

White Paper:

Understanding the Critical Difference Between Resolution and Accuracy

Why Accuracy Matters Far More Than Resolution in Measurement Systems

Abstract:

In measurement systems—whether in battery test equipment, sensors, manufacturing tools, or everyday household devices—the terms resolution and accuracy are often misunderstood or incorrectly used interchangeably, leading to significant misunderstandings and potentially flawed decisions. This misunderstanding leads to misinterpreted data, and flawed product comparisons. While both are important, their roles are distinct, and it is crucial to understand that **accuracy is almost invariably more important than resolution**. This white paper will delineate the differences, provide illustrative examples, and emphasize why prioritizing accuracy is paramount.

1. Introduction

Measurement systems are central to engineering, scientific research, and quality assurance. Yet, procurement decisions and system comparisons frequently give disproportionate weight to *resolution* because it appears impressive: more digits, finer increments, more detail.

However:

High resolution cannot compensate for poor accuracy.

High accuracy can still provide trustworthy results even with modest resolution.

Resolution describes *how finely* a system can display or record changes.

Accuracy describes *how close* a measurement is to the true value.

A system may have extremely high resolution but still be *inaccurate*, making the fine detail completely meaningless. Resolution without accuracy creates an illusion of precision that does not exist.

The reliability of test data, research outcomes, and production decisions depends overwhelmingly on accuracy, not resolution. This document explains the two concepts, highlights their differences, and demonstrates—through technical and practical examples—why accuracy is the far more important metric.

2. Definitions

2.1 Resolution

Resolution is the smallest increment a measurement system can display or detect.

It answers the question:

“How small of a change can be represented?”

Resolution is related to display capability, ADC bit depth, and digital scaling.

Examples:

- A digital scale with 0.01 g resolution can show differences as small as 0.01 g.
- A voltmeter with 1 μV resolution can display changes as small as one microvolt.

Resolution does not guarantee these increments are accurate—only that they can be shown.

2.2 Accuracy

Accuracy is how close a measured value is to the true or actual value.

It answers the question:

“Is the value correct?”

Examples:

- A meter reading 5.000 V when the true value is 5.010 V is inaccurate, regardless of its displayed digits.
- A temperature probe that reads within $\pm 0.5^{\circ}\text{C}$ of the true temperature is accurate.

Accuracy is influenced by calibration, sensor tolerance, circuit design, drift, environmental conditions, component quality, and system error.

2.3 Why Accuracy Matters More Than Resolution

Many systems advertise extreme resolution—6½ digits, 24-bit ADCs, nanoamp display capability—yet provide accuracy specifications that are much looser.

Resolution without accuracy = false confidence.

A system that can display 0.000001 units but is wrong by 0.01 units is misleading.

Accuracy provides real-world reliability.

A system with modest resolution but high accuracy will still produce trustworthy data.

Data-driven decisions depend on accuracy.

Whether designing batteries, controlling manufacturing processes, or verifying sensor performance, decisions must be based on *correct* values—not finely detailed incorrect ones.

3. Examples

3.1 16-bit versus 24-bit ADC's

To demonstrate why a high-resolution (24-bit) ADC can be less accurate than a lower-resolution (16-bit) ADC, we must distinguish between two fundamental concepts that are often confused: **Resolution** and **Accuracy**.

- **Resolution** is the smallest change in signal the ADC can detect (quantization). It is the number of distinct "steps."
- **Accuracy** is how close the ADC's output measurement is to the actual real-world value.

To make the math clear, we will assume a common Full-Scale Range (V_{FS}) for both ADCs.

$$V_{FS} = 10 \text{ V}$$

We are comparing: 24-bit resolution with $\pm 0.2\%$ error and a 16-bit resolution with $\pm 0.01\%$ error.

