NimbleSense™ Architecture: Transforming the Differential Pressure Sensor Market

White Paper

2H 2022

www.superiorsensors.com info@superiorsensors.com

Table of Contents

Differential Pressure Sensor Background and Applications

Background

Measuring the comparative difference between two inputs, differential pressure sensors are a critical part of most mechanical and electromechanical devices that require precise measurement of air, gases or liquids. For example, if there is a valve in a pipe, a differential pressure sensor will measure the pressure on both sides of the valve. If pressures do not match, then it signals that either the valve is not fully open or there is a potentially serious issue (such as blockage). Differential pressure sensors are a key element in many devices such as medical ventilators, sleep apnea machines, spirometers, anesthesia devices, clean rooms, UAVs and HVAC systems.

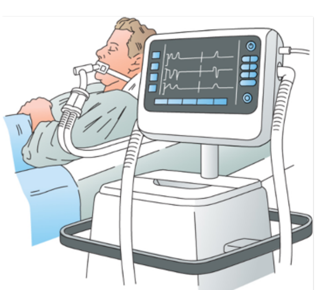
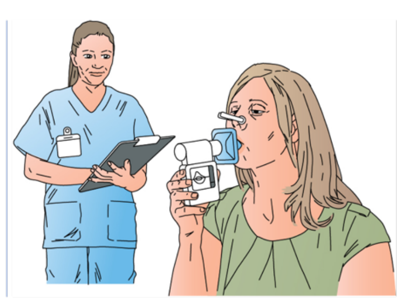
While some variation of differential pressure sensing has existed for hundreds of years, today's modern pressure sensors can trace their roots back to the late 1960s when Honeywell applied for the first patents in piezoresistive silicon sensor technology. Over the pursuant decades, the technology has been improved by further integrating electrical and mechanical components that are manufactured using silicon processes similar to integrated circuits. This process is known as Microelectromechanical Systems, or MEMS, and is commonly used today.

Today's devices, whether it be consumer electronics such as smartphones, medical equipment such as respirators or industrial ventilation systems, have become much more intelligent. But not all components have advanced at the same pace. Critical to many applications, differential pressure sensors have changed little over the past several decades. This has resulted in product designers having to put together piece-meal solutions that are often not performance optimized, usually resulting in extended product development timelines.

Applications

Differential pressure sensors are used in a variety of applications across a broad range of industries. While the list of uses is endless, for this white paper we will list some of the more common uses in the medical, industrial and HVAC industries.

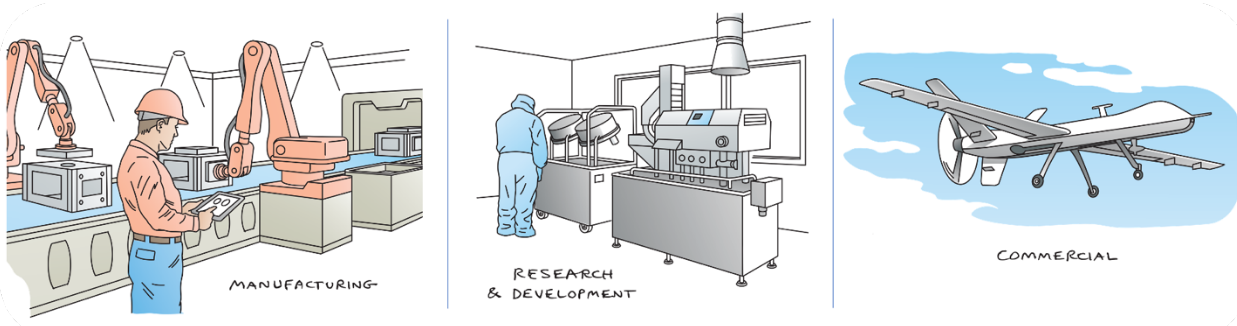
Medical Applications


Here are some of the more common medical devices utilizing differential pressure sensors:

- Ventilators: multiple differential pressure sensors are found in ventilators to ensure each channel is supplying the correct amount of air/gas, the right mix of air and gases are being administered, the right inflow is going to the patient and the patient's air outflow is at appropriate levels.
- Spirometers: differential pressure sensors are used in spirometry to accurately measure a patient's lung capacity and volume under various test conditions. These results help diagnose if there is – and type of – lung disease present.
- CPAP: differential pressure sensors are utilized in CPAP, BiPAP and APAP devices such as sleep apnea machines and nebulizers. They ensure the right mix of air/gas is going to the lungs and monitor to ensure the patient is breathing properly.
- Anesthesia machines: differential pressure sensors ensure the right dosage of anesthesia is administered to a patient.
- Oxygen concentrators: differential pressure sensors monitor the flow of oxygen to ensure the patient is receiving the correct amount and breathing properly.

Industrial Applications

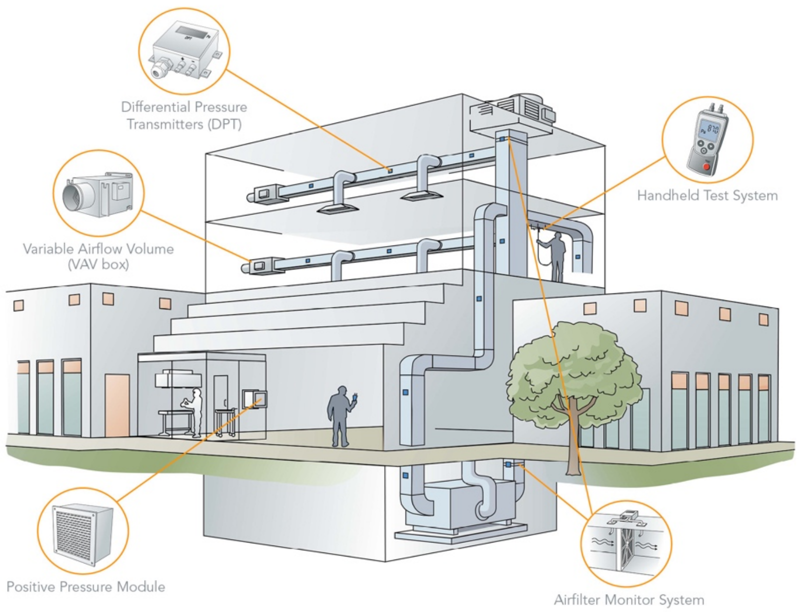


The list of industrial applications for differential pressure sensors is quite long. Here is a partial list of markets that utilize differential pressure sensors:

- 3D printing: measure the pressure within the print head when filament is being applied.
- Auto smog testing: verifying that pollution levels are within acceptable parameters.
- Aviation instrumentation: continually verifying that instrumentation readings are accurately reflecting performance of mechanical elements such as wing positioning, cabin pressure, performance of hydraulic brakes and engine performance.
- Chemical monitoring: verifying that chemical levels are within accepted parameters.
- Device calibration: ensuring various lab and manufacturing equipment are calibrated to their proper levels before and during process work.
- Environmental chambers: ensuring chambers are functioning correctly and are properly sealed.
- Leak testing: measuring differential pressure to determine if there is a leak in the system.
- Nuclear power monitoring: monitoring pressures in a nuclear power plant to avoid potential radiation exposure.

