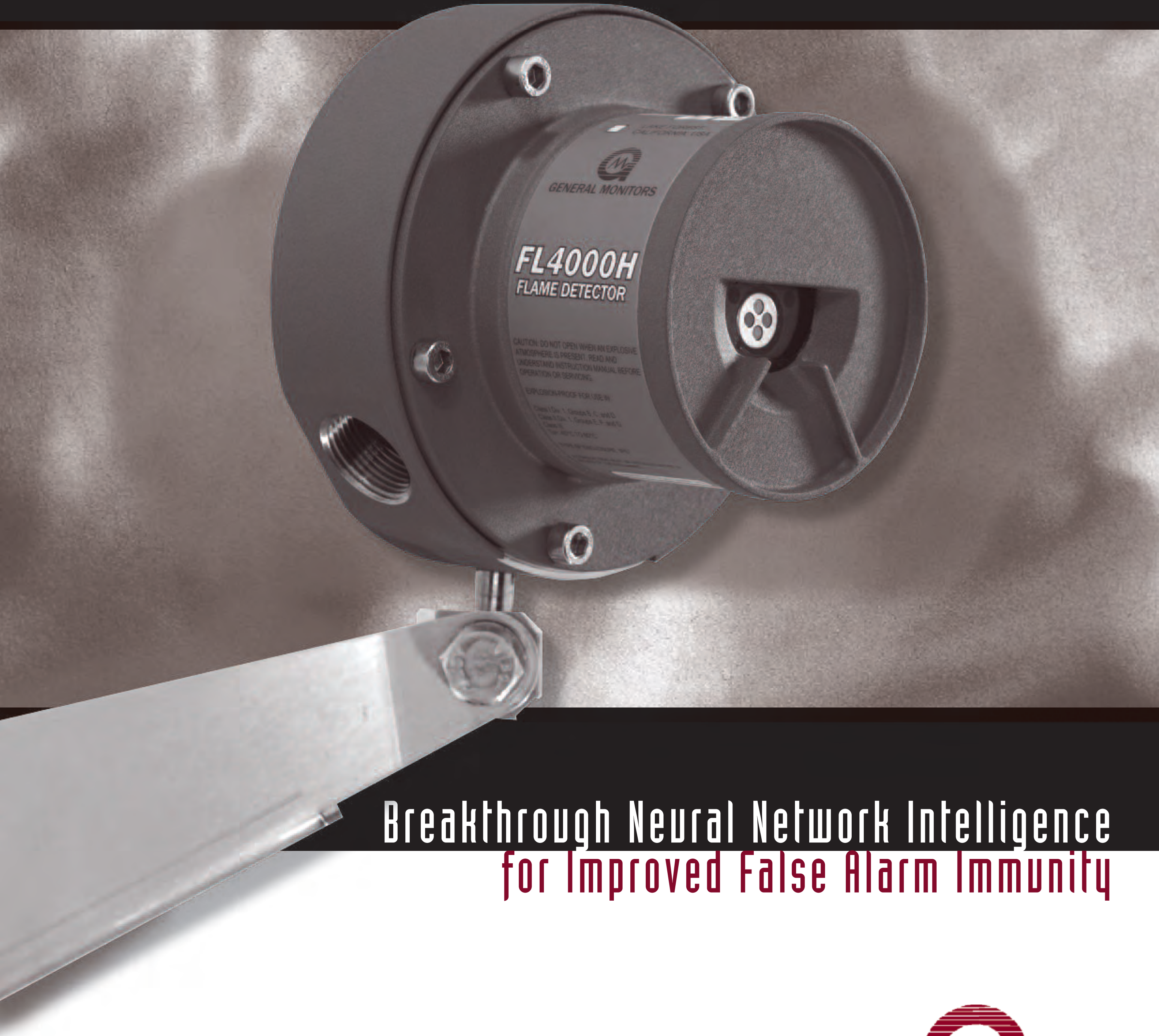
Applying Neural Network Technology to the Next Generation Flame Detector



Breakthrough Neural Network Intelligence for Improved False Alarm Immunity

GENERAL MONITORS

Protection for life.