3.1.1 Analysis of 24-Bit ADC

First, let's calculate the Resolution (the granularity). A 24-bit ADC has 2^{24} distinct counts.

$$2^{24} = 16,777,216 \text{ counts}$$

The size of one distinct step, or the Least Significant Bit (V_{LSB}), is:

$$V_{LSB} = \frac{V_{FS}}{2^{24}} = \frac{10 \text{ V}}{16,777,216} \approx 0.000000596 \text{ V} = 0.596 \mu\text{V}$$

A 24-bit ADC can distinguish extremely small voltage changes (fractions of a microvolt).

Now, let's calculate the **Accuracy** (the error). The error is specified as $\pm 0.2\%$ of the Full Scale.

$$V_{Error} = V_{FS} \times \pm 0.2\%$$

$$V_{Error} = 10 \text{ V} \times 0.002 = \pm 0.02 \text{ V (20 mV)}$$

The Reality:

Even though the 24-bit ADC can display changes as small as $0.596 \mu\text{V}$, its actual reading could be off by as much as $20,000 \mu\text{V}$ (20 mV).

To visualize this in "bits," we divide the error by the LSB size:

$$\text{Error in LSBs} = \frac{20 \text{ mV}}{0.596 \mu\text{V}} \approx 33,554 \text{ counts}$$

Result: The bottom 15 bits of data are essentially swamped by the inaccuracy of the device. **You have a very precise, wrong number.**

3.1.2 Analysis of 16-Bit ADC

First, calculate the Resolution. A 16-bit ADC has 2^{16} distinct codes.

$$2^{16} = 65,536 \text{ counts}$$

The size of one step (V_{LSB}) is:

$$V_{LSB} = \frac{V_{FS}}{2^{16}} = \frac{10 \text{ V}}{65,536} \approx 0.000152 \text{ V (152 } \mu\text{V)}$$

16-bit ADC has much coarser steps than the 24-bit ADC.

Now, calculate the Accuracy.

The error is specified as $\pm 0.01\%$ of the Full Scale.

$$V_{Error} = V_{FS} \times \pm 0.01\%$$

$$V_{Error} = 10 \text{ V} \times 0.0001 = \pm 0.001 \text{ V (}\pm 1 \text{ mV)}$$

The Reality:

The 16-bit ADC is accurate to within 1 mV. However, notice the difference in magnitude compared to the 24-bit ADC.

Let's view this error in LSBs:

$$\text{Error in LSBs} = \frac{1 \text{ mV}}{152 \mu\text{V}} \approx 6.5 \text{ counts}$$

Result: This ADC is trustworthy to within roughly 6 or 7 counts of the true value.

3.1.3 Final Comparison

Let's compare the maximum potential deviation from the true voltage for a 10V signal.

Metric	ADC A (24-bit)	ADC B (16-bit)	Winner
Total Steps	16,777,216	65,536	24-bit (Higher Res)
Step Size (V_{LSB})	0.000596 mV	0.152 mV	24-bit (Finer steps)
Error %	0.2%	0.01%	16-bit
Voltage Uncertainty	± 20 mV	± 1 mV	16-bit (More Accurate)

3.1.4 Summary

The 16-bit ADC is **20 times more accurate** than the 24-bit ADC.

Effective Number of Bits (ENOB)

Because the error of the 24-bit ADC is so high (0.2%), its "Effective Number of Bits"—the number of bits that actually carry meaningful information about the true signal amplitude—is drastically reduced.

$$ENOB = \log_2\left(\frac{1}{Error\ Fraction}\right)$$

For the 24-bit ADC with 0.2% error:

$$ENOB \approx \log_2\left(\frac{1}{0.002}\right) = \log_2(500) \approx 8.96\ bits$$

Despite paying for 24 bits, the accuracy limits you to the performance of roughly a **9-bit** ideal converter.

