CCi-MOBILE: Cochlear Implant & Hearing Aid Research Platform for Speech Scientists and Engineers

John H.L. Hansen, Hussnain Ali, Juliana Saba, Ram Charan M. C., Nursadul Mamun, Ria Ghosh, Avamarie Brueggeman, Soheil Khorram

CIAP-2019
July 16, 2019

CILab: Cochlear Implant Processing Lab

CRSS-CILab: Center for Robust Speech Systems
The University of Texas at Dallas
https://crss.utdallas.edu/CILab/

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Acknowledgements
Sponsors & Collaborators

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awarded from the NIH/NIDCD

Special thanks to our NIH RO1 collaborators: Dr. Ruth Litovsky & Dr. Mario Svirsky

Ruth Y. Litovsky

Mario Svirsky

Special thanks to Cochlear Corp. for their sustained contributions and collaborations

CCi-MOBILE Workshop AGENDA

- 3:00-3:20: **Overview Presentation on CCi-MOBILE**
  General functions & capabilities; web-site support; technical MEMOs; GetHub software; Hands-On Stations demo'ing software, hardware, and Android development software - share on GetHub for the community.

- 3:20-4:00: **PANEL DISCUSSION (Q&A)**
  Open panel discussion by Users of CCi-MOBILE research platform;
  - experiences? Areas to expand/improve on? Wish list?

- 4:05 – 4:45: **Hands-On Experience:**
  Attendees to talk with UTD team members at stations covering: Matlab software available; hardware – including Burn-In testing/safety; Android smartphone support; IRB support; NIH researchers access

- 4:45 – 5:00: **Final Q&A session:**
  opportunity for follow on questions from attendees.

CCi-MOBILE Motivation

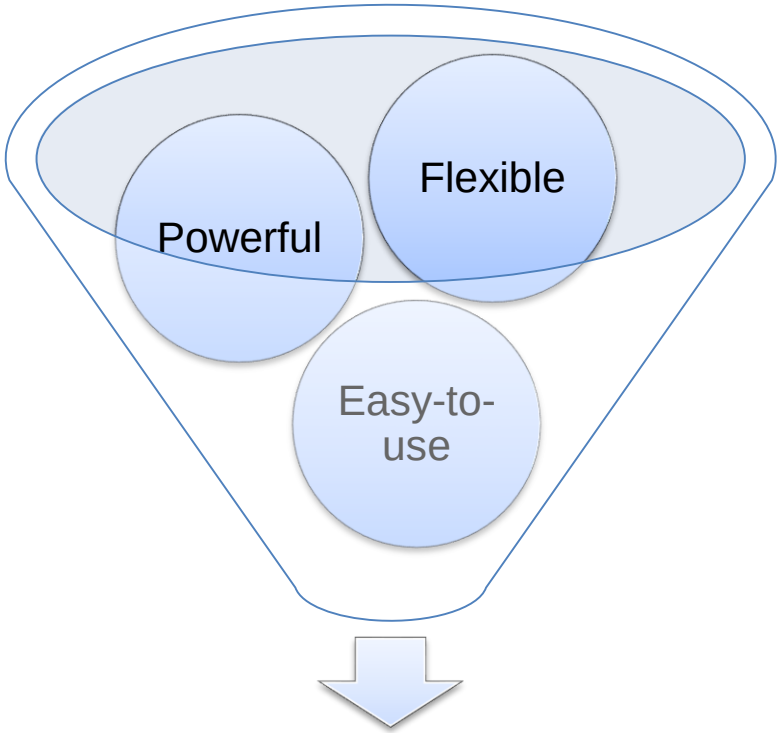
Limitations in existing research interfaces

- Functionality
  - Lack of bimodal support (electric + acoustic hearing)
- Computation power
  - Must sustain complex signal processing algorithms
- Portability – "Naturalistic Testing"
- Real-time evaluation
- Entry Barrier based on unfamiliar programming languages

Not suitable for a broad range of experiments

Proposed attributes

- Custom solutions (*i.e.*, direct connection to implants)



New research interface

CCi-MOBILE

CCi-MOBILE Research Platform

- USB/Wi-Fi research interface configured for both in-laboratory and field testing of sound processing strategies and/or data collection for CI/HA*
- Plug-and-play system (portable, wearable, on-the-go signal processing adjustments)
- Supports time synchronized acoustic and/or electric stimulation
  - Unilateral/bilateral CIs*
  - Bimodal (Electric-Acoustic-Stimulation)
- High-level language software suite (MATLAB, Java)

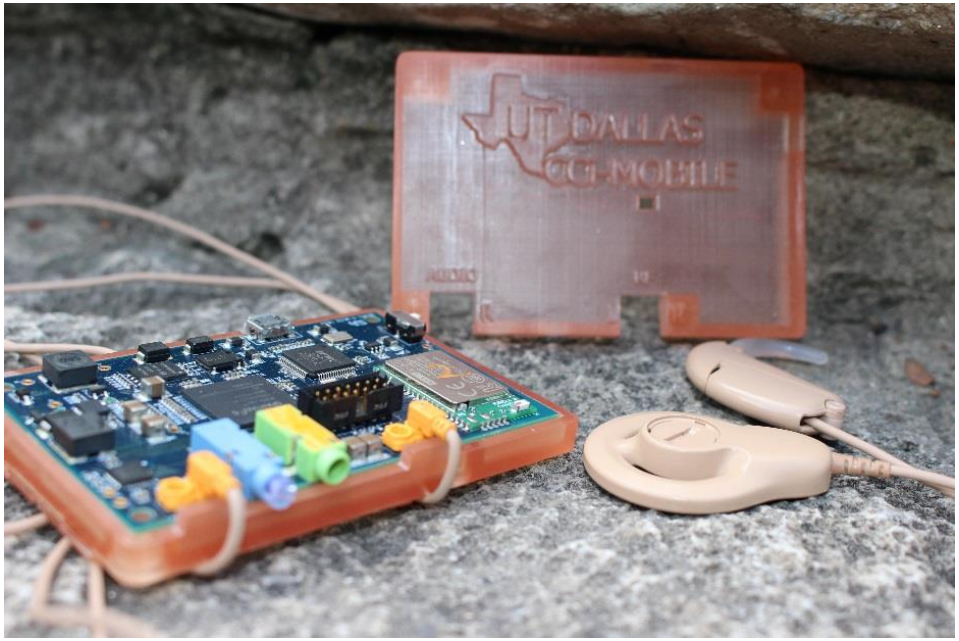


Figure 3. CCi-MOBILE Research Platform (open-case) in unilateral mode.

Investigational Parameters

- Number electrodes/channels configurations
- Stimulation mode
- Stimulation rate (pps/ch)
- Pulse width (bi-phasic stimulation)
- Proposed signal processing strategies (CIS-based**) for unilateral/bilateral

* Supports cochlear implants (CIs) manufactured from Cochlear Ltd. from the CI24 implant series.
** Supports signal processing strategies adapted using the Continuous-Interleaved-Strategy (CIS).

USER Sites with CCi-MOBILE

USER SITES (Since Fall 2017 – Summer 2019) = 17 Units Distributed

Cites with CCi-MOBILE (2 Platforms)

- **New York University** (New York, NY)
- **University of Wisconsin** – Madison (Madison, WI)
- **New Jersey Institute of Technology** (Newark, NJ)
- **Cadwell Industries** (Kennewick, WA)
- **McMaster University** (Hamilton, ON, Canada)
- Universidade Federal de Santa Cararna (Florianópolis, Santa Catarina, Brazil)
- South China University of Technology (Guangdong Sheng, China)

Cites with CCi-MOBILE (1 Platform)

- Split University (Split, Croatia)
- Shenzhen University (Guangdong Sheng, China)
- **Cochlear Corporation, LLC.**

So what does CCi-MOBILE stand for?

- Research platform intended to promote benchtop & field/MOBILE evaluations with CI Users: **Ci-MOBILE**
- UTDallas CRSS-CILab wanted to recognize our former colleague who committed his life/career to hearing/CI research – Philip Loizou; device named for his son

COSTAKIS Ci-MOBILE

CCi-MOBILE

Hardware Design

- FPGA design programmed in Verilog using Xilinx ISE software
- Real-time performance (minimal processing delay) achieved via buffering of incoming and outgoing data on a frame-by-frame basis
- Variable rate electric stimulation uses 16-bit wide RAM buffers to store information: electrodes and current levels

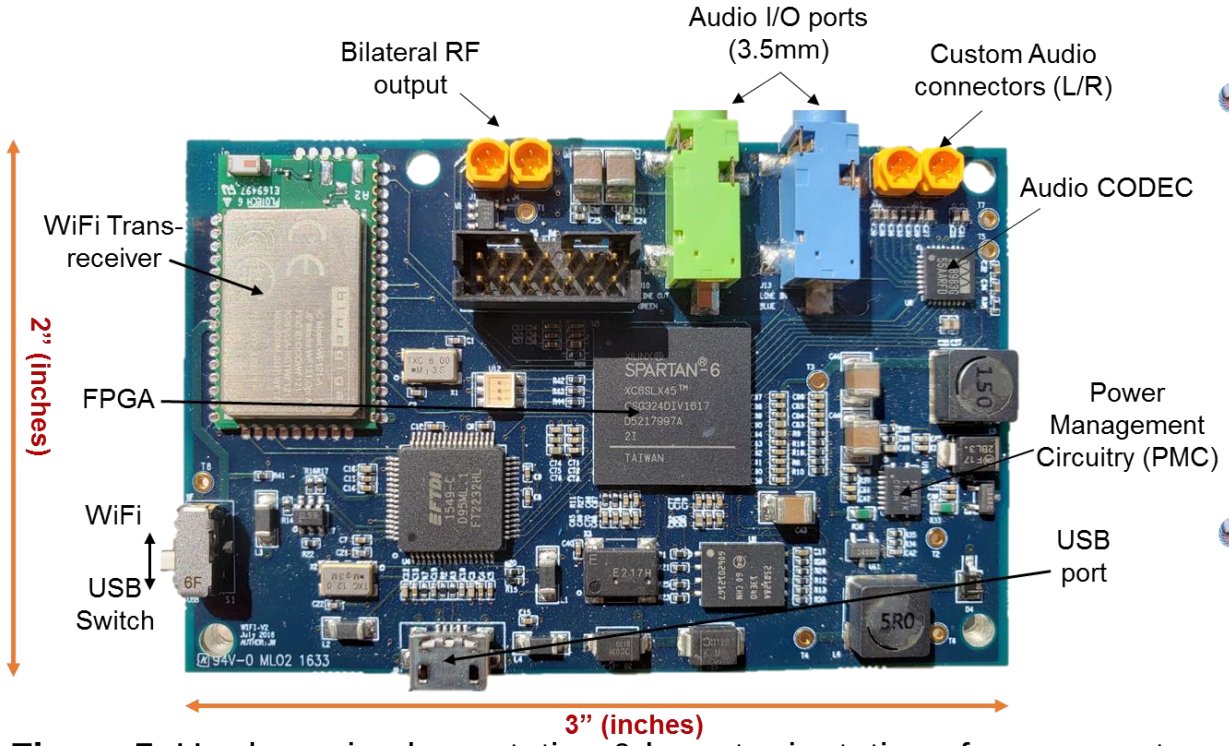


Figure 5. Hardware implementation & layout orientation of components.

