



HIGH TEMPERATURE BLADE
CLEARANCE & VIBRATION
MONITORING SYSTEMS

CapaciSense[™]

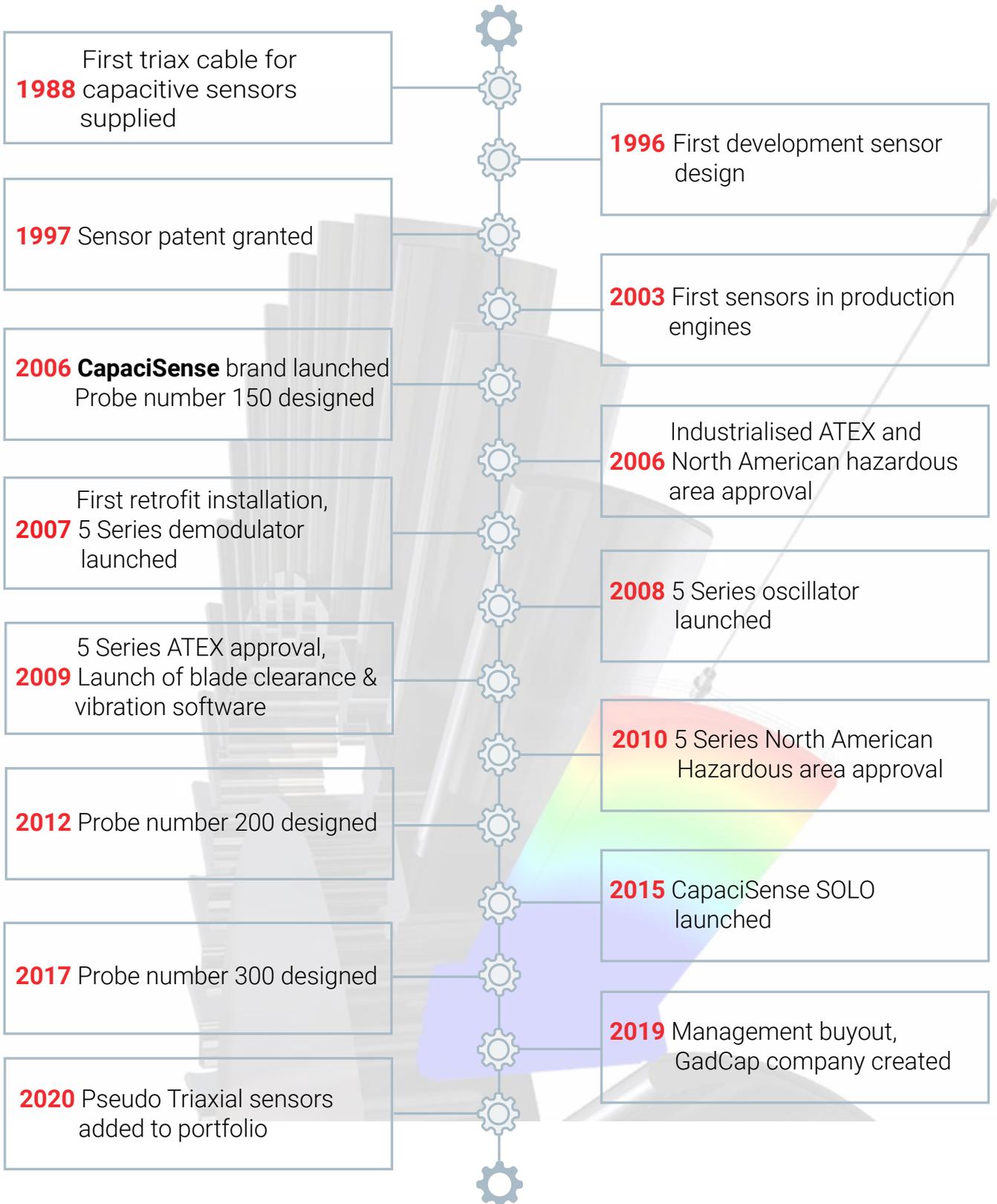
By



History

CapaciSense systems were developed in the 1980's with the support of Pyrotenax, the market leader in high temperature mineral insulated cable. The **CapaciSense** product has now matured into a full system and service package, employed worldwide within the power generation and aerospace industries. **CapaciSense** sensors are favoured for their ability to survive extreme conditions over several years, enabling both the compressor and turbine stages to be monitored continuously.

We have been part of many companies over the years, however the one thing that has remained the same throughout these changes are the people designing, manufacturing and supporting the **CapaciSense** system, with many decades of experience residing within GadCap Technical Solutions.



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About

MONITOR BLADES IN AN OPERATIONAL TURBINE, EVEN AT HIGH TEMPERATURES

GadCap **CapaciSense** systems combine blade tip clearance and vibration monitoring using high bandwidth electronics to provide two sets of data from one state-of-the-art turbine sensor. With sensors (probes) that are able to withstand temperatures of up to 1400°C/2552°F, **CapaciSense** systems enable you to monitor turbines at temperature and in continuous operation.

