NON-CONTACT VOLTAGE AND ELECTRIC FIELD MEASUREMENT USING THE ELECTRIC POTENTIAL SENSOR

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University of Sussex

EPSRC

RESEARCH COUNCILS UK

Outline

- Background to Electric Potential Sensor (EPS) technology
- Performance as non-contact voltage sensor
- Performance as non-contact electric field sensor
- Applications
- Array imaging 1-D and 2-D
- Conclusions

Background

Electric Potential Sensor (EPS)

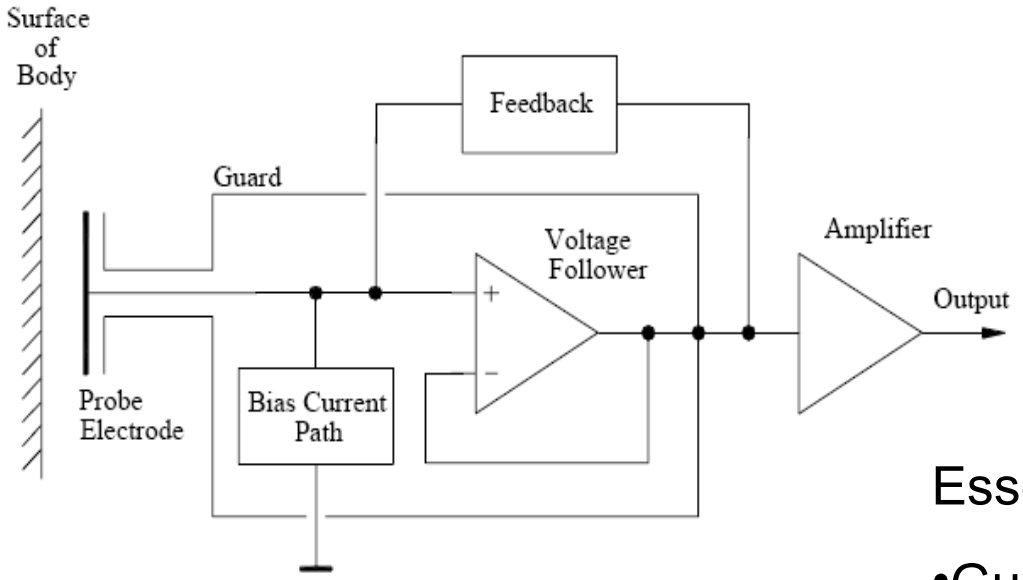
- Behaves like a 'perfect' voltmeter
- Measures spatial electric potential or electric field
- No real current is drawn from the sample (displacement current only)
- Non invasive/non contact capacitive measurement
- Sample is not loaded by sensor

Specifications (generic)

- Input resistance up to ~ $10^{18}\Omega$
- Input capacitance down to ~ $10^{-17}F$
- Voltage noise referred to input < 30nV/$\sqrt{Hz}$ (for >10Hz)
- Bandwidth quasi DC to 100MHz

An ultra low noise electric potential probe for human body scanning, R.J. Prance, A. Debray, T.D. Clark, H. Prance, M. Nock, C.J. Harland, A.J. Clippingdale, *Meas. Sci. and Tech.*,**11**, 291-297, (2000)

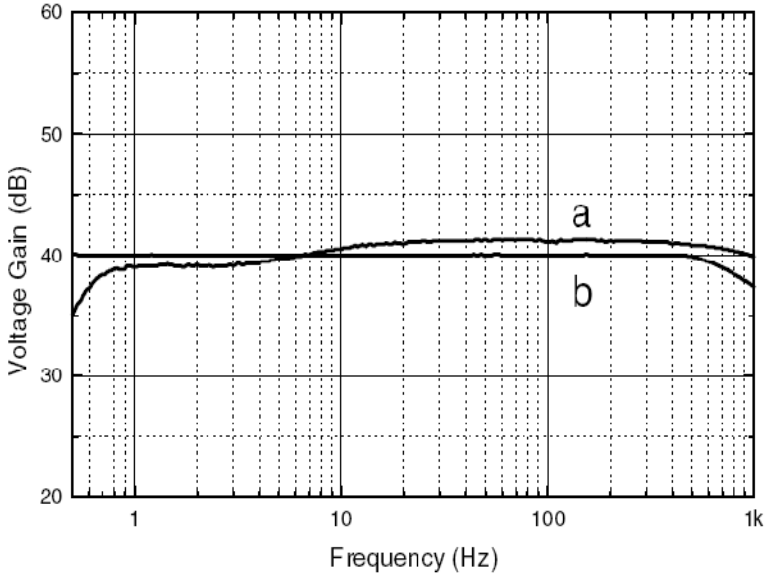
Generic Integrated Electric Potential Sensor (EPS)

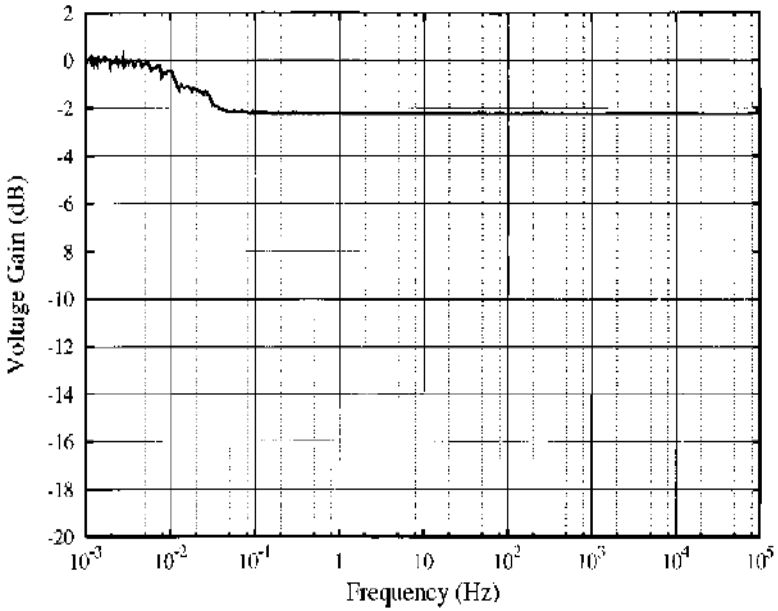


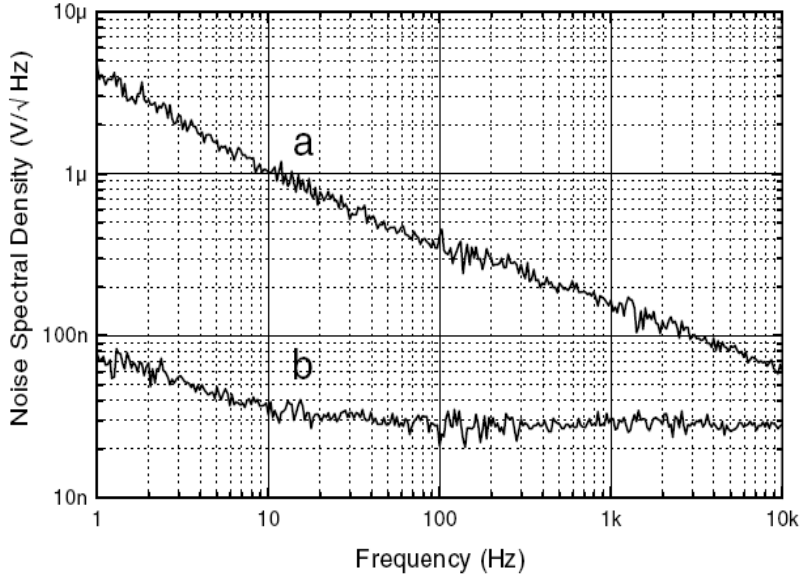
Essential features

- Guarding
- Bootstrap
- Neutralisation
- Stable DC bias current

Electric Potential Sensor





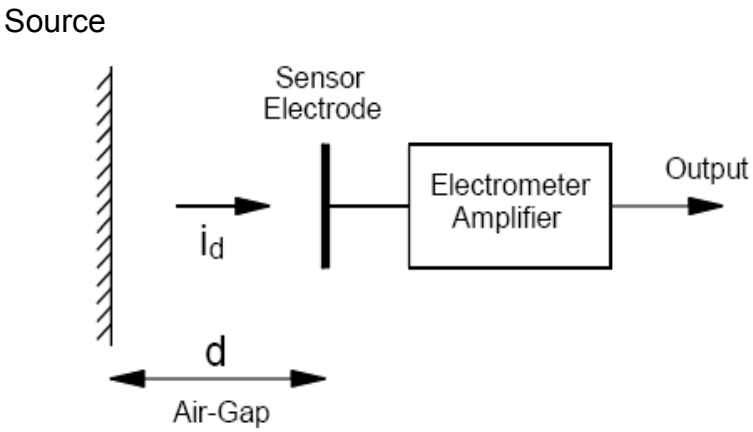


Noise performance and bandwidth are functions of both the probe design and the application

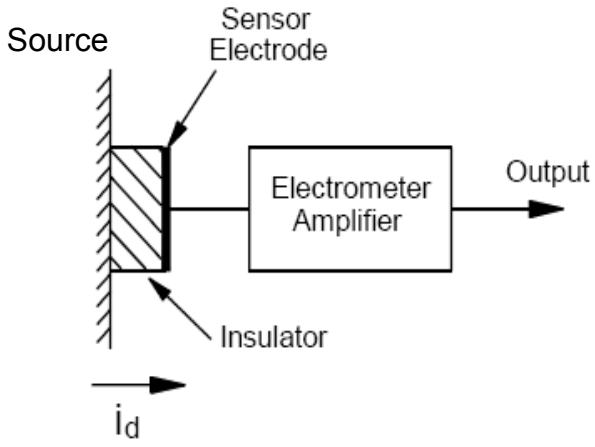
(b) Remote mode

(c) Contact mode

EPS- modes of operation



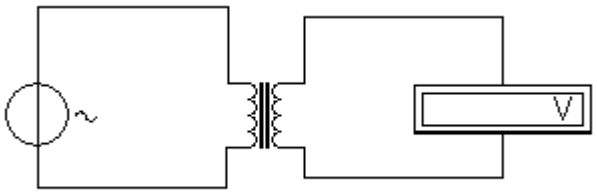
Remote mode



Contact mode

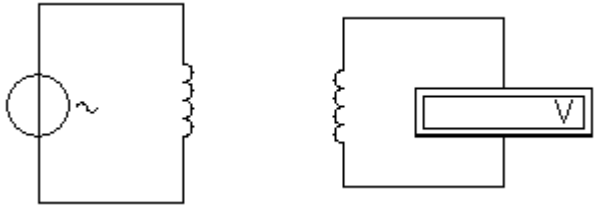
Signal coupling

Magnetic: strong coupling



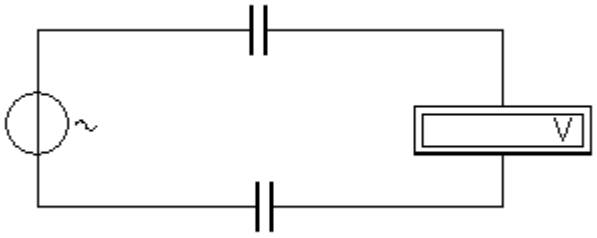
(Transformer)

weak coupling

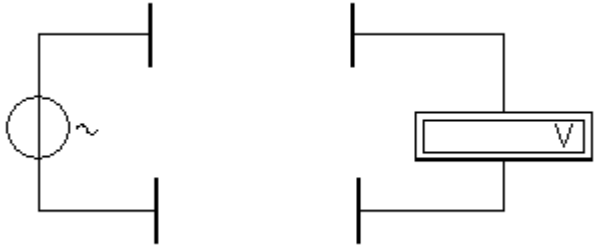


(Magnetometer)

