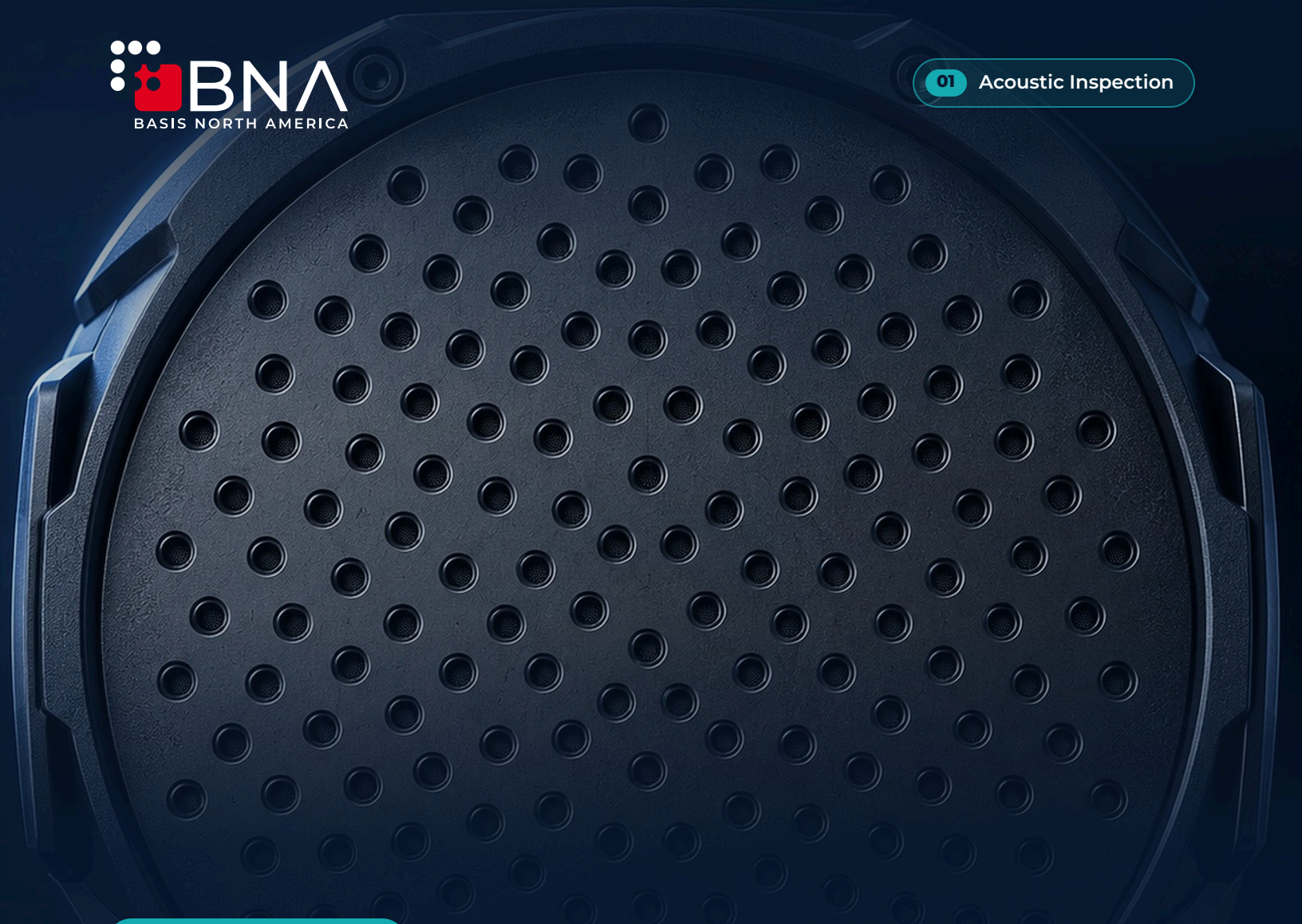
BNA
BASIS NORTH AMERICA

01 Acoustic Inspection



Technical White Paper

Industrial Acoustic Inspection

Physical principles of acoustic detection, professional imaging technology, and the role of acoustic inspection in predictive maintenance and condition monitoring

BNA GUARDIAN

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Contents

Executive Summary 03

01 Introduction: industrial acoustics in the condition monitoring journey 04

02 The cost of the invisible: the economic scale of the problem 06

03 The physical principles of industrial acoustic detection 09

04 Acoustic imaging technology: state of the art and Fotric H6-class instrumentation 13

05 Industrial applications: where acoustics is the most effective technology 16

06 Inspection methodology and reporting 19

07 Regulatory framework and reference standards 22

08 Market context: predictive maintenance trends 24

09 Acoustic inspection in BNA Guardian's Asset Health & Reliability journey 26

10 Conclusions 28

Bibliography and sources 29

Executive Summary

Compressed air and process gas leaks, like the deterioration of electrical insulation in the stage that precedes failure, share a common physical characteristic: they generate very high-frequency acoustic signals (ultrasound, largely beyond the threshold of human hearing) long before they show up as energy cost, downtime, or safety risk. Industrial acoustic inspection, or acoustic imaging, is the technology that makes these signals visible: it localizes them in space, classifies them by type, and translates them into a quantitative measure: flow rate, severity, intervention priority.

This document systematically covers: the physical principles underlying industrial acoustic detection (chapter 3); the state of the art in professional instrumentation available today, of which the Fotric H6, with its 162 MEMS microphones and a 2–100 kHz operating band, is a representative example of the highest performance tier (chapter 4); the industrial applications where this technology is the technically most effective choice, and those where it is not (chapter 5); the inspection methodology and the economic quantification of results (chapter 6); the regulatory framework and reference standards (chapter 7); and the predictive-maintenance market context in which this technology fits (chapter 8).

> **The Starting Point**
>
> Acoustic inspection is one of the technologies that make up a broader approach to predictive maintenance and condition monitoring, alongside infrared thermography and continuous vibration monitoring. In the BNA Guardian pathway, it typically represents the entry point: the fastest to activate, the least invasive, and the one with the most immediate return (chapter 9).

This document is written for a technical audience (reliability engineers, maintenance managers, plant leadership) and favors, wherever possible, published and verifiable data over generic claims. Every figure cited is accompanied by a numbered reference, collected in the bibliography.

