Electronics
A to D and D to A Converters

Terry Sturtevant

Wilfrid Laurier University

October 3, 2018
Digital to Analog Converter

[Diagram of DAC]

Digital to Analog Converters (D/A; DAC)
Analog to Digital Converters (A/D; ADC)
Zener diodes
Sample and Hold amplifiers

Black box model
Features
Parameters

Terry Sturtevant
Electronics A to D and D to A Converters
Digital to Analog Converter

[Diagram of a Digital to Analog Converter (DAC)]

- Digital to Analog Converters (D/A; DAC)
- Analog to Digital Converters (A/D; ADC)
- Zener diodes
- Sample and Hold amplifiers

Black box model
Features
Parameters

Terry Sturtevant
Electronics A to D and D to A Converters
Digital to Analog Converter

\[ n \]

\[ V_{\text{ref}} \]

DAC

\[ V_{\text{out}} \]
Digital to Analog Converter

\[ n \]

\[ V_{\text{ref}} \]

\[ V_{\text{out}} \]
Operation
Operation

Diagram of a digital to analog converter with input voltage $V_{ref}$ and output voltage $V_{out}$.
Operation

\[ V_{out} \]

\[ V_{ref} \]
Operation

![Diagram showing the operation of a digital to analog converter](image-url)
Operation

![Diagram of a digital to analog converter (D/A) with input and output voltages represented.](image)

- **Operation**

  - **V_{out}**
  - **V_{ref}**

---

**Terry Sturtevant**

**Electronics A to D and D to A Converters**
Operation

![Diagram of Digital to Analog Converter (D/A; DAC)]

- **Operation**: The diagram illustrates the operation of a D/A converter. The input is a binary signal (0 or 1), and the output is a voltage level corresponding to the digital input.

**Black box model**
- **Features**: Parameters

- **Operation**: The output voltage $V_{out}$ is plotted against the input voltage $V_{ref}$. The converter outputs a voltage level that is proportional to the input digital signal.

**Parameters**
- $V_{out}$: Output voltage
- $V_{ref}$: Reference voltage

---

**Terry Sturtevant**

Electronics A to D and D to A Converters
Operation

![Diagram showing operation of a digital to analog converter (DAC) with inputs and output voltage relationship.](image-url)
**Operation**

The diagram illustrates the operation of a digital to analog converter (DAC). The diagram shows a black box model with inputs labeled as $V_{ref}$ and binary inputs $0$ and $1$. The output voltage $V_{out}$ is shown to increase linearly with the input signal.

**Parameters**

- $V_{out}$
- $V_{ref}$

**Features**

- Digital to Analog Converters (D/A; DAC)
- Analog to Digital Converters (A/D; ADC)
- Zener diodes
- Sample and Hold amplifiers

**Black box model**
### Operation

<table>
<thead>
<tr>
<th>$V_{out}$</th>
<th>$V_{ref}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Diagram:**

- Inputs: 0, 1, 1, 0
- $V_{ref}$
- $V_{out}$

**Graph:**
- Linear relationship between $V_{ref}$ and $V_{out}$
Operation

- Digital to Analog Converters (D/A; DAC)
- Analog to Digital Converters (A/D; ADC)
- Zener diodes
- Sample and Hold amplifiers

Black box model
Features
Parameters

Operation graph showing the relationship between $V_{out}$ and $V_{ref}$.
Operation

![Graph showing the operation of a digital to analog converter (DAC) with input levels and output voltage.](image)

- **Operation**: Graph showing the relationship between input voltage levels and output voltage levels for a digital to analog converter (DAC). The input levels are labeled as '0' and '1', while the output voltage is labeled as $V_{out}$.

- **Features**:
  - Black box model
  - Zener diodes
  - Sample and Hold amplifiers

- **Parameters**:
  - $V_{out}$
  - $V_{ref}$

- **Features**:
  - Black box model
  - Zener diodes
  - Sample and Hold amplifiers

- **Parameters**:
  - $V_{out}$
  - $V_{ref}$

Terry Sturtevant

Electronics A to D and D to A Converters
Digital to Analog Converters (D/A; DAC)
Analog to Digital Converters (A/D; ADC)
Zener diodes
Sample and Hold amplifiers

Operation

![Diagram showing operation of a DAC or ADC with inputs and output voltage.]

