

IEEE Standard for Specifying Inertial Measurement Units (IMUs)

IEEE Aerospace and Electronic Systems Society

Developed by the
Gyro and Accelerometer Panel

IEEE Std 1780™-2022

STANDARDS

IEEE Standard for Specifying Inertial Measurement Units (IMUs)

Developed by the

Gyro and Accelerometer Panel
of the
IEEE Aerospace and Electronic Systems Society

Approved 9 February 2022

IEEE SA Standards Board

Abstract: Preparation of an inertial measurement unit (IMU) specification document is discussed in this standard. An outline is provided along with guidance for tailoring.

Keywords: IEEE 1780™, IMU, inertial measurement unit, inertial system, specification

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Introduction

This introduction is not part of IEEE Std 1780-2022, IEEE Standard for Specifying Inertial Measurement Units (IMUs).

This standard is a format guide for the preparation of an IMU requirements specification. It provides a common meeting ground of terminology and practice for manufacturers and users. The user is cautioned not to overspecify; only those parameters that are required to guarantee proper performance in the specific application should be controlled. Parameters in addition to those given in this standard are not precluded. However, the specification should contain only those requirements that can be verified.

Blank spaces in the text of this document permit the specification writer to insert specific information such as parameter values and their tolerances, as well as their clause numbers. Brackets are used to enclose alternative choices of dimensional units, signs, axes, and so on. Boxed statements are included for information only and are not part of the specification. The figures presented are to be used as a guide for the preparation of specific figures or drawings. The terminology used conforms to the *IEEE Standards Dictionary Online*.⁶ The units used conform to IEEE/ASTM SI 10TM-2016, American National Standard for Metric Practice [B3].⁷ The abbreviation of units conforms to IEEE Std 260.1TM-2004, IEEE Standard Letter Symbols for Units of Measurement (SI Customary Inch-Pound Units, and Certain Other Units) [B4], and IEEE Std 280TM-2021, IEEE Standard Letter Symbols for Quantities Used in Electrical Science and Electrical Engineering [B5]. The graphic symbols used conform to ANSI/IEEE Std 315TM-1975, IEEE Standard Graphic Symbols for Electrical and Electronics Diagrams [B1], and its supplement ANSI/IEEE Std 315ATM-1986 [B2].

Clause 1 and Clause 2 of this standard provide an overview of the standard and the normative references used in the creation of the standard. Clause 1 and Clause 2 are not to be included in a user's document, and Clause 3 through Clause 8 should be renumbered as Clause 1 through Clause 6, respectively.

This standard defines the requirements for a self-contained strapdown or gimbaled IMU in terms specific to the IMU treated as a "black box." The requirements contained herein cover applications where the IMU is used to provide compensated outputs for navigation and/or flight controls in an orthogonal reference frame.

The term "IMU" is accepted to include the electronics necessary to operate the IMU, provide built-in test (BIT), and condition the output signals. The IMU provides outputs for navigation (incremental angle and incremental velocity) and flight controls (angular rate and linear acceleration).

⁶ *IEEE Standards Dictionary Online* is available at: <http://dictionary.ieee.org>. An IEEE Account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

⁷ The numbers in brackets correspond to those of the bibliography in Annex A.

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IEEE Standard for Specifying Inertial Measurement Units (IMUs)

1. Overview

1.1 Scope

This standard provides an outline of an inertial measurement unit (IMU) specification document and guidance for tailoring the specification.

1.2 Purpose

This standard provides the specifications, typical units, format, and terminology to specify IMUs. This standard allows users to select which specifications are relevant to their particular applications. The terminology is that which is commonly used by the inertial navigation community.

1.3 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals *is required to*).^{8,9}

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

⁸ The use of the word *must* is deprecated and cannot be used when stating mandatory requirements, *must* is used only to describe unavoidable situations.

⁹ The use of *will* is deprecated and cannot be used when stating mandatory requirements, *will* is only used in statements of fact.

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.

IEEE Std 1559™, IEEE Standard for Inertial Systems Terminology.^{10, 11}

3. Specification overview

3.1 Specification scope

This specification defines requirements for an IMU to be used as a sensor in [a land vehicle, an aircraft, ____].

A mission timeline and/or a definition of operational usage may be included here.

3.2 Item description

The major components of the IMU herein specified are as follows: [gyroscopes, ____] that measure three axes of angular motion and [accelerometers, ____] that measure three axes linear motion, capture loop electronics and digital circuitry required to provide built-in test and compensated outputs for navigation [incremental angles ($\Delta\theta$ s), incremental velocities (ΔV s)] and flight controls (angular rates, linear accelerations) in an orthogonal reference frame.