01

Introduction: industrial acoustics in the condition monitoring journey



In the vast majority of cases, every industrial failure follows a predictable path: a defect arises, develops over time, and only at the end of this path does it manifest as an outright functional failure. This principle, popularized in the reliability engineering literature as the P-F curve (Potential Failure – Functional Failure), is the conceptual foundation on which any predictive maintenance strategy rests: the closer to point P (the onset) a defect is detected, the wider the intervention window available, and the lower the cost (economic, operational, and safety-related) of the corrective action.

Condition monitoring is the engineering practice that builds this early-detection capability, continuously or periodically measuring one or more physical quantities correlated with an asset's health (temperature, vibration, acoustic emission, fluid composition) and comparing them against an expected baseline. No single condition monitoring technology covers the entire spectrum of possible failure modes: each technology is sensitive to specific physical phenomena, and the choice of the most effective technology depends on the type of asset and the failure mode one wants to anticipate.

Why this document focuses on acoustics

This white paper specifically and thoroughly addresses industrial acoustic inspection (acoustic imaging): its physical principles, the instrumentation available, the applications where it is the most effective technology, its inspection methodology, and the relevant regulatory framework.

It is important to correctly frame this editorial choice: in BNA's view, acoustics is not a standalone service, but one of the technologies that make up a broader approach to predictive maintenance and condition monitoring, an approach that, in the BNA Guardian program, includes, alongside acoustic inspection, infrared thermography and continuous vibration monitoring (covered in depth in dedicated technical documents). Chapter 9 of this document places acoustics within this broader framework.

The decision to dedicate a specific document to acoustics is not incidental: among non-invasive condition monitoring technologies, it is typically the one with the lowest activation barrier (it requires no installed sensors, no plant shutdown, no years of training for an initial screening) and the one whose economic return is most immediately demonstrable, as illustrated in chapter 2.

Who this document is for

This document is written for a technical audience: reliability engineers, maintenance managers, and those responsible for plants and critical assets in Oil & Gas, petrochemical, and process industry settings. It is not a commercial document: where the technology has limitations, this document states them explicitly (see in particular section 5.4). The goal is to provide the technical elements needed to assess whether, where, and how acoustic inspection can be effectively applied in one's own plant environment.

02

The cost of the invisible: the economic scale of the problem



2.1 Compressed air and process gas leaks

Worldwide, leaks in compressed air systems are one of the most widespread, and systematically underestimated, energy problems in the process industry. The U.S. Department of Energy estimates that between 20% and 30% of the compressed air produced in an average industrial plant is lost to undetected leaks [1]; ENERGY STAR reports that, in systems not subject to regular maintenance, this percentage can rise to as much as 50% of the air produced [2].

Parameter	Value
Average loss, industrial plants (DOE)	20–30% of compressed air produced
Unmaintained systems (ENERGY STAR)	up to 50% of air produced
Single 1/4" leak at 100 PSI	~$2,500–3,500/year in energy cost alone
Average manufacturing plant (50–200 leak points)	$10,000–500,000+/year in direct energy waste
Cost of a sudden compressor failure	$50,000–200,000 (repair, downtime, lost production)
Failure rate, compressors over 15 years old	~30% higher than machines in their first 5 years

An empirical pattern observed across a large number of industrial inspections indicates that roughly 20% of the leaks detected in a plant are typically responsible for 80% of the overall energy waste, a distribution consistent with the Pareto principle, which carries a direct operational implication: the priority of an acoustic inspection program is not to find every single leak, but to quickly identify that high-impact 20%.

As one quantitative example (not generalizable to every context, but indicative of the order of magnitude of the problem) a case documented by manufacturer HIKMICRO reports leaks with an estimated value of $41,500 per year identified in 2.5 hours of acoustic inspection at a single plant, with a payback period for the instrument investment of roughly 32 minutes of inspection [11].

2.2 The cost of unplanned downtime

The "True Cost of Downtime 2022" report by Siemens/Senseye, based on an extensive survey of Fortune Global 500 companies, estimates the aggregate cost of unplanned downtime for these companies at nearly $1.5 trillion per year, equal to 11% of their revenue, up from 8% recorded two years earlier. The average cost per facility is estimated at $129 million/year. For the Oil & Gas sector specifically, the same report estimates an hourly downtime cost of roughly $500,000/hour, more than double the previous measurement [21].

ARC Advisory Group independently estimates that unplanned downtime costs the industrial and manufacturing sector, overall, more than $1 trillion per year in lost revenue [22]. Deloitte, in an analysis of the benefits of predictive maintenance over reactive approaches, reports an average 53% reduction in unplanned downtime and an 87% reduction in defects when moving from reactive to predictive maintenance [23].

2.3 Undetected electrical deterioration: partial discharge and electrical risk

Partial discharges (PD) are micro-scale electrical discharge phenomena that develop in the insulation of medium- and high-voltage equipment well before an outright failure. Their early detection has a dual value: economic (avoiding damage to a transformer or MV switchgear, often irreparable) and safety-related, an unanticipated electrical failure can evolve into an arc flash, an event with temperatures that can exceed 19,000 °C (35,000 °F) and blast pressures of up to roughly 2,000 pounds per square foot [14].

Available estimates of arc flash event incidence in the United States (Johns Hopkins University analysis of historical survey data, compiled from industry sources) indicate an order of magnitude of a few hundred events per year (estimates in the 350–1,050/year range, depending on counting methodology) [15]. Bureau of Labor Statistics data compiled by Electrical Safety Foundation International report an average of roughly 150 deaths per year from electrical accidents in the United States [15].

The technical literature qualitatively confirms that partial discharge activity precedes catastrophic insulation failure, offering a diagnostic window that can be exploited for planned intervention; this is the very premise on which PD monitoring programs in the electrical industry are built. However, the width of this window depends heavily on the type of discharge, the insulating material, and the level of electrical stress: the engineering literature offers no universal quantitative rule ("weeks" or "months"), and this document deliberately avoids proposing one.

