Nonlinear Frequency Compression - What’s In and Out

Joshua M. Alexander

Ph.D., CCC-A

www.tinyurl.com/PurdueEar

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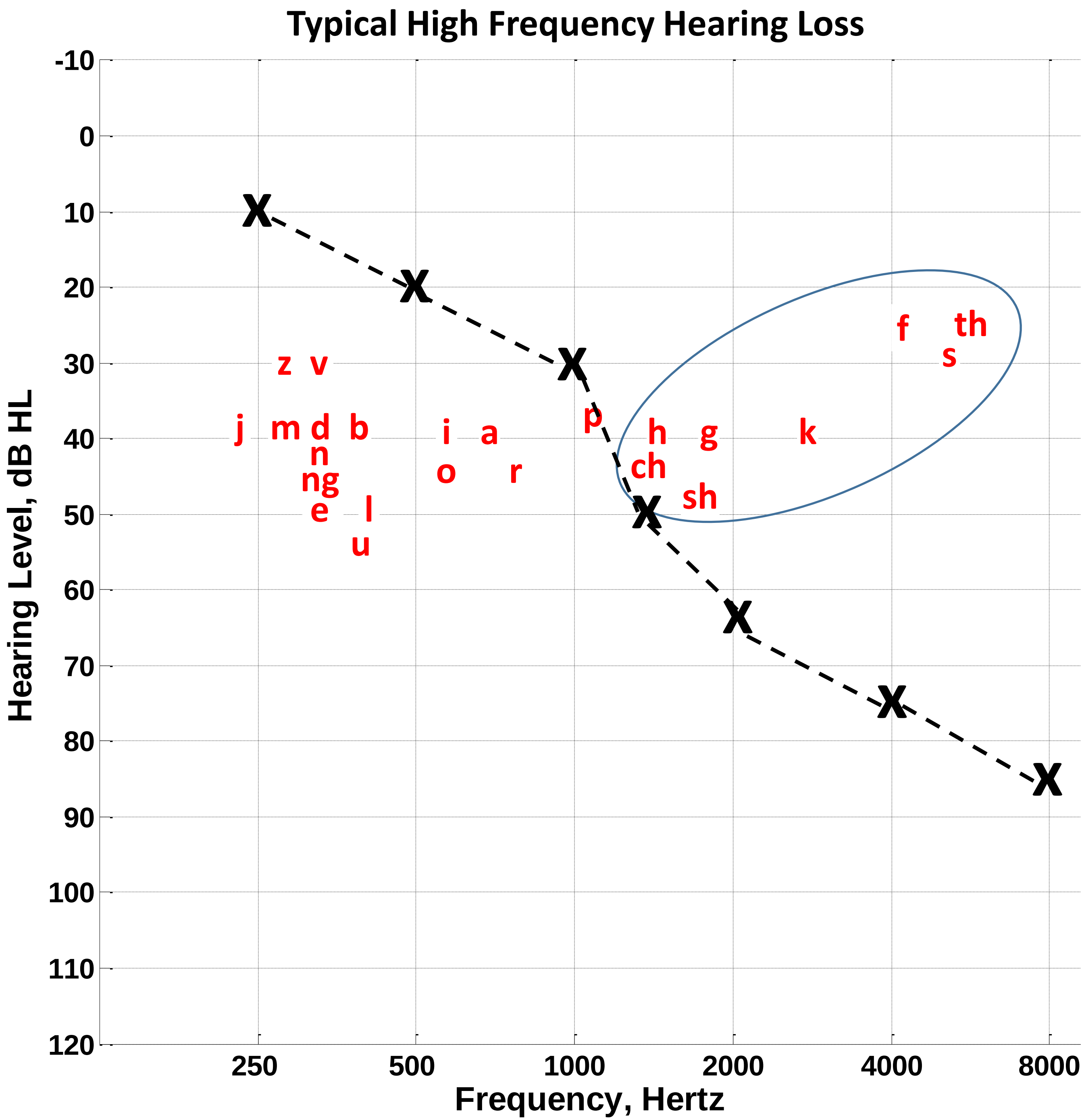
Typical High Frequency Hearing Loss
Hearing Level, dB HL
-10
0
10
20
30
40
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Frequency, Hertz
250
500
1000
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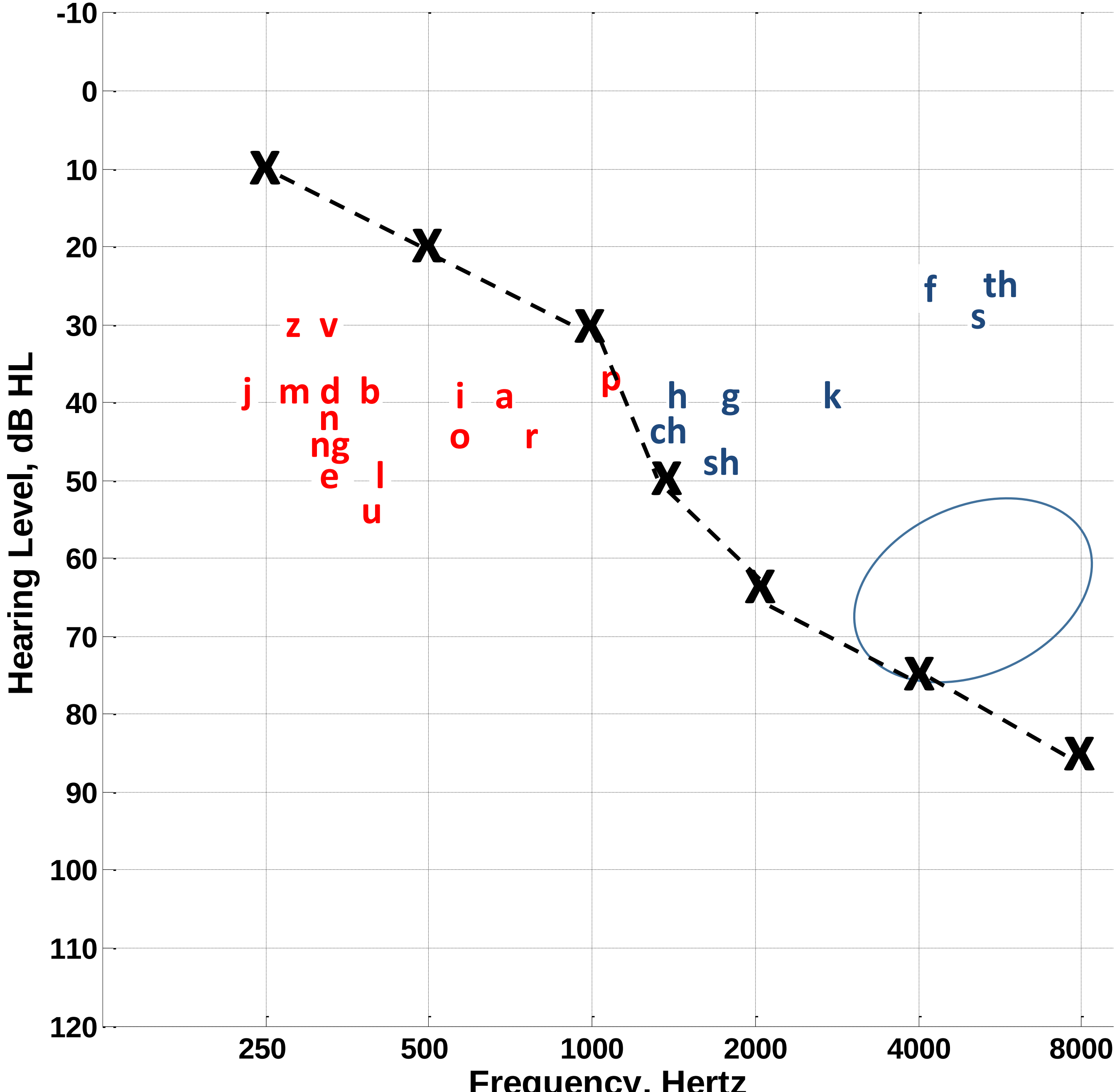
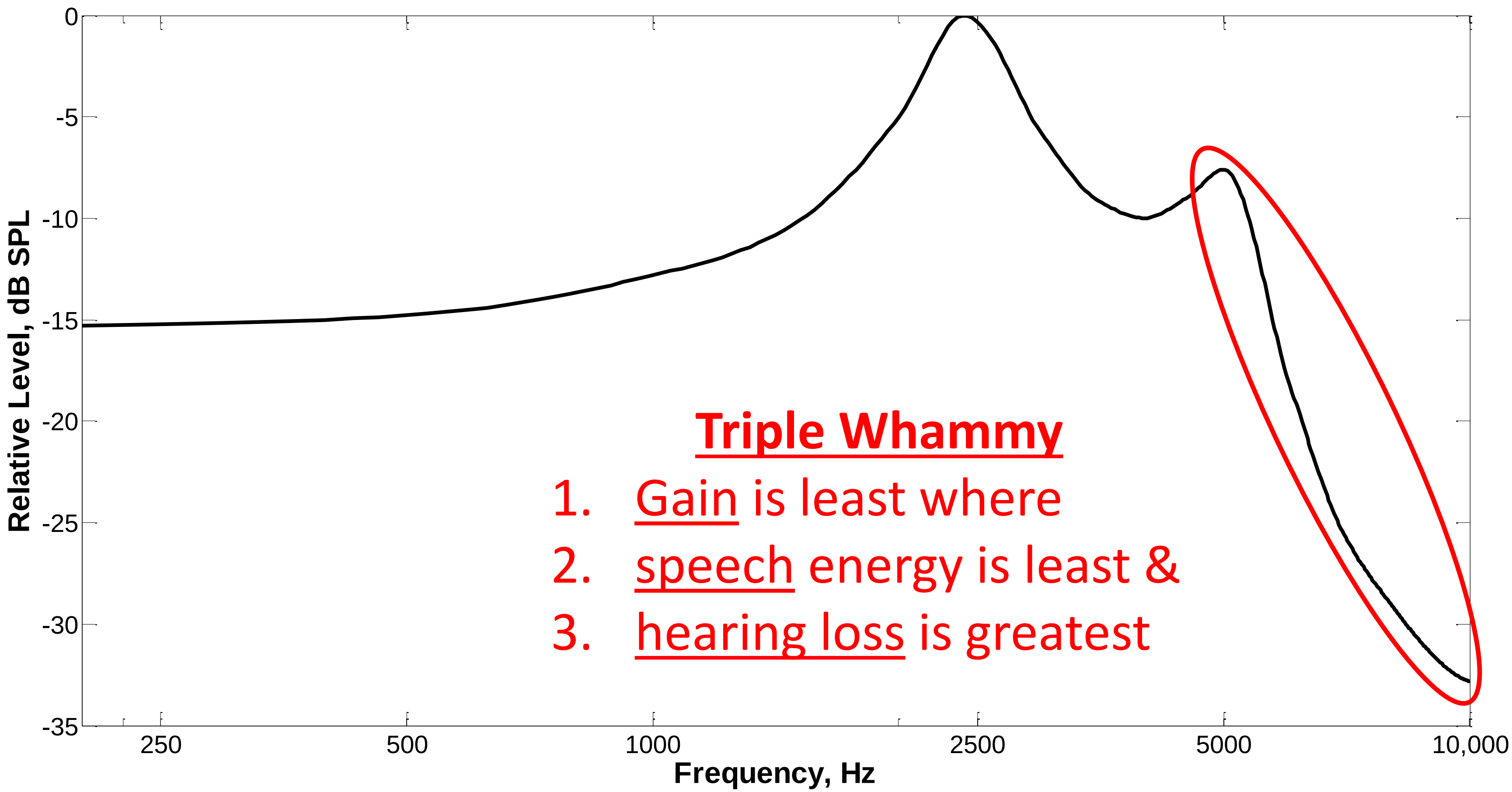
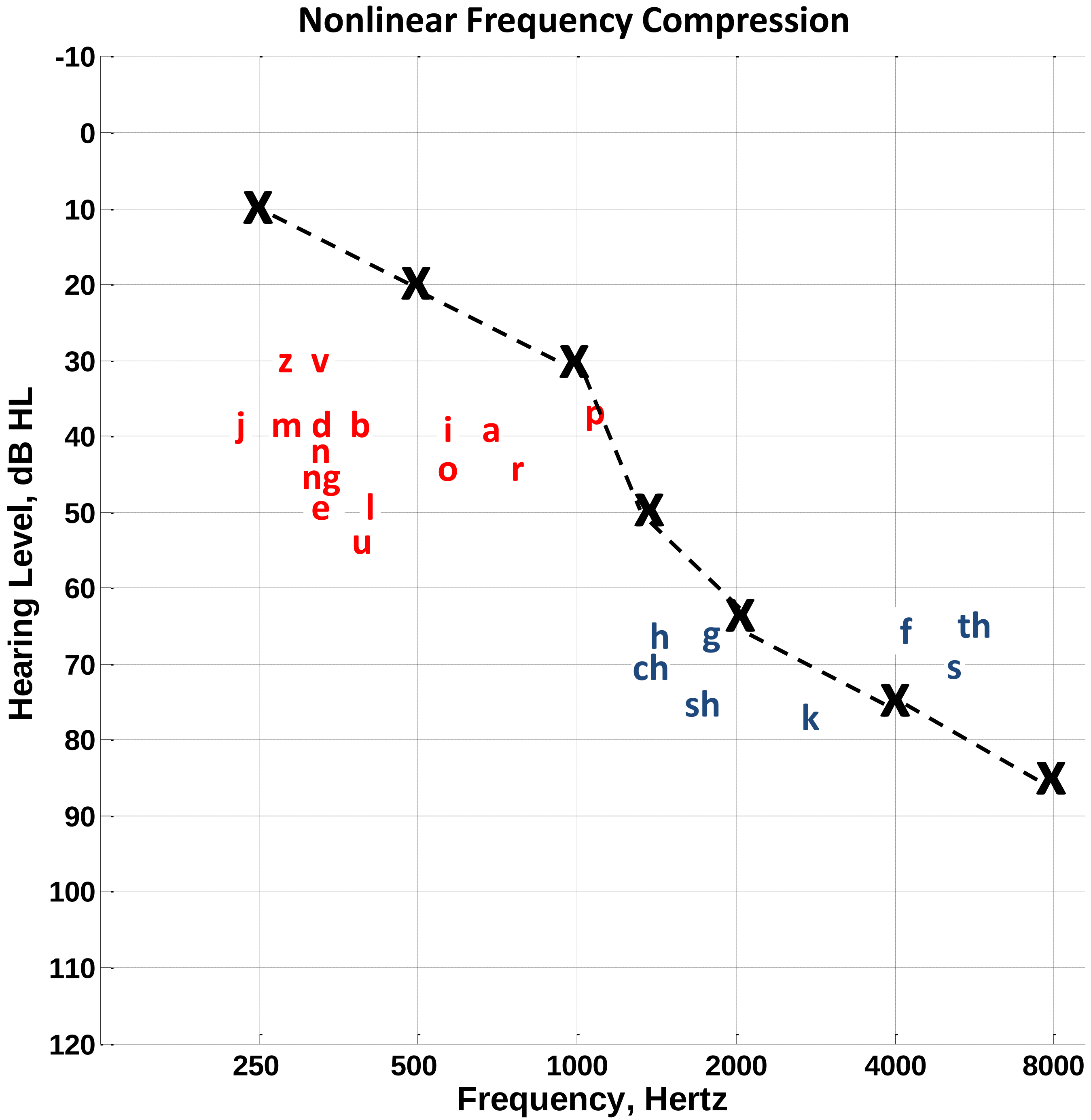
Limits of Conventional Amplification