Innovative Technology for Superior False Alarm Immunity

Accurate and reliable industrial flame monitoring has always represented a technical challenge. The main flame monitoring concern lies in the requirement to differentiate spectral radiation emitted by flames from that of background radiation, which is always present in the industrial environment. Insufficient differentiation of flames from background sources typically causes the highly undesirable condition of false alarm. When a false alarm condition occurs, it activates automated fire suppression equipment, causes operational interrupts, consumes extinguishing materials, and requires resolution of the alarm condition, which can include a complete system shutdown and restart.

[Insufficient differentiation of flames from background sources typically causes the highly undesirable condition of false alarm.]

Until recently, the state-of-the-art in optical flame detection was based on multi-spectral detection integrated with an expert signal processing system. This expert system is typically based on a fixed set of conditions derived from the spectral analysis of a selected group of flames and programmed into computer logic. With proper installation, these types of instruments fulfill basic flame detection requirements, however, they are prone to generate false alarms if exposed to adverse environmental conditions such as reflected light, welding, hot piping, movement of human operators, machinery, and others.

The development of Neural Network Technology (NNT) for multi-spectral optical flame detectors by General Monitors helps to resolve the problems described above. NNT is based on artificial neural networks (ANN), mathematical models of biological neurons in the human brain, which establish correlation between given signal patterns and target conditions. Combined with a multi-spectral optical sensor and implemented in software, neural network serves as an adaptive and intuitive decision mechanism with boundless optimization capability.

In the past decade, ANN has become a proven design technology applied to diverse industries such as automotive, aerospace, finance and industrial controls. In application to flame detection systems, the ability of neural networks to classify information from optical sensors contributes to increased flame detection range, greater field of view, and increased false alarm immunity in various adverse environments.

This ultimately helps plant managers, engineers and technicians to reduce operating costs by providing superior performance and reliable flame detection to protect lives.

With a next-generation multi-spectral infrared flame sensor that incorporates neural network technology, the new FL4000H Intelligent Multi-Spectral IR Flame Detection System from General Monitors offers the industry a new standard for performance, reliability and value that gives process and plant engineers a potent new tool in protecting people, equipment and facilities from dangerous hydrocarbon flame sources. The FL4000H is the industry's first flame detection system to combine precision multi-spectral IR (MSIR) flame sensing technology with highly intelligent neural network processors. The result is a breakthrough flame detector that provides the industry's most reliable discrimination between actual flames and nuisance false alarm sources, such as arc welding, hot objects, reflected sunlight and more.

Flame Detection Applications and Technologies

Engineers in a wide range of hazardous process and manufacturing industries, as well as government and institutional facilities, require continuous flame monitoring equipment to prevent catastrophic fires that endanger employees, equipment, infrastructure and surrounding communities.

Typical Applications

The range of potential flammable hazards is expansive and growing as materials and processes become more complex. Increasingly sophisticated flame sensing technologies with embedded intelligence are required to reliably detect the most common potential ignition sources:

> Alcohols	> Kerosene	> LNG/LPG
> Chemicals	> Jet Fuels	> Paper/Wood
> Diesel	> Hydrogen	> Textiles
> Gasoline	> n-Heptane	> Solvents

Some of the most challenging industrial environments for flame detection include:

> Automotive	> Oil/Gas Refineries
> Aerospace	> Pharmaceuticals
> Chemical Plants	> Textiles
> Power Generation	> Warehouses
> Food/Beverage	> Wood & Paper Plants
> Oil/Gas Production	> Oil/Gas Distribution

Flame Sensing Technologies

There are five primary optical flame-sensing technologies in use today: ultraviolet (UV), ultraviolet/infrared (UV/IR), dual infrared (IR^2), triple infrared (IR^3), and IR/Closed-Circuit Television (CCTV). They are all based on line-of-sight detection of radiation emitted in the UV and IR spectral bands by flames (please see Figure 1). Depending on the specific flame monitoring application and the requirements for detection range, field of view (FOV), response time and false alarm immunity to various sources, one of these technologies is selected.

