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Organic Spiking Neuromorphic Circuits: Flexible Embodied AI

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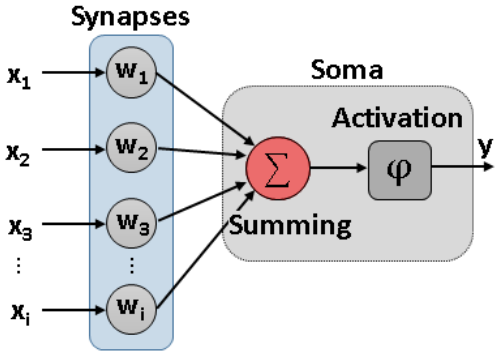
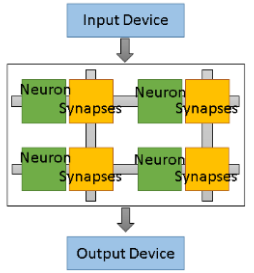
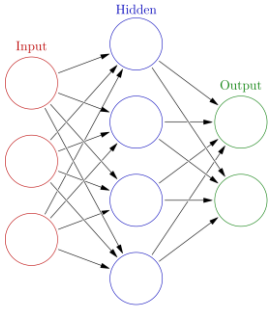
Artificial neurons are key components of neuromorphic computing systems, which aim to emulate the structure and functions of biological neural networks for efficient, brain-like computation. Most artificial neurons rely on rigid, silicon-based technologies that are poorly suited for integration with soft structures. **Our aim is to develop networks of artificial spiking neurons, implemented using physically flexible organic electronics, to perform pattern recognition, processing of input/output data, and control of mechanical actuators.** We fabricated an electrical circuit that approximates the behavior of a spiking neuron.