- Parameter matching using **inter-pulse-gap**, **pulse-width**, and **inter-phase-gap** used to determine accuracy received at the RF-coil
- Parameters are measured and verified using an externally connected oscilloscope

CCi Mobile Simulation Packages

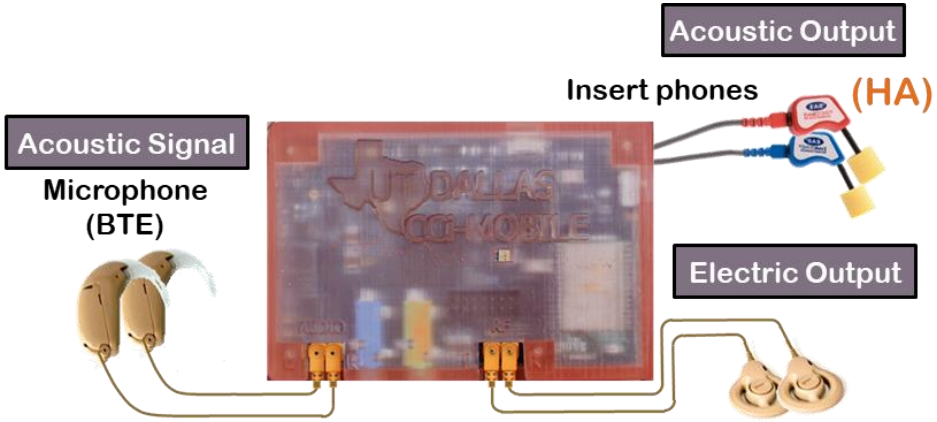
Bimodal Type

Input:

- BTE (acoustic) input

Output:

- Acoustic output (to HA)
- Electric output (to CI)



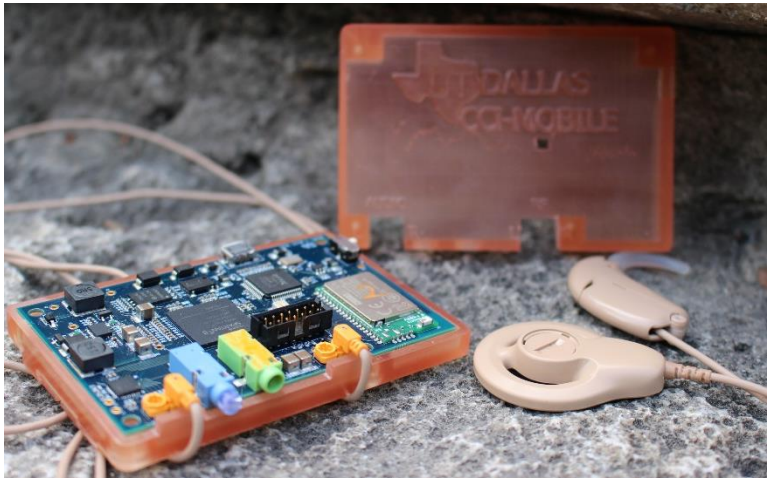
Electric Only Type

Input:

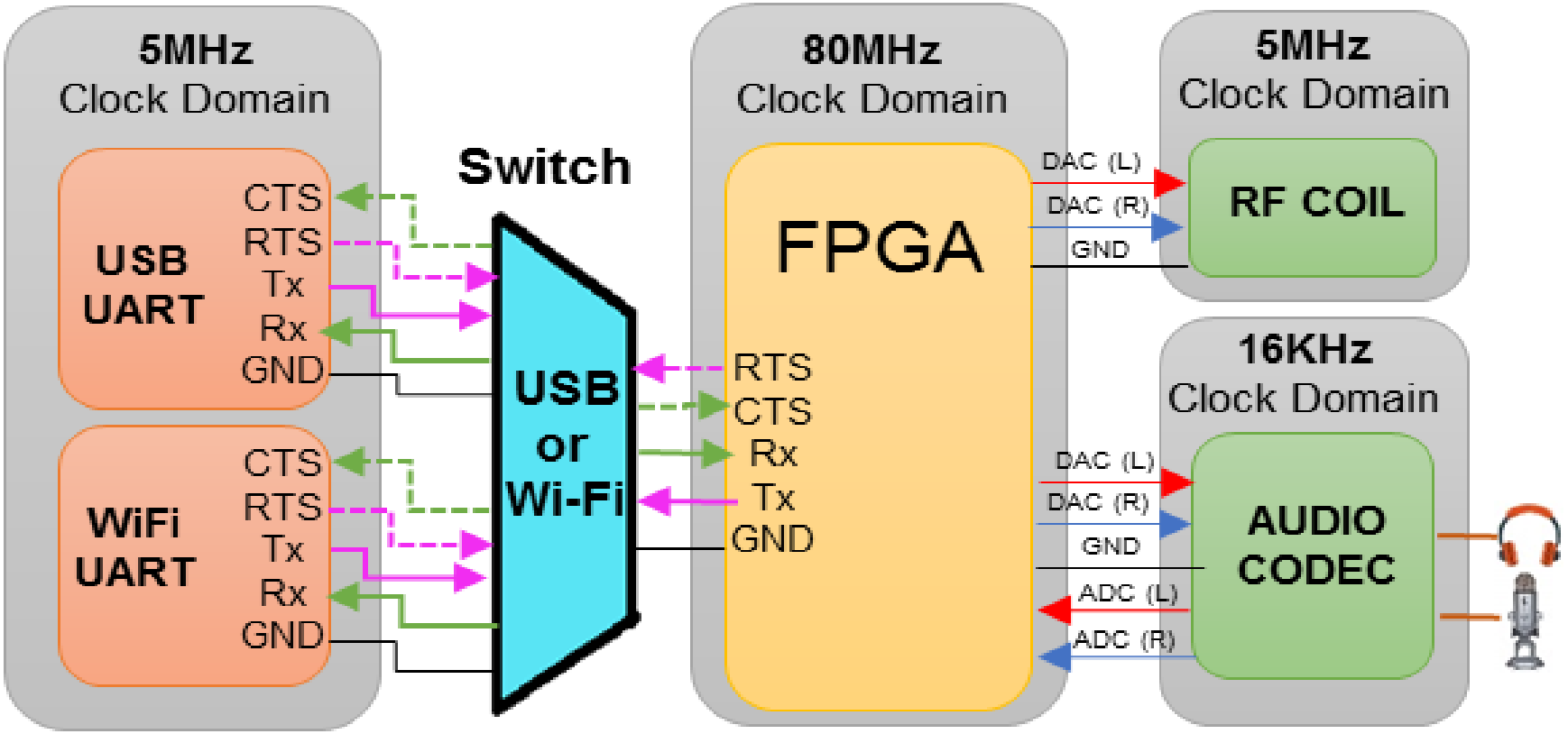
- BTE (acoustic) input

Output:

- Electric output only (to CI)



Hardware Design Modules

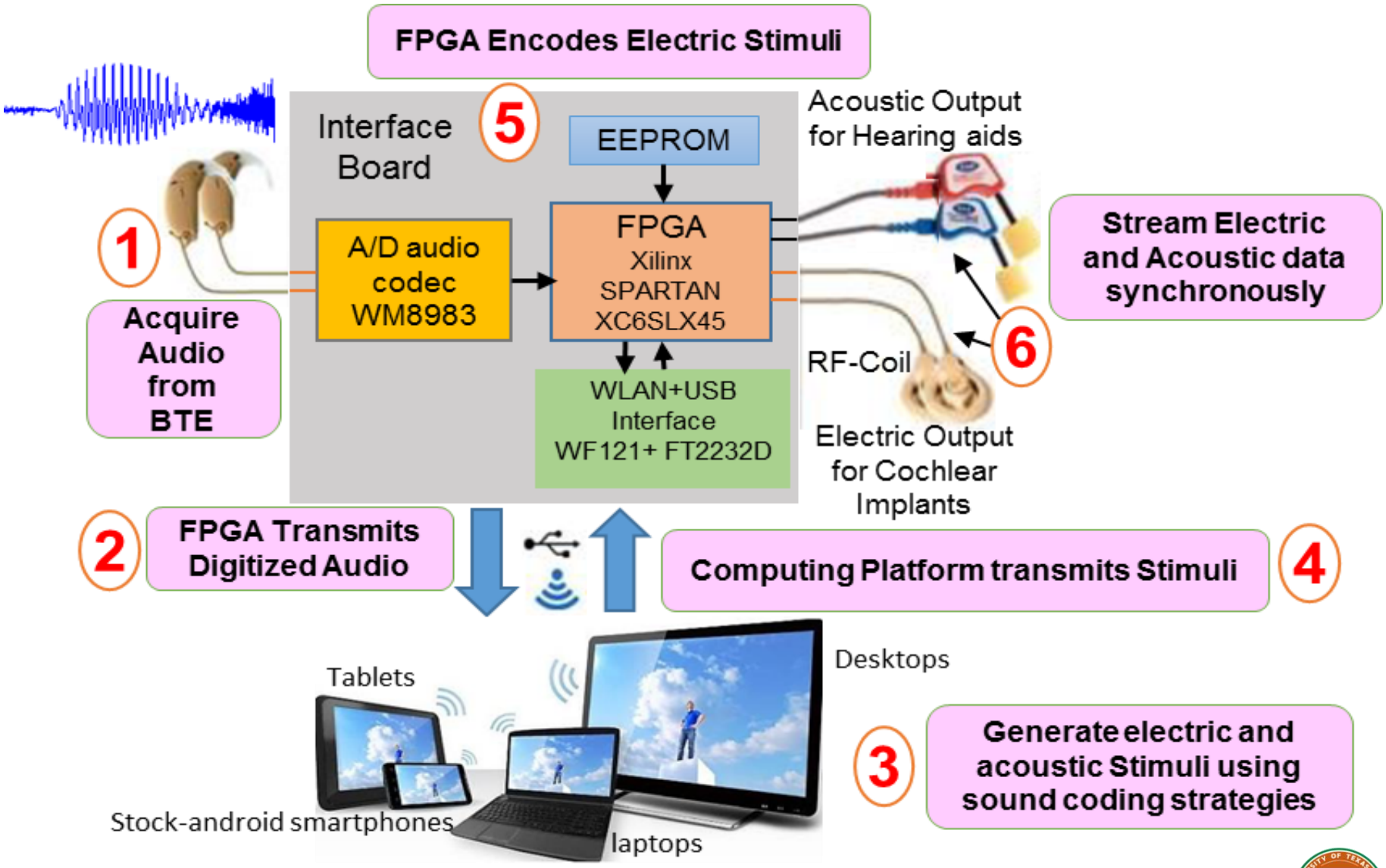


CCi-MOBILE Research Platform (open-case) in unilateral mode.

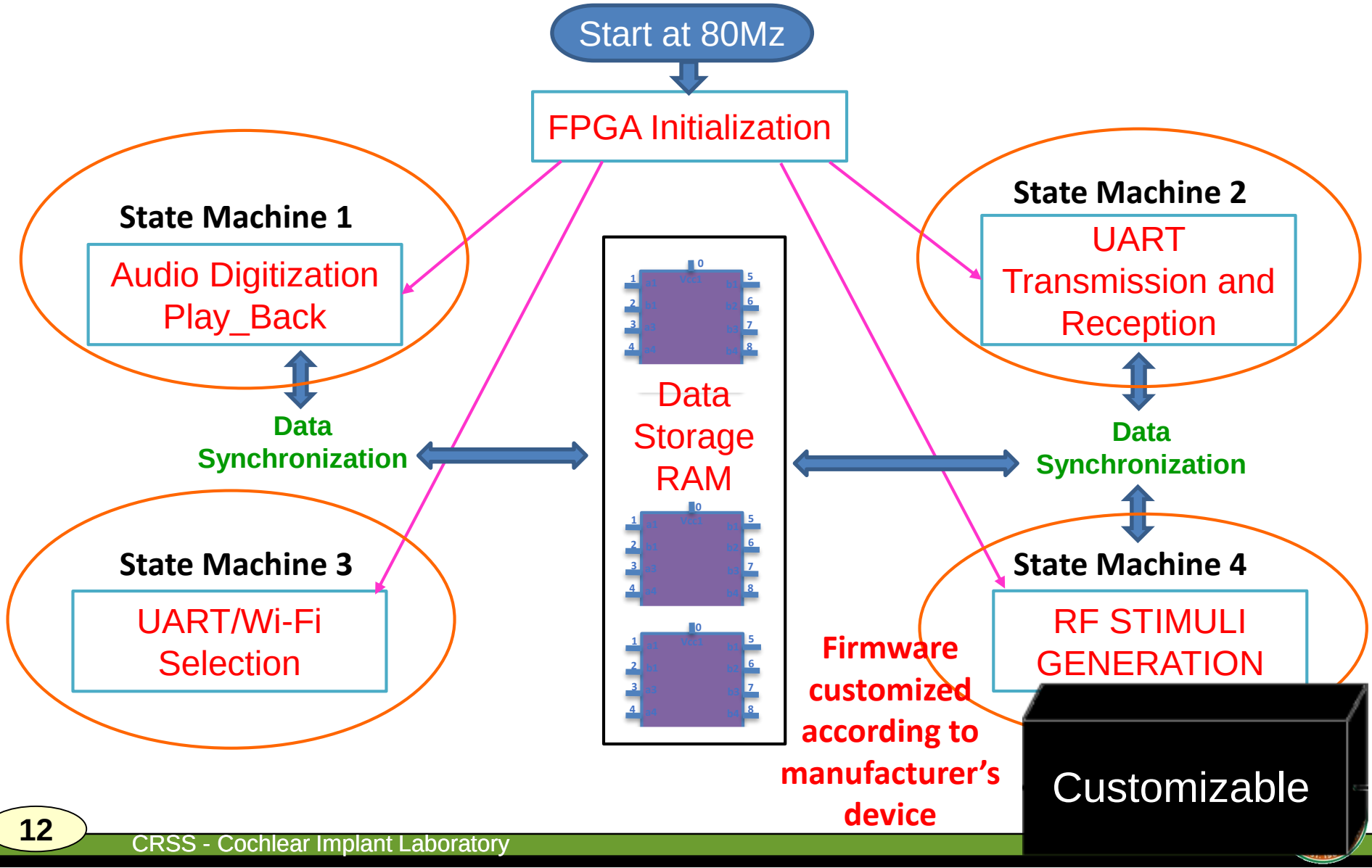
Keywords-

CTS- Clear To Send
RTS- Ready To Send
Tx- Transmitter
Rx- Receiver
DAC- Digital To Analog Converter
ADC- Analog to Digital Converter

