Electronics and
Computer Science

UNIVERSITY OF
Southampton

Printed electrode structures for bio-potential monitoring in wearable e-textile garments

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Overview

- Introduction to the Electronics and Computer Science (ECS) department at the University of Southampton and major research projects on smart fabrics.
- Applications and fabrication methods for smart textiles.
- Challenges of printing electronics on fabrics.
- Structure of printed electrodes for bio-potential monitoring.
- Examples of printed electrodes for ECG, EOG and FES.
- Conclusions and link to WEARPLEX.

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Research at Southampton

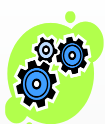
- 30+ years of developing microsystems and printed electronic materials
- 11 years of e-textiles, research funding to date: >£9 M
  - 2008 - EU FP7: project MICROFLEX (printed MEMS on textiles)
  - 2010 – EU FP7: project BRAVEHEALTH (printed electrodes on textiles for ECG monitoring)
  - 2010 – EPSRC: Energy Harvesting Materials for Smart Fabrics and Interactive Textiles
  - 2011 – Formed spinout: Smart Fabric Inks Ltd
  - 2013 – EU FP7: CREATIF Project (printed functional materials for creative industries)
  - 2013 – EPSRC: SPHERE project (EH for wearable applications)
  - 2015 - EPSRC: Novel manufacturing methods for Functional Electronic TexTiles (FETT) (packaging electronics in yarns)
  - 2016 – MRC: Smartmove – Printed FES devices for stroke rehabilitation
  - 2017 – DSTL: Woven integrated textile sensors for situational awareness and physiological monitoring
  - 2017 – EPSRC: Wearable and Autonomous Computing for Future Smart Cities: A Platform Grant
  - 2018 - EPSRC : Functional electronic textiles for light emitting and colour changing applications.
  - 2019 – EU H2020: WEARPLEX - Wearable multiplexed biomedical electrodes
- 2 Academic staff, 10 Research Fellows and 12 PhD Students working on e-textiles.

£100 million Mountbatten Building, housing state of the art cleanroom.

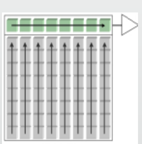
Printed Electronics and Materials Lab within Mountbatten complex

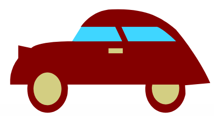
Example Functions and Applications for Smart Fabrics


Drug delivery


Mechanical action


Lighting


Sensor

	Medical	Smart bandage, auto sterilization uniform, bio-potential monitoring clothes
	Transport	Luminous cabin, smart driver seat, auto clean filters
	Workwear	Danger warning workwear (heating suit, high visibility, gas sensing, temperature sensing, movement sensing, alarm sounder)
	Consumer	Massage and cooling/heating armchair, surroundings customisation
	Architecture	Lighting, heating, advertising and interaction with building surfaces

E-textile system developments

ICD+ suit by Levi and Phillips Electronics (2003)

Bulky Components added to outside

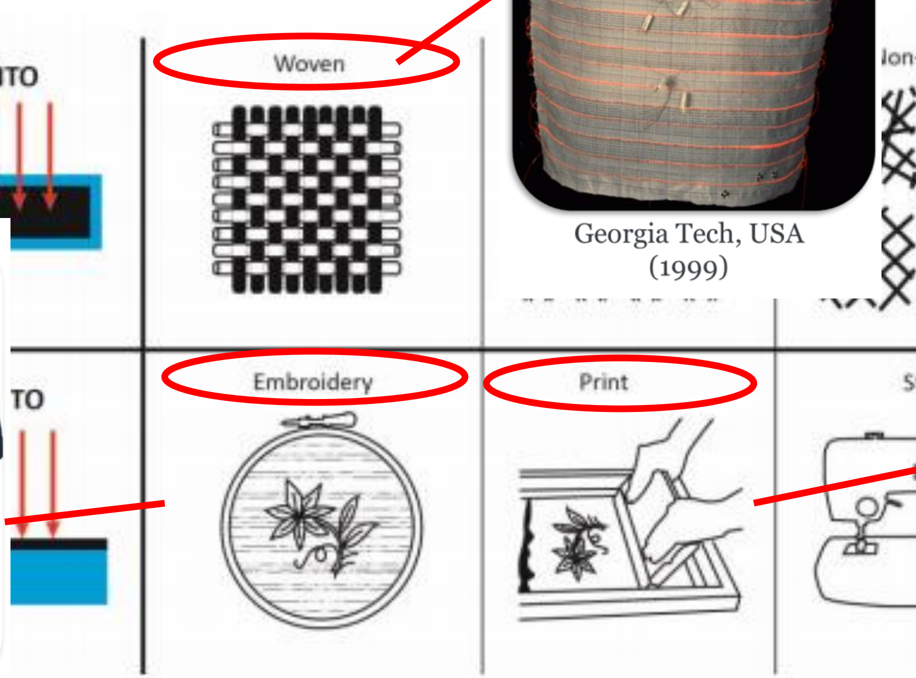
LED Jacket for singer Will.I.Am by Moritz Waldemeyer (2011)

Inflexible circuitry added to jacket

Bioman+ heart rate monitoring shirt by AiQ (2017)

