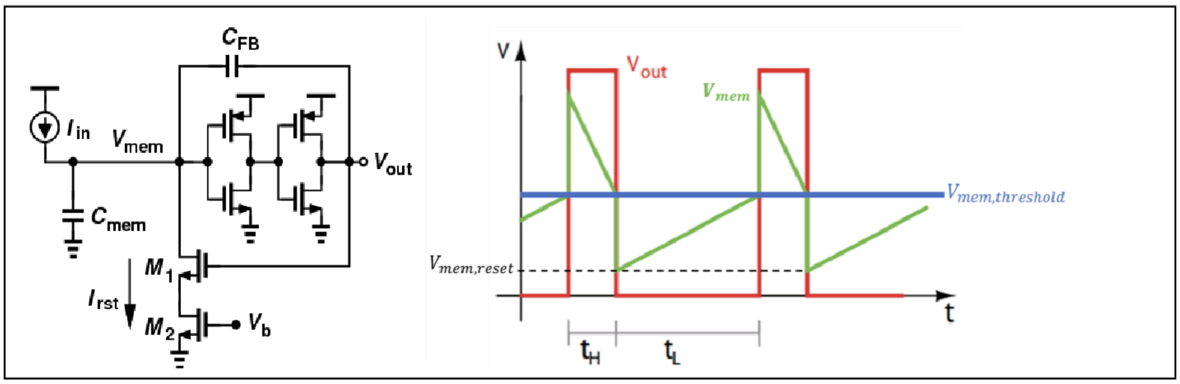
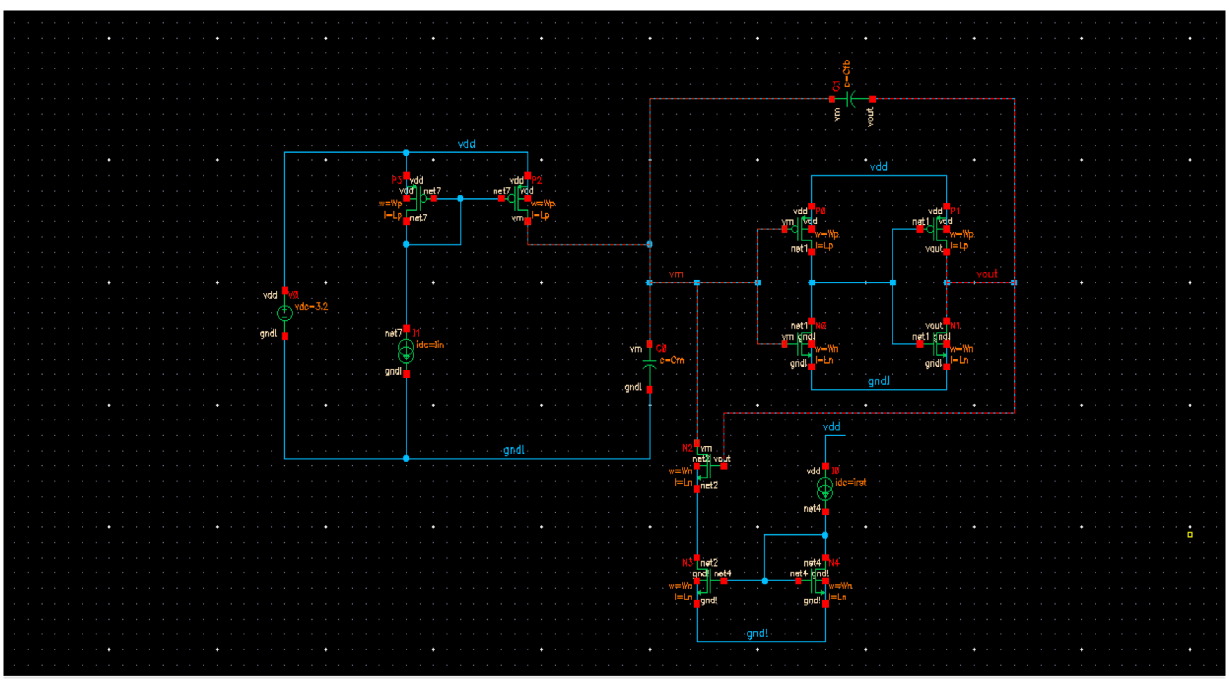
DESIGNING THE INTEGRATED AND FIRE(I&F) NEURON

1. Introduction:

The objective of this project is to design an Integrate-and-Fire (I&F) neuron circuit that receives a current as input and generates a pulse train at its output. The pulse train frequency is a function of the input current, and the design must satisfy the given specifications.



