ADVANCED FUNCTIONAL MATERIALS

Supporting Information

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Bio-Inspired Artificial Perceptual Devices for Neuromorphic Computing and Gesture Recognition

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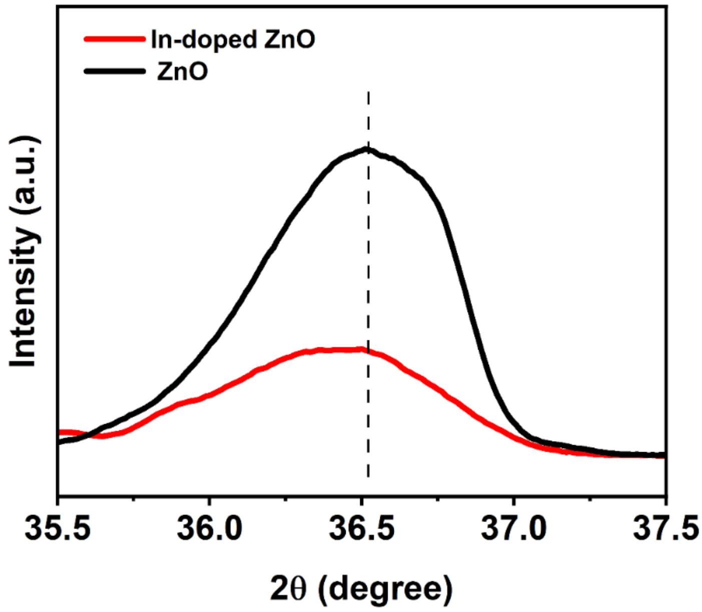

Figure S1. Zoomed XRD result shows (011) peak shifting to the left side after In doping.

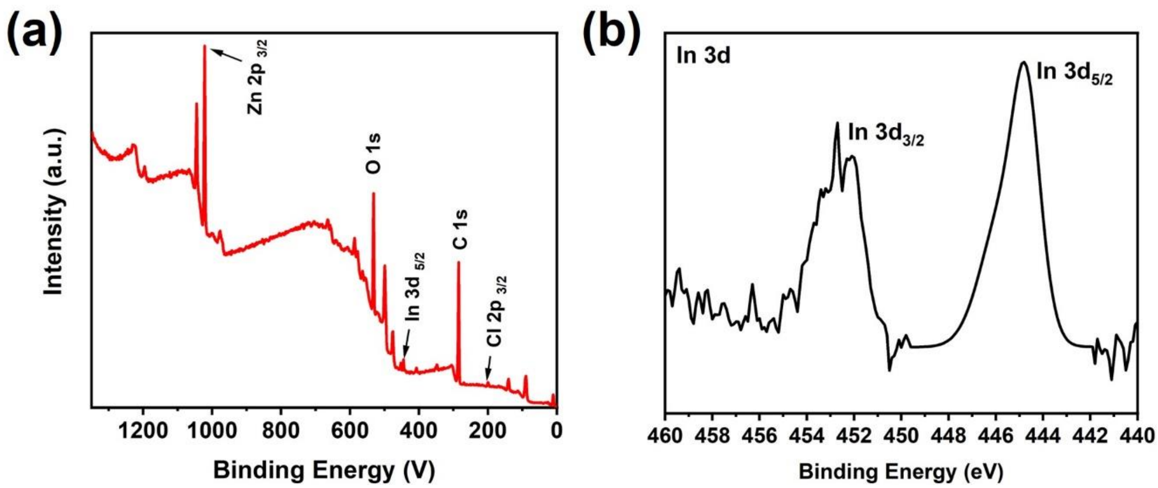

Figure S2. (a) XPS survey spectrum of ZnO:In film (b)XPS In 3d spectrum of ZnO:In film.

