Annual Progress Report

An Auditory-Model-Based Electrical Stimulation Strategy Incorporating Tonal Information for Cochlear Implant

Joint Research Centre for Biomedical Engineering

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Types of Hearing Loss

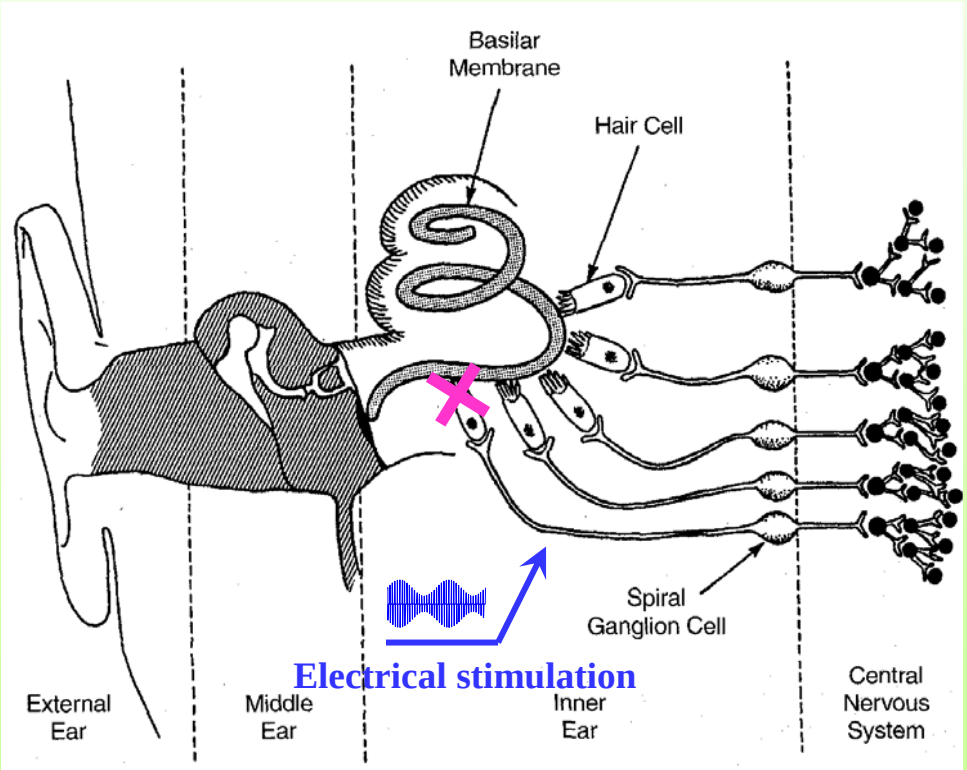
Hearing loss can be categorized by where or what part of the auditory system is damaged.

- Conductive hearing loss
  - Conductive hearing loss occurs when sound is not conducted efficiently through the outer and middle ears, including the ear canal, eardrum, and the tiny bones, or ossicles, of the middle ear.
- Sensorineural hearing loss
  - Sensorineural hearing loss occurs when there is damage to the inner ear (cochlea) or to the nerve pathways from the inner ear (retrocochlear pathway of the acoustic nerve) to the brain.
- Central auditory processing disorders
  - A central auditory processing disorder (CAPD) occurs when auditory centers of the brain are affected by injury, disease, tumor, heredity or unknown causes.

http://www.asha.org/public/hearing/disorders/types.htm

Cochlear Implant (CI) Background

- CI is the most useful solution for the treatment of severe to profound hearing loss.
  - Employ direct electrical stimulation of the auditory nerve to restore some degree of hearing.

