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IEEE Standard for Synchrophasor Data Transfer for Power Systems

1. Overview

1.1 Scope

This standard defines a method for exchange of synchronized phasor measurement data between power system equipment. It specifies messaging including types, use, contents, and data formats for real-time communication between *phasor measurement units* (PMU), *phasor data concentrators* (PDC), and other applications.

1.2 Purpose

The purpose for this standard is to facilitate data exchange among measurement, data collection, and application equipment. It provides a defined, open access method for all vendors to use to facilitate development and use of synchrophasors. It is a simple and direct method of data transmission and accretion within a phasor measurement system, which may be used directly or with other communication protocols. This method was initially established by IEEE Std C37.118™-2005 [B6].[1]

[1] The numbers in brackets correspond to those of the bibliography in Annex A.

1.3 General overview

This standard defines data transmission formats for real-time data reporting for synchronized phasor measurements used in electric power systems.

- Clause 1 provides the scope and need for the standard.
- Clause 2 references other standards that are related or may be useful in the study and application of this standard.
- Clause 3 defines terms, acronyms, and abbreviations found in this standard.
- Clause 4 provides background for synchrophasor measurement.
- Clause 5 describes synchrophasor measurement system.
- Clause 6 defines the real-time communication protocol and message formats.

Six informative annexes are provided to clarify the standard and give supporting information:

- Annex A is a bibliography.
- Annex B gives information about cyclic redundancy codes and the cyclic redundancy check (CRC) required by this standard.
- Annex C provides background in communication bandwidth.
- Annex D illustrates the message formats defined in Clause 6 with complete message examples.
- Annex E defines message mapping into standard communication protocols.
- Annex F discusses synchrophasor communications methods for Internet Protocol (IP).

1.4 Need for this standard

The 2005 version of IEEE Std C37.118 includes both measurement requirements and real-time data transfer requirements. To simplify widespread adoption of synchrophasor measurement technology and facilitate the use of other communication protocols for phasor data transmission, IEEE Std C37.118-2005 [B6] was split into two standards, one with measurement requirements and the other with the data transfer requirements. This allows other communication protocols and systems to be used with phasor measurement systems supporting the original purpose of the standard. This split facilitates harmonization of IEEE Std C37.118-2005 with IEC 61850. This standard includes only the data transfer portion of IEEE Std C37.118-2005, adding some corrections and improvements yet retaining the current messaging for backward compatibility. This approach supports the widely used method for current and developing deployments, and allows for a smooth transition of synchrophasor systems to new protocols as needed.

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 754™-1985, IEEE Standard for Binary Floating-Point Arithmetic.[2, 3]

IEEE Std C37.118.1™, IEEE Standard for Synchrophasor Measurements for Power Systems.

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. *The IEEE Standards Dictionary: Glossary of Terms & Definitions* [B1] should be consulted for terms not defined in this clause.[4]

Coordinated Universal Time (UTC): (Initials are ordered based on French language.) The time of day at the Earth's prime meridian (0° longitude). It is distributed by various media, including the Global Positioning System (GPS) system.

CRC-CCITT: 16-bit cyclic redundancy check (CRC) calculated using the generating polynomial $X^{16} + X^{12} + X^5 + 1$, seed value 0xFFFF (–1), no final mask.

data concentrator (DC): A device that combines data from several measurement devices.

Global Positioning System (GPS): A U.S. Department of Defense (DoD) navigation system that uses a constellation of 24 satellites broadcasting a precision signal for location and time synchronization. Basic time synchronization accuracy is ± 0.2 microseconds (µs).

IEEE floating point: A 32-bit representation of a real number.

NOTE—This definition is in accordance with IEEE Std 754-1985.[5, 6]

phasor: A complex equivalent of a sinusoidal wave quantity such that the complex modulus is the cosine wave amplitude and the complex angle (in polar form) is the cosine wave phase angle.

phasor data concentrator (PDC): A data concentrator (DC) used in phasor measurement systems.

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[2] IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (http://standards.ieee.org).
[3] The IEEE standards or products referred to in Clause 2 are trademarks owned by the Institute of Electrical and Electronics Engineers, Incorporated.
[4] The *IEEE Standards Dictionary: Glossary of Terms & Definitions* is available at http://shop.ieee.org/.
[5] Information on references can be found in Clause 2.
[6] Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

synchronism: The state in which connected alternating-current systems, machines, or a combination operate at the same frequency, and in which the phase angle displacements between voltages in them are constant, or vary about a steady and stable average value.

synchronized phasor or synchrophasor: A phasor calculated from data samples using a standard time signal as the reference for the measurement.

NOTE—In this standard, the phasors from remote sites have a defined common phase relationship.

3.2 Special terms

phasor measurement unit (PMU): In this standard, a device that produces synchronized phasor, frequency, and rate of change of frequency (ROCOF) estimates from voltage and/or current signals and a time synchronizing signal. Note that the same device may perform other functions and include another functional name [e.g., the device may also record power system waveforms and be called a *digital fault recorder* (DFR)].

3.3 Abbreviations and acronyms

BCD	binary coded decimal
IRIG-B	InterRange Instrumentation Group Time Code Format B
MMS	manufacturing messaging specification
NTP	Network Time Protocol
PPS	pulse per second
PTP	Precision Time Protocol
ROCOF	rate of change of frequency, as defined by IEEE Std C37.118.1
SCADA	Supervisory Control and Data Acquisition
SOC	second of century
UTF-8	Unicode character encoding scheme used to represent text in writing systems

4. Synchrophasor measurement

4.1 Introduction

Synchrophasor measurement definitions, detailed descriptions, and performance requirements are spelled out in the IEEE Std C37.118.1. That standard is based on the original performance requirements from IEEE Std C37.118-2005 [B6]. It extends them with dynamic performance requirements for synchrophasors and steady-state and dynamic performance requirements for frequency and rate of change of frequency (ROCOF) measurements. This clause includes the basic synchrophasor measurement definition from

IEEE Std C37.118.1 for background and clarity, and the requirements for synchronization and data rates, which are important for the transfer of these measurements.

4.2 Synchrophasor definition

Phasor representation of sinusoidal signals is commonly used in ac power system analysis. The sinusoidal waveform defined as shown in Equation (1):

$$x(t) = X_m \cos(\omega t + \phi) \tag{1}$$

is commonly represented as the phasor shown in Equation (2):

$$\begin{aligned} X &= (X_m / \sqrt{2})\, e^{j\phi} \\ &= (X_m / \sqrt{2})(\cos\phi + j\sin\phi) \\ &= X_r + jX_i \end{aligned} \tag{2}$$

where the magnitude is the rms value, $X_m/\sqrt{2}$, of the waveform and the subscripts r and i signify real and imaginary parts of a complex value in rectangular components. The value of ϕ depends on the time scale, particularly where $t = 0$. It is important to note this phasor is defined for the angular frequency ω; evaluations with other phasors must be done with the same time scale and frequency.

The *synchrophasor* representation of the signal $x(t)$ in Equation (1) is the value $\boldsymbol{X}$ in Equation (2) where ϕ is the instantaneous phase angle relative to a cosine function at the nominal system frequency synchronized to UTC.

Under this definition, ϕ is the offset from a cosine function at the nominal system frequency synchronized to UTC. A cosine has a maximum at $t = 0$, so the synchrophasor angle is 0 degrees when the maximum of $x(t)$ occurs at the UTC second rollover (1 PPS time signal), and –90 degrees when the positive zero crossing occurs at the UTC second rollover (sin waveform). Figure 1 illustrates the phase angle/UTC time relationship.

See IEEE Std C37.118.1 for details about synchrophasor definitions and measurements.

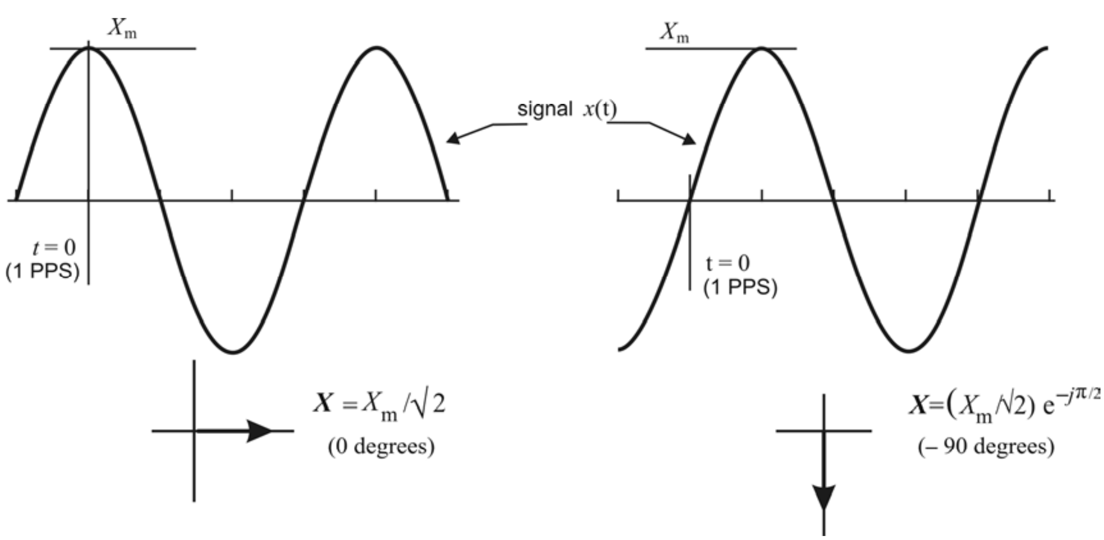

Figure 1—Convention for synchrophasor representation

4.3 Frequency and rate of change of frequency definition

A PMU shall be capable of reporting frequency and ROCOF. For this measurement, the following standard definitions shall be used. Given a sinusoidal signal as shown in Equation (3):

$$x(t) = X_m \cos [\psi(t)] \tag{3}$$

Frequency is defined by Equation (4):

$$f(t) = \frac{1}{2\pi} \cdot \frac{d\psi(t)}{dt} \tag{4}$$

The ROCOF is defined as shown in Equation (5):

$$\text{ROCOF}(t) = df(t)/dt \tag{5}$$

See IEEE Std C37.118.1 for details about frequency, and ROCOF definitions and measurements.