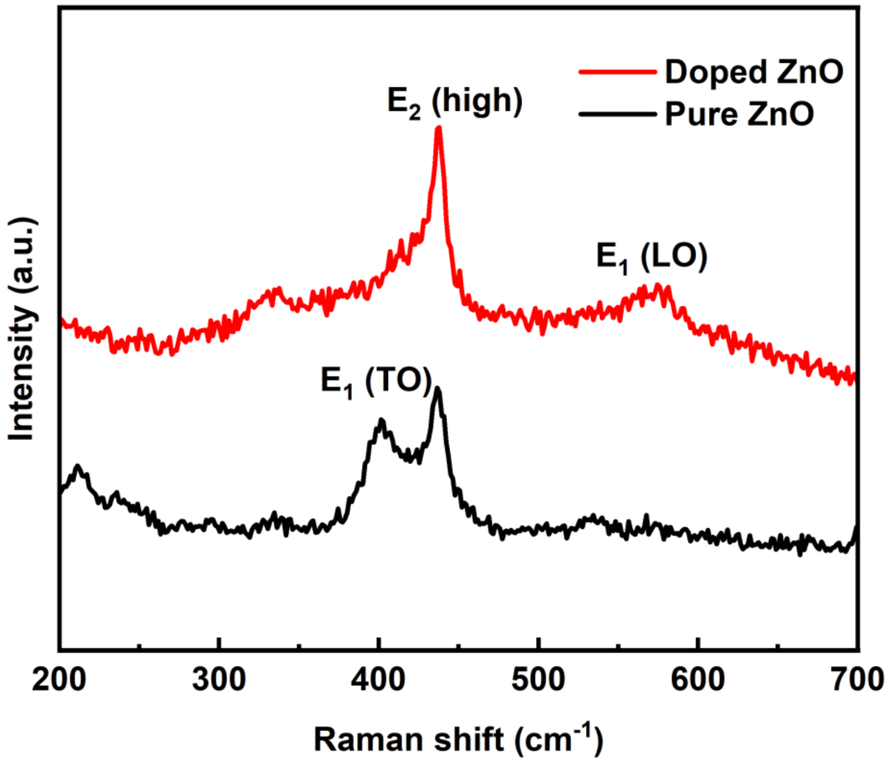

Figure S3. Raman results comparison of pure ZnO and In-doped ZnO film

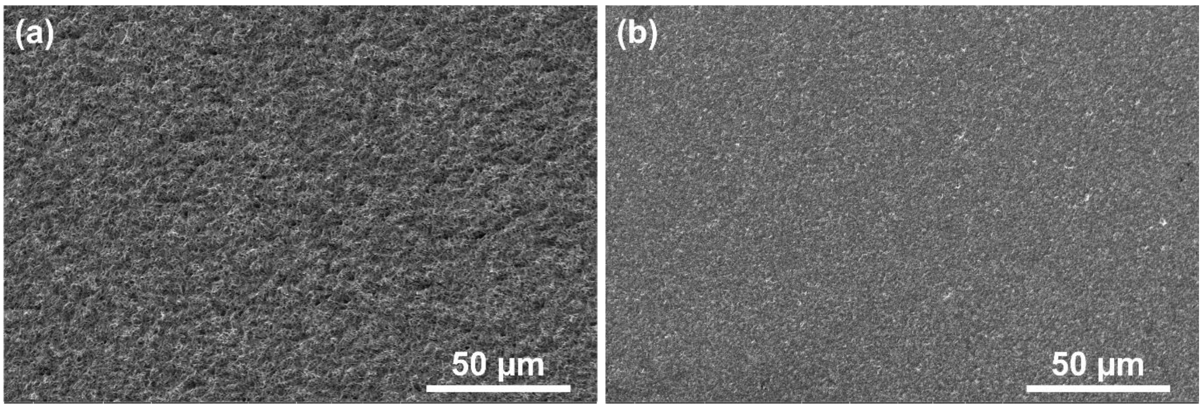

Figure S4. Surface Morphology of (a) In-doped ZnO and (b) pure ZnO film.

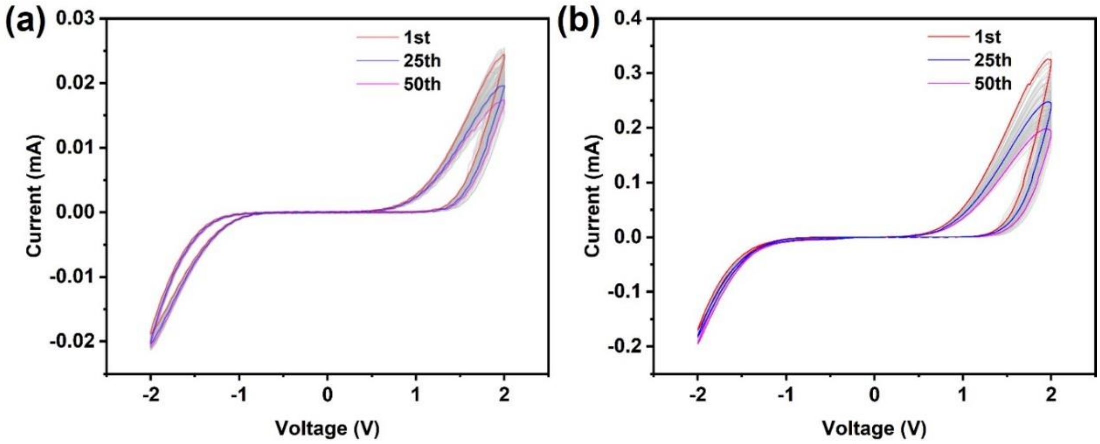

Figure S5. I-V curves under 50 positive and negative voltage sweeps (0V → +2V → 0V → -2V→ 0V): (a) In-doped ZnO and (b) pure ZnO film.