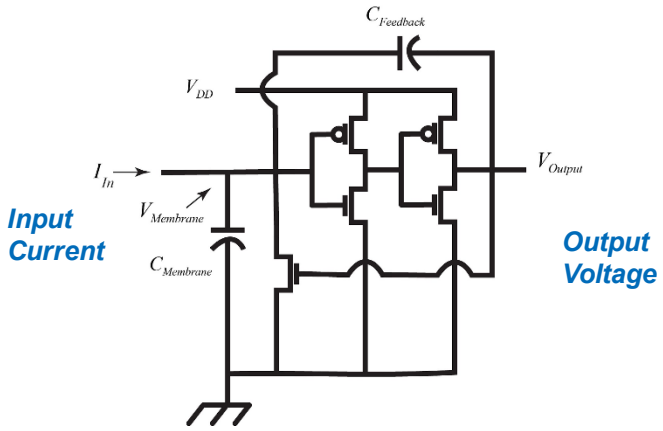


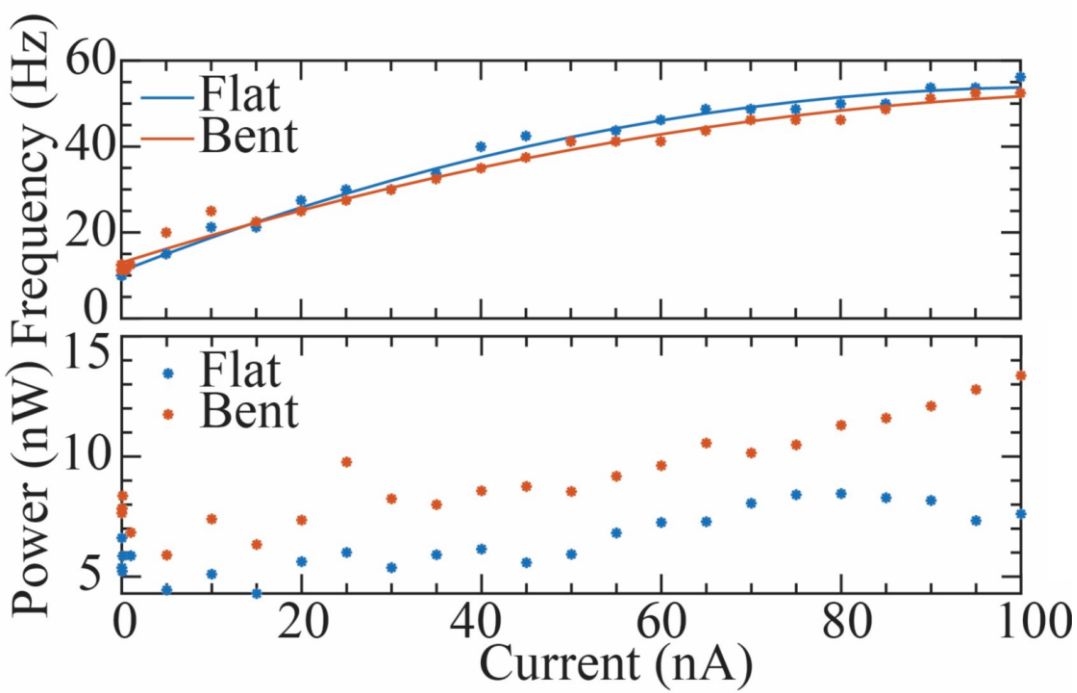
$$y = \varphi\left(\sum_i (x_i w_i)\right)$$

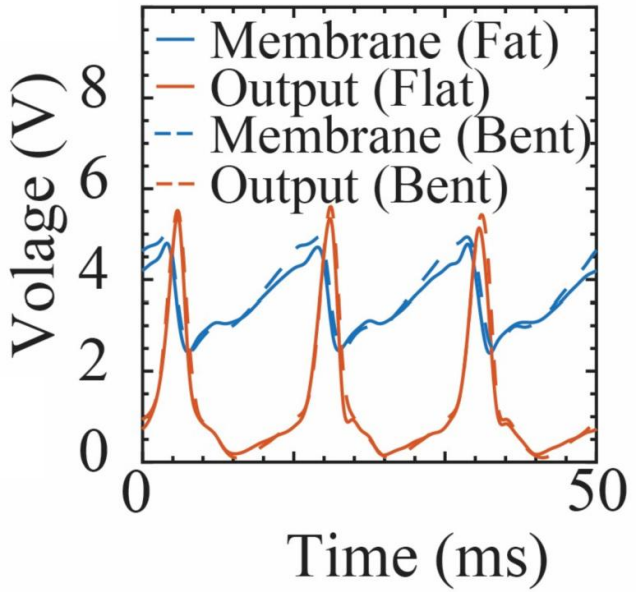


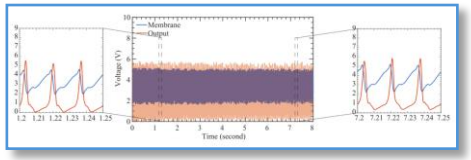
SOMA

- Integrate input currents
- Produce output voltage spikes;
  - Proportional to input current
- $I_{IN} \rightarrow V_{OUT}$
- Showed Integrate-and-Fire (I&F) Axon-Hillock (AH) artificial soma