High-Level Functionality



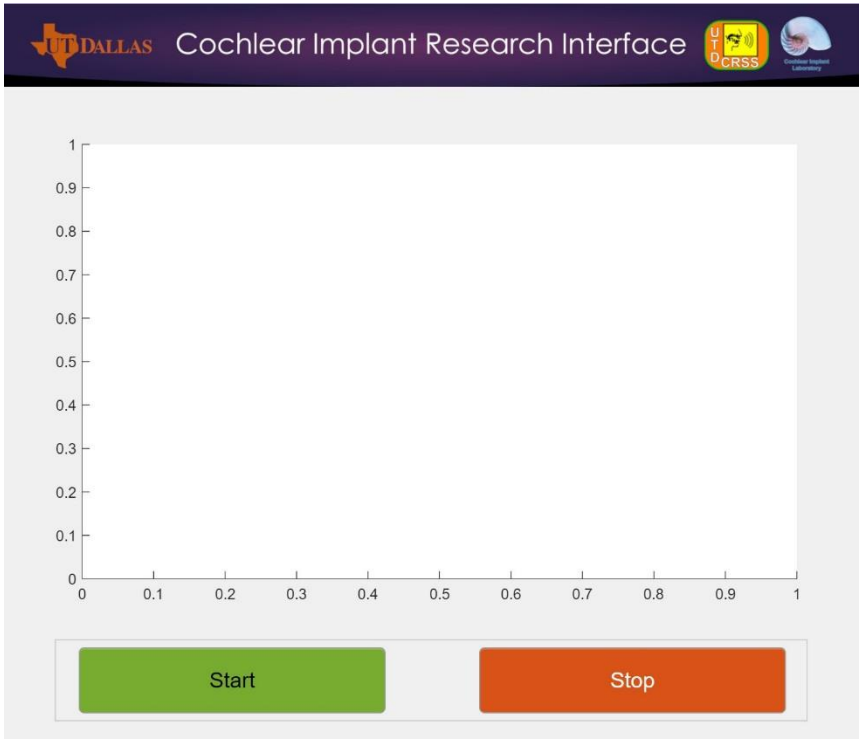
Modules Running Concurrently



Software Applications

AudioScope

- Generates a time-waveform of real-time microphone input (BTE or HA)



AudioRecorder

- Record audio either in-lab settings or in-field environment using the microphone

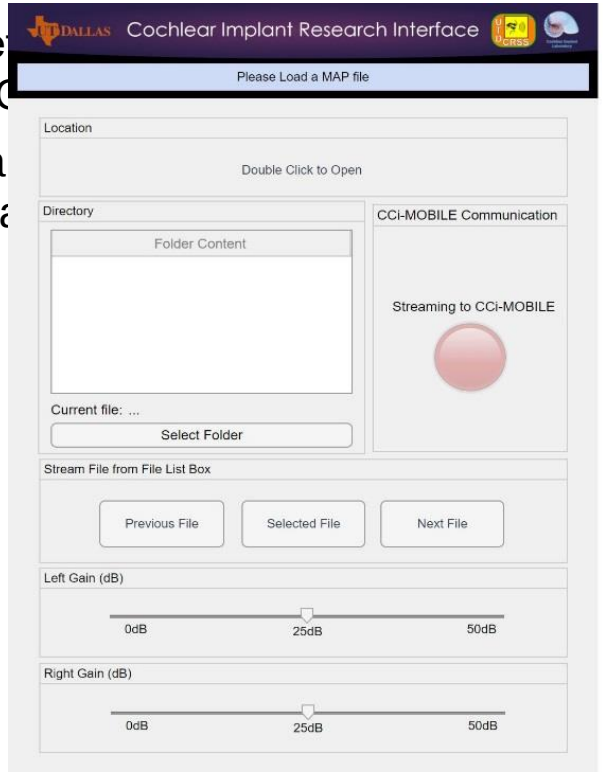
Software Applications

RealtimeStimulator (CI only)

- Implements subject-MAP using an ‘n’-of-’m’ strategy* (ACE) in real-time to RF coils

AudioFileProcessor (CI only)

- Stream individual audio files (.wav files) to subject in a direct connect set up (via RF)
- De ategy (AC
- Ca ng str ation

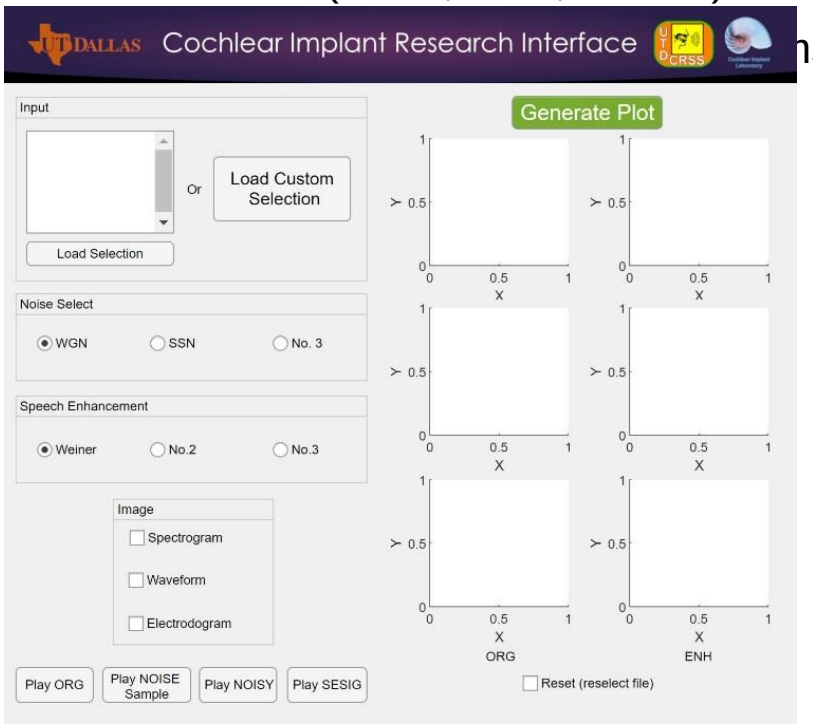


* Supports cochlear implants (CIs) manufactured from Cochlear Ltd. from the CI24 implant series.
** Supports signal processing strategies adapted using the Continuous-Interleaved-Strategy (CIS).

Software Applications

Speech Enhancement (CI only)

- Perform speech enhancement for acoustic I/O and electric I/O
- Perform speech enhancement with different noises (WGN, SSN, Babble)
- ns
-



Custom Signal Processing (CI only)

- Stream individual audio files (.wav files) to subject in a direct connect set up (via RF)
- al
-
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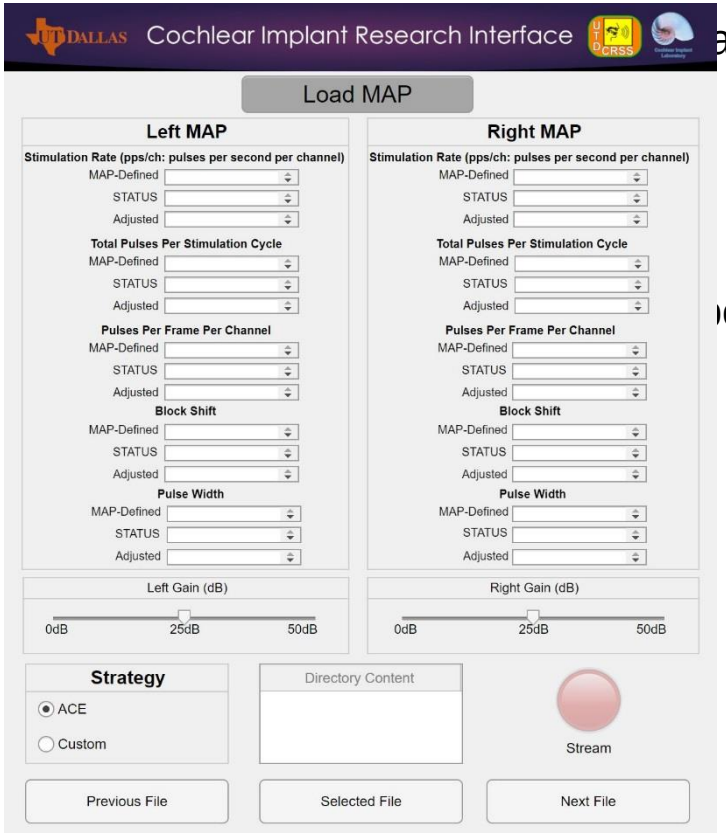


Signal Processing Pipeline

- Adapted from Nucleus MATLAB Toolbox into MATLAB AppDesigner and GUIDE formats for drop-and-play interface with custom signal processing scripts

- **Default Stimulation:** CIS
- **Default Sound Processing:** 'N-of-m' strategy

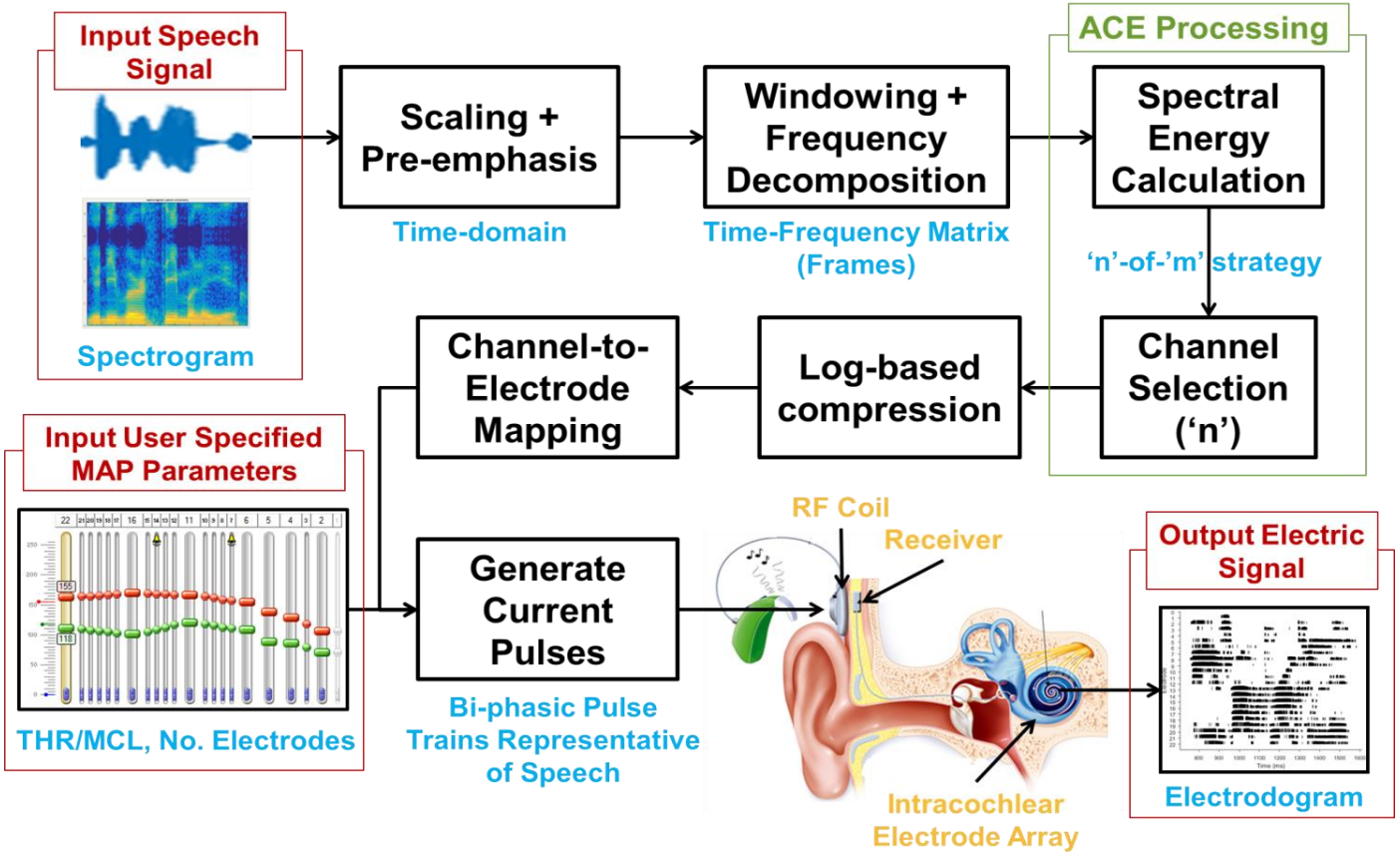
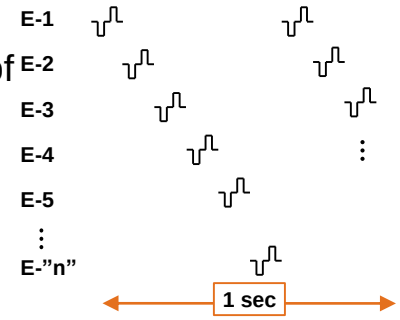


