CI Sound Coding:
The SpecRes Strategy

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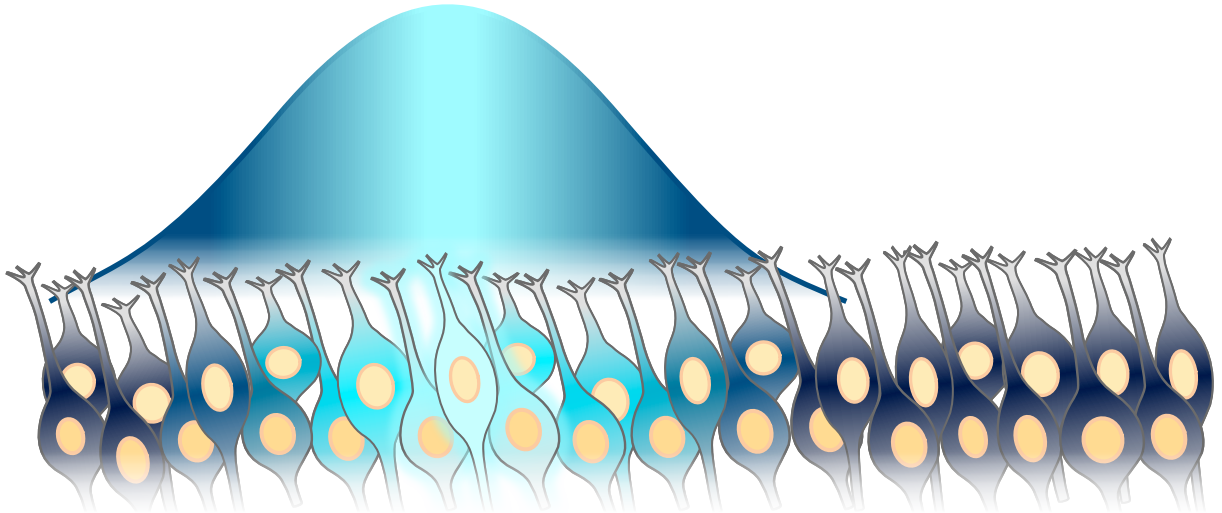
Introduction

- Advanced Bionics HiRes implant family
  - 16 stimulation electrodes over an active length of 15 - 20 mm
  - 16 independent current sources
  - Up to 90k pulses delivered per second

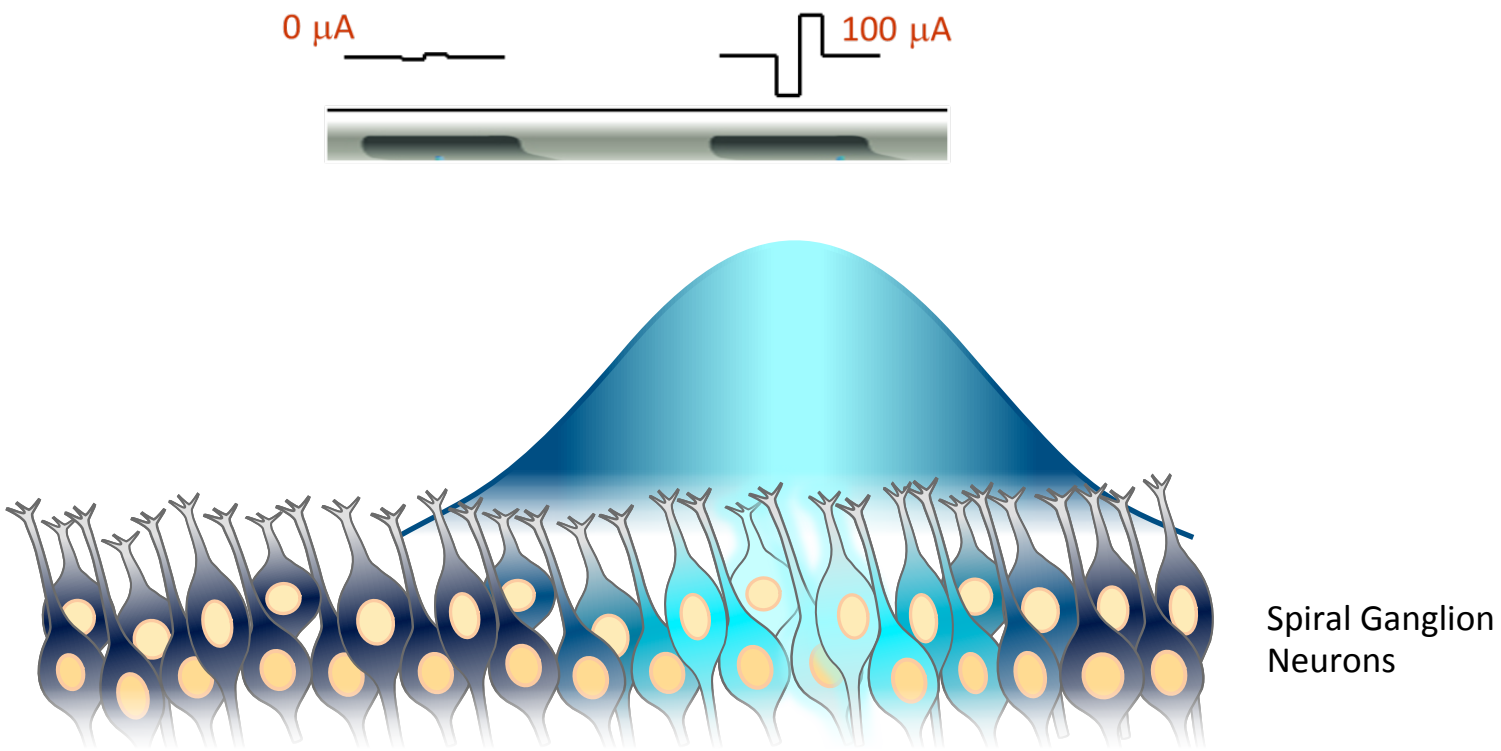
- Independent current sources
  - Implant electronics allow for stimulation of potentially all 16 electrodes *simultaneously* with independent amplitudes
  - Product use-case: Current Steering
    Controlled, paired stimulation of two neighboring electrodes (aka Virtual Channels)

Current Steering



Spiral Ganglion
Neurons

Current Steering



Spiral Ganglion Neurons

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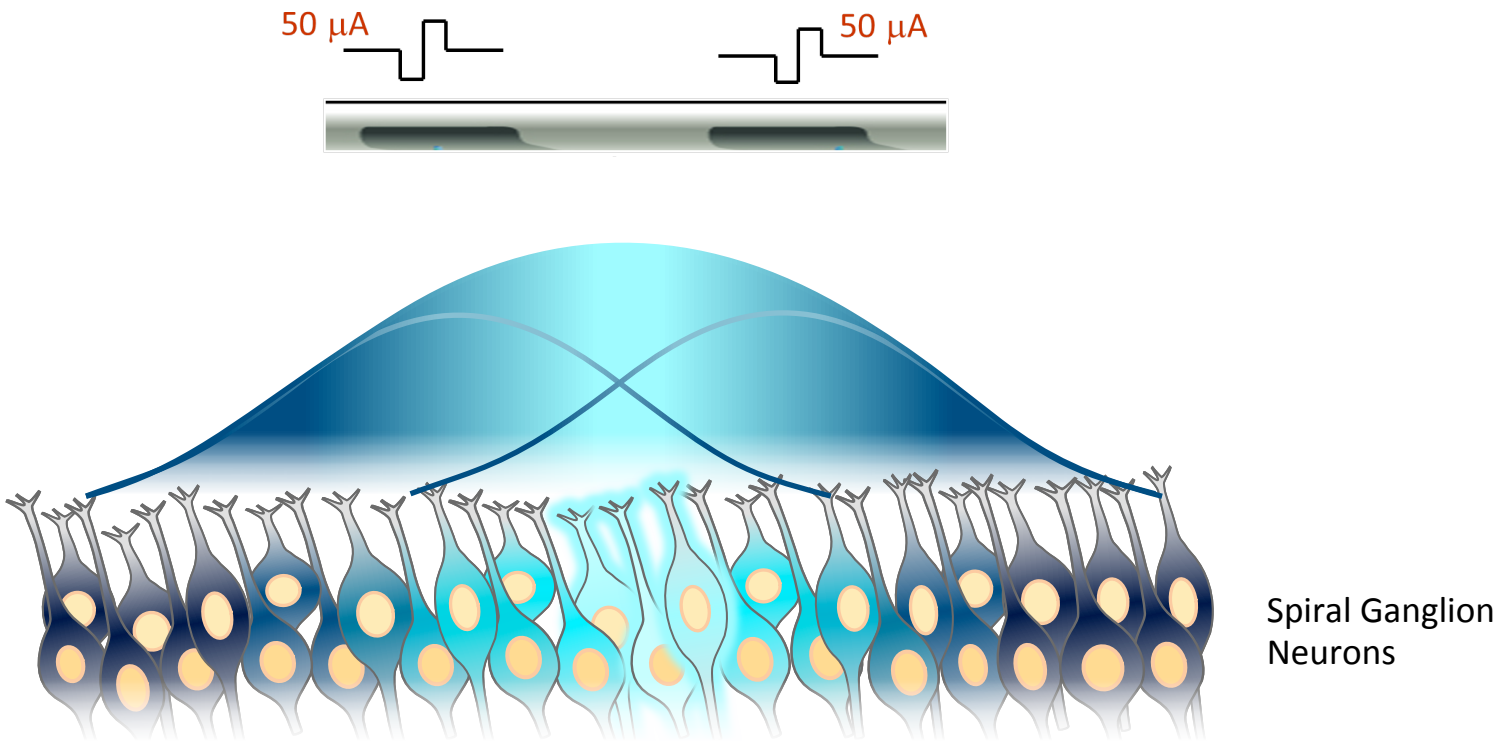

