WHITE PAPER | ALEKSANDAR DURIC | MAY 2021

Principles of ASA fire-detection technology

This paper presents the fundamentals of Siemens **ASA***technology*™ for fire detection.

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ASA stands for Advanced Signal Analysis, a patented technology that provides reliable and false-alarm resistant fire detection for the wide range of applications covered by each detector.

Exploitation of two different angles for sensing of scattered infrared light allows for discrimination of different fire types. In the same housing, two temperature sensors and in a separate product version a CO sensor provide signals that are combined together for evaluation of instantaneous fire threat. Signal processing makes use of real-time recognition of fire signatures that allow for the dynamic adjustment of detector response.

This approach leads to an equalized response in detection of both flaming (open) and smoldering fires, which is otherwise achievable only by combining fundamentally different and less environmental friendly technologies.

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Introduction

Scattered-light sensing for smoke detection is already a mature technology. It has existed for more than 40 years and has been continuously improved, leading to more accurate and more reliable detectors. However, even today, most of scattered-light (photoelectric) detectors are single-sensor forward-scattering devices as they were at the very beginning.

Comparing different products, ranging from inexpensive home detectors to more sophisticated and expensive detectors for industrial applications, shows that they all have a rather small scattering angle in common (forward scattering) which allows for strong scattering signals originating from aerosols entering the sensing chamber. Taking into account that the scattered light produces currents in the order of nA in the input detection stage, it is clear that this approach allows for both a cost effective and an EMC-robust design of photo-amplifiers.

The sensitivity of single-sensor photoelectric detectors is mainly governed by the test fires of applicable standards (ISO, EN, UL, and FM or even national standards). Since they all share the same physical principle, and the sensitivity of these detectors to nuisance sources (steam, dust, generally non-fire originated aerosols) is dependent on the knowledge and inventiveness of the manufacturer. An optimized mechanical design, in which a good compromise between protection from unwanted light of the detecting element and the smoke entry properties is found, requires great expertise and in-depth knowledge of several disciplines, including optics, aerodynamics and material science.

A single-scattering product derivative of **ASA***technology* makes use of both the above mentioned expertise and some of the key ASA signal-processing features (e.g. median and response time filter) [11], in order to increase the resilience to nuisance sources.

In order to overcome the physical limitations described above, approximately two decades ago the combination of different physical principles for sensing of fire phenomena lead to so-called multi-sensor and multi-criteria detectors [1] as more advanced representatives of the species.

Sensor design of an ASA Detector

Judging only by its name, Advanced Signal Analysis, it can be concluded that ASA stands for fire detection algorithms i.e. signal processing only. However, accurate measurement signals from the sensors are pre-requisites for a reliable danger evaluation.

A dual-scattering ASA detector consists of the following sensing components:

1. Two infrared semiconductor light sources positioned relative to the receiver (3) so that a forward scattering angle of approximately 60° degrees and a backward scattering angle of approximately 120° are obtained
2. In Figure 1, the red cone of light emerging from the two sources (1) are shown
3. Receiver for infrared light, with a spatial characteristic indicated in green, which intersects with the light cones from the two sources (2) and forms the so-called scattering volume
4. Labyrinth or light trap, which suppresses the biasing of the receiver element due to the light not scattered by smoke (e.g. external infrared radiation or reflected light from the two sources). The labyrinth must be open enough in order 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 temperature sensors measure the temperature of the ambient air. They are positioned 180° apart from each other allowing for equalized response to temperature changes measured in all directions, allowing at the same time for a low-profile detector.
6. CO sensor (a separate product variant) measures the instantaneous concentration of carbon monoxide in the ambient air, with a sub-ppm resolution. Together with, in terms of mass production, the precise absolute calibration of better than 10%, it allows detection of low levels of CO, increasing the sensitivity of the detector to fire without increasing the rate of false alarms [7].

