The Technology Partnership

Passive Wireless Sensing in a Wide Range of Applications: Turning Ideas into Reality

Michael Lukin

October 18th, 2019

Briefly about TTP

Creating new business and products through advances in science and technology

30 years of technology and product invention

260 scientists and engineers

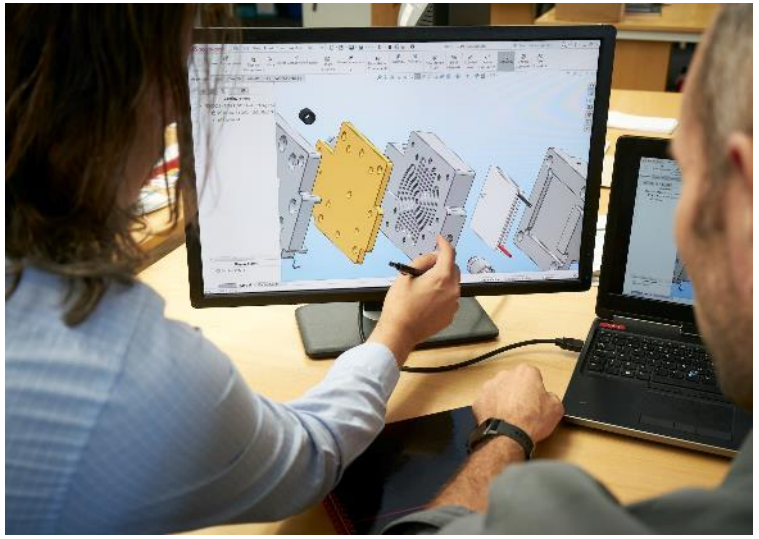
Employee owned

Based near Cambridge, UK

Worldwide client base

Telecoms

Healthcare

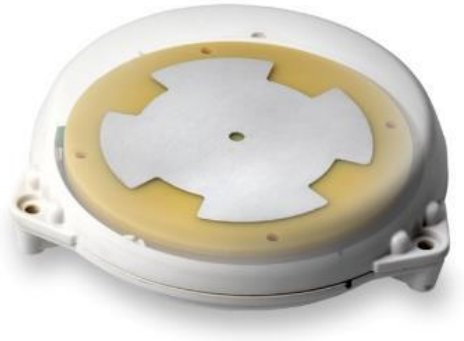


Consumer

Industrials

TTP: World Class *Product* Development

Bringing new technology to market through development of services, supply chain & products



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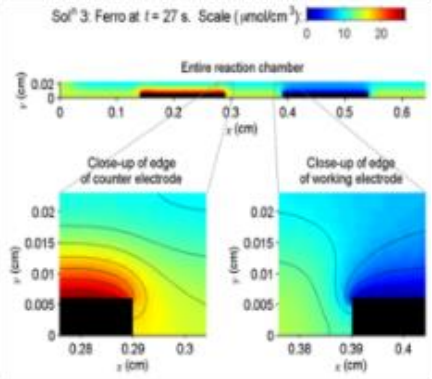
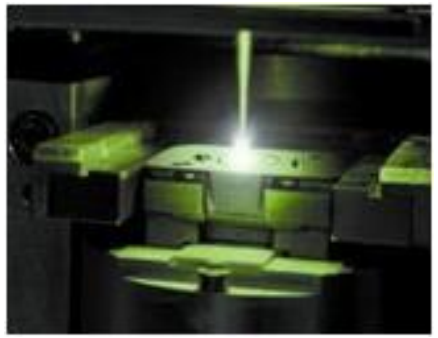
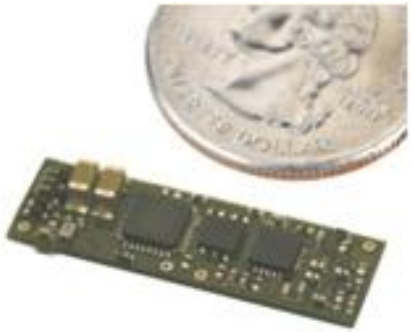
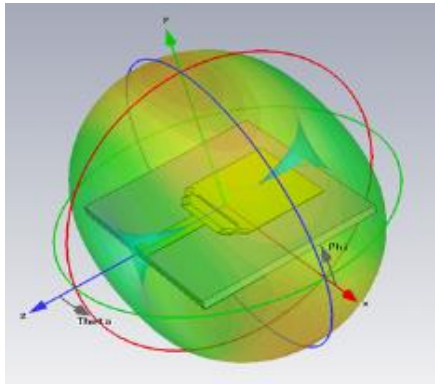
TTP: Enabling *Technology*

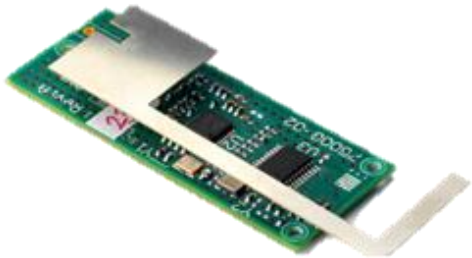
Creating new technologies that enable new and disruptive products











TTP: a multidisciplinary partner

heavy labs

communications technologies

optical labs & high energy laser rooms

fluidics & printing technology

metrology: SEMs, interferometers

droplet and spray characterisation: laser diffraction, high speed and strobe imaging

electronics and general projects labs

incubator start-up space

wet chemistry labs

RF labs & anechoic chamber

microfab lab: Si MEMS, nano-imprint, laser machining

biotech labs: fluidics, molecular diagnostic instrumentation

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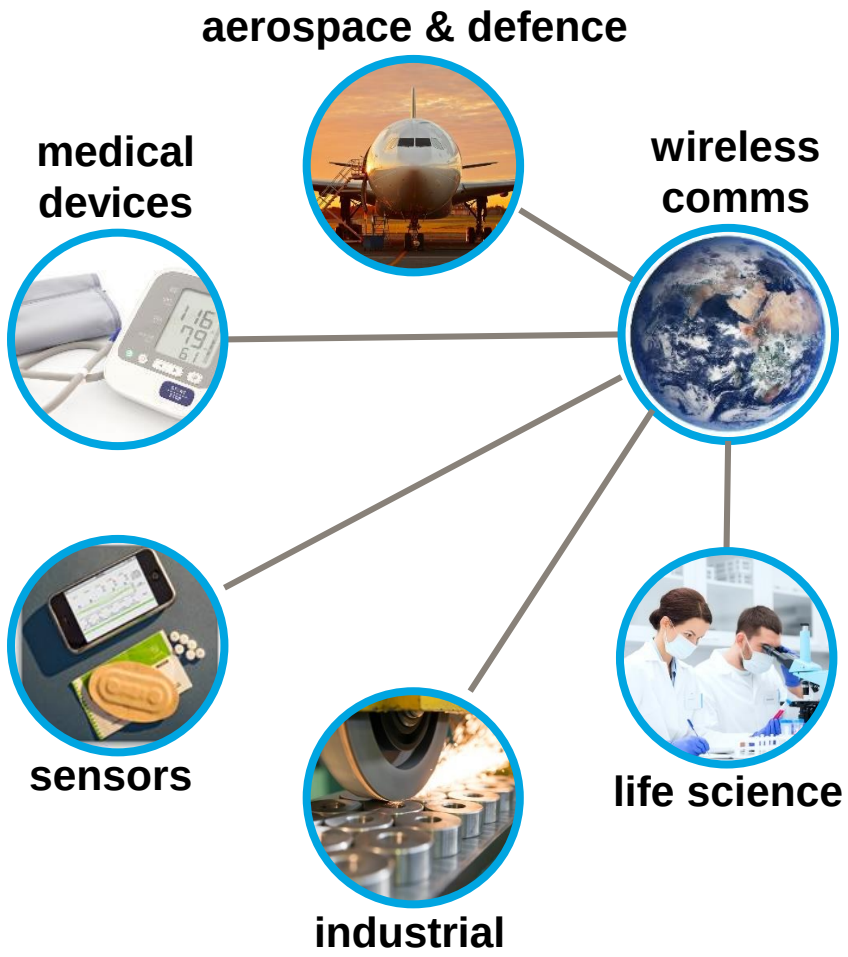
Our Markets and Business Model



- Cross-domain operation helps to generate **new ideas** for our customer's next generation products & services
- Most often we deliver high-end science & engineering design services (fees-for-time)
- Sometimes we create new IP and leverage that for our customers