- Particle counting: accurate counting of various particles in the air or within a system.
- Pneumatic system monitoring: monitoring hydraulic pressures to ensure proper system operation.
- UAV/UAS (drones): verifying engine performance, altitude and direction accurately reflect the commands provided to the drone.
- Water quality testing: ensuring various chemicals in water are not exceeding acceptable levels.

HVAC Applications



Like industrial applications, the list of HVAC applications is also quite long. Here is a partial list of how differential pressure sensors are used in HVAC systems:

- Air filter monitoring: monitoring the efficacy of air filters to notify personnel when to clean or change a filter.
- Air handler: monitoring the efficacy of air handlers and blowers to ensure the air flow matches what it is supposed to be – helps reduce energy cost by eliminating inefficiencies in the HVAC system.
- Air pressure monitoring: monitoring changes in air pressure.
- Air quality testing: ensuring the air we breathe is not contaminated beyond acceptable levels.
- Automated safety systems: act as a switch to automatically turn devices on or off depending on the differential pressure measurements.
- Clean room access: verifying dust levels do not exceed the requirement for a clean room in R&D or manufacturing.
- Hospital room monitoring: monitoring a hospital room to ensure the air quality meets acceptable parameters.

System-in-a-Sensor: Utilizing SoC Concepts to Transform Sensors

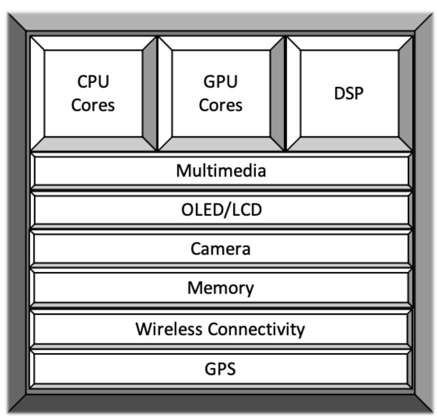
System-on-a-Chip (SoC): The drive to reduce power, cost and size

The integration of many components onto a single die revolutionized the consumer electronics industry. Instead of each feature having its own integrated circuit (IC), a system-on-a-chip IC integrates these distinct functions on a single die or substrate in order to reduce power, shrink the size and lower the cost of a product.

The first SoCs date back to the 1970s when many components were integrated into single chips to control the nascent digital watch market. This allowed the watches to be smaller in size and provide sufficient battery life. After watches, calculators started integrating new SoCs that made the devices lighter and substantially cheaper. By the 1990s, IC companies started embedding microcontrollers with DSPs and other components into system-level chips that drove the rapid adoption of handheld devices (games, instruments, phones), peripherals and other products. By taking the IC with the most intelligence, integrating it with other components and sharing its smarts across these additional functions, the electronics industry entered a new era of inventiveness.

Today, SoCs are in most electronic products from smartphones, TVs and automobiles to IoT devices and embedded systems. The ability to integrate many functions onto a single chip has led to an explosion of highly powered devices throughout all segments of the electronics industry. This has benefitted our daily lives. The SoC concept is now expanding to other products that will drive the next wave of innovation, such as sensors.

Figure 1: SoC – Smartphone AP Example



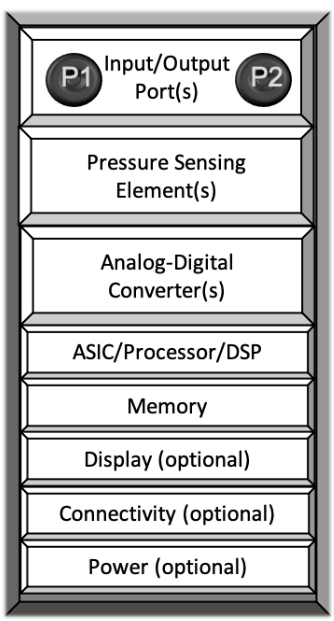
System-in-a-Sensor: Bringing SoC Concepts to Sensors

As most sensors detect or measure physical properties, they have a different fabrication process, and are typically not needed with every SoC as their volumes are much lower. Moreover, many sensors need to be placed where they are making measurements, so they often need to be location dependent. Acting as a bridge between the analog and digital worlds has made adding their full capability into an integrated circuit that sits on a centralized PCB extremely difficult. However, as a standalone sensor module, we can utilize the SoC concept in creating a new generation of sensors that are more efficient, reliable, flexible and functional.

Like SoCs, smart sensors are not new as these integrations started in the 1970s in advanced IR surveillance and warning systems. Originally commissioned by the military, the advances in computing power, component miniaturization and software algorithms are now opening up new doors for advanced sensor modules across industries and applications. Integrating a microcontroller or DSP in the sensor module gives it the intelligence to offer additional capabilities such as self-calibration, self-identification, digitization of sensor data and wireless communications.

Today, smart sensors are everywhere, including homes, automobiles and factories. We have all experienced situations where a motion sensor drives lighting and/or the HVAC in a building, a distance sensor turns a camera or spotlight on and off, a water/humidity sensor instructs a sprinkler system to turn on, and an alarm sensor that sends a wireless notification in case of a breach. This is accomplished by having the base sensor(s) directly interact with a microcontroller or DSP and a communications module. An integrated smart sensor solution is designed to work better than trying to piece-meal all the components together. The tighter integration reduces latency, better utilizes system resources and increases overall performance.