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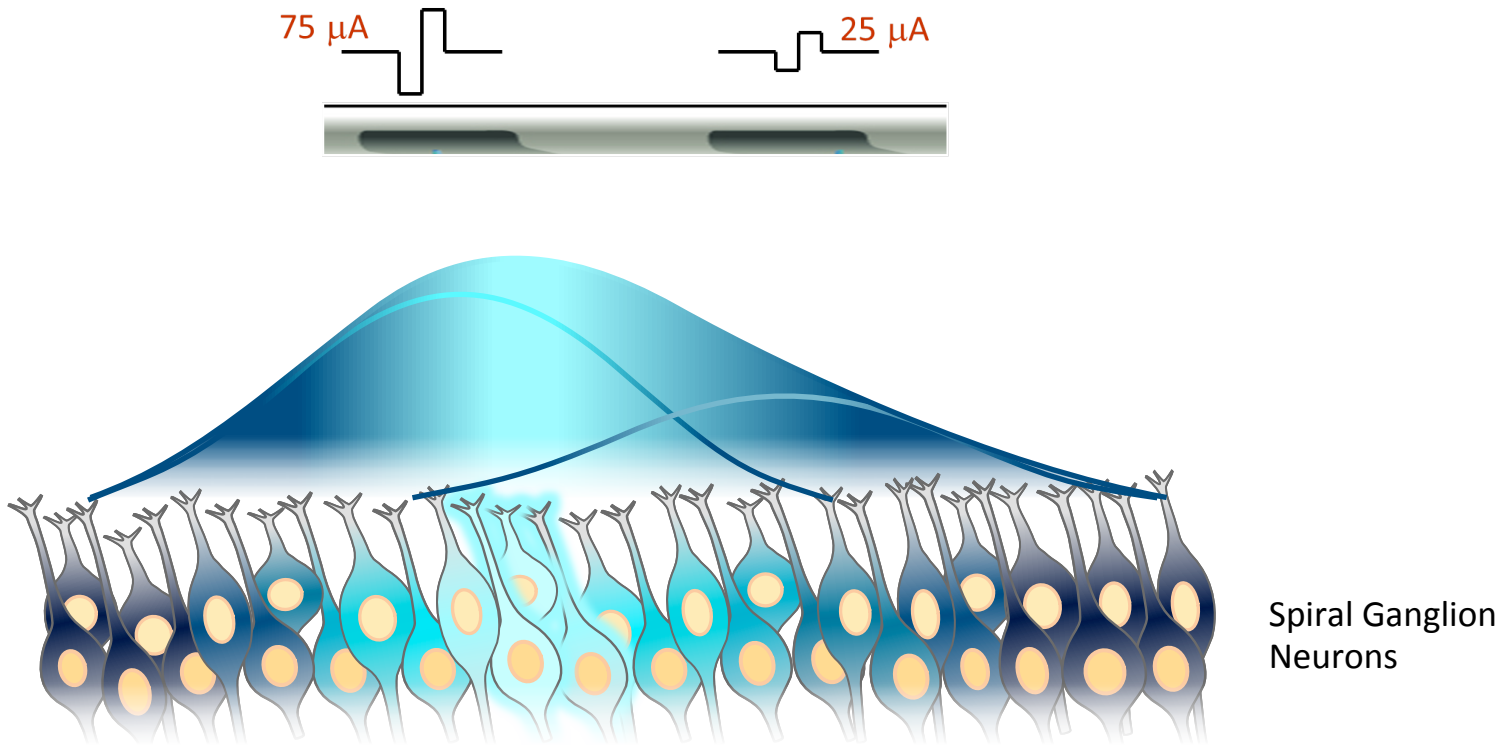

Spiral Ganglion
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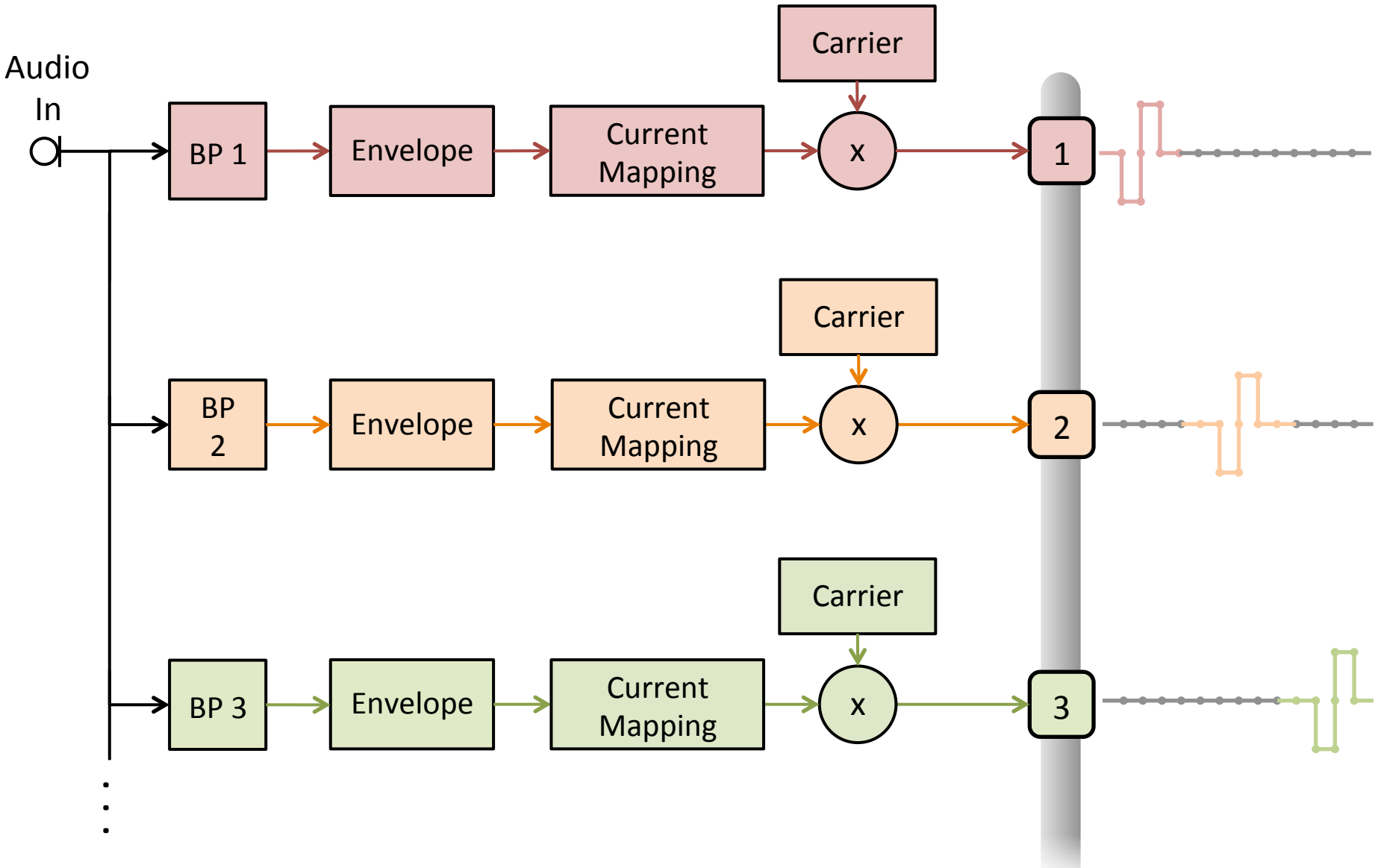
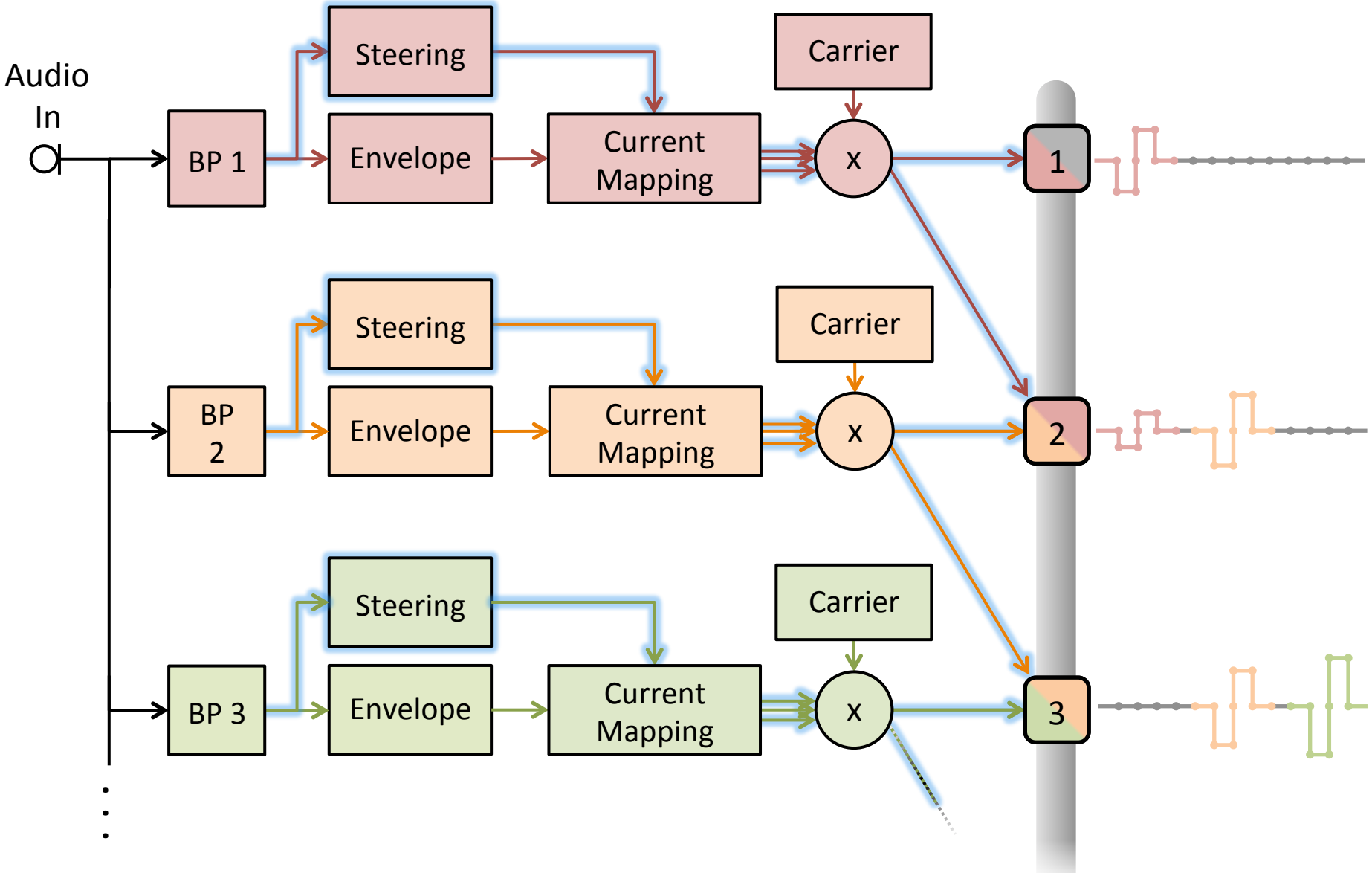
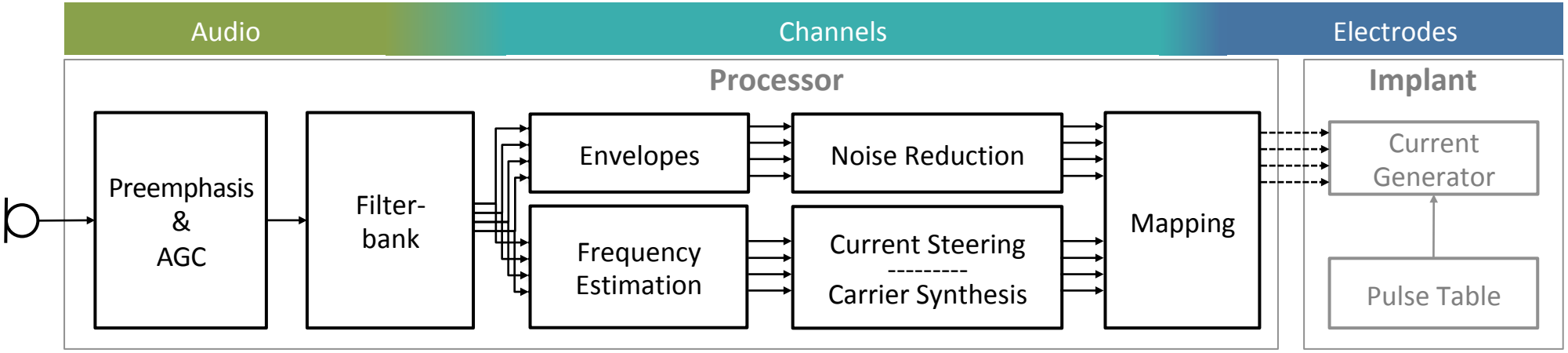
CIS with Current Steering



