

# Symphonies, Sand Dunes & Depth of Anesthesia!

Christian L Petersen

STA Annual Meeting, San Diego, CA

Jan 11–14, 2017



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# Disclosures

- No Personal Disclosures

( Prof. Guy A. Dumont:  
Equity in BioNova Technologies,  
holder of NeuroWave IP)

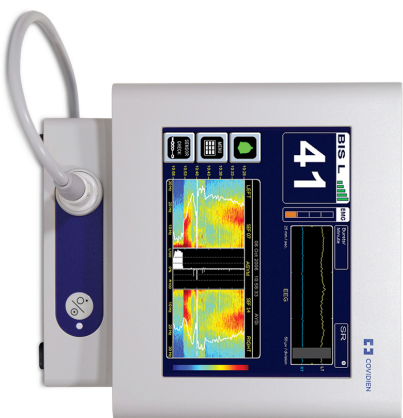


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# Motivation



?







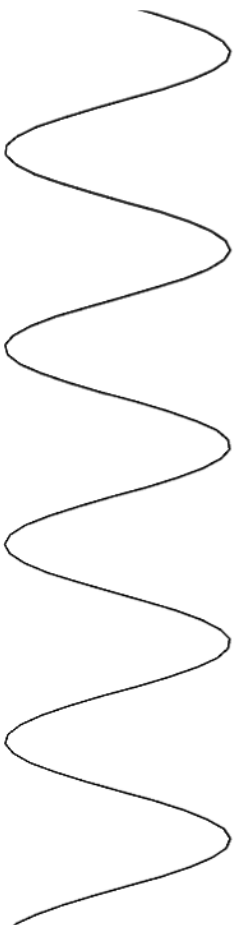
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# Test Signal vs. Live Signal



Test Signal: Constant Pure Tone

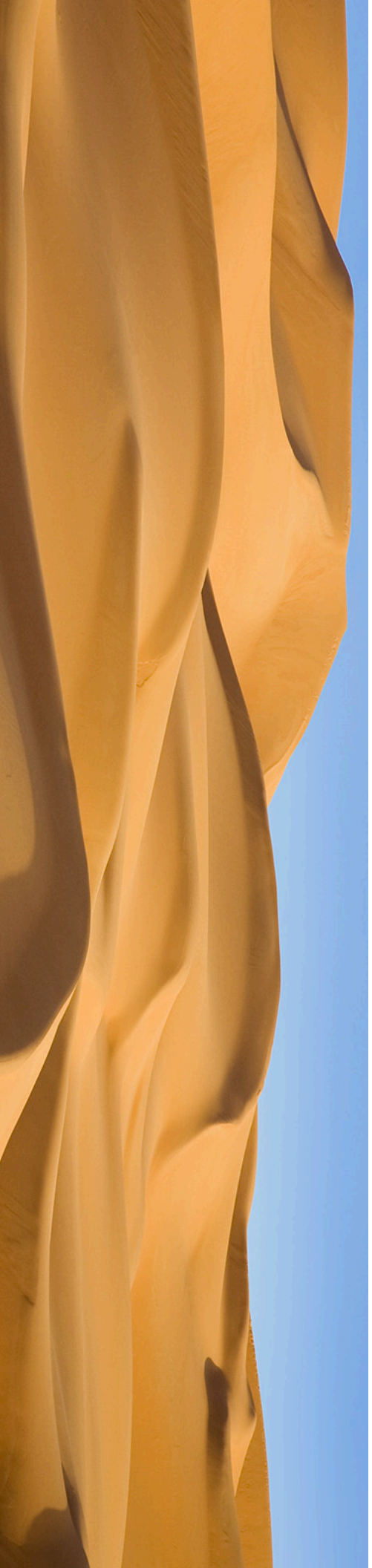


Live Signal: Beethoven's 5th Symphony!

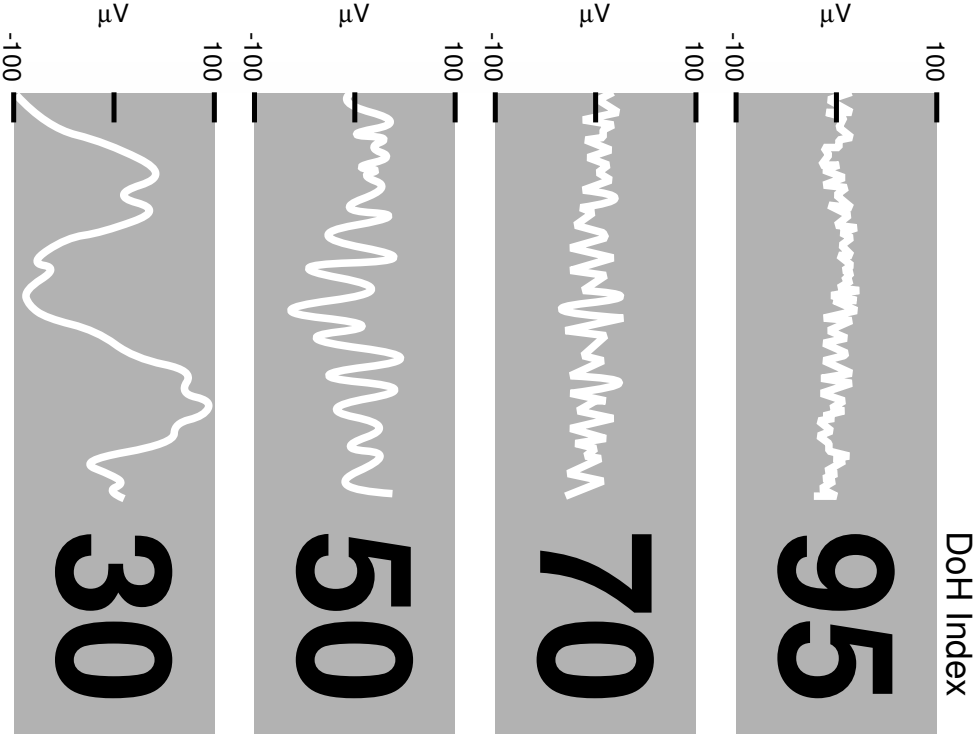


# EEG Monitor Test Signal?

- A pure sine wave triggers artifact alerts
  - Not a physiological signal
- Real EEG exhibits  $1/f$  spectrum
  - A critical system.. like sand dunes?



