MEMS SENSORS:
Real-World Performance vs. Datasheets

While specification sheets and marketing materials often emphasize idealized performance metrics, real-world performance can vary significantly due to environmental factors, system integration challenges, and operational conditions.

The field of high-performance Micro-Electro-Mechanical Systems (MEMS) has advanced significantly in recent years, making them suitable for a wide range of applications. MEMS inertial sensors, including accelerometers, gyroscopes and magnetometers, are increasingly being used in applications requiring high precision, such as autonomous vehicles, drones, industrial equipment, and navigation systems. These sensors are praised for their small size, low cost, and the promise of high performance in terms of bias stability, noise and drift. However, the numbers presented on datasheets or highlighted in marketing materials often fail to reflect the variability and limitations that users may experience in practical applications.

This can be frustrating for engineers who expect performance levels that can't be reached under the conditions they're operating in. Spec sheets and marketing materials should differentiate between what a sensor can achieve in a lab under perfect conditions and what actually can be achieved in the real world, which is often quite different.

UNDERSTANDING SPECIFICATIONS AND MARKETING MATERIALS

Before diving into real-world performance, it is important to understand how MEMS inertial sensors are specified in marketing materials and datasheets. Commonly highlighted specifications include:

Noise Density (or Allan Deviation): Indicates the sensor's random noise behavior, affecting the precision of measurements over time. Allan Deviation drives two of the most important parameters for navigation customers: in-run bias, or bias instability, and angle random walk (ARW).

Bias Instability:
Describes the stability of the sensor's zero point over time, which is a key determinant of drift.

Scale Factor Stability:
Defines how consistently the sensor's output relates to the actual physical input (acceleration or angular rate).

Bandwidth:
The frequency range over which the sensor can measure and remain accurate.

Power Consumption:
Often presented as an attractive low number for battery-operated or embedded systems.

Operating Temperature Range:
The range the sensor can operate in without performance degradation.

Many of the specifications listed on datasheets come from cherry picked units after just a few seconds of integration time, meaning they're not representative of how the sensor actually performs in the real world. This makes it difficult for engineers to understand the sensor's limitations in certain applications and under certain conditions. Stratification on spec sheets would change that and could be very powerful, enabling engineers to save time and money.

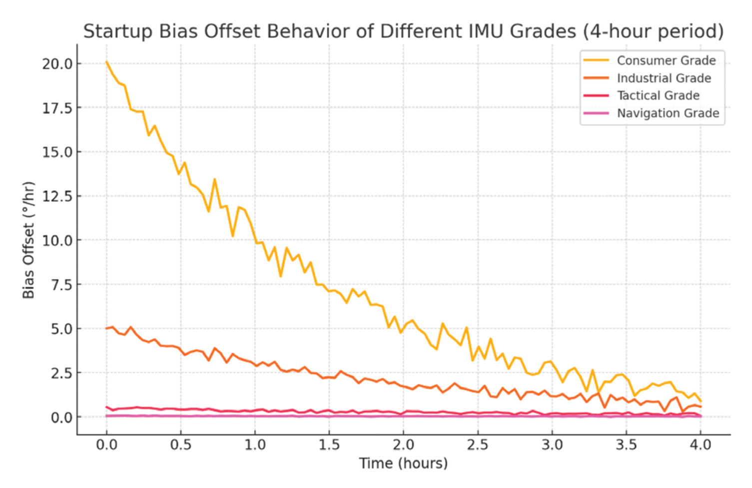

Figure 1: Though sometimes ignored or not considered during integration, startup bias offset often takes several hours to stabilize, leading to a positioning solution far less precise than expected based upon specified gyroscope in-run bias stability.

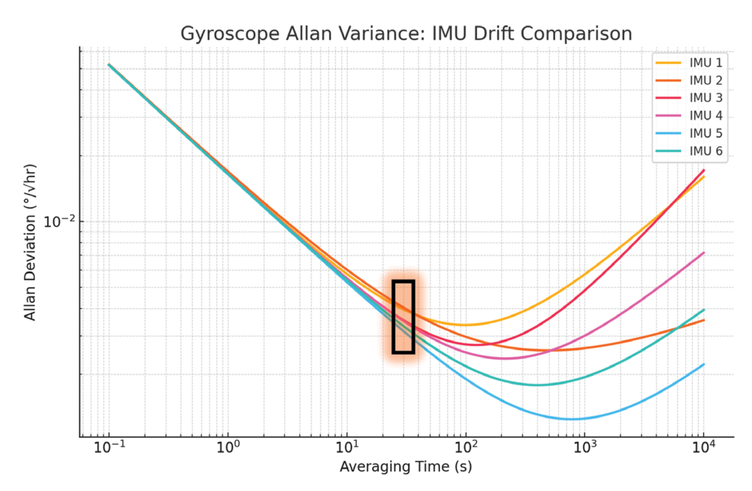

Figure 2: While ARW across all six IMUs is approximately equal at thirty seconds of averaging time (highlighted), performance varies widely as time elapses further.