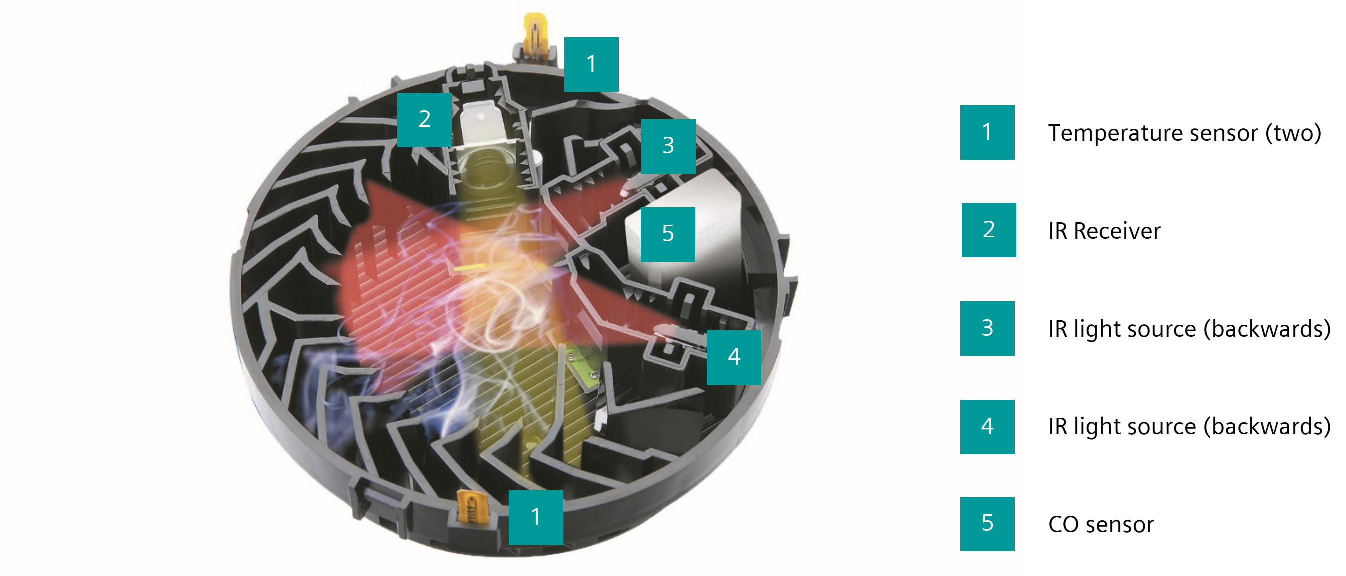

Figure 1: Main sensing components of an ASA Detector

Scattered-light sensing with discrimination of fire types

In the 1970’s and 80’s numerous reports and patent applications (e.g. [8] and [9]) existed offering solutions where a combination of several scattering angles and/or wavelengths was utilized for smoke detection sensitive to different particle sizes, offering a more balanced response to different fire types.

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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, in order 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 in order to realize mass production. The above mentioned means allow for the product to be used for a wide range of applications, affordable and not only for special applications.

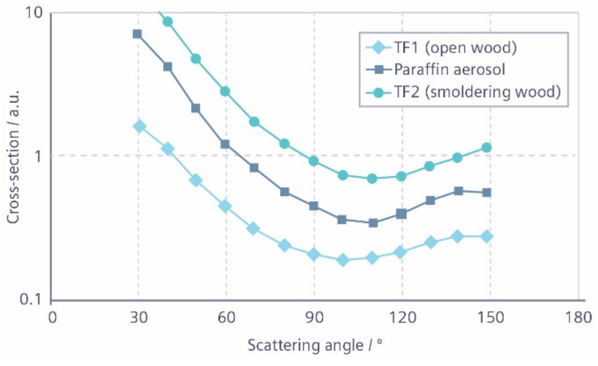

Figure 2: Measured scattering cross-sections of TF1 (flaming wood fire) and TF2 (smoldering wood) test fires after EN54-7 compared with paraffin aerosol as used in the CEN smoke tunnel at a wavelength of 532nm.

The above cited statement from [8] is quantified in Figure 2, which represents a basis for discrimination of different particle sizes, and thus of different smoke types [5, 17].

Figure 2 illustrates that flaming fires like open wood fires, which produce much smaller particles, generate much smaller signals than smoldering fires. This is due to the fact that the scattered signal amplitude scales very quickly (with the 4^{th} power of particle diameter for the particles much smaller than the wavelength [16]). Furthermore, the ratio of measured differential cross-sections (note the logarithmic scale) at different scattering angles, preferably one below 90° (forward) and one above 90° (backward) [8] is different for flaming (TF1) and smoldering fires (TF2).

[1] Translated from German by the author

This fact is used for the design of algorithms that provide recognition of different fire types ([10], [11] and [12]). Although it can be concluded from Figure 2 that the maximum difference in ratios of forward to backward scattering is achieved for smaller forward scattering, our test database showed that in the dual optical detector, the combination of 60° and 120° is a very good compromise in terms of sensitivity to fire aerosols and not too great a sensitivity to nuisance aerosols (mainly large particles).

As already mentioned, in the 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 also special care must be taken to match the forward and backward scattering signals together. If the latter is not possible for each and every detector leaving the production site, then accurate fire-type discrimination can not be guaranteed in the field.

As described in [11] and [12] (the patents that provide a detailed description of ASA signal processing), it follows that during the course of smoke development in a fire event, the detector constantly monitors both scattering signals and based on the ratio of forward to backward scattering signal makes a real-time selection of a suitable linear combination with the general form given in Eq. (1) in order to achieve a more or less equalized sensitivity to different fire types:

$$S = k_1 \cdot (FW + BW) + k_2 \cdot (FW - BW) \quad (1)$$

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

Multi-sensor/multi-criteria detection for a wide range of applications

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 information useful for both faster fire detection and the suppression of nuisance signals.