Inflexible circuitry with integrated conductive thread electrodes

E-textile fabrication



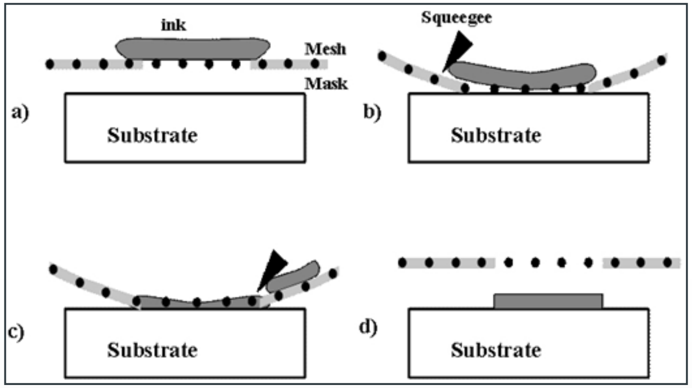
Georgia Tech, USA (1999)

Fraunhofer, Germany (2006)

Southampton, UK (2014)

Screen Printed Smart Fabrics

- Screen printing requires a screen, squeegee and a printable paste.



- Key advantage: Any pattern can be printed, not restricted to warp and weft directions.
- Key advantage: Printed on top of the fabric so the fabric properties next to the skin are not affected.
- Key advantage: Roll to roll process so can be printed as part of the fabric manufacturing process.
- It can be used to deposit standard materials such as conductors, resistors and dielectrics.
- We have also developed more exotic printable materials such as piezoelectric, piezoresistive, thermochromic, sacrificial and electroluminescent.
- Typical print thickness after drying is between 5 and 50μm depending on the materials.

Functional Inks Development

- Research underpinned by novel ink development
- Inks need to be flexible, low temperature (<150°C) and robust
- Numerous ink types are required:

Passive	Basic functional	Advanced functional
Interface layer	Conductive	Piezoresistive
Encapsulation layer	Dielectric	Piezoelectric
Structural	Conductive rubber	Electroluminescent
Sacrificial		Gas sensitive
		Semiconducting
		Thermochromic
		Electrochromic
		Photovoltaic
		Electrochemical

Challenges of Printing on Fabric

- Very high surface roughness compared to PCB or plastic films.
- Very high absorption of inks/pastes into the fabric materials reducing minimum resolution of printed patterns.
- Weave structure presents a network of voids to the printer.
- Fabrics typically cannot sustain the same harsh processing temperatures or chemicals as ceramics, PCB's or plastic films.
- Printing defects have much greater consequences compared to graphical printing.

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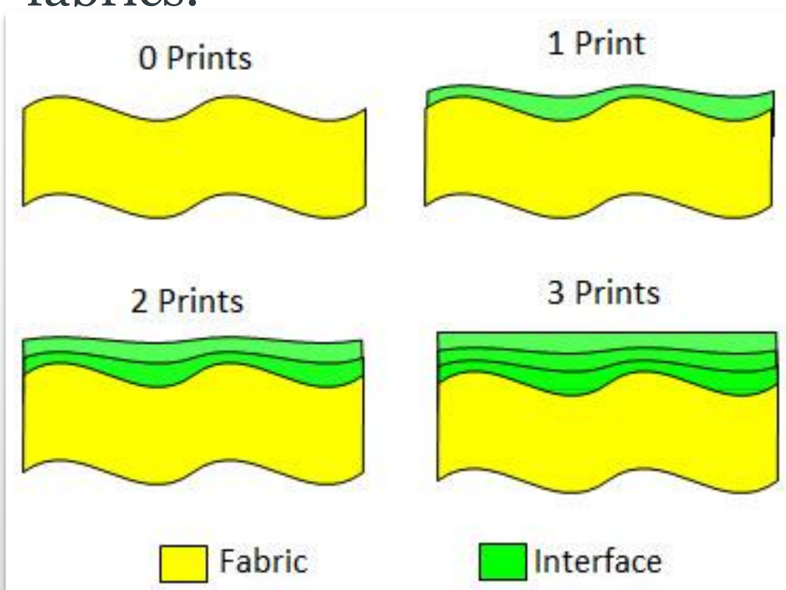
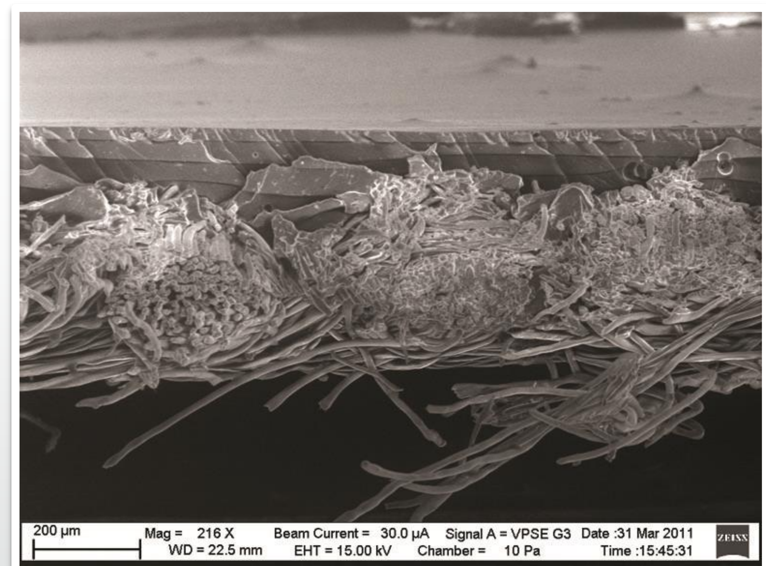
Printed Interface Layer

- Overcomes surface roughness and pilosity of fabric substrate providing a continuous planar surface for subsequent printed layers.
- Only printed where required, unlike laminated or transfer coated fabrics.





