# Efficient Sensing in Biosystems

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## Event-Based Readout in Lab-on-CMOS: Spike Processing

### Introduction

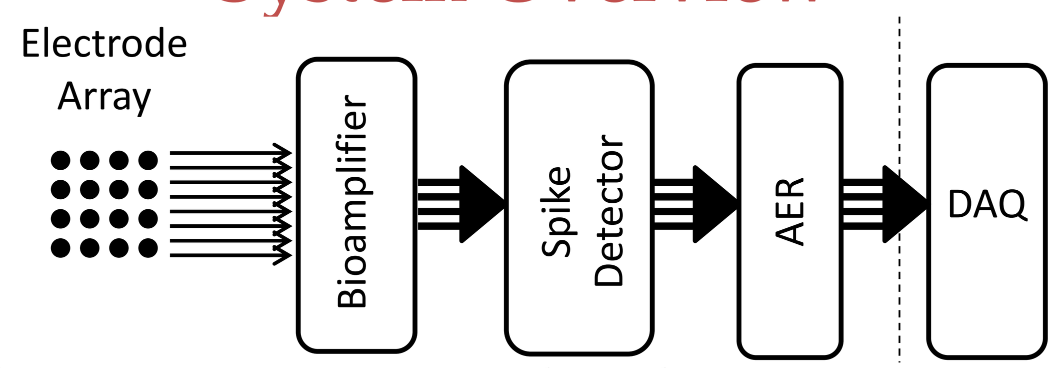
Sampling bio-potential data yields a large amount of data, however the actual information content of the signals is much sparser than the data being collected.

- Transient waveforms require high sampling rates:
  40 kSamples/s x 16 b/Sample x 32 channels → **154 MB/min**
- Spike information is quite sparse:
  < 100 Spikes/s x 32 channels → **< 3.75 kB/min**

Instead of reading out the raw data by itself, we can match the asynchronous signal source with an event-driven readout

- This requires local spike detection capability
- Bandwidth requirements are reduced by a factor of 1600

### System Overview



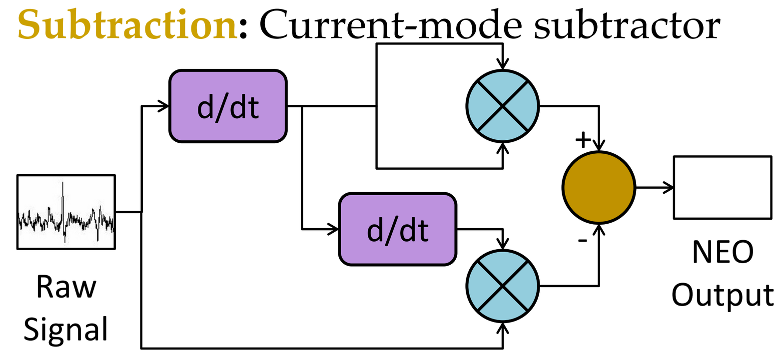

The system is an active micro-electrode array

- Array of sensor pixels
- Pixel: Electrode pair, bioamplifier, spike detection circuit, and Address Event Representation (AER) interface
  - **Bioamplifier**: Operational Transconductance Amplifier (OTA): $A_v = C_{in}/C_{fb} = 46$ dB, $C_{in} = 20$ pF, $C_{fb} = 100$ fF, Passband: 280 mHz to 8.1 kHz
  - **Spike Detector**: Nonlinear Energy Operator (NEO) algorithm
  - **AER**: Asynchronous readout with full handshaking or autonomous self-timing operation
- Digital pulses sent off-chip to external Data Acquisition system (DAQ)

### Circuit Implementation

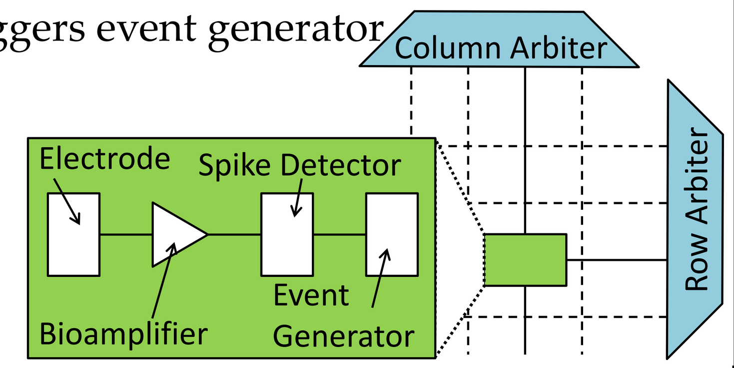
NEO requires three fundamental computations:

