COLORATION METRICS FOR HEADPHONE EQUALIZATION

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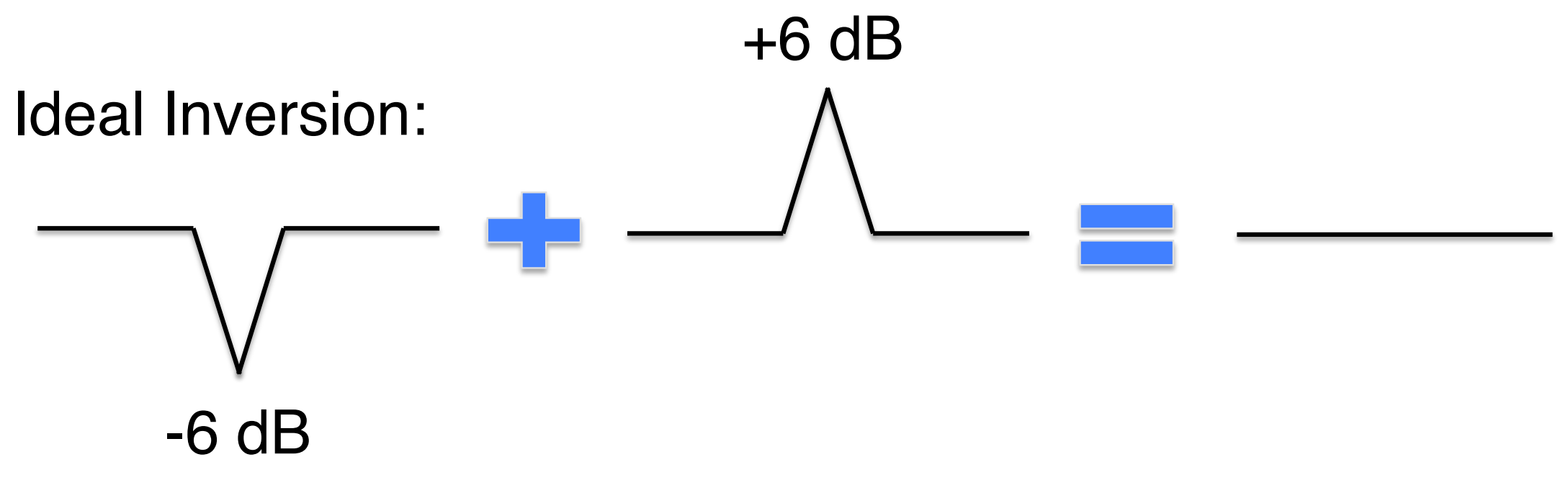
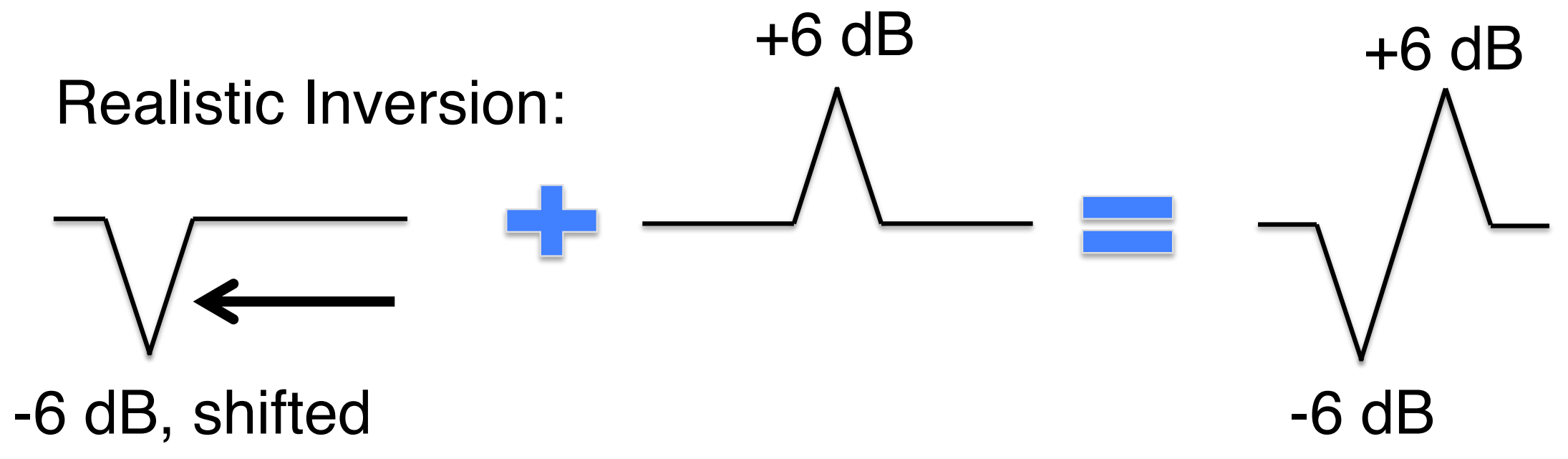
1 Abstract.