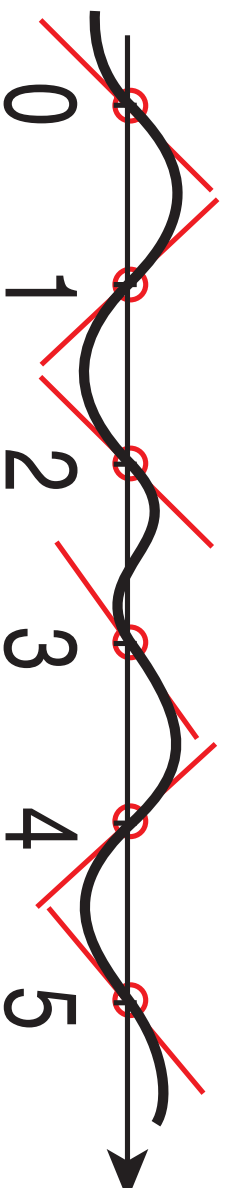
# EEG Terrain Equivalence!





# Perlin Surface Rendering

- Gradient noise for textures
  - Random gradient at fixed points
  - Smooth interpolation between points
  - Continuous 1st and 2nd derivative



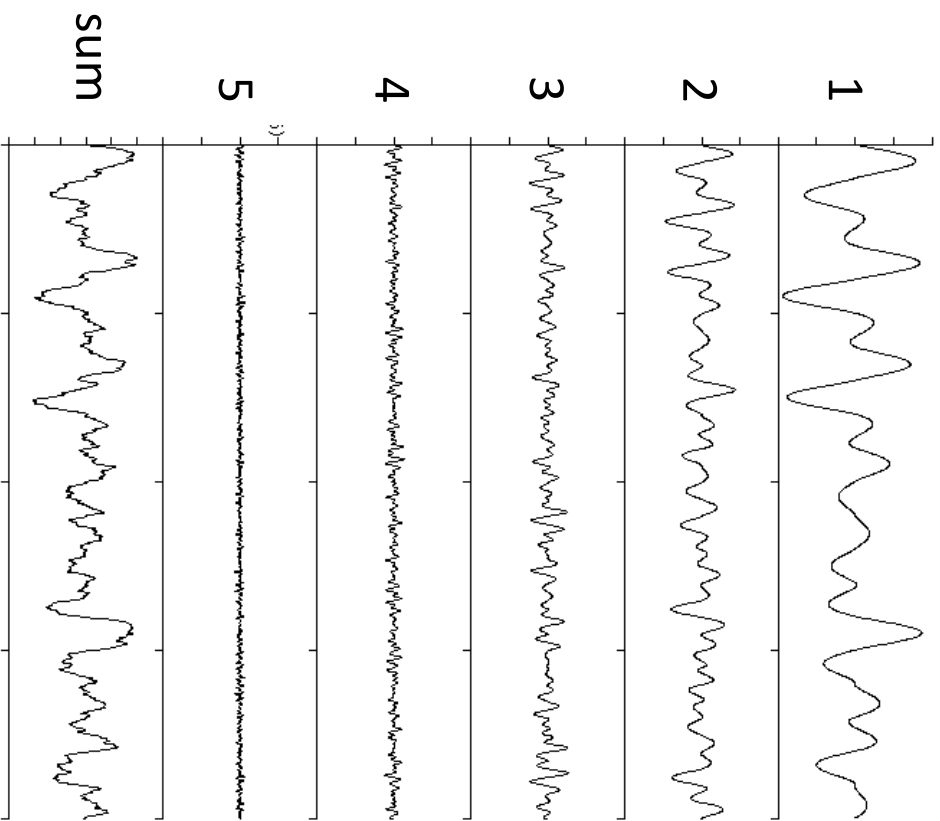
1997

Motion Picture Academy  
Technical Achievement Award  
Ken Perlin

# Perlin 1/f<sup>n</sup> Noise

$$1/f^n \text{Noise}(t) =$$

$$\sum_{i=0}^{N-1} \frac{\text{Perlin}(b^i t)}{a^i}$$



[http://paulbourke.net/texture\\_colour/perlin/](http://paulbourke.net/texture_colour/perlin/)

# Bilateral Perlman Test Signal

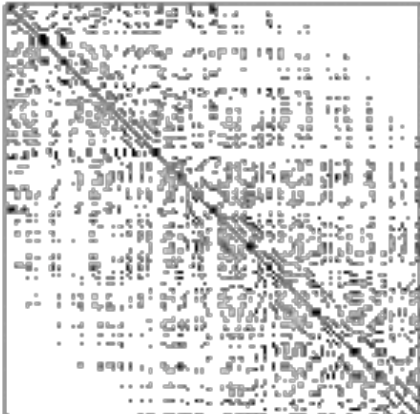
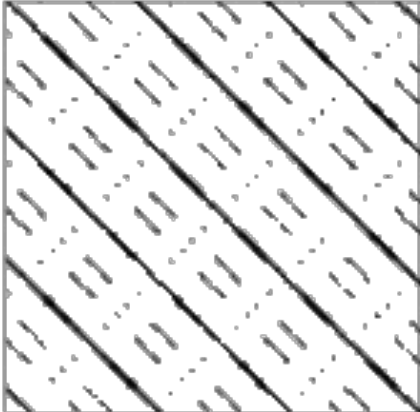
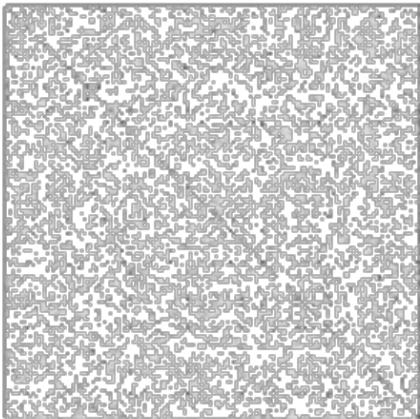
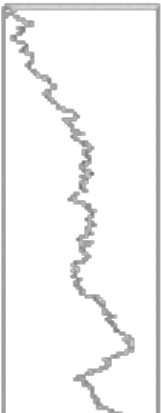
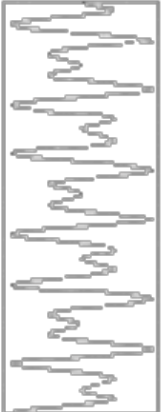
$$EEG_1(t, k) = \frac{Perlman(2\pi kt)}{\alpha k}$$