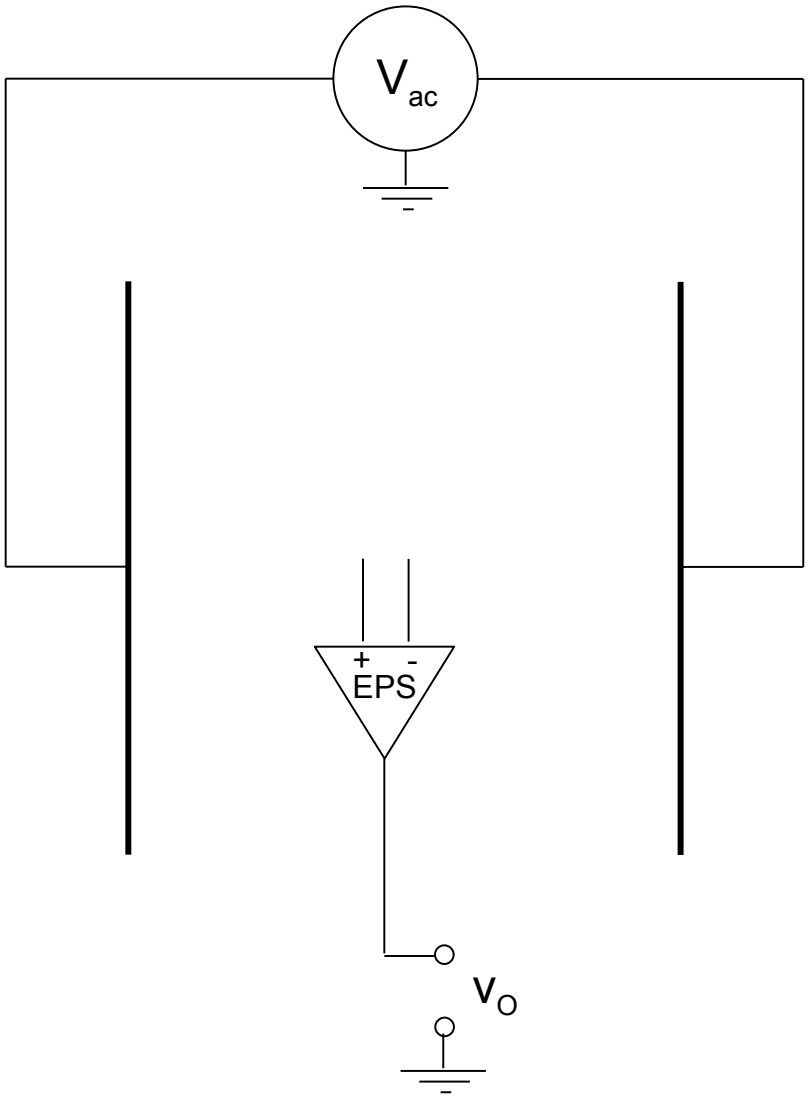
Electric:



Contact mode



Remote mode



Electric Field testing

Balanced AC source.

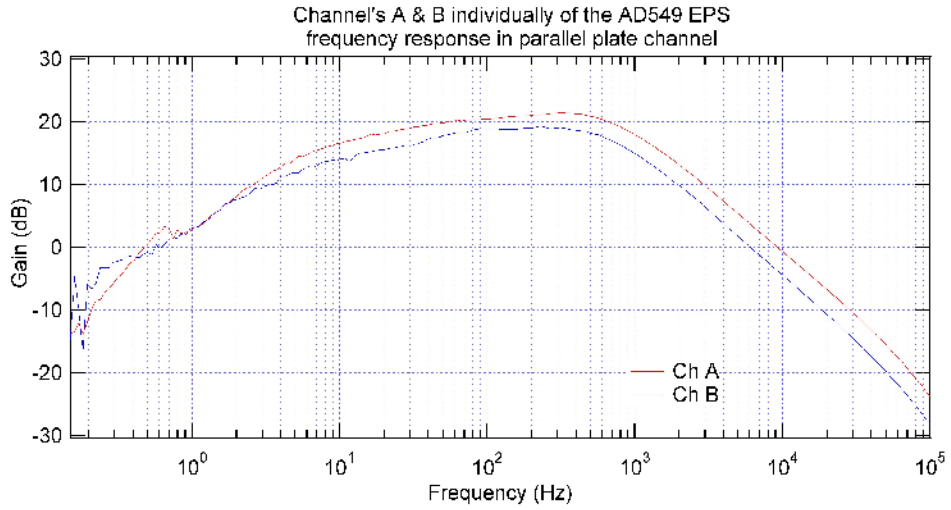
Differential EPS.

10 cm baseline.

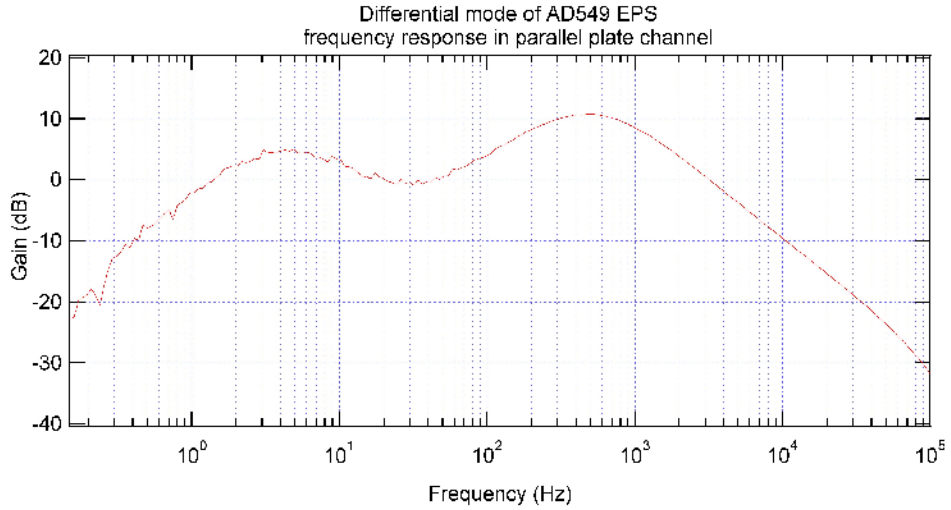
1cm exposed electrode tip.

Tip area 10 mm^2.

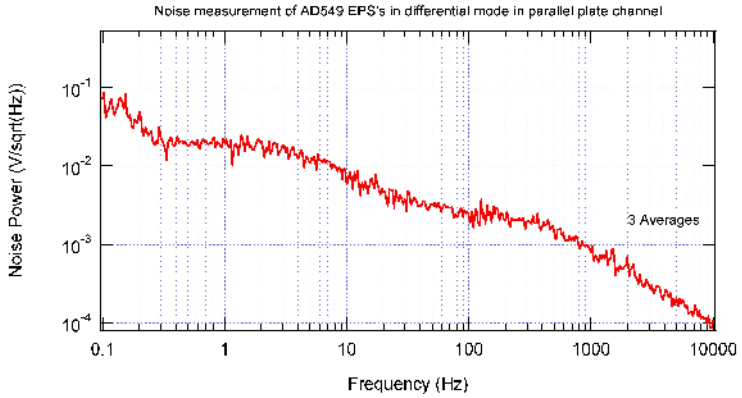
Coupling capacitance < 10^{-14} F

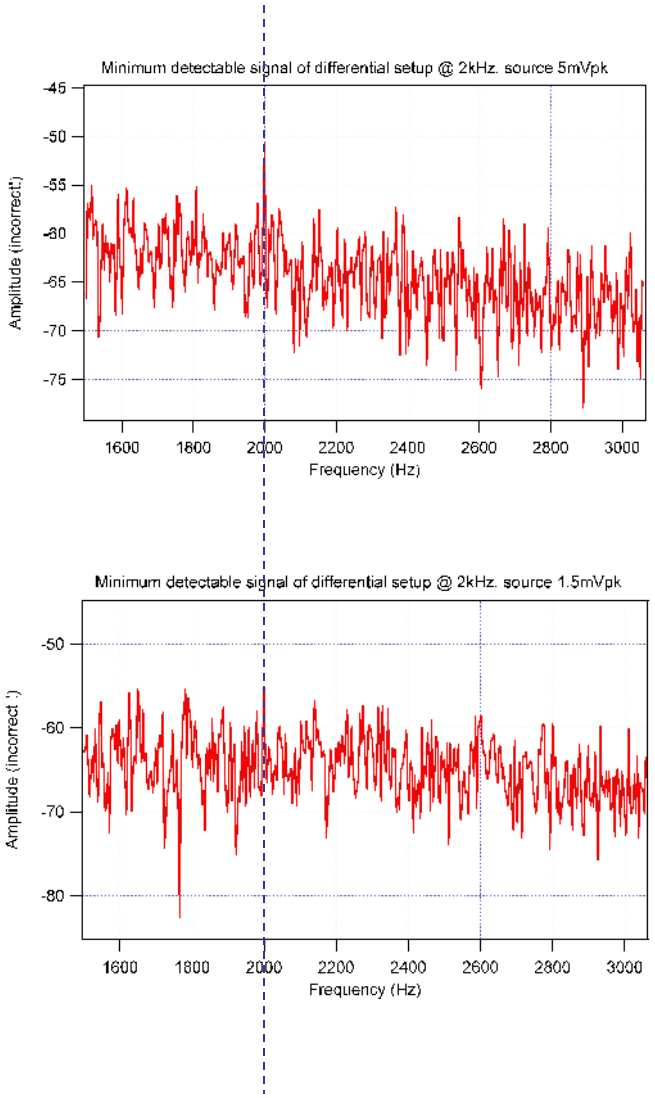


Individual EPS frequency response curves.



Combined differential frequency response (preliminary data only)





Noise and minimum detectable signal in agreement.

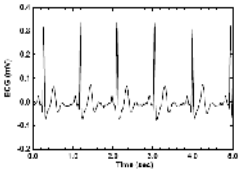
Corresponds to ~1 mV/m.

Rotating vane E field meters ~ 10 V/m.

Lab based instrument ~ 10 mV/m.

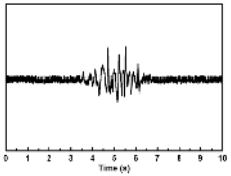
Applications

- Body electrophysiology, ECG, EEG, EOG, EMG;



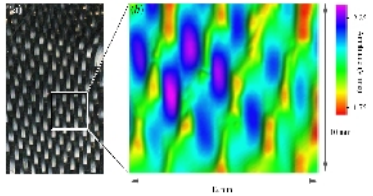
Electric potential probes – new directions in the remote sensing of the human body, C. Harland, T.D. Clark, R.J. Prance, J. Meas. Sci. and Technol. **13**, 163-169, (2002)

- Security, dielectric movement;



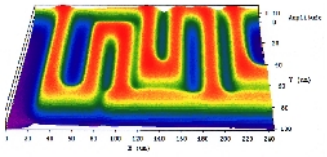
Remote monitoring of biodynamic activity using electric potential sensors, C.J. Harland, R.J. Prance, H. Prance, Proc. 'Electrostatics 2007', 25-29 March 2007, Oxford.