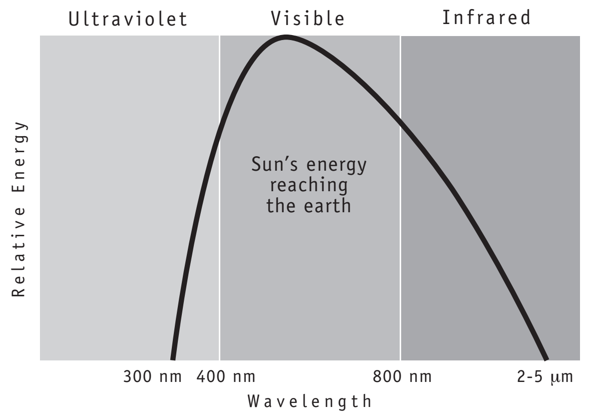


Figure 1: Emission Energy Spectrum

UV Technology

UV detectors respond to radiation in the UV region of approximately 180-260 nanometers. UV flame detectors operate at relatively high speed with good sensitivity up to 50 feet from the flame source. These detectors are best suited for indoor use and are unaffected by sunlight (solar blind) and hot objects. They are, however, vulnerable to false alarms triggered by other UV sources such as: arc welding, lightning, halogen lamps and electrical sparks. Thick smoke and /or grease build-up on the sensor window can also cause failures due to attenuation of the incident UV radiation. Their cost is relatively low compared to other types of flame detectors.

UV/IR Technology

When a UV optical sensor is integrated with an IR sensor, a dual band detector is created which is sensitive to both UV and IR radiation emitted by a flame. The combined UV/IR flame detector offers increased immunity over the UV detector. UV/ IR flame detectors, when combined with flicker discrimination circuitry, reduce the possibility of false alarms caused by arc welding, lightning, sunlight and hot objects. They operate at moderate speed, are suited for both indoor and outdoor use up to 50 feet from the flame source, but are affected by thick smoke and grease deposits on the detector window. Cost is moderate as compared to other flame detector types.

Infrared Technologies

Dual and triple IR flame detectors use multiple infrared spectral regions to further improve differentiation of flame sources from non-flame background radiation. Both types of IR flame detectors are well suited to locations where combustion sources produce particularly smoky fires. These flame detectors operate at moderate speed with a range of up to 200 feet from the flame source -- both indoors and outdoors. These instruments exhibit relatively high immunity to infrared radiation produced by arc welding, lightning, sunlight and other hot objects that might be encountered in industrial backgrounds. Their cost is high relative to other types of flame detectors.

CCTV/IR^3 Technologies

CCTV/IR^3 flame detectors combine three IR sensors covering multiple infrared spectral regions with video cameras. These devices have the same benefits as IR^3 detectors, but also include viewing capabilities. The addition of video allows operators to monitor areas remotely for fire and to checkout alarms prior to determining the best response. Their cost is higher relative to other flame detector types.

The detection range of the infrared detectors is up to 200 feet from the flame source; however, the video camera coverage is typically less than the full infrared detection range. The operating temperature range for the video camera is narrower than for the IR3 detector array.

Flame Detection Performance Requirements

When configuring a flame detection system for a plant and evaluating the various flame detection technology alternatives available today on the market, the following flame detector performance criteria should be considered relative to plant and regulatory requirements:

- **>** False Alarm Immunity
- **>** Detection Range
- **>** Response Time
- **>** Field of View (FOV)
- **>** Operating Temperature Range
- **>** Communication Capabilities
- **>** Self Diagnostics (COPM)

False Alarm Immunity

Once the performance requirements for a flame detector have been determined based on the assessment of potential combustion sources, the next important consideration is false alarm immunity. False alarms are more than a nuisance -- they are both a productivity and cost issue. It is essential that flame detectors discriminate between actual flames and radiation from sunlight, lightning, arc welding, hot objects and other non-flame sources.

