High-Channel Count Electrophysiology (HiCCE)

Kasun S. Mannatunga

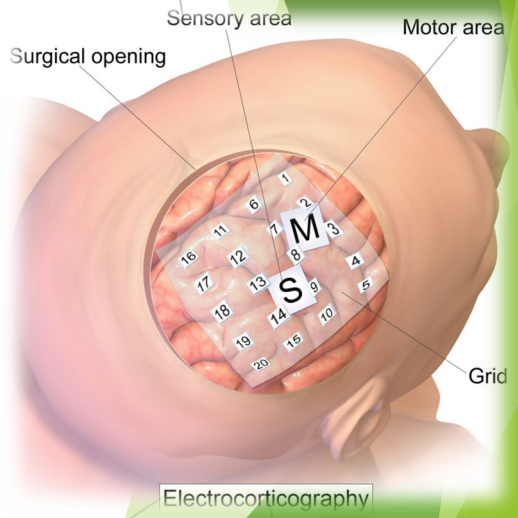
University of Sri Jayewardenepura

Sri Lanka

Electrophysiology

- The study of electrical signals originating in the activity of the nervous system called the electrophysiology.
- Neurons produce temporally localized electric discharges.
- These discharges can be captured,
  using non-invasive methods

https://en.wikipedia.org/wiki/Electrocorticography

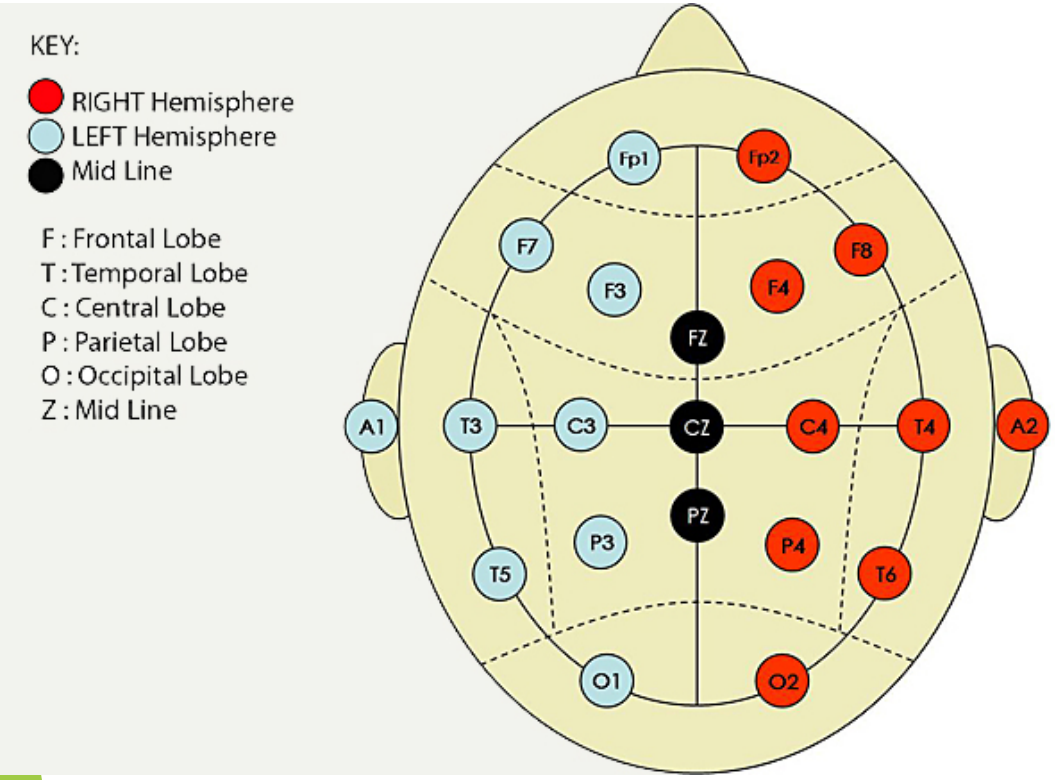


using invasive methods

http://www.psychologie.uzh.ch/fachrichtungen/plasti/Labor_en.html

Electrophysiology

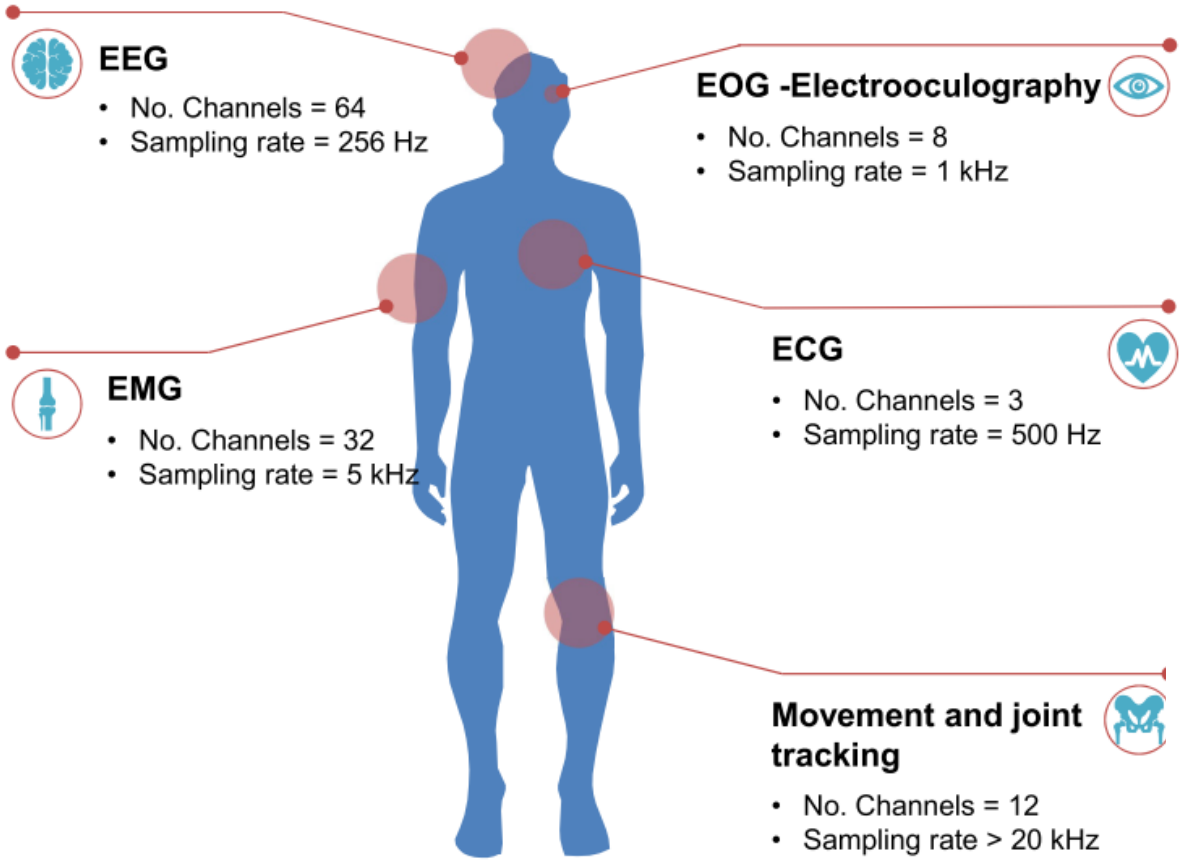
➢ Electroencephalography (EEG)



- EEG has been traditionally measured using the standard international 10-20 electrode system.
- The spatial resolution of the traditional 10-20 electrode system is not sufficient.

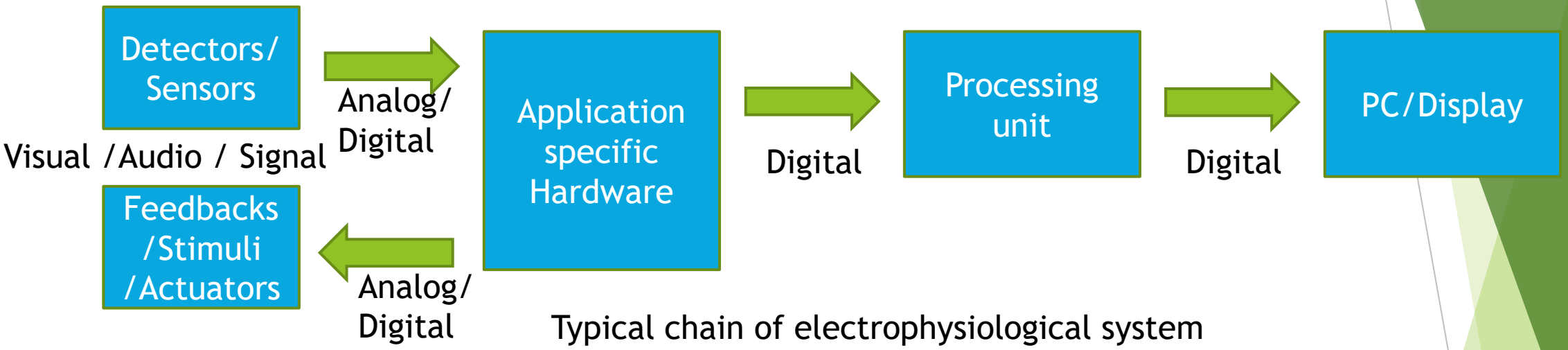
•This can be improved by recording from hundreds of sites using state-of-the-art probes.

Electrophysiology



Biopotential	Frequency range (Hz)	Amplitude range (mV)	No. of channels
Electrocardiogram (ECG)	0.05 – 150 (diagnostic) 0.5 – 40 (monitoring)	0.1 – 5	12 (in hospital) 3 (in field)
Electroencephalogram (EEG)	0.1 – 100	0.025 – 0.1	21 (10 – 20 system) 345 (10 – 5 system)
Electrocorticography (ECoG)	0.1 – 500	0.1 – 0.5	>500
Electromyography (EMG)	25 – 5000	0.1 – 100	<15

Electrophysiology



Typical chain of electrophysiological system

- Detectors/Sensors

  In electrophysiology, these are just electrodes.

- Feedbacks/Stimuli or actuators

  Visual/audio or digital responses

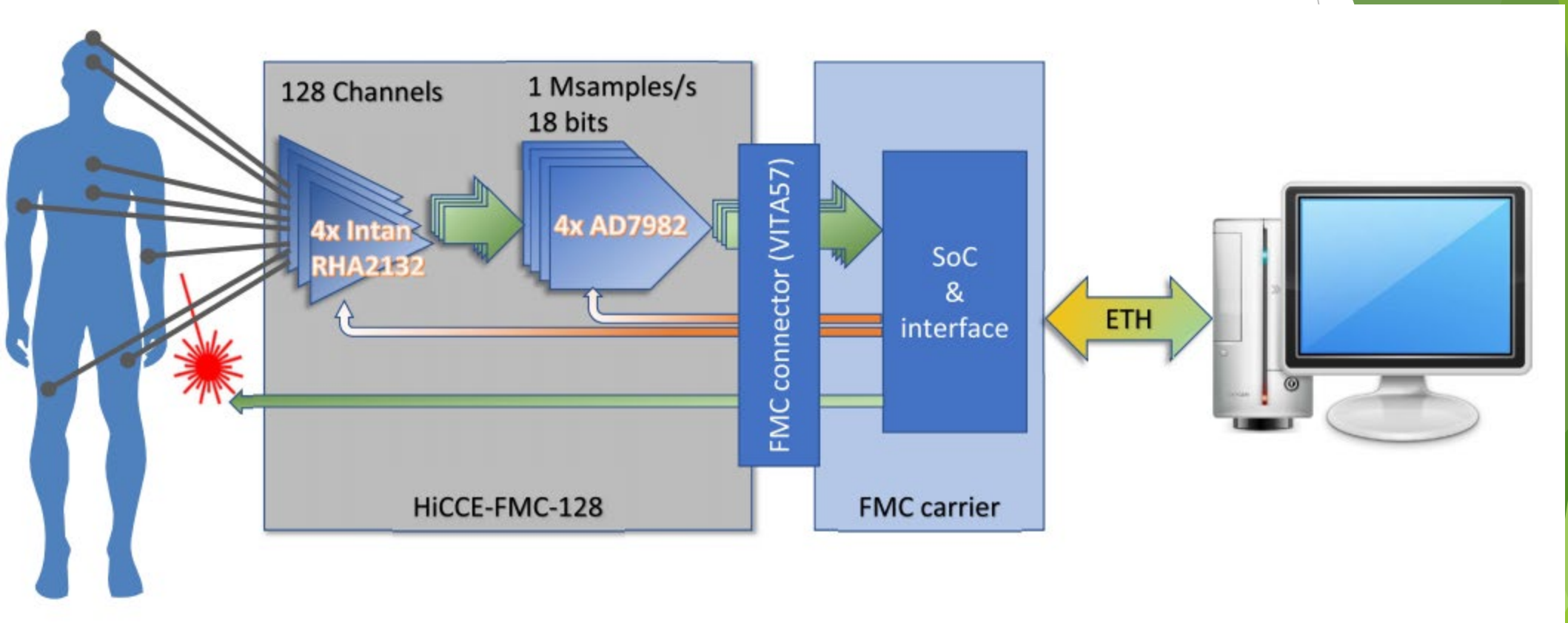
Commercial data acquisition systems

System	Max. Sampling Rate (SPS)	No. of Channels	Digital Output Resolution	Input Range (mV)	Noise Level (RMS)	Processor	Connectivity	CMRR	Price (€)
g.tec Nautilus [9]	500	64	24-bits	±187.5	<0.6 μV @ 1-30 Hz	TI DSP	Wireless 2.4 GHz/ USB 2.0	>90 dB	>4.5 k
g.tec HIamp [10]	38.4 k	256	24-bits	±340	<0.5 μV @ 1-30 Hz	TI DSP	USB 2.0	>90 dB	>31 k
TMSi Mobita [11]	2000	32	24-bits	±200	<0.4 μV @ 0.1-10 Hz	N/A	Wi-Fi IEEE 802.11 b/g	>100 dB	N/A
TMSi Refa [12]	2048	136	24-bits	±150	<1 μV @ 128 Hz	N/A	USB 2.0	>90 dB	N/A
Emotiv [13] EPOC Flex	128	32	14-bits	±4.12	N/A	N/A	Wireless proprietary 2.4 GHz	N/A	>2 k
BioSemi [14] ActiveTwo AD-box	16 k	256	24-bits	±262	<2 μV @ 16 kHz	N/A	USB 2.0	>90 dB	>40 k
ANT Neuro [15] eego mylab	16 k	256	24-bits	±50	<1 μV @ Lowest Freq.	N/A	USB 2.0	>100 dB	>25 k
Brain Products [16] actiCHamp	25 k	168	24-bits	±400	<2 μV @ 0-35 Hz	N/A	USB 2.0	>100dB	>25 k