- Non-Destructive Testing of materials;



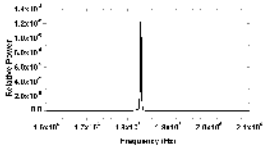
Non-contact imaging of carbon composite structures using electric potential sensors, W Gebrial, R J Prance, C J Harland, P B Stiffell, H Prance, T D Clark, Meas. Sci & Tech. **17**(6), 1470-1476, (2006)

- Imaging of circuits;



Noninvasive imaging of signals in digital circuits, W. Gebrial, R.J. Prance, T.D. Clark, C. J. Harland, H. Prance, M.J. Everitt, Rev. Sci. Instrum. **73**(3), 1293-1298, (2002)

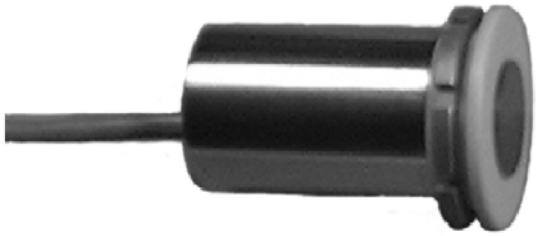
- Nuclear Magnetic Resonance;



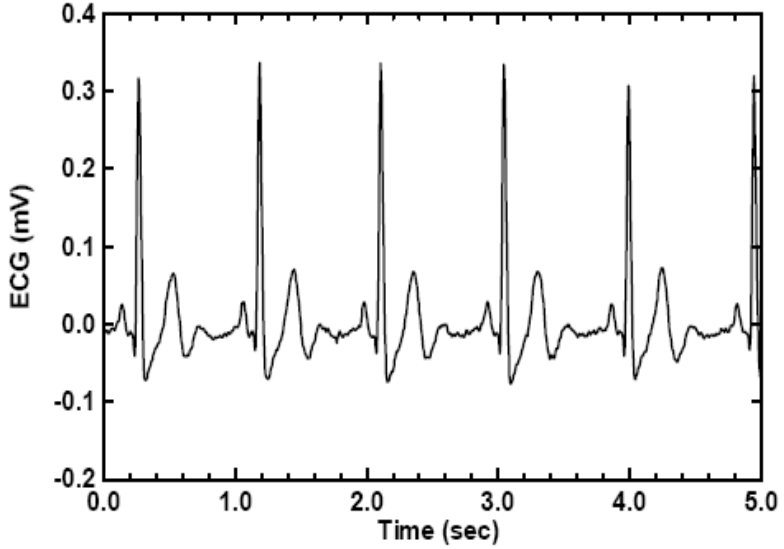
Acquisition of a nuclear magnetic resonance signal using an electric field detection technique, R J Prance, A Aydin, *Appl. Phys. Lett.* **91** (2007)

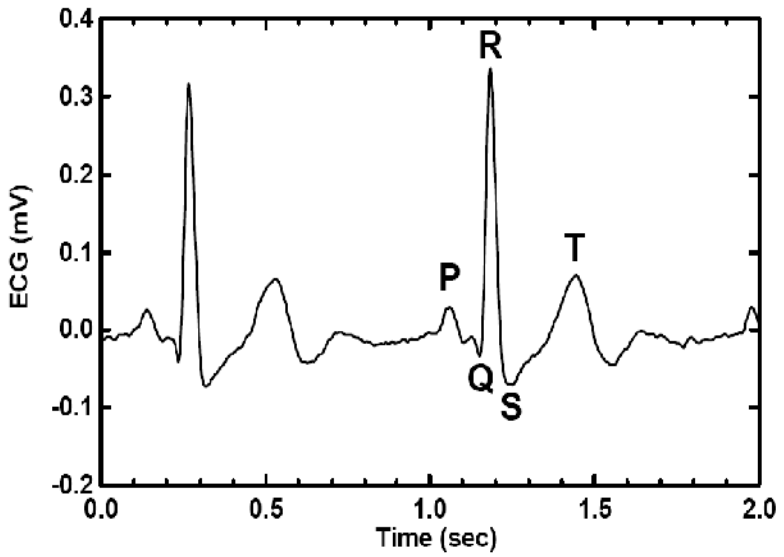
Electrophysiology

ECG contact mode



High resolution ECG traces (0.5 - 30Hz)



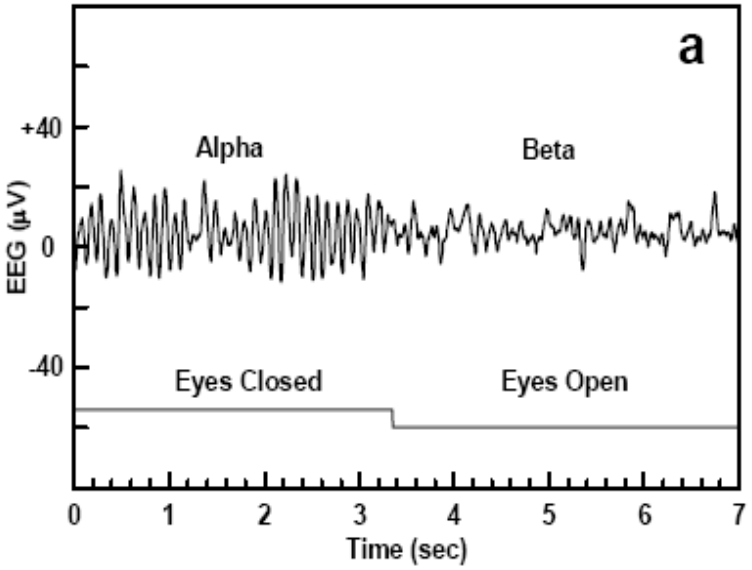


Electric potential probes – new directions in the remote sensing of the human body, C. Harland, T.D. Clark, R.J. Prance, J. Meas. Sci. and Technol. **13**, 163-169, (2002)

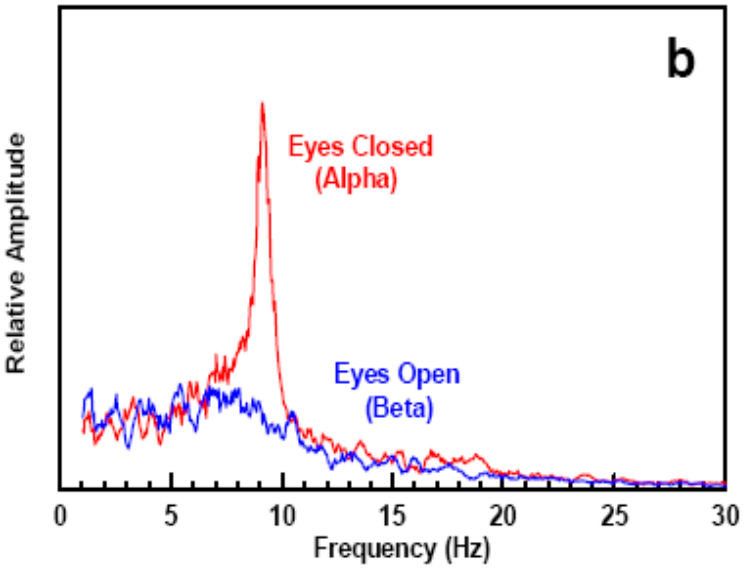
EEG contact mode

EEG from occipital region of brain through hair showing α-blocking

a) Time domain

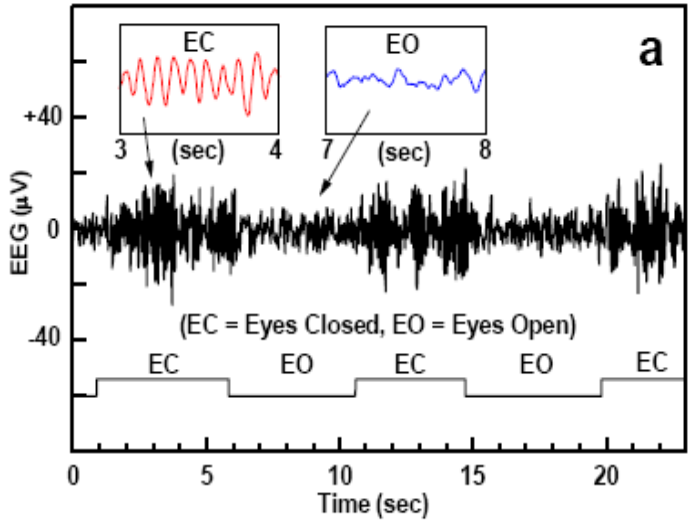


f) Frequency domain

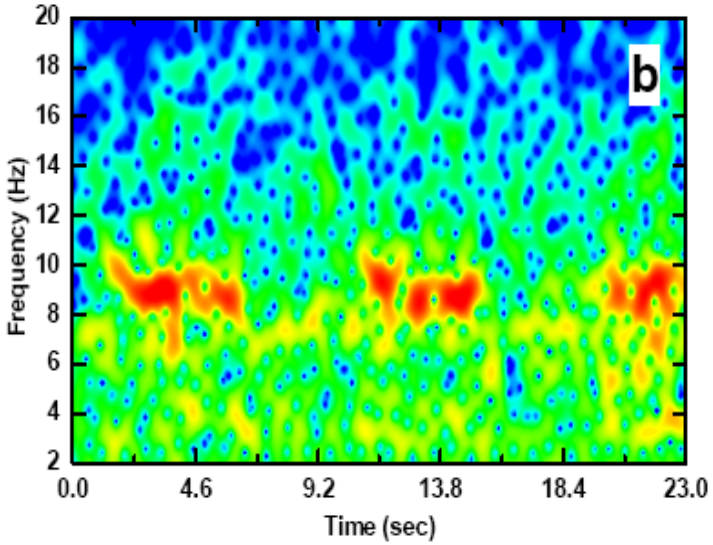


EEG contact mode

EEG from occipital region of brain showing α-blocking

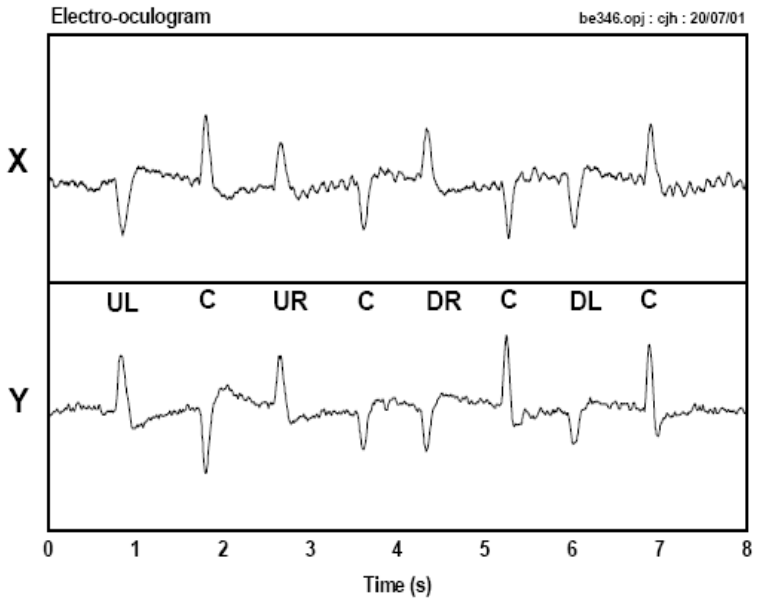


Joint time-frequency spectrogram (red regions show α rhythm)

