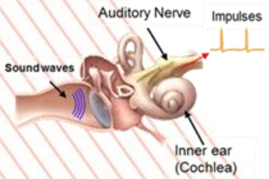
ELEC3104: Mini-Project – Cochlear Signal Processing



TLT – Level 3 (Credit Level): Using the Level 2 IIR cochlear filter bank model, implement a spectral analysis system.

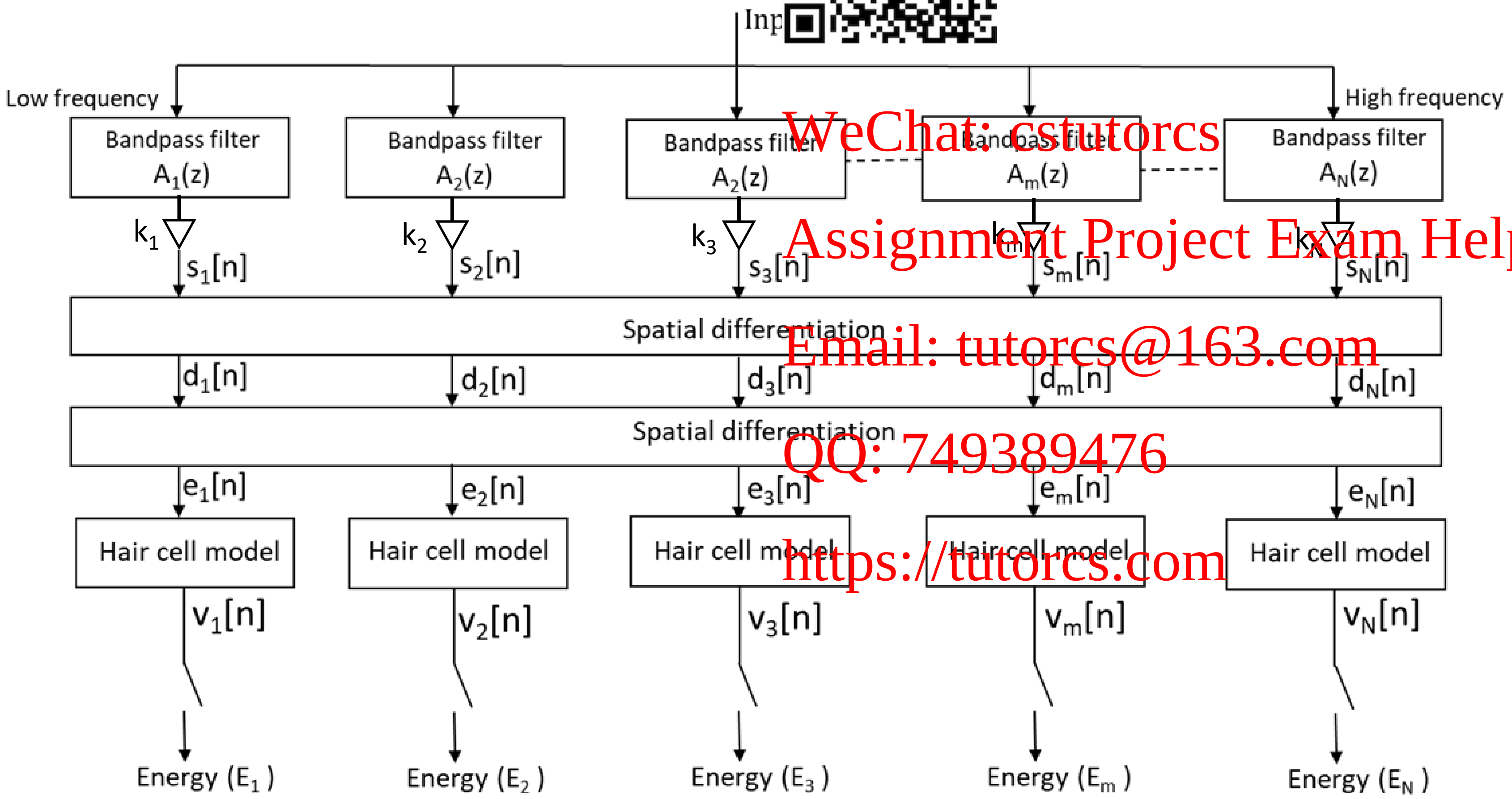
Complete TLT-Level 2 first and ensure that you are on the right track before proceeding to TLT – Level 3