Figure 2: Smart Sensor Example



Taking it a step further, the new System-in-a-Sensor concept brings advanced capabilities that are application or use-case specific and can be adjusted even after a sensor is deployed in the field. Much like a smartphone's usage pattern is controlled by a user, a system-in-a-sensor's usage pattern can be controlled either by an operator or based on system or external events.

Parallels with the Evolution of Smartphones

Most of the computing functions in a smartphone are driven by an application processor (AP) that is an extremely intricate SoC controlling many of the functions of the phone including the display, applications, power and communications modules. The AP is very intelligent – depending on what you are trying to do with the smartphone, the SoC 'structures' itself to optimize the performance for the desired function. It is like a swiss army knife – depending on what you are trying to do, it pulls out the right tool so you can do it as efficiently as possible.

Shouldn't sensors have this same level of ingenuity? As many sensors are powered by ASICs, microprocessors, controllers or DSPs, they can be architected to be flexible and intelligent to optimally perform different functions like an AP does on a smartphone. Having one sensor that can be integrated into many devices and then configure itself based on the immediate need is the future of sensor technology. This can be seen in the NimbleSense architecture deployed in the Superior Sensor Technology pressure sensor products. One sensor can support a wide array of pressure ranges without any degradation in accuracy, and various features can be turned on and off depending on the application for its use.

System-in-a-Sensor: Benefits

Bringing intelligence into a system-in-a-sensor implementation can provide lots of benefits. For example, by procuring the same system-in-a-sensor for numerous projects, you gain the benefit of lower inventory costs, simplified manufacturing and a more straightforward supply chain. As a manufacturer, you only need to worry about building and creating inventory of one system. This lowers your inventory costs and simplifies your manufacturing as you do not need to reconfigure production lines for each product. Further, by using one sensor for multiple purposes and projects, you significantly reduce supply chain complexity by procuring a single part. You gain the benefit of economies of scale as your business ramps up.

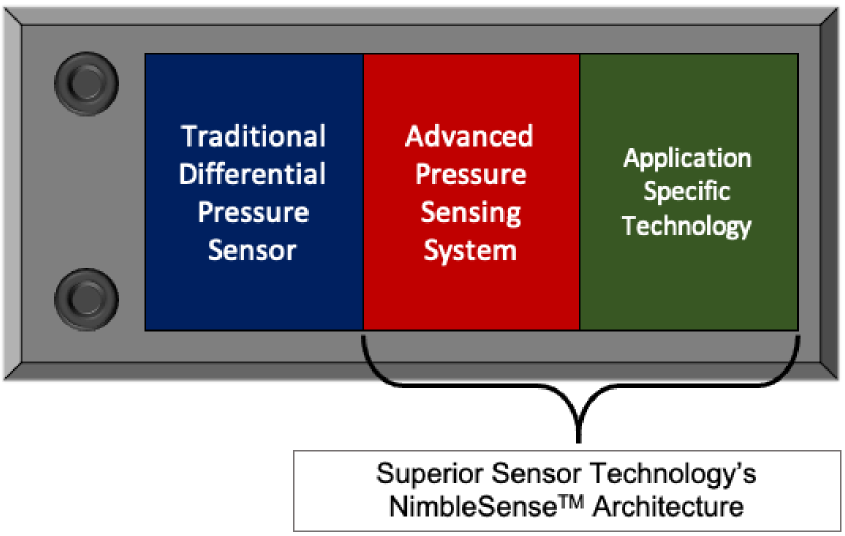
In addition, a sensor can be configured 'on the fly' to support various applications and features. This enables engineers to more rapidly design their products by integrating the same sensor in many devices and applications. Development cycles will be shorter, and engineers can freely optimize their design throughout the development phase without the risk of having to change to a new component that can possibly cause production delays.

Finally, overall system performance is enhanced due to the customizable capabilities of the system-in-a-sensor. If architected correctly, like a smartphone AP the sensor will ensure peak performance across many use cases. This is due to the sensor being optimized for flexible general use (e.g., supporting multiple pressure ranges while maintaining the same levels of accuracy) and having the ability to turn on specific features for certain applications. Like an SoC, the system-in-a-sensor is designed to operate at maximum capability across a wide array of applications and configurations. Moreover, a company can quickly bring out derivatives to expand product lines and further segment its offerings since one sensor solution can be deployed to support many different products.

NimbleSense Architecture Introduction

Superior Sensor Technology has created an innovative architecture enabling product designers to move beyond a piece-meal approach to a fully integrated module that combines the MEMS sensor with additional circuitry and software. This modular approach is driven by intelligent software that is programmable for each end application. We call this architecture NimbleSense, and it is the industry's first System-in-a-Sensor. This approach is the same as IC designers have used in designing many of the complex SoCs that power today's smartphones, automobiles, data centers, etc.

Figure 3: System in a Sensor Block Diagram



Using the NimbleSense architecture enables product designers to create highly differentiated advanced pressure sensing systems from a technology toolbox consisting of many building blocks. This methodology greatly improves system performance in the end application, while providing enhanced features and cost-optimized manufacturing solutions.

The NimbleSense architecture combines processing intelligence with signal path integration and proprietary algorithms to enable a much simpler system design and a higher level of sensor performance. Choosing from a wide array of proven and tested building blocks, product designers integrate the appropriate modules to create a differential pressure system optimized for their specific application requirements.

These different modules provide significant design flexibility and greatly speed up time to market. With this System-in-a-Sensor approach, a product designer can quickly and easily develop the pressure sensing solution required in their specific end product. Along with its unique core technology, these NimbleSense architecture building blocks enable significant performance improvements as well as a variety of application-specific features.

The Core Technology

The NimbleSense architecture was developed with the overarching goal to knock out every bit of noise before reaching the customer's system. We broadly define noise as anything that is not the ideal sensor response, and this approach includes mixing noise, long-term drift, thermal errors, and thermal or pressure hysteresis. The NimbleSense architecture has been designed to maximize performance while also being flexible to easily insert 'building blocks' that add application specific functionality. The result is a pressure sensor architecture having a very clear signal and practically no noise. This leads to the incredible accuracy, TEB and long-term stability performance numbers we offer with our entire product line.

At the heart of our advanced architecture is our controller, which is an extremely stable die that minimizes offset drift. In addition, our die is mechanically double isolated so that external pressures do not influence it, which could otherwise result in offset drift. The implication of this is that any package stress put on the sensor can easily be detected and we compensate for it.