4.4 Measurement time tag from synchrophasors

Synchrophasor measurements shall be tagged with the UTC time corresponding to the time of measurement. This shall consist of three numbers: a second-of-century (SOC) count, a fraction-of-second (FRACSEC) count, and a message time quality flag. The SOC count shall be a four (4) byte binary count of seconds from UTC midnight (00:00:00) of January 1, 1970, to the current second. This count shall be represented as a 32-bit unsigned integer. Leap seconds shall be added to or deleted from this count as necessary to keep it synchronized with UTC. Insertion of a leap second results in two successive seconds having the same SOC count, which are differentiated by the Leap Second bit in the FRACSEC word, defined as follows. Conversely, the deletion of a leap second results in a second that is missing, so the second count only goes to 58. (With this convention, time count can always be determined from current time by multiplying the number of days since 1/1/70 by the number of seconds per day: 86 400.) This SOC time stamp will roll over to 0 in 2106 (136+ years of seconds). It is similar to the time counts used in most computer systems such as UNIX, LINUX, and DOS as well as networks [Network Time Protocol (NTP), Precision Time Protocol (PTP)].

The second shall be divided into an integer number of subdivisions by the TIME_BASE integer specified in 6.4, Table 8. The FRACSEC count shall be an integer representing the numerator of the FRACSEC with TIME_BASE as the denominator. Compatibility with IEC 61850 requires a TIME_BASE value of 2^24. The FRACSEC count shall be zero when it coincides with the one-second roll over. This time tag shall be applied to all communication frames as described in Clause 6.

4.5 System time synchronization

Synchrophasor measurements shall be synchronized to UTC time with accuracy sufficient to meet the accuracy requirements of IEEE Std C37.118.1. A phase error of 0.01 radian (0.57 degrees) in the synchrophasor measurement will cause 1% *total vector error* (TVE), which is the maximum steady-state error allowed in IEEE Std C37.118.1. A 0.01 radian phase error corresponds to a time error of ±26 μs for a 60 Hz system, and ±31 μs for a 50 Hz system.

The system shall be capable of receiving time from a highly reliable source, such as the Global Positioning System (GPS), which can provide sufficient time accuracy to keep the TVE within the required limits and provide indication of loss of synchronization. The flag in the data output (6.3, Table 6, STAT word Bit 13) is provided to indicate a loss of time synchronization and shall be set to 1 when loss of synchronization could cause the TVE to exceed the limit or within 1 min of actual loss of synchronization, whichever is less. The flag shall remain set until data acquisition is resynchronized to the required accuracy level.

4.6 Synchrophasor transmission

Synchrophasor estimates shall be made so they can be reported (transmitted) as data frames at a rate F_s that is an integer number of times per second or integer number of seconds per frame as specified by the DATA_RATE variable in the configuration frame (6.4, Table 8 and Table 10). A data frame is a set of measurements that may include multiple channels of phasor estimates, analog words, and digital words with a measurement status word and a time tag as defined in Clause 6.

4.6.1 Reporting rates

The PMU shall support data reporting (by recording or output) at sub-multiples of the nominal power-line (system) frequency. Required rates for 50 Hz and 60 Hz systems are listed in Table 1.

Table 1—Required PMU reporting rates

System frequency	50 Hz			60 Hz					
Reporting rates (F_s—frames per second)	10	25	50	10	12	15	20	30	60

The actual rate to be used shall be user selectable. Support for other reporting is permissible, and higher rates such as 100 frames/s or 120 frames/s and rates lower than 10 frames/s such as 1 frame/s are encouraged.

4.6.2 Reporting times

For a reporting rate, N frames per second where N is a positive integer, the reporting times shall be evenly spaced through each second with the time of the first frame coincident with the UTC second rollover. Thus the first frame will be frame number 0 (frames numbered 0 thru N–1) with a FRACSEC time of 0, the next frame number 1 with a fractional time 1/N, and so on through frame N–1 with a fractional time (N–1)/N. These reporting times (time tags) are to be used for determining the instantaneous values of the synchrophasor as defined in 4.1. If rates lower than 1/s are used, there shall be one report on the hour (xx:00:00) and evenly spaced thereafter according to the chosen rate.

4.7 Synchrophasor measurement

Requirements for synchrophasor, frequency, and ROCOF estimates are detailed in IEEE Std C37.118.1. Refer to that standard for measurement requirements.

5. Synchrophasor measurement system overview

5.1 Synchrophasor network

A simple structure of a synchrophasor network consists of the PMU and PDC as shown in Figure 2. If multiple *intelligent electronic devices* (IEDs) in a substation provide synchrophasor measurements, a local PDC may be deployed in the substation. Typically, many PMUs located at various key substations gather data and send it in real time to a PDC at the utility location where the data is aggregated. The data collected by PDCs may be used to support many applications, ranging from visualization of information and alarms for situational awareness, to ones that provide sophisticated analytical, control, or protection functionality. Applications, such as dynamics monitoring, use full-resolution real-time data along with grid models to support both operating and planning functions. The application displays locally measured frequency, primary voltages, currents, real and reactive power flows, and other quantities for system operators. Many PDCs belonging to different utilities can be connected to a common central PDC to aggregate data across the utilities, in order to provide an interconnection-wide snapshot of the power grid measurements.

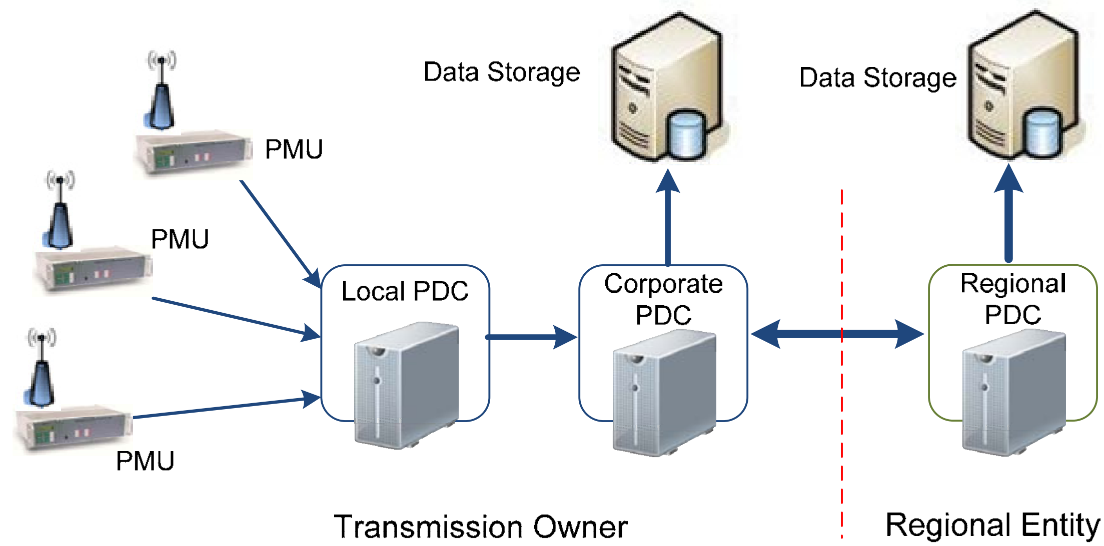

Figure 2—Synchrophasor data collection network

5.2 Synchrophasor network elements

5.2.1 Synchrophasor measurement unit

The PMU is a function or logical device that provides synchrophasor and system frequency estimates, as well as other optional information such as calculated megawatts (MW) and megavars (MVAR), sampled measurements, and Boolean status words. The PMU may provide synchrophasor estimates from one or more voltage or current waveforms. The PMU can be realized as a stand-alone physical device or as a part of a multifunction device such as a protective relay, DFR, or meter. This information may be recorded locally or transmitted in real time to a central location as illustrated in Figure 2. This standard addresses the real-time transfer of data from the PMU to the PDC or other devices.

5.2.2 Phasor data concentrator

A PDC works as a node in a communication network where synchrophasor data from a number of PMUs or PDCs is correlated and fed out as a single stream to the higher level PDCs and/or applications. The PDC correlates synchrophasor data by time tag to create a system wide measurement set.

Additional functions may be provided, as follows:

a) Various quality checks on the phasor data and insertion of appropriate flags into the correlated data stream.

b) Checks for disturbance flags and recordings of data files for analysis.

c) Monitoring of the overall measurement system and displaying the results, as well as recording of the performance.

d) Number of specialized outputs, such as a direct interface to a SCADA or EMS system.

Local PDCs as shown in Figure 2 aggregate and time-align synchrophasor data from multiple IEDs and feed the data to applications. Mid-level regional PDCs collect synchrophasor data from multiple PDCs, conduct data quality checks, and feed the data to applications. Higher level PDCs (SuperPDCs) both aggregate and archive synchrophasor data. The PDCs may be recognized as a function rather than as a stand-alone device or hardware-software package, and can be integrated into other systems and devices. A structured hierarchy of distributed PDCs may be formed to serve a hierarchy of systems: substation, utility, control area, reliability coordinator, and interconnection level. Each layer in the hierarchy may be serving different data requirements (latency, quality, resolution), with archival and event triggering and data capture requirements driven by applications. Since local PDCs represent a local point of failure for the data stream, backups and bypass options are needed for mitigating such failures.

5.3 Multiple data streams from PMUs and PDCs

A PMU or PDC may transmit its data in one or more separate data streams. Each stream may have different contents and may be sent at a different rate. The destination of each stream may be a different device and location. Each stream must then be individually controllable, have its own IDCODE, and a separation configuration control. This feature is useful for sending data to different devices with different purposes, allowing latency control and class of service (M and P class) supply.

6. Synchrophasor message format

6.1 Message application

This clause describes the format of messages to and from a PMU or PDC for use in real-time communication of phasor data. *Real-time data transmission* here is defined as taking place concurrently with the measurement process. If the PMU device is to be used with other systems where the phasor data information is to be transmitted in real time, implementation of this protocol is required for conformance with this standard. If the PMU device is used only for phasor data archiving or recording, then this protocol is not required. This standard does not address requirements for stored phasor data. Implementation of additional protocols for phasor data communication is not restricted.

