# ELEC3104: Mini-Project – Cochlear Signal Processing




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Term 3, 2022

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**TLT – Level 3 (Credit Level):** Implementation of a cascaded filter bank model of the cochlea for spectral analysis.





Complete TLT-Level 2 first, and ensure that you are on the right track before proceeding to TLT – Level 3

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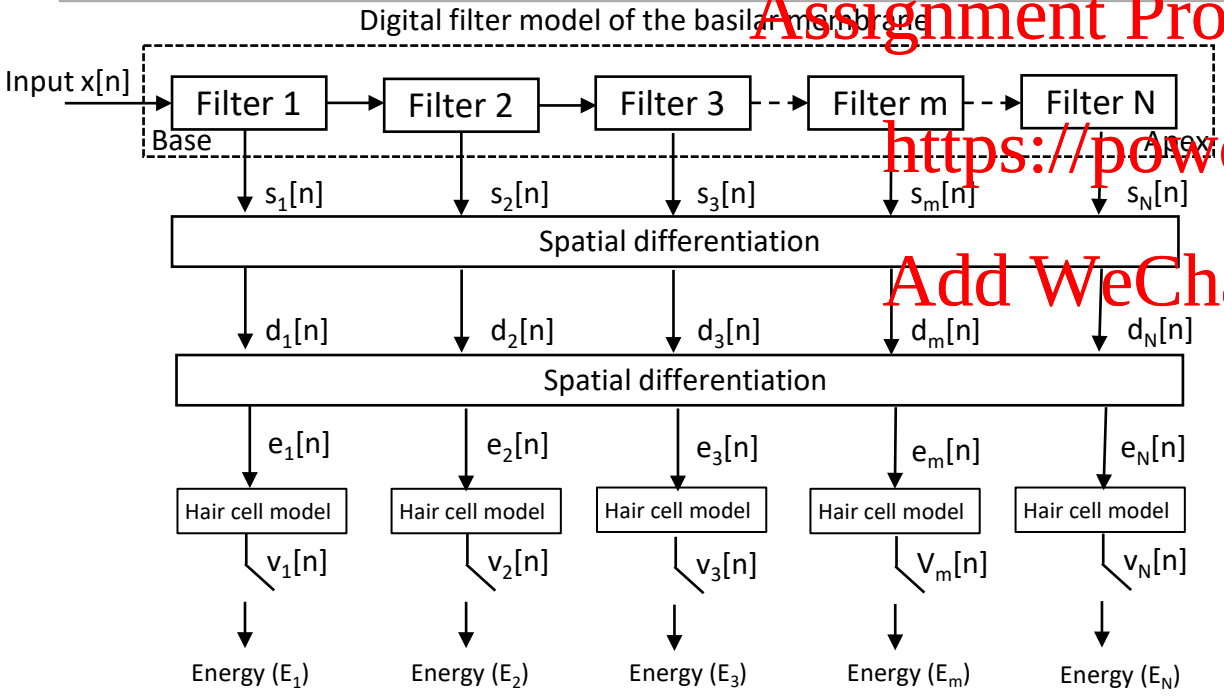
# TLT-Level 3: Short-time Spectrum Analyser

