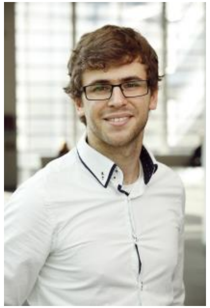
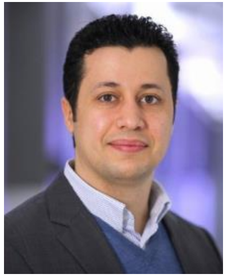
An Ion-to-Frequency ISFET Architecture for Ultra-Low Power Applications

Miguel Cacho-Soblechero [1,2], Tor Sverre Lande [2] and Pantelis Georgiou [1,2]

1 Dept. of Electrical and Electronic Engineering, Imperial College London, United Kingdom

2 Centre for Bio-Inspired Technology, Institute of Biomedical Engineering, Imperial College London, United Kingdom





2020 IEEE International Symposium on Circuits and Systems Virtual, October 10-21, 2020

IEEE Xplore® Digital Library

ISCAS 2020 Virtual, October 10-21

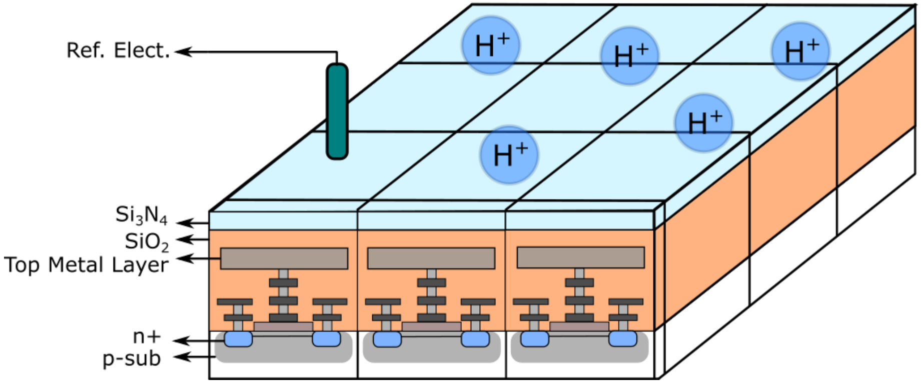
IEEE INTERNATIONAL SYMPOSIUM ON CIRCUITS AND SYSTEMS

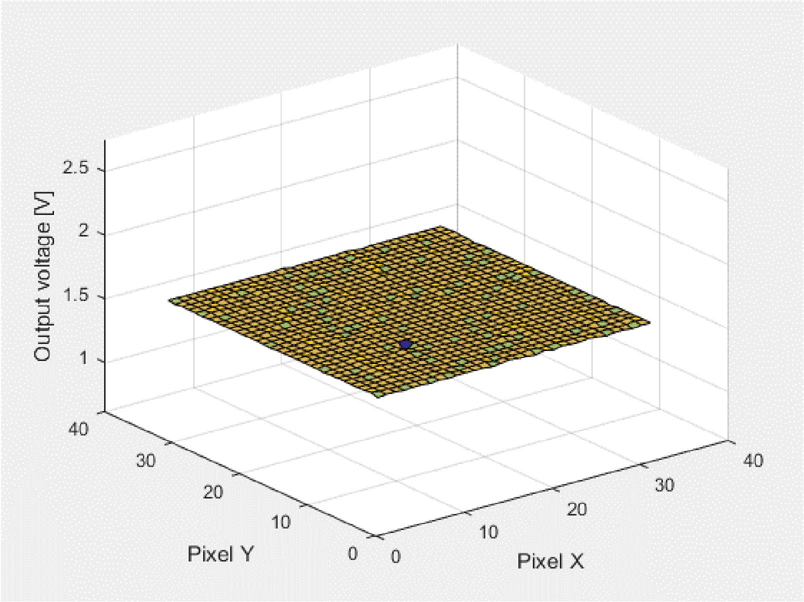
Imperial College London

EPSRC Pioneering research and skills

Imperial College London

ISFET – Ion Sensitive Field Effect Transistor



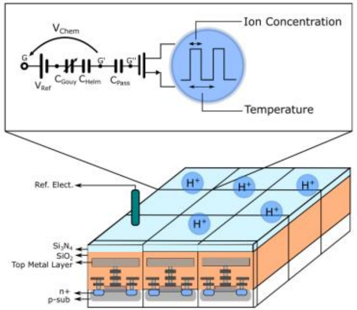