2.4 The P-F curve: why when a defect is detected matters more than the detection itself

The P-F curve concept, widely used in the reliability engineering literature, describes the typical path of an industrial failure through three conceptual zones: a predictive zone, in which the defect is detectable only with high-sensitivity technologies (vibration, acoustic, oil analysis) and the cost of intervention is minimal; a preventive zone, in which the defect is already detectable with technologies such as thermography and the cost of intervention is higher, but the shutdown can still be planned within the next maintenance window; and a reactive zone, in which the defect is perceptible even without instrumentation (obvious noise, heat, vibration) and the cost (including unplanned downtime, secondary damage, and safety risk) is highest.

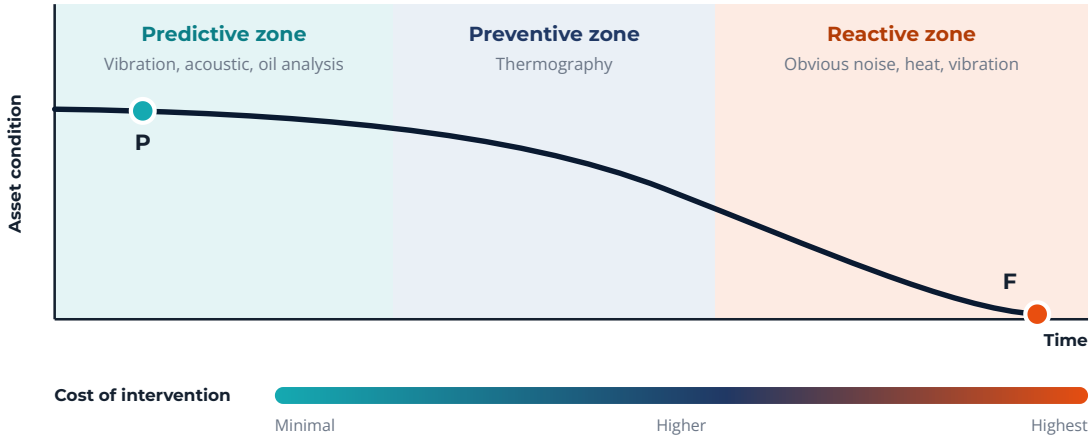


Figure 1 The P-F curve

Operational Implication

The message of the P-F curve is not technological but economic: it is not the detection technology itself that generates value, but the timing of detection relative to the defect's progression toward failure. This is why the choice of inspection technology, and its sensitivity to a given failure mode, is a technical and economic decision at once.

03

The physical principles of industrial acoustic detection



3.1 Sound propagation, ultrasound, and the physics of leaks

When a pressurized gas escapes through an orifice (a worn gasket, a loose fitting, a crack) the flow generates turbulence: rapid local variations in pressure and velocity that propagate as broadband sound waves, spanning both the audible spectrum and the ultrasonic range (typically from 20,000 to over 100,000 Hz). Several experimental studies have characterized this phenomenon: Holstein et al. (2016) measured that, as a leak's flow rate increases, so does the acoustic energy present above 50 kHz, with a spectral peak that, at the maximum flow rate measured in the study, sits around 80 kHz [4].

The choice to operate in the ultrasonic band rather than the audible one is not arbitrary: narrowband ultrasonic sensors, typically centered around 40 kHz, are a historically widespread tool for leak localization, but have documented limitations, high-frequency sound is subject to rapid atmospheric attenuation, the sound pressure level generated by a leak varies significantly with the measurement angle, and noisy industrial environments degrade their performance [5] [6][7]. Broadband instruments, which operate across both the audible and ultrasonic spectra, compensate for these limitations by increasing the overall robustness of detection.

Factors that influence detection

The intensity of the acoustic signal generated by a leak depends on a set of interacting variables, documented in the industry technical literature:

- **System pressure and flow rate**
  Higher pressure and higher flow rate generate greater sound intensity at the leak point, making it easier to detect.
- **Size, shape, and type of orifice**
  The most common leak sources (a cut flexible hose, an open end, a damaged quick-connect fitting, a loose threaded plug) have distinct acoustic signatures.
- **Fluid properties**
  Gas density directly affects the sound pressure level generated: a low-density gas such as helium, at the same flow rate and pressure, generates a weaker acoustic signal, which is why helium leaks are notoriously harder to detect than compressed-air leaks.
- **Distance and environmental conditions**
  Sound pressure level decreases with distance from the source (doubling the distance in free field reduces the level by roughly 5 dB); temperature and humidity affect the atmospheric absorption of acoustic energy, with a noticeable effect especially at higher frequencies and over longer distances [6][7].

3.2 From ultrasound to image: the beamforming principle

An acoustic camera does not simply measure a sound pressure level at a point: it builds an image, overlaid on the optical scene, that shows where in space each acoustic signal originates. This is achieved through an array of MEMS (Micro-Electro-Mechanical Systems) microphones and a delay-and-sum beamforming algorithm: because sound reaches microphones positioned at different points in the array with minimal time differences (on the order of microseconds), the algorithm uses these differences (Time Difference of Arrival, TDOA) to calculate the direction each sound source is coming from.