Typical HA Receiver Response

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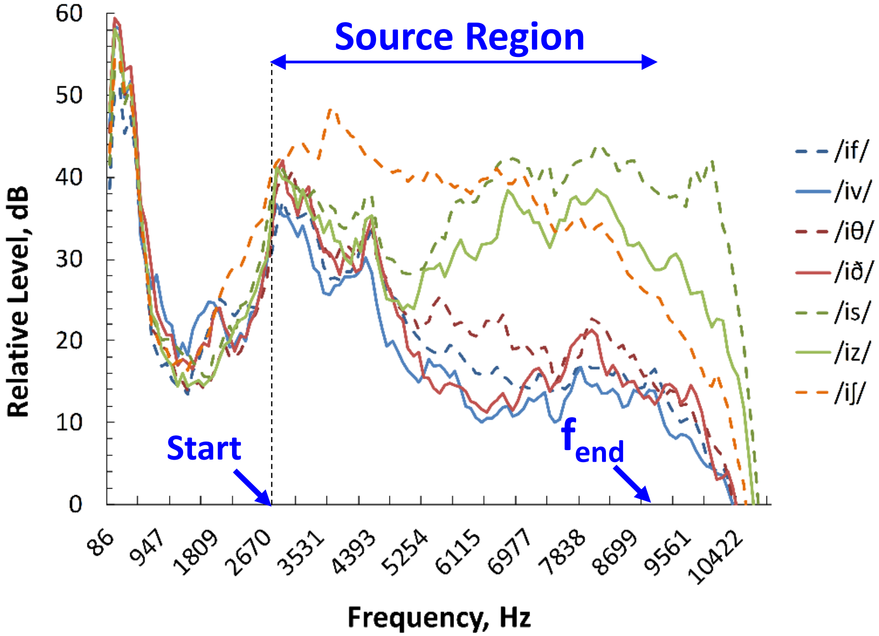
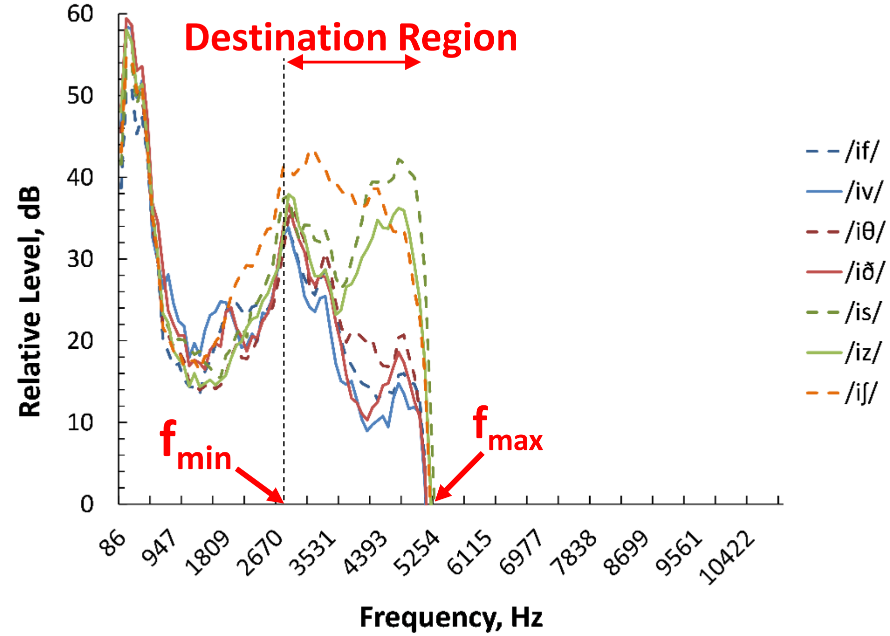
Nonlinear Frequency Compression (NFC)

Input



Output



Related Terminology

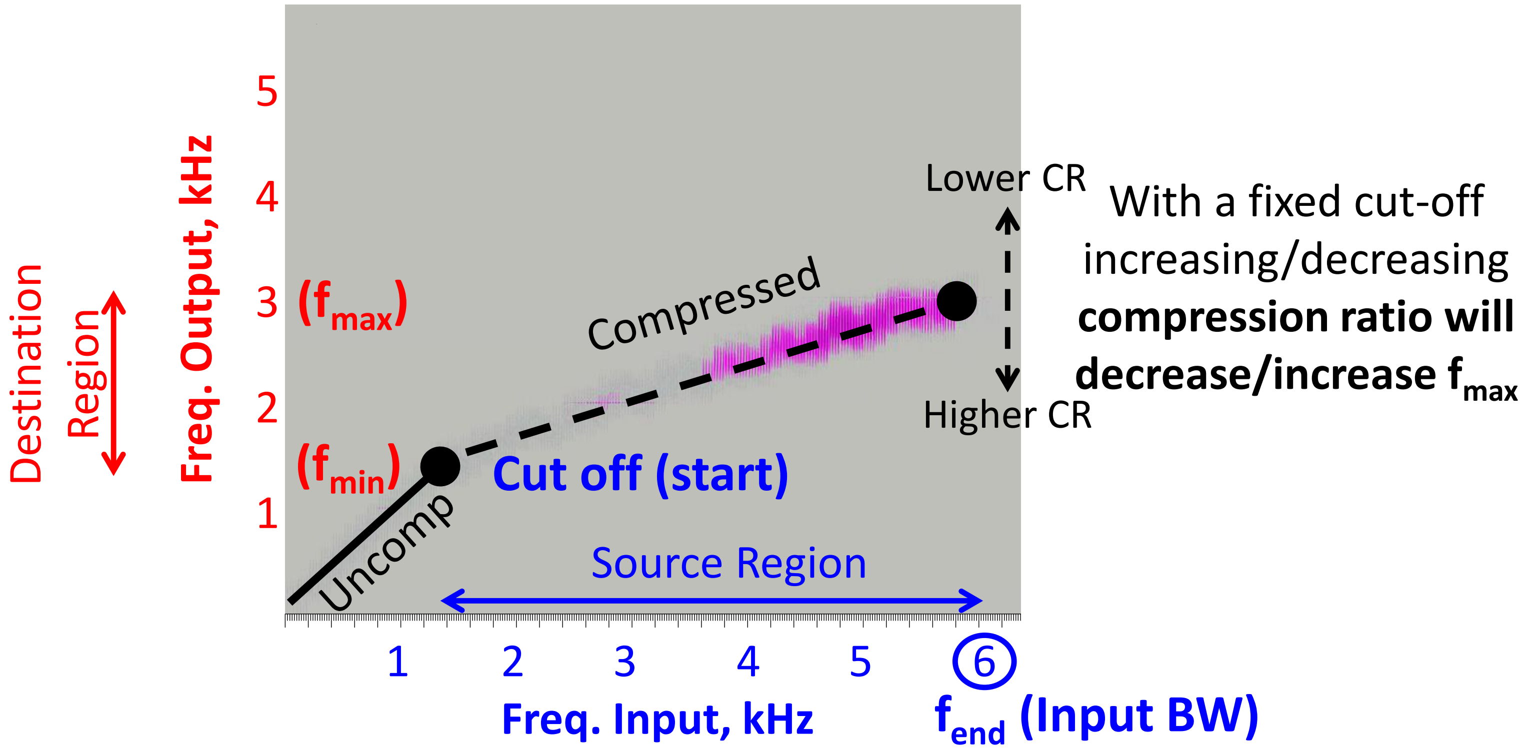
f_{end} = Input bandwidth

f_{min} (start) = cut-off freq

f_{max} = max output freq

(Alexander & Rallapalli 2017)

Frequency Input-Output Plot



- **Key feature is that frequencies below the cut-off frequency are unaltered**
- Adjustable cut-off frequency (f_{min}) and CR (f_{max})

NFC Differs between Manufacturers

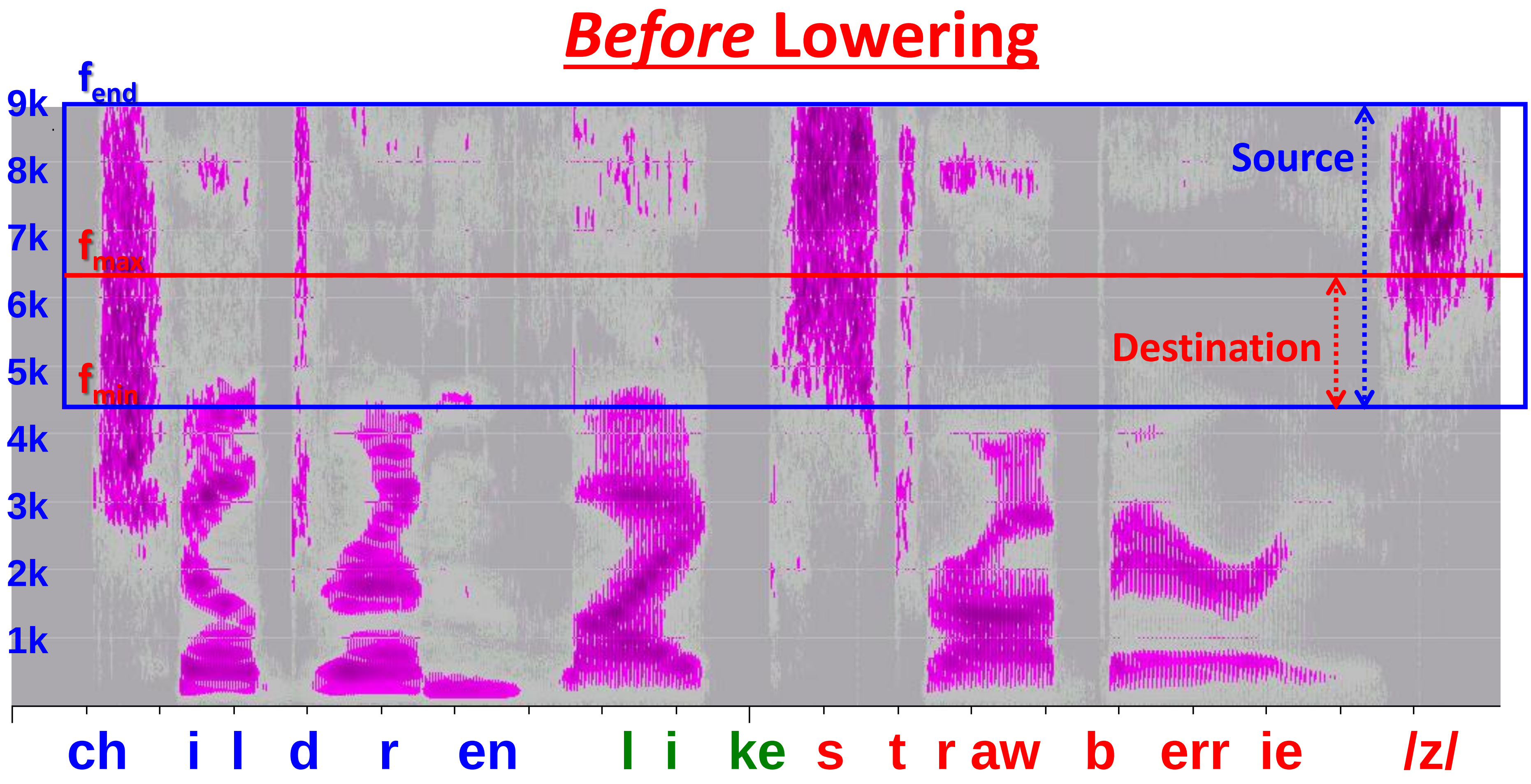
- What does "*nonlinear*" mean anyway???

- From the cut-off frequency, the input-output frequency relationship is **defined by the compression ratio** (CR)
  - Higher CRs = greater reduction of output bandwidth
  - The *mathematical* relationship on a Hz scale is

1. **Nonlinear** (but linear on a log scale) – Phonak/Unitron
2. **Linear** – ReSound
3. **Other** – Signia

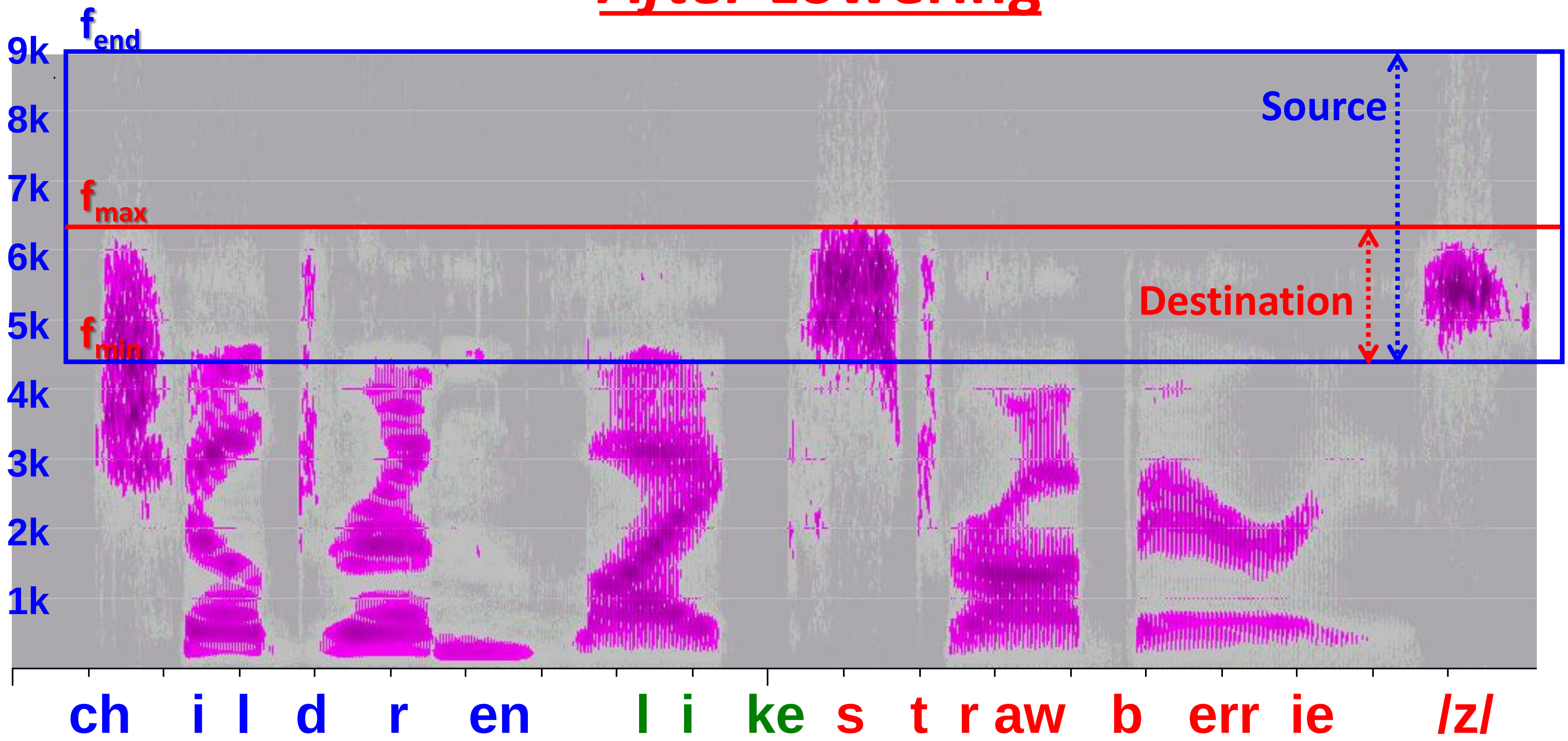
CR is not compatible across manufacturers!
Cannot apply same settings when switching brands and expect the same output.

