Conformable & wireless-interrogated pressure sensors for medical compression garments

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Smart compression garments:

Treatment & prevention of …

Dietetic & pressure ulcers

(Image from BDA British Dietetic Association)

Lymphoedema

(Image from www.mediuk.co.uk)

Hypertrophic scars

(Image from Wikimedia Commons)

Fitting and monitoring of Anti-Embolism Stockings (AES)

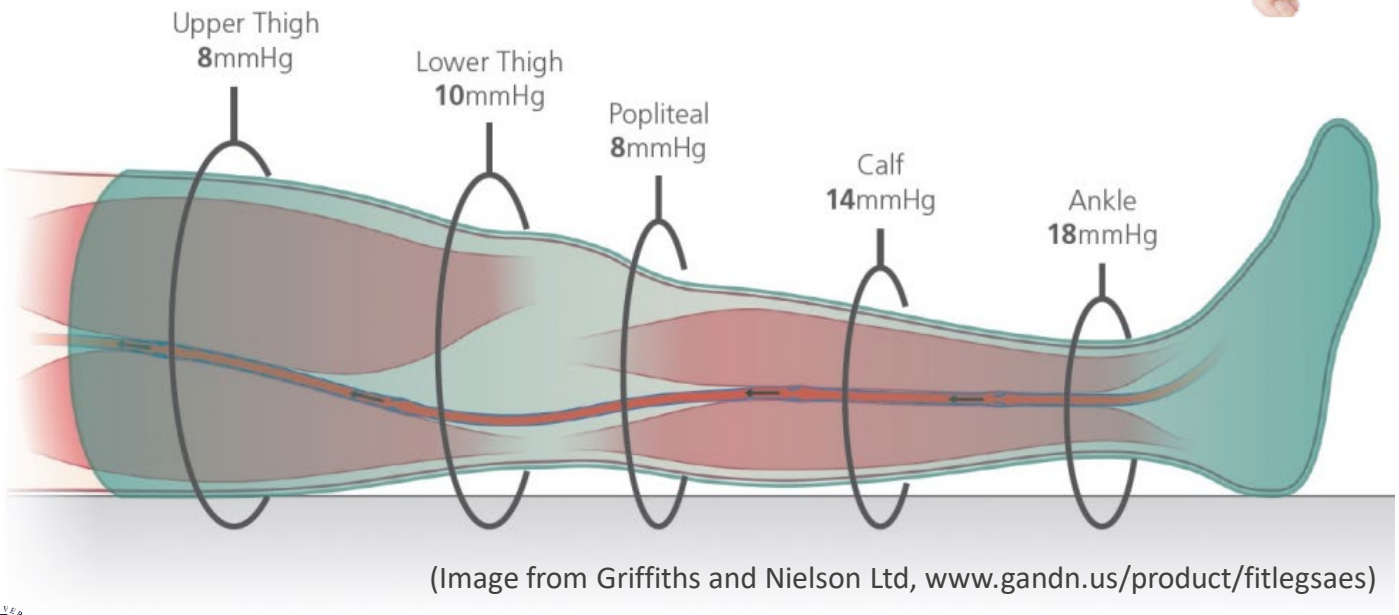
Sigel profile:

Recommended pressure profile exerted by stockings on the leg, in supine position, which is most effective at lowering the risk of DVT.

Reducing the risk of venous thromboembolism (deep vein thrombosis & pulmonary embolism) in patients admitted to hospital

Conditions, National Clinical Guideline Centre - Acute and Chronic (UK),

NICE Clinical Guidelines, 92, 44–68, (2010)



(Image from Griffiths and Nielson Ltd, www.gandn.us/product/fitlegsaes)

Pressure sensor requirements for smart medical compression garments

- Sensitive: <1 kPa (8 mmHg) detection limit
- Flexible: Conformable to patient anatomy (ankles, wrists, etc.)
- Thin: Minimal distortion to compression garment
- Wireless: No pressure-related damage to patient skin
- Disposable: Low-cost, scalable manufacture
- Easy & fast to use: Simple user interface
- Continuous monitoring

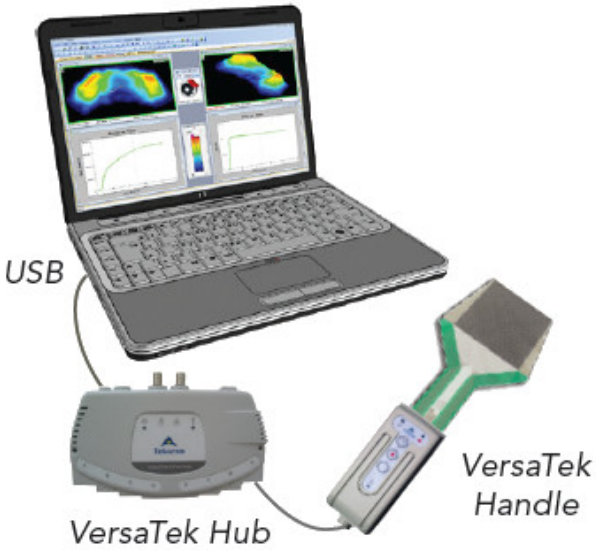
1. *Do anti-embolism stockings fit our legs? Leg survey & data analysis*
   L. Macintyre, K. Kent, D. McPhee, **International Journal of Nursing Studies**, 50 (7), 914-923, (2013)
2. *Validation of the Pliance X System in measuring interface pressure generated by pressure garment*
   C.H.Y. Lai, C.W.P. Li-Tsang, **Burns**, 35, 845–851, (2009)
3. *Comparison of three portable instruments to measure compression pressure*
   H. Partsch, G. Mosti, **International Angiology**, 29 (5), 426-30, (2010)
4. *New calibration method for I-scan sensors to enable the precise measurement of pressures delivered by pressure garments,*
   L. Macintyre, **Burns**, 37 (7), 1174-1181, (2011)
5. *Under Pressure: Investigating anti-embolism stockings and the pressures they exert*
   E. Sealy, Reproductive Biology Honours Project, (Supervisors F. Denison, P.J.W. Hands), University of Edinburgh (2018)

Existing pressure sensor technology

PicoPress (MediGROUP)

Pliance X

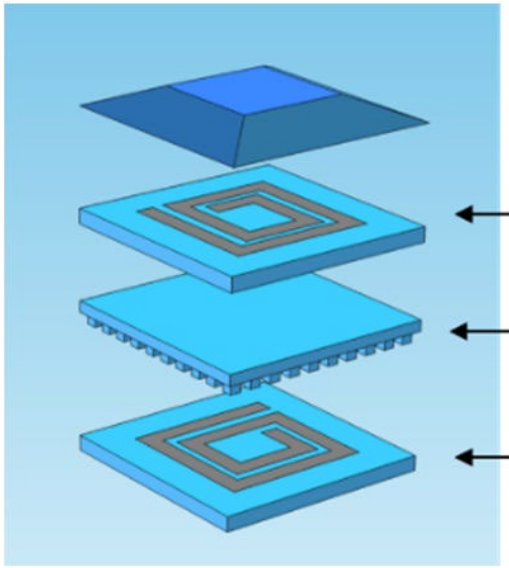
I-Scan (Tekscan)