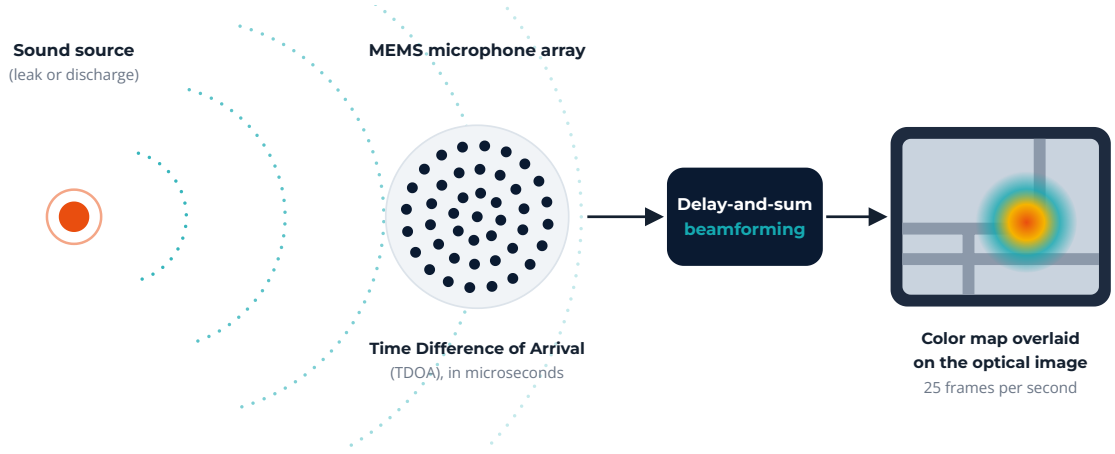


Figure 2 From ultrasound to image: the beamforming principle

The engineering principle is the same one used in sonar systems and phased-array radar: in passive sonar, the signal received by each hydrophone is combined after a calibrated time delay so that all contributions reach the output in phase; in narrowband systems, this same time delay is equivalent to a phase shift, hence the term "phased array". A recent systematic review published in the journal Measurement (Wang et al., 2025) traces more than forty years of development of these techniques (from classic delay-and-sum to adaptive beamforming, up to deep-learning-based approaches) applied to acoustic imaging [27].

From a performance standpoint, two parameters govern the quality of the resulting acoustic image: the angular resolution of the array's main lobe, which improves as the array's physical aperture increases (more microphones, spread over a larger surface, produce a sharper image); and the phenomenon of spatial aliasing, an upper limit on usable frequency that depends on the spacing between microphones. This is why high-end professional instruments use a significantly higher number of microphones than entry-level models, a topic revisited in chapter 4.

The operational outcome of this physical principle is direct: the technician does not need to manually scan every suspect point with a single-point detector. They point the camera at an area, and the beamforming algorithm processes, in real time, typically at 25 frames per second, a color map overlaid on the optical image that visually indicates where the problem is located.

3.3 Partial discharge: physics and progression toward failure

Partial discharges are localized electrical discharges that affect only part of the insulation between two conductors, without producing a complete short circuit. They manifest in three main physical forms, each with a distinct mechanism:

- **Corona discharge**
  Develops around a conductor with strongly non-uniform geometry (a point, a sharp edge), where the local electric field exceeds the ionization threshold of the surrounding gas while remaining well below the full breakdown voltage between the electrodes. It typically manifests as a glow or brush discharge, often accompanied by ozone production.
- **Surface discharge (tracking)**
  Occurs when the tangential electric field on the surface of an insulator is high enough to cause a discharge along the surface itself; it is aggravated by surface contamination (moisture, salt, dust), which is why it is more common in coastal or humid environments.

- **Internal discharge (void discharge)**
  Is triggered in gas-filled cavities inside a solid dielectric. Because the dielectric constant of the gas in the cavity is much lower than that of the surrounding solid material, continuity of the electric displacement vector causes the field to concentrate strongly in the cavity, exceeding the gas breakdown threshold even when the operating voltage is nominally adequate for defect-free insulation. This is the most insidious type of discharge, because it remains externally silent until advanced stages.

Repeated discharges cause irreversible mechanical and chemical deterioration of the insulating material, through three parallel degradation pathways documented by the IEEE Dielectrics and Electrical Insulation Society: a thermal pathway (localized carbonization), an electrical pathway (progressive formation of partially conductive channels, the phenomenon known as electrical treeing, that eventually bridge the electrodes), and a chemical pathway (oxidative degradation with breakdown of the insulating material's molecular chains) [15].

All three forms of partial discharge emit acoustic energy in the ultrasonic band, which makes them detectable using the same acoustic imaging principle used for gas leaks, a point of technological convergence that allows a single instrument to cover both applications. The reference electrical measurement for partial discharge, which quantifies the phenomenon in terms of apparent charge (measured in picocoulombs, pC), is governed by the international standard IEC 60270, now in its fourth edition (2025) [12]; acoustic imaging does not replace this laboratory-grade electrical measurement, but offers a fast, non-contact screening tool applicable to energized, in-service equipment.

3.4 Why imaging outperforms single-point measurement

Before acoustic cameras became widespread, ultrasonic detection of leaks and discharges relied on narrowband single-point sensors: instruments that return a sound level but not an image, forcing the technician to manually scan the suspect area by orienting the sensor and interpreting changes in intensity. Wolstencroft and Neale (2008) documented how this approach is prone to localization errors in noisy or geometrically complex environments [5]. Acoustic imaging resolves this structural limitation: the microphone array simultaneously captures the entire scene, and the beamforming algorithm localizes all acoustic sources present in the field of view in a single survey, drastically reducing inspection time and dependence on the technician's subjective experience.

A recent study (Semitela et al., 2025) conducted with a commercial acoustic camera on calibrated orifices from 0.25 to 1 mm measured localization times within 2 seconds under all tested conditions, at distances between 0.5 and 1.5 meters and angles up to 130°, with an optimal operating range around 1–1.5 meters for small orifices [8], a finding consistent with the operating guidance from leading professional instrument manufacturers.

04

Acoustic imaging technology: state of the art and Fotric H6-class instrumentation

4.1 The architecture of a modern acoustic camera

A modern industrial acoustic camera integrates three components into a single handheld instrument: a low-noise array of MEMS microphones, arranged in a calibrated geometric pattern; a digital optical camera, positioned at or near the center of the array, which provides the reference image of the scene; and a processing unit that runs the beamforming algorithm in real time, overlaying the resulting acoustic map on the optical image on a touchscreen display. The result is an instrument a technician can point at a piece of equipment (a valve manifold, an MV switchgear panel, a piping run) and immediately see, as a color map, where an acoustic anomaly originates.

4.2 Key performance parameters

In the technical evaluation of a professional acoustic camera, the parameters that determine its real-world field performance are:

- **Number of microphones in the array**
  Determines the array's physical aperture and, as a result, its angular resolution and sensitivity to weak or distant signals. An array with more microphones distinguishes more closely spaced acoustic sources and detects lower-intensity signals.
- **Operating frequency band**
  Must cover both the audible and ultrasonic spectra to adapt to different leak and discharge types; professional instruments typically cover a range from 2 kHz up to 100–130 kHz.
- **Operating distance**
  The ability to detect a signal at increasing distance is critical for inspecting elevated equipment, areas with limited access, or for safety reasons (maintaining distance from energized MV/HV equipment).