Cross-section SEM micrograph of 4 screen printed Fabinks UV-IF-1004 interface layers on polyester cotton fabric

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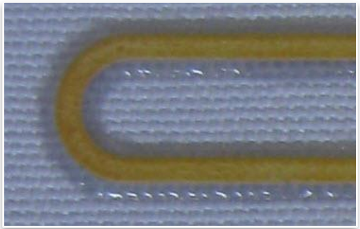
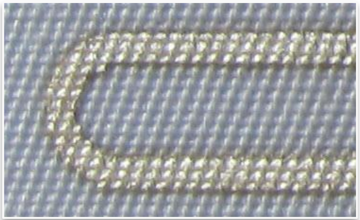
Influence of Interface Layer



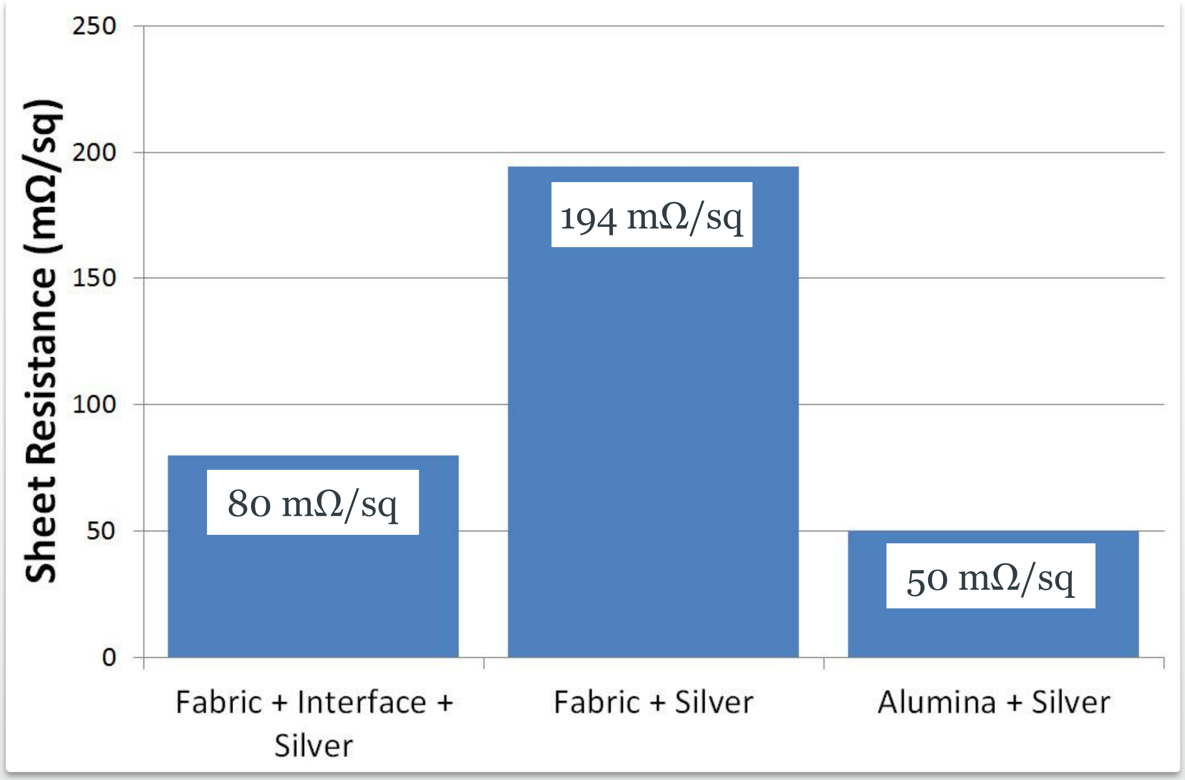
Interface



Fabric

Alumina

Printed track on each substrate



Printed track calculated sheet resistance for each substrate

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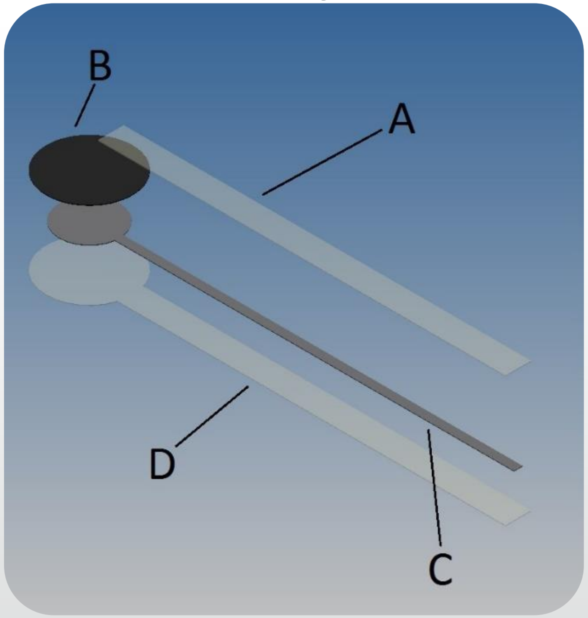
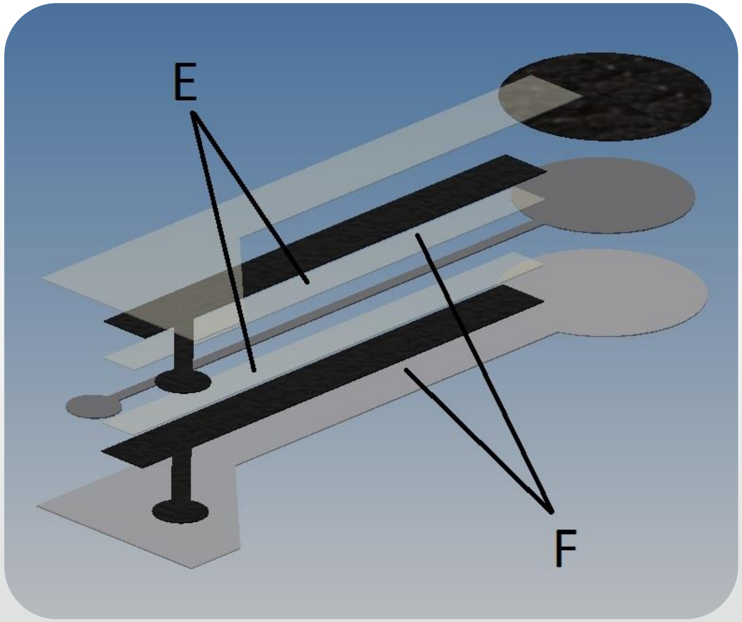
Printed Electrodes for Medical Applications

- Printed electrodes can be used for any bio-potential monitoring – ECG, EEG, EMG, EOG as well as activation via FES and TENS.
