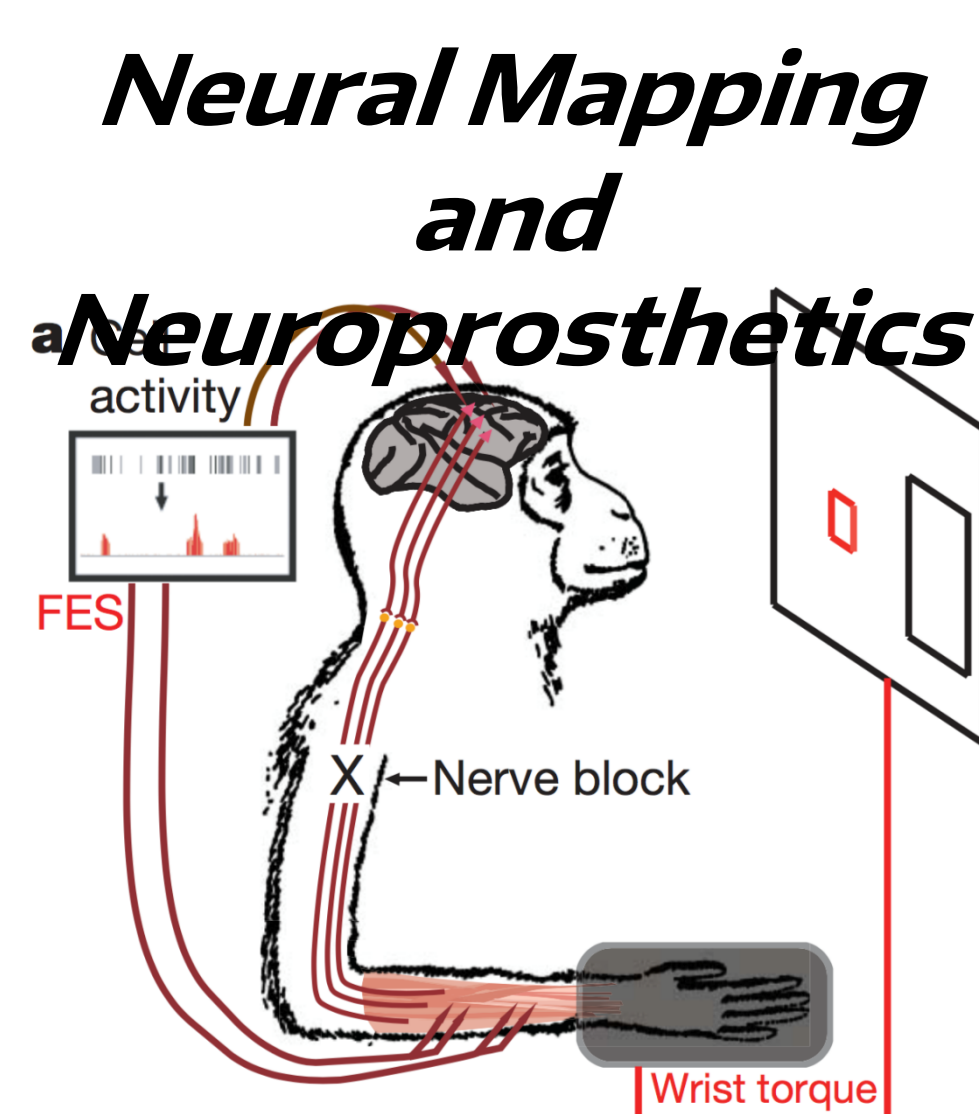


Bidirectional Brain-Computer Interfaces

- BBCIs allow investigation of the nervous system and treatment of neurophysiological disorders.



Direct limb control via single-unit-activity-triggered FES

C. Moritz, S. Perlmutter, E. Fetz; Nature 2008

- Electrical stimulation forces neurons to fire.
- Electrical recording interprets natural neural signals.
- Requires digital processing and high stimulation power.