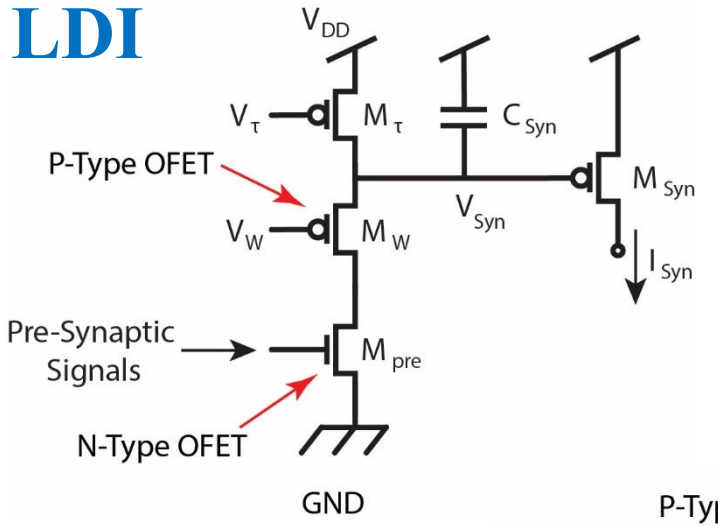


M.J.M. Hosseini, et al., J. Phys D, 54, 10 (**2021**) doi: 10.1088/1361-6463/abc585.
M.J.M. Hosseini, et al., npj Flex Ele., 10, 14 (**2026**) doi: 10.1038/s41528-025-00512-6

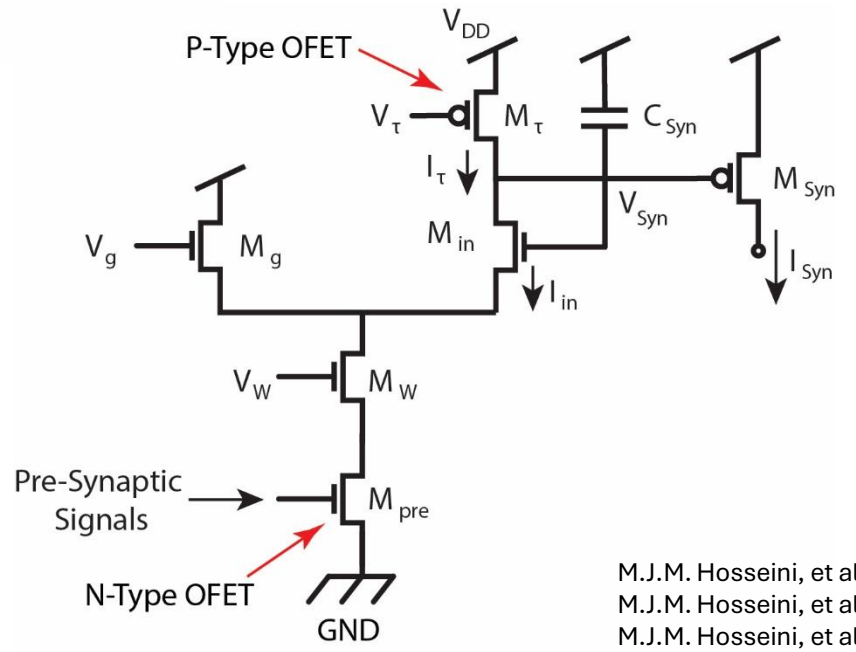
SYNAPSE

- Input voltage → output current
- Tunable output (Vw)
- Showed Pulsed-Current (PCS), Log-Domain Integrator (LDI), Differential-Pair Integrator (DPI) excitatory & inhibitory artificial synapses