Any communication system or media may be used for data transmission. The message frames shall be transmitted in their entirety as they are specified. When used with a stacked protocol such as manufacturing messaging specification (MMS) or IP, the entire frame including sync and CRC-CCITT shall be written into and read from the application layer interface. When used with more direct systems like raw Ethernet or RS-232, the entire frame will also be sent with the CRC-CCITT to assure data integrity.

This message protocol may be used for communication with a single PMU or a secondary system that receives data from several PMUs. The secondary system, a PDC, shall have its own user assigned IDCODE. The protocol allows for necessary identifying information, such as the PMU IDCODE and status, to be embedded in the data frame for proper interpretation of the measured data.

6.2 Message framework

Four message types are defined here: *data*, *configuration*, *header*, and *command*. The first three message types are transmitted from the PMU/PDC that serves as the data source, and the last (command) is received by the PMU/PDC.

- Data messages are the measurements made by a PMU.

- Configuration is a machine-readable message describing the data types, calibration factors, and other meta-data for the data that the PMU/PDC sends.
- Header information is human readable descriptive information sent from the PMU/PDC but provided by the user.
- Commands are machine-readable codes sent to the PMU/PDC for control or configuration.
- A PMU or PDC may transmit multiple data streams, each with different content, rate, format, etc. Each data stream shall have its own IDCODE so that the data, configuration, header, and command messages can be appropriately identified. Each stream shall be independently operable including command execution and data, header, and configuration messages.

Information may be stored in any convenient form in the PMU/PDC itself, but when transmitted it shall be formatted as frames described in the following sections. Commands and other messages received by a connected device that are not understood (such as an unimplemented feature, incorrect IDCODE, bad CRC) shall be silently discarded. This messaging framework implements no error or retransmit messages.

Only data, configuration, header, and command frames are defined in this standard. Other types may be designated in the future. In normal operation, the PMU only sends data frames. Annex D contains examples of data, configuration, and command frames.

6.2.1 Overall message

All message frames start with a 2-byte SYNC word followed by a 2-byte FRAMESIZE word, a 2-byte IDCODE, a time stamp consisting of a 4-byte second-of-century (SOC) and 4-byte FRACSEC, which includes a 24-bit FRACSEC integer and an 8-bit Time Quality flag described in 6.2.2.

The SYNC word provides synchronization and frame identification. Bits 6-4 in the SYNC word designate the frame type. This word is detailed Table 2. Bits 3–0 describe version number. Since this is the second published edition of the synchrophasor standard, new messages shall be designated version 2 (binary 0010). The CFG-3 message introduced with this standard shall be designated version 2; all previously defined messages are unchanged in this standard and shall remain version 1. The IDCODE positively identifies the source of a data, header, or configuration message, or the destination of a command message. Note that the message IDCODE is associated with a data stream and ties data frames with the associated configuration and header information. All frames terminate in check word (CHK) which is a CRC-CCITT. This CRC-CCITT uses the generating polynomial $X^{16} + X^{12} + X^5 + 1$ with an initial value of –1 (hex FFFF) and no final mask.

All frames are transmitted exactly as described with no delimiters. Figure 3 illustrates frame transmission order. The SYNC word is transmitted first and CHECK word last. Two- and four-byte words including integer and floating-point numbers are transmitted most significant byte first (network or “big endian” order). All frame types use this same order and format.

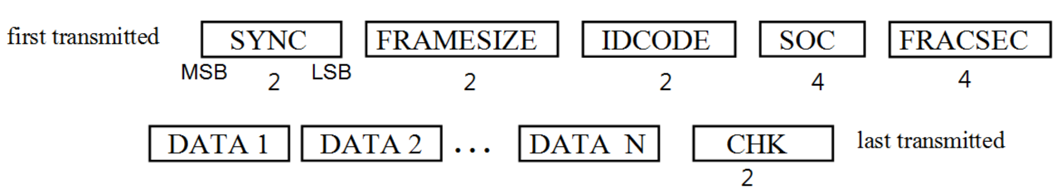

Figure 3—Example of frame transmission order

Table 2—Word definitions common to all frame types

Field	Size (bytes)	Comments
SYNC	2	Frame synchronization word. Leading byte: AA hex Second byte: Frame type and version, divided as follows: Bit 7: Reserved for future definition, must be 0 for this standard version. Bits 6–4: 000: Data Frame 001: Header Frame 010: Configuration Frame 1 011: Configuration Frame 2 101: Configuration Frame 3 100: Command Frame (received message) Bits 3–0: Version number, in binary (1–15) Version 1 (0001) for messages defined in IEEE Std C37.118-2005 [B6]. Version 2 (0010) for messages added in this revision, IEEE Std C37.118.2-2011.
FRAMESIZE	2	Total number of bytes in the frame, including CHK. 16-bit unsigned number. Range = maximum 65535
IDCODE	2	Data stream ID number, 16-bit integer, assigned by user, 1–65534 (0 and 65535 are reserved). Identifies destination data stream for commands and source data stream for other messages. A stream will be hosted by a device that can be physical or virtual. If a device only hosts one data stream, the IDCODE identifies the device as well as the stream. If the device hosts more than one data stream, there shall be a different IDCODE for each stream.
SOC	4	Time stamp, 32-bit unsigned number, SOC count starting at midnight 01-Jan-1970 (UNIX time base). Range is 136 years, rolls over 2106 AD. Leap seconds are not included in count, so each year has the same number of seconds except leap years, which have an extra day (86 400 s).
FRACSEC	4	Fraction of second and Time Quality, time of measurement for data frames or time of frame transmission for non-data frames. Bits 31–24: Message Time Quality as defined in 6.2.2. Bits 23–00: FRACSEC, 24-bit integer number. When divided by TIME_BASE yields the actual fractional second. FRACSEC used in all messages to and from a given PMU shall use the same TIME_BASE that is provided in the configuration message from that PMU.
CHK	2	CRC-CCITT, 16-bit unsigned integer.

6.2.2 Time and message time quality

The 32-bit (4-byte) FRACSEC is divided into two components: a 24-bit unsigned integer that is the actual FRACSEC count and an 8-bit message time quality flag. The time of measurement or data transmission for non-data frames is the SOC time stamp, which fixes the integer second plus the fractional time. The fractional time is determined by dividing the 24-bit integer FRACSEC by the TIME_BASE integer given in configuration frame.

Time = SOC + FRACSEC / TIME_BASE

The bits of the Message Time Quality flag indicate the "quality" of the time being reported as well as indication of *leap second* status. Table 3 details these assignments. Bit 7 is reserved for future use. Bit 4 is the Leap Second Pending bit and shall be set as soon as it is known, but no more than 60 s or less than 1 s before a leap second occurs. It shall be cleared in the first second after the leap second occurs. Bit 5 is the Leap Second Occurred bit and shall be set in the first second after the leap second and remains set for 24 h afterward. Bit 6 is the Leap Second Direction bit, which is 0 for adding a leap second and 1 for deleting a leap second. It shall be set (to 0 or 1 as required) at the same time or before the leap second pending bit is set, and remains the same for at least 24 h afterward. This will allow analysis programs to factor in a ± Leap Second in any analysis or time difference calculation.

Table 3—Time quality flag bit definitions

Bit #	Description
7	Reserved
6	Leap Second Direction—0 for add, 1 for delete
5	Leap Second Occurred—set in the first second after the leap second occurs and remains set for 24 h
4	Leap Second Pending—shall be set not more than 60 s nor less than 1 s before a leap second occurs, and cleared in the second after the leap second occurs
3–0	Message Time Quality indicator code—see Table 4.

The Message Time Quality indicator code contained in the lowest 4 bits indicates the maximum time error as determined by the PMU/PDC clock function. Bits 0–3 shall be cleared to 0 when the time function is locked to a UTC traceable source, such as GPS. Either bits 0–3 shall be all set to 1 when there is a clock failure or the clock has never been initially set. The codes for this indicator are detailed in Table 4. Note that an additional time quality indication has been added to the STATUS word. That time quality indicates the maximum time error at all times and uses a different set of code values.

Table 4—4-bit Message Time Quality indication codes (MSG_TQ)

BINARY	HEX	Value (worst-case accuracy)
1111	F	Fault—clock failure, time not reliable
1011	B	Time within 10 s of UTC
1010	A	Time within 1 s of UTC
1001	9	Time within 10^{-1} s of UTC
1000	8	Time within 10^{-2} s of UTC
0111	7	Time within 10^{-3} s of UTC
0110	6	Time within 10^{-4} s of UTC
0101	5	Time within 10^{-5} s of UTC
0100	4	Time within 10^{-6} s of UTC
0011	3	Time within 10^{-7} s of UTC
0010	2	Time within 10^{-8} s of UTC
0001	1	Time within 10^{-9} s of UTC
0000	0	Normal operation, clock locked to UTC traceable source

6.2.3 Leap second bit timing examples

The following examples show how the time count and leap second bits will actually appear for both a positive (added) leap second and a negative (deleted) leap second. The direction bit can be at any state before the Leap Second Pending bit is set and after the leap Second Occurred bit clears. When either of these bits is set, the direction bit shall be set in the state properly indicating insertion or deletion. The pending bit shall be set as soon as a leap second occurrence is known but not more than 59 s or less than 1 s before the change will occur.

Added leap second:

SOC Time	Time of day	Direction Bit 6	Occurred bit 5	Pending bit 4	Comments
1114991939	23:58:59	X	0	0	Direction bit any state before pending
1114991940	23:59:00	0	0	1	Pending can be set no earlier than here
1114991941	23:59:01	0	0	1	
. . . . . .					
1114991998	23:59:58	0	0	1	
1114991999	23:59:59	0	0	1	Pending and direction shall be set by here
1114992000	23:59:60	0	0	1	Leap second occurs here
1114992000	00:00:00	0	1	0	Occurred and direction remain set
1114992001	00:00:01	0	1	0	
. . . . . .					
1115078399	23:59:59	0	1	0	
1115078400	00:00:00	X	0	0	Occurred cleared, direction don't care
. . . . . .					

