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Fibre Optic Radar System for Fire Detection in Cable Trays

Abstract

With the development of heat and radiation sensitive cable designs and further development of the optical OFDR Raman radar measuring method with high location resolution and high temperature accuracy a fire detection system for fire monitoring in cable trays has been successfully realised. Complex measurement of Raman back-scatter light, calculation of the Raman back-scatter curve from the Fourier transformation of the measurement signal and application of the mathematical correspondence between frequency and location-space for correction of disturbance variables are the unique exclusive features of OFDR Raman technology. Based on these special qualities the OFDR Raman technology has technical and also economic advantages compared to all commercial fire detection systems. This new fibre optic radar system contains the possibility to detect thermal overloading of cables in the first phase of initial damage (build-up phase) prior to or during the early pyrolysis phase.

1. Introduction

The LIOS Technology Company, founded in early 2000, is developer and producer of fibre-optic radars which monitor temperature as a function of location and time via silica fibre (optic) cable over a distance of many kilometres. The invention is based on development of a novel optical radar monitoring process awarded second prize in the Cologne Innovation competition [1]. Basic development was supported financially by the Federal Ministry for Education, Science, Research and Technology (BMBF) technical training program "Microsystems Technology" [2]. In cooperation with a leading world company in the field of fire prevention,

Siemens Building Technologies Ltd, the product was successfully launched under the name FibroLaserII for fire monitoring in road tunnels. The monitoring system has been optimized in recent years and developed to series production models now available for further innovative applications. Since early 2004 a total of 500 systems have been installed worldwide using optical fibre cable lengths providing monitoring ranges of some 1000km. Application for early fire detection in cable trays with which this paper deals is on the other hand new and is still under development. Currently field trials under authentic environmental conditions are under way.

Greater and greater demands are being placed on fire prevention. On the one hand the operator wants real value protection and on the other public authorities demands the greatest possible protection of the general public from systems fraught with risk. Retention of function of important monitoring units over a specific timescale (fire detection equipment, escape route signalling etc.) and cost-intensive operational units (e.g. computer centres, control rooms etc.) are additional fire prevention system requirements which must also be met by modern fire detection systems.

Cabling systems are important components of building infrastructure in communications, decentralised data processing and electrical equipment power supplies. By laying cables in cable trays the risk of an undetected fire and fire spreading to other areas of the building increases. It is true that by bundling cables in cable trays great ease of installation is achieved, at the cost however of a greater risk of fire through cables overheating in the absence of adequate heat dissipation or ventilation. In addition to spontaneous cable ignition cable systems also run the risk that the naked flame will jump across and spread uncontrollably through the building.

If there is cable ignition the flames can very rapidly spread to all cables in the tray. The spread rate is highly dependent on the cable insulation characteristics. Cable insulation burnout is associated with strong smoke generation with toxic fumes. Due to access routes and the seat of the fire being shrouded in smoke the fire services are unable to efficiently combat the fire.

In this paper initially some background facts regarding the cause and generation of cable fires is provided. Subsequently the specification profile of fire prevention systems for fire monitoring of cable networks from the viewpoint of the operator and the emergency rescue services management is dealt with. There then follows a product overview of commercially available fire and smoke detections including a comparison of the technical and economic advantages of fibre-optic Raman-based temperature sensors. The operating principle and technical improvement to a heat and radiation-sensitive optical fibre cable with the associated evaluation processor unit is presented which meets the technical demands of cable tray fire monitoring. The paper ends with a summary with an outlook for the future.

2. Generation of Fire in Cable Tray Electrical Cabling

Electrical cables transmit energy for power supply and control of electrical equipment. During energy transmission current-dependent losses occur in the conductors, metal sheathing and cable armouring plus current-dependent losses within the insulation. These losses are dissipated to the cable surface via the cable's thermal resistance and from there to the atmosphere. Maximum cable loading is determined by the cable's electrical and thermal stability and heat dissipation from cable surface to the surrounding atmosphere. If there are several cables in a cable trough or tray they affect one another mutually. The consequence is an additional heat influx. For this reason in cable bundlings thermal bottlenecks occur which must be taken into account at the planning stage by a current reduction of the overall installation. Conditioned by high assignment densities in cable ducts there is a risk of heat build-up, especially during subsequent installations. Errors in laying, e.g. mechanical damage to insulation, kinks etc. may give rise to initial cable damage which greatly reduces the thermal capacity of the cable.

The operator of electrical equipment must ensure at all times that the permissible temperature is not exceeded, otherwise accelerated cable-aging results. In the worst-case scenario thermal breakdown occur leading to destruction of the power cable. For cross-linked polyethylene (XLPE) cables VDE regulations state that permissible cable temperature is 90°C.

Point of origin for every occurrence of fire is the thermal loading of oxidizable compounds, which for the most part have a carbon or hydrocarbon content, leading to spontaneous combustion of the material. In this process even in the build-up phase various mutational processes in the material may be observed - note that we only consider plastics as cable insulation materials [5]. An injection of heat into the insulation material up to some 80-90°C leads initially to no appreciable change - most types of insulation are designed for a continuous operating temperature of up to 90°C (s. table 1).

