Efficient ADC Testing Condition with Histogram Method

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Outline

• Objective
• ADC Test with Histogram Method
• Input Sine Wave and Sampling Frequency Relationship in ADC Histogram Test Method
  ➢ Sine Wave Histogram and Waveform Missing
  ➢ Metallic Ratio and Prime Number Ratio
• Conclusion
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IoT (Internet of Things)

The application of digital signal and analog signal conversion is very extensive.

- Analog signal (sound, light)
- Digital signal (Binary number)

High quality & Low cost test is required
Research Objective & Approach

Analog-to-Digital Converter (ADC) Linearity Test

Test cost is proportional to test time

the low-sampling-rate high-resolution ADC

- low-speed sampling
- high-resolution
  take a long time

This Work

Increasing the sampling efficiency

Propose “short-time” Relationship Between Input Frequency and Sampling Frequency
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Histogram method (Ramp wave input)

- ADC output histograms for all bins are equal if ADC is perfectly linear
- Highly linear ramp signal generation is difficult
Conventional Linearity Testing 2

Histogram method (Single sine wave input)

- The number of samples is small around the middle of output codes
- High accuracy sine wave can be generated using an analog filter
DNL & INL

- Important testing for ADCs

DNL : Difference between an actual step width and the ideal value

INL  : Deviation from ideal conversion line

\[ INL(k) = \sum_{i=1}^{k} DNL(i) \]
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Sine Wave Histogram

The sampled histogram is compared with the PDF. The histogram is measured, DNL and INL are calculated.

Probability Distribution Function

\[ p(v) = \frac{1}{\pi \sqrt{A^2 - v^2}} \]

Repetitive waveform sampled with asynchronous

Compose a 1-period waveform
A large amount of data is required to reproduce the waveform. Test time: long.
\[ f_{CLK} \gg f_{sig} \]

\[ f_{CLK} \approx \frac{1}{\alpha} f_{sig} \]

\( \alpha = 1, \frac{1}{2}, \frac{1}{3}, \frac{2}{3}, \ldots, \frac{1}{6}, \ldots \)

Special ratio \( T_{CLK} \) and \( T_{sig} \), \( f_{CLK} \) and \( f_{sig} \)

\[ f_{CLK} \approx f_{sig} \]

Yuto Sasaki, Yujie Zhao, Anna Kuwana and Haruo Kobayashi, "Highly Efficient Waveform Acquisition Condition in Equivalent-Time Sampling System", 27th IEEE Asian Test Symposium, Hefei, Anhui, China (Oct. 2018)
Waveform Missing

Normal situation

Waveform Missing
Golden Ratio

Golden Ratio: \( \lim_{n \to \infty} \frac{F_n}{F_{n-1}} = 1.618033988749895 = \varphi \)

The most beautiful ratio
Golden Ratio

Golden ratio $\varphi$

$$f_{CLK} = \varphi \times f_{sig}$$

$\varphi = 1.6180339887…$
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## Metallic ratio

**Golden Ratio**:

\[
\lim_{n \to \infty} \frac{F_n}{F_{n-1}} = 1.618033988749895 = \varphi
\]

<table>
<thead>
<tr>
<th>n</th>
<th>Decimal</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>( \frac{1 + \sqrt{5}}{2} )</td>
<td>1.6180339887… Golden ratio ( \varphi )</td>
</tr>
<tr>
<td>2</td>
<td>( 1 + \sqrt{2} )</td>
<td>2.4142135623… Silver ratio</td>
</tr>
<tr>
<td>3</td>
<td>( \frac{3 + \sqrt{13}}{2} )</td>
<td>3.3027756377… Bronze ratio</td>
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<tr>
<td>4</td>
<td>( 2 + \sqrt{5} )</td>
<td>4.2360679774…</td>
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<tr>
<td>…</td>
<td>…</td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>( \frac{n + \sqrt{n^2 + 4}}{2} )</td>
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</tr>
</tbody>
</table>
Histogram of Saw wave

Total number of samples is $M$ and ADC resolution (the number of the histogram) is $N$.

Ideal value $h_i(k) = \frac{M}{N}$, $k = 1,2,3,\ldots,N$

Error $e(k) = \frac{N \cdot h(k)}{M} - 1$
ADC Resolution 3Bit N = 8, Increase M

Root-Mean-Square of the errors between the actual and ideal histograms:

\[ RMS = \sqrt{\frac{\sum (e(k))^2}{N}} \]
RMS between the actual and ideal

Total number of samples $M = 2048$, Increase resolution $N$. Compare RATIO
Most of the RMS results are not as good as Metallic ratio.

Total number of samples $M = 2048$, Increase resolution $N$. Compare RATIO.
Therefore, we calculated the RMS within a certain range (1~4) to find a good ratio.
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Conclusion

Golden ratio sampling
Efficiency: Highest
Sampling frequency: low

Metallic ratio sampling
Efficiency: Good
Sampling frequency: High

Prime number ratio sampling
Efficiency: Not Good
Sampling frequency: High

next issue

- Find a ratio that is more efficient and has a smaller RMS like the golden ratio