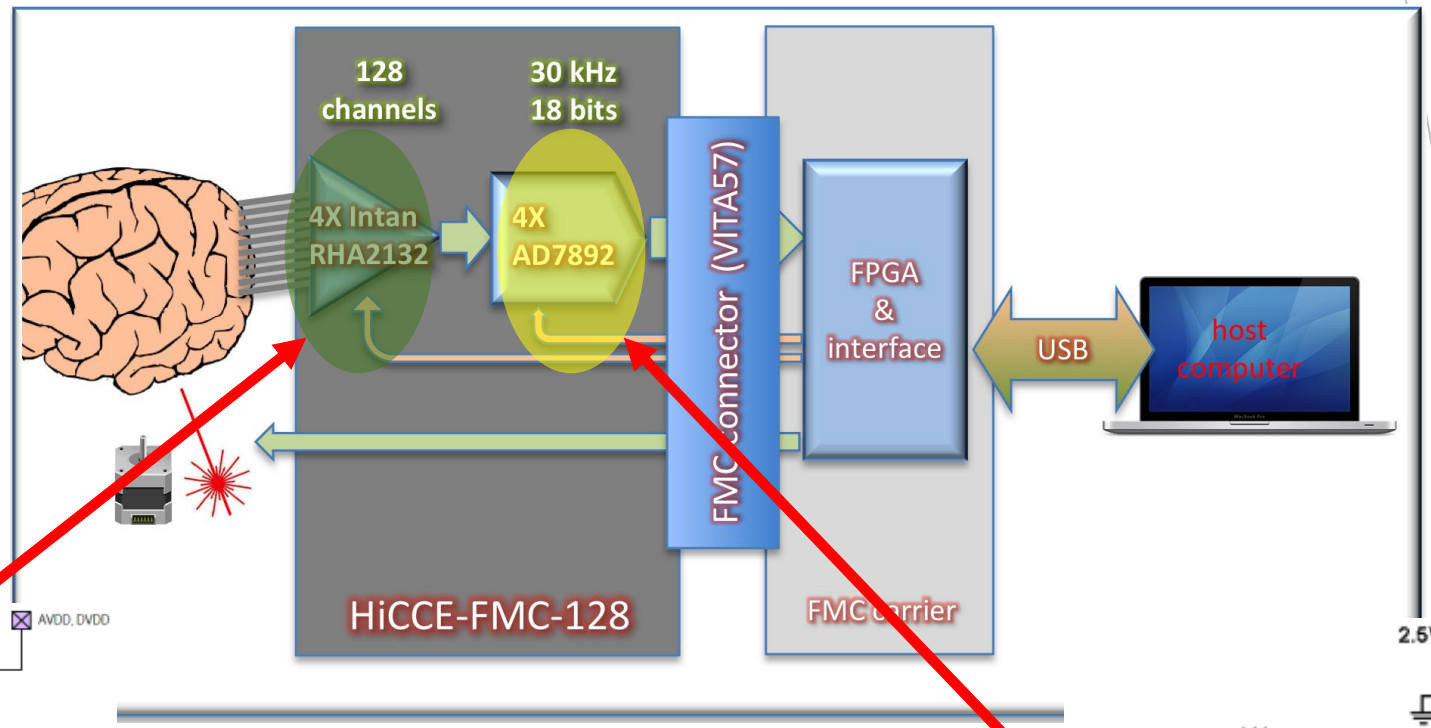
Non-commercial solutions

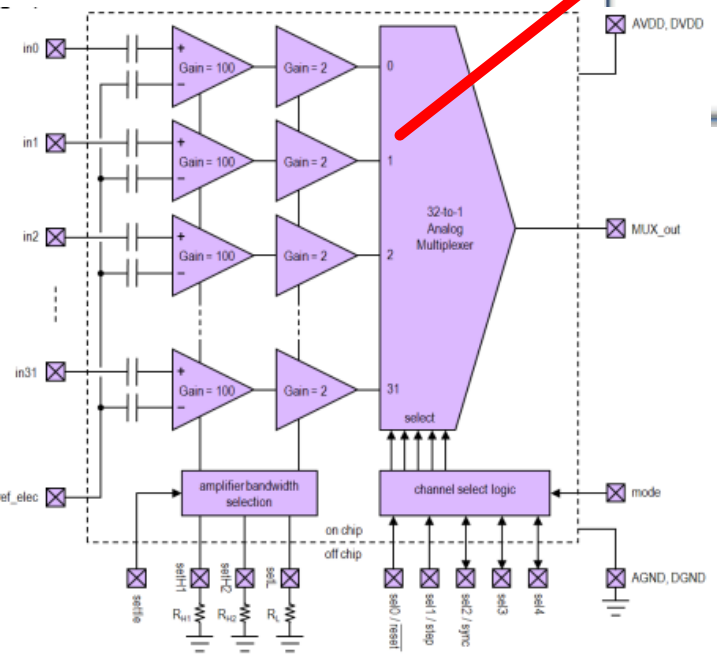
Property	Proposed system	Pinho et al. [21]	Feng et al. [22]	Vo et al. [23]	Wild et al. [24]	Nathan et al. [25]	Shyu et al. [26], [28]	Khurana et al. [27]	Annese et al. [7]
Modular	Yes	No	No	Yes	No	No	No	No	No
Channels	128	32	16	8	4	16	2	N/A	16
Sampling frequency, Hz	31.25k	1000	1024	250	250	N/A	8k	250	500
ADC number of bits	18	24	24	24	24	24	12	N/A	16/24
Connectivity	Ethernet	Wi-Fi 802.11 b/g/n	Wi-Fi 802.11 b/g/n	Bluetooth	Bluetooth	Bluetooth	413 MHz RF	Ethernet	N/A
Processing device	Xilinx Zynq 7020	Texas Instruments DM3730	BeagleBone Black	ST Microelectronics STM32F4	Microchip ATmega328p	Texas Instruments MSP430	Altera Cyclone II FPGA	Xilinx Spartan 3E FPGA	Altera Cyclone V FPGA
CMRR, dB	-81	-115	N/A	-110	-110	-110	130	N/A	N/A
Local processing[a]	Yes	Yes	No	No	No	No	Yes	Yes	Yes

HiCCE cont…


128 Channels
1 Msamples/s
18 bits
4x Intan
RHA2132
4x AD7982
FMC connector (VITA57)
SoC
&
interface
ETH
HiCCE-FMC-128
FMC carrier

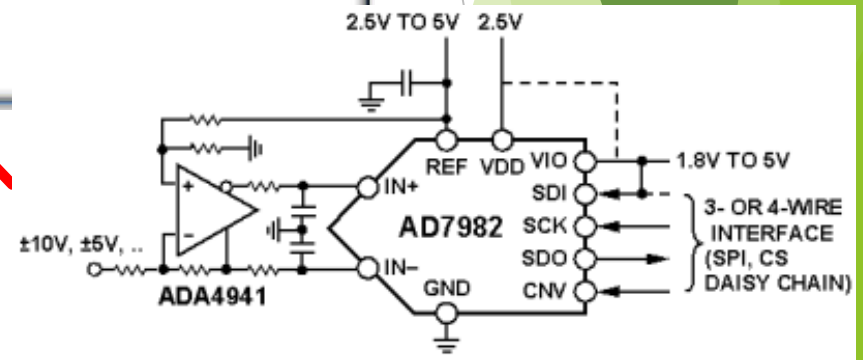
HiCCE Hardware





Intan RHA2132

- 32-channel multiplexing amplifier
- Has programmable band pass filter
- Can be individually addressed the channels



Analog Devices AD7982

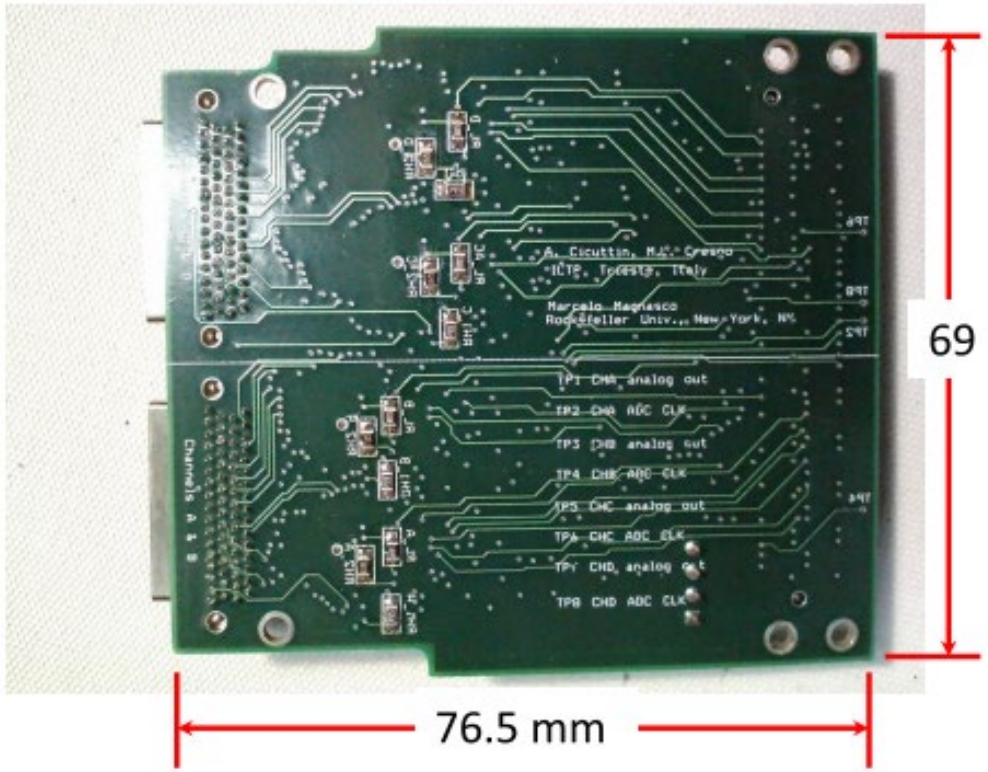
- 18 – bits Successive approximation
- 1 MS/s throughput
- Low power – 7 mW at 1 MS/s

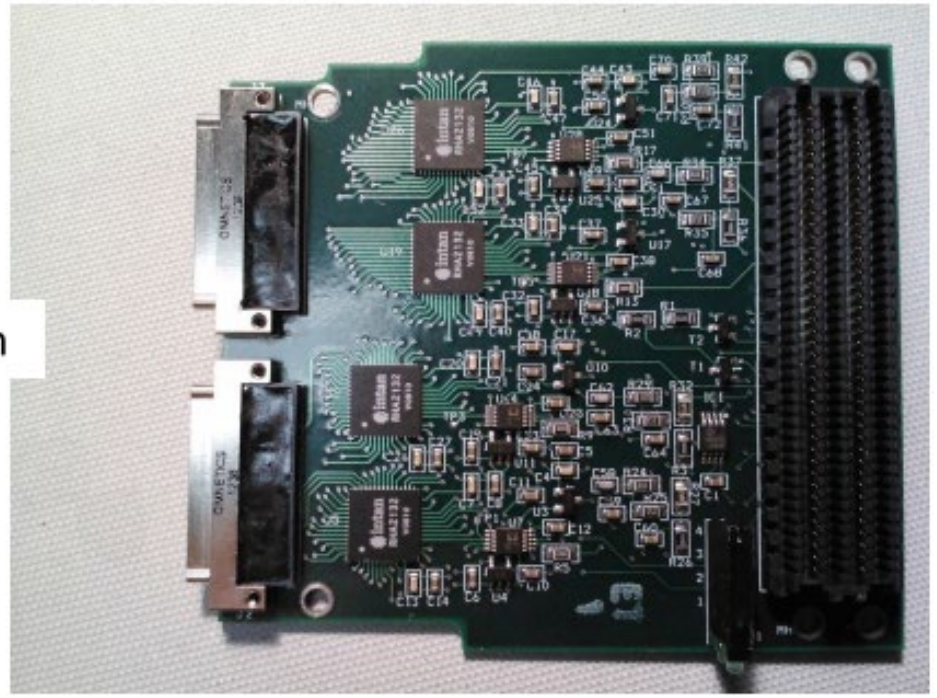
HiCCE Hardware

First prototype of the HiCCE

- 128 channels

- 31.25 kSamples per second on each channel





HiCCE Hardware

INPUT REFERRED NOISE

- The measured IRN is less than 5 μV for all channels and the average value is about 3 μV.