Deleted leap second:

SOC Time	Time of day	Direction Bit 6	Occurred bit 5	Pending bit 4	Comments
1114991939	23:58:59	X	0	0	Direction bit any state before pending
1114991940	23:59:00	1	0	1	Pending can be set no earlier than here
1114991941	23:59:01	1	0	1	
. . . . . .					
1114991997	23:59:57	1	0	1	
1114991998	23:59:58	1	0	1	Pending and direction shall be set by here
1114992000	00:00:00	1	1	0	Leap second occurred, pending cleared
1114992001	00:00:01	1	1	0	Occurred and direction remain set
1114992002	00:00:02	1	1	0	
. . . . . .					
1115078399	23:59:59	1	1	0	
1115078400	00:00:00	X	0	0	Occurred cleared, direction don't care
. . . . . .					

6.3 Data frame

A data frame shall contain measured data and shall be identified by having bits 4–6 in the SYNC word set to zero as shown in Table 2. The real-time phasor data frame shall consist of binary data ordered as shown in Table 5 and described in detail in Table 6. All fields shall be fixed length as described and no delimiters shall be used. The frame starts with SYNC, FRAMESIZE, IDCODE, SOC and FRACSEC, and terminates with a CRC-CCITT as shown in 6.2.

Table 5—Data frame organization

No.	Field	Size (bytes)	Comment
1	SYNC	2	Sync byte followed by frame type and version number.
2	FRAMESIZE	2	Number of bytes in frame, defined in 6.2.
3	IDCODE	2	Stream source ID number, 16-bit integer, defined in 6.2.
4	SOC	4	SOC time stamp, defined in 6.2, for all measurements in frame.
5	FRACSEC	4	Fraction of Second and Time Quality, defined in 6.2, for all measurements in frame.
6	STAT	2	Bit-mapped flags.
7	PHASORS	4 × PHNMR or 8 × PHNMR	Phasor estimates. May be single phase or 3-phase positive, negative, or zero sequence. Four or 8 bytes each depending on the fixed 16-bit or floating-point format used, as indicated by the FORMAT field in the configuration frame. The number of values is determined by the PHNMR field in configuration 1, 2, and 3 frames.
8	FREQ	2 / 4	Frequency (fixed or floating point).
9	DFREQ	2 / 4	ROCOF (fixed or floating point).
10	ANALOG	2 × ANNMR or 4 × ANNMR	Analog data, 2 or 4 bytes per value depending on fixed or floating-point format used, as indicated by the FORMAT field in configuration 1, 2, and 3 frames. The number of values is determined by the ANNMR field in configuration 1, 2, and 3 frames.
11	DIGITAL	2 × DGNMR	Digital data, usually representing 16 digital status points (channels). The number of values is determined by the DGNMR field in configuration 1, 2, and 3 frames.
	Repeat 6–11		Fields 6–11 are repeated for as many PMUs as in NUM_PMU field in configuration frame.
12+	CHK	2	CRC-CCITT

Table 6—Word definitions unique to data frames

Field	Size (bytes)	Comments
SYNC	2	First byte: AA hex Second byte: 01 hex (frame is version 1, IEEE Std C37.118-2005 [B6])
STAT	2	Bit mapped flags. Bit 15–14: Data error: 00 = good measurement data, no errors 01 = PMU error. No information about data 10 = PMU in test mode (do not use values) or *absent data tags* have been inserted (do not use values) 11 = PMU error (do not use values) Bit 13: PMU sync, 0 when in sync with a UTC traceable time source Bit 12: Data sorting, 0 by time stamp, 1 by arrival Bit 11: PMU trigger detected, 0 when no trigger Bit 10: Configuration change, set to 1 for 1 min to advise configuration will change, and clear to 0 when change effected. Bit 09: Data modified, 1 if data modified by post processing, 0 otherwise Bits 08–06: PMU Time Quality. Refer to codes in Table 7. Bits 05–04: Unlocked time: 00 = sync locked or unlocked < 10 s (best quality) \01 = 10 s ≤ unlocked time < 100 s 10 = 100 s < unlock time ≤ 1000 s 11 = unlocked time > 1000 s Bits 03–00: Trigger reason: 1111–1000: Available for user definition 0111: Digital 0110: Reserved 0101: df/dt High 0100: Frequency high or low 0011: Phase angle diff 0010: Magnitude high 0001: Magnitude low 0000: Manual
PHASORS	4 / 8	Data type indicated by the FORMAT field in configuration 1, 2, and 3 frames **16-bit integer values:** *Rectangular format:* —real and imaginary, real value first —16-bit signed integers, range –32 767 to +32 767 *Polar format:* —magnitude and angle, magnitude first —magnitude 16-bit unsigned integer range 0 to 65535 —angle 16-bit signed integer, in radians × 10^4, range –31 416 to +31 416 **32-bit values in IEEE floating-point format:** *Rectangular format:* —real and imaginary, in engineering units, real value first *Polar format:* —magnitude and angle, magnitude first and in engineering units —angle in radians, range $-\pi$ to $+\pi$
FREQ	2 / 4	Frequency deviation from nominal, in mHz Range–nominal (50 Hz or 60 Hz) –32.767 to +32.767 Hz 16-bit integer or 32-bit floating point 16-bit integer: 16-bit signed integers, range –32 767 to +32 767 32-bit floating point: actual frequency value in IEEE floating-point format. Data type indicated by the FORMAT field in configuration 1, 2, and 3 frames
DFREQ	2 / 4	ROCOF, in hertz per second times 100 Range –327.67 to +327.67 Hz per second Can be 16-bit integer or IEEE floating point, same as FREQ above. Data type indicated by the FORMAT field in configuration 1, 2, and 3 frames
ANALOG	2 / 4	Analog word. 16-bit integer. It could be sampled data such as control signal or transducer value. Values and ranges defined by user. Can be 16-bit integer or IEEE floating point. Data type indicated by the FORMAT field in configuration 1, 2, and 3 frames
DIGITAL	2	Digital status word. It could be bit mapped status or flag. Values and ranges defined by user.

6.3.1 Explanation for STAT word in the data frame

The data frame consists of time and data sections with framing. The data can be one block from a single PMU or multiple blocks from multiple PMUs. Each PMU data block is headed by a STAT word that has complete status for that block; this STAT applies to that block only. Bits are set in this STAT flag initially by the PMU that generates the data, and can be altered by other processors in the data chain, such as by a DC. The STAT word gives a complete status for the data in its data block within the bounds of this standard.

Bit 15–Bit 14 Data Error Indicator: set as noted in Table 6. A PDC is expected to receive data from several PMUs and transmit the aligned data to its destination(s). However, due to the latency requirements of applications, the PDC will not wait indefinitely for the arriving data, but implement a *wait time*. Once the wait time is over, the PDC will send whatever data has arrived within this interval. The IEEE C37.118 message format requires sending fixed-size data frames, so if any data that goes in a frame is not present when the frame is assembled, the PDC will need to provide a filler. So a receiving device will not interpret this filler as data, the PDC must set these bits to 10 in the status word to indicate the data in this PMU section is not valid. In addition, the data itself can be written as invalid. For floating-point data NaN (not a number) will be inserted for the absent data. For fixed-point data in rectangular format the PDC will use 0x8000 (–32768) as the substitute for the absent data. The standard allows values of +32 767 to –32 767 for valid data (see Table 6). For fixed-point data in polar format all values are permissible for the magnitude field. However, the angle field is restricted to ±31416. A value of 0x8000 (–32768) used in the angle field will be used to signify absent data.

Bit 13—PMU Sync Error: set to 1 to indicate the PMU has detected a loss of external time synchronization such as a loss of satellite tracking or a time input connection failure. It shall be used both when the time synchronization input fails and when the source of time synchronization loses lock to UTC traceable time. The measuring PMU shall set this bit to 1 when the 4-bit time quality field in the FRACSEC field becomes non-zero. A DC may also set Bit 13 to 1 if it detects a synchronization error in the data stream from a particular PMU. The length of time between detecting a sync error and setting Bit 13 to 1 shall not exceed the time for the estimated time error to exceed 31 µs in a 50 Hz system or 26 µs in a 60 Hz system (equivalent to 1% TVE due to phase only) or 1 min, whichever is less.

Bit 12—Data Sorting Type: set to 1 when the data for the particular PMU is not integrated into the data frame by using its time tag. A concentrator will normally integrate data from a number of PMUs into a single frame by the time tags provided by the PMUs. If a PMU in the group loses external time sync for an extended period, a time tag provided by the PMU may prevent this integration, or make time alignment worse than using another integration method. As an alternative to simply discarding all the data, the concentrator can include the data in the frame using a “best guess” as to which frame it goes in, and a warning of lack of precise time correlation by setting bit 12. The simplest approach for the concentrator in a real-time system is to include the unsynchronized data with the most current synchronized data using the assumption that data communication delays are equal. This “sort-by-arrival” method is a simple best guess data alignment. Other methods can be used. In all cases, Bit 12 will be set to 1 when data is not correlated into its frame by time tag and cleared to 0 when data is correlated by time tag.

Bit 11—PMU Trigger pick-up: set to indicate a trigger condition has been detected for PMUs that have trigger capability. The bit shall be set for a mandatory set period of at least one data frame or one second, whichever is longer. It may remain set as long as the trigger condition is detected or may be cleared after this mandatory set period to allow for detection of other triggers.

Bit 10—Configuration change bit shall be set to a 1 to indicate that the PMU configuration will change. Transition of bit 10 from 0 to 1 indicates that a configuration change will become effective in 1 min. This bit is to be reset to 0 after 1 min and the configuration change shall be effective beginning with the first message where bit 10 is 0. The bit serves as an indication that the receiving device should request the configuration file to be sure configuration data is up to date. To be certain of having a valid configuration file, the receiving device shall request a configuration file whenever it has been off-line for more than a minute.

Bit 9—Data modified indicator. If phasor data in frame is modified by a post-processing device such as a PDC, this bit shall be set to 1. This shall include data points inserted by interpolation or lost point reconstruction, and data modified by down-sampling methods, offset adjustment, or error correction. In all other cases this bit shall be set to 0. It shall not be used to indicate conversions such as polar-rectangular and integer-floating point.

Bits 6–8—PMU_TQ (PMU Time Quality): This 3-bit time quality code shall indicate the maximum uncertainty in the measurement time at the time of measurement. It shall be derived from the time source and be adjusted to include uncertainties in the PMU measuring process. This time quality information indicates time quality at all times, both when time is considered locked and unlocked. The codes and their range of time uncertainty indication are detailed in Table 7. When the time quality is not known during startup, a code of 111b shall be used. A time quality of 000b indicates a previous version of this message that does not indicate time quality in these bits.