Calibration  
parameter 

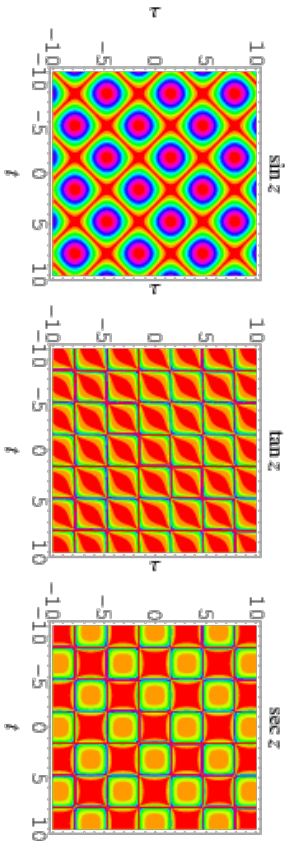
$$EEG_2(t, k) = EEG_1(-t, k)$$



# Cross-Recurrence Plots

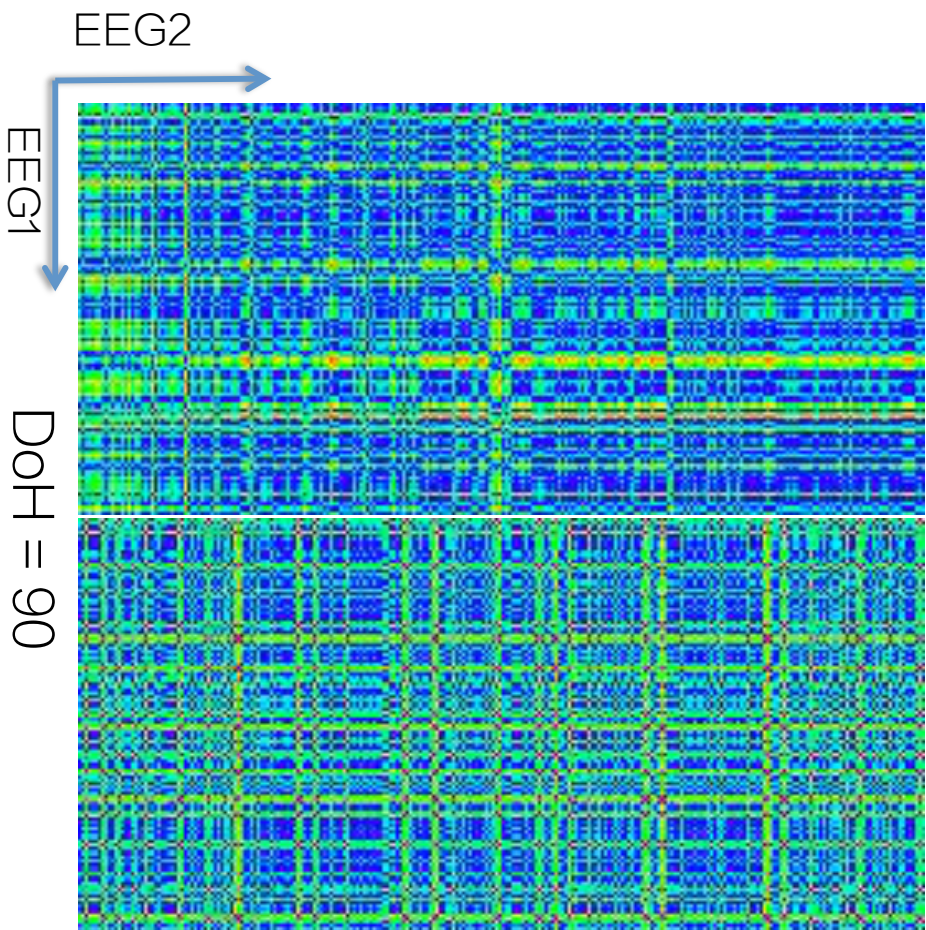


$$R(i, j) = \begin{cases} 1 & \text{if } \|\vec{x}(i) - \vec{x}(j)\| \leq \epsilon \\ 0 & \text{otherwise,} \end{cases}$$