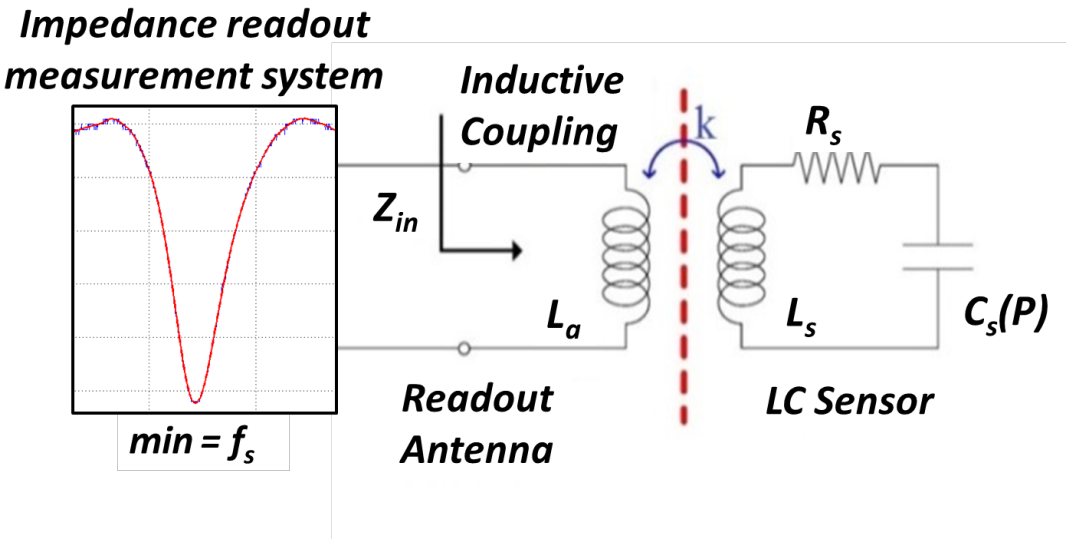
- Bulky and/or semi-rigid sensors – unsuitable for high curvature regions
- Cable connection – causes injury, unsuitable for long-term operation

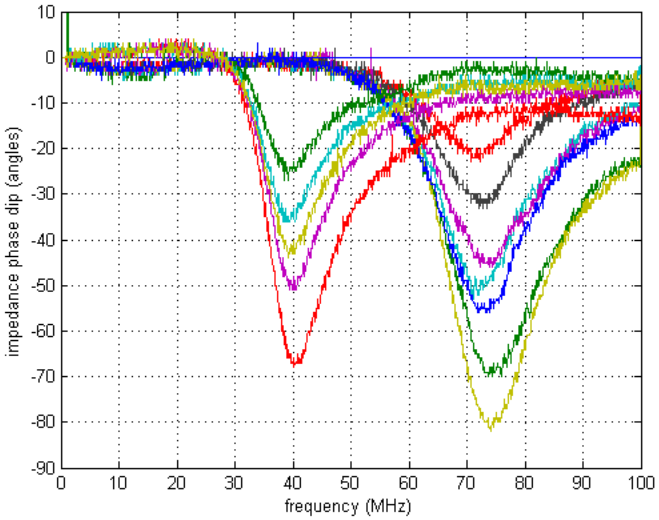
- Single-sensor, single-reading operation (multi-sensor mapping with Pliance X)
- Poor repeatability
- Poor sensitivity
- Non-disposable

New pressure sensor design



- Disposable RLC passive electronic circuit
- Compressive variable capacitor
- Resonance frequency dependent upon pressure
- Wireless interrogation via inductive coupling

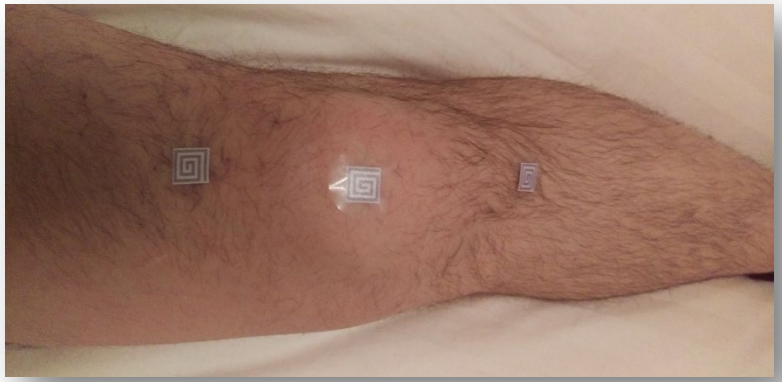




Continuous wireless pressure monitoring & mapping with ultra-small passive sensors for health monitoring & critical care

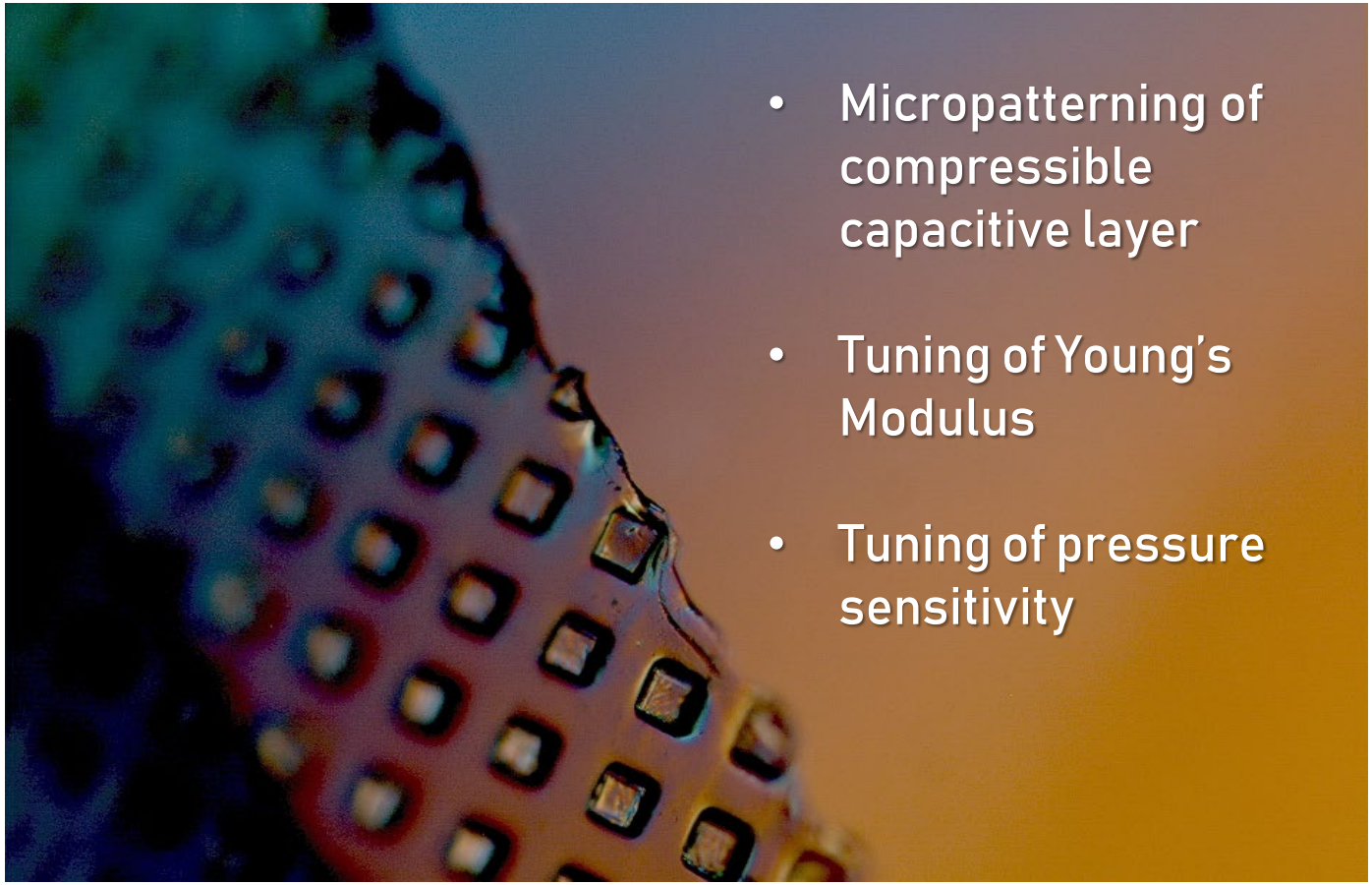
L.Y. Chen, et. al, **Nature Communications**, 5, 5028, (2014)