3.2 Stacked Tolerances – 1-meter Sticks

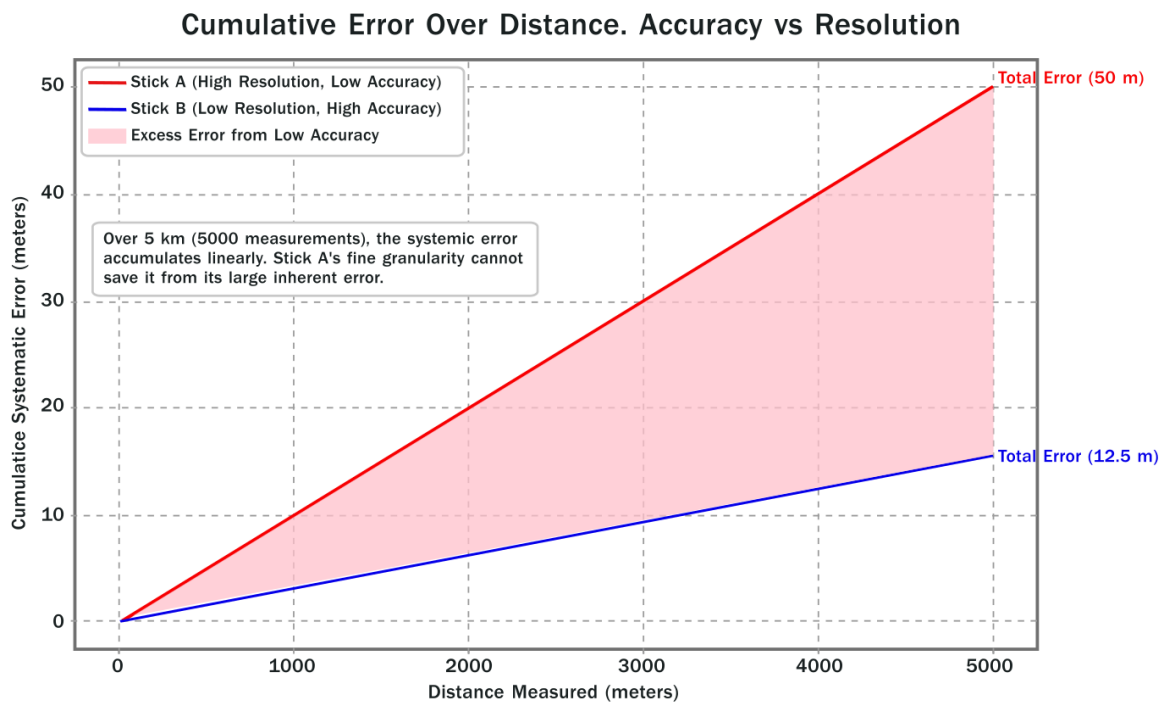
You have two measuring sticks one meter in length on-hand. Stick A has a hash mark every 0.01 mm with a 10 mm (1%) accuracy. Stick B has a hash mark every 0.1 mm with a 0.25% accuracy. Stick A has 10 times more resolution than Stick B.

3.2.1 Analysis

The key distinction here is between **Resolution** (Granularity) and **Accuracy** (Bias/Error).

- **Stick A (Red Line):** It has very fine granularity 0.00001m, meaning you can read very precise numbers from it. However, it has low accuracy 0.9900m to 1.0100m, meaning each measurement is systematically off by up to 0.01m.
- **Stick B (Blue Line):** It has coarser granularity 0.0001m, but it is more accurate (error of only 0.0025m).

As you can see, the "fine granularity" of Stick A does not prevent the massive accumulation of error. Over 5000m, the small systematic bias in Stick A adds up to four times the total error of Stick B.



Why does this happen?

When measuring a long distance by moving a meter stick repeatedly, you are performing a summation operation. If your stick is consistently too long or too short (systematic error), that error E is multiplied by the number of measurements N .

$$\text{Total Error} = E \times N.$$

- **Stick A:** 5000 measurements times 0.01m error = 50m total error
- **Stick B:** 5000 measurements times 0.0025m error = 12.5m total error

The number of decimal places (resolution) on the ruler is irrelevant if the ruler itself is the wrong length.