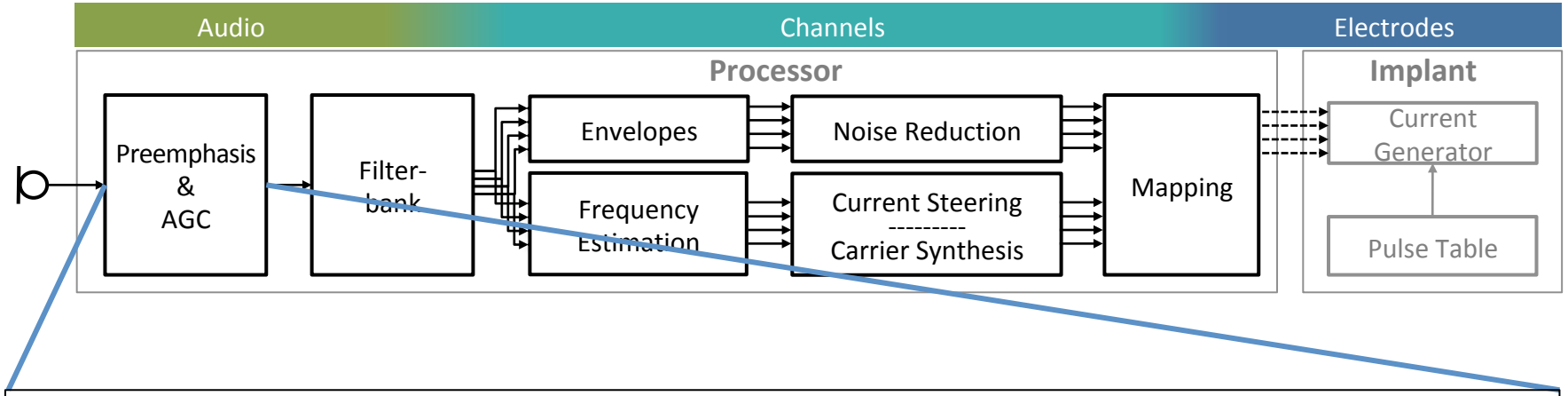
CIS with Current Steering



SpecRes Overview

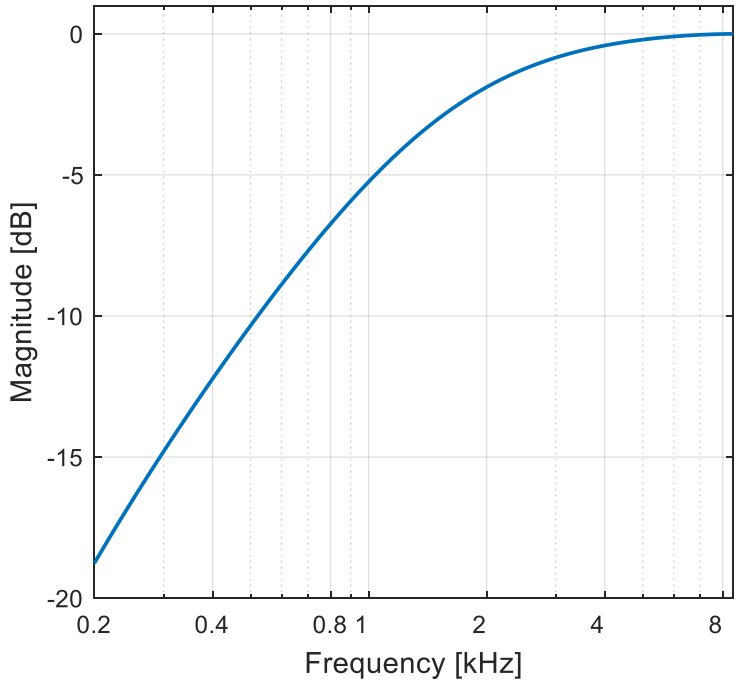


Pre-Emphasis

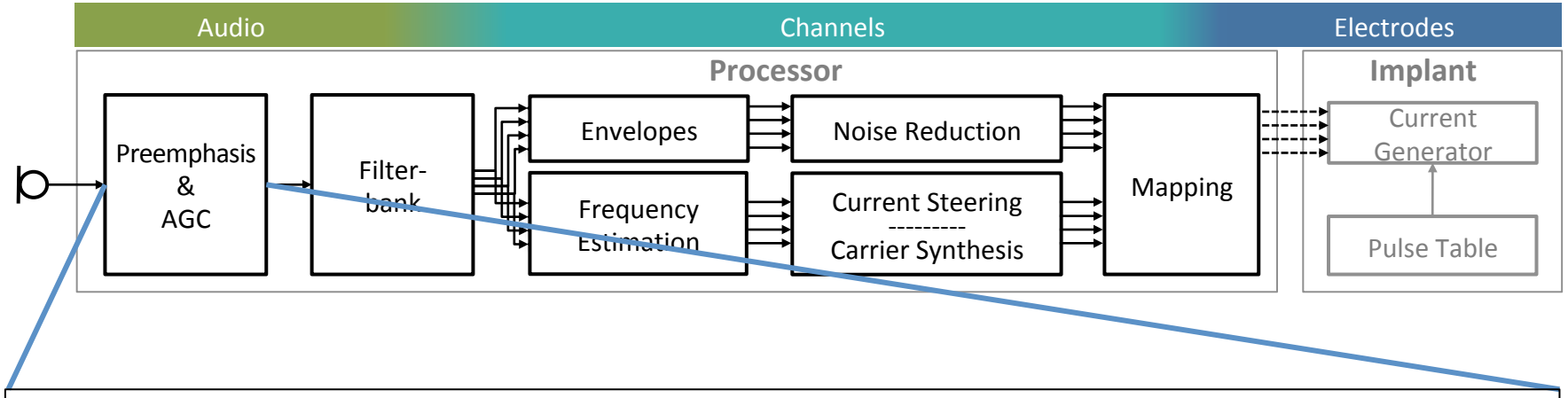


High-pass filter:

- Reduce impact of low-frequency noises
  - Digital range saturation
  - AGC compression
  - Perceptual masking
- Whitens typical input spectra
- Mimicks reduced sensitivity of normal hearing listeners to low-frequency sounds



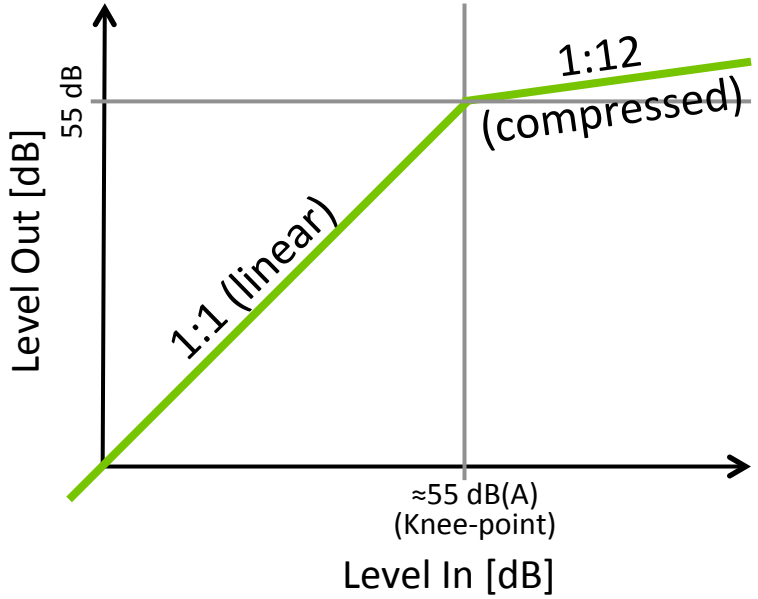
Automatic Gain Control



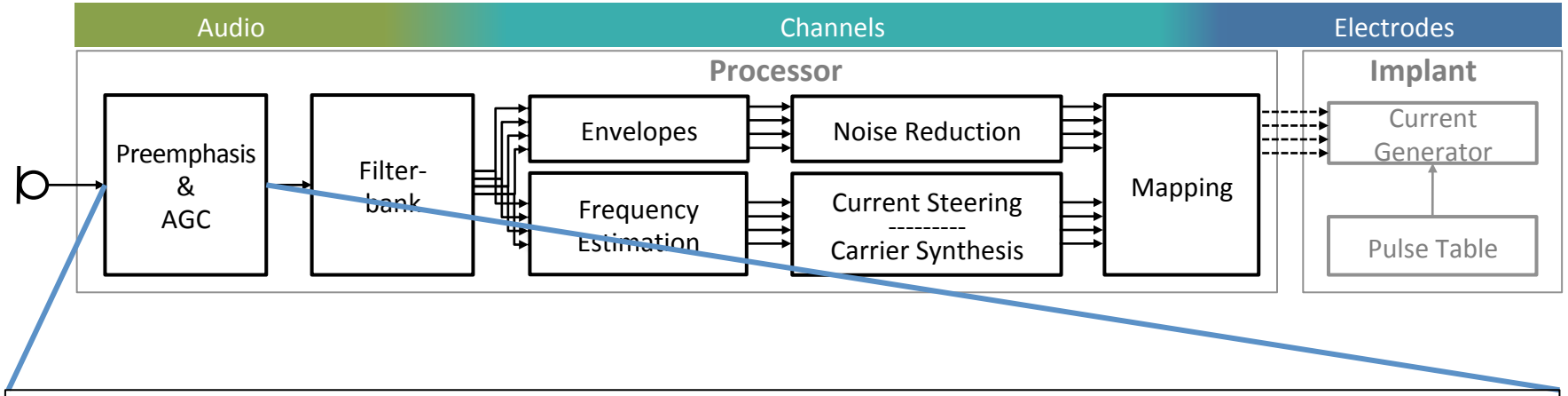
- Broadband gain control
- Dual loop design
- Slow loop:

  Low knee-point, slow dynamics
  - ➢ Comfortable level, full range of speech modulations
- Fast loop:

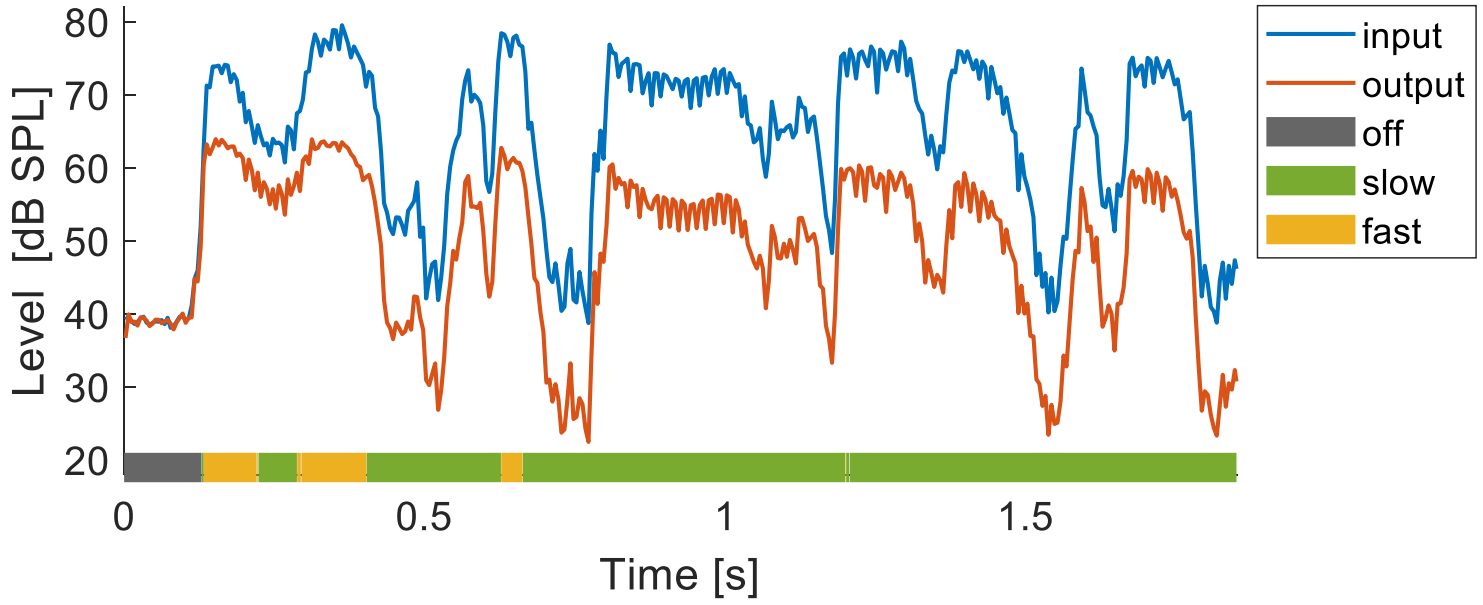
  Higher knee-point, fast dynamics
  - ➢ Avoids sudden loudness discomfort