- **Operation**
  - $V_{out}$
  - $V_{ref}$

- **Parameters**
  - $V_{ref}$
  - $V_{out}$

- **Features**
  - Black box model

Terry Sturtevant
Electronics A to D and D to A Converters
Digital to Analog Converters (D/A; DAC)
Analog to Digital Converters (A/D; ADC)
Zener diodes
Sample and Hold amplifiers

Black box model
Features
Parameters

Operation

![Diagram showing operation of a digital to analog converter](image)

- $V_{out}$
- $V_{ref}$

<table>
<thead>
<tr>
<th>Features</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation</td>
<td>$V_{out}$</td>
</tr>
<tr>
<td>$V_{ref}$</td>
<td>1 0 1 0</td>
</tr>
</tbody>
</table>

Terry Sturtevant
Electronics A to D and D to A Converters
Operation

![Diagram of Digital to Analog Converter (D/A; DAC)]

- **Features**
  - Sample and Hold amplifiers
  - Zener diodes

- **Parameters**
  - $V_{out}$
  - $V_{ref}$

- **Operation**

  - Input: Digital signals (0, 1, 1, 1)
  - Output: Analog voltage ($V_{out}$)

---

**Terry Sturtevant**
Electronics A to D and D to A Converters
Operation

Digital to Analog Converters (D/A; DAC)
Analog to Digital Converters (A/D; ADC)
Zener diodes
Sample and Hold amplifiers

Black box model
Features
Parameters

Operation

1
1
0
0

$V_{\text{ref}}$

$V_{\text{out}}$

Terry Sturtevant
Electronics A to D and D to A Converters
Operation

Black box model
Features
Parameters
Operation

\[ V_{out} \]

\[ V_{ref} \]

- 1
- 1
- 1
- 0
Operation

Operation

\[ V_{out} \]

\[ V_{ref} \]

1
1
1
1
Features

<table>
<thead>
<tr>
<th>Features</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital inputs (N)</td>
<td></td>
</tr>
<tr>
<td>Analog reference</td>
<td></td>
</tr>
<tr>
<td>Analog output, (single or complementary)</td>
<td>V_{out} = n \cdot V_{ref}^2, where ( n \in [0, 2^N - 1] )</td>
</tr>
</tbody>
</table>
Features

- digital inputs ($N$)
Features

- digital inputs ($N$)
- analog reference
Features

- digital inputs ($N$)
- analog reference
- analog output, (single or complementary)
## Features

- digital inputs ($N$)
- analog reference
- analog output, (single or complementary)
- $V_{out} = n \cdot \frac{V_{ref}}{2^N}$, where $n \in [0, 2^N - 1]$
Parameters
<table>
<thead>
<tr>
<th>Black box model</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameters</td>
<td>Parameters</td>
</tr>
</tbody>
</table>

- resolution
Parameters

- resolution
- settling time
Parameters

- resolution
- settling time
- buffered inputs
Parameters

- resolution
- settling time
- buffered inputs
- power supply sensitivity
Analog to Digital Converter
Analog to Digital Converter

$V_{in}$

ADC

$V_{ref}$

$V_{in}$

ADC

Black box model
Features
Parameters
Analog to Digital Converter

$V_{in}$

$V_{ref}$

$ADC$
Analog to Digital Converter

\[ V_{in} \rightarrow \text{ADC} \rightarrow n \]

\[ V_{ref} \]
Operation
Operation

![Diagram of a digital to analog converter](image)

- **Operation**
  - $V_{in}$
  - $V_{ref}$
Operation

\( V_{in} \)

\( V_{ref} \)

\( 0 \)

\( 0 \)

\( 0 \)

\( 0 \)
Operation

![Diagram of operation](image)

- **$V_{in}$**: Input voltage
- **$V_{ref}$**: Reference voltage
Operation

![Diagram showing operation of a digital to analog converter (D/A) or analog to digital converter (A/D)]

- **Input Voltage** ($V_{in}$)
- **Reference Voltage** ($V_{ref}$)
- **Output Representation**
  - 0
  - 1
  - 0
Operation

![Diagram of a black box model with inputs and outputs labeled as $V_{in}$ and $V_{ref}$ with input values 0 and 1, and output values 0 and 1.]
Operation

![Diagram of black box model with input and reference voltage](image)