ASA*technology* makes use of 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, short-term variations, etc. – and dynamically adapts the response time and the sensitivity of the detector [18]. A summary of the most important signatures and their effects is given in Table 1:

Table 1: Features in an ASA Detector

Fire Signature	**Characteristics**	**Typical Result**
Smoldering	Detected particles mainly large	Slower response, it may be also nuisance*
Fire type changes	Fire type was smoldering and changes towards 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 significant, indicates open fire	Faster response
Increased CO**	Significant amount of CO present	More sensitive and faster

*Depends on the parameter set

**Only at UL detectors

These features are combined in ASA detectors in different ways: e.g. no features for simulation of a simple detector, all features weighed for a faster response, equalized response – faster for flaming and slower for nuisance sources, and very slow and/or insensitive for nuisance sources, but still within the limits of applicable standards.

In this way, by combining two different temperature values with the optical sensitivity setting for the S in Eq. 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 many fundamentally different combined parameter sets covering various applications.

In certain cases the definition of the parameter set for a particular application can be achieved by on-site measurements taking into consideration local criteria like room geometry, fire risk, nuisance sources, value concentration or danger to lives. The resulting defined set of parameters can be downloaded into an ASA detector and is unique for this specific case.[2]

The inclusion of a CO-sensor signal, a new sensing criterion, yields even more advanced fire detection. It allows for both faster fire detection (for a more detailed description see [7]) and for adapting the optical sensitivity from very insensitive to very sensitive (Table 1, last row). The CO sensor also allows for a new class of applications – life safety. By having accurate measurements of carbon monoxide in the ambient air, it is possible to provide a separate alarm based on CO only [7].

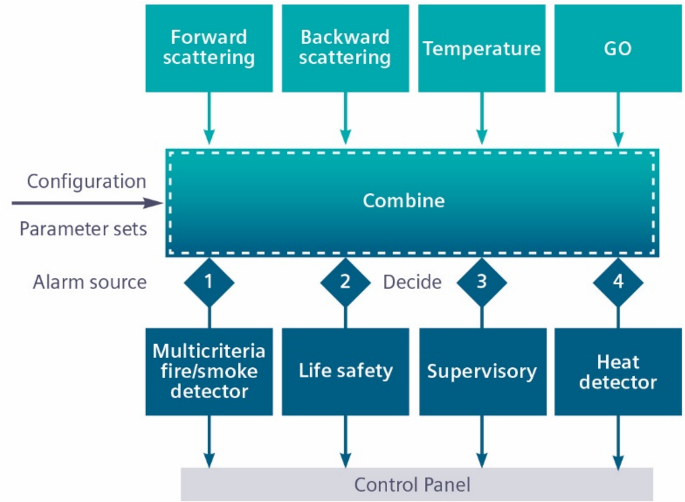

Figure 3: Different alarm channels of ASA detectors (UL version)

Additionally, by having several sensing elements it is possible to create different types of alarms, based on single sensor signals accommodated in the same housing and thus integrate different detectors in one. In the UL-approved optical-thermal-CO detector, one detector simultaneously supports separate alarming according to UL521 (Alarm Channel 4, heat), UL268 (Alarm source 1, multi-criteria or smoke) and UL2075 (Alarm source 2, CO) or Supervisory (alarm source 3, CO/temperature). In EN-regulated markets, similar detectors are listed according to EN54-7, EN54-5, CEA 4021 etc.

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 and require typically a 25% shorter reaction time and allow for a smaller variation 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 a comparison of the ASA detector response in the reference sensitivity measurement 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 alternatively aerosol), which produces particles with a distribution that comprises both, very small particles, but also 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 detector 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. This in turn requires, due to the before described sensitivity of ASA detectors to the particle size and absolute limits in UL268, 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.

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[2] This feature is available on the detector level and is under development on the system level. For the approval (listing) conformity of these parameter sets, an individual analysis is necessary.

Performance in detection of smoldering and open fires

Today there is wide discussion on optimum performance of fire (smoke) detectors. In this context, the term "optimum performance" comprises reliable fire detection and at the same time high resistance to false alarms.

NFPA has suggested that a combination of ionization and photoelectric (optical) detectors offers better performance in terms of reliable smoke detection: "Typically, dual alarms respond before ionization alarms in smoldering fires and before photoelectric alarms in flaming fires." ([4] and [5]). Other authors ([2] and [3]) have proposed further combination with temperature and CO signals as an optimum solution additionally considering the aspect of false-alarm resistance.