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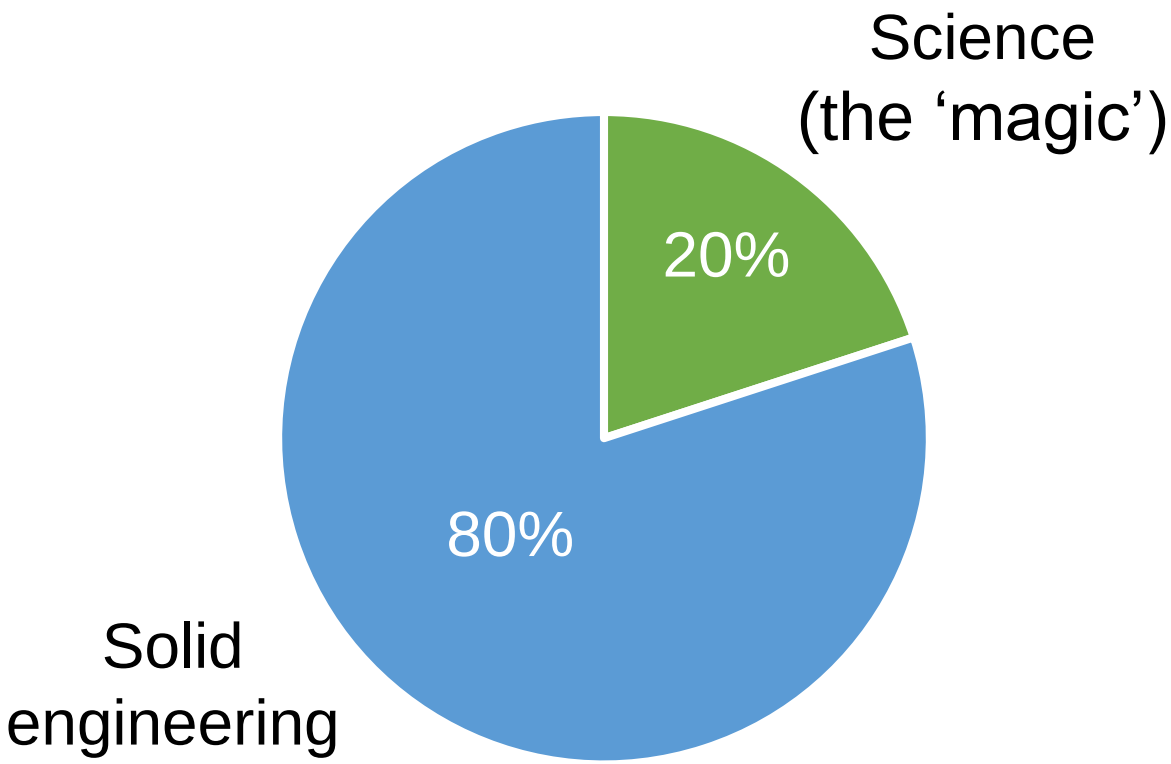
The expertise in breakthrough solutions



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Disclaimer

- TTP develops technology and products for its clients
- Some of our clients prefer not to publicise those projects, even the fact that they contracted TTP
- So, we are limited in what we can tell the world about our work (although we'd love to!)
- Therefore, the information presented here may be somewhat sketchy...

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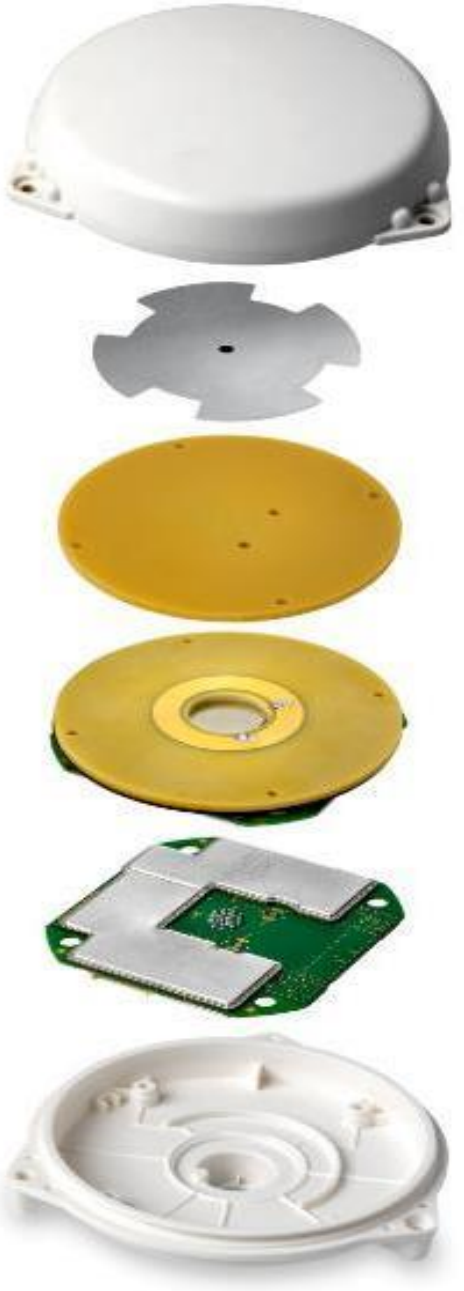
Wireless communications: from RFID to Satcom



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Industrial Internet of Things (IIoT)

IoT network for commercial premises & industrial parks

- Helps to meet regulatory requirements at low operational cost
- A small (25x32mm) LoRa module with integrated low cost antenna
- Operates in the 868/915 MHz unlicensed bands and is suitable for worldwide operation
- To meet the specific operating range, power consumption and messaging requirements of the client, LoRa modulation is used with a *custom* protocol
- 1xAA size batteries last for >6 years (messages every 15 minutes)

"Rats have ruled New York for 355 years..."

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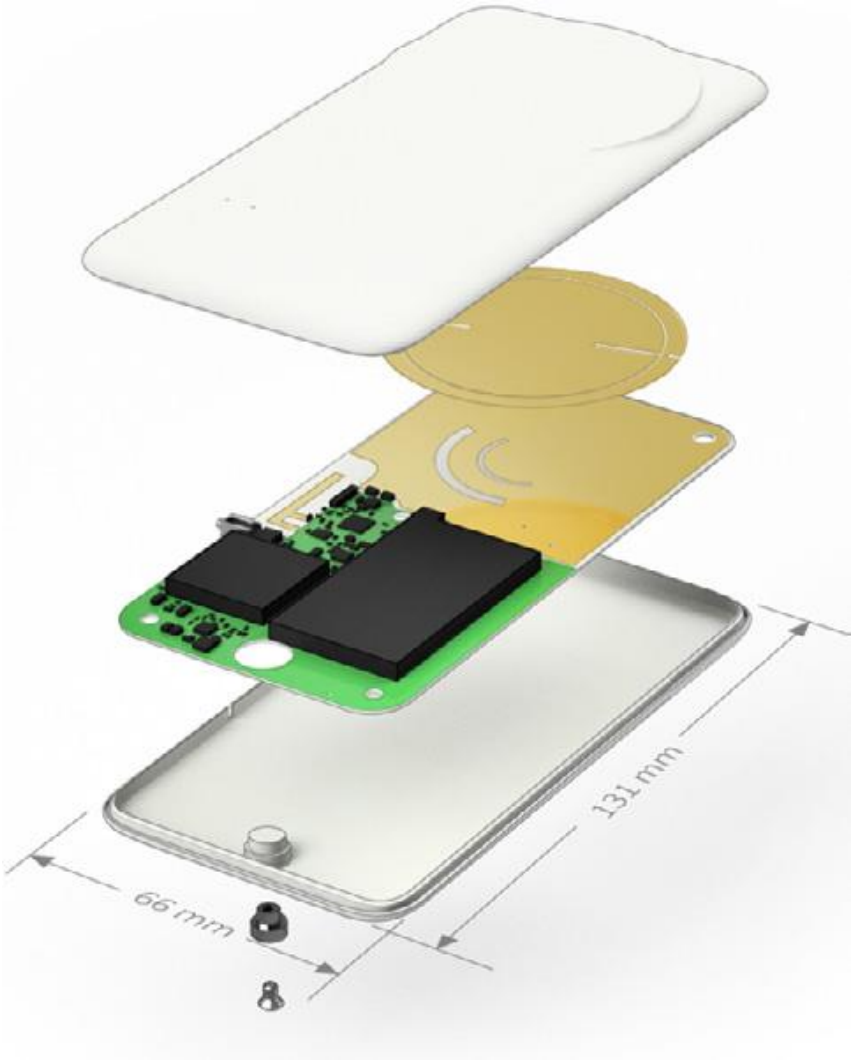
External examples

Battery-less Air Pollution Sensor (1)

CleanSpace Tag from Drayson Technologies (UK)