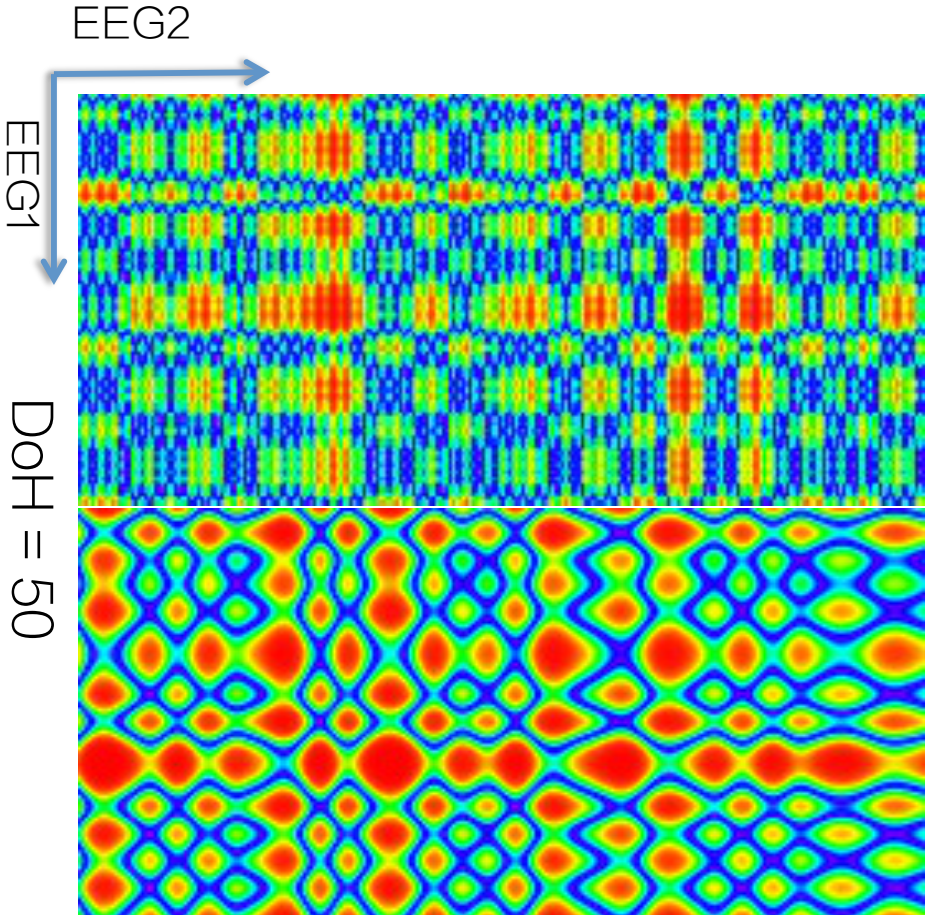


[https://en.wikipedia.org/wiki/Recurrence\\_plot](https://en.wikipedia.org/wiki/Recurrence_plot)

Real EEG      Simulation



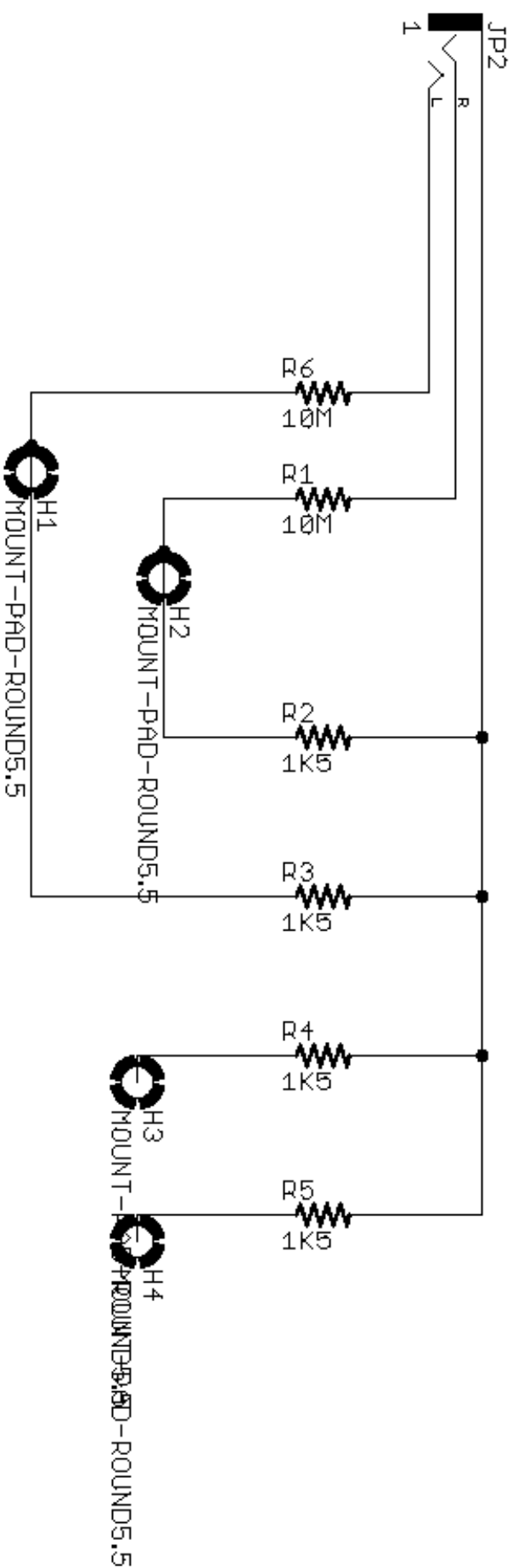
Real EEG      Simulation



Petersen CL, G6rges M, Massey R, Dumont GA, Ansermino JM  
A Procedural Electroencephalogram Simulator for Evaluation of Anesthesia Monitors  
Anesthesia & Analgesia July 2016 DOI: 10.1213/ANE.0000000000001506