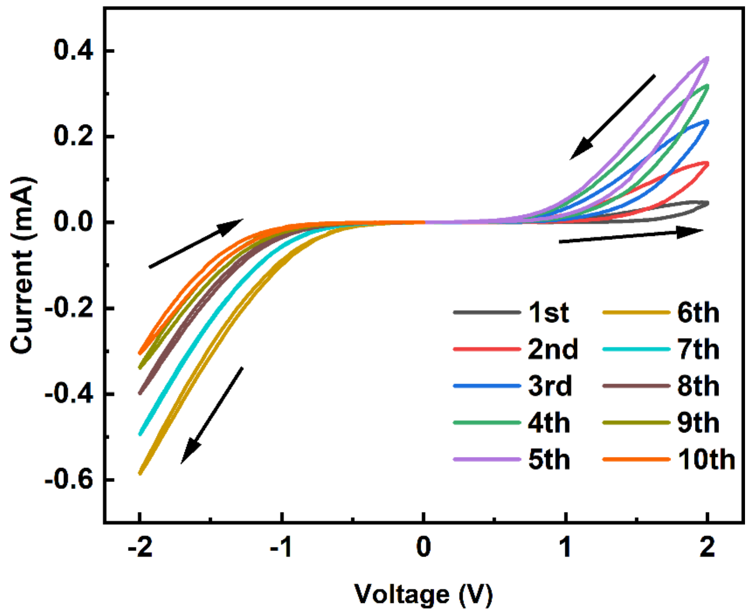

Figure S6. I-V curves of the In-doped ZnO-based device under 5 consecutive positive and 5 negative voltage sweeps.

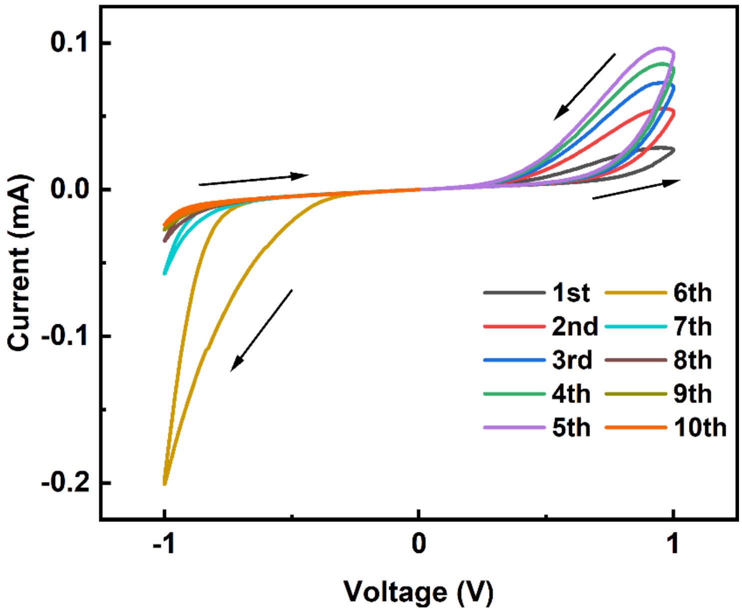

Figure S7. I-V curves of the ZnO-based device under 5 consecutive positive and 5 negative voltage sweeps.

