HIGH TEMPERATURE BLADE CLEARANCE & VIBRATION MONITORING SYSTEMS

CapaciSense™

By GADCAP© TECHNICAL SOLUTIONS

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

1988 First triax cable for capacitive sensors supplied

1996 First development sensor design

1997 Sensor patent granted

2003 First sensors in production engines

2006 **CapaciSense** brand launched Probe number 150 designed

2006 Industrialised ATEX and North American hazardous area approval

2007 First retrofit installation, 5 Series demodulator launched

2008 5 Series oscillator launched

2009 5 Series ATEX approval, Launch of blade clearance & vibration software

2010 5 Series North American Hazardous area approval

2012 Probe number 200 designed

2015 CapaciSense SOLO launched

2017 Probe number 300 designed

2019 Management buyout, GadCap company created

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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 1400°C/2552°F, **CapaciSense** systems enable you to monitor turbines at temperature and in continuous operation.

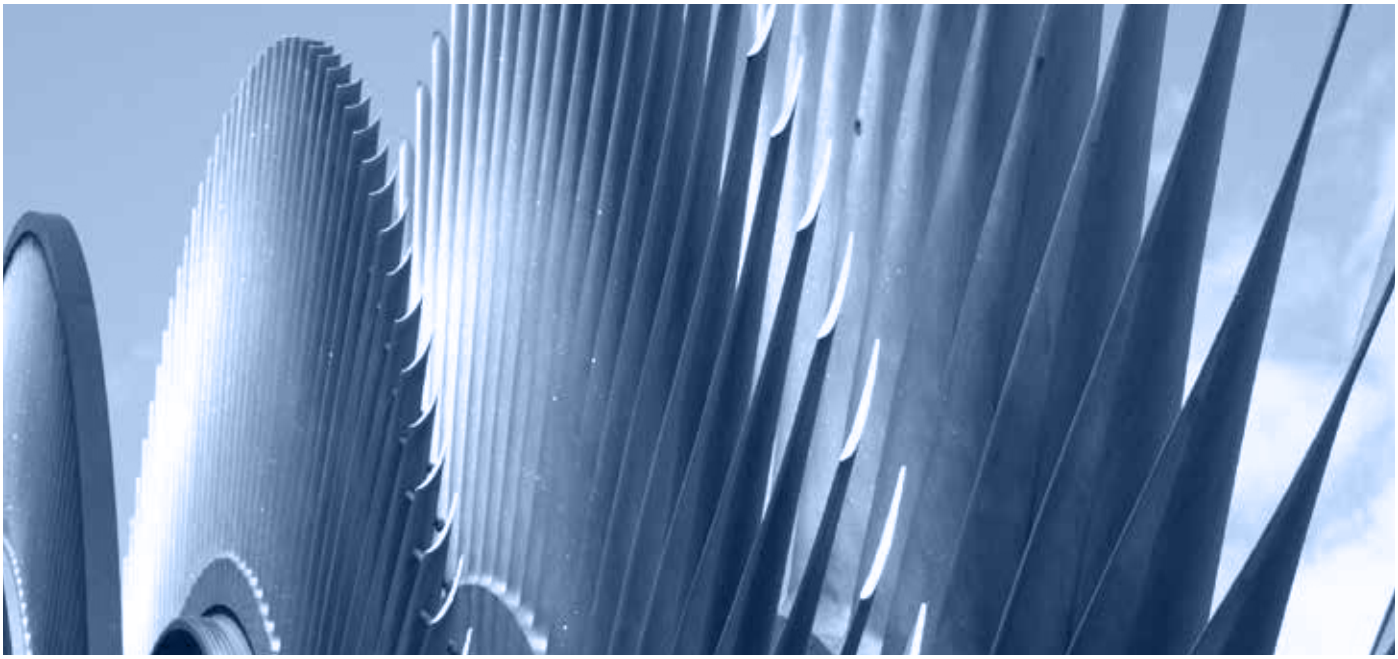
By providing a virtual window to see inside your operating turbine engine, **CapaciSense** condition monitoring systems:

- Provide accurate real-time data to help achieve smaller clearances; optimise the machine's efficiency therefore cutting down 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. Contact your local representative to discuss your needs or obtain more information..