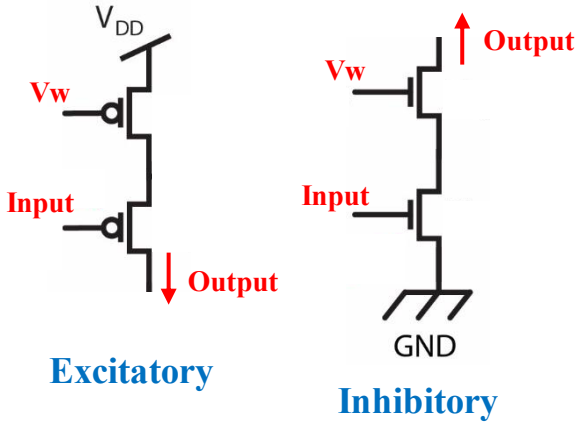
LDI

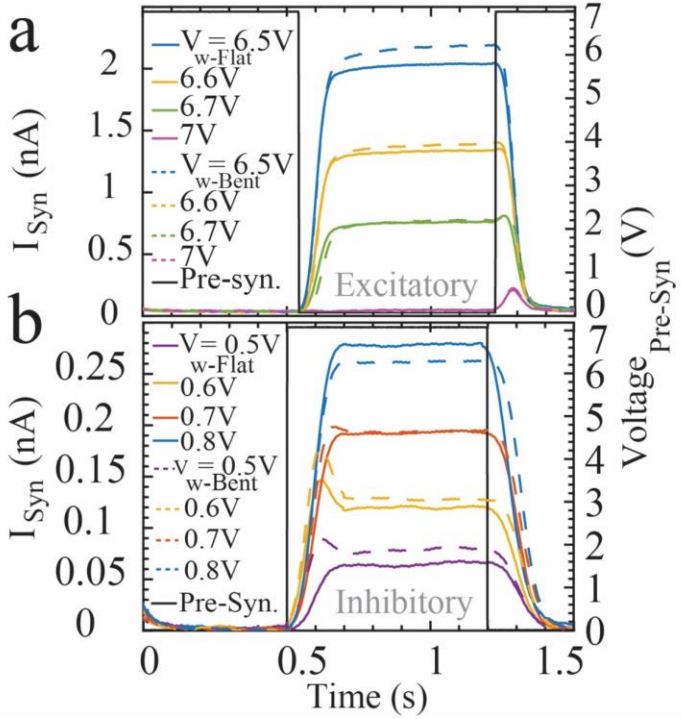


DPI



PCS





M.J.M. Hosseini, et al., Adv. Ele. Mat., 8, 2 (**2022**) doi: 10.1002/aelm.202100724
M.J.M. Hosseini, et al., Neuro. Com. Eng., 2, 3 (**2022**) doi: 10.1088/2634-4386/ac830c
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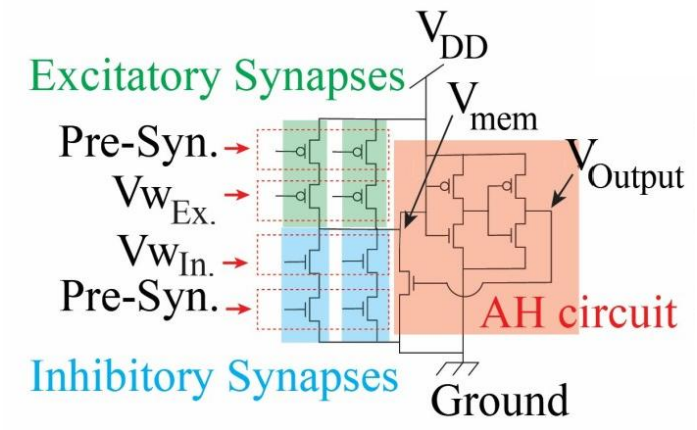
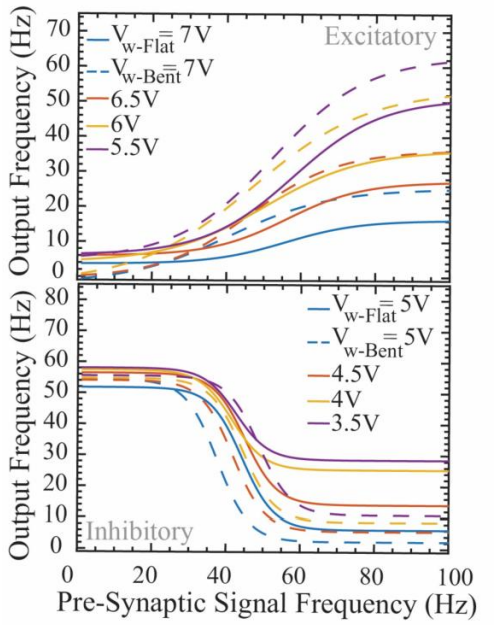
NEURON