- **Sensitivity**
  Typically expressed as the minimum detectable flow rate at a given pressure and distance; it is the parameter that determines the instrument's ability to detect small leaks before they become significant.
- **Sampling and image refresh rate**
  Determines the smoothness and accuracy of the real-time acoustic map, typically on the order of 25 frames per second for high-end instruments.

4.3 The Fotric H6: an example of high-end instrumentation

Among the professional instruments available on the market today, the Fotric H6 exemplifies the performance level reached by the high end of the category. Its technical specifications, as published by the manufacturer [25], place it among the instruments with the largest microphone array in its class:

Parameter	Fotric H6 specification
Microphone array	162 digital MEMS microphones
Acoustic field of view	66° × 52°
Frequency band	2 – 100 kHz (with selectable scenario presets)
Sampling / refresh rate	200 kHz / 25 Hz
Operating distance	0.3 – 200 m
Sensitivity	> 0.03 L/min at 0.3 MPa, at 3 m distance
Integrated optical camera	13 megapixels
Display	5" LCD touchscreen, 1280×720, reinforced protective glass
Detection modes	Gas/air leaks Partial discharge (corona, floating, surface) with PRPD chart Mechanical vibration
Ingress protection / weight	IP54 (IEC 60529) 1.3 kg
Battery life	hot-swappable batteries, 2.5–4 hours each depending on configuration

The 162-microphone array figure is technically significant: a larger array improves both angular resolution and sensitivity to weak or distant signals, enabling inspection of equipment at a safe distance (up to a stated 200 meters) without compromising localization accuracy. The 2–100 kHz bandwidth and the presence of a dedicated partial discharge mode with a PRPD (Phase Resolved Partial Discharge) chart place the instrument in the multi-application instrumentation tier (gas, electrical discharge, mechanical vibration) in a single device.

4.4 Quantification indices and automatic classification

Beyond simple localization, the most advanced professional instruments translate raw acoustic data into information directly usable for planning interventions. Two capabilities are particularly relevant:

- **Leak severity index**

  Some manufacturers (for example Fluke, with its own LRQ, Leak Rate Quantification, index) convert the flow-rate estimate into a score on a 0–10 scale, where a higher value suggests a higher intervention priority. These are algorithms developed experimentally in a semi-anechoic chamber, specific to each type of leak source.

- **Automatic leak-type classification**

  Distinguishing a leak from a flexible hose, an open end, a quick-connect fitting, or a threaded joint is a proprietary algorithmic implementation (first documented on the Fluke ii900/ii910 instruments), but it is built on leak-source categories that are widely recognized in industrial practice: the Compressed Air Challenge, a nonprofit industry organization, independently identifies the same problem areas (fittings, flexible hoses, regulators, condensate drains, gaskets) as the most common causes of leaks in compressed air systems [9].

05

Industrial applications: where acoustics is the most effective technology



Choosing the condition monitoring technology best suited to a given failure mode is not a matter of preference but of physics: every degradation phenomenon generates different signals (acoustic, thermal, vibrational) with different intensities and timing. This chapter describes, with technical honesty, the applications where acoustic inspection is the most effective primary technology, those where it is complementary to other techniques, and those where it is not.

5.1 Gas and compressed air leaks

This is the application where acoustics is, unambiguously, the reference technology. A pressurized gas leak generates an immediate, well-localizable ultrasonic signal, with essentially no thermal gradient (which is why thermography, effective for other phenomena, contributes little in this specific case. This category includes: compressed air, nitrogen, and industrial gas leaks generally (immediate source localization); methane gas leaks, where acoustics complements) without replacing, the OGI (Optical Gas Imaging) technique required for EPA regulatory compliance on regulated compounds; leaks in vacuum systems, where the ultrasonic signal is particularly evident; and steam trap operation, where acoustics assesses the device's internal open/close behavior.

5.2 Partial discharge on MV/HV electrical equipment

The second primary application of acoustics involves inspecting medium- and high-voltage electrical equipment (switchgear, transformers, insulators) for partial discharge detection. As described in chapter 3, all forms of discharge (corona, surface, internal, and the related floating discharge phenomenon, caused by metal components not properly grounded that discharge by induction) emit acoustic energy well before producing a detectable temperature rise, which is why acoustic inspection typically precedes thermography on this specific failure mode, which becomes visible to thermography only at already-advanced stages.

Discharge type	Mechanism	Indicative monitoring frequency	Risk level
Corona	Ionization of air around points/edges	Predictive, quarterly	**Medium** slow degradation, early signal
Floating	Induced discharge from ungrounded metal	Address upon detection	**High** rapid carbon tracking
Surface	Discharge along contaminated insulator	Predictive, bimonthly	**High** accelerates in humid/coastal environments
Internal	Cavity in insulation, invisible from outside	Predictive, monthly	**Very high** silent until catastrophic failure

The operational advantage of this application is significant: the inspection is performed with the panel closed, the equipment energized and in service, with no need for electrical work permits, production shutdowns, or physical contact, reducing personnel exposure to electrical risk compared with traditional test techniques that require opening the panel.

5.3 Other mechanical applications detectable acoustically

The technology application matrix recognizes a limited number of mechanical phenomena, outside the primary scope of leaks and electrical discharges, where the acoustic signal significantly precedes other detectable signals: cavitation in centrifugal pumps, which produces an intense, characteristic ultrasonic noise well before any measurable overheating; and certain lubrication-deficiency conditions, where the acoustic signature precedes the temperature rise. These phenomena are noted for technical completeness: they do not represent the primary scope of the acoustic inspection services described in this document, which remain focused on leaks and partial discharge.

5.4 Where acoustics is not the primary technology: technical honesty

A rigorous technical document must state, with equal clarity, where a technology is not the most effective choice. For a broad group of failure modes, particularly those of a resistive nature on low-voltage electrical circuits, infrared thermography remains the primary technology, because the dominant physical phenomenon is a temperature rise, not a significant acoustic emission:

- **Loose connections and bolts**
  The main issue is increased electrical resistance at the contact point, which manifests as a localized temperature rise, detectable well in advance by thermography.
- **Fuses and breakers**
  The temperature difference between a component in normal condition and one in a degraded state is immediately visible to a thermal camera, with very little additional contribution from acoustics.
- **Low-voltage panels, MCCs, and busbars**
  The most frequent anomalies in these contexts are predominantly thermal in nature (overloads, phase imbalances, faulty connections).
- **An active arc fault**
  The arc generates an intense release of heat that is, by definition, the primary indicator; acoustics can detect its noise, but it is not the reference technique for this phenomenon.

