzer. Even worse, ionization-type smoke sensors were used, containing radioactive elements. Clearly the fire detection system was considered as an equipment extraneous to the railway environment, and the rigid standards applicable to electronic equipment on rolling stocks, starting from EN 50155 [1], have not even been taken into consideration, just a mere compliance to the existing standards for residential use.

2. The Development Process of a New Generation of Fire Detection System

Having taken the decision to enter the field of fire detection system for railways rolling stocks, a not-so-obvious choice about the development process had to be taken. At the time our company had already a consolidated experience on safety-related electronic equipment for rolling stocks, with more that twenty years of experience in the field, but yet without a specific experience in fire detection. The choice was between following the existing guidelines for fire detection systems for buildings, and then apply the necessary modifications to adapt it to the railway world, or instead to stick from the beginning to the well documented development process for electronic equipment on rolling stocks.

In favour of the first was a well-established set of standards and many useful references and experience to ease the path. Briefly the conventional roadmap for the development of a smoke detection system for buildings implies:

- development and testing according to the relevant standard. For point-type smoke detectors in Europe EN 54-7,
- approval by one or more approved notify body, like VDS (Verband der Sachversicherer) in Europe,
- product marking with the CE logo and name of the referenced standard.

With these prerequisite the device can be placed on the market, as prescribed by the Construction Products Regulation 89/106/ECC. Once obtained and affixed the CE mark the product can be freely sold and installed all over Europe, without any further testing of qualification; actually it would be illegal to even question the technical characteristics and compliance to the standard of a device that has been approved by whatsoever European notify body.

How is this applicable to railway rolling stocks? In no way. Of course the Building Construction ECC directive is not applicable, then the CE / EN 54-7 marking is not a prerequisite and is not even a valid quality certificate: any railway company or car-builder will have the right to test, accept or discard any device, irrespective of the marking or the listing made by organizations without authority on railways. There is a rationale on this: it is not expected and is not reasonable that a company active in building may be competent in every single subsystem, specially in a specialized and safety-related one like the fire detection system, so it is understandable that the approval of these systems is delegated, once for all, to third-parties.

On the other side the railway industries are absolutely competent in the field, have well established and proprietary standards and testing capabilities, no reason or need to rely to third-parties certifications. As an example consider the case of the electronic printed circuit board base material, an epoxy laminate with glass fibers. For all industrial application their fire and smoke behaviour is certified with the UL94V-0 standard, but for railway application this certificate is not relevant and it has to be replaced by a specific one, for example in France according to the standard NF F 16-101, in Italy to UNI CEI 11170, or all over Europe to the new EN 45545-2.

The unavoidable conclusion is that for the development of fire detection systems for rolling stocks the standards, codes of practice or guidelines issued by organizations with no legal authority over railways should be neglected, or considered at an informative level only. The selected development process thus implies sticking to the railway standards from the beginning, considering the fire detection system as any other electronic safety-related systems already existing on rolling stocks, using the above mentioned standards (for building) only as a reference for the functional performances.

3. Basic Design Criteria

The basic design criteria for the new fire detection system for rolling stocks are:

- complete conformance to the applicable standards for railway safety-related electronic equipment, see Table 1,

Table 1

List of relevant standards

EN 45545 series	Railway applications – Fire protection on railway vehicles
EN 50121 series	Railway applications – Electromagnetic Compatibility
EN 50126	Railway applications – The specification and demonstration of reliability, availability, maintainability and safety (RAMS)
EN 50128	Railway applications – Communications, signalling and processing system. Software for railway control and protection system
EN 50129	Railway applications – Communications, signalling and processing system. Safety related electronic systems for signalling
EN 50155	Railway applications – Electronic equipment used on rolling stock
EN 50159	Railway applications – Communication, signalling and processing systems. Safety-related communication in transmission systems
UNI CEI 11170	Guidelines for fire protection of railway, tramway and guided path vehicles (Italian standard)
NFPA 130	Standard for fixed guideway transit and passenger rail systems (US standards)

- functional performances derived from the existing building standards, but adapted to the rolling stock environment,
- system ready to be upgraded to control extinguishing functions, without additional electronic equipment,
- possibility to update the FW of all parts of the system at any time using standard tools.