BUILDING CONFIDENCE

Because of the lack of transparency on spec sheets, engineers are forced to verify parameters on their own. Many characterize the sensors themselves, every time, because they don't trust what the manufacturer provided or don't fully understand the methodologies used. Characterizing parameters takes time, money and resources. While everyone's use case is different, application specific considerations addressed in marketing materials, particularly integration times, would help give engineers more confidence in the solution and how well it will work for their specific application. Providing more accurate, detailed data would alleviate frustration, save time and reduce surprises.

Let's look at precision agriculture as an example. IMUs are typically used to provide heading for equipment when GNSS is degraded or lost—which can happen for several minutes—making bias stability critical. Spec sheets typically highlight very low values for in-run bias that aren't representative of how the sensor will perform if it must be relied on exclusively for several minutes, leading to end user frustration. The number used often comes from just a few seconds of integration time under ideal conditions in a lab. It doesn't take into account the many factors, including vibration and temperature, that can impact integration time on a field.

Specifying bias instability and ARW at certain elapsed time intervals on the Allan variance (AVAR) could be very useful in precision agriculture as well as other applications. Engineers would either gain confidence in how the sensor will perform in a specific application or realize on day one that because the sensor drifts after three minutes, for example, it won't work for their application. Realizing it's not the right fit from the beginning saves them time and the manufacturer engineering time.

Not knowing the accurate specifications is especially challenging for engineers who may not be as inertially sophisticated as other customers. They may not know what to look for or what to ask when choosing an inertial sensor, and don't realize the impact of bias drift. They turn the sensor on, see the initial bias and compensate it out. They don't take into account that, though the goal is to make them identical, every unit has a little bit of randomness about the bias, the ARW. Many don't consider angle random walk until their product is in production and end customers are calling with issues.

Providing more transparent, detailed spec sheets encourages curiosity from the outset. Engineers will ask more questions that manufacturers can address before production begins, again saving time and reducing frustration in the long run.

MARKETING MATERIALS VS. REAL-WORLD EXPECTATIONS

Marketing materials often focus on the best-case scenario, emphasizing optimal performance in controlled lab settings or ideal conditions. However, these conditions do not always reflect real-world challenges like environmental disturbances, mechanical vibrations, or power supply fluctuations. In many cases, the specifications provided may be based on tests conducted in laboratories or under ideal conditions that differ significantly from typical usage environments.

In-run stability is crucial for navigation applications, for instance. Including in-run bias stability on a spec sheet is helpful, but only if you know how long they let the Allan variants run. The number provided typically only shows the bias in a moment in time, not how it will perform in a specific application.

In precision agriculture, for example, tractors lose GPS at the edge of the field for about a minute but must maintain a half a degree of heading accuracy when coming down the next row of crops. End users must be able to trust the sensor to deliver that level of accuracy when there's vibration, bumps, extreme temperatures and a host of other factors that could impact performance. Today, they can't determine that just by looking at the spec sheet.

REAL-WORLD PERFORMANCE FACTORS

Real-world performance is influenced by various factors that are not always represented in specification sheets or marketing claims. These include:

Environmental Conditions:

Temperature Variability:
Sensors may exhibit drift or noise as a function of temperature, especially when the sensor's thermal environment deviates from the controlled conditions under which it was calibrated.

Mechanical Vibrations:
Real-world applications often expose sensors to mechanical vibrations from motors, equipment, or external forces that are not present during calibration. MEMS sensors, in particular, are sensitive to these vibrations, which can increase noise and reduce accuracy.

Magnetic Fields:
In some applications, particularly in autonomous navigation or aerospace, external magnetic fields can influence the performance of MEMS magnetometers, leading to inaccuracies in heading measurements.