Next, we turn our attention to data acquisition. Here again, we continue to focus on eliminating noise. We start by utilizing a very low noise analog front end and our proprietary analog-to-digital converter with two key features. The first uses a variable frequency response that optimizes data acquisition for the particular application. The second incorporates a continuous high speed acquisition system that allows recognition and subsequent information filtering outside the band of interest. This eliminates any out of band noise that is typically mixed to the band of interest causing errors and ultimately results in the highest fidelity signal for the users' application. In one application, with this architecture we have successfully reduced undesirable noise by a factor of over 1,000.

Then we get to compensation. Most sensor companies are constrained to a 2nd order curve fitting model included with standard sensor ASICs. We have engineered a flexible variable term compensation model that better matches the characteristics of the sensor die and results in much higher levels of accuracy. For example, standard ASICs are limited to 5 to 8 compensation terms, whereas we utilize 20 to 26. This allows compensation of multiple pressure ranges with substantially improved linearity and thermal effect minimization.

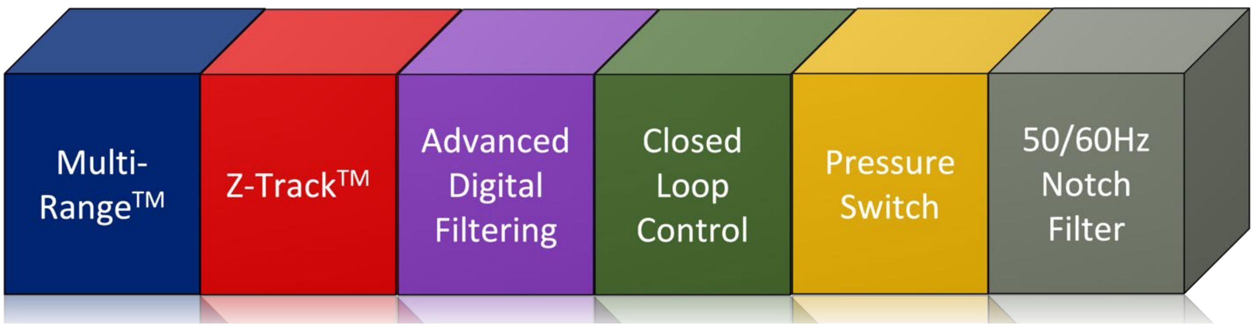
In summary, we start with a very clean core that has the industry's lowest noise floor and highest levels of accuracy. This provides a superior sensing output than traditional pressure sensors. The net result is that we typically see a 5 to 10x performance increase over these other solutions. From this advantage we then move on to the flexibility of our NimbleSense architecture by adding unique building blocks that provide application specific features for various industrial, HVAC and medical devices.

Application Specific Building Blocks

Flexibility is at the core of the NimbleSense architecture. This unique technology allows you to quickly prototype and design the sensor into your product, support multiple product lines with one particular sensor, add new capabilities and features via *software* updates and reduce system cost through lower component count and greater product reliability.

Based on customer feedback, the Superior Sensor Technology engineering team is constantly innovating and introducing new building blocks in the NimbleSense architecture. Here is a listing of the currently available blocks.

Figure 4: NimbleSense Architecture Building Blocks



1. **Multi-Range^{TM}**: Multi-range capability allows a single sensor unit to be factory calibrated and performance optimized to support up to 8 different pressure ranges.

2. **Z-Track^{TM}**: Z-Track employs a proprietary algorithm to virtually eliminate zero drift. Zero error reduction is critical in medical devices such as Spirometers, where an inaccurate reading can have life changing effects.

3. **Advanced Digital Filtering**: Advanced digital filtering optimizes and applies complex filters for applications to ensure sampling artifacts do not reach the user's application.

4. **Closed Loop Control**: Integrated closed loop control manages the control loop to set and maintain flow rates or pressure levels by directly controlling motors, valves, and actuators. This offloads the application from the high-speed requirements of the control loop.

5. **Pressure Switch**: Integrated pressure switch changes state depending on measured pressure being above or below a certain threshold. Includes three modes for setting the threshold pressure, one fixed and two variable.

6. **50/60Hz Notch Filter**: The integrated notch filter allows designers to easily remove noise at either 50Hz or 60Hz that can impact overall system performance. Commonly used in HVAC applications, our integrated notch filter simplifies system design.

Multi-Range Technology

'Ordinary' Pressure Sensors

Differential pressure sensors are designed to optimally support one specific pressure range. Traditional sensors are factory calibrated to perform best at that single range. Once this is predetermined in manufacturing, there is no flexibility. If you need to support multiple ranges within your product line without sacrificing performance, you need to buy separate sensors for each distinct pressure range and set up your production line to calibrate each of these individual devices.

Not having the intelligence to support multiple ranges presents several economic and design challenges. On the economic front, if a product line requires pressure sensors supporting varying ranges, you lose the economies of scale of purchasing one single item in larger quantities. In manufacturing, you incur additional time and costs to calibrate each of the individual sensors when producing your end product. To further complicate matters, in your factory you will need to carry volumes of multiple parts, thus increasing your inventory costs and obsolescence risk.

The biggest economic impact is having to build several end systems to support various pressure ranges. This adds time and complexity to your build schedule and requires building many end product inventories. Having a sensor that supports multiple ranges enables a manufacturer to build fewer product, significantly lowering working capital requirements and inventory costs.

For the product designer, not being able to rely on one part for many pressure ranges complicates the design effort. Having to design in multiple pressure sensors increases your design work, especially if you are sourcing the sensors from multiple vendors. The designer also loses flexibility during the design process, as the pressure ranges need to be predetermined without the ability to 'tweak' the design during the latter stages of development.