Material	PVC	PE	LDPE	HDPE	PP	PA	FEP	PTFE	PFA
Max. operating temp (°C)	85	90	70	100	100	105	180	260	260
Breakdown Temp (°C)	120	100	100	120	180	140	290	327	327

Table 1: Thermal Characteristics of Typical Plastics

A continuous operating temperature of just under 90°C however leads to accelerated aging a associated mutation processes leading to increasing brittleness of the material. Above the continuous operating temperature the material markedly softens. Significant in the case of plastics is the absence of any discrete softening point - one refers rather to softening range characterized by the break-up of intermolecular bonds - as a rule van der Waals bondings. The degree of softening and reduction in viscosity depends inter alia on the macromolecule chain length. The spectrum above the so-called breakdown point (100-120°C) is characterized by break-up of intermolecular bonds. Pyrolysis follows initially with oxygen deficiency leading primarily to fragmentation of the macromolecules with associated of unsaturated and radical compounds (crack process). Other products of pyrolysis may be CO, HCl, HCN and soot. Pyrolysis is a process in flux and depending on heat input, availability of oxygen, the material and the morphological state of the insulation the most widely varying - mostly toxic and combustible - pyrolysis gases result which add significantly to the problems of fighting fires in cable trays:

- Intense smoke emission during cable insulation burn-down filling rescue routes and fire teams approach routes.
- Long-term damage and high clean-up costs following combustion of halogen-compound cable insulations [6].
- Human health danger from toxic fumes and fire residues.
- "Flash-over" via escaping pyrolysis gases following intense pre-heating by a secondary fire.

If the critical heat flow density, i.e. that heat flow density at which a material does not ignite after an infinite period, is exceeded the insulation material ignites, the consequence being an open fire. A realistic critical heat flow density is around 13 kW/m².

The cause of cable fires in the final analysis is the limited thermal stability of the electrical cable insulations. In the event of short circuits at the operator's site, incorrectly set power limits, inadequate heat extraction or cable damage electrical cables may be so intensively heated that the maximum permissible cable temperature is exceeded and thermal damage set in motion. This first phase of initial damage (build-up phase) subsequently moves on to the pyrolysis phase and if heat continues to be added leads to spontaneous ignition of the cable.

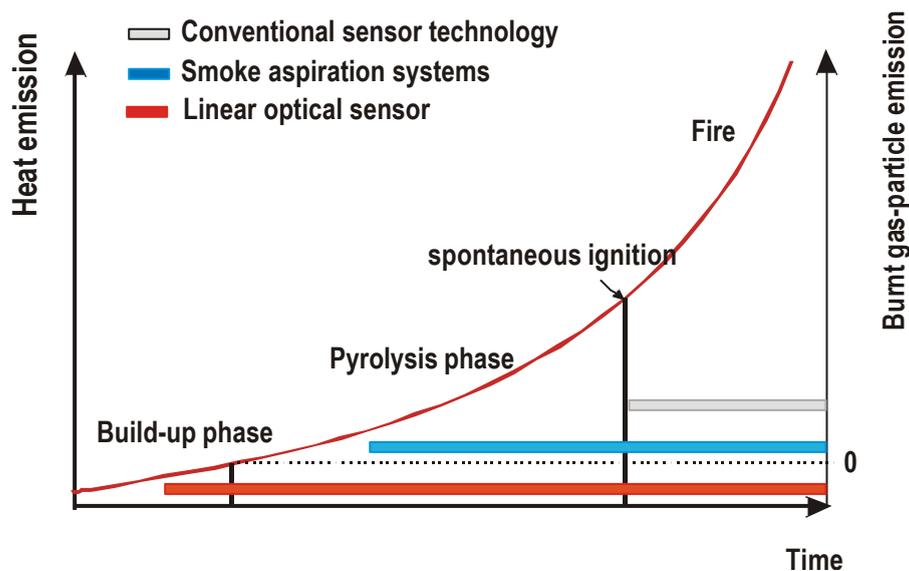


Diagram 1: Fire process profile and detection limitations of various detection technologies

If one considers the problems of the pyrolysis phase in particular with a view to fire prevention in cable trays then a compelling precondition is earliest possible early fire warning prior to or during the early pyrolysis phase. The main problem is prompt monitoring and localization of these spatially very limited points of overheating of the cable (e.g. at cable crossings, insulation damage sites etc.).

Electrical equipment is combustible to a greater or lesser degree depending on the material used so that even with a fire which has broken out at another location there the combustible insulation is a contributory factor to the fire occurrence and the fire can spread out as with an explosive fire to unaffected areas of the building. The upshot is that there is optimum fire prevention for cable trays if fire early detection, fire localization and fire fighting is covered by one single fire monitoring and alarm system. A precondition is uninterrupted (without gaps) temperature monitoring in the immediate vicinity of the electric conductors as a function of the site where the cables are laid.

3. Catalogues of Specifications from Operator and Rescue Services Management Perspective

From the viewpoint of operator and rescue services management the requirements list for the fire detection system for cable trays is very clear-cut and concise:

- Prompt reliable detection at the early stage (if possible prior to pyrolysis)
- Simplicity of installation and low maintenance costs
- Location of the seat of the fire to within a metre with clear correlation within the building
- Information regarding spread of fire and smoke (fire progress monitoring)
- Automatic interactions, e.g. signalling, shutdown of faulty conductors etc.

