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IEEE Standard for Sensor Performance Parameter Definitions

IEEE Electron Devices Society

Sponsored by the
Microelectromechanical Systems Standards Development Committee

IEEE
3 Park Avenue
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USA

IEEE Std 2700™-2017
(Revision of IEEE Std 2700-2014)

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Approved 15 June 2017

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Abstract: A common framework for sensor performance specification terminology, units, conditions, and limits is provided. Specifically, the accelerometer, magnetometer, gyrometer/gyroscope, accelerometer/magnetometer/gyroscope combination sensors, barometer/pressure sensors, hygrometer/humidity sensors, temperature sensors, light sensors (ambient and RGB), and proximity sensors are discussed.

Keywords: accelerometer, ambient light, barometer, combination sensor, gyroscope, humidity, IEEE 2700™, magnetometer, MEMS, microelectromechanical, pressure, proximity, sensors systems, temperature, terminology

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Introduction

This introduction is not part of IEEE Std 2700-2017, IEEE Standard for Sensor Performance Parameter Definitions.

Microelectromechanical systems (MEMS) have become a key enabling technology for many of today's high-technology products, including automotive sensors, smart phones, and the new consumer market of wearable fitness devices. MEMS are also supporting new breakthroughs in areas such as green energy and portable medical diagnostic and treatment technologies. These factors make them a keystone for advanced manufacturing, jobs, and technology innovation. The MEMS & Sensors Industry Group® (MSIG) and its member companies, large and small, have recognized standardized MEMS device performance definitions as an industrial need and a pre-competitive place in the value chain where cooperation would benefit all competitors and customers.

MSIG has documented that the lack of performance definitions and testing standards contributes to increasing costs of MEMS device manufacturing. Furthermore, the most advanced devices have the highest performance testing requirements. This standard addresses the issue of non-uniformity in MEMS sensor data sheets, by defining the sensor performance parameters that are used in typical MEMS sensor technologies. Potential customers use data sheets to compare the performance of devices from multiple manufacturers and select the devices that they will design into their systems. Data sheets contain specifications of the device performance, the package design, operating temperature, input and output signals, etc. Even though the data sheets may not reflect the type of testing that goes into qualification or production test, they should not conflict with those measurements.

This standard is expected to be the first in many that will follow. The performance parameters defined in this standard will each need standard testing protocols to help ensure that device performance data measured by any party (buyer or seller) is in agreement and within a determined uncertainty.

Contents

IEEE Standard for Sensor Performance Parameter Definitions

1. Overview

1.1 Scope

This standard provides a common framework for sensor performance specification terminology, units, conditions, and limits. This standard is intended for sensor technologies with digital I/O interfaces. The specific sensors discussed in this standard are the accelerometer, magnetometer, gyrometer/gyroscope, accelerometer/magnetometer/gyroscope combination sensors, barometer/pressure sensors, hygrometer/humidity sensors, temperature sensors, light sensors (ambient and RGB), and proximity sensors.

1.2 Objective

Given the explosive adoption of sensor technologies in the consumer electronics industry and the variety of sensor types, vendors, and integration considerations, it is acknowledged that original equipment manufacturers (OEMs), independent software vendors (ISVs), and other platform providers are faced with a non-scalable integration challenge. Therefore, it is imperative that a common methodology for specifying sensor performance is adopted by the ever-expanding industry. It is intended that adoption burden be reduced and distributed while preserving product differentiation and innovation.

Additionally, as this standard strives to reflect innovations in the sensor industry, it has been revised with the following additions:

- Accelerometer Allan Variance parameter
- Accelerometer, magnetometer, and gyroscope combination sensor with a sensor to sensor axis aligment parameter
- Relative humidity (RH) sensor hysteresis parameter
- Red green blue (RGB) light sensor added to appropriate ambient light sensor (ALS) parameters

1.3 Purpose

This standard presents a standard methodology for defining sensor performance parameters with the intent to ease system integration burden and accelerate time to market (TTM). Here within, a minimum set of performance parameters are defined with required units, conditions, and distributions for each sensor. Note that these performance parameters shall be included with all other industry accepted performance parameters.

1.4 Sensors discussed in this standard

This standard is intended to drive the sensor industry toward common nomenclature and practices as cooperatively requested by mobile platform architects. It clearly outlines a common framework for sensor performance specification terminology, units, conditions, and limits. The intent is that this is a living document, scalable through future revisions to expand as new sensors are adopted by the platforms. The intended audience of this document is sensor vendors, ISVs, platform providers, and OEMs. Table 1 shows the sensors discussed in this standard (in order of appearance).

Table 1—Sensors discussed in this standard

Sensor	Functionality
Accelerometer	A sensor that measures the rate of change of velocity (i.e., acceleration), typically in the International System of Units (SI) form of meters per second squared (m/s^2) or g[a]
Magnetometer	A sensor that measures magnetic field strength, typically in the SI unit form of tesla (1 μT = 10 mG)
Gyrometer/Gyroscope	A sensor that measures rotation velocity (i.e., angular rate), typically in the unit forms of degrees per second (dps) or radians per second (rad/s)
Accelerometer/Magnetometer/ Gyroscope combination sensor	Any accelerometer/magnetometer/gyroscope combination sensor
Barometer/Pressure sensor	A sensor that measures atmospheric pressure, typically in the SI unit form of hecto-pascal (1 hPa = 100 Pa = 1 millibar)
Hygrometer/Humidity sensor	A sensor that measures environmental % relative humidity
Temperature sensor	A sensor that measures environmental ambient temperature in the unit forms of degrees Celsius (°C), degrees Fahrenheit (°F), or Kelvin (K)
Light sensor (ambient and RGB)	A sensor that measures visible red, green, and/or blue light intensity in unit form of Lux
Proximity sensor	A sensor that measures object locality in the distance unit form of centimeters (cm)

[a] $g_n = 9.08865\ m/s^2$.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

AEC-Q100-Rev-G, 2007, Failure Mechanism Based Stress Test Qualification for Integrated Circuits.[1]

IEEE Std 647™-2006, IEEE Standard Specification Format Guide and Test Procedure for Single-Axis Laser Gyros.[2,3]

IEEE Std 1431™-2004, IEEE Standard Specification Format Guide and Test Procedure for Coriolis Vibratory Gyros.

IPC/JEDEC J-STD-020D.1, 2008, Moisture/Reflow Sensitivity Classification for Nonhermetic Solid State Surface Mount Devices.[4,5]

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3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.[6]

after mechanical shock: Sensor performance after a representative population is exposed to sensor vendor's best known method for helping ensure 10 000 g mechanical shock survivability.

NOTE—g refers to the average acceleration produced by gravity at the Earth's surface (sea level), $g_n = 9.08865$ m/s^2.[7]

after printed circuit board (PCB) assembly (place and reflow): Sensor performance after a representative population is exposed to MSL3 preconditioning (PC3). (adapted from IPC/JEDEC J-STD-020D.1 and AEC-Q100-Rev-G)

command ready: The state in which the device is able to receive/send digital communications.

disabled state: The state in which the device is powered and able to receive/send digital communications but is not actively sensing.

fast ready: The state in which the device, typically a gyroscope, is mechanically driven but not outputting sensor data.

implementation: A realization of the standardized sensor performance parameter definitions in a device product specification.

mean: Also known as arithmetic mean; refers to the mathematical sum of all measurements in the population divided by the size of the population.

measurement accuracy: Closeness of agreement between a measured quantity value and a true quantity value of a measurand.

measurement precision: Closeness of agreement between indications or measured quantity values obtained by replicate measurements on the same or similar objects under specified conditions.

measurement ready: The state in which the device will output valid sensor data.

mechanical shock recovery: The state immediately after the device is exposed to a vendor-specified mechanical shock, often one that would help ensure 10 000 g mechanical shock survivability, and in which the device is recovering to reenter the measurement ready state.

NOTE—g refers to the average acceleration produced by gravity at the Earth's surface (sea level), $g_n = 9.08865$ m/s^2.

operational change: A change, often one of many, in the functional state of the device. For example, changing the output data rate from one rate to another.

over life: Sensor performance after a representative population is exposed to all applicable extended-life qualification tests.

platform: A software and hardware architecture that supports sensors and their applications.

[6] *IEEE Standards Dictionary Online* is available at: http://dictionary.ieee.org.
[7] Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

power on: The state in which the device has received adequate power supplies.

specified for each selectable power mode: Parameter performance for each of the sensor's operational modes, such as disabled, standby, operating, low-resolution, high-resolution, or motion wakeup. It is assumed that the internal sensor sampling rate may vary across these modes and thus not necessarily have a direct relationship with the output data rate.

vendor: A company that provides sensor devices and/or software solutions.

3.2 Acronyms and abbreviations

ADC	analog-to-digital conversion
ALS	ambient light sensor
CCT	correlated color temperature
FSR	full scale range
g	average acceleration produced by gravity at the Earth's surface (sea level)[8]
ISV	independent software vendor
LSB	least significant bit (the unit in which digital values are counted)
LTS	long-term stability
MSL3	Moisture Sensitivity Level 3 (per IPC/JEDEC J-STD-020D.1)
ODR	output data rate
OEM	original equipment manufacturer
PC3	MSL3 preconditioning test (as called by AEC-Q100-Rev-G and defined by IPC/JEDEC J-STD-020D.1)
PCB	printed circuit board
RGB	red green blue
RH	relative humidity
RT	room temperature
SI	International System of Units
STS	short-term stability
TTM	time to market

[8] $g_n = 9.08865\ m/s^2$.

4. Conventions

4.1 Symbols and equations

Table 2 enumerates the symbols and equations used in this standard.