Applications

ENGINE DESIGN VERIFICATION

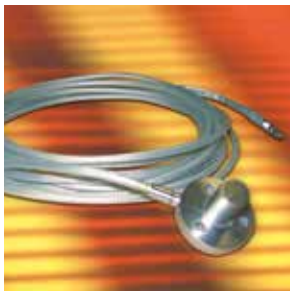
A driving factor when designing gas turbines, whether it be power generation or aerospace, is their fuel efficiency. Higher fuel efficiency means lower operating costs, often driving the decision on which turbine to adopt. Most of the world's leading developers of turbines have used our systems for design 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** has been used to provide the valuable data required to drive these systems.

Designers of some of the world's largest power generating turbines are now choosing to install our condition monitoring system to continuously monitor blade clearances and vibration. Whilst not as far advanced as their power-gen colleagues, aerospace customers have 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 operator 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 will 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** systems 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, you will access early warning signals of potential problems, which will help you to make 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 will monitor differential thermal growth during warm restarts and the information provided helps you to prevent tip damage caused by blade rubbing.

Our tip timing functionality will monitor the arrival time of a blade tip and use this to calculate blade deflections and identify vibration.

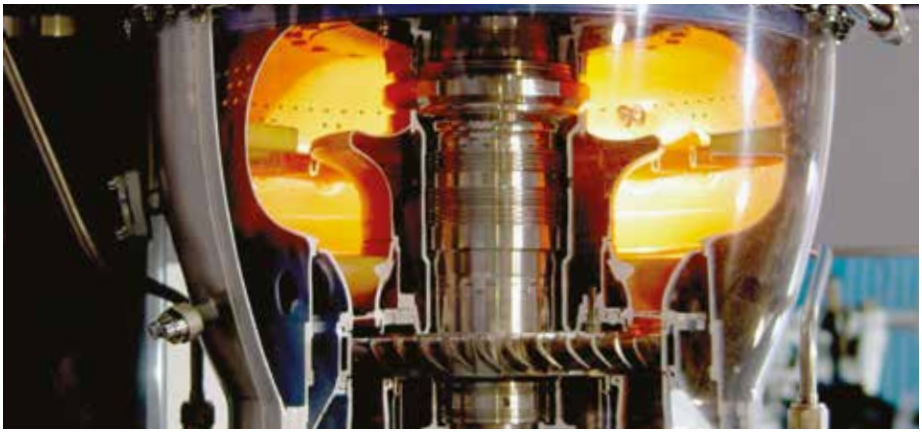
IMPROVED OUTPUT AND EFFICIENCY

Due to the high temperatures within an engine our sensors are designed to perform at 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 are using the live outputs to adjust clearances to a minimum on working turbines and therefore gaining greater fuel efficiencies.

SUITABLE FOR HAZARDOUS LOCATIONS

Both the 5 Series FM system and **CapaciSense** SOLO are approved for use in hazardous locations in both Europe and North America. The FM system gives you 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. 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 blades vibration characteristics.

Optical sensors provide excellent tip timing data but only for short periods of time before their optics became fogged with contamination. 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 well 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:

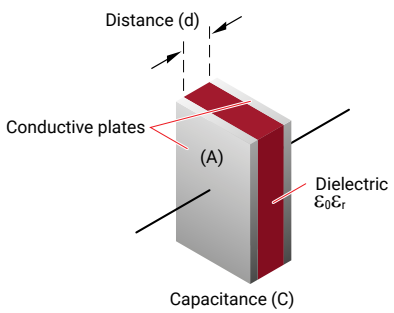
- Temperature extremes (>1400°C/2552°F)
- Temperature cycling
- Vibration
- Moisture (including on-line water wash)

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

In 2007/2008 when the 5 Series was launched not only did we improve 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! You can now plug any **CapaciSense** probe into any SOLO device and measure clearance without the need to genuinely recalibrate or assess calibration data.

How CapaciSense Works



$$C=\frac{\varepsilon_o\varepsilon_r A}{d}$$

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.

