

EE 591L – Neuromorphic Analog VLSI

Project 3 – Subthreshold Amplifier Design

Objective

To become familiar with the design process of simple analog IC amplifiers.

Simulation Models

As will be standard with all projects involving circuit simulations, we will be using the 0.5 μ m EKV model for MOSFETs because it correctly handles both subthreshold and above-threshold currents very well. With a 0.5 μ m process, the supply voltage (V_{dd}) is 3.3V.

Special Instructions for This Project

Along with your project report, please send me an *electronic* copy of your SPICE deck from Part 1. If it contains multiple files, please compress them before sending them to me (.zip, .tar, etc.).

Part 1 – Design of an All-Transistor Amplifier

Design an amplifier using only transistors operating in the subthreshold regime (no ideal current sources, resistors, etc.) with the following specifications.

- $|\text{Gain}| = 1000$
- Trigger Point at 0.5V

Each of these specifications must be met within an accuracy of 5%.

The gain may be inverting or non-inverting.

The trigger point will be defined as the input DC voltage for which the output DC voltage is at mid-rail ($V_{out} = 0.5V_{dd} = 1.65V$).

Clearly describe your design procedure. In your description, please include answers to the following questions.

- How can you design for a specific gain (what parameters need to be modified)?
- Can the gain be modified after fabrication? Explain.
- How can you modify the trigger point?
- Can the trigger point be modified after fabrication? Explain.

Also, you must generate a plot of the DC characteristics of this amplifier (DC sweep of the input voltage). Clearly indicate the amplification region, along with the respective gain, and the curve fit used to extract the gain.

Please include either a table or a circuit schematic that includes all the relevant information regarding your design including (but not limited to) transistor sizes, bias voltages/currents, etc.

Part 2 – Approximation of the “Small-Signal” Voltages

Determine the largest amplitude of input voltages over which the output remains undistorted (no clipping and no noticeable distortion to the output sinusoidal waveform). We will refer to this maximum input amplitude as the “linear range.” In order to determine this, you will need to

perform a transient analysis on the amplifier design of Part 1. Use an input voltage that is a sinusoidal waveform with a frequency of 10Hz.

To obtain a “rough estimate” of the linear range, increase the input amplitude until there is noticeable distortion in the output sinusoidal waveform. To get a more accurate value of the linear range, you will need to perform a `.FOUR` analysis to determine the Total Harmonic Distortion (THD) at the output. Effectively, the THD operation performs a Fourier analysis of the signal of interest to determine the presence of additional frequency components. THD is typically expressed in a percentage with respect to the fundamental, so a smaller THD is desirable. Determine the largest input amplitude for which the $THD \leq 5\%$. Additional information regarding finding the THD is provided in the Appendix.

Answer the following questions.

- What is the gain using the result of your transient analysis. Is the gain what you would have expected based on your design?
- What is the optimal DC voltage offset to maximize the linear range?
- What happens to the output signal if you alter the DC offset of your input voltage? Why?

Please include a plot showing the gain of the amplifier using this transient analysis. Also, include any plots that will aid your description of these questions.

Thought Question

No matter how well you matched the specifications, the amplifier has a serious, fundamental problem when dealing with real-world, non-ideal input signals. Can you determine what this issue is? (HINT – Think about what happens if the input signal is noisy or has jitter (some sort of fluctuations)). We will be spending time over the next couple of weeks taking care of this serious issue.

Appendix

Total harmonic distortion (THD) is defined as

$$THD = \sqrt{\frac{a_2^2 + a_3^2 + \dots + a_n^2}{a_1^2}}$$

where a_i is the amplitude of the i^{th} frequency component. THD can be found with SPICE by using the Fourier analysis statement. The format for this statement is

`.FOUR FREQ OUT1 (OUT2 ...)`

where `FREQ` is the fundamental frequency of the input and `OUT*` are the nodes for which you wish to know the distortion. The `.FOUR` statement displays the THD and the values of the first ten harmonics.

The Fourier statement should be used *in combination with* the transient analysis (meaning that you must *also* perform a `.TRAN` analysis, simultaneously).

- `.FOUR` computes the Fourier transform over the last full period of the fundamental, so the length of the transient simulation must be long enough to have one full period after all of the start-up transients have died out.
- The step size for the transient simulation should be around 1% of the period of the fundamental to guarantee sufficient frequency resolution for the higher harmonics.
- To view the THD in WinSPICE, simply run the SPICE deck with WinSPICE (you do not need to run it through MATLAB using the `runwinspice.m` function). Simply double-click on the file that you wish to run, and it will run WinSPICE for you. The THD will be printed to the WinSPICE screen.
- To view the THD in HSPICE, open the `.out` file. Towards the end of this file will be a table summarizing the harmonic contributions as well as the THD.