Sensor deployment on patient's skin



Highly flexible & conformable sensor (typically 10-50 µm thick PDMS)

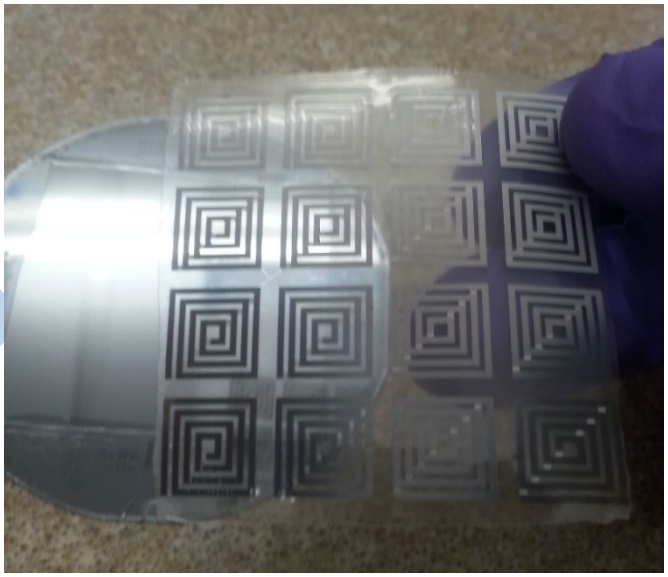
Tuneable compressibility & sensitivity



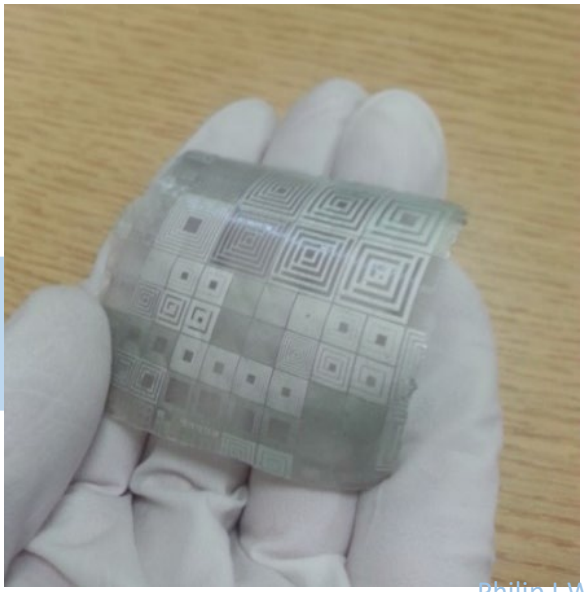
Design, manufacture & testing of capacitive pressure sensors for low-pressure measurement ranges
V. Mitrakos, L. Macintyre, F.C. Denison, P.J.W. Hands, M.P.Y. Desmulliez
Micromachines, 8, 41 (2017)

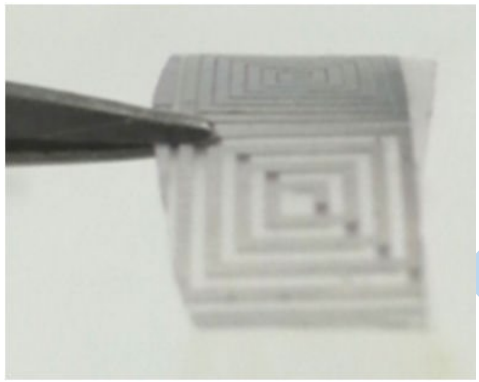
Sensor microfabrication

Scalable manufacture using microfabrication techniques for silicon wafer processing