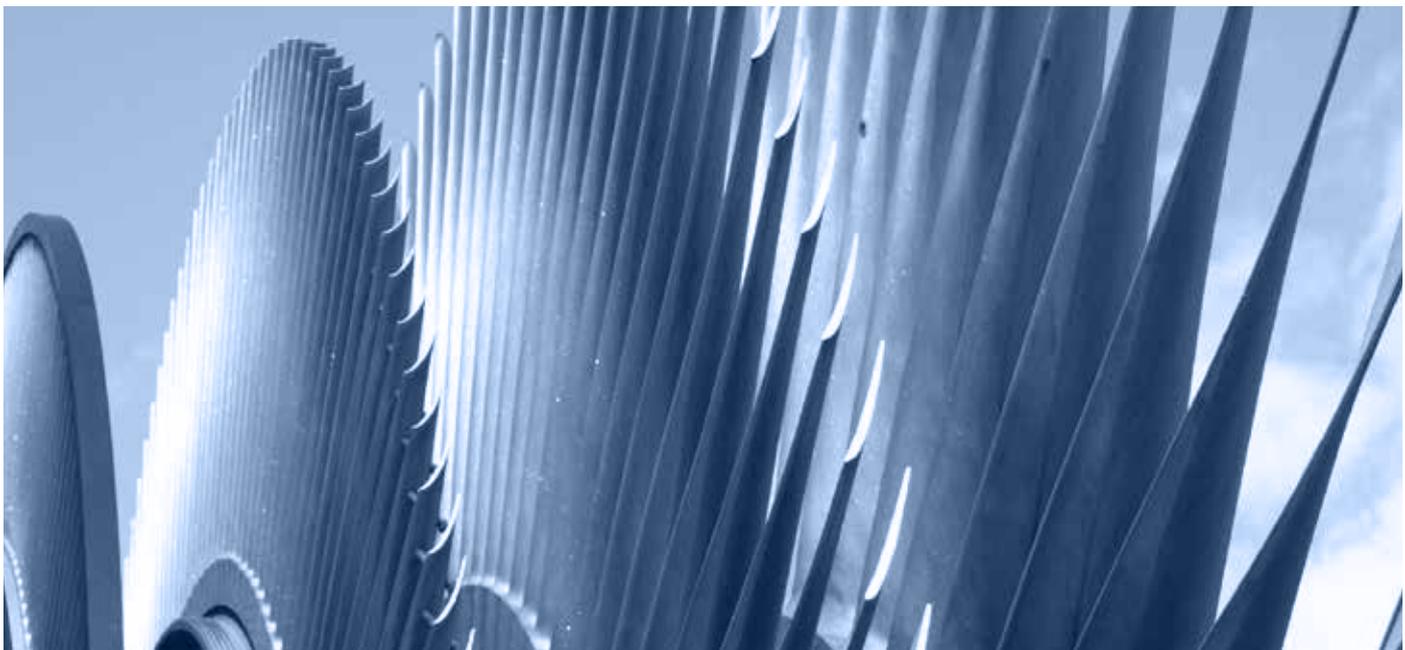
By providing a virtual window to see inside the operating turbine engine, **CapaciSense** condition monitoring systems:

- Provide accurate real-time data to help achieve smaller clearances; optimise the machine's efficiency reducing fuel costs
- Monitor differential thermal growth during warm restarts to prevent tip damage caused by blade rubbing
- Monitor vibrations through tip timing to provide an early warning of problems or potential failure, preventing unplanned and expensive outages or even catastrophic failure

CapaciSense systems are used in gas turbines within the power generation and aerospace industries, although they are also suitable for other applications where a conventional proximity probe would not survive the environment.

CapaciSense systems are based on capacitance theory and contain sensors, turbine mounted/local electronics, remote electronics and a control and processing module with analysis software.

This document gives a brief overview of what **CapaciSense** has to offer.



Applications

ENGINE DESIGN VERIFICATION

A driving factor when designing gas turbines, whether it be power generation or aerospace, is efficiency. Higher fuel efficiency means lower operating costs, often driving the decision on which turbine to adopt. Most of the world's leading developers of turbines have used our systems for design verification of blade tip-to-shroud clearances at high temperatures, supplanting the older technologies.

By using our **CapaciSense** system, turbine designers can get a live picture of the blade tip clearances in prototype engines during all phases of the engine's operation.

OPERATING ENGINE

Some of the most efficient engines use adaptive clearance control to optimise blade clearances while running. **CapaciSense** is used to provide the valuable data required to drive these systems.

Designers of some of the world's largest power generating turbines have chosen to install our condition monitoring system to continuously monitor blade clearances and vibration. Aerospace customers have also used **CapaciSense** on flying test engines, proving aero-engine condition monitoring is possible.

If you are responsible for insuring an operator engine, by installing a **CapaciSense** system you can have extra confidence that the asset is being correctly operated and potential damage caused by warm re-starts can be prevented.

RETROFIT

As downtime for maintenance is expensive, it is imperative that this is minimised and performed at the right time with informed knowledge of current engine conditions. By retrofitting with a **CapaciSense** system, the user can be given forward notice of potential blade failure due to blade rubbing or vibration. This additional intelligence on the engine operation allows warm restarts to be safely performed with the knowledge that differential thermal expansion isn't going to cause a blade rub which could result in costly repairs.

With Europe and North America approvals, our systems can be used safely in hazardous areas. This is of particular interest for those considering retrofitting turbines with additional condition monitoring sensors for predictive maintenance or to check blades in "near rubbing" conditions.