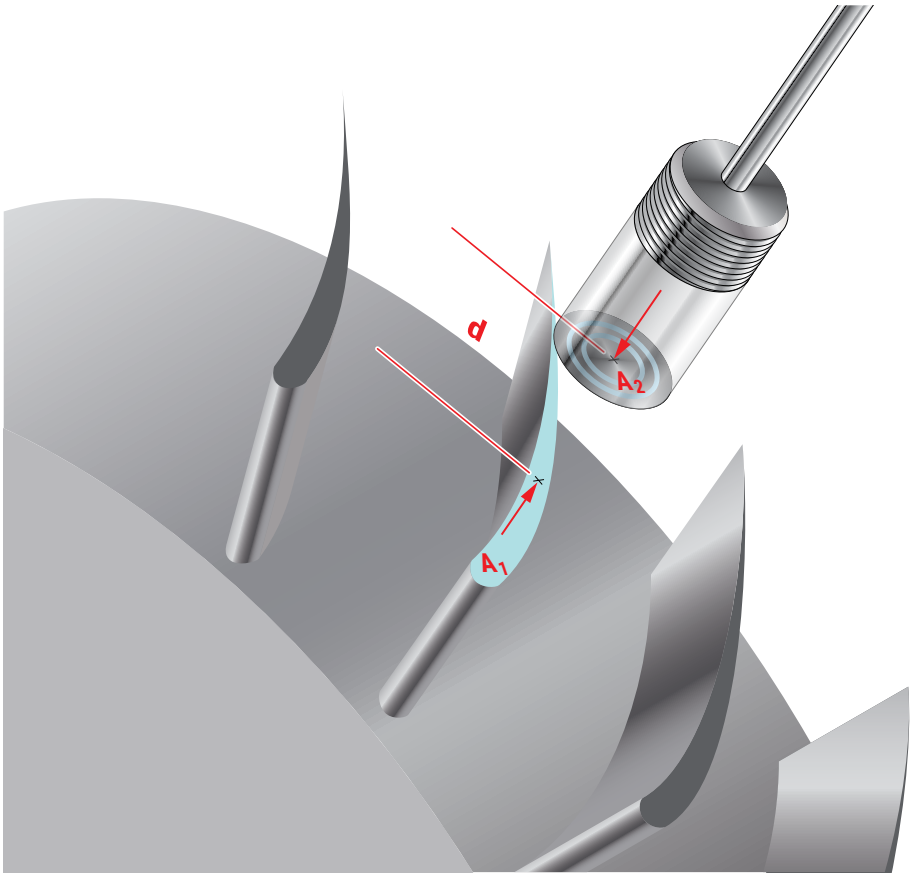
CAPACITIVE TECHNOLOGY

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

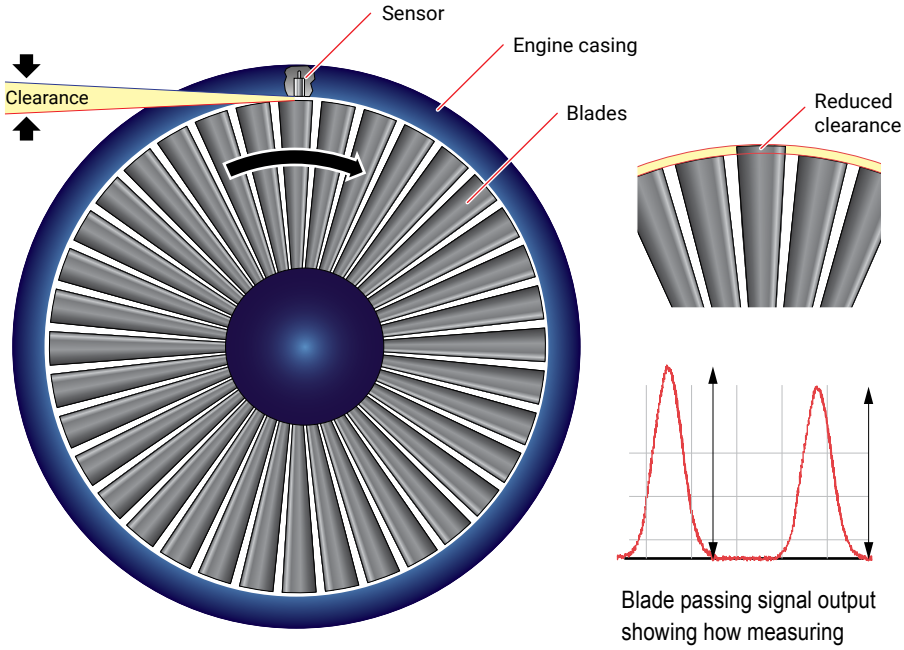
The overlapping electrode area, which is specific to blade profile (A1) and electrode dimensions (A2), is assumed to be constant. The permittivity can also be considered to be constant as the small changes which do occur due to combustion have proven to be negligible.