- The Tag tracks air pollution indoors and outside, recording your exposure to harmful carbon monoxide (CO) to help avoid harmful air pollution.
- Automatic upload of measurements to a phone via Bluetooth
- Works with CleanSpace App to plan clean routes, avoid pollution hotspots and visualise trends
- Tags are powered by Freevolt technology – RF power harvesting
- Dual-frequency high-gain antenna



https://our.clean.space/

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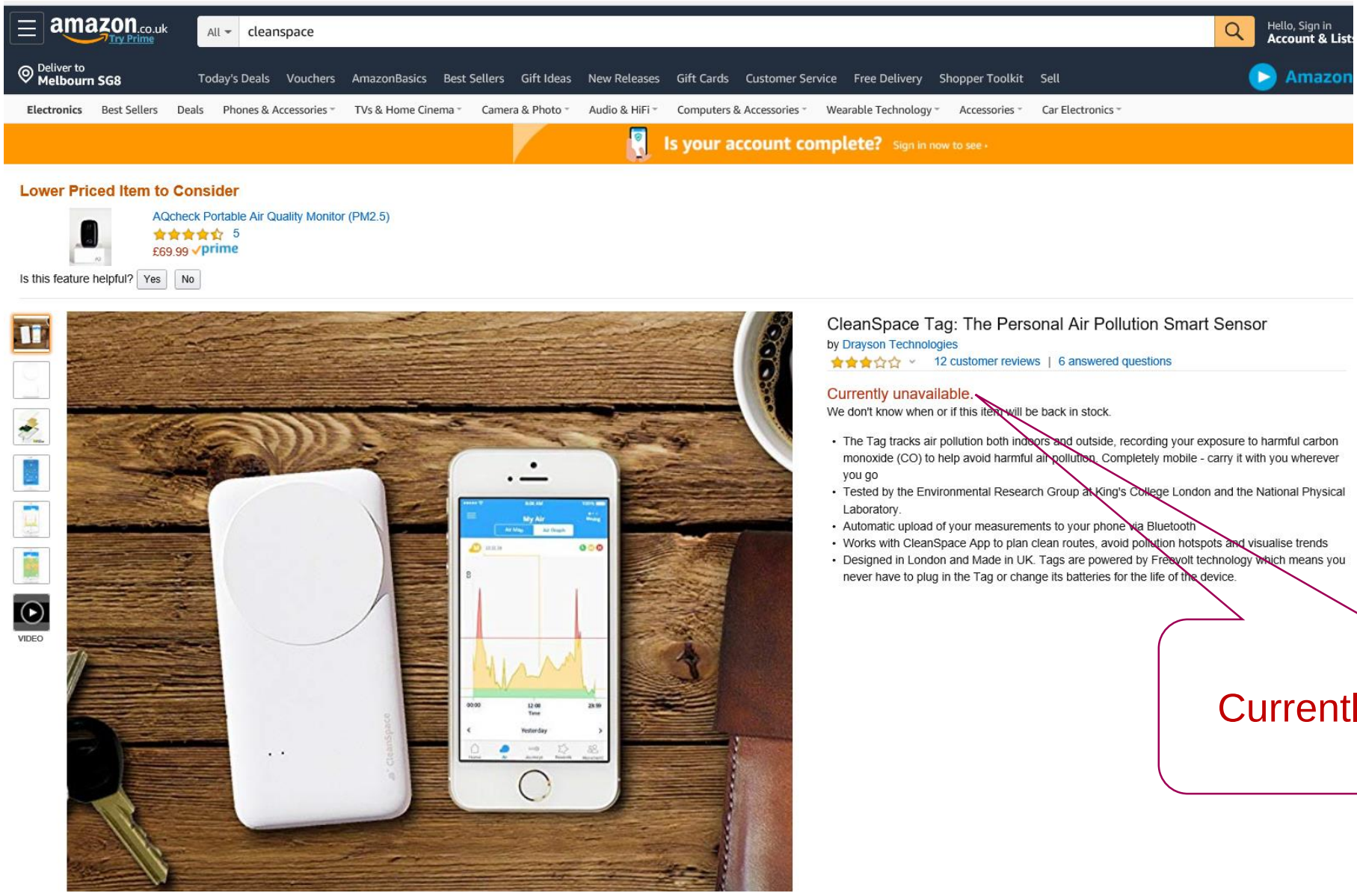
Battery-less Air Pollution Sensor (2)



Currently unavailable!

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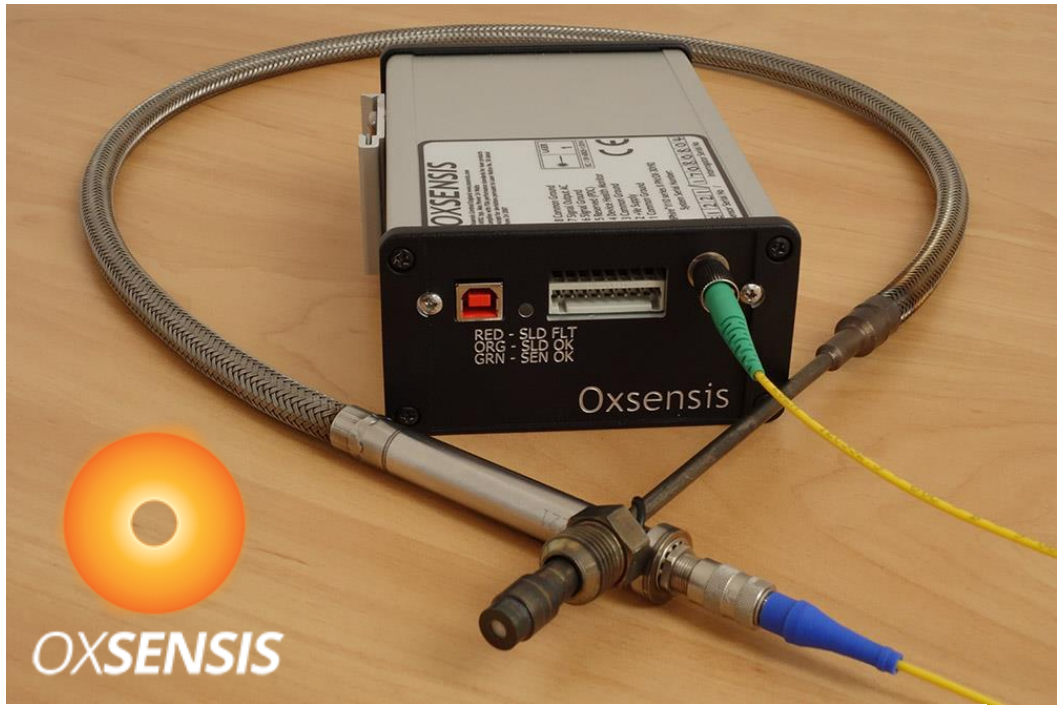
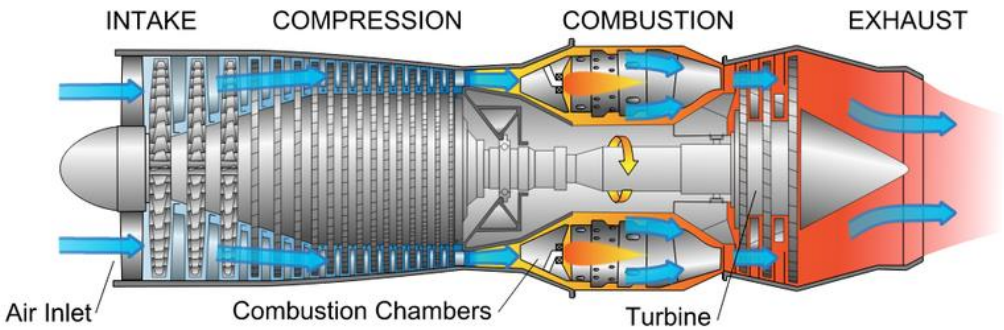
Extreme temperature optical sensor: OxSensis (UK)

- PD1100 optical sensing system
- Measures dynamic pressure in harsh environments
- Ideal for gas turbine combustion monitoring. The sensor incorporates a micro-machined sapphire (melting point >2000°C) sensing element packaged with a high temperature fibre-optic lead-out
- Based on optical interferometry Wave-Phire™ technology
- The properties of the sensor make it suitable for directly mounting on gas turbine combustors
- Extreme temperature operation up to 1000°C
- Harsh environment operation
- EMI immunity
- Planning to introduce a temperature sensor as well





https://oxsensis.com/

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SAW-based wireless sensors: Transense (UK)

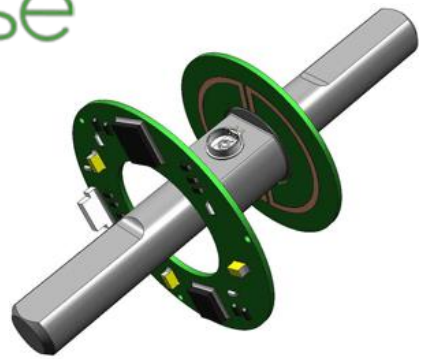
SAW-based wireless sensors:

