Written Examination EITP25

June 3rd 2021

Useful constants:

$$\hbar = 1.055 \times 10^{-34}\ Js$$

$$k_B = 1.381 \times 10^{-23}\ J/K$$

$$m_0 = 9.109 \times 10^{-31}\ kg$$

$$\varepsilon_0 = 8.85 \times 10^{-12}\ Fm^{-1}$$

$$e = q = 1.602 \times 10^{-19}\ C$$

$$c = 2.998 \times 10^{8}\ m/s$$

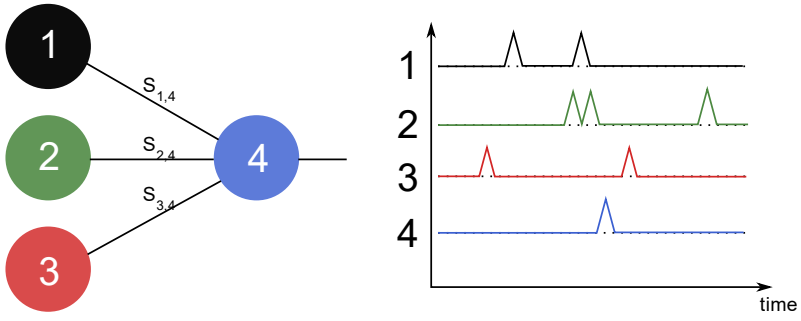
Solve the Five tasks below. Maximum score is 60p.

1. Conventional memory technology: (12 p)
   a. SRAM is the fastest memory thus far. What is the reason why this is not used for the main memory? (3p)
   b. Which of NOR and NAND Flash has the slowest READ speed, and explain why. (4p)
   c. Consider a small convolutional neural network that is trained on a GPU with 1000 Gbyte/s memory transfer rate and specified maximum performance of 100 Teraflops. The network is used for image classification of 1 byte gray scale images, with a 3x3 kernel and stride 1 in the first layer. In a first approximation this information can be used to estimate the flops/byte. Calculate the actual performance of this setup (Gigaflops) and give a suggestion for how to improve it. (5p)

2. In-memory computing and SNNs (12p)
   a. Using a 3x3 array of PCM devices explain how one goes about to multiply the array

$$\begin{bmatrix} 4 & 2 & 1 \\ 3 & 4 & 0 \\ 5 & 6 & 3 \end{bmatrix}$$ and the vector $$\begin{bmatrix} 3 \\ 2 \\ 1 \end{bmatrix}$$. Also give the correct for the output vector. (4p)

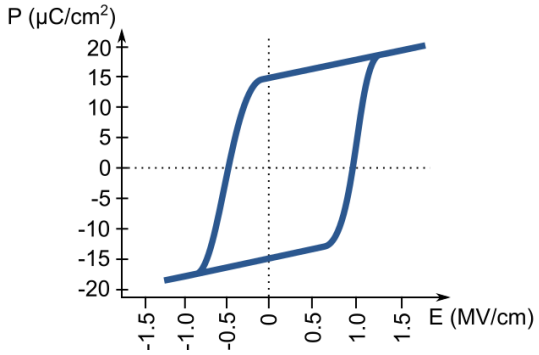
   b. Which of the synapses in the following network will be potentiated and which will be depressed? Explain your reasoning in terms of STDP. (4p)



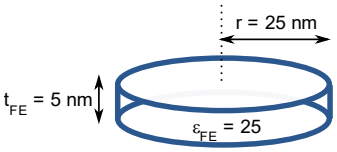
c. Explain what are the essential functionalities that a leaky-integrate-and-fire neuron implements, and how these could be realized in an electronic circuit. (4p)

3. MRAM: (12p)
   a. Explain giant tunnelling magnetic resistance in a magnetic tunnel junction and how it leads to R_{off}/R_{on}. (4p)
   b. Given a transistor that has an on current of 2 mA/µm and an MTJ with F = 40 nm and J_c = 3 MA/cm^2, what total MRAM size (in F^2) is needed to successfully switch the memory state? (4p)
   c. Given that MRAMs are binary devices, explain how they can still be used as synapse devices in a spiking neural network. (4p)

4. Ferroelectric devices: (12p)
   a. Extract the remanent polarisation and coercive field from the following graph (4p):



   b. Based on the ferroelectric film ($\varepsilon_{FE} = 25$) shown above, what is the expected energy needed to switch the state of a circular ferroelectric capacitor with the dimensions shown to the right? (4p)



   c. Explain how FeFETs work in terms of the WRITE and READ operations, and why obtaining long retention time and endurance are challenges. (4p)

5. Selector device: (12p)
   a. What is the purpose of adding a selector device to a memory node in a crossbar memory array? (4p)
   b. What are the benefits of p-n diodes as a selector device? And for what type of memory device can you use it? Explain why? (4p)
   c. Consider a FTJ with current given by $I = \alpha * (exp(\beta V) - 1)$, with parameters $\alpha_{on} = 1\ fA$ and $\beta_{on} = 25\ V^{-1}$ for the on-state and $\alpha_{off} = 0.1\ fA$ and $\beta_{off} = 26\ V^{-1}$ for the off-state. Using V/2 biasing scheme with V_{read} = 1 V, on a 1000x1000 memory array, calculate the signal to noise ratio $SNR = \frac{I_{selected}}{I_{unselected} + I_{halfselected}}$. for the worst-case scenario. (4p)