A functional block diagram may be included here.

If the IMU is a gimbaled system, then add the gimbal as a major component of the IMU.

3.3 Definitions, acronyms, and abbreviations

3.3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online*,¹² IEEE Std 1559,¹³ and the compensation equations of 8.3 should be consulted for terms not defined in this clause.

deactivation time: The time from removal of all power forms to the time at which the inertial measurement unit (IMU) may be moved without damaging the internal components.

jitter (message): The variability in the transmission time of a message.

repeatability: The closeness of agreement among repeated measurements of the same variable under the same operating conditions when changes in conditions or nonoperating periods occur between measurements. Nonoperating periods include turn-on to turn-on.

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¹¹ IEEE publications are available from The Institute of Electrical and Electronics Engineers (<https://standards.ieee.org/>).

¹² *IEEE Standards Dictionary Online* is available at: <http://dictionary.ieee.org>. An IEEE Account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

¹³ Information on references can be found in Clause 2.

stability: A measure of the ability of a specific mechanism or performance coefficient to remain invariant when continuously exposed to a fixed operating condition.

time of validity: The instant in time when a measured event occurred.

time of validity error: The difference between an indicated time of validity and the time of validity.

turn-on time: The time from when inertial measurement unit (IMU) power forms reach specified limits and all external reset signals are unasserted until an IMU produces a specified useful output, though not necessarily at the accuracy of full specification performance.

3.4 Acronyms and abbreviations

BIT	built-in test
CAGE	commercial and governmental entity
CMOS	complementary metal oxide semiconductor
CRC	cyclic redundancy check
dc	direct current
DVT	design verification test
E3	electromagnetic environmental effects
ESD	electrostatic discharge
ESS	environmental stress screening
ETI	elapsed time indicator
FPGA	field programmable gate array
HALT	highly accelerated life testing
IEEE	institute of electrical and electronic engineers
IMU	inertial measurement unit
I/O	input/output
IP	ingress protection
JTAG	joint test action group
LVDS	low-voltage differential signal
MEK	methyl ethyl ketone
MIBK	methyl isobutyl ketone
MTFB	mean time between failure
MTTR	mean time to repair
NBC	nuclear, biological, and chemical
SDLC	synchronous data link control
SPI	serial peripheral interface
SRS	shock response spectrum
TTL	transistor-transistor logic
UART	universal asynchronous receiver/transmitter
USB	universal serial bus

4. Applicable documents

The following documents form a part of the specification to the extent specified herein. In the event of any conflict between the requirements of this specification and the listed documents, the requirements of this specification shall take precedence.

Give identification number, title, date of issue, and revision letter of each listed document.
--

4.1 Government

4.1.1 Specifications

EMC Directive 2004/108/EC, Electromagnetic compatibility of electrical and electronic apparatus
MIL-DTL-5002E, Surface Treatments and Inorganic Coatings for Metal Surfaces of Weapons Systems
MIL-DTL-7793, Meter, Time Totalizing
MIL-DTL-53039E, Primer Coating, Epoxy, Water Based, Lead And Chromate Free
MIL-DTL-64159, Camouflage Coating, Water Dispersible Aliphatic Polyurethane, Chemical Agent Resistant
MIL-HDBK-217, Reliability Prediction of Electronic Equipment
MIL-HDBK-454, General Guidelines for Electronic Equipment
MIL-HDBK-470A, Designing and Developing Maintainable Products and Systems
MIL-HDBK-781, Handbook for Reliability Test Methods, Plans, and Environments for Engineering, Development Qualification, and Production
MIL-HDBK-1568, Materials and Processes for Corrosion Prevention and Control in Aerospace Weapons Systems
MIL-HDBK-5400, Electronic Equipment, Airborne, General Specification for

4.1.2 Standards

AFOSH Standard 48-8, Controlling Exposures to Hazardous Materials
FED-STD-123, Marking for Shipment (Civil Agencies), Federal Standard
FED-STD-595, Colors Used in Government Procurement, Federal Standard
HF-STD-001, Human Factors Design Standard
MIL-STD-129, Standard Practice for Military Marking for Shipment and Storage
MIL-STD-130, Identification Marking of U.S. Military Property, Standard Practice
MIL-STD-461, Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment

MIL-STD-464, Electromagnetic Environmental Effects Requirements for Systems

MIL-STD-810, Environmental Engineering Considerations and Laboratory Tests

MIL-STD-882E, Standard Practice for System Safety

MIL-STD-883K, Department of Defense Test Method Standard: Microcircuits

MIL-STD-889B, Dissimilar Metals

MIL-STD-1285, Marking of Electrical and Electronic Parts, Standard Practice

MIL-STD-1472, Design Criteria Standard: Human Engineering

MIL-STD-1553, Military Standard: Aircraft Internal Time Division Command/Response Multiplex Data Bus

MIL-STD-1916, DoD Preferred Methods for Acceptance of Product, Department of Defense Test Methods Standard

MIL-STD-2073, Department of Defense Standard Practice for Military Packaging

MIL-STD-2217, Memory Loader/Verifier Multiplex Bus Interface with Avionic Systems

MIL-STD-7179A, Finishes, Coatings and Sealants for the Protection of Aerospace Weapons Systems

MSFC-STD-3029A, Guidelines for the Selection of Metallic Materials for Stress Corrosion Cracking Resistance in Sodium Chloride Environments

MIL-STD-13231, Marking Electronic Items, Standard Practice

4.1.3 Drawings

4.1.4 Bulletins

4.2 Nongovernment

4.2.1 Specifications

HDBK-217PLUS, Reliability Prediction Models

4.2.2 Standards

ADS-37A-PRF, Electromagnetic Environmental Effects (E3) Performance and Verification Requirements

AEC Q100-003, Failure Mechanism Based Stress Test Qualification for Packaged Integrated Circuits

ANSI/AQS Z1.4, Sampling Procedures and Tables for Inspection by Attributes

ANSI/IEC-60529, Degrees of Protection Provided by Enclosures (IP Code)

CEI/IEC 61000-4-2, Electromagnetic compatibility (EMC)

IEC 61709, Electric Components—Reliability

IEEE Std 1394, IEEE Standard for a High-Performance Serial Bus

IEST-RP-PR003, HALT and HASS

IPC-A-600, Acceptability of Printed Boards

IPC-A-610, Acceptability of Electronic Assemblies

ISO-2859, Sampling Procedures for Inspection by Attributes

J-STD-001, Requirements for Soldered Electrical and Electronic Assemblies

RTCA/DO-160, Environmental Conditions and Test Procedures for Airborne Equipment

RTCA/DO-178, Software Considerations in Airborne Systems and Equipment Certification

RTCA/DO-254, Design Assurance Guidance for Airborne Electronic Hardware

RTCA/DO-331, Model-Based Development and Verification Supplement to DO-178C and DO-278A

4.2.3 Drawings

4.2.4 Bulletins

5. Requirements

5.1 System interfaces

5.1.1 Electrical interface

Electrical characteristics are specified in this subclause.

5.1.1.1 External connector

5.1.1.1.1 Type and location

The IMU connector shall be a [pin, ____] connector, part number ____ manufactured by ____.

The IMU connector shall be located as shown in [drawing number ____, Figure ____].

Multiple connectors may be specified to accommodate different functions, such as a dedicated test connector or a separate power connector.

5.1.1.1.2 Pin assignments

The external connector pin assignments shall be as specified in [drawing number ____, Figure ____, Table ____].

Multiple drawings, figures, or tables may be specified for multiple connectors.

Tables may include pin numbers, signal names and descriptions (pins may be multiplexed), shielding, twisted pair, impedance, termination, or other characteristics.

5.1.1.2 Input power forms

The IMU shall perform when supplied with [+5 V, +15 V, -15 V, +28 V, ____] input power that varies by no more than -____ [V, %, ____] and +____ [V, %, ____].

The IMU shall perform when supplied with a [+5 V, +15 V, -15 V, +28 V, ____] input power form that has no more than ____ [mV, ____] [p-p, ____] of noise and ripple that has a bandwidth defined by the frequency range of ____ [Hz, ____] to ____ [MHz, ____].

The IMU [steady state, start up, inrush, ____] current shall be less than ____ [mA, A, ____] on the [+5 V, +15 V, -15 V, +28 V, ____] input power form.

The duration of the IMU [start up, inrush, ____] current shall be less than ____ [ms, s, ____] on the [+5 V, +15 V, -15 V, +28 V, ____] input power form.

The IMU shall not be damaged by an undervoltage up to ____ [V, ____] for up to ____ [s, min, ____] on the [+5 V, +15 V, -15 V, +28 V, ____] input power form.

The IMU shall not be damaged by an overvoltage up to ____ [V, ____] for up to ____ [s, min, ____] on the [+5 V, +15 V, -15 V, +28 V, ____] input power form.