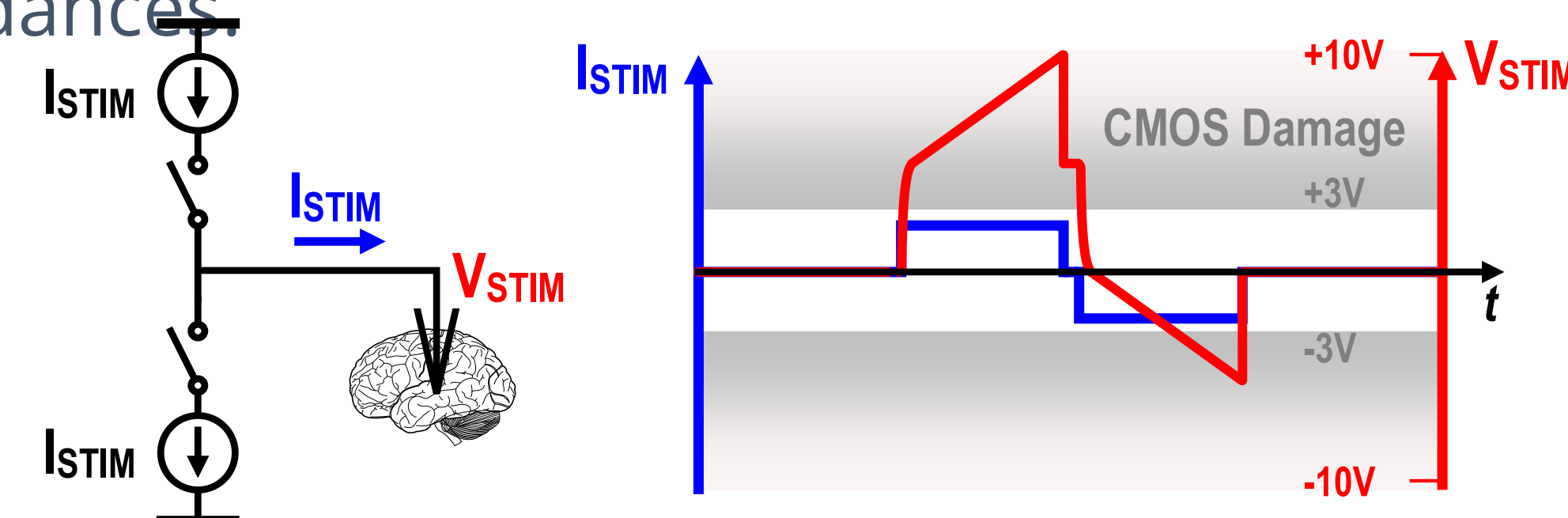
Therapeutic Deep Brain Stimulation



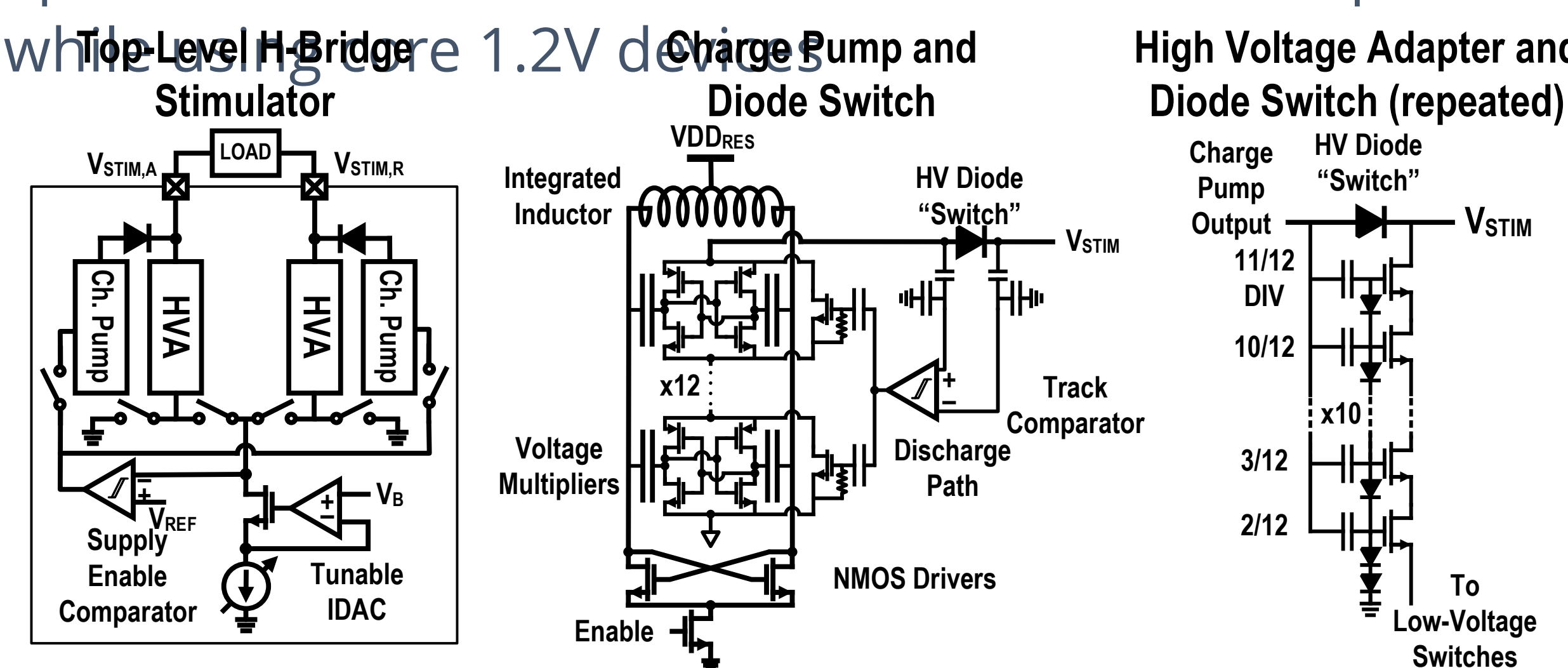
Can Treat: Parkinsons, Essential Tremor, Dystonia, Depression, OCD

