Tutorial 6: Data Converters (fundamentals, D/A)
What is the SQNR for an ideal 12-bit unipolar A/D converter with $V_{ref} = 3 \, V$, when a sinusoid input of $1 \, V_{pp}$ is applied?\(^1\) What signal size input would result in an SQNR of $0 \, dB$?\(^2\)

\(^1\) $SQNR = 64.5 \, dB$

\(^2\) $V_{pp,\text{input}} = 0.6 \, mV$
Exercise 2 (1st, P11.7,8/2nd, P15.11,12)

The following measurements are found from a 3-bit unipolar D/A converter with \( V_{\text{ref}} = 8 \, V \):

\[ \{-0.01, 1.03, 2.02, 2.96, 3.95, 5.02, 6.00, 7.08\} \cdot \]

1. In units of LSBs, find the offset error, gain error, maximum DNL, and maximum INL. \(^3\)
2. How many bits of absolute accuracy does the converter have? \(^4\)
3. How many bits of relative accuracy does it have? \(^5\)
4. Based on the previous results, and assuming the same process technology (or components accuracy) is used, what would be the maximum number of bits of such a converter? \(^6\)

\(^3\) \( O_{\text{err}} = -0.01 \, \text{LSB} \), \( G_{\text{err}} = 0.09 \, \text{LSB} \), \( \text{DNL}_{\text{max}} = -0.073 \), \( \text{INL}_{\text{max}} = -0.091 \)

\(^4\) \( N_{\text{eff, abs}} = 6.64 \, \text{bits} \)

\(^5\) \( N_{\text{eff, rel}} = 6.46 \, \text{bits} \)

\(^6\) \( N_{\text{max}} = 6 \, \text{bits} \)
Exercise 2 (continued)

The following table lists the different words, with the corresponding ideal values, actual measurements, compensated values, INL, and DNL:

<table>
<thead>
<tr>
<th>word</th>
<th>$V_{\text{ideal}}$ (V)</th>
<th>$V_{\text{actual}}$ (V)</th>
<th>$V_{\text{compensated}}$ (V)</th>
<th>INL</th>
<th>DNL</th>
</tr>
</thead>
<tbody>
<tr>
<td>000</td>
<td>0</td>
<td>−0.01</td>
<td>0</td>
<td>0</td>
<td>+0.027</td>
</tr>
<tr>
<td>001</td>
<td>1</td>
<td>1.03</td>
<td>1.027</td>
<td>−0.027</td>
<td>−0.023</td>
</tr>
<tr>
<td>010</td>
<td>2</td>
<td>2.02</td>
<td>2.004</td>
<td>0.004</td>
<td>−0.073</td>
</tr>
<tr>
<td>011</td>
<td>3</td>
<td>2.96</td>
<td>2.931</td>
<td>0.069</td>
<td>−0.022</td>
</tr>
<tr>
<td>100</td>
<td>4</td>
<td>3.95</td>
<td>3.909</td>
<td>0.091</td>
<td>−0.057</td>
</tr>
<tr>
<td>101</td>
<td>5</td>
<td>5.02</td>
<td>4.966</td>
<td>0.034</td>
<td>−0.033</td>
</tr>
<tr>
<td>110</td>
<td>6</td>
<td>6.00</td>
<td>5.933</td>
<td>0.067</td>
<td>+0.067</td>
</tr>
<tr>
<td>111</td>
<td>7</td>
<td>7.08</td>
<td>7</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
A 10-bit A/D converter has a reference voltage $V_{ref} = 10.24$ V, calibrated at $T = 25^\circ C$. Find the maximum allowable temperature coefficient in terms of $\mu V/\degree C$ for the reference voltage if the reference voltage is allowed to cause a maximum error of $\pm 1/2$ LSB over the temperature range of 0 to 50°C.\footnote{\textit{Coeff}_{temp} = 200.2 \, \mu V/\degree C}$
Exercise 4 (1st, P11.10/2nd, P15.14)

Consider the following measured voltages for a 2-bit D/A converter with $V_{\text{ref}} = 4\ V$:

\[ \{00 \leftrightarrow 0.01\ V, \ 01 \leftrightarrow 1.02\ V, \ 10 \leftrightarrow 1.97\ V, \ 11 \leftrightarrow 3.02\ V \} . \]

1. In units of LSBs, find the offset error, gain error, maximum DNL, and maximum INL.\(^8\)
2. How many bits of absolute accuracy does the converter have?\(^9\)
3. How many bits of relative accuracy does it have?\(^10\)
4. Based on the previous results, and assuming the same process technology (or components accuracy) is used, what would be the maximum number of bits of such a converter?\(^11\)

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\(^8\) $O_{\text{err}} = 0.01 \text{ LSB}$, $G_{\text{err}} = 0.01 \text{ LSB}$, $DNL_{\text{max}} = 0.05$, $INL_{\text{max}} = -0.047$

\(^9\) $N_{\text{eff, abs}} = 7.06 \text{ bits}$

\(^10\) $N_{\text{eff, rel}} = 6.4 \text{ bits}$

\(^11\) $N_{\text{max}} = 6 \text{ bits}$
Find the maximum magnitude of quantization error for a 12-bit A/D converter having $V_{\text{ref}} = 5 \, \text{V}$ and $\frac{1}{2} \, \text{LSB}$ additional absolute accuracy.$^{12}$

$^{12}$ $E_{\text{max}} = 1.22 \, \text{mV}$
What sampling-time uncertainty can be tolerated for a 16-bit A/D converter operating on an input signal from 0 – 20 kHz?\textsuperscript{13} (We assume a full scale input sine wave, and we allow an absolute error $\Delta V = V_{\text{LSB}}$.)

\textsuperscript{13}$\Delta t < 0.24 \text{ ns}$
Exercise 7 (1st, P12.11/2nd, P16.11)

For the 4-bit R-2R-ladder D/A converter shown hereafter, what is the output error (in LSBs) when $R_A = 2.01R_B$?\(^{14}\) What is the output error (in LSBs) when $R_C = 2.01R$?\(^{15}\)

\[^{14}\text{Output error} = 0.04 \text{ LSB}\]
\[^{15}\text{Output error} = 0.005 \text{ LSB}\]