Peel-off sensors from carrier wafer

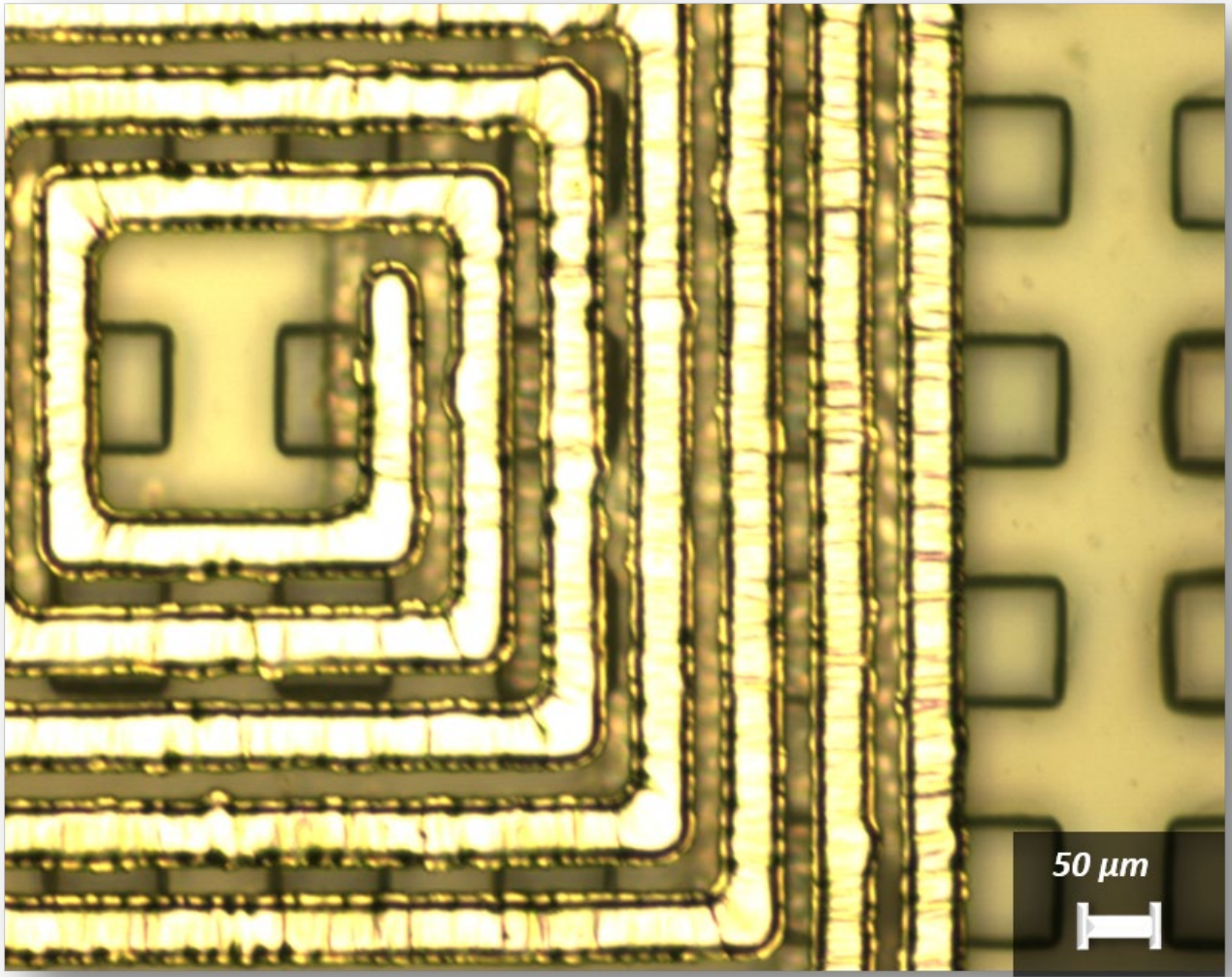




Dice into individual sensors

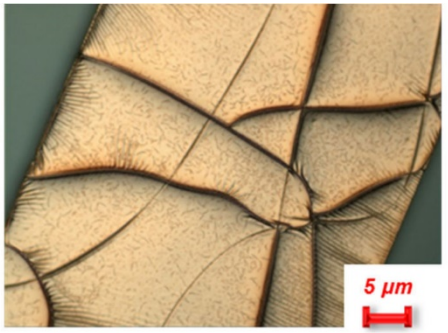
Sensor microfabrication

Unique 'bottom-up' fabrication process enables high precision alignment of inductive spirals, AND better compatibility with industrial manufacturing



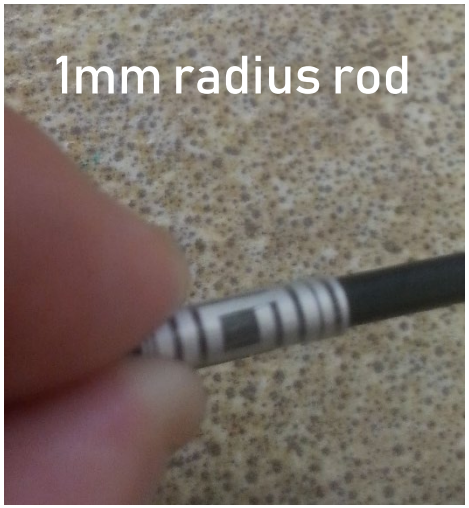
Resilience to extreme deformation

Cracking of electrodes occurs with conventional fabrication processes:

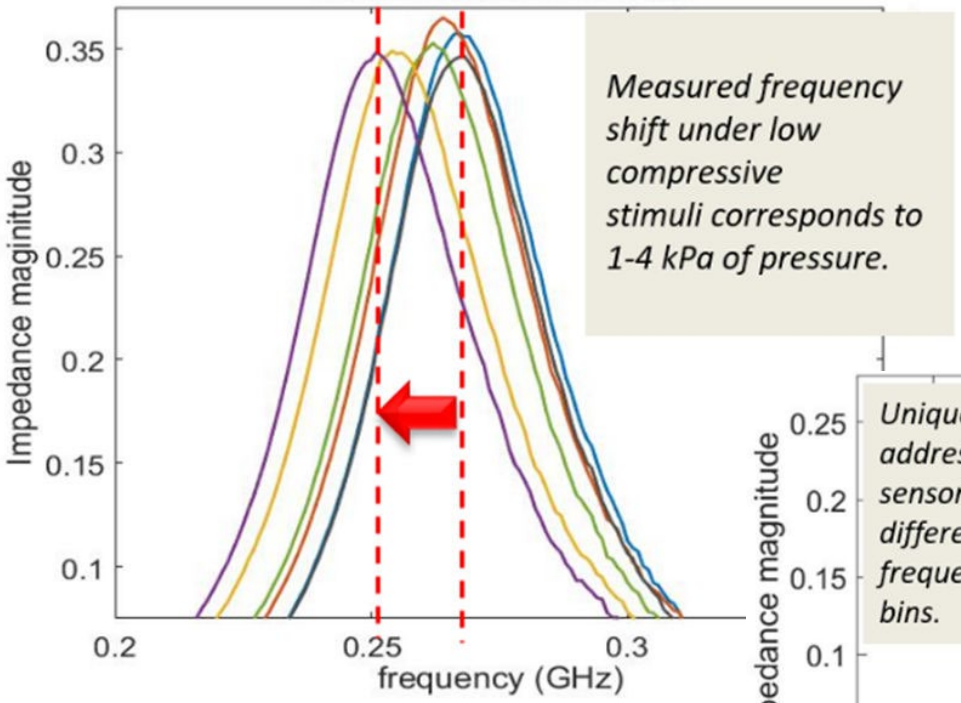


Our fabrication process results in no operational failure, even at extreme bending or folding:

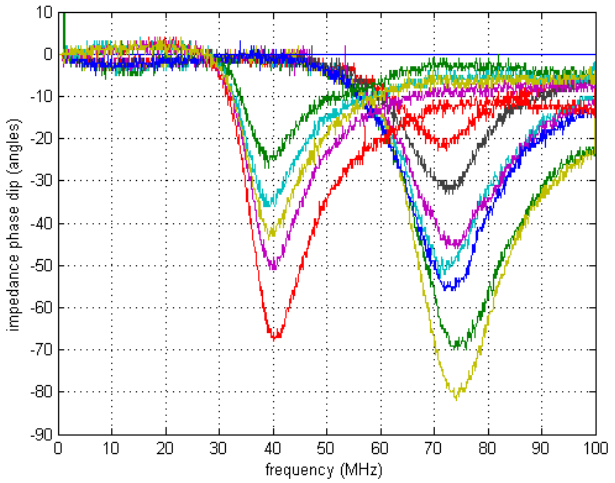
(Patent application currently in preparation).

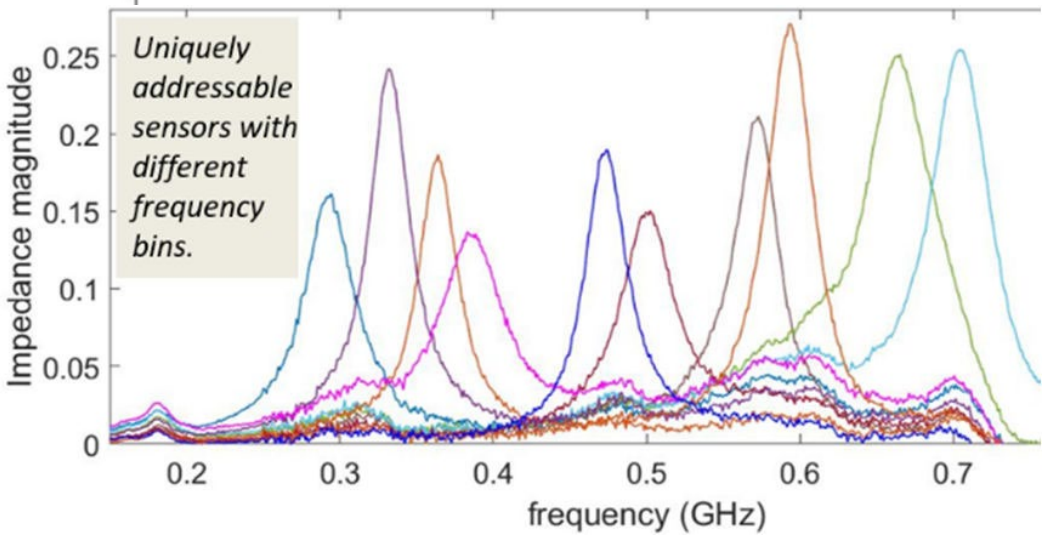


Electrical response



Measured frequency shift under low compressive stimuli corresponds to 1-4 kPa of pressure.