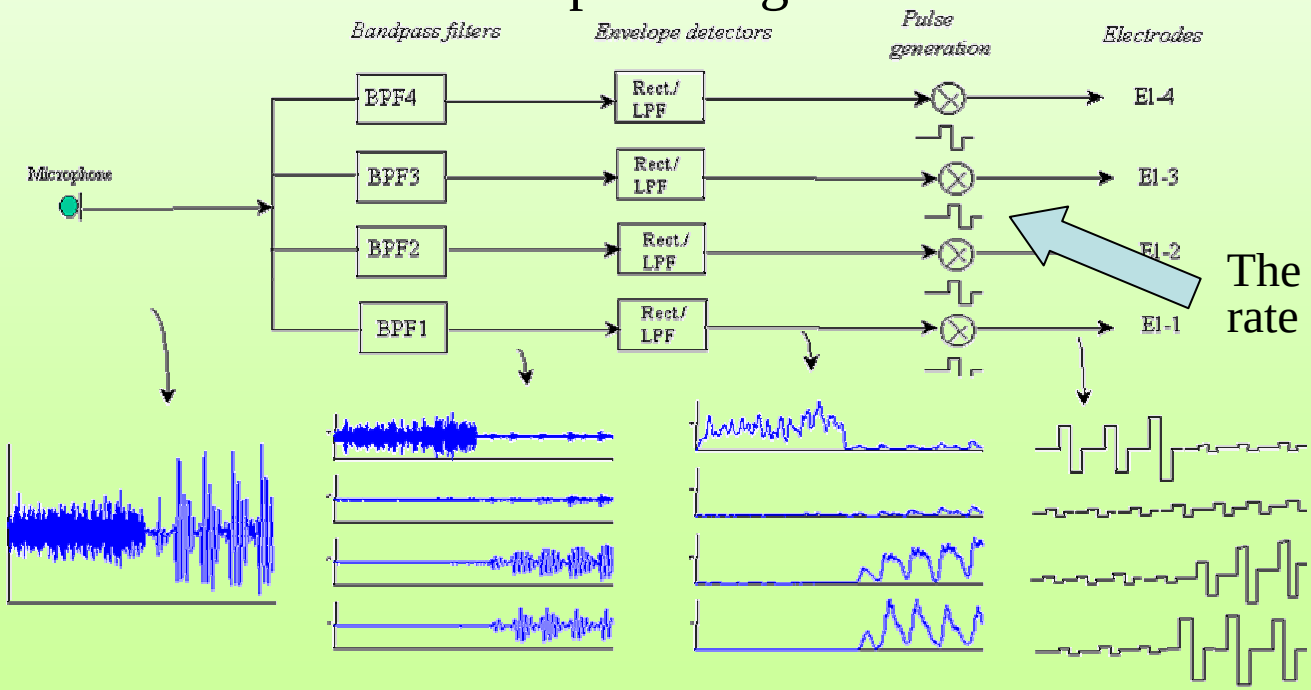


A diagram (not to scale) of the human ear [1].

1. P.C. Loizou, "Introduction to cochlear implants," IEEE Eng. in Med. and Bio. Mag., vol.18, pp.32-42, 1999.

Motivation for Novel Electrical Stimulation Strategy

1. CI users gain little tonal information from present electrical stimulation strategies, although it has been well known that the tonal language uses different tones (or variation of fundamental frequency F0 of speech signal) to indicate diverse lexical meanings.
   - Most present electrical stimulation only convey the envelope information from speech signal.



The same invariant pulse rate across multi-channels

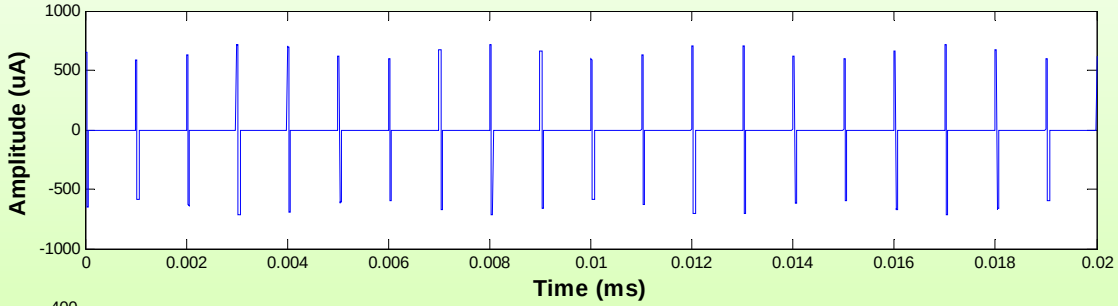
Continuous-interleaved-sampling (CIS) strategy

(P.C. Loizou, "Introduction to cochlear implants," IEEE Eng. in Med. and Bio. Mag., vol.18, pp.32-42, 1999.)