NON-GAS TURBINES

While the **CapaciSense** system's primary application is in turbines, it can also be used for proximity applications where conventional systems are inadequate, for example gas seal clearances; impellers such as turbo chargers; or piston clearance measurement.



Why Choose a CapaciSense System?



IMPROVED RELIABILITY AND REDUCED MAINTENANCE COSTS

By providing real time data, early warning signals of potential problems are given, which will help to make informed decisions and avoid unplanned and expensive outages or even catastrophic failure.

Turbines are extremely sensitive to blade tip rubbing, which can be a cause of failure. Our tip clearance functionality monitors differential thermal growth during warm restarts and the information provided helps prevent tip damage caused by blade rubbing.

The tip timing functionality monitors the arrival time of a blade tip and uses this to calculate blade deflections and identify vibration.

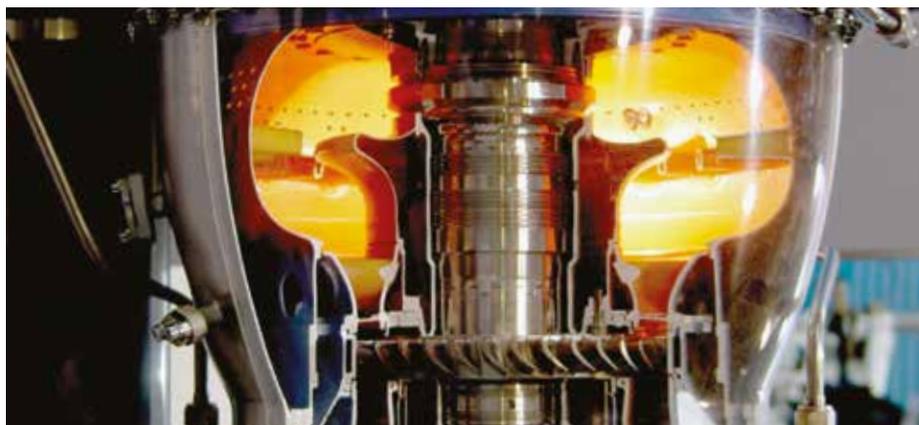
IMPROVED OUTPUT AND EFFICIENCY

Due to the high temperatures within an engine our sensors are designed to perform at up to 1400°C/2552°F temperatures. Even the turbine stage blade clearance can be measured, an important factor as this means the whole engine can be monitored, not just the lower temperature compressor areas. This raises the possibility of controlling the various stages independently and optimising the whole turbine rather than just one zone.

As the turbine's fuel efficiency is directly affected by the size of the clearance, designers and manufacturers use the live outputs to adjust clearances to a minimum on working turbines and therefore gaining greater fuel efficiencies.

SUITABLE FOR HAZARDOUS LOCATIONS

The 5 Series FM system is approved for use in hazardous locations in North America and the **CapaciSense** SOLO system is approved for use in hazardous locations in both Europe and North America. The FM system gives the option of installing the oscillators within the hazardous area and connecting to 6 m (19.7 ft) of probe cabling where as the **CapaciSense** SOLO has to be in a safe area but can drive up to 20 m (65.6ft) of cable into a hazardous area.



TIP TIMING AND CLEARANCE FROM ONE SENSOR

CapaciSense systems can provide both tip clearance and tip timing from one state-of-the-art sensor. With the advent of high speed electronics and software, the blade passing signal, which has traditionally provided only clearance information, is now capable of resolving blade time of arrival.

Traditional methods for measuring blade fatigue include strain gauging and optical tip timing and whilst strain gauges provide accurate information, they only provide that information for the blades which are instrumented and these gauges are not suitable for a production environment. Their very installation even changes the blade vibration characteristics.

Optical sensors provide excellent tip timing data but only for short periods of time as their optics can become fogged. By using already proven **CapaciSense** clearance sensors, additional data can be derived on blade vibration without the need to install additional instrumentation.

LONG LASTING

For condition monitoring applications, sensors need to perform optimally over extended periods of time. **CapaciSense** sensors are proven to be robust. The four sensors, removed during regular servicing, pictured at the top right, have had years of continuous operation in the hottest turbine zone in one of the worlds largest turbines. One sensor has been polished to remove combustion product deposits - it shows it is still close to its original condition. All **CapaciSense** sensors have patented fully captive components which limits the risk of the sensor breaking apart into the engine, even if it becomes damaged.

TRUSTED HISTORY

Our systems have been successfully used worldwide by gas turbine manufacturers to verify the frame clearances in extreme environments since development began in 1996.

CUSTOMISED SOLUTIONS

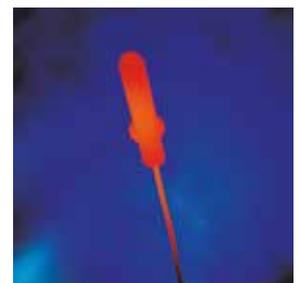
The **CapaciSense** team provides a full design and development service on every project in order to meet the requirements of your application. We custom make our sensors to suit your environment:

- Temperature extremes (1400°C/2552°F)
- Temperature cycling
- Vibration
- Moisture (including on-line water wash)

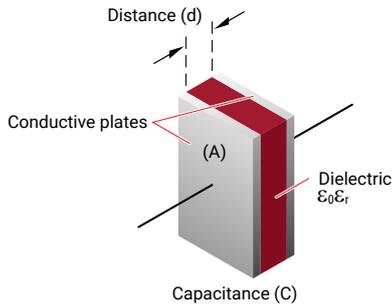
Calibration disc design and manufacture to replicate actual blade tip profiles, sensor calibration and a full installation service are offered as part of our solution. It is our goal not to provide components but to provide whole solutions.

