Mission Critical Voice Speech-Based Access Time Measurement

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#PSCR2019

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***Please note, unless mentioned in reference to a NIST Publication, all information and data presented is preliminary/in-progress and subject to change**

Overview

- User Experience for Push-to-talk (PTT) Communications
- Access Definitions in Other Standards
- Speech Intelligibility
- Measurement Concept
- Measurement Results
- Future Work

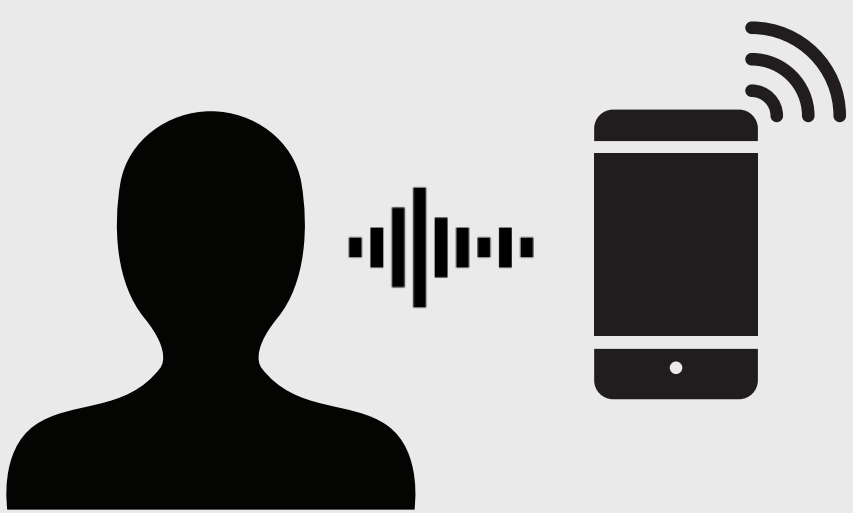
The User Experience: PTT Communications

- **Press PTT and speak into a device**
- **Listening to speech output from a device**
- **It's all about speech**

- **Goal - Create an access time measurement system that is:**
  - **Based upon the user experience -- speech**
  - **Comparable and fair across technologies**
- **This is not:**
  - **Diagnosing internal components of specific systems**

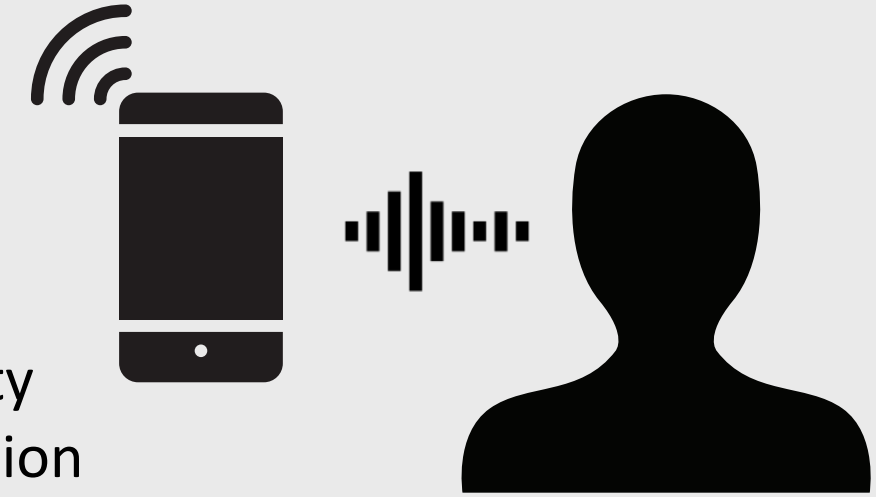
Technology Agnostic Measurements

Communications System



KPIs:

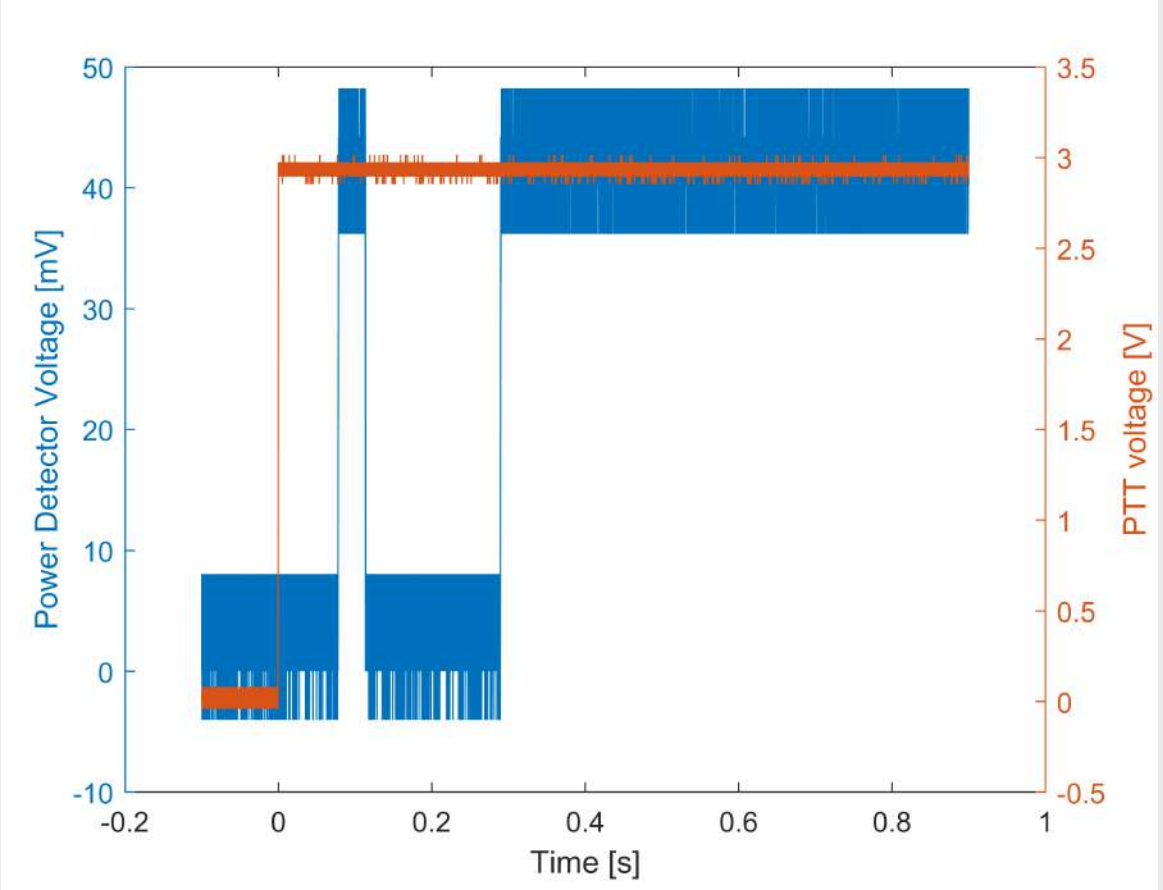
- Mouth-to-ear Latency
- End to End Access Time
- Audio Quality/Intelligibility
- Access Probability/Retention