COMMON MODE REJECTION RATIO

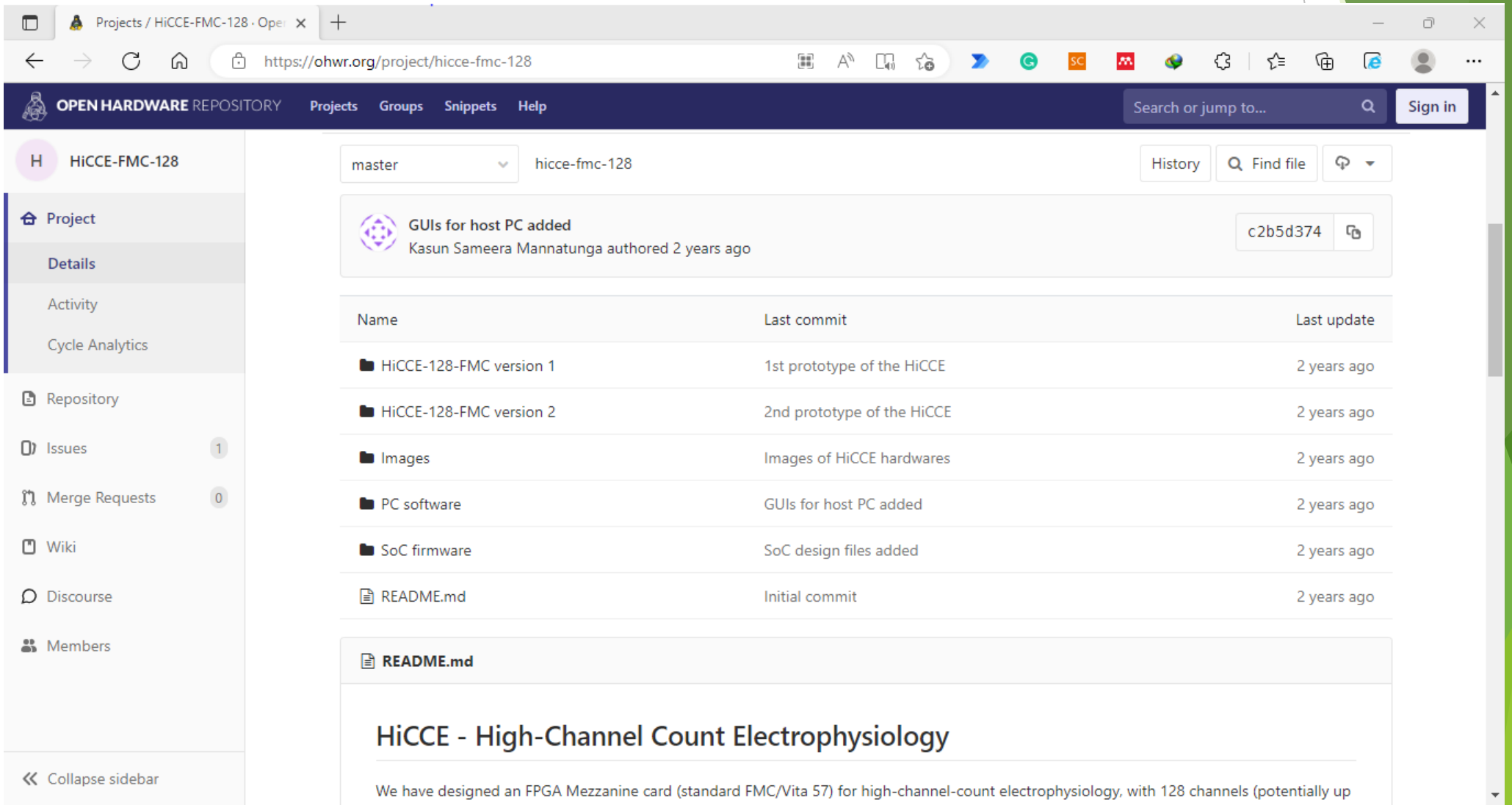
- The measured CMRR is about 82 dB.

ELECTRICAL CHARACTERISTICS

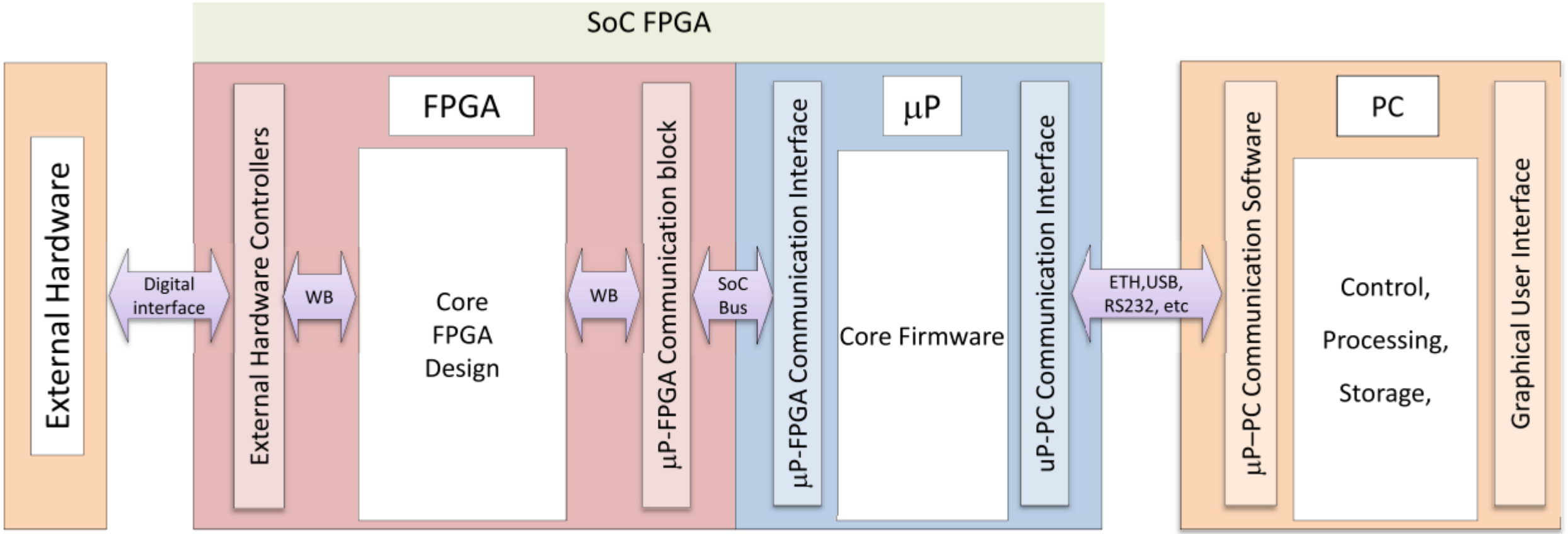
- Each channel has different baselines around 1.2376 V
- Spread in the range of approximately 20 mV, which is 100 µV referred to the analog input voltages

HiCCE-128 Repository

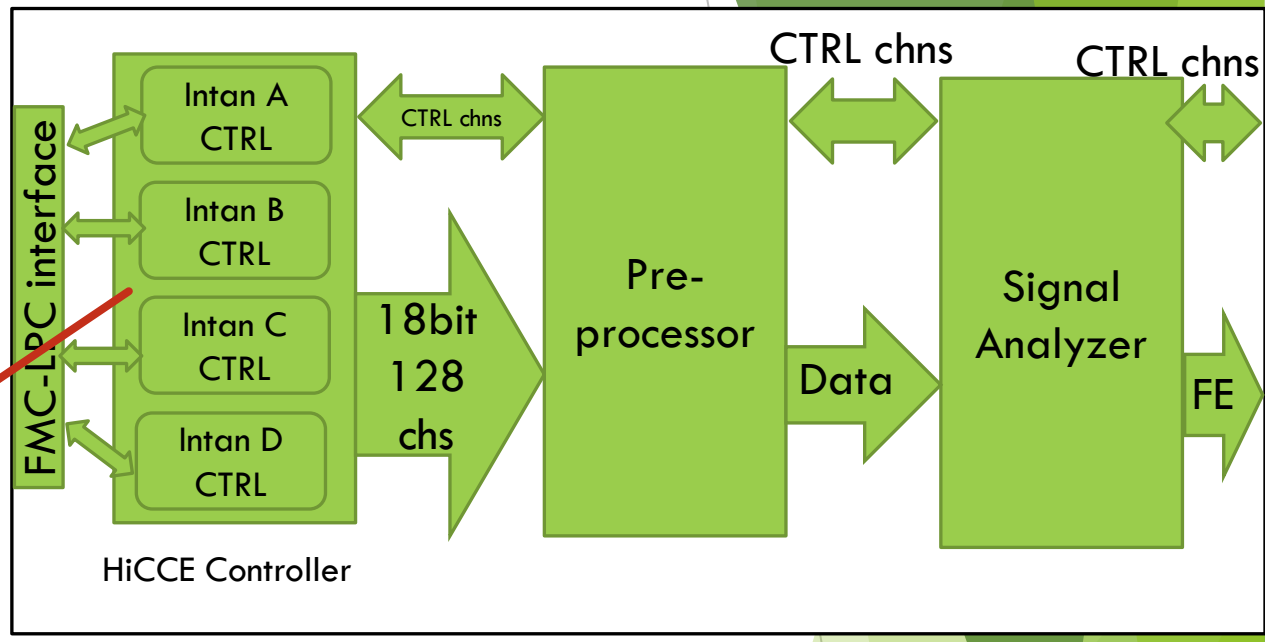
https://ohwr.org/project/hicce-fmc-128



Processing Unit



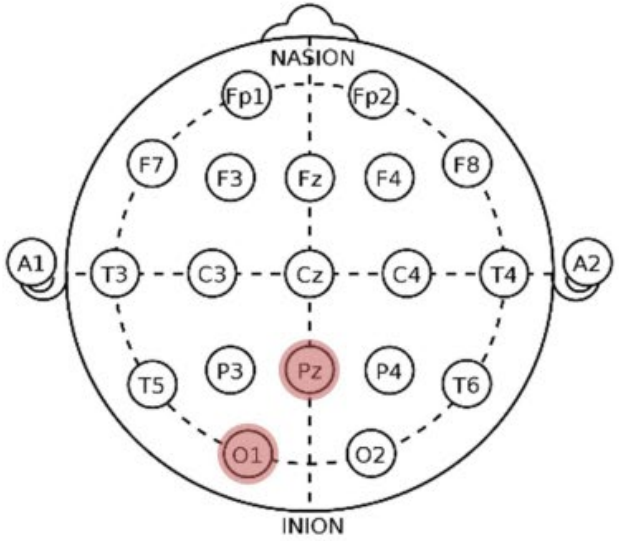
Application Specific IPs

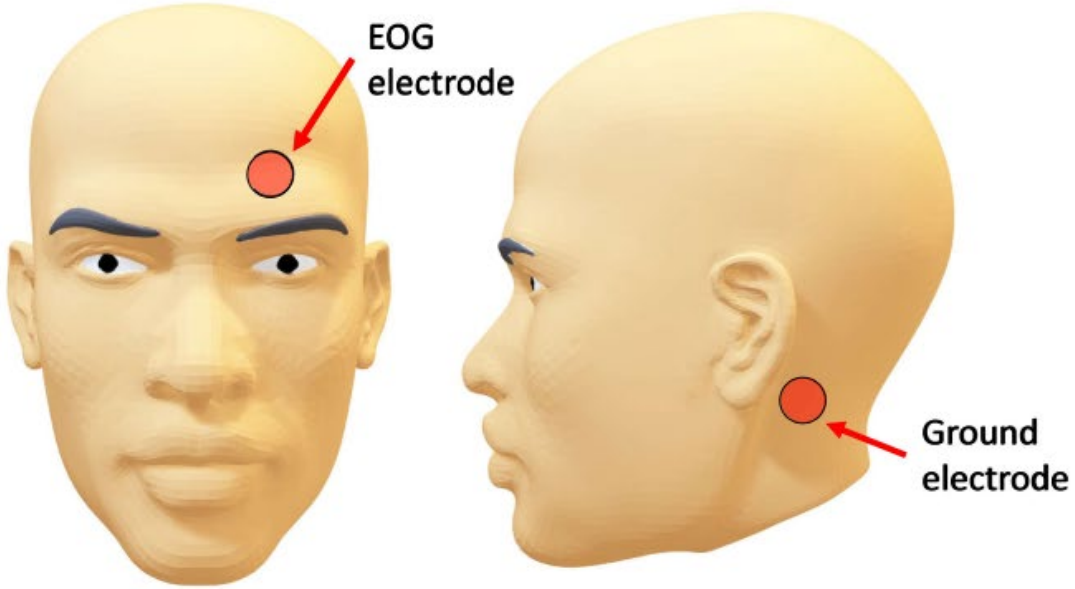


- HiCCE Controller
  - Controls individual intan chips and ADCs
    - Channel selection
    - Control sampling rate
  - Decimation
    - Change the data rate

