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Principles of ASA fire-detection technology in data center environments

White paper

Abstract

Today's digital era means organizations rely on data centers and the valuable information they enable and store for all aspects of connected life. The nature of data center operations, power supplies and wiring, however, means they are more prone to fire mishaps, which can have a devastating impact, including downtime, loss of data and equipment, economic losses, and damage to professional reputations. Major fires may be rare, be even minor ones can cause significant disruption.

The primary goal of fire protection programs is to minimize operational interruptions; protect people, property, and data effectively; and to achieve compliance with local, state, and national codes and regulations. Fire detection measures help achieve these goals, and it is essential that a fire is detected as early as possible while virtually eliminating any potential for false alarms.

This paper presents the fundamentals of Siemens' ASA*technology*™ for fire detection. ASA, which stands for Advanced Signal Analysis, is a patented technology that provides reliable, false-alarm resistant fire detection for a wide range of applications.

With ASA*technology*™, two different angles for sensing scattered infrared light allow different fire types to be detected. In the same housing, two temperature sensors and an inclusive carbon monoxide (CO) sensor (in some models) provide signals that can be combined to instantaneously evaluate a fire threat. Signal processing uses real-time fire signature recognition to dynamically adjust the detector response.

This approach equalizes response in detection of both open, flaming fires and smoldering fires while minimizing the effect of nuisance phenomena, which is otherwise only achievable by combining fundamentally different and less environmentally-friendly technologies.

Introduction

For nearly 50 years, scattered-light, or photoelectric, sensing technology for smoke detection has been continuously improved and matured, leading to day's more accurate and reliable detectors. Even so, most of today's scattered-light detectors remain single-sensor, forward-scattering devices. Comparing different products, ranging from inexpensive home detectors to sophisticated, industrial models, reveals that most of these devices have a small, forward-scattering angle in common. This allows strong scattering signals from aerosols to enter the sensing chamber, a cost-effective and robust approach to very early fire detection.

The sensitivity of single-sensor photoelectric detectors is mainly governed by the test fires of applicable standards (ISO, EN, UL, FM, and some national standards). These devices generally share the same physical principle, and the sensitivity of these detectors to nuisance sources such as steam, dust, and non-fire originated aerosols (which may include outside air from economizer operations) depends on the knowledge and inventiveness of the manufacturer. An optimized mechanical design that balances protection from unwanted light of the detecting element and the smoke entry properties requires great expertise and in-depth knowledge of several disciplines, including optics, aerodynamics, and material science.

A single-scattering product derivative of ASA*technology*™ uses both the aforementioned expertise and some of the key ASA-signal processing features, such as median and response time filter, to increase the resilience to nuisance sources. To overcome these physical limitations, multi-sensor and multi-criteria detectors [1] have emerged as more advanced technologies.

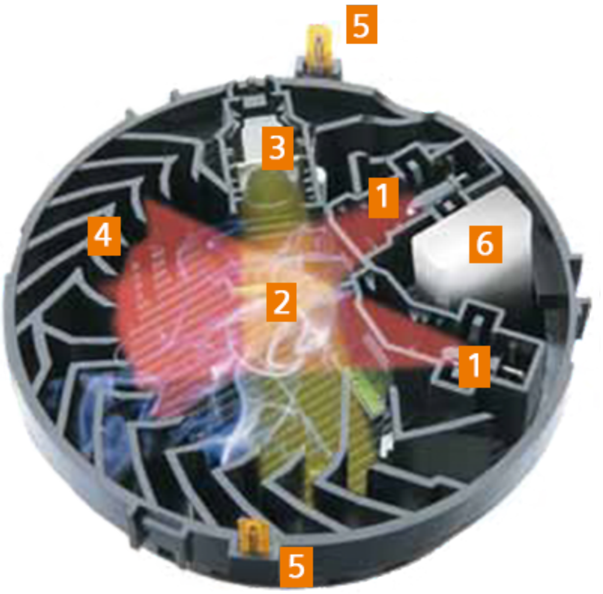

Figure 1: Main sensing components of an ASA detector

Sensor design of an ASA detector

A dual-scattering ASA detector consists of the following sensing components (Figure 1):

1. Two infrared semi-conductor light sources positioned relative to the receiver (3) to obtain a forward-scattering angle of approximately 60 degrees and a backward-scattering angle of approximately 120 degrees.
2. A red cone of light emerging from the two light sources (1).
3. Receiver for infrared light with spatial characteristics indicated in green; these intersect with the light cones (2) and form the scattering volume.
4. Labyrinth or light trap, which suppresses the biasing of the receiver element due to the light not scattered by smoke; labyrinth must be open enough to allow for smoke penetration into the measurement volume and ensure a uniform directional response. This is one of the key detection components [6].
5. Two sensors to measure the temperature of ambient air; these are positioned 180 degrees apart to equalize response to temperature changes, measured in all directions, while also enabling a low-profile detector.
6. CO sensor (in some models) to measure the instantaneous concentration of carbon monoxide in the ambient air; these sensors detect low levels of CO to increase the sensitivity of the detector without increasing the rate of false alarms [7].

