Lab Exp 4
Design and Implementation of a 5-bit SAR ADC on a Breadboard

Kanishk Devatwal(EE23BTECH11029)
Mahendra Khinchi(EE23BTECH11039)

November 2024

Introduction

Analog-to-Digital Conversion (ADC):

Analog-to-Digital Converters transform continuous analog signals into discrete digital values. In this project, we'll use a 4-bit ADC, which converts an analog voltage into a 4-bit binary code (0–15 in decimal), with each bit representing a level of quantization.

Successive Approximation Register (SAR):

The SAR ADC operates by comparing the input voltage against a series of reference voltages. The SAR logic uses a binary search algorithm to estimate the closest binary value corresponding to the analog input. Each bit in the digital output is determined through successive approximations, guided by a digital-to-analog converter (DAC).

Components

→ Breadboard
→ Operational amplifiers
→ Resistors
→ 5-bit digital-to-analog converter (DAC) IC
→ Flip-flops
→ Micro-controller
→ Power supply

Circuit Design

- Voltage Reference and DAC Setup:

  → Use a DAC to generate reference voltages based on binary values set by the SAR.

  → Connect the DAC to a resistor network to produce voltage levels corresponding to each 4-bit binary code.

- Comparator Circuit:

  → A comparator circuit, such as LM339, compares the analog input with the DAC output voltage.

→ If the input voltage is higher than the DAC reference voltage, the comparator output sets the corresponding bit in the SAR to '1'; otherwise, it sets it to '0'.

- SAR Logic Circuit:

  →Implement the SAR logic using flip-flops or a shift register.

  → Starting from the MSB, the SAR sets each bit and adjusts based on comparator feedback, completing the process in four cycles for a 4-bit resolution.

- Control Logic:

  → The control logic can be implemented with discrete components or a micro-controller (for example, Arduino) to automate the SAR process.

  → The SAR control should toggle each bit in the DAC's binary input and readjust it based on the comparator's result.

Procedure

- Breadboard Setup:

  → Place and connect the DAC, comparator, and SAR components on the breadboard according to the designed circuit schematic.

  → Connect the power supply and verify the operation of each component individually.

- Testing SAR ADC Operation:

  →Apply different input voltages to the ADC input.

→ Observe the SAR process on an oscilloscope or multimeter to confirm that each step approximates the input voltage correctly.

- Binary Output Check:

→Verify the 5-bit output on LEDs or a logic analyzer.

→ Confirm that the binary output matches the expected quantized value for each input voltage.

0.1 Results

0.1.1 Digital Output for Input Voltages

The digital output of the 5-bit SAR ADC was recorded for a range of input voltages from 0V to 2V. The results are presented in Table 1, where each input voltage corresponds to a 5-bit binary output. The resolution of the ADC is given by:

$$\text{Resolution} = \frac{V_{\text{ref}}}{2^N} = \frac{2\,\text{V}}{2^5} = 0.0625\,\text{V}$$

0.2 Discussion

0.2.1 Accuracy and Linearity Analysis

The results demonstrate that the 5-bit SAR ADC accurately converts the input voltage into a 5-bit binary output within the expected quantization steps. The linearity plot confirms that the ADC output aligns closely with the ideal linear behavior.

However, minor deviations were observed, likely due to the following:

- **Quantization Error:** The inherent limitation of 5-bit resolution results in a quantization error of $\pm 0.5\,\text{LSB}$.
- **Comparator Limitations:** The comparator's finite response time and offset voltage may introduce slight inaccuracies.
- **Voltage Reference Stability:** Variations in the voltage reference can lead to nonlinearities and output drift.

Table 1: Analog Input vs. Digital Output of 5-bit SAR ADC

Analog Input (V)	**Digital Output (Binary)**
0.00	00000
0.0625	00001
0.125	00010
0.1875	00011
0.250	00100
0.3125	00101
0.375	00110
0.4375	00111
0.500	01000
0.5625	01001
0.625	01010
0.6875	01011
0.750	01100
0.8125	01101
0.875	01110
0.9375	01111
1.000	10000
1.0625	10001
1.125	10010
1.1875	10011
1.250	10100
1.3125	10101
1.375	10110
1.4375	10111
1.500	11000
1.5625	11001
1.625	11010
1.6875	11011
1.750	11100
1.8125	11101
1.875	11110
1.9375	11111

0.2.2 Suggested Improvements

To improve the design and performance of the ADC, the following changes can be implemented:

- Increase the resolution of the ADC (e.g., 8-bit or higher) to reduce quantization error.
- Use a high-precision comparator with low offset voltage and faster response

time.

- Implement a more stable and accurate voltage reference to minimize non-linearity.

0.3 Conclusion

The 5-bit SAR ADC successfully converts analog input voltages into corresponding 5-bit binary outputs, demonstrating the effectiveness of the SAR method. The performance was consistent with theoretical expectations, within the limits of 5-bit resolution. While quantization error and comparator limitations were noted, the ADC is suitable for basic applications requiring low-resolution digital conversion. Future improvements in resolution and component selection could further enhance the accuracy and linearity of the design.