2. Schematic Design:



The **Integrate-and-Fire (I&F) Neuron** circuit is designed using the following key components:

Component	Function
Membrane Capacitor (C_mem)	Stores and integrates the input current over time, increasing V_mem.
Feedback Capacitor (C_fb)	Provides feedback to reset the neuron after firing a pulse.
Input Current Source (I_in)	Acts as a stimulus, charging C_mem and influencing the pulse rate.
Reset Current (I_rst)	Discharges C_mem after a spike, resetting V_mem to its initial state.
Inverter-based Threshold Detection	Detects when V_mem crosses a threshold, triggering an output pulse.

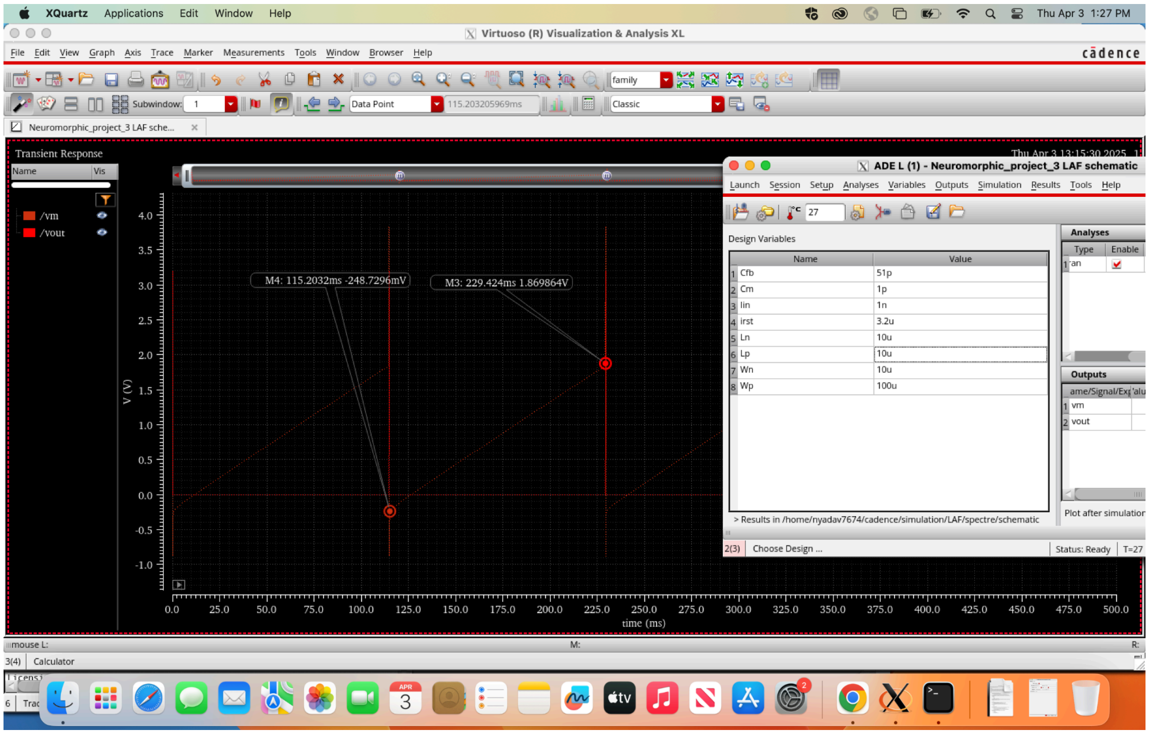
3. Device and Capacitor Sizing

The following table summarizes the device and capacitor sizes used in the design:

Component	Value
Membrane Capacitor (C_mem)	1 pF
Feedback Capacitor (C_fb)	51 pF
NMOS Channel Length (L_n)	10 µm
PMOS Channel Length (L_p)	10 µm
NMOS Channel Width (W_n)	10 µm
PMOS Channel Width (W_p)	100 µm