Further requirements are listed in Chapter 4.2.

4. Cable Tray Fire Monitoring

4.1 State of the Art

Below are outlined the advantages and disadvantages of currently established cable tray fire detection techniques:

4.1.1 Classical Smoke Detectors

4.1.1.1 Optical Smoke Detectors: Characteristic feature is the drop in intensity of IR source by absorption in the radiation pathway.

4.1.1.2 Ionisation Detectors: "Geiger counter" with constantly radiating ^{60}Co radiation source.

Advantages:

- Low procurement costs.
- Simple technology proven in buildings fire protection.

Disadvantages:

- For cable trays inadequate false alarm performance (dust exposure).
- Inadequate sensitivity, no detection possible in early pyrolysis phase.
- Maintenance costly - if not impossible - in inaccessible locations.
- Low monitoring density.

4.1.2 Classical Heat Detector

4.1.2.1 Heat Detector: Measurement of temperature rise within and interval or measurement of maximum temperature. This group includes heat-differential detectors and heat-maximum detectors.

4.1.2.2 Flame Detection: Measurement of radiations given off by the fire (infrared, visible spectrum ultraviolet) IR and UV flame detectors primarily used with this method.

Advantages:

- Low procurement costs.
- Simple technology proven in buildings fire protection.

Disadvantages:

- Sensitivity too low, no detection possible in early pyrolysis phase.
- Maintenance costly - if not impossible - in inaccessible locations.
- Low monitoring density.
- Flame detection requires an unobstructed radiation field, which is not guaranteed in cable trays with corners.

4.1.3 Linear Fire Detectors

4.1.3.1 Smoke Extraction System: The monitored object ambient air is extracted via pipework to a special detector unit. There then takes place evaluation of incoming air (smoke quality). If needed filter boxes may be fitted before the detector unit (in the case of extreme exposure to dust) or condensation filters (where there are condensation problems).

Advantages:

- High sensitivity due to extraction system's cumulative effect - therefore fire detection in the early pyrolysis phase.
- By comparison with discrete detectors a high monitoring density is realizable.

Disadvantages:

- Detector site not clearly identifiable.
- High maintenance costs due to filter replacement.
- After many years of operation lower sensitivity possibly to be feared.

4.1.3.2 Linear electronic heat detectors: These are mostly a thick cable in which discrete addressable sensors are fitted at freely optional intervals and therefore represent a hybrid between discrete and genuine linear fire detector technology.

Advantages:

- Simple installation.
- Sturdy low-cost technology.

Disadvantages:

- Low monitoring density.
- Too insensitive, no advanced early warning possible.

4.1.3.3 Other linear detector systems: One very robust technology is measurement of temperature variation by means of pressure changes within a copper tube. A further possibility is measurement of the electrical resistance of a cable as a marker for temperature variations. Both techniques are too insensitive for advanced early warning in cable trays and are associated with high installation and maintenance costs.

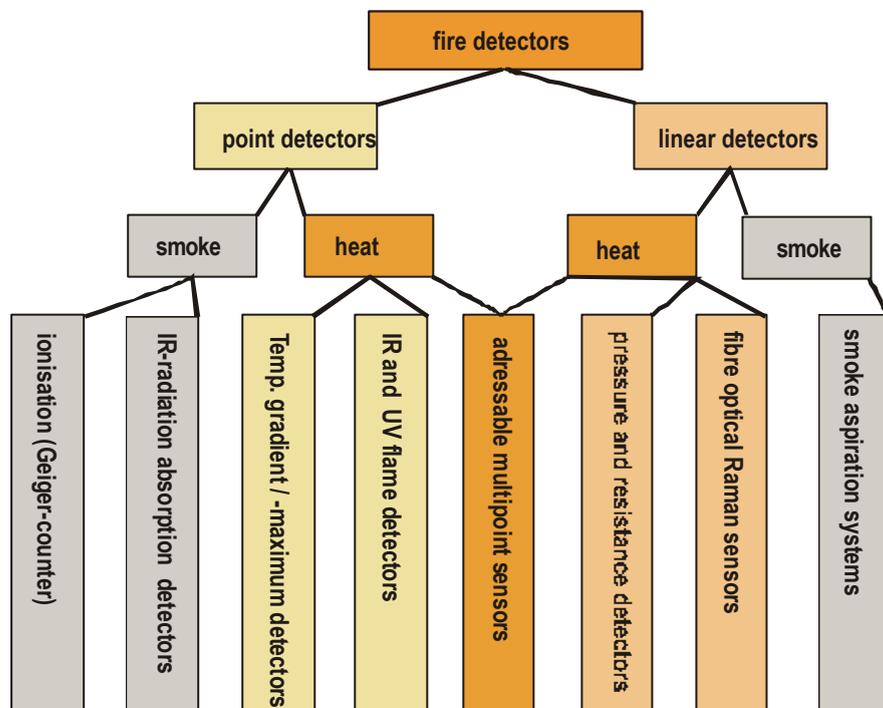


Diagram 2: Classification according to various fire detection technologies

4.2 Linear Optical Fire Detectors - Basis for Optimum Fire Protection in Cable Trays.

Cable trays are long and extensive objects, and are difficult to access so that the installation and maintenance expenditure involved with classical heat detectors cannot be justified on economic grounds. Even the linear fire detectors presented here do not fulfil the requirement