- Electrodes printed directly on to fabric avoiding the need for disposable stick on electrodes.

Conductive rubber electrode and connecting track



Shielded track for sensitive signals

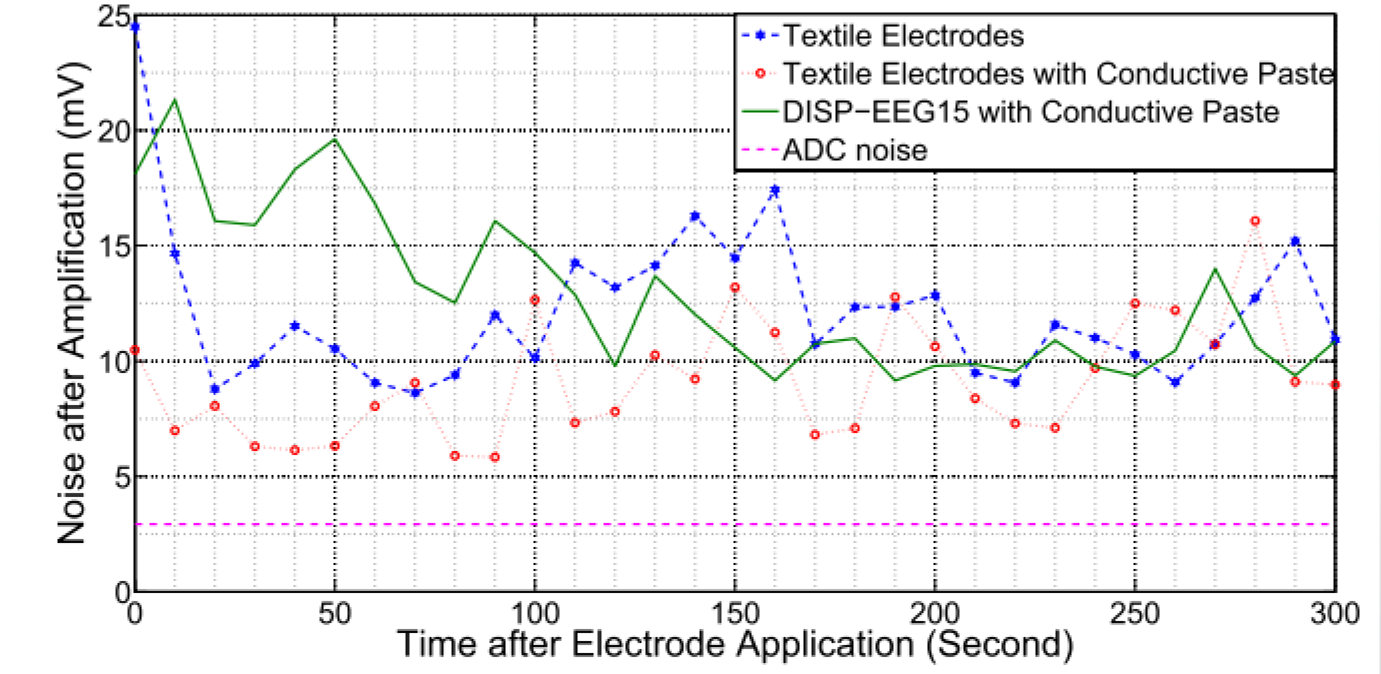


A- Encapsulation
B- Waterproof Covering
C- Conductor

D- Interface Layer
E- Internal Interface
F- Shielding

Printed Electrodes Electrical Performance

- Printed electrodes do not require any additional gel, thus reduced setup time.
- Signal to noise ration is comparable for printed electrodes and disposable electrodes.
- Trials using conductive paste (Weaver Ten20) on all electrodes as comparison.