Showing For an input current range from 1nA to 10nA,the output pulse rate,PR,is linearly varying between 10 Hz and 100 Hz

a)Iin= 1nA ; PR=10HZ



<u>Hand calculation:</u>

$\boxed{I_{in} = 1nA}$

$$PR \simeq \frac{1}{t_L} = \frac{I_{in}}{C_{total} \times \Delta V_{mem}}$$

$C_{fb} = 51\,pF$

$C_{mem} = 1\,pF$

$I_{in} = 1nA$

$C_{total} = C_{fb} + C_{mem}$

$= (51+1)pF$

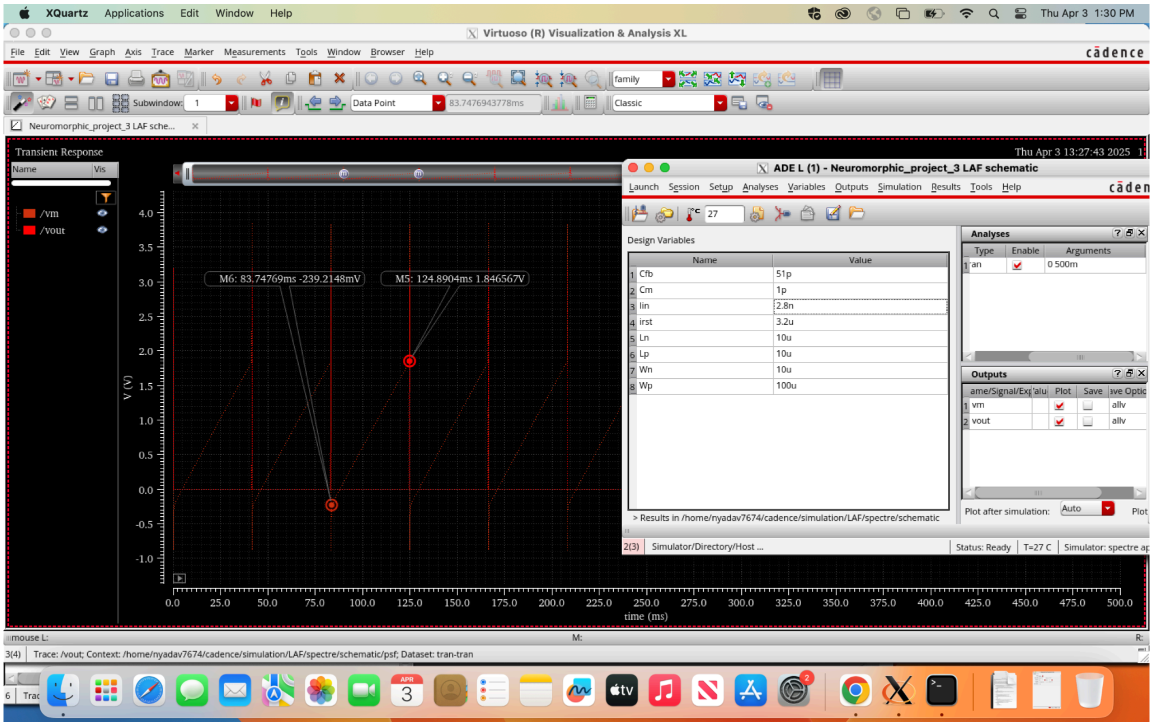