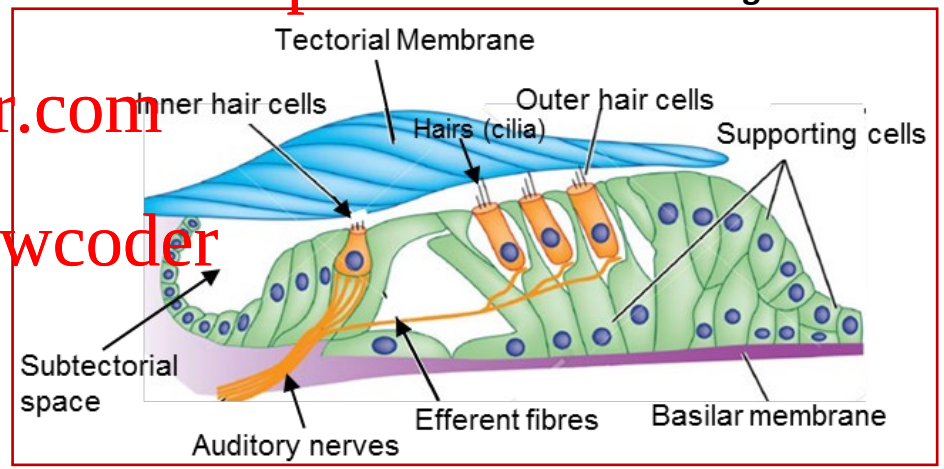
- ✓ You should use the cochlear model that you have designed in TLT-Level 2 to implement a short-time spectrum analyser. The cascaded filters separate the frequency spectrum of interest (96.5 Hz to 20000 Hz) into N (=128) frequency bands.
- ✓ In this mini-project we will continue to use two spatial differentiations in order to sharpen the magnitude response of the filters.
- ✓ The spatially differentiated filter output is then passed through a hair cell model (a rectifier followed by a first-order lowpass filter). The output of the hair cell model is a measure of energy (E) of the signal in a particular frequency band (i.e: A Spectrum analyser).

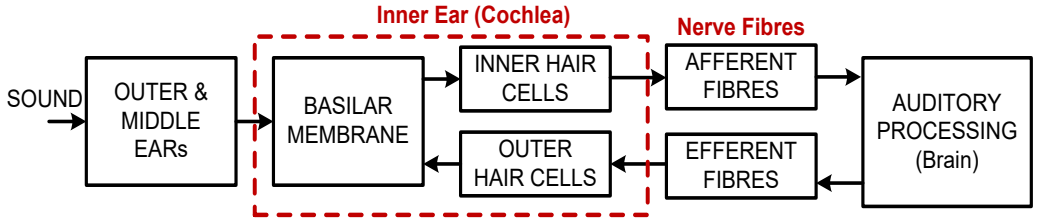





Ouput Energy $E_m$ is read (switch closed) once every 16 ms or so.

**Organ of Corti**



# TLT-Level 3: Inner hair cell model

## Inner hair cell model

- ✓ The model of an inner hair cell is a capacitor model, in which the input voltage corresponds to the spatially differentiated membrane displacement output of the filter bank model.
- ✓ Bending the inner hair cell cilia (Half-wave rectification) is simulated by charging of the capacitor and returning to the initial position of the cilia is equivalent to discharging the capacitor.
- ✓ This model is given by the following input-output relationship:

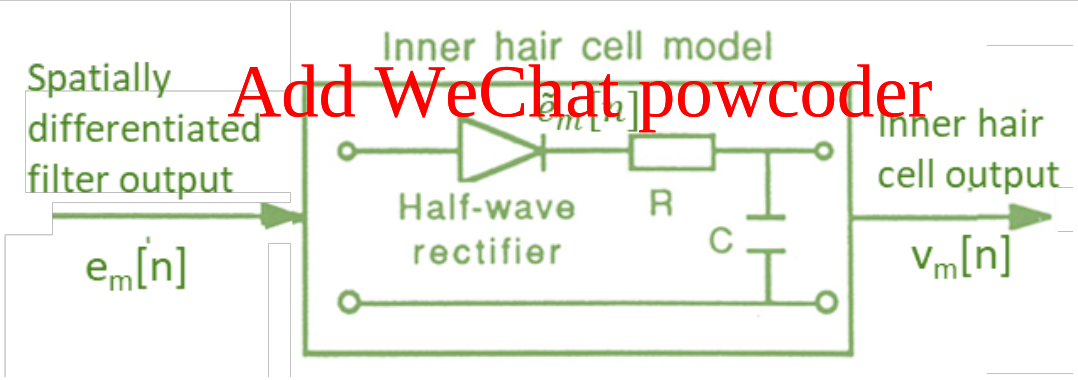


$$v_m[n] = (1 - c_0)\tilde{e}_m[n] + c_0 v_m[n-1] \quad \text{where } c_0 = e^{-2\pi\frac{f_c}{f_s}}$$



Where, $v(n)$ is the output electrical energy.