> **False alarms are more than a nuisance -- they are both a productivity and cost issue.**

From the perspective of productivity alone, a false alarm incident in most process control and manufacturing industries requires a system shut-down, probable evacuation and investigation. Turning off and then re-starting a process control or manufacturing line may take anywhere from an hour to a whole shift or longer, especially if there are complex material, batching or quality requirements and/or environmental regulatory reporting requirements to consider.

When we think about productivity loss, we generally think about down time first and then the associated costs. False alarms drain labor productivity, and start with emergency responders and worker downtime. They often require investigations, written reports and discussions with regulatory agencies. Beyond the cost of labor, false alarms often trigger automated fire suppression systems: there is the replacement cost for extinguishing agents to consider, the costs of materials lost within a process batch or on a manufacturing line are real as well. Deliveries can be delayed and customers can be annoyed.

Reliable discrimination between actual flames and ordinary environmental and normal plant activities is essential. Today's best UV/IR and MSIR detectors reduce the possibility of false alarms from typical environmental and plant sources. They do, however, have some well-known limitations and they are not foolproof by any means.

Until now, plant engineers facing persistent false alarm problems have had to choose between accepting the cost of false alarms, changing the process or installing complex redundant flame detection systems at a high cost and with high maintenance requirements. There had to be a better solution to false alarms.

Detection Range and Response Time

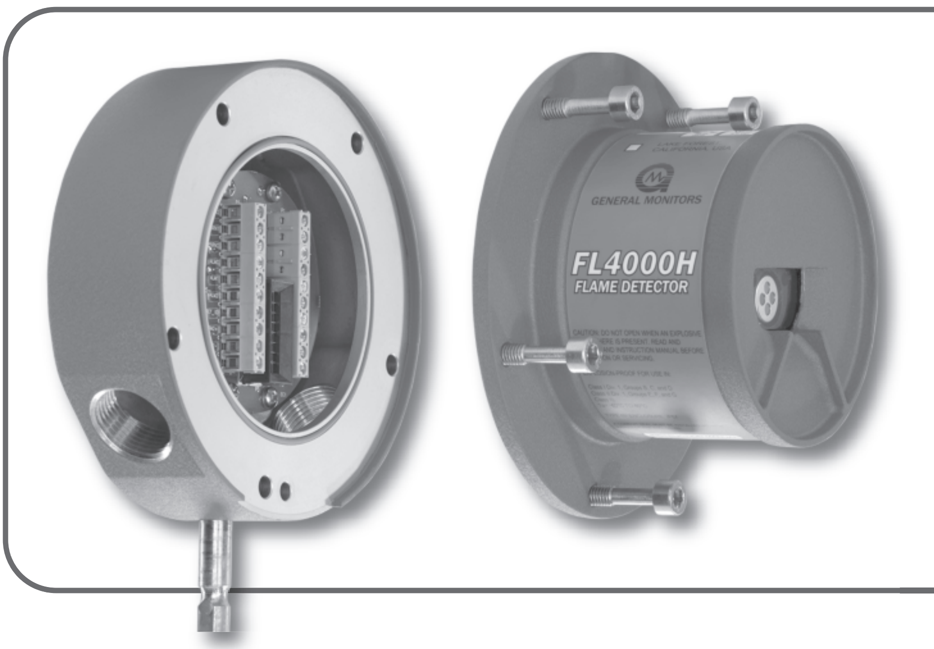
The most basic performance criteria are detection range and the response time provided by the various flame detector technologies. Depending on a specific plant application environment, each of the alternative flame detection technologies will recognize a flame to a maximum distance with a response time dependent on the sensing technology. The greater the distance and the shorter the time that a given flame sensing technology requires to detect a flame, then the better the technology is in providing for advance flame warning.