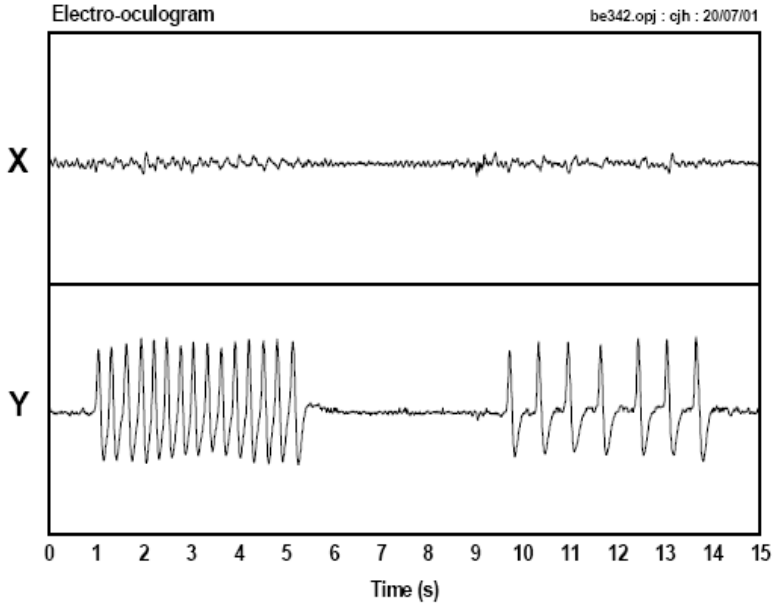


Remote detection of human electroencephalograms using ultrahigh input impedance electric potential sensors, C. J. Harland, T. D. Clark, and R. J. Prance, *App. Phys. Lett.* **81**(17), 3284-3286 (2002)

EOG contact mode



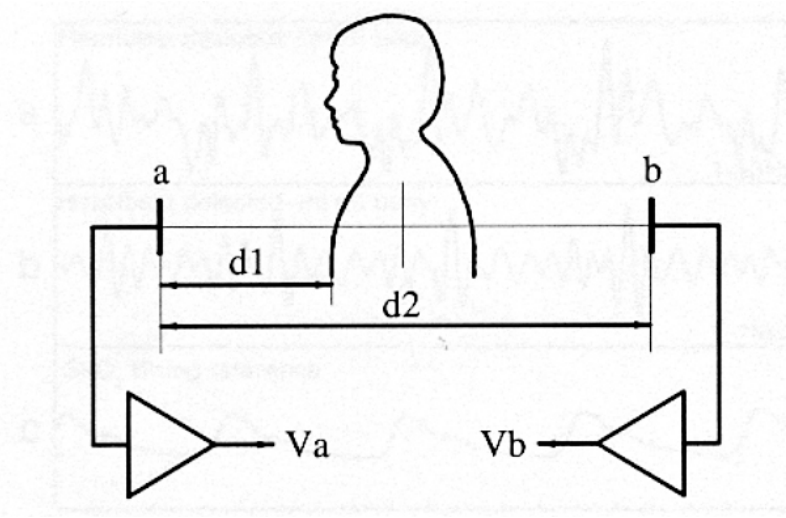
Eyeball movement

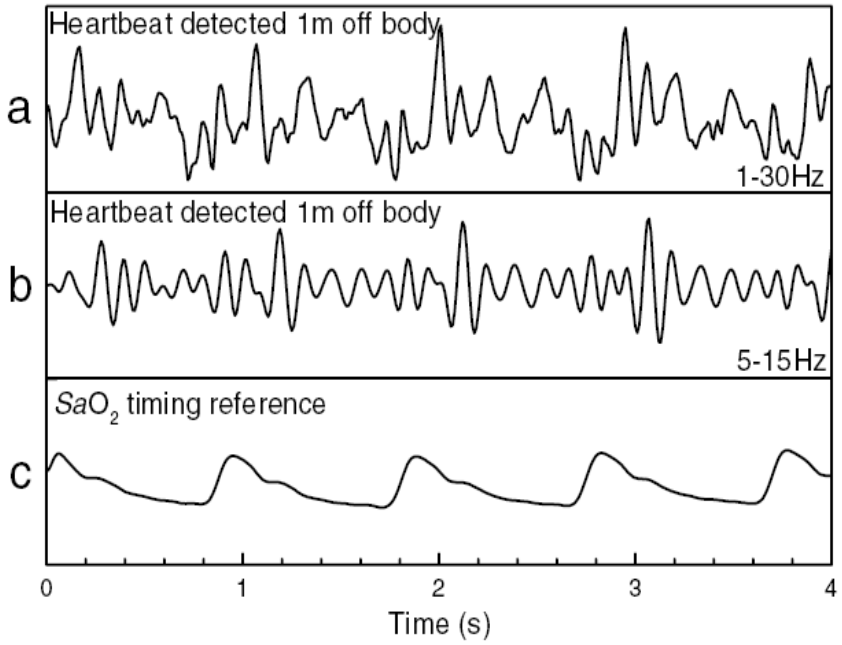


Eyelid movement

Applications of Electric Potential (Displacement Current) Sensors in Human Body Electrophysiology, C. J. Harland, T. D. Clark and R. J. Prance, Proc. 3rd World Congress on Industrial Process Tomography, Banff, Canada, 485-490, (2003)

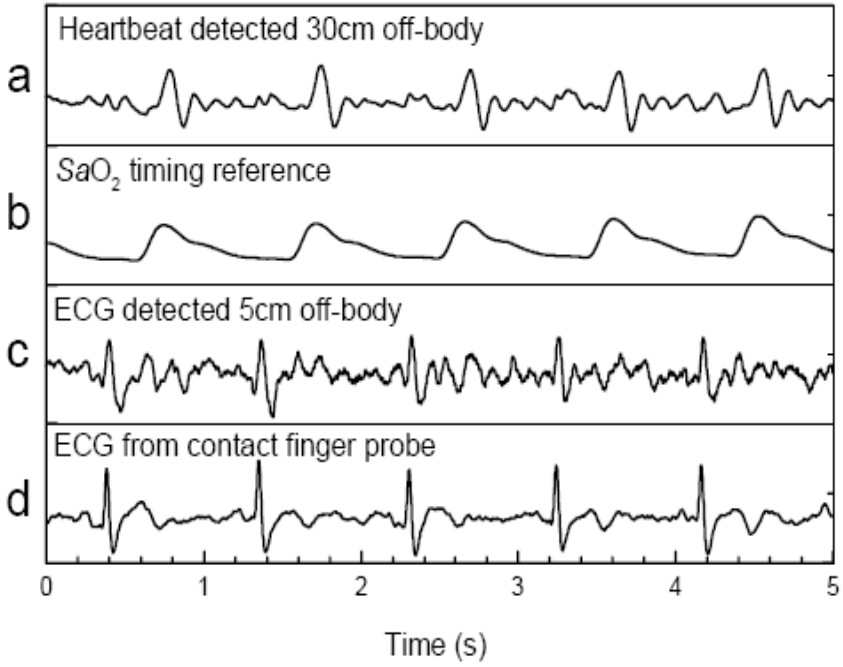
ECG remote mode





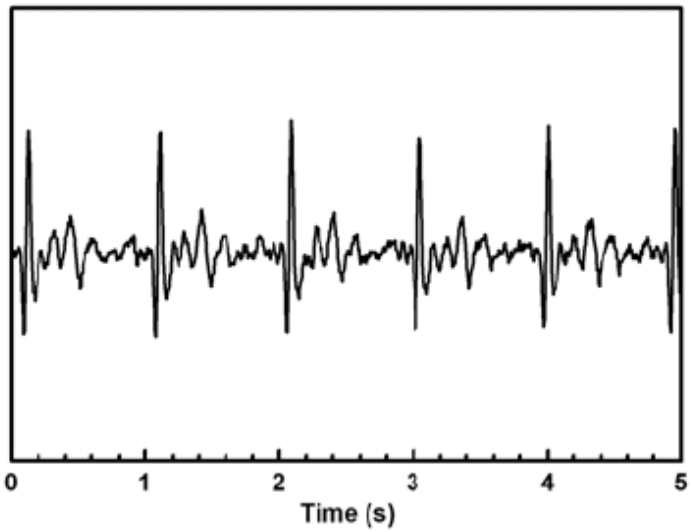
Electric potential probes – new directions in the remote sensing of the human body, C. Harland, T.D. Clark, R.J. Prance, J. Meas. Sci. and Technol. **13**, 163-169, (2002)

ECG remote mode

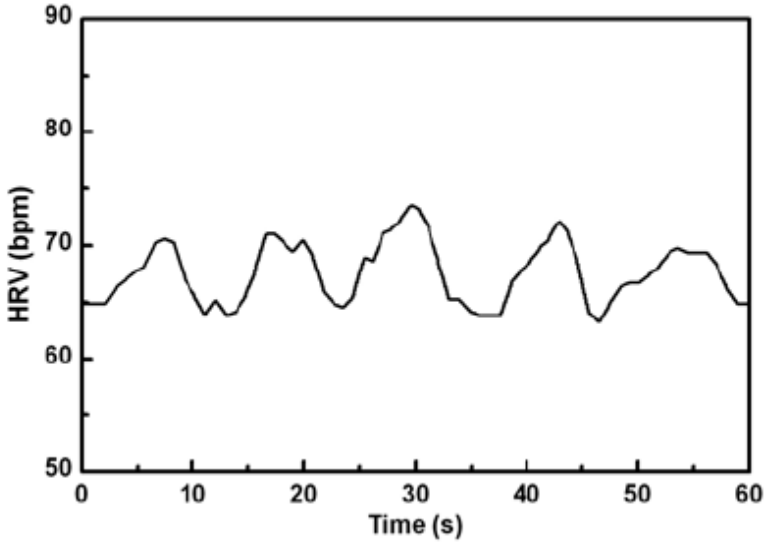


Comparison of remote cardiac signals at different distances with an SaO_2 timing reference.