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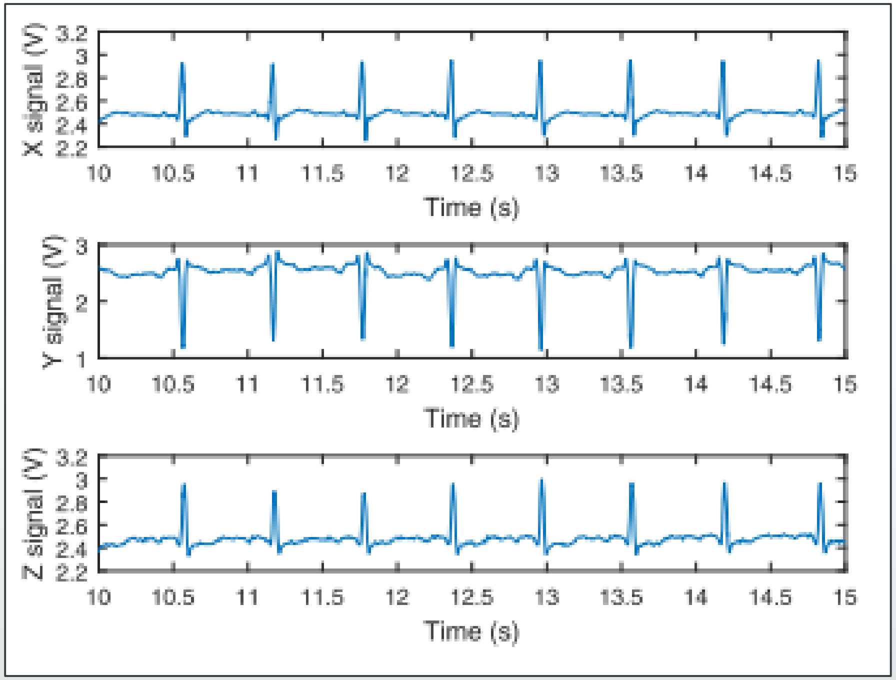
Frank Configuration Printed Vest

- Fully printed Frank Configuration ECG monitoring vest.
- Alternative to full 12-lead ECG (10 electrodes) producing clinically similar results.
- 7 electrodes, 3 lead ECG monitoring.
- All dry electrodes, printed rubber conforms to skin to give good signal quality.
- SNR comparable to standard 3M electrodes.

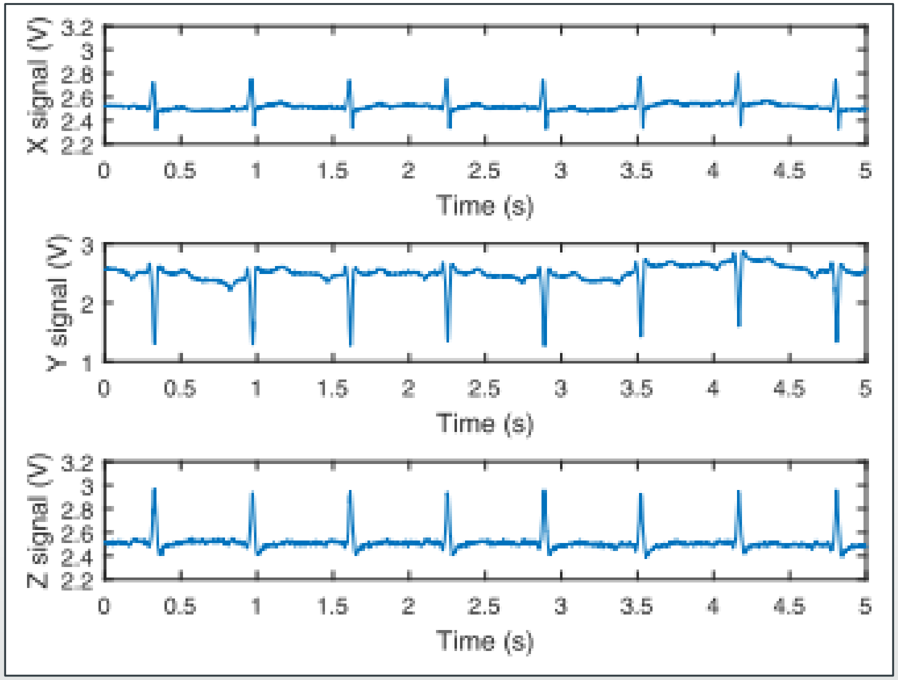
Printed ECG Frank configuration vest

Reduced Frank Configuration Printed Vest

- Comparison between standard stick on electrodes and printed vest Frank configuration.
- Results are evenly matched, reduced slightly in Vx, which is across the chest.