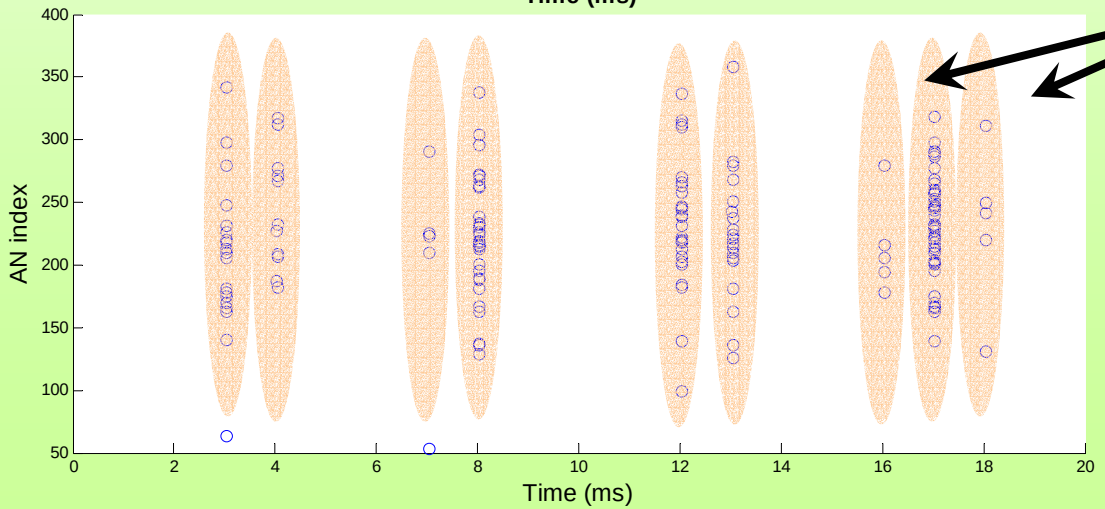
Motivation for Novel Electrical Stimulation Strategy (Cont.)

2. The neural firing pattern from electrical stimulation varies from that of normal acoustic hearing.
   - The neural firing from present electrical stimulation results in a highly synchronized firing pattern, which would causes a poor temporal presentation of the stimulus waveform [1].

Electrical pulse train



The spread of action potentials across nerve position and time under electrical stimulation.

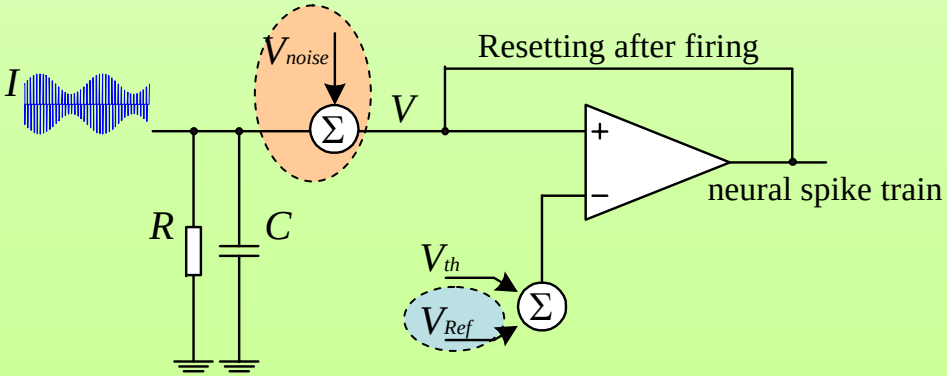


synchrony

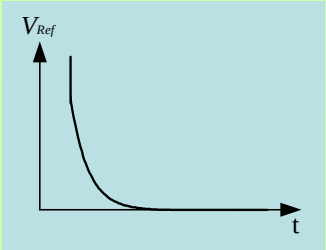
1.F.G. Zeng, Trends in cochlear implants, Trends Amplification 8 (2004) 1-34.