Headphone equalization is necessary for accurate binaural reproduction over headphones, but so far no metrics have been adopted for evaluating human perception of spectral coloration in post-equalization headphone transfer functions (HpTFs). A metric for peak error is proposed that represents the average HpTF error from narrow peaks per third octave band. In addition, a new metric for broadband error is defined by subtracting the average error from narrow peaks and notches from that of an auditory filter bank model. Used together, the peak error and broadband error terms are shown to represent the critical information necessary for transparent headphone reproduction.

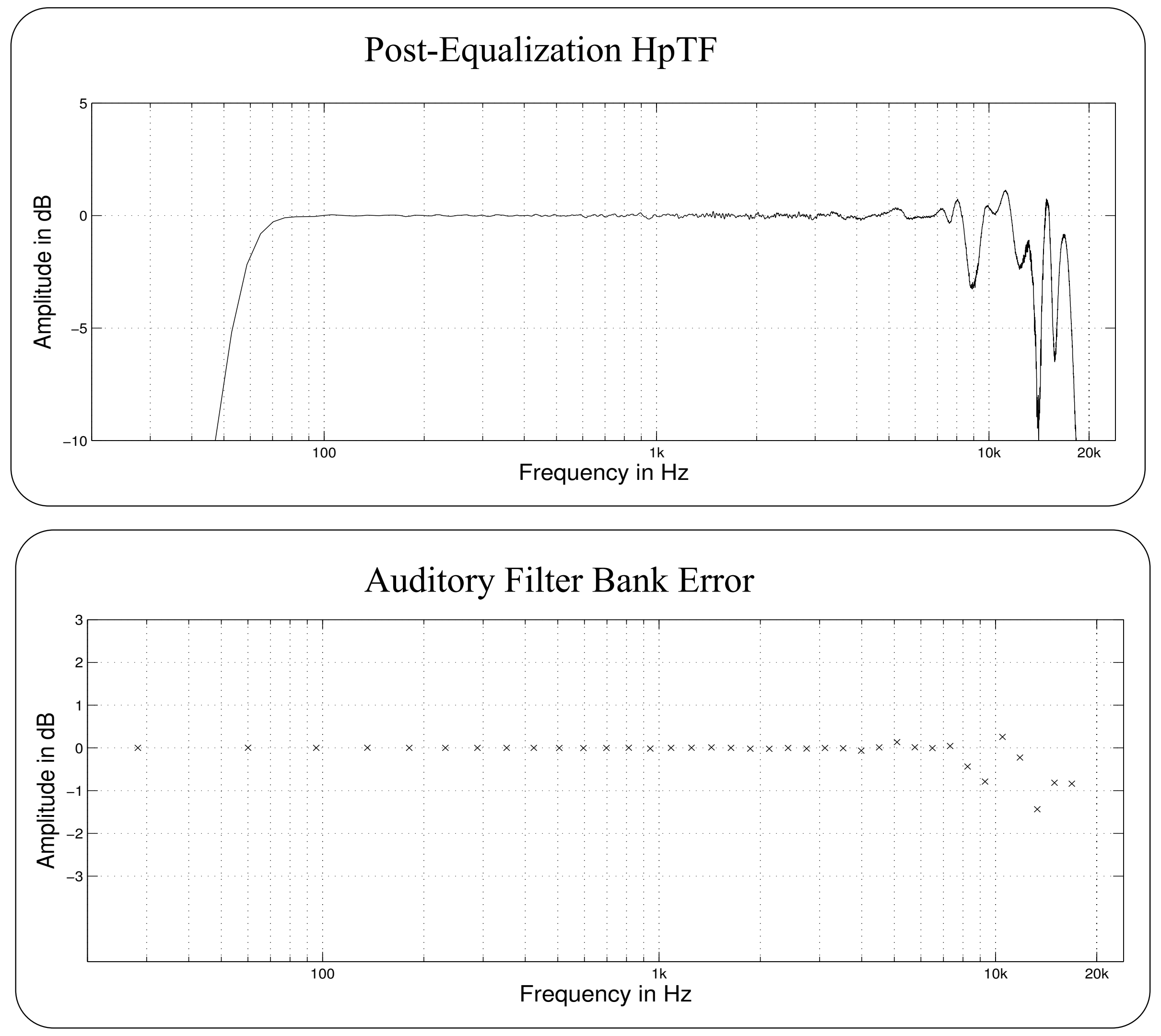
2 Introduction

- The Headphone Transfer Function (HpTF)
- Variations based on
    - Different headphones
    - Different Listeners
    - Different positioning of same headphones!
- High frequency notches move around
    - Naïve HpTF inversion makes things worse:





ERB Error E_{ERB}



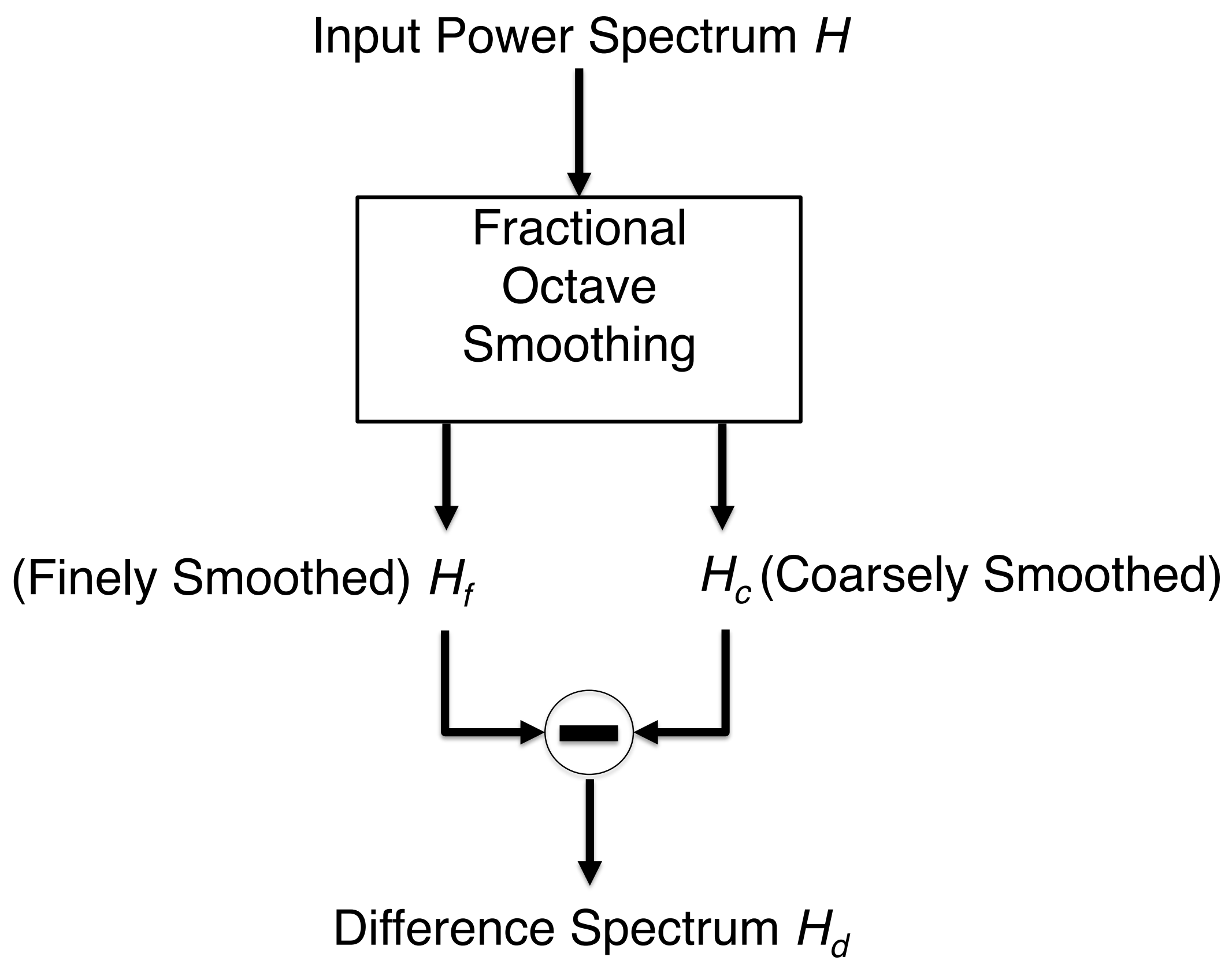
The top panel shows a typical HpTF for a subject after equalization has been applied. Previously, the standard error measurement for this was based on a bank of *equivalent rectangular bandwidth* (ERB) filters that mimic the cochlea's auditory critical bands (bottom panel). The ERB error is the mean of the average error in each filter bank.