The IMU shall [not be damaged by, remain operating through] power dropouts of duration up to ____ [ms, s, ____] with at least ____ [ms, s, ____] between dropouts.

The IMU shall not be damaged by spikes of durations less than ____ [ms, ____] on its input power forms up to ____ [mV, V, ____] with a source impedance greater than ____ Ω .

For systems with multiple input power forms, the required power forms should be specified and the requirements for each power form should be included. Additionally, if restrictions on the sequencing of the power forms exist for power application and/or removal, they should be specified; otherwise it should be specified that none exist. Sample requirements for the case where no restrictions exist are as follows:

The IMU shall perform and not be damaged when the input power forms are applied in any order.

The IMU shall not be damaged when the input power forms are removed in any order.

Requirements, including tolerances, for parameters such as frequency, power factor, and rise time may need to be specified.

The impedance or equivalent circuit of each power form may need to be specified.

5.1.1.3 Discrete I/O

The IMU shall provide a(n) ____ discrete [input, output] signal compatible with [TTL, CMOS, ____].

The ____ discrete [input, output] signal shall be used to ____.

A discrete signal should be specified with a unique identifier and a reference that specifies the characteristics of the discrete such as initial state; active state; termination; triggering; state changes; reference, low and high levels; overshoot; undershoot; rise, fall, transient and settling times; voltages or currents; source or sink capabilities; low- and high-level hold durations; and stability. A figure may be included/referenced to provide a visual representation of the discrete characteristics.

Describe the use of the discrete signal (e.g., “The IMU On-Off discrete signal shall be used to power-up and power-down the IMU.”).

For input signals, specify the response time and the related external condition.

For output signals, specify the assertion time and the related internal condition.

In the case of multiple discrete input and/or outputs, define each discrete in its own subclause using the above format.

5.1.1.4 Serial I/O

The electrical characteristics of the _____ interface shall be compatible with _____.

The _____ interface shall support data rates up to _____ [Gb/s, Mb/s, kb/s, _____].

The specification above is used for asynchronous interfaces.

The _____ interface shall [provide, receive] a _____ [MHz, _____] clock.

The specification above is used for synchronous interfaces.

In the case of multiple serial interfaces, define each interface in its own subclause using the above format. Each interface should be given a unique identifier.

Example serial interfaces are JTAG, IEEE Std 1394™, USB, Ethernet, SPI, SDLC, and UART.

Example electrical characteristics that the serial I/O may be compatible with are TTL, CMOS, RS-422, and LVDS.

The protocol for each serial interface should be specified.

For certain serial I/O buses, the type of duplexing (full, half), biasing, and termination may need to be specified.

5.1.2 Data interface(s)

In the case of multiple data interfaces, define each interface in its own subclause. Each interface should be given a unique identifier.

5.1.2.1 Message rate(s)

The _____ interface shall [provide, receive] the _____ message at _____ [Hz, _____].

In the case of multiple messages with different rates, define the message rate for each message.

5.1.2.2 Message format(s)

Message content (including data content and, when applicable, header content) should be specified here.

Message content may include:

- Incremental angles ($\Delta\theta$ s) and incremental velocities (ΔV s) used for navigation
- Angular rates and linear accelerations used for flight control
- BIT Status
- Temperature
- Time

Tables and/or figures may be added to describe the message content.

5.1.2.3 Message time of validity

The indicated time of validity shall be defined with respect to [the end of a data sample, a user input signal, ____].

The time of validity error shall be less than ____ [μ s, ____].

Every IMU message that contains inertial data shall have an associated [discrete rising edge, discrete falling edge, data time tag(s), ____] that defines the time of validity for the data contained in the message.

Multiple times of validity may be specified for multiple messages or various types of data within the same message.

When a discrete is used to indicate the time of validity, the supplier should define any fixed time difference of the message data with respect to the discrete.

5.1.2.4 Data latency

The IMU ____ data latency shall be less than ____ [μ s, ____].

Only specify the data latency of parameters where it is important to do so (e.g., inertial instrument data).

In the case of multiple parameters with different data latencies, specify the data latency for each parameter.

In some cases, the variability of the data latency may need to be specified.

Clarification of when a measurement is available (e.g., last bit transmitted or data written to the transmit buffer) may be required.

Inertial instrument data latencies contained in data messages may be defined relative to discrete time of validity indicators.

5.1.2.5 Message jitter

The message jitter shall be less than ____ [ms, μ s, ____].