M. Cacho-Soblechero, K. Malpartida-Cardenas, C. Cicatiello, J. Rodriguez-Manzano and P. Georgiou IEEE Transactions on Biomedical Circuits and Systems, April 2020.
Y. Hu, P. Georgiou, IEEE Transactions on Biomedical Circuits and Systems, vol. 8, no. 2, pp. 177-185, April 2014.

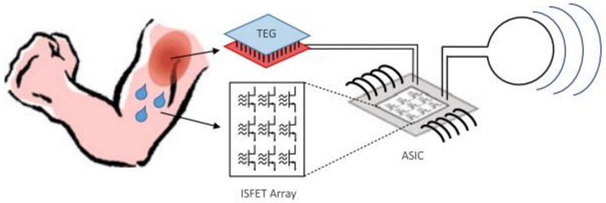
Imperial College London

ISFET Applications

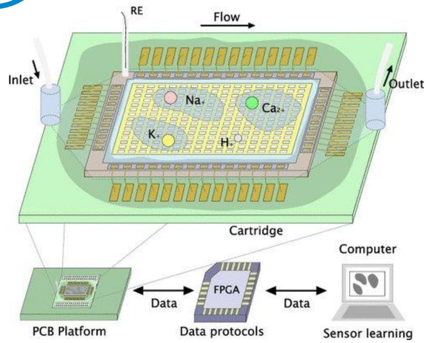
1 PoC Diagnosis



2 Sweat Analysis



3 Multi-ion Imaging



Imperial College London

State-of-the-art Challenges

1 Spatial Resolution

- Compact pixel size
- Scalability to smaller tech. process
- Scalability to larger arrays

2 Power

- Sweat monitoring requires operation over long periods of time
- Power harvesting relies on low power

3 pH Resolution

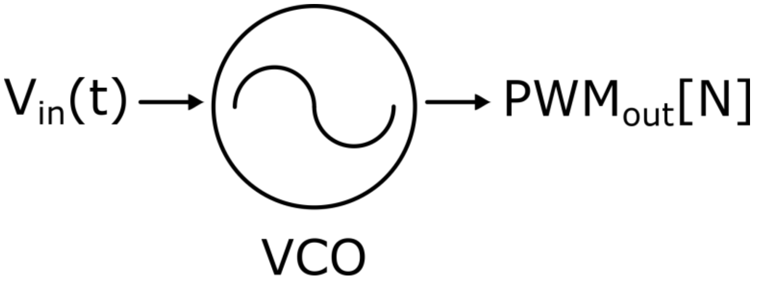
- Chemical and electronical noise limits the maximum pH resolution