MAKING YOUR LIFE EASIER

When the 5 Series was launched as well as improving the signal quality, we introduced calibration download from the oscillator to the demodulator and the ability to confirm the electronics were connected to the right channel. With **CapaciSense** SOLO we have gone one better, where the calibration data is now stored on the probe itself. A **CapaciSense** probe can be plugged into any SOLO device and measure clearance without the need to recalibrate or assess calibration data.



How CapaciSense Works



$$C = \frac{\epsilon_0 \epsilon_r A}{d}$$

Where:

C= Capacitance

ϵ_r = Relative permittivity
(constant in this application)

ϵ_0 = Permittivity of free space (constant)

A= Overlapping electrode area
(constant in this application)

d= Electrode separation

As C is proportional to 1/d, by measuring C, d can be determined.

CapaciSense is a non-contact measurement system that uses capacitance to detect the distance of an object and its time of arrival.

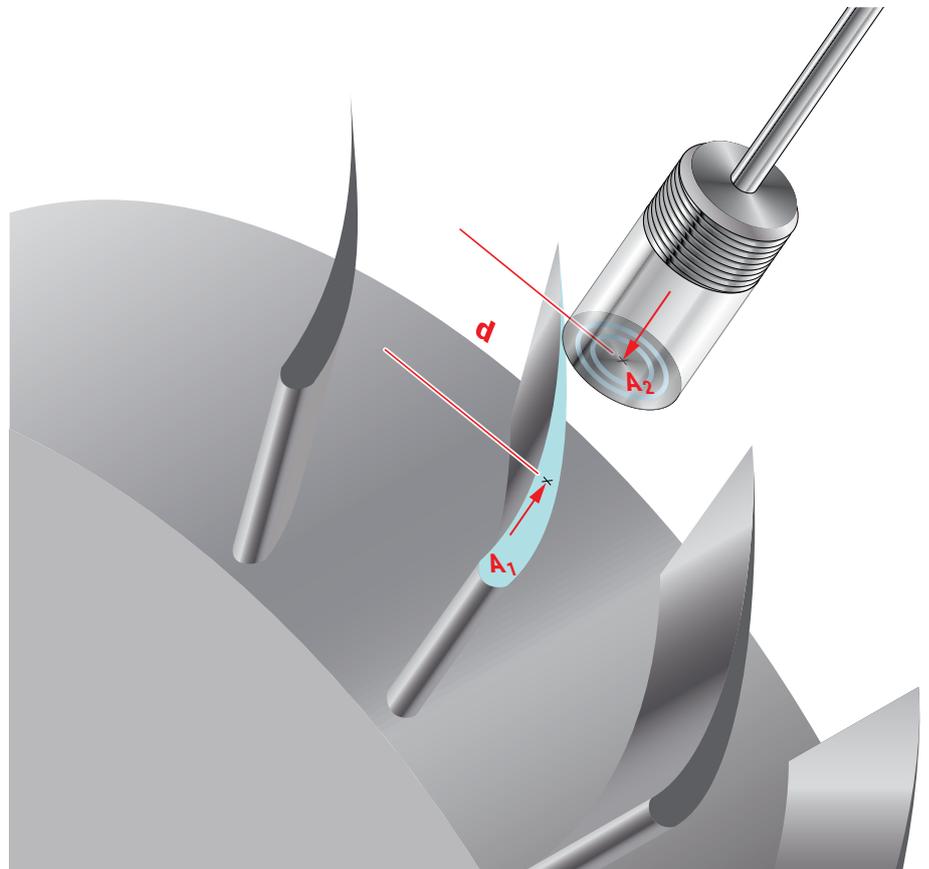
CAPACITIVE TECHNOLOGY

The core functionality of the system is relatively simple and uses capacitance parallel plate theory.

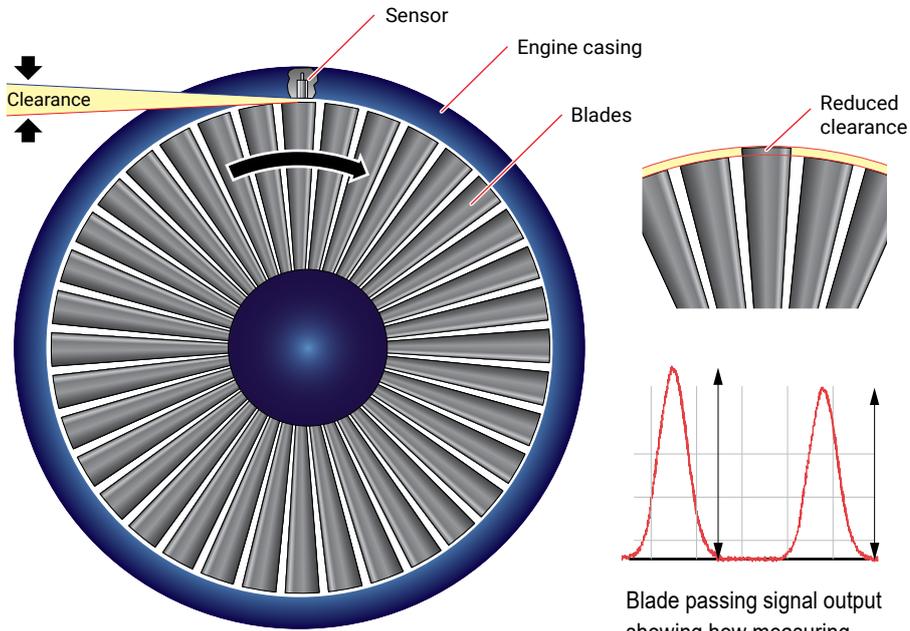
The overlapping electrode area, which is specific to blade profile (A1) and electrode dimensions (A2), is assumed to be constant. The permittivity can also be considered to be constant as the small changes which do occur due to combustion have proven to be negligible.