NOTE—The previous version of this standard, IEEE Std C37.118-2005 [B6], reserved bits 6–9 for adding security and required them to be set to 0. The security addition proved impractical, so these bits have been reassigned as above. The new TQ code remains with the measurement so the maximum time uncertainty can be used with any processing system. Since these bits were previously always zero, a non-zero value indicates time quality. A zero value indicates the bits are not used or PMU Time Quality is unknown (and so is compatible with the previous version of the standard).

This TQ has been added since the previous TQ does not report actual TQ during lock condition and it is not preserved with the measurements. Once data is passed to a higher level, the TQ that was observed during the measurement is lost. This code is the same as the CTQ specified for the IRIG-B profile in Annex D of IEEE Std C37.118.1-2011.

Table 7—3-bit PMU Time Quality indication codes (PMU_TQ)

BINARY	HEX	VALUE (worst-case accuracy)
111	7	Estimated maximum time error > 10 ms or time error unknown
110	6	Estimated maximum time error < 10 ms
101	5	Estimated maximum time error < 1 ms
100	4	Estimated maximum time error < 100 μs
011	3	Estimated maximum time error < 10 μs
010	2	Estimated maximum time error < 1 μs
001	1	Estimated maximum time error < 100 ns
000	0	Not used (indicates code from previous version of profile)

Bits 4–5—Unlocked time: indicates a range of seconds since loss of synch was detected. This counts seconds from the loss of lock on time synch until it is reacquired. When sync is reacquired, the code goes to 00. The criteria for determining when lock on time synch is achieved or lost is not specified in this standard. This will be normally implemented as follows:

Bit code	Indication
00	Locked or unlocked less than 10 s
01	Unlocked 10 s or longer but less than 100 s
10	Unlocked 100 s or longer but less than 1000 s
11	Unlocked 1000 s or more

Bits 0–3—Trigger reason: a 4-bit code indicating the initial cause of a trigger. See Table 6 for encoding.

6.4 Configuration frame

A configuration frame is a machine-readable BINARY data set containing information and processing parameters for a synchrophasor data stream. Three configuration frame types are specified and are identified by bits 4–6 of the SYNC word as shown in Table 2. CFG-1 and CFG-2 are part of the version 1 (IEEE Std C37.118-2005 [B6]) message set, and optional CFG-3 is introduced with version 2 (IEEE Std C37.118.2-2011). CFG-1 denotes the PMU/PDC capability, indicating all the data that the

PMU/PDC is capable of reporting. CFG-2 indicates measurements currently being reported (transmitted) in the data frame. This may be only a subset of available data. Both frames have identical structure with 19 fields, and with fields 8–19 repeated as necessary. In these frames, all fields are fixed length as described and no delimiters shall be used. The frame contents are shown in Table 8, and described in Table 9.

CFG-3 is similar to the other configuration frames and contains much of the same data but with added information and flexible framing. CFG-3 indicates measurements currently being reported in the data frame (the same as CFG-2). CFG-3 has variable length fields, added PMU and signal information, and extendable frame. The frame contents are shown in Table 10 and described in Table 11. Note CFG-3 is optional; a synchrophasor device does not have to implement this message to be considered compliant with this standard.

Table 8—Configuration frame 1 and 2 organization

No	Field	Size (bytes)	Short description
1	SYNC	2	Sync byte followed by frame type and version number.
2	FRAMESIZE	2	Number of bytes in frame, defined in 6.2.
3	IDCODE	2	Stream source ID number, 16-bit integer, defined in 6.2.
4	SOC	4	SOC time stamp, defined in 6.2.
5	FRACSEC	4	Fraction of Second and Message Time Quality, defined in 6.2.
6	TIME_BASE	4	Resolution of FRACSEC time stamp.
7	NUM_PMU	2	The number of PMUs included in the data frame.
8	STN	16	Station Name—16 bytes in ASCII format.
9	IDCODE	2	Data source ID number identifies source of each data block.
10	FORMAT	2	Data format within the data frame.
11	PHNMR	2	Number of phasors—2-byte integer (0 to 32 767).
12	ANNMR	2	Number of analog values—2-byte integer.
13	DGNMR	2	Number of digital status words—2-byte integer.
14	CHNAM	16 × (PHNMR + ANNMR + 16 × DGNMR)	Phasor and channel names—16 bytes for each phasor, analog, and each digital channel (16 channels in each digital word) in ASCII format in the same order as they are transmitted. For digital channels, the channel name order will be from the least significant to the most significant. (The first name is for bit 0 of the first 16-bit status word, the second is for bit 1, etc., up to bit 15. If there is more than 1 digital status, the next name will apply to bit 0 of the second word and so on.)
15	PHUNIT	4 × PHNMR	Conversion factor for phasor channels.
16	ANUNIT	4 × ANNMR	Conversion factor for analog channels.
17	DIGUNIT	4 × DGNMR	Mask words for digital status words.
18	FNOM	2	Nominal line frequency code and flags.
19	*CFGCNT*	2	Configuration change count.
	Repeat 8–19		Fields 8—19, repeated for as many PMUs as in field 7 (NUM_PMU).
20+	DATA_RATE	2	Rate of data transmissions.
21+	CHK	2	CRC-CCITT.

Table 9—Word definitions unique to configuration frames 1 and 2

Field	Size (bytes)	Description
SYNC	2	First byte: AA hex Second byte: 21 hex for configuration 1 31 hex for configuration 2 Both frames are version 1 (IEEE Std C37.118-2005 [B6])
TIME_BASE	4	Resolution of the fractional second time stamp (FRACSEC) in all frames. Bits 31–24: Reserved for flags (high 8 bits). Bits 23–0: 24-bit unsigned integer, which is the subdivision of the second that the FRACSEC is based on. The actual "fractional second of the data frame" = FRACSEC / TIME_BASE.
NUM_PMU	2	The number of PMUs included in the data frame. No limit specified. The actual limit will be determined by the limit of 65 535 bytes in one frame ("FRAMESIZE" field).
STN	16	Station Name—16 bytes in ASCII format.
IDCODE	2	Data stream ID number, 16-bit integer, defined in 6.2. It identifies the data stream in field 3 and the data source in fields 9 and higher. Field 3 identifies the stream that is being received. The IDCODEs in field 9 (and higher if more than one PMU data is present) identify the original source of the data and will usually be associated with a particular PMU. The IDCODEs in a data stream received directly from a PMU will usually be the same.
FORMAT	2	Data format in data frames, 16-bit flag. Bits 15–4: Unused Bit 3: 0 = FREQ/DFREQ 16-bit integer, 1 = floating point Bit 2: 0 = analogs 16-bit integer, 1 = floating point Bit 1: 0 = phasors 16-bit integer, 1 = floating point Bit 0: 0 = phasor real and imaginary (rectangular), 1 = magnitude and angle (polar)
PHNMR	2	Number of phasors—2-byte integer.
ANNMR	2	Number of analog values—2-byte integer.
DGNMR	2	Number of digital status words—2-byte integer. Digital status words are normally 16-bit Boolean numbers with each bit representing a digital status channel measured by a PMU. A digital status word may be used in other user-designated ways.
CHNAM	16	Phasor and channel names—16 bytes for each phasor, analog and digital status word in ASCII format in the same order as they are transmitted.
PHUNIT	4	Conversion factor for phasor channels. Four bytes for each phasor. Most significant byte: 0—voltage; 1—current. Least significant bytes: An unsigned 24-bit word in 10^{-5} V or amperes per bit to scale 16-bit integer data (if transmitted data is in floating-point format, this 24-bit value shall be ignored).
ANUNIT	4	Conversion factor for analog channels. Four bytes for each analog value. Most significant byte: 0—single point-on-wave, 1—rms of analog input, 2—peak of analog input, 5–64—reserved for future definition; 65–255—user definable. Least significant bytes: A signed 24-bit word, user defined scaling.
DIGUNIT	4	Mask words for digital status words. Two 16-bit words are provided for each digital word. The first will be used to indicate the normal status of the digital inputs by returning a 0 when exclusive ORed (XOR) with the status word. The second will indicate the current valid inputs to the PMU by having a bit set in the binary position corresponding to the digital input and all other bits set to 0. See NOTE.
FNOM	2	Nominal line frequency code (16 bit unsigned integer) Bits 15–1:Reserved Bit 0: 1—Fundamental frequency = 50 Hz 0—Fundamental frequency = 60 Hz

Table 9—Word definitions unique to configuration frames 1 and 2 *(continued)*

Field	Size (bytes)	Description
DATA_RATE	2	Rate of phasor data transmissions—2-byte integer word (–32 767 to +32 767) If DATA_RATE > 0, rate is number of frames per second. If DATA_RATE < 0, rate is negative of seconds per frame. E.g., DATA_RATE = 15 is 15 frames per second; DATA_RATE = –5 is 1 frame per 5 s.
CFGCNT	2	Configuration change count is incremented each time a change is made in the PMU configuration. 0 is the factory default and the initial value. This count identifies the number of changes in the configuration of this message stream. The count will be the same in all configuration messages (CFG-1, CFG-2, and CFG-3) for the same message revision.
NOTE—If digital status words are used for something other than Boolean status indications, the use of masks is left to the user, such as min or max settings.		

The CFG-3 frame includes the basic information that is in CFG-2, but adds a number of fields further defining PMU characteristics and quantities being sent. It adds an index for frame continuation in case the configuration gets too large to be sent as a single frame (frames are limited by the frame size field to 65535 bytes). The name fields have an index byte that specifies the field size. This allows name lengths up to 255 bytes and enables compressing the field size to the actual name length. The phasor and analog scaling has been expanded to include a multiplier and offset. Additional information has been added including PMU location, data measurement class, and algorithm factors. CFG-3 reports the contents of the data currently being sent (same as CFG-2). CFG-3 has 29 fields, with 9–27 repeated as necessary. The structure is the same as the other configuration messages, except there are more fields and the name fields are not fixed length (decoding requires reading the name field indexes). No delimiters are used. The frame contents are shown in Table 10, and described in Table 11.