Figure: Processing pipeline (implemented in MATLAB) to develop stimulation parameters from an input acoustic signal using a CIS stimulation strategy and an 'n-of-m' signal processing strategy (ACE).

Custom Signal Processing

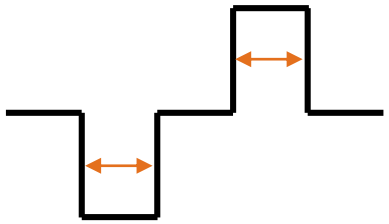
Stimulation Rate (pps/ch)

- Temporal measurement controlling the number of pulses per second per electrode/channel



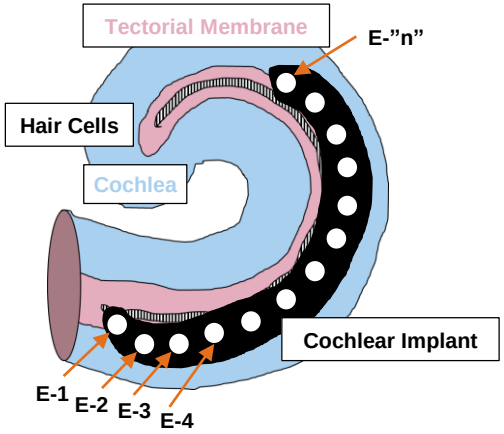
Pulse-width (PW)

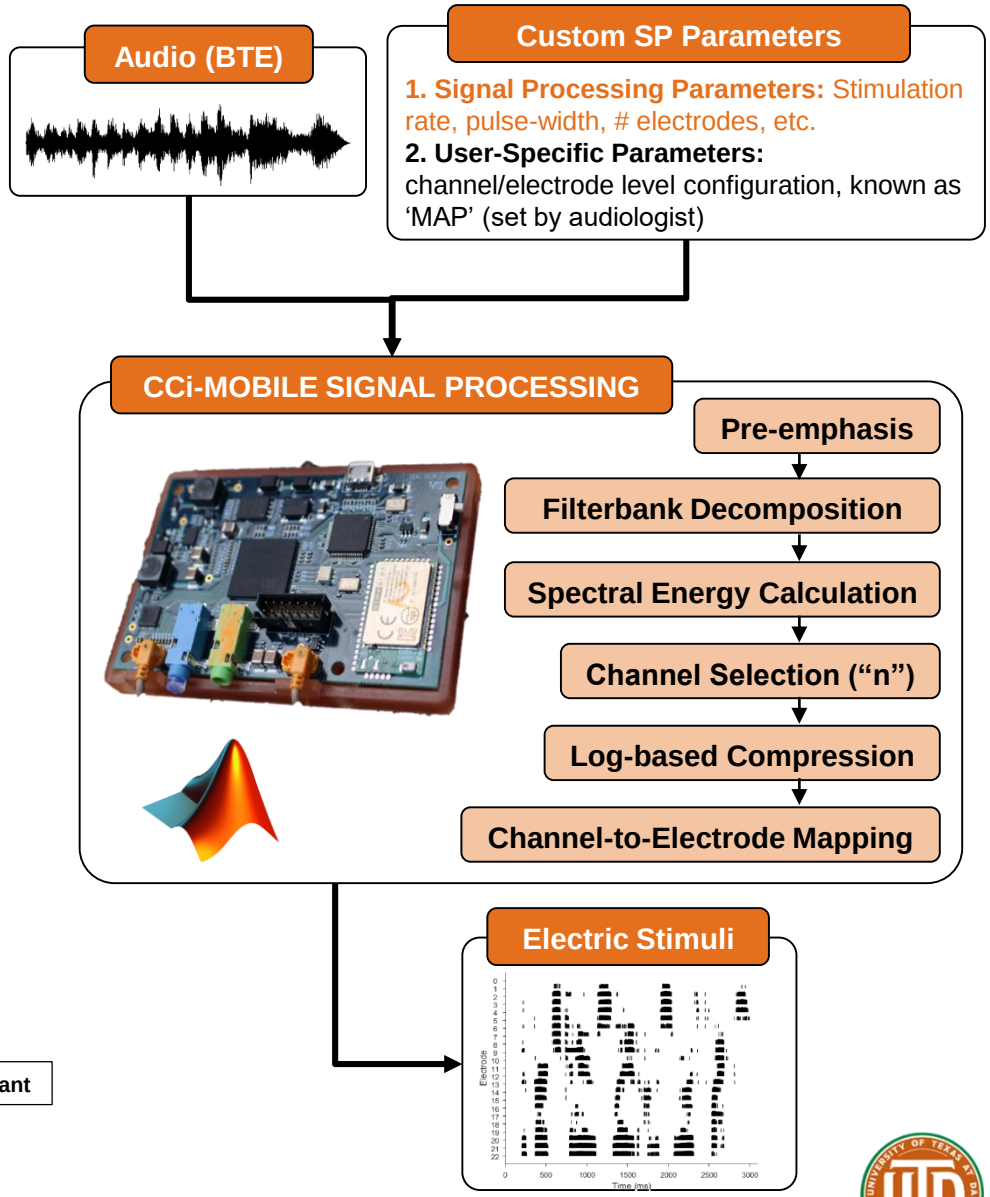
- Width (μs) of anodic and cathodic pulses



Number of Electrodes

- Number of available electrodes for stimulation within a single cycle
- Max number of electrodes = 22 (**"n-maxima"**)





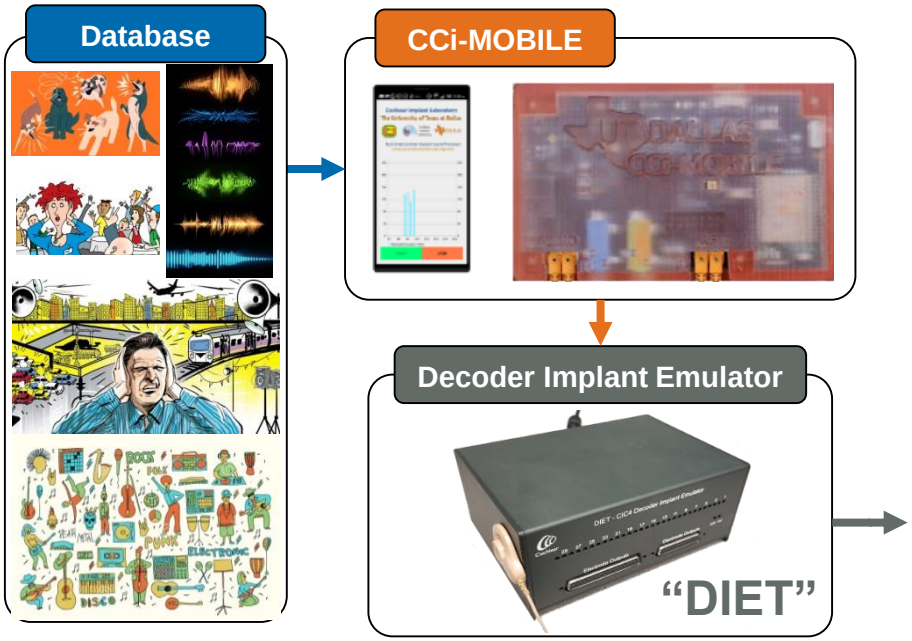
Acoustical Evaluation

PHASE-1: Acoustic-Diversity Evaluation

- Determine charge (current) from various acoustic input (**380 hrs.**) of audio, speech, music, noise, etc.

PHASE-2: Experimental Set-Up and Results

- All charge/current values produced from CCi-MOBILE were **within clinical safety** limits (safety limit = 350 mC/s^2)



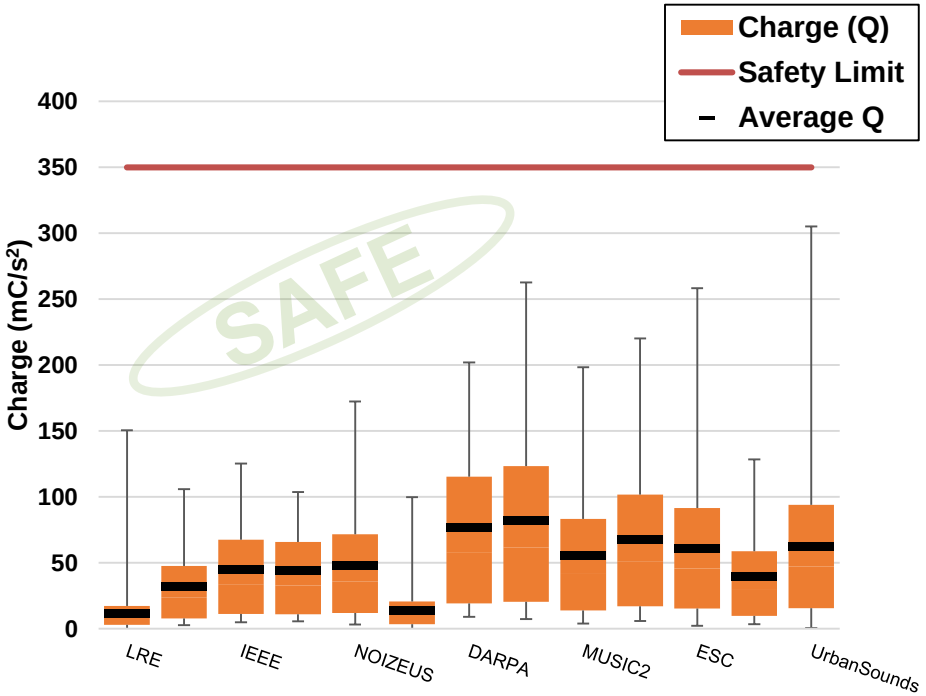


Figure: Box plot of charge associated with each acoustical database (orange) compared to the clinical safety limit (green).