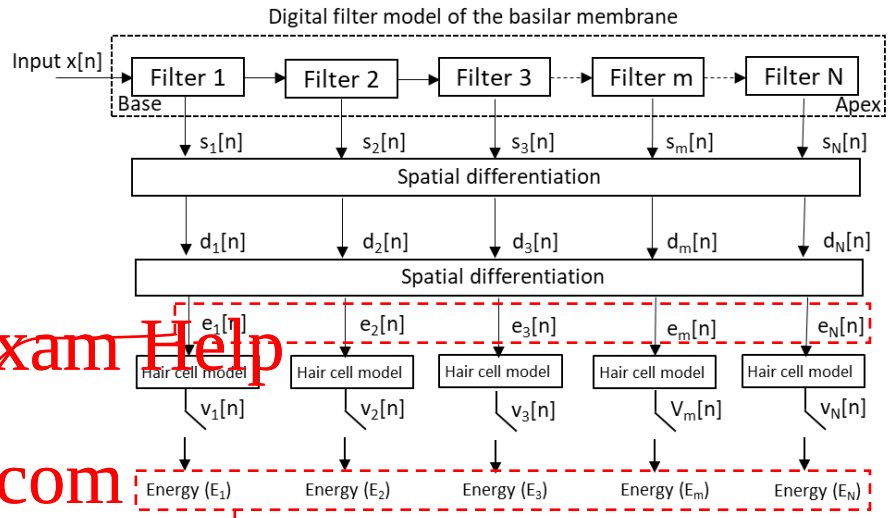


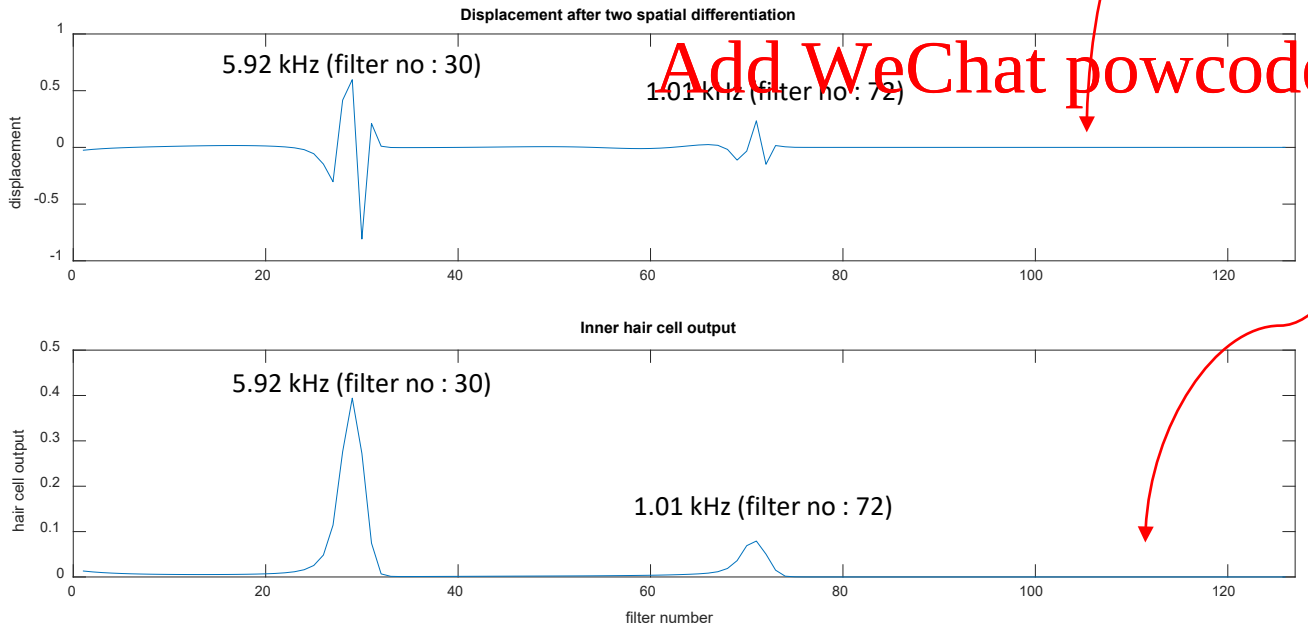

$\tilde{e}[n]$ is the spatially differentiated displacement after half-wave rectification.