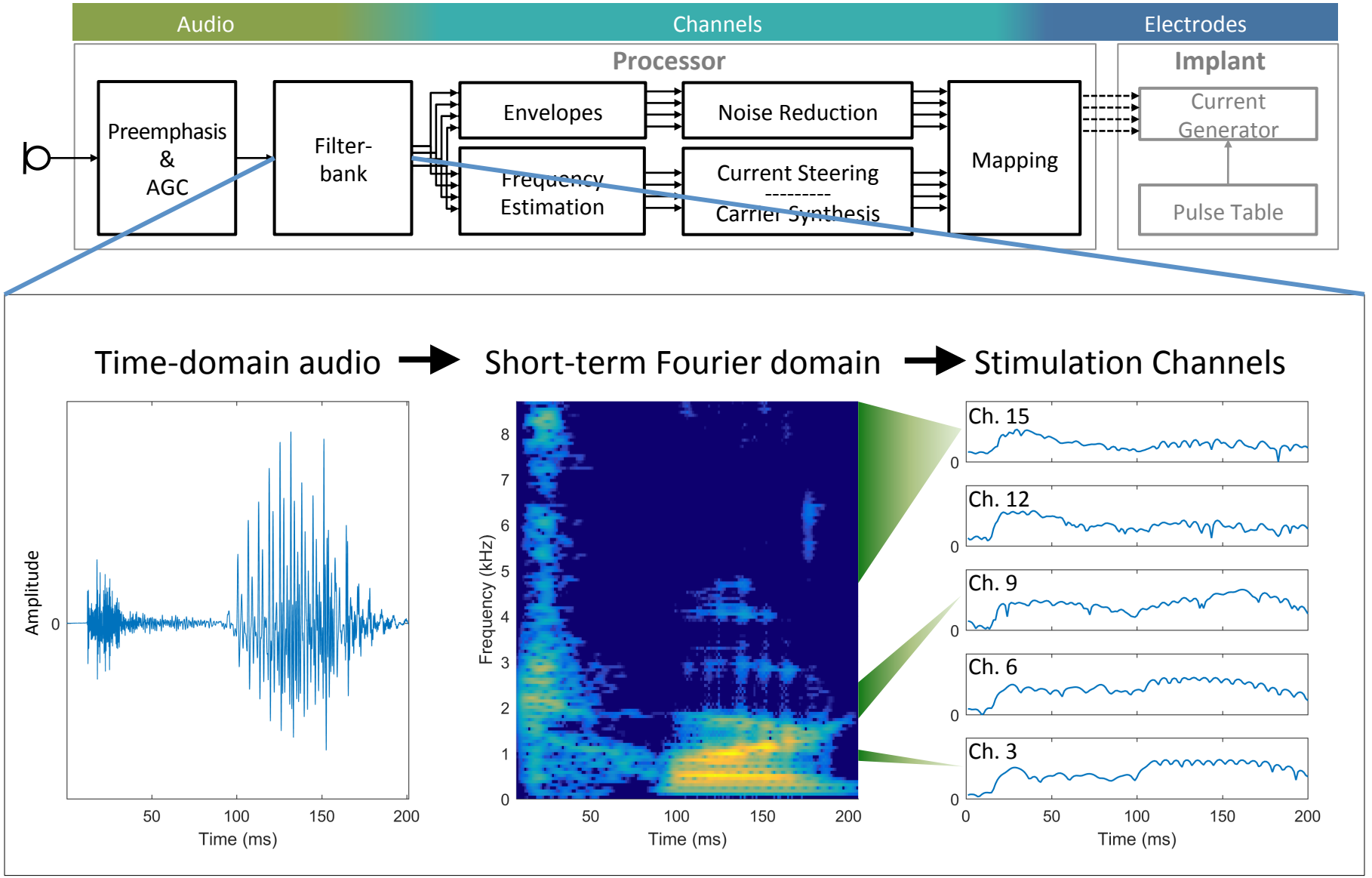
Automatic Gain Control



Example: Speech at 70dB SPL



Filterbank


Audio
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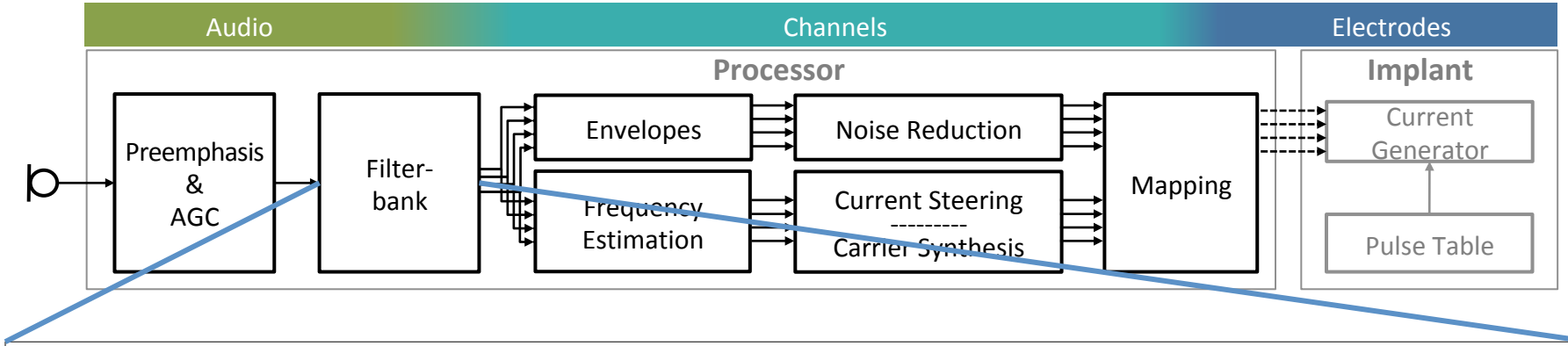
Implant
Preemphasis & AGC
Filter-bank
Envelopes
Frequency Estimation
Noise Reduction
Current Steering
Carrier Synthesis
Mapping
Current Generator
Pulse Table
Time-domain audio
Short-term Fourier domain
Stimulation Channels
Amplitude
Time (ms)
Frequency (kHz)
Ch. 15
Ch. 12
Ch. 9
Ch. 6
Ch. 3

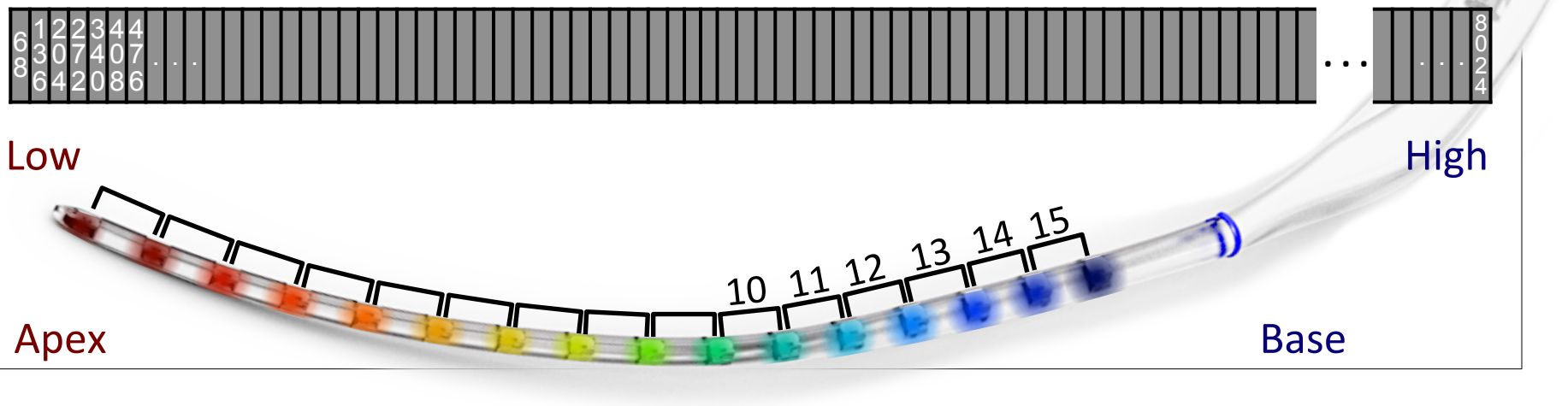
Filterbank



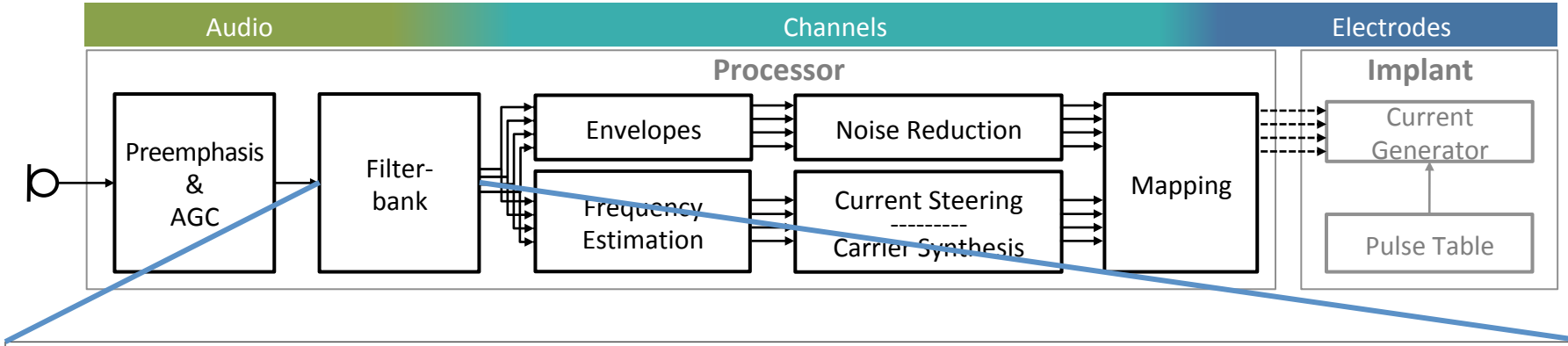
1. Fourier transform
   - Sampling rate: 17400 Hz
   - FFT length: 256 samples
   - Frequency resolution: 68 Hz