Table 2—Symbols and equations

Name	Symbol	Description	Equation/Model
Universal			
Output	V_d	Digital output from a sensor	—
Full scale range	FSR	Peak-to-peak measurement range of the sensor per each orthogonal axis	±*Sensor Span (units)*
Digital bit depth	n	Total register bit depth (n) used for all sensor measurement conversions to the digital domain; n can be a non-integer value	2^n
Sensitivity	S_0, S_{xx}, S_{yy}, S_{zz}	Scale factor	$\frac{Sensor\ output\ span\,(units)}{Digital\ span\,(LSB)}$
Sensitivity error	ε_{ko}	Scale factor error at nominal conditions	Measured Sensitivity (units) – Expected Sensitivity (units)
Sensitivity temperature coefficient	ε_T	Scale factor temperature sensitivity coefficient	$\Delta T\begin{bmatrix}\varepsilon_{Tx} & 0 & 0\\ 0 & \varepsilon_{Tx} & 0\\ 0 & 0 & \varepsilon_{Tx}\end{bmatrix}$
Bias/Offset temperature coefficient	D_T	Bias/Offset drift attributable to change in temperature	$\Delta T\begin{bmatrix}D_{Tx}\\ D_{Ty}\\ D_{Tz}\end{bmatrix}$
Noise	S_N	rms noise, as observed at the sensor's digital output	$N = number\ of\ samples$ $X_i = measured\ values$ $\overline{X} = population\ mean$ $\sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(X_i - \overline{X}\right)^2}$
Cross-axis sensitivity	S_{xy}, S_{xz}, S_{yx}, S_{yz}, S_{zx}, S_{zy}	Output error due to off-axis input	$\begin{bmatrix}1 & S_{XY} & S_{XY}\\ S_{YX} & 1 & S_{YZ}\\ S_{ZX} & S_{ZY} & 1\end{bmatrix}$
Integral non-linearity	INL	Deviation from best-fit straight line	$\frac{maximum\ deviation\,(LSB)}{full\ scale\ range\,(LSB)}\times 100\%$
Command ready time	T_{on}	Measured time from when the device achieves valid V_d to when it can communicate via I^2C	—
Fast ready time	T_{fr}	Measured time from when the device receives a command to the next transition from a disabled state to a fast ready state	—
Measurement ready time 1	T_{mr1}	Measured time from when the device receives a command to the next transition from a disabled state to a measurement ready state	—
Measurement ready time 2	T_{mr2}	Measured time from when the device receives a command to the next transition from a fast ready state to a measurement ready state	—

Table continues

Table 2—Symbols and equations *(continued)*

Name	Symbol	Description	Equation/Model
Operational change time	T_{op}	Measured time from when the device receives a command to the next transition from one operational state to another operational state	—
Mechanical shock recovery time	T_{mech}	Measured time needed for a device to return to a measurement ready state after the end of a vendor-specified mechanical shock event	—
Acquisition time	T_{acq}	Measured time to track, sample, and hold a sensor output prior to analog-to-digital conversion	—
Data ready delay	T_{delay}	Measured time from when the device starts a sensor analog-to-digital conversion to when it generates a data ready interrupt	—
Accelerometer			
0g offset	Off	Measurement error under zero acceleration	Measured Output (mg) – Expected Output (mg)
Cluster Time	T	The total time for each sample cluster used in the Allan variance calculation	$T = nt_0$ n = group of consecutive data points t_0 = sample time
Quantization noise coefficient	Q	The random variation in the digitized output signal due to sampling and quantizing a continuous signal with a finite word length conversion	As read from Allan variance plot at $T = 3^{1/2}$
Velocity random walk coefficient	N	The cumulative velocity deviation over time that is due to the white noise in the acceleration	As read from Allan variance plot at T = 1
Bias instability coefficient	B	The random variation in bias as computed over specified finite sample time and averaging time intervals	As read from Allan variance plot at Slope = 0
Acceleration Random Walk Coefficient	K	The cumulative drift acceleration error over time that is due to white noise in acceleration	As read from Allan variance plot at T = 3
Magnetometer			
Offset at zero magnetic field	Off	Measurement error under zero magnetic field	Measured Output (µT) – Expected Output (µT)
Gyrometer/Gyroscope			
Zero rate bias	D_F	Measurement error under zero rotation	Measured Output (dps) – Expected Output (dps)
Linear acceleration sensitivity	S_a	Scale factor error due to acceleration	$\begin{bmatrix} S_{XX} & S_{XY} & S_{XZ} \\ S_{YX} & S_{YY} & S_{YZ} \\ S_{ZX} & S_{ZY} & S_{ZZ} \end{bmatrix}$
Cluster time	T	The total time for each sample cluster used in the Allan variance calculation	$T = nt_0$ n = group of consecutive data points t_0 = sample time
Quantization noise coefficient	Q	The random variation in the digitized output signal due to sampling and quantizing a continuous signal with a finite word length conversion	As read from Allan variance plot at $T = 3^{1/2}$
Angle random walk coefficient	N	The cumulative angular deviation over time that is due to the white noise in the angular rate	As read from Allan variance plot at T = 1

Table continues

Table 2—Symbols and equations *(continued)*

Name	Symbol	Description	Equation/Model
Bias instability coefficient	B	The random variation in bias as computed over specified finite sample time and averaging time intervals	As read from Allan variance plot at Slope = 0
Rate random walk coefficient	K	The cumulative drift rate error over time that is due to white noise in angular acceleration	As read from Allan variance plot at T = 3
Barometer/Pressure sensor			
Pressure accuracy over range	P_{acc}	Pressure measurement accuracy over the entire measurement range	Measured Output (hPa) – Expected Output (hPa)
Short-term stability	STS	The maximum measured deviation from target over a 24-hour time	
Long-term stability	LTS	The maximum measured deviation from target over a one-year interval	
Hygrometer/Humidity sensor			
Relative humidity accuracy	RH_{acc}	Relative humidity measurement accuracy over the entire measurement range	Measured Output (%RH) – Expected Output (%RH)
Temperature			
Absolute temperature error	T_{acc}	Temperature measurement accuracy over the entire measurement range	Measured Output (°C) – Expected Output (°C)

4.2 Measurement unit conversion table

Table 3 shows the measurement unit conversions used in this standard.

Table 3—Measurement unit conversions

Preferred unit	Equivalent values	
1 g	9.806 65 m/s^2	32.1737 ft/s^2
1 µT	10 mG	
1 dps	0.0174 532 925 rad/s	
1 hPa	1 mbar	

5. Motivation

Sensors continue to drive new user experiences and platform usages across the mobile computing ecosystem. They inspire innovation and present a smart platform for ever-increasing ISV and OEM differentiation. Known sensor-based innovations include, but are not limited to, the following:

— Augmented reality

— Contextual awareness

— Smart platform management

At the foundation of these innovations are sensor solutions, born from a broad array of physical sensors, virtual sensors, and analytics that are rapidly being developed to meet the market's need for differentiated user experiences. Unfortunately, the system integration challenges are compounding and, without industry change, are not scalable (see Figure 1).

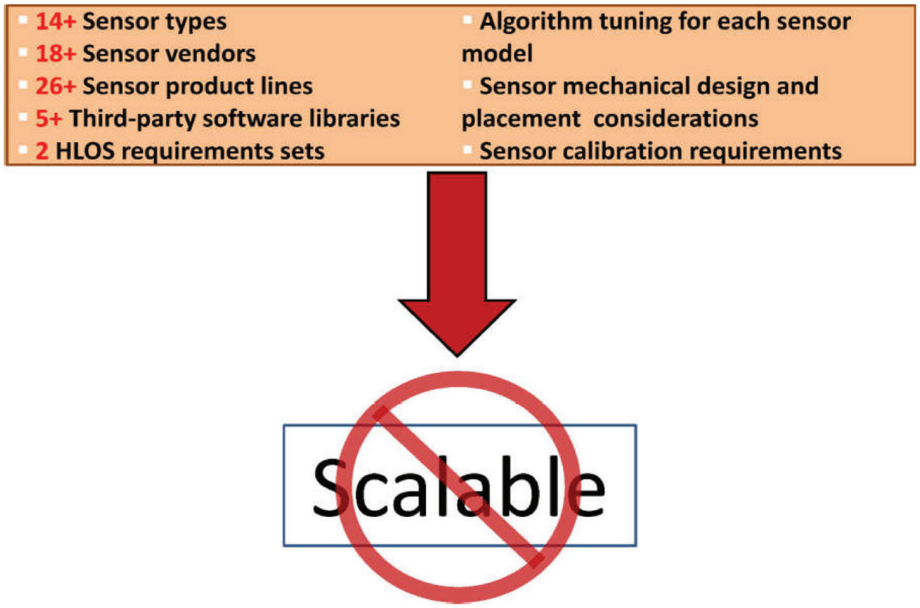

Figure 1—Scalability issues

The motivation for this standard is to define a common methodology for specifying sensor performance to be adopted by the ever-expanding sensor industry. It is intended that adoption burden be reduced and distributed, while preserving product differentiation and innovation. When adhered to, industry adoption of these proposed sensor performance definitions will help to provide many industry-wide advantages while mitigating unwanted burden. Possible advantages include the following:

- Improved TTM
- Reduced platform/system validation burden
- Simplified device-sourcing process

6. Interpretation guideline

Given that the intent of this standard is not to push unwarranted burden onto the industry, proper perspective should be considered when reviewing the proposed definitions. Upon review, it can be surmised that some parameters, when specified under all conditions, are excessive and burdensome. Therefore, it should be understood that the ultimate intent is to thoroughly comprehend only strong dependencies that key parameters may have on said conditions.

For example, when specifying current consumption, it is important to thoroughly specify Idd for all conditions that show strong dependency. Therefore, if Idd does not vary by more than a vendor-specified percentage over the specified temperature range, then the Idd versus temperature parameter does not need to be specified. However, if there is a strong dependency, then the relationship should be appropriately specified, perhaps by providing an Idd versus temperature slope.

7. Accelerometer

Given the importance of an accelerometer's absolute accuracy as the pitch-and-roll reference in a fused inclinometer system, it is very important to fully understand the primary contributors to absolute acceleration error. The following parameters require thorough specification and are intended for digital sensors only:

— Full-scale range (FSR)
— Digital bit depth
— Zero-g offset
— Zero-g offset temperature coefficient
— Sensitivity
— Sensitivity temperature coefficient
— Root Allen variance parameters
— Noise
— Current consumption
— Output data rate (ODR)
— Filter −3 dB cutoff
— Internal oscillator tolerance
— Cross-axis sensitivity
— Integral non-linearity
— Transition time
— Data-ready delay

7.1 Full scale range

Aliases for FSR are “measurement range” and “dynamic range.”

Definition		Peak-to-peak measurement range of the sensor per each orthogonal axis
Unit of measure		g (9.81 m/s^2)
Conditions		At RT (25 °C)
		At operating voltage
		At final test
		After PCB assembly (place and reflow)
		Over life
		After mechanical shock
		For each selectable mode
Distribution	Minimum	−3 sigma limit
	Typical	± (Target FSR (g)) / 2
	Maximum	+3 sigma limit

7.2 Digital bit depth

Aliases for digital bit depth are "digital span," "2^n bits," "resolution," and "2^n LSB."

Definition		Total register bit depth (n) used for all sensor measurement conversions to the digital domain. n can be a non-integer value. It is understood that the data may be stored in a wider register with unused bits.
Unit of measure		bits
Distribution	Typical	2^n bits

7.3 Zero-g offset

Aliases for zero-g offset are "0g offset," "zero-g level offset," and "zero-g output."