4. Component Drift: The Silent Enemy of Accuracy

While resolution is determined by the number of digits on the display, Accuracy is determined by the stability of the physical components inside the meter. Even if a device is perfectly calibrated at the factory, its accuracy can degrade over time due to a phenomenon known as Component Drift.

4.1 The Role of Component Quality

All electronic components (resistors, voltage references, capacitors) change their value over time as they age. This is "Drift."

- **Generic Components (Low Cost):** A standard resistor might drift by 1% or more over a year. If your measurement "ruler" stretches by 1%, your measurement is wrong, no matter how fine your resolution is.
- **Precision Components (High Cost):** High-end, "instrument-grade" components are manufactured with exotic materials and aging processes to ensure they remain stable. They might drift only 0.001% (or 10 ppm) over the same period.

The Impact: using cheap components is like using a wooden ruler that warps with humidity. Using expensive components is like using a ruler made of Invar (a metal alloy that does not change size).

4.2. Temperature: The Major variable

Temperature is the primary driver of short-term drift. Every electronic component has a Temperature Coefficient (Tempco), usually measured in parts per million per degree Celsius (*ppm / °C*).

- **The Physics:** As components heat up (from ambient room heat or self-heating during use), their internal resistance changes.
- **The Error:** If a device uses a voltage reference with a high Tempco (e.g., 100 ppm / °C), a mere 10 °C shift in temperature introduces a 0.1% error immediately.

4.3 The Maccor Advantage: Stability by Design

At Maccor, we recognize that high resolution is meaningless without the stability to back it up. We address drift through a two-pronged engineering approach:

4.3.1 Premium Component Selection

We refuse to compromise on the "building blocks" of our measurement systems. We utilize high-cost, instrument-grade components with ultra-low aging rates. This ensures that the "ruler" inside a Maccor tester remains the exact same length years after it leaves the factory.

4.3.2 Active Temperature Compensation

Hardware selection alone is not enough. Maccor systems employ advanced temperature compensation algorithms.

- How it works: We characterize the thermal behavior of our critical components. As the system operates, we continuously monitor the internal temperature.
- The Result: If the temperature rises, the system calculates the expected physical drift and mathematically cancels it out in real-time.

4.3.3 Summary

By combining superior hardware with intelligent software compensation, Maccor virtually eliminates drift, ensuring that the accuracy you specify is the accuracy you actually get—regardless of time or temperature.

5. Conclusion

Resolution may be the most visible specification on a datasheet, but accuracy is the specification that determines whether measurement data can be trusted. As demonstrated through ADC analysis, ruler summation examples, and real-world component behavior, fine granularity alone cannot overcome the limitations imposed by drift, tolerance, error percentage, and environmental influence. A system that can display micro-increments but is fundamentally wrong by millivolts or millimeters provides an illusion of precision, not meaningful information.

Accurate measurement depends on the integrity and stability of the underlying hardware. Component drift, temperature effects, and stacked tolerances quietly erode accuracy over time, often without the user's awareness. These error sources dominate real-world performance far more than the number of digits a system can display. Long-term stability



requires both high-quality components and intelligent compensation techniques—factors that are invisible in resolution specs but crucial for dependable results.

This is why, at Maccor, our engineering philosophy prioritizes accuracy and stability above superficial resolution. By selecting premium, ultra-low-drift components and implementing active temperature compensation, we ensure that the measurement “ruler” inside every Maccor test system remains consistent, predictable, and trustworthy for years of continuous operation. The result is meaningful resolution—resolution backed by real accuracy—not just extra digits on a screen.

In measurement science, **resolution tells you what you can see; accuracy tells you what you can believe.** And only accuracy can support the high-confidence decisions needed in advanced research, product development, and production-scale testing. High resolution may look impressive, but high accuracy delivers results you can rely on.