HiCCE experimental tests

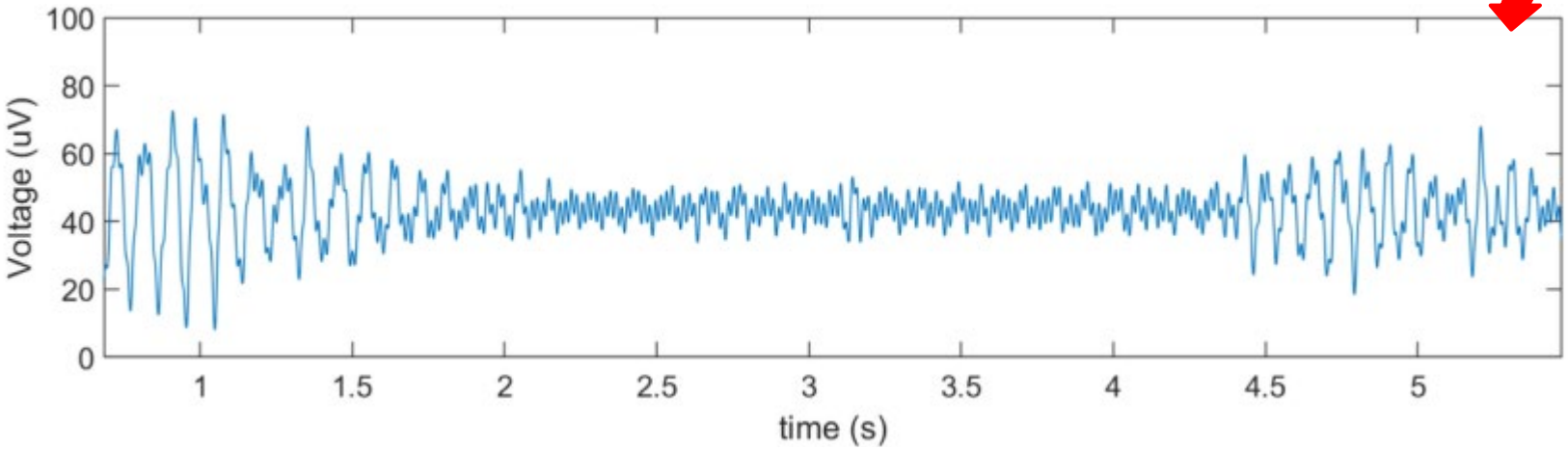
1. ALPHA WAVES AND EYE BLINKS

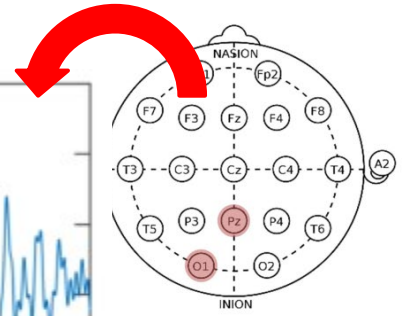


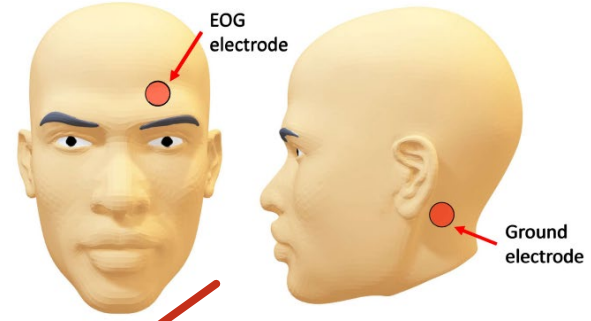


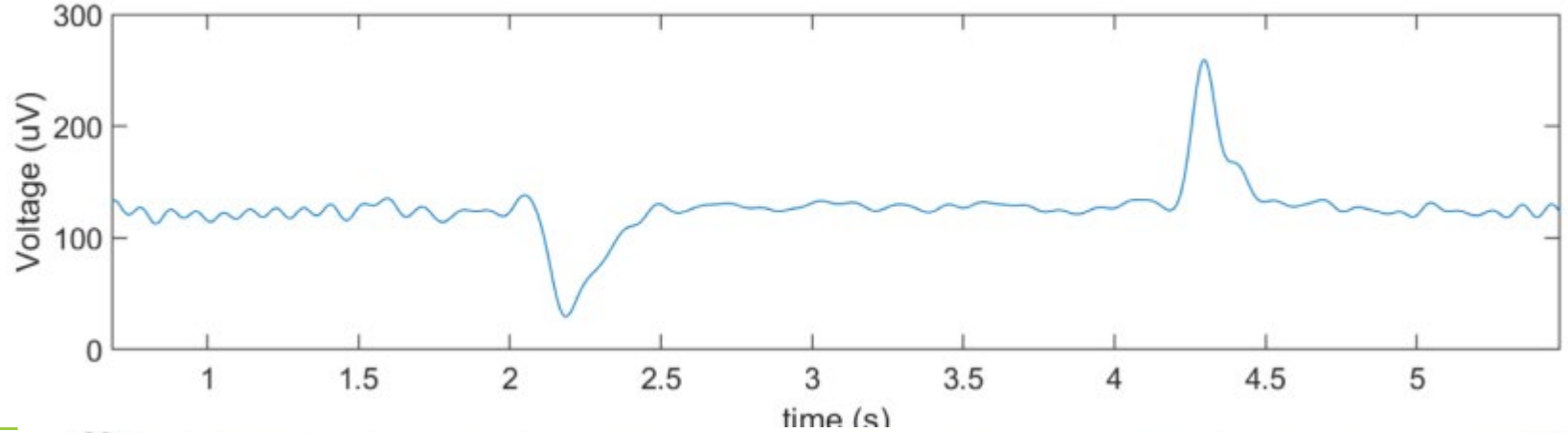
EEG recording - O1 occipital region
Reference - the Pz location
Ground - left earlobe