Access Time in Other Standards

TIA-102 P25 Standard

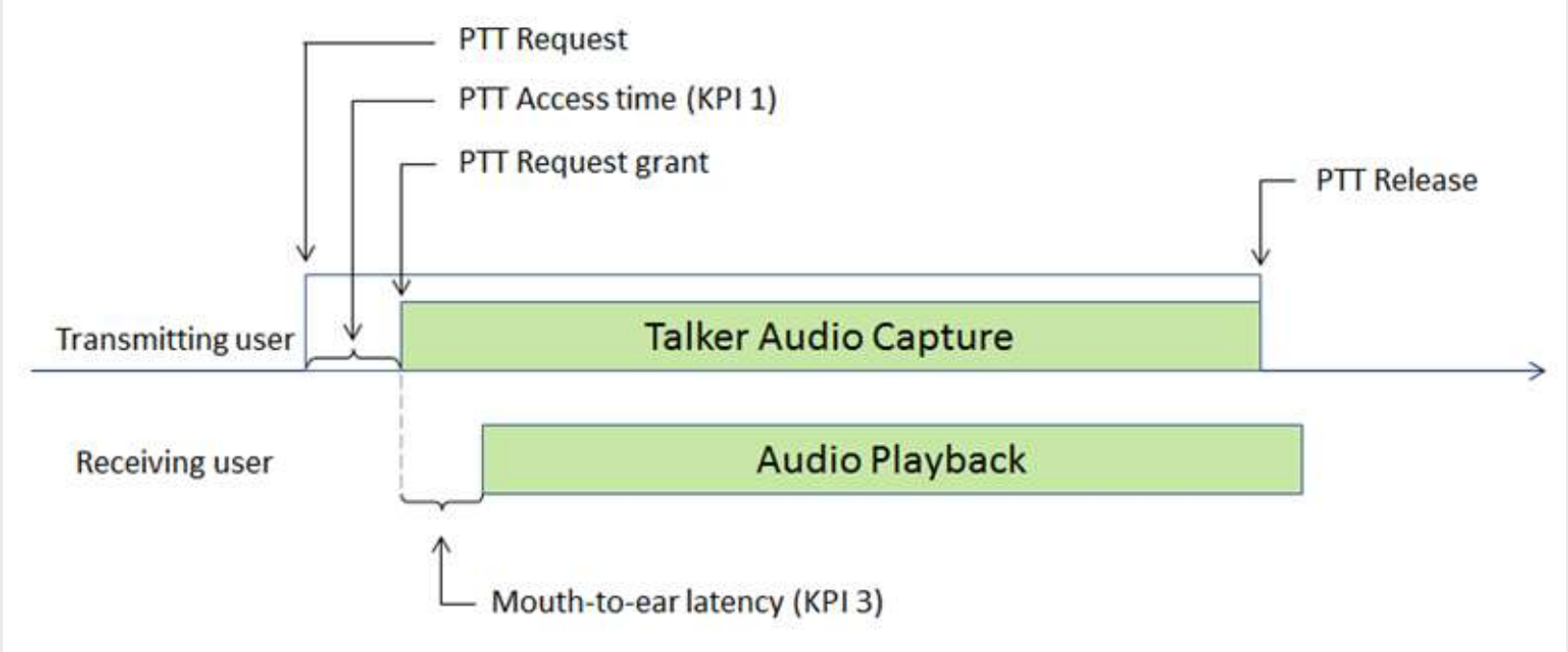
- **TIA-102 P25 Access Time**
  - **Completely focused on transmitting user**
  - **No reference to receiving user**
  - **No reference to speech**



Access Time in Other Standards

3GPP LTE PTT

- **3GPP M2E Latency and Access Time[1]**
  - Primary definition focused on transmit user
  - End-to-end **definition incorporates acknowledgement by receiving user**
  - **No guarantees on what receiving user experience is**



1: 3GPP (2017) Mission Critical Push to Talk (MCPTT). 3rd Generation Partner-ship Project (3GPP), Technical Specification (TS) 22.179. Version 16.0.0 URLhttps://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=623.

Access Time in Other Standards

Compatibility Across Technologies

- **TIA Access**
  - **Analog FM LMR**
    - **Technically compatible**
    - **Not meaningful**
  - **P25 Direct**
    - **Technically compatible**
    - **Not meaningful**
  - **LTE**
    - **Not compatible**
- **3GPP Access**
  - **Analog FM LMR**
    - **Not applicable**
  - **P25 Direct**
    - **Not applicable**
  - **P25 Trunked**
    - **End-to-end definition is compatible and meaningful**

User Driven Access Definition

- **End-to-end Access Time**
  - ***The total amount of time from when a transmitting user first presses PTT until a receiving user hears intelligible audio.***
- **Two Components:**
  - **Mouth-to-ear Latency**
    - ***The time between speech being input into one device and its output through another***
  - **Access Delay**
    - ***The minimum length of time a user must wait between pressing a PTT button and starting to speak to ensure that the start of the message is not lost***

Formalizing Access Delay

- **Access Delay**
  - **All about if a message is lost or not**
  - **Intelligibility is the key to the measurement**
- **Formal Definition:**
  - ***The minimum length of time a user must wait between pressing a PTT button and starting to speak to ensure that the first word of the message has an average intelligibility that is no lower than*** $\alpha \cdot I_0$
  - $0 < \alpha < 1$, **defines acceptable intelligibility level**
  - I_0 **is the baseline intelligibility of that word through the communications system**
    - **No system is perfectly intelligible**
    - **Some level of degradation almost always present**

Intelligibility

Modified Rhyme Test (MRT)

- **Modified Rhyme Test (MRT)**
  - **Used to test intelligibility of SCBA masks[1]**
  - **Batches of six words**
    - ***went, sent, bent, dent, tent, rent***
    - **Words: consonant-vowel-consonant**
    - **Each batch: Either leading or trailing consonant varies**
  - **MRT Trial**
    - **Carrier phrase + word**
    - **e.g. "Please select the word *went*"**
    - **Success (identified) or Failure (mis-identified)**
  - **Over lots of trials scores are generated**
    - **Score is value between 0 and 1**
    - **Corrected for guessing**
  - **High time cost**

1: NFPA 1981 Standard on open-circuit self-contained breathing apparatus (SCBA) for emergency services (2007)

Intelligibility

Intended Use Case Examples

Batch: *fun, sun, bun, gun, run, nun*
Distortion: Background noise + system

- **Extreme** 
- **Moderate** 
- **Mild** 
- **None** 

Intelligibility

Articulation Band Correlated Modified Rhyme Test (ABC-MRT)

- **Articulation Band Correlated Modified Rhyme Test (ABC-MRT)**
  - **Objective algorithm to provide estimates of true MRT scores**
  - **Developed by Stephen Voran and DJ Atkinson, ITS-NTIA**
  - **Most recent version is ABC-MRT16**
  - **Relies on temporal correlations within articulation index bands**
    - **Break speech into a “musical score”**
    - **Representation of speech in time and frequency**
  - **Costs: Cheaper and faster**
    - **Relatively low time cost**
      - **Can get estimated MRT scores “on demand”**
    - **Much lower infrastructure cost**

Measurement Concept

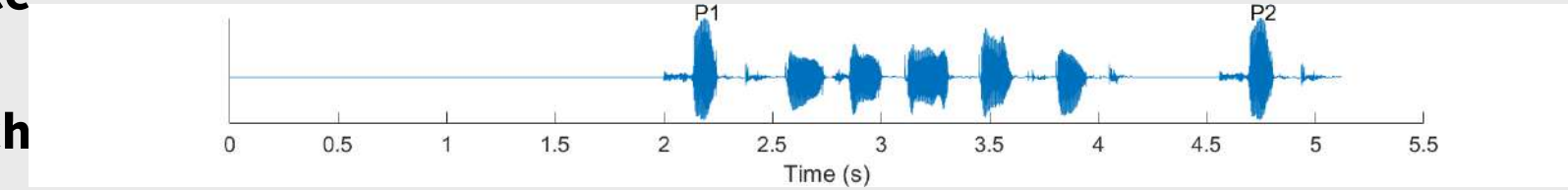
Overview

- **Access Delay definition:**
  - ***The minimum length of time a user must wait between pressing a PTT button and starting to speak to ensure that the first word of the message has an average intelligibility that is no lower than*** $\alpha \cdot I_0$
- **Repeatedly send pre-defined audio clips through communications system**
- **Vary where in the clip PTT is triggered**
- **Measure relationship between PTT time and intelligibility of the first word in the clip**
  - **No more carrier phrase**