Scattered-light sensing with discrimination of fire types

In the 1970s and 80s, there were many reports of and patent applications [8,9] for solutions that used a combination of several scattering angles and/or wavelengths for smoke detection sensitive to different particle sizes, offering a more balanced response to different fire types. The setup of these devices uses "different ratios of scattering at a large to [. . .] a smaller angle for different smoke types possible, and by using an appropriate evaluation circuit" [8] to determine smoke types. "The larger scattering angle can be more than 90 degrees so that one collimator focuses the forward-[scattered] and the other one the backward-scattered light. Thus, a discrimination of strongly-absorbing black smoke from the strongly reflecting white smoke is possible."

However, it took time until reliable and affordable light sources and detection components became available. Here, it is of substantial interest to evaluate the degradation of electro-optical components to predict their detection performance after years of operation and not only at the time of production. It is also important to point out that besides the possibility of cost-efficient assembly, a precise but time-efficient optical calibration had to be developed to realize mass production. The above-mentioned means allow for the product to be used affordably in a wide range of applications, including data center environments.

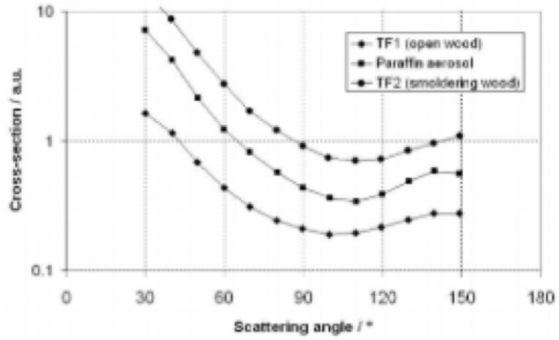

Figure 2: Measured scattering cross-sections of TF1 (flaming wood fire) and TF2 (smoldering wood) test fires after EN54-7 compared with paraffin aerosol as used in the CEN smoke tunnel at a wavelength of 532nm.

Figure 2 illustrates that flaming, open fires, which produce much smaller particles, generate much smaller signals than smoldering fires because the scattered signal amplitude scales very quickly (with the fourth power of particle diameter for the particles much smaller than the wavelength [16]). Furthermore, the ratio of measured differential cross-sections at different scattering angles is different for flaming (TF1) and smoldering fires (TF2).

In a dual scattering system, in order to achieve the desired sensitivity to different fire aerosols, a precise optical calibration (typically better than 10%) is required, but special care must also be taken to match the forward and backward scattering signals together. If the latter is not possible for every detector leaving the production site, then accurate fire-type discrimination cannot be guaranteed in practice.

During the course of smoke development in a fire event, the detector constantly monitors both scattering signals based on the ratio of forward to backward scattering and makes a real-time selection of a suitable linear combination (Equation 1) to achieve an equalized sensitivity to different fire types.

$$S = k_1 \cdot (FW + BW) + k_2 \cdot (FW - BW)$$

Equation 1

The resulting quantity S represents the instantaneous measure of danger originating from particulate smoke. By further suitable weighting of S, different sensitivities for different applications can be achieved with the same detector.

Multi-sensor / multi-criteria detection

The above-described combination of forward and backward scattering signals is combined in ASA detectors with both static and differential temperature measurements. This combination is not new, but in the context of sensitivity to the particle size, it offers additional useful information to both detect fires faster while minimizing nuisance signals.

ASA*technology* uses the concept of signatures, figures of merit that characterize an ongoing fire (or non-fire) event derived from a real-time evaluation of signal characteristics, such as instantaneous amplitude, slope, and short-term variations. The technology then adapts the response time and the detector's sensitivity [18]. Refer to Table 1 for a summary of the most important signatures and their effects.

These features are combined in ASA detectors in different ways; for example, no features for simulation of a simple detector, all features weighed for a faster response, equalized response (faster for flaming, slower for nuisance, very slow or insensitive for nuisances) but within the limits of applicable standards.