- **Derivative**: Input capacitor preceding a high-gain inverting amplifier with resistive feedback
- **Multiplier**: Translinear four quadrant multiplier with core voltage loop created by six PMOS transistors
- **Subtraction**: Current-mode subtractor




### AER Protocol

- Spike detector triggers event generator
- Row and column arbitration controls address generation
- Single spatial address per spike event




**Bandwidth Reduction Factor† (BRF)**

With typical data acquisition scheme:
40 kSamples/s x 16 b/Sample x 1 B/8 b = 80 kB/s

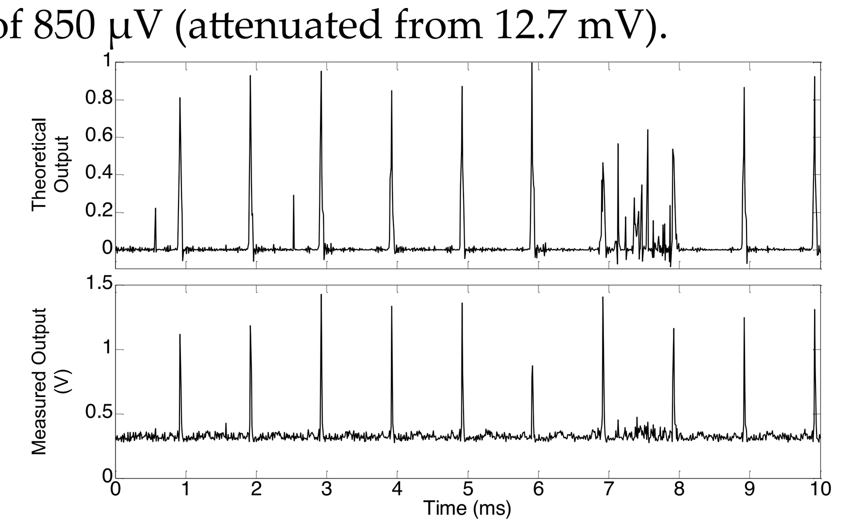
With asynchronous readout:
50 AP/s x 8 b/AP x 1 B/8 b = 50 B/s

**BRF**: 1600

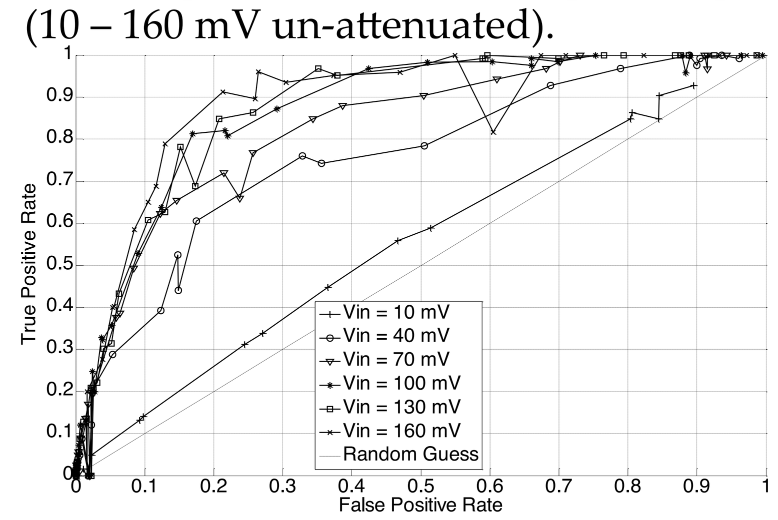
† per channel in a 16 channel system

### Experimental Verification

Computational accuracy of NEO circuit measured by providing a 1 kHz spike train with amplitudes of 850 μV (attenuated from 12.7 mV).




Receiver operating characteristic showing detection rate (DR) vs. false positive rate (FPR). Spike amplitudes of 55 – 900 μV (10 – 160 mV un-attenuated).