Prof. Eliathamby Ambikairajah, School of EE&T

Term 3, 2024

Short-time Spectrum Analyser

- ✓ You should use the IIR filter bank that you have designed in TLT-Level 2 to implement a short-time spectrum analyser. The bank of filters separates the frequency spectrum of interest (88 Hz to 7723 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 bandpass filter o[illegible] passed through a hair cell model (a rectifier followed by a first-order lowpass filter). The output of the hair c[illegible] measure of energy (E) of the signal in a particular frequency band.



Note: $k_1 - k_N$ are the gain factors

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

Gain Factor Calculation (k_1 to k_N)

Gain Factor Calculation for Filters k_1 to k_N

1. **Input Signal**: For each filter n (where $n = 1, 2, \ldots \ldots N$) provide a sine wave of amplitude 1. The sine wave should have a centre frequency corresponding to the centre [illegible] the filter under consideration.
2. **Filter Output**: Apply the sine wave to the filter [illegible] the filter's output.
3. **Maximum Value**: Measure the absolute maximum value of the filter's output, denoted as $k_{max}^{(n)}$ for the n^th filter.
4. **Gain Calculation**: The gain factor k_n for the n^th filter is calculated using the formula: $k_n = \frac{1}{k_{max}^{(n)}}$
5. **Repeat for All Filters**: Repeat steps 1 to 4 for all N filters to obtain the gain values k_1 to k_N.

Spatial Differentiation and Inner hair cell model

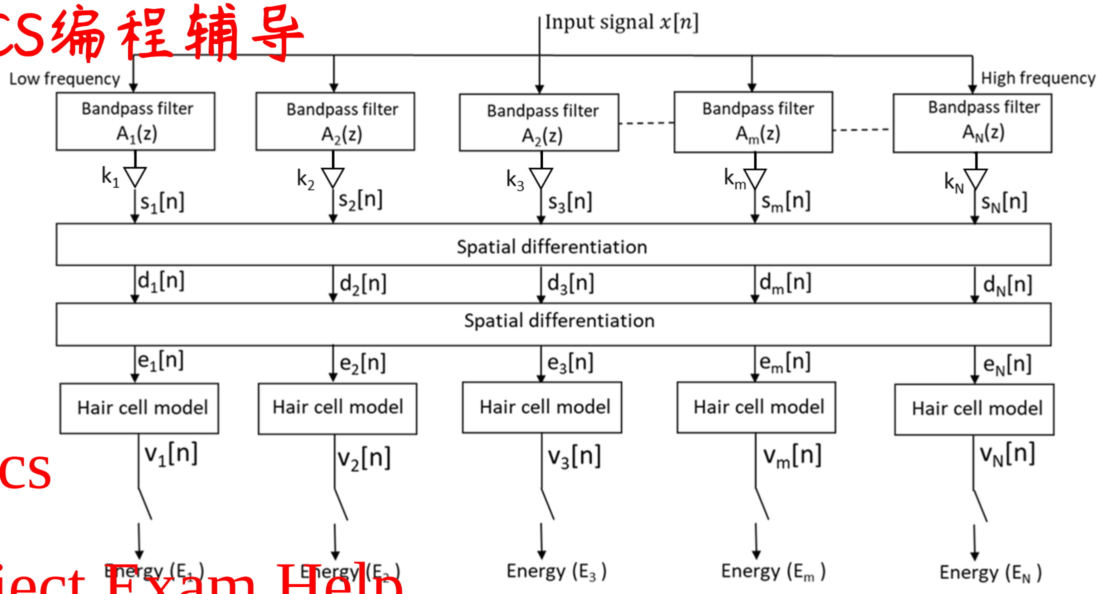
Spatial Differentiation

- ✓ Spatial differentiation of the membrane displacement represents coupling between the cilia of the inner hair cells, through the fluid in the subtectorial space.
- ✓ Spatial differentiation refers to taking the d[illegible] respect to the position (along the basilar m[illegible] discrete model is given by:

$$d_m[\text{n}]=s_m[\text{n}]\text{-}\ s_{m+1}[\text{n}] \qquad \{e.g.\ d_1[\text{n}]=s_1[\text{n}]\text{-}\ s_2[\text{n}]\}$$

