Neuromorphic Engineering I Study Guide

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This is the collection of "What we expect you to know" sections from the individual labs. If you can tell someone else with confidence about these topics, you will do well at the exam. We recommend that you try to study with another student. Take turns explaining to each other about these topics, and drawing schematics and diagrams for each other.

1.1 Semiconductors

What is neuromorphic aVLSI all about? Who came up with it? Where is it being done?

Semiconductors, bands, band gap of silicon, the Fermi-Dirac distribution, doners and acceptors, PN junction, reverse and forward characteristics.

Using the Keithley voltage source (K230) and source-measure electrometer (K236) instruments. E.g. what is the K236 DC input impedance when measuring voltage with it? Basic knowledge of matlab. How to use the pot-boxes.

1.2 Subthresold FET operation

What does it mean for a MOS transistor channel to be accumulated, flatband, depleted, inverted? Knowledge of how subthreshold transistor operation is a diffusion process and why it depends exponentially on the terminal voltages. What is the meaning of "saturation"? What is the triode or linear operating range? I_{ds} vs V_{gs} on log scale. Differences between n- and p-fets. Typical values of I_0, κ and subthreshold operating range. What are wells and how should the wells be biased relative to the substrate? What is the "back gate" or "body effect"? How is the back gate is related to κ? How to make a MOS capacitor and what is its C-V relationship. How a source follower works and how to compute the gain of a source follower.

1.3 Above-threshold FET operation

How transistors work above threshold. What is the linear or triode region and what is the saturation region? How do they depend on gate and threshold voltage. How the Early effect comes about. Typical values for Early voltage. How to sketch graphs of transistor current vs. gate voltage and drain-source voltage. How above-threshold transistors go into saturation and why the saturation voltage is equal to the gate overdrive. The above-threshold current equations. How above-threshold current depends on C_{ox} and mobility. How transconductance and drain resistance combine to generate voltage gain and what is the intrinsic voltage gain of a transistor. What effect does velocity saturation have on transistor operation? What is DIBL (drain induced barrier lowering) and II (impact ionization)? How transconductance and drain resistance combine to generate voltage gain.

1.4 Differential pairs, current correlator, bump circuits

How does a diff pair work? How does the common-node voltage go with the inputs? How can you compute the differential tail currents from the subthreshold equations, and how do you get the result in terms of the differential input voltage? How does a current-correlator work? How does a bump circuit work?

1.5 Transconductance amplifier

The I-V characteristics of a transconductance amplifier below threshold. How the open-circuit characteristics differ between simple and wide-output-range transamp. The subthreshold transconductance g_m. The relation between A, g_d, and g_m.

1.6 Followers, transimpendance amplifiers

How to use a non-linear circuit, such as a operational amplifier, to compute linear functions. What a unity-gain follower is used for. How to build a linear current-to-voltage converter (although we didn't build one in the lab).

1.7 Linear systems analysis, Time domain, follower integrator and differentiator, Hysteretic differentiator, Second-order systems

How to compute the time-constant of a low-pass filter and how to estimate it from the measurements. How to change the time-constant of a follower-integrator circuit.

The idea of using a lowpass filter (an integrator) to make a highpass filter (a differentiator). How the differentiator circuit is not a real differentiator but only an approximation over some frequencies defined by the time constant. How to sketch the transfer function of a differentiator circuit, showing the time constant on the sketch. How to implement a simple follower-differentiator, and a hysteretic differentiator, using followers. How to estimate the time-constants of both type of differentiators and how to estimate them from the measurements. How these circuits behave when driven with large signals. What is a canonical second-order system, and how to compute stability.

1.8 Winner-take-all circuit (WTA)

How does the WTA circuit work? Can you reason through its behavior? How does the bias current affect its performance? How can you adjust the gain of the circuit by layout of the transistors?

1.9 Photodiodes, photoreceptor

How does the I-V curve of a diode change in the presence of light? How does phototransduction occur in silicon? How you can use adaptation in a feedback loop to cancel out circuit mismatch. How you can build a fast logarithmic current-sense amplifier, by using feedback to make a virtual ground. How you can use a capacitive divider in the feedback loop of an amplifier to set a gain. How you can use a cascode configuration to increase effective drain resistance. What is the Miller effect? How can a cascode can be used to reduce it?

1.10 Neurons, axon-hillock circuit

What is a neuron and what are its components (synapse, soma, dendrite)? What types of models are used to simulate neurons? How does the spike-generating mechanism work? What is an FI curve? Can you draw the circuit schematic of the axon-hillock neuron?

1.11 Synapses, adaptive neuron circuit

The schematic for a synapse circuit. How the synaptic current changes as a function of the presynaptic frequency and the synaptic weight. How the firing frequency of an adaptive neuron changes as a function of the presynaptic frequency and the biases to the adapting synapse.

1.12 Learning in silicon: Tunneling, hot electron injection

How do tunneling and injection mechanisms work? What is the shape of the energy band diagram in the channel and oxide during tunneling and injection? How are the memory cell circuits used to control tunneling and injection?

1.13 Long range communication, Address-Event representation

What is AER? How does an AER system mimic biology's use of nerves? What constraints on firing rate are important for an AER system? What does it mean to be asynchronous? To be delay insensitive? What are the advantages and disadvantages of asynchronous designs? What is an isochronous fork assumption? What does the term bundled data mean? What is a dual rail encoding? What are the advantages and disadvantages of bundled data? How does a 4-phase handshake work? What is an arbiter? What is a C-element and can you draw a circuit for one? What is a staticizer and can you draw the circuit for one? Can you sketch the communication architecture and timing for a 2-d AER chip (like a retina)?