3 Minimizing Coloration.

- Many HpTF equalizations have been proposed
- Need to compare these over a large population
    - PHOnA dataset of HpTFs
- This requires objective metrics of coloration
- Existing method: ERB error (above)
    - Mainly captures broadband effects
    - Doesn't account for 'ringing' from bad EQ
- Peaks are more noticeable than notches

4 Peak Error

- Given an input power spectrum H, we may calculate peak error E_{pk} as follows:


Input Power Spectrum H

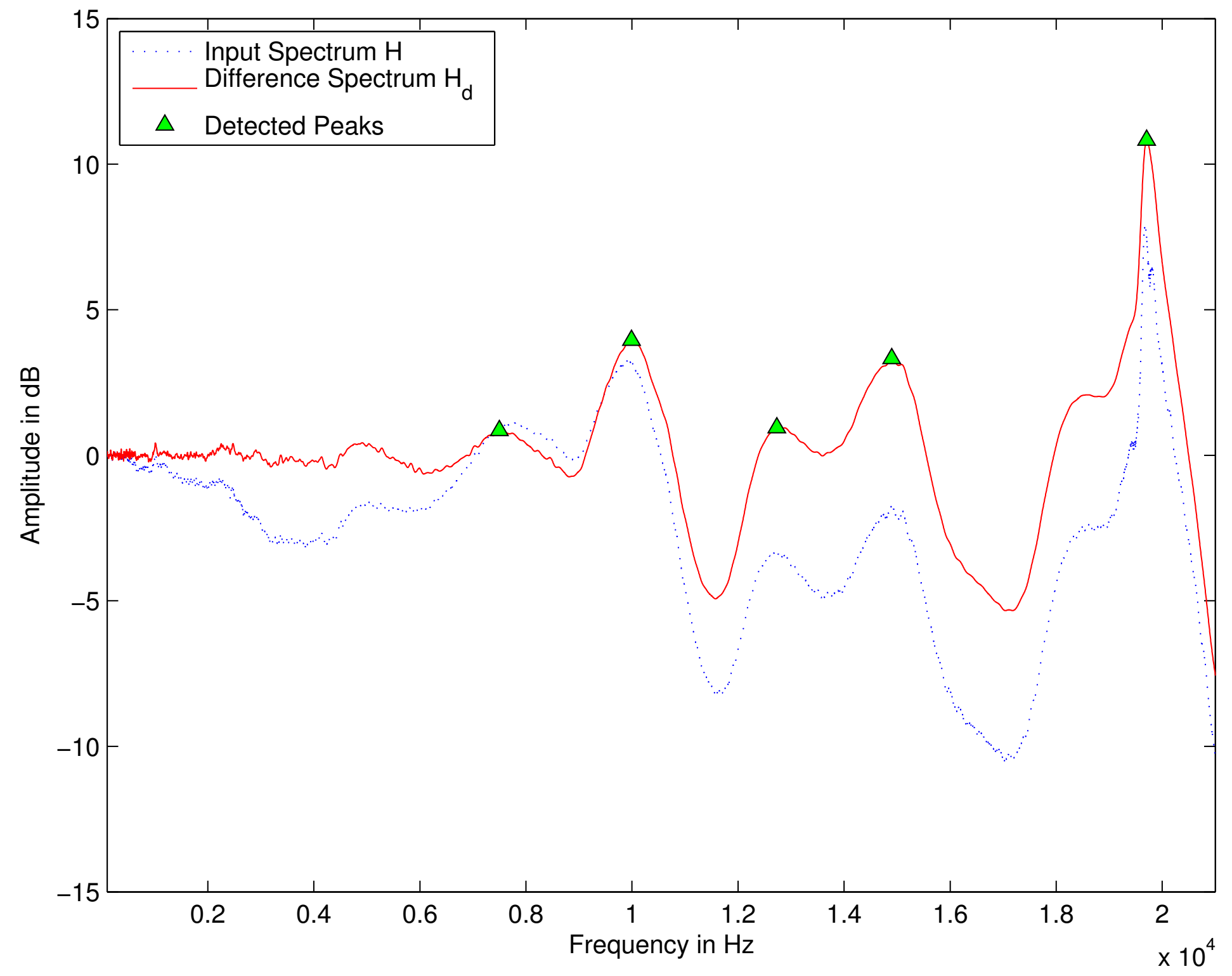
Fractional Octave Smoothing

(Finely Smoothed) H_f

H_c (Coarsely Smoothed)