Humidity and Moisture:
Environmental moisture can affect the sensor's internal components, especially when sensors are not rated for such exposure, leading to performance degradation.

Power Supply and Electrical Noise

Power Supply Variations:
Variability in power supply can impact sensor performance, especially in MEMS sensors with low power consumption. Fluctuations can introduce noise or distort sensor readings, affecting stability and accuracy.

Electrical Interference:
High-frequency electrical interference, common in industrial or automotive environments, can affect MEMS sensors. The shielding and filtering capabilities of the sensor's circuitry often play a role in mitigating these effects, which may not be fully outlined in datasheets.

INTEGRATION AND CALIBRATION CHALLENGES

Sensor Fusion and Calibration:
When sensors are used in conjunction with other sensors (e.g., accelerometers with gyros or magnetometers), the fusion of data can introduce errors if the sensors are not well-calibrated. Integration with other components, such as GPS or external aids, can also add uncertainty if the alignment or calibration is not ideal.

Alignment and Mounting:
Even small misalignments during installation can introduce significant errors in real-world applications. For example, a slight tilt or improper orientation during mounting can lead to angular errors that are not accounted for in lab tests.

Dynamic Testing Conditions:
Many high-performance MEMS sensors are tested under static conditions, but real-world applications involve dynamic forces, such as accelerations or rapid changes in velocity, that can affect sensor accuracy. The response of the sensor to these dynamic conditions is often not reflected in datasheet specifications.

ADDRESSING THE GAP BETWEEN SPEC SHEETS AND ACTUAL PERFORMANCE

To close the gap between idealized specifications and real-world performance, manufacturers can adopt several strategies. To start, manufacturers should include test data from real-world environments (e.g., varying temperatures, vibrations and power fluctuations) alongside idealized test conditions. This provides users with a more comprehensive understanding of the sensor's performance across different scenarios.

Specification sheets also should include performance metrics under different conditions or scenarios, such as variations in bias instability or noise density across different operational environments.

Then there's transparency in marketing, which includes clarifying performance conditions. Marketing materials should clearly state the testing conditions, including the controlled laboratory environment, calibration conditions, and potential limitations of the sensor in more dynamic or uncontrolled settings. And instead of presenting a single "ideal" value, marketing materials should include typical error margins and tolerances that reflect the range of real-world performance. This allows users to better understand the practical limits of the sensor.

For mission-critical applications, manufacturers should provide guidance on how to best integrate and use sensors in real-world conditions, including recommendations on calibration, filtering and noise mitigation techniques. Allowing users to calibrate the sensors for their specific application environment also can help mitigate errors due to environmental and mechanical factors.

Industry collaboration through standardization of performance metrics and testing protocols is also key. This will provide a more accurate benchmark for real-world performance.

WHAT ENGINEERS CAN DO

For engineers, it's important to perform extensive testing and calibration of MEMS sensors in the actual environment they'll be operating in to gain a better understanding of performance characteristics. It's also critical to invest in IMUs like Epson's that provide superior performance in real-world, demanding applications, particularly when there's vibration or shock.

To find the best solutions for your application, look at the data on product spec sheets critically and reach out to the manufacturer for more information if you have questions. Ask the manufacturer you currently work with to send you an AVAR plot that goes out about 2 minutes. This will give you a better understanding of actual performance. Then, start reaching out to other manufacturers to see how they compare. With more information, you might find there's a better option for your specific application.

CONCLUSION

While specification sheets and marketing materials for high-performance MEMS inertial sensors provide valuable insights into the theoretical capabilities of the sensors, real-world performance can differ significantly due to environmental factors, integration issues, and operational challenges. Manufacturers and users must be aware of the potential performance gaps and take steps to ensure sensors are tested, integrated and calibrated properly for their specific application. By promoting transparency, offering more comprehensive testing data, and providing application-specific guidance, the gap between specification sheets and real-world performance can be reduced, leading to more reliable and accurate sensor deployments across various industries.

AUTHOR

David Gaber has overseen the Inertial Sensors Group at Epson America since 2012 and is responsible for scaling the division's growth. Prior to joining Epson, He led the applications engineering team at Systron Donner Inertial, supporting quartz MEMS sensor integration on the U.S. Navy's Mark 48 and 54 torpedoes as well as JDAM and various military aircraft upgrade programs. Previously, David worked as a program manager for U.S. Air Force contracts performed abroad in support of numerous manned and unmanned aircraft initiatives.