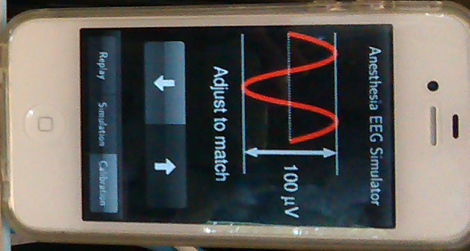
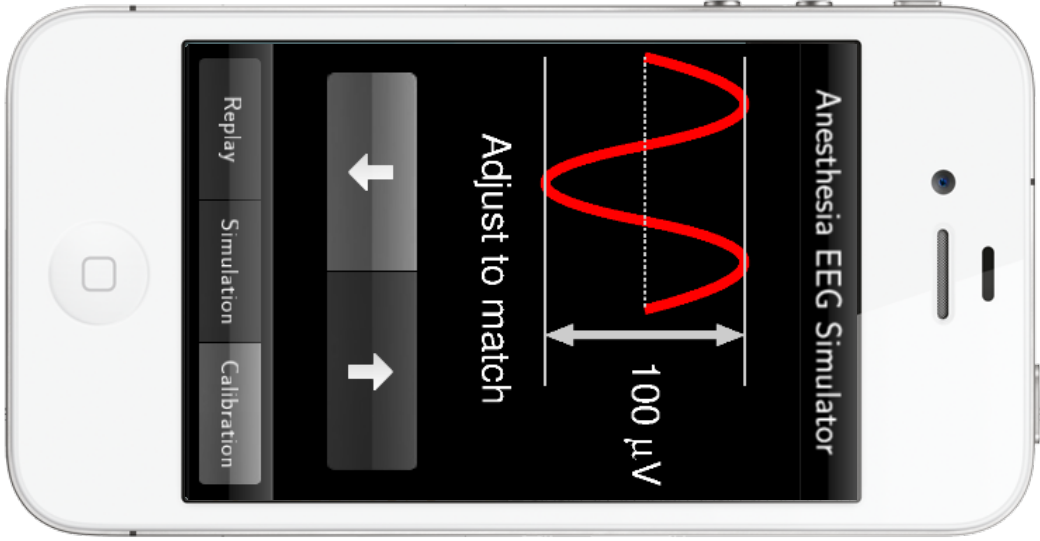
# Audio Interface



<https://twitter.com/eegsimulator>



Petersen CL, Ansermino JM, Dumont GA  
A Smartphone-based EEG Anesthesia Simulator  
6th NWAC World Anesthesia Convention, Vancouver, BC, April 29 – May 2 2015