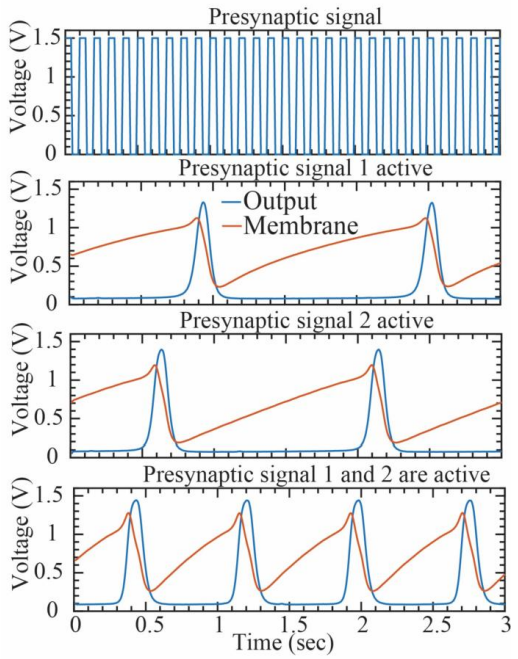


- Many (excitatory, inhibitory) synapses (e.g. PCS, LDI, DPI)
- Single soma (e.g. I&F AH)
- Input Voltage spikes → output Voltage spikes
- Output voltage once integral of all inputs exceeds threshold voltage
- Inter Stimulus Interval