From these basic choices the following detail consequences are derived:

1. The standards EN 50155 and EN 50126 [2] dictate not only specifications and tests, but mainly how the full life cycle of the equipment has to be managed, thus including the design criteria for both HW and SW, the component selection criteria, the documentation of each phase till the end of the life cycle. Among others points this means that the equipment has to be designed for a typical lifespan of 25 / 30 years, no special or single sourced devices should be used, severe derating has to be applied to all components, strict observance of well defined rules in the SW development, definition of an obsolescence management plan. Note that these aspects are not considered in the standards for commercial applications, and they cannot be assessed with tests on the finished product, but do require audits, design reviews and validation during the whole development phase.

2. For the functional aspects in rolling stocks there is a need to detect fire and / or smoke in several different locations with different requirements:
   - passenger area, both chairs or sleeping cars,
   - lavatories,
   - driving compartments,
   - technical areas, both internal (electrical cabinets) and external (under or over car body equipment).

   Besides it is necessary to have a centralized information collection with the identification of the exact location originating the alarm.
3. The backbone of the system shall be a safe and robust communication link suitable to collect all different information and report to centralized supervisory units and to the train's TCMS. This communication link has to comply with EN 50159 and use physical, electrical, data link and protocol layers well proven and accepted on rolling stocks. The fancy, proprietary, single wire DC link used by commercial systems in the so-called addressable devices cannot even be taken into consideration.

4. System Description

The system architecture is structured on a car-level base, with a supervisory unit SDCU in each car, that is connected to several multifunction point-type sensors RFMF, as shown in Fig. 2.

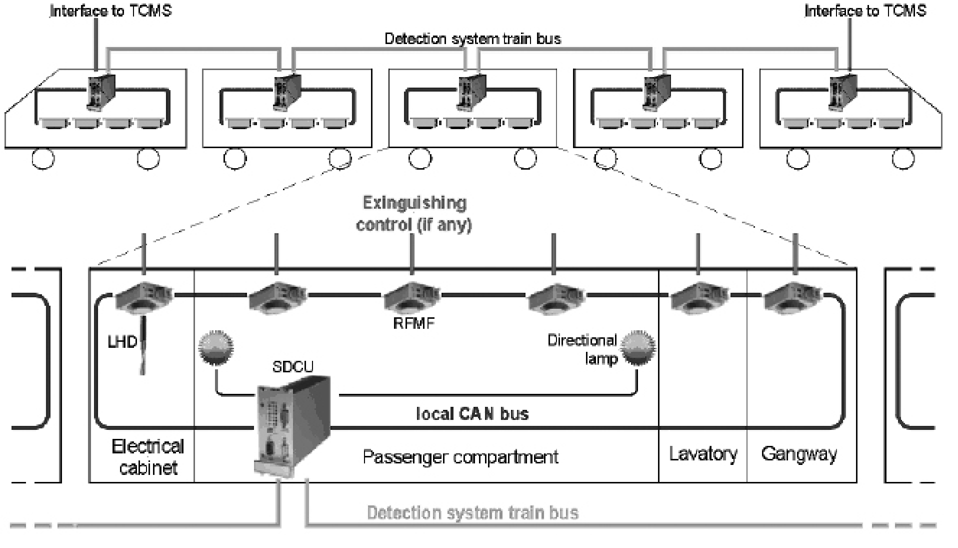

Fig. 2. System architecture

Each sensor not only measures the local smoke opacity and the air temperature, but also checks the status of external devices, and can command external devices, for example extinguishing equipment. The systems can work independently in each car , however it is possible to link all the supervisory units of a train for full exploitation of the capability of the system. All information from each sensor are collected and made available at any supervisory unit, the ones at both ends can be connected to the train's TCMS.

5. Car Communication Link

The car communication link is made with a double redundant CANopen safety bus, arranged in a ring configuration, see Fig. 3. It is EN 50159 compliant, category 1, and carries both the information collected from the sensors and the commands sent to them.

