Experiment 11: Analog-to-Digital Converter (ADC) Design Project

NOTE: This is a two-week experiment worth double credit (100 total points).

Introduction

An important objective of this experiment is to introduce you to the engineering design process. The word "design" as used here refers both to *designing a circuit* and to *designing the experimental methods to test the circuit*. It will be up to you to create a circuit to meet given specifications, and to figure out how best to demonstrate that it works.

The objectives of this experiment are to:

- Learn about analog to digital converter (ADC) circuits,
- Develop an understanding of the engineering design process by:
  - designing a circuit to meet specifications, and
  - designing experiments to test your circuit,
- Continue to develop professional communication skills.

The project specifications, calendar, and reporting requirements are given later in this document.. The report will be somewhat more extensive for this project than for the previous experiments in this course, mainly because you will need to explain and justify your design process besides providing the results.

Theory

There are a number of different approaches to ADC design[*]. The type of ADC you will design is called a *counting* ADC. A block diagram is shown in Fig. 1. In this circuit, the 555 timer circuit runs continuously, so the clock continuously counts either up or down. When properly configured, the comparator (it is suggested you use an LM 339) produces a logic HIGH output when v_{in} is greater than v_{guess}, and a logic LOW otherwise. This logic signal can be used to change the count direction. As a result, if the input changes to a value below the current value, the counter will count down to the new level. As soon as the counter counts 1 bit too low, the count direction will change and it will start counting up. Because the counter is always running, the ADC will always "hunt" between two adjacent levels when the input is constant. This is acceptable performance for the current project. More advanced designs would provide digital logic connected to the chip enable input(s) to stop the counter when it reached the desired level.

Definitions and measurements

Figure 2 shows the output of an ideal 3-bit ADC. The output is a "staircase," in which the horizontal width of each step is the voltage corresponding to 1 LSB, except for the first step (0.5 LSB) and the last step (1.5 LSB). The dots on the corners of the staircase indicate the transition voltages.

For this project, you must create a similar ideal graph for a 4-bit ADC. Then record the ideal dot locations in a table. When you test your circuit, measure the actual dot locations and compare to the ideal values. We will define the non-linearity as the root-mean-squared (RMS) error value:

Non-linearity = square-root of the average of the squares of all the ΔV , where ΔV = voltage difference between each dot and its ideal value. Mathematically, we can express this as shown in Eq. 1:

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[*] One good overview is provided in Chapt. 16 of *Microelectronic Circuit Design* by R.C. Jaeger (McGraw-Hill, 1997, ISBN 0-07-114386-6)

$$Nonlinearity = NL = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\Delta V_i\right)^2} \qquad (1)$$

where $\Delta V_i = V_i^{actual\ dot} - V_i^{ideal\ dot}$ and N is the total number of dots.

Specifications

For this project, you are to design an analog-to-digital converter (ADC) which converts analog voltages into 4-bit binary digital words. The detailed requirements and evaluation criteria are listed below.

STATIC SPECIFICATIONS (Non time-dependent)

Parameter	**Symbol**	**Range or Value** *Ideal*	*Actual*	**Required Measurement**
Input voltage	V_{IN}		0 V – 5 V	Measure with DMM
Minimum count voltage range	V_{MIN}	Zero volts.	As close as possible to zero volts without becoming negative.	The analog input voltage range for which the digital output hunts between 0000_2 and 0001_2 .
Maximum count input voltage range	V_{MAX}	5.0 V.	As close as possible to 5.0 V without exceeding it.	Measure the input voltage range for which the digital output hunts between 1110_2 and 1111_2 .
Non-Linearity	NL	0	As close as possible to ideal over full range of V_{IN}.	Measure according to Fig. 2 and Eq. 1.

DYNAMIC SPECIFICATIONS (time-dependent)

Parameter	**Symbol**	**Range or Value** *Ideal*	*Actual*	**Required Measurement**
Tracking delay for maximum size step input	T_{step}	0 s	As small as possible	Measure the time required for the digital output to change from its minimum to maximum value when an input step from V_{MIN} to V_{MAX} is applied.