Measurement Concept

Audio Clips

- **Select single word from ABC-MRT16 database[1]**
  - **Use only words from batches where leading consonant varies**
    - **E.g. *went, sent, bent, dent, tent, rent***
    - **Places majority of intelligibility emphasis on beginning of word**
- **Structure:**
  - **T seconds of silence**
  - **Play word, P_1**
  - **T seconds of speech**
  - **Play word again, P_2**

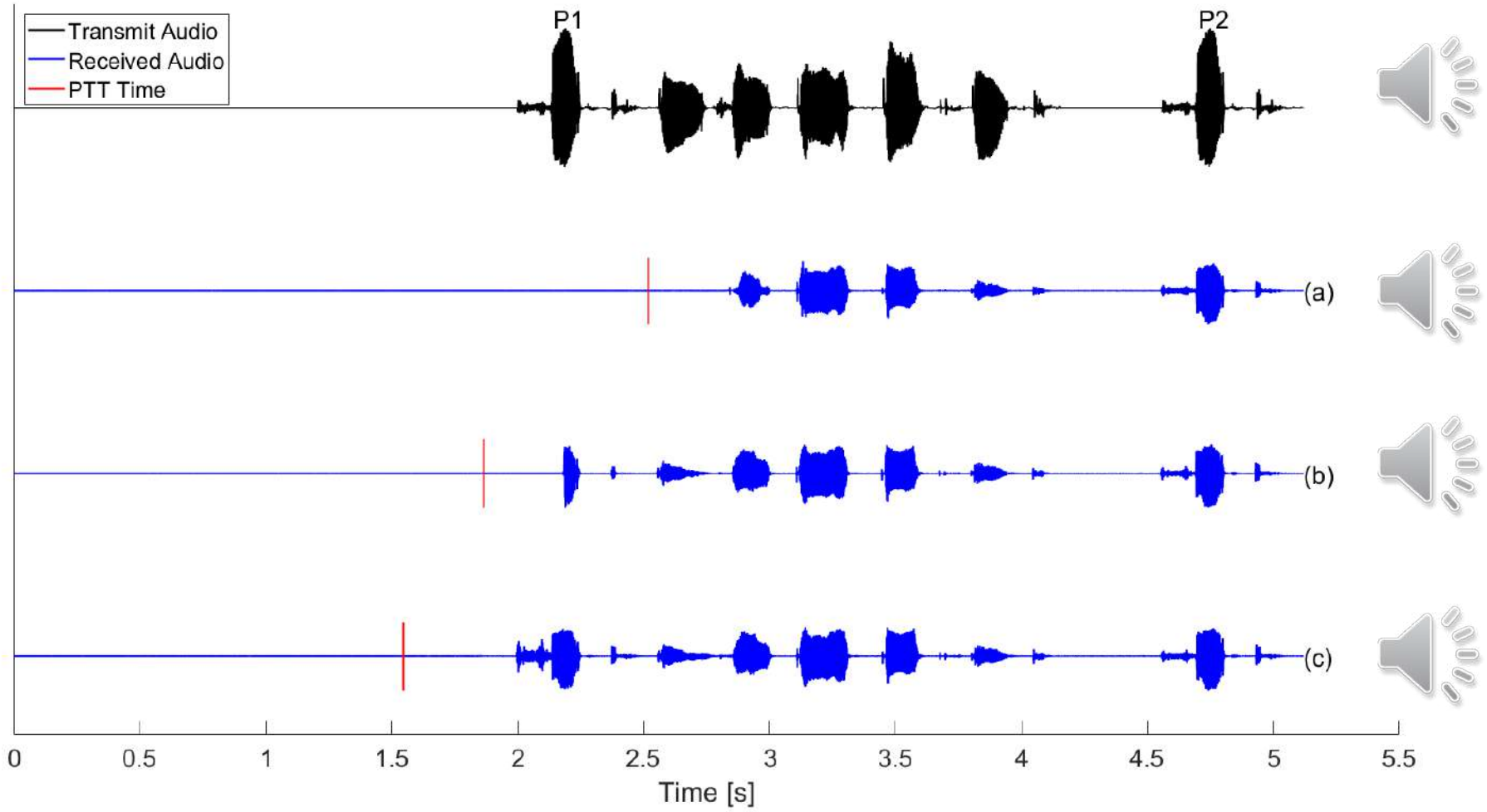


- **T chosen so that system access time is less than T seconds**
- **Intelligibility of P_2 describes the asymptotic intelligibility, I_0**
- **Intelligibility of P_1 relates PTT time with intelligibility**

1: Voran SD (2017) A multiple bandwidth objective speech intelligibility estimator based on articulation index band correlations and attention. 2017 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), pp 5100–5104.doi: 10.1109/ICASSP.2017.7953128