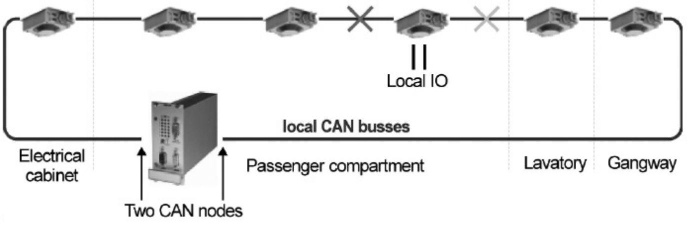

Fig. 3. CAN bus loop

Due to the ring configuration even in case of cable interruption (yellow cross) the full communication is automatically restored, setting the operating mode of both CAN nodes in the supervisory unit as master so the two sections of the CAN bus operate independently. Even in case of a second interruption (red cross) the basic function is maintained, because the isolated sensor, when detects its condition, stops sending data and receiving commands and starts to operates as a stand-alone unit taking autonomously decision and actuating local commands depending on how it is programmed.

6. Multifunction Sensor RFMF

The multifunction sensor RFMF is housed in a solid stainless-steel case and controlled by a safety-type microcontroller, see Fig. 4.

Fig. 4. Multifunction RFMF sensor

The choice of a stainless-steel case, although initially more expensive, is consistent with the expected lifetime of 25/30 years. The case is tied to the vehicle frame via an integral grounding bolt to provide electrical safety and EMI shielding, and fulfils current and future requirements for fire and smoke behaviour of materials, as EN 45545-2. It is hard to believe that the same may be guaranteed by plastic-housed commercial devices for buildings.

Even the system connector is a special version for railways, certified to EN 45545-2. The same connector, as well the Dsub connectors for the CAN bus, can house fire resistant cabling according to the railway accepted standard EN 50200. The sensor is called „multifunction” because it integrates the all the features shown in the block diagram, Fig. 5.

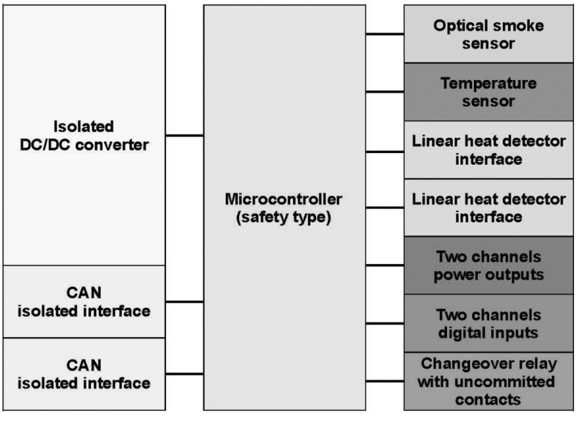

Fig. 5. RFMF multifunction sensor block diagram

It includes the following sections:

- smoke sensor, optical scattering type, functionally similar to standard EN 54-7,
- temperature sensor, functionally similar to EN 54-5,

- linear heat detectors LHD interface, two of them,
- two power outputs, to drive electro-valves or aerosol initiator for extinguishing systems,
- relay with potential free changeover contacts, for local warning devices,
- two digital inputs to monitor manual actuating devices or the status of the extinguishing system,
- dual isolated safety CAN interfaces,
- fully isolated DC / DC converter to power the unit, with wide input range to railway standards.

All functions are under complete control of a safety type microcontroller that performs also the complete real-time diagnostic of all the peripheral blocks, including the optical components of the smoke sensor, and also the functionality of each digital input and output. Note that if the linear heat detectors LHD are not required, these interfaces can be configured to read data from external devices over a 4–20 ma loop, for example to control the pressure values in the extinguishing system.

The RFMF can be directly connected to the train's battery, fully meeting the requirements of EN 50155 and the internal DC / DC converter can be set to operate with all possible car battery voltages.

6.1. Smoke Sensing Section

The optical smoke sensor is made by a specially designed cell that uses a combination of selected infrared emitters and detectors to achieve both an high sensitivity to the incoming smoke particles and the capability to perform in real time the automatic diagnostic test of all the components.