With input spikes at 390 μV:

- 76% DR vs. 5% FPR
- 100% DR vs. 14% FPR

## Statistical Bandwidth Reduction: Compressed EEG Sensing

### Introduction

The study of brain diseases such as schizophrenia has traditionally been performed using laboratory-based EEG and MEG devices. Wireless mobile sensing platforms can be a valuable tool in studying EEG patterns:

- Recording responses that are uncontrolled (e.g. hallucinations)
- Facilitates patient comfort

**Problem:**

- Battery lifetime: system should run continuously throughout the day

**Proposed Solution:**

- Compress EEG signals prior to data transmission in a computationally-simple manner

### Low Cost Mobile EEG

Built from commercial-of-the-shelf components and facilitates on-board compressive sensing.

- Biopotential ADC: TI ADS1299
- High performance microcontroller: Atmel SAM G55
- Up to 7 EEG channels and one audio envelope channel
- Up to 500 samples/s
- Bluetooth connectivity
- Low cost ($200)

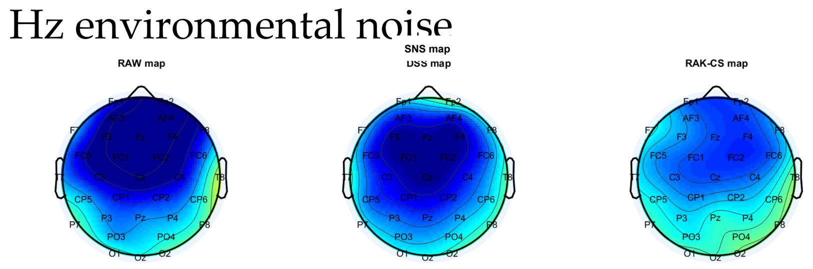
### Compressed Sensing

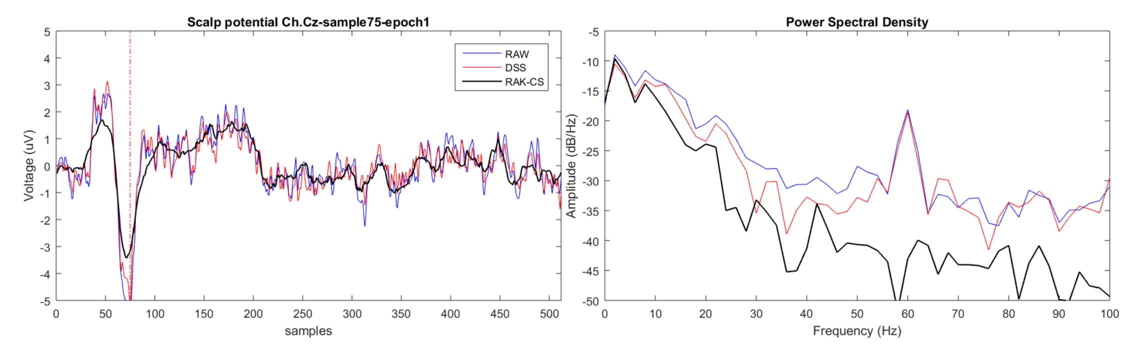
Compressive sensing (CS) is a technique of compressing acquired signals in real-time and in a low-power manner.

- Move bulk of computational effort in compression away from the battery-powered wireless node to a base station.
- Compression algorithm is designed to be simple (i.e. made of a few elementary operations)
- Decompression algorithm is inherently non-linear and usually more time- and energy-consuming.