Measurement Concept

Intelligibility Examples: *hook*



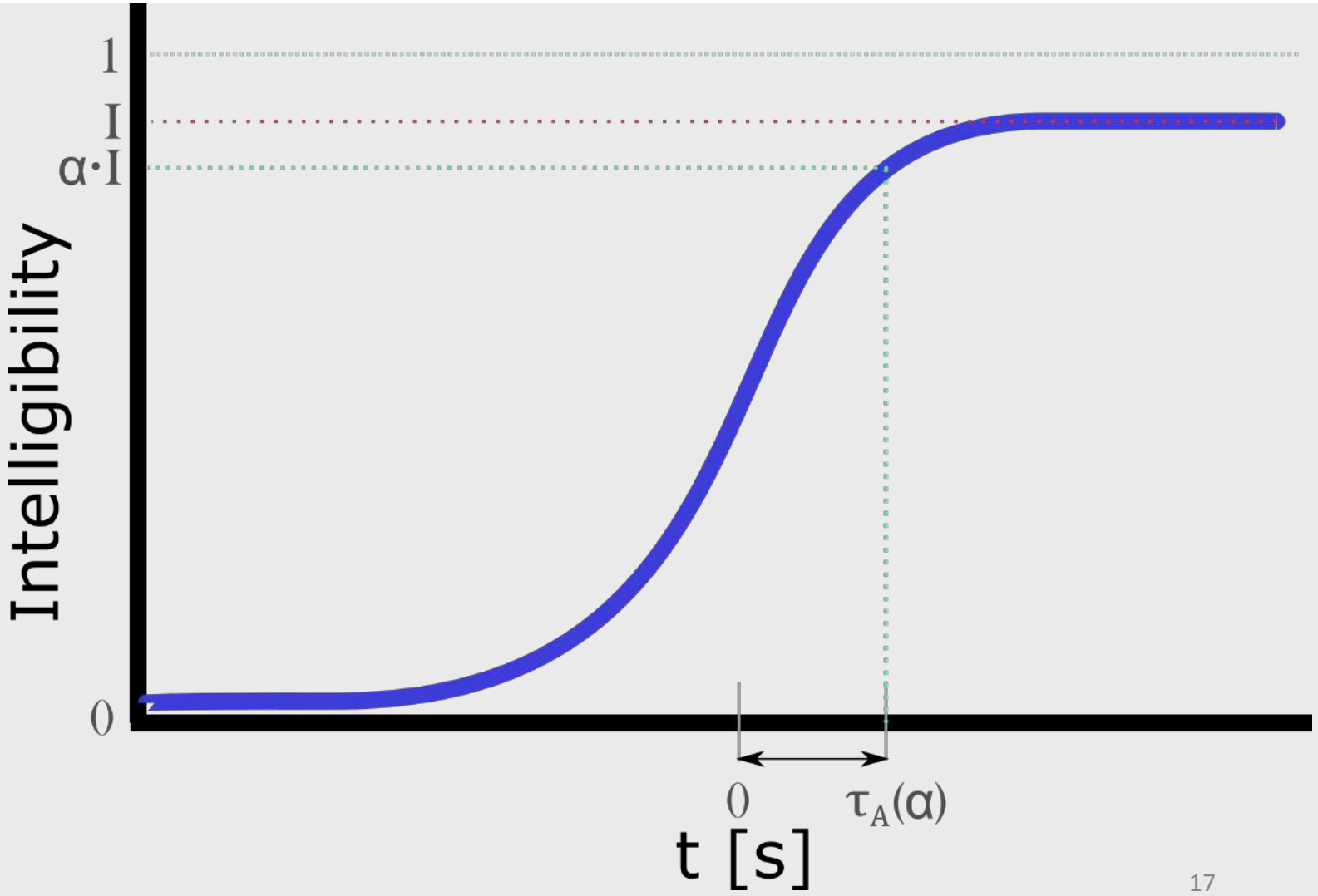
Measurement Concept

Intelligibility Curve

- **Fit a curve to data**
- **Logistic curve has properties we want**

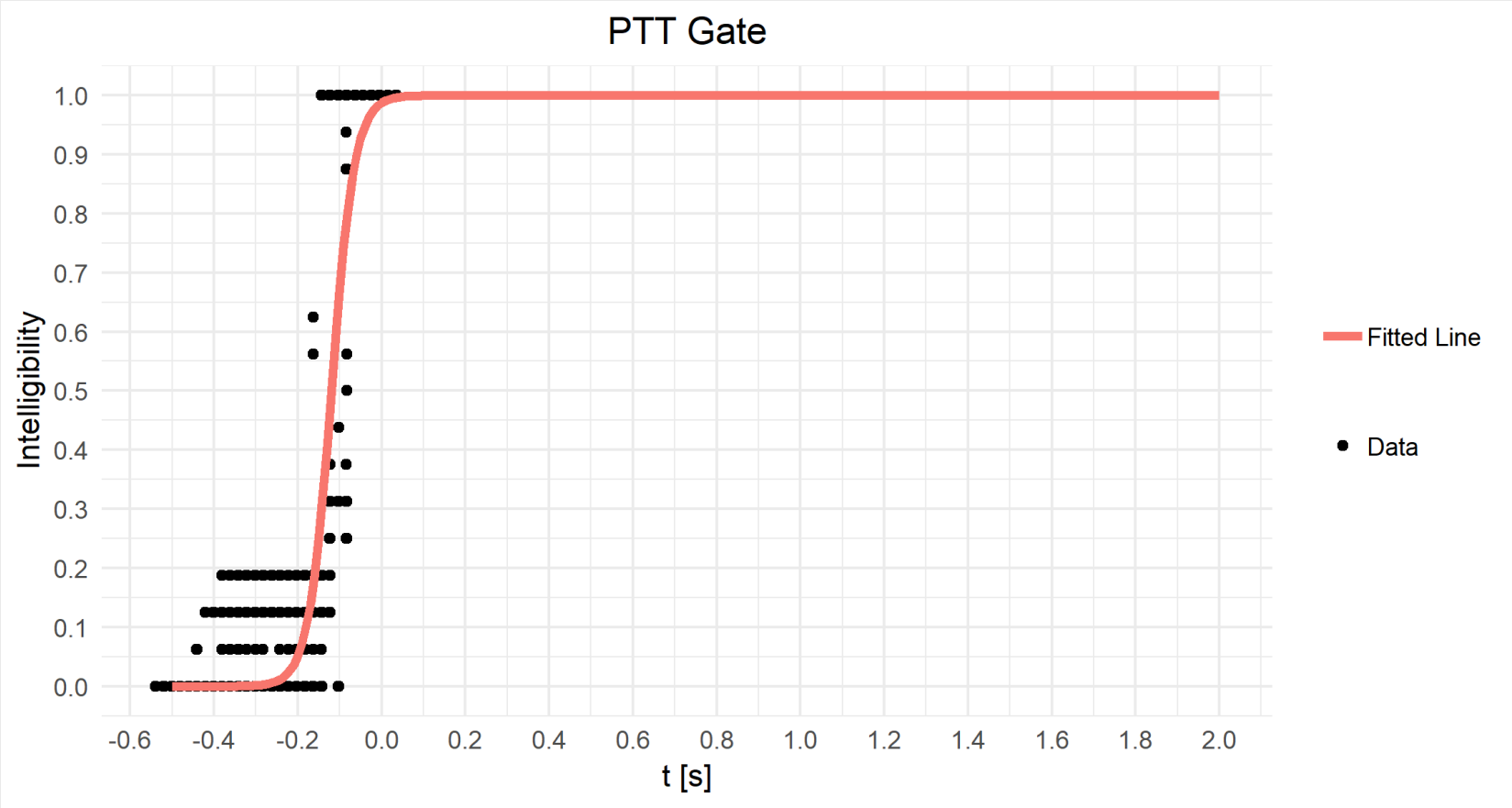
$$I(t) = \frac{I_0}{1 + e^{(t - t_0)/\lambda}}$$

- λ: **Steepness of intelligibility transition**
- t_0: **50% intelligibility point**