The associated electronics is also of totally proprietary design, and uses only railway-grade components, but no proprietary or single sourced devices: no ASICS, no custom programmed devices, all items not conforming the railway philosophy. All functions rely only on ingenious design, strict component selection and careful processing. A special circuit arrangement makes the sensor totally insensible to the environmental conditions, including ambient light and humidity, even for quick changes and subsequent condensation.

Laboratory measurements in a standard smoke tunnel according to EN 54-7 give the sensitivity curve shown in the graph (Fig. 6), measured for a set of sensors as a function of the obscuration expressed in dB/m.

Since the digitized analog value is computed and evaluated by the supervisory unit to set a warning and an alarm condition, a detection threshold can reliably be placed at very low values of obscuration. Consider also that the detection algorithm evaluates also the rate of change of the obscuration, and the correlation with temperature.

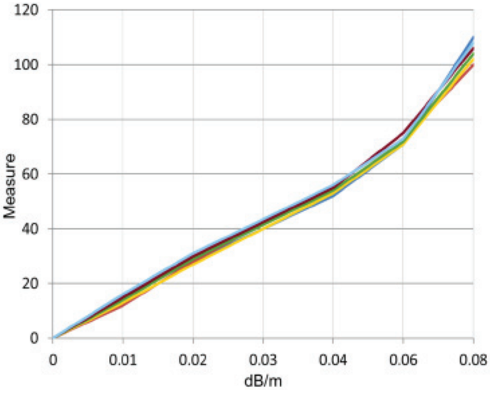

Fig. 6. Smoke obscuration response

6.2. Temperature Measuring Section

The temperature measuring section provides a linear measure of the air temperature in the range from 0°C to 80°C, see Fig. 7.

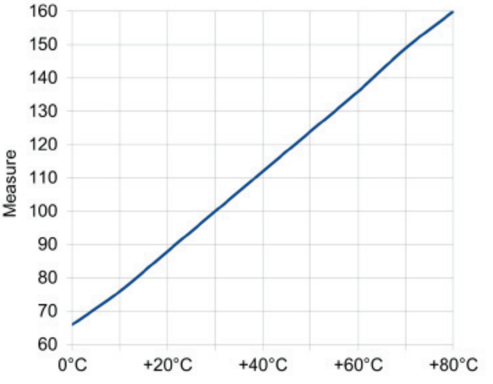

Fig. 7. Temperature measuring response

Setting the proper parameters in the supervisory unit, the requirements of standard EN 54-5 for class B static detectors and for class BR velocimetric sensors can be fully met.

6.3. Sample connection

A sample connection of the RFMF multifunction sensor is shown in Fig. 8, where a sensor transmits over the CAN busses the real-time values of the internally measured physical quantities, smoke obscuration and temperature, the status of two external Linear Heat Detectors and of two additional digital inputs. It also receives commands from the supervisory unit to operate, when necessary, a change-over relay or two power outputs to drive for example the electro valves of the extinguishing system.

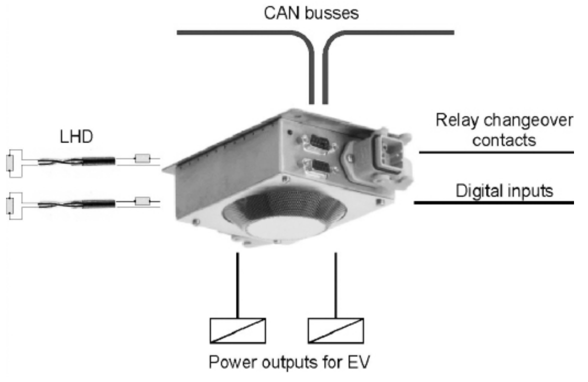

Fig. 8. Sample connection

7. System's Advantages

The basic concept of the system is that the sensors do not evaluate an alarm condition by themselves but only act as peripheral measuring devices to report to the supervisory units the local situation: it is a task of the supervisory unit to evaluate the full set of information, and decide in case to actuate an alarm. Only in special degraded mode (double interruption of the communication link, as explained in the relevant paragraph), the sensors will use their internal „intelligence" and actuate the alarm outputs.