Imperial College London

Opportunities - Voltage-Controlled Oscillator ADC

Highly digital

Suitable for low supply voltage



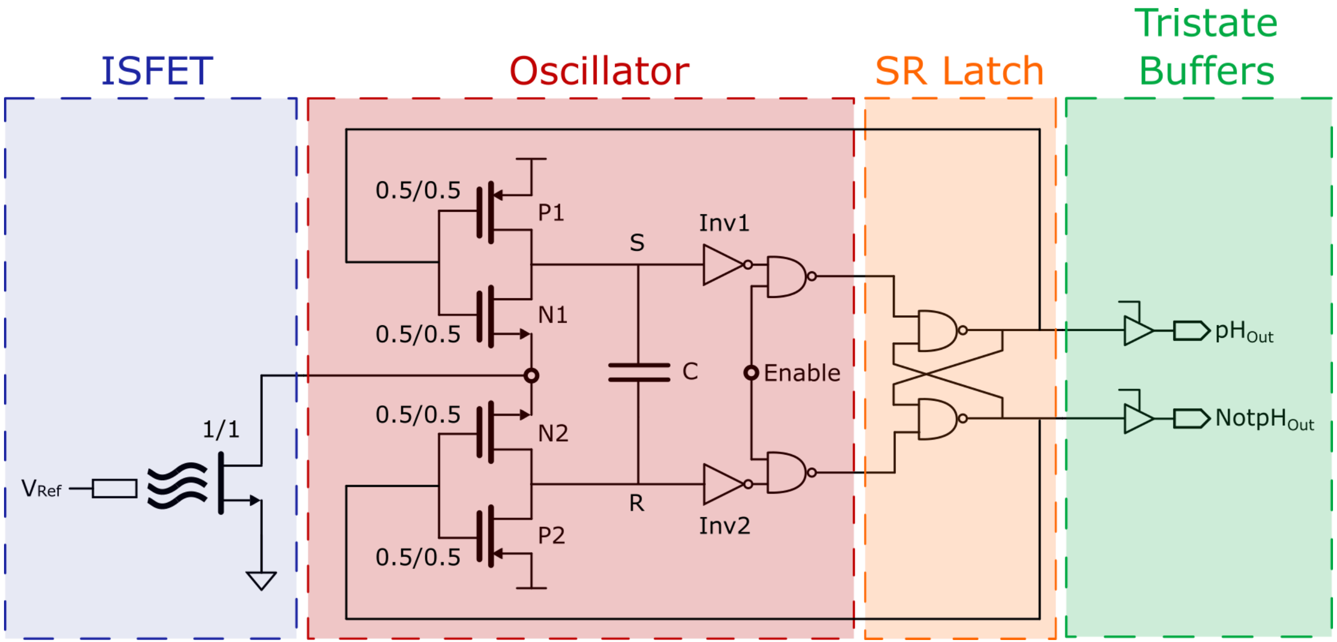
Energy Efficient

First-Order Noise-Shaping

Integration with digital processing

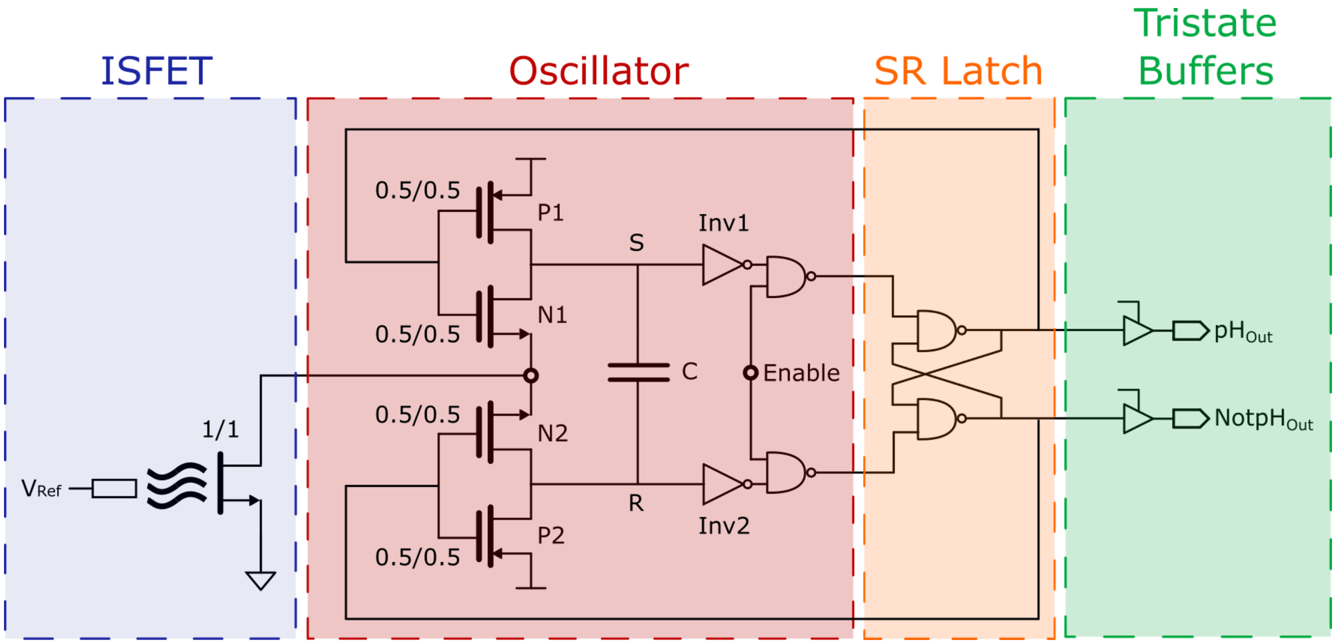
Imperial College London

Ion-to-Frequency ISFET Architecture



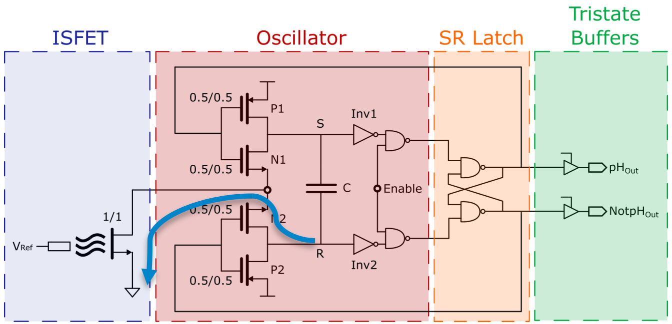
Imperial College London

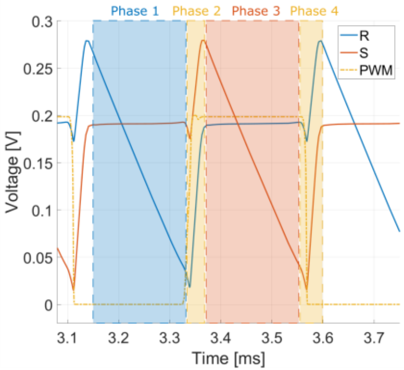
Ion-to-Frequency ISFET Architecture – Pixel Operation



Ion-to-Frequency ISFET Architecture – Pixel Operation

- Phase 1 → $pH_{Out} = 0$ & $R > V_{th\ Inv2}$
  - Node S forced to V_{dd}