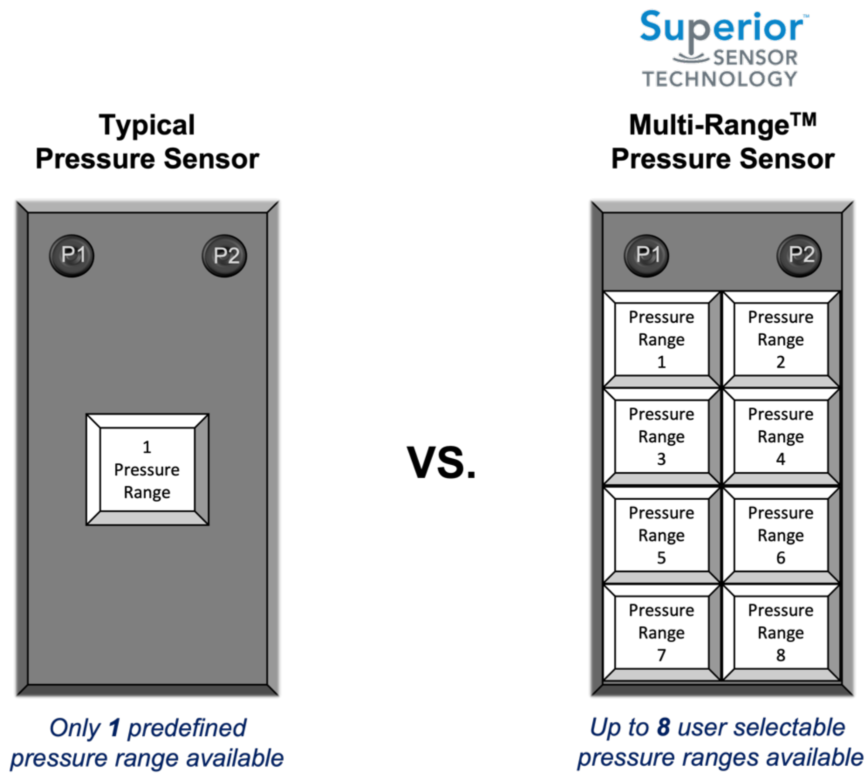
Lastly, having a design with sensors that support only one pressure range impacts your ability to quickly introduce product variants. If your systems can be selected to support multiple pressure ranges, you can easily introduce new product versions without having to change any of your hardware. In addition, without this intelligence you lose the ability to easily introduce enhancements on existing hardware.

One Sensor, Many Pressures

One of the most innovative NimbleSense architecture blocks is Multi-Range technology that enables a single sensor to support a wide range of pressures. This eliminates the complexity and headaches of working with multiple sensors.

Current iterations of our Multi-Range technology can support up to 8 different pressure ranges without sacrificing performance. Each of the pressure ranges is optimized and factory calibrated, ensuring no degradation in a total error band, accuracy or stability regardless of the range selected. Instead of having to research, purchase and design-in multiple parts, a single Multi-Range part simplifies both the design and manufacturing of a product.

Figure 5: Typical Pressure Sensor vs. Multi-Range Pressure Sensor



Designing in the same part throughout your designs is much more efficient than having to select multiple components. When you design in each of the Superior Sensor differential pressure sensors, the setting of the pressure is done via a single software command. It's that simple. Add the fact that there is only one product to inventory, and your manufacturing team will also appreciate the value of Multi-Range!

Perhaps the greatest benefit of Multi-Range technology is that the pressure range can be changed 'on the fly' after a product is deployed. With a change that takes only one cycle to complete, devices with Multi-Range technology can serve multiple purposes. For example, a single air monitoring device can be used to measure and test air flow or air quality throughout a complex HVAC implementation where different pressures are required. Another example is a single handheld testing device can test for different levels of pollutants or chemicals that have varying safety threshold requirements. A third example is a single spirometer or FOT that can be used to accurately measure air flow for people with significantly varying lung capacities such as adults and infants.

Benefits and Availability

Here are some of the various benefits of Multi-Range technology:

1) Design flexibility with ability to 'tweak' pressure range throughout development cycle
2) Simplify product design with one sensor replacing up to 8 different sensors
3) Ability to quickly develop product variants at different pressure ranges without changing hardware design
4) Greater economies of scale by purchasing larger quantities of the same product
5) Reduce manufacturing complexity and costs due to simplified calibration of sensors
6) Up to 8x reduction in sensor inventory costs and product obsolescence
7) Allows manufacturers to build fewer product variants, significantly lowering working capital requirements and inventory
8) Very easily and quickly change the pressure range being measured once a product is deployed in the field, eliminating the need to have multiple devices

Figure 6: 1 Multi-Range Sensor Replaces Up To 8 'Ordinary' Sensors

As a key building block of the NimbleSense architecture, Multi-Range technology is available with all Superior Sensor Technology differential pressure sensors.

Z-Track Technology

The Importance of Precision in Medical Diagnostics

To properly diagnose, medical diagnostic equipment must be accurate – very accurate. Often times the difference between an effective and ineffective treatment plan depends on the precision of the diagnosis. A small difference in a measurement can alter the dosage or even the type of medication a patient should take. This is true for many types of medical tests including blood work, MRIs, temperature measurements and lung capacity.

With increases in air pollution, higher smoking prevalence and aging populations, chronic lung disease is on the rise. Illnesses such as chronic obstructive pulmonary disease (COPD) and asthma are affecting a larger portion of the world's population. A spirometer is a vital tool to diagnose and manage these and other lung diseases by measuring the lung capacity and volume under various conditions.

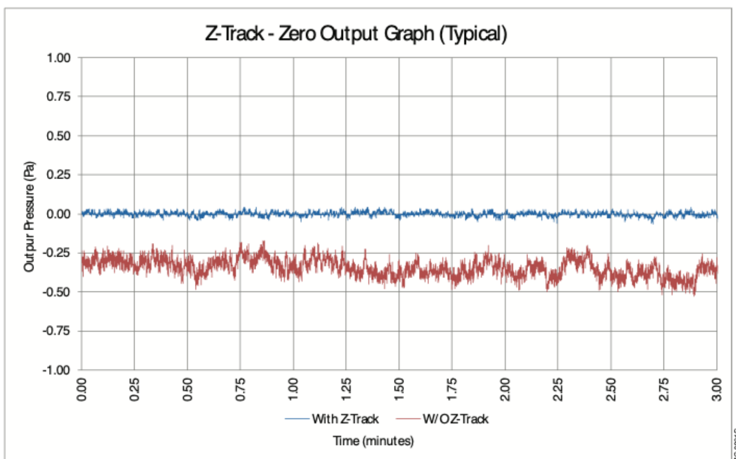
Superior SENSOR TECHNOLOGY

Spirometers rely on differential pressure sensors to accurately diagnose a patient's lungs. The sensors measure air flow when you inhale and exhale to provide accurate data. With each breath, the spirometry equipment re-zeroes the sensor to capture the next reading. The doctor then uses this data to diagnose the patient and devise a treatment plan. However, during the diagnostic cycle, which can last up to 10 seconds or more, the spirometer can 'drift' from its zero position and lead to less accurate readings. Ensuring an accurate reading is paramount for the best patient care.