Table 10 —Configuration frame 3 organization

No	Field	Size (bytes)	Short description
1	SYNC	2	Sync byte followed by frame type and version number.
2	FRAMESIZE	2	Number of bytes in frame, defined in 6.2.
3	IDCODE	2	PMU/PDC data stream ID number, 16-bit integer, defined in 6.2.
4	SOC	4	SOC time stamp, defined in 6.2.
5	FRACSEC	4	Fraction of Second and Message Time Quality, defined in 6.2.
6	CONT_IDX	2	Continuation index for fragmented frames.
7	TIME_BASE	4	Resolution of FRACSEC time stamp.
8	NUM_PMU	2	The number of PMUs included in the data frame.
9	STN	1–256	Station Name—in ASCII format with field index (see Table 12).
10	IDCODE	2	Data source ID number identifies source of each data block.
11	G_PMU_ID	16	Global PMU ID.
12	FORMAT	2	Data format within the data frame.
13	PHNMR	2	Number of phasors—2-byte integer (0 to 32 767).
14	ANNMR	2	Number of analog values—2-byte integer.
15	DGNMR	2	Number of digital status words—2-byte integer.
16	CHNAM	1–256 per name	Phasor and channel names—in ASCII with field index (see Table 12). Minimum of 1 byte for each phasor, analog, and digital channel. Names are in the same order as they are transmitted: all phasors, all analogs, and all digitals. For digital channels, the channel name order will be from the least significant to the most significant. (The first name is for bit 0 of the first 16-bit status word, the second is for bit 1, etc., up to bit 15. If there is more than 1 digital status, the next name will apply to bit 0 of the second word and so on.)
17	PHSCALE	12 × PHNMR	Conversion factor for phasor channels with flags.
18	ANSCALE	8 × ANNMR	Conversion factor for analog channels.
19	DIGUNIT	4 × DGNMR	Mask words for digital status words.
20	PMU_LAT	4	PMU Latitude in degrees, 32-bit floating point, WGS84 datum.
21	PMU_LON	4	PMU Longitude in degrees, 32-bit floating point, WGS84 datum.
22	PMU_ELEV	4	PMU Elevation in meters, 32-bit floating point, WGS84 datum.
23	SVC_CLASS	1	Service class, as defined in IEEE Std C37.118.1, a single ASCII character that is M or P for IEEE Std C37.118.1.
24	WINDOW	4	Phasor measurement window length including all filters and estimation windows in effect. Value is in microseconds, 4-byte integer value (to nearest microsecond).
25	GRP_DLY	4	Phasor measurement group delay including all filters and estimation windows in effect. Value is in microseconds, 4-byte integer value (to nearest microsecond).
26	FNOM	2	Nominal line frequency code and flags.
27	CFGCNT	2	Configuration change count.
	Repeat 9–27		Fields 9–27, repeated for as many PMUs as in field 8 (NUM_PMU).
28+	DATA_RATE	2	Rate of data transmissions.
29+	CHK	2	CRC-CCITT.

Table 11 —Word definitions unique to configuration frame 3

Field	Size (bytes)	Description
SYNC	2	First byte: AA hex Second byte: 52 hex for configuration 3 Frame is version 2
CONT_IDX	2	Continuation index for fragmented frames: 0: only frame in configuration, no further frames 1: first frame in series, more to follow 2–65534: number of each succeeding frame, in order 65535 (hex FFFF): last frame in series
TIME_BASE	4	Same as CFG-1 and CFG-2.
NUM_PMU	2	Same as CFG-1 and CFG-2.
STN	1–256	Station Name—in UTF-8 format, up to 255 bytes using the name field format (see Table 11).
IDCODE	2	Same as CFG-1 and CFG-2.
G_PMU_ID	16	This 128-bit Global PMU ID shall be a user-assigned value. It shall be stored in the PMU or other sending device so it can be sent with this configuration 3 message. It allows uniquely identifying PMUs in a system that has more than 65535 PMUs. The coding for the 16 bytes is left to the user for assignment.
FORMAT	2	Same as CFG-1 and CFG-2.
PHNMR	2	Same as CFG-1 and CFG-2.
ANNMR	2	Same as CFG-1 and CFG-2.
DGNMR	2	Same as CFG-1 and CFG-2.
CHNAM	1–256	Channel Names—one name for each phasor, analog, and digital channel in UTF-8 using the name field format (see Table 12). Names appear in the same order as they are transmitted: all phasors followed by all analogs followed by all digitals. For digital channels, the order is the same as described for configurations 1 and 2.
PHSCALE	12	Magnitude and angle scaling for phasors with data flags. This factor has three 4-byte long words: the first is bit-mapped flags, the second is a magnitude scale factor, and the third is an angle offset. First 4-byte word First 2 bytes: 16-bit flag that indicates the type of data modification when data is being modified by a continuous process. When no modification process is being applied, all bits shall be set to 0. (Bit 0 is the LSB, Bit 15 is the MSB.) This flag shall be used in conjunction with the data modification bit (Bit 9) in the status word. That bit shall be set in any frame that data has been modified by any process including those indicated in this flag.

Table 11—Word definitions unique to configuration frame 3 *(continued)*

Field	Size (bytes)	Description
		Bit # — Meaning when bit set 0 Not used, reserved 1 Up sampled with interpolation 2 Upsampled with extrapolation 3 Down sampled by reselection (selecting every Nth sample) 4 Down sampled with FIR filter 5 Down sampled with non-FIR filter 6 Filtered without changing sampling 7 Phasor magnitude adjusted for calibration 8 Phasor phase adjusted for calibration 9 Phasor phase adjusted for rotation (±30º, ±120º, etc.) 10 Pseudo-phasor value (combined from other phasors) 11–14 Reserved for future assignment 15 Modification applied, type not here defined Third byte: phasor type indication (Bit 0 is the LSB, Bit 7 is the MSB) Bits 07–04: Reserved for future use Bit 03: 0—voltage; 1—current. Bits 02–00: Phasor component, coded as follows 111: Reserved 110: Phase C 101: Phase B 100: Phase A 011: Reserved 010: Negative sequence 001: Positive sequence 000: Zero sequence Fourth byte: available for user designation Second and third 4-byte words For phasor $\boldsymbol{X} = X_m e^{j\varphi}$, this defines the scaling Y and angle offset θ to be applied to the phasor as follows: $\boldsymbol{X'} = Y \times X_m e^{j(\varphi-\theta)}$ The second 4-byte word is the scale factor Y in 32-bit IEEE floating point. This scales phasor data to primary volts or amperes. If phasors are transmitted in floating-point format and scaled already, this value shall be set to 1. The third 4-byte word is the phasor angle adjustment θ in radians represented in 32-bit IEEE floating point. If phasors are transmitted in floating-point format and scaled already, this value shall be set to 0.
ANSCALE	8	Linear scaling for analog channels. For analog value X, this defines scale M and offset B for $X' = M \times X + B$. First 4 bytes: Magnitude scaling M in 32-bit floating point. Last 4 bytes: Offset B in 32-bit floating point.
DIGUNIT	4	Mask words for digital status words. Two 16-bit words are provided for each digital word. The first will be used to indicate the normal status of the digital inputs by returning a 0 when exclusive Ored (XOR) with the status word. The second will indicate the current valid inputs to the PMU by having a bit set in the binary position corresponding to the digital input and all other bits set to 0. See NOTE.

Table 11—Word definitions unique to configuration frame 3 *(continued)*

Field	Size (bytes)	Description
PMU_LAT	4	PMU Latitude in degrees, range –90.0 to +90.0. Positive values are N of equator. WGS 84 datum. Number in 32-bit IEEE floating-point format. For unspecified locations, infinity shall be used.
PMU_LON	4	PMU Longitude in degrees, range –179.99999999 to +180. Positive values are E of the prime meridian. WGS 84 datum. Number in 32-bit IEEE floating-point format. For unspecified locations, infinity shall be used.
PMU_ELEV	4	PMU Elevation in meters, Positive values are above mean sea level. WGS 84 datum. Number in 32-bit IEEE floating-point format. For unspecified locations, infinity shall be used.
SVC_CLASS	1	Service class, as defined in IEEE Std C37.118.1, a single ASCII character. In 2011 it is M or P.
WINDOW	4	Phasor measurement window length including all filters and estimation windows in effect. Value is in microseconds, 4-byte signed integer value (to nearest microsecond). (For information only, any required compensation is already applied to the measurement.)
GRP_DLY	4	Phasor measurement group delay including all filters and estimation windows in effect. Value is in microseconds, 4-byte signed integer value (to nearest microsecond). (For information only, any required compensation is already applied to the measurement.)
FNOM	2	Nominal line frequency code (16 bit unsigned integer) Bits 15–1: Reserved Bit 0: 1—Fundamental frequency = 50 Hz 0—Fundamental frequency = 60 Hz
DATA_RATE	2	Rate of phasor data transmissions—2-byte integer word (–32 767 to +32 767) If DATA_RATE > 0, rate is number of frames per second. If DATA_RATE < 0, rate is negative of seconds per frame. E.g.: DATA_RATE = 15 is 15 frames per second; DATA_RATE = –5 is 1 frame per 5 s.
CFGCNT	2	Same as CFG-1 and CFG-2.
NOTE—If digital status words are used for something other than Boolean status indications, the use of masks is left to the user, such as min or max settings.		

Station and signal names shall be listed in fields whose length can vary from 1 to 256 bytes. The first byte in each name field is the length, which is an unsigned 8-bit integer that indicates the length of the name in bytes. A length of 0 indicates no further bytes (no name). All name fields will have at least one byte that is the name length. All names shall use UTF-8 coding.

Table 12—Name field description

More names	Name field (single station or signal name)		More names
…	1 byte	0–255 bytes	…
—	Name length—unsigned 8-bit integer, 0–255	Name, UTF-8 coding Note that standard 7-bit ASCII characters are the same as UTF-8 and no conversions are required	—

6.5 Header frame

This frame shall be human-readable information about the PMU, the data sources, scaling, algorithms, filtering, or other related information. The frame has the same SYNC, FRAMESIZE, SOC, FRACSEC, and CHK as the other frames, and is identified by bits 4–6 the SYNC word as shown in Table 2. The data section has no fixed format (Table 13).