High-Voltage Stimulation in Low-Voltage CMOS

- Stimulation pulses range from 10 μ A to several mA.
- Creates large voltages when driving large electrode impedances

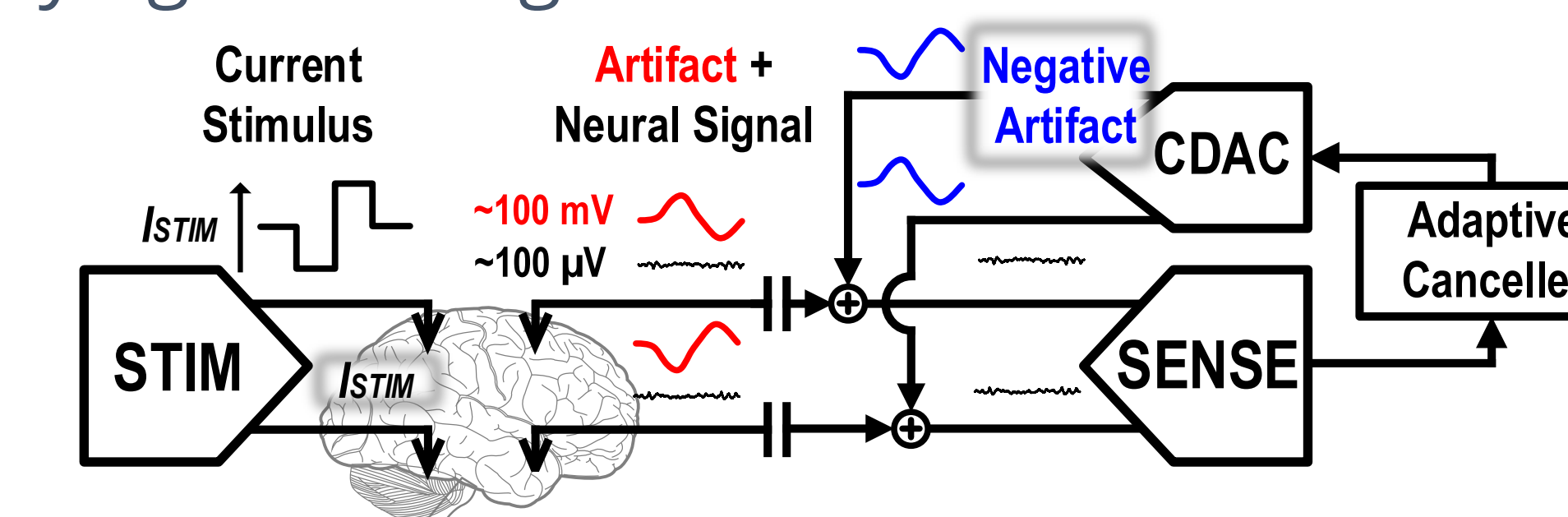


- Low-voltage CMOS is preferable for fast and efficient digital
- Specialized stacked circuits allow stimulator outputs of 12V while the core is 1.2V