2. Stimulation channels
   - 15 channels (max.)
   - Spaced after *Greenwood* function:

$$f(x) = f_{apex} + a \cdot \exp(bx)$$



Filterbank



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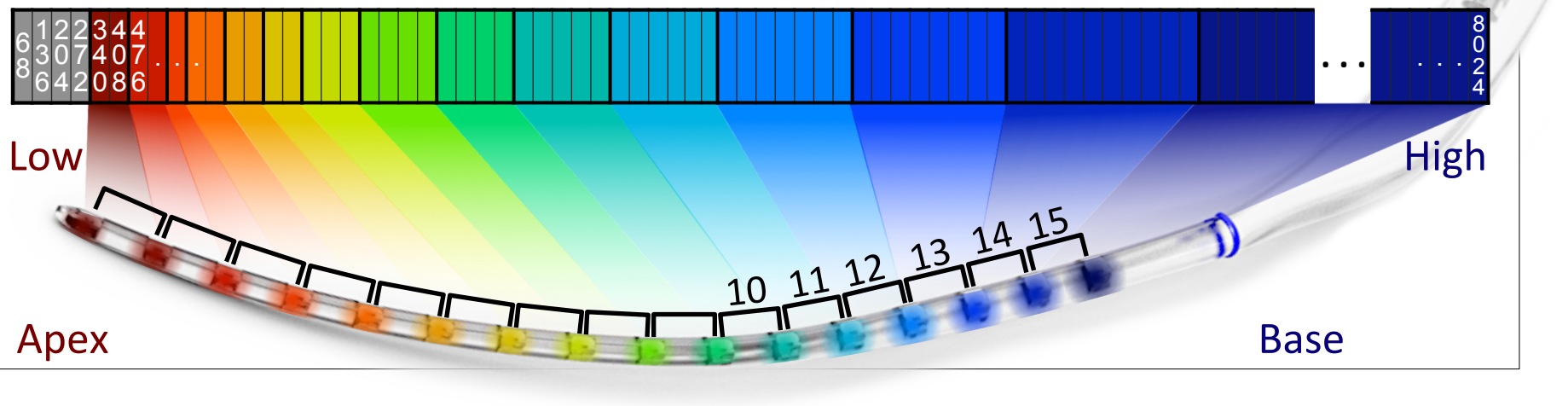
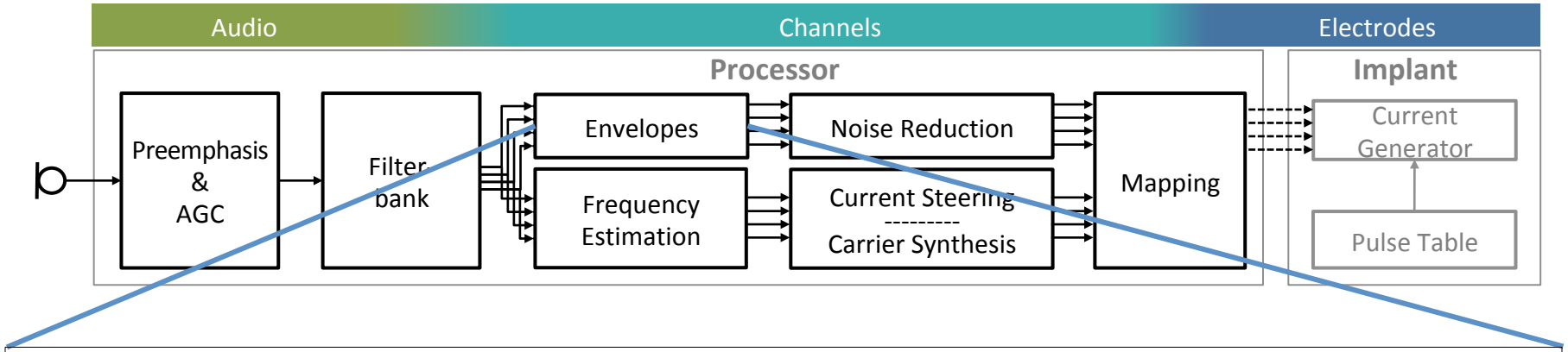
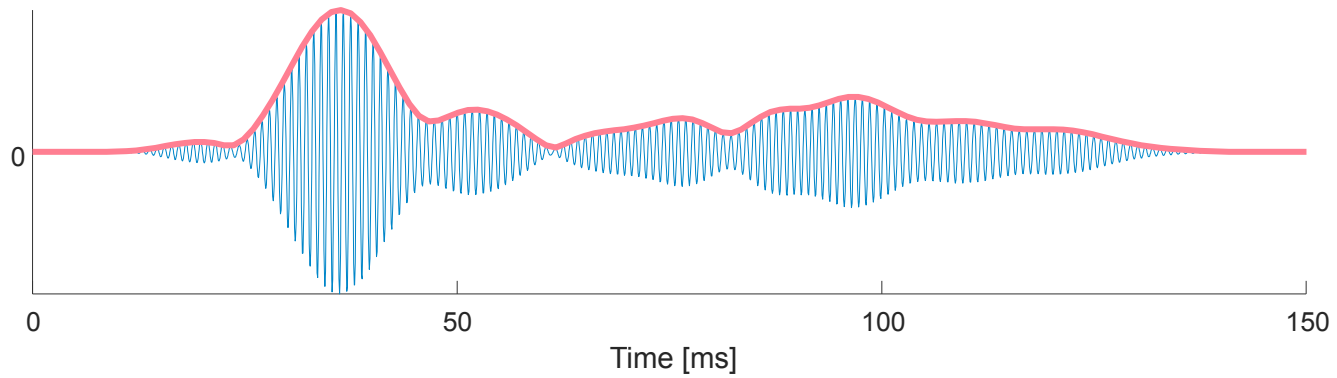


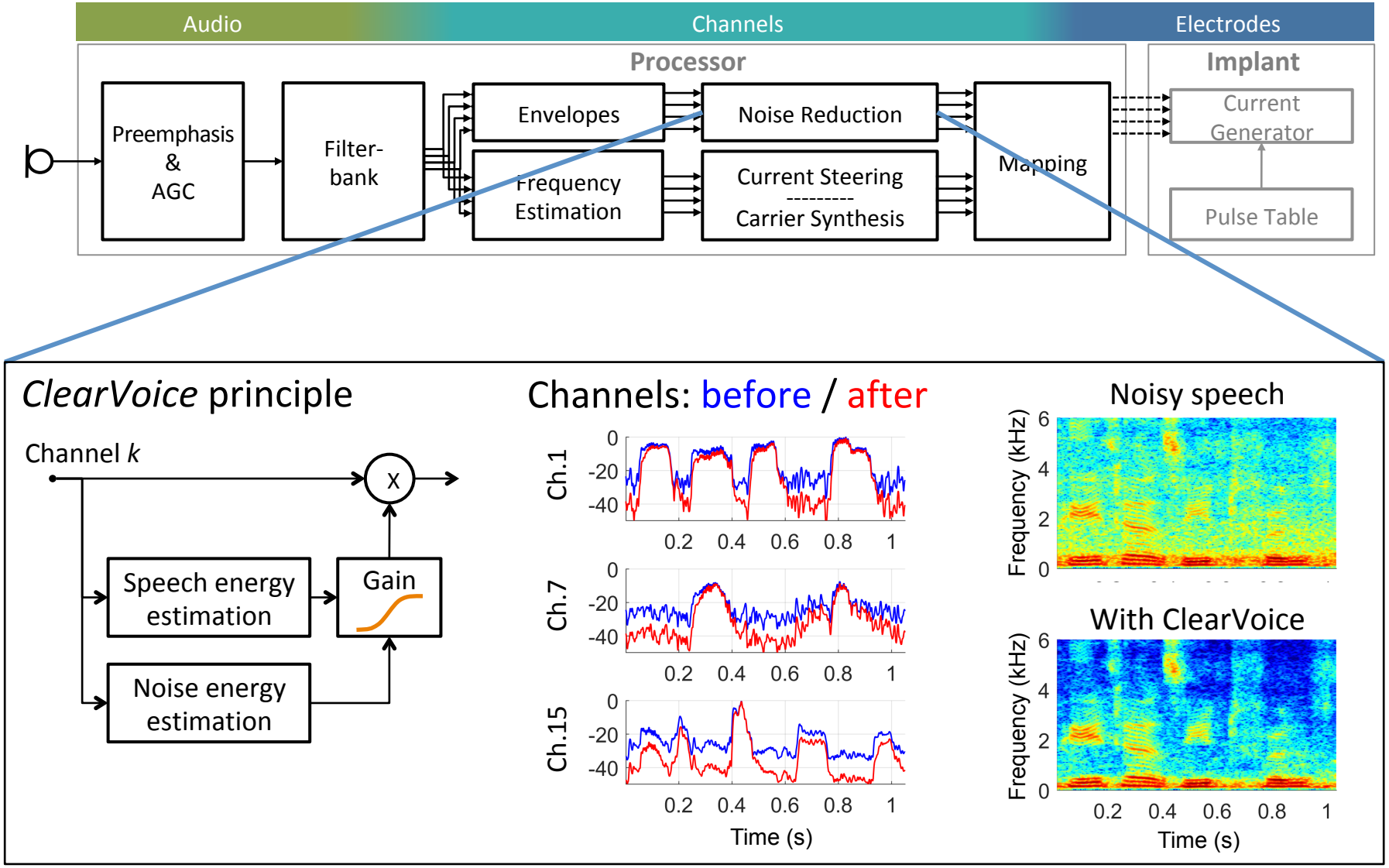
Envelopes



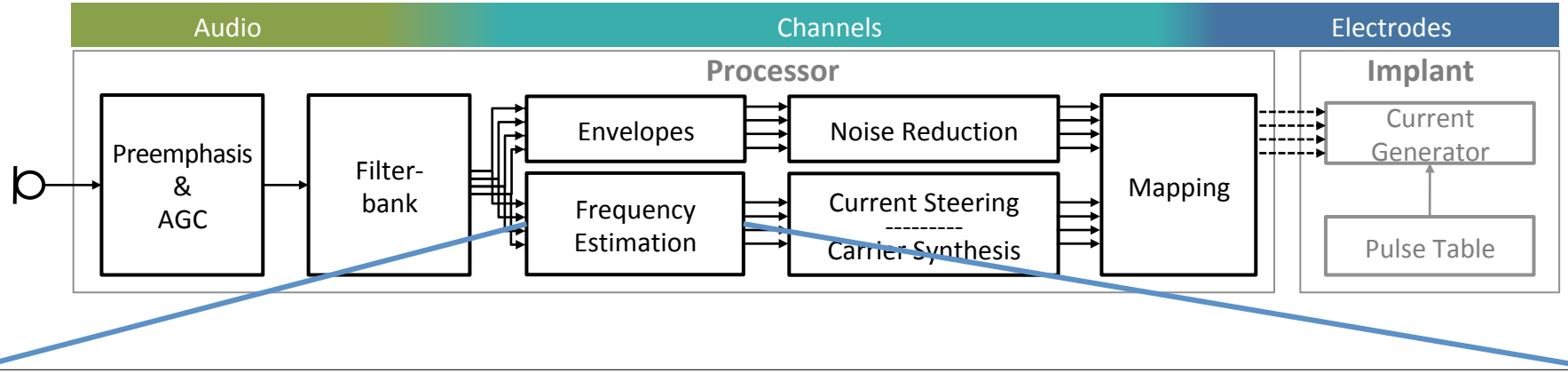


- Short-term sound intensity estimate for each filterbank channel
- Hilbert Envelope:
  Magnitude of the “analytic signal”, obtained by Hilbert transform
- Simple, efficient calculation in the freq.-domain