ECG remote mode

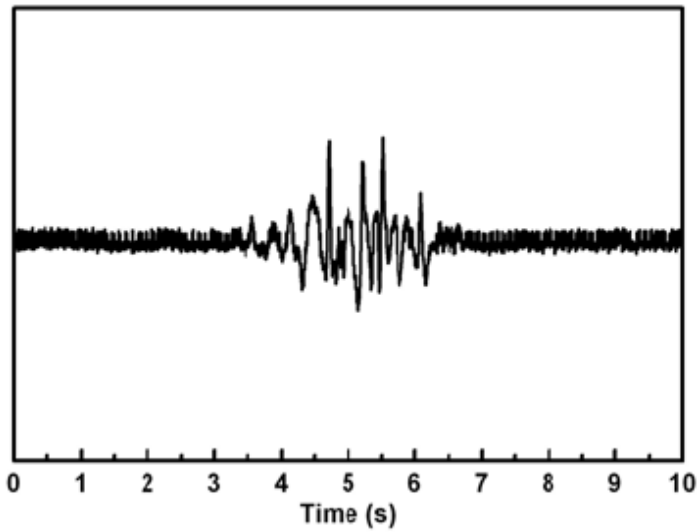


Cardiac signal from sensors mounted in chair back

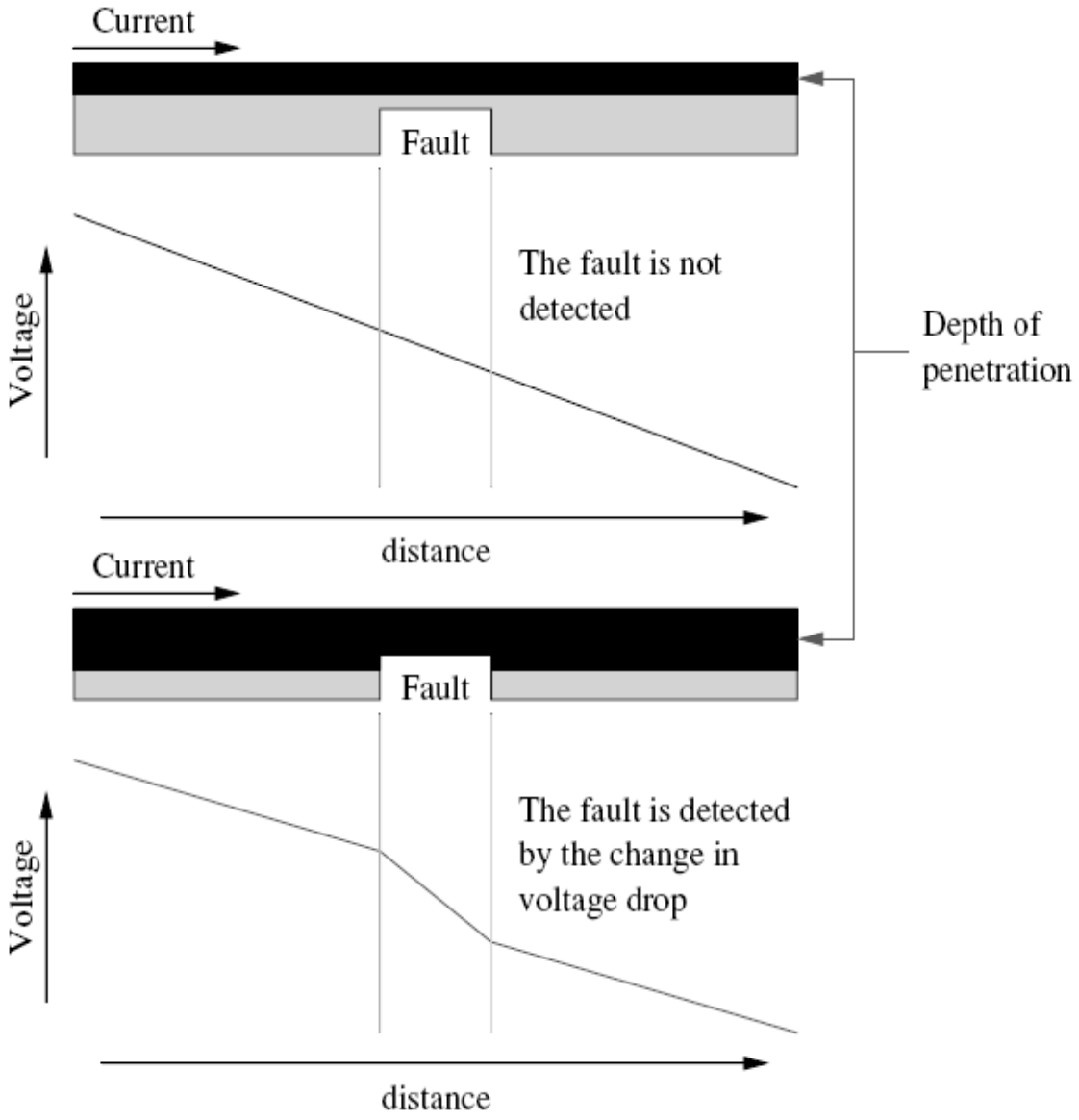


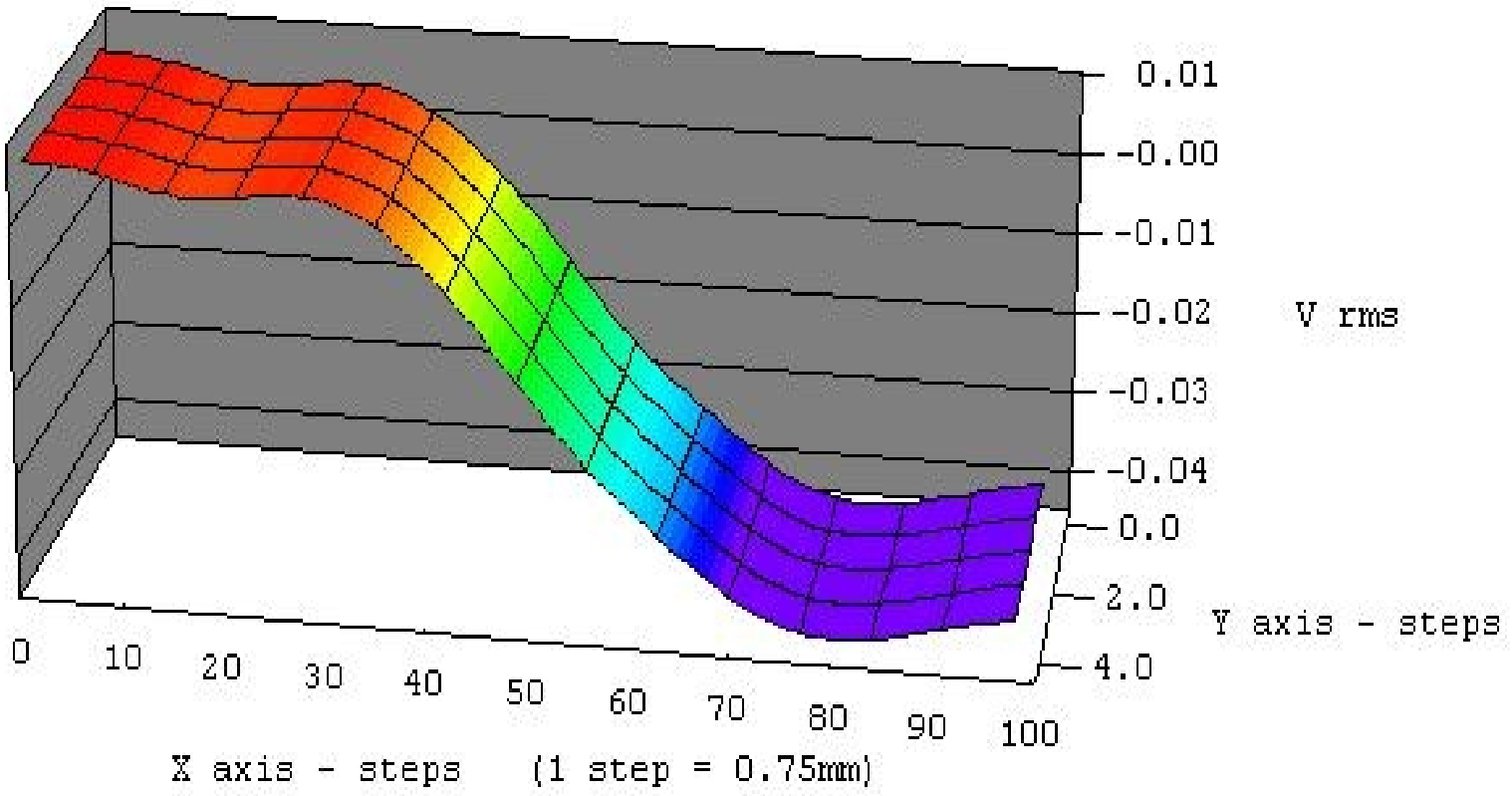
Respiration signal obtained from heart rate variability data.

Dielectric movement - remote mode



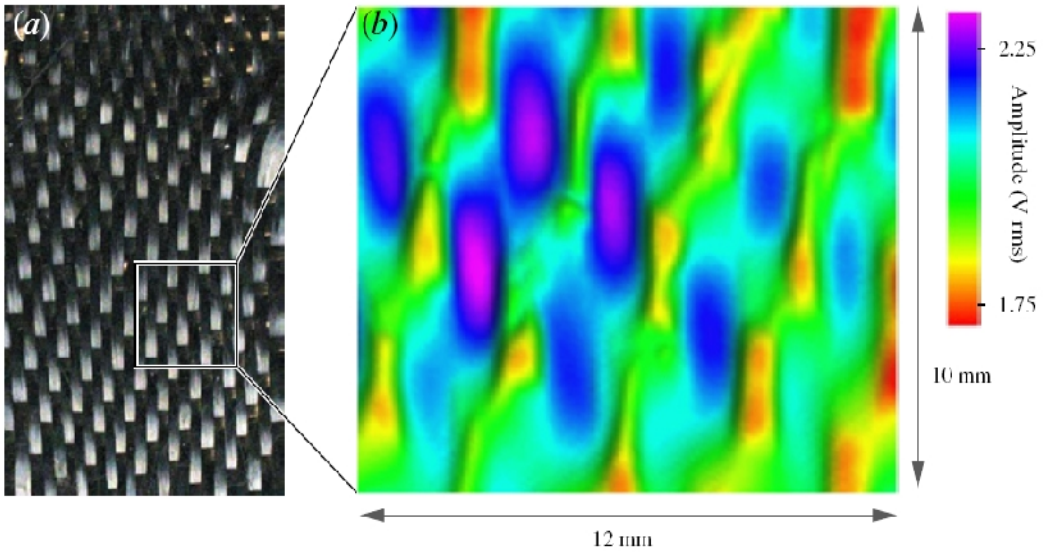
Signal from the remote sensing of human body movement using the EPS as a ‘through-the-wall surveillance’ (TWS) device.