- temperature and pressure (e.g. in TPMS – Tyre Pressure Monitoring System)
- torque (e.g. in EPAS - Electrical Power Assisted Steering)

transense technologies plc

translogik®
www.trans-logik.com

SAW sense



Torque sensor

https://www.transense.co.uk/

https://sawsense.com/

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TTP examples

TTP sensor [legacy] developments

industrial
gas detector

Cadburys ultrasonic
chocolate particle
sizer

Zellweger Analytics
domestic CO monitor
fuel cell based
electrochemical sensor

TagTec
Inductive motion
detector

Bayer
enzyme-based
electrochemical
glucose sensor

high speed fabric
inspection system

Chemunex SA
Chemscan microbial detector
fluorescence based detector

Biotrace
ATP food hygiene swab
chemiluminescence

Zellweger Uster
quantum yarn clearer
high speed capacitive and optical sensors

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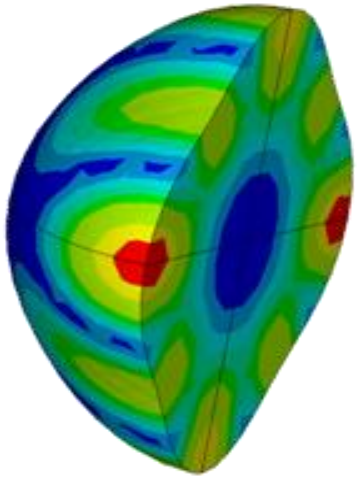
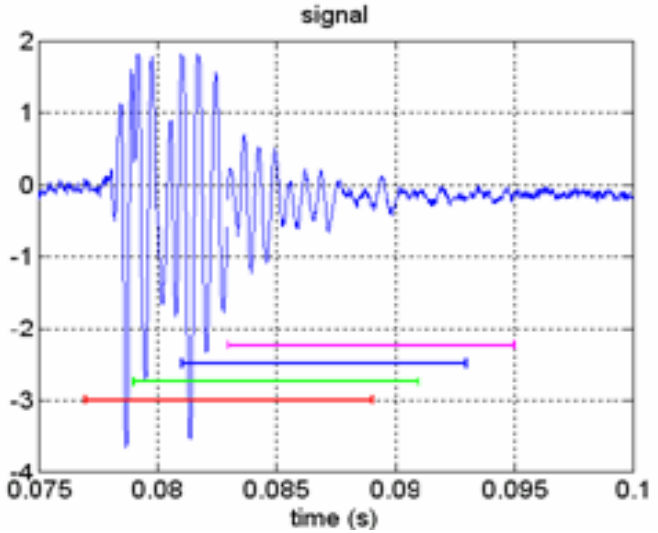
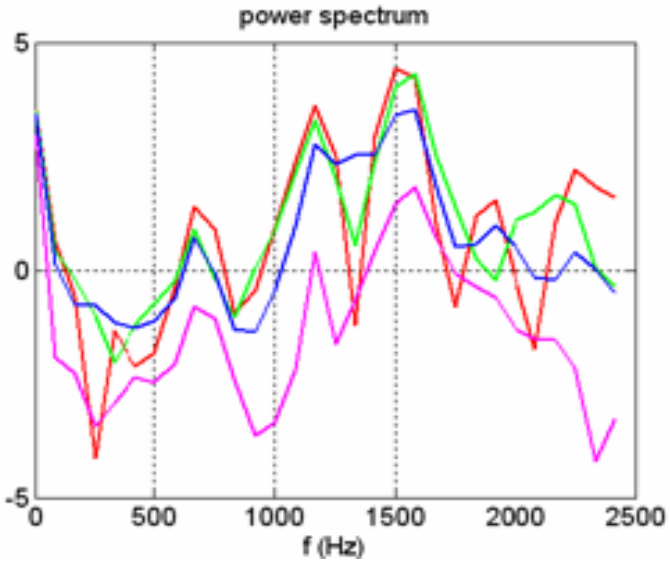
Acoustic inspection – non-destructive testing

Case study: fruit acoustic response measurement

- Shift in frequency peak related to freshness
- TTP developed a robust system design for harsh fruit-packing environment
- Real-time rapid signal processing and data capture
- Increased process speed and efficiency







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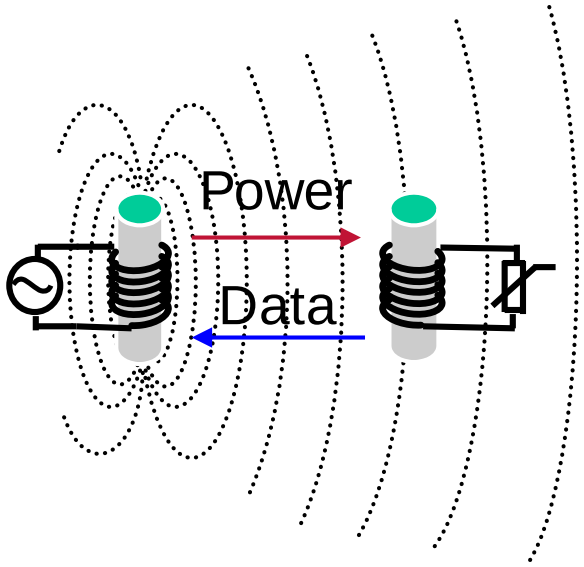
Case study: wireless sensing in motorsport

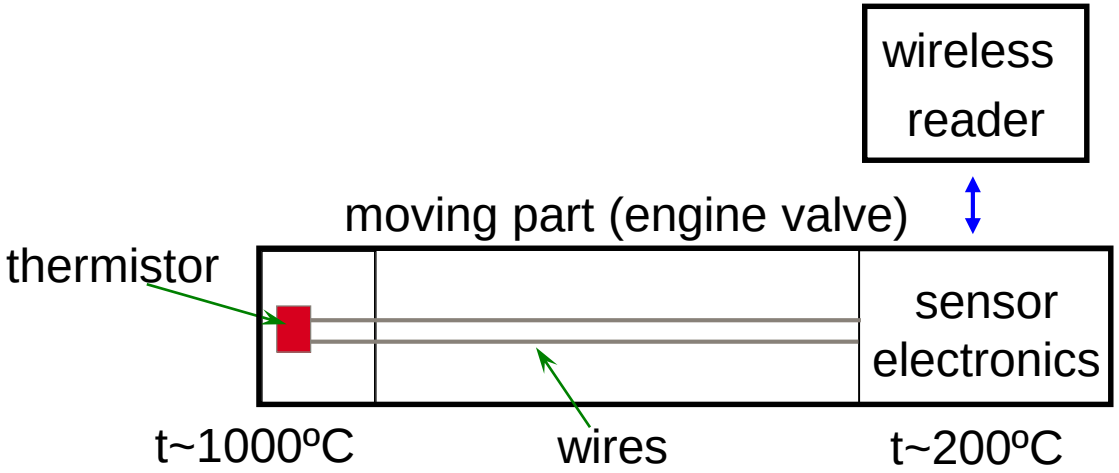
Short range wireless sensor in the harsh environment of an engine:

- no batteries
- temperature >150degC
- vibration: 10,000g
- high precision sensing
- digital data communications
- close proximity to metal

Also, a passive tyre sensor:

- pressure
- internal temperature





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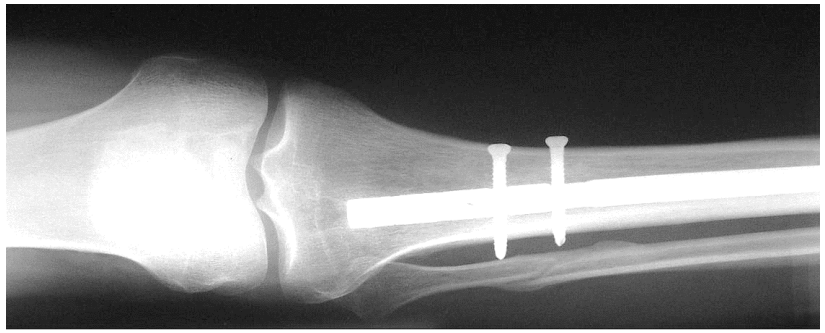
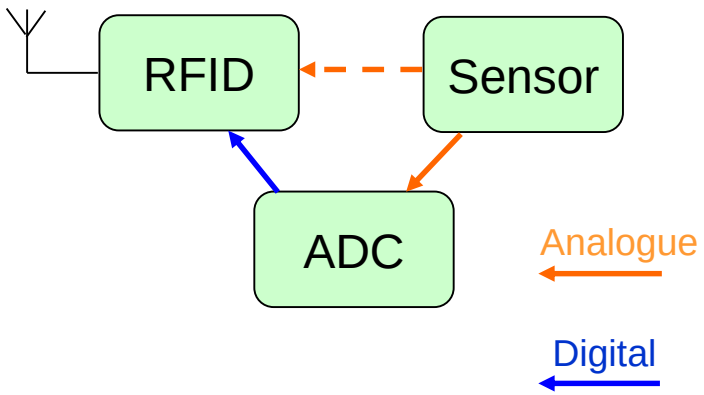
Case study: orthopaedic sensor implant