Field Of View (FOV)

In addition to the detection range, the flame detector's field of view is typically proportional to the effective range of the detection distance. For example, the most common types of optical flame detectors have a 90 to 120 degree field of view. One might think that the wider the FOV, the larger the area and volume of effective coverage. That is not necessarily the case, as a wider field of view can limit the maximum detection distance. For this reason, it is often necessary to place flame detectors at the corners of buildings or aligned in a series with overlapping coverage to achieve the required coverage.

Self Diagnostics

To meet the highest reliability standards, continuous optical path monitoring (COPM) diagnostics are often built into optical flame detectors, as is the case with those manufactured by General Monitors. The self-check procedure is designed to ensure that the optical path is clear, the detectors are functioning and additionally, the electronic circuitry is operational. Self-check routines are programmed into the flame detector's control circuitry to activate about once every minute. If the same fault occurs twice in a row, then a fault is indicated via the 0-20 mA output, and also initiated over the RS-485 serial communication link and processed via a Modbus or HART operator interface system to alert the maintenance staff.



Operating Temperature Range

In today's rigorous process and manufacturing industries, optical flame detectors need to operate over a wide temperature range. For example, flame detectors on Alaskan drilling rigs and North Sea offshore platforms must be able to withstand extremely low temperatures down to -40°F (-40°C). Oil and gas refining facilities in the Middle East and plants in the steel manufacturing industry have the opposite problem -- temperatures can reach to 176°F (80°C). In addition to extreme temperatures, flame detectors must support explosion-proof requirements, as well as operating in high humidity, harsh marine and other rugged environments.

Communication Interface

With advanced automation introducing increasingly intelligent process control and manufacturing systems, flame detectors not only need built-in embedded microprocessor-based intelligence -- they must also be able to communicate effectively. At a minimum, a 0-20 mA analog output is required for remote alarm and fault indication, as well as a RS-485 serial communication link that is Modbus or HART RTU compatible to network multiple detectors for the protection of larger areas and for communication with distributed (DCS), programmable logic (PLC) or PC-based control systems with operator interfaces for alarm conditions.

MSIR / NNT Multi-Spectral Infrared Flame Detection Using Neural Network Technology

The popularity of optical IR flame detectors is dictated by the fixed emission wavelengths of hydrocarbon flames in the infrared spectrum, which can be separated from most non-flame sources and analyzed in various domains. Classical optical hydrocarbon flame detectors are based on an expert system, where analog signals are collected from the optical sensors, converted into digital format, processed, and an output decision is reported on the presence of flame or lack thereof.

Although simple in appearance, the described model of flame detection becomes more complex when dealing with infrared data from real industrial environments. Infrared signals at flame emission wavelengths can be easily generated by a random motion, modulation of heated surfaces, hot air flow, arc welding, reflection off water surfaces, and other non-flame related environmental nuisance.

Optical flame detection manufacturers have attempted to resolve this problem by using multiple sensors, each at a different wavelength. In addition to wavelength discrimination via use of multiple sensors, most optical detectors measure the temporal characteristics of the signal, thereby analyzing the flame flicker properties. Various signal-processing techniques such as correlation, taking ratios, frequency analysis, periodicity check, and threshold crossing are used in industrial flame detection to discriminate flames from non-flames.

The apparent difficulty of linear separation of flames from non-flame sources drives the usage of more sensors at a variety of wavelengths. In practice, this solution is very laborious and difficult to implement as an expert system. So, there arises an interest in non-linear classification methods, in particular, artificial neural networks to discriminate between radiation from flame and non-flame sources of radiation.
Neural network technology (NNT) is used for analyzing data when mathematical relationships between the inputs and the outputs of a system are not easily derivable. We call the application of NNT with multiple infrared sensors at different wavelengths MSIR/NNT flame detection.