Definition		0g output deviation from 0g output value for each sensing axis
Unit of measure		mG
Conditions		Specified for each orthogonal sensing axis
		At RT (25 °C)
		At operating voltage
		After PCB assembly (place and reflow)
		Over life
		After mechanical shock
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

7.4 Zero-g offset temperature coefficient

Aliases for zero-g offset temperature coefficient are "offset thermal response," "offset thermal drift," and "offset temperature slope."

Definition		0g output deviation from the expected 0g output value due to temperature change from 25 °C for each sensing axis. Vendor shall describe the dominant behavior of the thermal performance as being primarily linear/non-linear or indicate the presence of any discontinuities or jumps in thermal response. For example, if the dominant behavior is non-linear, it may make more sense to specify a maximum deviation instead of a slope. Zero-g offset versus temperature plots recommended.
Unit of measure		mG/°C
Conditions		Specified for each orthogonal sensing axis
		−40 °C to 85 °C
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

7.5 Sensitivity

Aliases for sensitivity are "gain" and "scale factor."

Definition		The change in acceleration input corresponding to 1 LSB change in output.
Unit of measure		g/LSB
Conditions		Specified for each orthogonal sensing axis
		Specified for each selectable FSR
		At RT (25 °C)
		At operating voltage
		After PCB assembly (place and reflow)
		Over life
		After mechanical shock
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

7.6 Sensitivity temperature coefficient

Aliases for sensitivity temperature coefficient are "sensitivity thermal drift," "gain thermal drift," and "sensitivity vs. temp."

Definition		Given that sensitivity is the change in output due to known acceleration input, this parameter is the sensitivity error corresponding to a 1 °C change in sensor temperature. Vendor shall describe the dominant behavior of the thermal performance as being primarily linear/non-linear or indicate the presence of any discontinuities or jumps in thermal response. For example, if the dominant behavior is non-linear, it may make more sense to specify a maximum deviation instead of a slope. Sensitivity versus temperature plots recommended.
Unit of measure		%/°C (percent per °C)
Conditions		Specified for each orthogonal sensing axis
		−40 °C to 85 °C
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

7.7 Root Allan variance parameters

Root Allan variance parameters as computed per IEEE Std 647™-2006[9] are listed in the following table. An example accelerometer root Allan variance plot is provided in Figure 2.

[9]Information on references can be found in Clause 2.

Parameter		Description	Equation/ Measurement	Units
Cluster time		The total time for each sample cluster used in the Allan variance calculation.	$T = nt_0$ n = group of consecutive data points t_0 = sample time	s
Quantization noise		The random variation in the digitized output signal due to sampling and quantizing a continuous signal with a finite word length conversion.	As read from Allan variance plot at $T = 3^{1/2}$ s	g
Velocity random walk		The velocity buildup with time that is due to the white noise in the acceleration.	As read from Allan variance plot at T = 1 s	g/√Hz
Bias instability		The random variation in bias as computed over specified finite sample time and averaging time intervals.	As read from Allan variance plot at Slope = 0	g
Acceleration random walk		The drift acceleration error buildup with time that is due to white noise in acceleration.	As read from Allan variance plot at T = 3 s	g/√Hz
Conditions		Specified for each orthogonal sensing axis		
		At RT (25 °C)		
		At operating voltage		
Distribution	Typical	Mean		
	Dispersion	Standard deviation		

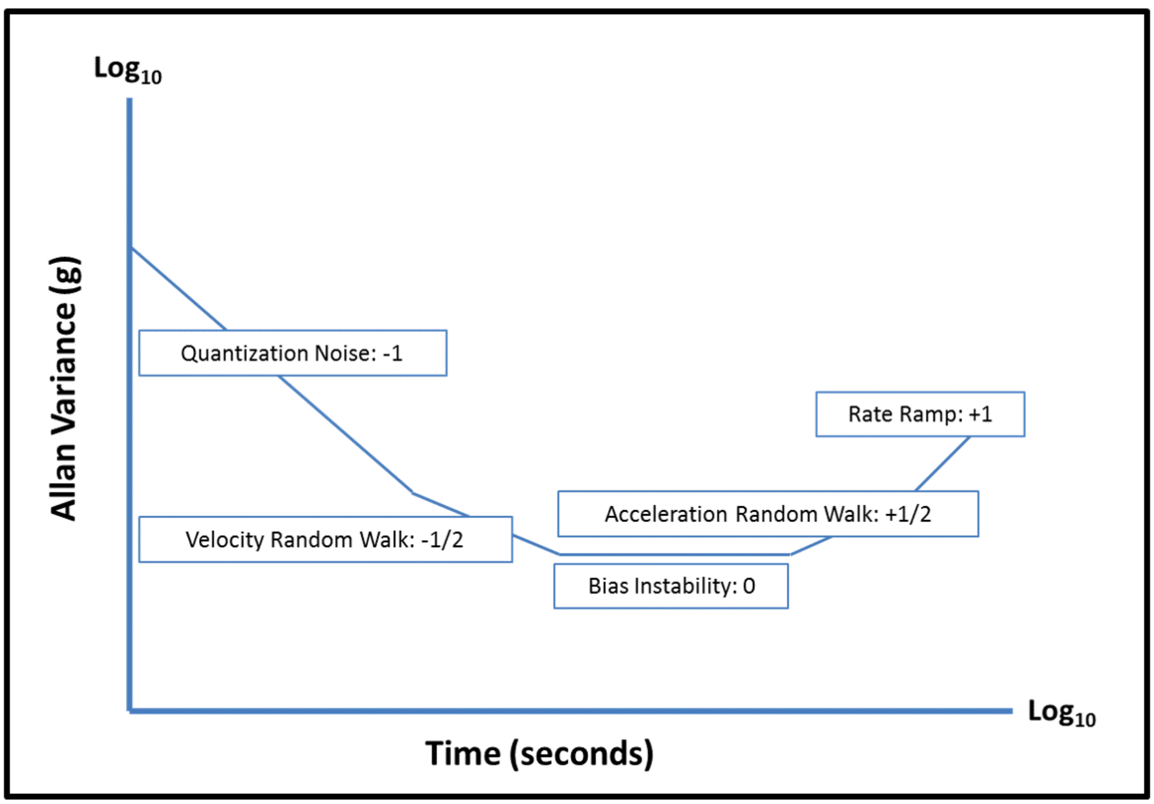

Figure 2—Example accelerometer root Allan variance plot

7.8 Noise

The alias for noise is "precision."

Definition		The smallest measurable change in acceleration expressed as rms and calculated as the standard deviation of a minimum 10 000 sample points under vibration isolation.
Unit of measure		mg (rms)
Conditions		Specified for each orthogonal sensing axis
		Specified for each selectable ODR/filter combination
		Specified for each selectable FSR
		At RT (25 °C)
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	Mean RMS Noise
	Maximum	+3 sigma limit

7.9 Current Consumption

The alias for current consumption is "Idd."

Definition		Measured current consumption.
Unit of measure		μA (micro-ampere)
Conditions		−40 °C to 85 °C
		For operating voltage range
		Specified for each selectable power mode
		Specified for each ODR
Distribution	Minimum	−3 sigma limit
	Typical	Mean Idd
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

7.10 Output data rate

The alias for ODR is "update rate."

Definition		Sensor output register update rate.
Unit of measure		Hz (register updates per s)
Conditions		Specified for each programmable ODR
		At room temperature (25 °C)
		At operating voltage
Distribution	Typical	Target ODR

7.11 Filter −3 dB cutoff

Aliases for filter −3 dB cutoff are “corner frequency,” “filter point,” and “bandwidth.”

Definition		−3 dB cutoff of the combined effect of all internal filters, if any.
Unit of measure		Hz
Conditions		Specified for each orthogonal sensing axis
		Specified for each selectable bandwidth and ODR
		At RT (25 °C)
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	Mean −3 dB cutoff
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

7.12 Internal oscillator tolerance

The alias for internal oscillator tolerance is “oscillator error.”

Definition		The expected error away from the target frequency of the primary internal oscillator.
Unit of measure		% (percent from target)
Conditions		Operating temperature (−40 °C to +85 °C)
		For operating voltage range
Distribution	Minimum	−3 sigma limit
	Maximum	+3 sigma limit

7.13 Cross-axis sensitivity

Aliases for cross-axis sensitivity are “cross-axis coupling error” and “skew.”

Definition		Ratio of the measured acceleration for an axis to the input acceleration along each axis orthogonal to the measured axis.
Unit of measure		%
Conditions		Specified for S_{XZ}, S_{XY}, S_{YX}, S_{YZ}, S_{ZX}, S_{ZY}
		At RT (25 °C)
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

7.14 Integral non-linearity

Aliases for integral non-linearity are "INL" and "non-linearity."

Definition		Maximum deviation of measured output from the best-fit straight line.
Unit of measure		% FSR
Conditions		Specified for each orthogonal sensing axis
		Specified over FSR
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	±1 sigma
	Maximum	+3 sigma limit

7.15 Transition time

Aliases for transition time are "turn on time," "wake up time," and "enable time."

Definition		Measured transition time between two specified states as illustrated in Figure 2, from an event to the time the sensor meets all operational specs. It is expected that some of these parameters may only be validated through design simulation. See Clause 3 and 4.1 for state definitions.
Unit of measure		ms
Conditions		Specified for power on to ready state (T_{on})
		Specified for inactive to active state (T_{mr1})
		Specified for operational mode changes (Res, FSR) (T_{op})
		At RT (25 °C)
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

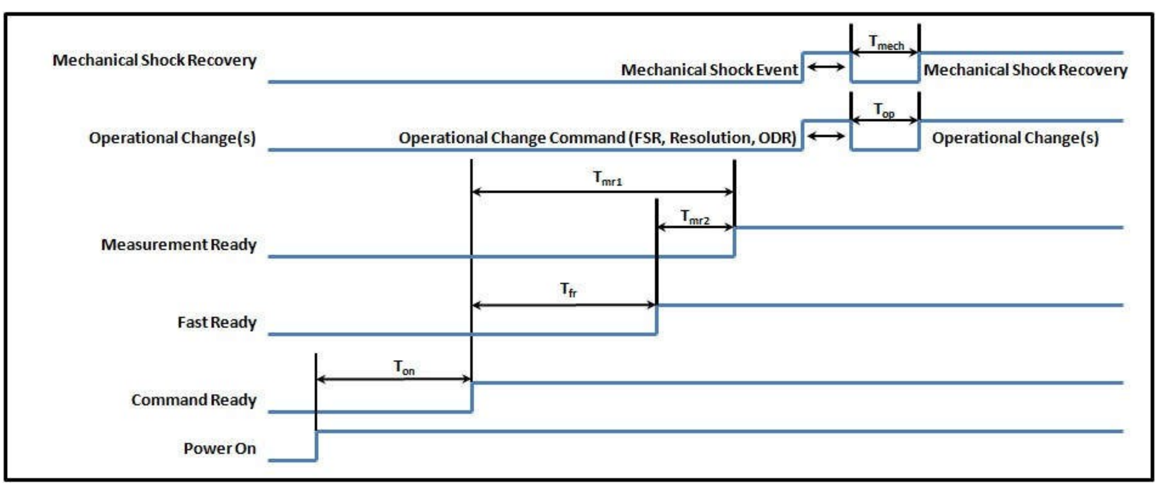

Figure 3—Transition timing diagram

7.16 Data ready delay

Aliases for data ready delay are “measurement delay,” “capture delay,” and “sample delay.”