NFC for Mild-Moderate Loss

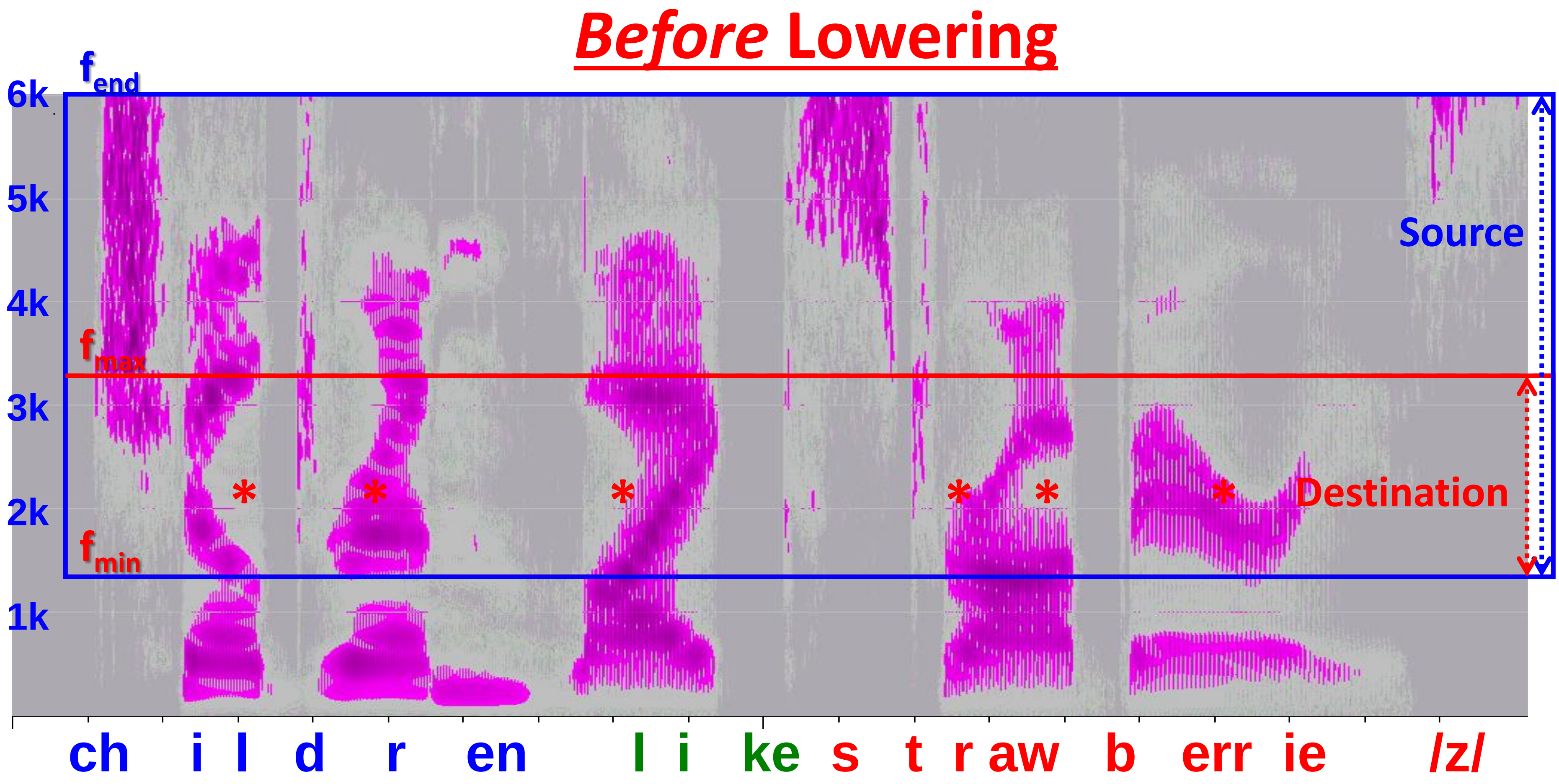


NFC for Mild-Moderate Loss

After **Lowering**

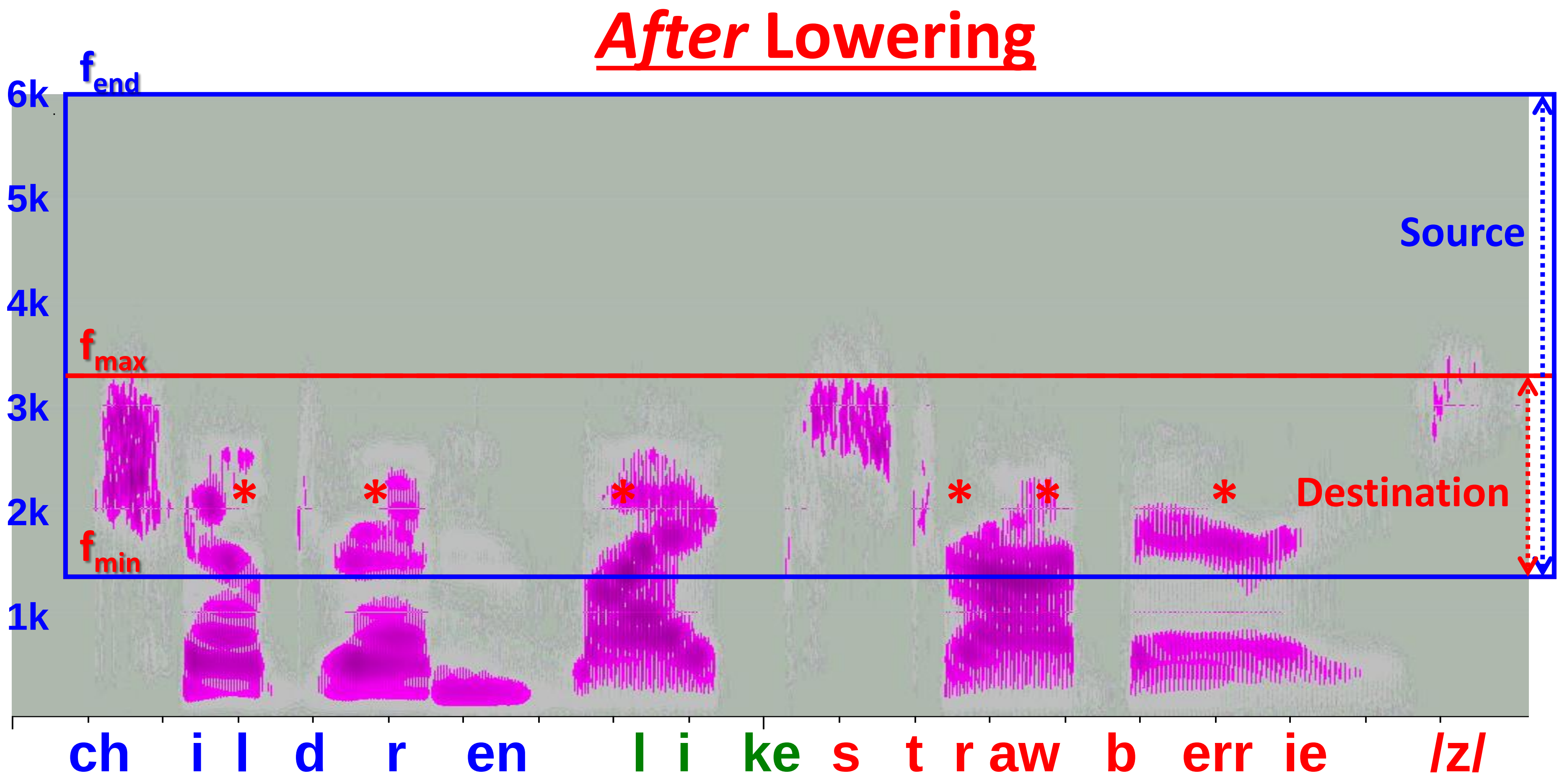


NFC for Moderately Severe Loss



* *Formant transitions*

NFC for Moderately Severe Loss



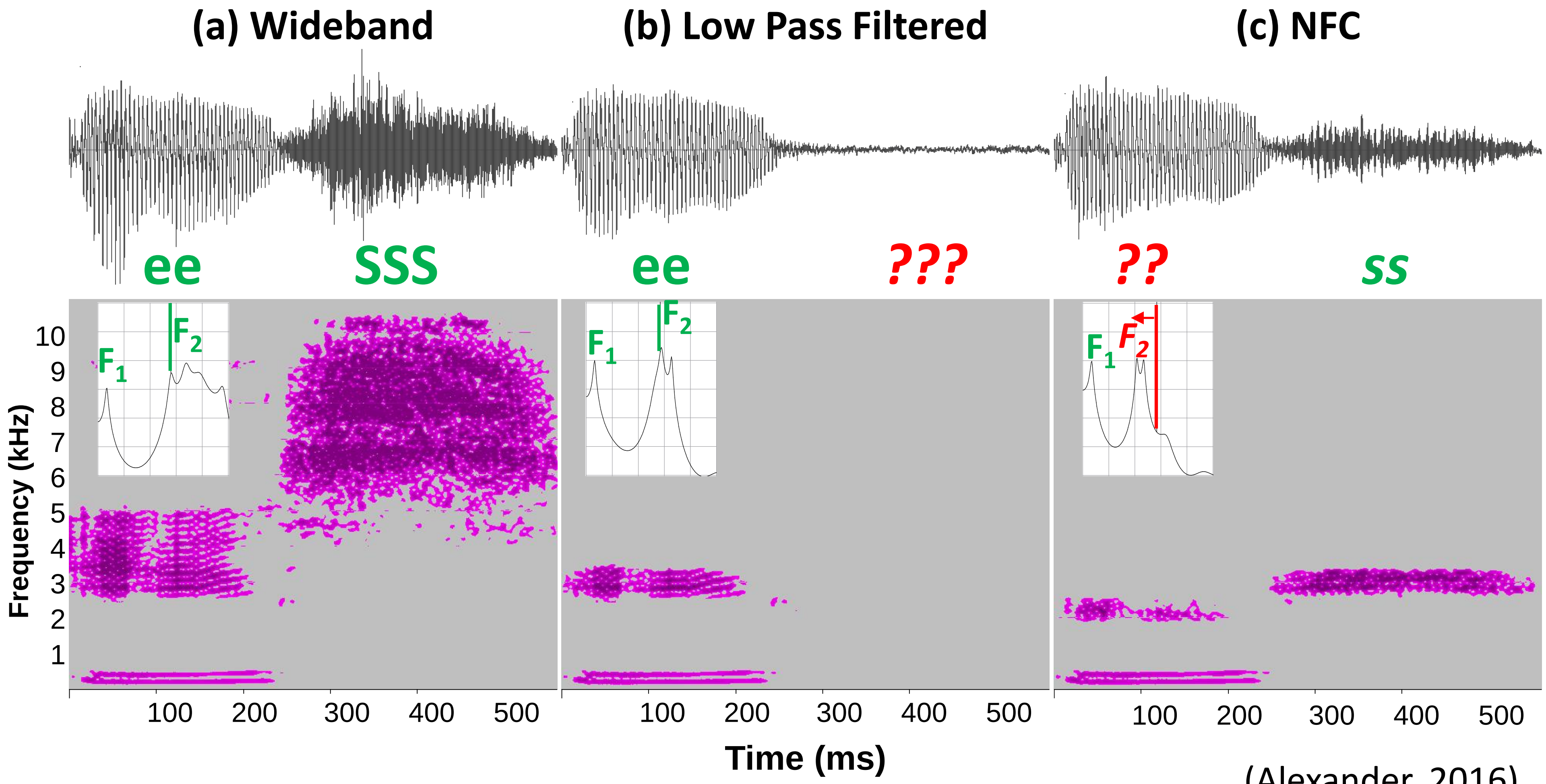
* *Formant transitions (now flattened)*

Potential Side Effects

- While the speech code is relatively ‘scale invariant,’ it is heavily dependent on frequency
  - No other hearing aid feature has as much potential to change the **identity of individual speech sounds**
  - Potential to make speech understanding worse because **low-frequency information has to be altered** to accommodate displaced high-frequency information

- **Re-coded information must go somewhere**
  - Regions that otherwise would be amplified normally
  - Concern is not so much fidelity of re-coded information as it is **newly introduced distortion** and **sound quality**

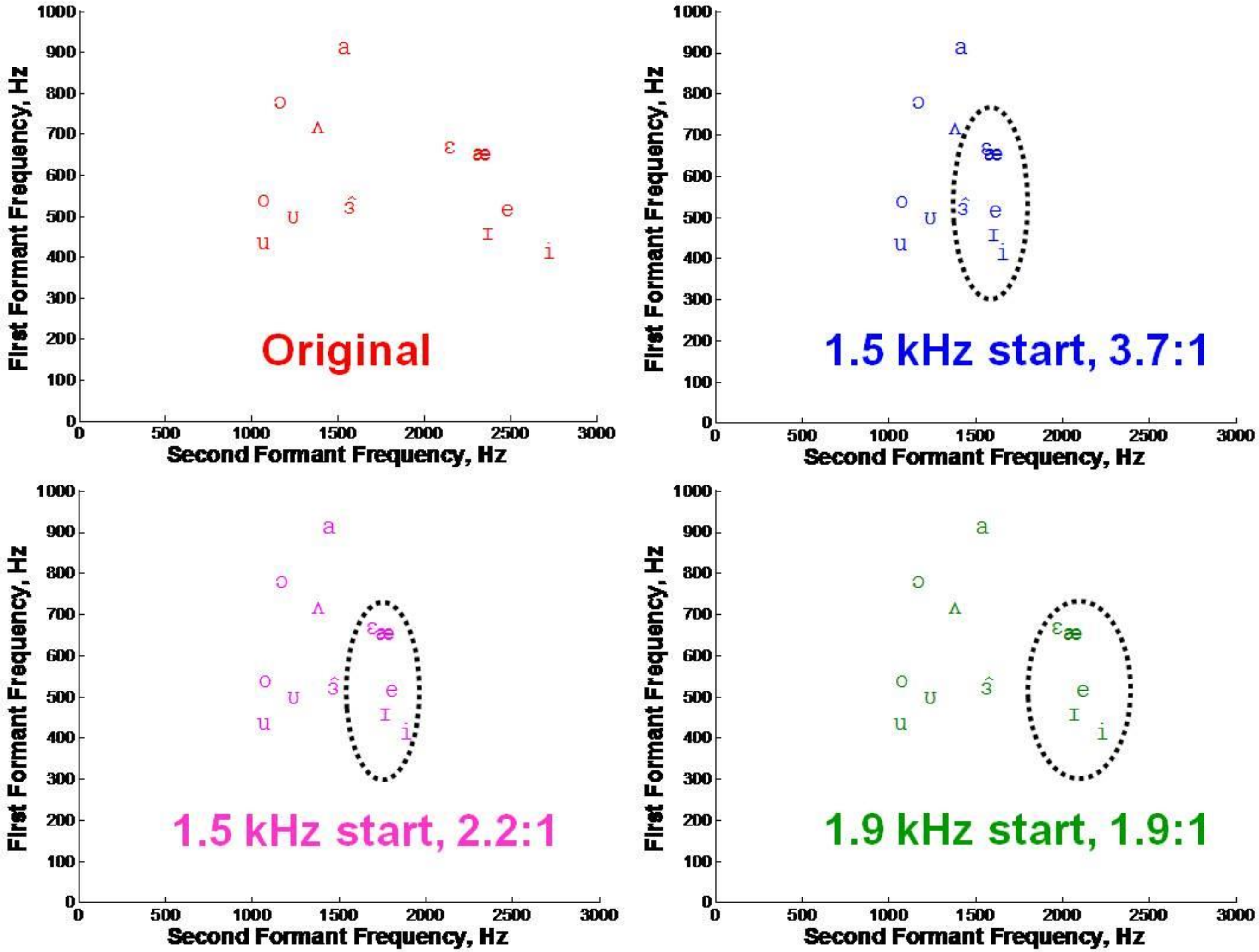
Potential Pros vs. Cons



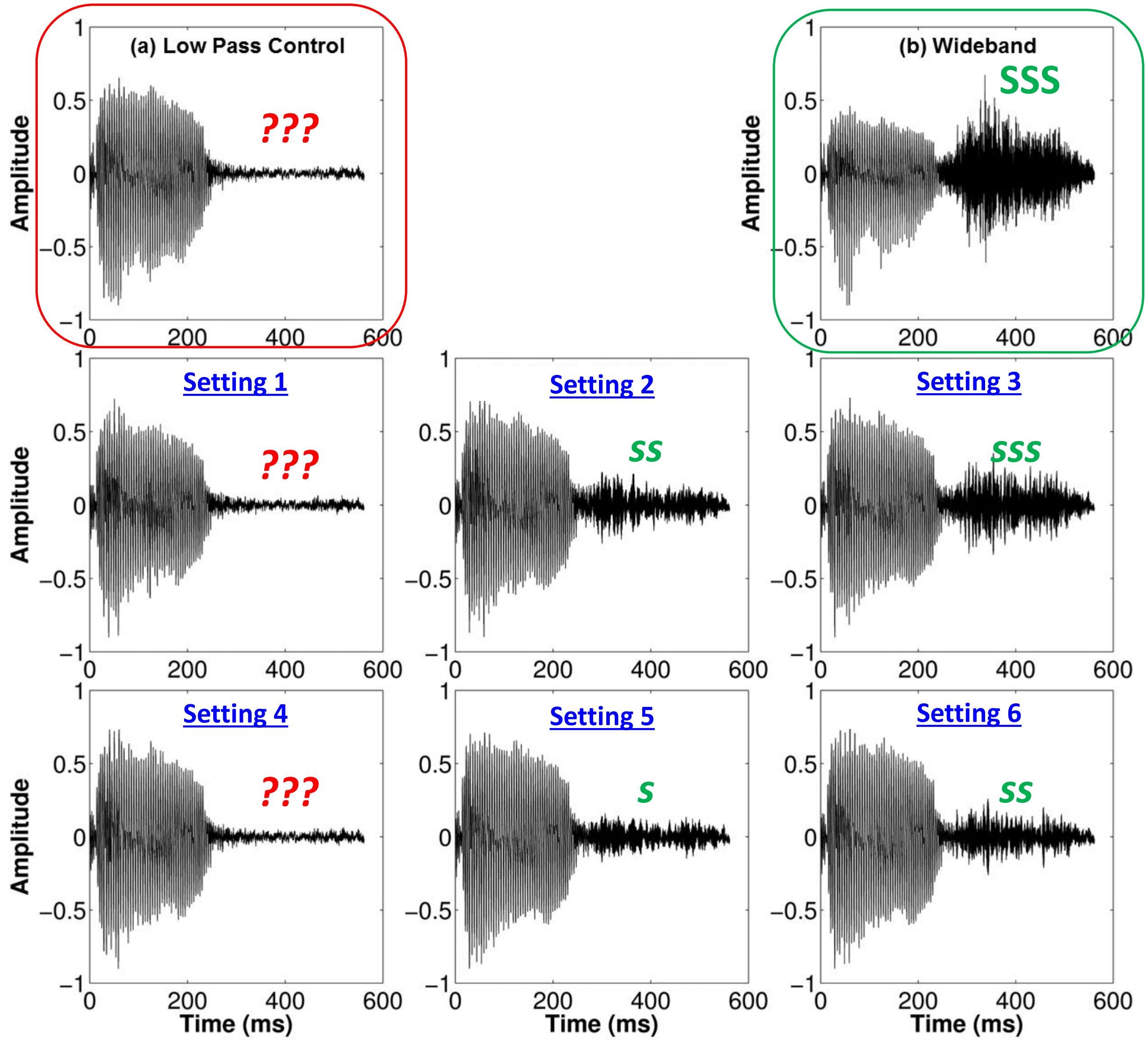
(Alexander, 2016)