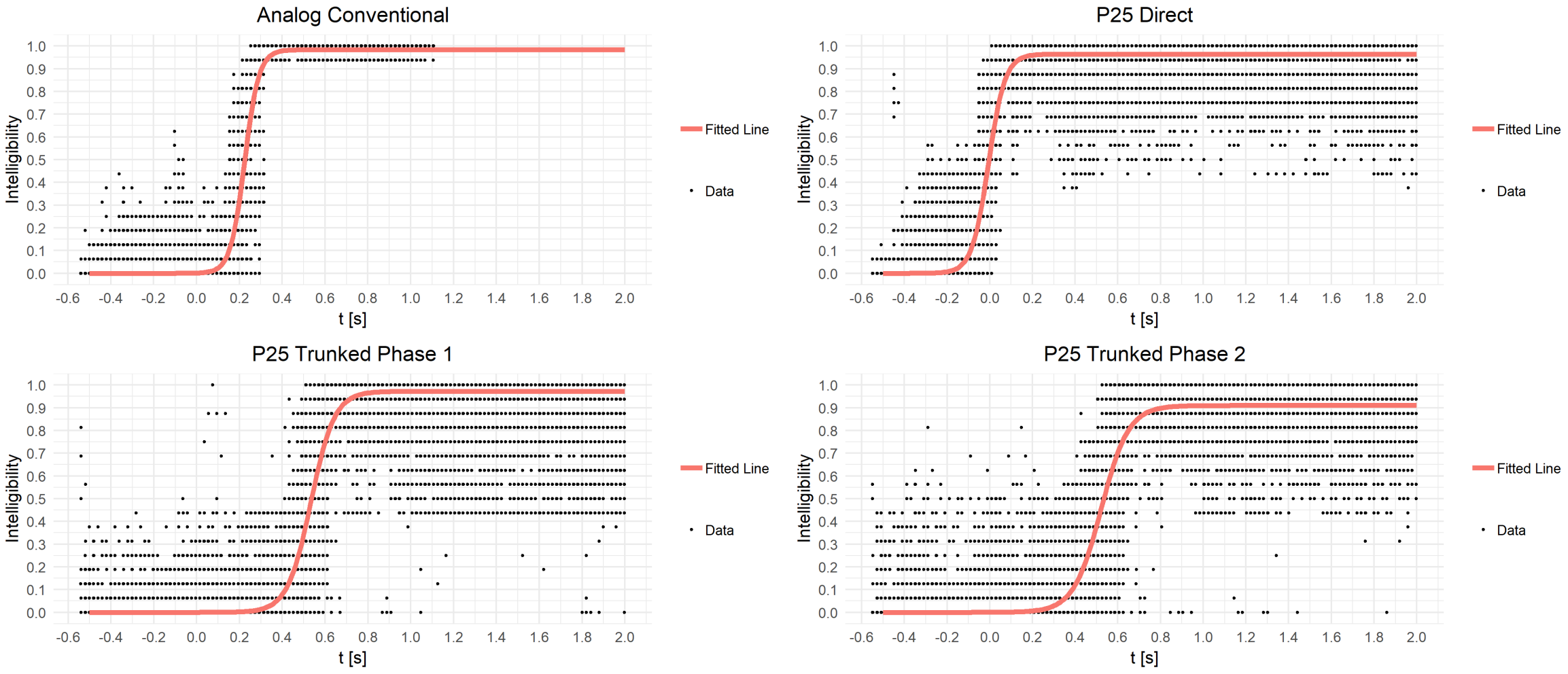


Measurement Concept

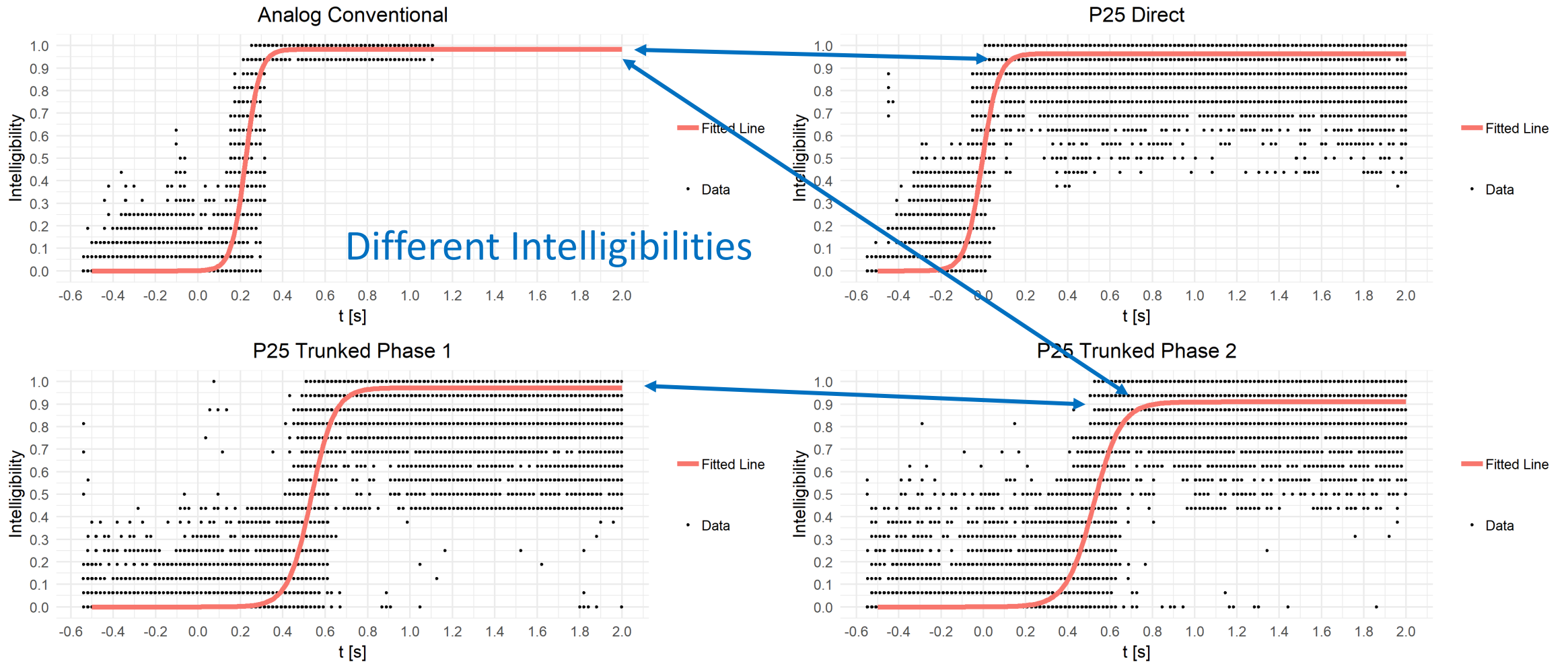
Simple Radio Replacement



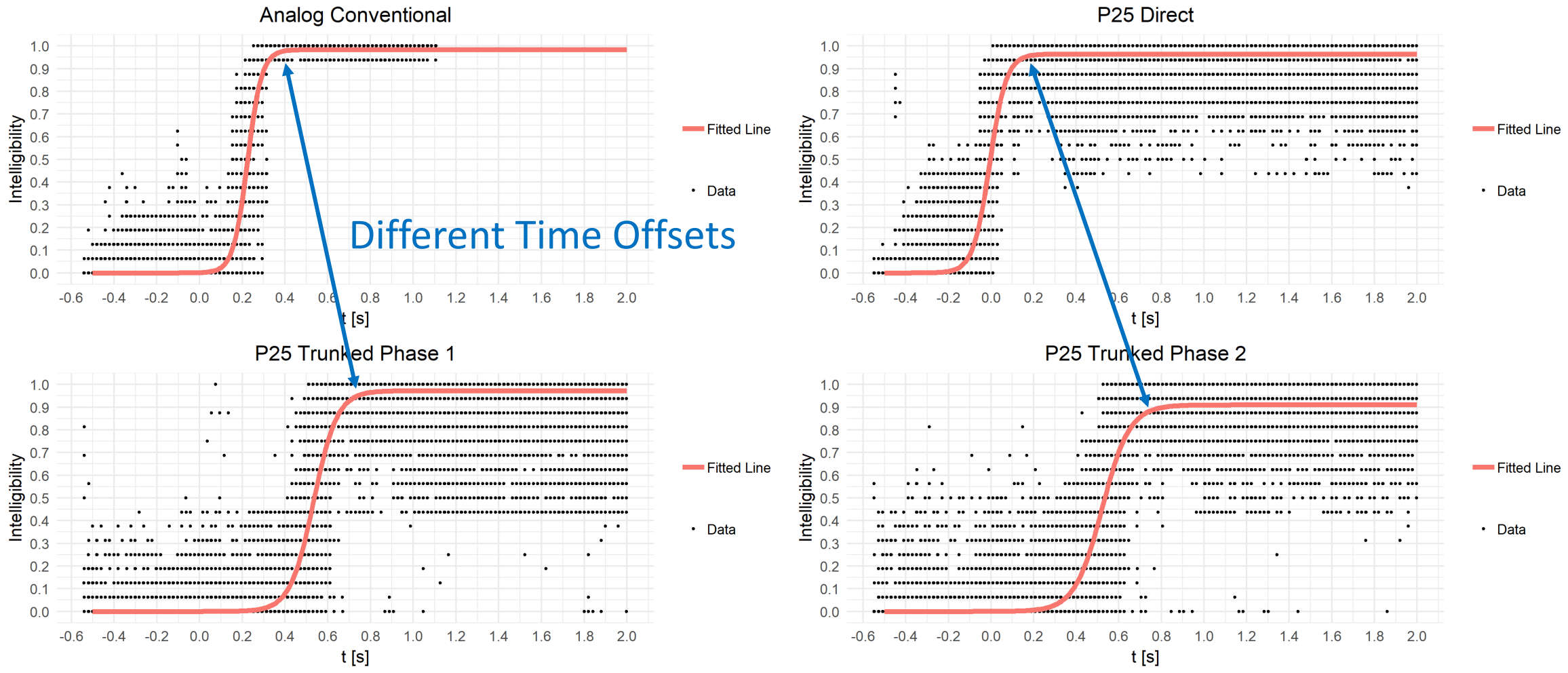
Intelligibility Curves for PTT Technologies