1. ALPHA WAVES AND EYE BLINKS

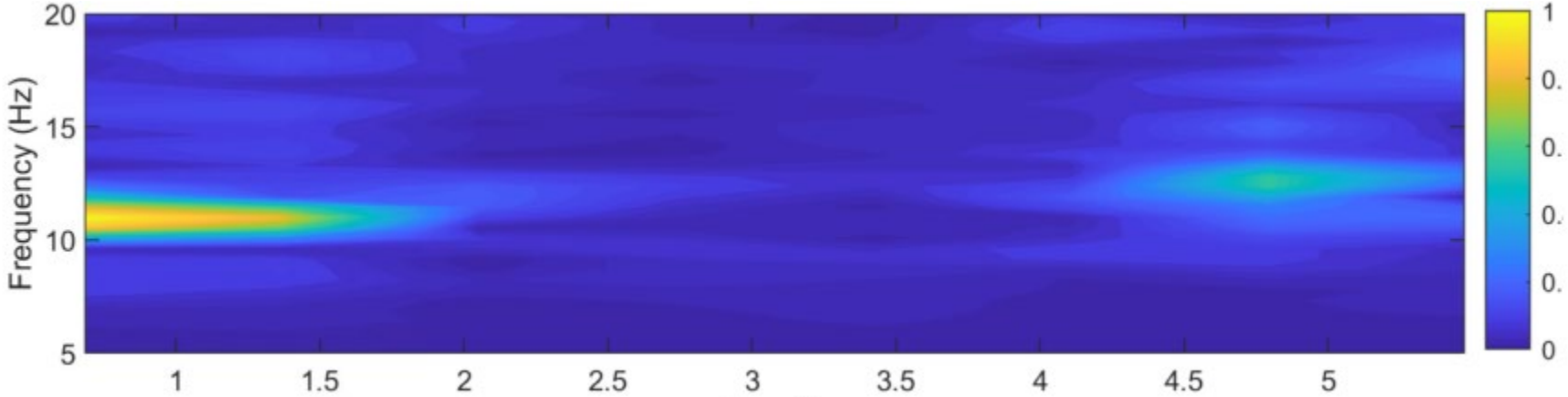






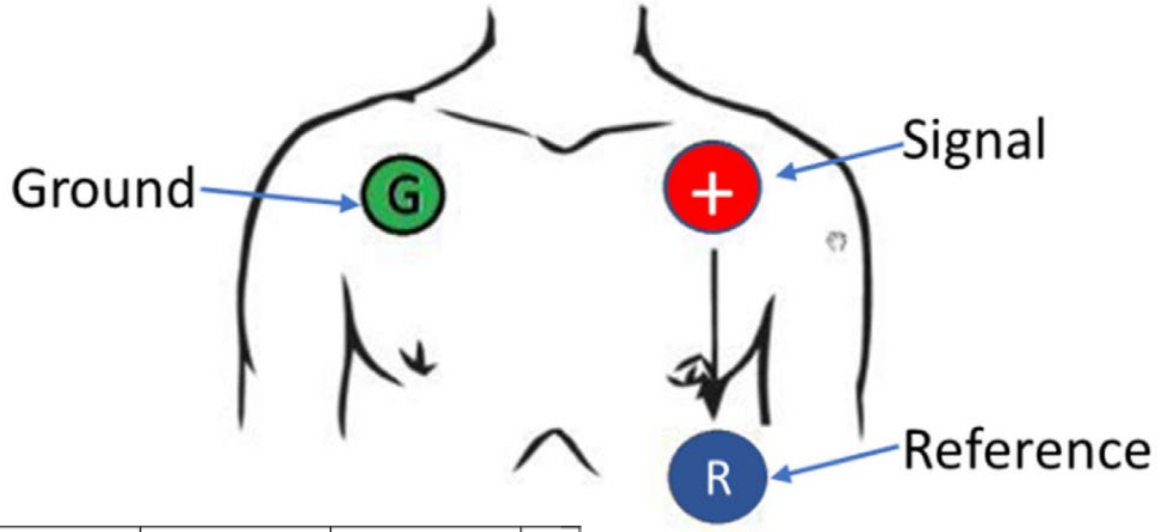


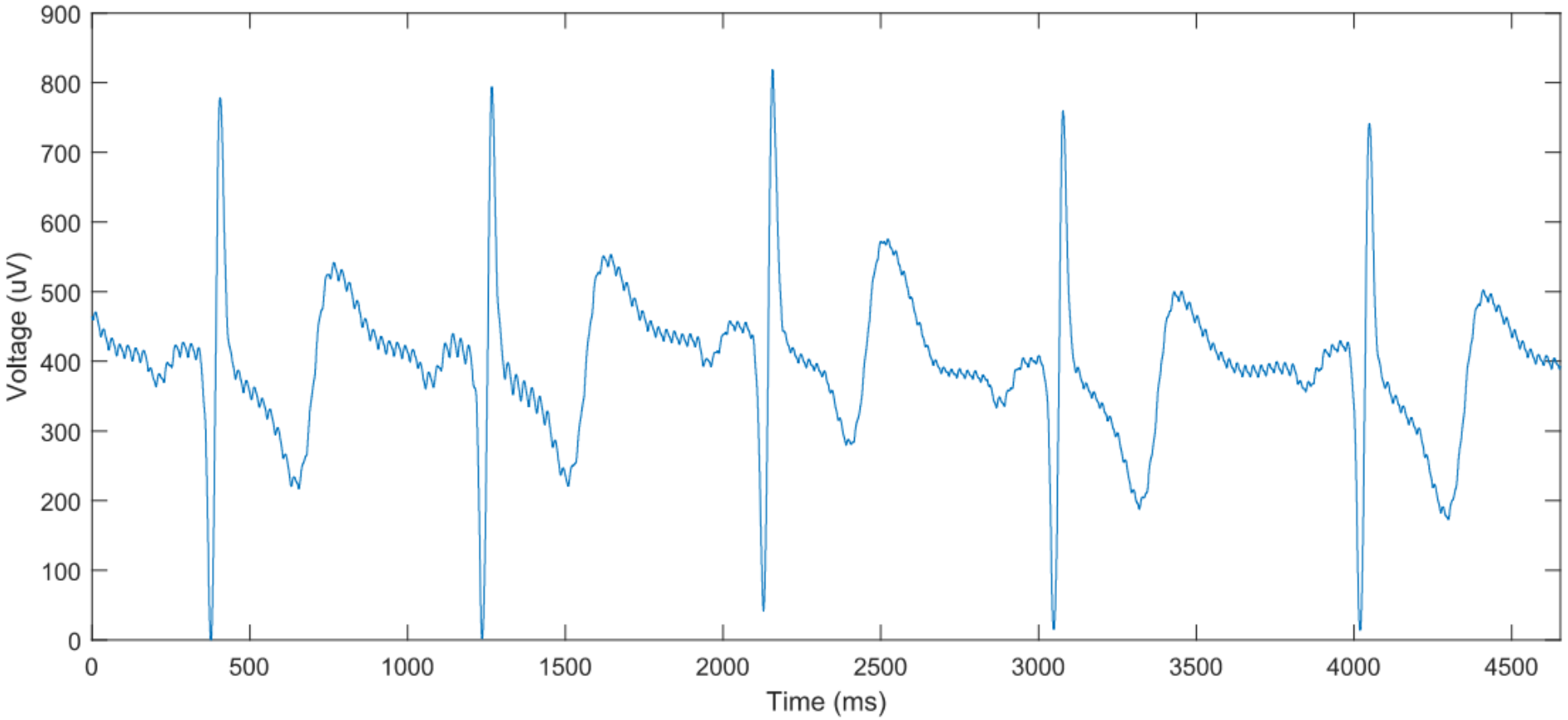
HiCCE experimental tests



HiCCE experimental tests

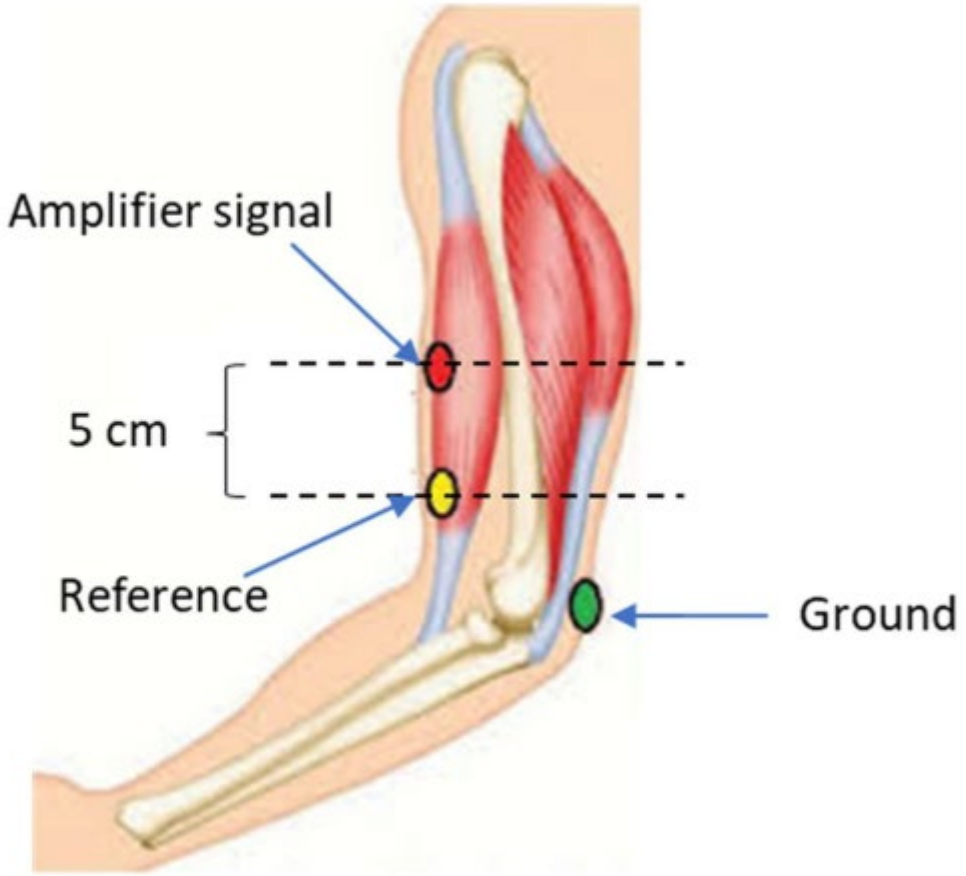
2. ECG SIGNAL ACQUISITION

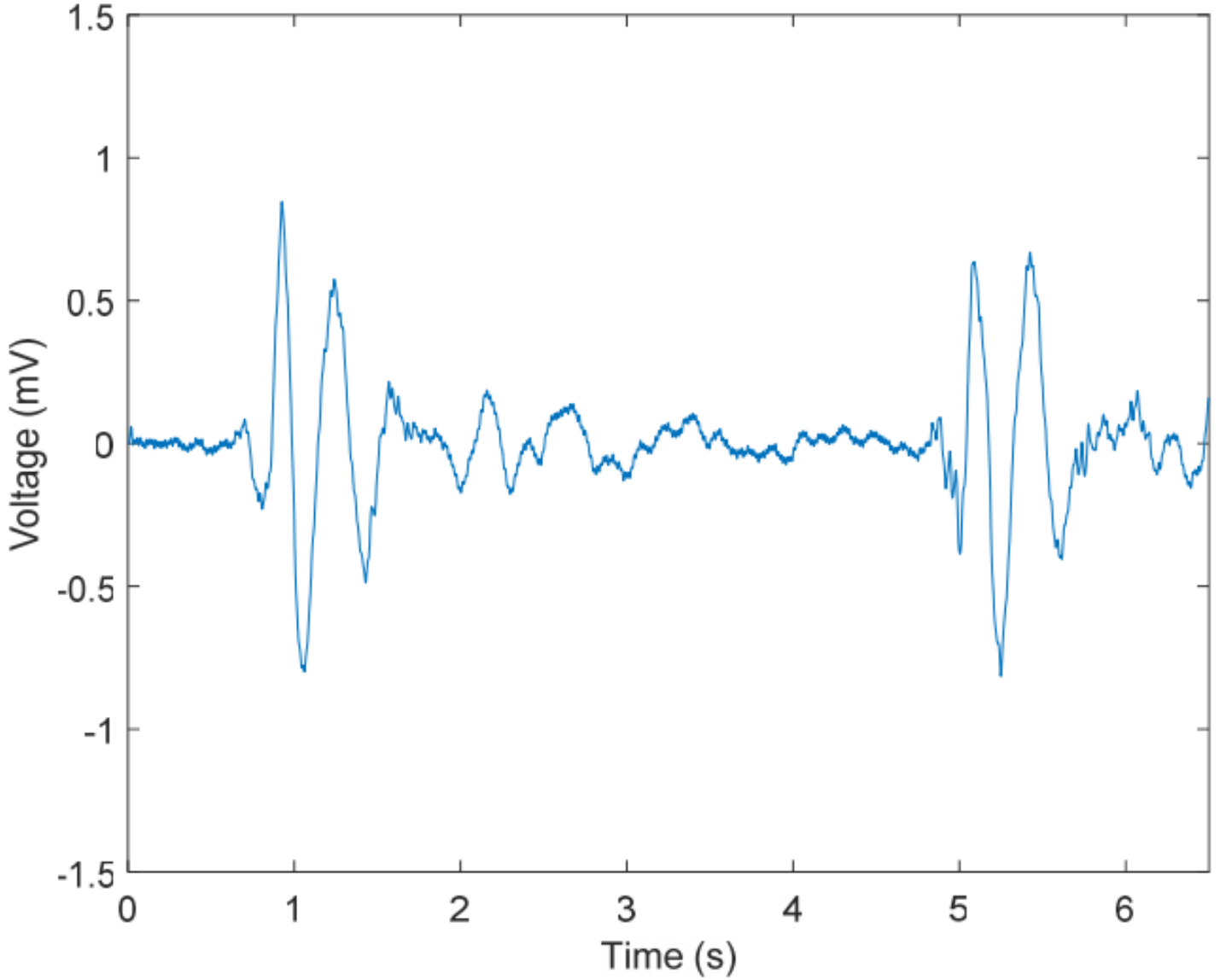




HiCCE experimental tests

3. EMG TEST





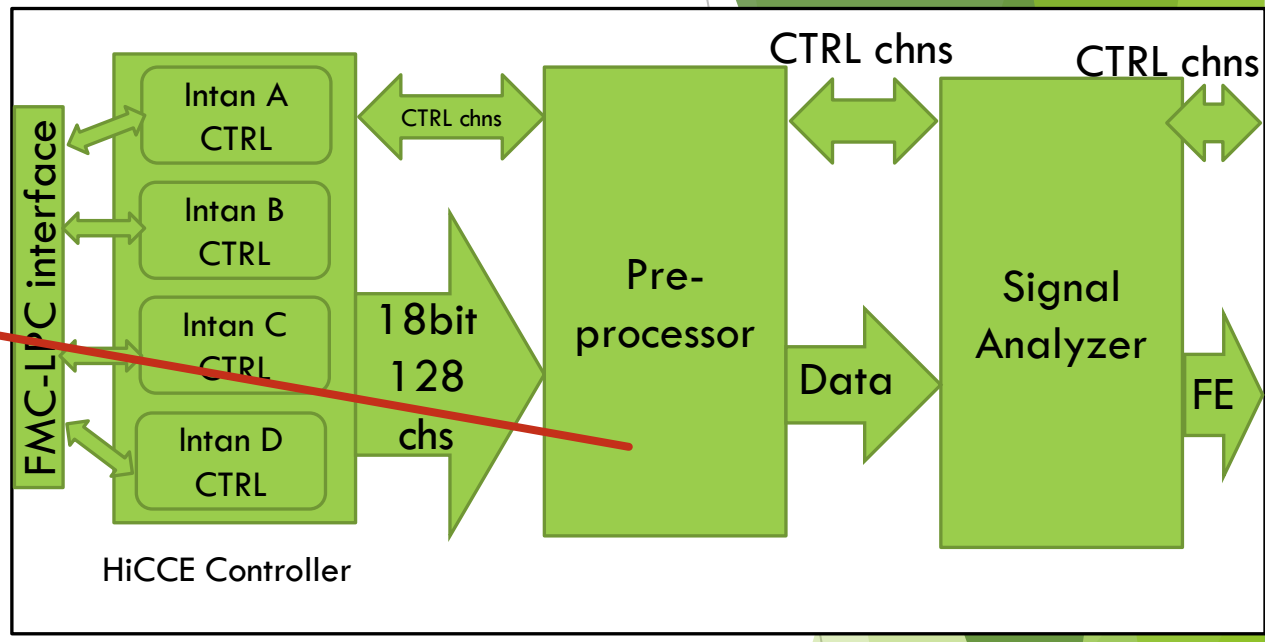
POWER USAGE

Resource		Power		
		(W)	(W)	(%)
FPGA Dynamic	CLOCK	0.013	0.036	2
	LOGIC	0.004		
	BRAM	0.014		
	DSP	0.000		
	PLL	0.000		
	MMCM	0.000		
	Other	0.000		
	IO	0.004		
FPGA Static		0.041	0.041	3
Processor Dynamic	LOGIC	0.348	1.390	91
	DDR	1.004		
	IO	0.038		
Processor Static		0.055	0.055	4
Total On-Chip Power			1.521	100

Condition	Voltage (mV)	Current (A)	Power (W)
Device static power	1.7	0.17	2.04
Total Power	2.4	0.24	2.85

Application Specific IPs

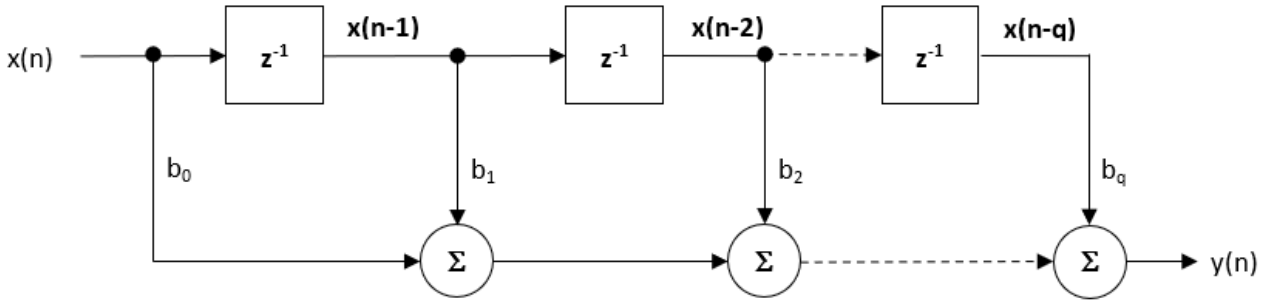
- Pre-processor
  - Remove Offset
  - Normalize all channels
  - Remove artifacts
  - filtering
    - Low Cutoff frequency = 0.5 Hz
    - High Cutoff frequency = 40 Hz
    - (suppression of Offset + power line interference)

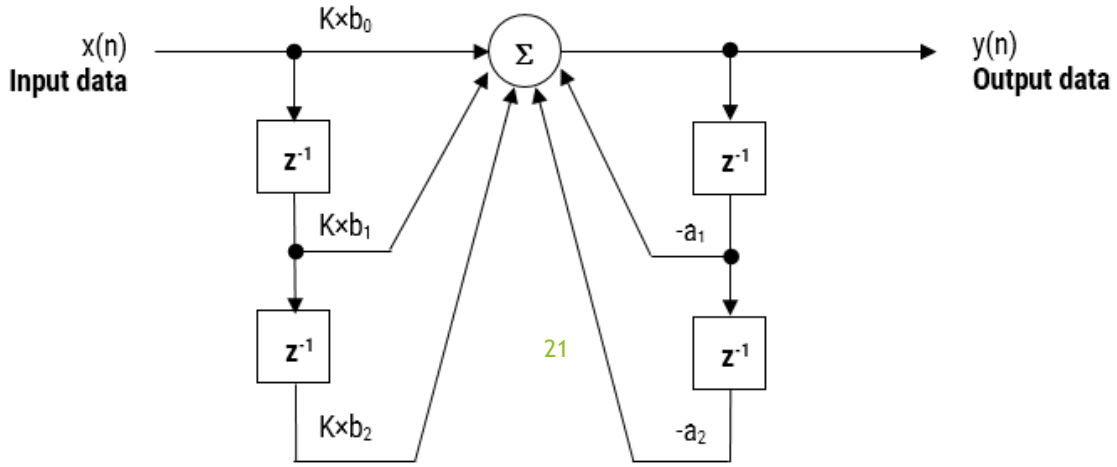


Pre-processing

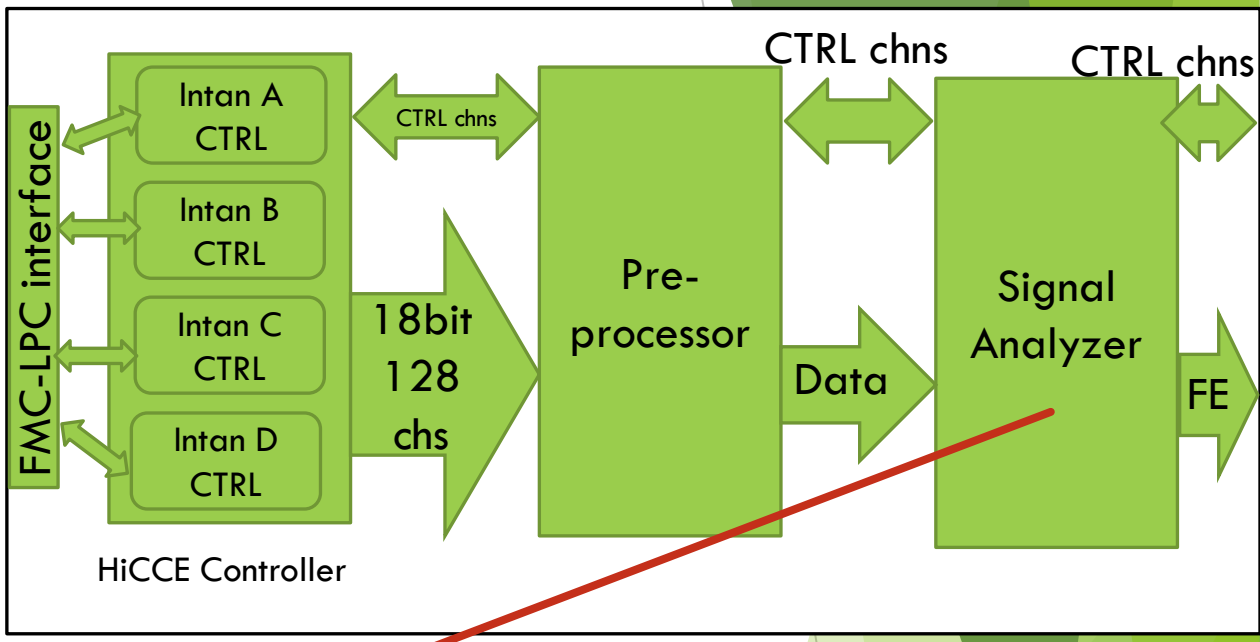
Digital filtering

- FIR - Finite impulse response
  - Stability
  - Linear phase
  - Arbitrary frequency response
  - High implementation cost
  - Higher latency
- IIR - Infinite impulse response
  - Simple structure
  - Low implementation cost
  - Low latency
  - Analog equivalent
  - Less numerical stability
  - Non-linear phase characteristics