Noise Reduction

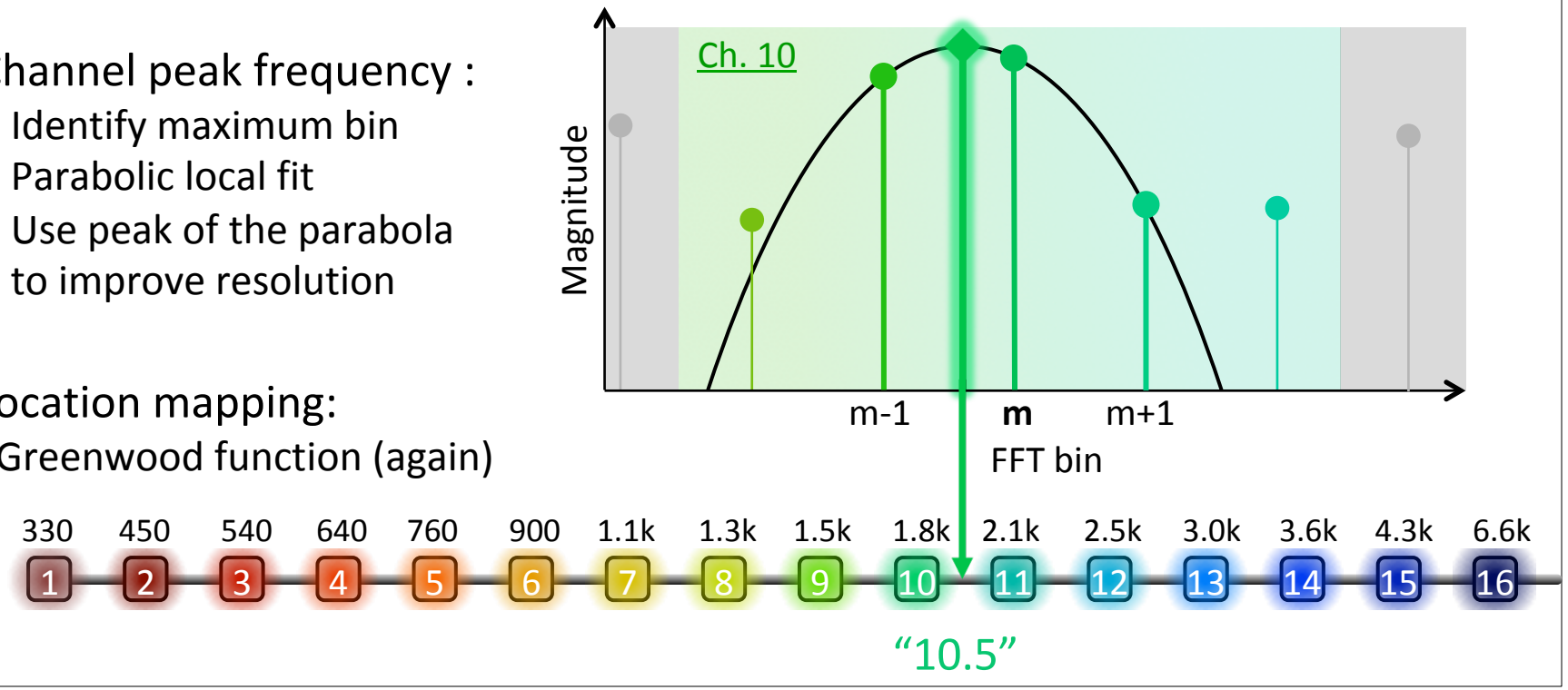


Frequency Estimation

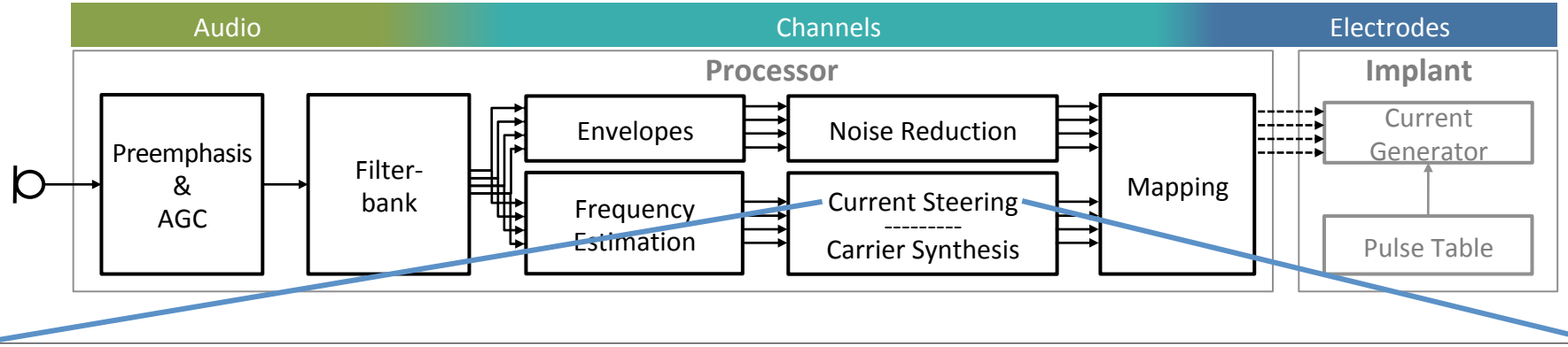


1. Channel peak frequency :
   - Identify maximum bin
   - Parabolic local fit
   - Use peak of the parabola to improve resolution

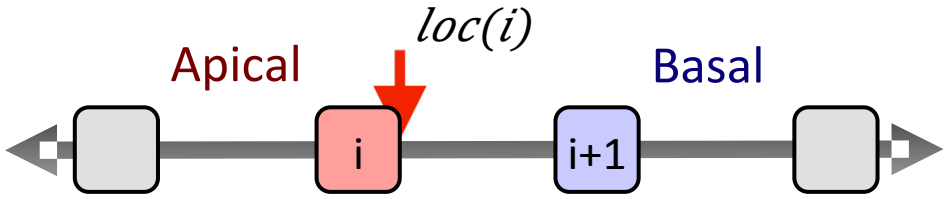
2. Location mapping:
   - Greenwood function (again)



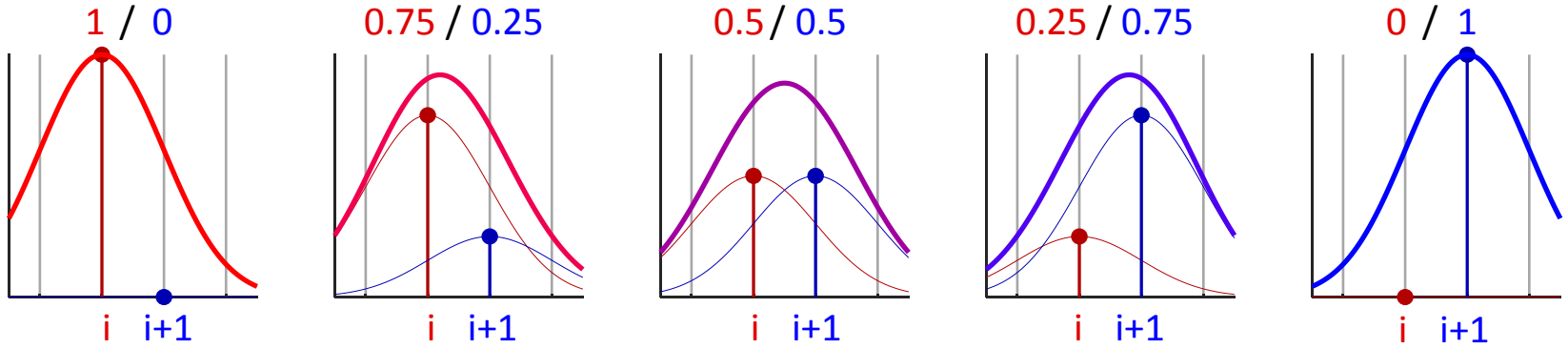
Current Steering



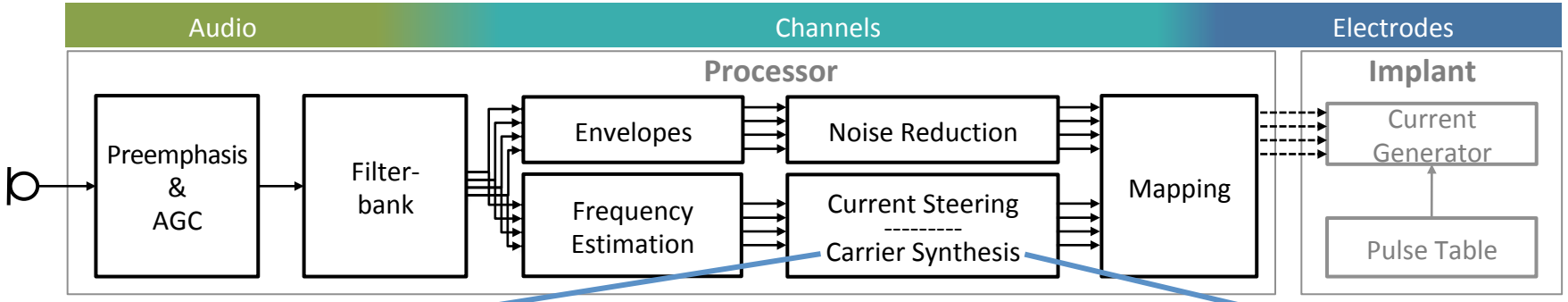
- Target locations $loc(i)$ for channels i:
  - $i \leq loc(i) \leq i+1$
  - Quantized into steps of 1/8
- Steering weights for apical and basal electrodes forming channel i:



$$W(i, \text{base}) = loc(i) - i$$
$$W(i, \text{apex}) = 1 - (loc(i) - i)$$



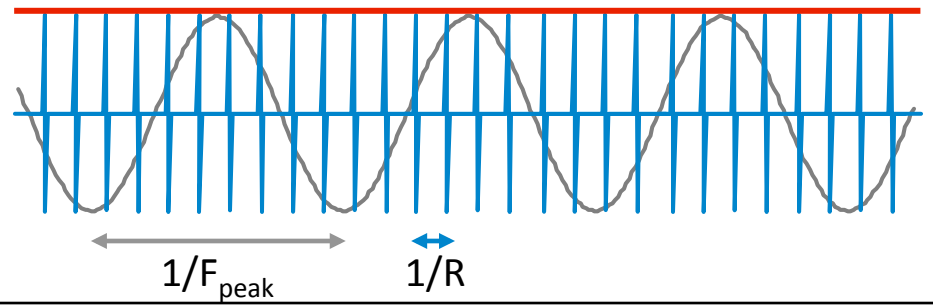
Carrier Synthesis

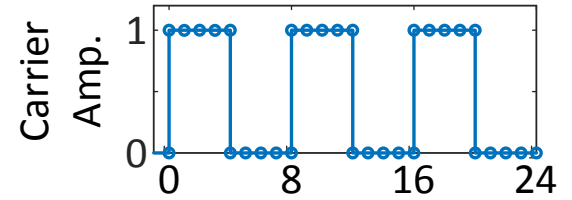


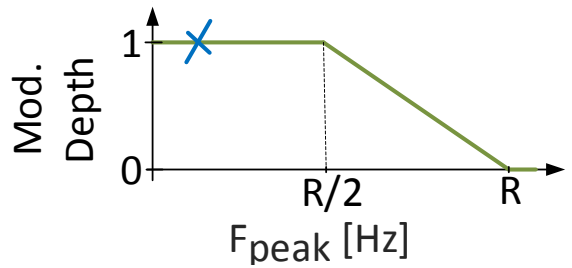
Carrier Synthesis

Creates *temporal periodicity cue* for the channel peak frequency F_{peak}:

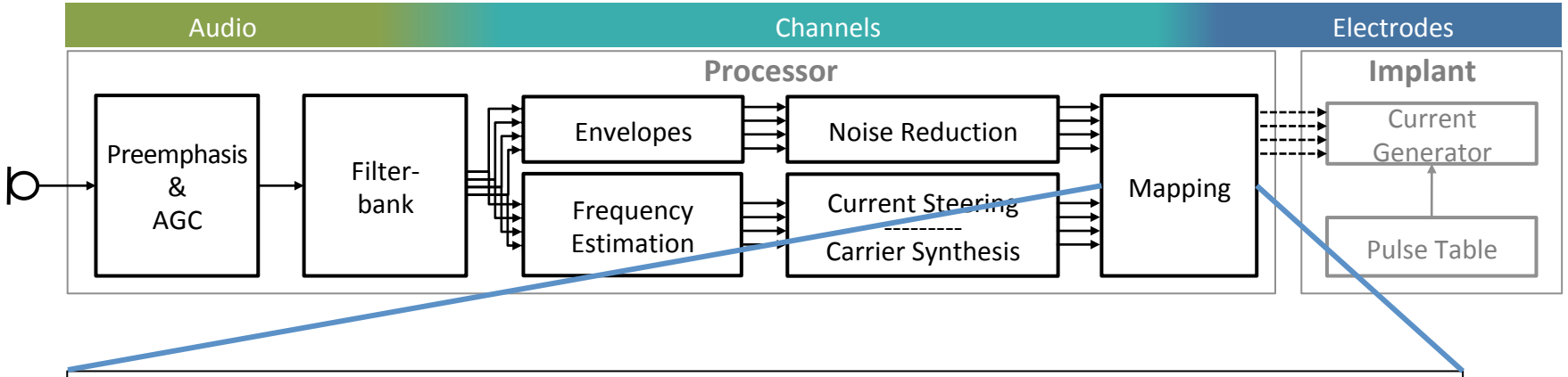
- Square wave with period $1/F_{peak}$
- Modulation depth depends on F_{peak} and channel stimulation rate R



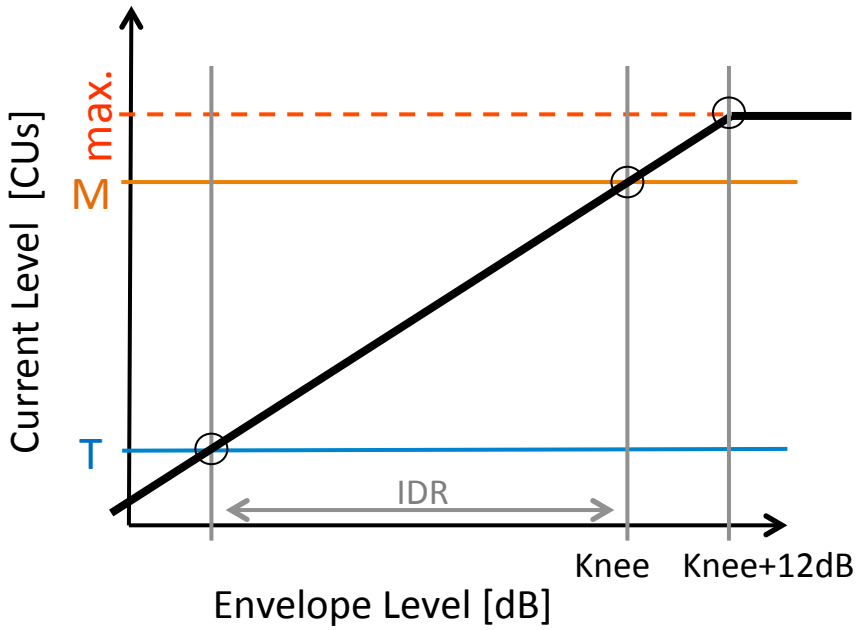




Mapping



Abbreviations	
CU	Clinical Units (current × pulse width)
M	Most comfortable electric stim. level
T	Threshold stim. level
Knee	Acoustic compression knee-point (AGC), 55-65dB
IDR	Input Dynamic Range
AGC	Automatic Gain Control



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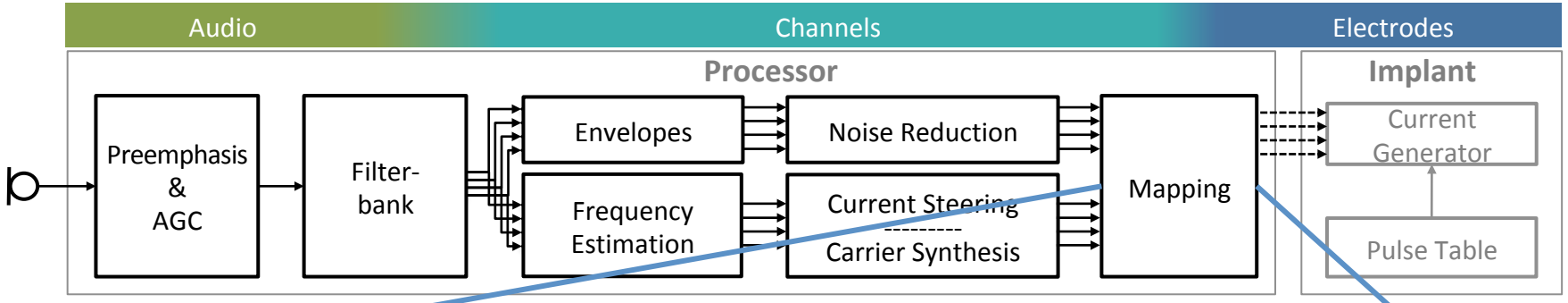


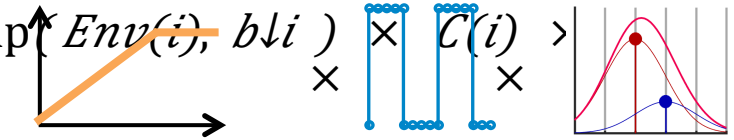
Weaving it all together:

- Envelopes $Env(i)$
- Carrier $C(i)$
- Current Steering weights: $W(i, \text{apex}), W(i, \text{base})$
- Pair of stimulating electrodes: a_i , b_i

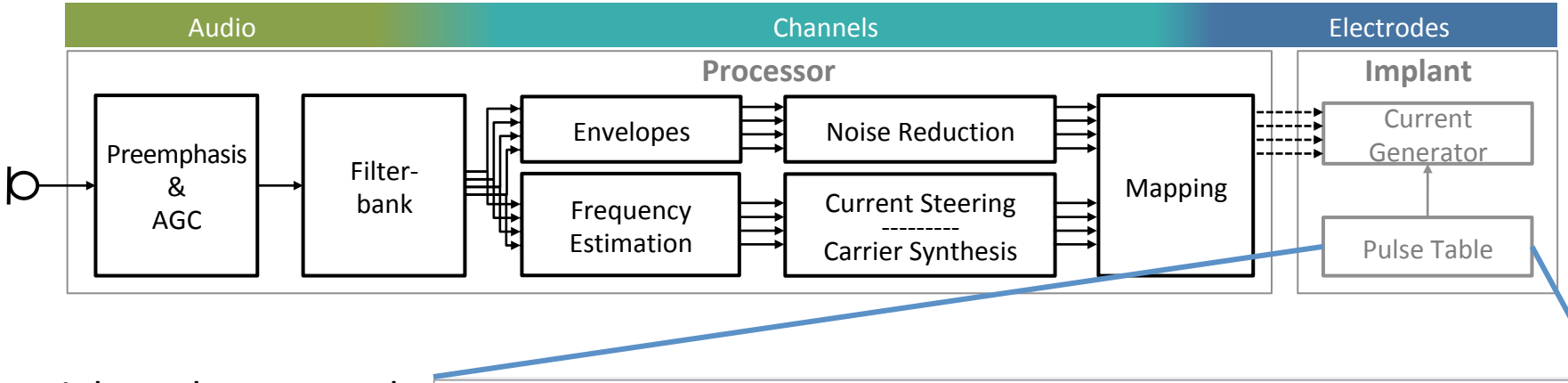
Mapper generates a pair of amplitudes for each channel i:

$$A(i,\text{apex}) = \text{map}(Env(i), a_i) \times C(i) \times W(i, \text{apex})$$

$$A(i,\text{base}) = \text{map}(Env(i), b_i) \times C(i) \times W(i, \text{base})$$