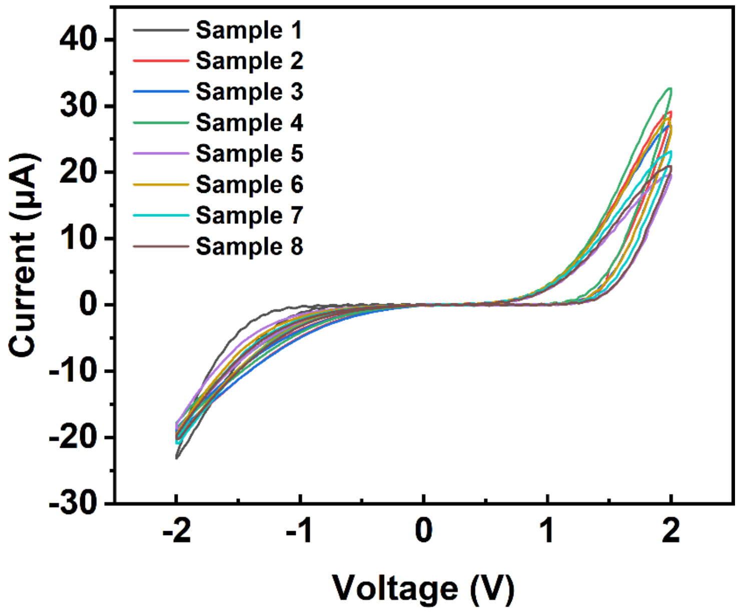

Figure S8. I-V curves of 8 different In-doped ZnO samples.

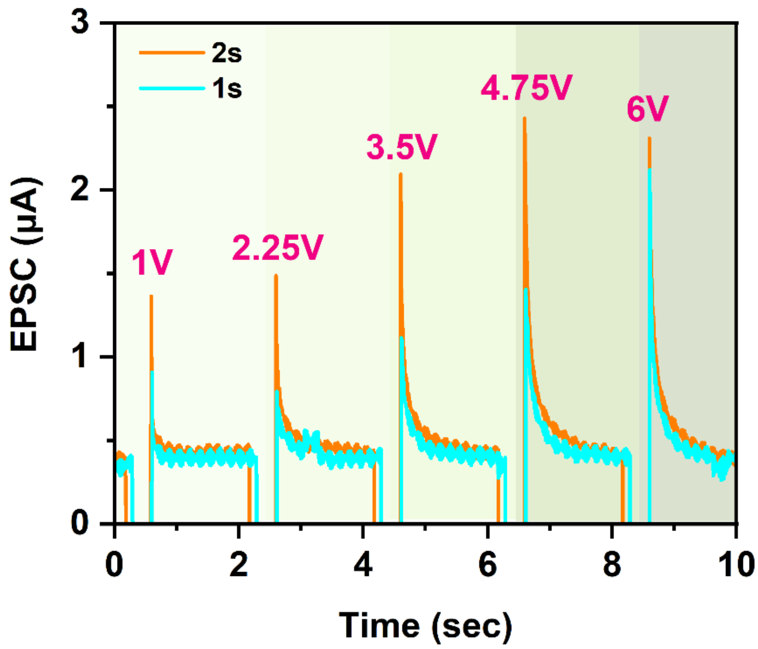

Figure S9. EPSC comparison under different pulse width (1s period)

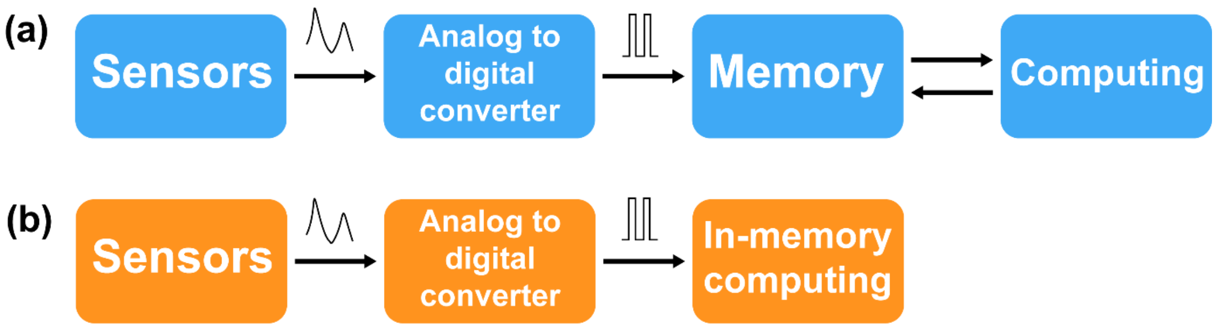

Figure S10. Schematic illustration of (a) Integrated sensor based on Von Neumann architecture (b) Integrated neuromorphic sensor.[1]

Handwriting and gestures are distinct patterns that are subject to far more constraints and limitations than simple pattern recognition (real-time recognition, unique statistical characteristics, etc.), where neural networks have the ability to circumvent some of these restrictions.[2] While hardware-based neuromorphic computing is still in its early stages, researchers have turned to neural network approaches to advance handwriting recognition algorithms in recent years.[3-6]

In addition, as an in-memory computing device, artificial synapse can sidestep the energy loss during transportation between the memory and computing unit (Figure S10).[1] It can also enhance the device performance by improving the space utilization and reducing energy consumption.