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 femto Farrads), advanced techniques need to be utilised to accurately measure them - see our electronic options described on page 12.

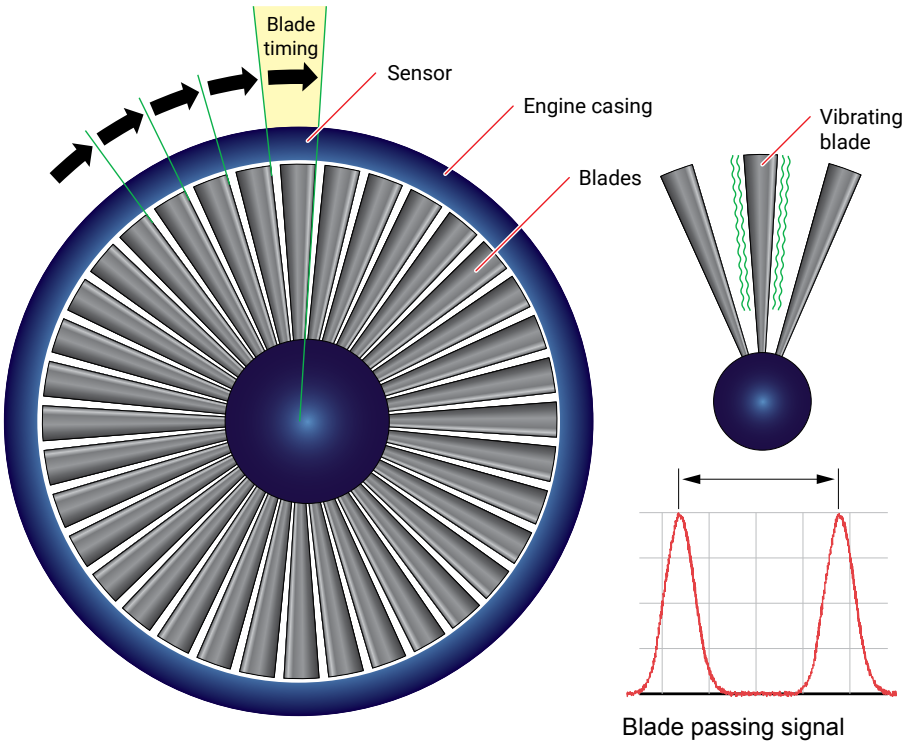


TIP CLEARANCE



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

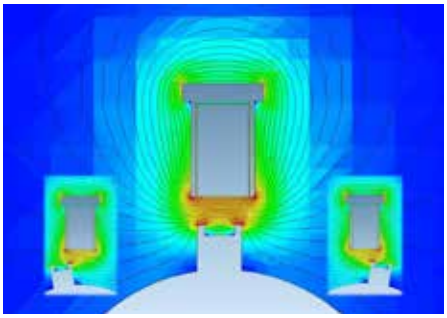
Sensor and Cable Assemblies (Probes)

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.

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 on site. The Mineral Insulated (MI) cable at the heart of higher temperature probes, continues to be manufactured and therefore also controlled in Washington.