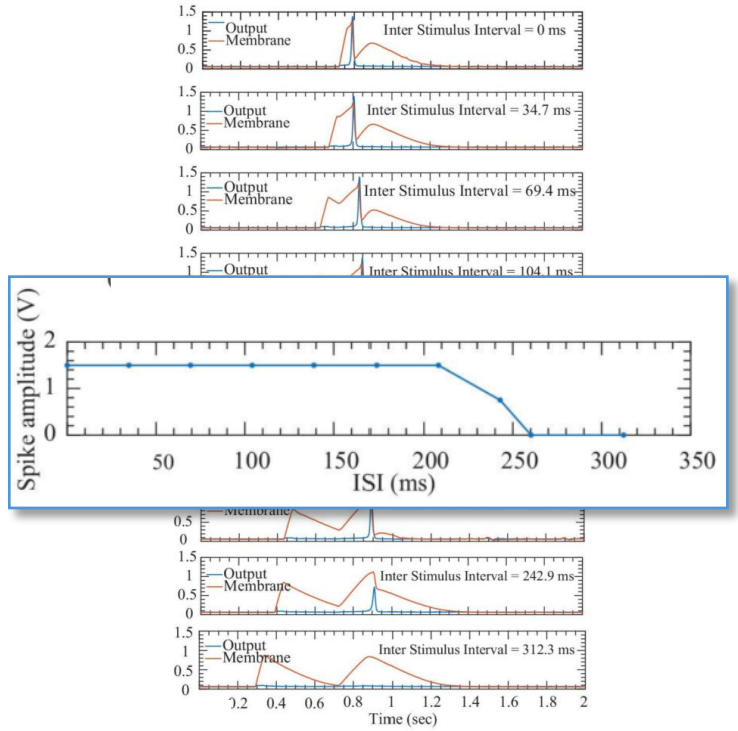
Activation Function



Input Summation



Inter Stimulus Interval



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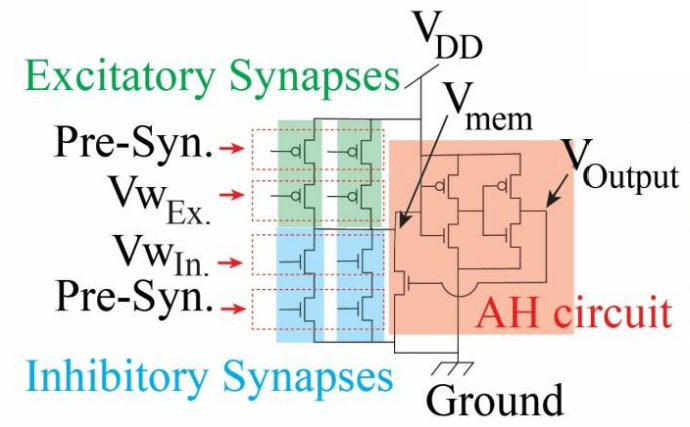
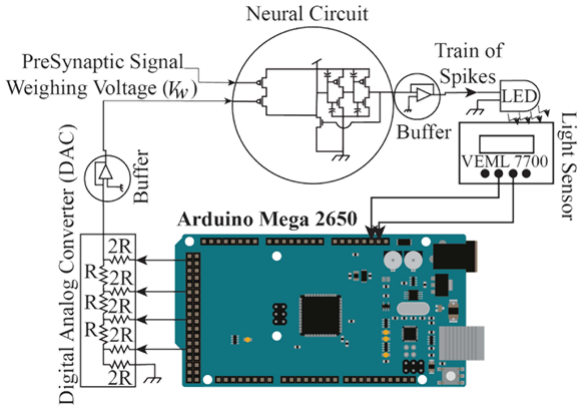
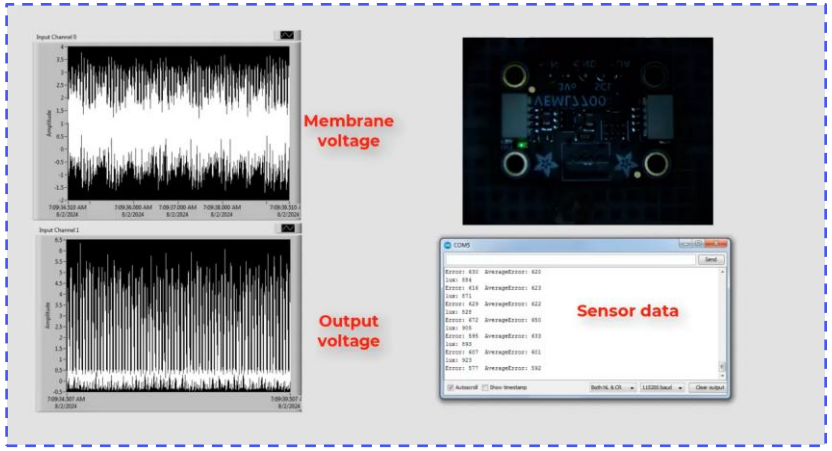
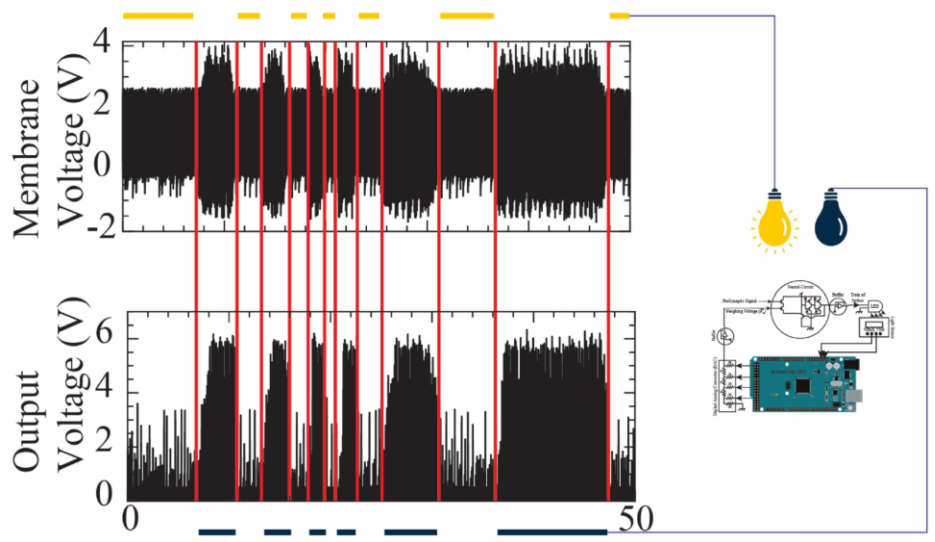
NEURON demo