- ✓ The second spatial differentiation is given by:

$$e_m[\text{n}]=d_m[\text{n}]\text{-}\ d_{m+1}[\text{n}] \qquad \{e.g.\ e_1[\text{n}]=d_1[\text{n}]\text{-}\ d_2[\text{n}]\}$$



Inner hair cell model

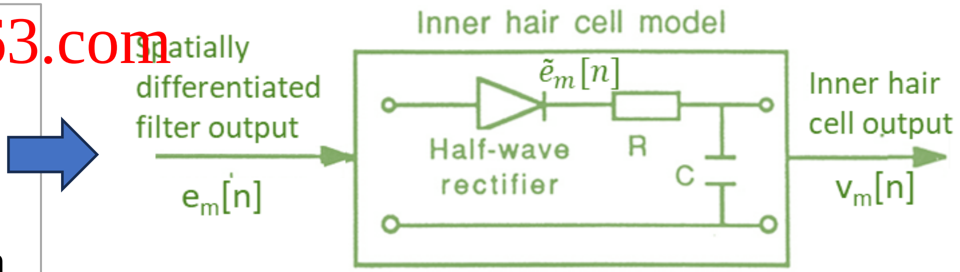
- ✓ The model of an inner hair cell is a capacitor model, in which the input voltage corresponds to the spatially differentiated membrane displacement output of the filter bank model.

- ✓ 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:

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

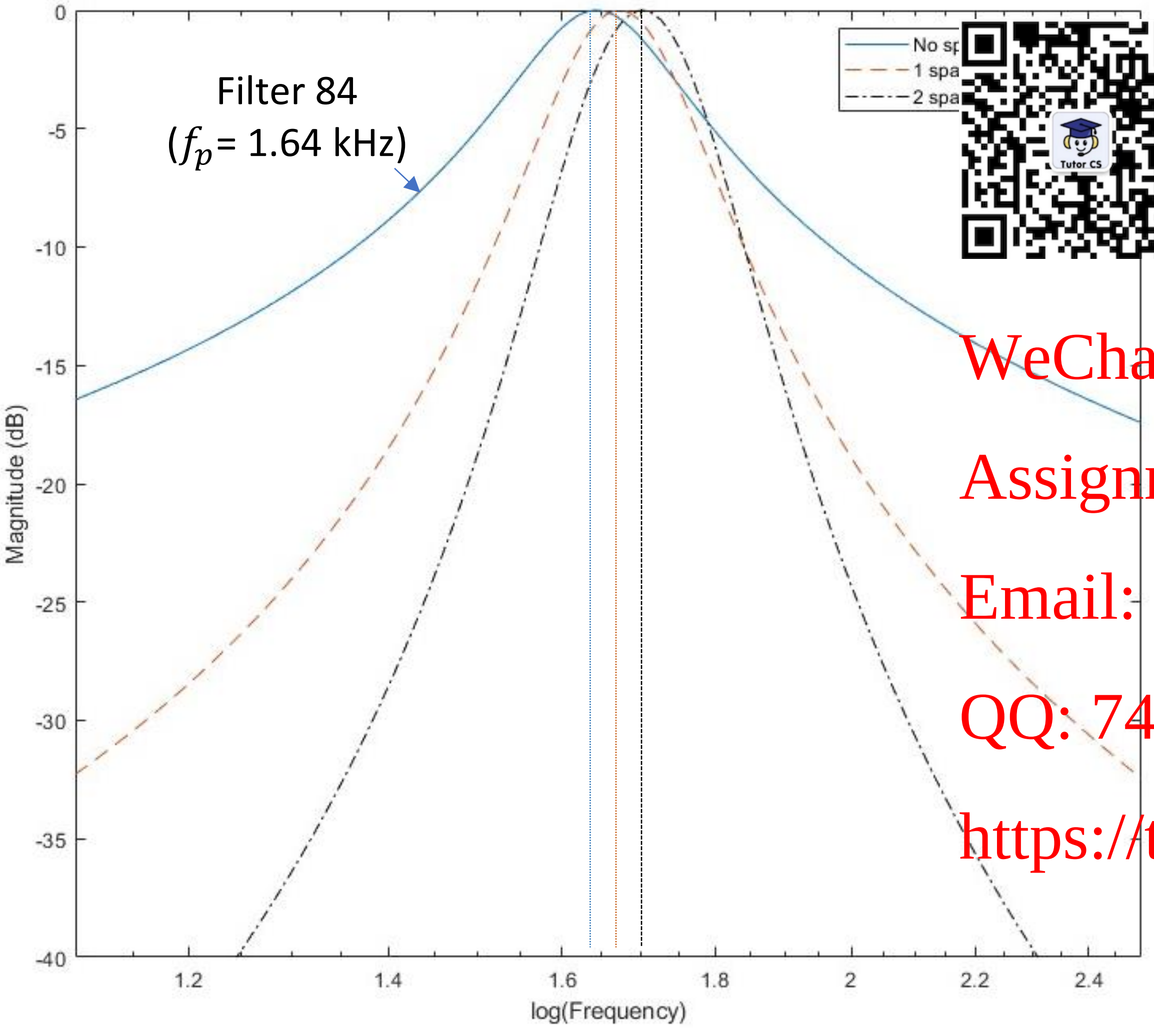
Where, $v(n)$ is the output electrical energy,