The supervisory unit evaluates the information from all sensors, taking into account their location, the current measured values, their rate-of-change, the correlation between different sensors. This system architecture combines the advantages of two previously existing technologies, standard point type detectors and aspirating type detectors. As with the standard point type detectors it is possible to identify the location of the alarm source and as with the aspirating type detectors the alarm is evaluated by a centralized unit, easily programmable and evaluating the global area controlled.

But as an advantage respect aspirating type systems the data from each sensor are evaluated first individually and then also globally, so there is no loss of information due to dilution or averaging effect of the raw data and the full detailed picture is available to the supervisory unit. Not to mention that the detailed, real-time temperature information for each location of the sensors is not available to aspirating type systems.

The smart, co-operative evaluation of all this information allows the early detection of fire / smoke minimizing the risk of false alarms, giving also its location within the coach. Note that there is a close correlation between all the previous point. The sequence of the events for an effective detection system should be the following:

1. A possible fire should be detected as soon as possible, typically within a few seconds from the fire onset (test to be made on a train mock-up with one standardized ignition model according to EN 45545-1 [3]), and a warning status generated.
2. The warning status shall not cause any automatic action but only shall notify to the travelling staff, in a discrete manner to remain unnoticed to the passengers, the warning and the location of the possible fire with the highest possible accuracy.
3. Only if the warning is not acknowledged and cleared by the travelling staff and a second, higher threshold is surpassed, an alarm is generated and further measures shall be taken, even automatically.

It is clear that both early warning and positive identification of the location of the source must be assured for an effective fire protection. The comparative performances of this new system in respect to traditional point-type and aspirating type systems are summarized in the following Table 2.

Table 2

Detection systems comparison

Performance	New system multifunction sensors	Traditional point-type detectors[1]	Aspirating type detector[2]
Single spot smoke detection	Yes	Yes	No
Average smoke detection, early warning	Yes	No	Yes
Single spot temperature detection	Yes	Yes	No
Average temperature detection	Yes	No	No
Alarm source location	Yes	Yes	No
Easy modification of average detection parameters	Yes	No	Yes
Easy modification of spot detection parameters	Yes	No	No
Easy deployment	Yes, electrical wiring	Yes, electrical wiring	No, calibrated tubing
Easy system modification during operation	Yes	Yes	No
Maintenance tasks	Cleaning of the sensors	Cleaning of the sensors	Cleaning of the filters, periodic replacement of the pump motor

[1] Standard system with addressable detectors.
[2] Standard system with one aspirating central unit.

8. Representative Case

Let assume that we have a system configured as in Fig. 9, with multifunction sensors RFMF located in the passenger area, in the lavatory, in the electrical cabinet and in the gangway of the same coach, ignoring at the moment the possibility to use them in other technical areas.

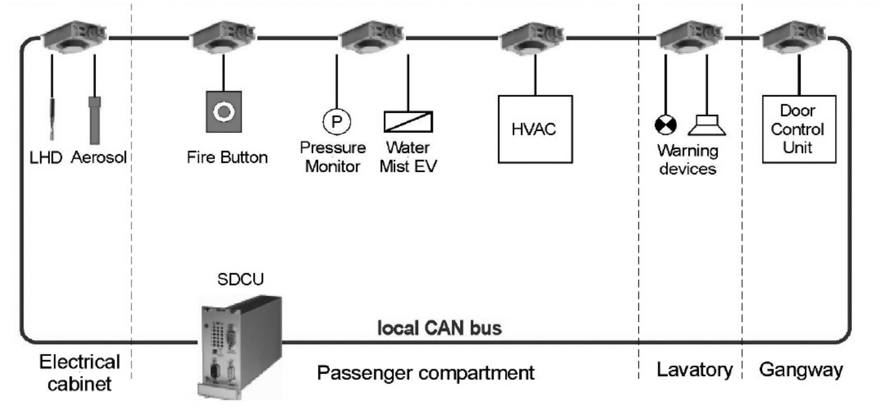

Fig. 9. Representative case

All the RFMF are identical, they just have an individual address (set in the system connector with jumpers) for the proper communication protocol. They all transmit the measured physical values to the supervisory unit SDCU in real time. The SDCU evaluates this data taking into account the location of each sensor, know from a configuration file where to each address is associated a location. For each location there will be a different set of parameters to establish both the warning and alarm thresholds, and the subsequent actions at the local level (at train level a different set of rules may apply).