This theory gives us the ability to calculate the distance separating blade tip to sensor 'plates' by measuring the capacitance. The advanced electronics of the system convert this capacitance into a voltage, allowing a direct correlation between voltage and distance to be established while the blade is passing at over the speed of sound.

As the returned capacitance from a system such as this is extremely small (tens of femtofarads, fF), advanced techniques need to be utilised to accurately measure them - see our electronic options described on page 12.



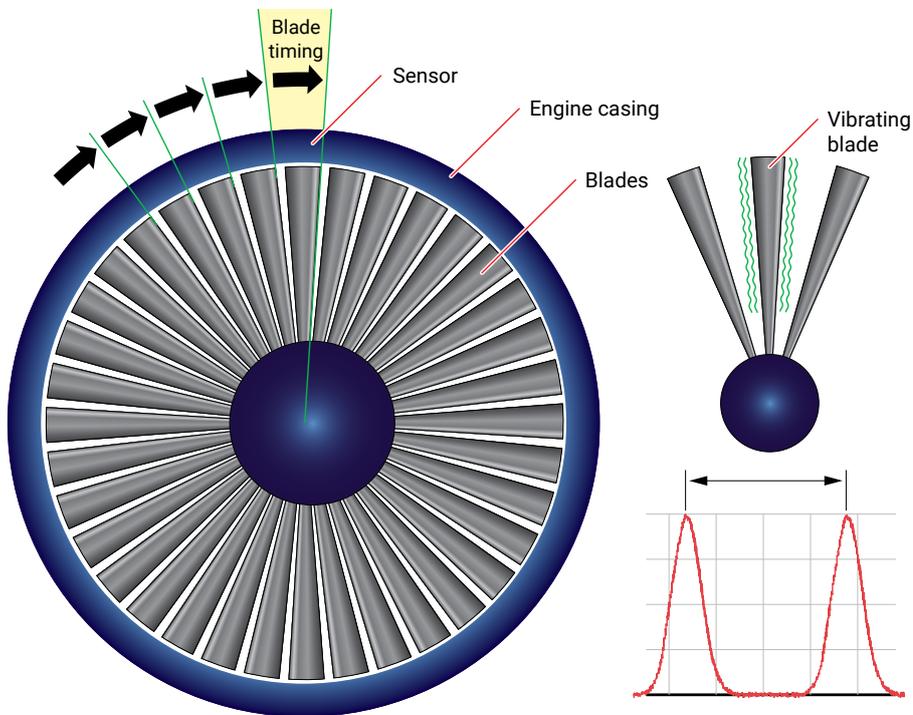
TIP CLEARANCE



Blade passing signal output showing how measuring pulse amplitude is used for clearance monitoring



TIP TIMING



Blade passing signal output showing how measuring time of arrival is used for vibration monitoring

Sensor and Cable Assemblies (Probes)

APPROVALS AND CERTIFICATIONS

CapaciSense high temperature clearance and vibration monitoring systems are approved and certified for use in nonhazardous and hazardous locations by globally recognised Certification Bodies.

Certificate Numbers:

FM20US0059

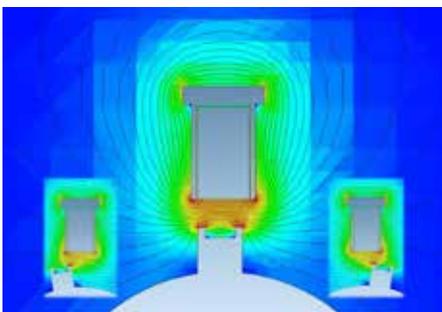
FM20CA0027X

Baseefa 15ATEX0173X/2

IECEX BAS 15.0127X

All **CapaciSense** probes are designed and manufactured in the Washington UK facility. Significant investment has been made over recent years to update the laser welding of the probes and to allow parts to be machined in house.

Finite Element Analysis (FEA) tools are used to gain further understanding of the technology to help make the next generation of probes even better.



Traditionally all of the **CapaciSense** Probes are triaxial in construction, meaning the inner electrode is surrounded by a guard electrode and then the bodyfeaturing:

- A central "sensing" electrode
- A driven guard for reduction of leakage capacitance
- Outer screen/body for noise reduction
- All inner components are captive to prevent metallic parts falling into the blades
- Custom designs (over 300 to date)
- Optimised for continuous surfaces or bladed systems depending on the application
- Super-alloy construction to allow use up to 1400°C (2552°F)
- Rugged construction allow for a potential life span of over 10,000 hours of run time

Triaxial or Pseudo Triaxial?