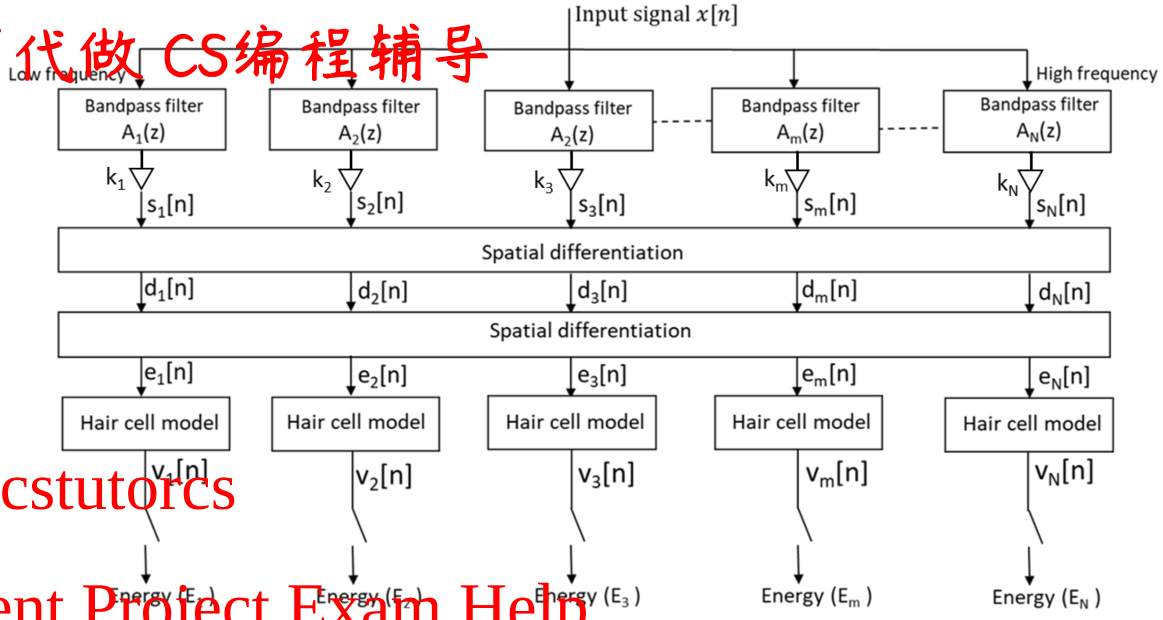


$\tilde{e}[n]$ is the spatially differentiated displacement after half-wave rectification.

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, $f_c \le 31.25\ Hz$. Let's choose f_c=30Hz; Sampling frequency (f_s)=16000Hz.

Are you on the right track?