  - Potential @ Node R discharges through ISFET
- Phase 2 → $pH_{Out} = 0$ & $R < V_{th\ Inv2}$
  - Potential @ Node R crosses inverter threshold voltage
  - SR Latch switch pH_{Out} from 0 to 1

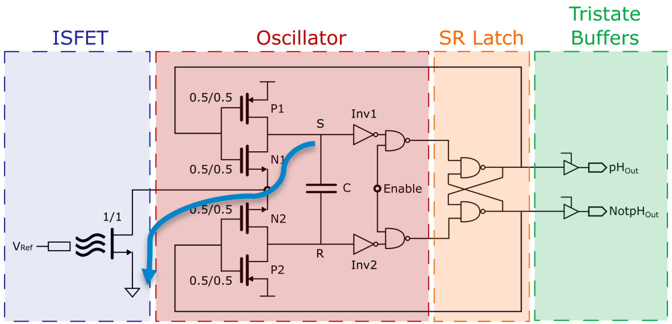


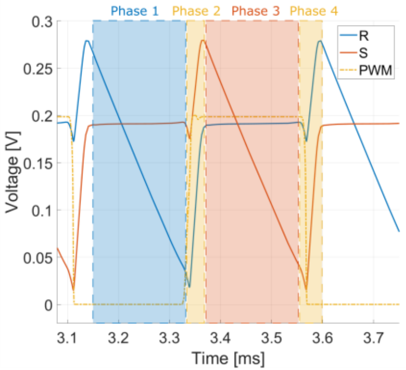


Imperial College London

Ion-to-Frequency ISFET Architecture – Pixel Operation

- Phase 3 → pH_{Out} = 1 & S > $V_{th\ Inv1}$
  - Node R forced to V_{dd}
  - Potential @ Node S discharges through ISFET
- Phase 4 → pH_{Out} = 1 & S < $V_{th\ Inv1}$
  - Potential @ Node R crosses inverter threshold voltage
  - SR Latch switch pH_{Out} from 1 to 0
  - Oscillatory behaviour achieved