Figure 4 shows a comparison of two single-sensor smoke detection technologies: photoelectric (scattering light) with two scattering-light and two heat sensors (compared with Figure 1, without CO sensor). The comparison is based on the whole 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 burned mass ratio (ratio of material burned at the moment of detector response), normalized to the initial fuel mass. This means, the more sensitive the detector, the less the burned mass ratio (in Figure 4, 100% burned mass ratio corresponds to 10 units) at the moment of alarm. TF2 and TF1/TF5 have been selected, since they represent the limits of particle sizes of EN54-9 test fires.

Figure 4 illustrates that there is a clear distinction between photoelectric and ionization detector response, which is 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 standard forward scattering detector, whereas the ionization detector exhibits a superior performance. However, the sensitivity of the ionization detector to smoldering fires is rather low. TF1 is introduced again as the mandatory test in the upcoming EN standards for multi-criteria detectors (e.g. 54-29 and -31). It can be concluded that the combination of single scattering photoelectric and ionization detectors undeniably covers a very 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 a most types of fires offering optimum detection performance. Furthermore, by selecting the application specific parameters, the response to other phenomena can be actively controlled (e.g. movement along the diagonal in Figure 4).

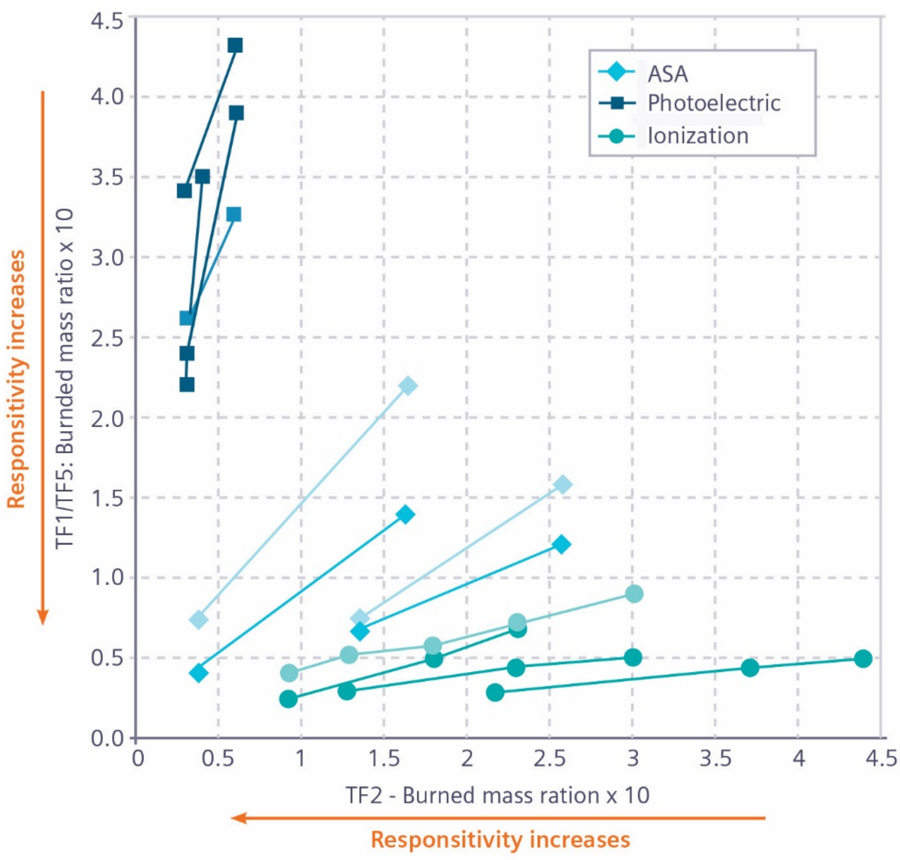

Figure 4: Response of photoelectric, ionization and ASA detectors to open fires: TF1 (darker) and TF5 (lighter of the two colors) versus smoldering (TF2) expressed in terms of burned mass ratio (x10).

Conclusions

In this paper, basic principles underlying the **ASA***technology* for fire detection are presented, with the focus on the exploitation of forward and backward sensing principles and their performance at detecting different fire types.

By combining them with heat sensors a high sensitivity to open (flaming) fires is achieved, at the same time maintaining the sensitivity to smoldering fires due to the scattering light sensing principle. In this way optimum fire detection is achieved. Furthermore, in a separate product variant a CO sensor allows 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 dynamic and adaptive response of the detector to different fire types but also to different environments and application cases.

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Published by
Siemens Switzerland Ltd

Smart Infrastructure
Global Headquarters
Theilerstrasse 1a
6300 Zug
Switzerland
Tel +41 58 724 24 24

For the U.S. published by
Siemens Industry Inc.

100 Technology Drive
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United States

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