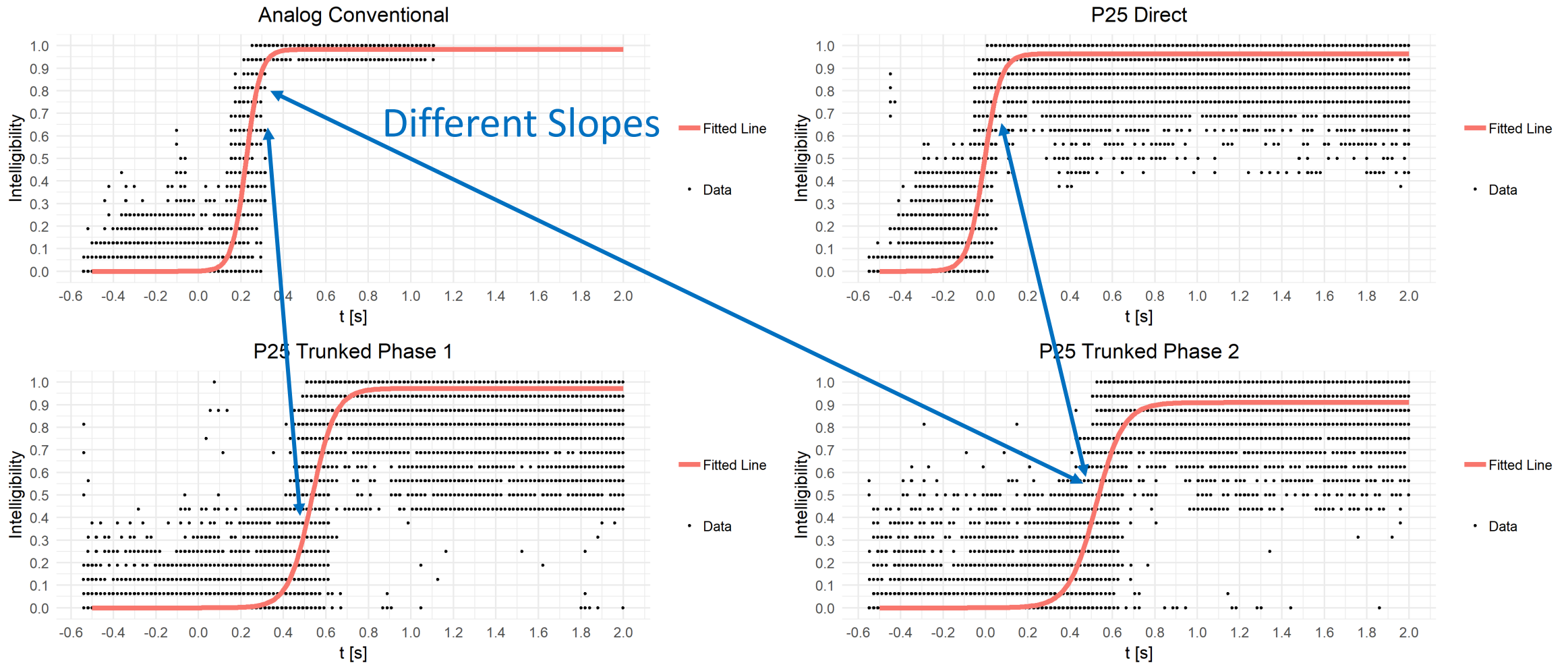
Intelligibility Curves for PTT Technologies



Intelligibility Curves for PTT Technologies



Intelligibility Curves for PTT Technologies



Measurement Concept

Access Delay Function

$$I(t) = \frac{I_0}{1 + e^{(t-t_0)/\lambda}}$$

Given $0 < \alpha < 1$, **an intelligibility of** $\alpha \cdot I_0$ **can be achieved with** $t = I^{-1}(\alpha \cdot I_0)$.

Access Delay defined as:

$$\tau_A(\alpha) = \lambda \cdot \ln\left(\frac{1-\alpha}{\alpha}\right) + t_0$$

Measurement Concept

Uncertainty of Access Delay

For an access delay estimate, $\hat{t}$, for some choice of α:

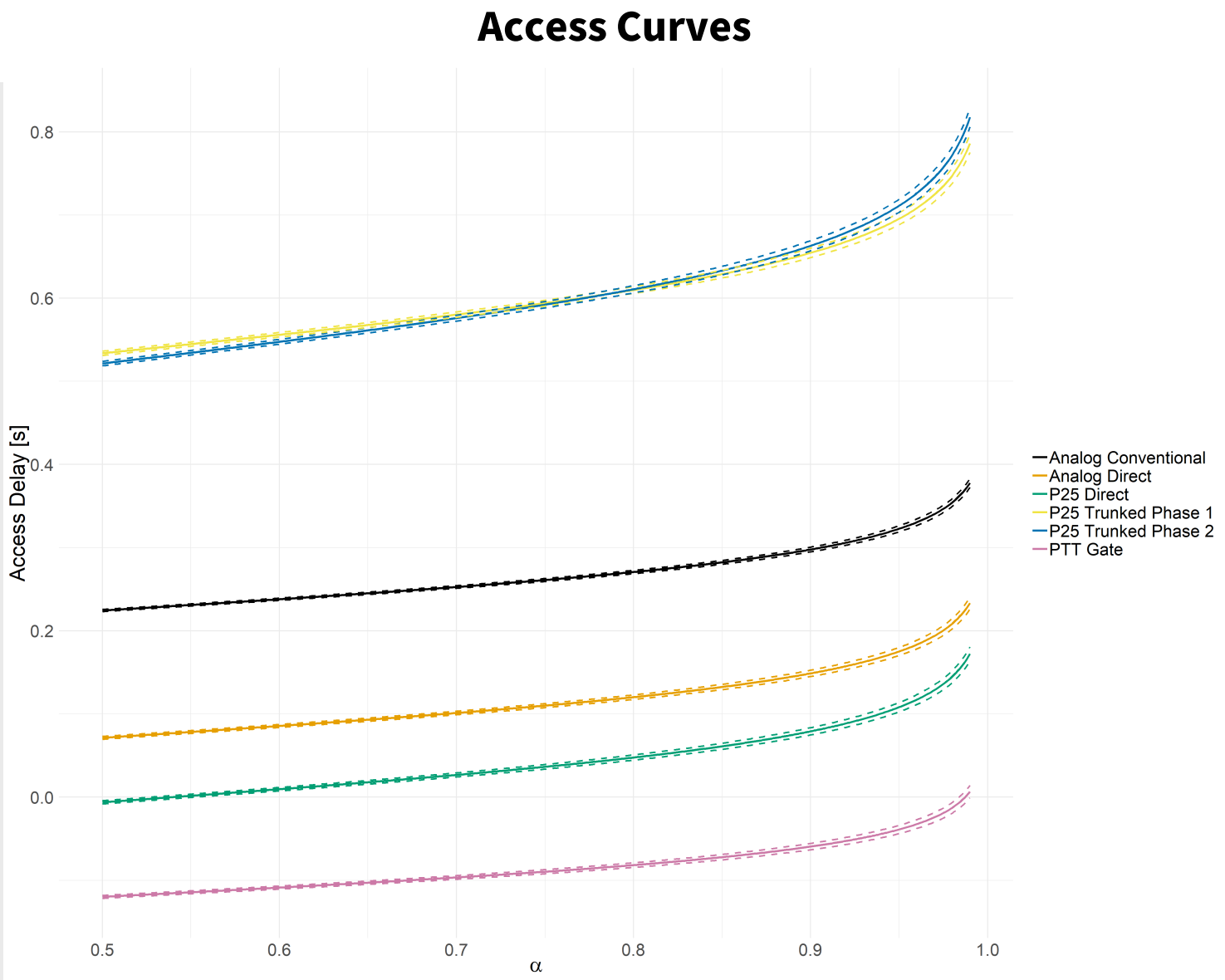
$$\hat{t} = \hat{\lambda} \cdot \ln\left(\frac{1-\alpha}{\alpha}\right) + \widehat{t_0}$$