In addition to full triaxial probes we also offer pseudo triaxial probes. These probes terminate the cable guard within the sensor without being connected to a guard electrode. This allows them to be smaller and due to the reduced number of internal components they are also less expensive. However they have some disadvantages compared to fully triaxial, including higher noise levels and reduced range. Starting in 2020, GadCap have started to offer these budget pseudo triaxial sensors for use with the **CapaciSense** Solo where price is of more importance than signal quality.

HIGH TEMPERATURE SENSORS



Used predominantly for turbine applications. The inclusion of flutes and cooling apertures has advanced the operational capabilities of these designs up to 1400°C/2552°F

MID-RANGE TEMPERATURE SENSORS



Typically for compressor applications or AM systems, the mid-temperature range of designs have an operating temperature of up to 1000°C/1832°F. The mid-range sensors have the same characteristics as the high temperature range without the cooling functionality. These sensors can still be used at higher temperatures although their life will be shortened.

LOWER TEMPERATURE SENSORS



For operational use at temperatures below 200°C/392°F, the low temperature design incorporates flexible triaxial cable as opposed to mineral insulated cable. Whilst still using the specialist assembly techniques, the sensors benefit from a lower cost and an easier installation.

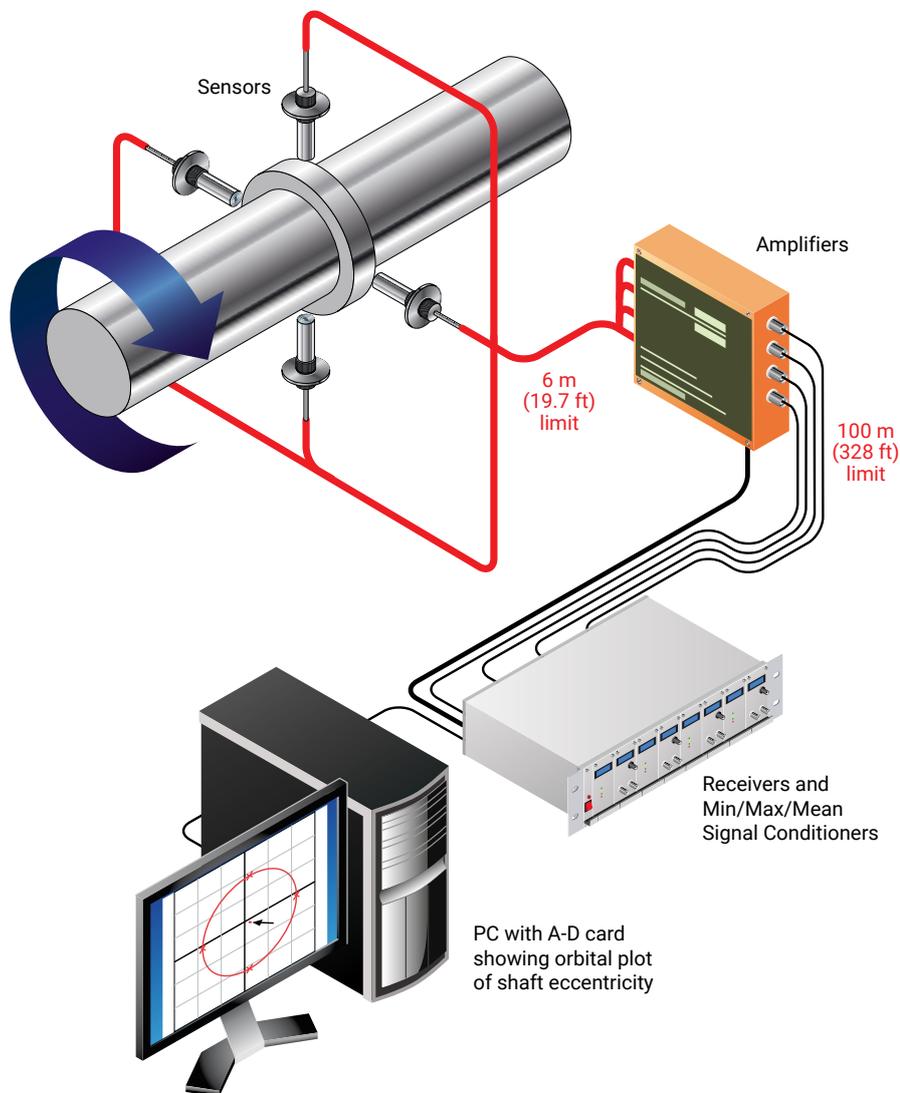
Electronics for Continuous Surfaces

AM SYSTEM

The system is ideally suited to measuring slow moving clearances in harsh conditions.

Probes, with cable up to 6m (19.7ft) connect to a locally mounted AM Oscillator Enclosure. The enclosure can house up to four amplifiers, allowing up to four probes to be connected. Output leads from the enclosure plug into a 19" Rack holding up to eight receivers so can be used with two enclosures. A "DC" signal is available which is either proportional to clearance or capacitance. As this is such a low frequency application, most measurement systems can record and linearise it into engineering clearance units using suitable calibration data. Optional MIN/MAX/MEAN modules are also available to reduce the measurement demands.