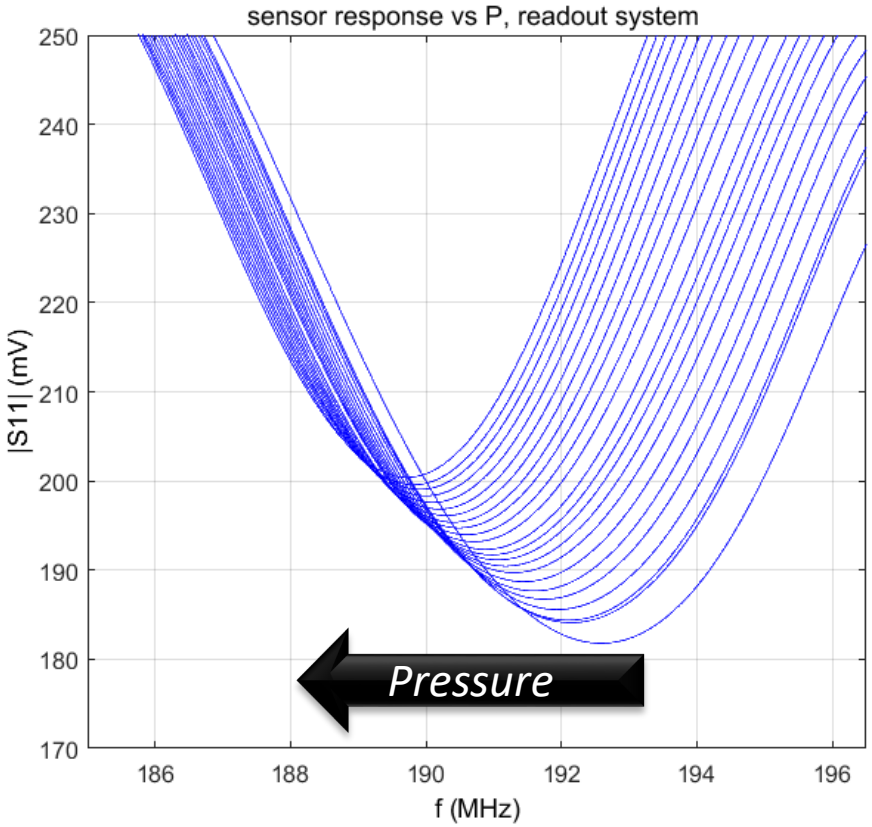


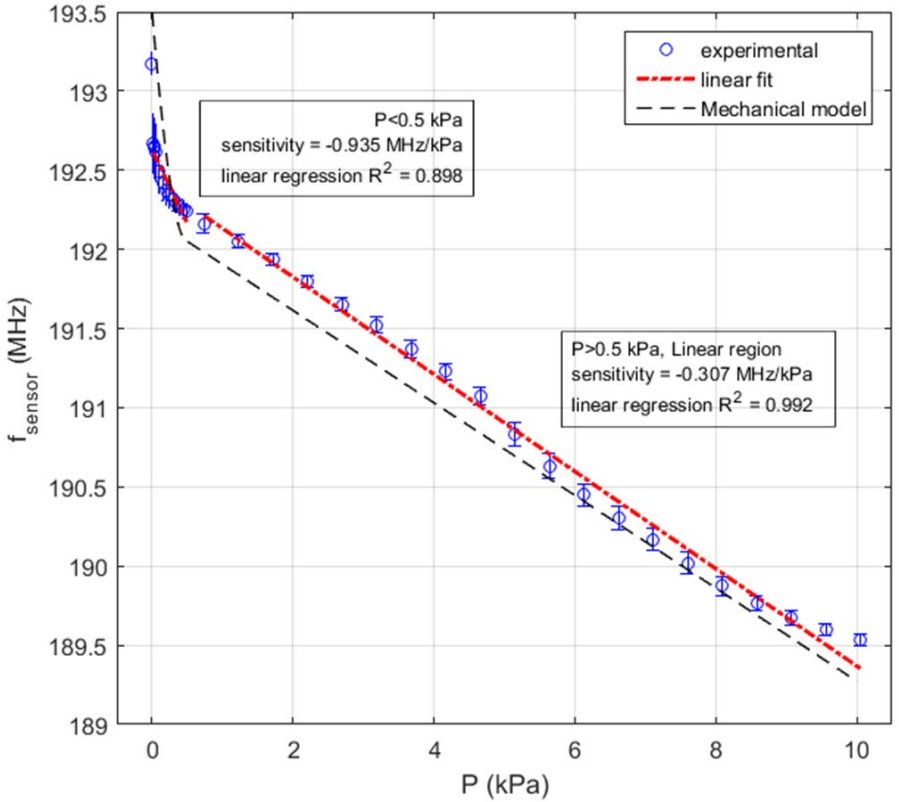


Uniquely addressable sensors with different frequency bins.

- Resonant frequency decreases under applied pressure
- Frequency binning enables simultaneous interrogation of multiple sensors
- Reader distance (mostly) affects only signal strength.