A Stochastic Model of Electrically Stimulated Auditory Nerve

- Since the electrical pulses straightforwardly talk to the auditory nerve (AN) in CI, modeling the AN's response to electrical stimulation may
  - improve our understanding on how auditory percepts are produced by CI, and
  - facilitate our development of new electrical stimulation strategies.
- Integrate-and-fire based AN model

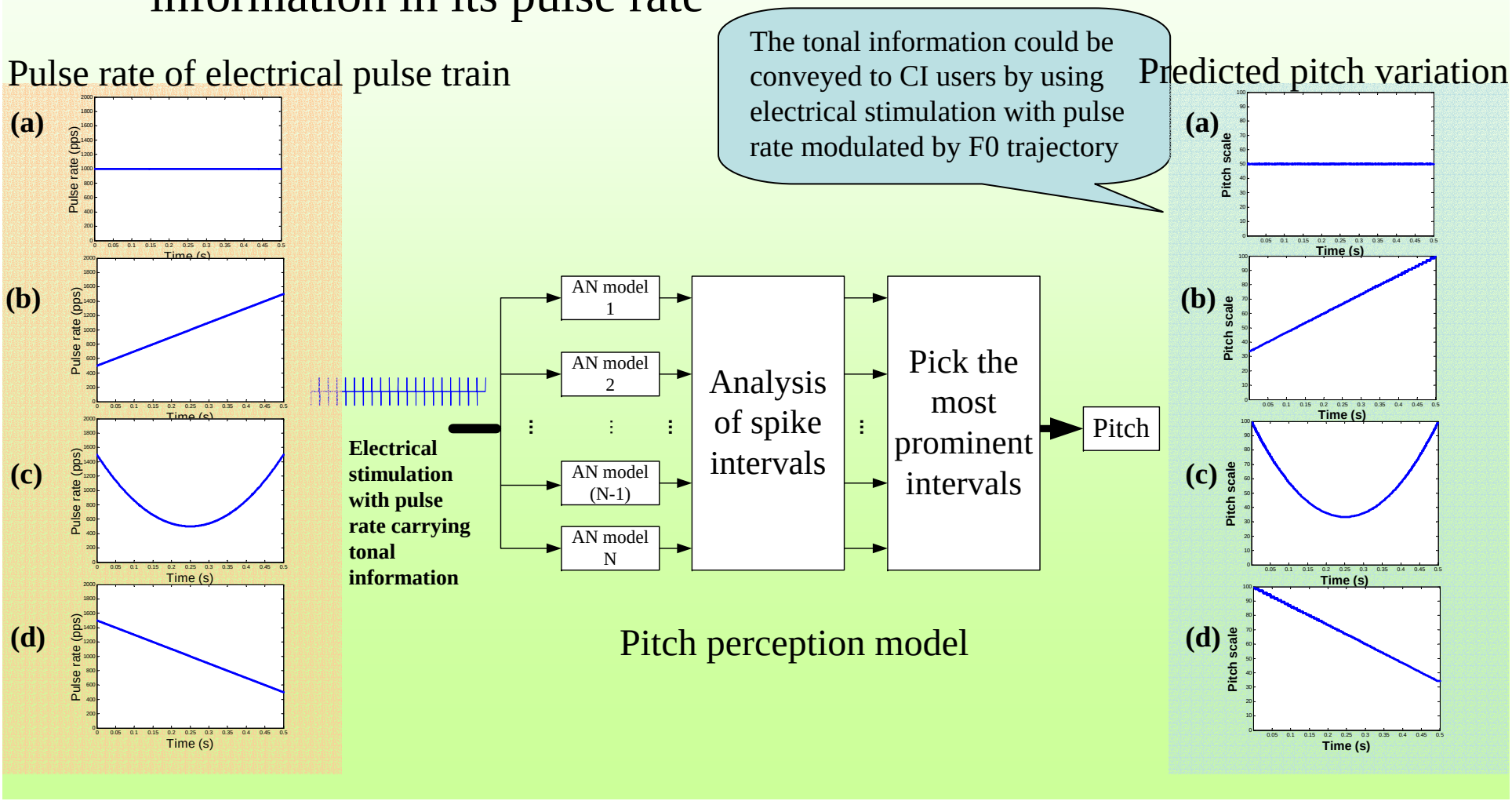


V_{noise}: stochastic membrane potential fluctuation
V_{ref} : refractory effect during neural firing



AN Response to Electrical Stimulation

- Predict pitch variation when electrical pulse train carries tonal information in its pulse rate