Eliminating Zero Drift

To ensure the utmost accuracy in medical devices, Superior Sensors has developed its proprietary Z-Track technology that virtually eliminates zero drift. This provides greater accuracy to devices such as spirometers, resulting in more effective diagnosis and better treatment plans.

Figure 7: Z-Track Output Graph vs. Traditional Pressure Sensors



Z-Track virtually eliminates zero errors to ensure the most accurate spirometry readings in the industry. As you can see from Figure 7, Z-Track maintains minimal zero-point deviation with results that are consistent regardless of elapsed time. When combined with the Superior's position insensitivity capability, the company's differential pressure sensors provide the most accurate readings for all types of spirometry equipment including handheld and desktop units. Not only are you certain that the device has virtually eliminated all zero errors, but you can be sure of accurate readings regardless of how the spirometer is positioned or used.

Benefits and Availability

Here are some of the various benefits of Z-Track technology:

1) Eliminate zero errors to ensure the most accurate spirometer readings in the industry
2) Consistent performance regardless of elapsed time
3) Extremely fast data transfer rate
4) More effective medical diagnoses and treatment plans

Z-Track technology is currently available on all the SP Series of differential pressure sensors, the SP110, SP160 and SP210. The SP Series sensors have the following attributes:

- Very fast data rate of 2 ms
- Selectable bandwidth filter from 10 Hz to 250 Hz
- 16-bit resolution
- Ultra low noise, 19-bit effective resolution
- Best in class position insensitivity (SP210 model)
- Total Error Band (TEB) less than 0.15% FSS
- Accuracy range better than 0.10%
- Multi-Range technology support with 4 calibrated ranges per device:
  - SP110 supports 4 pressure ranges ±250 Pa to ±2.5K Pa (±1" H_2O to ±10" H_2O)
  - SP160 supports 4 pressure ranges ±5K Pa to ±40K Pa (±20" H_2O to ±160" H_2O)
  - SP210 supports 4 pressure ranges ±250 Pa to ±2.5K Pa (±1" H_2O to ±10" H_2O)

Advanced Digital Filtering

The Many Sources of Noise in Electrical System

Electromechanical devices, such as HVAC systems, hospital ventilators and monitoring systems, are comprised of many parts that generate noise when these parts move, or the systems have air/gas/liquids flowing through them. Unfortunately, when this noise is superimposed on the signal to be measured it can have a major impact on the product's accuracy and performance.

Noise filtering is the process of removing noise from a signal. The more noise that can be removed, the more accurate a system will perform. This is easily observed in audio and video systems. In audio, the elimination of noise leads to a clearer, hi-fidelity sound. While in video, noise is the culprit behind any blurriness, ghosting and judder of a video stream.

A common term used to measure signal quality is signal-to-noise ratio, or SNR for short. This measure takes the strength of a signal and divides it by the noise level. For example, in audio you take the signal level divided by the noise level generated by the audio equipment and express this value in decibels (dB). The higher the SNR, the better the audio quality.

The lower the overall signal strength, the greater effect noise will have on the system. If you are measuring radioactivity or chemicals in the air, for example, all it takes is a very low level of gas to create a toxic environment. The measurement device must be capable of filtering out all system noise to ensure an accurate reading. Being off by just a little can have a significant impact on the health of those in the area.

With regard to HVAC, industrial and medical devices, many components generate noise including fans, air blowers and motors. When pressure sensors are involved, especially differential pressure sensors, every small reduction in noise can have a significant impact on the accuracy of the reading. If you are measuring the levels of poisonous gas in a facility, air pressure levels in aviation or patient air flow through a respirator, just a small amount of system noise can have a major impact.

Greatly Reduce System Noise Level to Improve Accuracy

Superior Sensor’s advanced digital filter is a multi-order filter that utilizes advanced filtering capabilities on the front-end of the sub-system to eliminate critical noise created by fans, blowers or other dry air/gas sources prior to reaching the user’s application. The NimbleSense advanced filtering capability removes sensor induced mechanical noise before it becomes an error signal that can adversely impact overall system performance.

In customer deployments where our sensor replaced a competing component, we have seen greater than 10x reduction in sensor induced noise, thus greatly improving the SNR of the sensor output. With very low pressure systems, the improvement is even more significant. With both standard and optional digital filters, this feature provides significantly better noise reduction and eliminates the need to design an external filtering system, resulting in more efficient, more reliable and less costly products.

The example below is of a 4th order FIR filter customized to block pump noise above 50 Hz, which has noise of equal magnitude as the signal of interest.

Figure 10: 4th Order FIR Filter Blocking Pump Noise above 50 Hz

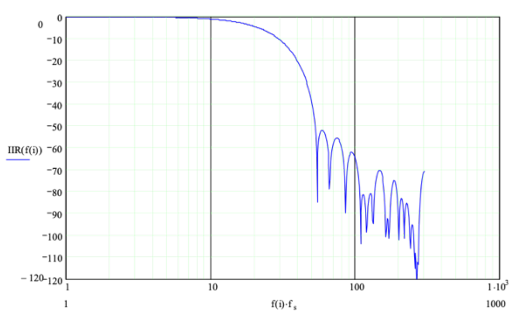
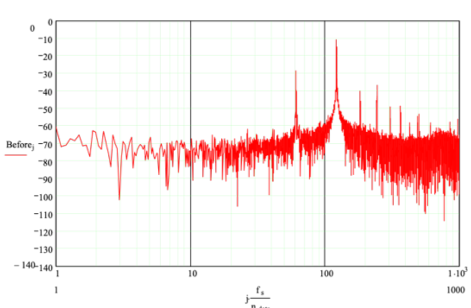
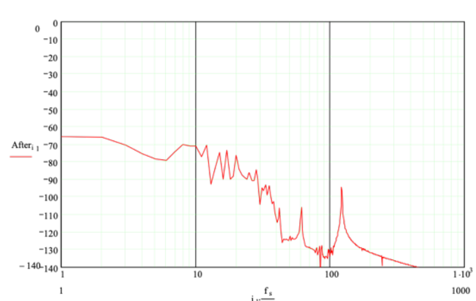


Figure 11: Before & After Results from NimbleSense 4th Order FIR Filter



Before Filtering



After Filtering

Benefits and Availability

The NimbleSense advanced digital filtering capability can be beneficial for all electromechanical products including ventilators, sleep apnea machines (CPAP, BiPAP), oxygen concentrators, anesthesia machines, industrial devices and HVAC systems. Here are some of the various benefits of Superior's advanced digital filtering:

1) Greatly reduce system noise levels by 10x or more, especially important in very low pressure applications. For noise prone systems, an improvement of 100x to 1000x is not unreasonable.
2) Eliminate noise sources such as fans and blowers before they reach the user's application.
3) Simplify product design with an integrated approach.
4) Speed time to market by not having to design an external filtering system.