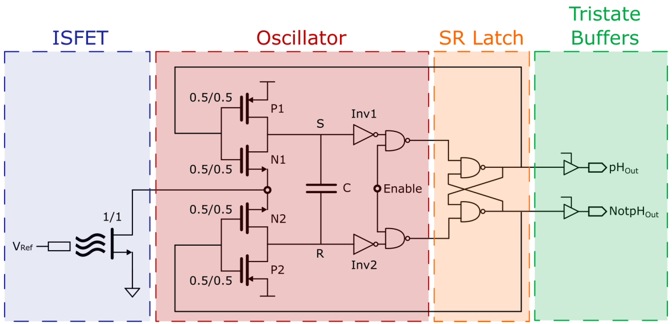
Ion-to-Frequency ISFET Architecture – Transfer Function

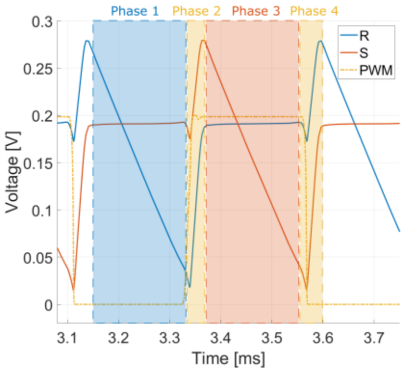
- Standard FM sensor function

$$f_{pH} = f_{pH=7} + G \cdot \Delta f_{pH}$$

- Both the centre frequency & the sensitivity are defined by:

$$f_{pH} \propto \frac{1}{V_{th\ Inv} \cdot C}\left(I_{ISFET[pH=7]} + \Delta I_{ISFET}\right)$$





Ion-to-Frequency ISFET Architecture – Transfer Function

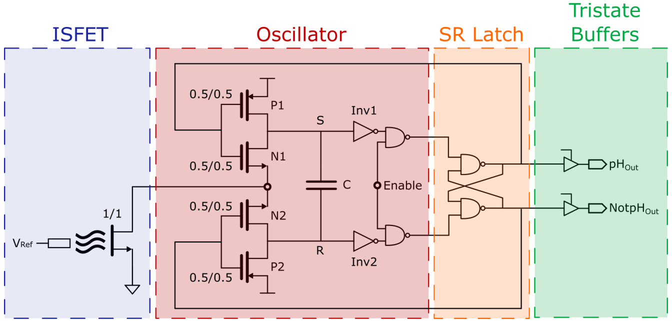
- ISFET weak inversion transfer function

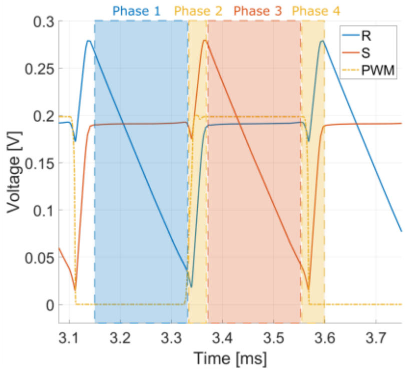
$$I_{ISFET} = I_0 \cdot \exp\left(\frac{V_{g''s}}{n \cdot U_t}\right) \cdot \left[1 - \exp\left(\frac{-V_{ds}}{U_t}\right)\right]$$

$$I_{ISFET} \propto I_0 \cdot \exp\left(\frac{\alpha S_N pH}{n \cdot U_t}\right)$$

- Merging with frequency transfer function

$$f_{pH} \propto \frac{I_0}{V_{th\ Inv} \cdot C} \cdot \exp\left(\frac{\alpha S_N (pH_7 + \Delta pH)}{n \cdot U_t}\right)$$