$C_{total} = 52pF$

$$PR = \frac{1nA}{[52pF].[1.8698 - 0.2487]}$$

$$PR = \frac{10^3}{52 \times 1.6} = 0.01 \times 10^3$$

$\boxed{PR = 10\,Hz}$

b) Iin= 2.8nA : PR=28HZ



$$\boxed{I_{in} = 2.8nA}$$

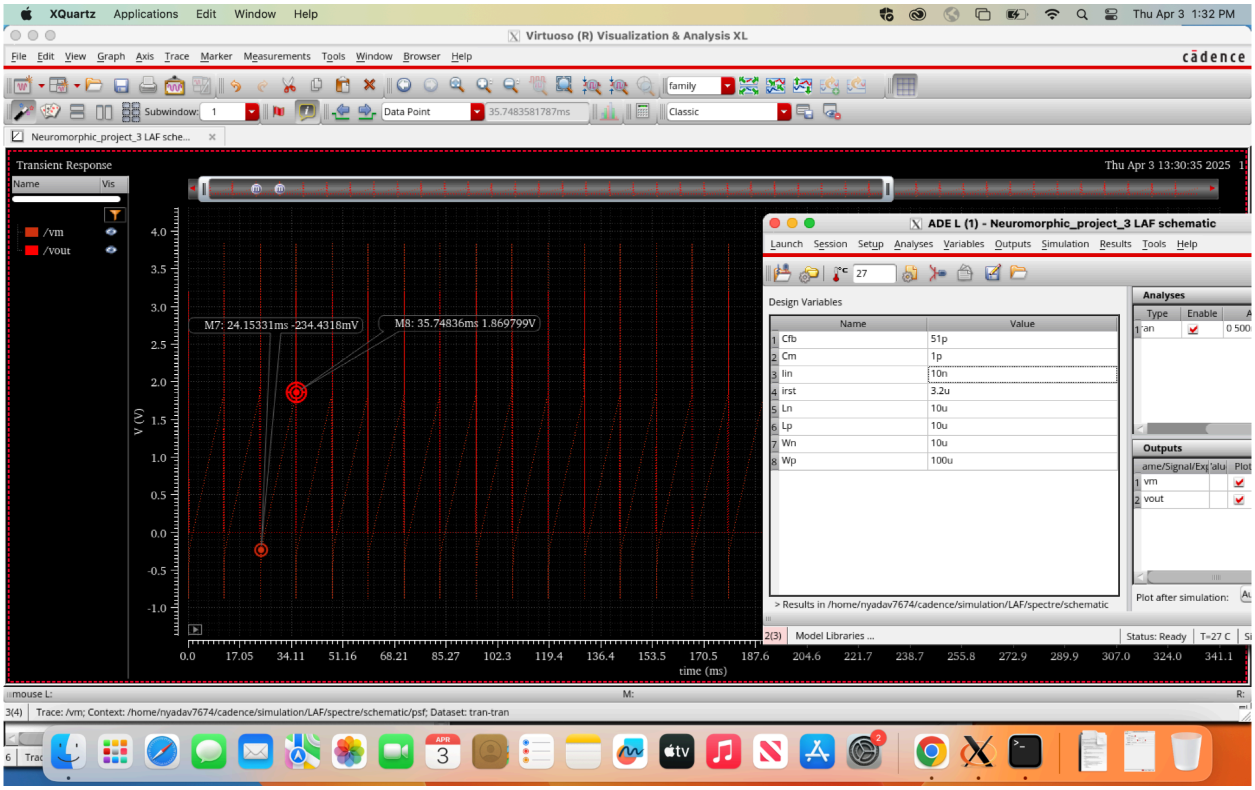
$$PR \simeq \frac{1}{t_L} = \frac{I_{in}}{C_{total} \times \Delta V_{mem}}$$

$$\Rightarrow PR = \frac{2.8 \times 10^{-9}}{[52 \times 10^{-12}][1.8465 - 0.2392]}$$