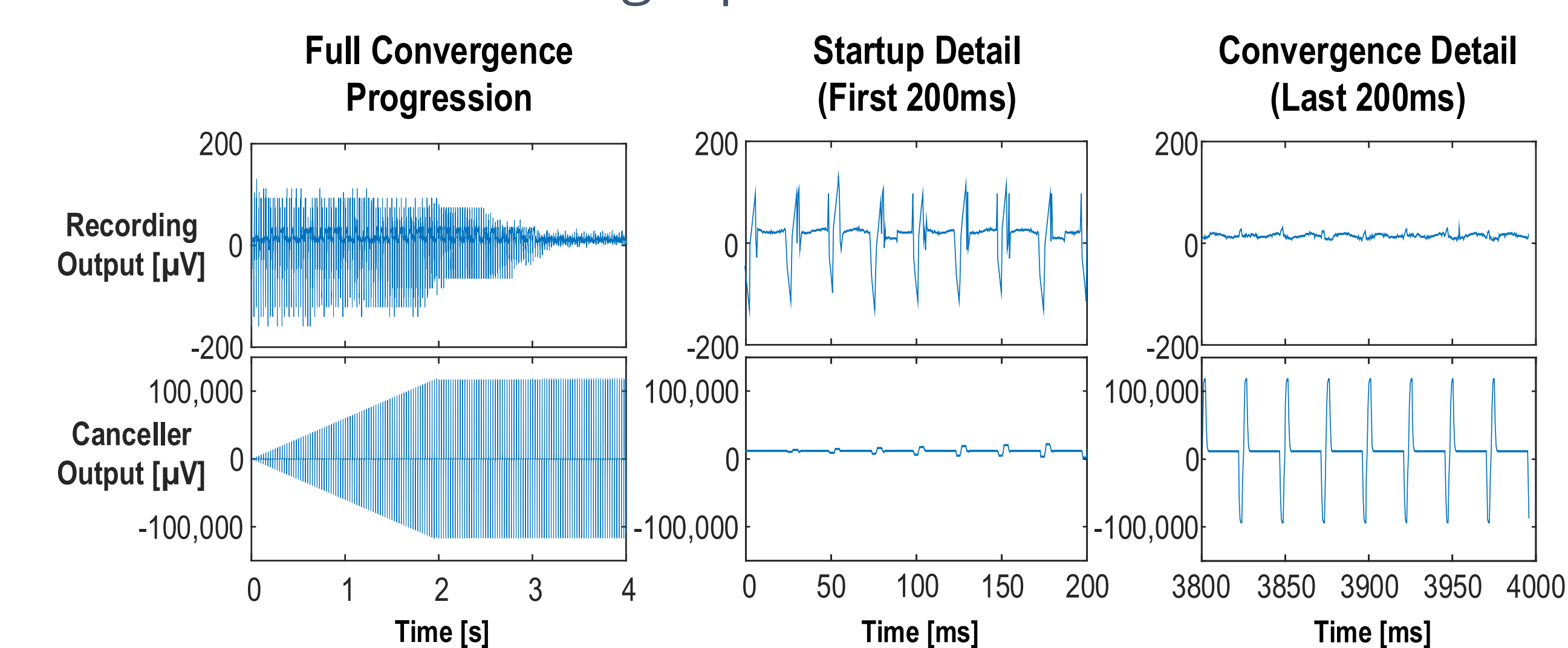


Stimulus Artifact Cancellation

- Stimulation energy jams connected recording systems.
- Large (10mV), prolonged (10ms) voltage artifacts obscure underlying recording data.