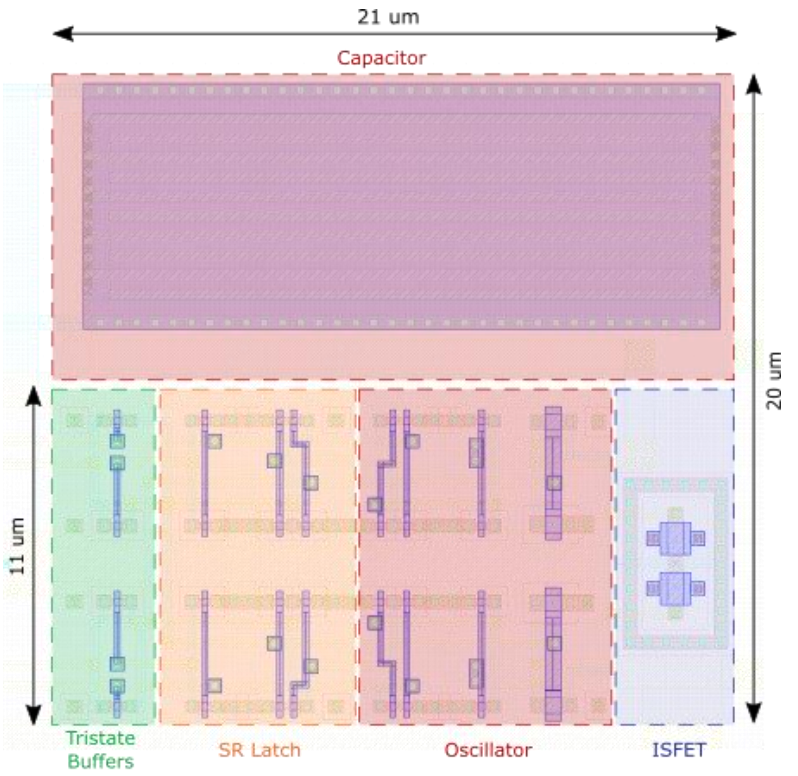




Imperial College London

Pixel Layout

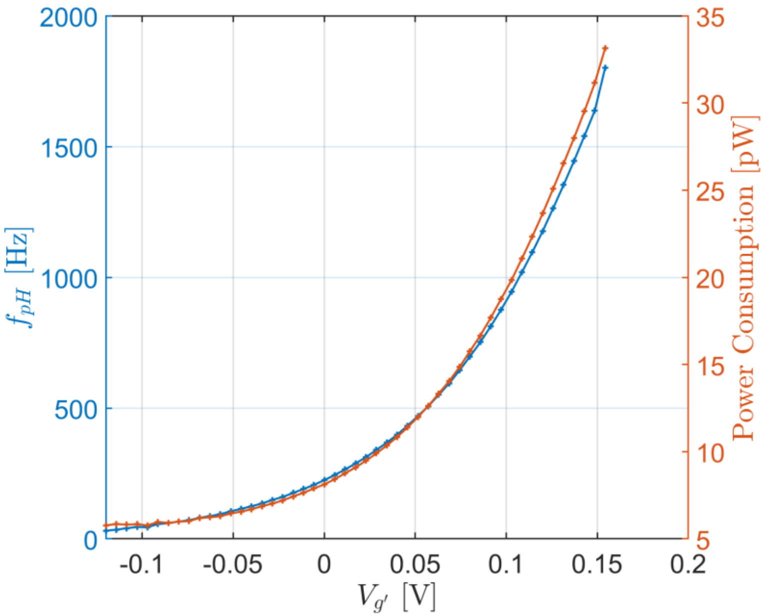
- Fabricated in 180nm process
- Compact form factor 20x21 um^2
  - Chemical area limited to 11x21 um^2 to minimise floating gate coupling