for continuous temperature sensing. This requirement is only met by a linear optical fire detector (see Diagram 2). The linear optical fire detector is based on a fibre-optic Raman back-scattering procedure. The actual heat detector (temperature sensor) is a heat and radiation-sensitive optical fibre cable. With the addition of an evaluation set (optical Raman reflectometer radar) temperature values in the cable fibre optics can be determined broken down by location.

Optical fibre cables have a very low attenuation. The minimal attenuation of optical fibre is limited by the Rayleigh scatter of the light, which is caused by the amorphous structure of the optical fibres. In addition to Rayleigh scatter, when affected by heat an additional scattering takes place in fibre-optic material, so-called Raman scatter. Temperature variations induce grid oscillations in the silica glass fibre molecular bond. If light falls on these thermally excited molecular oscillations the result is an interaction between the light particles (photons) and the electrons of the molecule. In the fibre-optic cable a temperature-dependent light scatter occurs (Raman scatter) which is spectrally displaced vis-à-vis the incidental light by the amount of the grid oscillation resonance frequency (Diagram 3). Raman scatter possesses - in comparison to Rayleigh scatter - only a very small, inter alia negligible degree of scatter and can be measured using the classical OTDR technique.

The intensity of the Anti-Stokes bandwidth is temperature-dependent, whereby the Stokes bandwidth is practically independent of the temperature. Measurement of the local temperature at any given point along the fibre-optic cable is derived from the relative intensities of the Anti-Stokes and Stokes light. A feature of this Raman technique is direct temperature measurement with a Kelvin scale. By using an optical Raman back-scatter procedure the temperature along the fibre optic can be measured as a function of location and time. The most familiar back-scatter procedure is OTDR (Optical Time Domain Reflectometry). It operates on the principle of a pulse-echo procedure whereby the echo time difference between transmission and detection of the light impulse determine the level of scatter and the scatter site. In comparison to Rayleigh scatter in the case of Raman light scatter measurement the signal is less by a factor of 1000. A locally assigned Raman temperature sensor with

OTDR is therefore only viable with powerful (expensive) pulse laser sources (in general solid state lasers) and rapid, similarly expensive signal communication techniques. The OFDR (Optical Frequency Domain Reflectometry) technology developed by LIOS Technology does not work as does OTDR in the time range, but in the frequency range. With OFDR a statement regarding the local temperature pattern when the back-scatter signal detected over the entire measurement period is measured as a function of the frequency and therefore subjected to complex measurement (complex transfer function) and subsequently goes through a Fourier transformation.