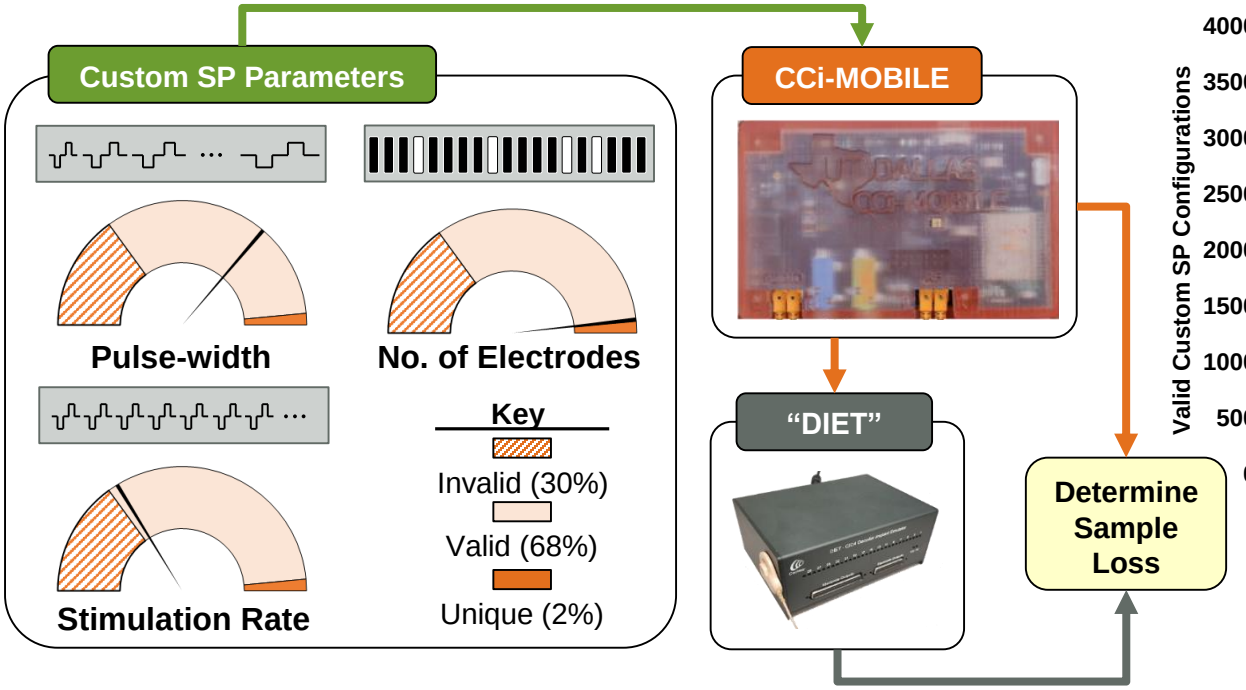
Custom-Parameter Evaluation

Custom Signal Processing (SP) Parameter Evaluation

- Determine sample loss from customized SP input parameters (stimulation rate, pulse-width, number of electrodes) using a standard **0-150 user-defined MAP**

Experimental Set-Up and Results

- 99.008% of valid configurations resulted in <1% sample loss



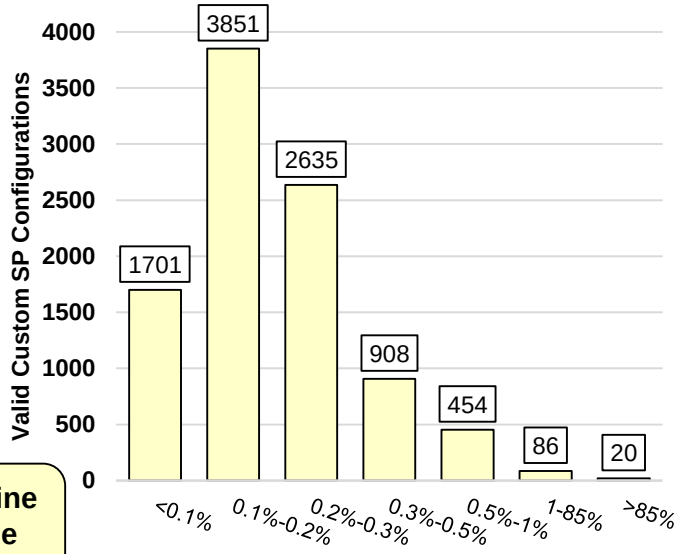


Figure: Histogram of 7 different categories of sample loss as a percentage of the total number of valid configurations.

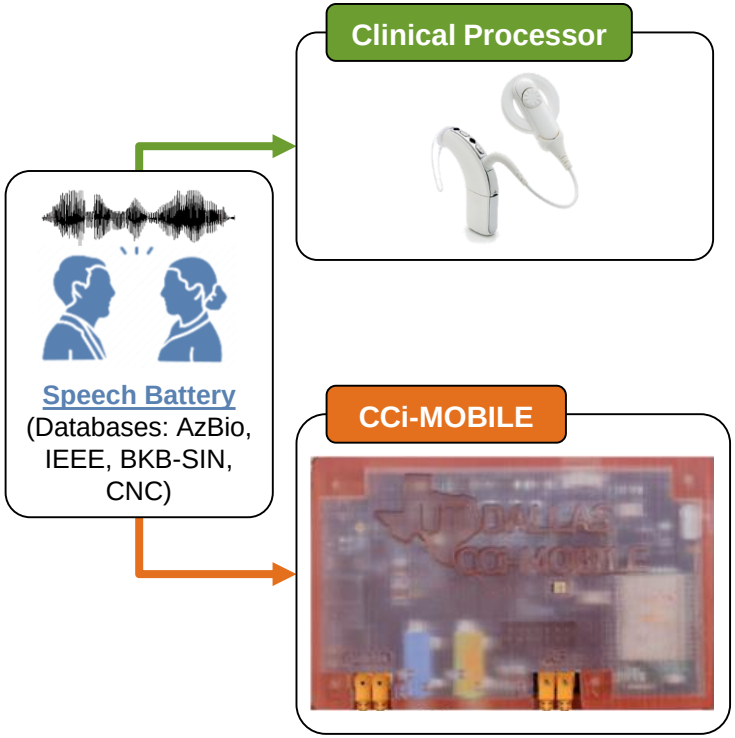
Intelligibility Evaluation

Clinical-Processor-vs-CCi-MOBILE Evaluation

- Compare speech intelligibility of CI users (N=8) using their commercial processors (Cochlear Ltd.) and CCi-MOBILE

Experimental Set-Up and Results

- Comparable performance to clinical processors achieved ($F[7,49]=4.882$, $p<0.069$)



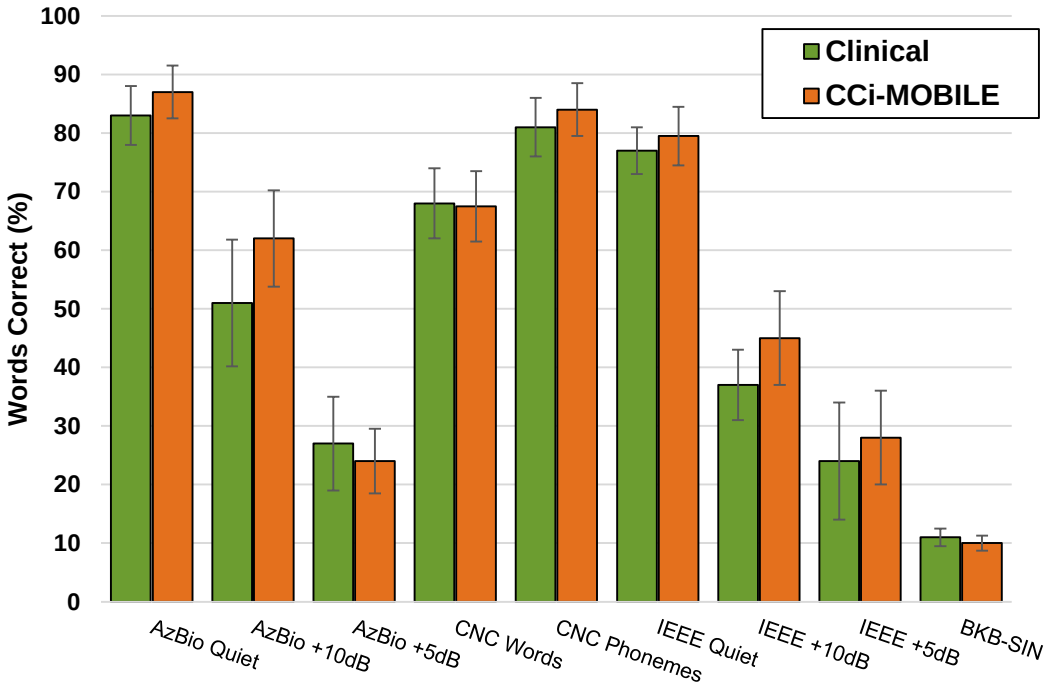


Figure 8. Subject evaluation of commercial processor (green) compared to performance using CCi-MOBILE (orange).

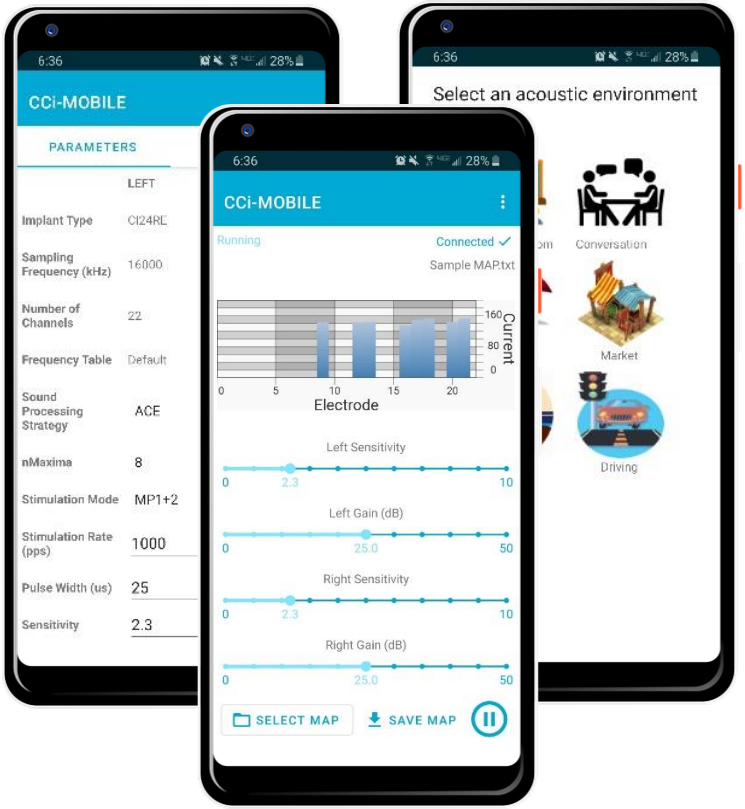
Applications & Android

CCi-MOBILE Applications

- Easily record naturalistic audio using build-in audio-recording application(s)
  - Stereo and mono recordings
- Perform lateralization and localization experiments
- Implementation of novel signal processing algorithms for CIs/HAs
  - Speech enhancement, noise suppression, etc.
- Built-in vocoder application to simulate electric-hearing for normal hearing (NH) listeners[3]

Android App

- Real-time performance on Android smartphones and tablets



- Highly suitable for in-field or take-home trials
- Easily adjust signal processing/MAP parameters in real-time
- Quickly select/define pre-programmed environments