- **Input Voltage (V\text{in})**
- **Reference Voltage (V\text{ref})**

<table>
<thead>
<tr>
<th>Operation Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>V\text{in}</strong></td>
</tr>
<tr>
<td><strong>V\text{ref}</strong></td>
</tr>
</tbody>
</table>

0 1 0 0
Operation

The diagram shows a black box model of a converter with inputs and outputs. The input voltage $V_{in}$ is connected to the input terminals, and the reference voltage $V_{ref}$ is connected to the reference terminals. The output shows a binary representation with $V_{in}$ increasing and $V_{ref}$ remaining constant. The output levels are represented by the binary digits 0 and 1.
Operation

![Diagram of a black box model with input $V_{in}$ and reference voltage $V_{ref}$.]
Operation

![Diagram of a digital to analog converter (DAC) or analog to digital converter (ADC)]

- **Operation**
  
  - **Graphical Representation:**
    - Input voltage ($V_{in}$) vs. reference voltage ($V_{ref}$)
    - Output values: 0, 1, 1, 1

- **Black box model**

- **Features**

- **Parameters**

- **Terry Sturtevant**
  
  Electronics A to D and D to A Converters
Operation

Operation of a digital to analog converter (DAC)

- Input voltage $V_{in}$
- Reference voltage $V_{ref}$

Diagram showing the input and reference voltages.
Operation

![Diagram of Digital to Analog Converters (D/A; DAC) and Analog to Digital Converters (A/D; ADC)]

- **Operation**: The diagram illustrates the operation of a D/A and A/D converter. The input voltage $V_{in}$ is linearly related to the output voltage $V_{ref}$.

- **Features**: The diagram shows a black box model with input and output signals.

- **Parameters**: The diagram includes input and reference voltages, indicated by $V_{in}$ and $V_{ref}$, respectively.
Operation

Digital to Analog Converters (D/A; DAC)
Analog to Digital Converters (A/D; ADC)
Zener diodes
Sample and Hold amplifiers

Black box model
Features
Parameters

Terry Sturtevant
Electronics A to D and D to A Converters
Operation
Operation

\[ V_{in} \]
\[ V_{ref} \]
Operation

- Operation
  - $V_{in}$
  - $V_{ref}$

Black box model
- Features
- Parameters

Terry Sturtevant
Electronics A to D and D to A Converters
Operation

![Diagram showing operation of a converter with inputs and outputs labeled: $V_{in}$ and $V_{ref}$, with binary outputs 1, 1, 0.](image)
Operation

- **Operation** diagram showing input voltage \( V_{in} \) and reference voltage \( V_{ref} \) as inputs to a black box model.
Features

- analog input, (single or differential)
Features

- analog input, (single or differential)
- analog reference
Features

- analog input, (single or differential)
- analog reference
- digital outputs \((N)\)
Features

- analog input, (single or differential)
- analog reference
- digital outputs ($N$)
- $n = \|2^N \frac{V_{in}}{V_{ref}}\|$, where $n \in [0, 2^N - 1]$
Parameters

Terry Sturtevant

Electronics A to D and D to A Converters
Parameters

- resolution
Parameters

- resolution
- conversion time
Parameters

- resolution
- conversion time
- tri-state outputs
Zener diodes

One of the ways to produce a stable reference voltage, such as for an ADC or a DAC, is to use a Zener diode.
Zener diodes

One of the ways to produce a stable reference voltage, such as for an ADC or a DAC, is to use a Zener diode.
Zener diodes

One of the ways to produce a stable reference voltage, such as for an ADC or a DAC, is to use a Zener diode.
Zener diodes

One of the ways to produce a stable reference voltage, such as for an ADC or a DAC, is to use a Zener diode.
Zener diodes

One of the ways to produce a stable reference voltage, such as for an ADC or a DAC, is to use a Zener diode.

\[ V_{in} \quad R \quad V_{out} \]
Zener diodes

One of the ways to produce a stable reference voltage, such as for an ADC or a DAC, is to use a Zener diode.
### Parameters

<table>
<thead>
<tr>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zener voltage</td>
</tr>
<tr>
<td>Required current</td>
</tr>
<tr>
<td>Temperature sensitivity</td>
</tr>
<tr>
<td>Variation with current</td>
</tr>
</tbody>
</table>

**Terry Sturtevant**  
Electronics A to D and D to A Converters
Parameters

- Zener voltage
Parameters

- Zener voltage
- required current
Parameters

- Zener voltage
- required current
- temperature sensitivity
Parameters

- Zener voltage
- required current
- temperature sensitivity
- variation with current (ac resistance)
Sample and Hold amplifiers