8.1. Lavatory

The parameters for the data collected by the sensor in the lavatory can be set to trigger a warning status at a relatively low level of smoke obscuration and temperature and actuate the general discrete signalling to the travelling staff – the „blue light" system detailed after – but the SDCU can also generate an optical and acoustic warning signal just inside the toilet, sending the proper command code to the RFMF.

8.2. Passenger Area

If a source of fire is detected in the passenger area, at the warning stage the SDCU can, besides the general signalling to the staff, stop the air ventilation from the HVAC (Heat Ventilation and Air Conditioning system) to avoid propagation of smoke and fire, sending the proper command to the nearest RFMF.

At the higher level of alarm can actuate a water-mist extinguishing system, driving the electro-valve at the more appropriate location, while the pressure level of the system are under control. Also a simple but effective manual fire button can be linked to the system without the need of a dedicated cabling.

8.3. Gangway

As another example if fire is initially detected in the gangway the SDCU can send a command to the local RFMF to force the gangway door control unit (if any) to stop the automatic door opening, usually controlled by infrared presence sensor, and avoid that the smoke may keep the door open. At the higher alarm level the SDCU may also, if foreseen and accepted by the local safety authorities, send a command to the RFMF to force the door control unit to close the door, if the door has a fire confinement rating.

8.4. Electrical Cabinet

For the electrical cabinet is likely that a somewhat higher threshold for temperature is set, but at the same time the smoke obscuration and possibly the status of one or more linear heat detectors is controlled. In this case normally is not useful to have a double threshold, at the alarm level an immediate local action, still originated by the SDCU via the RFMF, can be automatically performed, for example actuating a small aerosol generator. This is just to give an overview of the capability of a system composed by the intelligent multifunction RFMFs that act as sensors and actuators under the control of the supervisory unit SDCU.

9. Train Level Functions

As already stated the supervisory units SDCU communicate with each other via a proprietary link and with the train's control and monitoring system TCMS. The system is enough flexible to allow an optimal implementation both on variable composition trains (rakes), Fig. 10, and on fixed composition trains, Fig. 11.

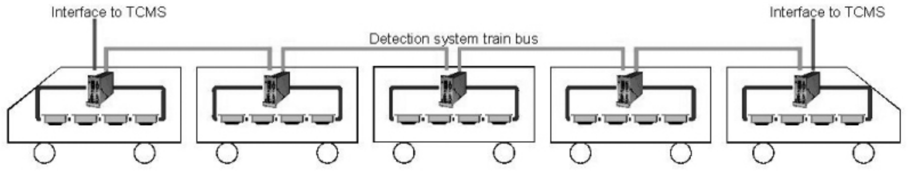

Fig. 10. Variable composition train (rake)

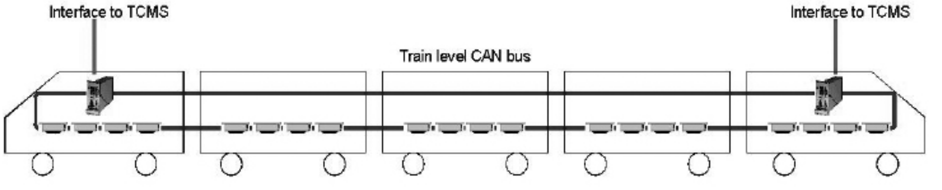

Fig. 11. Fixed composition train

On variable composition trains one SDCU for each car is deployedand the communication between the SDCUs is made using spare pins in the standardized coupling connectors. In case of fixed composition trains in most cases is possibly to simplify the installation running the dual CAN bus across the full trainset, spanning up to 60 multifunction sensors in a single loop.