Let $C = \ln\left(\frac{1-\alpha}{\alpha}\right)$

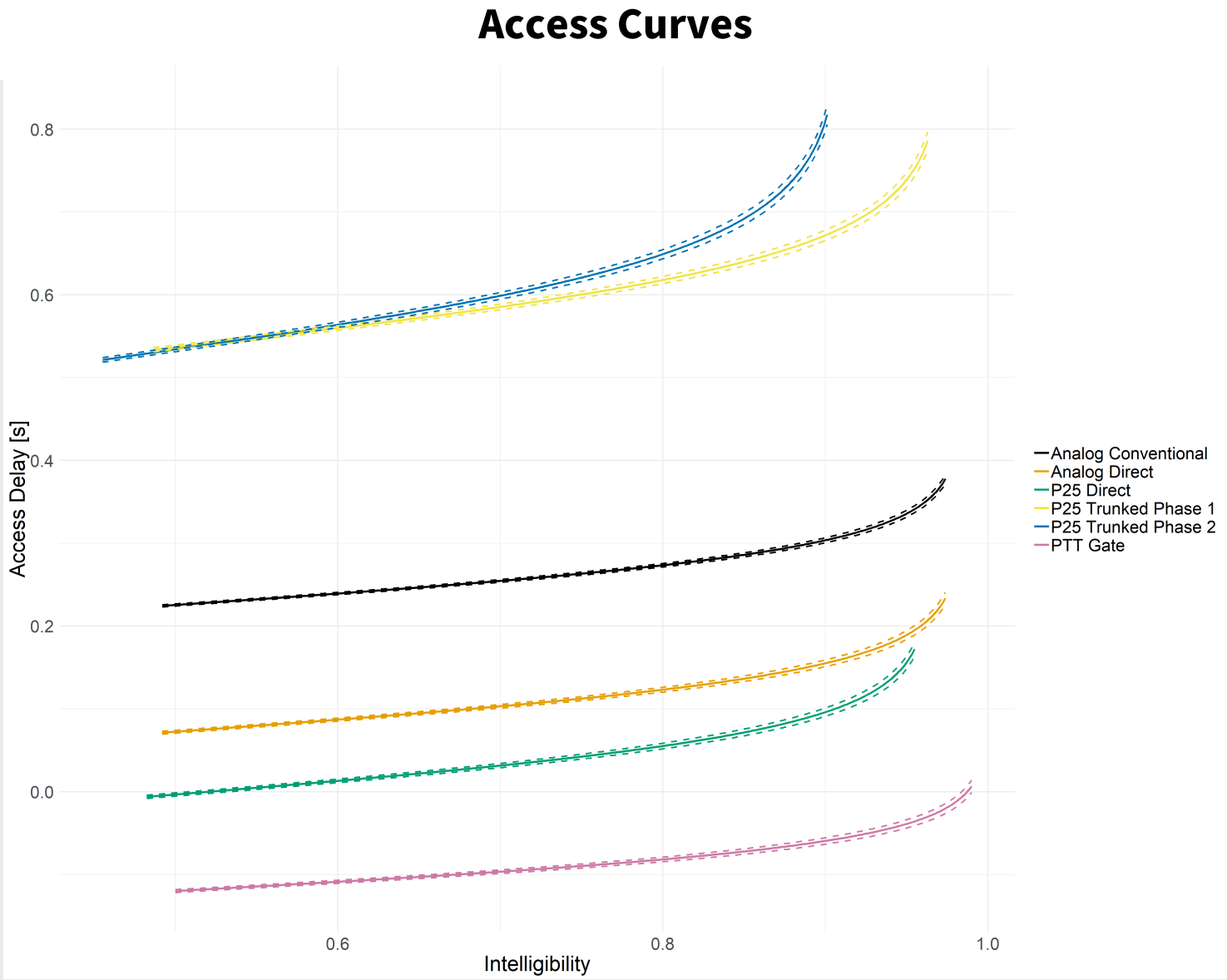
Uncertainty from variance of estimate:

$$\mathrm{Var}(\hat{t}) = C^2\mathrm{Var}\left(\hat{\lambda}\right) + \mathrm{Var}(\widehat{t_0}) + 2C \cdot \mathrm{Cov}(\hat{\lambda}, \widehat{t_0})$$

Measurement Concept



Measurement Concept



End-to-end Access Time Results for 85% Intelligibility

PTT Technology*	M2E Latency (ms)	Access Delay (ms)	End-to-End Access Time (ms)
Analog Direct	76.5 ± 0.3	136.5 ± 3.3	213.1 ± 3.3
Analog Conventional	78.5 ± 0.3	286.1 ± 2.5	364.7 ± 2.5
P25 Direct	220.9 ± 0.3	71.6 ± 4.1	292.4 ± 4.1
P25 Trunked (Phase 1 – FDMA)	356.6 ± 3.8	640.1 ± 5.1	996.7 ± 6.3
P25 Trunked (Phase 2 – TDMA)	575.9 ± 8.1	692.2 ± 7.1	1268.1 ± 10.7

*Analog Conventional operates in VHF band (30 MHz to 300 MHz).
All P25 technologies operating in 700 MHz band.

Please note all information and data presented is preliminary/in-progress and subject to change.

Future Work

Limitations of the Measurement

- **Aggregate Measure**
  - **Only get an access delay value after extensive testing/data collection**
  - **Cost of measuring the whole curve is very high**
- **ABC-MRT never tested under these impairments**
  - **No guarantee that the MRT estimates are accurate for partially muted words**

Future Work

Improving the Measurement System

- Collect truth data
  - Perform MRT tests with real people
  - Focus on specific impairment of access delay problem
    - E.g. receiving portions of words
- Compute accuracy of ABC-MRT16 access delay system
- Develop specialized intelligibility estimator
  - Focused on partially muted words
- Develop algorithm to differentiate intelligibility on a more fine tuned scale than whole words
  - One-to-one measurement
  - Requires fine time resolution