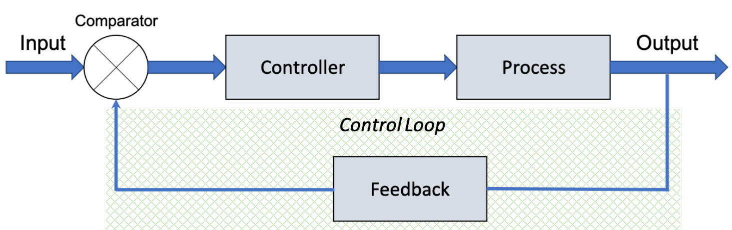
As a key building block of the NimbleSense architecture, advanced digital filtering is available with all Superior Sensor Technology differential pressure sensors. If you have an application that has a challenging noise environment and can benefit from a lower noise floor, implementing the NimbleSense advanced digital filtering capability into your product will help you achieve maximum overall system performance.

Closed Loop Control

Effective Pressure Sensor Implementations Require an Accurate Closed Loop

A closed loop control system automatically regulates a process to a desired state based on continuous feedback from the system. It contains one or more mechanical or electronic devices that are adjusted based on feedback of the current state in order to potentially adjust the system to reach the desired state. In many devices, closed loop systems, sometimes known as feedback control systems, are designed to automatically achieve and maintain the desired state without any human interaction.

Figure 8: Basic Control Loop System



Pressure sensors are often used to measure the pressure or flow in systems. And often, the sensor output is directly used as the feedback in a closed loop system. Differential pressure sensors measure the flow, level or density of air and gas. They are frequently the key feedback component of many important systems in the medical, industrial, aviation, automotive, energy and HVAC fields.

While many systems use the pressure sensor as the center of a control loop feedback system, they often employ software as the external control mechanism. But utilizing software requires a higher speed CPU that draws more power. In addition, there is a need for added hardware and the system is beholden to injected system noise that impacts sensor performance. To minimize the noise, the sensor is typically run at a higher speed as well. There are several drawbacks to this kind of implementation:

1) Cost: the additional components add to the bill of materials (BOM) of a product
2) Accuracy/Timing: the more complex the feedback loop, the longer the loop takes to complete, resulting in a greater time lag that ultimately impacts accuracy
3) Design Complexity: the overall product design is more complex, taking more time and resources to develop
4) Reliability: the more components in a product, the greater the number of possible failure points
5) CPU Requirements: to run the system requires a higher-end, faster CPU that consumes more power and generates more heat

Reduce Loop Delays Up To 100x

Superior Sensor's closed loop controller adds the control capability to set and maintain flow rates via pressure measurement in the sensor. It can directly control motors, valves and actuators to maintain flow rate targets. In addition, NimbleSense runs at a very high speed with advanced filtering capability that removes sensor induced mechanical noise before it becomes an error signal that can adversely impact overall system performance.

The integrated closed loop controller design significantly reduces loop delays in the electronic circuit by up to 100x. This optional capability eliminates the need to design and implement a complex control loop system, resulting in more efficient, more reliable and less costly products.

Figure 9: Closed Loop Control – Air Quality Application Example

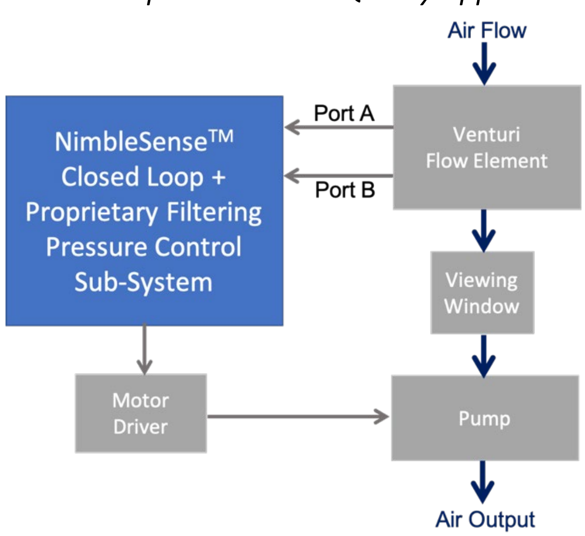


Figure 9 shows a block diagram of an implementation of the Superior Sensor closed loop controller for an air quality application. In order to effectively measure the air quality, we require maintaining a constant/known airflow through the viewing window. The differential pressure across the venturi directly measures the flow into this viewing window. The system sets a target pressure level across the venturi and the differential pressure sensor automatically increases or decreases the drive to the pump to maintain the targeted differential pressure, ensuring a constant airflow into the viewing window. This is accomplished with the NimbleSense closed loop circuit and used in combination with the company's proprietary noise filtering, resulted in greater than 100x reduction in loop delay.

Benefits and Availability

The NimbleSense closed loop capability can be beneficial for many products including, but not limited to, ventilators, sleep apnea machines (CPAP, BiPAP), oxygen concentrators, anesthesia machines, flow meters and HVAC systems.

To summarize the benefits on the NimbleSense integrated closed loop control capability:

1) Greatly reduce loop delays to improve accuracy and product responsiveness.
2) Improve product reliability by eliminating discrete parts.
3) Reduce overall system costs.
4) Minimize system power and heat.
5) Simplify product design.
6) Speed time to market.

If you have an application where you need closed loop control capability, please contact us so we can discuss how best to implement the NimbleSense closed loop control into your product leveraging the benefits listed above.