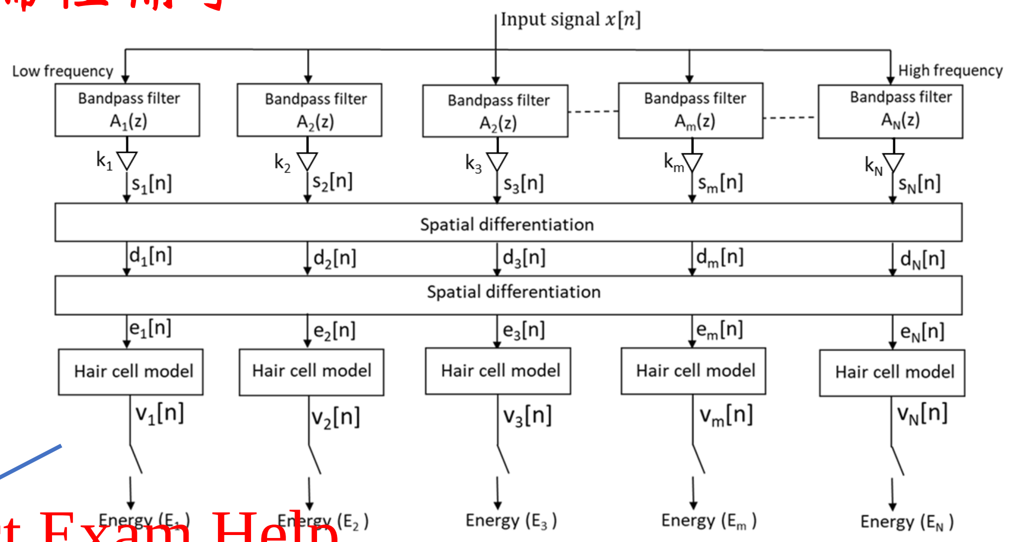


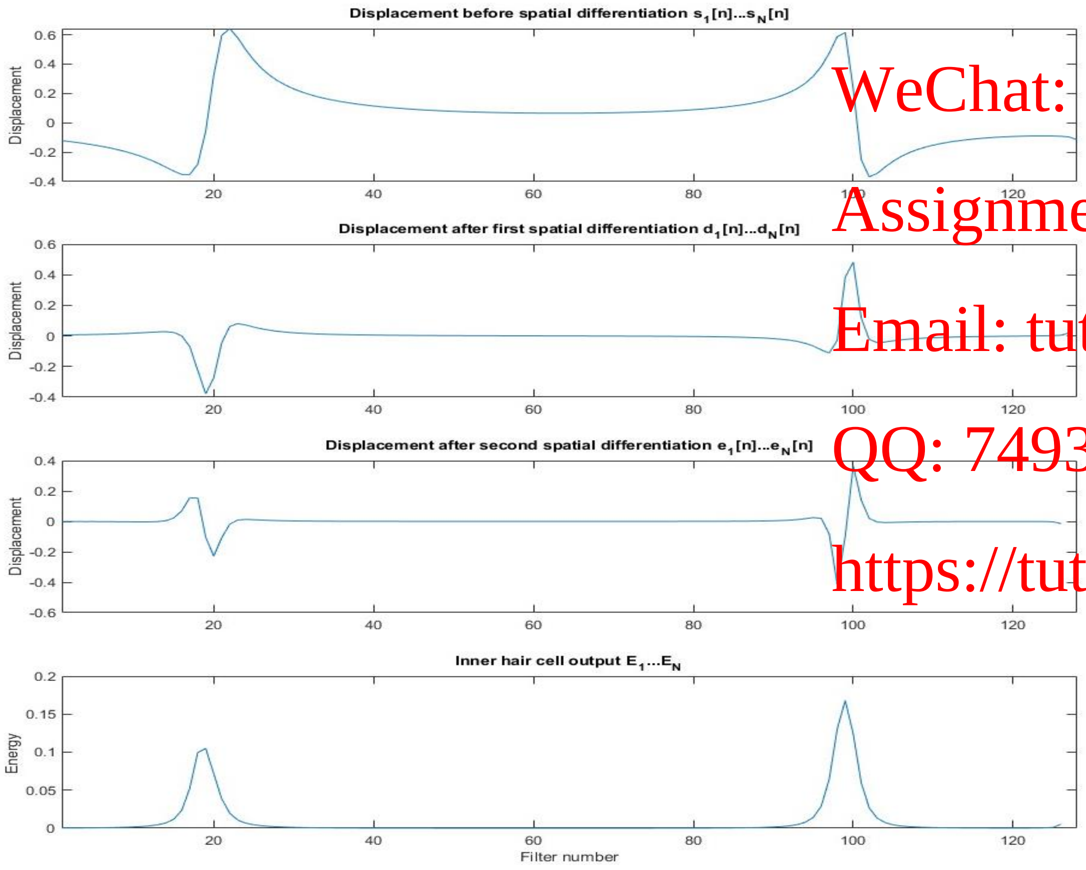


- ✓ If your implementation of the spatial differentiation is correct, you should get the magnitude response similar to the one shown in the diagram on the left, for the filter 84 with a centre frequency of 1640 Hz.
- ✓ You might notice that the centre frequency of each filter has shifted slightly with each spatial differentiation, and the filter shapes have become sharper, with a steeper slope. Why do you think this is the case?

Are you on the right track?

- ✓ Apply a sum of two sinusoidal components (704.6 Hz [Filter no:60] and 2.88 kHz [Filter no: 100]) at the input $x[n]$.
- ✓ Plot the output $\{s_1[n]\ to\ s_N[n]\}$ of each filter against the filter number at a particular time instant .
- ✓ Repeat the above step for the output $\{d_1[n]\ to\ d_N[n]\}$ a[...]t $\{e_1[n]\ to\ e_N[n]\}$
- ✓ Do you notice any differences between these three plots[...]plain briefly.
- ✓ The inner hair cell output shows the spectral component[...] input signal.





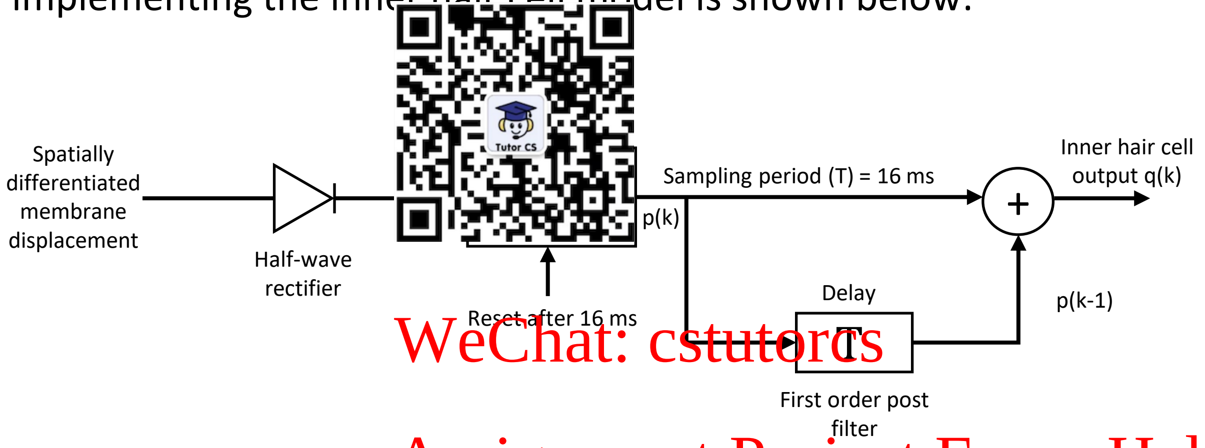
- ✓ The figure on the left shows the spatially differentiated basilar membrane displacement ($e_1[n]$ to $e_N[n]$ } and the corresponding inner hair cell output in response to a sum of two sinusoidal components applied at the input (704.6 Hz [Filter no:60] and 2.88 kHz [Filter no: 100]).

- ✓ If your implementation of the spatial differentiation is correct, you should get results that are very similar to the diagram on the left for a sum of two sinusoidal input.

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.

Are you on the right track?

Final Implementation

- Apply a signal which is a sum of six sinusoids, 1000-2000 samples, of equal amplitude and frequencies of your choice, to the input of the filter bank. Plot the output of the sp[illegible]ser (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 [illegible]al 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)?

- Apply your own recorded voice at 16 kHz sampling frequency as an input and observe the hair cell output at a particular time instant. What do you notice? Discuss your observations with your lab demonstrator.