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



All of the **CapaciSense** Probes are triaxial in construction, featuring:

- 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 over 1400°C (2552°F)
- Rugged construction allow for a potential life span of over 10,000 hours of run time

HIGH TEMPERATURE SENSORS

Used predominantly for turbine applications. The inclusion of flutes and cooling apertures has advanced the operational capabilities of these designs to over 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 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.

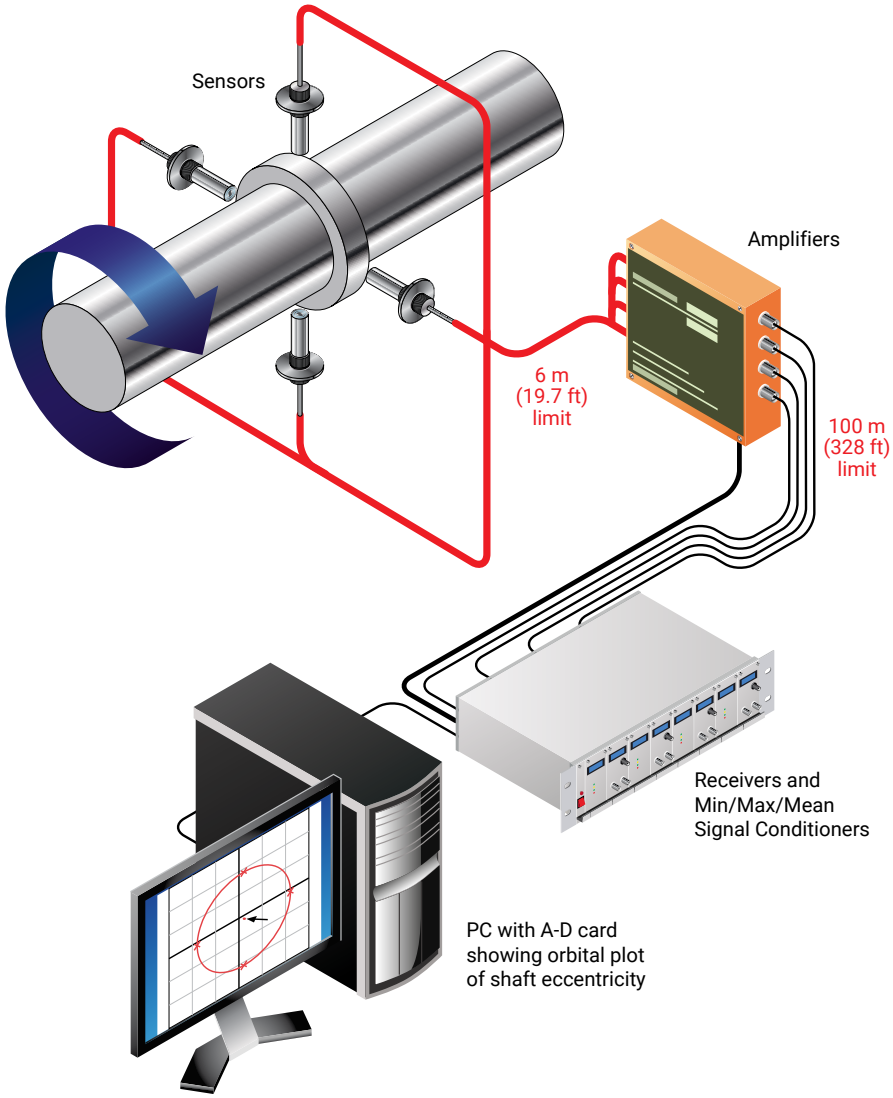
Electronics for Continuous Surfaces

AM SYSTEM

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

Probes, with cable up to 6m (19.7ft) long 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 and 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.