This distinction is not academic: it is the technical reason why a mature condition monitoring program does not rely on a single technology, but combines them based on the failure mode to be anticipated, a topic revisited in chapter 9.

06

Inspection methodology and reporting



6.1 The survey process

Acoustic inspection is, by nature, a non-invasive technique: it does not require shutting down the plant, opening energized electrical panels, or entering confined spaces. This characteristic, however, imposes a few precise operating conditions, without which the measurement loses its meaning:

- The pressurized system must actually be in operation at the time of the survey, acoustic detection of a leak is only possible under live pressure; a minimum system pressure of roughly 4 bar (60 PSI) is generally recommended to ensure an acoustic signal sufficiently distinguishable from background noise.
- **MV/HV electrical equipment must be energized and in normal operation**
  PD inspection is, by definition, an in-service technique: it does not require, and in fact does not benefit from, de-energization.
- The areas to be inspected must be accessible without the need for scaffolding, confined-space entry, or PPE beyond the industrial standard, conditions that, if not met, should be flagged in advance.
- It is advisable to have plant drawings available (P&IDs for pressurized systems, single-line diagrams for electrical equipment), which help prioritize inspection coverage and support mapping the results in the final report.

6.2 From acoustic detection to the economic figure: how savings are quantified

A central methodological principle, often overlooked in the commercial communication around this type of service, deserves to be made explicit: the clean separation between the physical measurement and the economic calculation. The typical process unfolds in three phases:

01

First inspection
The survey produces a list of all detected leaks, each quantified in objective physical units (volumetric flow rate, typically in liters per minute or cubic feet per minute, CFM). At this stage, no economic value is assigned: only measured physical data.

02

Repair interventions
Carried out according to the agreed priority, typically based on the severity/flow-rate index of each leak.

03

Second inspection (verification)
The same points are re-measured after the intervention; the difference in flow rate between the first and second measurement is the volumetric savings actually documented, not estimated, but field-verified.

Calculating the economic value of the savings (applying the customer's specific energy rate to the volume of gas saved) is a step distinct from the physical measurement, and typically falls to the customer or is explicitly agreed upon, a methodological distinction that preserves the credibility of the reported figure: the objective part (the acoustic measurement) and the contextual part (the dollar value, which depends on the site's energy rate) remain separately traceable.

6.3 Report structure and prioritization criteria

A technically complete acoustic inspection report typically includes the following sections:

- **Executive summary**
  A concise overview of the findings: number of leaks detected, estimated aggregate annual cost, number and severity of PD findings, priority actions.
- **Inspection metadata**
  Date, technician, instrumentation used, areas and systems covered, operating conditions at the time of the survey.

- **Acoustic leak survey**

  A numbered table of every detected leak: location, acoustic image, estimated flow rate, severity (high/medium/low), estimated annual cost, recommended action.

- **Partial discharge survey**

  A numbered table of every PD finding: equipment, acoustic image, discharge type, severity level, urgency of the recommended action.

- **Plant map**

  A schematic or annotated layout showing the location of each finding, when a reference drawing is available.

- **Prioritized action plan**

  A list of recommended corrective actions, organized by time horizon: immediate (critical discharges or large leaks), short term (within 90 days), medium term (within 12 months).

A report built on this structure is designed to be directly usable by a reliability engineer or maintenance manager to justify and plan corrective interventions with their own leadership, not just as a technical record, but as a decision-making tool.

07

Regulatory framework and reference standards

Industrial acoustic inspection does not operate in a regulatory vacuum: it fits within a framework of international standards that define its technical context, its reference measurement, or its compliance obligations. The table below summarizes the most relevant standards, with a technically accurate description of their core content.

Standard	Scope and core content
IEC 60270 (ed. 4, 2025)	High-voltage test techniques, partial discharge measurements. Defines the apparent charge measurement (pC) and calibration procedures for PD measuring instrumentation [12].
NFPA 70B (2023 ed.)	Standard for Electrical Equipment Maintenance. As of 2023 it is no longer a mere recommended practice but a binding standard ("shall" language): it requires a documented electrical maintenance program, a qualified coordinator, and scheduled inspections [13].
NFPA 70E	Standard for Electrical Safety in the Workplace. Defines safe work practices and personal protective equipment (PPE) for protection against electric shock and arc flash [14].
ISO 55001:2014	Asset management, Management systems, Requirements. Specifies the requirements for an asset management system that balances performance, risk, and cost across the entire lifecycle [16].
ISO 17359:2018	Condition monitoring and diagnostics of machines, General guidelines. General guidance for setting up a condition monitoring program: asset identification, monitoring methodology, data analysis, maintenance decision criteria [17].
ISO 18436 (series)	Condition monitoring and diagnostics of machines, Requirements for qualification and certification of personnel, structured in multiple parts (vibration, acoustic emission, ultrasound) [18].
ISO 20816-1:2016	Mechanical vibration, Measurement and evaluation of machine vibration. Successor to ISO 10816; establishes vibration severity criteria for operational monitoring and acceptance testing [19].
EPA Method 21 / LDAR	EPA reference method (Clean Air Act, 40 CFR) for Leak Detection and Repair of regulated compounds, VOCs and gases governed by NSPS/NESHAP [20].
ISO 50001	Energy management systems, provides the framework within which the energy-consumption reduction from repairing identified leaks fits.

Two technical clarifications are important for correct use of this regulatory framework. First, acoustic inspection for detecting leaks of compressed air and unregulated gases does not, by itself, produce documentation compliant with EPA Method 21: for compounds subject to a compliance obligation (methane, regulated VOCs), the reference technique remains OGI (Optical Gas Imaging) or an FID analyzer per the applicable regulatory requirements, acoustics is complementary, not a substitute, in this specific regulatory context.