In this way, by combining two different temperature values with the optical sensitivity setting for the S in Equation 1 and one of the different feature combinations and several other auxiliary criteria, an application-specific set of parameters can be formed. Intensive testing and field experience made it possible to use fundamentally different combined parameter sets covering various applications.

In certain cases, the definition of the parameter set for an application such as a data center can be achieved by onsite measurements that take into consideration local criteria, including geometry, risk, nuisance sources, value concentration, and danger to people and assets. The resulting defined set of parameters can be downloaded into an ASA detector and is unique to this specific case.

Table 1: Features in an ASA detector

Fire Signature	Characteristics	Typical Result
Smoldering	Detected particles, mainly large	Slower response, may also be a nuisance*
Fire type changes	Fire type was smoldering and changes toward flaming	Faster response*
Flaming	Detected fire type flaming	Faster response
Monotonous rise	Optical signals rise significantly	Faster response
Nuisance patterns	Short-term optical signal variations characteristic for steam, electromagnetic fields, etc.	Slower response
Temperature increase	Temperature rise is significant, indicates open fire	Faster response
Increased CO**	Significant amount of CO present	More sensitive, faster

* Depends on parameter set

** Only at UL detectors

Including a CO sensor signal yield even more advanced fire detection. It allows for both faster fire detection [7] and for adapting the optical sensitivity from very insensitive to very sensitive (Table 1). The CO sensor also allows for life safety applications; by enabling accurate measurements of carbon monoxide in the ambient air, it is possible to provide a separate alarm based only on CO [7].

In addition, by having several sensing elements encased in a single housing, it is possible to create different types of alarms. In the UL-approved optical-thermal CO detector in Figure 3, for example, one device can simultaneously support separate alarming according to UL521 (Alarm Channel 4, heat), UL268 (Alarm source 1, multi-criteria or smoke), and UL2075 (Alarm source 2, CO or Alarm source 3, CO/temperature). In EN-regulated markets, similar detectors are listed according to EN54-7, EN54-5, CEA 4021, and so on.

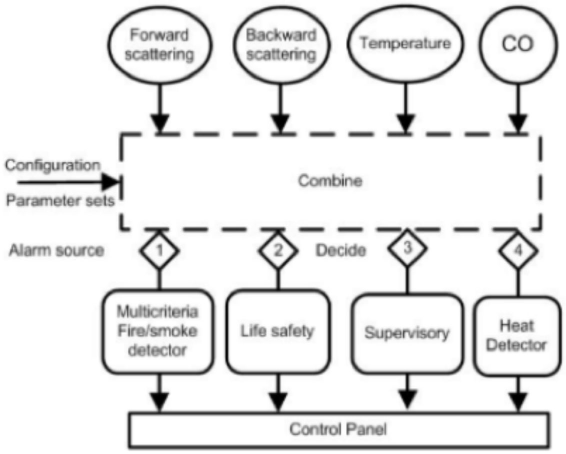

Figure 3: Different alarm channels of ASA detectors (UL version)

Although many common characteristics exist between EN- and UL-based detectors, the standards can still cause significant differences in the detector response. For example, due to the nature of fire tests, the EN54-7 standard allows for generally longer reaction times, but UL268 test fires contain more dynamics and are thus more restrictive, typically requiring 25% shorter reaction time and allowing for smaller variations due to the evaluation of fire signatures.

Another example that also illustrates the limitations of today's fire-detection standards in terms of applicability to new technologies is the comparison of the ASA detector response in the reference sensitivity systems from EN54-7 and UL268 standards. In summary, the CEN smoke tunnel, as defined in EN54-7 uses a poly-disperse aerosol with a maximum of particle mass distribution between 500nm and 1000nm, and with a refractive index of 1.4. Paraffin oil is used for the production of such an aerosol. Additionally, the extinction measurement is performed at 900nm [13].

On the other hand, the smoke box as defined in UL268 uses a cotton lamp wick (or aerosol) that produces particles with a distribution that comprises both very small and larger particles [19] and exhibits a particulate smoke signature of an open fire. The extinction measurement is performed at 530nm [15]. In addition to EN standards, UL268 requires absolute measurements: the detector sensitivity must be within 0.5%/ft and 4%/ft.

Both standards use the same physical quantity to express the sensor sensitivity: extinction in %/ft or %/m (or alternatively dB/m), but due to differences in aerosols and the wavelength the recalculation on a theoretical basis leads to inaccurate results. The measurement remains as the only means for accurate correlation. Due to the sensitivity of ASA detectors to the particle size and absolute limits in UL268, this in turn requires additional means for the control of aerosol stability (both short- and long-term) with respect to its optical properties and leads to difficulties in prediction when new products are developed.