Side Effects

Formant alteration, vowel reduction with a low cut off (**start)**

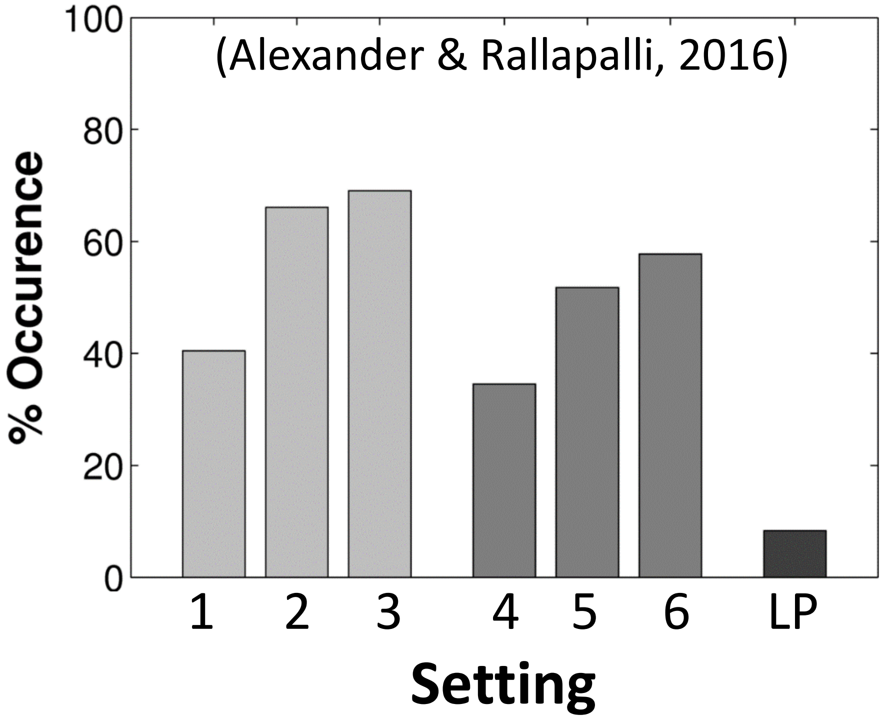


Settings vary Potential Pros vs. Cons

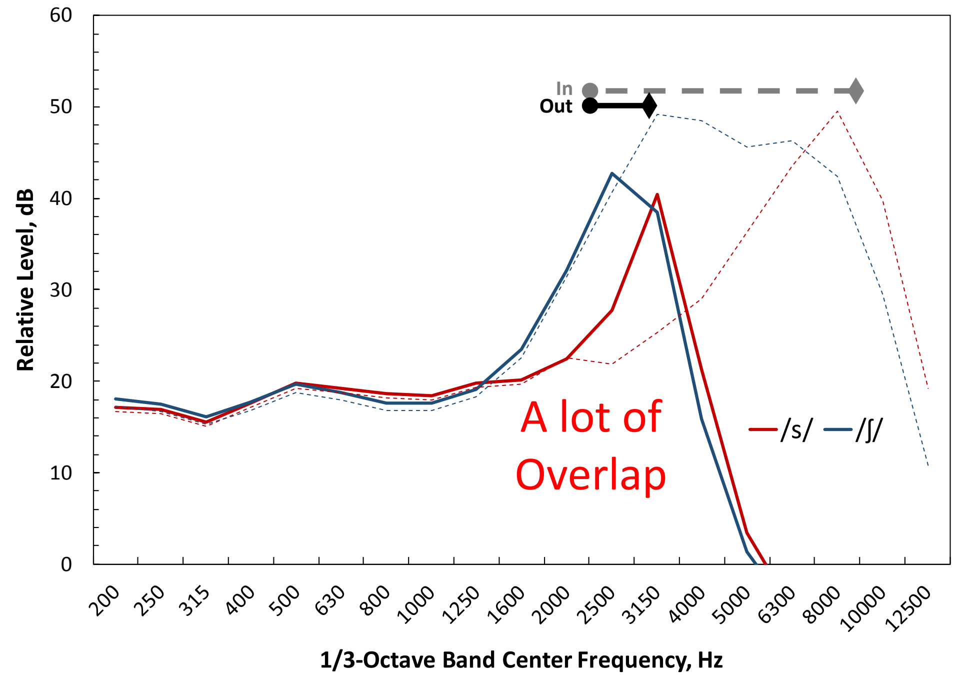


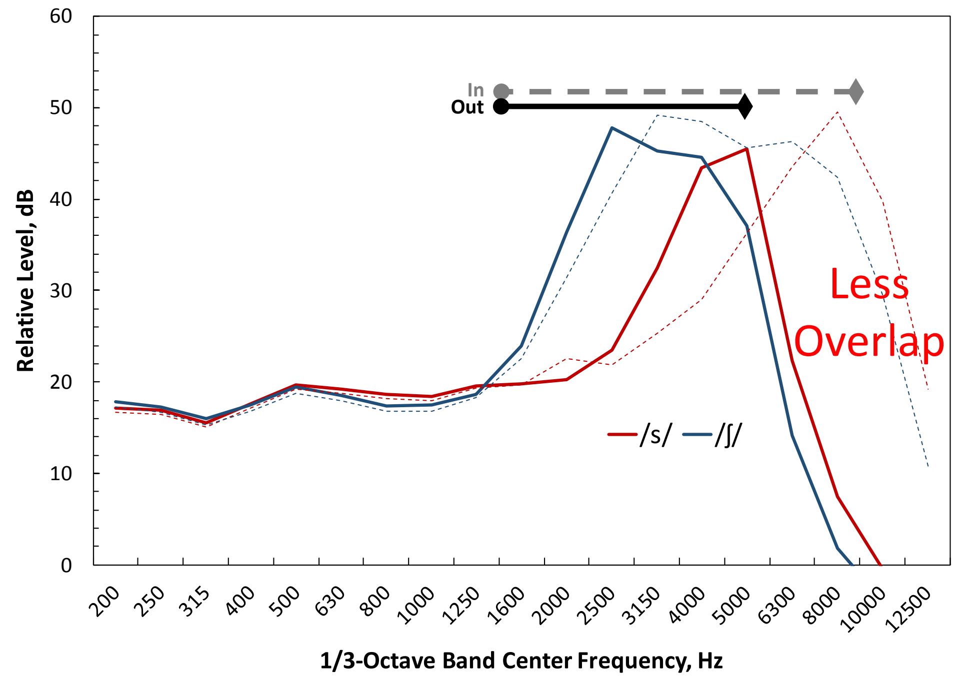
(Rallapalli & Alexander, 2016)

/ʃ/ for /s/ Confusions



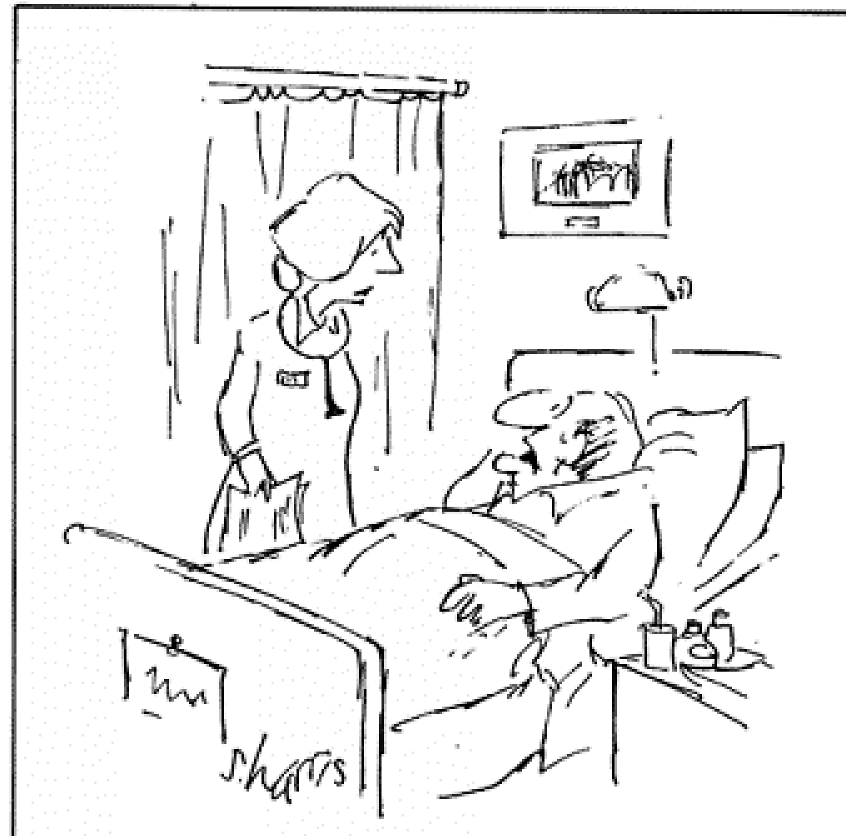
Settings 3 and 6 had the most energy for /s/ after lowering, but also had the most confusions with /ʃ/





Importance of Probe Mic Measures

With the possibility of **side effects** causing ‘harm,’ if you plan to fit a hearing aid with NFC, you must **<u>know what you are delivering to the patient</u>**



"I stopped taking the medicine because I prefer the original disease to the side effects."

Primary Goals for Probe Mic Measures

1. The audible bandwidth after NFC is activated should not be less than it was before it was activated
   - **Do NOT reduce the audible bandwidth!**

2. The lowered information should be audible

3. The 'weakest' NFC setting should be used to accomplish your *objective*
   - **Frequency Lowering Fitting Assistants:** www.tinyURL.com/FLassist

Frequency Lowering Fitting Assistants

- Purpose is not to determine ‘optimal’ settings, but rather to **empower the clinician**
  - Provide information for how sounds are changed with the different settings
  - Par down all of the available settings into a reasonable set based on **‘first principles’** (e.g., maintaining audible bandwidth)

- May improve uniformity across clinicians, protocols, test sites, etc.

Protocol for Fitting NFC Hearing Aids

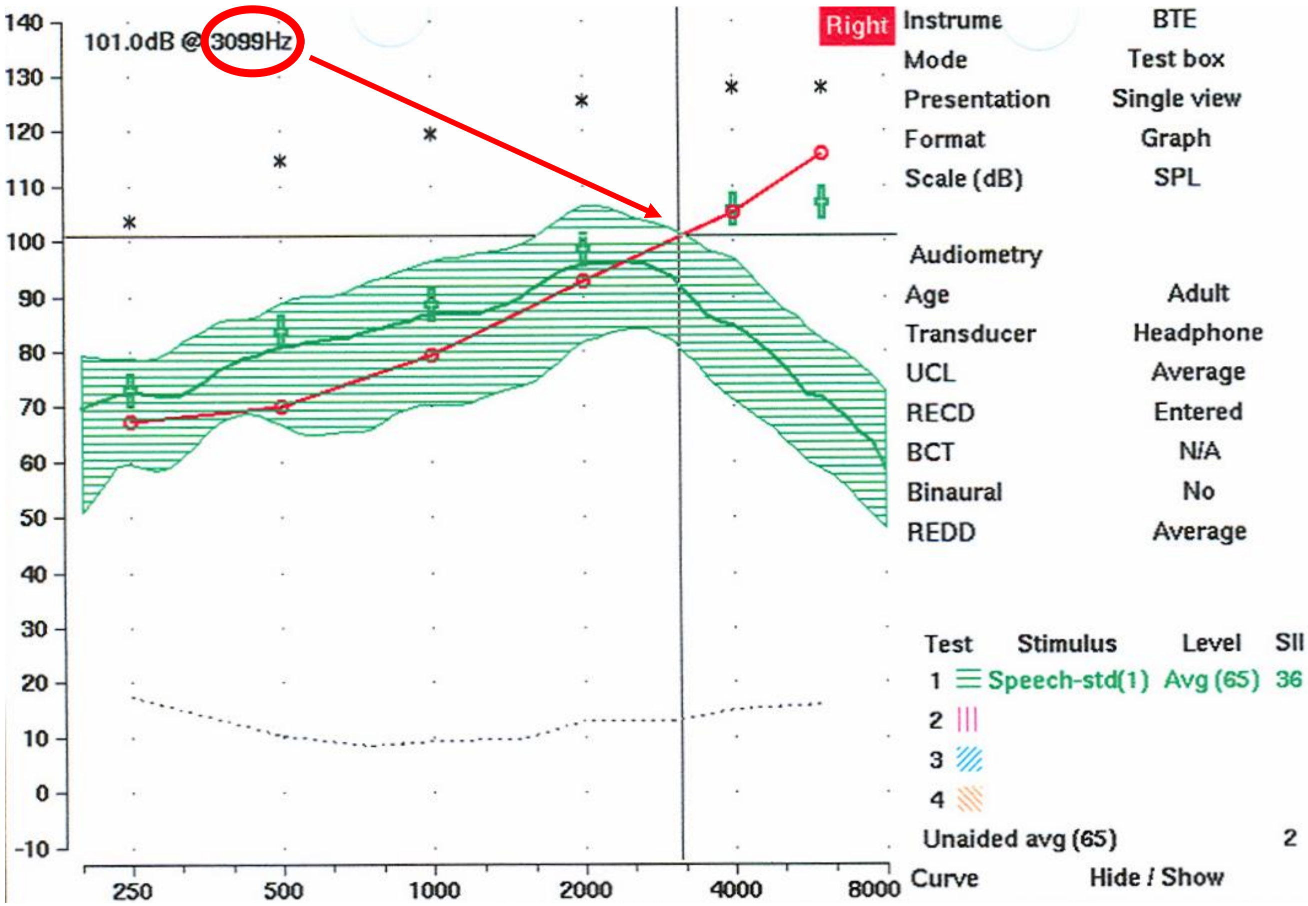
1. **Deactivate NFC** and fit hearing aid to targets using probe mic as for a conventional aid

2. Find **maximum audible output frequency**, MAOF
   - The highest frequency at which output **exceeds threshold** on the SPL-o-gram (Speechmap)
   - **Activate NFC** and position the lowered speech in the audible bandwidth (MAOF) while not reducing it further
     - Most of the destination region should be **audible**
     - **Avoid too much lowering**, which will unnecessarily restrict the bandwidth you had to begin with and **reduce intelligibility**

3. **Verify** that the MAOF is reasonably close to what it was when it was deactivated