Petersen CL, Ansermino JM, Dumont GA  
Towards a Depth of Hypnosis EEG Simulator  
Society of Technology in Anesthesia (STA) 2015, Phoenix AZ

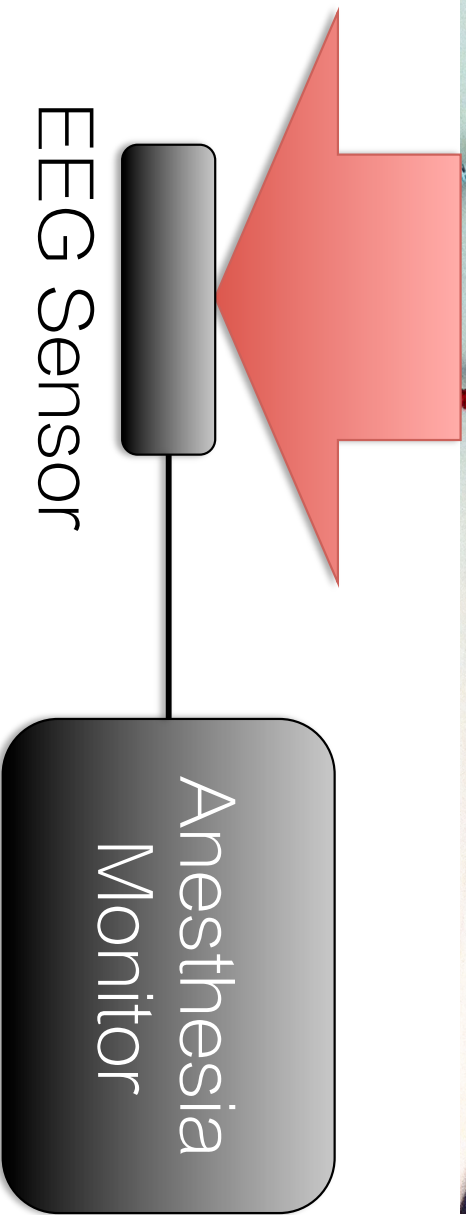
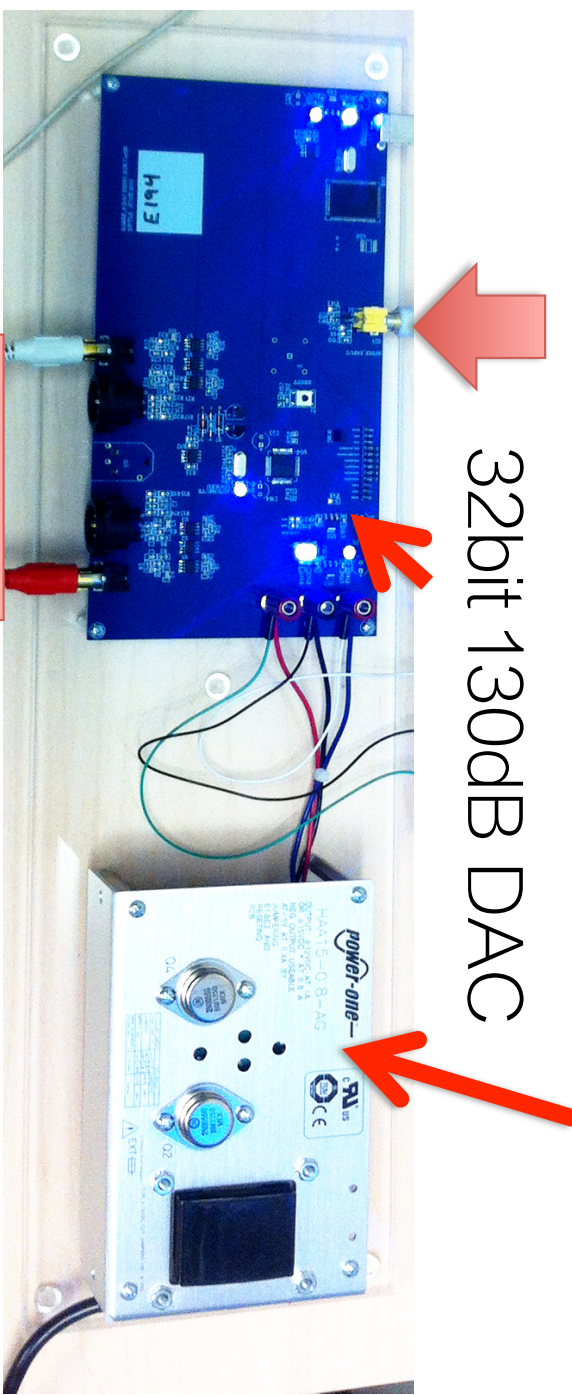
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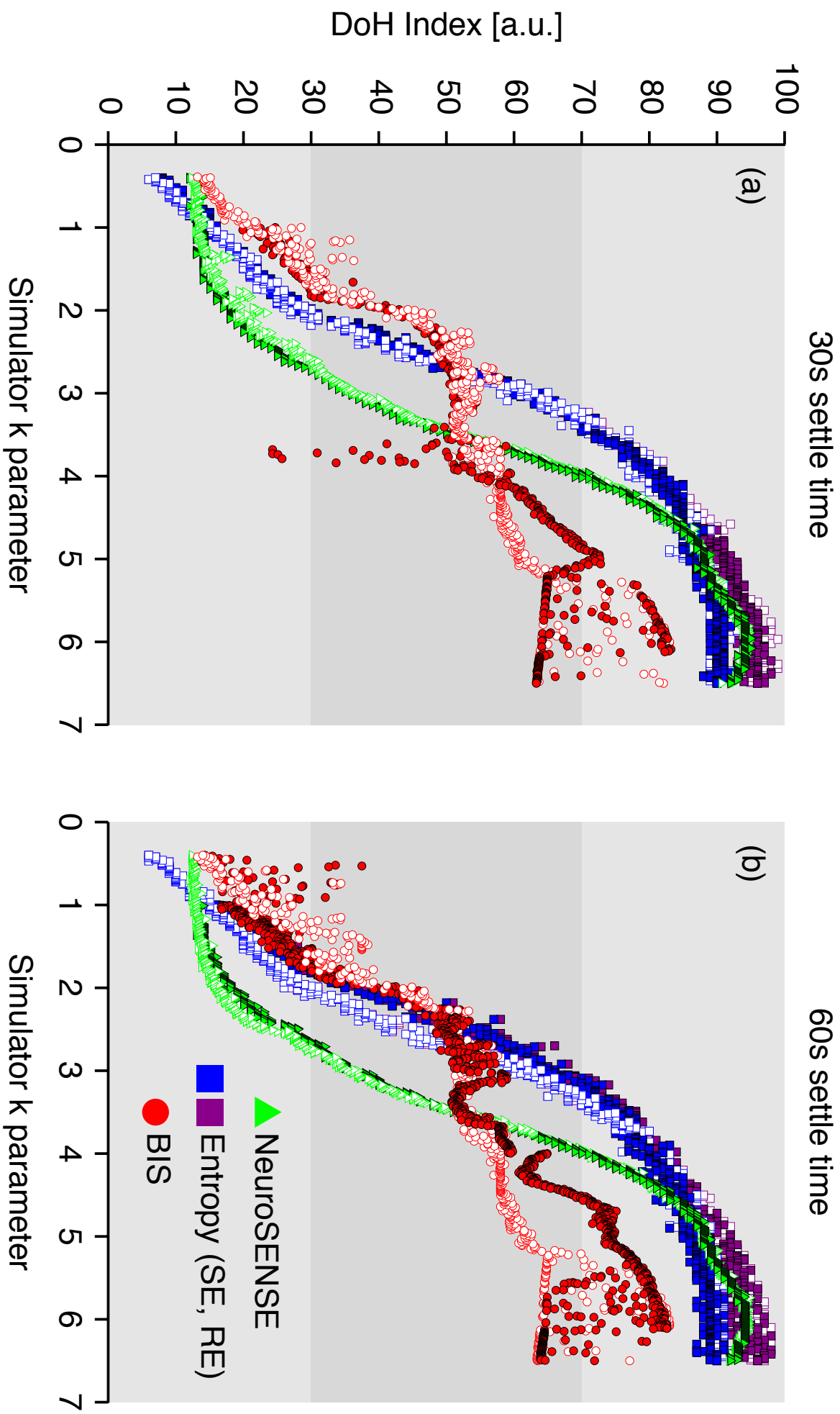