Definition		Expected time from when a sensor is sampled to when the data ready interrupt is triggered (see Figure 3). This applies to any measurement, whether single (asynchronous) or repetitive (synchronous). It is expected that this parameter will be validated through design simulation.
Unit of measure		µs
Conditions		Specified for each orthogonal sensing axis
		At RT (25 °C)
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

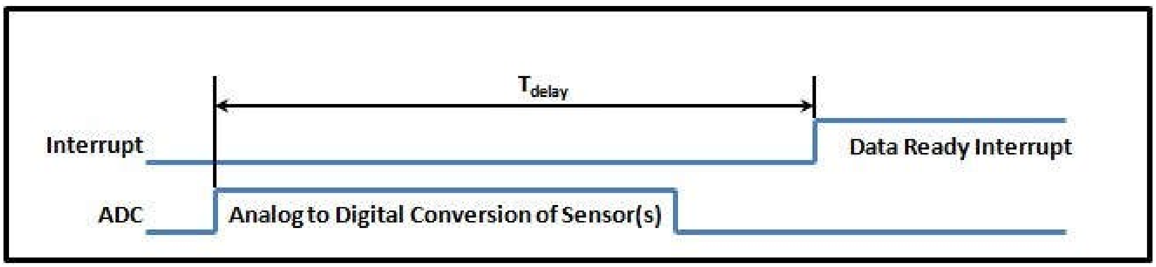

Figure 4—Data ready delay timing diagram

8. Magnetometer

Given the importance of a magnetometer’s absolute accuracy as the yaw/heading reference in a fused inclinometer system, it is very important to fully understand the primary contributors to absolute magnetic field measurement error. The following parameters require thorough specification and are intended for digital sensors only:

— FSR
— Digital bit depth
— Offset at zero magnetic field
— Offset temperature coefficient
— Sensitivity
— Sensitivity temperature coefficient
— Noise
— Current consumption
— Output data rate (ODR)
— Filter −3 dB cutoff

- Internal oscillator tolerance
- Cross-axis sensitivity
- Integral non-linearity
- Transition time
- Acquisition time
- Data ready delay

8.1 Full scale range

Aliases for FSR are "measurement range" and "dynamic range."

Definition		Peak-to-peak measurement range over monotonic region of the sensor measurement range for each orthogonal axis.
Unit of measure		μT
Conditions		Specified for each selectable mode
		At RT (25 °C)
		At operating voltage
		At final test
		After PCB assembly (place and reflow)
		Over life
		After mechanical shock
Distribution	Minimum	−3 sigma limit
	Typical	± (Target FSR (μT)) / 2
	Maximum	+3 sigma limit

8.2 Digital bit depth

Aliases for digital bit depth are "digital span," "2^n bits," "resolution," and "2^n LSB."

Definition		Total register bit depth (n) used for all parametric conversions to the digital domain. n can be a non-integer value. It is understood that the data may be stored in a wider register with unused bits.
Unit of measure		bits
Distribution	Typical	2^n bits

8.3 Offset at zero magnetic field

Aliases for offset at zero magnetic field are “output/offset at null field,” “offset,” and “output.”

Definition		Measurement output deviation from ideal for each sensing axis under zero/null magnetic field.
Unit of measure		μT
Conditions		Specified for each orthogonal sensing axis
		At RT (25 °C)
		At operating voltage
		After PCB assembly (place and reflow)
		Over life
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

8.4 Offset temperature coefficient

Aliases for offset temperature coefficient are “offset thermal response,” “offset thermal drift,” and “offset temperature slope.”

Definition		Zero magnetic field output deviation from expected zero magnetic field output value due to temperature change from 25 °C for each sensing axis. Vendor shall describe the dominant behavior of the thermal performance as being primarily linear/non-linear or indicate the presence of any discontinuities or jumps in thermal response. For example, if the dominant behavior is non-linear, it may make more sense to specify a maximum deviation instead of a slope. Offset versus temperature plots recommended.
Unit of measure		μT/°C
Conditions		Specified for each orthogonal sensing axis
		−40 °C to 85 °C
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

8.5 Sensitivity

Aliases for sensitivity are "gain" and "scale factor."

Definition		The change in magnetic field input corresponding to 1 LSB change in output.
Unit of measure		µT/LSB
Conditions		Specified for each orthogonal sensing axis
		Specified for each selectable FSR
		At RT (25 °C)
		At operating voltage
		After PCB assembly (place and reflow)
		Over life
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

8.6 Sensitivity temperature coefficient

Aliases for sensitivity temperature coefficient are "sensitivity thermal drift," "gain thermal drift," and "sensitivity vs. temp."

Definition		Given that sensitivity is the change in output due to known magnetic field, this parameter is the sensitivity error over changing temperature. Vendor shall describe the dominant behavior of the thermal performance as being primarily linear/non-linear or indicate the presence of any discontinuities or jumps in thermal response. For example, if the dominant behavior is non-linear, it may make more sense to specify a maximum deviation instead of a slope. Sensitivity versus temperature plots recommended.
Unit of measure		%/°C
Conditions		Specified for each orthogonal sensing axis
		−40 °C to 85 °C
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

8.7 Noise

The alias for noise is "precision."

Definition		The smallest measurable change in magnetic field expressed as rms and calculated as the standard deviation of a minimum of 10 s of sensor sampling at a minimum of 20 samples per s under static magnetic field and vibration isolation.
Unit of measure		µT (rms)
Conditions		Specified for each orthogonal sensing axis
		Specified for each selectable ODR/filter combination
		Specified for each selectable FSR
		At RT (25 °C)
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	Mean rms noise
	Maximum	+3 sigma limit

8.8 Current consumption

The alias for current consumption is "Idd."

Definition		Measured current consumption.
Unit of measure		µA
Conditions		Specified for each power mode
		Specified for each selectable ODR
		−40 °C to 85 °C
		For operating voltage range
Distribution	Minimum	−3 sigma limit
	Typical	Mean Idd
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

8.9 Output data rate

The alias for ODR is "update rate."

Definition		Sensor output register update rate.
Unit of measure		Hz (samples per s)
Conditions		Specified for each programmable ODR
		At RT (25 °C)
		At operating voltage
Distribution	Typical	Target ODR

8.10 Filter −3 dB cutoff

Aliases: corner frequency, filter point, bandwidth

Definition		−3 dB cutoff of any internal filter.
Unit of measure		Hz
Conditions		Specified for each orthogonal sensing axis
		Specified for each selectable bandwidth and ODR
		At RT (25 °C)
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	Mean −3 dB cutoff
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

8.11 Internal oscillator tolerance

The alias for internal oscillator tolerance is “oscillator error.”

Definition		The expected error away from target of the primary internal oscillator.
Unit of measure		% (percent from target)
Conditions		For operating temperature (−40 °C to +85 °C)
		For operating voltage
Distribution	Minimum	−3 sigma limit
	Maximum	+3 sigma limit

8.12 Cross-axis sensitivity

Aliases for cross-axis sensitivity are “cross-axis coupling error” and “skew.”

Definition		Ratio of the measured magnetic field for an axis to the applied magnetic field along each axis orthogonal to the measured axis.
Unit of measure		%
Conditions		Specified for S_{XZ}, S_{XY}, S_{YX}, S_{YZ}, S_{ZX}, S_{ZY}
		At RT (25 °C)
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

8.13 Integral non-linearity

Aliases for integral non-linearity are "INL" and "non-linearity."

Definition		Maximum deviation of measured output from the best-fit straight line.
Unit of measure		% FSR
Conditions		Specified for each orthogonal sensing axis
		Specified over FSR
		Specified over linear regime range
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	±1 sigma
	Maximum	+3 sigma limit

8.14 Transition time

Aliases for transition time are "turn on time," "wake up time," and "enable time."

Definition		Measured transition ^{time} between two specified states as illustrated in Figure 2. It is expected that some of these parameters may only be validated through design simulation. See Clause 3 and 4.1 for state definitions.
Unit of measure		ms
Conditions		Specified for power on to ready state (T_{on})
		Specified for inactive to active state (T_{mr1})
		Specified for operational mode changes (Res, FSR) (T_{op})
		At RT (25 °C)
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

8.15 Acquisition time

The alias for acquisition time is "measurement time."

Definition		Measured time (T_{acq}) to track sample and hold a sensor output prior to analog-to-digital conversion.
Unit of measure		µs
Conditions		At RT (25 °C)
		At operating voltage
		Specified for each axis
		Specified for all axes
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

8.16 Data ready delay

Aliases for data ready delay are "measurement delay," "capture delay," and "sample delay."