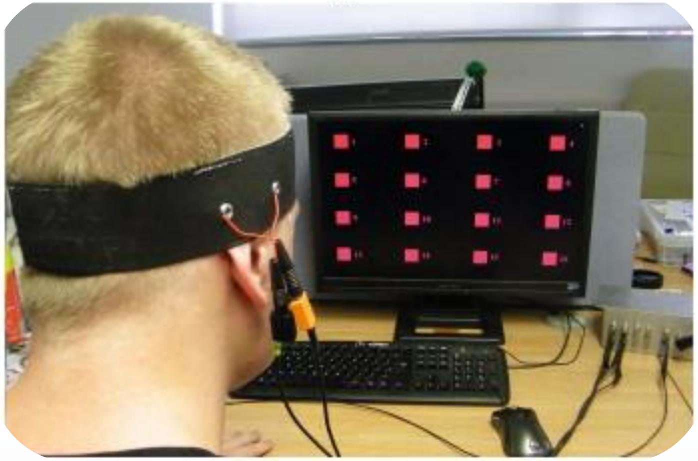
ECG signals using conventional stick on electrodes in Frank configuration

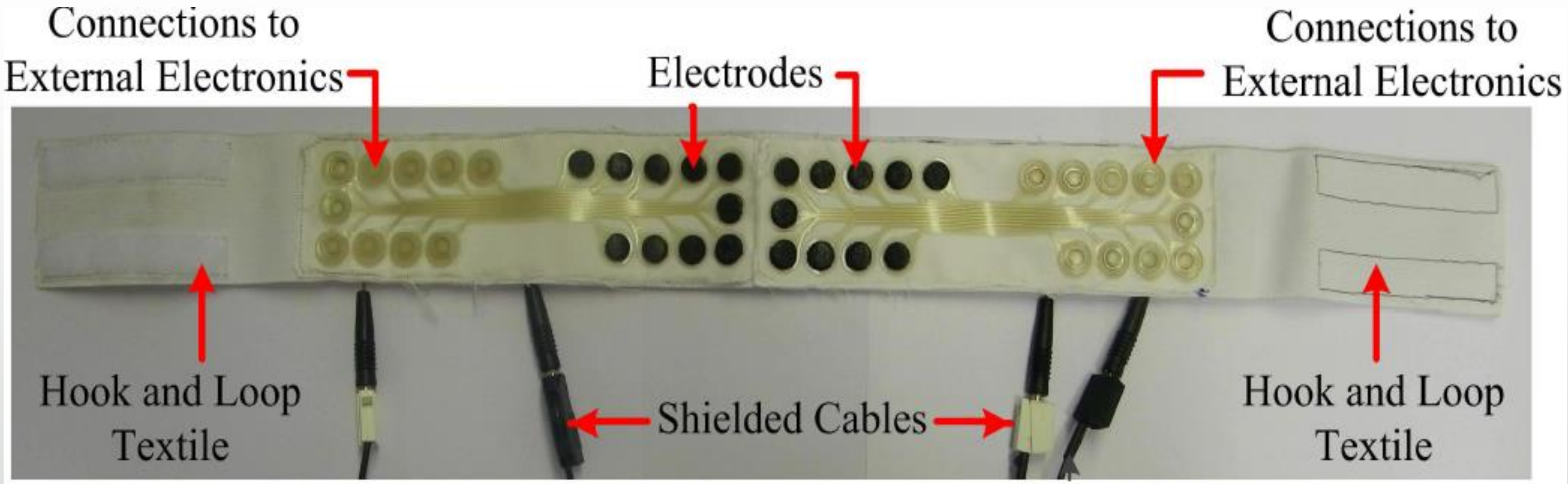


ECG signals using printed electrodes vest electrodes in Frank configuration

Printed Electrodes for EMG/EOG controller

- Printed facial EMG and EOG controller headband (eyes, jaw, eyebrows).
- Controls cursor on PC, potential use for paraplegics or other mobility impaired people.
- Simple software test program times movement of cursor to square

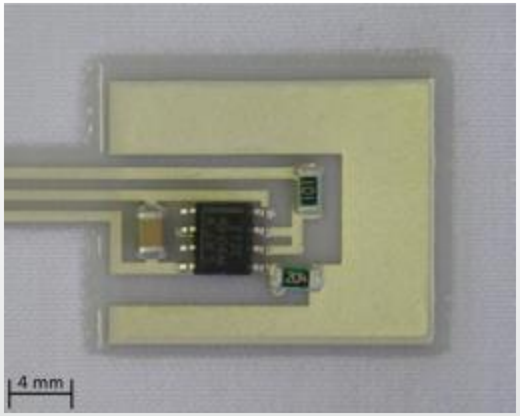




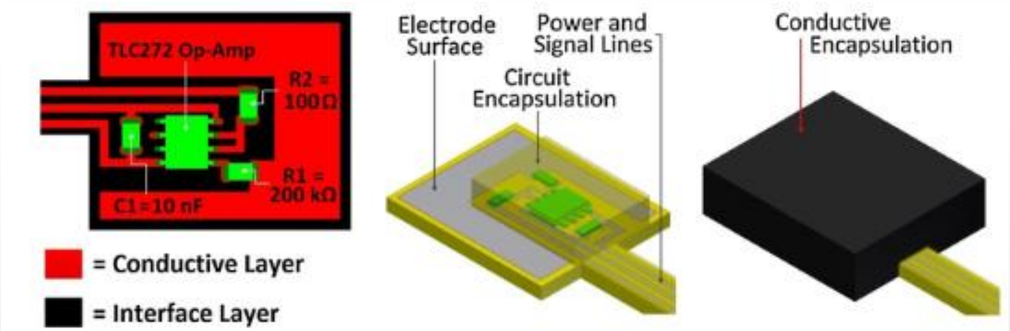
Wearable EOG detection printed electrodes head band