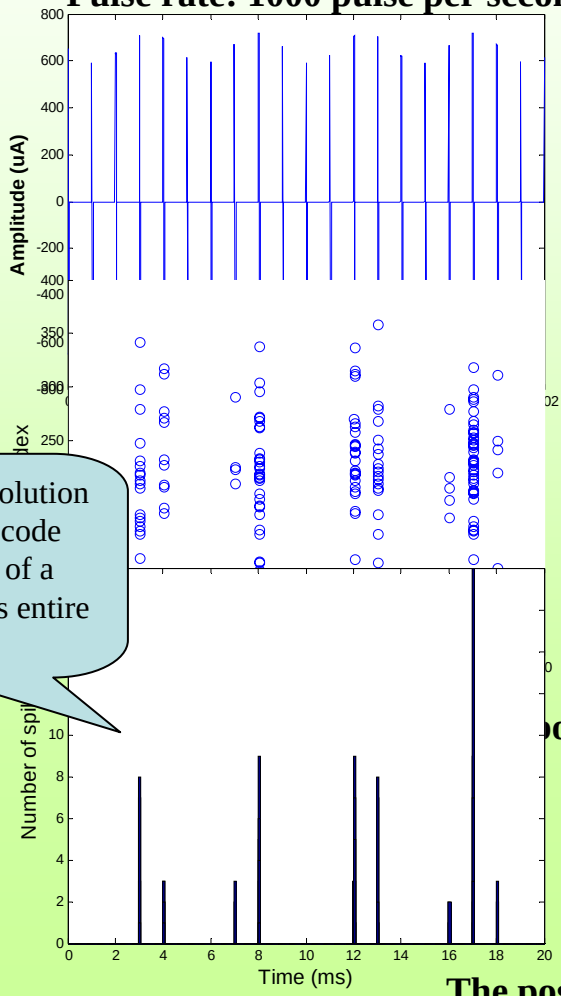


AN Response to Electrical Stimulation (Cont.)

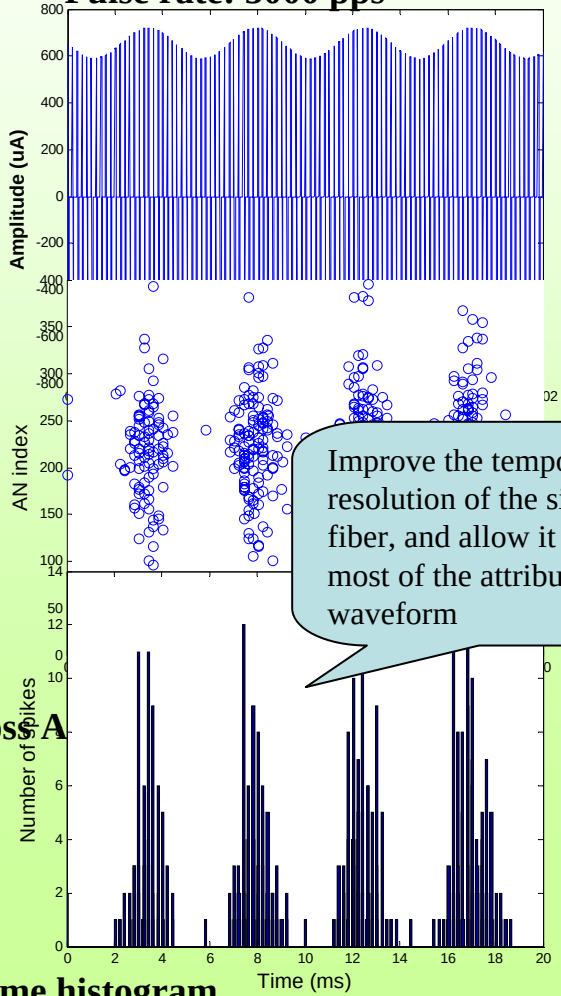
- Response to high-rate electrical pulse train to encode the temporal fine structure

Modulation frequency:
220Hz
Modulation depth:
0.1
Pulse width/ intensity:
33 us/ 760uA

Pulse rate: 1000 pulse per second (pps)