Current
Fault
The fault is not detected
Voltage
distance
Depth of penetration
Current
Fault
The fault is detected by the change in voltage drop
Voltage
distance



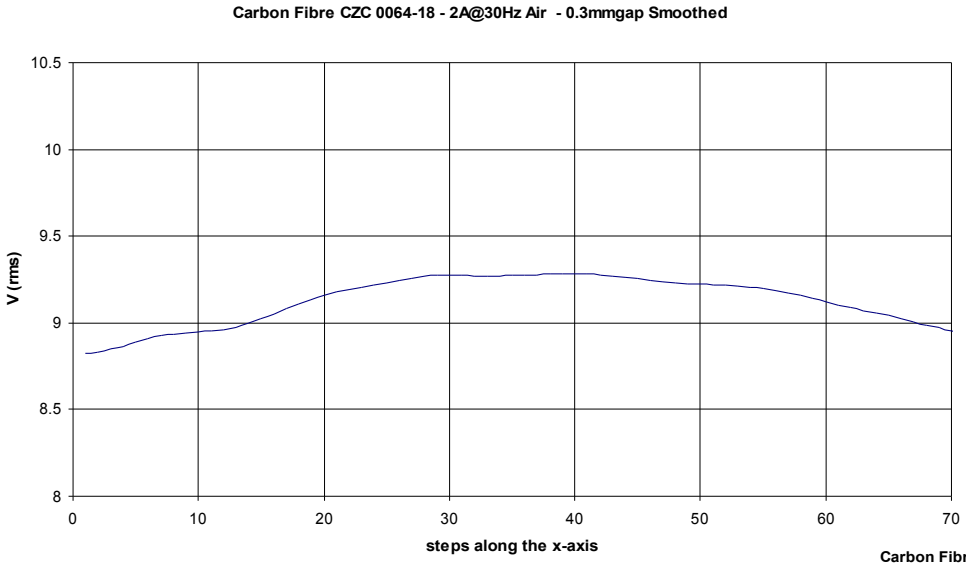
Two dimensional raster scan of a sample with a 2mm fault using 200A at 23Hz (line of best fit data subtraction used)

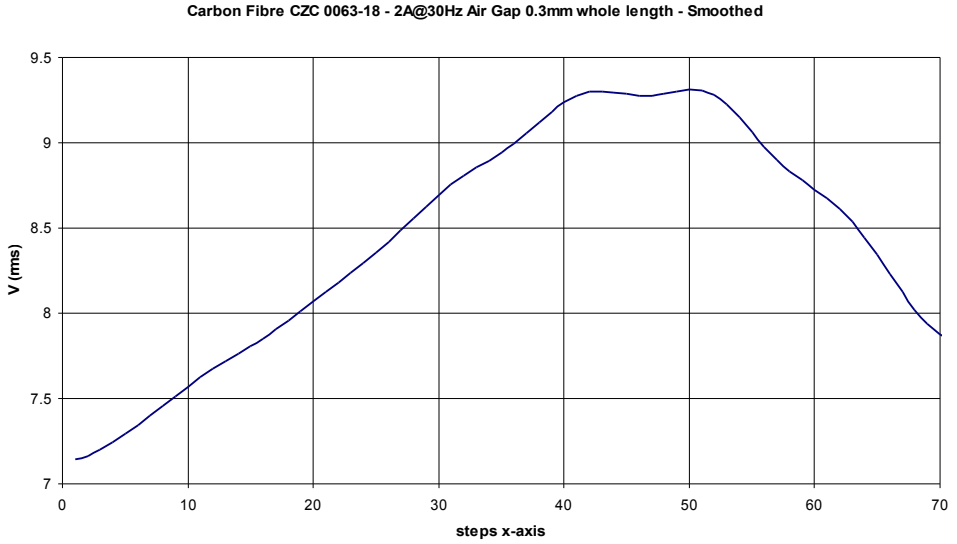
Composites - Voltage scan mode



(*a*) Photograph of an uncoated woven carbon fibre fabric Sample.
(*b*) EPS voltage scan image of (*a*) for a sample–probe distance and scan step interval both set at 0.15 mm.

Non-contact imaging of carbon composite structures using electric potential sensors, W. Gebrial, R. J. Prance, C. J. Harland, P. B. Stiffell, H. Prance, T. D. Clark, Meas. Sci and Tech. **17**(6), 1470-1476, (2006).



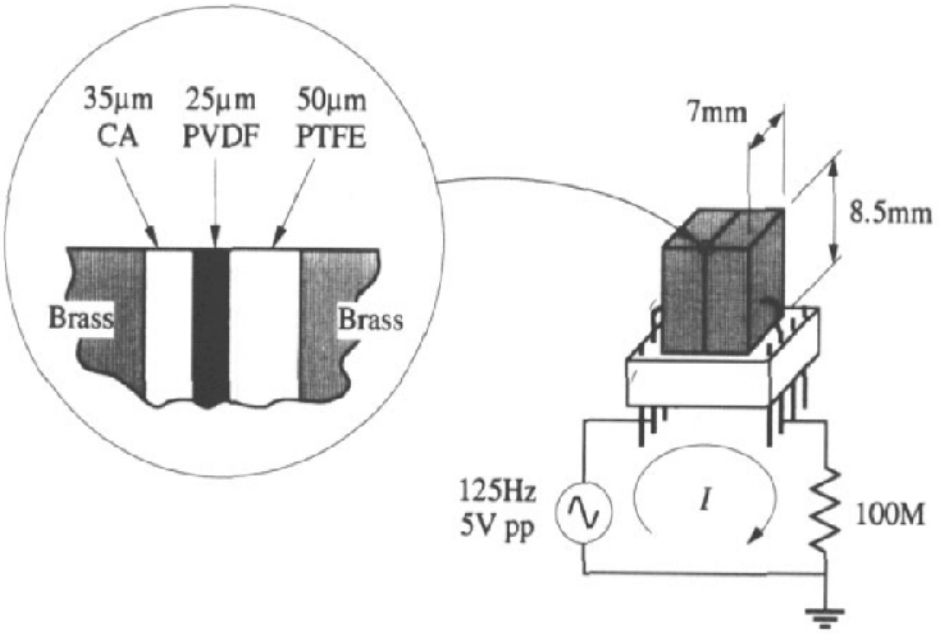


Composites - Current scan mode

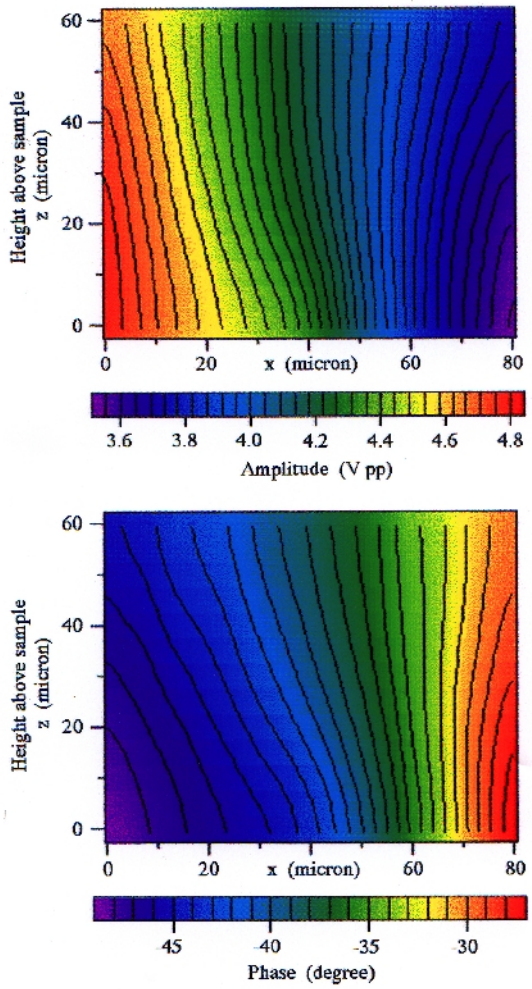
Blind trial; one control sample and one preloaded sample

Technique for determining the internal integrity of composite laminates, Prance RJ, Antrobus C, invited talk, NAFEMS 2006 conference, 14-15 June 2006, Crewe Hall, Cheshire

Insulating materials - dielectric properties

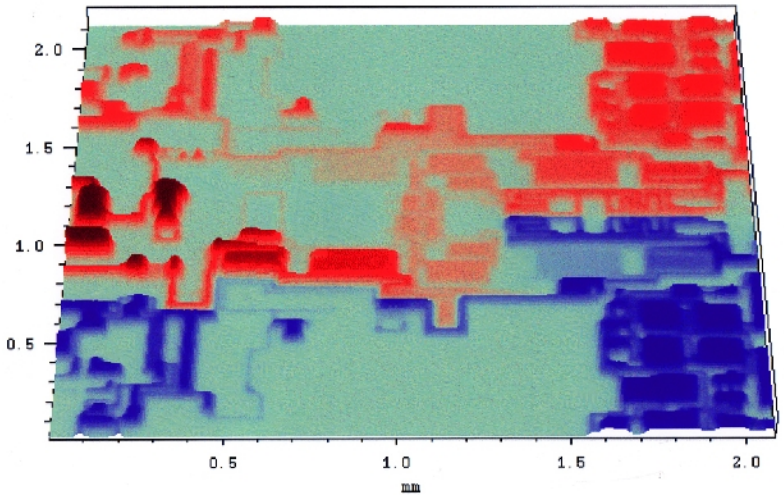


	CA	PVDF	PTFE
Real: $\nabla V' \times 10^3$ V m^{-1}	0.1	0.0	0.0
Imag: $\nabla V'' \times 10^3$ V m^{-1}	8.6	4.8	20.0
$\epsilon_r'(=\epsilon'/\epsilon_0)$	4.9	8.5	2.1



Non-invasive dielectric measurements with the Scanning Potential Microscope, A J Clippingdale, R J Prance, T D Clark and F Brouers, J Phys D **27**, 2426-2430, (1994)

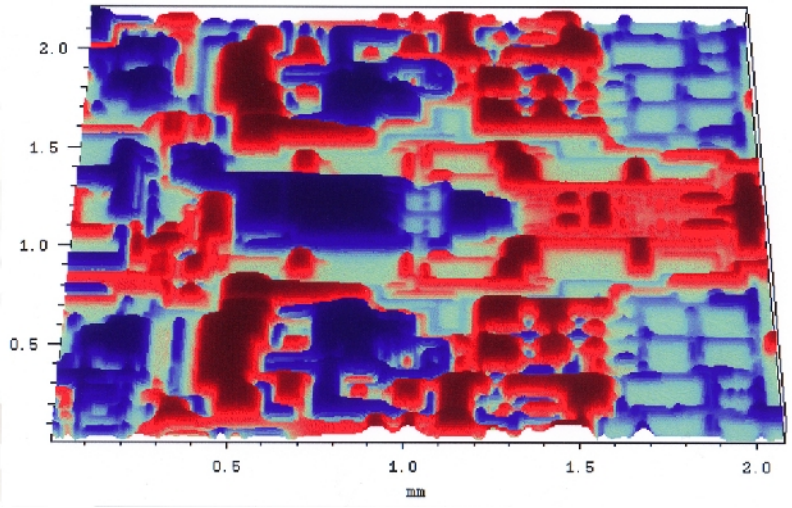
Applications - scanning IC surfaces (potential distributions)