Definition		Expected time (T_{delay}) from when a sensor is sampled to when the data ready interrupt is triggered (see Figure 4). This applies to any measurement, whether single (asynchronous) or repetitive (synchronous). It is expected that this parameter will be validated through design simulation.
Unit of measure		µs
Conditions		Specified for each orthogonal sensing axis
		At RT (25 °C)
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	Mean

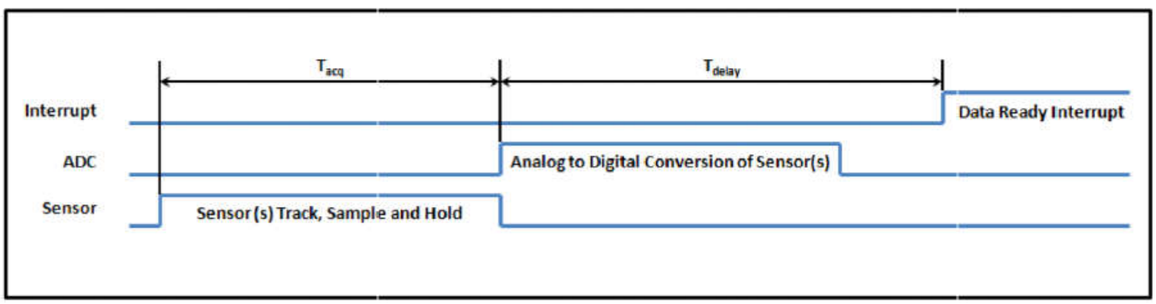

Figure 5—Acquisition time and data ready delay timing diagram

9. Gyrometer/Gyroscope

Given the importance of a gyrometer's/gyroscope's stability as a primary yaw/pitch/roll input into in a fused inclinometer system, it is very important to fully understand the primary contributors to measurement instability. The following parameters require thorough specification and are intended for digital sensors only:

— FSR
— Digital bit depth
— Zero rate bias
— Zero rate bias temperature coefficient
— Sensitivity
— Sensitivity temperature coefficient
— Root Allan variance parameters
— Noise
— Current consumption
— ODR
— Filter −3 dB cutoff

— Internal oscillator tolerance
— Cross-axis sensitivity
— Linear acceleration sensitivity
— Integral non-linearity
— State-to-state transition time
— Mechanical resonance
— Data ready delay

9.1 Full scale range

Aliases for FSR are “measurement range and “dynamic range.”

Definition		Peak-to-peak measurement range of the sensor per each orthogonal axis.
Unit of measure		dps
Conditions		Specified for each selectable mode
		At RT (25 °C)
		At operating voltage
		At final test
		After PCB assembly (place and reflow)
		Over life
		After mechanical shock
Distribution	Minimum	−3 sigma limit
	Typical	± (Target FSR (dps)) / 2
	Maximum	+3 sigma limit

9.2 Digital bit depth

Aliases for digital bit depth are “digital span,” “2^n bits,” “resolution,” and “2^n LSB.”

Definition		Total register bit depth (n) used for all parametric conversions to the digital domain. n can be a non-integer value. It is understood that the data may be stored in a wider register with unused bits.
Unit of measure		bits
Distribution	Typical	2^n bits

9.3 Zero rate bias

Aliases for zero rate bias are "offset at zero rate" and "offset."

Definition		Zero rotation rate output deviation from expected zero rotation rate output value for each sensing axis.
Unit of measure		dps
Conditions		Specified for each orthogonal sensing axis
		At RT (25 °C)
		At operating voltage
		After PCB assembly (place and reflow)
		Over life
		After mechanical shock
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

9.4 Zero rate bias temperature coefficient

Aliases for zero rate bias temperature coefficient are "bias thermal response," "bias thermal drift," and "bias temperature slope."

Definition		Zero rate output deviation from expected zero rate output value due to temperature change from 25 °C for each sensing axis. Vendor shall describe the dominant behavior of the thermal performance as being primarily linear/non-linear or indicate the presence of any discontinuities or jumps in thermal response. For example, if the dominant behavior is non- linear, it may make more sense to specify a maximum deviation instead of a slope. Zero rate output versus temperature plots recommended.
Unit of measure		dps/°C
Conditions		Specified for each orthogonal sensing axis
		−40 °C to 85 °C
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

9.5 Sensitivity

Aliases for sensitivity are "gain" and "scale factor."

Definition		The change in rotation rate input corresponding to 1 LSB change in output.
Unit of measure		dps/LSB
Conditions		Specified for each orthogonal sensing axis
		Specified for each selectable FSR
		At RT (25 °C)
		At operating voltage
		After PCB assembly (place and reflow)
		Over life
		After mechanical shock
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

9.6 Sensitivity temperature coefficient

Aliases for sensitivity temperature coefficient are "sensitivity thermal drift," "gain thermal drift," and "sensitivity vs. temp."

Definition		Given that sensitivity is the change in output due to known input rotation rate, this parameter is the sensitivity error over changing temperature. Vendor shall describe the dominant behavior of the thermal performance as being primarily linear/non-linear or indicate the presence of any discontinuities or jumps in thermal response. For example, if the dominant behavior is non-linear, it may make more sense to specify a maximum deviation instead of a slope. Sensitivity versus temperature plots recommended.
Unit of measure		%/°C
Conditions		Specified for each orthogonal sensing axis
		−40 °C to 85 °C
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

9.7 Root Allan variance parameters

Root Allan variance parameters as computed per IEEE Std 647-2006 are listed in the following table. An example root Allan variance plot is provided in Figure 5.

Parameter		**Description**	**Equation/ Measurement**	**Units**
Cluster time		The total time for each sample cluster used in the Allan variance calculation.	$T = nt_0$ n = group of consecutive data points t_0 = sample time	s
Quantization noise		The random variation in the digitized output signal due to sampling and quantizing a continuous signal with a finite word length conversion.	As read from Allan variance plot at $T = 3^{1/2}$ s	°
Angle random walk		The angular buildup with time that is due to the white noise in the angular rate.	As read from Allan variance plot at T = 1 s	°/s / √Hz
Bias instability		The random variation in bias as computed over specified finite sample time and averaging time intervals.	As read from Allan variance plot at Slope = 0	°/s
Rate random walk		The drift rate error buildup with time that is due to white noise in angular acceleration.	As read from Allan variance plot at T = 3 s	(°/s) / √Hz
Conditions		Specified for each orthogonal sensing axis		
		At RT (25 °C)		
		At operating voltage		
Distribution	Typical	Mean		
	Dispersion	Standard deviation		

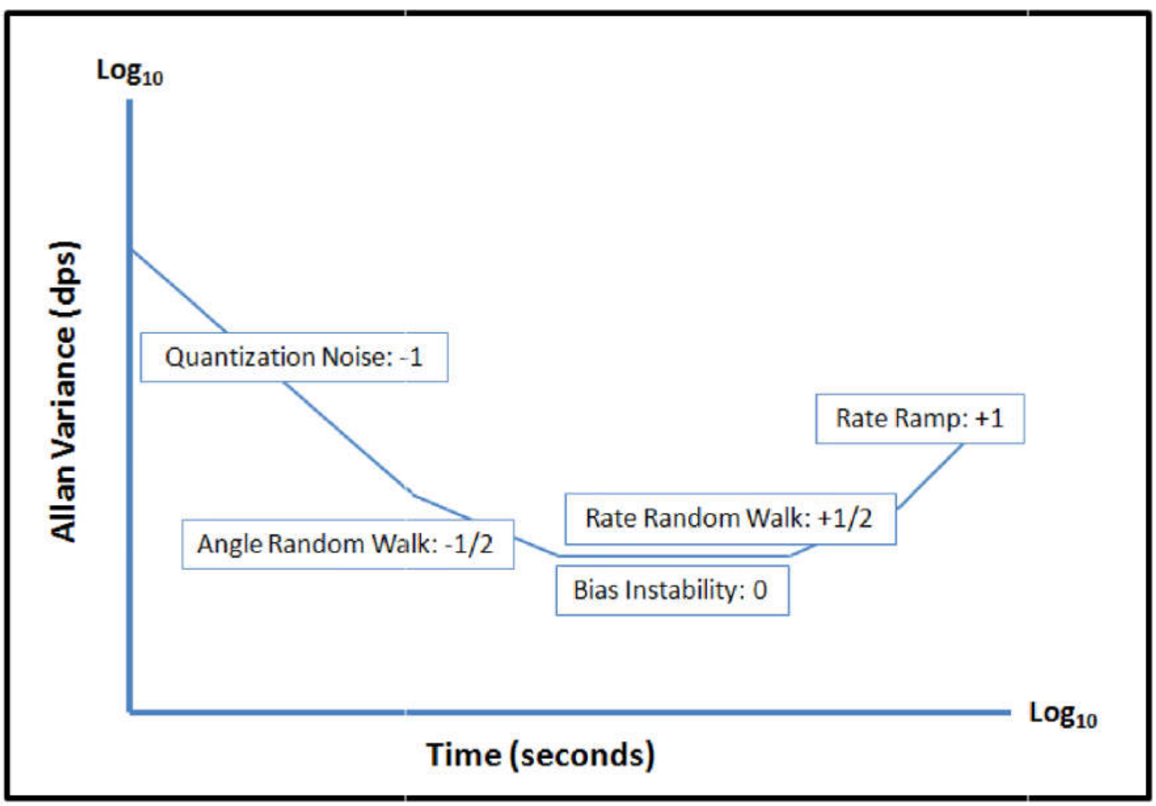

Figure 6—Example root Allan variance plot

9.8 Noise

An alias of noise is "precision."

Definition		The smallest measureable change in rotation rate expressed as rms and calculated as the standard deviation of a minimum of 10 000 sample points under vibration isolation and zero rotation input.
Unit of measure		dps (rms)
Conditions		Specified for each orthogonal sensing axis
		Specified for each ODR/filter combination
		Specified for each selectable FSR
		At RT (25 °C)
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	Mean rms noise
	Maximum	+3 sigma limit

9.9 Current consumption

An alias of current consumption is "Idd."

Definition		Measured current consumption.
Unit of measure		mA
Conditions		Specified for each power mode
		Specified for each selectable ODR
		−40 °C to 85 °C
		For operating voltage range
Distribution	Minimum	−3 sigma limit
	Typical	Mean Idd
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

9.10 Output data rate

An alias of ODR is "update rate."

Definition		Sensor output register update rate.
Unit of measure		Hz (samples per s)
Conditions		Specified for each programmable ODR
		At RT (25 °C)
		At operating voltage
Distribution	Typical	Target ODR

9.11 Filter −3 dB cutoff

Aliases of filter −3 dB cutoff are “corner frequency,” “filter point,” and “bandwidth.”

Definition		−3 dB cutoff of any internal filter.
Unit of measure		Hz
Conditions		Specified for each orthogonal sensing axis
		Specified for each selectable bandwidth and ODR
		At RT (25 °C)
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	Mean −3 dB cutoff
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

9.12 Internal oscillator tolerance

An alias of internal oscillator tolerance is “oscillator error.”

Definition		The expected error away from target of the primary internal oscillator
Unit of measure		% (percent from target)
Conditions		Operating temperature (−40 °C to +85 °C)
		For operating voltage
Distribution	Minimum	−3 sigma limit
	Maximum	+3 sigma limit

9.13 Cross-axis sensitivity

Aliases for cross-axis sensitivity are “cross-axis coupling error” and “skew.”