Neural network processing involves training and classification phases. In the training phase, collected signals of interest are pre-processed using time and/or frequency analysis (Fourier Transform, Wavelets, etc.), and the resulting data is used for training the neural network with known targets. A recursive training algorithm generates a set of neuron connection weights to be used for classification. In the classification phase, the same form of pre-processing is applied to the signal for input into the trained neural network algorithm. After neural network processing, a decision is matched to a certain target. The advantage of neural network processing over expert systems is the fact that the increased ability of classification does not make the classification algorithm more complex. It only involves more training outside the classification system, on a separate workstation, to improve constant connection weights. This advantage is particularly important in an embedded system, where performance of the application is dependent on a fixed set of neural network connection weights, and not on the complexity of algorithmic implementation.

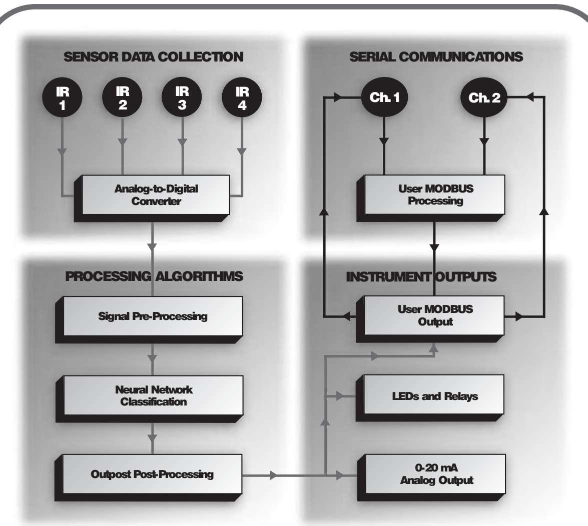


Figure 2: MSIR/NNT Flame Detector Model

Signals coming from sensors at various spectral wavelengths are converted into digital format and pre-processed to extract time and frequency information. This information is then processed by the neural network algorithm, which classifies it as being emitted from flame or non-flame source. Further processing is applied to the output of the neural network to report the instrument's decision via HART, MODBUS, 0-20 mA analog output, LEDs and relays.

FL4000H: General Monitors' Next Generation Flame Detector

The Model FL4000H, General Monitors' next generation flame detector, is designed to provide superior false alarm immunity while also providing the broadest detection coverage area. The horizontal field-of-view

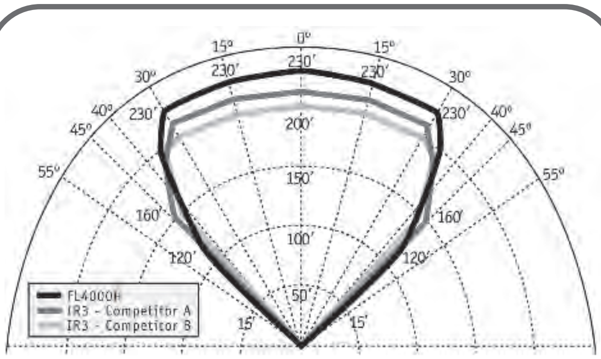


Figure 3: FL4000H vs. FOV of Competitors' Products.

comparison of the FL4000H vs. competitive technologies is presented in Figure 3 above for the high sensitivity setting. The FL4000H provides a longer range of flame detection (230 feet) while maintaining a wide field of view. Table 1 shows the FL4000H's field of view at various distances. The FL4000H offers the largest angular coverage at the longest detection distance amongst flame detectors within the marketplace.