INA101 differential amplifier

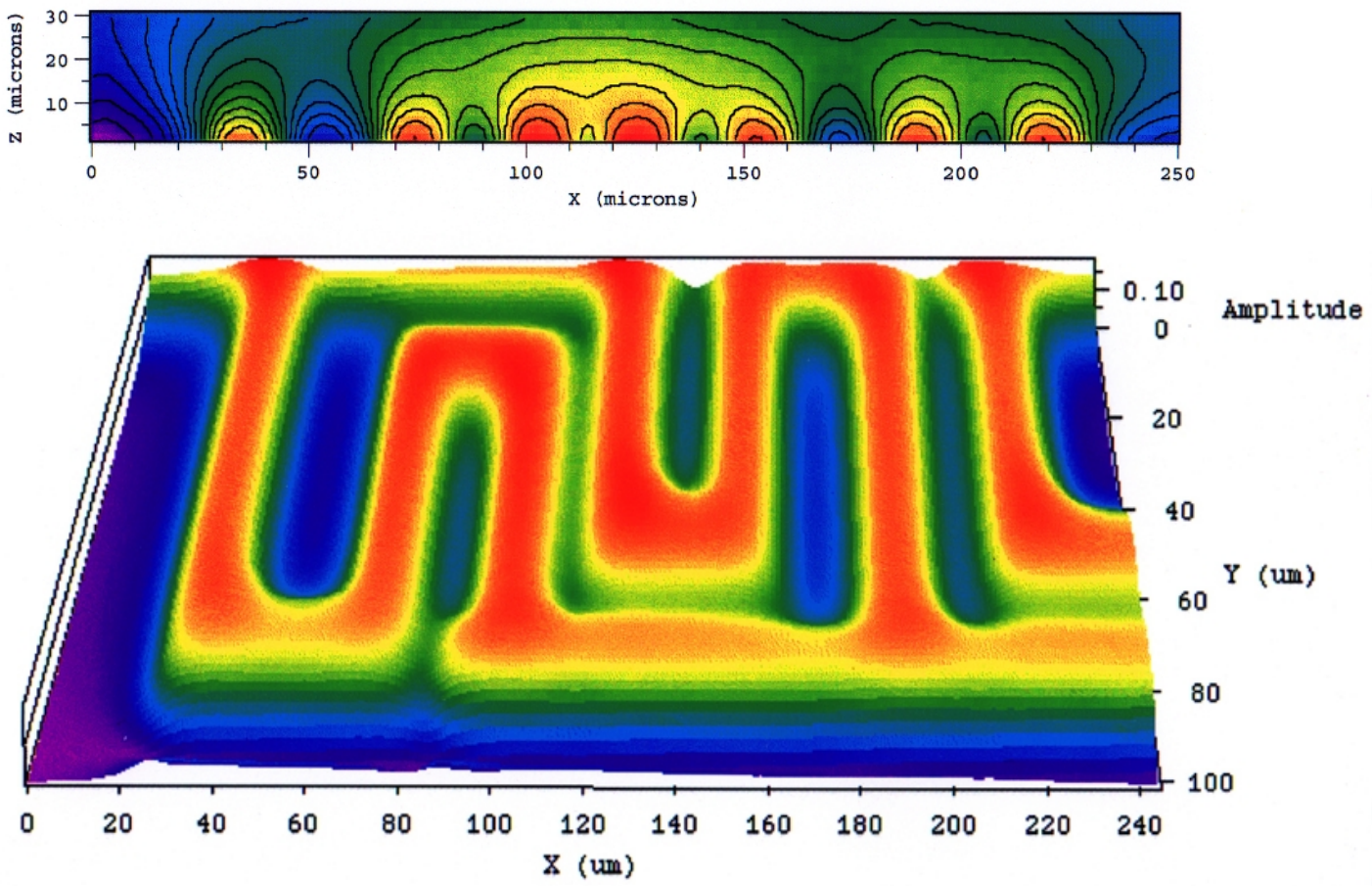
100Hz signal amplitude

(red in phase, blue out of phase)



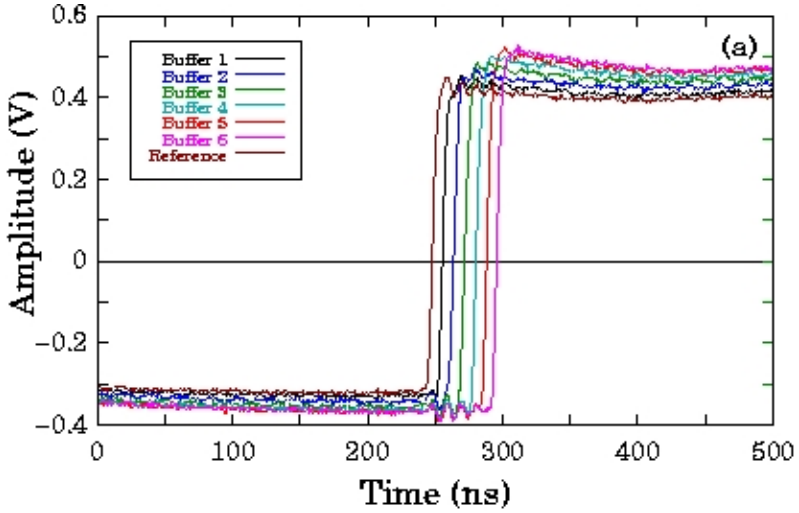
INA101 differential amplifier
100Hz modulation applied to power supplies
(red in phase, blue out of phase)

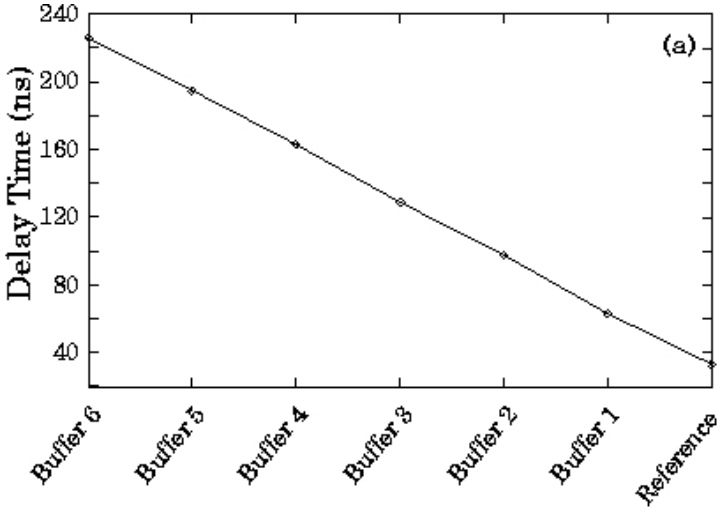
Non-contact VLSI imaging using a scanning electric potential microscope, R.J. Prance, T.D. Clark, H. Prance, A. Clippingdale, *Meas. Sci. and Tech.* **9**(8), 1229-1235, (1998)

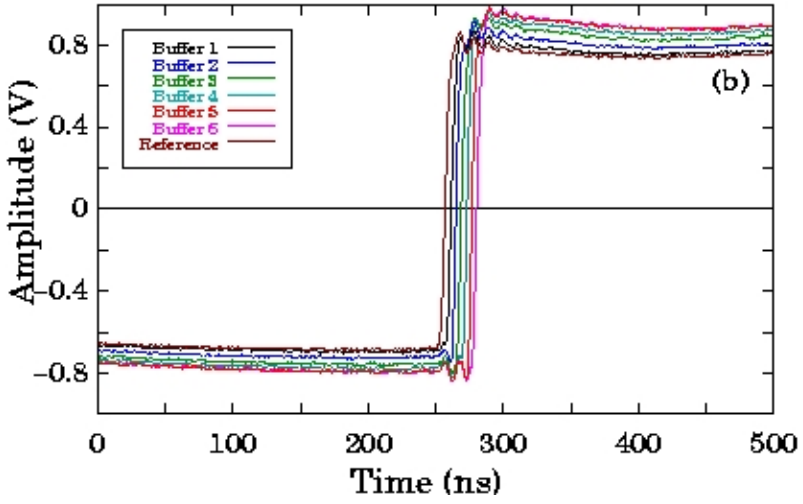


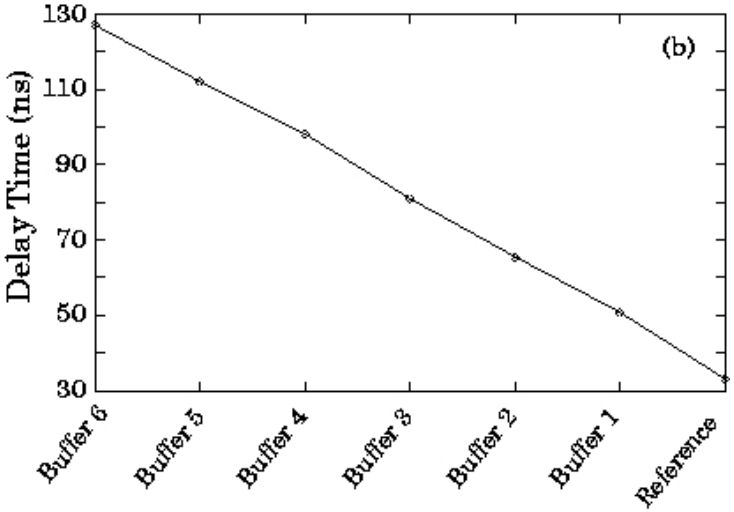
High resolution image of 240µm x 100µm area of INA101showing variation of spatial potential above surface

Applications - scanning IC surfaces (propagation delay)





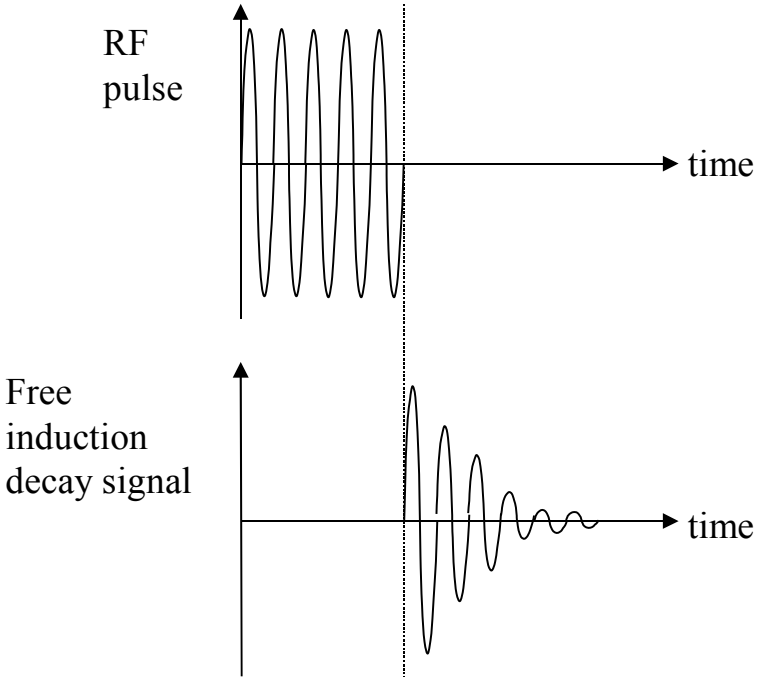


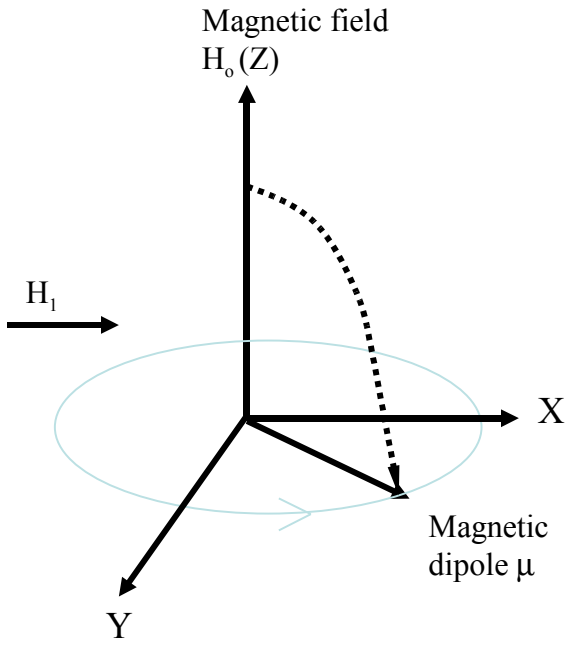


Noninvasive imaging of signals in digital circuits, W. Gebrial, R.J. Prance, T.D. Clark, C. J. Harland, H. Prance, M.J. Everitt, Rev. Sci. Instrum. **73**(3), 1293-1298, (2002)