Pressure Switch

The Importance of Pressure Switches

A pressure switch is a mechanical or electronic device that is activated when a certain pressure threshold or setpoint is reached. These failsafe response components instruct the system to perform an action if a certain pressure threshold is met. Pressure switches can be deployed to ensure there is enough flow going through the system (e.g., enough air flowing through an air filter). They can also be implemented to ensure there is not too much pressure applied to the patient (e.g., a ventilator delivering air to a patient's lungs).

Traditionally, these switches have been mechanical in nature; however, advancements in technology are starting to phase them out in favor of electronic controls. There are several reasons for the shift to electronic pressure switches, including:

- Faster adjustments, resulting in better response time and greater accuracy

- Field programmability
- Better usability and more ‘plug and play’ setup
- Higher reliability and easier to service
- Greater operating flexibility

Types of Pressure Switches

With regards to electronic pressure switches, there are both fixed and variable types.

Fixed Pressure Switches

As their name implies, fixed pressure switches have pre-set, non-changeable pressure thresholds that are set by the pressure switch manufacturer. The device maker receives the pressure switch already configured and cannot change values. Examples where fixed pressure switches are common are certain types of medical devices, such as ventilators.

Variable Pressure Switches

With variable pressure switches, the threshold value can be set either by the device maker or dynamically in the field. If it is controlled by the device maker, when they build their product they select certain resistor pairs that control the voltage input that determines the threshold. Once they build the product, the threshold value cannot be changed.

In cases where the threshold can be set in the field, this is typically done via software or a mechanical knob/switch. In this scenario, the pressure switch is usually not implemented as a safety feature. A good example is with air filters – where depending on the system implementation, the threshold value needs to be adjusted to account for any head loss in the flow stream.

The NimbleSense™ Pressure Switch

Like other pressure switches, Superior Sensor’s pressure switch changes state depending on the measured pressure being above or below a certain threshold. This can be used as a fast response failsafe feature for overpressure conditions, and to provide other simplified on/off system feedback.

However, unlike other more common pressure switches, the Superior Sensor pressure switch includes three modes for setting threshold pressure, one fixed and two variable:

- **Fixed mode**: Superior Sensor Technology sets the threshold and provides the ‘ready for use’ configured sensor (with integrated pressure switch) to the device manufacturer.
- **Variable mode 1**: The device manufacturer can configure and set the proper thresholds at the time of product manufacturing.
- **Variable mode 2**: Pressure thresholds are field programmable via software, so the pressure switch can be ‘tuned’ after product manufacture depending on the use case.

The three modes provide the manufacturer full implementation flexibility. Moreover, as an integrated part of the pressure sensor, the Superior Sensor pressure switch does not require the addition of an external switch, so it:

- eliminates the cost of an external pressure switch
- reduces product PCB space requirements
- lowers system-level power consumption

System Benefits and Availability

The NimbleSense pressure switch capability can be beneficial for all electromechanical products including HVAC systems, medical ventilators, CPAP/BiPAP/APAP, oxygen concentrators, anesthesia machines and various industrial devices.

At the systems level, the NimbleSense pressure switch provides several benefits:

1) Simplifies product design with an integrated approach.
2) Speeds time to market by not having to design-in an external pressure switch.
3) Reduces system costs by eliminating the need for additional components.
4) Provides maximum design flexibility due to its three modes for setting threshold pressure.

Superior Sensor's pressure switch capability is available with the CP, HV, ND and VN Series of pressure sensors. If you have an application that requires a pressure switch, our integrated pressure switch can simplify your design and speed your time to market.

50/60Hz Notch Filter

Power Line Interference

Power line noise can interfere with electrical, radio and TV signals. This noise is typically exhibited near power lines or power sources and is extremely frustrating when trying to make sensitive measurements at low voltages. Depending on your geographic location, this AC induced noise is typically at either 50Hz or 60Hz.

Many systems are generally noisy and power line interference just 'blends' in. But what about systems making highly accurate pressure measurements, thus requiring a very low noise floor? In these systems the power line noise can become dominant to the signal being measured. This can result in a humming sound in a radio broadcast, blur in a video stream or the inability to accurately measure pressures in a sensor system.

When it comes to making accurate measurements with high resolution pressure sensors, the impact of this power line noise can be significant. To make precise measurements, you need to isolate the noise at these frequencies and eliminate it. The most common way to eliminate this AC noise is by adding a 50Hz or 60Hz notch filter to your product. A notch filter rejects the signals within a specified narrow band of frequencies and only allows signals outside of that band to be passed along.

Most electrical systems and household appliances emit this power grid noise at the 50Hz or 60Hz frequency. This is why, for example, your cell phone or Wi-Fi signal weakens when you are near certain appliances in your home. Engineers need to design/implement a notch filter circuit in order to block out those suspect frequencies. This is typically done via an external circuit to the pressure sensor.

Simplify Your Design with an Integrated Notch Filter

As all of Superior's pressure sensors have an extremely low noise floor, theoretically power line interference can be 'heard' when taking measurements. The integrated 50Hz/60Hz notch filter eliminates this noise so you maintain the advantage of having such a low noise floor pressure sensor without any external interference.

With the notch filter seamlessly integrated in the differential pressure sensor module, the sensor blocks out the interference caused by these frequencies before it reaches the user application. Further, as the notch filter is internal to the sensor module, it eliminates the need for an engineer to design and implement an external notch filter. This feature removes an external notch filter, so the overall system is more efficient, more reliable and less costly.

Benefits and Availability

The NimbleSense integrated 50Hz/60Hz notch filter can be beneficial for products that operate near power lines, a power source or are coupled through a power supply, such as industrial devices and HVAC systems. To summarize the benefits of the NimbleSense integrated 50Hz/60Hz notch filter:

1) Eliminate the noise from the power grid and AC devices before it impacts system performance.
2) Simplify product design with an integrated approach.
3) Speed time to market by not having to design and/or implement an external notch filter.
4) Lower overall system cost as an external notch filter is no longer required.

Superior Sensor's 50Hz/60Hz notch filter is available on the HV and ND Series of products. If you have an application that has potential power line interference, implementing the NimbleSense integrated 50Hz/60Hz notch filter will enable you to more easily eliminate this noise easily and at no additional cost.

Superior™ SENSOR TECHNOLOGY

www.superiorsensors.com info@superiorsensors.com