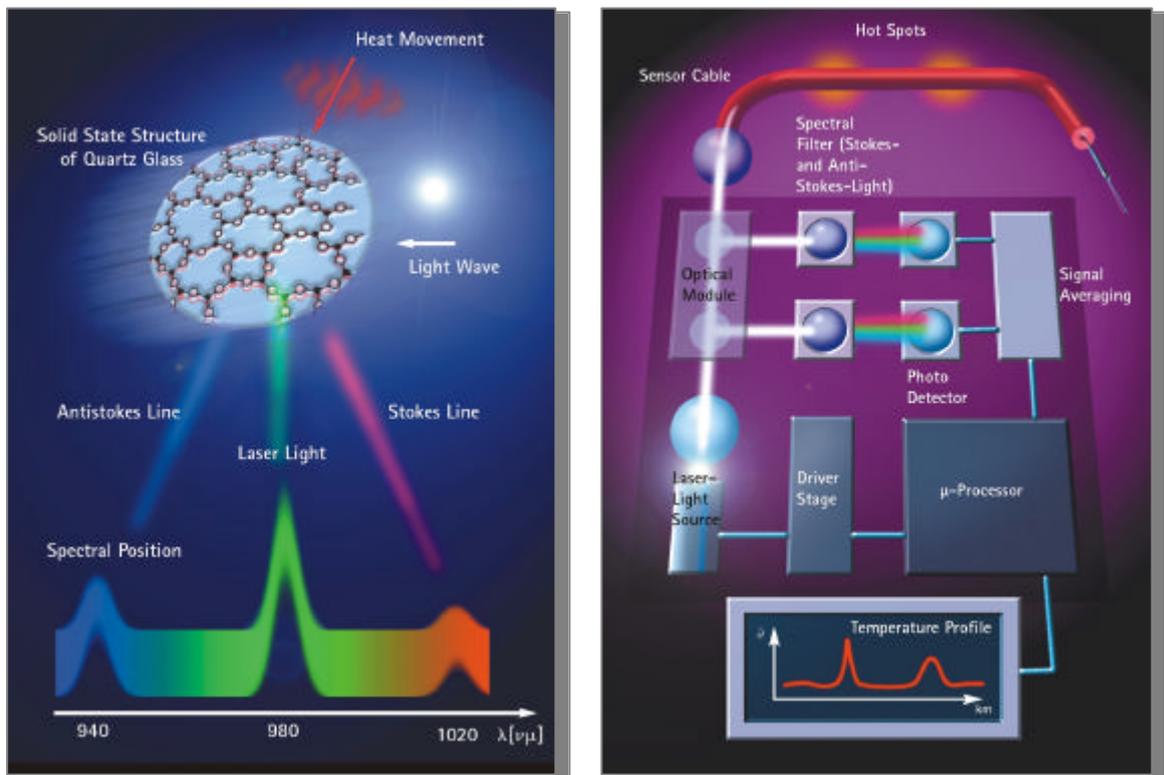


Diagram 3: a) Raman Spectrum,

b) Linear Optical Heat Detector

The unique exclusive features of the OFDR Raman Technique are:

1. Complex measurement of Raman back-scatter light as a function of the laser frequency
2. Calculation of the Raman back-scatter graph using the Fourier transformation rule

3. Use of a clear mathematical mapping rule between frequency and location-space with the option of online disturbance variable correction

In relation to these unique exclusive features of OFDR Raman technology the result is a series of technical and commercial advantages as against OTDR Raman technology which are listed below and briefly elaborated on:

A) Technical Advantages of OFDR Raman as against OTDR Raman Technology:

1. **Higher SNR:** Through the almost continuous-wave operation of the laser and the narrow-band detection of the optical back-scatter signal with OFDR technology a distinctly higher signal-to-noise ratio is achieved than with pulse technology.
2. **Greater Range:** Conditioned by the better SNR achievable distinctly greater ranges may be monitored with the identical fibre-optic type. Without using optical amplifiers with OFDR measured sections exceeding 30km in extent can be monitored [8].
3. **Longer working life of the cw Raman Light Source:** For fibre optic Raman backscatter measurement laser light sources of some 100 milliwatt light output or pulse light sources of some kilowatts output are used. The thermal loading of the laser medium is clearly less with the cw laser and therefore the working life is clearly longer than that of pulsed light sources.
4. **Less interference from optical Fresnel reflections:** The lower optical power of the OFDR laser source (mW instead of kW) clearly reduces the widely known "dead zone" OTDR interference effect of optical overloading of the receiver phase by Fresnel reflections (e.g. in the case of plug-and-socket connectors).
5. **Better local measuring accuracy:** As against the OTDR measuring signal the OFDR measuring signal has a narrower spectral bandwidth. Signal distortions caused by fibre optic dispersion effects are less strongly pronounced so that greater locational accuracy is

achieved.

6. Simple signal averaging technique: With the OFDR method digital signal processors are used to compute the Fourier transformation. The FT algorithm corresponds to a numeric signal averaging which is technically considerably simpler and more elegant as against the OTDR technology electronic boxcar integrators.
7. Application of system theory algorithms to improve signal quality: To improve measuring time and signal quality with OFDR efficient and generally applicable numeric computing algorithms may be used such as for example the FFT averaging method or the window function for noise suppression.
8. Simple online calibration of the fibre optic measuring instrument (frequency calibration): Calibration data (frequency data) can be very simply ascertained on the basis of device-specific frequency and location-space parameters without the need for access to the measuring instrument.
9. Simple automatic recalibration of the fibre optic measuring instrument (field calibration): On the basis of device-specific frequency and location-space parameters correction data (frequency data) can be calculated which make possible precise determination of the spectral attenuation per unit length of the optical fibre. Based on these correction data one achieves a simple automatic recalibration of the fibre optic OFDR measuring instrument (field calibration).

B) Economic Advantages of OFDR Raman as against OTDR Raman Technology:

1. Use of less costly system components: By using semi-conductor laser diode, use of comparatively "slow" electronic modules, application of numeric signal averaging techniques including the option of single-end measurement less costly system components can be used by comparison with OTDR Raman technology.

2. Greater reliability: The OFDR laser light source works in virtual cw mode. The working life, longer than with pulse operation, also means greater reliability of the overall system.
3. Simpler maintenance schedule: Due to the complex OFDR measurement of Raman back-scatter light and the clarity of the Fourier transformation mapping rule between frequency and location-space new possibilities for a simple, automated and field unit calibration of the fibre optic temperature measurement system.

These technical and economic advantages of OFDR Raman technology are countered by the technically difficult measurement of Raman back-scatter light (complex measurement by amount and phase) and expensive signal processing using the FFT calculation with higher linearity demands on electronic modules.

Diagram 3b shows the schematic configuration of the linear optic heat detector. It consists of an evaluation unit including frequency generator, laser, optical module, receiver and microprocessor unit plus a (silica) fibre optic cable as linear temperature sensor.