Linear response to applied pressure

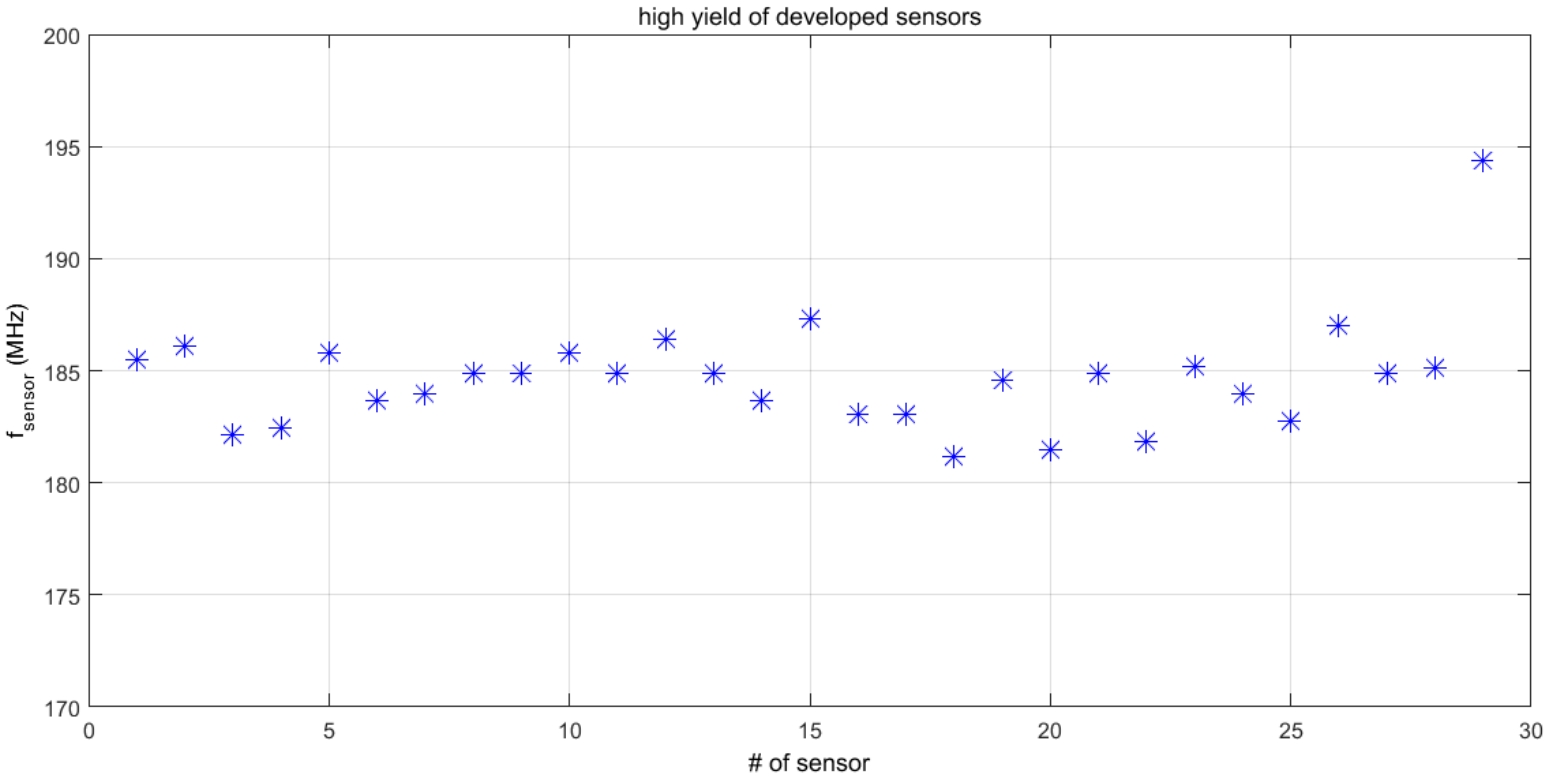




Repeatable and linear sensor response

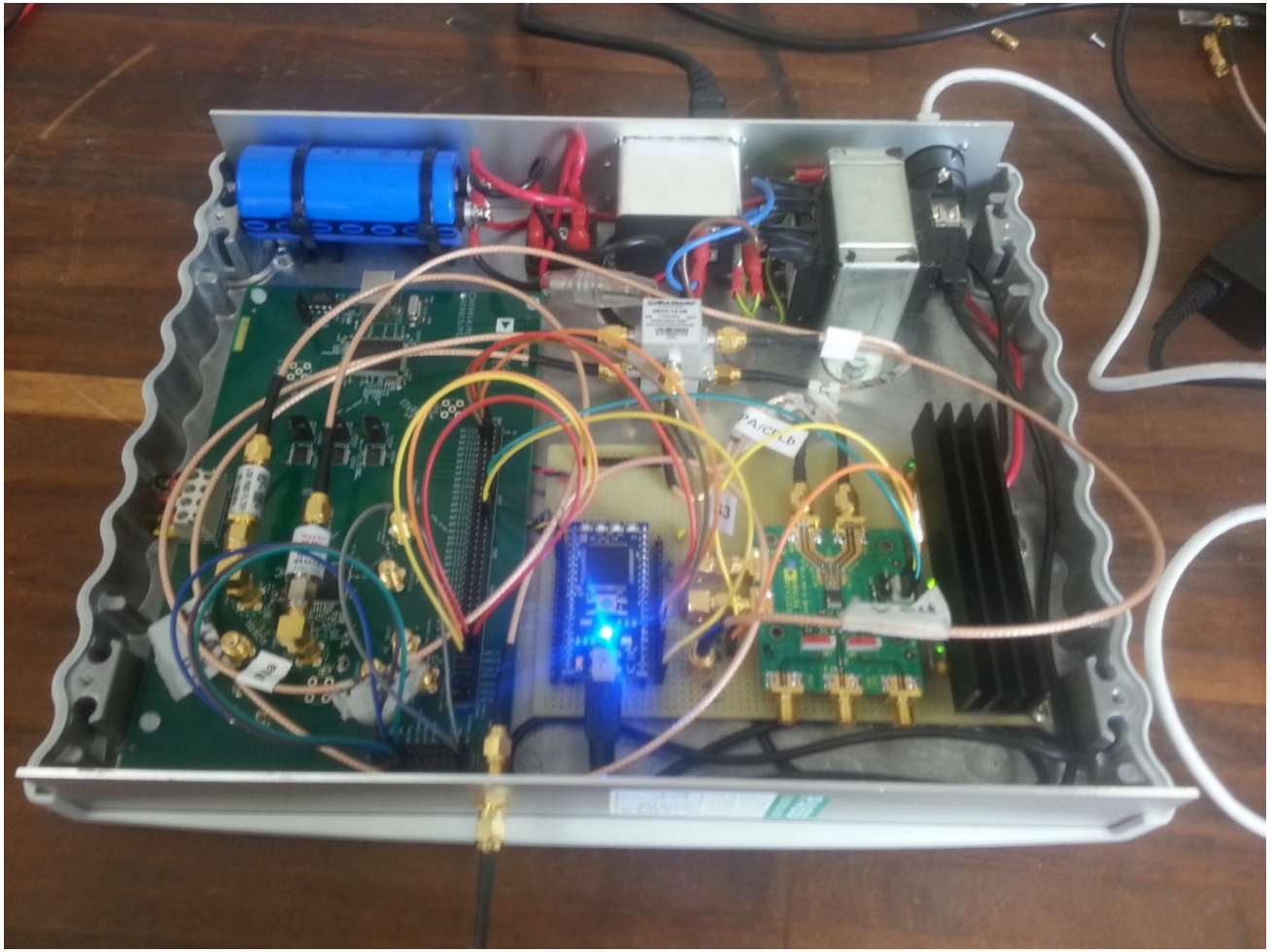
< 0.1 kPa detection limit (tuneable)