SYSTEM COMPONENTS



Electronics for Bladed Systems



5 SERIES FM SYSTEM

Built on the hugely successful 4 Series, the 5 Series offers a “two box” solution to your capacitive sensing needs. A small oscillator is installed at the end of a probe, up to 6m (19.7ft) long, this is then connected to a 19" rack by a length of coax cable up to 100m (328ft) long. The 19" rack can hold up to 12 demodulators and hence be connected to up to 12 oscillators and probes.

The 5 Series offers backward compatibility with the 4 Series solution and single channels can be purchased to allow channel count upgrades to existing installations.

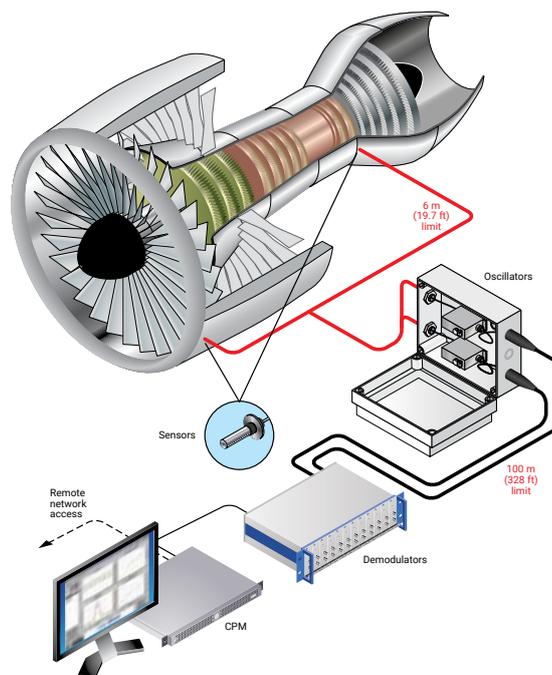
While GadCap recommends the 5 Series be connected to our Control and Processing Module (CPM) for full control and flexibility, it is possible to manually configure the system and use your own data recording systems to measure an “average” RMS clearance signal or the raw blade passing signal (BPS) for processing into blade by blade clearance.

When used with the CPM, 12 voltage-free alarm contacts are available on each demodulator rack and these can be configured to warn the user of clearances falling outside of tolerance.

Probe calibration data can be stored within the oscillators to be automatically downloaded to the CPM for signal linearisation, and confirmation of which probe is being monitored

The 5 series has an impressive 400kHz maximum bandwidth and has North American approval for use in hazardous areas.

SYSTEM COMPONENTS



SOLO SYSTEM

Designed to be a perfect solution for industrial installations, the SOLO is a “one box” electronic solution. Each SOLO unit can be connected up to 4 probes, with each having a combined length of up to 20m (65.6ft) of cables, although longer cables may be possible in some situations. The system outputs a blade passing signal (BPS) for each channel which can be recorded by your own measurement system, but is truly designed to work in conjunction with the **CapaciSense** CPM to give live average and blade by blade clearance data, as well as time of arrival (TOA) tip timing data. The CPM's are also used to perform full configuration of the SOLO via its RJ45 network connection.

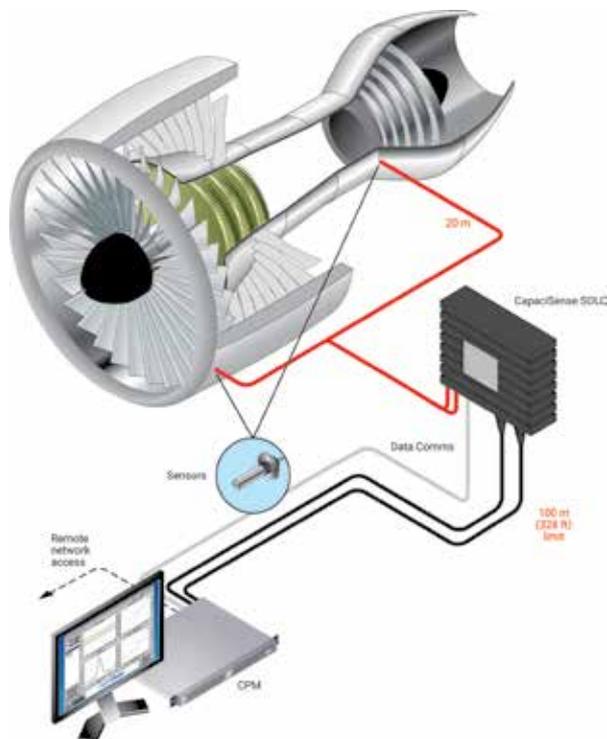


Unlike the 5 Series, custom matching of probes to the electronics is no longer required, meaning probes can be swapped from one system to another. To facilitate the ease of use, **CapaciSense** probes now offer “smart” labels which are read by SOLO. Upon installation all of the probe details, including calibration, are passed to the CPM. To ensure there is no cross wiring, SOLO produces a test signal to confirm the channel numbers.

With a bandwidth of over 350 kHz, it doesn't quite equal the 5 Series but is more than fast enough for most applications.

As a one box solution SOLO is ideally suited for retrofitting to existing rotating equipment. **CapaciSense** SOLO has North American and ATEX approval for use in hazardous areas.