Cut-off frequency ($f_c$) of the hair cell model is based on the rate at which the switch is closed. (every 16 ms – 62.5 Hz). Therefore $f_c \leq 31.25\ Hz$. Let's choose $f_c$=30Hz; Sampling frequency ($f_s$)=48,000Hz;

# Are you on the right track?

- ✓ Apply a sum of two sinusoidal components (5.92 kHz and 1.01 kHz) at the input $x[n]$.
- ✓ The figure below shows the spatially differentiated basilar membrane displacement $\{e_1[n]\ to\ e_N[n]\}$ of each filter against the filter number at a particular time instant and the corresponding inner hair cell output in response to a sum of two sinusoidal components.
- ✓ If your inner hair cell model implementation is correct, you should observe something similar to what is shown below
- ✓ The inner hair cell output shows the spectral components that present in the input signal.

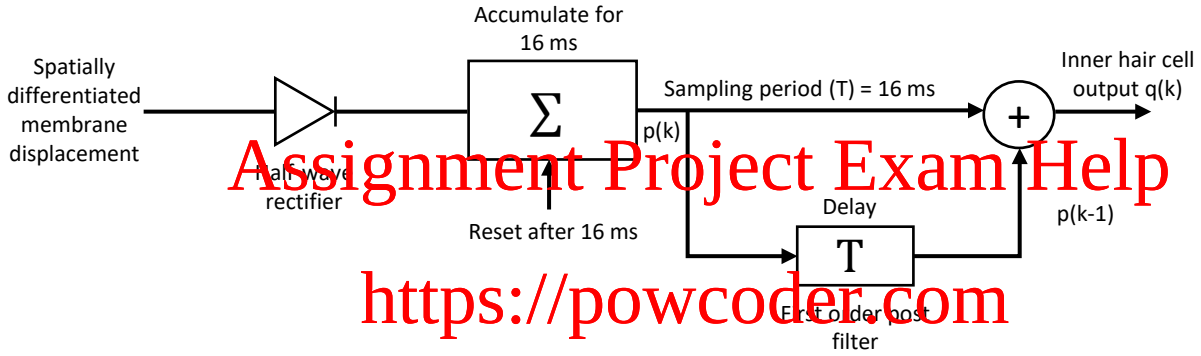


# TLT-Level 3: An alternative inner hair cell model

## An alternative inner hair cell model

- A second method of implementing the inner hair cell model is shown below:






- In this model the positive cycle of the spatially differentiated (twice) membrane displacement is accumulated at each sampling instant and then the accumulated value is digitally filtered (Post-filtering) at the end of each 16 ms frame. The accumulator is reset at the end of 16 ms frame.
- Replace the previous hair cell model with the above model.
- What is the main difference between the above hair cell model and the previous hair cell model in slide 4, TLT level 3? Discuss your understanding with your lab demonstrator.

# TLT Level 3 : Final Implementation

## Final Implementation

- Apply a signal which is a sum of four sinusoids, 1000-2000 samples, of equal amplitude and frequencies of your choice, to the input of the filter bank. Plot the output of your spectrum analyser (i.e the output of each filter in dB against the filter number) at a particular time instant.

- Plot the magnitude spectrum (using FFT) of the input signal and compare it with the filter bank output. Discuss the results that you get.



- Note that the sampling frequency of the input signal is 16kHz and the output signal has a sampling interval of 16ms (62.5Hz). Explain why it is necessary to have a lower sampling rate at the output? What are the implications for the cut-off of the output LPF (see hair cell model) if we require a sampling of the output (close the switch) twice as often (125Hz)?



- Discuss your results with your lab demonstrator.