If a train is fully connected, when the warning status is set in a coach all other supervisory units in the whole train receive the same information, so several further actions can be performed:

- notify to the TCMS and to the driver the alarm status,
- notify to the staff scattered along the train about the warning or alarm and its source (coach and detailed location), driving a series of unobtrusive signalling lamps, as detailed later.

If the higher level alarm status is reached the following additional actions can be performed:

- actuate extinguishing measures sending through the CAN bus a command to the relevant multifunction sensor to open centralized or local electro-valves (for example water-mist system in the passenger area) or to initiate an aerosol generator (electrical cabinet or technical box),
- execute immediate or delayed global action, as stopping the complete ventilation system and / or eventually actuating the brakes, if this functions are consistent with the application.

All functions and operating parameters (including the sensors' map) are programmable to meet specific requirements.

9.1. Blue Lights

Since each SDCU has the complete knowledge of the detailed train status, they can drive local directional lamps (high reliability and redundant blue LEDs) to indicate to the travelling staff the exact location of the fire: in the drawing below (Fig. 12) the flashing lights in the other coaches point to coach 3, where a steady light indicates the fire on the left-side. No additional wiring is required, each lamp can be driven by the nearest RFMF.

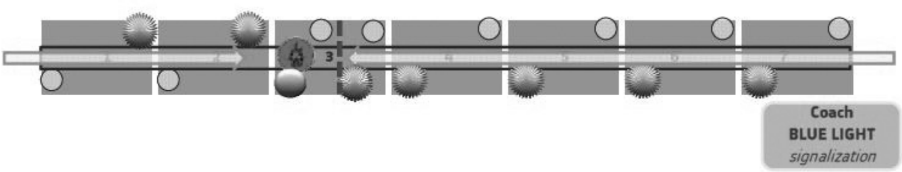

Fig. 12. Example of indication of the location of the fire

A sample installation of the blue light is shown in Fig. 13, where by choice no clear indication of the lamp function is present, because it should be as much as possible not noticed by the passengers.

Fig. 13. Blue light installation

10. Installation and Maintenance

The multifunction sensors can be easily deployed even in already existing trains, requiring only a simple non-critical electrical wiring (CAN bus) than can be made by operators of standard skill, requiring the same competence normally required for all others wirings in the train. If fire resistant cables according to EN 50200 are used (as recommended) they can be easily fitted in the system connector of the RFMF, that is apt to accept the wide insulating walls of this type of cables.

Additional sensors can be added later if necessary, with simple update of the configuration data. No other wiring besides the CAN bus is required even for all other functions, like control of local warning indication, control of the extinguishing system, control of the blue light signalization, only short drop wire to the nearest multifunction sensor.

The supervisory unit SDCU is extremely compact and can be installed easily in the electrical cabinet, while the sensors can be installed both on the ceiling of the coach or in the ventilation ducts, as shown in Fig. 14, 15, 16.

Fig. 14. Installation in the air duct

Fig. 15. Installation on the ceiling

Fig. 16. Installation in a toilet

The only maintenance task required is cleaning the sensors when the system calls for this, well in advance of any possible performance reduction. No scheduled maintenance tasks, no replacement of parts with intrinsically limited lifetime (motors etc.) and the wirings do not require dedicated maintenance.

Also the SW application for diagnostic and maintenance according the railway standards is included in the delivery, see in Fig. 17 a screenshot when connected to one supervisory unit. A set of ancillary equipment (Fig. 18) is available to address all possible installation requirements.