Second, acoustic inspection for detecting partial discharge is, strictly speaking, a qualitative screening and localization tool, not an electrical measurement calibrated to IEC 60270: applications requiring formal certification or an apparent-charge figure in picocoulombs need a dedicated electrical measurement. This distinction, often blurred in commercial communication, is instead a matter of technical accuracy that any inspection program should state explicitly to the customer.

08

Market context: predictive maintenance trends

8.1 The growth of the predictive maintenance market

The global predictive maintenance market is in a phase of sustained growth, although estimates from different analysts diverge significantly depending on the scope definition adopted. MarketsandMarkets estimates the global market at roughly $12.1 billion in 2025, with growth projected to $23.8 billion by 2031 (an 11.4% CAGR) [24]. Other analysts (Mordor Intelligence, Grand View Research) publish comparable baseline estimates for 2025 (on the order of $14 billion) but significantly more aggressive growth projections, with CAGRs exceeding 30%, a divergence that mainly reflects differences in what is included within the "predictive maintenance" scope (software, hardware, services, or all three) rather than disagreement on market fundamentals.

The underlying signal, common to all sources analyzed, is unambiguous: the market is growing at a double-digit rate, driven by the convergence of three factors: the maturation of low-cost sensor technologies (IoT, MEMS), growing pressure on energy and operating costs, and greater awareness, documented in the Siemens/Senseye and Deloitte reports cited in chapter 2, of the economic impact of unplanned downtime.

8.2 Why acoustics as an entry point

Within a portfolio of condition monitoring technologies, acoustic inspection occupies a particular position from an industrial-adoption standpoint: compared with continuous vibration monitoring, it requires no installation of permanent sensors nor any upfront infrastructure investment; compared with a predictive maintenance program built on multiple technologies, it requires no organizational transformation: a single survey produces a tangible, quantified result within a single day of inspection.

In practice, this makes it the technology with the lowest activation barrier among non-invasive condition monitoring options, a natural entry point for an organization that does not yet have a structured reliability engineering function, before evaluating a broader investment in continuous sensing or a multi-technology monitoring program.

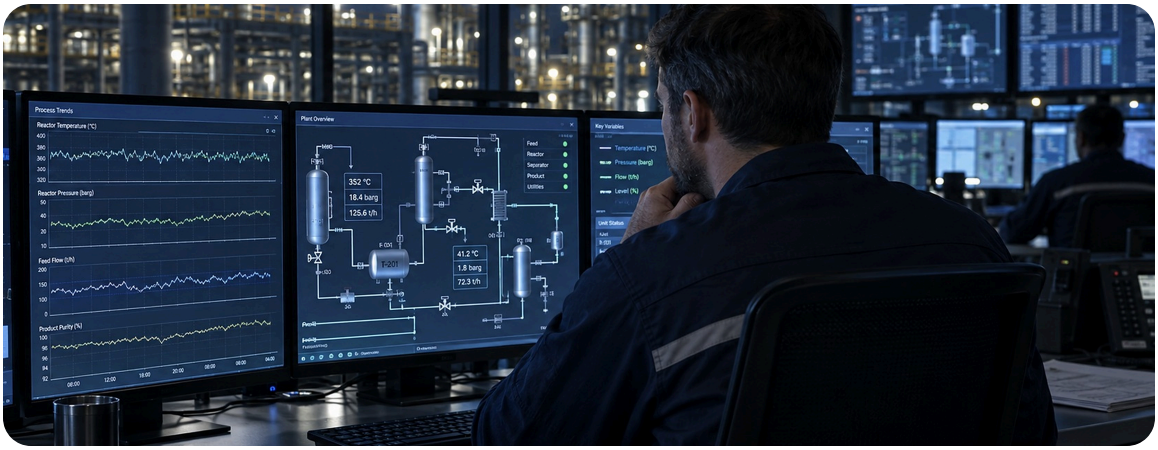
8.3 Industrial adoption: drivers and barriers

Industry literature and field experience converge in identifying a specific market segment as the most receptive to this type of technology: mid-sized industrial operators (Oil & Gas, petrochemical, and manufacturing plants) that lack an in-house reliability engineer or a structured predictive maintenance program, and that typically manage maintenance in a predominantly reactive mode. For this segment, the main barrier to adoption is not technological but organizational and informational: a lack of awareness of the true scale of the problem (how many leaks, what cost) and the absence of in-house expertise to independently interpret the results of a technical inspection.

> **The Key Point**
>
> In most cases, the barrier to predictive maintenance adoption is not the cost of the technology; it is the absence of a first concrete data point on which to base a decision. This is the technical and economic reason why a targeted acoustic inspection represents, for many organizations, the most efficient way to acquire that first data point.

09

Acoustic inspection in BNA Guardian's Asset Health & Reliability journey



9.1 The three-pillar framework

As anticipated in the introduction, this document treats acoustic inspection as a self-contained technical chapter, but its strategic position within BNA Guardian, Basis North America's Asset Health & Reliability (AHR) program, is that of the first building block in a three-technology condition monitoring framework, each sensitive to a different dimension of an asset's health:

Acoustic inspection	Gas and compressed air leaks, partial discharge on MV/HV electrical equipment. The subject of this document.
Infrared thermography	Detection of thermal anomalies on electrical equipment (connections, load imbalances) and mechanical equipment, with particular relevance for compliance with standards such as NFPA 70B.
Continuous vibration monitoring	IoT sensors permanently installed on critical rotating assets, for round-the-clock monitoring that, on the P-F curve, anticipates even the signals detectable by periodic inspection technologies.

Each of these three technologies will be the subject of a dedicated technical document, with the same level of depth given here to acoustics. This document is limited to framing the logic of their integration.

9.2 How they integrate over time

The logic underlying this framework is not to stack three technologies at once, but to build, over time, an increasingly complete picture of the health of a plant's critical assets, starting from the technology with the most immediate return and the lowest activation barrier. For the reasons described in chapter 8, acoustic inspection is typically that starting point: a single survey produces a quantified result (localized leaks, classified discharges, intervention priorities) without requiring any upfront infrastructure investment.

From this first data point, an organization can choose to extend its condition monitoring capability toward thermography (to cover the thermally dominant failure modes described in section 5.4) and toward continuous vibration monitoring (for critical rotating assets, where round-the-clock monitoring offers the widest diagnostic lead time on the P-F curve), a path that is built around each plant's specific priorities, not according to a fixed template.