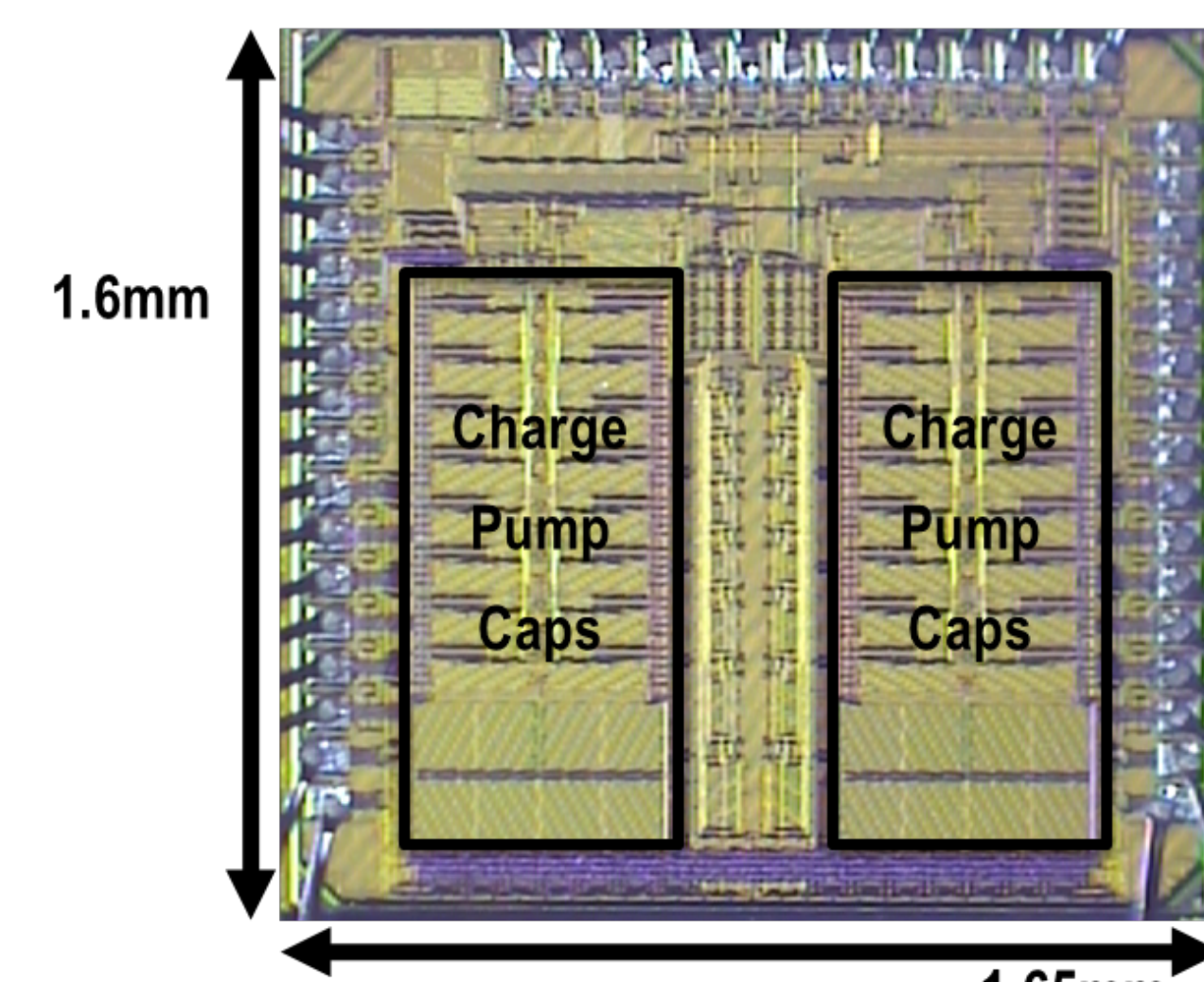


- Using the recording (SENSE) output, on-chip digital learns the artifact shape through iterative voltage subtraction at the sensitive recording input.