Imperial College London

Pixel Simulated Performance – Sensitivity & Power

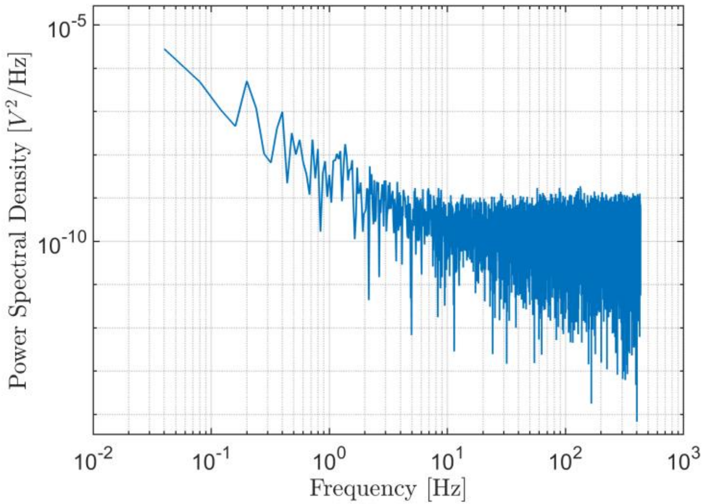
- Supply voltage = 0.2 V
- Sensitivity curve follows expected pattern from transfer function
  - $f_{pH7} = 697\ Hz$
  - $S[f_{pH7}] = 286.58 \frac{Hz}{pH}$
- Maximum power consumption – 33pW



Imperial College London

Pixel Simulated Performance – Noise

- Noise performance obtained from Power Spectral Density (PSD)
- PSD integrated between 10 mHz & 8 Hz
  - pH resolution 0.0119 pH
- Further validation required to obtain any conclusion on this result



Imperial College London

State-of-the-art Comparison

Specification	**This Work**	[7]	[16]	[17]	[9]
Technology	$0.18\mu m$	$0.35\mu m$	$0.35\mu m$	$0.35\mu m$	$0.18\mu m$
Sensing Domain	Frequency	Time	Current	Voltage	Duty Cycle
Pixel pitch [μm^2]	20x21	37x31	6.5x7.8	50x50	40x40
Sensitivity	287 Hz/pH	$3.26\mu s/pH$	$1.03\ \mu A/pH$	42.1 mV/pH	11.78 %/pH
Input Range	9.15pH	-	$200\mu A$	1.92 V	3.39pH
Supply [V]	0.2	3.3	3.3	3.3	1.8
Min. Detectable pH	0.0119	0.017	0.01	0.06	0.0176
Pixel Power Consumption	33 pW	$99\ \mu W$	$\dagger 150\mu W$	$1.98\ \mu W$	$61\ \mu W$
In-Pixel Quantization	✓	✓	✗	✗	✓
Scalability	✓	✓	✓	✗	✓

Imperial College London

Conclusions

- Presented an ultra-low power pixel architecture, which addresses some of the most urgent challenges on ISFET technology
  - Realised with **digital components** → Enable scalability to smaller nodes
  - High **energy efficiency**, ideal for wearable devices → 33pW at 0.2 V
  - Compact pixel **form factor** → 20x21 um^2
  - Provides **in-pixel quantisation** → No need for ADC

Imperial College London

EPSRC
Pioneering research and skills

Dr. Pantelis Georgiou
Department of Electrical and Electronic Engineering
Centre for Bio-inspired Technology

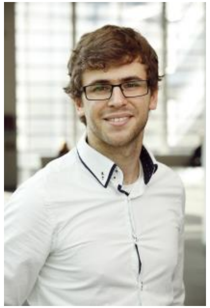
pantelis@imperial.ac.uk

@pgeorgiou_ic

Prof. Tor Sverre Lande
Centre for Bio-Inspired Technology
Institute of Biomedical Engineering

bassen@ifi.uio.no

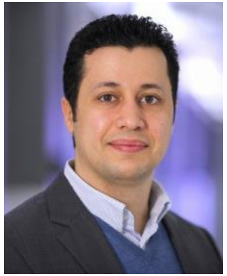
An Ion-to-Frequency ISFET Architecture for Ultra-Low Power Applications



Miguel Cacho-Soblechero [1,2], Tor Sverre Lande [2] and Pantelis Georgiou [1,2]

1 Dept. of Electrical and Electronic Engineering, Imperial College London, United Kingdom

2 Centre for Bio-Inspired Technology, Institute of Biomedical Engineering, Imperial College London, United Kingdom



2020 IEEE International Symposium on Circuits and Systems Virtual, October 10-21, 2020

Imperial College London

Q&A

Imperial College London

Ion-to-Frequency ISFET Architecture – Pixel Operation