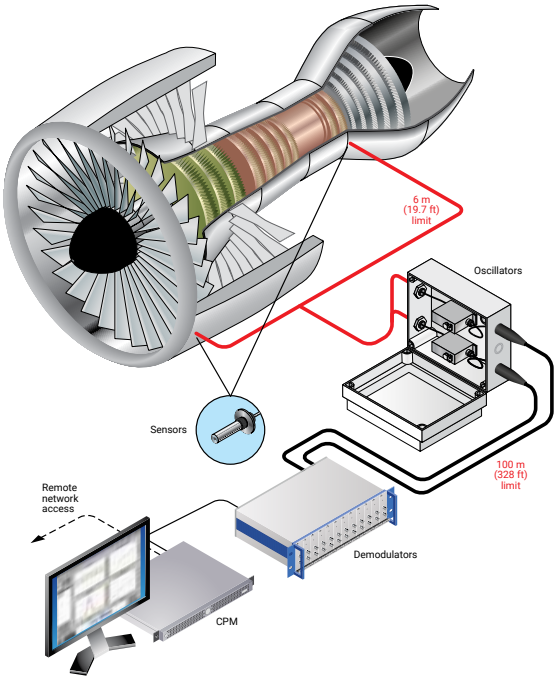
When used with the CPM, 12 voltage-free alarm contacts are available on each demodulator rack and these can be configured to warn the user of clearances falling outside of tolerance.

Probe calibration data can be stored within the oscillators to be automatically downloaded to the CPM for signal linearisation, and confirmation that you know which probe you are monitoring.

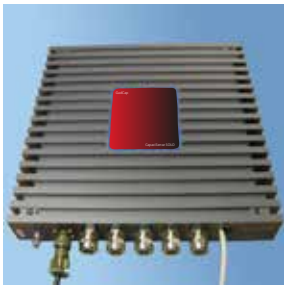
With an impressive 400 kHz maximum bandwidth, the 5 Series is the fastest commercial capacitive monitoring system currently available.

The 5 Series has both European and North American approval for use in Hazardous areas.

SYSTEM COMPONENTS



SOLO SYSTEM



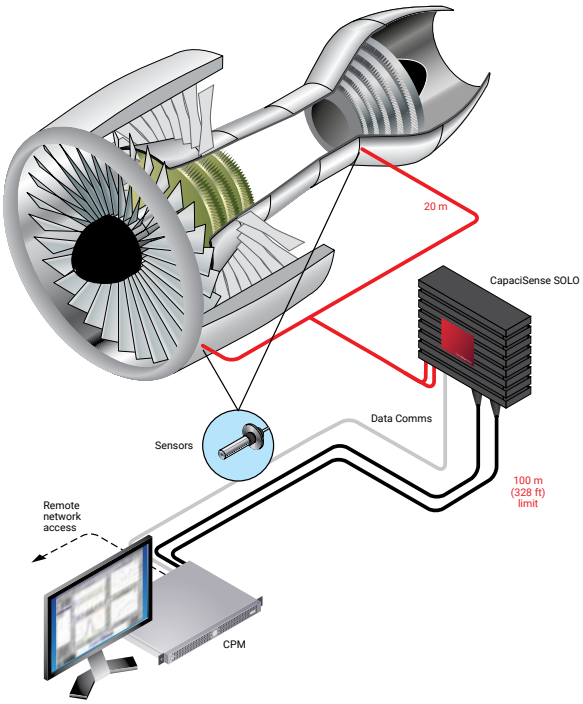
Designed to be a perfect solution for industrial installations, the SOLO is a “one box” electronic solution. Each SOLO unit can be connected up to 4 probes, with each having a combined length of up to 20m (65.6ft) of cables. Longer cables may be possible in some situations. The system outputs a blade 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 you don't have your cables crossed, SOLO produces a test signal to confirm the channel numbers.

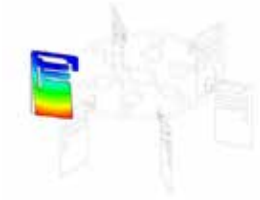
With a bandwidth of over 350 kHz, it doesn’t quite equal the 5 Series bandwidth but is more than fast enough for most applications.

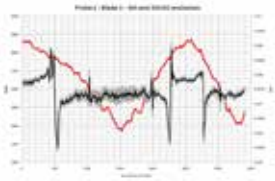
As a one box solution SOLO is ideally suited for retrofitting to existing rotating equipment. **CapaciSense** SOLO has North American and ATEX approval.