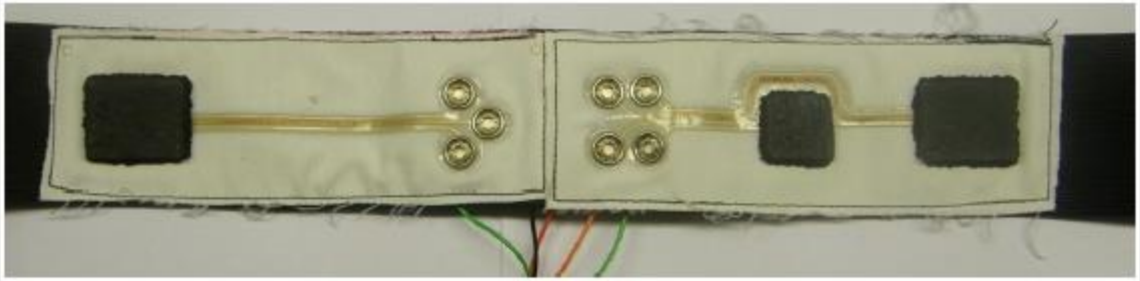
Printed Active Electrodes for Bipolar ECG

- Active electrodes printed on a fabric chest band to measure ECG.
- Active electrode reduces the signal impedance using a buffer amplifier at the electrode source.
- Results show they perform as well as standard electrodes when still or walking up to 4 km/h but begin to show greater divergence when going up to 12 km/h due to motion artefacts.



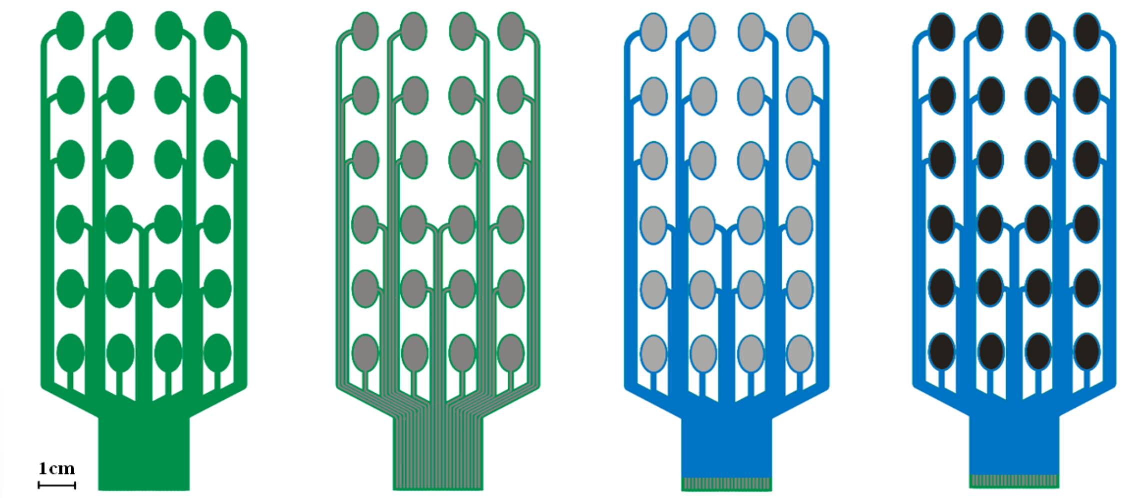
Buffer circuit and routing before encapsulation





Printed wearable ECG detection chest band

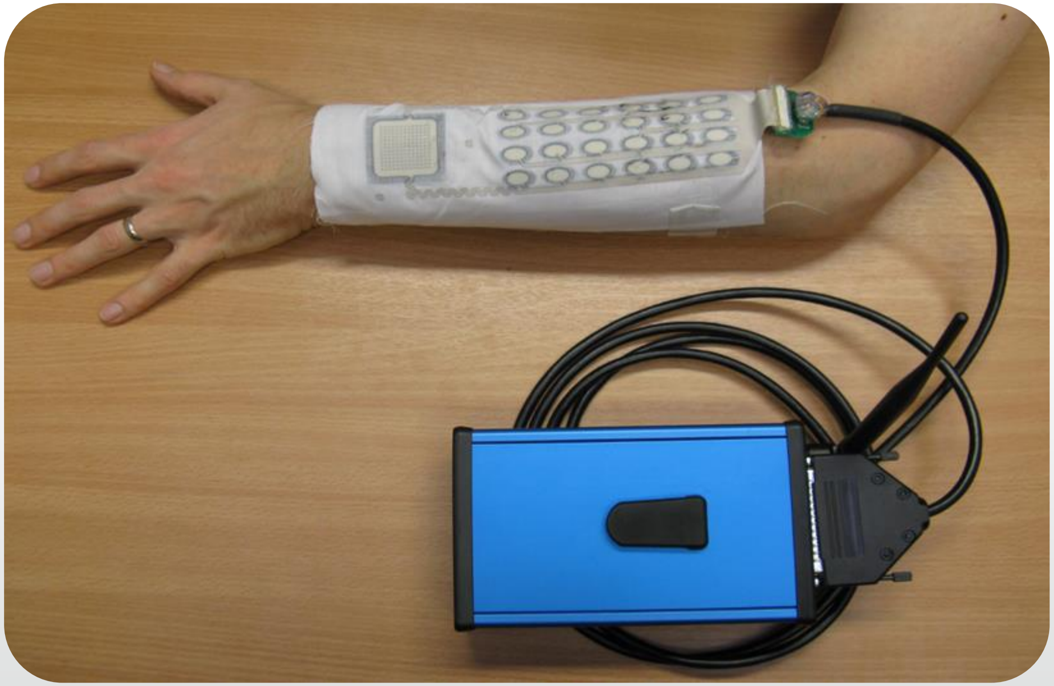
Printed Electrodes on Fabric Used for FES



Step 1: Interface | **Step 2:** Conductor | **Step 3:** Insulator | **Step 4:** Electrode

Printed Electrodes on Fabric Used for FES

- Printed FES electrode networks on textile and integrated within a sleeve for easy use by patients.
- Current stimulation box is battery powered and controlled wirelessly but not fully integrated and is bulky.