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Digital SPDIF encoded  
bilateral signal      Linear Power Supply





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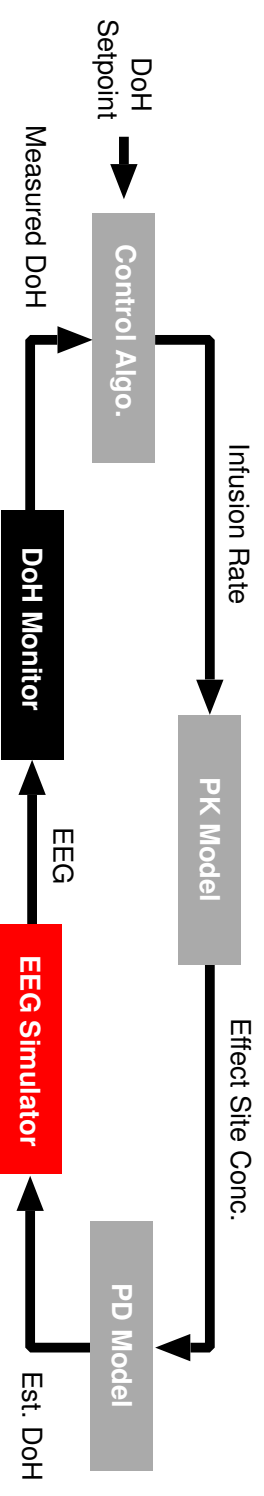
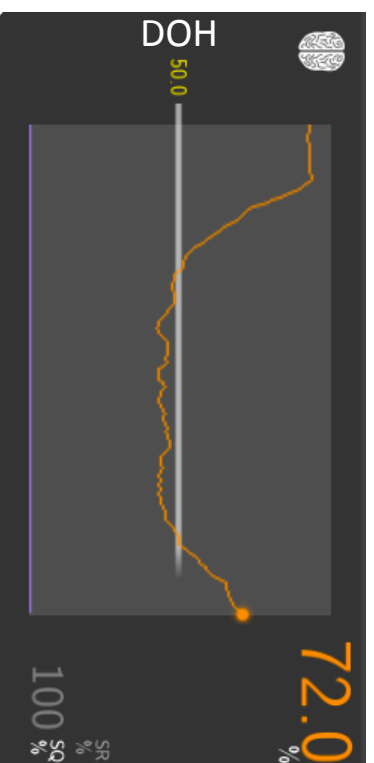
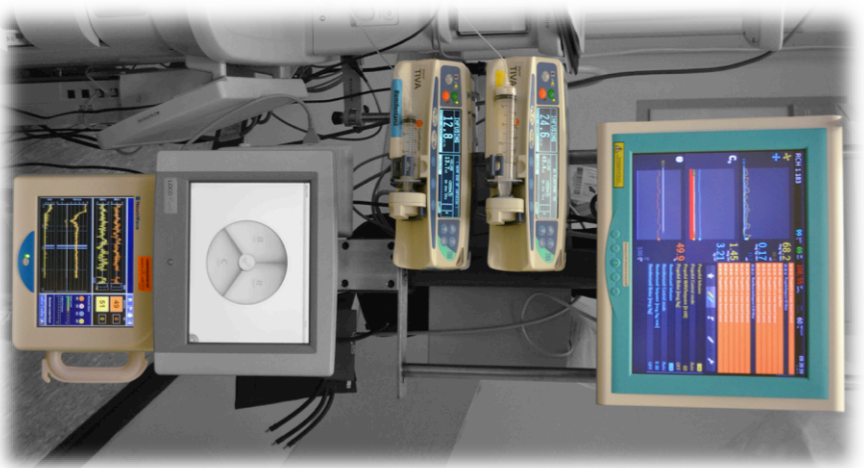
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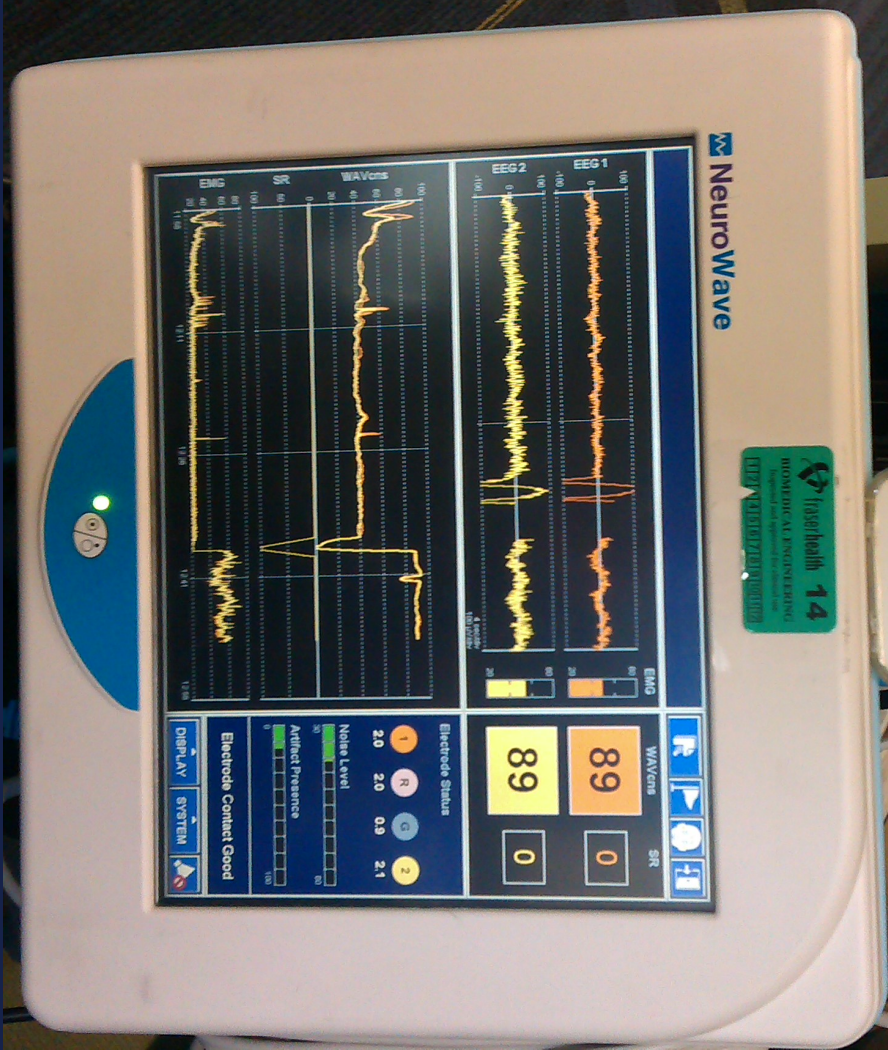


# Closed-Loop Simulations

Single-valued response profile allows hardware-in-the-loop simulations!