10

Conclusions

Compressed air and process gas leaks, and the deterioration of electrical insulation before failure, are physical phenomena that the human ear cannot perceive but an instrument can measure: both generate acoustic energy in the ultrasonic band well before manifesting as cost, downtime, or safety risk. This is the physical, not commercial, foundation on which industrial acoustic inspection rests.

The data gathered in this document (from DOE estimates on average compressed-air loss in industrial plants, to documented costs of unplanned downtime, to statistics on the electrical risk from undetected partial discharge) converge on a single conclusion: in this domain, the cost of inaction is nearly always higher than the cost of inspection. Not for every company, not in every circumstance, but as an underlying trend solid enough to justify, at the very least, an initial technical assessment.

The professional instrumentation available today (of which the Fotric H6 is a representative example of the high end, with a 162 MEMS-microphone array and 2 to 100 kHz bandwidth coverage) has reached a level of technological maturity that makes this assessment accessible, fast, and non-invasive. Chapter 5 of this document also deliberately made clear where this technology is not the most effective choice: a mature approach to condition monitoring is not built on a single technology, but on the combination of multiple techniques, each applied where the physics of the phenomenon makes it most effective.

It is within this logic, not of replacement but of progressive combination, that acoustic inspection fits into BNA Guardian's Asset Health & Reliability journey: as the first building block of a broader condition monitoring framework, described in chapter 9, which over time can extend to infrared thermography and continuous vibration monitoring, the subjects of dedicated technical documents.

Bibliography and sources

1 U.S. Department of Energy, Compressed Air program: estimate of average compressed-air loss in industrial plants (20–30% of output).

2 ENERGY STAR, estimate of loss in compressed-air systems without regular maintenance (up to 50% of output).

3 Eret, P., Meskell, C. (2012). "Microphone Arrays for Compressed Air Leakage Detection." 4th Berlin Beamforming Conference, BeBeC-2012-17, Trinity College Dublin.

4 Holstein, P., Barth, M., Probst, C. (2016). "Acoustic methods for leak detection and sealing verification." Proceedings, 19th World Conference on Non-Destructive Testing, pp. 13–17.

5 Wolstencroft, H., Neale, J. (2008). "Characterisation of compressed air leaks using airborne ultrasound." Proceedings of Acoustics (AAS'08).

6 Harris, C. M. (1966). "Absorption of sound in air versus humidity and temperature." The Journal of the Acoustical Society of America, 40(1), 148–159.

7 Vladišauskas, A., Jakevičius, L. (2004). "Absorption of ultrasonic waves in air." Ultragarsas, 50(1), 46–49.

8 Semitela, Â., Girão, A. F., Verdasca, S., Completo, A. (2025). "Visualizing Sound: Localization of Air Leaks with Acoustic Technology for Product Testing." Advances in Design, Simulation and Manufacturing VIII (DSMIE 2025), Springer, pp. 201–210.

9 Compressed Air Challenge, Fact Sheet #7, "Compressed Air System Leaks", nonprofit industry organization.

10 Aggregate industry analysis based on DOE/ENERGY STAR data, cost of a single leak, 20/80 waste distribution, compressor failure rate as a function of plant age.

11 HIKMICRO, manufacturer-documented case: leaks with an estimated value of $41,500/year identified in 2.5 hours of acoustic inspection.

12 IEC 60270:2025 (ed. 4). "High-voltage test techniques, Partial discharge measurements." International Electrotechnical Commission.

13 NFPA 70B (2023 ed.). "Standard for Electrical Equipment Maintenance." National Fire Protection Association.

14 NFPA 70E. "Standard for Electrical Safety in the Workplace." National Fire Protection Association.

15 IEEE Dielectrics and Electrical Insulation Society, partial-discharge degradation mechanisms (thermal, electrical, chemical pathways); arc flash incidence and electrical fatality data compiled by Johns Hopkins University / Electrical Safety Foundation International (ESFI) from Bureau of Labor Statistics data.

16 ISO 55001:2014. "Asset management, Management systems, Requirements." International Organization for Standardization.

17 ISO 17359:2018. "Condition monitoring and diagnostics of machines, General guidelines." International Organization for Standardization.

18 ISO 18436 (series). "Condition monitoring and diagnostics of machines, Requirements for qualification and assessment of personnel." International Organization for Standardization.

19 ISO 20816-1:2016. "Mechanical vibration, Measurement and evaluation of machine vibration." International Organization for Standardization (successor to ISO 10816).

20 U.S. Environmental Protection Agency, Method 21 / Leak Detection and Repair (LDAR), Clean Air Act, 40 CFR (NSPS/NESHAP).

21 Siemens / Senseye Predictive Maintenance (2022). "The True Cost of Downtime 2022."

22 ARC Advisory Group. "Making Predictive Maintenance Effective, Scalable, and Repeatable."

23 Deloitte (2024). "Smart manufacturing: predictive maintenance", citing Emerson/IndustryWeek (2023) data.

24 MarketsandMarkets. "Predictive Maintenance Market Report 2026–2031, by Monitoring Infrastructure, Geo, Tech."

25 FOTRIC, official technical specifications for the Fotric H6 Acoustic Imaging Camera, fotric.com.

26 DigiKey, Rose, B. "An Introduction to Beamforming with MEMS Microphones", technical application article, June 5, 2019.

27 Wang, Y., Deng, Z., Zhao, J., Kopiev, V. F., Gao, D., Chen, W.-L. (2025). "Progress in beamforming acoustic imaging based on phased microphone arrays: Algorithms and applications." Measurement, vol. 242, art. 116100.

Methodological Note

This document favors, where available, data published by standards bodies, government agencies, and peer-reviewed academic literature. Where a figure comes from a manufacturer or a non-independent industry source, this is stated explicitly in the text. Certain claims that recur in the industry's commercial communication (for example, precise figures on the diagnostic lead time of partial discharge) do not, as far as the research conducted could establish, have a verifiable primary source, and have been deliberately excluded.

BNA GUARDIAN

ASSET HEALTH & RELIABILITY



sales@basisnorthamerica.us

+1 713 779-3008

BNA
BASIS NORTH AMERICA

Basis North America Inc.
Houston, TX