1. Deactivate NFC and Fit to Targets

2. Find the maximum audible frequency



3. Activate NFC, adjust settings

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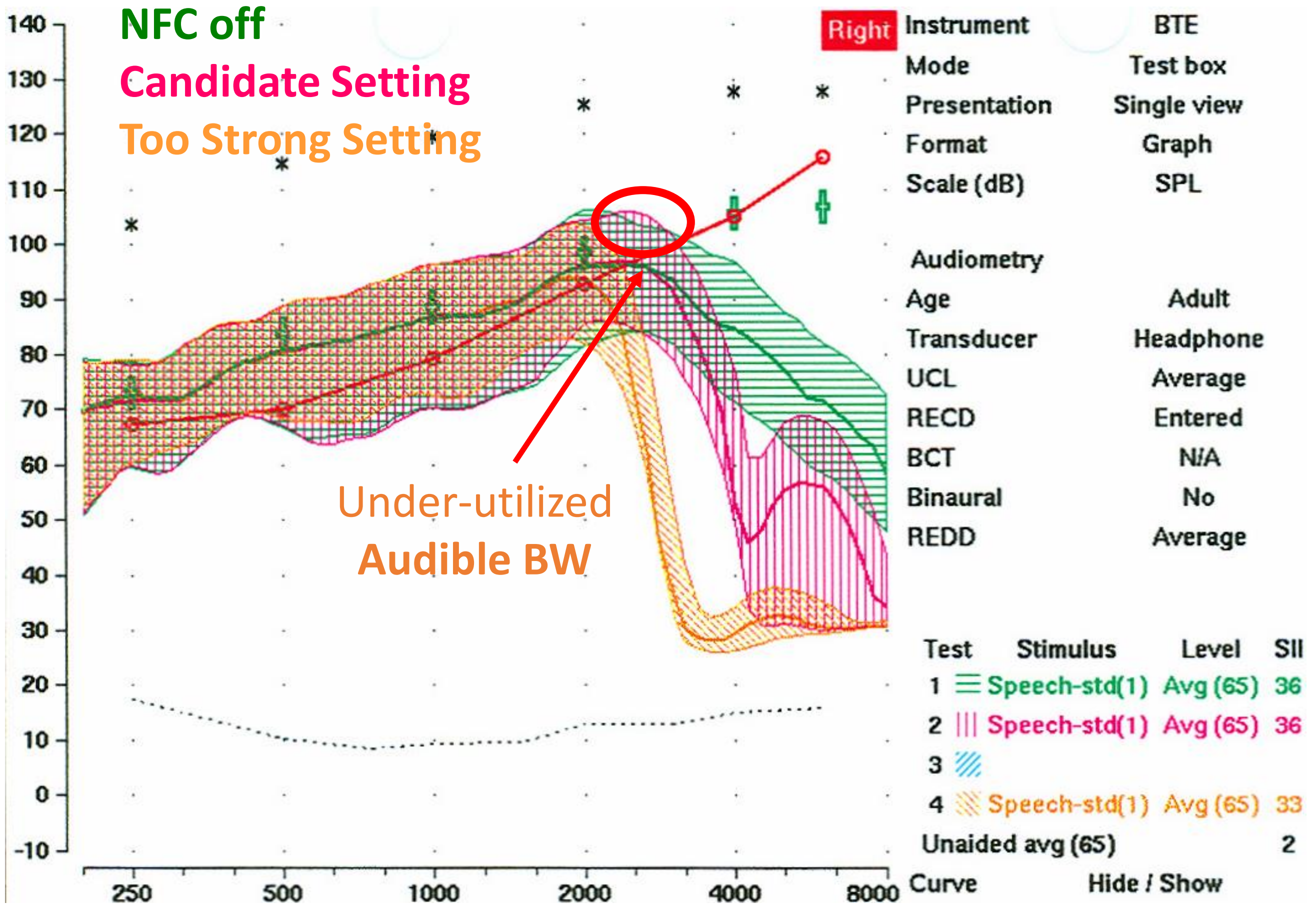
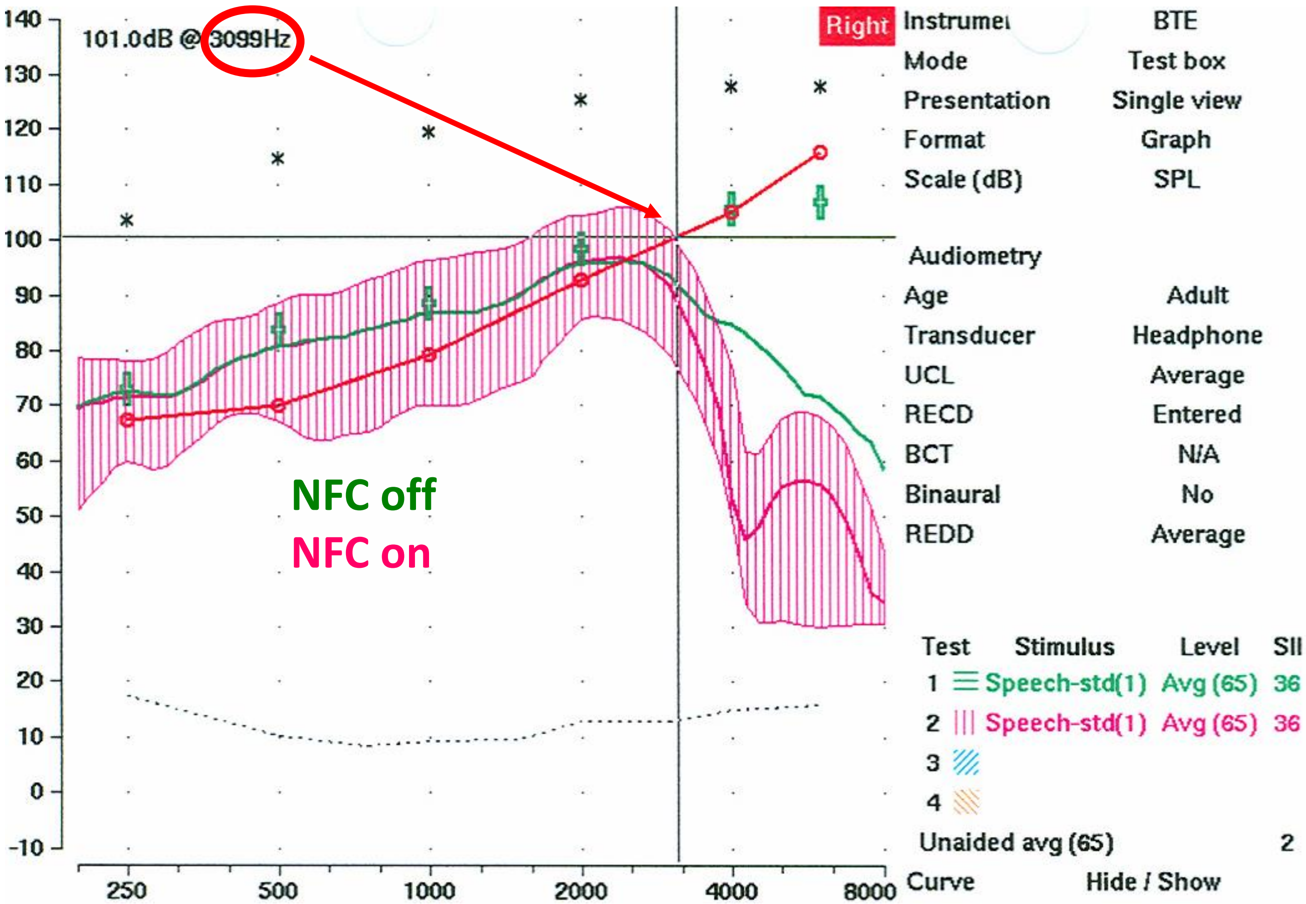


3. Verify Bandwidth of Chosen Setting



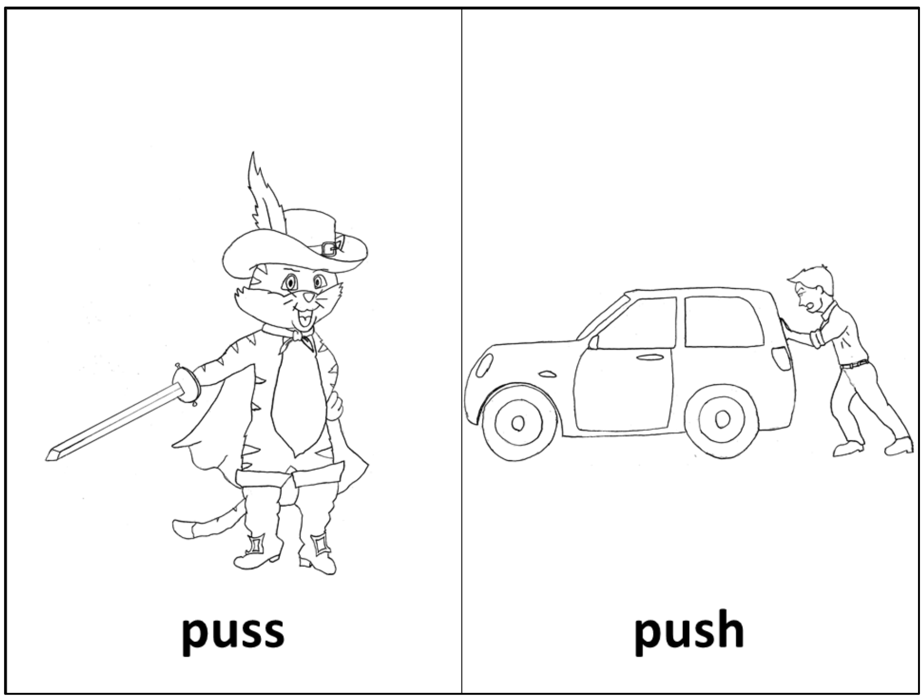
To Fit or Not to Fit

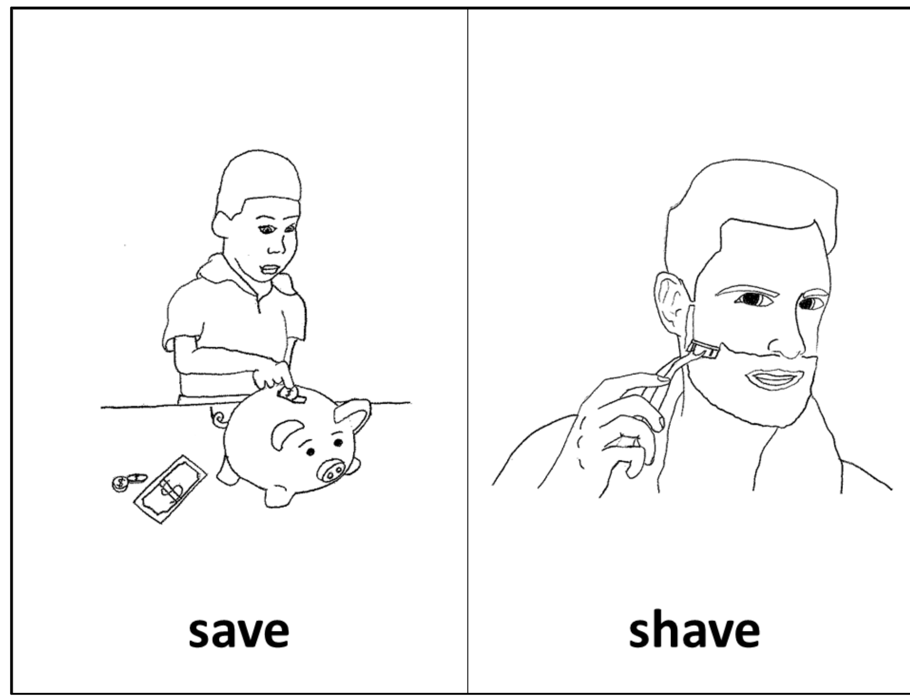
- Ultimately, a decision has to be made whether the **potential pros** outweigh the **cons**
  - *Does the patient experience speech perception deficits with conventional amplification, despite your* ***best efforts*** *to achieve high-frequency audibility?*

- If the decision is to fit, there are a few things to ask:
  1. *How does the technology of choice work?*
     - **Fundamental differences between manufacturers**: techniques, terminology, adjustments, etc.
  2. *How much of the lowered information is* ***audible****?*
     - Frequency Lowering Fitting Assistants
  3. *Can the patient* ***use*** *the lowered information?*
     - Validation measures of outcomes

Speech Tests to Help Validate

- **ORCA Nonsense Syllable Test:** Kuk *et al.* (2010)
- **UWO Plurals Test:** Glista & Scollie (2012)
- **Phoneme Perception Test (PPT):** Schmitt *et al.* (2015)
- **Purdue s-sh Test (PUSSH):** Alexander (201X)



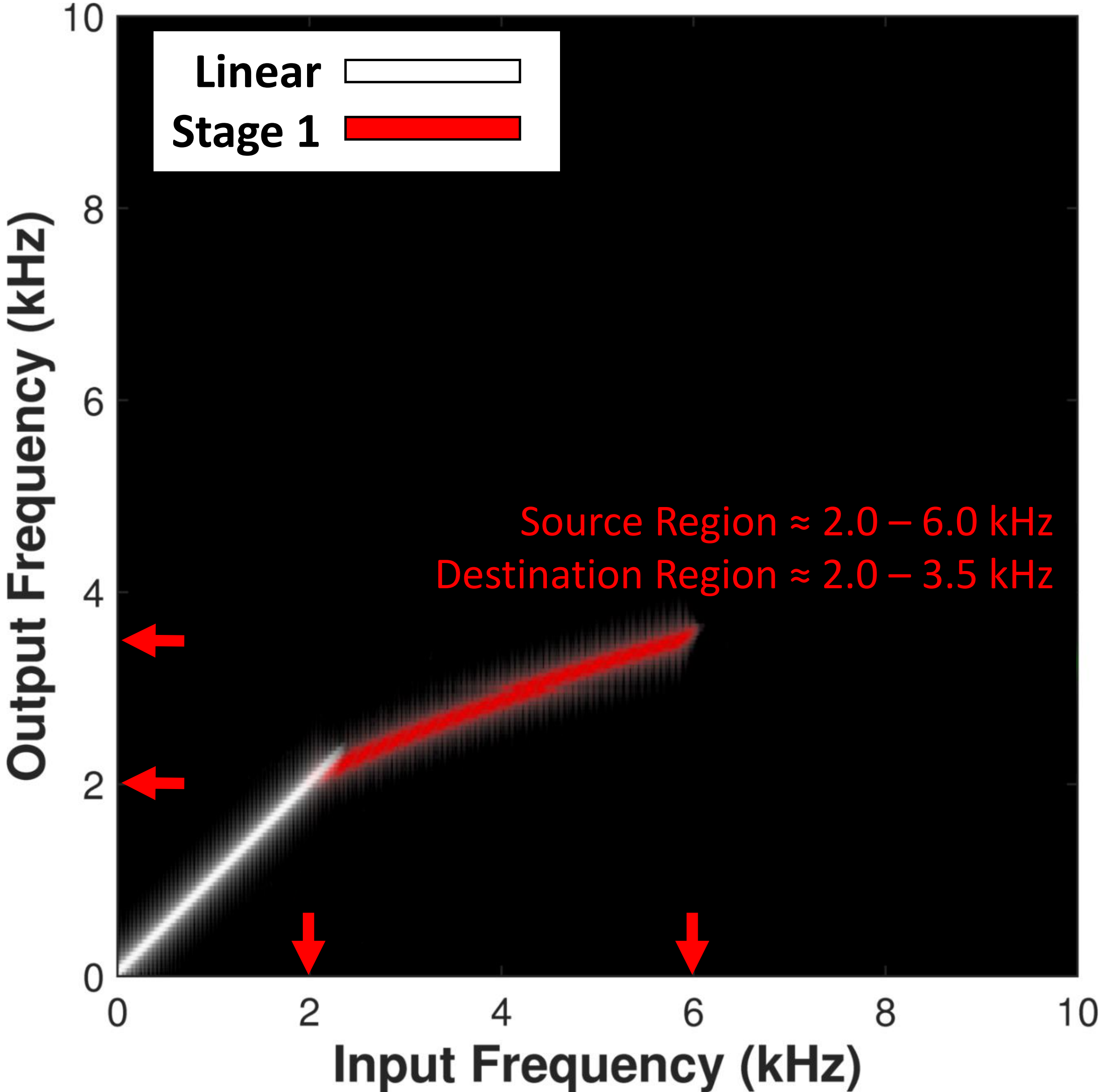


Adaptive Nonlinear Frequency Compression (Phonak SoundRecover2)