Definition *Update Under Review*		Ratio of the measured rotation rate for an axis to the input rotation rate along each axis orthogonal to the measured axis.
Unit of measure		%
Conditions		Specified for S_{XZ}, S_{XY}, S_{YX}, S_{YZ}, S_{ZX}, S_{ZY}
		At RT (25 °C)
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

9.14 Linear acceleration sensitivity

Aliases for linear acceleration sensitivity are “sensitivity to acceleration” and “linear acceleration effects.”

Definition		Error in rotation rate measurement due to the existence of linear acceleration along any axis. See 5.3.2.2.2 in IEEE Std 1431™-2004 for guidance.
Unit of measure		dps/g
Conditions		Specified for each orthogonal sensing axis
		At RT (25 °C)
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

9.15 Integral non-linearity

Aliases for integral non-linearity are “INL” and “non-linearity.”

Definition		Maximum deviation of measured output from the best-fit straight line
Unit of measure		% FSR
Conditions		Specified for each orthogonal sensing axis
		Specified over FSR
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	±1 sigma
	Maximum	+3 sigma limit

9.16 State-to-state transition time

Aliases for state-to-state transition time are “measurement time,” “startup time,” “operational time,” and “recovery time.”

Definition		Time required to transition between all available operational states. For example, this shall include transitions to/from power-on/off, valid data, valid communication, disable, operational, active standby, sleep mode, etc. Figure 2 identifies six transition times, though new states are expected over time. It is expected that some of these parameters may only be validated through design simulation. See Clause 3 and 4.1 for state definitions.
Unit of measure		ms
Conditions		At RT (25 °C)
		At operating voltage
		Specified to ±5% of final for non-Boolean states
		Specified for all operational states
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

9.17 Mechanical resonance

Aliases for mechanical resonance are "resonance" and "resonant frequency."

Definition		Mechanical resonance frequency of a sensor structure.
Unit of measure		kHz (frequency in kilohertz)
Conditions		Specified for each orthogonal sensing axis and resonating mass
		At RT (25 °C)
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

9.18 Data ready delay

Aliases for data ready delay are "measurement delay," "capture delay," and "sample delay."

Definition		Expected time from when a sensor is sampled to when the data ready interrupt is triggered (see Figure 6). This applies to any measurement, whether single (asynchronous) or repetitive (synchronous). It is expected that this parameter will be validated through design simulation.
Unit of measure		µs
Conditions		Specified for each orthogonal sensing axis
		At RT (25 °C)
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	Mean

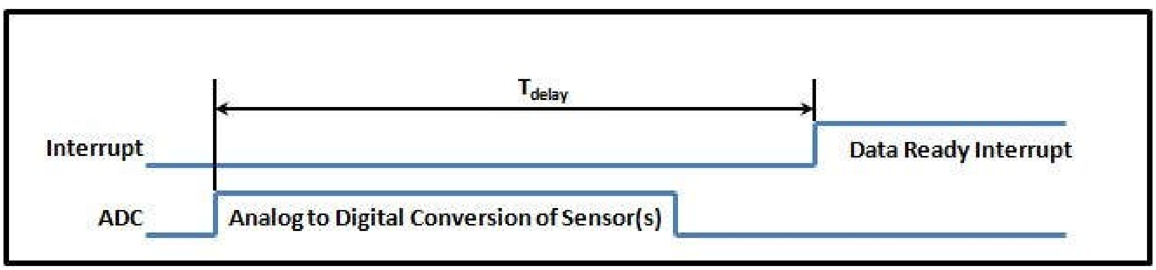

Figure 7—Data ready delay timing diagram

10. Accelerometer/Magnetometer/Gyroscope Combination Sensor

Given the industry trend to collocate any combination of accelerometer, magnetometer and gyroscope sensors into a common package, it is important to fully understand the primary contributors of sensor error uniquely attributed to such co-packaging. The following parameter requires thorough specification and are intended for combined sensors only:

— Sensor to sensor axis alignment error

10.1 Sensor to sensor axis alignment error

An aliases of sensor to sensor axis alignment error is "sensor to sensor misalignment."

Definition		The relative alignment angle error from ideal of parallel axes of combined inertial sensors.
Unit of measure		° (degrees)
Conditions		Specified for A_{AxGx}, A_{AxMx}, A_{MxGx}, A_{AyGy}, A_{AyMy}, A_{MyGy}, A_{AzGz}, A_{AzMz}, A_{MzxGz}
		At RT (25 °C)
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

11. Barometer/Pressure Sensor

Given the importance of a barometer's/pressure sensor's relative accuracy as the altitude reference in a fused location system, it is very important to fully understand the primary contributors to relative pressure error. The following parameters require thorough specification and are intended for digital sensors only:

— FSR
— Digital bit depth
— Pressure temperature coefficient
— Pressure accuracy
— Sensitivity
— Noise
— Current consumption
— Integral non-linearity
— Acquisition time
— Transition time
— Short-term stability (STS)
— Long-term stability (LTS)
— Over pressure maximum

11.1 Full scale range

Aliases of FSR are “measurement range” and “dynamic range.”

Definition		Peak-to-peak measurement range of the sensor
Unit of measure		hPa
Conditions		Specified for each selectable mode
		At RT (25 °C)
		At operating voltage
		At final test
		After PCB assembly (place and reflow)
		Over life
		After mechanical shock
Distribution	Minimum	Mean and standard deviation of minimum
	Typical	—
	Maximum	Mean and standard deviation of maximum

11.2 Digital bit depth

Aliases for digital bit depth are “digital span,” “2^n bits,” “resolution,” and “2^n LSB.”

Definition		Total register bit depth (n) used for all parametric conversions to the digital domain. n can be a non-integer value. It is understood that the data may be stored in a wider register with unused bits.
Unit of measure		bits
Distribution	Typical	2^n bits

11.3 Pressure temperature coefficient

Aliases for pressure temperature coefficient are “pressure thermal response,” “pressure thermal drift,” and “temperature slope.”

Definition		Pressure measurement deviation from expected pressure measurement value due to temperature change from 25 °C. Vendor shall describe the dominant behavior of the thermal performance as being primarily linear/non-linear or indicate the presence of any discontinuities or jumps in thermal response. For example, if the dominant behavior is non- linear, it may make more sense to specify a maximum deviation instead of a slope. Relative pressure versus temperature plot recommended.
Unit of measure		hPa/°C
Conditions		Over user measurement range
		Over full measurement range
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

11.4 Pressure accuracy

An alias for pressure accuracy is "absolute accuracy."

Definition		Pressure measurement accuracy over the entire measurement range
Unit of measure		hPa
Conditions		Over FSR
		At RT (25 °C)
		At operating voltage
		After PCB assembly (place and reflow)
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

11.5 Sensitivity

Aliases for sensitivity are "gain," "scale factor," and "relative accuracy."

Definition		The change in pressure input corresponding to 1 LSB change in output
Unit of measure		hPa/LSB
Conditions		At RT (25 °C)
		At operating voltage
		For 700 hPa to 1100 hPa range
		After PCB assembly (place and reflow)
		Over life
Distribution	Minimum	−3 sigma limit
	Typical	Computed target (LSB range / FSR)
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

11.6 Noise

The alias for noise is "precision."

Definition		The smallest measurable change in pressure expressed as rms and calculated using sensor vendor's best known method for performance characterization. A comprehensive test description shall be provided upon request.
Unit of measure		hPa (hecto-Pascal rms)
Conditions		Specified for each ODR/filter combination
		Specified for each selectable FSR
		At RT (25 °C)
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	Mean rms noise
	Maximum	+3 sigma limit

11.7 Current Consumption

The alias for current consumption is "Idd."

Definition		Measured current consumption.
Unit of measure		μA
Conditions		Specified for each selectable power mode
		Specified for each selectable ODR
		−40 °C to 85 °C
		For operating voltage range
Distribution	Minimum	−3 sigma limit
	Typical	Mean Idd
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

11.8 Integral non-linearity

Aliases for integral non-linearity are "INL" and "non-linearity."

Definition		Maximum deviation of measured output from the best-fit straight line.
Unit of measure		% FSR
Conditions		Specified for each sensing axis
		Specified over FSR
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	±1 sigma
	Maximum	+3 sigma limit

11.9 Acquisition time

Aliases of acquisition time are "conversion time" and "measurement time."

Definition		Time required to acquire a valid sample.
Unit of measure		ms
Conditions		At RT (25 °C)
		At operating voltage
		To ±1% of final
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

11.10 Transition time

Aliases of transition time are "turn on time," "wake up time," and "enable time."

Definition		Measured transition time between two specified states as illustrated in Figure 2. It is expected that some of these parameters may only be validated through design simulation. See Clause 3 and 4.1 for state definitions.
Unit of measure		ms
Conditions		Specified for power on to ready state (T_{on})
		Specified for inactive to active state (T_{mr1})
		Specified for operational mode changes (Res, FSR) (T_{op})
		At RT (25 °C)
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

11.11 Short-term stability

Short-term stability is described as follows:

Definition		Short-term pressure drift of 24 hour time.
Unit of measure		hPa
Conditions		At RT (25 °C)
		At operating voltage
		For 24 h
		For 300 hPa to 1100 hPa range
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

11.12 Long-term stability

Long-term stability is described as follows:

Definition		Long-term pressure drift of 1 year time.
Unit of measure		hPa
Conditions		At RT (25 °C)
		At operating voltage
		For 1 year
		For 300 hPa to 1100 hPa range
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

11.13 Overpressure maximum

Overpressure maximum is described as follows:

Definition		Minimum over pressure exposure that results in out of specification operation.
Unit of measure		hPa
Conditions		At RT (25 °C)
		At operating voltage
Distribution	Minimum	−3 sigma limit

12. Hygrometer/Humidity sensor

As the hygrometer/humidity sensor gains traction as a user interface and environmental sensor in mobile devices, it is important that the following parameters receive thorough specification and are intended for digital sensors only:

— FSR
— Digital bit depth
— Relative humidity accuracy
— Sensitivity
— Noise
— Current consumption
— Integral non-linearity
— Response time
— Transition time
— Long-term drift
— Hysteresis

12.1 Full scale range

Aliases of FSR are “measurement range” and “dynamic range.”

Definition		Peak-to-peak measurement range of the sensor.
Unit of measure		%RH (percent relative humidity)
Conditions		Specified for each selectable mode
		At RT (25 °C)
		At operating voltage
		At final test
		After PCB assembly (place and reflow)
		Over life
		After mechanical shock
Distribution	Minimum	−3 sigma limit
	Maximum	+3 sigma limit

12.2 Digital bit depth

Aliases of digital bit depth are “digital span,” “2^n bits,” “resolution,” and “2^n LSB.”