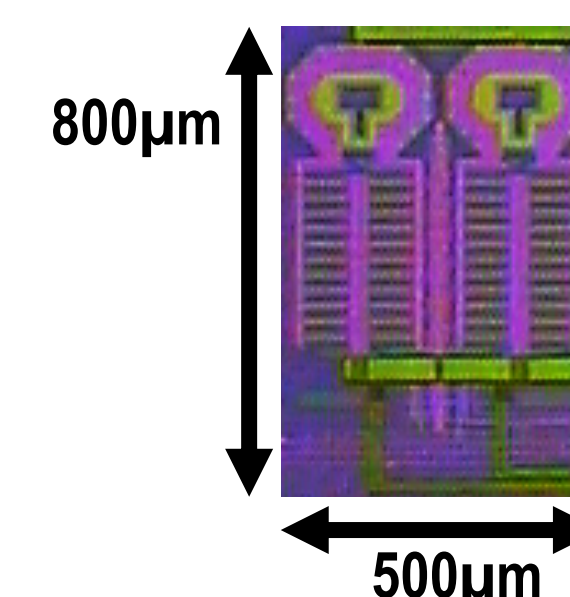
Miniaturizing with Resonant Charge Pumps

- Previous work with 100MHz-clock charge pumps required 2.56mm² for **ONE** stimulator channel



Pepin, et.al. ESSCIRC 2016

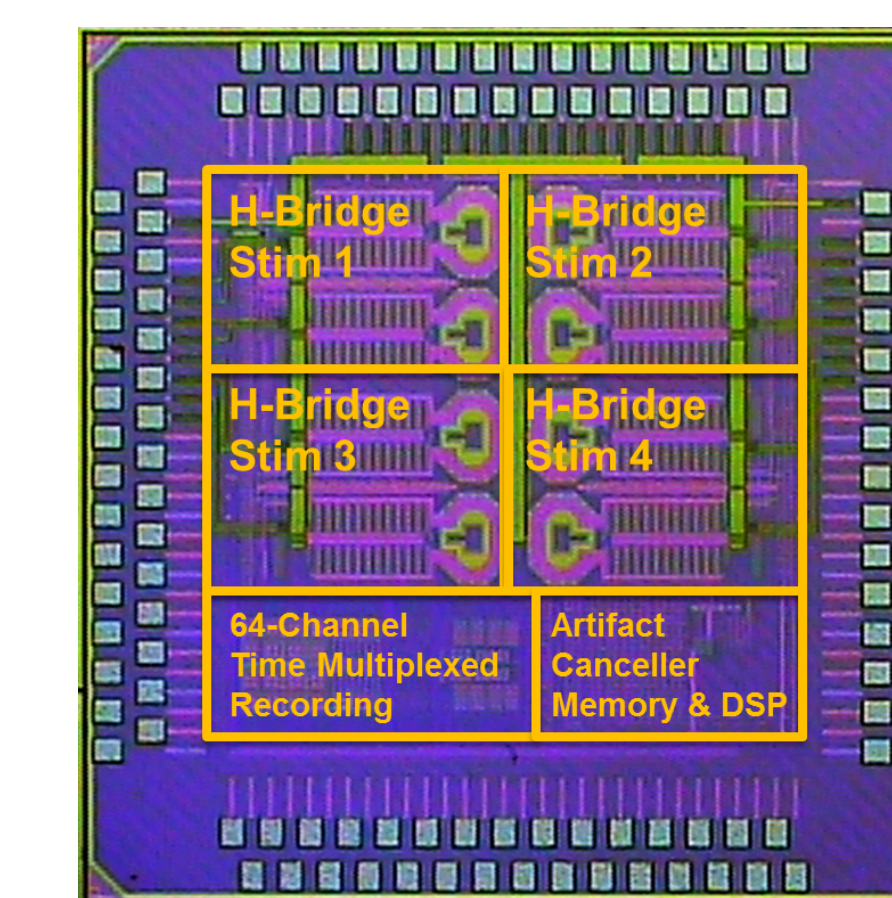
- This work achieves equal power output in 0.4mm² with 3GHz clocks and integrated inductors**



Fully Integrated Bidirectional Interface in 65nm CMOS

65nm CMOS Test Chip Includes:

- 4-Channel 12V, 2mA Max STIM
- 64-Channel 2kS/s Recording
- Real-time Adaptive Digital Artifact Cancellation



Future Work

- Productize test chip for use in research labs.
- Integrate circuit ideas in future Medtronic products.
- Published in ESSCIRC 2019 and to appear in JSSC 2020.