Detection Distance*	Max. FOV
230 ft	60°
120 ft	90°
50 ft	100°

Table 1: Field of View vs. Detection Distances

The advanced MSIR/NNT sensing system is highly immune to false alarms caused by lightning, arc-welding, hot objects, and other sources of radiation. In addition, the MSIR/NNT flame detector can see through dense smoke created by fires such as those from diesel, rubber, and plastics. The FL4000H is a highly discriminating multi-spectral IR flame detector, which makes use of infrared detectors covering different IR spectrum wavelengths and characteristics. With its highly reliable NNT flame discrimination algorithm, it classifies the output signals from the detector as either flame or non-flame. This combination of MSIR sensor package with NNT provides a flame detection system that is highly immune to false alarms. The MSIR/NNT-based FL4000H has a flame detection range of 230 ft. yet provides far superior false alarm immunity, for example, to arc welding, see Table 2.

Technology Distance	Detection Range*	Immunity Distance
FL4000H (MSIR)	230 ft	> 10 ft
IR^3 (Competitor A)	210 ft	>40 ft
IR^3 (Competitor B)	200 ft	>40 ft

Table 2: Arc Welding Immunity Comparison

For applications that do not require long range flame detection, the FL4000H can be used with medium or low sensitivity settings. Reducing sensitivity may also prevent the flame detector from responding to controlled flame sources outside the area that is being monitored. Figure 4 shows the detection coverage of the FL4000H as a function of sensitivity setting. Note that the field of view is not compromised by choice of sensitivity. Additionally, the application of NNT enables the FL4000H to detect large flames or close-by flames that fill the entire field of view of the detector.

*Measured with a standard n-heptane fire in a 1 sq. ft pan at high sensitivity.

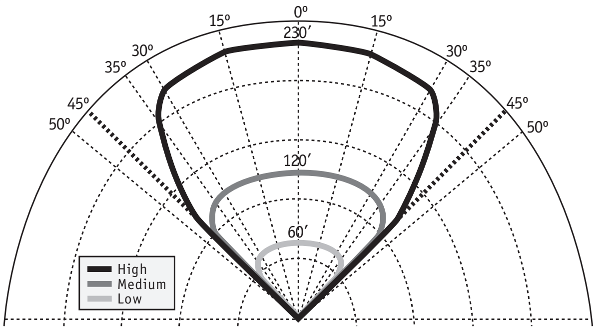


Figure 4: FL4000H detection coverage for three sensitivities

MSIR/NNT optical flame detection also allows the user to customize the detector to ignore difficult-to-recognize facility-specific false alarm sources. Often the unique design of a company's proprietary process or assembly line creates flame false alarm sources. In such situations the characteristics can be programmed into the detector as known nuisance sources (utilizing the MSIR/NNT algorithms) to be ignored by the flame detector. Large companies with multiple facilities relying on standardized plant designs can then replicate the lessons learned at a single facility to all their installations. This adaptive learning capability further enhances the false alarm discrimination and widens the applications for the MSIR/NNT.

Built-in COPM (Continuous Optical Path Monitoring) self-diagnostic circuitry in the FL4000H checks both the optical path integrity (window cleanliness) and the detector's electronic circuitry once every two minutes. Serial communication ports designed into the instrument allow 128 units (247 units using repeaters) to be linked up to a host computer using the RTU or HART protocol. The communication registers provide alarm status, fault and other information for operation, trouble-shooting or programming the unit. The electronics are integral within an explosion-proof stainless steel housing, allowing detector information to be processed at the point of detection.

Conclusion

Neural network technology is a proven solution across a wide range of industries. When NNT is combined with a multi-spectral optical IR sensor package, the resulting MSIR/NNT technology becomes a powerful next generation solution for flame detection with distinct advantages over the various UV, UV/IR, and IR flame detection devices on the market today.

MSIR/NNT flame detectors, with their custom programming capabilities, also represent a highly productive and cost-effective solution to persistent nuisance alarm sources. They can be programmed to recognize and ignore the footprints of such false alarm sources. This knowledge can be easily replicated in flame detection systems supporting large plant or standardized multi-plant operations.

