

Lab 04: Digital Data & Logic

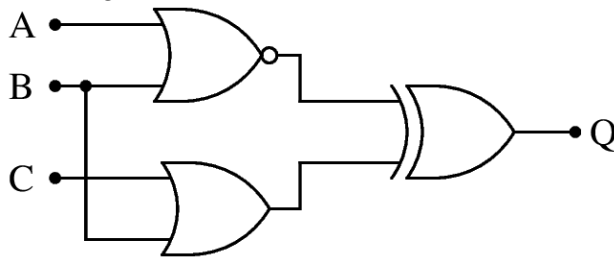
Medical Electrical Equipment (BME590L)

2023-03-27

Be sure to submit all of your code along with the results of your analysis. You can use any programming language that you are comfortable in (Python, using a Jupyter notebook, is strongly recommended).

1 Logic

Determine the truth table for this logical network.



2 Binary Search Algorithms / Successive Approximation ADC

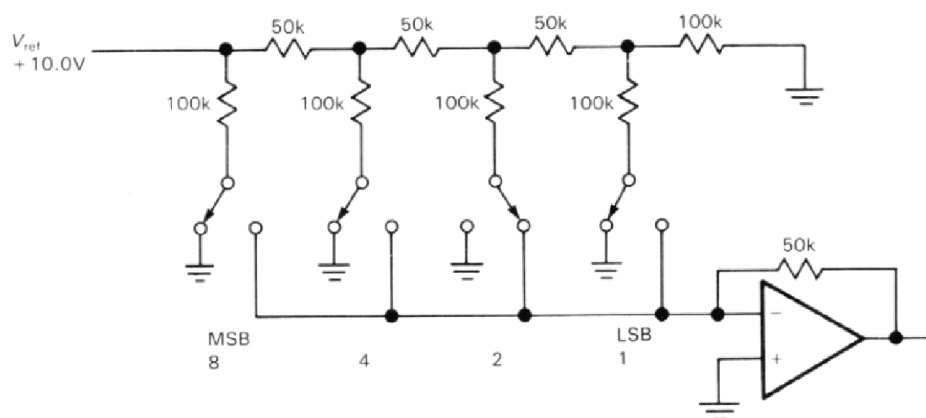
The successive approximation ADC that we covered in lecture uses a binary search algorithm to determine the most accurate binary representation of a base-10 number. Write a Python function that does the following:

- Accepts input arguments of:
 - Base-10 number to approximate with a binary number
 - Number of bits in binary representation
 - Minimum base-10 number to represent
 - Maximum base-10 number to represent
- Outputs:
 - Each of the binary numbers approximated during the successive approximation
 - The final binary number
 - The final binary number's base-10 equivalent, and the percentage error from the input base-10 number

Use your binary search algorithm that you wrote for the following problem. An EMG experiment records the number of fasciculations of the eye lid that occur overnight. It is expected that between 10,000 and 10,000,000 discrete events will be recorded, with a precision of ± 1000 discrete events.

1. Determine the fewest number of bits that you need to represent your final event count from the experiment as a binary number.
2. For your chosen bit depth, your least significant bit (LSB) corresponds to how many “events”?
3. Record the output of your code for the binary representation at your specified bit depth for 3,500,000 events.

3 DAC: R-2R ladder



1. Solve for the currents through the $2R$ ($100\text{ k}\Omega$) resistors associated with each bit branch for the binary numbers 1100 and 0011 . A switch will be connected to GND when it represents a '0'. Remember that because the op amp is configured with negative feedback, $V_- = V_+ = \text{GND}$.
2. How do the bit branch currents (1) compare to one another, and (2) change as a function of the binary digit they represent (0 or 1)? Does this make sense?
3. What is V_o , the output voltage from the op amp, for the two binary numbers?

4 HDF5 Data

Working with raw binary data is very efficient from a data storage perspective, but quite cumbersome without additional metadata to describe variables, units, etc. Hierarchical Data Format v5 (HDF5) is one of the most common data formats to store both raw data and associated metadata.¹

We will work with some ECG data from one of my dogs for this assignment, first in HDF5 format. You can access the ECG data in HDF5 format (*canine_ecg.h5*) on Teams. The ECG data (*ecg*) are in millivolts and the time data (*t*) are in seconds.

1. Plot the ECG signal as a function of time, with the axes properly labeled with units.

¹Most newer Matlab (*.mat) files are actually HDF5 files.

2. What is the range of voltages for the ECG signal? What is the approximate voltage range for the noise? *Note - there are several different ways that you can quantify these values that are equally valid but may provide different values. Clearly state/show the way that you estimated these values.*
3. What is the minimum number of bits that we need to accurately represent the data? What was the approximate SNR for this ECG trace?
4. What should the voltage of the least-significant-bit (LSB) be set to in your ADC?
5. What is the sampling frequency (f_s) for these data?
6. Generate a plot clearly showing the frequency (spectral) content of this ECG data trace.

Next, we're going to manually downsample the data to qualitatively get a feel for what minimum sampling frequency can be to still accurately represent the morphology of the ECG signal.

7. Downsample the ECG data (and the time data) by factors of 10, 50, 100, 200, 500, and 1000. Generate plots comparing these waveforms (zoom in on just one of the wave complexes) and notice the aliasing / signal corruption that occurs when the waveform is undersampled.
8. Generate plots of the frequency content of these downsampled ECG data traces and comment on what you expected these to look like relative to the original signal and if your plots match your intuition.
9. Based on visual inspection of your plots that show the effects of aliasing, what is the minimum sampling frequency that could be used to adequately represent these data digitally? What does this imply about the maximum frequency content of the ECG signal? How does this compare with the Nyquist limit that you would have chosen based on your FFT power spectrum?
10. How much greater than this minimum sampling frequency was the data acquisition sampling frequency? Is this adequate?

5 Raw Binary Data

Many datasets in research and industry are saved as "raw" binary files, as opposed to ASCII files (too large) or proprietary formats. Download `canine_ecg.bin` from Teams and load the raw binary data file. These data are 32-bit floating point numbers and were saved as a serial stream of time/voltage pairs (e.g., $t_1, V_1, t_2, V_2, \dots$).

There are many ways to load binary data in Python. Options include (listed in order of preference):

- `numpy.fromfile` - NumPy v1.23 Manual
 - Built-in Functions - Python 3.10.7 documentation
 - `struct` - Interpret bytes as packed binary data - Python 3.10.7 documentation
1. Plot the ECG data trace from the binary data file and compare with the HDF5 version of the file. Note any differences (if any exist).
 2. Comment on the pros/cons of using HDF5 vs. raw binary data for saving data.