In accordance with the OFDR method the laser is sine wave modulated within a measuring time interval and chirped into the frequency. The frequency deviation is a direct measure for the locational resolution of the reflectometer. The frequency modulated laser light is launched into the fibre optic (Diagram 3b). At every location along the fibre Raman scatter light is produced which radiates in all spatial directions. A proportion of this Raman scatter light travelling in a reverse direction reaches the evaluator unit. The back-scattered light is spectrally filtered and converted to electrical signals in the measuring channels by means of photodetectors, amplified and electronically processed further. The μ -processor performs the Fourier transformation calculation. As an interim result the Raman back-scatter curves are received as a function of cable length. The amplitudes of the back-scatter curves are proportional to the intensity of prevailing Raman scatter. From the relationship of the back-scatter curves the fibre temperature along the length of the fibre optic cable. The technical specifications of the Raman temperature-sensing system can be optimised in line with the

application by adjustment of unit parameters (range, locational resolution, temperature precision, measuring time etc.). Example: The temperature profile of a 4km fibre optic cable run can be measured to a temperature accuracy of $\pm 2\text{K}$ and a location resolution of 3m in 12 seconds overall measuring time.

The fibre optic cable can similarly be adapted by variations in the respective application configuration. The thermal stability of the glass fibre coating limits the fibre optic cable's maximum temperature range. Standard fibres for information transmission are provided with an acrylic type or UV-hardened coating and are designed for a temperature range up to some 80°C. With for example polyamide glass fibre coatings these can be used up to a maximum of 400°C.



Diagram 4: Sensor cables (standard cables)

For fire monitoring in road tunnels stainless steel tubes are used as the basic element of the sensor cable in which the fibre optic cable is then housed. The stainless steel coating can be adapted to requirement regarding wall thickness (8mm and 5mm external diameter) and choice of coating material (HDPE, HM4) - left side cable sample in Diagram 4). For applications requiring a high degree of mechanical resilience, e.g. fire monitoring in explosion risk areas aluminium or stainless steel armouring can be inserted between the stainless steel tube and the extrusion sheathing (right side cable sample Diagram 4).

For fire advance early warning in cable trays there are more stringent system requirements by comparison with fire monitoring in subterranean tunnels. Consequently both evaluation units and the sensor cable must be further developed and optimised in line with the following aims:

- Greater location resolution ($\leq 0.5\text{m}$, measurement of hotspots with small longitudinal dimensions)
- Reduced evaluation unit measuring times (to meet DIN EN 54 Class 1A)
- More rapid response characteristic in the sensor cable (to meet DIN EN 54 Class 1A)
- Fire detection system multi-channelling (option of simultaneous monitoring of different fire sectors or cable trays)
- Graphic display of temperature occurrences along the length of the cable trays

Diagram 5 shows the fire detection system (radar) and associated fibre optic cable. Vis-à-vis the cable design in Diagram 4 there is a clearly improved heat and radiation sensitivity. In contrast to both standard cables the new cable design has a lower heat capacity, an improved temperature response and a larger effective cross-section.



Diagram 5: Fire detection system and fibre optic cables for fire advance early warning in cable trays.

These characteristics were achieved by a reduction in the cable diameter, insertion of good heat conductors between tube and outer sheathing plus a radiation-absorbing sheath. Comparison of the response characteristic of both fibre optic cables is illustrated in Diagram 6.

A silica glass fibre as a reference point, being the most rapid possible response characteristic of the heat detector is similarly depicted in Diagram 6.

In this trial the cable samples including the bare optical fibre were simultaneously heated in an oven with a maximum temperature gradient of 3K/min. On reaching the maximum permissible temperature of the samples used the cable samples were spontaneously cooled by opening the oven door. In the top curve the hotspots of individual samples over the location range at a point in time. The bottom curve shows the development over time of the respective samples. As expected the bare optical fibre shows a very spontaneous response characteristic and follows the ambient temperature gradient with virtually no time lag. (Diagram 6b top curve). The standard cable responds clearly later, follows the gradient only hesitantly and reaches a maximum temperature of barely 70°C when an ambient temperature of 90°C is reached (Diagram 6b bottom curve). The middle curve in the time lapse clearly shows the successful optimisation of the sensor cable.