$$= \frac{10^3}{52 \times 1.6} = 2.8 \times 0.01 \times 10^3$$

$$\Rightarrow \boxed{PR = 28\,Hz}$$

c) Iin=10nA PR = 10HZ



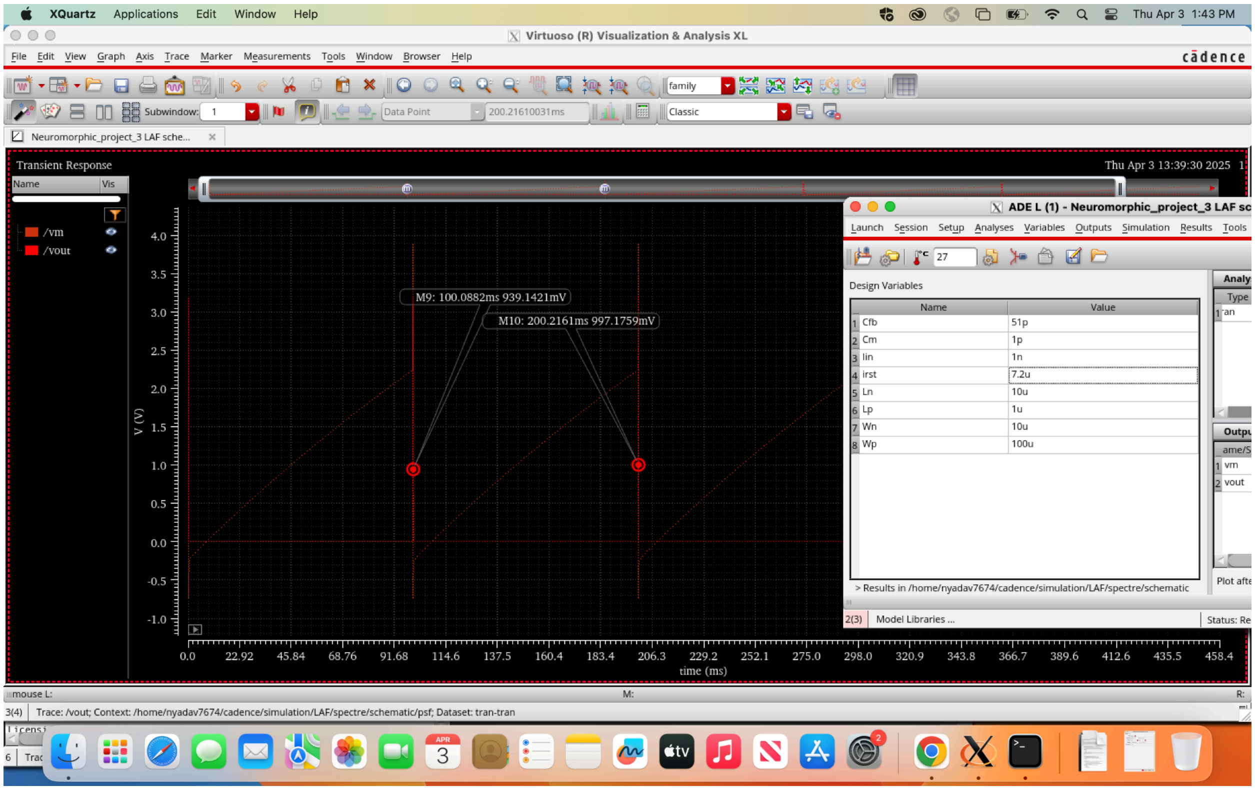
$$\boxed{I_{in} = 10nA}$$

$$PR \simeq \frac{1}{t_L} = \frac{I_{in}}{C_{total} \times \Delta V_{mem}} = \frac{10 \times 10^{-9}}{[52 \times 10^{-12}][1.8697 - 0.2344]}$$