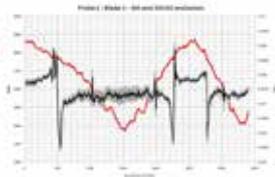
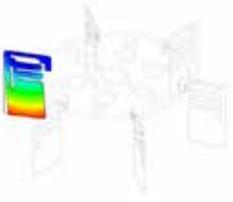
SYSTEM COMPONENTS



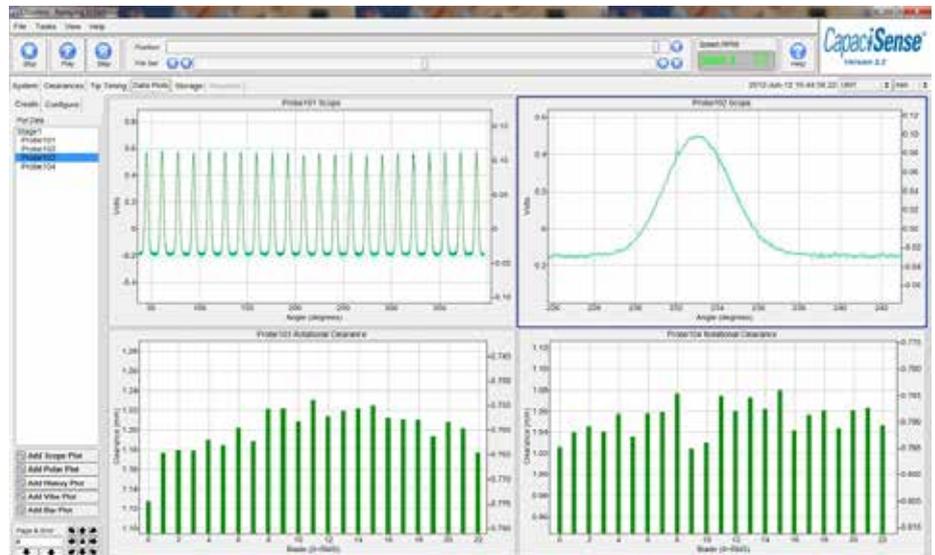
Software

CONTROL AND PROCESSING MODULE WITH SOFTWARE (CPM)

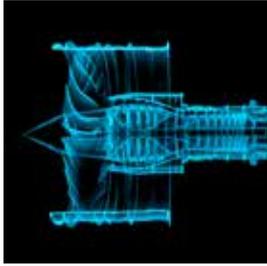
Used initially to configure the system and to present the data in values, figures, visual plots and charts:



- Can control both 5 Series and SOLO
- Up to 10 MHz simultaneous sampling in control and processing modules (CPM) from analogue BPS signal
- Built-in data acquisition and software means no analogue data for the user to acquire and analyse, although the raw data is presented for advanced users to analyse
- Gain and bandwidth settings controlled via CPM
- Auto download of sensor calibration means no mixing of signals
- Auto setup - no jumper settings
- Sync signal - used to synchronise multiple racks for the pooling of data
- Hard disc for data storage and further analysis
- 5 Series and SOLO configuration to allow Ultra Slow Mode
- Once per rev input (engine speed/blade identification)
- Addition of blade vibration monitoring from the same system that gives the tip clearance (simple software update)
- Remote access from Microsoft Windows® or Linux® based machines - no software needs to be installed.
- Modbus and DLL interface to other systems

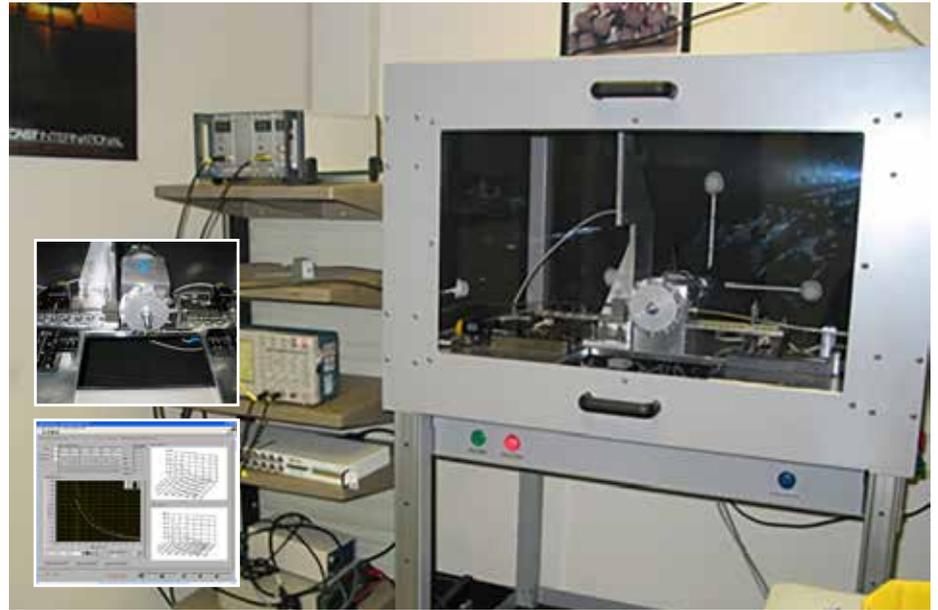


Service & Support



GadCap offers a full design service to provide a turnkey solution to your measurement needs. As well as providing custom designed probes and user tailored electronics, all systems can be calibrated to your specific targets – something which is especially important for bladed systems.

Once you have purchased our system, you can rely upon first class after sales support for training, site installation assistance or simply to ask a question. We are here to help. Contact your local representative or the GadCap headquarters to discuss your needs or obtain more information.



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