Table 13 —Header frame organization

No	Field	Size (bytes)	Comment
1	SYNC	2	Sync byte followed by frame type and version number (AA11 hex).
2	FRAMESIZE	2	Number of bytes in frame, defined in 6.2.
3	IDCODE	2	PMU/PDC data stream ID number, 16-bit integer, defined in 6.2.
4	SOC	4	SOC time stamp, defined in 6.2.
5	FRACSEC	4	Fraction of Second and Time Quality, defined in 6.2.
6	DATA 1	1	ASCII character, 1st byte.
K+6	DATA k	1	ASCII character, Kth byte, K>0 is an integer.
K+7	CHK	2	CRC-CCITT.

6.6 Command frame

A data sending device (PMU or PDC) shall be able to receive commands and take appropriate actions. This Command Frame uses the same SYNC, FRAMESIZE, SOC, FRACSEC, and CHK words as all other messages and is identified by bits 4–6 of the SYNC word as shown in Table 2. The command message frame is shown in Table 14. IDCODE shall be a 2-byte identification code assigned to a PMU/PDC data stream output and is the same as field 3 in the configuration frame. The CHK is the 16-bit CRC-CCITT described previously. The PMU/PDC shall match the IDCODE with a valid code stored internally before accepting and executing the command. The IDCODE for each output stream shall be user settable. The PMU/PDC shall match the command code with that of a configured output stream and execute the command for the indicated data stream output, leaving other streams, if there are any, unchanged. CMD shall be a 2-byte command code as defined in 0.

Table 14 —Command frame organization

No	Field	Size (bytes)	Comment
1	SYNC	2	Sync byte followed by frame type and version number (AA41 hex).
2	FRAMESIZE	2	Number of bytes in frame, defined in 6.2.
3	IDCODE	2	PMU/PDC ID data stream number, 16-bit integer, defined in 6.2.
4	SOC	4	SOC time stamp, defined in 6.2.
5	FRACSEC	4	Fraction of Second and Time Quality, defined in 6.2.
6	CMD	2	Command being sent to the PMU/PDC (0).
7	EXTFRAME	0–65518	Extended frame data, 16-bit words, 0 to 65518 bytes as indicated by frame size, data user defined.
8	CHK	2	CRC-CCITT.

Table 15—Commands sent to the PMU/PDC

Command word bits	Definition
Bits 15–0:	
0000 0000 0000 0001	Turn off transmission of data frames.
0000 0000 0000 0010	Turn on transmission of data frames.
0000 0000 0000 0011	Send HDR frame.
0000 0000 0000 0100	Send CFG-1 frame.
0000 0000 0000 0101	Send CFG-2 frame.
0000 0000 0000 0110	Send CFG-3 frame (optional command).
0000 0000 0000 1000	Extended frame.
0000 0000 xxxx xxxx	All undesignated codes reserved.
0000 yyyy xxxx xxxx	All codes where yyyy ≠ 0 available for user designation.
zzzz xxxx xxxx xxxx	All codes where zzzz ≠ 0 reserved.

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.

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[B3] IEEE Std 1344™-1995, IEEE Standard for Synchrophasors for Power Systems.

[B4] IEEE Std 1588™-2008, IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems.

[B5] IEEE Std C37.111™-1999, IEEE Standard Common Format for Transient Data Exchange (COMTRADE) for Power Systems.

[B6] IEEE Std C37.118™-2005, IEEE Standard for Synchrophasors for Power Systems.

[B7] IEEE Std C37.238™-2011, IEEE Standard Profile for Use of IEEE 1588™ Precision Time Protocol in Power System Applications.

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[B10] Wells, R. B., *Applied Coding and Information Theory for Engineers.* Upper Saddle River, NJ: Prentice Hall, 1999.

[B11] Wicker, S. B., *Error Control Systems for Digital Communications and Storage.* Upper Saddle River, NJ: Prentice Hall, 1995.

[B12] Witzke, K. A., and Leung, C., “A Comparison of Some Error Detecting CRC Code Standards,” *IEEE Transactions on Communications,* Vol. COM-33, No. 9, September 1985, pp. 996–998.

[7] The *IEEE Standards Dictionary: Glossary of Terms & Definitions* is available at http://shop.ieee.org/

[8] IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (http://standards.ieee.org).

[9] The IEEE standards or products referred to in Annex A are trademarks owned by the Institute of Electrical and Electronics Engineers, Incorporated.

Annex B

(informative)

Cyclic redundancy codes

CRC

Cyclic redundancy codes are used to verify (or at least indicate) that a set of data has not been corrupted. They are specified by a polynomial, the initial value of the shift registers, the direction the bits are shifted, and optionally a mask to be XORed with the final register values. The CRC commonly referred to as CRC-CCITT is illustrated in Figure B.1.

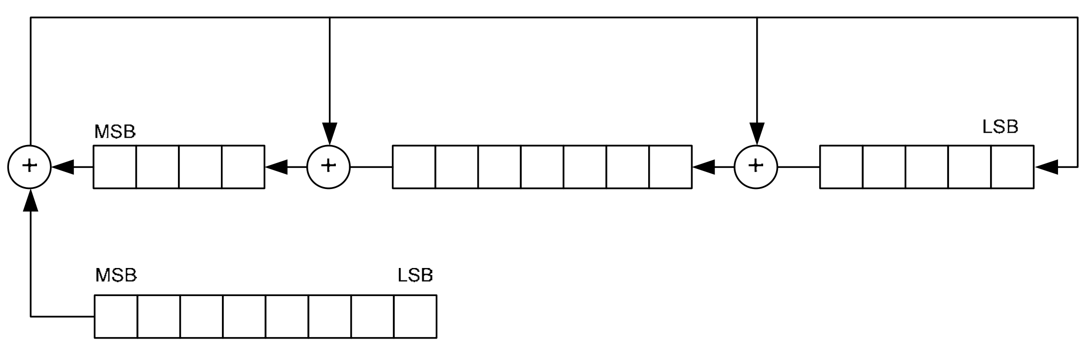
CRC-CCITT

This annex describes the CRC calculation used in this standard and commonly referred to as CRC-CCITT. It shall be noted, however, that the CRC-CCITT described here, and which is in common usage, does not seem to be specified in any CCITT/ITU standard. ITU-T Recommendation V.41 describes a very similar CRC calculation; however, that document proscribes a different initial value than is used in the common implementation of CRC-CCITT. Other ITU documents describe CRC calculations using the same polynomial and initial conditions, but require a final XOR mask not used in CRC-CCITT.

CRC-CCITT definition

Since no CCITT/ITU document could be found to describe the CRC calculation commonly referred to as CRC-CCITT, we define it as follows in conjunction with Figure B.1.

CRC-CCITT



$g(x) = x^{16} + x^{12} + x^5 + 1$

Initial Conditions: FFFFh
No Final Mask

Figure B.1—CRC-CCITT encoder

Polynomial

$$g(x) = x^{16} + x^{12} + x^5 + 1$$

Initial condition
The Shift registers of Figure B.1 are initialized to 1.

Final mask
No final mask is XORed with the final register values.

CRC-CCITT properties
Three important properties of CRCs are often discussed, their error pattern coverage, their burst error detection capability, and the probability of an undetected error occurring.

Error pattern coverage
Error pattern coverage λ is defined as the ratio of the number of invalid bit patterns over the number of valid bit patterns.

$$\lambda = \frac{2^n - 2^k}{2^n} = 1 - 2^{k-n} = 0.999985$$

where k is the number of bits in the message excluding the CRC value, and n is the number of bits including the CRC value. Therefore, the error pattern coverage is solely a function of the size of the CRC value.

Burst error detection
Another important property of CRCs is their ability to detect burst errors. Burst errors are transient or intermittent corruptions of several symbols in a transmitted data stream. By definition, there can be no more than one burst error per message. For binary data, the burst spans all corrupted bits and is bounded by ones. In the following example, let V be an uncorrupted bit, 1 be a nonzero bit, and X be a corrupted bit, a zero, or a one with corrupted bits to both its left and right.

…VVV1XXXX1VVV…

Therefore, the burst error length of the above message is 6.

Burst error detection probability of CRC-CCITT
Both Wells [B10] and Wicker [B11] show that the burst error detection probability of a 16-bit binary CRC is as follows[10]:

- 100% of all bursts less < 17 bits long
- 99.997% of all bursts which are 17 bits long
- 99.9985% of all bursts that are greater than 17 bits long

[10] These burst error detection probabilities are valid when the order of transmitted data matches the order of the data during CRC calculation.

Probability of an undetected error
The lower bound for the probability of an undetected error, over a noisy binary symmetric channel is given in Wicker [B11] as follows:

> *For any CRC code of length p used for error detection on the binary symmetric channel, the undetected error probability approaches* 2^{-p} *as the crossover probability and the dimension k of the code increases.*

Sample "C" code calculation example
A number of algorithms are available for calculating the CRC-CCITT. Common and probably the fastest are look-up table routines. The following example is very compact, simple, and does not need a look-up table.

```
/* Compute CRC-CCITT. *Message is a pointer to the first character in the
message; MessLen is the number of characters in the message (not
counting the
CRC on the end) */

uint16_t ComputeCRC(unsigned char *Message, unsigned char MessLen)
{
   uint16_t crc=0xFFFF;
   uint16_t temp;
   uint16_t quick;
   int      i;

   for(i=0;i<MessLen;i++)
   {
      temp = (crc>>8) ^ Message[i];
      crc <<= 8;
      quick = temp ^ (temp >> 4);
      crc ^= quick;
                                     quick <<=5;
      crc ^= quick;
      quick <<= 7;
      crc ^= quick;
   }
   return crc;
}
```

Examples
Table B.1 contains example data, shown both as ASCII characters and as hexadecimal values, and the resulting CRC value.

Table B.1—Example data

ASCII data	Equivalent hexadecimal data	Resultant CRC value
ABCD	0x41 0x42 0x43 0x44	0xBFFA
123456	0x31 0x32 0x33 0x34 0x35 0x36	0x2EF4
abc	0x61 0x62 0x63	0x514A

Annex C

(informative)

System communications considerations

C.1 Communication bandwidth

This standard does not impose any restriction on the communication system or media itself. It defines four message types—*data, configuration, header,* and *command*—to and from a PMU or PDC for real-time synchrophasor communication. It also prescribes the message contents and format. These are detailed in Clause 6.