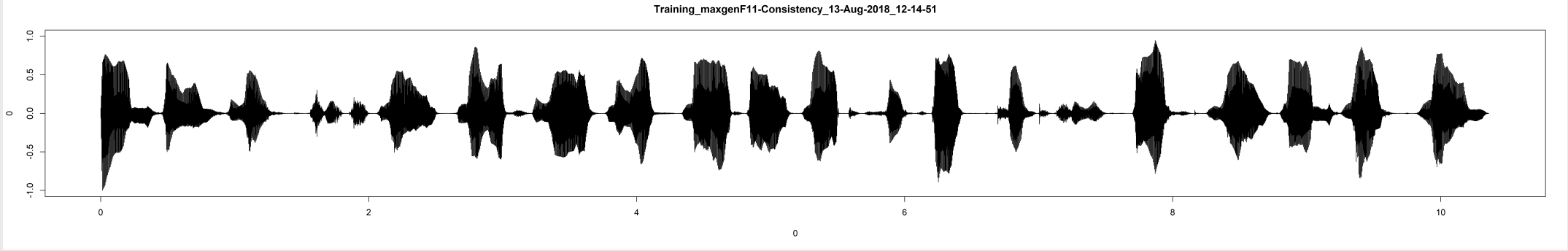
Future Work

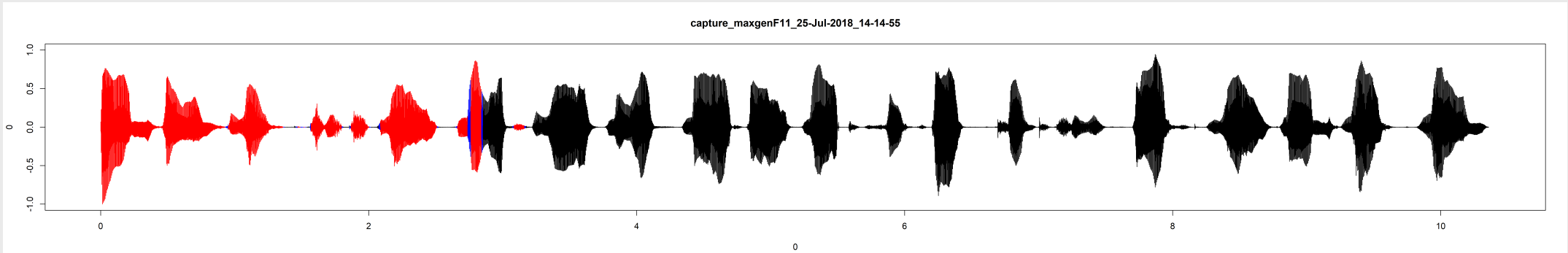
MFCC Intelligibility

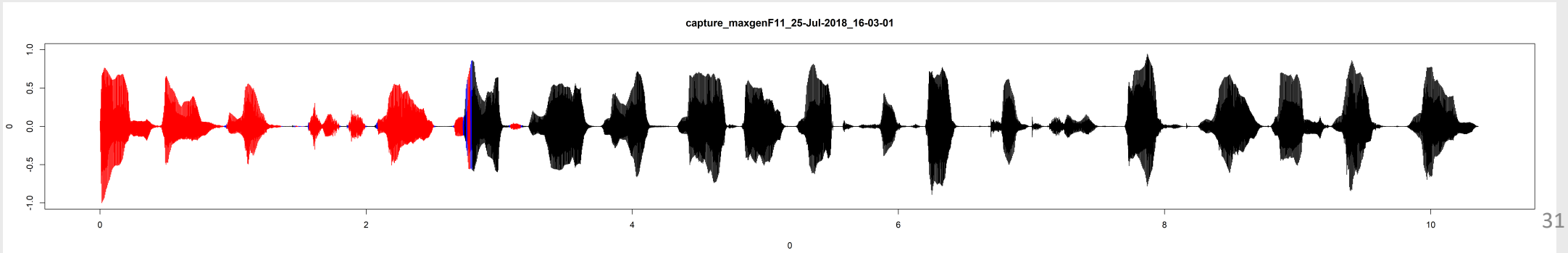
- Mel Frequency Cepstral Coefficients (MFCCs)
  - Turns speech into a musical score
  - Related to the perceived loudness in the human ear of different frequencies
  - Can we make intelligibility distinctions on a smaller time scale?
    - e.g. within a word
- Train a model with intelligible and unintelligible speech
  - Labeled by human MRT trials
  - Tune to the structure of intelligible speech
  - Example model: Multivariate Normal Distribution
- One-to-one measurement
  - Each trial yields an end-to-end access time value

Future Work

Small timescale intelligibility decisions

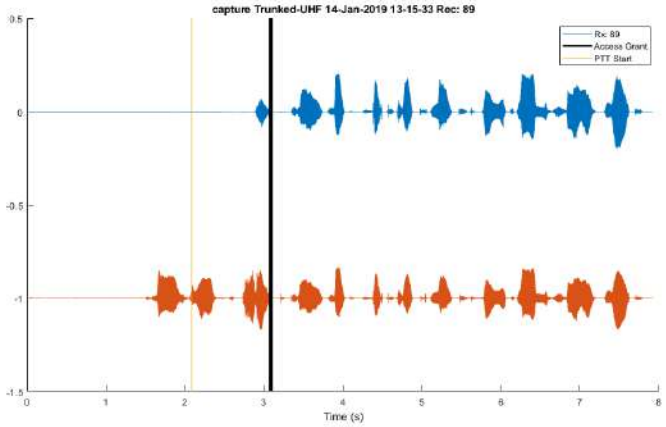


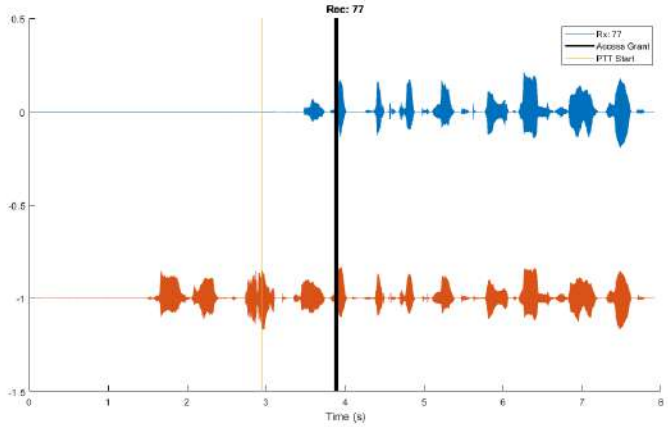


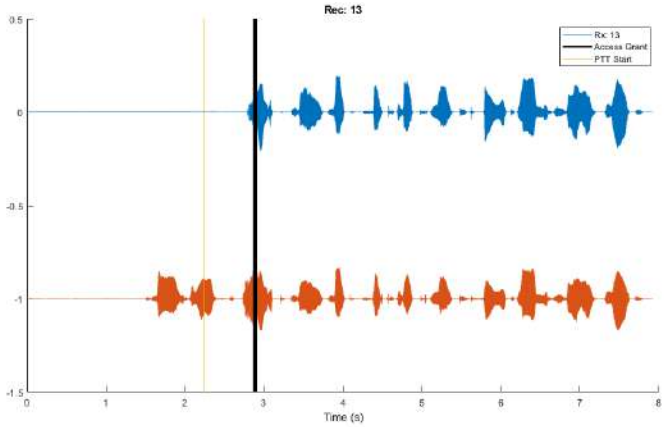


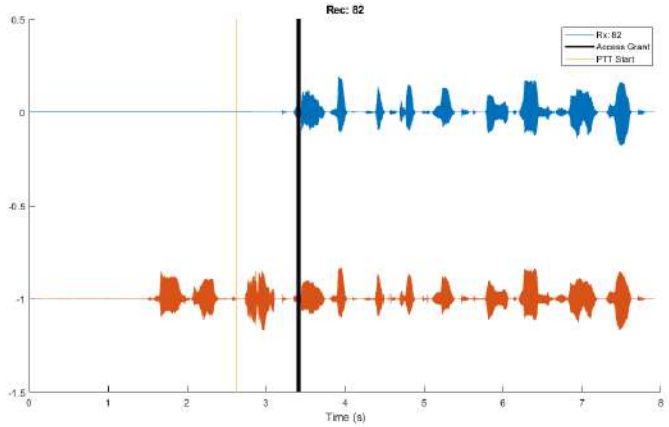
Future Work

MFCC Intelligibility









Team Members

- **Back Row**
  - **Steve Voran**
  - **Tim Thompson**
  - **Jesse Frey**
  - **Zainab Soetan**
- **Front Row**
  - **Hossein Zarrini**
  - **Don Bradshaw**
  - **Chelsea Greene**
  - **Jaden Pieper**


THANK YOU

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Come back for the

Next Session

2:40 PM