Performance in detection of smoldering and open fires

Today, there is wide discussion on the optimum performance of fire/smoke detectors; in this context, the term "optimum performance" comprises both reliable fire detection and high resistance to false alarms. NFPA has suggested that a combination of ionization and photoelectric, or optical, detectors offers better, more reliable detection and performance [4, 5]. Other authors have proposed further combination with temperature and CO signals as an optimum solution [2,3].

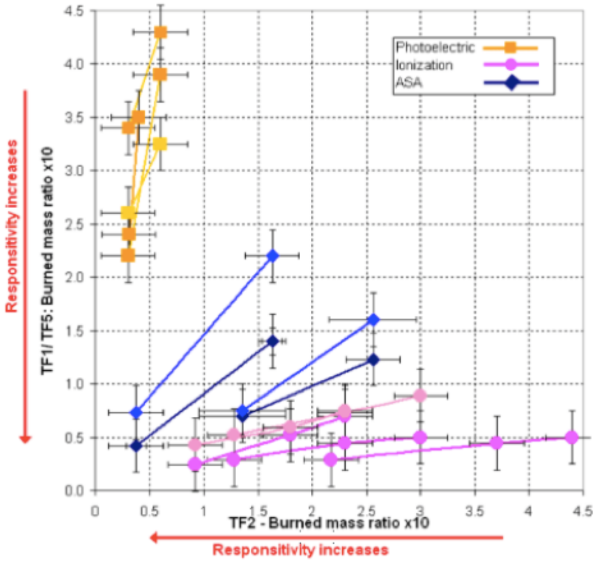

Figure 4: Response of photoelectric, ionization, and ASA detectors to open fires. TF1 (darker) and TF5 (lighter of the two colors) versus smoldering (TF2) expressed in terms of burned mass ratio (x10).

Figure 4 compares various smoke detection technologies: photoelectric (scattering light), ASA*technology* with two scattering-light and two heat sensors (Figure 1, but without the CO sensor), and ionization. The comparison is based on the entire range of applicable sensitivities for the corresponding detector type. The error bars indicate statistical errors for the evaluated samples. Where only a single value is used, an average standard deviation of 0.25 is applied.

The comparison is made between smoldering wood (TF2) on one side, and open flaming (TF5) and open wood (TF1) fires on the other side [14]. The response of the detector is expressed in terms of the ratio of material burned at the moment of detector response (burned mass ratio), normalized to the initial fuel mass. This means that the more sensitive the detector, the less burned mass ratio at the moment of alarm. In Figure 4, 100% burned mass ratio corresponds to 10 units. TF2 and TF5/TF5 have been selected because they represent the limits of particle sizes for EN54-9 test fires.

Figure 4 illustrates the clear distinction between photoelectric and ionization detector response based on their different physical sensing principles. Both of the technologies are predominantly responsive to one of the fire types. It is well known that TF1 represents a challenge for the forward scattering detector, whereas the ionization detector exhibits superior performance. The sensitivity of the ionization detector, however, is rather low. It can be concluded that the combination of photoelectric and ionization detectors undeniably covers a broad spectrum of fire aerosols.

The dual-scattering principle with the aid of heat sensing makes ASA detectors very sensitive in detection of open fires, comparable to the performance of ionization technology. Likewise, ASA detectors share the same basic sensing principle and thus maintain the sensitivity to smoldering fires of single-sensor photoelectric detectors. Thus, their response is equalized over most types of fires, offering optimum detection performance. Furthermore, by selecting application-specific parameters, the response to other phenomena can be actively controlled, for example, movement along the diagonal in Figure 4.

Conclusions

The earlier a fire is detected, the more time there is for extinguishing and evacuation, and less damage can occur. The principal requirement for any fire detection system is early and reliable alarming in the event of a fire, and the earliest possible detection is thus the key to minimizing damage, protecting data center operations and assets, and gaining intervention time:

- All people in the danger zone should be able to safely evacuate.
- Fire control systems can be activated to prevent the spread of fire to more than one sector.
- Response measures can be initiated as early as possible to minimize damage to property and operations.

Optimum fire detection is achieved by combining forward- and backward-scattering principles with heat sensors. That is, these detectors feature a high sensitivity to open, or flaming, fires while maintaining sensitivity to smoldering fires. Furthermore, adding a CO sensor allows for even higher fire sensitivity without increasing the false alarm rate due to nuisance phenomena like dust and steam.

The ASA signal processing based on the reliable sensor signals enables the detector to dynamically adapt and respond to different fire types, different environments, and different application parameters.

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