Definition		Total register bit depth (n) used for all parametric conversions to the digital domain. n can be a non-integer value. It is understood that the data may be stored in a wider register with unused bits.
Unit of measure		bits
Distribution	Typical	2^n bits

12.3 Relative humidity accuracy

An alias of relative humidity accuracy is “accuracy.”

Definition		Relative humidity measurement accuracy over the entire measurement range. Measured relative humidity versus ideal relative humidity plot recommended.
Unit of measure		%RH
Conditions		Over FSR
		At RT (25 °C)
		At operating voltage
		After PCB assembly (place and reflow)
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

12.4 Sensitivity

Aliases of sensitivity are “gain” and “scale factor.”

Definition		The change in %RH input corresponding to 1 LSB change in output.
Unit of measure		%RH/LSB
Conditions		At RT (25 °C)
		At operating voltage
		After PCB assembly (place and reflow)
		Over life
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

12.5 Noise

An alias of noise is "precision."

Definition		The smallest measurable change in %RH expressed as rms and calculated using sensor vendor's best known method for performance characterization. A comprehensive test description shall be provided upon request.
Unit of measure		%RH (rms) percent relative humidity
Conditions		Specified for each selectable ODR/filter combination, if applicable
		At RT (25 °C)
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	Mean rms noise
	Maximum	+3 sigma limit

12.6 Current consumption

An alias of current consumption is "Idd."

Definition		Measured current consumption.
Unit of measure		µA
Conditions		Specified for each selectable power mode
		Specified for each selectable ODR
		−40 °C to 85 °C
		For operating voltage range
Distribution	Minimum	−3 sigma limit
	Typical	Mean Idd
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

12.7 Integral non-linearity

Aliases of integral non-linearity are "INL" and "non-linearity."

Definition		Maximum deviation of measured relative humidity from the ideal slope over the FSR. Measured using sensor vendor's best known methods for characterization.
Unit of measure		% FSR
Conditions		Specified for each sensing axis
		Specified over FSR
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	±1 sigma
	Maximum	+3 sigma limit

12.8 Response time

Response time is defined as follows:

Definition		Transient response time for achieving an accurate and stable measurement.
Unit of measure		s
Conditions		At RT (25 °C)
		At operating voltage
		To 63% of a step function
		1 m/s airflow
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

12.9 Transition time

Aliases of transition time are “turn on time,” “wake up time,” and “enable time.”

Definition		Measured transition time between two specified states as illustrated in Figure 2. It is expected that some of these parameters may only be validated through design simulation. See Clause 3 and 4.1 for state definitions.
Unit of measure		ms
Conditions		Specified for power on to ready state (T_{on})
		Specified for inactive to active state (T_{mr1})
		Specified for operational mode changes (Res, FSR) (T_{op})
		At RT (25 °C)
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

12.10 Long-term drift

An alias of long-term drift is “stability.”

Definition		Long-term %RH drift of 1 year time.
Unit of measure		%RH/yr (percent relative humidity per year)
Conditions		At RT (25 °C)
		At operating voltage
		For 1 year
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

12.11 Hysteresis

An alias for hysteresis is "repeatability."

<table>
<tr><td colspan="2">Definition</td><td>Repeatability of %RH measurement after defined %RH ramp.</td></tr>
<tr><td colspan="2">Unit of measure</td><td>%</td></tr>
<tr><td colspan="2" rowspan="3">Conditions</td><td>At RT (25 °C)</td></tr>
<tr><td>At operating voltage</td></tr>
<tr><td>10%RH to 90%RH to 10%RH</td></tr>
<tr><td rowspan="4">Distribution</td><td>Minimum</td><td>−3 sigma limit</td></tr>
<tr><td>Typical</td><td>Mean</td></tr>
<tr><td>Maximum</td><td>+3 sigma limit</td></tr>
<tr><td>Dispersion</td><td>Standard deviation</td></tr>
</table>

13. Temperature

Given the importance of a temperature sensor's absolute accuracy as the ambient environmental temperature reference in a sensor-fused awareness system (not device temperature), it is very important to fully understand the primary contributors to absolute temperature error. The following parameters require thorough specification and are intended for digital sensors only. Note that these parameters should also be applied to temperature sensors that are integrated into other sensors, are often used for thermal compensation, and are exposed to the user.

— FSR
— Digital bit depth
— Absolute temperature error
— Sensitivity
— Noise
— Current consumption
— Integral non-linearity
— Transition time
— Long-term drift

13.1 Full scale range

Aliases of FSR are "measurement range" and "dynamic range."

<table>
<tr><td colspan="2">Definition</td><td>Peak-to-peak measurement range of the sensor.</td></tr>
<tr><td colspan="2">Unit of measure</td><td>°C</td></tr>
<tr><td colspan="2" rowspan="5">Conditions</td><td>Specified for each selectable mode</td></tr>
<tr><td>At operating voltage</td></tr>
<tr><td>At final test</td></tr>
<tr><td>After PCB assembly (place and reflow)</td></tr>
<tr><td>Over life</td></tr>
<tr><td rowspan="3">Distribution</td><td>Minimum</td><td>Mean of the minimum measurement</td></tr>
<tr><td>Typical</td><td></td></tr>
<tr><td>Maximum</td><td>Mean of the maximum measurement</td></tr>
</table>

13.2 Digital bit depth

Aliases of digital bit depth are "digital span," "2^n bits," "resolution," and "2^n LSB."

Definition		Total register bit depth (n) used for all parametric conversions to the digital domain. n can be a non-integer value. It is understood that the data may be stored in a wider register with unused bits.
Unit of measure		bits
Distribution	Typical	2^n bits

13.3 Absolute temperature error

The alias of absolute temperature error is "temperature accuracy."

Definition		Temperature measurement accuracy over the entire measurement range.
Unit of measure		°C
Conditions		At RT (25 °C)
		For operating temperature range
		At operating voltage
		After PCB assembly (place and reflow)
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

13.4 Sensitivity

Aliases of sensitivity are "gain" and "scale factor."

Definition		The change in temperature input corresponding to 1 LSB change in output.
Unit of measure		°C/LSB
Conditions		At operating voltage
		After PCB assembly (place and reflow)
		Over life
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

13.5 Noise

An alias of noise is “precision.”

Definition		The smallest measurable change in temperature expressed as rms and calculated using sensor vendor’s best known method for performance characterization. A comprehensive test description shall be provided upon request.
Unit of measure		°C rms
Conditions		Specified for each selectable ODR/filter combination
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	Mean rms noise
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

13.6 Current consumption

An alias of current consumption is “Idd.”

Definition		Measured current consumption.
Unit of measure		μA
Conditions		Specified for each selectable power mode
		Specified for each selectable sample rate/ODR
		−40 °C to 85 °C
		For operating voltage range
Distribution	Minimum	−3 sigma limit
	Typical	Mean Idd
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

13.7 Integral non-linearity

Aliases of integral non-linearity are “INL” and “non-linearity.”

Definition		Maximum deviation of measured output from the best-fit straight line.
Unit of measure		% FSR
Conditions		Specified for each sensing axis
		Specified over FSR
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	±1 sigma
	Maximum	+3 sigma limit

13.8 Transition time

Aliases of transition time are “turn on time,” “wake up time,” and “enable time.”

Definition		Measured transition time between two specified states as illustrated in Figure 2. It is expected that some of these parameters may only be validated through design simulation. See Clause 3 and 4.1 for state definitions.
Unit of measure		ms
Conditions		Specified for power on to ready state (T_{on})
		Specified for inactive to active state (T_{mr1})
		Specified for operational mode changes (Res, FSR) (T_{op})
		At RT (25 °C)
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

13.9 Long-term drift

An alias of long-term drift is “stability.”

Definition		Long-term temperature drift of 1 year time.
Unit of measure		°C/yr
Conditions		At RT (25 °C)
		At operating voltage
		For 1 year
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

14. Light sensor (ambient and RGB)

Given the system integration complexities that accompany an ALS from one platform to the next, it is very important to fully understand the primary contributors to absolute measurement error. The following parameters require thorough specification and are intended for digital sensors only:

— Digital bit depth
— Refresh time versus maximum detection range
— Measurement accuracy
— Normalized spectral response
— Responsivity versus angle
— Sensitivity
— Noise
— Current consumption
— Transition time

14.1 Digital bit depth

Aliases of digital bit depth are "digital span," "2^n bits," "resolution," and "2^n LSB."

Definition		Total register bit depth (n) used for all parametric conversions to the digital domain. n can be a non-integer value. It is understood that the data may be stored in a wider register with unused bits.
Unit of measure		bits
Distribution	Typical	2^n bits

14.2 Refresh time versus maximum detection range

Aliases of ALS refresh time versus maximum detection range are "dynamic range" and "ambient analog-to-digital conversion (ADC) conversion time with ambient light measurement gain."

Definition		Curves showing ALS refresh time versus maximum detection range for multiple refresh times with minimum, typical, and maximum representation (see Figure 7).
Unit of measure		Conversion time (ms) versus lux detection range
Conditions		Specified for representative range of refresh times
		At RT (25 °C)
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	Mean response curve
	Maximum	+3 sigma limit

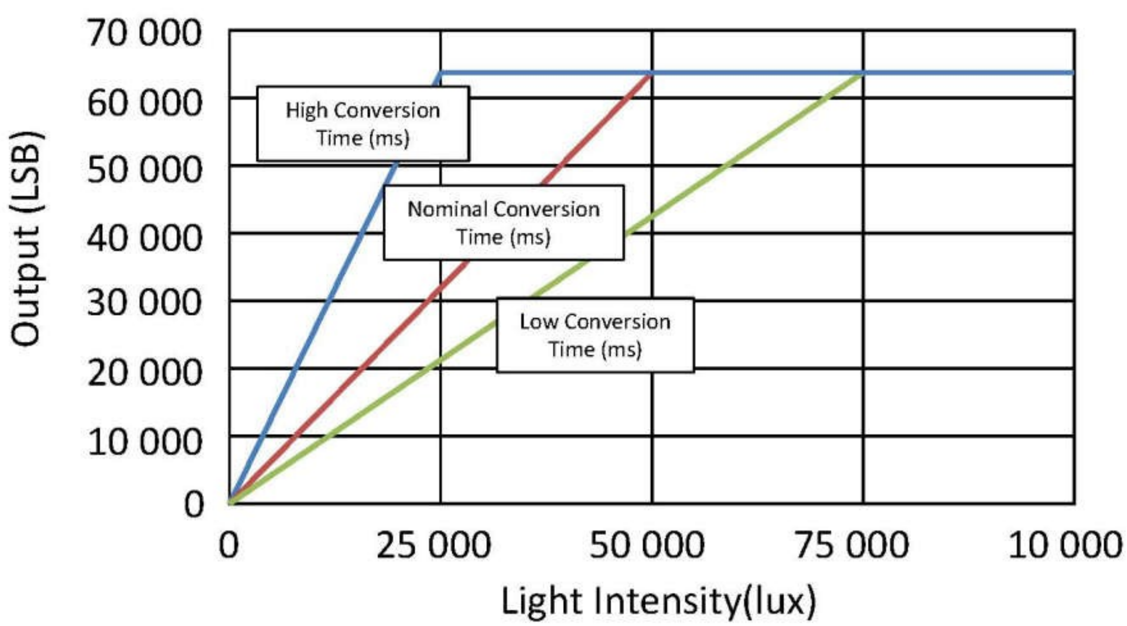

Figure 8—Example of conversion time versus lux detection range

14.3 Measurement accuracy

Aliases of measurement accuracy are "accuracy" and "gain error."