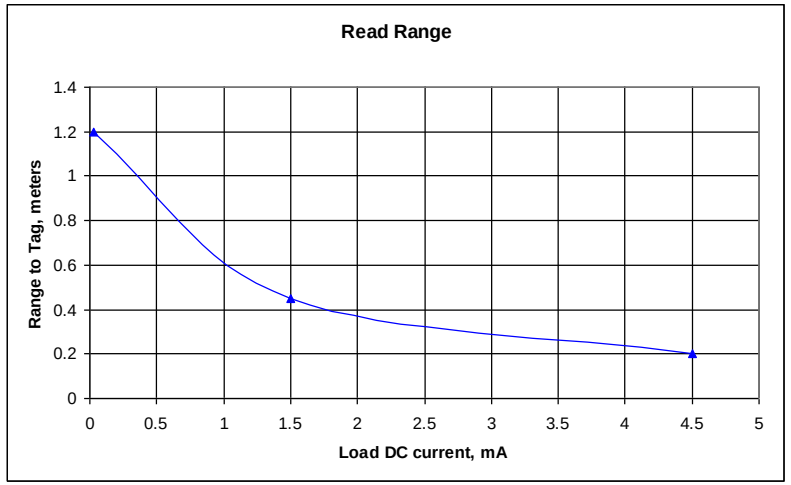
Medullary nail with integrated strain gauge

- goal is to detect bone healing without X-rays
  - bone recovers => measured strain is reduced
- batteries not allowed due to biocompatibility
- **metal** encapsulation for lifetime implantation
- communication **through metal** encapsulation and up to 30 cm of tissue
- in the future: ASIC – to reduce the size

- Currently TTP is working on another, similar project: passive strain gauge sensors embedded into titanium screws for spinal implants







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Case study: industrial furnace t° monitoring

Analytical model, FEA and experiment in excellent agreement

Layered formulation with defined source antenna for electromagnetic sensing of temperature profile via conductivity

1D Helmholtz equation with Bessel function basis vectors

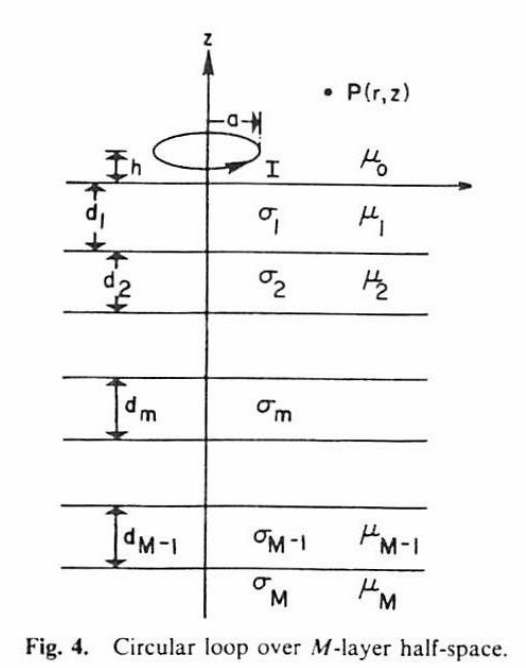
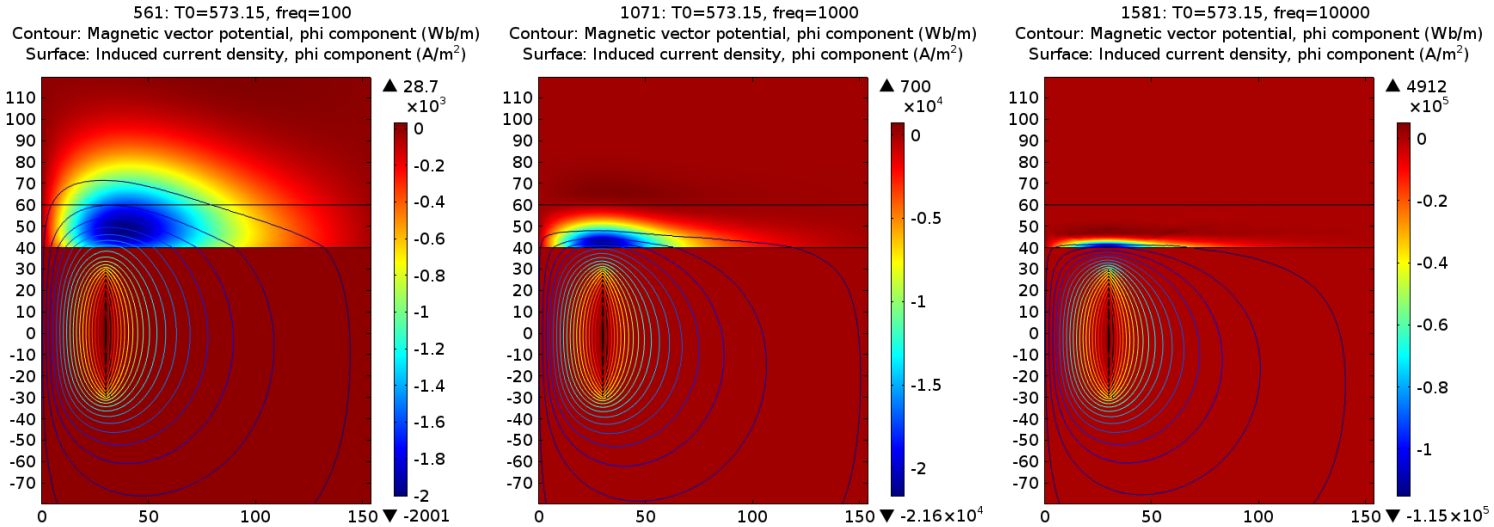
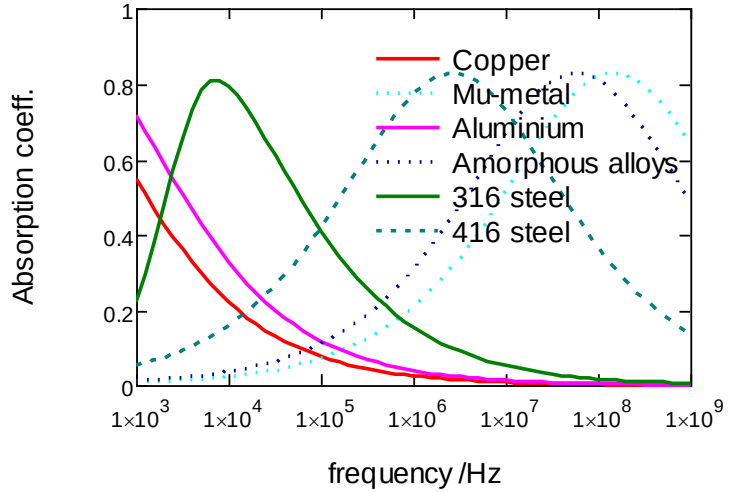


Fig. 4. Circular loop over M-layer half-space.



- analytical model allows **addition of 3D and E-field effects with fast solve time**

- similar formulations applied by TTP in controlled-source electromagnetics (CSEM), eddy current non-destructive test (NDT), thermography, currency validators, through-metal comms, RFID on metal



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Cow in-rumen wireless sensor (1)

The *Well Cow* wireless pH sensor allows farmers to optimise the diets for their cattle and improve the efficiency of milk production

The bolus is ingested by the cow and remains

in the rumen, wirelessly relaying pH and temperature data to a handheld reader on the internal temperature and pH at intervals of 15 minutes

Data can then be transmitted to the cloud to be analysed and the dietary health of the animals can be monitored

The bolus can remain active in the cow's rumen for up to 100 days.

Main challenges:

- sensor reliability (clogging)
- sensor packaging

Quite an extreme environment!

http://wellcow.co.uk/

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Cow in-rumen wireless sensor (2)

- Farmers improve bovine diets through data insights
- Improved production efficiency and profitability
- Sub-Acute Ruminal Acidosis (SARA) costs the North American dairy industry between $500 Million to $1 Billion annually at a cost of $1.40/day per cow
- 20% of cows develop acidosis
- Prevention rather than cure of SARA is the ultimate aim and in order to do this, the pH of the cow's rumen needs to be monitored
- Feeding regimes can then be altered accordingly to prevent acidosis
- Present techniques to monitor rumen pH are either invasive or only effective over short periods of time
- Improving production efficiency can also reduce the amount of methane that is produced per unit of milk
- A single cow can produce up to 200 litres of methane a day
- Monitoring rumen pH and optimising diets can play an added role in reducing the environmental impact of milk