$$\Rightarrow PR = 10 \times 0.01 \times 10^{3} \Rightarrow \boxed{PR = 100\ Hz}$$

Verifying the frequency of the simulation output pulses

a) Iin=1na Frequency = 10 hz



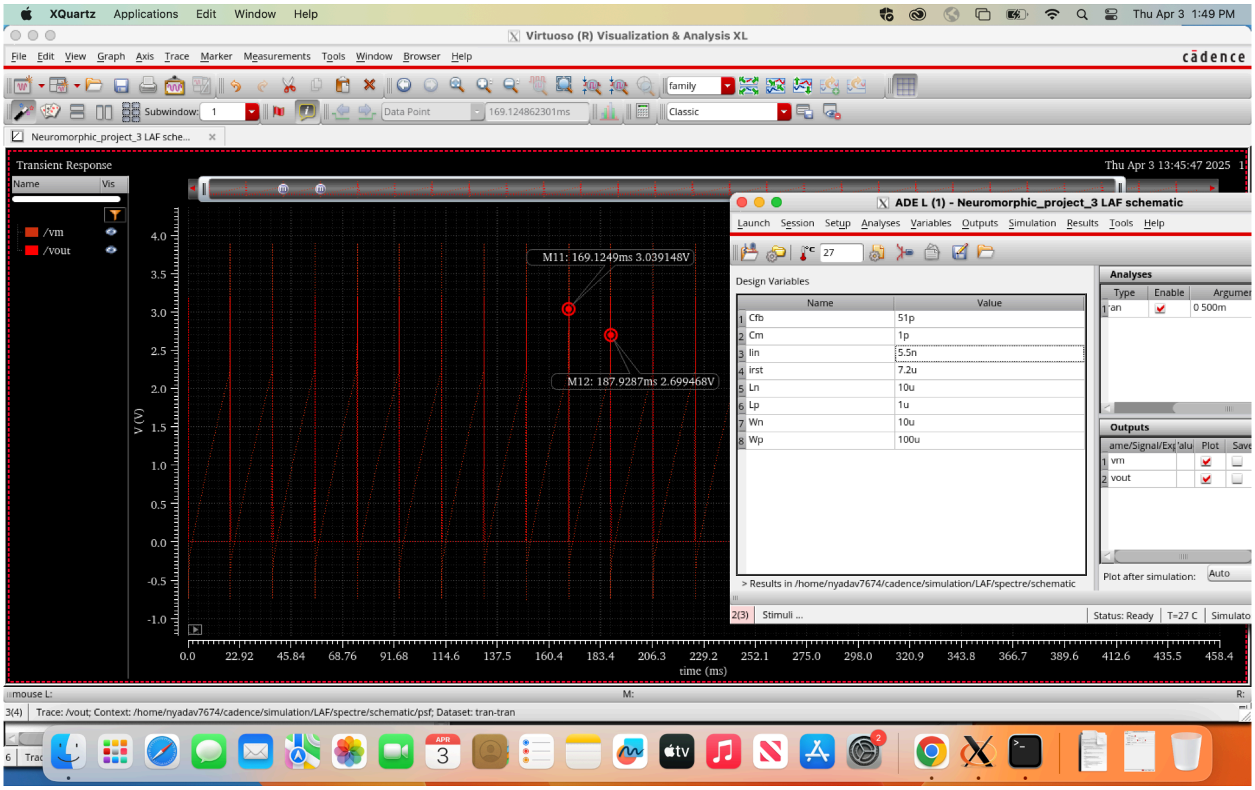
$$\text{frequency} = \frac{1}{\text{Time Period}}$$

