Report: Verifying Oscilloscope Hardware for 12-bit Resolution

The purpose of this project is to verify whether the oscilloscope hardware under evaluation genuinely supports a 12-bit vertical resolution. By analyzing and processing the raw data captured from the oscilloscope, we aim to assess its effective resolution and determine if it meets the stringent requirements of high-precision applications. Accurate data handling and thorough analysis are essential to ensure the oscilloscope's reliability and performance in industrial environments where precise measurements are critical.

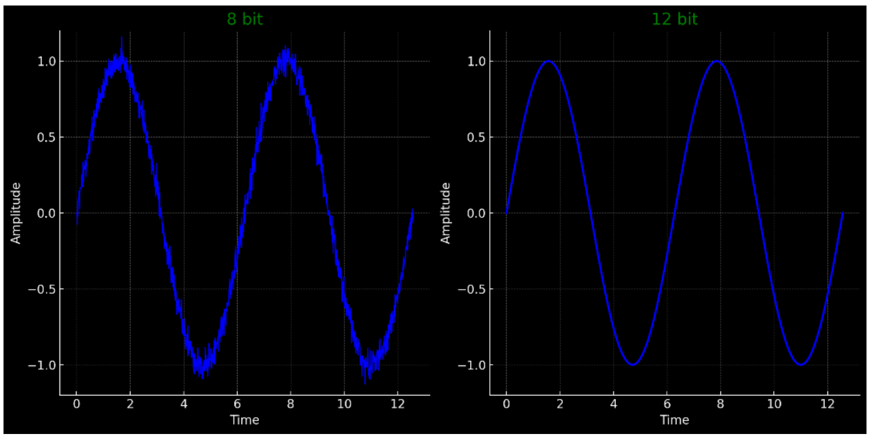

Figure 1. 8-bit vs. 12-bit resolution comparison

Oscilloscopes are indispensable tools in electronics for observing and measuring electrical signals. The vertical resolution of an oscilloscope determines its ability to detect and display small voltage differences, which is crucial in applications like high-speed data communications, medical instrumentation, and advanced research. In this project, we analyzed a dataset containing **100,000 data points** of a sine wave captured by the oscilloscope hardware. The sine wave encompasses **100 cycles**, providing a comprehensive dataset for evaluation. The primary goal is to determine whether the oscilloscope hardware provides a true 12-bit resolution, corresponding to **4,096 unique quantization levels** ranging from 0 to $2^{12}-1$ (0 to 4095 in decimal or 000 to FFF in hexadecimal).

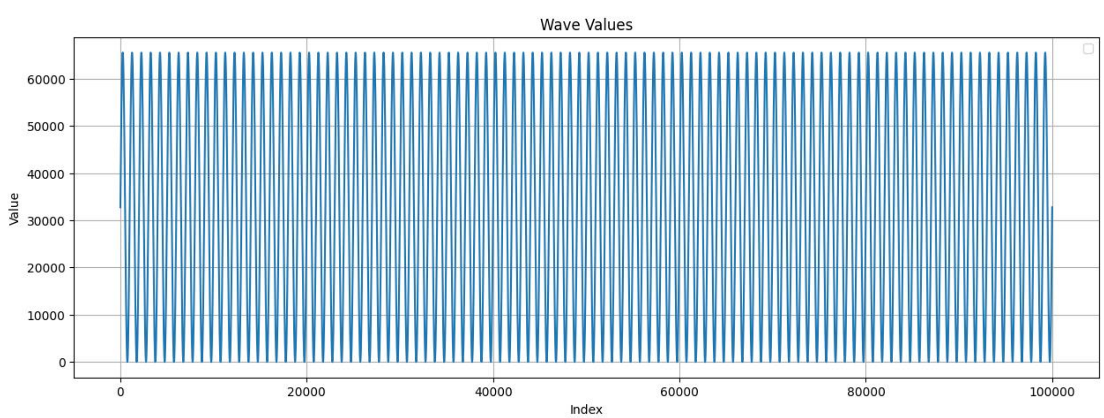

Figure 2. Raw Signal Data Visualization

Methodology | 方法

1. Data Acquisition

The oscilloscope was configured to capture a high-fidelity sine wave signal that fully utilizes its dynamic range. Ensuring the input signal spans the entire vertical range is essential for accurately assessing the oscilloscope's resolution capabilities. The data was exported in its raw numerical format for subsequent analysis.

2. Data Conversion and Processing | 数据转换和处理

Hexadecimal representation offers a concise and human-readable format for binary data. Each hexadecimal digit represents four binary bits, simplifying the visualization and analysis of high-resolution data.

Data Processing Steps:

- **Conversion to Hexadecimal:** Each raw data point was converted to its corresponding hexadecimal value using Python scripts. This step ensures that the data is in a standardized format for bit-level analysis.

```
def convert_to_hex(num):
    if num < 0:
        return hex((1 << 32) + num)[2:]
    else:
        return format(num, '04x')
```

- **Extraction of Relevant Bits:** To focus on the 12-bit resolution, the 12 least significant bits (LSBs) were extracted from each data point. This extraction isolates the portion of the data that directly corresponds to the oscilloscope's vertical resolution.

```
def extract_12_bits(hex_str):
    binary_str = bin(int(hex_str, 16))[2:].zfill(16)
    return binary_str[-12:]
```

- **Conversion to Binary Representation:** The extracted 12-bit data was converted to binary format for detailed bit-level analysis, enabling us to inspect the distribution and utilization of the quantization levels.

3. Coverage Analysis | 覆盖范围分析

A thorough analysis was conducted to determine whether all possible 12-bit values are represented in the dataset, which is essential for verifying the oscilloscope's true resolution.

- **Generation of All Possible Values:** We generated a complete list of all possible 12-bit hexadecimal values from 000 to FFF, totaling 4,096 possible values.
- **Identification of Unique Values:** Unique 12-bit values present in the captured data were extracted to assess the coverage.
- **Detection of Missing Values:** By comparing the complete list of possible values with the unique values from the dataset, we identified which quantization levels were not utilized.

Results | 结果

The analysis revealed that the oscilloscope did not utilize the full range of 12-bit values in the captured data:

- **Total Possible Quantization Levels:** 4,096
- **Unique Quantization Levels Observed: 3,005**
- **Missing Quantization Levels: 1,091**, indicating gaps in the resolution.

Implications for Precision Measurements

The absence of 1,091 quantization levels suggests limitations in the oscilloscope's ability to resolve fine signal details. In high-precision applications, this could lead to measurement inaccuracies and a failure to detect subtle signal variations essential for accurate diagnostics and analysis.

Recommendation to Increase Sample Size

To address the gaps identified in the quantization levels, it is recommended to increase the sample size from **100,000** to **500,000** data points. By increasing the sample size:

- **Improved Data Resolution:** A higher number of samples increases the likelihood of covering all possible quantization levels, enhancing the oscilloscope's effective resolution.
- **Enhanced Signal Representation:** Capturing more data points allows for a more detailed representation of the signal, improving the ability to detect subtle changes.
- **Statistical Reliability:** A larger dataset provides better statistical significance, reducing the impact of anomalies and improving the overall accuracy of the analysis.