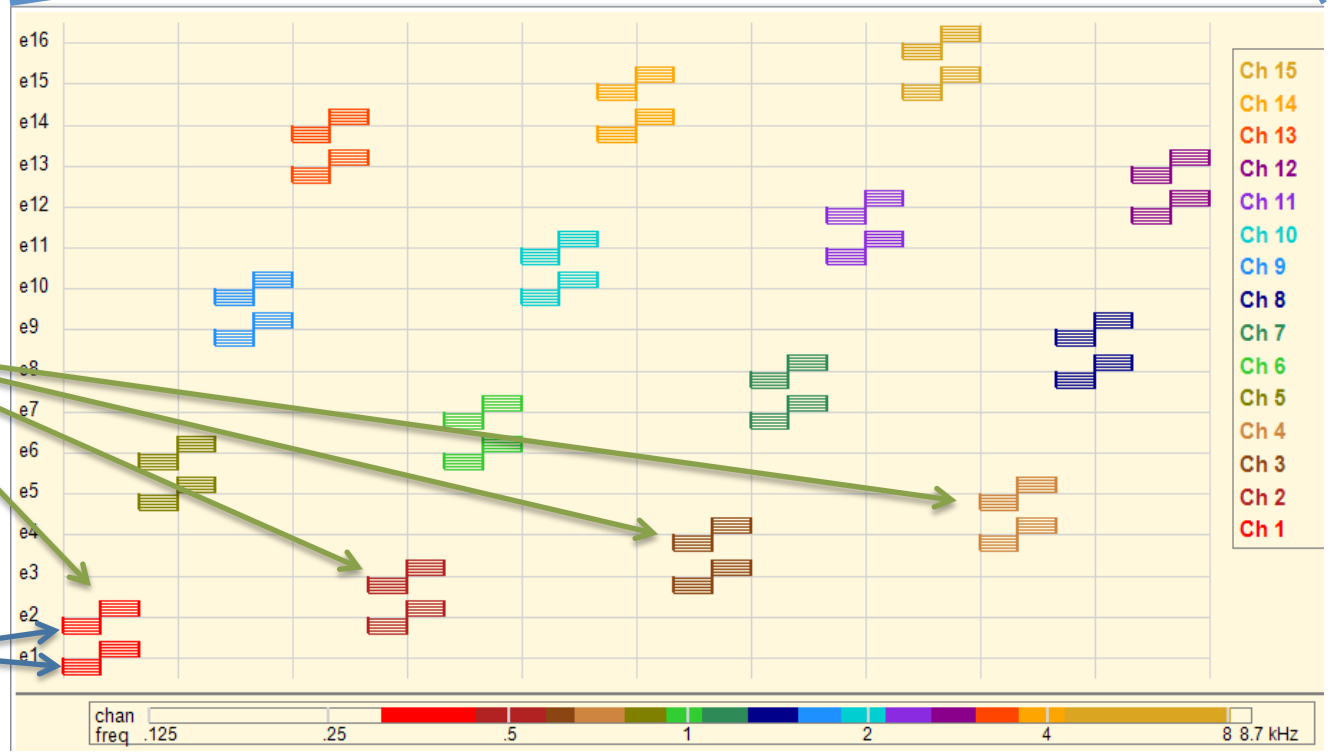
Current Generation



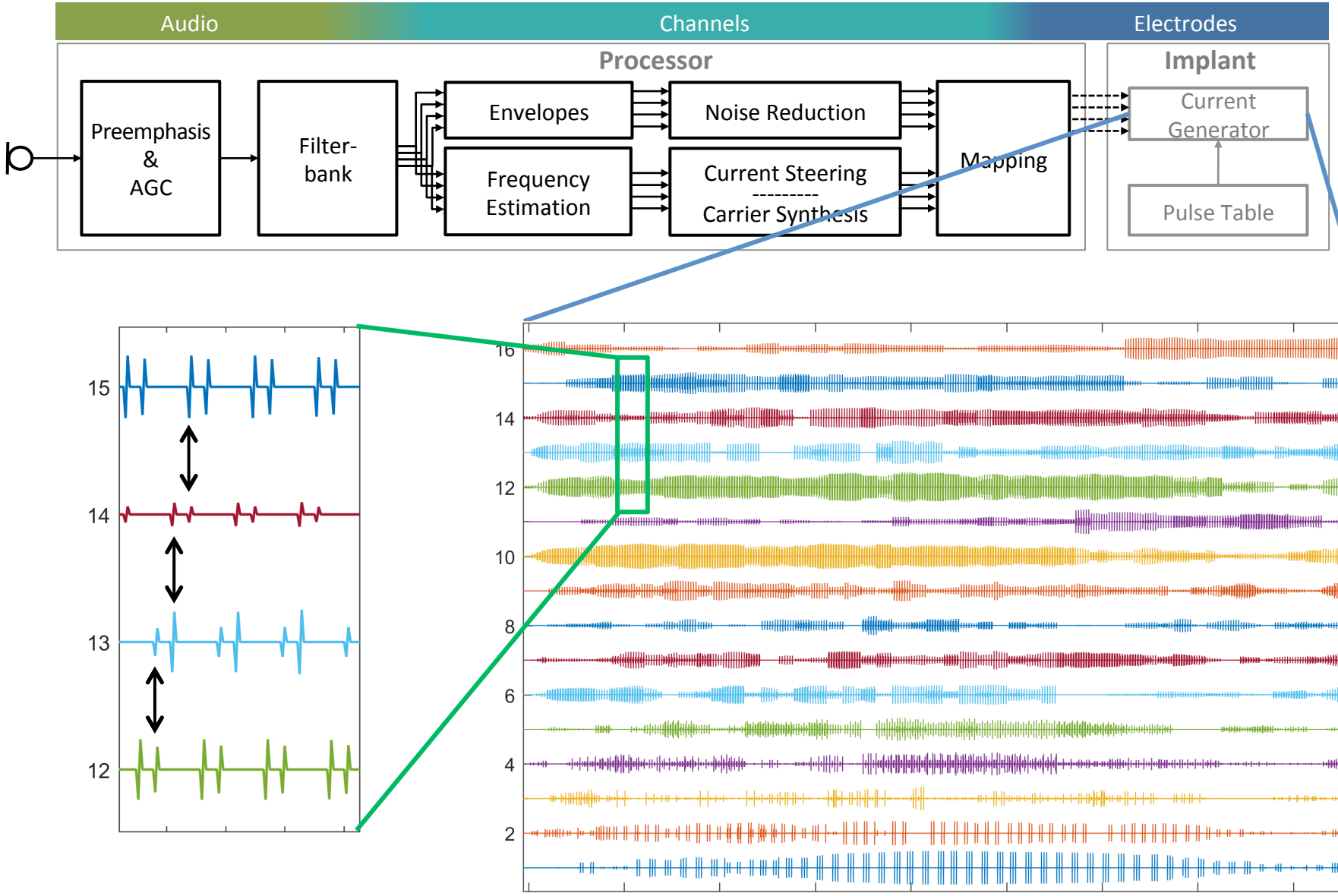
Spatial and temporal template for one full stimulation cycle:

Staggered, sequential stimulation of paired virtual channels

2-electrode steering in each virt. channel



Current Generation



References

Function	Literature reference	Source reference
AGC	[2]: sec. 3 (p. 6/8)	`AGC/dualLoopTdAgcFunc.[py|m]`
Filterbank	[1]: sec. 2.1.1, Table 1 (p.3-4)	`Filterbank/fftFilterbankFunc.[py|m]`
Envelope	[1]: sec. 2.1.1 (p. 4)	`Filterbank/` `hilbertEnvelopeFunc.[py|m]`
Noise Reduction	none	`Clearvoice/` `clearvoiceFunc.[py|m]`

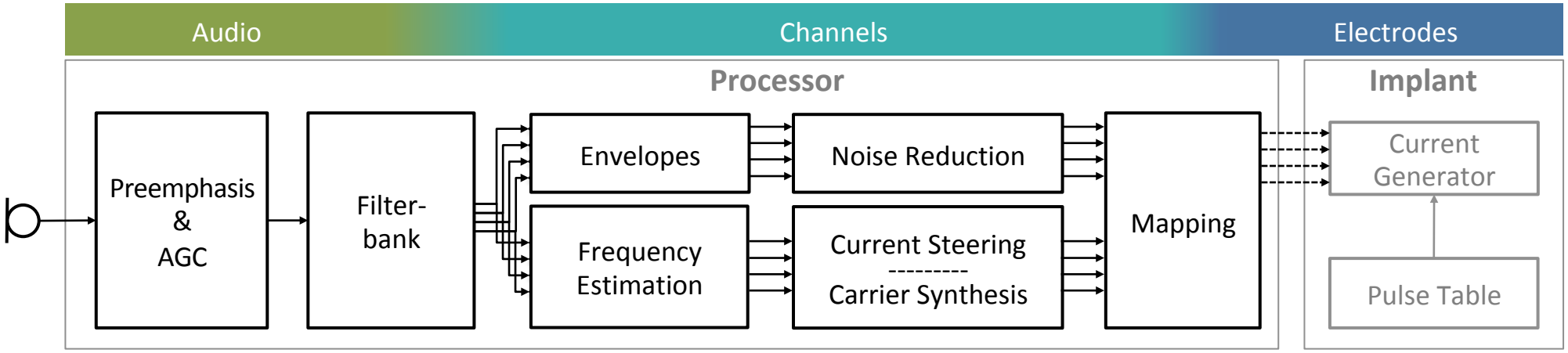
Current Steering	[1]: sec. 2.2.2 and 2.2.3 (p. 4-5)	`PostFilterbank/`
		`specPeakLocatorFunc.[py|m]`
		`currentSteeringWeightsFunc.[py|m]`

Carrier Synthesis	[1]: sec. 2.2.4 (p. 5)	`PostFilterbank/` `carrierSynthesisFunc.[py|m]`
Mapping	[1]: sec. 2.1, eq. 1 (p.2 bottom) [2]: sec. 5 (p. 12)	`Mapping/` `f120MappingFunc.[py|m]`

[1] *"Signal Processing Strategies for Cochlear Implants Using Current Steering"*, Nogueira et al., EURASIP J. Adv. Signal Process, 2009:531213 (2009)

[2] *"Intensity Coding: From dB SPL to CU"*, Advanced Bionics (2016)

Outlook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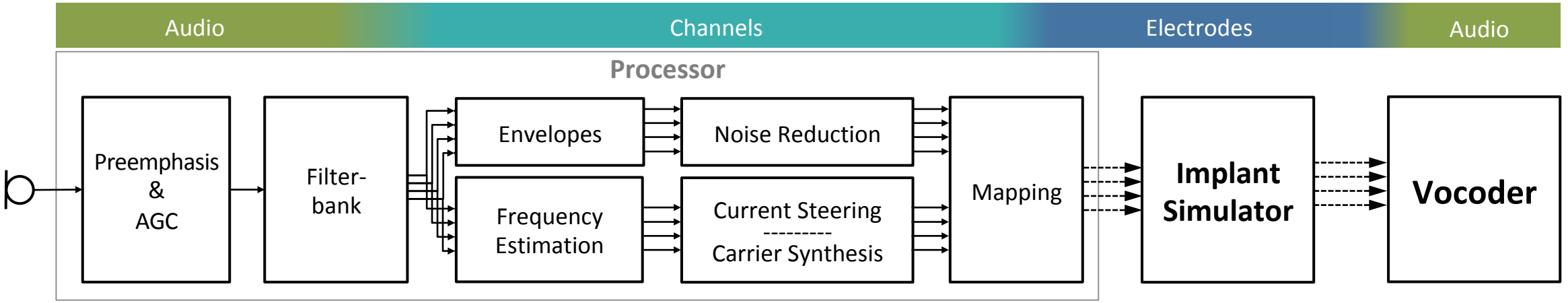
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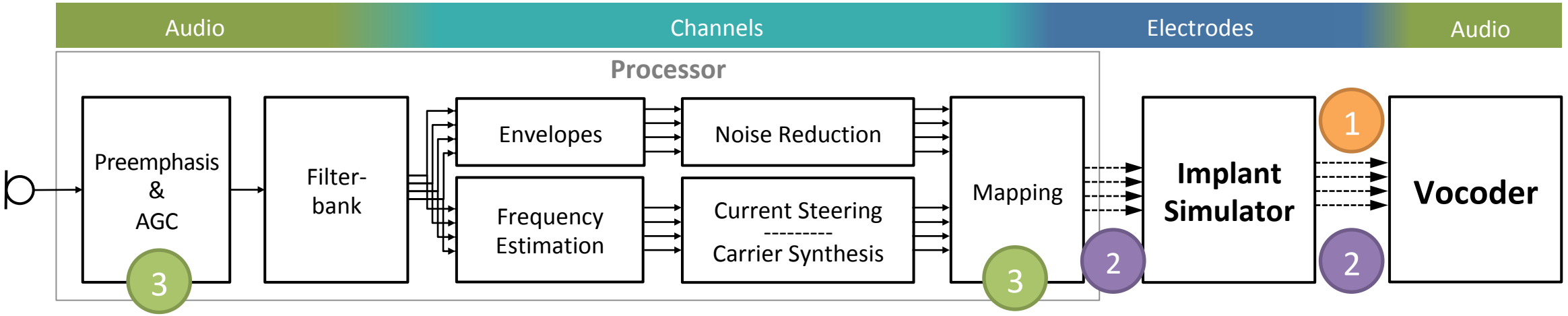
Implant Simulator
Vocoder

I/O Constraints



1 **Charge balance**

- For every electrode, stimulation currents have to integrate to 0 over time

2 **Stimulation currents: range and rate**

- Threshold: 50 µA
- Most Comfortable Level: 500 µA
- Saturation: 600 µA
- 55,556 Hz sample rate, 16 channels

3 **Audio inputs**

- Full-scale digital amplitude (± 1.0) equivalent to 111.6 dB SPL peak

Good luck and enjoy!

CI Hackathon