In the “digital world”, signals change quickly and in large jumps.
Sample and Hold amplifiers

In the “digital world”, signals change quickly and in large jumps. In the “analog world”, usually signals change more slowly and continuously.
## Sample and Hold amplifiers

In the “digital world”, signals change quickly and in large jumps. In the “analog world”, usually signals change more slowly and continuously. This often causes problems working with ADCs and DACs.
Sample and Hold amplifiers

In the “digital world”, signals change quickly and in large jumps. In the “analog world”, usually signals change more slowly and continuously. This often causes problems working with ADCs and DACs.
Sample and Hold amplifier
Sample and Hold amplifier

S/H amplifier

V_{in} \rightarrow S/H \rightarrow V_{out}
Sample and Hold amplifier

$V_{in}$

$S/H$ amplifier

$V_{out}$
Sample and Hold amplifier

$V_{in}$

$S/H$

$V_{out}$
Sample and Hold amplifier

$V_{in}$

$S/H$

$S/H$ amplifier

$V_{out}$
Sample and Hold amplifier

![Sample and Hold amplifier circuit diagram]

\[ V_{in} \rightarrow S/H \rightarrow V_{out} \]
Sample and Hold amplifier

\[ V_{in} \rightarrow S/H \rightarrow V_{out} \]
Sample and Hold amplifier
Black box model

Parameters

Usage
Black box model

- analog input
Black box model

- analog input
- analog output
Black box model

- analog input
- analog output
- digital sample/hold signal
<table>
<thead>
<tr>
<th>Parameters</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>acquisition time ($\propto C$)</td>
<td></td>
</tr>
<tr>
<td>droop ($\propto 1/C$)</td>
<td></td>
</tr>
</tbody>
</table>

Combining these two indicates a trade-off.
Parameters

- acquisition time ($\propto C$)
Parameters

- acquisition time ($\propto C$)
- droop ($\propto 1/C$)
Parameters

- acquisition time ($\propto C$)
- droop ($\propto 1/C$)

Combining these two indicates a trade-off.
Usage

with ADC to maintain steady input during conversion
with DAC to prevent glitches when several input bits change at once
Usage

- with ADC
Usage

- with ADC
to maintain steady input during conversion
Usage

- with ADC
to maintain steady input during conversion
- with DAC
Usage

- with ADC
  to maintain steady input during conversion
- with DAC
  to prevent glitches when several input bits change at once
<table>
<thead>
<tr>
<th>Digital to Analog Converters (D/A; DAC)</th>
<th>Analog to Digital Converters (A/D; ADC)</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zener diodes</td>
<td>Sample and Hold amplifiers</td>
<td>Usage</td>
</tr>
</tbody>
</table>

**ADC**
ADC

Sample
ADC

Conversion happens now
ADC

Sample
ADC

Sample

Hold

Sample
<table>
<thead>
<tr>
<th>Digital to Analog Converters (D/A; DAC)</th>
<th>Analog to Digital Converters (A/D; ADC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zener diodes</td>
<td>Sample and Hold amplifiers</td>
</tr>
</tbody>
</table>

**DAC**

**Black box model**

**Parameters**

**Usage**
Digital to Analog Converters (D/A; DAC)  
Analog to Digital Converters (A/D; ADC)  
Zener diodes  
Sample and Hold amplifiers  

DAC

7 (0111)
DAC
<table>
<thead>
<tr>
<th>Digital to Analog Converters (D/A; DAC)</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analog to Digital Converters (A/D; ADC)</td>
<td></td>
</tr>
<tr>
<td>Zener diodes</td>
<td>Usage</td>
</tr>
<tr>
<td>Sample and Hold amplifiers</td>
<td></td>
</tr>
</tbody>
</table>

**Closeup**

Terry Sturtevant | Electronics A to D and D to A Converters
Digital to Analog Converters (D/A; DAC)
Analog to Digital Converters (A/D; ADC)
Zener diodes
Sample and Hold amplifiers

Closeup
Digital to Analog Converters (D/A; DAC)
Analog to Digital Converters (A/D; ADC)
Zener diodes
Sample and Hold amplifiers

Black box model
Parameters
Usage

Closeup

Sample
A glitch occurring now won’t matter
Closeup