Difference Spectrum H_d

- Taking the gradient of H_d we can find changes in the sign to detect peaks, applying thresholding to keep those above 1 dB:



- Given peak locations p, we define peak error as

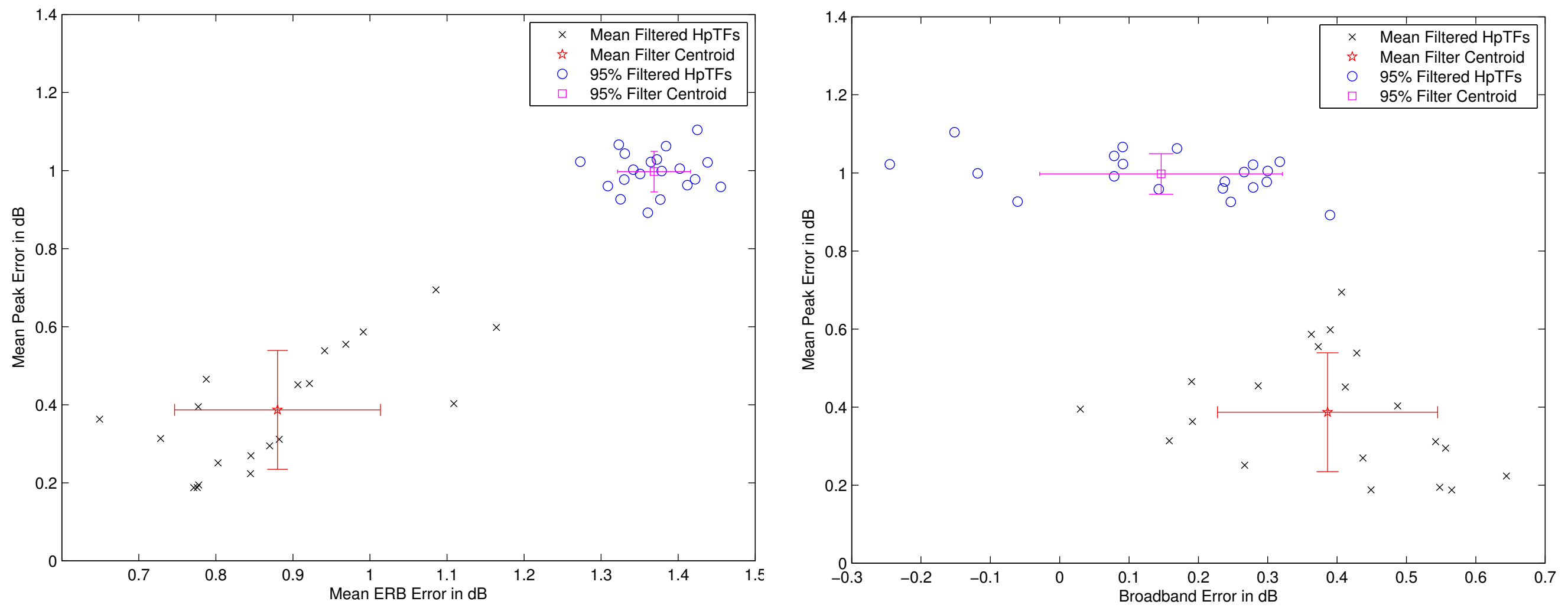
$$E_{pk} = \frac{\sum_p H_d(p)}{3[\log_2(f_{high}/f_{low})]}$$

- E_{pk} gives average peak height per 1/3 octave band
- Notch error E_n is calculated on $-H_d$ instead
    - Notch error is not perceptually relevant but is needed to calculate broadband error

5 Broadband Error

- In some cases E_{pk} and E_{ERB} are highly correlated, so we define broadband error by subtracting the mean of peak and notch error from ERB error:

$$E_{br} = E_{ERB} - \frac{E_{pk} + E_n}{2}$$



These plots show 2D error plots for two different equalization algorithms. E_{pk} is plotted against E_{ERB} and against E_{br} on the right. In the left plot both metrics are highly correlated and it appears one algorithm is objectively superior. On the right, peak and broadband effects are separated, and we see that one algorithm has greater peak error, while the other has greater broadband error.

6 Future Work

- Using these metrics we can now compare peak and broadband performance of many different equalization algorithms over the entire PHOnA dataset
- This allows us to build new equalizations that will minimize error terms as well as variance over many different listeners and headphones

7 References

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