Repeatable sensor manufacture



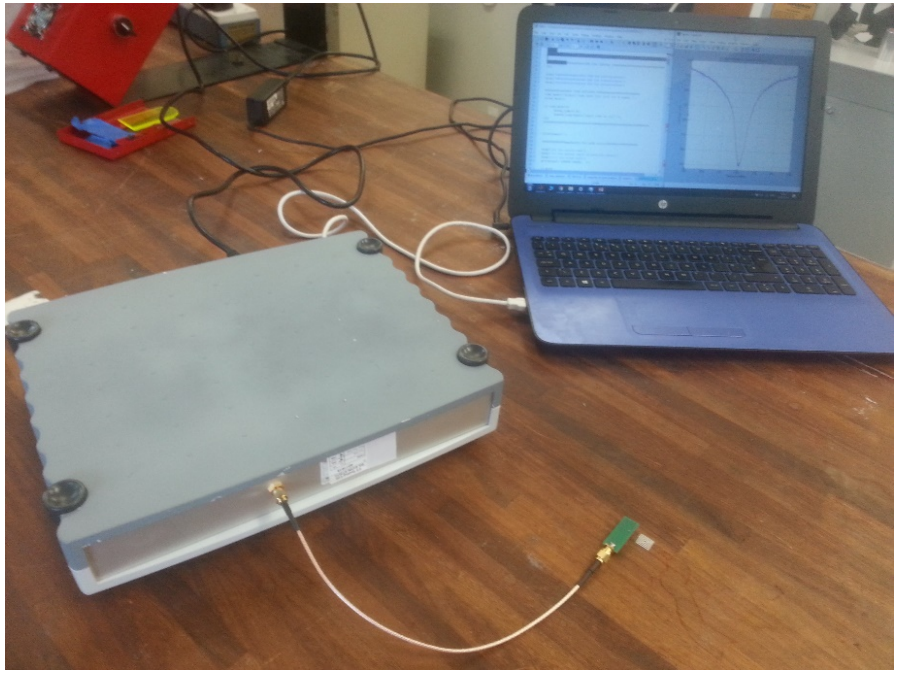
- **Current fabrication** at Scottish Microelectronics Centre (SMC):
  Small research facility, within Institute for Integrated Micro & Nano Systems (IMNS), School of Engineering, University of Edinburgh.
- **Future fabrication**:
  Agreement with SemeFab, for translation to large-scale industrial production.

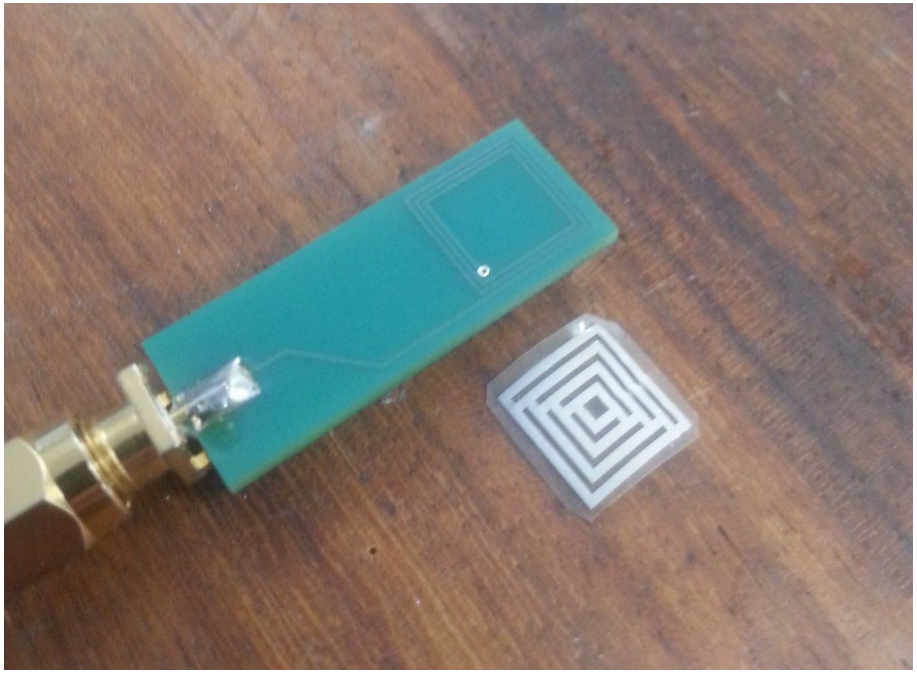
Portable reader system development



Portable demonstration system, for clinical testing & proof-of-principle.
Reader system made using off-the-shelf electrical components.

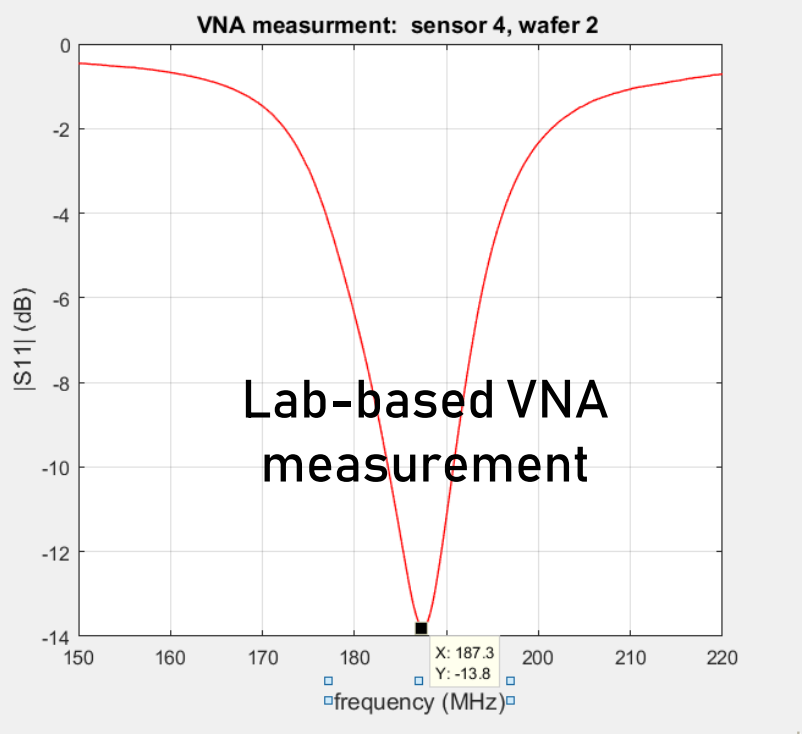
Portable reader system development

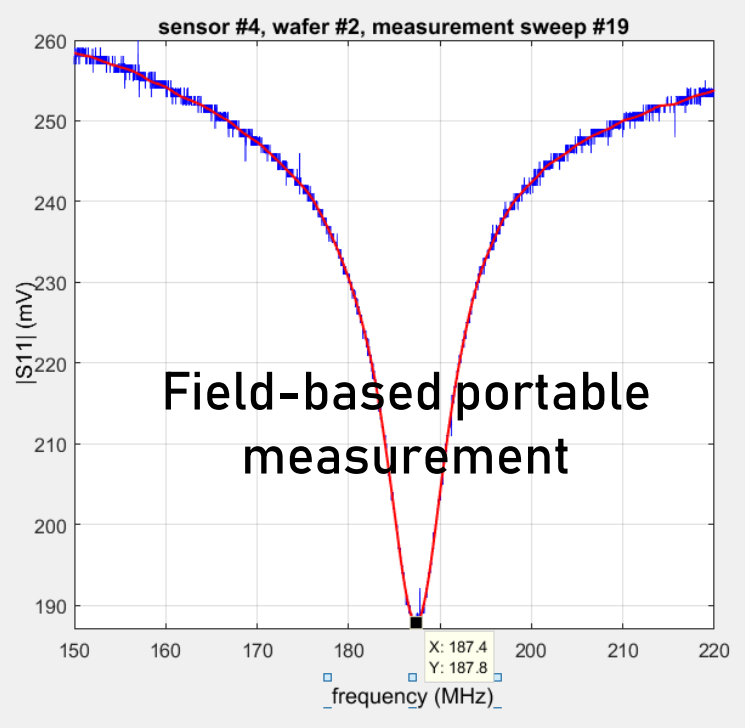


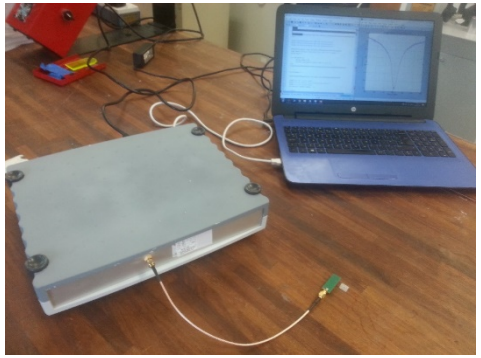


Portable demonstration system, for clinical testing & proof-of-principle.
Reader system made using off-the-shelf electrical components.
Custom antenna fabricated for standard sensor design.