http://wellcow.co.uk/

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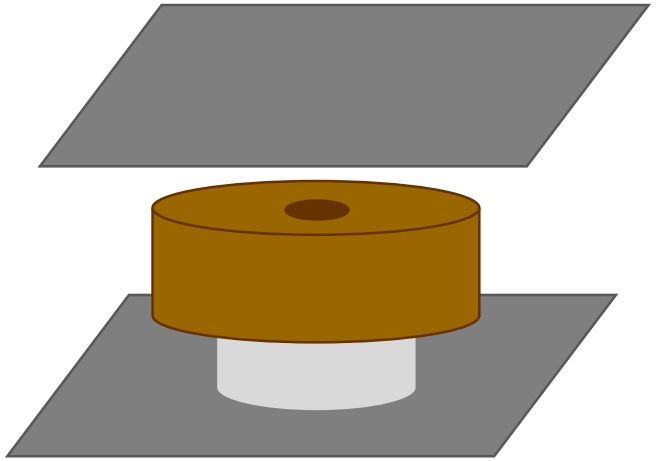
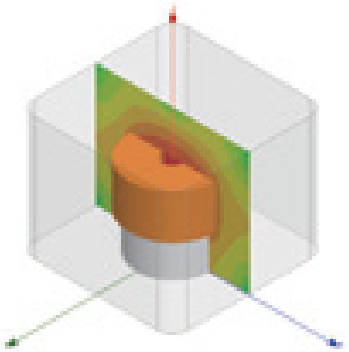
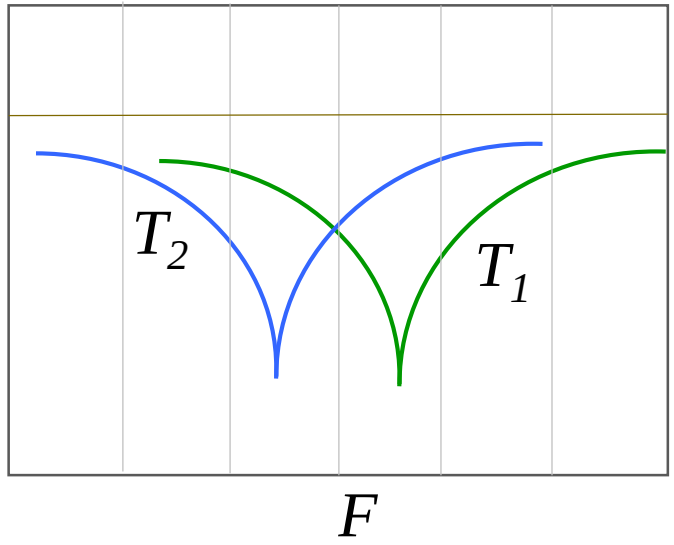
Dielectric resonator based sensing

- Temperature sensor
- Pressure sensor, strain gauge

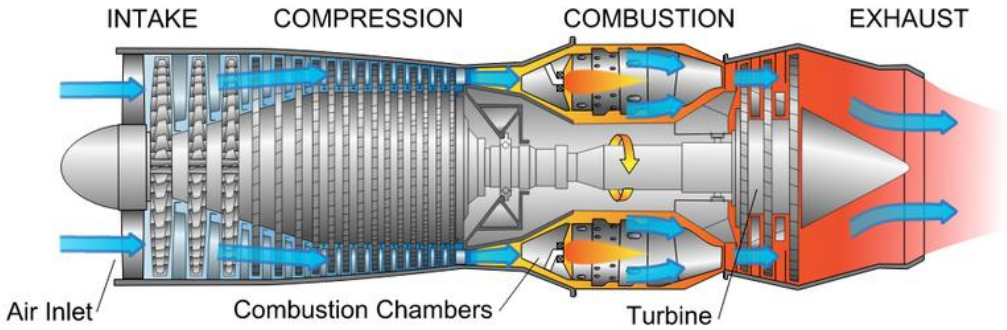






Effects of:

- Proximity of moving metal surfaces
- Plasma in gas turbines



- EVI-GTI
- PIWG
- Lab-Gap Matrix

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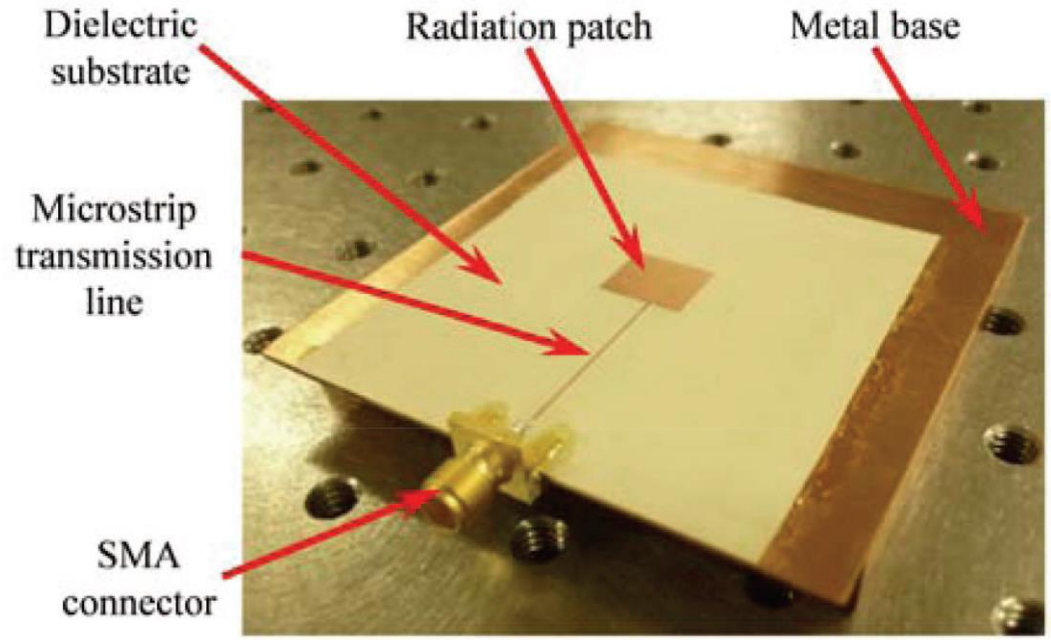
External examples

Microstrip Patch Antenna Temperature Sensor



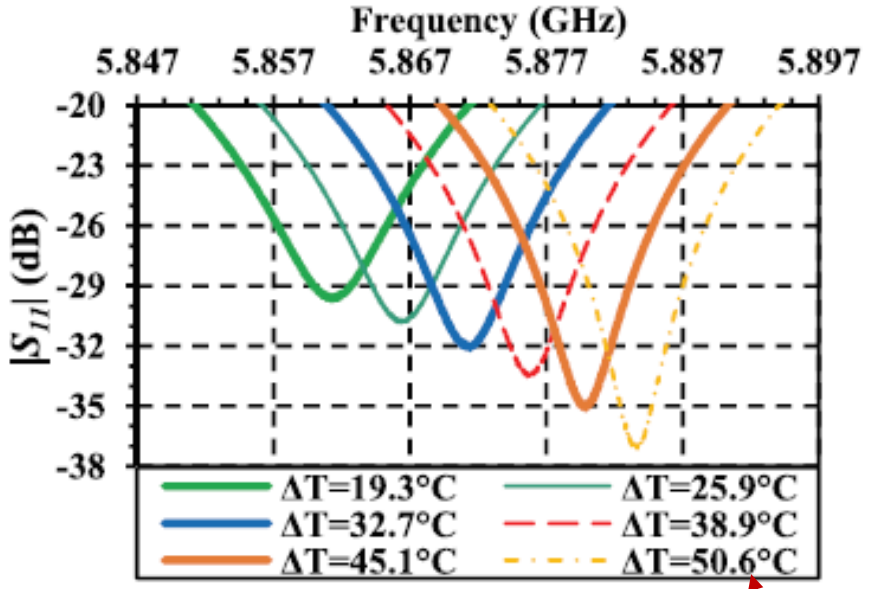
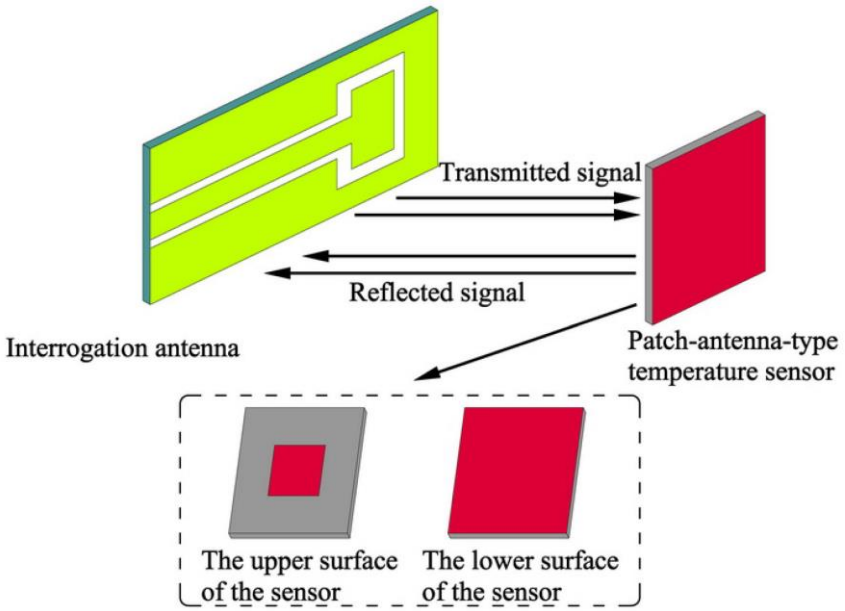