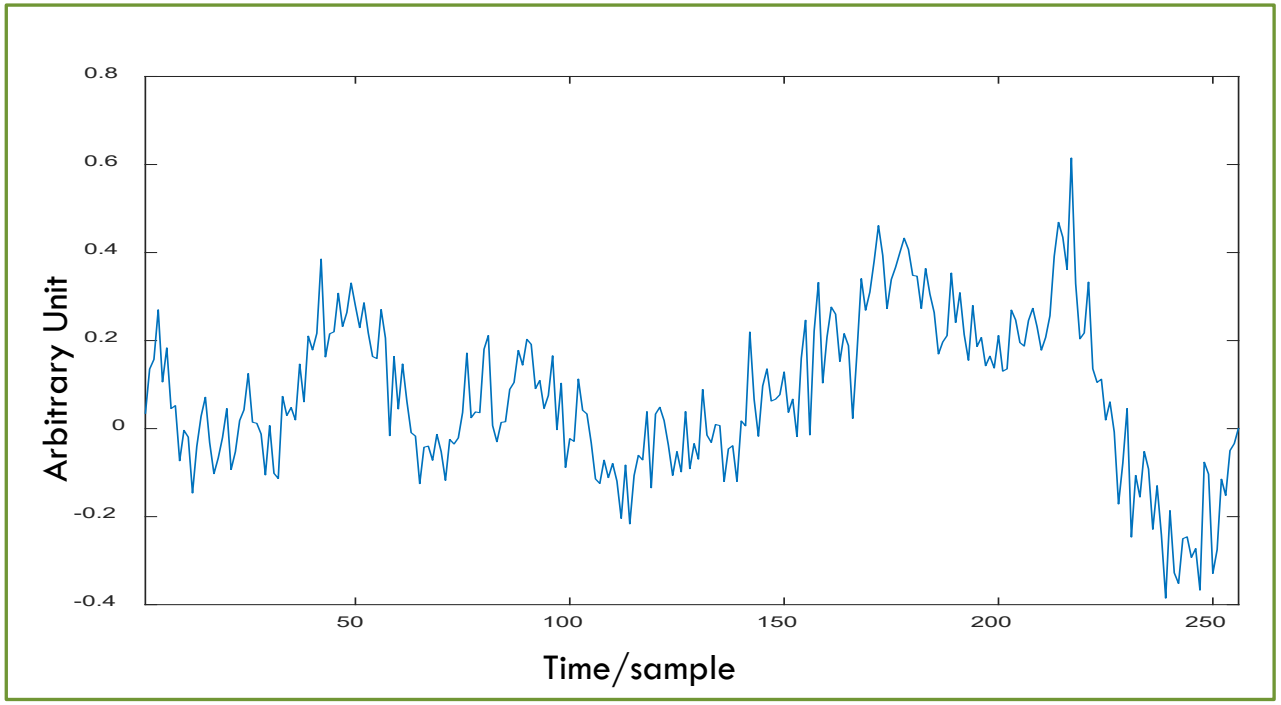
Application Specific IPs



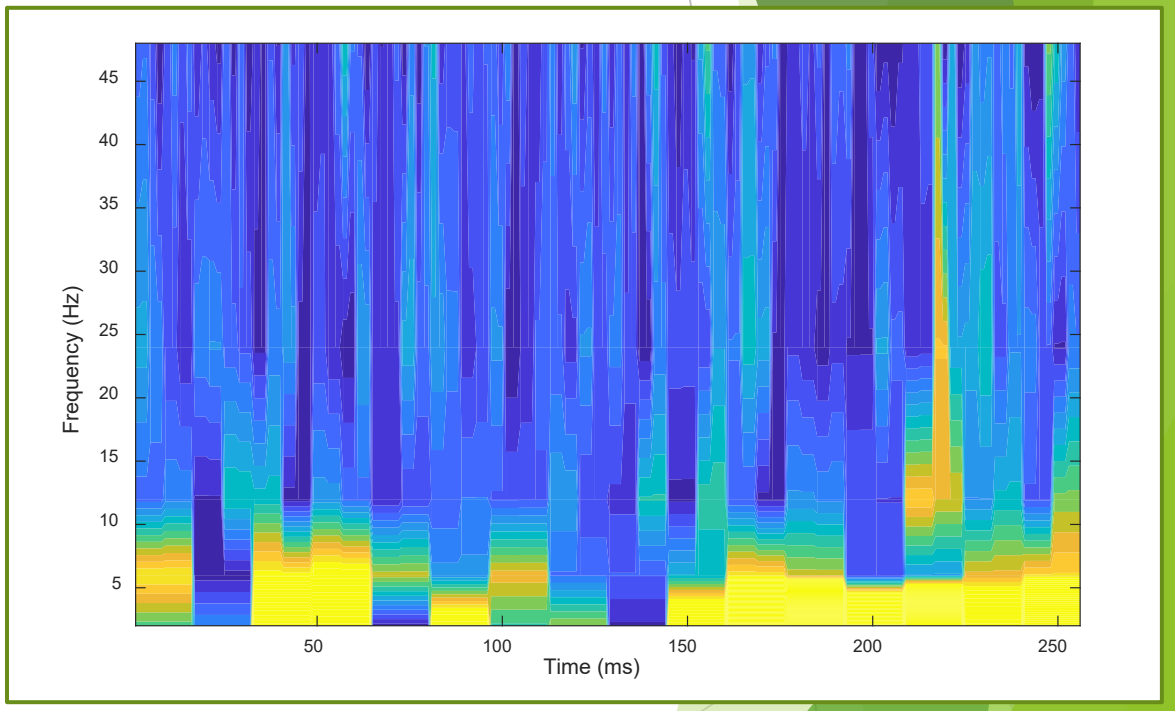
- Signal Analyzer
  - Time-Frequency Analyzer
    - *Discrete Wavelet Transform (DWT)*
    - Continuous *Wavelet Transform (CWT)*
    - Short-Time Fast Fourier Transform *(STFFT)*
    - Filter-Hilbert Transform *(FHT)*

Signal Analyzer IP

- Discrete Wavelet Transform (DWT)



EEG Signal

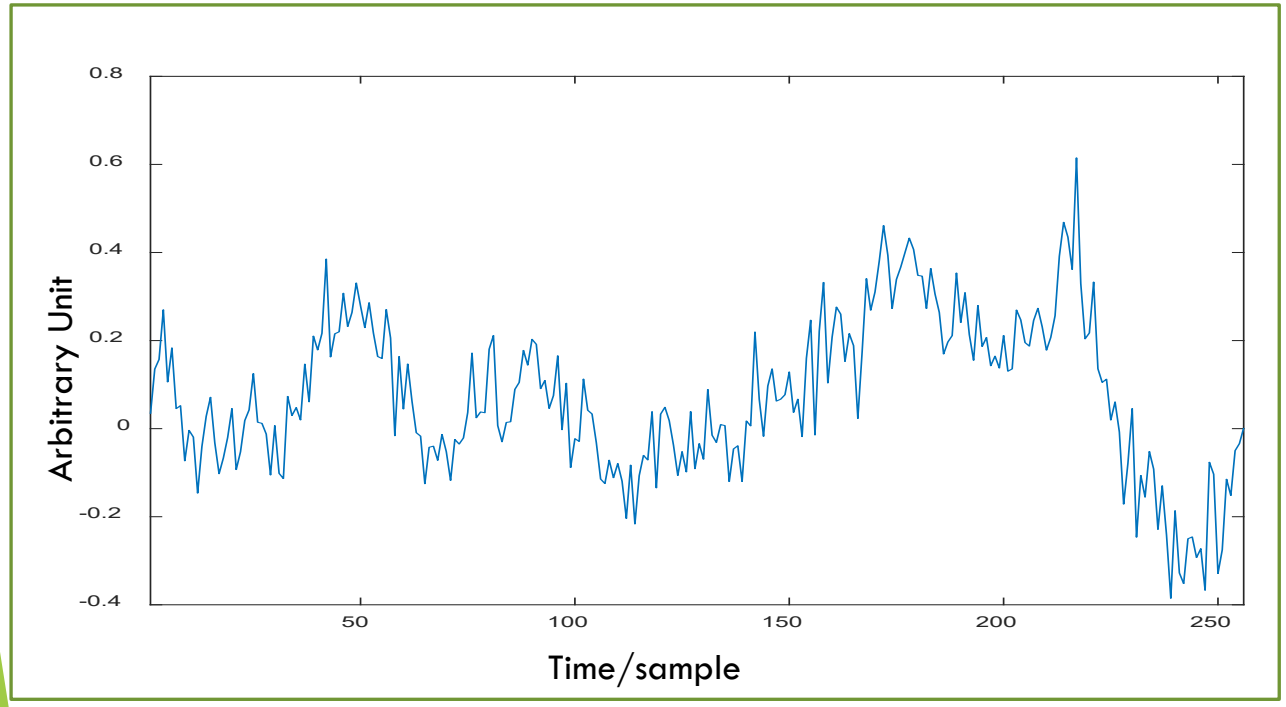


Time – Frequency Graph

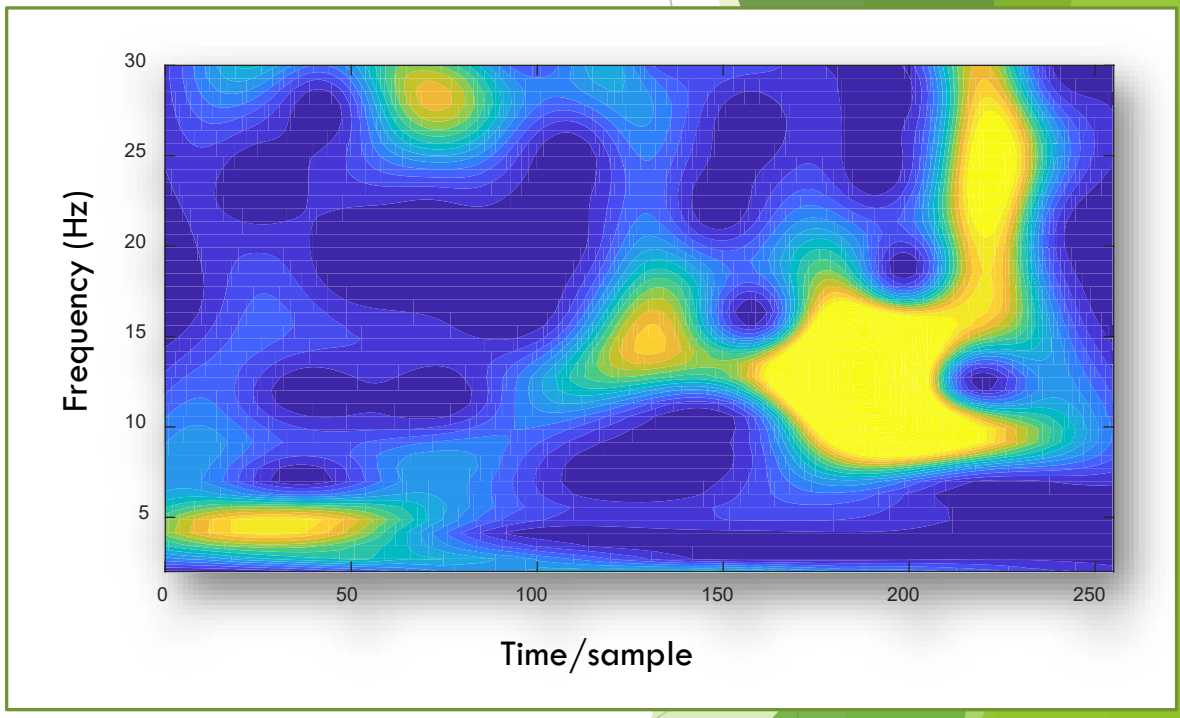
Number of clock cycles = 1028

Signal Analyzer IP

- Continuous Wavelet Transform (CWT)