The Model FL4000H Flame Detector extends the performance parameters of existing optical flame detectors in terms of distance, field of view, accuracy and false alarm immunity. These advantages, in many applications, will reduce the number of detectors necessary for optimum coverage, thus cutting total installation cost while still providing superior performance and protection from false alarms.

26776 Simpatica Circle
Lake Forest, California USA 92630
Phone: +1-949-581-4464 or +1-866-686-0741
Fax: +1-949- 581-1151
Email: info@generalmonitors.com

9776 Whithorn Drive
Houston, Texas USA 77095
Phone: +1-281-855-6000
Fax: +1-281-855-3290
Email: gmhou@generalmonitors.com

Ballybrit Business Park
Galway, Republic of Ireland
Phone: +353-91-751175
Fax: +353-91-751317
Email: info@gmil.ie

P.O. Box 61209
Jebel Ali, Dubai
United Arab Emirates
Phone: +971-4-8143814
Fax: +971-4-8857587
Email: gmme@generalmonitors.ae

Block 5, Amk Tech II, #05-20/22/23
Ang Mo Kio Industrial Park 2A
Singapore 567760
Phone: +65-6-748-3488
Fax: +65-6-748-3488
Email: genmon@gmpacifica.com.sg

Heather Close
Lyme Green Business Park
Macclesfield, Cheshire
United Kingdom, SK11 0LR
Phone: +44-1625-619-583
Fax: +44-1625-619-098
Email: info@generalmonitors.co.uk

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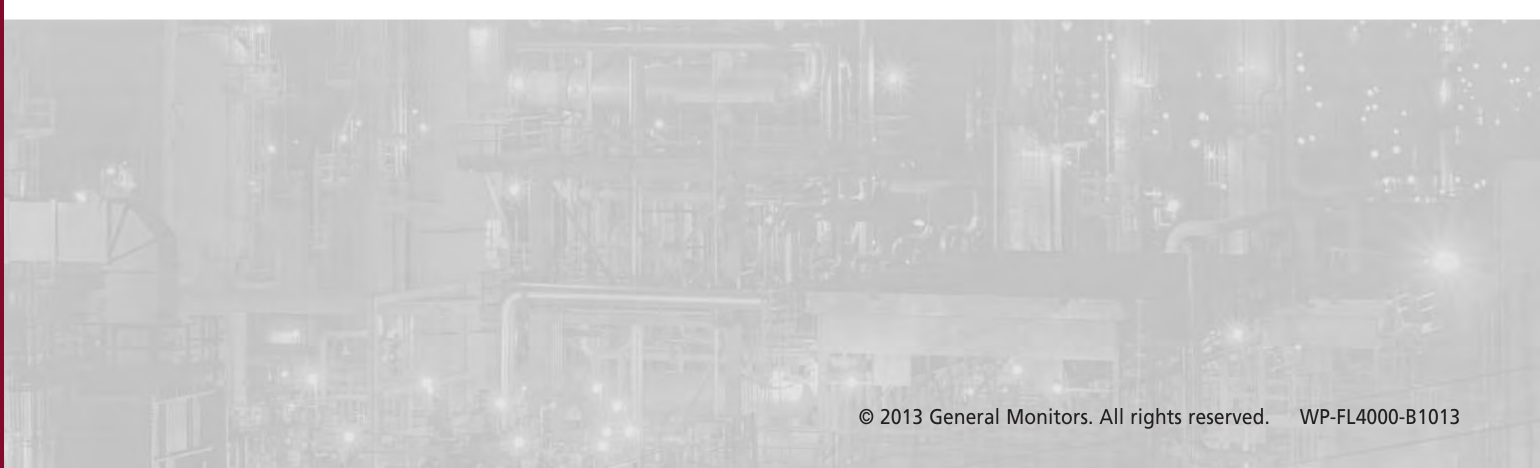

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