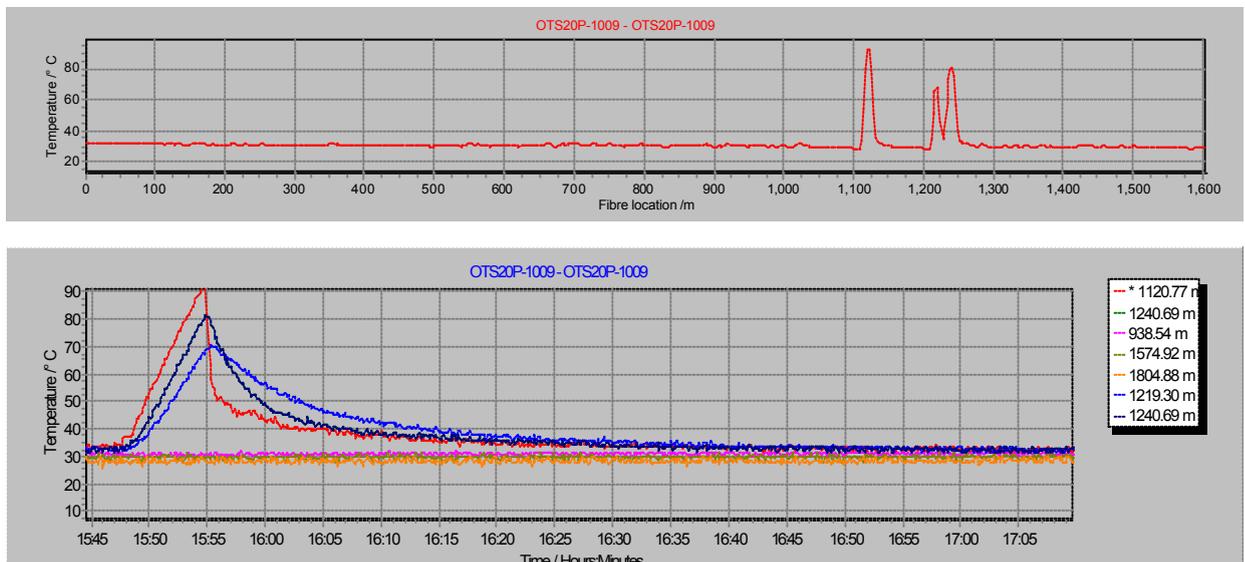


Diagram 6: a) Temperature as Function of location, oven area with three fibre optic sensor runs (1121m), standard cable (1220m) and EN54 cable (1240m)

b) Temperature as function of time, selected points inside and outside the oven

In further series of experiments it was confirmed that with improved cable design the requirements of DIN EN 54 Class A1 are met. DIN EN 54 relates to the response characteristic of point heat detectors. Transferred to the linear optical heat detector this means that with a 2km long sensor run and a location resolution of 0.5m all 4000 of these measuring points meet the requirements of DIN EN 54. Or, expressed differently, the linear optical heat detector is equal in terms of its monitoring function to 4000 point heat detectors.

With the OFDR Raman back scatter method the temperature profile is received as a function of time and cable location. By computer-assisted evaluation of the temporal and spatial temperature variations the fire can be located to one metre accuracy and tracked along the cable tray. Similarly in the temperature pattern the spread of hot fumes can be clearly recognised, so that even fume spread is captured. An example of visual display of a temperature occurrence for building monitoring is shown in Diagram 7.

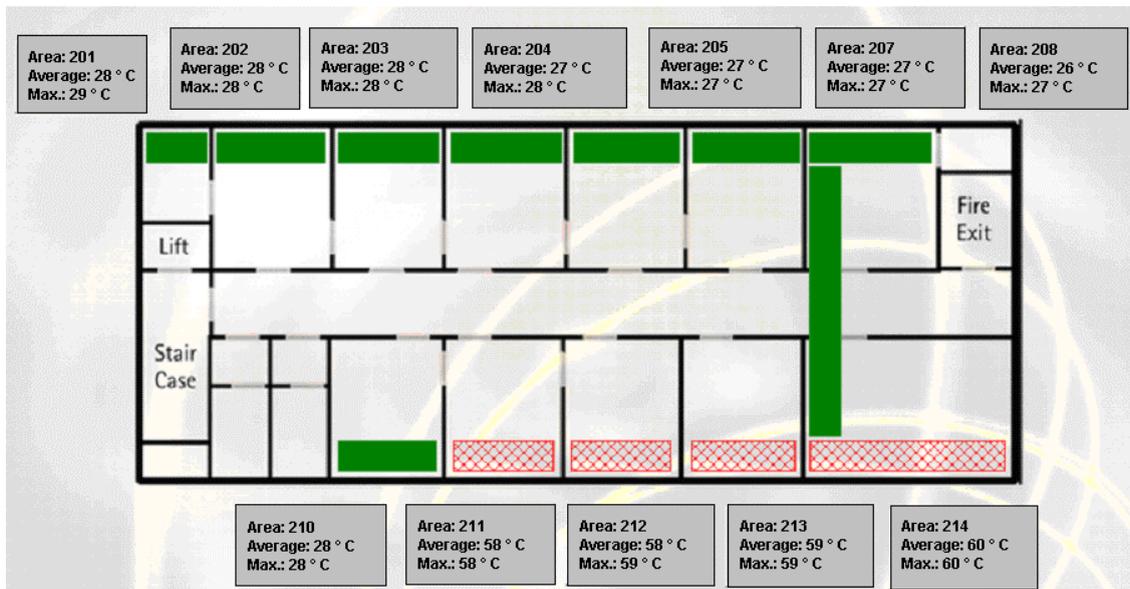


Diagram 7: 2D Visual Display of Temperature Occurrences

The fire detector cable was installed inside the cable duct of one floor. The sections of each office were combined in fire detection groups and the maximum and mean temperature values were calculated. If as the result of a temperature anomaly one of the three detection criteria is triggered there is a change in the colour/structure of the zones concerned. With an evaluation

unit location resolution of 50cm the information density is very high so that the local trigger point and the direction of fire spread can be determined extremely precisely and rapidly.

To conclude the Chapter customer and operator requirements in respect of the linear optical heat detector for fire monitoring in cable trays are listed and broken down by the parameters of fire detector system sensor and evaluation unit, design and cost effectiveness (Table 2). These requirements are set against the LIOS products' technical system characteristics. This presentation may serve as an aid to decision-making in the choice and appraisal of fire detector systems.