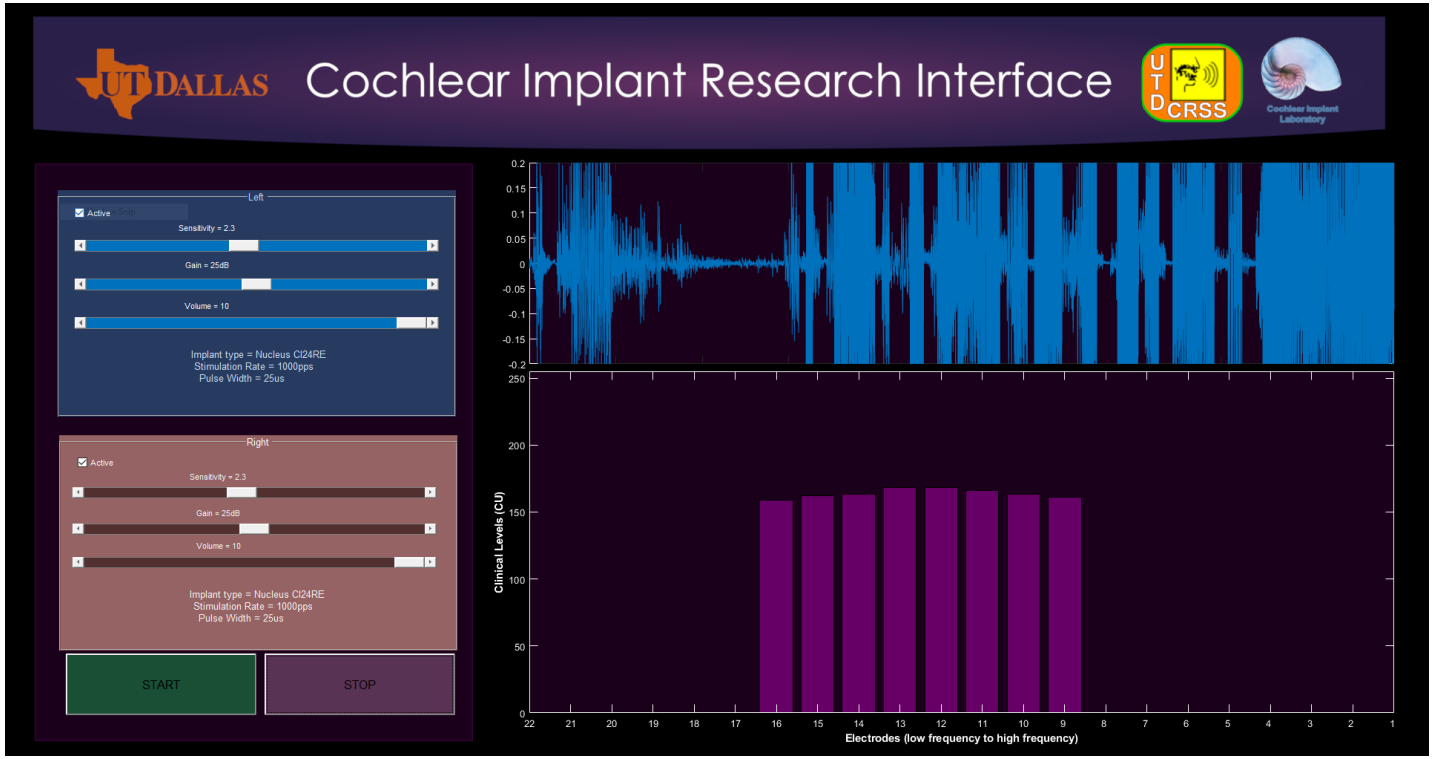
Figure 4. Android app for CCi-MOBILE program windows.

[3] H. Ali, N. Mamun, A. Brueggeman, R.C.M.C. Shekar, J.N. Saba, J.H.L. Hansen (**2018**) Conf. Acoust. Soc. Am., 144:1872.

Software Applications

CCi-MOBILE Demo

- Controls and executes real-time ACE processing and displays the corresponding stimuli.



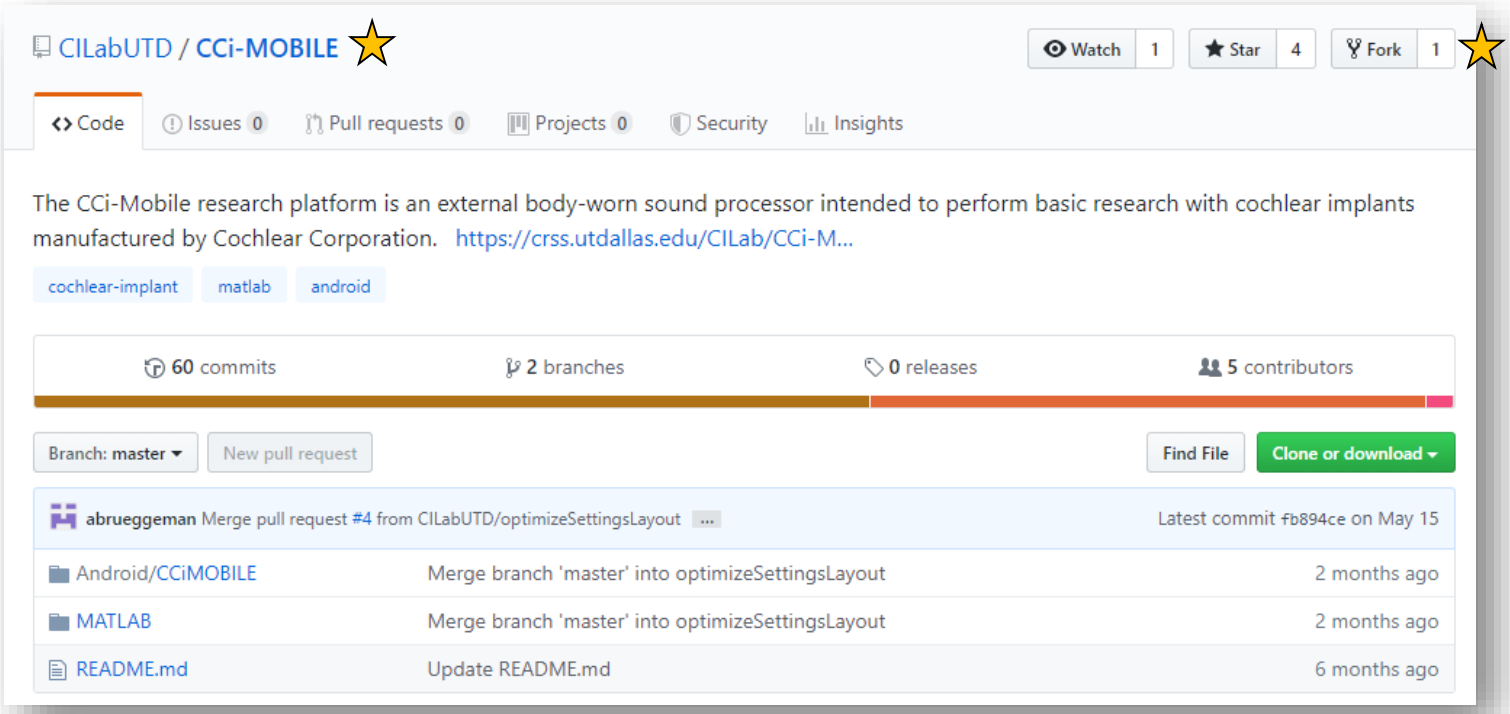
Find Our Code on GitHub

What is a fork on GitHub?

- Fork: a copy of a repository
- Use our code as a starting point for your own project
- Collaborate with us by submitting your changes via “pull requests”

How to fork our code

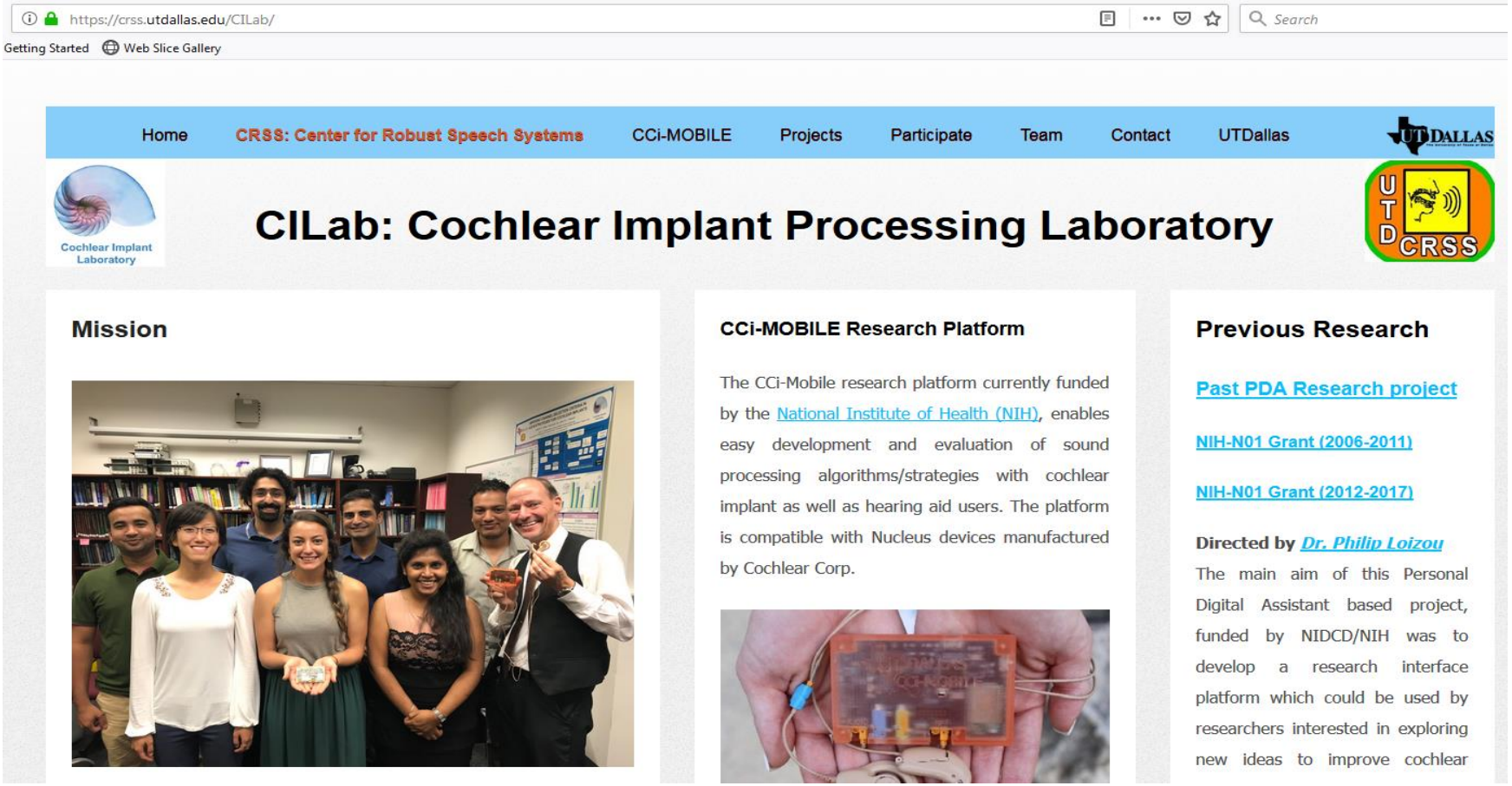
- Go to our repository
- Press the fork button to make your own copy
- Download your fork to save it to your local machine



Website Launched!

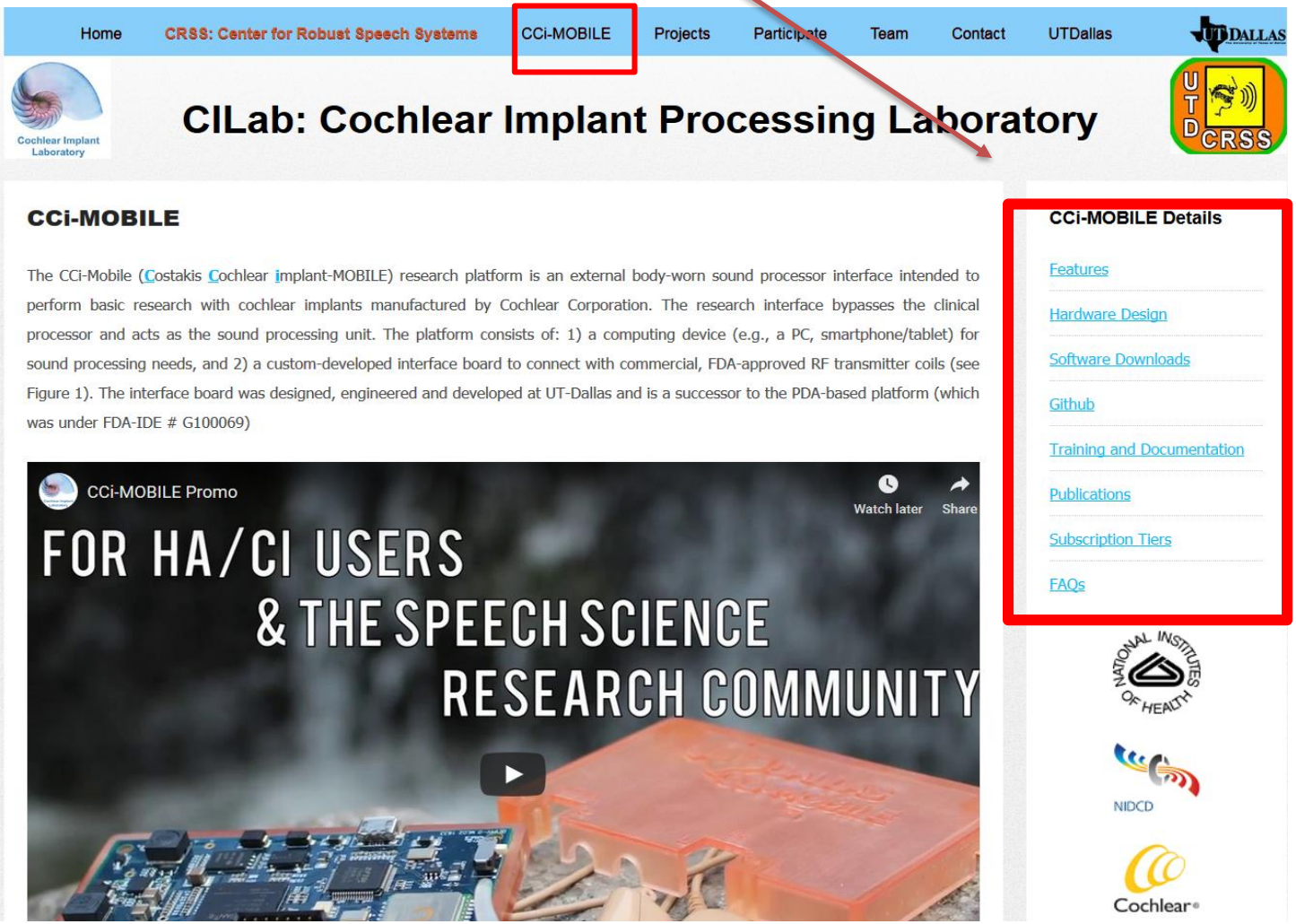
- Website launched Monday, Feb. 25, 2019