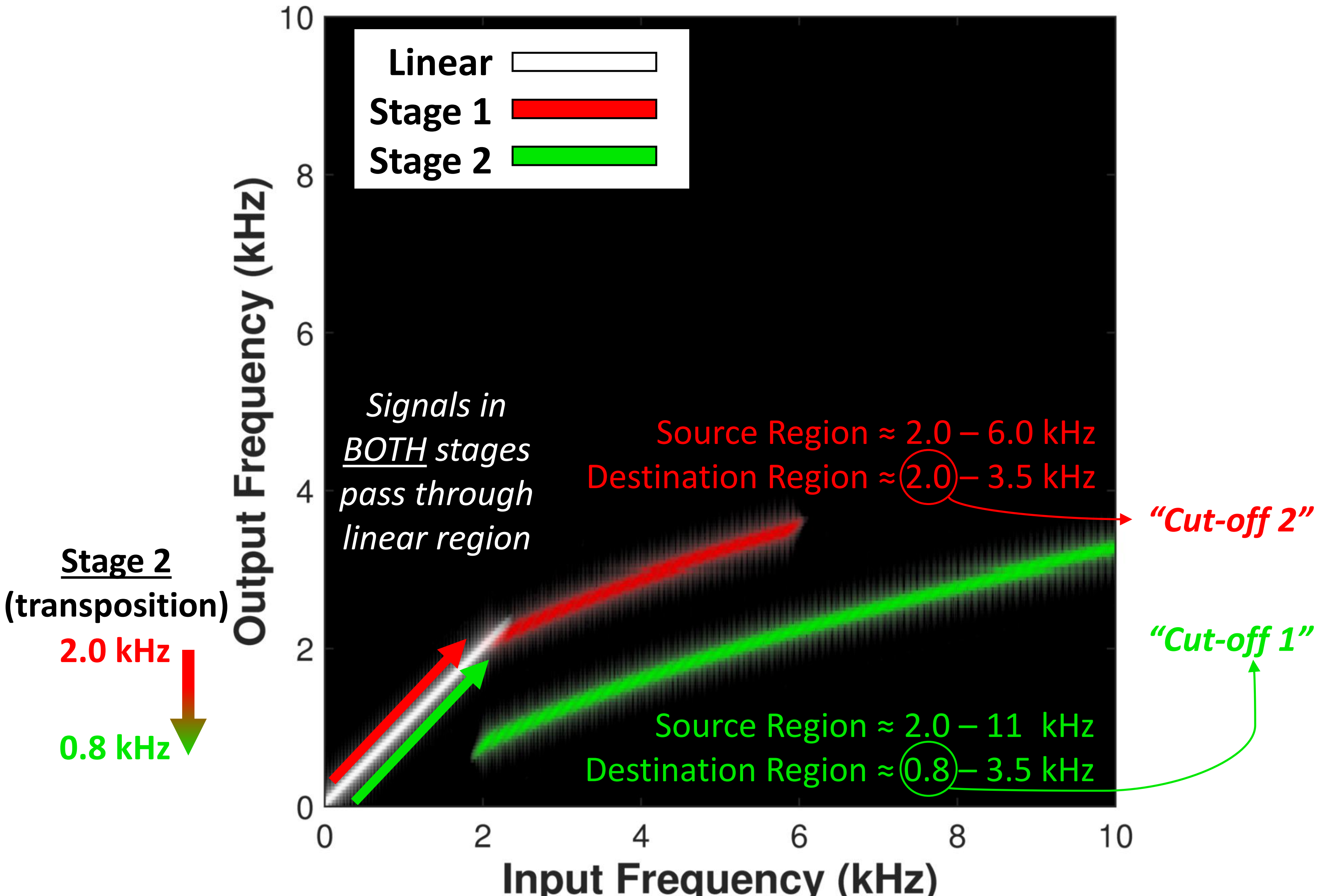
- **2 stages of frequency lowering**
  1. Sounds with **low-frequency emphasis** are processed with **'conventional' NFC**
  2. Sounds with **high-frequency emphasis** are also processed with NFC (Stage 1), but are then **transposed** to an even lower frequency region (Stage 2)

- **Rationale** (*potential benefits*)
  - Less aggressive NFC can be used for vowels and other low-frequency emphasis consonants to **preserve intelligibility and sound quality**
  - Lower cut-off frequencies possible with Stage 2 NFC compared to conventional NFC
    - **A.** **Expand candidacy** to those with very restricted range of audibility
    - B. Transposed NFC speech cues span a wider destination range → less compression → better **preservation of spectral detail**

Conventional NFC



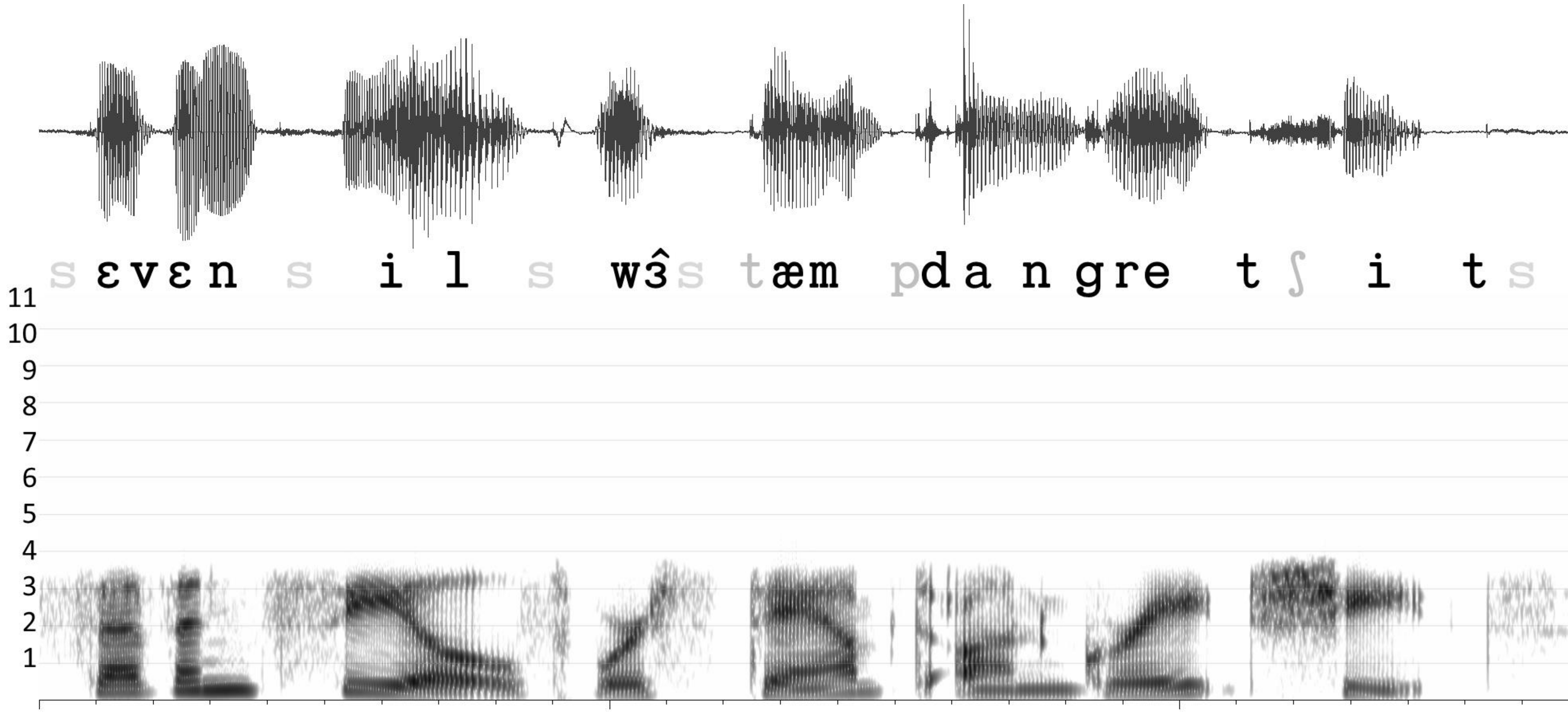
Adaptive NFC (ANFC)



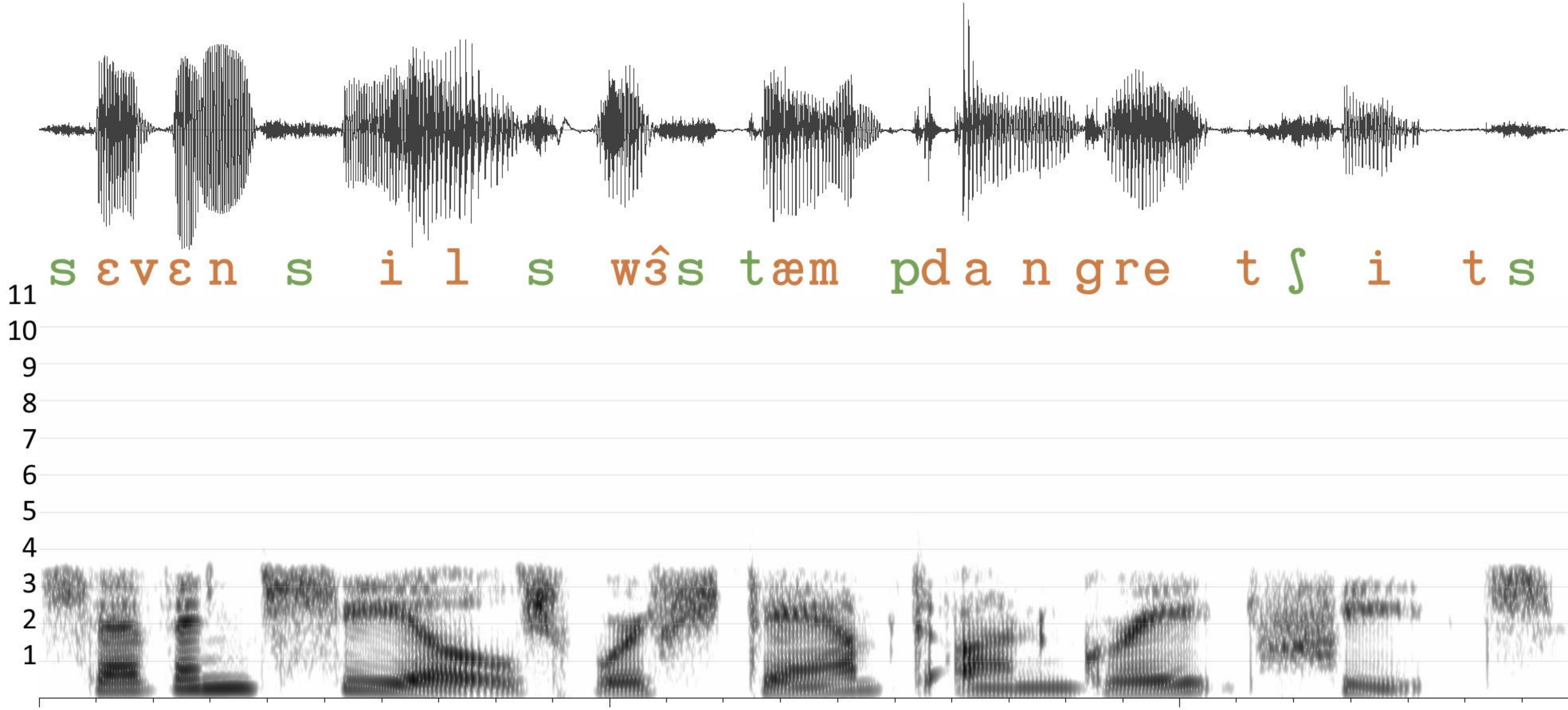
Full Bandwidth

“seven seals were stamped on great sheets”

Simulated Loss
(Filtered >3.5kHz)



Processed with ANFC



Stage 1

Source Region ≈ 2.0 – 6.0 kHz

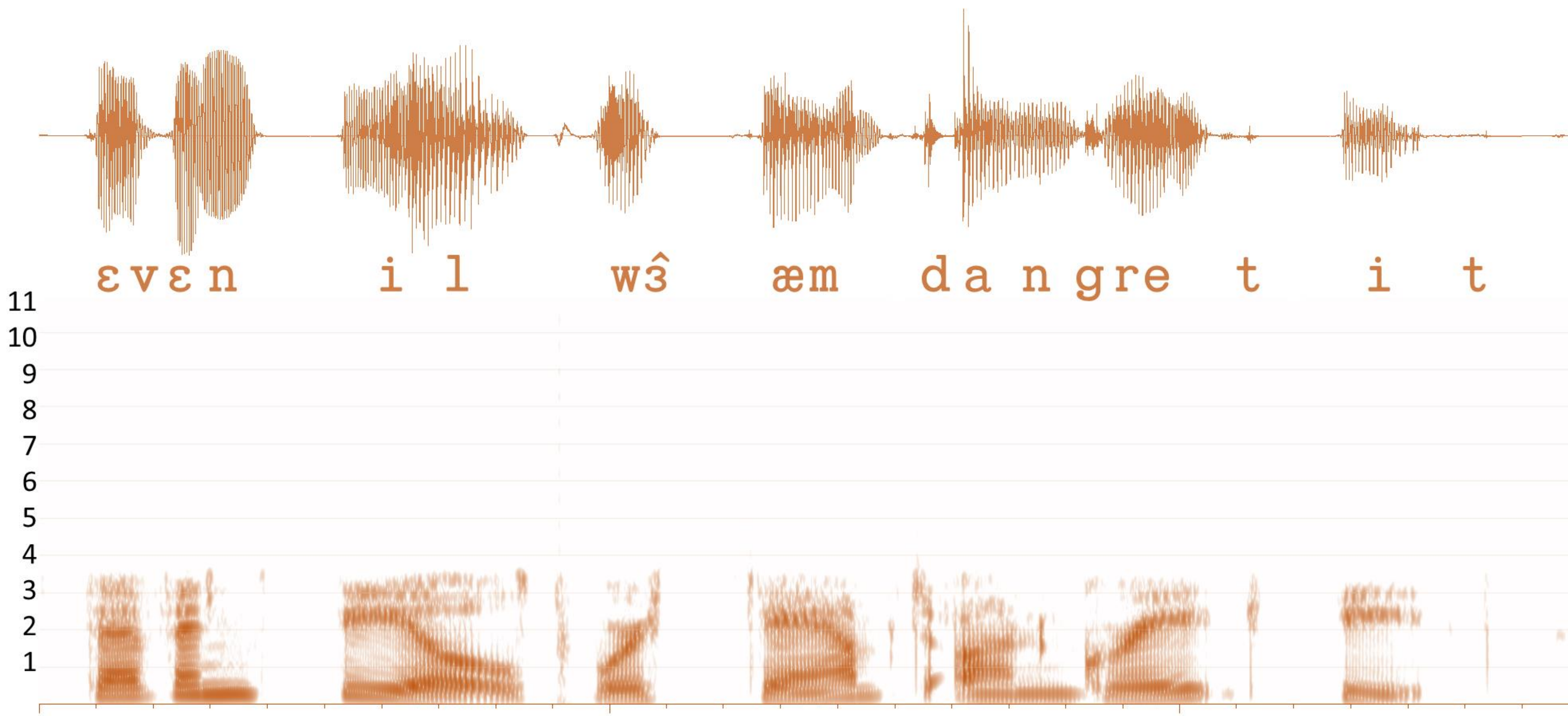
Destination Region ≈ 2.0 – 3.5 kHz

Stage 2

Source Region ≈ 2.0 – 11 kHz

Destination Region ≈ 0.8 – 3.5 kHz

Processed with ANFC (Stage 1)

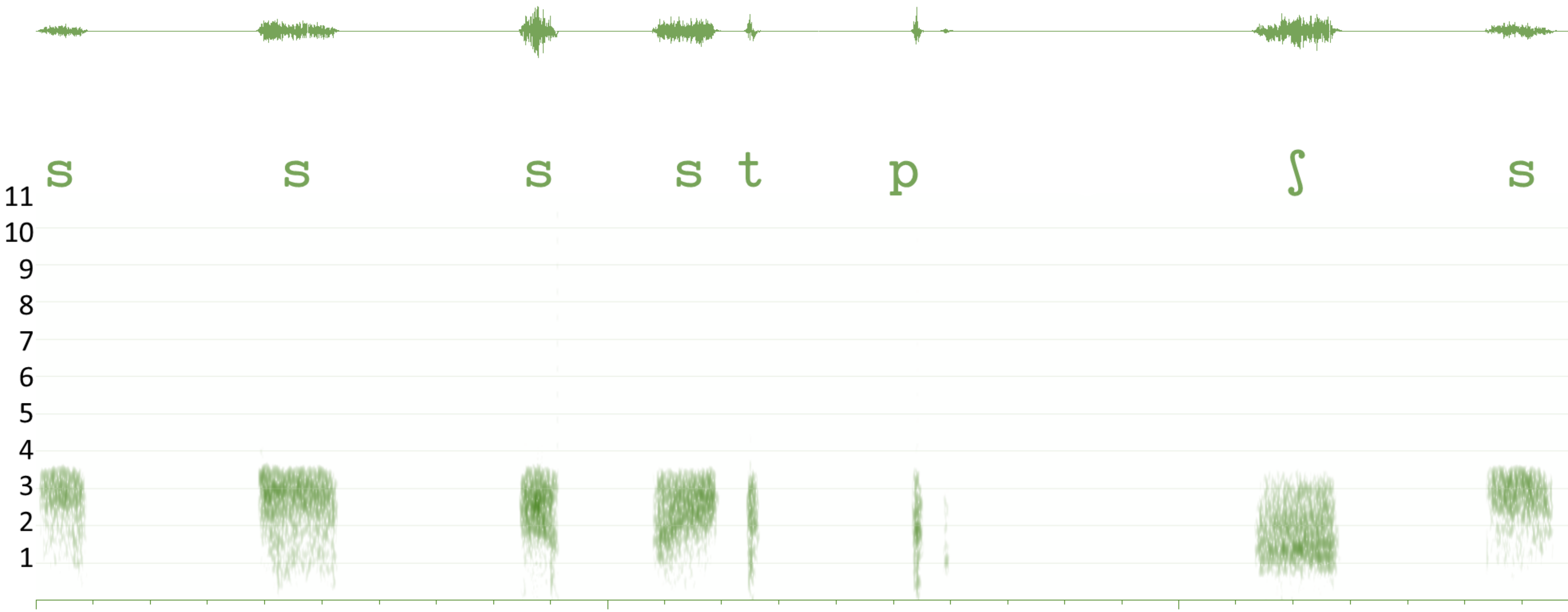


Stage 1

Source Region ≈ 2.0 – 6.0 kHz

Destination Region ≈ 2.0 – 3.5 kHz

Processed with ANFC (Stage 2)