EEG Signal

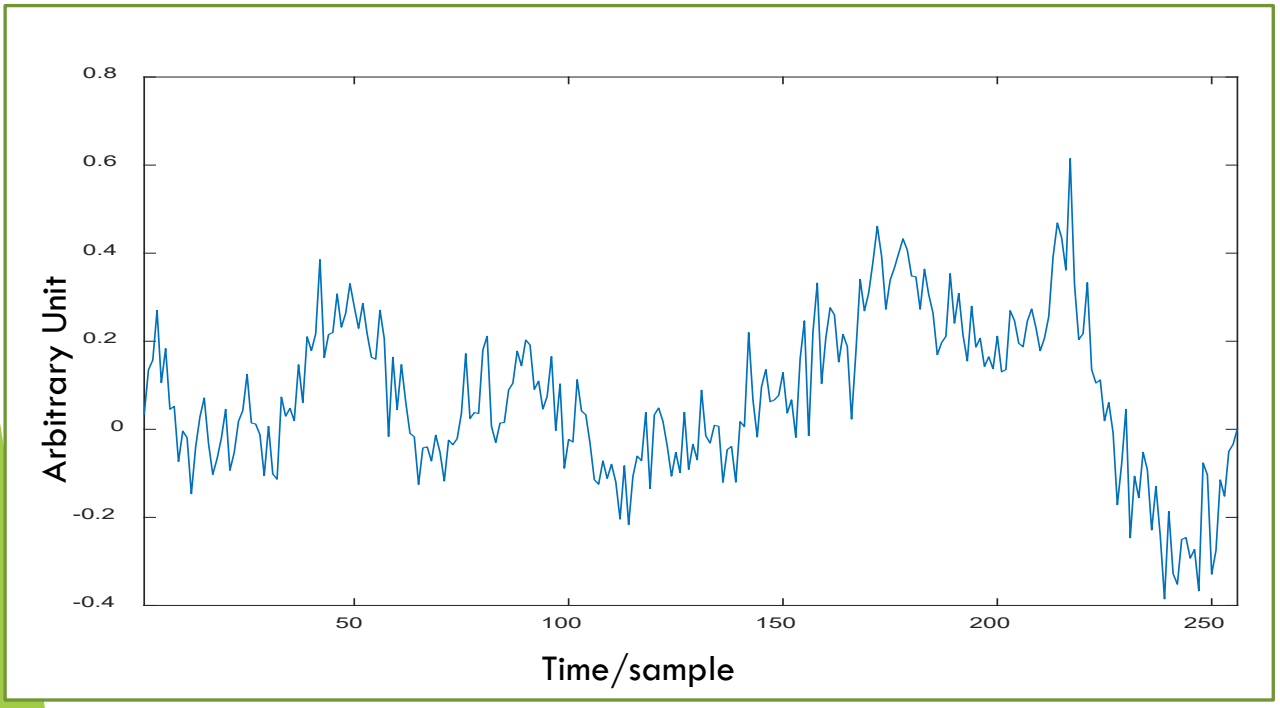


Time – Frequency Graph

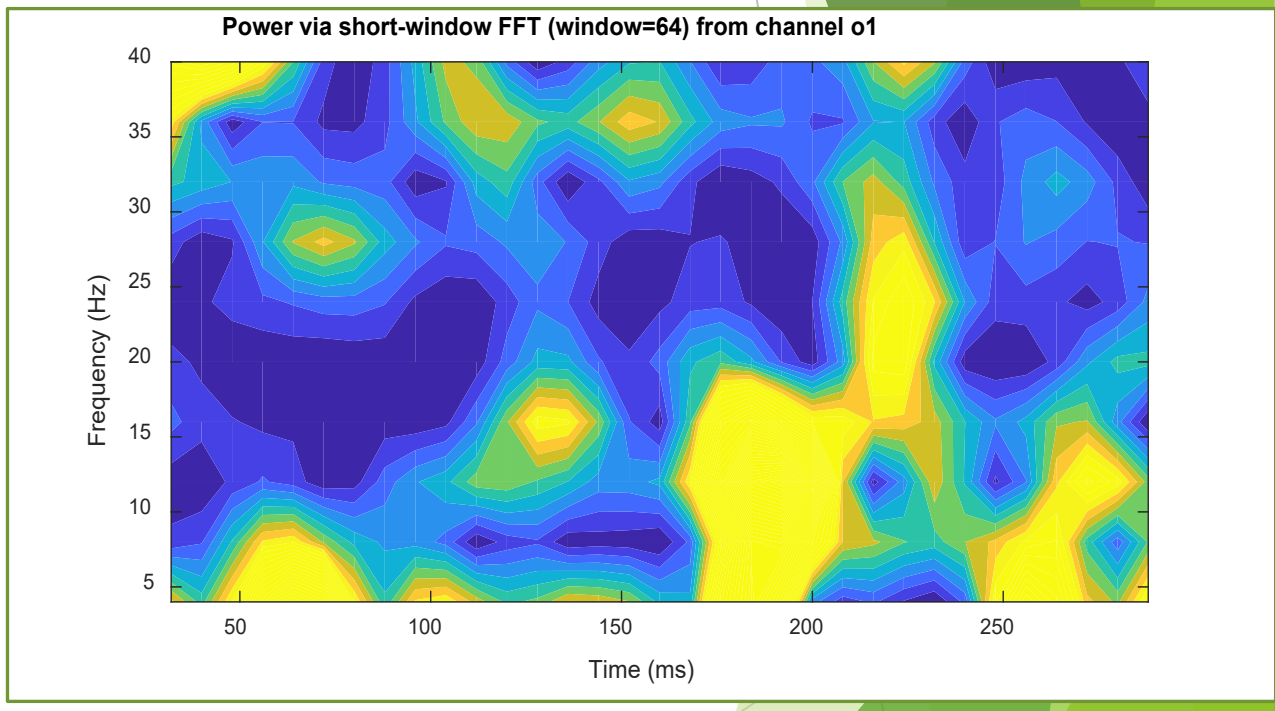
Number of clock cycles = 22809

Signal Analyzer IP

- Short-Time Fast Fourier Transform (STFFT)



EEG Signal

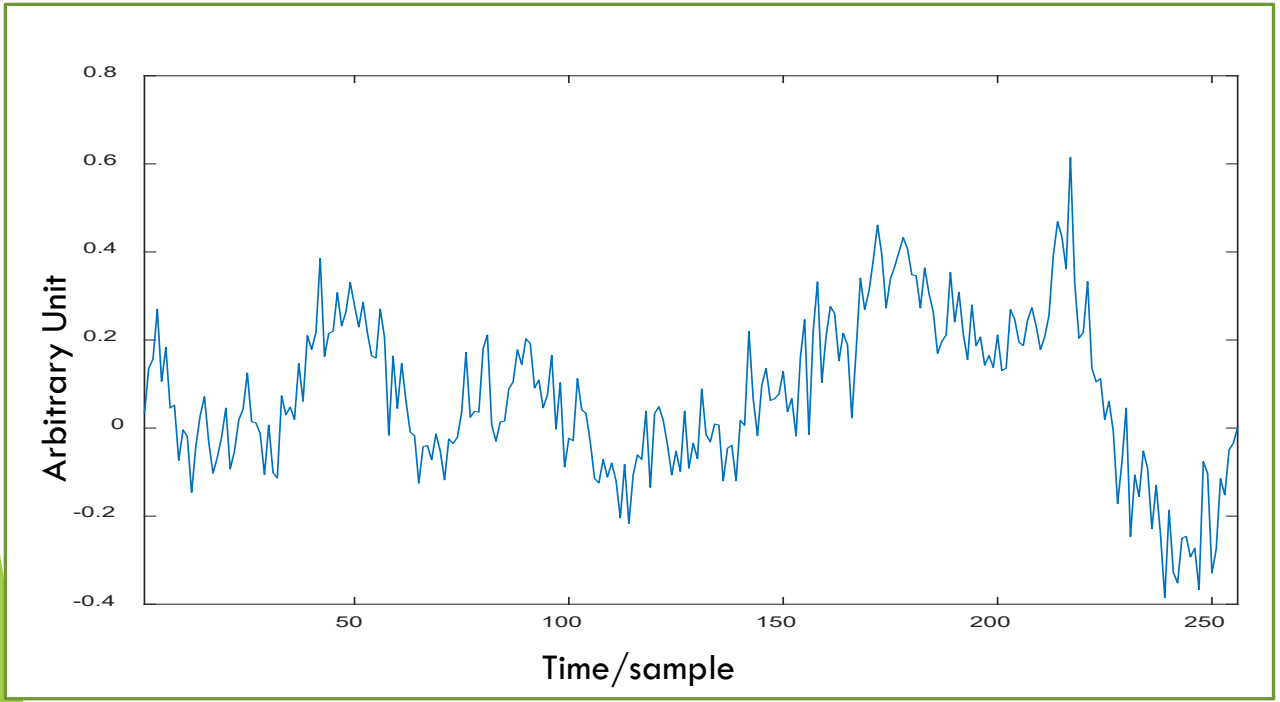


Time – Frequency Graph

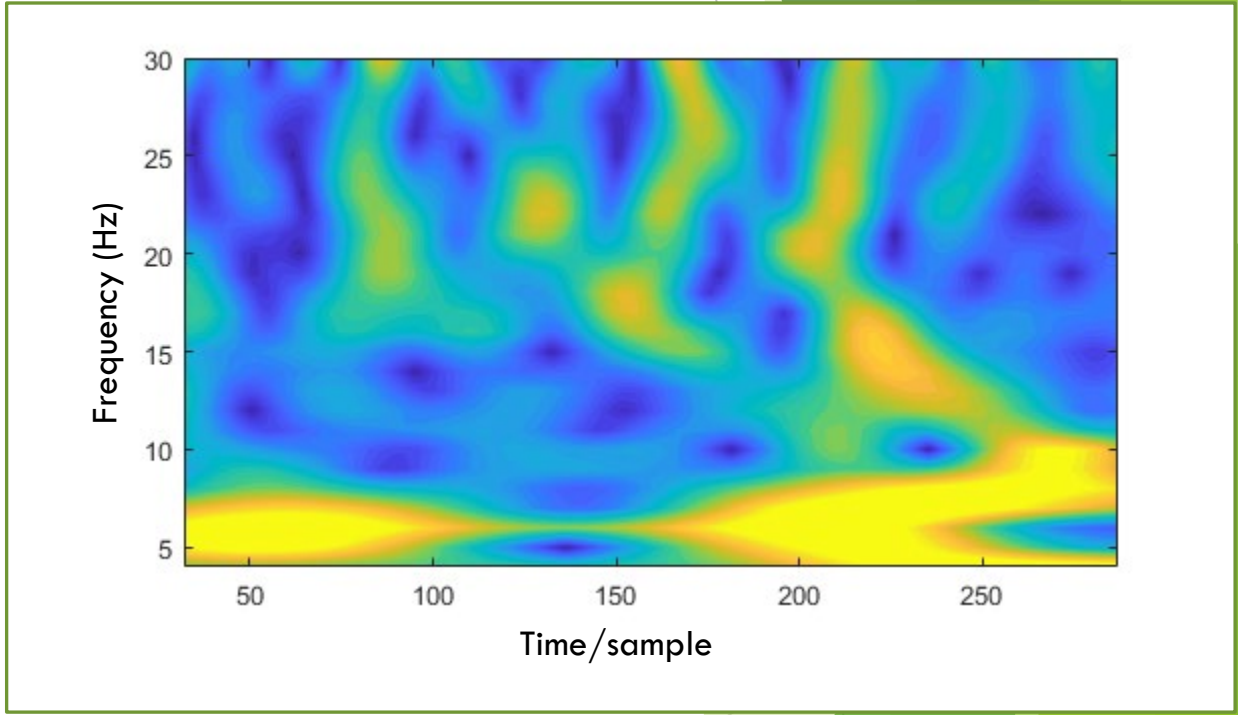
Number of clock cycles = 2346

Signal Analyzer IP

- Filter-Hilbert Transform (FHT)



EEG Signal



Time – Frequency Graph

Number of clock cycles = 21273

Signal Analyzer IP

- Resource utilization

Resources / Method	Registers (106400)	LUTs (53200)	DSPs (220)	BRAMs (140)
Haar	377 (0.35 %)	1181 (2.22 %)	0	0
CWT	12147 (11.42 %)	8920 (16.77 %)	144 (65.45 %)	9.5 (6.78 %)
STFFT	4140 (3.89 %)	3125 (5.87 %)	48 (21.82 %)	2.5 (1.78 %)
Filter - Hilbert	8199 (7.71 %)	6001 (11.28 %)	100 (45.45 %)	8.5 (6.07 %)