SYSTEM COMPONENTS



Software

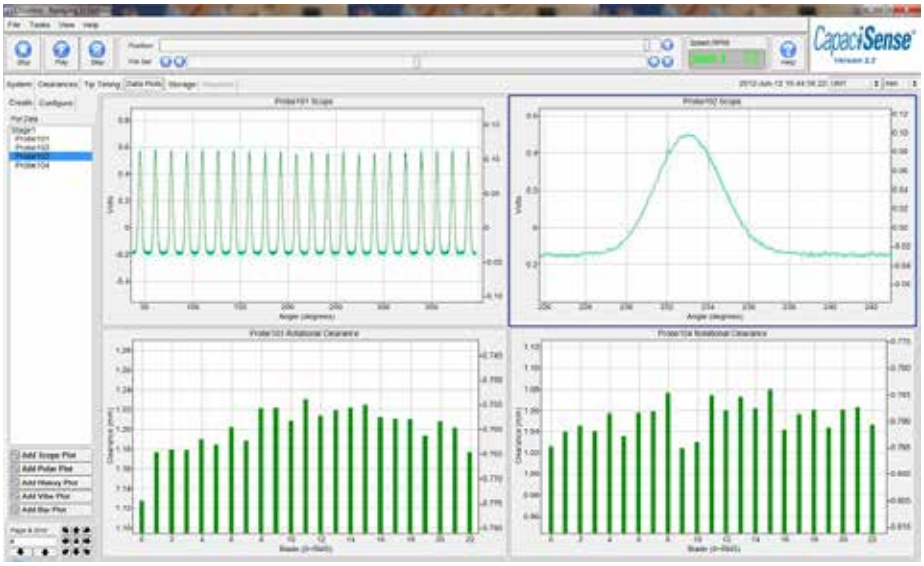




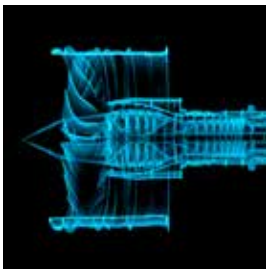
CONTROL AND PROCESSING MODULE WITH SOFTWARE (CPM)

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 you can never mix your 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 you 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

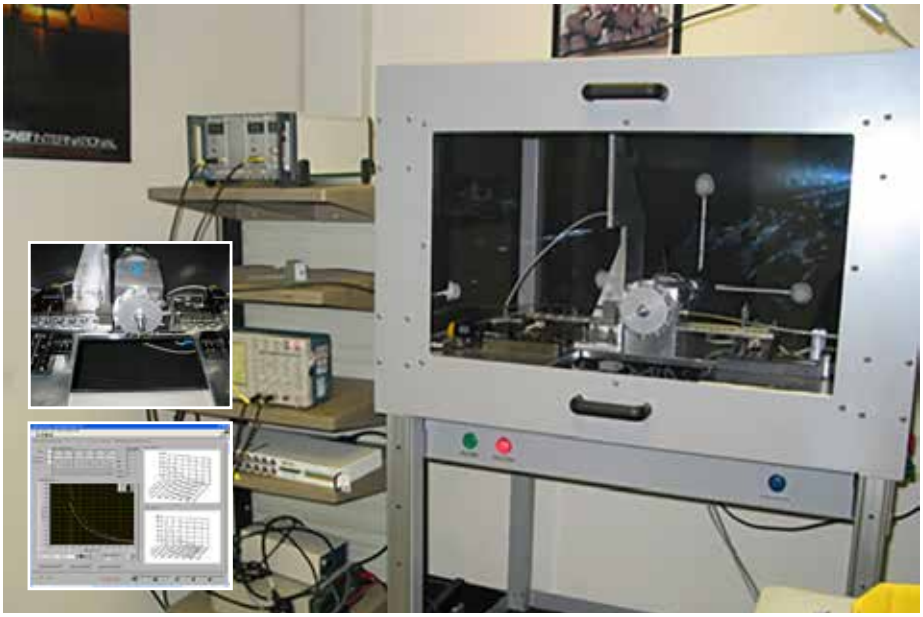


Service & Support



GadCap offers a full design service to provide a turnkey solution to your measurement needs. As well as providing the 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.



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