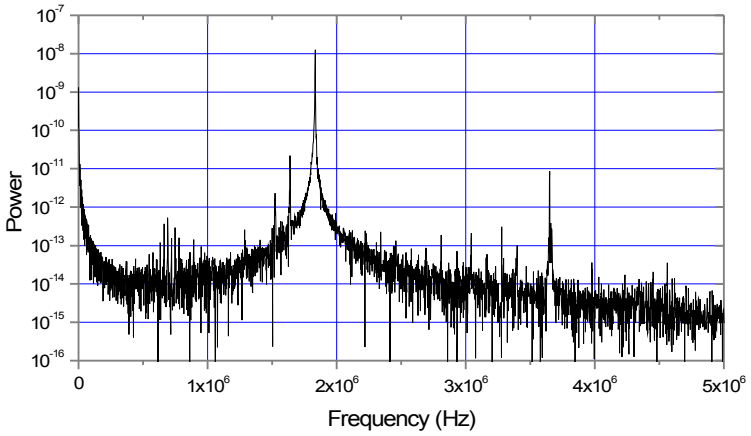
Pulse NMR - Demonstration of pulse NMR E-field readout system

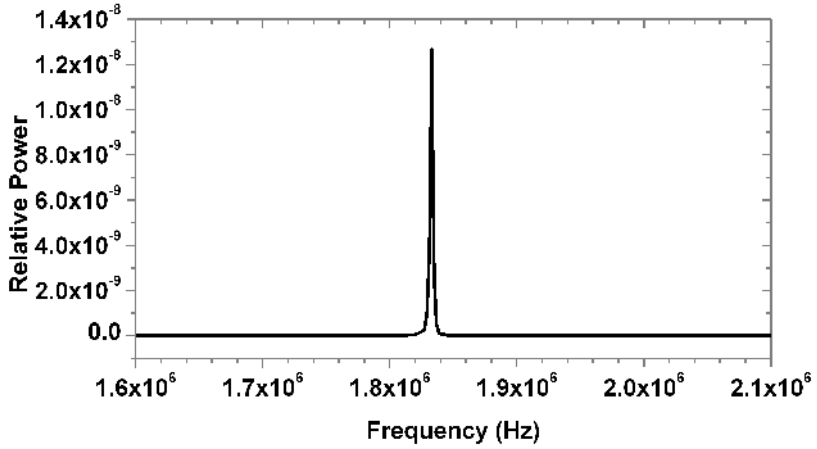
- Use a 90° RF pulse to tip the magnetisation into the X-Y plane.
- When the pulse stops look for the free induction decay signal (FID) from the Larmor precession of the spins.





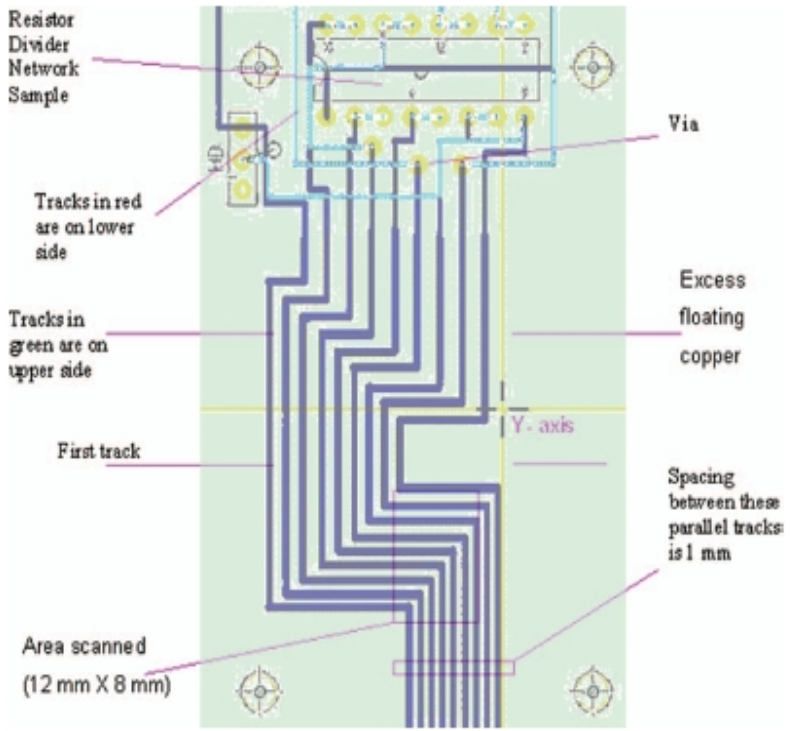
NMR results - frequency domain

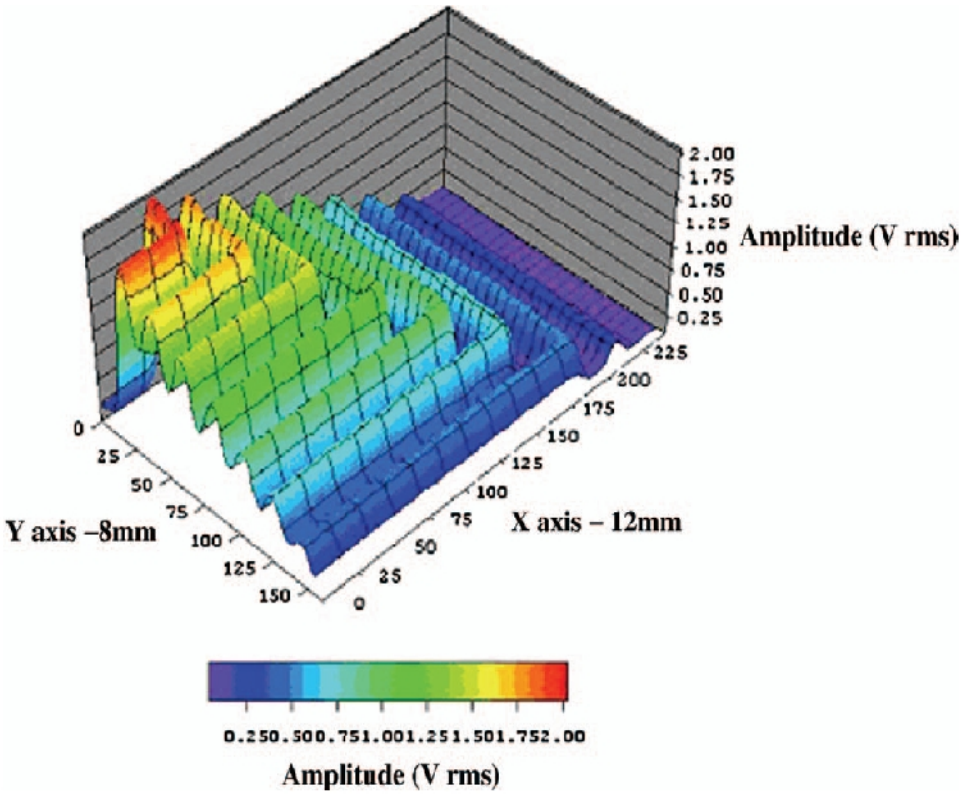




*Electric field NMR a new technique, R. J.*Prance, A. Aydin et al, EUROMAR conf., 16-21 July 2006, York

Circuit imaging





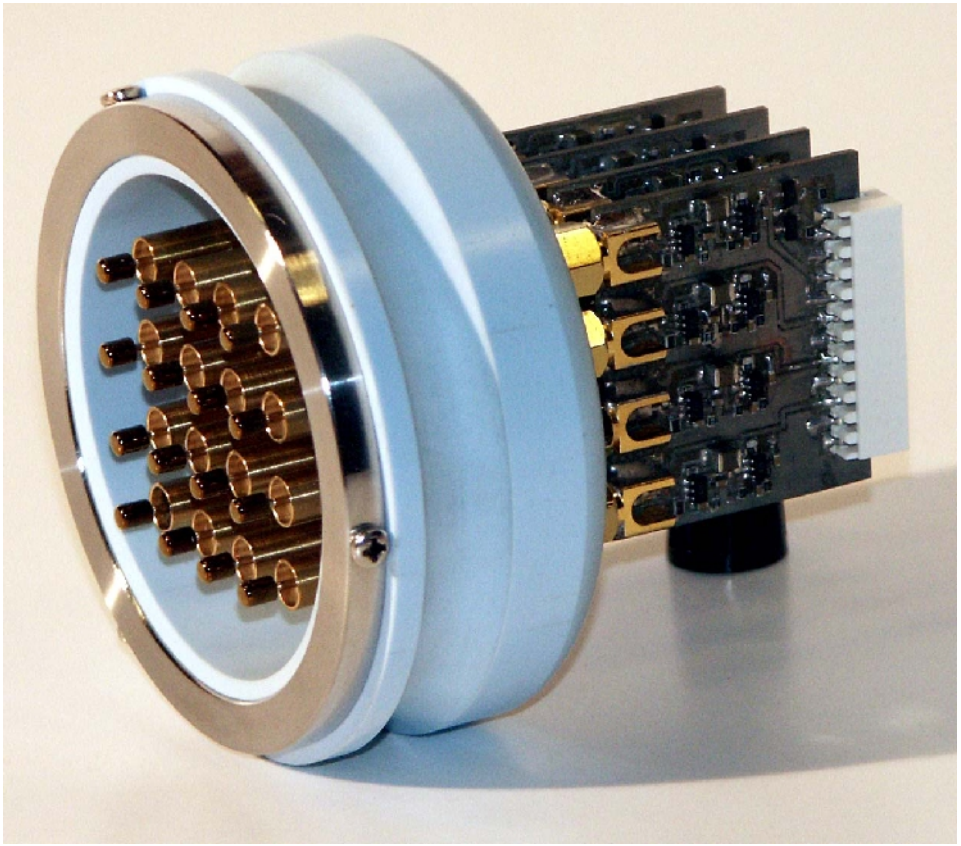
Voltage scan of 12mm x 8mm section of circuit board using a linear array of 8 sensors

Non-invasive imaging using an array of electric potential sensors, W. Gebrial, R. J. Prance, C. J. Harland, T. D. Clark, Rev. Sci. Inst., **77,** (2006)

Conclusions

- Non-contact potential and electric field sensing demonstrated.
- Wide range of applications already at proof of principle stage.
- Enhanced sensors under development.
- 1-D and 2-D arrays now operational.
- Technology moving to commercialisation with partners.

Electric Potential Sensor



16 element array for body surface potential mapping.

International patents

WO 03/048789, basic EPS sensor technology (2002)

Filing 0602229.7, NMR electric field technique (2006)

Filing 0605717.8, new measurement techniques (2006)

Filing 0614261.6, enhanced sensor techniques (2006)

Filing XXXXXXX.X, signal to noise enhancement (2007)

Further Information

URL - http://www.sussex.ac.uk/pei/