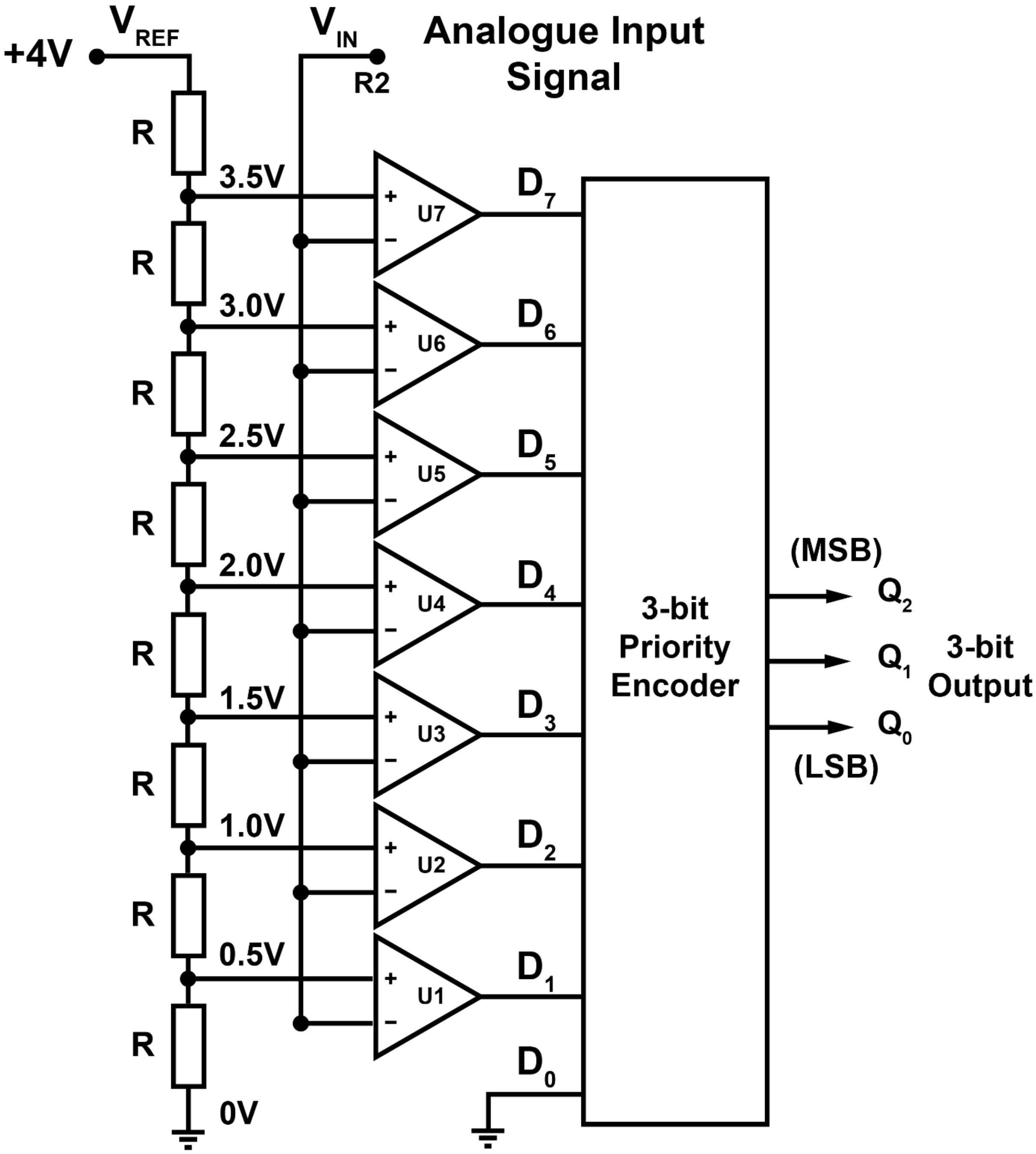

Figure S11. Circuit of analog to digital converter.[7]

This circuit is an example of a 3-bit analog to digital converter, Where the input signal is compared with the reference voltage and then encoded to the corresponding digital output. Maintaining a constant voltage is crucial for modern electronic devices since unexpected fluctuations can lead to damaged device. Achieving multiple pulse amplitudes requires complex circuitry with the fixed supplied voltage. Modulating the pulse width, on the other hand, only requires adjusting the duty cycle. Furthermore, in biological synapse, the variation of pulse width plays an important role for pain sensing.[8] Therefore, based on these factors, pulse width or SDDP was chosen as the basis for this synaptic device.