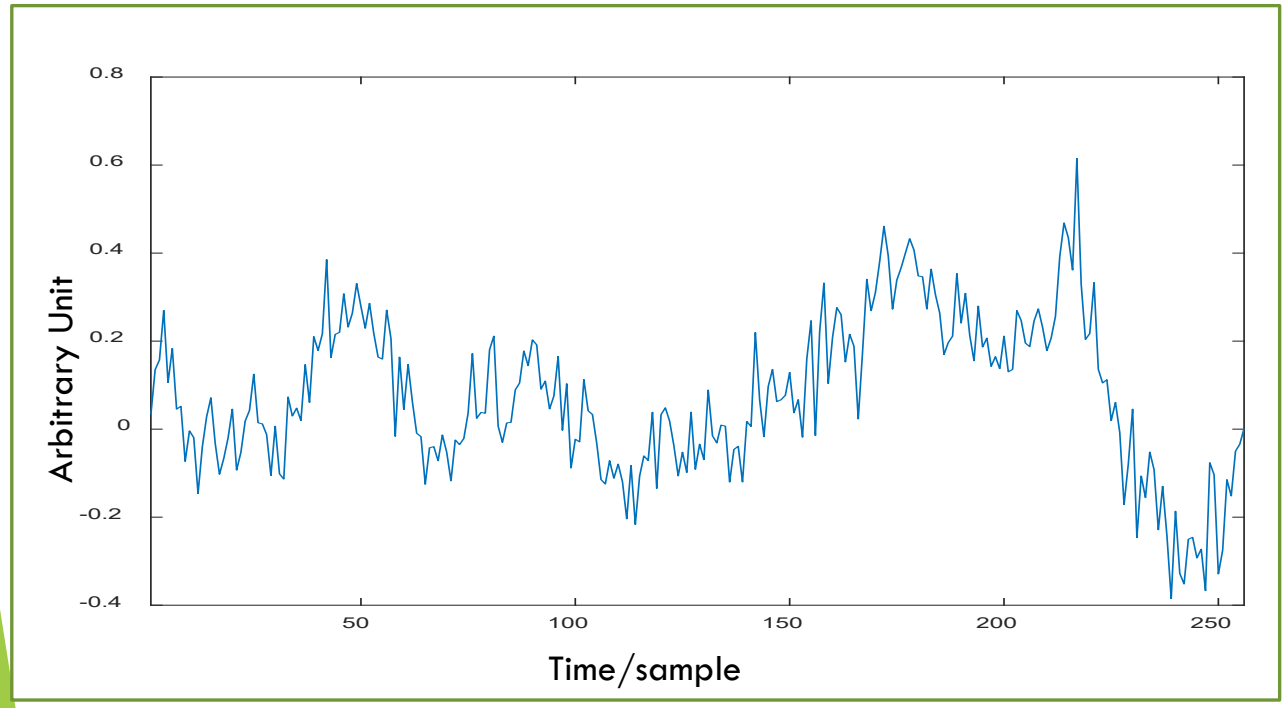
Signal Analyzer IP

- Number of clocks per TF output

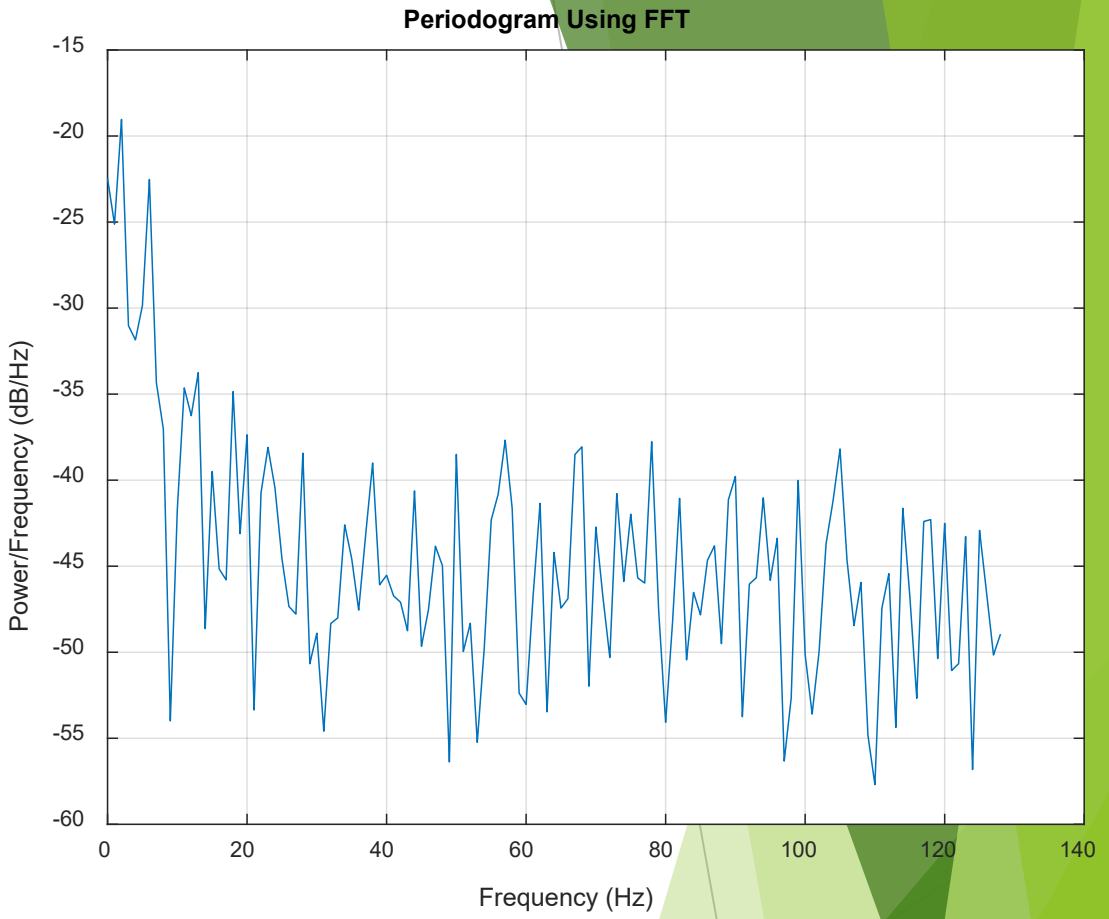
Resources / Method	No. clk cycles	Time with 50 MHz clk
Haar	1028	20.56 us
CWT	22809	459.18 us
STFFT	2346	46.92 us
Filter - Hilbert	21273	425.46 us

Feature extractor IP

- Power Spectral Density (PSD)



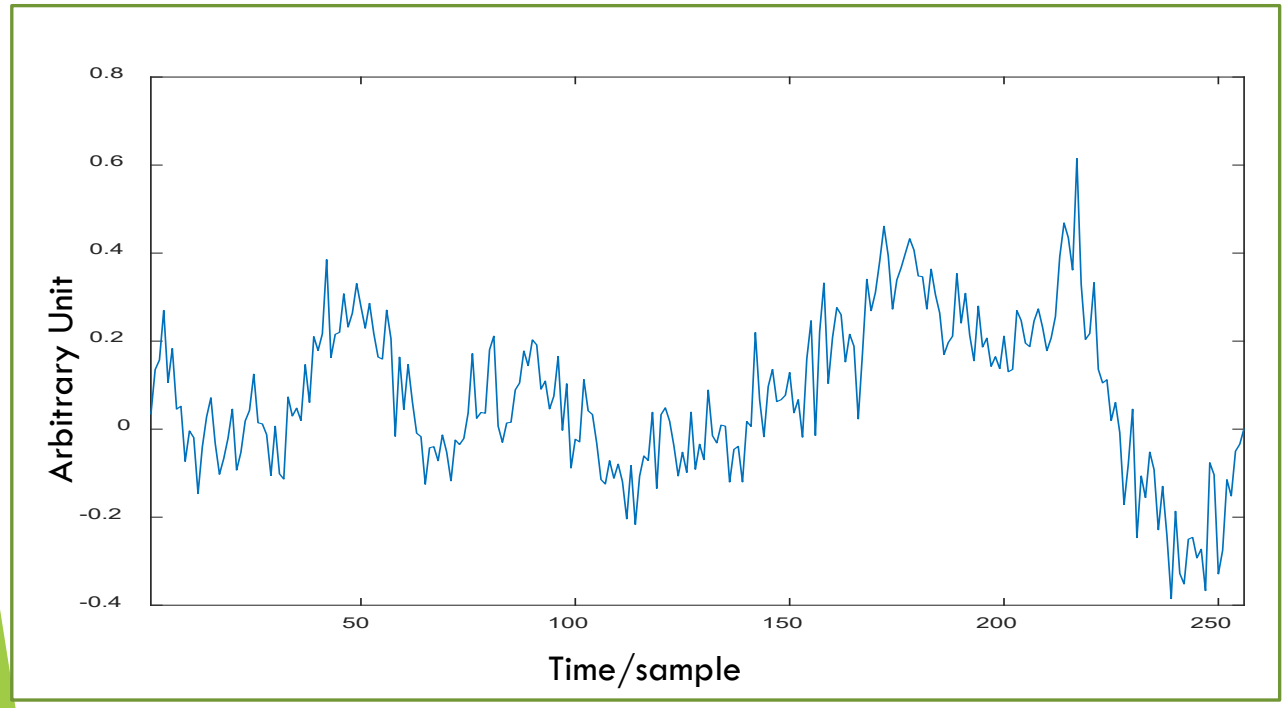
EEG Signal



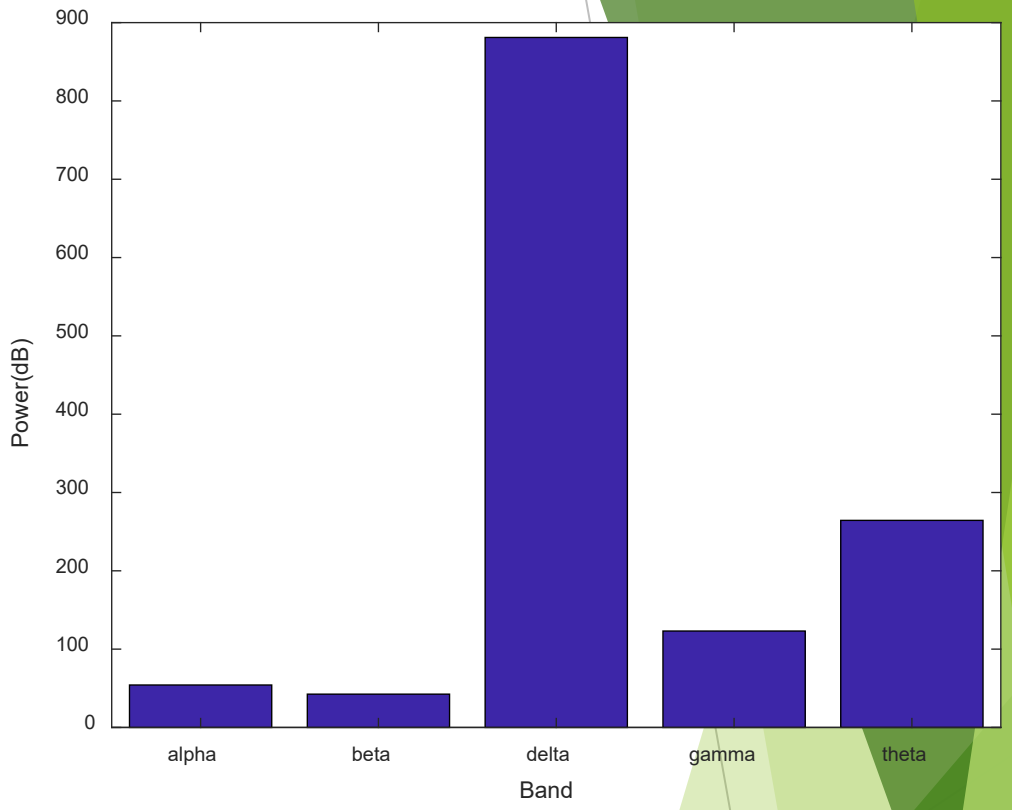
Resourses	
Registers	4656
LUTs	3843
BRAMs	5
DSPs	28

Feature extractor IP

- Band Energies (BE)



EEG Signal



Resourses	
Registers	9180
LUTs	13505
BRAMs	1
DSPs	18

Upper limb rehabilitation

End-effector

->simpler structure

->complex movements

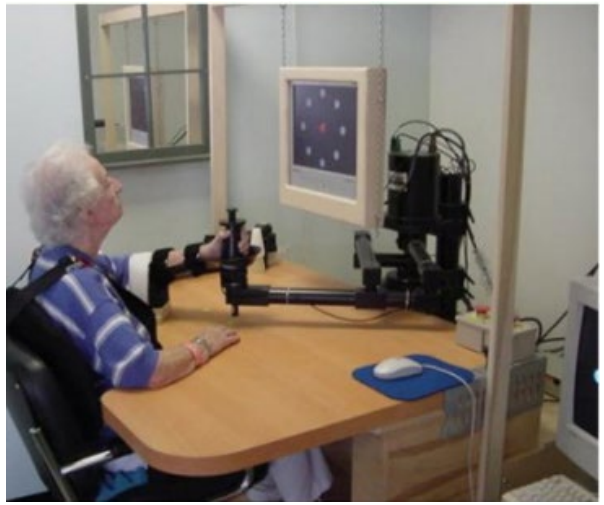
->complicated control algorithms

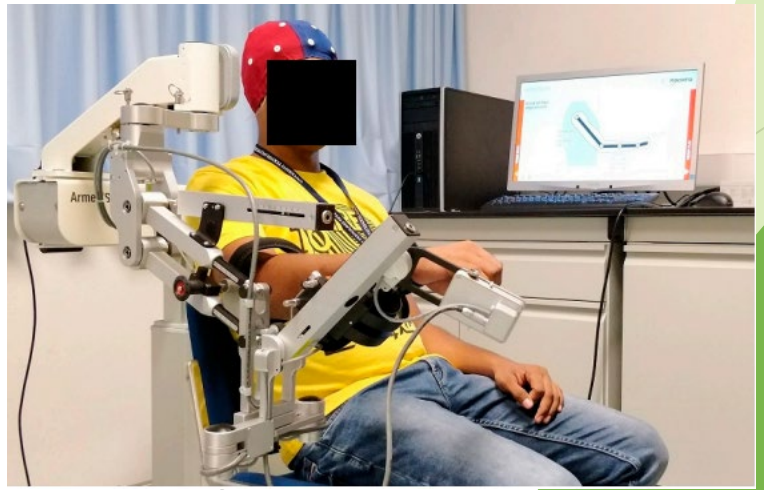
Exoskeleton

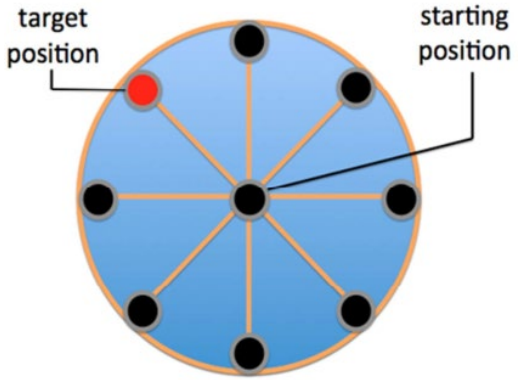
->Long setting-up

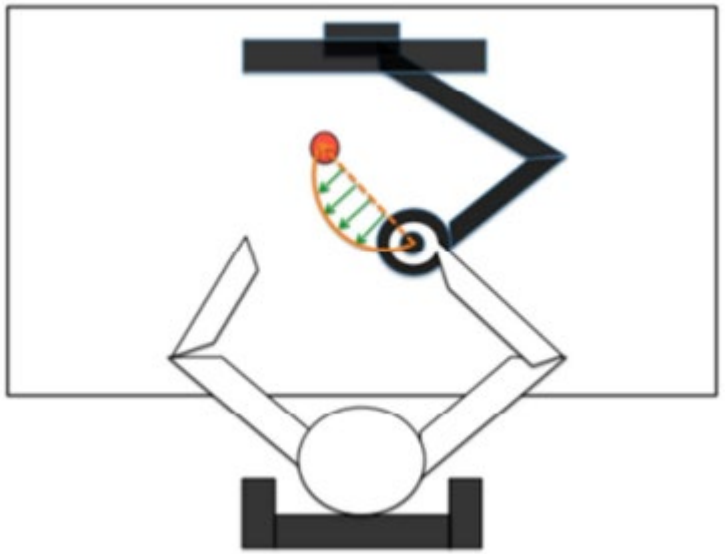
->Safety and comfort concerns

->complicated control algorithms

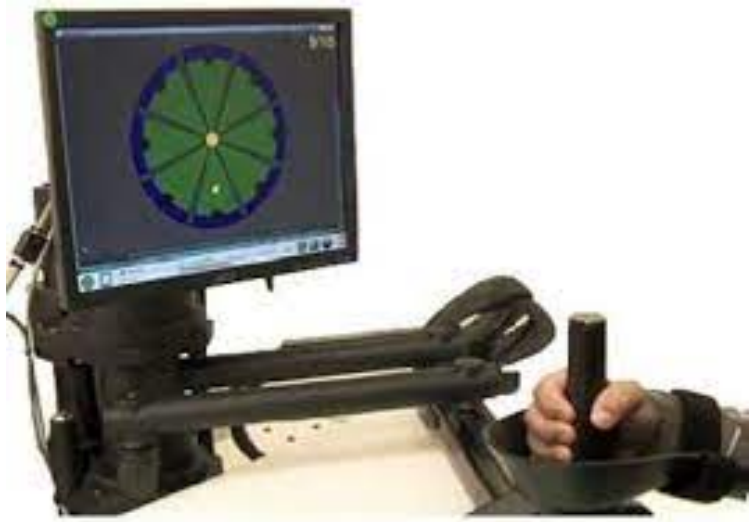








- Movements tracking
- EEG
- EMG
- Force field feedbacks
- Visual feedbacks




Thank you!