**Environmental Noise Shaping**

Tune Rakeness CS algorithm to filter out 60 Hz environmental noise

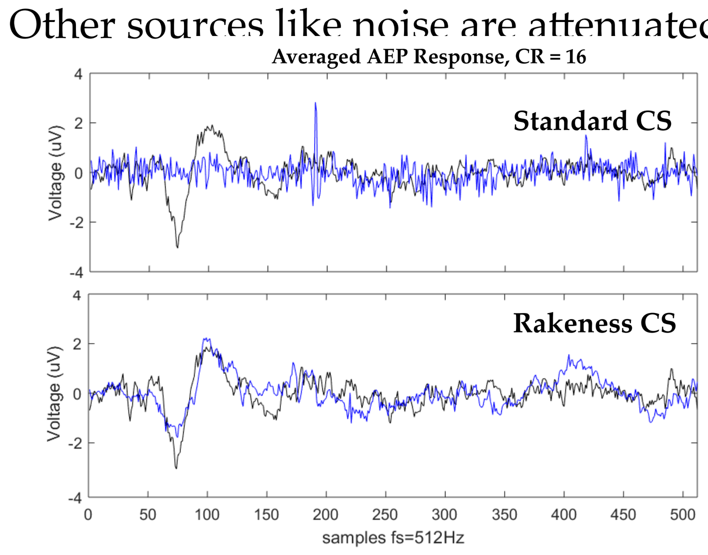



**Rakeness CS**

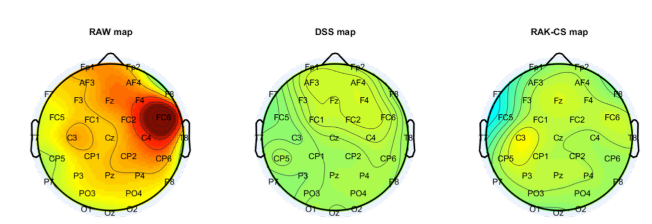
Statistical tuning of the CS algorithm to the EEG signals of interest, resulting in implicit signal filtering

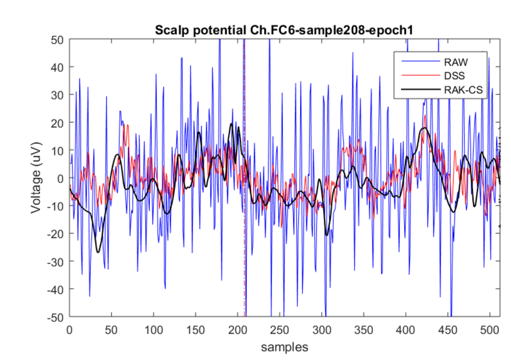
- Matched features are enhanced
- Other sources like noise are attenuated




**Sensor Noise Shaping**

Unwanted sensor motion filtered using Rakeness CS

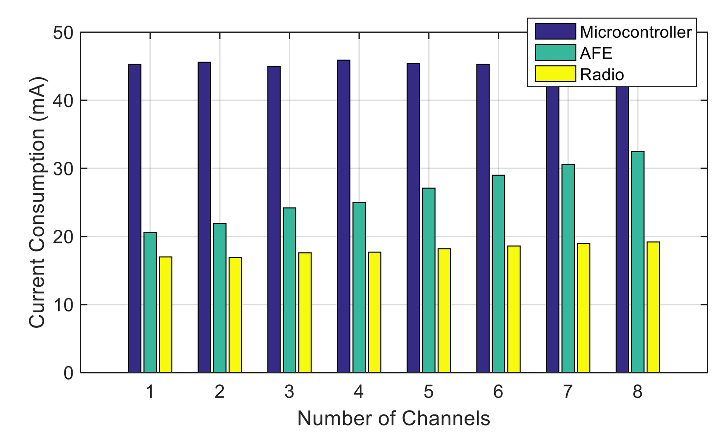


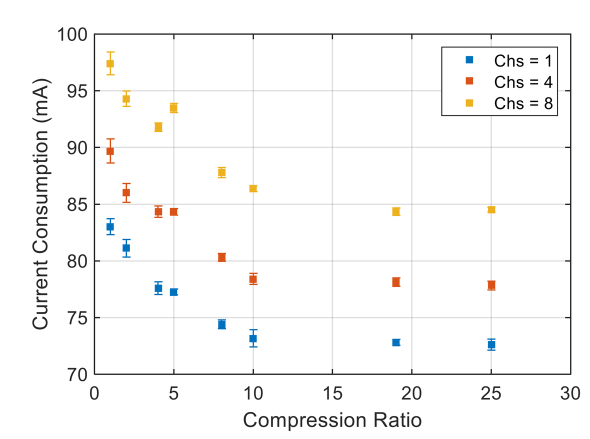


### Power Measurements

Power consumption of the mobile EEG system was measured as a function of the compression ratio and number of EEG channels being recorded

- Diminishing returns as compression ratio is increased
- AFE contributes most to increase in power consumption as more channels are added (58% increase in consumption vs. 13% increase)
- Microcontroller processing cost was negligible compared to overhead

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*Integrated Biomorphic Information Systems Lab*