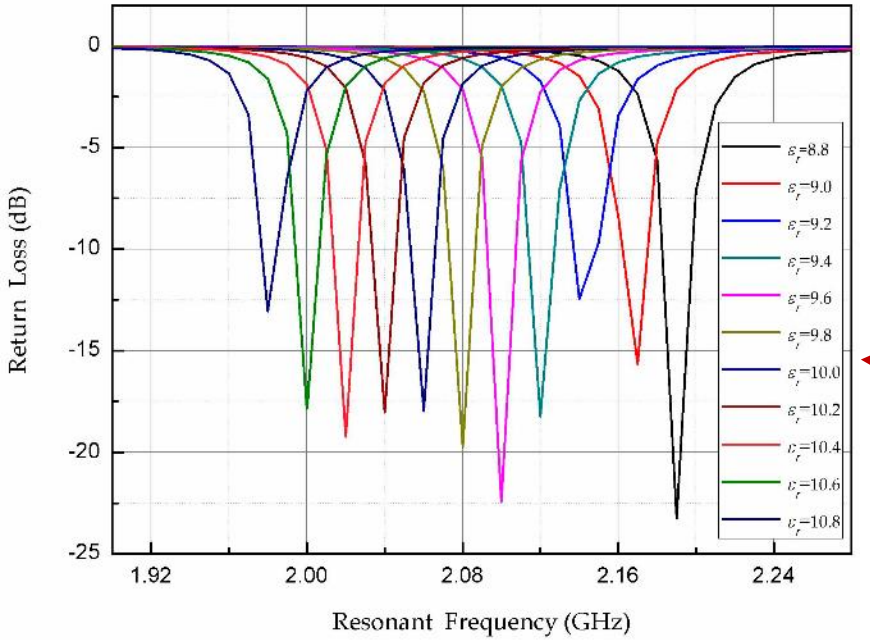
Fig. 7. The S_{11} curves measured from the antenna sensor bonded on a copper base at different temperature increments.

Fairly low ΔT°

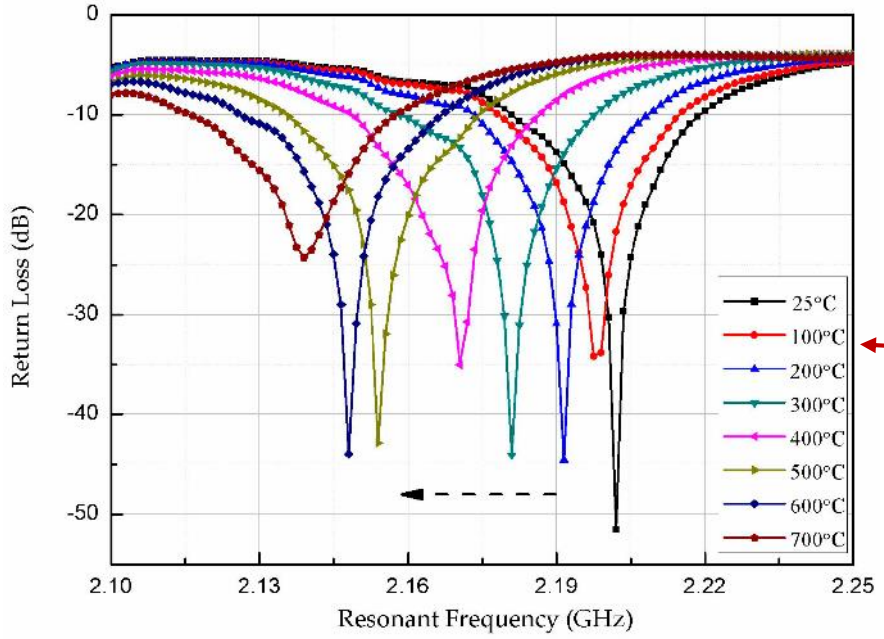
Jeremiah W. Sanders, Jun Yao, and Haiying Huang. Microstrip Patch Antenna Temperature Sensor, IEEE Sensors Journal, vol. 15, No. 9, September 2015

Ceramic Patch Antenna Sensor





ε_0



t°

Dan Yan, Yong Yang, Yingping Hong, Ting Liang, Zong Yao, Xiaoyong Chen, Jijun Xiong. AlN-Based Ceramic Patch Antenna-Type Wireless Passive High-Temperature Sensor, Micromachines 2017, 8(10), 301

Dielectric resonator based sensing

- A temperature sensor using dielectric resonator structure, a low-profile *reflective patch* temperature sensor
- A pressure sensor based on evanescent-mode resonator structure
- Demonstrated up to 1300°C
- Made of high-temperature-stable and corrosion-resistant Silicoboron Carbonitride (SiBCN) ceramic materials – suitable for harsh-environment applications.
- The dielectric constant of SiBCN materials monotonically increases versus temperature.
- Temperature of the sensor can be extracted from the resonant frequency.
- The pressure sensor uses an evanescent-mode resonator structure, in which an air gap dimension decreases when the external pressure increases, causing a decrease in the resonant frequency.

https://www.sensatek.com/about/

Energy Harvesting

Power sources for sensing in extreme environments

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Energy harvesting

Wireless industrial sensor

- powered by vibration energy harvester – electrical supplies proximal but inaccessible
- *review sensor and harvester design*
- *key goal: to confirm robustness and design life*

Wireless tyre sensor for F1 team

- sensor embedded in tyre, with wireless interface for telemetry
- batteries unacceptable owing to extreme operating environment
- *development of sensor, radio and EM energy harvester*

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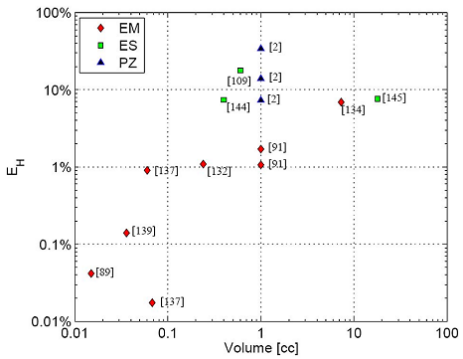
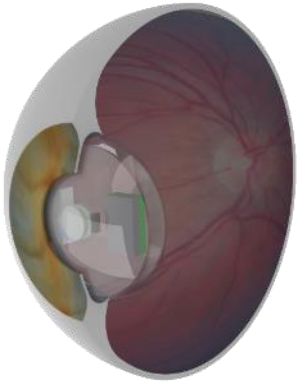
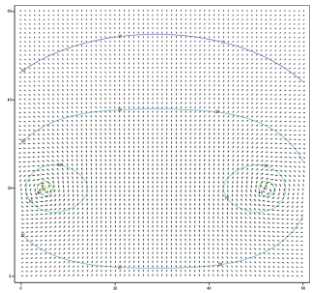
Energy harvesting for ‘human-implantables’

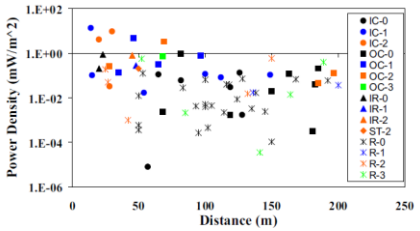
A study for a medical client who wished to implant battery-free active electronics within a human body

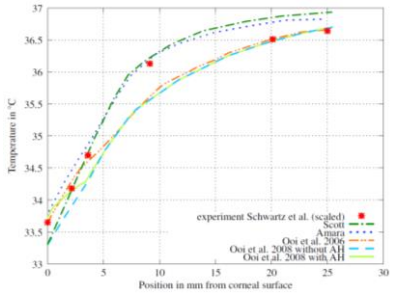
- TTP examined the full range of irradiance, thermal, electromagnetic, acoustic, body motion and glucose / oxygen energy sources
- for each source, the total available energy was determined and potential harvesting techniques were identified
- the performance of each harvesting technique was evaluated to draw up a shortlist of viable approaches for this particularly challenging application

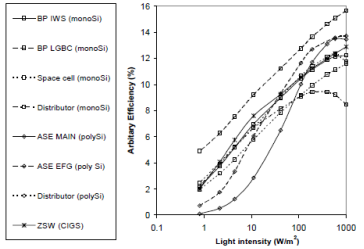












Energy harvesting – cow collar

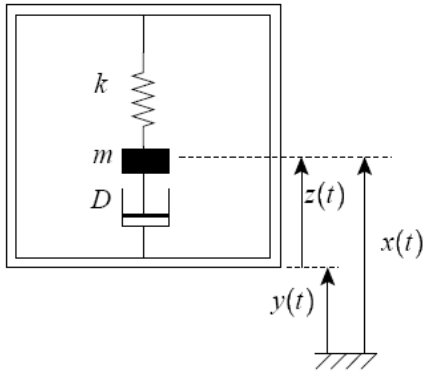
Inertial electromagnetic generator analysis for health-monitoring cow collar