OTHER SPECIFICATIONS

Parameter	**Symbol**	**Range or Value** *Ideal*	*Actual*	**Required Measurement**
Total cost of components	C_{TOT}	As small as possible while meeting all specifications.		Record costs of individual components, and total cost.
Number of different components	N_{COMP}	As small as possible while meeting all specifications.		Provide a count of the number of different components. (For example, same-valued resistors count as a single item. In a real-world design, this would impact the cost of maintaining inventory.)
Design time	T_{DES}	As small as possible while meeting all specifications.		Provide an estimate of the total hours spent designing and planning the circuit.
Assembly and testing time	T_{BUILD}	As small as possible while meeting all specifications.		Estimate of the total hours for building and testing the circuit.
Reporting time	T_{REP}	As small as possible while meeting all specifications.		Estimate of the total time to write the report.

Report Format

Your report should follow the same outline as all previous reports for this course, as detailed in the Course Information . However, you must include the following additional components in the appropriate section(s) of your report:

- Make a careful drawing of your final design. Label all IC pins, component values, supply voltages, etc. Anyone should be able to build your circuit from your drawing with no additional information.
- Include a paragraph explaining your design. What was your starting point? How did you arrive at the final design? How did you choose component values?
- Write a separate paragraph explaining how you tested your circuit. State how you measured each parameter listed in the specifications tables.
- Give measured values for each parameter listed in the specifications tables, and compare with the ideal values. The comparison should be quantitative (numerical) where possible.
- Explain what factors affect each measured parameter, and suggest how the actual value could be made closer to ideal.

Figure 1. Block diagram of a 4-bit counting-type ADC.

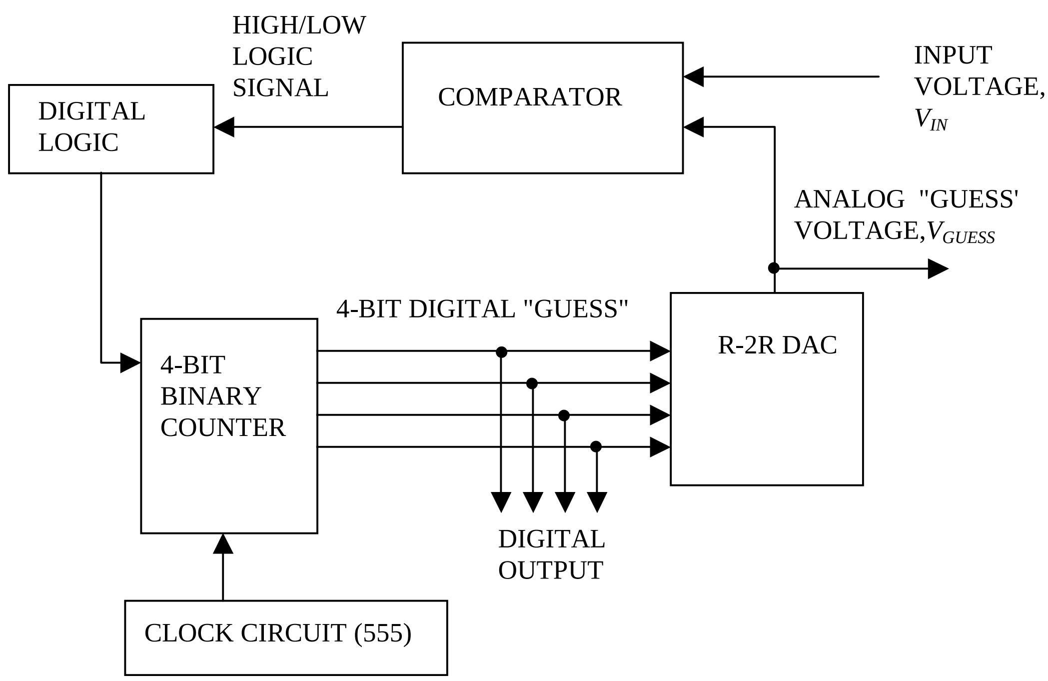

Figure 2. Ideal output for a 3-bit ADC.