Pulse rate: 5000 pps



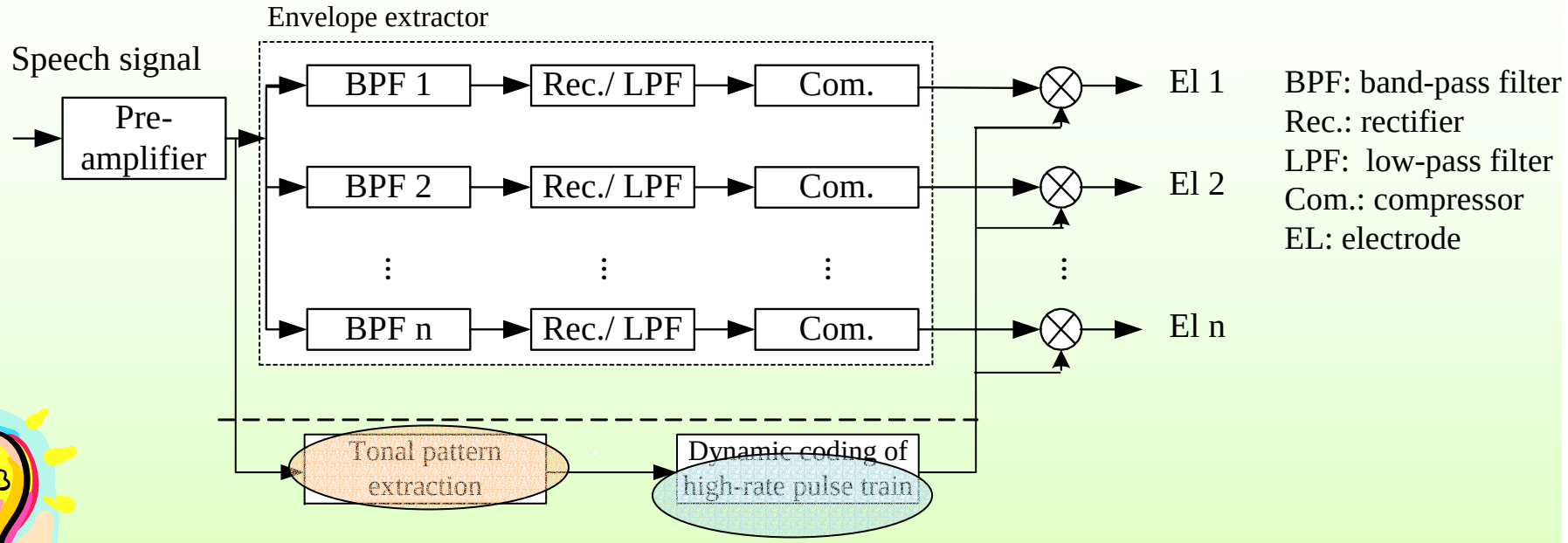
A loss of temporal resolution in that multiple fibers code the timing of the peak of a stimulus rather than its entire waveform

Improve the temporal resolution of the simulation fiber, and allow it to encode most of the attributes of the waveform

otentials across A

The post-stimulus time histogram.

Novel Electrical Stimulation Strategy



1. Extract tonal information (F0 trajectory) by pitch extraction algorithm to modulate the pulse rate of electrical stimulation.
   - The electrical pulses in different channels work sequentially and non-simultaneously with the *same rate* to avoid the cross-talk from adjacent channels.
2. Use high pulse rate to reduce the synchrony of neural firing, and enhance the representation of speech waveform with improved resolution.

Summary

1. An integrate-and-fire based stochastic model of electrically stimulated auditory nerve was developed. Model based studies supported that:
   - The tonal information could be efficiently conveyed to CI users by using electrical stimulation with pulse rate modulated by F0 trajectory, and
   - The encoding of fine structure of speech waveform can be improved by using electrical stimulation with high pulse rate.
2. A novel electrical stimulation strategy was proposed, which incorporates the above two features.

Future Work

- The evaluation of the performance of proposed electrical stimulation strategy using auditory model, and
- The implementation of the proposed electrical stimulation strategy for CI stimulation studies .

Appendix:

Two papers have been resulted from this project supported by the Shun Hing Institute of Advanced Engineering.

1. “An Integrated-and-Fire Based Auditory Nerve Model and Its Response to High-Rate Pulse Train,” submitted to an International Journal (acceptance subject to revision).

2. “Frequency-Specific Fine Structure Cues from Mandarin for Designing Electrical Stimulation Strategy of Cochlear Implant”, submitted to World Congress on Medical Physics and Biomedical Engineering 2006.

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