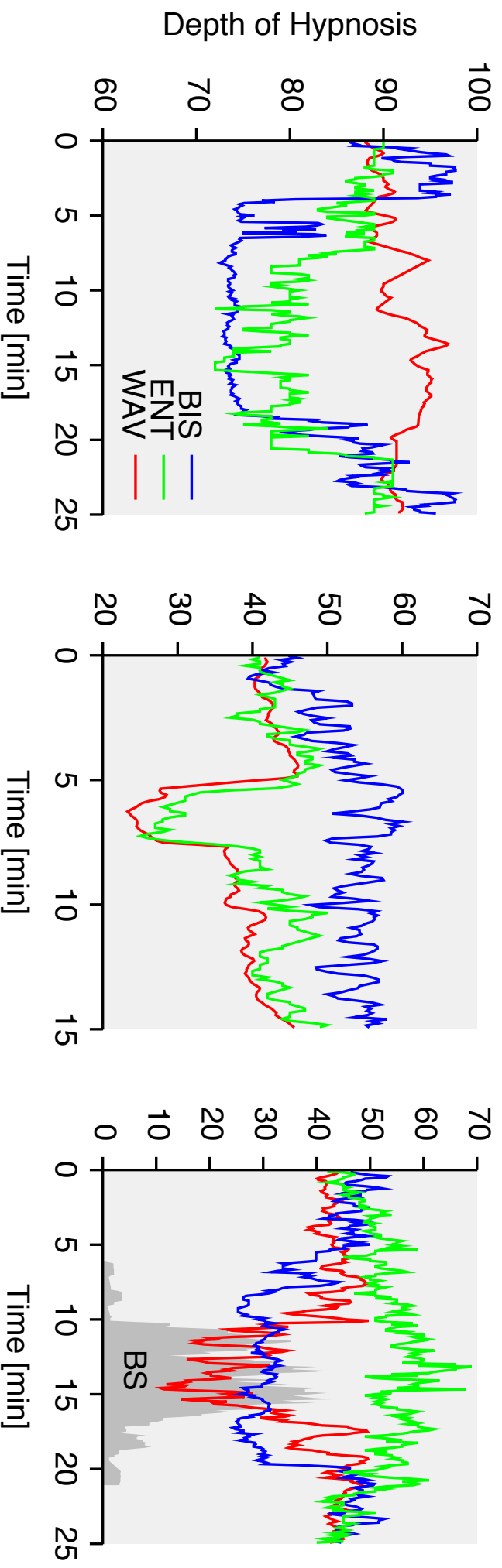


Petersen CL, Görge M, Ansermino JM, Dumont GA  
 Simulating Dynamic Hypnotic Drug Effects with an EEG Anesthesia Simulator  
 6th NWAC World Anesthesia Convention, Vancouver, BC, April 29 – May 2 2015



# Replay Epochs

- Monitors can intermittently disagree!



Epochs of Clinically Relevant Disagreements in Depth of Hypnosis Monitors Observed by Replay of the Electroencephalogram

Petersen CL, Katz Z, G6rges M, West N, Dumont GA, Ansermino JM  
STA Annual Meeting, January 2016, Palm Beach, FL



# Replay Statistics

- 40,241 DoH samples (0.2Hz)

| DES     | Bias    | RMS     | TIVA    | Bias   | RMS     |
|---------|---------|---------|---------|--------|---------|
| WAV-BIS | 0.0293  | 8.4282  | WAV-BIS | 0.2835 | 7.2529  |
| WAV-ENT | -0.7486 | 11.6166 | WAV-ENT | 1.1113 | 10.2531 |
| BIS-ENT | -1.0717 | 12.0658 | BIS-ENT | 0.5957 | 11.2951 |

- Minimal bias overall, but prolonged periods of substantial disagreement?

A Systematic Comparison of Depth of Hypnosis Indices during Intravenous and Volatile Anesthesia by Electroencephalogram Replay

Petersen CL, Katz Z, Görges M, Dumont GA, Ansermino JM  
STA Annual Meeting, January 2016, Palm Beach, FL



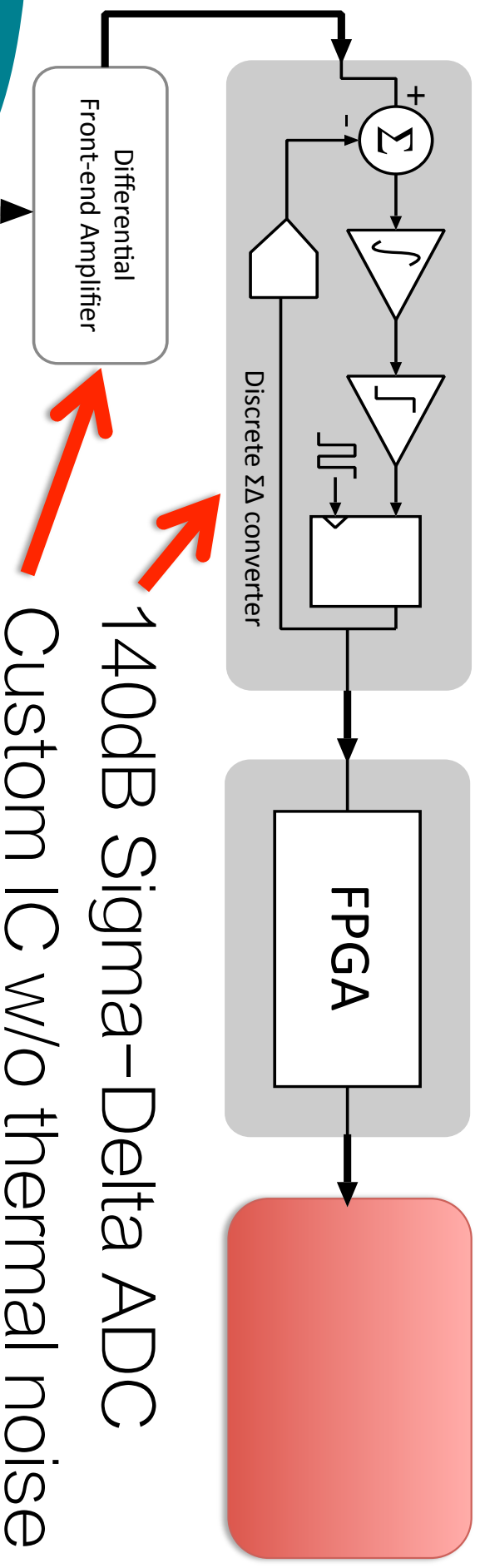
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# Future Work

- Burst Suppression
- High-Resolution EEG



Towards an Ultra-High Resolution Signal Converter for Electroencephalogram Monitoring  
 Petersen CL, Mallinson M, Venn R, Dumont GA, Ansermino JM  
 STA Annual Meeting, January 2016, Palm Beach, FL

# Summary

- New EEG monitor test signal concept
  - Audio-based simulation & replay
- Differences in EEG monitor response
  - Linearity, offset, hysteresis?
  - Large intermittent disagreements
- More work needed!



# Thank You!

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