Key constraints:

- mass, size (which limits displacement)

Performance estimate:

- P = 10mW
  - c.f. 8 x alkaline AA cells: ~ 1mW for 2 yrs
- assumptions:
  - Y_0 = 1 cm, f_0 = 1.6 Hz)
  - m = 100 g, Z_L = 2 cm



$$P = \frac{1}{2} Y_0 \omega^3 m Z_L$$

output power; amplitude of motion (Y_0); resonant frequency (ω); mass (m); mass-frame displacement limit (Z_L)

Model of a velocity-damped resonant generator system (P. D. Mitcheson *et al*, Jan 2003)

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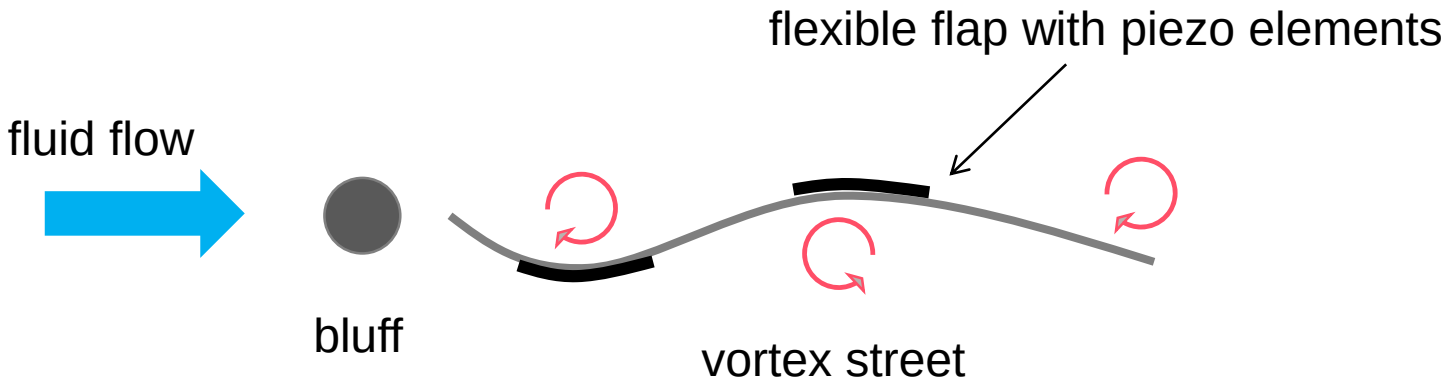
Energy harvesting – oscillating ‘MicroFlag’

- Oscillating vortex stream drives ‘flap’, e.g. for harvesting from fluid flow
- Flap drives piezoelectric /PVDF/ electroactive material to convert motion into electrical energy
- Energy generated during flow



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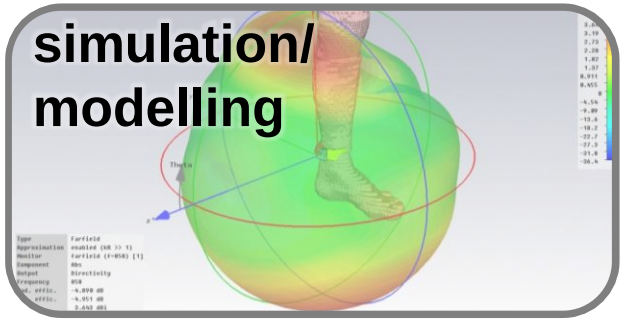
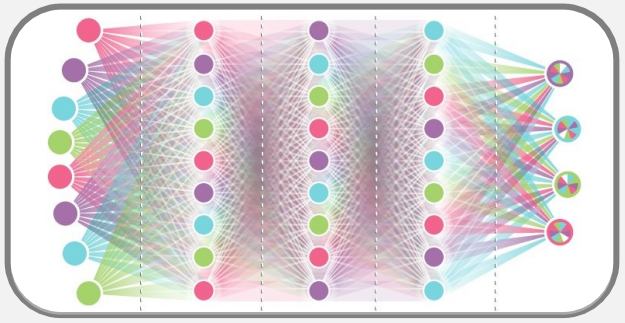
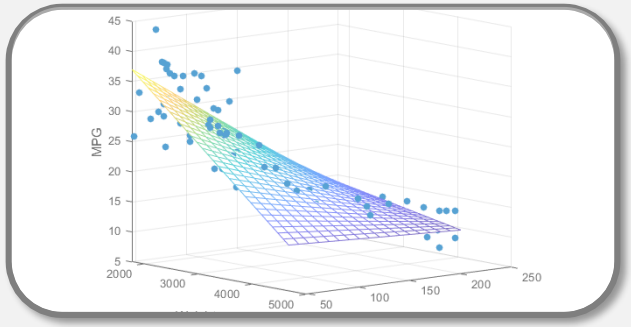
Artificial Intelligence and sensing

dataset generation and labelling	developing predictive models	deployment and integration







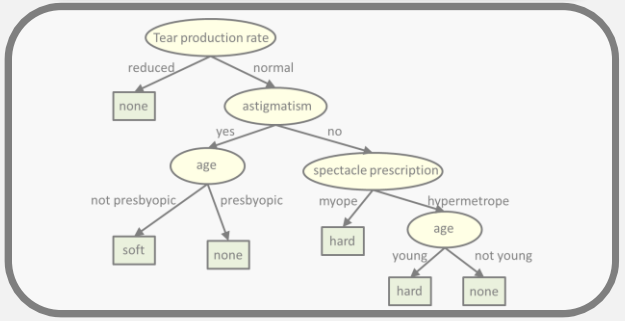


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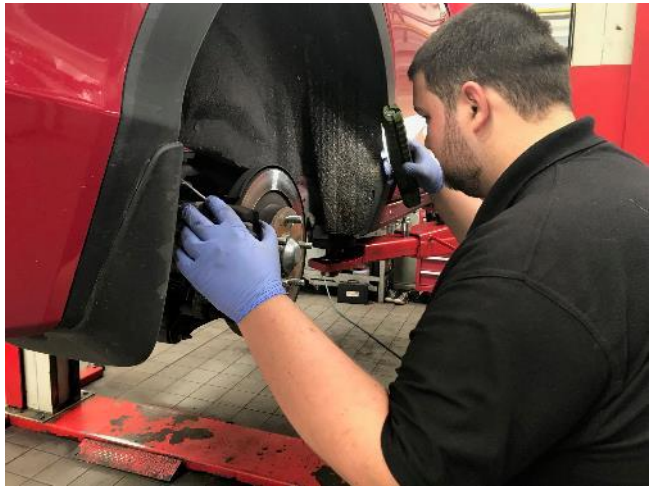
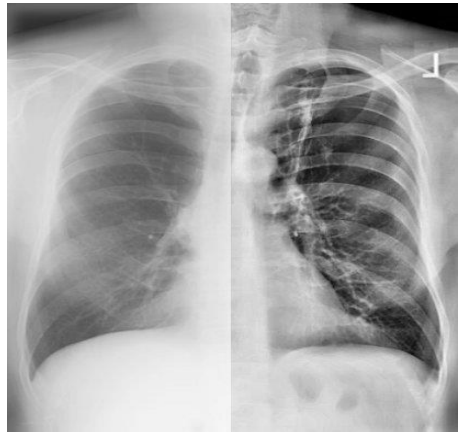
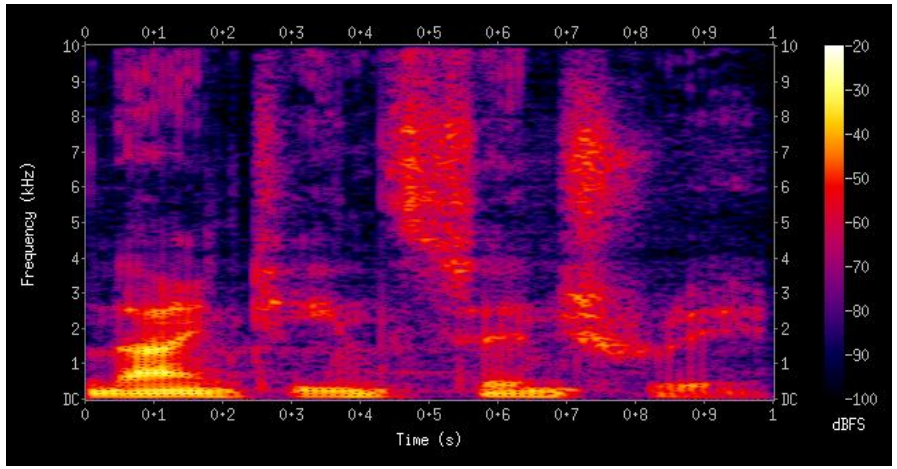
Image processing

Often on a low processing power platform







Audio event detection using edge hardware

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