Definition		Light intensity measurement versus actual input accuracy over the entire measurement range. The following light sources are assumed Ambient: White fluorescent (CCT = 4000 K) Red: 630 nm LED Green: 530 nm LED Blue: 470 nm LED
Unit of measure		Lux ratio
Conditions		Over FSR
		At operating voltage
		After PCB assembly (place and reflow)
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

14.4 Normalized spectral response

An alias of normalized spectral response is "relative response vs. light intensity."

Definition		Curves showing relative response versus wavelength for minimum, typical, and maximum representation (see Figure 8).
Unit of measure		Relative response (%) versus wavelength (nm)
Conditions		Over FSR
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	Mean response curve
	Maximum	+3 sigma limit

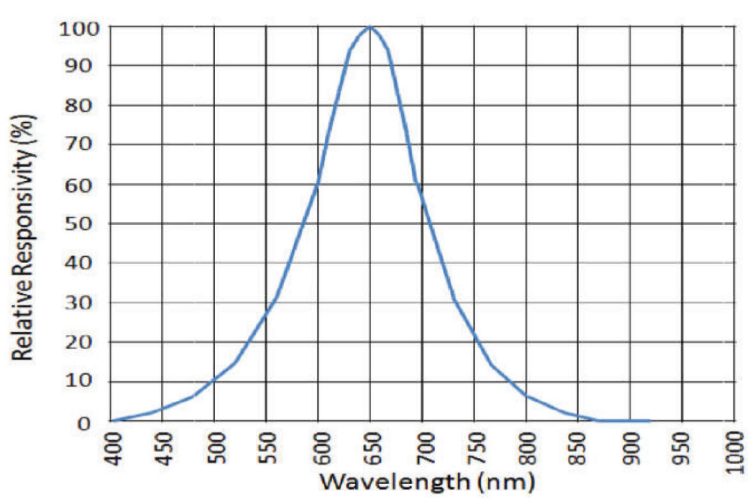

Figure 9—Example of normalized spectral response curve

14.5 Responsivity versus angle

Aliases of responsivity versus angle are "normalized responsivity vs. angular displacement" and "normalized output vs. view angle."

Definition		Curves showing responsivity versus angle for minimum, typical, and maximum representation using a white fluorescent light source (CCT = 4000 K). See Figure 9.
Unit of measure		Normalized response versus angle (degrees)
Conditions		Over FSR
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	Mean response curve
	Maximum	+3 sigma limit

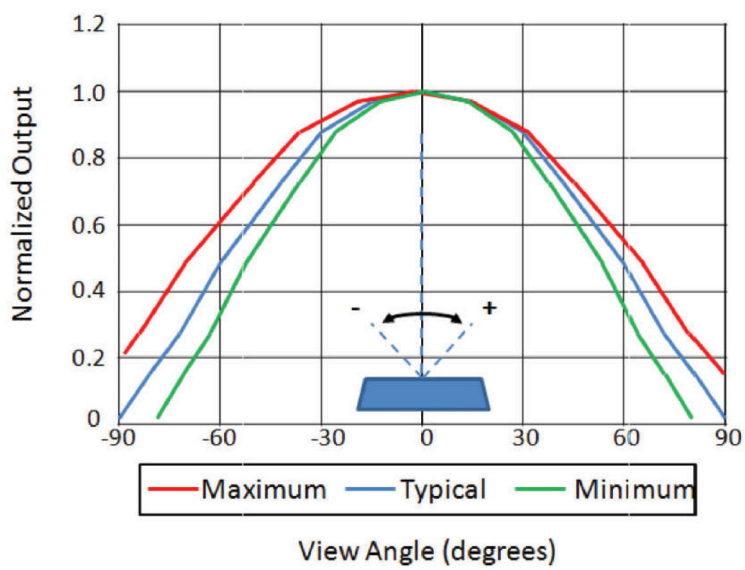

Figure 10—Example of responsivity versus angle curve

14.6 Sensitivity

Aliases of sensitivity are "gain" and "scale factor."

Definition		The change in light input corresponding to 1 LSB change in output.
Unit of measure		Lux/LSB (luminous flux per unit area per least significant bit)
Conditions		At operating voltage
		After PCB assembly (place and reflow)
		Over life
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

14.7 Noise

An alias of noise is "precision."

Definition		The smallest measurable change in ambient light expressed as rms and calculated as the standard deviation of a minimum 10 000 sample points under static lux.
Unit of measure		Lux (luminous flux per unit area rms)
Conditions		Specified for a representative sample of refresh times
		Specified for each selectable FSR
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	Mean rms resolution
	Maximum	+3 sigma limit

14.8 Current consumption

Aliases of current consumption are "Idd" and "supply current."

Definition		Measured current consumption.
Unit of measure		µA
Conditions		Specified for each selectable power mode
		−40 °C to 85 °C
		For operating voltage range
Distribution	Minimum	−3 sigma limit
	Typical	Mean Idd
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

14.9 Transition time

Aliases of transition time are "turn on time," "wake up time," and "enable time."

Definition		Measured transition time between two specified states as illustrated in Figure 2. It is expected that some of these parameters may only be validated through design simulation. See Clause 3 and 4.1 for state definitions.
Unit of measure		ms
Conditions		Specified for power on to ready state (T_{on})
		Specified for inactive to active state (T_{mr1})
		Specified for operational mode changes (Res, FSR) (T_{op})
		At RT (25 °C)
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

15. Proximity sensor

Given the system integration complexities that accompany a proximity sensor from one platform to the next, it is very important to fully understand the primary contributors to absolute measurement error. The following parameters require thorough specification and are intended for digital sensors only:

— Digital bit depth
— Sensitivity
— Sensing current consumption
— Transition time

15.1 Digital bit depth

Aliases of digital bit depth are “digital span,” “2^n bits,” “resolution,” and “2^n LSB.”

Definition		Total register bit depth (n) used for all parametric conversions to the digital domain. n can be a non-integer value. It is understood that the data may be stored in a wider register with unused bits.
Unit of measure		bits
Distribution	Typical	2^n bits

15.2 Sensitivity

Aliases of sensitivity are “gain,” “object distance measurement,” “range,” “scale factor,” and “ADC counts vs. distance vs. LED current.”

Definition		This is applicable to proximity modules that leverage integrated LEDs. Curves showing the proximity sensor’s detection sensitivity over its FSR represented by a minimum, typical, and maximum distribution (see Figure 10).
Unit of measure		LSB
Conditions		Specified for range of reflective material properties
		Specified for range of IR LED drive current
		Specified for range of IR LED drive pulses
		At vendor’s recommended ADC conversion time
		At RT (25 °C)
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

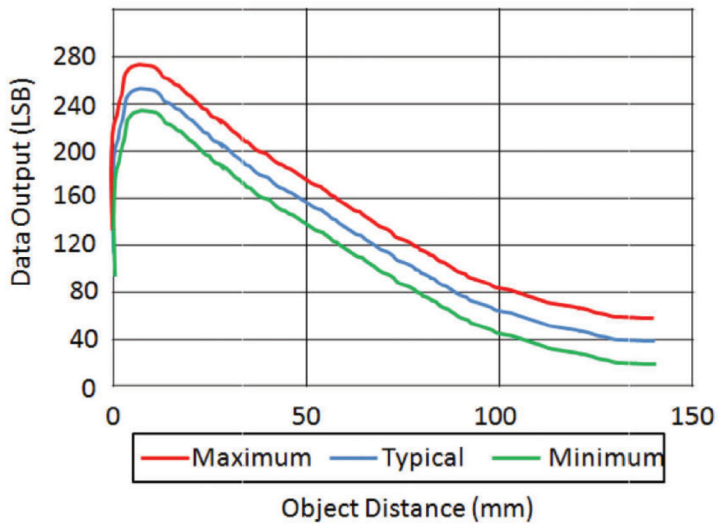

Figure 11—Example of proximity sensitivity curve

15.3 Sensing current consumption

Aliases of sensing current consumption are “Idd” and “supply current.”

Definition		Measured current consumption.
Unit of measure		µA
Conditions		Specified for all selectable operating modes
		−40 °C to 85 °C
		For operating voltage range
Distribution	Minimum	−3 sigma limit
	Typical	Mean Idd
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

15.4 Transition time

Aliases of transition time are “turn on time, “wake up time,” and “enable time.”

Definition		Measured transition time between two specified states as illustrated in Figure 2. It is expected that some of these parameters may only be validated through design simulation. See Clause 3 and 4.1 for state definitions.
Unit of measure		ms
Conditions		Specified for power on to ready state (T_{on})
		Specified for inactive to active state (T_{mr1})
		Specified for operational mode changes (Res, FSR) (T_{op})
		At RT (25 °C)
		At operating voltage
Distribution	Minimum	−3 sigma limit
	Typical	Mean
	Maximum	+3 sigma limit
	Dispersion	Standard deviation

Annex A

(informative)

Bibliography

Bibliographical references are resources that provide additional or helpful material but do not need to be understood or used to implement this standard. Reference to these resources is made for informational use only.

[B1] El-Sheimy, N., H. Hou, and X. Niu, "Analysis and modeling of inertial sensors using Allan variance," IEEE Transactions on Instrumentation and Measurement, vol. 57, no. 1, pp. 140–149, January 2008, https://doi.org/10.1109/TIM.2007.908635.

[B2] IEEE Std 528™-2001, IEEE Standard for Inertial Sensor Terminology.[10,11]

[B3] IEEE Std 1293™-1998, IEEE Standard Specification Format Guide and Test Procedure for Linear, Single-Axis, Non-Gyroscopic Accelerometers.

[10]IEEE publications are available from The Institute of Electrical and Electronics Engineers (http://standards.ieee.org/).
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