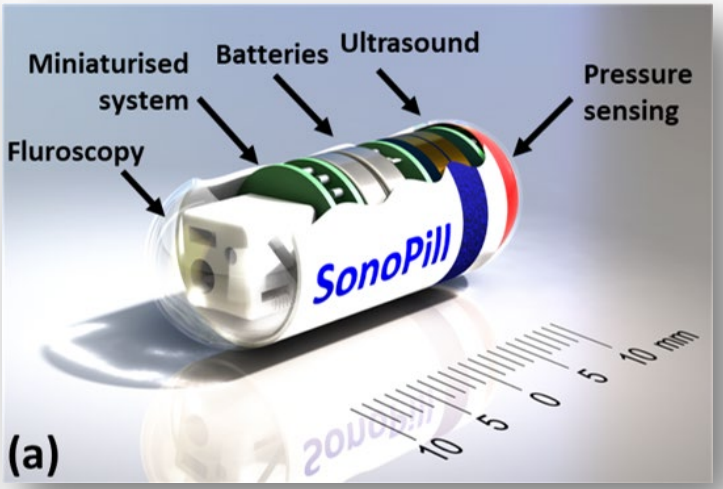
Portable reader system development







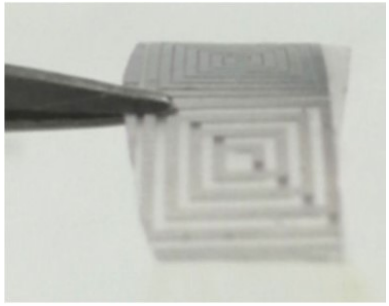
Ultra-compact reader system development for gastro-intestinal deployment



- Capsule-based reader system, for gastro-intestinal pressure monitoring (in collaboration with Sonopill research project).
- Custom PCB designed in-house ~ 15 mm length (externally powered via tether)
- Future dedicated ASIC (with integrated power & data storage/transmission) would enable further miniaturisation
- Initial testing complete in artificial gut & in live porcine test subjects

Summary:

- Description of new wireless & flexible pressure-measurement system, designed for medical compression garments.
- Demonstration of new portable reader system for point-of-care testing.
- Clinically-relevant measurements obtained.
- End-user engagement provides validation of our approach.
- New patentable fabrication process, compatible with semiconductor processing & large-scale manufacture.
- Multiple follow-on projects in planning or secured.



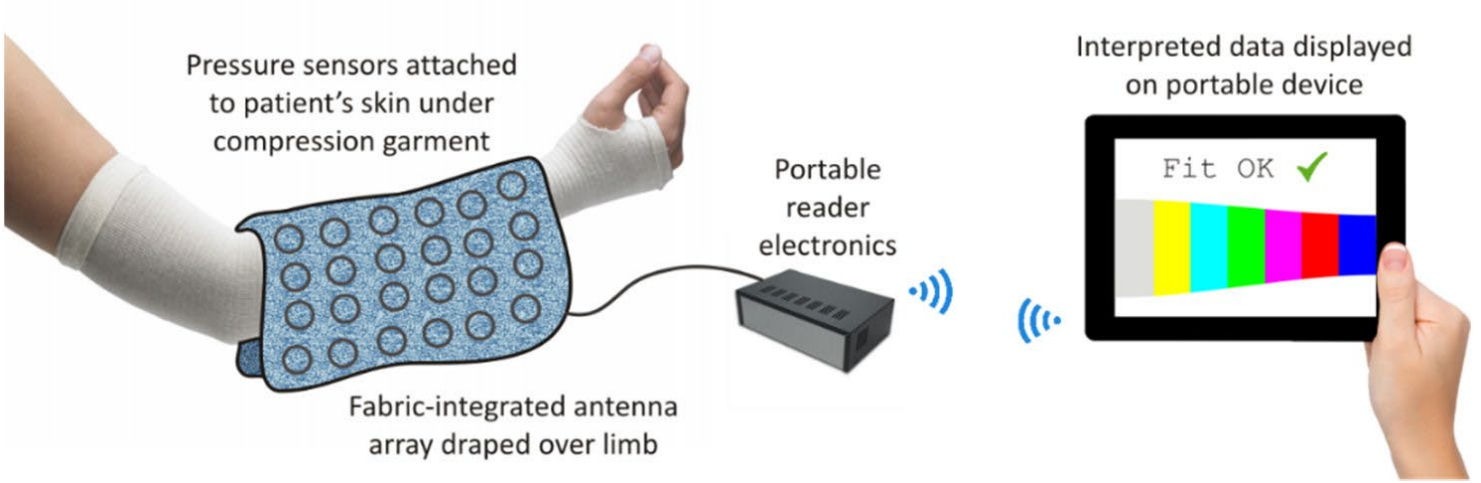
Next steps:

Medical compression devices

Ongoing testing on dummy limbs & human volunteers for system benchmarking

Seeking research funding for further sensor & reader development, including:

- Medical trials with clinical partners
- Smart blanket reader, for simultaneous monitoring/mapping of multiple sensors over large areas
- Increasing range of wireless measurements, using RFID technology or similar
- Capsule-based gastro-intestinal pressure measurements



Next steps:

Sports compression garments

2x EPSRC Impact Acceleration Awards, jointly awarded by Edinburgh & Heriot-Watt Universities, in collaboration with Semefab & the Pentland Group

£81.4k, for 6 months, starting late summer 2019

- Begin migration of sensor fabrication to industrial facilities (Semefab)
- Development of pool-side reader system for swimsuit compression measurement studies
- Inform swimsuit design for 2020 Olympics & 2022 Commonwealth Games
- Later technology deployment to other Pentland brands

speedo

Pentland

Semefab

EPSRC
Engineering and Physical Sciences Research Council

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Next steps:

Tactile robot sensing

New PhD studentship opportunity being pursued through Edinburgh CDT in Robotics & Autonomous Systems

Smart composites for structural monitoring

Collaboration with Dr Eddie McCarthy, Mechanical Engineering, University of Edinburgh

2x final year UG projects demonstrating proof-of-principle operation within laminated glass-reinforced composites

New research funding opportunities being pursued, towards continuous structural monitoring of composites for wind and marine turbine blades

Thank you

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Prof Marc Desmulliez
School of Engineering & Physical Sciences, Heriot Watt University

Dr Lisa Macintyre
School of Textiles & Design, Heriot Watt University

Prof Fiona Denison
Queen's Medical Research Institute (QMRI), University of Edinburgh

Dr Vasileios Mitrakos
University of Edinburgh & Heriot Watt University

MDVSN
Medical Devices and Vulnerable Skin Network

EPSRC
Engineering and Physical Sciences Research Council

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