https://crss.utdallas.edu/CILab/



Website Layout

- CCi-MOBILE related detailed information



FAQs answered on the website

Home | CRSS: Center for Robust Speech Systems | CCi-MOBILE | Projects | Participate | Team | Contact | UTDallas

CILab: Cochlear Implant Processing Laboratory

Frequently Asked Questions about the CCi-MOBILE

(Click the question for answers)

1. What can the CCi-MOBILE research interface do?
KEYWORDS: purpose, goal, operating specifications, experiments, general, research

A lot! The research platform allows researchers to investigate new HA/CI signal processing, record audio in naturalistic conditions, test real-time algorithms on HA/CI stimulated processors, enable in-lab, in-booth, and field experiments, and exploration of signal processing parameters, MAP parameters, and processing pipelines with more freedom than manufacturer research interfaces. CCi-MOBILE is written in a low-level language environment (MATLAB) with a large number of template user-interfaces, basic implementation, easy-to-adjustment MAP/signal processing parameters, and general applications such as an audio recorder, a visual temporal audio signal, and so much more. The goal of developing the CCi-MOBILE research interface was to stimulate the field of speech science by providing a tool to allow the investigation of otherwise proprietary signal processing techniques and field experimentation outside the general confinements of the sound booth. For applications of how to use CCi-MOBILE for your research, we encourage you to attend one of our conference workshops at appropriate meetings (Acoustical Society, Alliance of Cochlear Implants, Conference on Implantable Auditory Prosthesis, etc.).

2. How can my institution get the CCi-MOBILE research interface?
KEYWORDS: subscription, purchase, rent, obtain, receive, own, membership, tiers

3. Can my institution rent-to-own the CCi-MOBILE research interface?
KEYWORDS: subscription tiers, rent, transfer, upgrade, cost, memberships

4. Is there external support for obtaining CCi-MOBILE?

5. Where does the money for CCi-MOBILE go?
KEYWORDS: cost, money, motivation, rationale, intent, purpose, hardware

6. Is CCi-MOBILE safe to use with cochlear implant and hearing-aid users?
KEYWORDS: safe, clinical level, standards, safety, limitations

CCi-MOBILE Details

- Features
- Hardware Design
- Software Downloads
- Github
- Training and Documentation
- Publications
- Subscription Tiers
- FAQs

NIDCD

Cochlear

CCi-MOBILE: Q&A release notes

CCi-MOBILE Research Interface
for Cochlear Implant and Hearing-Aid Research
Release Notes: Jan-22-2019

These release notes address the following from version 2.2c:

- Realtime vs. offline processing
- Operating specifications – non-integer number of pulses per frame
- Data loss
- Other possible solutions for non-integer pulses per frame
- User-specified MAP and signal processing parameters
- Data communication

Question: Is there a difference between real-time and offline processing?

ANSWER: Yes. Differences between real-time and offline include: pre-emphasis step, user-specific parameter adjustment, communication to the board, and a few minor function calls/for loops. The real-time implementation was specifically designed to minimize the latency in data communication and signal processing. The offline implementation was predominately adopted from Nucleus MATLAB Toolbox (Cochlear

- For engineers, compare the functions (CCi-MOBI
  (CCi-MOBIE\MATLAB\Realtime) 'ACE_Processin

Question: What is the operating specification: 'non-integer n

ANSWER: Non-integer pulses per frame will result in a selecting
(i.e. 4 samples verses 4.348 samples). The number of pulses pe
stimulation rate (Hz) and the number of selected electrodes ('n-m
samples used in the overlap-and-add method (i.e. the variable,
demonstrated in equation [2]. To account for this, a change in the
of pulses.

$$Pulses_{total\ for\ 1\ RF\ cycle} = \left[\frac{(Frame_{(seconds)}}{(\frac{Fs}{Stimulation\ Ra}}\right.$$

$$Block\ shift_{(samples)} = \left[\frac{Fs}{(Stimulation\ Rate)}\right.$$

Question: Is CCi-MOBILE losing data and/or dropping samples?

ANSWER: It is dependent on the real-time and/or offline implementation.

- For offline ACE/CIS implementation, there is not a loss in data. The remaining non-integer data bytes (RF cycles) are processed with the subsequent frame and the remaining byte-size shift is applied throughout the entire length of the offline speech token to provide stimulation without data loss. Because the signal is processing offline, the buffer function (overlap-and-add) will automatically zero pad the data to ensure all frames can be processed.
  NOTE: Adjustments to the user-specified parameters may ensure no data is lost.
  - For engineers, see the function (CCi-MOBILE\MATLAB\AudioFileProcessor\...) 'Stream.m' lines 38-46 and lines 54-62 (ver 2.2c)
- For real-time ACE/CIS implementation, there is a loss in data. The numerical amount of data loss is in the form of samples. The numerical amount of samples per stimulation cycle (RF cycle) is dependent on the user-specified stimulation rate. The maximum number of dropped samples is equivalent to: (sampling frequency) / (stimulation rate)[1]. **NOTE**: Adjustments to the user-specified parameters may ensure no data is lost.
  - For engineers, see the function (CCi-MOBILE\MATLAB\Realtime\...) 'ACE_Processing_Realtime.m' line 7 (ver 2.2c), variable output 'z' are the dropped samples.
  - **NOTE**: While there is a loss in a small amount of data for the real-time implementation of ACE/CIS, the subject performance (N=8) with their clinical processor against the real-time implementation of ACE/CIS

[1] NOTE: A non-integer value from this calculation will be rounded toward positive infinity (i.e. the MATLAB function, 'ceil')

Cochlear Implant Processing Laboratory
The University of Texas at Dallas

FDA guidelines

- CCi-MOBILE platform is meant for “non-clinical” experimental investigation of research ideas
- Platform does not fall under the scope of an FDA IDE
- Your organization must have IRB approval from your respective institution to conduct any human testing.
- CRSS-CILab submitted an Overview Summary of CCi-MOBILE to FDA to assess FDA-IDE status; their response:

> “…we have determined that your study does not fall within the scope of the IDE regulation, and an IDE application is not required to be submitted to FDA for your proposed study.”
> FDA – Feb., 2017

CCi-MOBILE: IRB & NIH supplement

- IRB: CCi-MOBILE platform is intended for research investigations; if you need help with n IRB, we can provide you with sample IRB for which you can obtain IRB approval at your institution.
- Hardware Cost: There is a cost for CCi-MOBILE Hardware production; all funds from hardware are folded back to support hardware units in the field (update, repair, etc.); as well as produce additional units for distribution
- Various User Options: full ownership (2 or 1 platform), year lease; monthly lease ($15k - $250/month)
- NIH Investigators – you can submit a supplement request to obtain CCi-MOBILE; CRSS-UTDallas will provide you with a sample request letter if needed.

Availability

Open source software, and Hardware available to the research community

(35 New Platforms recently completed; an Access Sub-Committee from multiple institutions will review all requests and make recommendations**)**

Contact us on how you can get one

CRSS - Cochlear Implant Laboratory

CCi-MOBILE Workshop AGENDA

- 4:00-4:20: **Overview Presentation on CCi-MOBILE**
  General functions & capabilities; web-site support; technical MEMOs; GetHub software; Hands-On Stations demo'ing software, hardware, and Android development software - share on GetHub for the community.

- 4:20-5:00: **PANEL DISCUSSION (Q&A)**
  Open panel discussion by Users of CCi-MOBILE research platform;
  - experiences? Areas to expand/improve on? Wish list?

- 5:05 – 5:45: **Hands-On Experience:**
  Attendees to talk with UTD team members at stations covering:
  Matlab software available; hardware – including Burn-In testing/safety; Android smartphone support; IRB support; NIH researchers access

- 5:45 – 6:00: **Final Q&A session:**
  opportunity for follow on questions from attendees.

PANEL DISCUSSION (Q&A)


Mario Svirsky (NYU);


Tanvi Thakkar (UW – Madison)


John Cadwell CADWELL®


Alan Kan (Sydney & UWM)


Mahan Azadpour (NYU)

- **Initial Impressions/Experience: CCi-MOBILE platform**
- **What Testing Have you done? Research Plans/Interests?**
- **Given BASE OPEN Source software Suite, issues in coding?**
- **What new directions could CCi-MOBILE be used for?**
- **Wish List? – what support/directions/options do you need?**

CCi-MOBILE Workshop AGENDA

- 3:00-3:20: **Overview Presentation on CCi-MOBILE**
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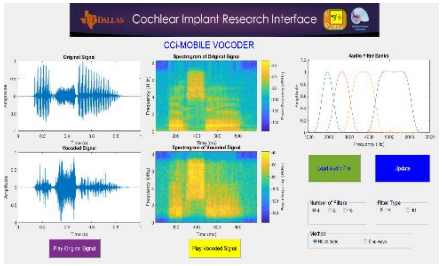
STATION #1: MATLAB Software Demo

Audio Scope

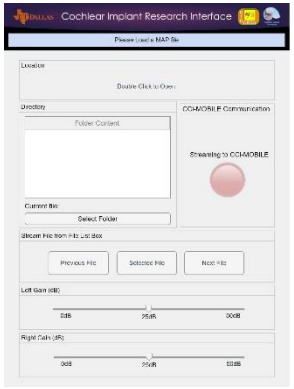
Vocoder

NEW



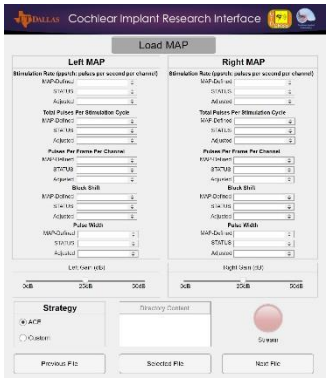
AudioFileProcessor

NEW



Custom Signal Processing

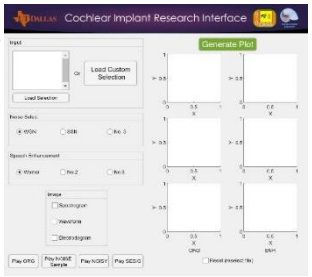
NEW



RealtimeStimulator

Speech Enhancement

NEW



Station Leader(s)

- **Name:** Juliana N. Saba
- **Year:** Y3 PhD Student
- **Research Areas:** Lombard Effect, CI Signal Processing Strategies