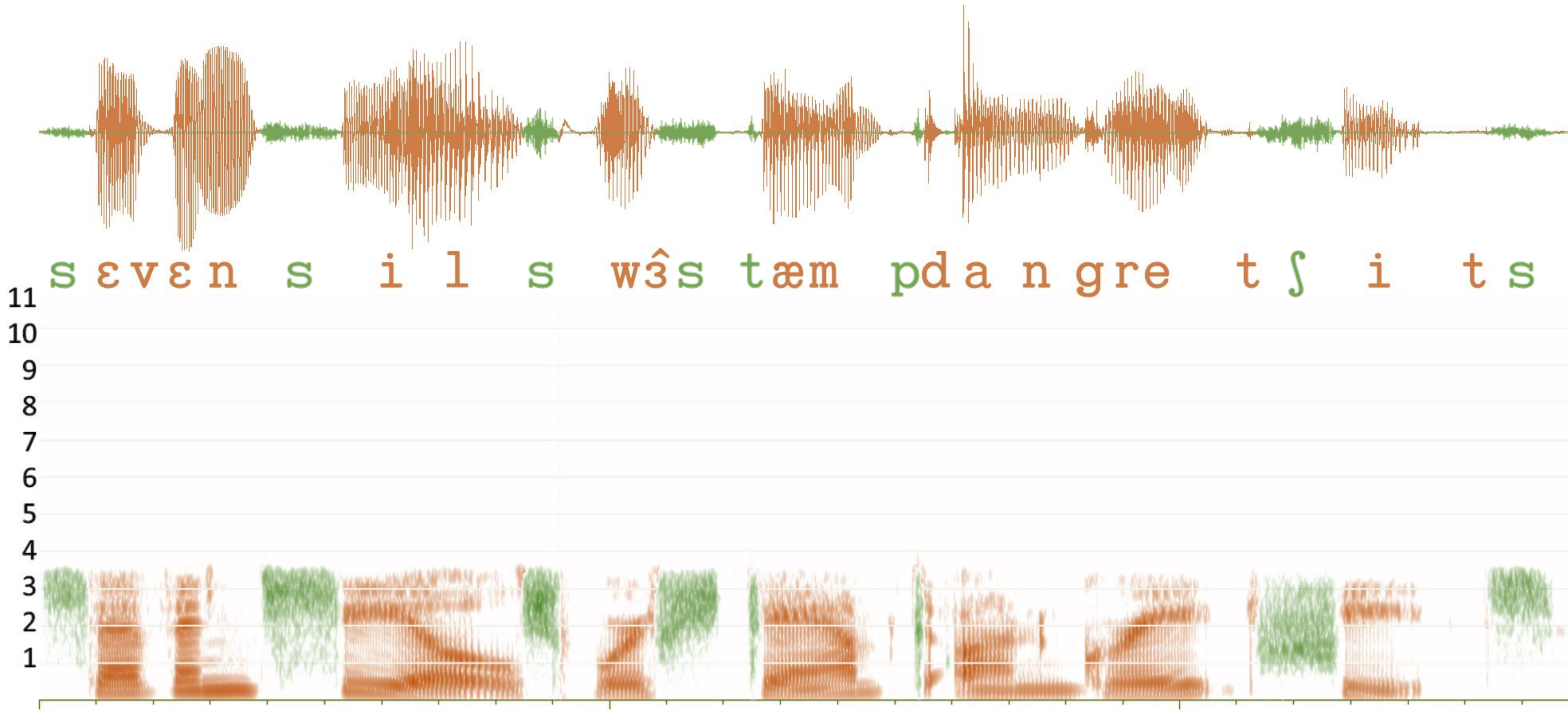


Stage 2

Source Region ≈ 2.0 – 11 kHz

Destination Region ≈ 0.8 – 3.5 kHz

Processed with ANFC



Stage 1

Source Region ≈ 2.0 – 6.0 kHz

Destination Region ≈ 2.0 – 3.5 kHz

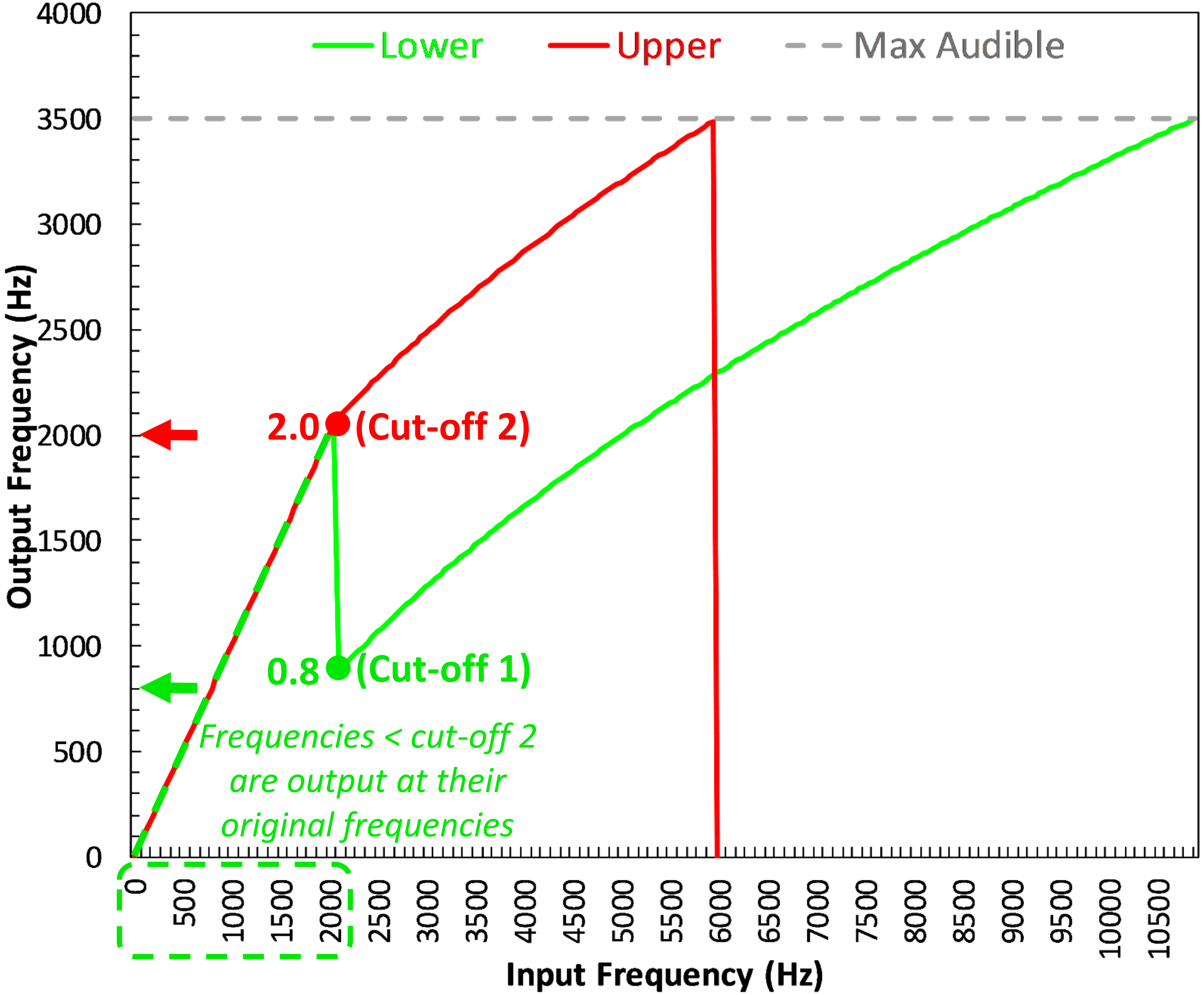
Stage 2

Source Region ≈ 2.0 – 11 kHz

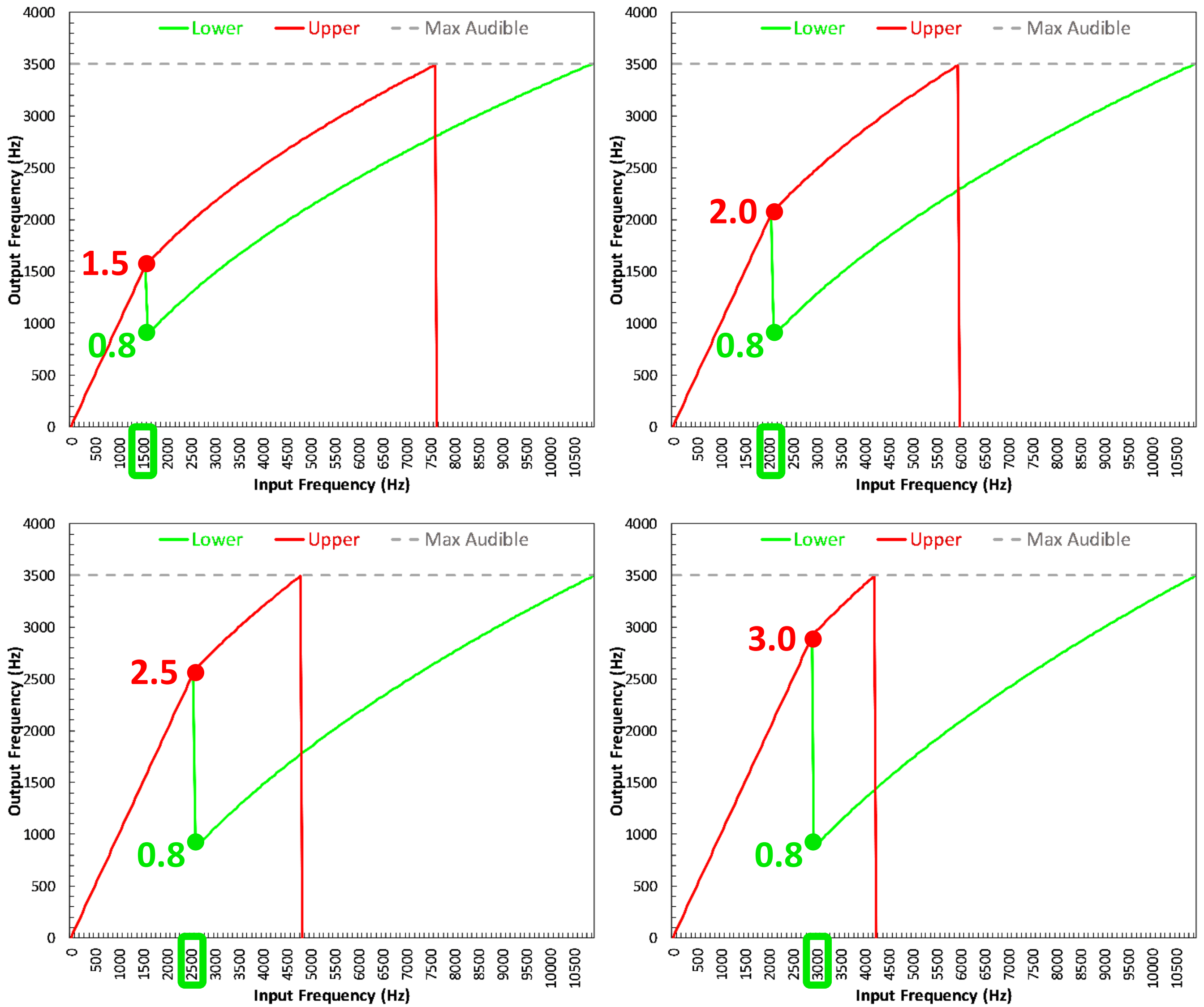
Destination Region ≈ 0.8 – 3.5 kHz

Frequency Input-Output Plot

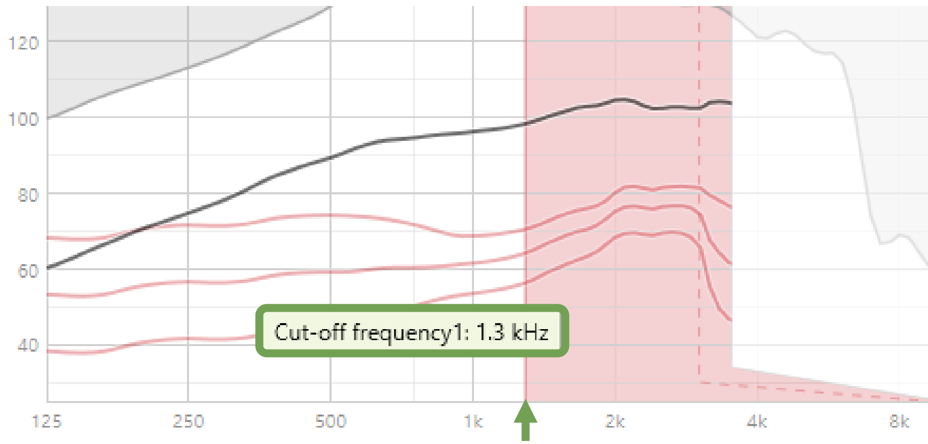
http://tinyURL.com/FLassist

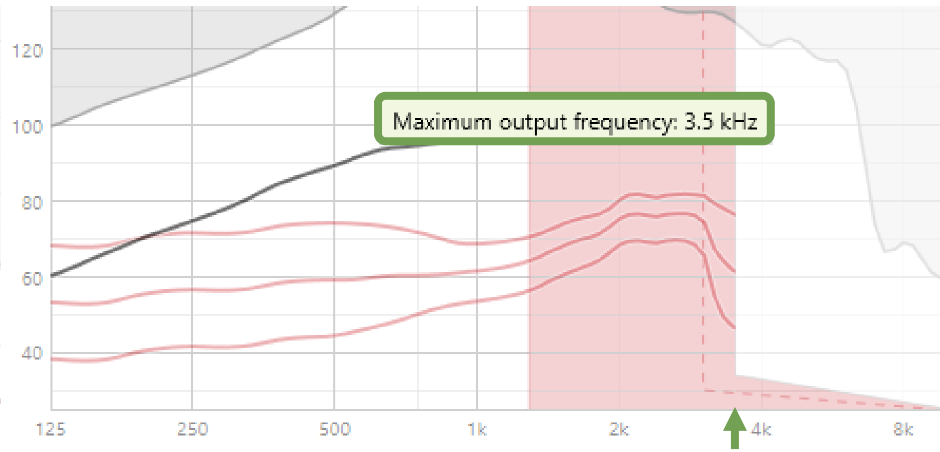


Source Region for Stage 2 (lower cutoff) *Depends* on Stage 1 (upper cutoff)

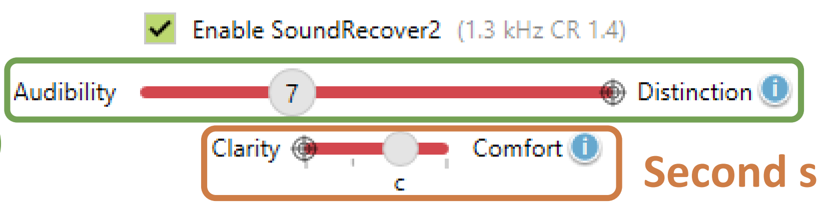


Programming Software Adjustments



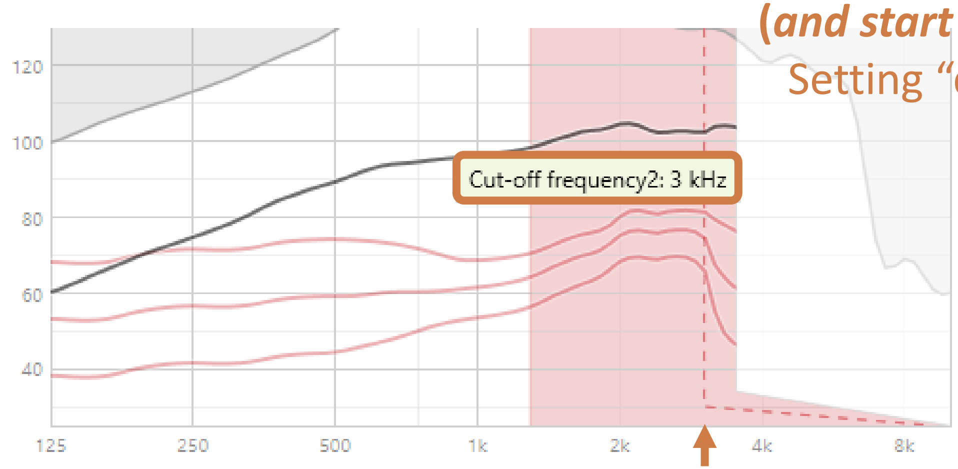


First slider controls destination region (cut-off 1 – max output)



Second slider controls cut-off 2 (*and start of source region*)