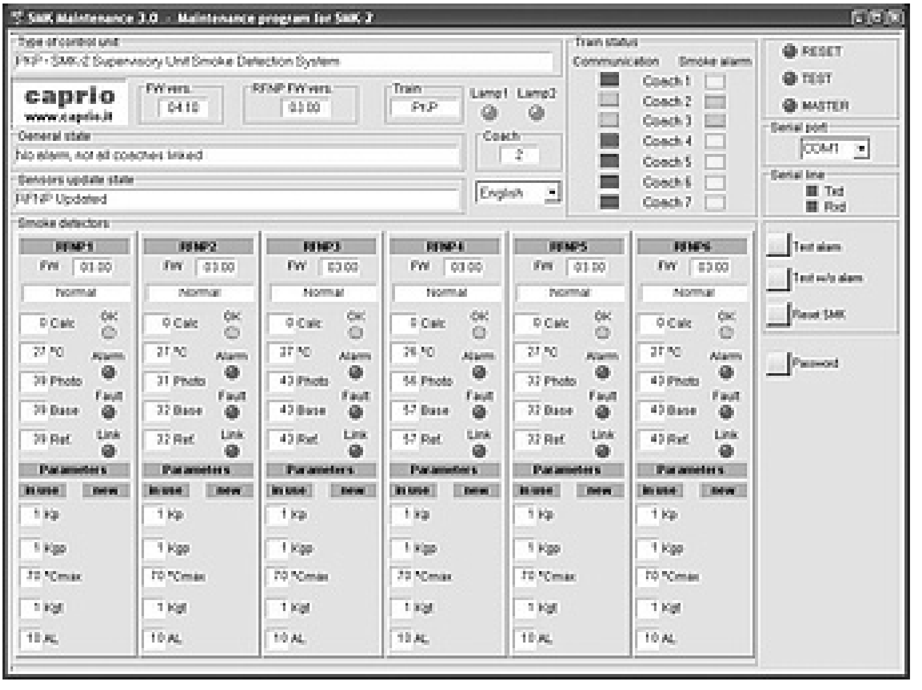

Fig. 17. Screen shot of diagnostic tool

Fig. 18. Ancillary equipment

11. Verification, Validation, Commissioning

The safety assessment is made according to the mandatory railway standards and to the SIL level of the safety functions. Functional verification is made according to the relevant individual functional requirements, derived from EN 54. Functional validation is made with railway specific laboratory tests, with reference to realistic ignition models [4] as indicated in the EN 45545 [3] standard, with smoke, heat and toxic gases generation.

Commissioning on real trains (Fig. 19) can be practically made only making tests with theatrical fog generators, with procedures to be agreed (no general standard applicable).

Fig. 19. Real life smoke test

12. References

More than 120 trains fitted with our systems are in operation all over the world.

Fig. 20. ETR 600/610 Italy and Switzerland

Fig. 21. PKP Intercity Poland

Fig. 22. SM6 Finland and Russia

Fig. 23. EMU 250 China

13. Reliability

The following Table 3 resumes the reliability data collected from the field, updated at the end of year 2013.

Table 3

Reliability data from the field

Units in commercial operation	5 730
Years of evaluation	2007–2013
Cumulated hours of operation	185 926 800
Failures	9
Failure/10^6 hours	0.048406147
MTBF (million hours)	20.66

The cumulated hours of operation are evaluated from the beginning of commercial operation for each lot delivered, and on the train mission profile. The number of failures includes both critical and basic failures.

14. Conclusion

The development process of a fire detection system for passengers rolling stocks based on new concepts has been illustrated, with normative references. The resulting system, totally compliant to all safety-related railway standards, has been described, highlighting the following features:

- safe and robust communication link, dual CANopen bus compliant to EN 50159,
- multifunction smoke sensors, capable to command and control external devices,
- elaboration of the information transmitted in real-time by each sensor,
- ready to be integrated with an extinguishing system.

The criteria to verify, validate and test the system have been detailed.

A comparison with other conventional systems shows that the use of this innovative fire detection system based on point-type detectors with multifunction capability and specifically designed for railway application is perfectly suitable to achieve the functional and safety performances required by the current and foreseeable international standards. It is also easy to deploy, requiring only simple wiring, and for similar reasons can be applied also to existing coaches.

The availability of both distributed and centralized intelligence allows a safe operation even in case of significant failures and gives the extra feature of easy localization of the fire source, feature that will become mandatory with the new standards under development.

Moreover this type of system gives the greatest flexibility and is ready to be integrated by an extinguishing system without the need to add any other electronic unit. The system illustrated has been proven in use in several countries in large quantities and the collected field data demonstrate an outstanding reliability.

Literature

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