- Showed Short-term adaptive modulation
- Organic neuron + light sensor + microcontroller
- Temp adjustment of Vws due to light
- LED adjusted (via Vws → spike *f*) based on light level
  - Dim light → Vws & *f* ↓;
  - Bright light → Vws & *f* ↑







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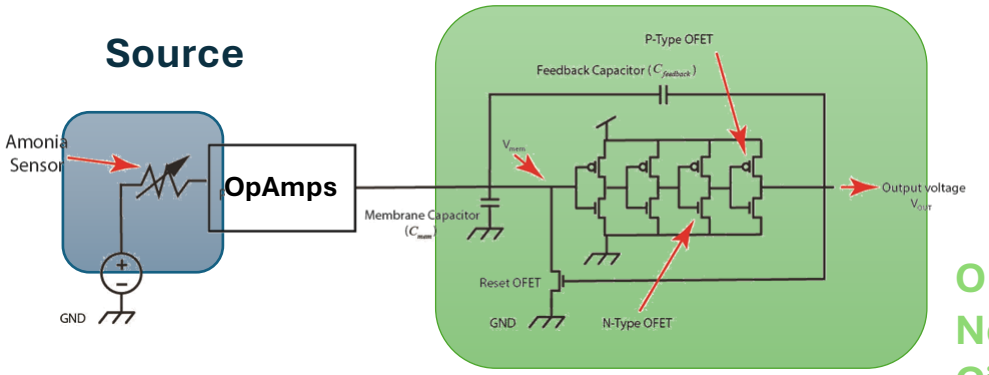
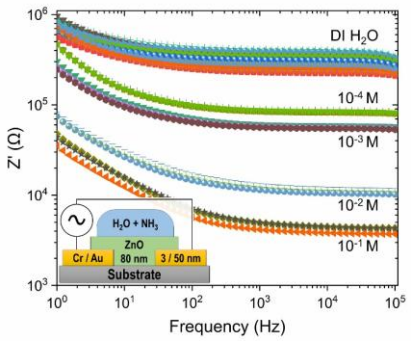
NEUROMORPHIC SENSOR