Customer and operator requirements	System Requirement / Fire Detector Specifications
<p>Fire detection system (sensor cable):</p> <ul style="list-style-type: none"> - High reliability - Simple installation - Rapid response - Good radiation sensitivity - Simple connection - Long working life - Large temperature measurement range - Long sensor range 	<ul style="list-style-type: none"> Fibre optic in protective tubing with sheath Temperature sensor in the form of a cable Small cable diameter, metal sheath Black radiation-absorbing cable sheath Standard fibre Fibre optic cable with additional length in protective tubing Fibre optic cable with special coating Standard fibre with low attenuation
<p>Fire detection system (evaluation unit):</p> <ul style="list-style-type: none"> - Distributed sensing without gaps - Fire tracking - Redundant design - Great temperature precision - Open system - Autonomous system - Event recorder (black box) - Data archiving - Battery backup 	<ul style="list-style-type: none"> Use of back-scatter method Use of back-scatter method Loop configuration with optical switch Calibratable measurement system, Standard interface with standard protocols µ-processor system EPROM, non-volatile storage µ-processor system DC supply
<p>Design:</p> <ul style="list-style-type: none"> - User-oriented field calibration 	<ul style="list-style-type: none"> Automatic and simple measurement procedure

- User-oriented evaluation	Project oriented parameterisation by PC
- Automatic interactions	Interconnection with conductors (see open system)
- Approved as fire detection system	Classification to DIN EN54
- Simple installation technology	19" rack housing
- Data visual display	Open software package
Cost Effectiveness:	
- Low overall system price	Use of economically priced unit technology
- Low operating and maintenance costs	System-conditioned self-test
- Low installation costs	Economically priced mounting system
- Low repair costs	Established connector technology
- Low consequential costs after damage	Modular design, exchangeable system components

Table 2: Comparison of customer with the fire detection system requirements.

5. Summary and Outlook

Cable systems are increasingly important components in building infrastructure for communications, decentralised data processing and electrical equipment power supply. By laying cables in cable trays increased ease of installation is achieved whilst on the other hand the risk of an undetected cable fire is increased.

By comparison with classical fire monitoring there are more stringent requirements for fire monitoring of cable trays. In the early stage cable overheating (e.g. at cable crossings, damaged insulation etc.) is limited to a very short section of cable (<1m) so that the cable heating is only measurable in the immediate vicinity of the point of damage site. If this increasing overheating is recognised too late cable ignition results and therefore the fire will jump across to neighbouring cables in the tray, this being associated with intense smoke formation. By filling the access routes and the seat of the fire with smoke efficient fire fighting by the fire service is not then possible. Therefore there is a strong interest in locating instances of cable overheating during the build-up phase in order to be in a position to initiate damage limitation measures (e.g. switching off electrical power supply before ignition of the cable takes place so that no risk of smoke formation arises. Since cable trays are lengthy and extensive monitoring objects difficult to access more than a thousand measuring points (detectors) are

needed. No fire detector systems for cable trays are available on the market which meets an optimum asset value and personal protection from economically justifiable points of view.

With the development of heat and radiation sensitive cable designs and further development of the optical OFDR Raman radar measuring method a fire detection system for fire monitoring in cable trays, which meets the requirements of plant operators and rescue service management, has been successfully realised:

- Rapid, reliable sounding in the early stage (if possible prior to pyrolysis)
- Simple installation and low maintenance costs
- Seat of fire location to within one metre with clear correlation within the building
- Information regarding spread of fire and smoke (fire tracking)
- Automatic interactions, e.g. signalling, disconnection of faulty conductors etc.

Highlighted is the important requirement of advance fire recognition. Related to fire detection in cable ducts and false ceilings this means the possibility of recognising cable fires as early as the build-up phase and determining the direction of spread early and with great precision. In the early stage damage limitation measures may be initiated which not only save human lives but also prevent great physical damage and damage by fire-fighting water. In addition to the high information density by comparison with other technologies further advantages of the method are worthy of note, such as simplicity of installation, great range and the maintenance-free sensor cable, which permits laying in areas no longer accessible. Therefore a synergy of largely conflicting aspects has been successfully achieved, in which a high technological demand is combined with economic justifiability.

The unique exclusive features of OFDR Raman technology are the complex measurement of Raman back-scatter light, the calculation of the Raman back-scatter curve from the Fourier transformation of the measurement signal and the application of the mathematical correspondence between frequency and location-space for correction of disturbance

variables.

Compared to OTDR Raman technology OFDR Raman technology possesses the following technical and economic advantages:

- High SNR
- Great range
- Long working life of laser source
- Low interference from optical Fresnel reflections
- Possibility of using algorithm to improve signal quality
- Simple online (frequency) calibration of fibre optic measuring instrument
- Simple recalibration of fibre optic measuring instrument (field calibration)

- Use of economically priced system components
- Greater reliability
- Simplified maintenance schedule.

At present further field trials are taking place with our customers. Under investigation are solution designs regarding the optimum laying of the fibre optic cable in cable trays with a high cable density. A further development objective is technical realisation of a multi-channel optical fire detection system for buildings monitoring in order to cover several fire sectors with a single monitoring system.

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