Setting "d" = max output



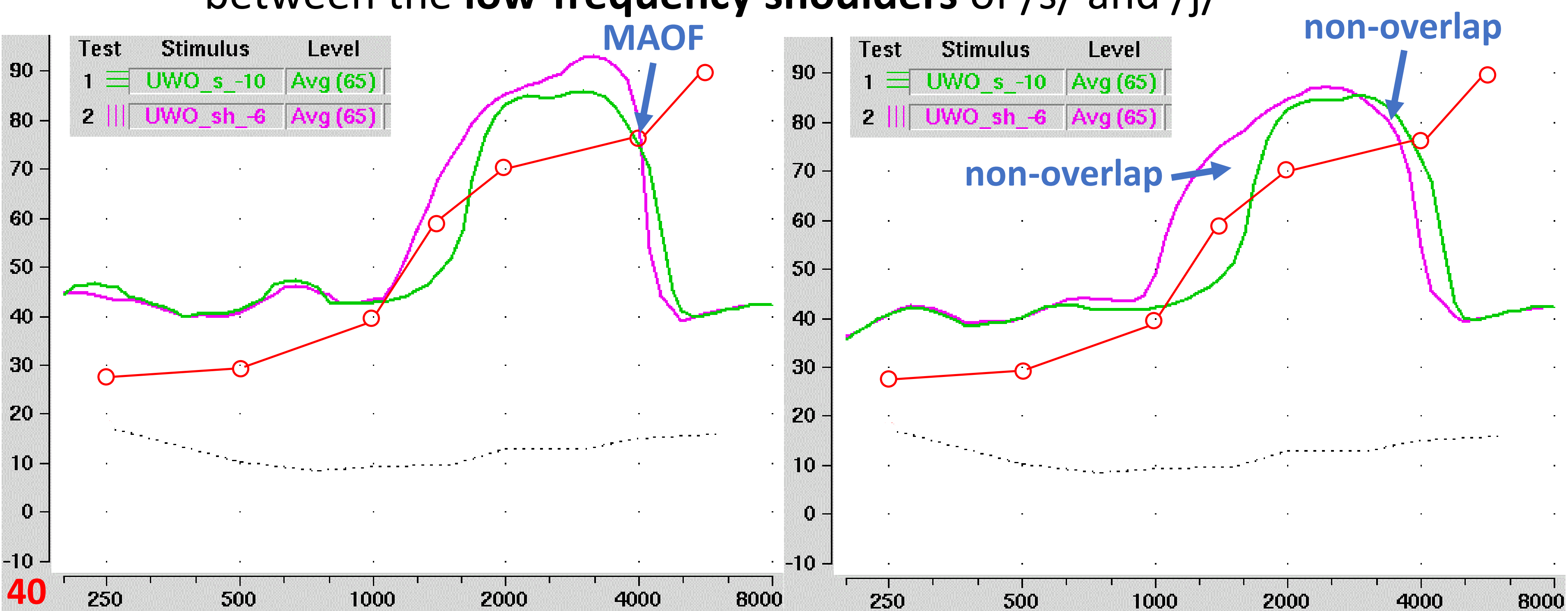
Which Setting to Choose?

1. Only settings on the **"Audibility-Distinction" slider** ("1" to "20") where the max output frequency ≥ MAOF should be considered
   - **Do NOT reduce the audible bandwidth!**
   - Consequences of setting max output frequency > MAOF
     - Full source region up to 11 kHz will NOT be audible
     - May **improve overall benefit** by reducing amount of compression

2. Choose from one of four settings ("a" to "d") on the **"Clarity-Comfort" slider**
   - Sets upper cutoff (cut-off 2)
     - Controls how *low-frequency* emphasis sounds are processed
       - Setting "d" essentially turns off frequency lowering for these sounds
     - Sets lower limit of source region for *high-frequency* emphasis sounds

Verification Using /s/,/ʃ/

- Susan Scollie recommends a 2-step procedure using calibrated /s/ and /ʃ/ (Scollie *et al.*, 2016)
    1. Make high-frequency 'shoulder' of /s/ audible (≤ MAOF)
    2. Make high-frequency shoulders of /s/ and /ʃ/ non-overlapping, if possible
        - Phonak also recommends at least 1/3-octave (≈1 ERB) separation between the **low-frequency shoulders** of /s/ and /ʃ/



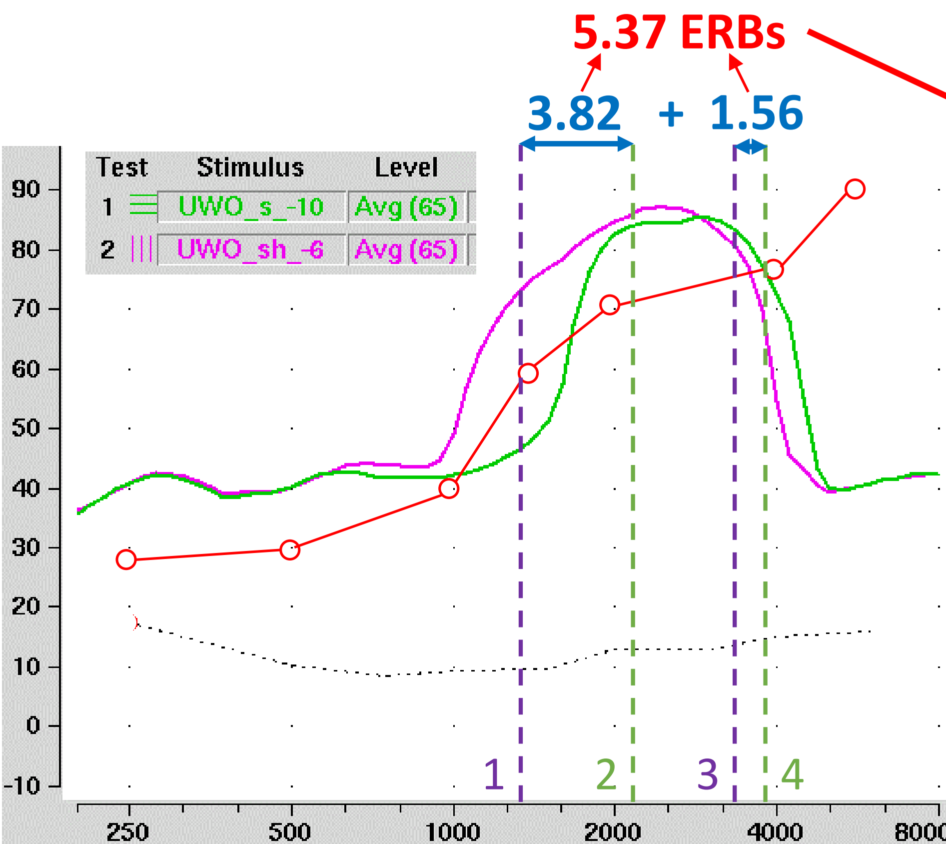
SoundRecover2 Fitting Assistant

http://tinyURL.com/FLassist

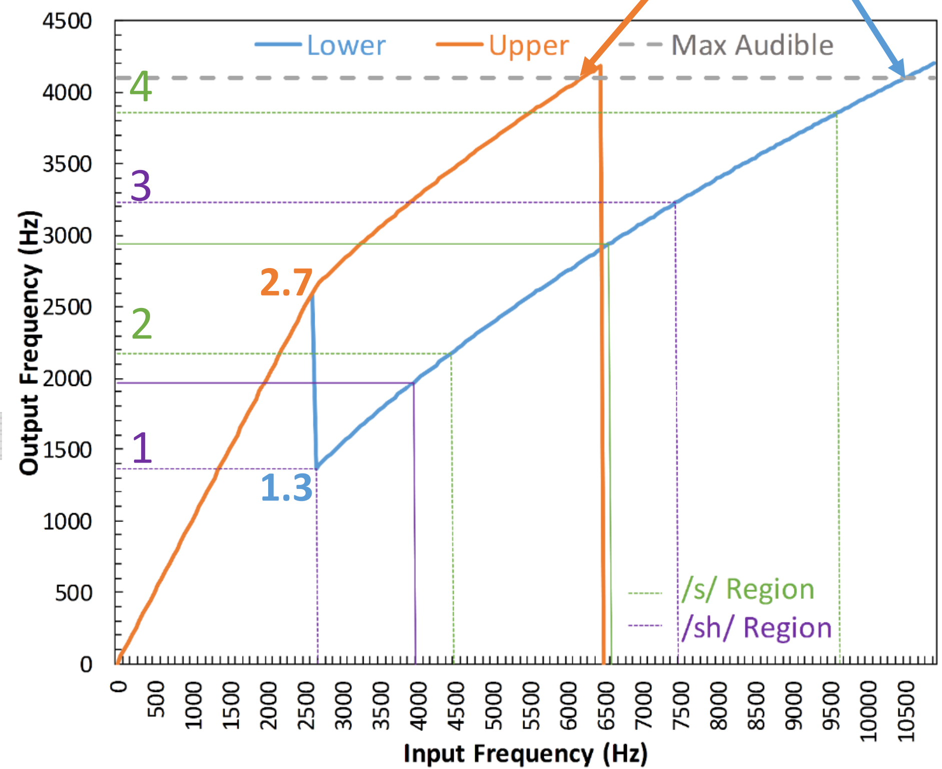
- **Given that we know . . .**
  1. The frequencies of the shoulders of the source UWO /s/ and /ʃ/ files
  2. The range of aided audibility (MAOF)
  3. The relationship between input and output frequencies for the different ANFC settings
     - *Cut-off 1, Cut-off 2, and Maximum Output frequencies*
- **Then, we can compute . . .**
  1. The amount of separation between the **high-frequency shoulders** of the UWO /s/ and /ʃ/
  2. The amount of separation between the **low-frequency shoulders** of the UWO /s/ and /ʃ/
  3. The **bandwidths** of the lowered UWO /s/ and /ʃ/
  4. All of the above on a **psychophysical scale** that resembles normal cochlear filtering (ERB scale)

SoundRecover2 Fitting Assistant **v1.0**

http://tinyURL.com/FLassist



Max Audible Output (SR off)	**4100**	**Hz**
Lower Cutoff	1.3	kHz
Upper Cutoff	2.7	kHz
HA Max Ouput (SR on)	4.2	kHz
/s/-/ʃ/ Non-overlap	**5.37**	**ERBs**
Max Audible Input (Lower)	10505	Hz
Max Audible Input (Upper)	6201	Hz



Preliminary Data

- 10-12 normal-hearing listeners with bandwidth limited to 3.3 kHz

- 10 different ANFC conditions processed in MATLAB that varied cut-off 1 and cut-off 2 with identical input/output bandwidth

- Tested on:
  - /s/-/ʃ/ discrimination in words (Purdue s-sh Test, PUSSH)
  - Fricative discrimination (/iC/)
  - Consonant discrimination (/VCV/)
  - Vowel discrimination (/hVD/)

Preliminary Data

- Correlated RAU scores with **acoustic analyses of /s/, /ʃ/** from processed PUSSH stimuli (in ERB units)
  - Separation of the low-frequency shoulders
  - Separation of the high-frequency shoulders
  - Average bandwidth

	LF shoulder	HF shoulder	Bandwidth	????
PUSSH	-0.71	-0.38	-0.88	0.94
Fricatives	-0.53	-0.61	-0.71	0.87
VCVs	-0.16	-0.68	-0.16	0.60

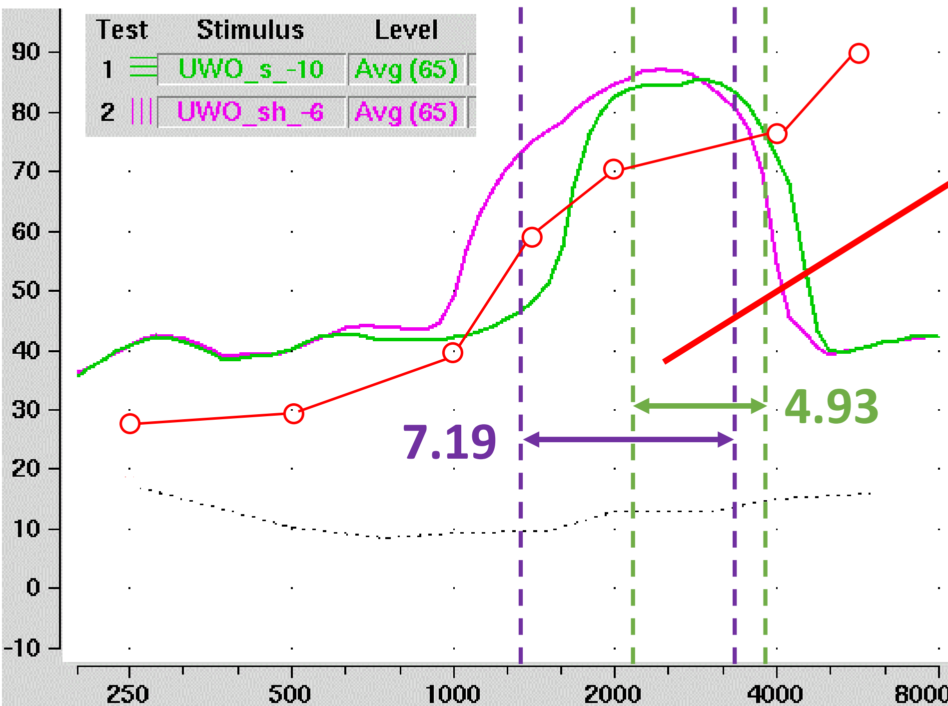
  - If anything, settings that increase separation between LF/HF shoulders seem to *increase* errors (negative correlations)
  - **Reducing bandwidth of /s/,/ʃ/ seems to *decrease* errors**
  - Another emergent property (????) seems to be best predictor

- Much work to be done . . . stay tuned!
  - Different severities of loss, hearing-impaired listeners, clinical devices, acoustics based on test stimuli (fricatives and VCVs)

SoundRecover2 Fitting Assistant **v2.0**

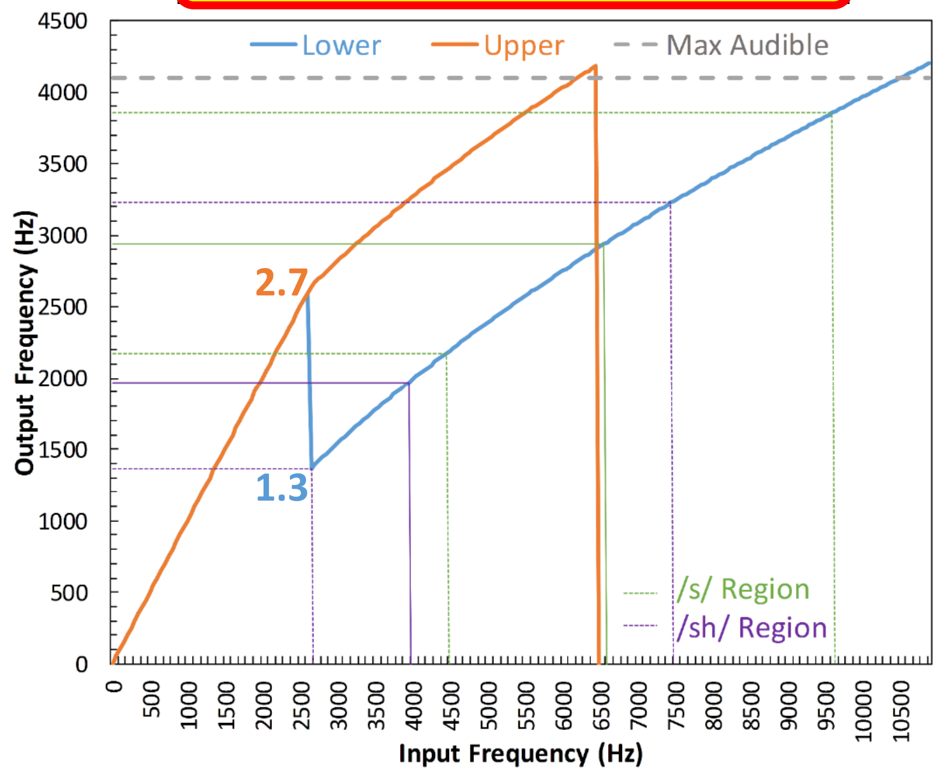
http://tinyURL.com/FLassist

Max Audible Output (SR off)	**4100**	**Hz**
Lower Cutoff	1.3	kHz
* Upper Cutoff	2.7	kHz
* HA Max Ouput (SR on)	4.2	kHz



*** Mean /s/, /ʃ/ Bandwidth**	**6.06**	**ERBs**
Max Audible Input (Lower)	10505	Hz
Max Audible Input (Upper)	6201	Hz

* Recommend (1) HA Max ≥ MAOF, (2) upper cutoff ≥ 2.2 kHz, (3) ***Minimize*** /s/, /ʃ/ Bandwidth




Thank You!
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