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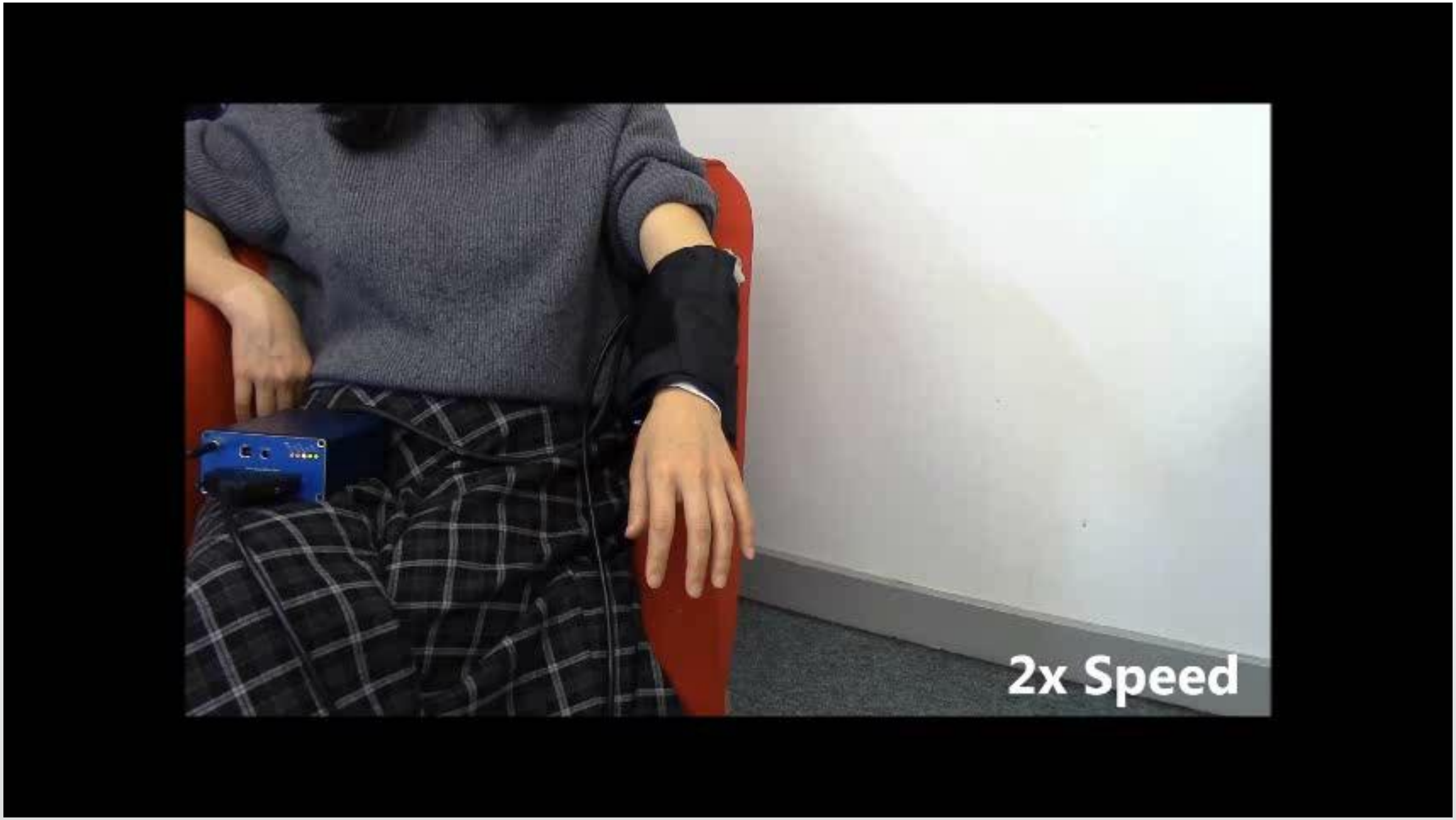
Printed Electrodes on Fabric Used for FES

- Example of FES in action with printed electrode system.



Conclusions and link to WEARPLEX

- We have developed the materials and processes required to fabricate screen printed smart fabrics.
- Wide range of printable active inks have been developed.
- Numerous wearable prototypes using printed electrodes have been developed and shown to work as well as conventional electrodes.
- Textile implementations provide a universal platform but place constraints on materials processing.
- This experience will be used in WEARPLEX to make the system printable on to fabric; identifying the optimal fabric, layout and processing.

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Acknowledgements

- Thanks to colleagues at Southampton, project partners, and EU, EPSRC, DSTL and MRC for funding.

- Time line of projects and links to publications can be found here:

  https://www.e-textiles.ecs.soton.ac.uk/

E-Textiles Network

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Join the network at : www.e-textiles-network.com

Next Event: E-Textiles 2019 Conference, 12th November 2019, London

Smart Fabric Inks Ltd

- Company launched February 2011
- Selling inks developed at the University of Southampton
- Please visit www.fabinks.com for further information