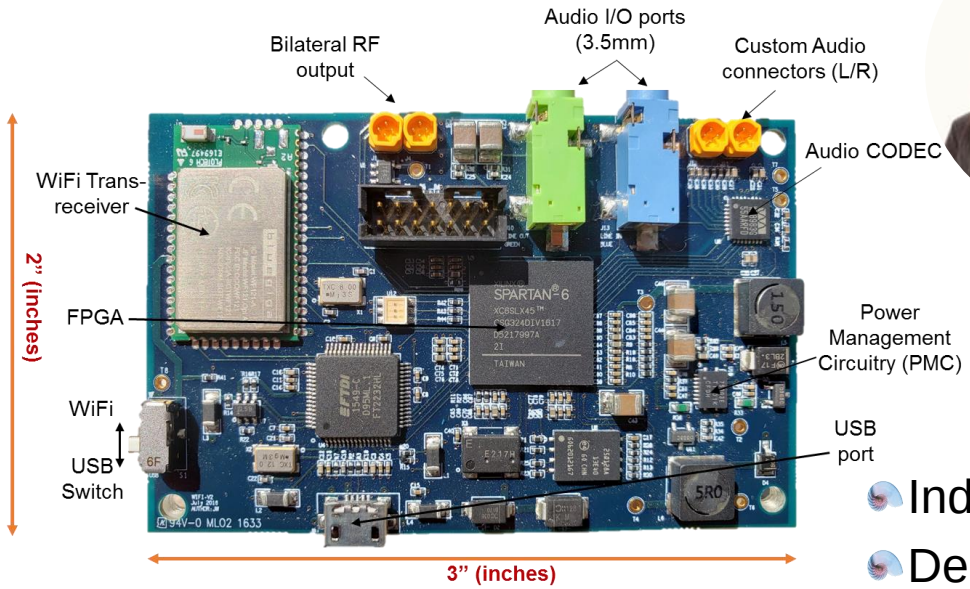
- **Name:** Nursadul Mamun
- **Year:** Y1 PhD Student
- **Research Areas:** Speech Enhancement, Machine Learning for CI

Station Overview

- Demo of Desktop Applications (AudioScope, AudioRecorder, AudioFileProcessor, RealtimeStimulator)
- **Demo of Vocoder, Speech Enhancement, Custom Signal Processing Applications**
- How to create custom GUI (AppDesigner)
- How to use/run MATLAB Scripts

STATION #2: Hardware Demo

Hardware Overview



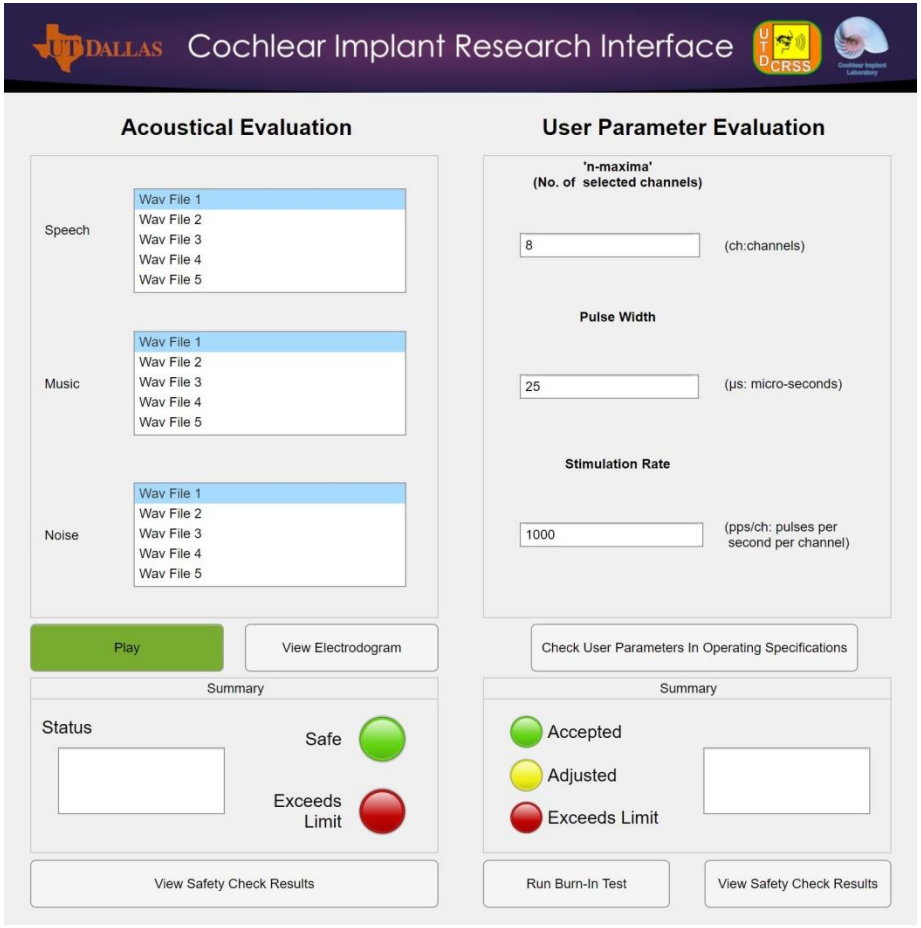
Station Leader

- **Name:** Ria Ghosh
- **Year:** Y1 PhD Student
- **Research Areas:** Hardware and Firmware Development

Station Overview

- Individual FPGA Components of CCi-MOBILE
- Demo of Desktop Application (CCi-MOBILE Demo)
- How CCi-MOBILE Communicates with Tablet/PC
- How CCi-MOBILE Communicated Stimuli/RF Data using UART/FPGA Routines

STATION #3: SAFETY & TESTING DEMO



Station Leader

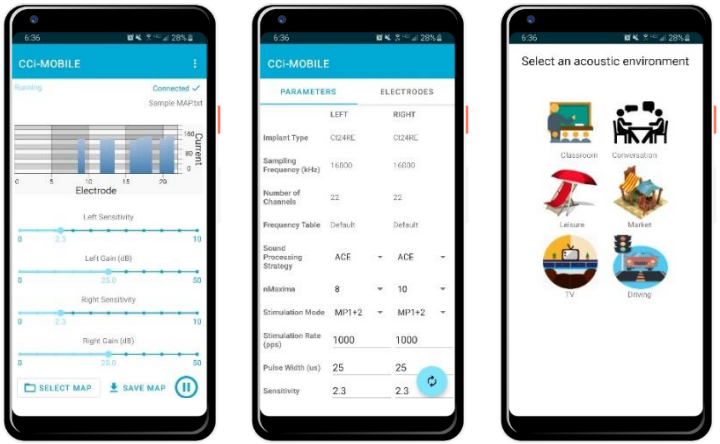
- **Name:** Ram Charan M. Chandra.Shekar
- **Year:** Y3 PhD Student
- **Research Areas:** Safety and Performance Assessment of Research Platform

Station Overview

- Safety and Performance Assessment
- Acoustical Diversity Assessment
- User Specified Parameter Testing

STATION #4: Android App Demo

Android App Overview



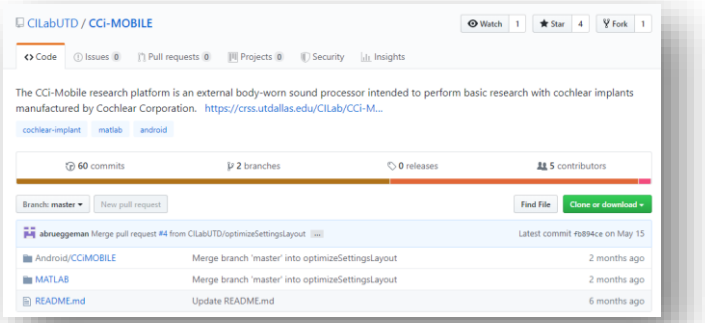
Station Leader

- **Name:** Avamarie Brueggeman
- **Year:** Y1 PhD Student
- **Research Areas:** Music Appreciation for CIs, Machine Learning

Station Overview

- How to run the Android app
  - Selecting a MAP file
  - Streaming to the board
  - Adjusting realtime parameters
  - Saving the new MAP file
- How to find our open-source code
  - How to fork a GitHub repository

GitHub Repository



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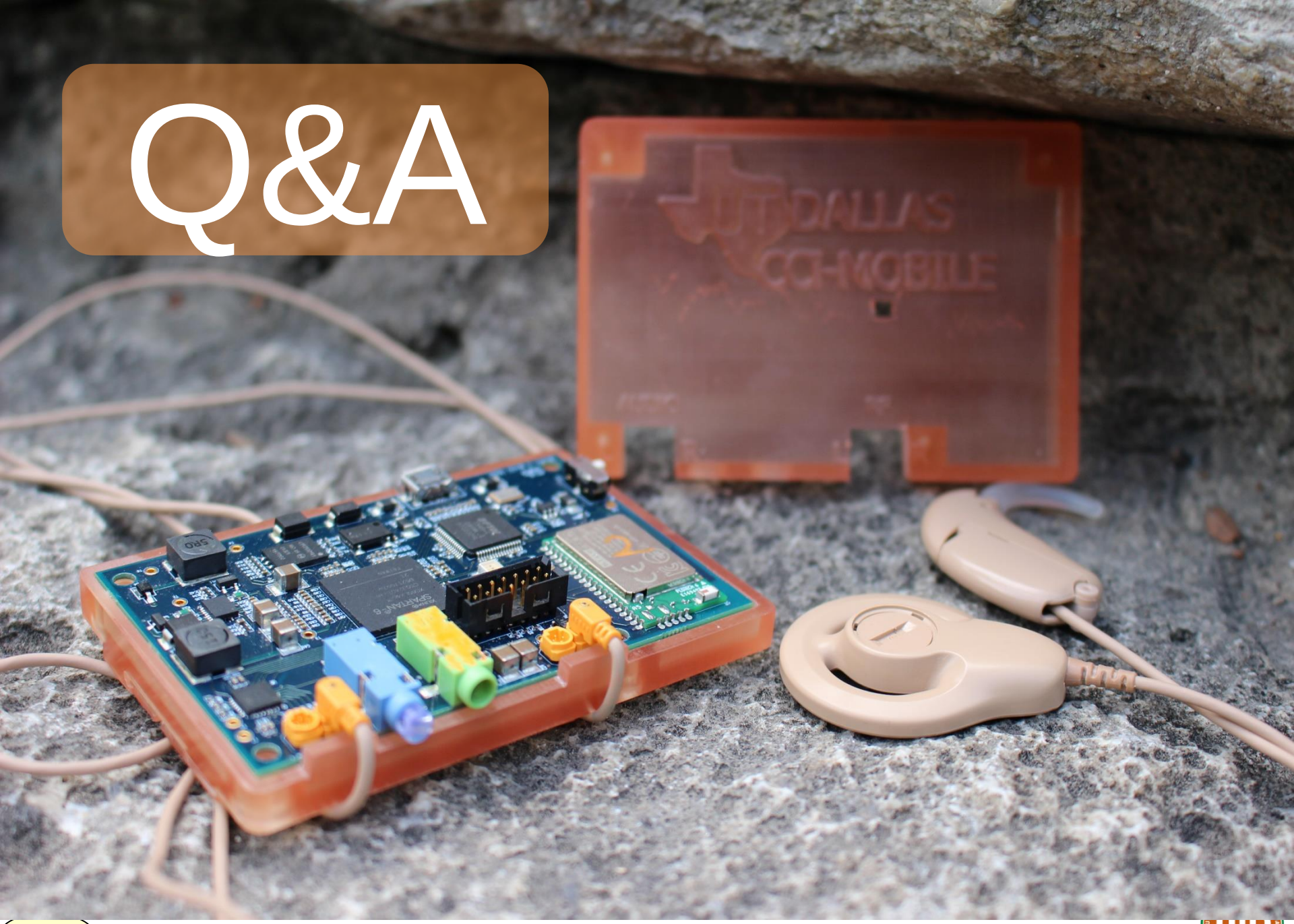
Conclusions

- CCi-MOBILE is an open-source, flexible research platform compatible with cochlear implants and hearing aids
- Easy-to-use, adaptable applications and templates available for speech scientists in a high-language environment
- Hardware and software verification routines ensure safety and reliability of CCi-MOBILE
- Suited to address multi-disciplinary hearing research topics such as: speech-in-noise, sound localization/lateralization, speech enhancement, custom environmental MAP changes, etc.
- Enables bench-top, in-lab, and field experiments for all speech and hearing scientists

Q&A



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