(1) $I_{in} = 1nA$

$$F = \frac{1}{(200.216 - 100.0)\,ms} = \frac{10^3}{100.2} \simeq 10\ Hz$$

$$\boxed{F = 10Hz}$$

b) Iin=5.5nA Frequency = 52.9 hz

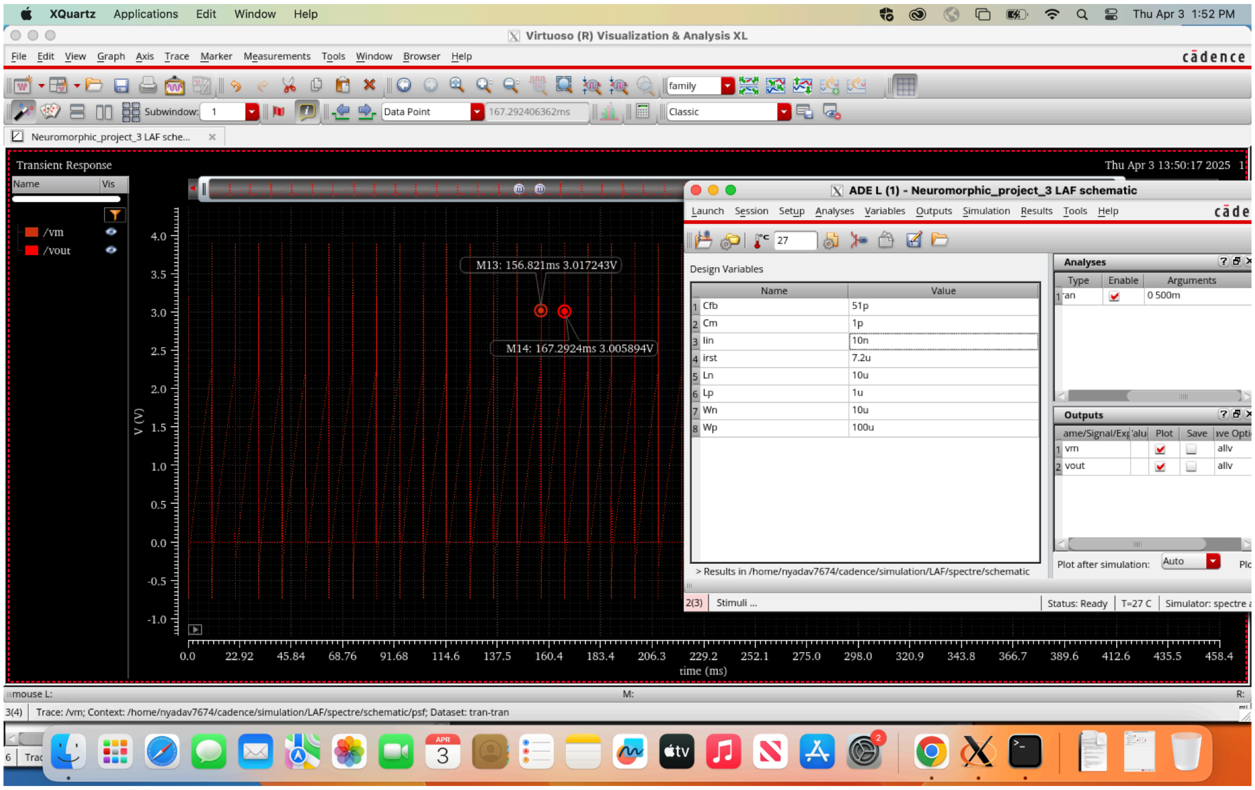


(ii) $I_{in} = 5.5nA$

$$F = \frac{1}{(187.928 - 169.124)\,ms} = \frac{10^3}{18.9} = 52.9 \approx 53\ Hz$$

$$\boxed{F = 53\ Hz}$$

c) Iin=10na Frequency = 95.5hz



(iii) $I_{in} = 10\,nA$

$$F = \frac{1}{(167.292 - 156.821)\,ms} = \frac{10^3}{10.47}$$

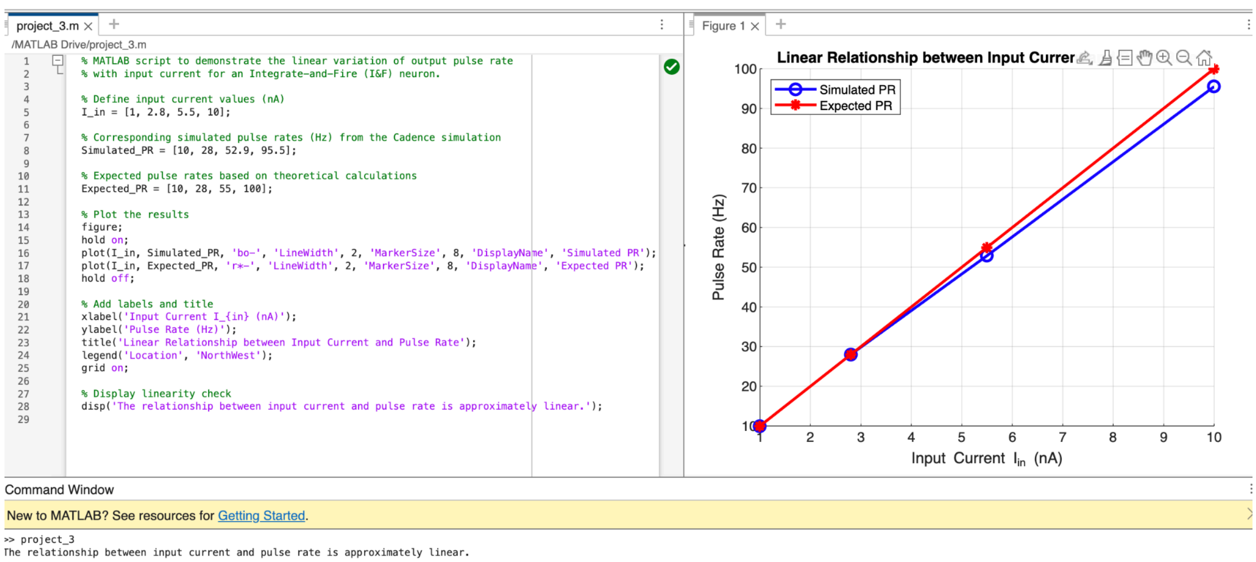
$$\boxed{F = 95.5\,Hz}$$

4. Simulation Results

Simulation was performed for a duration of 500 ms with different input currents. The results are summarized below:

Input Current (nA)	Simulated PR (Hz)	Expected PR (Hz)
1 nA	10 Hz	10 Hz
2.8 nA	28 Hz	28 Hz
5.5 nA	52.9 Hz	55 Hz
10 nA	95.5 Hz	100 Hz

5. MATLAB Simulation



8. Conclusion

The I&F neuron was successfully designed and simulated in Cadence Virtuoso. The pulse frequency varies linearly with input current, meeting the required specifications.