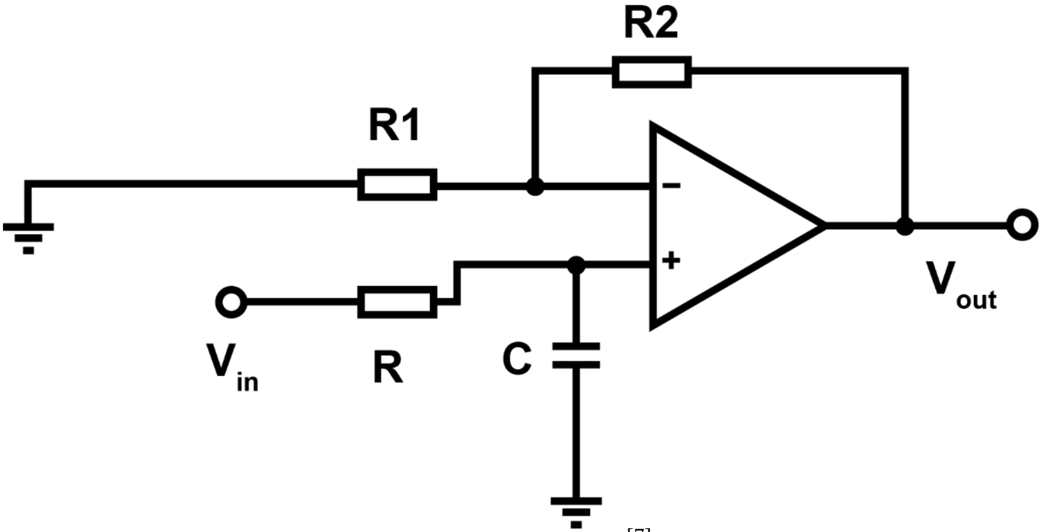

Figure S12. The First order low pass Butterworth filter.[7]

The filter gain is given by:

$$A = 1 + \frac{R1}{R2}$$

The cut off frequency is calculated by:

$$f = \frac{1}{2\pi RC}$$

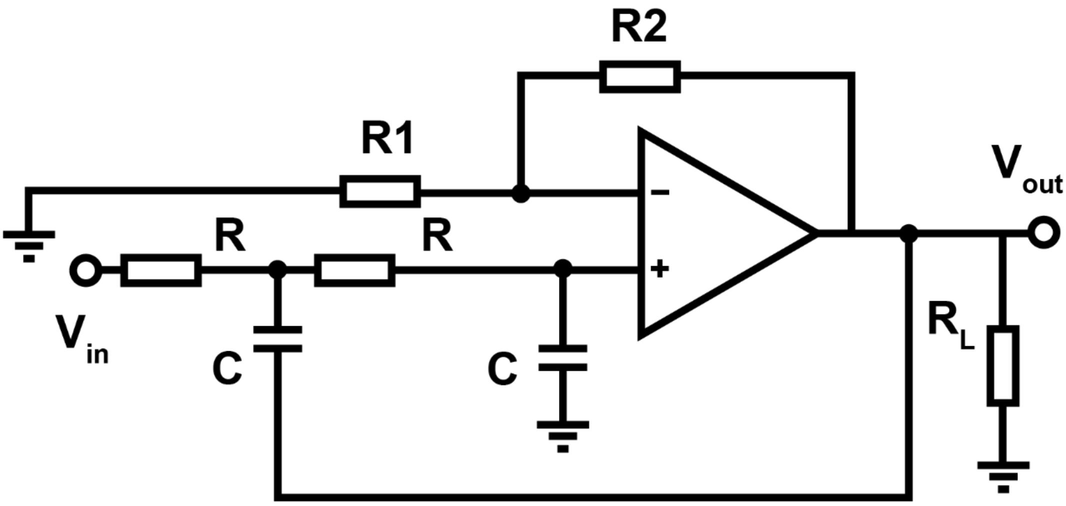

Figure S13. The second order low pass Butterworth filter.[7]

This filter is accomplished by connecting an additional RC network to the first order Butterworth filter. With cascaded first and second order Butterworth filter, a higher order filter can be obtained.

References

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