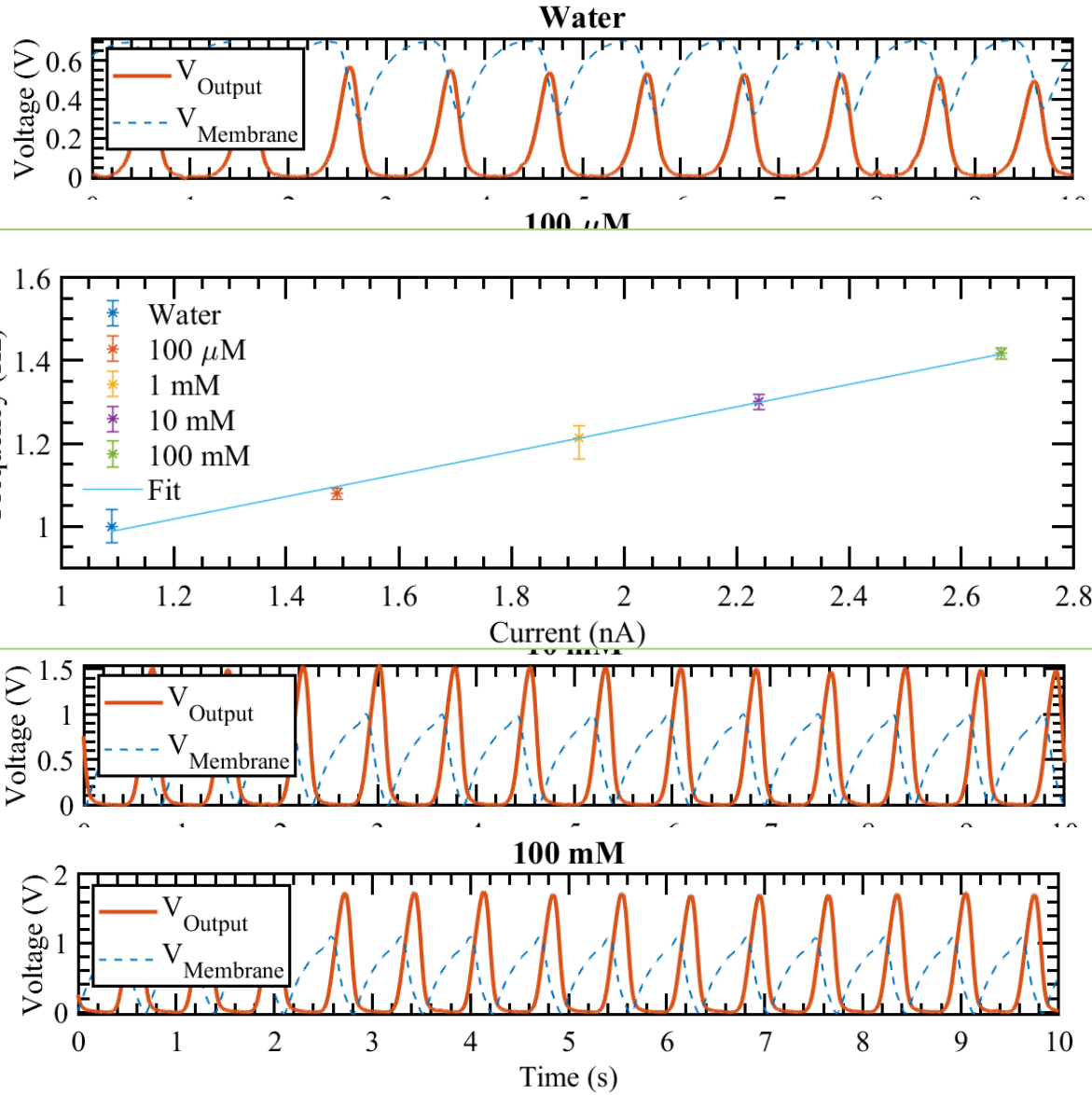


Organic Neuromorphi Circuit

Impedance

- Integrated chemical sensor with neuromorphic (AH) circuit
- Encoded (sensor) analyte (aqueous ammonia) concentration into voltage spikes of proportional frequencies





K. Vyshniakova, et al., Adv. Ele. Mat., 10, 12 (**2024**), doi: 10.1002/aelm.202400509

Circuit Fabrication

- Mohammad Javad Mirshojaeian Hosseini
- Masoome Fatahi
- Katia Vyshniakova

Simulation and Algorithm

- Yi Yang
- Undergrads (too many too list)

Collaboration

- Giacomo Indiveri (ETH, INI)
- Miad Faezipour (Purdue)
- Chiara Bartolozzi (IIT Genoa)

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References

1. M.J.M. Hosseini, et al., J. Phys D, 54, 10 (**2021**) doi: 10.1088/1361-6463/abc585
2. K. Vyshniakova, et al., Adv. Ele. Mat., 10, 12 (**2024**), doi: 10.1002/aelm.202400509
3. A.J. Prendergast, et al., IEEE Eng. Med. Bio. Soc., 707-710 (**2022**) doi: 10.1109/EMBC48229.2022.9870915
4. M.J.M. Hosseini, et al., Adv. Ele. Mat., 8, 2 (**2022**) doi: 10.1002/aelm.202100724
5. M.J.M. Hosseini, et al., Neuro. Com. Eng., 2, 3 (**2022**) doi: 10.1088/2634-4386/ac830c
6. M.J.M. Hosseini, et al., npj Flex Ele., 10, 14 (**2026**) doi: 10.1038/s41528-025-00512-6