Typically, the receiving device requests a configuration and header using the commands at startup or a configuration change only. Most of the time the data frame is transmitted continuously from the PMU or PDC at the designated reporting rate. Consequently the required bandwidth is determined by the data frame size, data rate, and communication overheads. The frame size is precisely described in this standard and varies depending on the number of phasors and analog and digital words included in the frame. Typical sizes vary from 40–70 bytes for frames from a single PMU to over 1000 bytes in a frame from a PDC with data from many PMUs. Table C.1 gives some examples in bits per second (bps) for some typical PMU configurations. Note that the communication media will add overhead, which can be considerable. Asynchronous serial communication adds 2 bits per byte (25% overhead) and TCP adds 44 bytes/frame, which can amount to more than 50% overhead.

Table C.1—Estimation of bandwidth requirements for example PMU configurations

Transmission rate in bits per second (bps) for example messages using UDP/IP over Ethernet							
PMU reporting rate (data frames/second)	10	12	15	25	30	50	60
Message content: 2 phasors, all quantities integer	6 720	8 064	10 080	16 800	20 160	33 600	40 320
Message content: 2 phasors, all quantities floating point	7 680	9 216	11 520	19 200	23 040	38 400	46 080
Message content: 12 phasors, all integer	9 920	11 904	14 880	24 800	29 760	49 600	59 520
Message content: 12 phasors, 2 analog, 2 digital, all integer	10 560	12 762	15 840	26 400	31 680	52 800	63 360

C.2 Communication delay

An interval of time is required to make a measurement, send the measurement data to a device that will use the measurement, and then use the data. This interval of time from when the signal has a certain value to when the measurement is consumed by the application is called *delay* in this subclause. The first aspect of this delay is in the measurement process. That includes the window over which data is gathered to make a measurement, the estimation method and filtering, and the time to process that data. The second aspect is the communication of the data including the time to send each bit of the message, the distance and type of communication, and various communication buffering, multiplexing, conversion processes. Finally the last aspect is the processing of the receiving device and application algorithms.

Delay in measurement is largely dependent on the processing window and filtering, which vary with the data reporting rate and the PMU class of service. Processing delays for calculating the measurement are generally very small compared with other delays. Additional delays caused by servicing other processing needs such as a multifunction device may cause large interruptions or may be insignificant.

Communication delay starts with clocking the bits out of the PMU and is easily measured. With RS-232 serial this delay can be in the millisecond range, but at network speeds is insignificant. Once multiplexed onto a communication baseband, data travels at 0.6 to 0.99 times the speed of light. For example, data sent 500 mi would only be delayed 3 ms to 5 ms, a relatively small number that is predictable based on the communication network. However buffering, de-multiplex/multiplex points, forwarding, and routing can add tens to hundreds of milliseconds and may not be very predictable. Error detection/correction can add hundreds of milliseconds to seconds. Data concentration with delays allowed for data with various delays can also add seconds. Some typical values for delays are summarized in Table C.2.

Table C.2—Summary of delays' causes and typical ranges

Cause of delay	Typical range of delay
Sampling window (delay ½ of window)	17 ms to100 ms
Measurement filtering	8 ms to 100 ms
PMU processing	0.005 ms to 30 ms
PDC processing & alignment	2 ms to 2+ s
Serializing output	0.05 ms to 20 ms
Communication system I/O	0.05 ms to 30 ms
Communication distance	3.4 µs/km to 6 µs/km
Communication system buffering and error correction	0.05 ms to 8 s
Application input	0.05 ms to 5 ms

Note that while these are typical, actual values can be different and systems need to be evaluated on a case-by-case basis. The minimum overall delay one could anticipate is in the order of 20 ms (no added filtering). The maximum delay in a real-time system could be in the 10 s range or longer. A typical system from PMU to PDC will be in the 20 ms to 50 ms range. Each level above that will add some PDC processing and wait times, probably in the 30 ms to 80 ms range (and in addition to the PMU to PDC time). If delay in data delivery is critical to applications, the designers need to examine all communication aspects they are incorporating to make sure delivery time meets specifications and there are no unexpected delays.

Annex D

(informative)

Message examples

D.1 Introduction

IEEE Std C37.118-2005 [B6] describes four message types: *data, configuration, header,* and *command.* The configuration, data, and command messages are binary messages, and the header message is in a human-readable format.

This annex provides examples of the three binary message types. Command messages control the operation of the synchrophasor measurement device. Data messages contain the actual measurements. Configuration messages contain information required to decode the data messages.

In general, the data communication structure is designed to support the following requirements:

a) Only measured and computed data shall be transmitted in real time. Informational data shall be transmitted only on request.

b) All real-time data shall be traceable to an absolute time reference. This data shall be in the most compact form possible to fit the available channel bandwidth. However, consideration shall be given to optimization of host computer hardware and software.

c) A wide range of data transmission rates shall be supported.

d) The format shall support bi-directional real-time control functions in a full-duplex communication mode.

e) A mechanism to transmit bi-directional status information shall be provided.

f) Data integrity checks shall be provided.

g) The amount and type of data transmitted shall be user definable to adjust to the wide range of data requirements.

D.2 Data message

Table D.1 contains an example data frame. Each row of the table contains a field of the message described in 6.2 and 6.3 of this standard. The first column contains the field name. The second column contains a brief description of the data contained in the field (see Clause 6 for details). The third column contains specific example data. The fourth column contains the number of 8-bit bytes of data in the field. The fifth column contains the hexadecimal equivalent of the example data.

The time of this example is 9:00.016667 AM (UTC) on June 6, 2006. The data frame indicates a balanced 3-phase phase-to-neutral voltage of 134 000 V and a constant system frequency of 62.5 Hz. There are no triggers and the measurement was made referenced to a high quality time source.

Use the information contained in the configuration frame, shown in Table D.2, to decode this data frame. For example, the PHUNIT fields of the configuration frame indicate the scaling of the voltage phasors is 9.15527 (0xDF847) V per bit. The real part of the A phase voltage has a magnitude of 14 635 (0x392B) counts. Multiply 9.15527 V per count by 14 635 counts to get 133 987 V.

Table D.1—Data message example

Field	Short description	Example entry	Size (bytes)	Hexadecimal value
SYNC	Synchronization and Frame Format Field.	Data Frame, Version 1	2	AA 01
FRAMESIZE	Total number of bytes in this frame.	52 bytes in this frame	2	00 34
IDCODE	PMU/PDC data stream ID number, 16-bit integer, 1–65534.	7734	2	1E 36
SOC	Second count. (UNIX time, starting midnight 01-Jan-1970 neglecting leap seconds).	9:00 AM on 6/6/2006 = 1 149 580 800	4	44 85 36 00
FRACSEC	Time of phasor measurement in microseconds with Time Quality.	Not a leap second, none pending; time locked. 16817 µs after the second mark	4	00 00 41 B1
STAT	Bit mapped flags: Data valid?, PMU OK?, PMU sync?, Data align by time?, PMU Trigger?, Reserved, Time Error, Trigger Cause	Data valid, no PMU error, PMU sync, data sorted by time stamp, no PMU trigger, best time quality	2	00 00
PHASORS	Phasor data, 16-bit integer, rectangular format. The first two bytes contain the real part of the phasor and the second two contain the imaginary part.	VA = 14 635 ∠ 0° (= 134.0 kV ∠ 0°)	4	39 2B 00 00
		VB = 14 635 ∠ -120° (= 134.0 kV ∠ –120°)	4	E3 6A CE 7C
		VC = 14 635 ∠ 120° (= 134.0 kV ∠ 120°)	4	E3 6A 31 83
		I1 = 1092 ∠ 0° (= 500 A ∠ 0°)	4	04 44 00 00
FREQ	16-bit signed integer. Frequency deviation from nominal in mHz.	+2500 mHz (nominal 60 Hz with measured 62.5 Hz)	2	09 C4
DFREQ	ROCOF.		2	00 00
ANALOG	32-bit floating point.	ANALOG1 = 100	4	42 C8 00 00
		ANALOG2 = 1000	4	44 7A 00 00
		ANALOG3 = 10000	4	46 1C 40 00
DIGITAL	Digital data, 16-bit bit fields.	0011 1100 0001 0010	2	3C 12
CHK	CRC-CCITT.	—	2	D4 3F

D.3 Configuration message

Use the configuration frame described in Table D.2 to decode the data frame of Table D.1. In the standard, 6.2 and 6.4 describe the format of the fields listed in each row of Table D.2. As in Table D.1, the first column of Table D.2 contains the field names, the second column contains brief descriptions of the data in the fields, the third column contains example data, the fourth column indicates the number of bytes of data, and the last column shows the hexadecimal values of the example data.

Table D.2—Configuration message example

Field	Short description	Example	Size (bytes)	Hexadecimal value
SYNC	Synchronization byte and version number.	Configuration Frame 2 Version 1	2	AA 31
FRAMESIZE	Number of bytes in frame.	This frame contains 454 bytes	2	01 C6
IDCODE	PMU/PDC data stream ID number, 16-bit integer, 1–65534.	7734	2	1E 36
SOC	SOC time stamp (UNIX time, starting midnight 01-Jan-1970).	8:00 AM on 6/6/2006 = 1 149 577 200	4	44 85 27 F0
FRACSEC	Fraction of second with Time Quality.	Leap second pending, to be deleted, clock unlocked but within 100 µs. Fractional time is 0.463 s.	4	56 07 10 98
TIME_BASE	Flag and divisor for time stamping the data.	1 000 000 µs	4	00 0F 42 40
NUM_PMU	The number of PMUs included in the data frame.	Data from 1 PMU	2	00 01
STN	Station Name—16 bytes in ASCII format.	The station name for this example is: “Station A ”	16	53 74 61 74 69 6F 6E 20 41 20 20 20 20 20 20 20
IDCODE	PMU/PDC data source ID number, 16-bit integer, 1–65534.	7734	2	1E 36
FORMAT	Data format within the data frame.	Phasors are represented using rectangular coordinates and 16-bit integers. Analogs are 32-bit floating-point numbers.	2	00 04
PHNMR	Number of phasors—2 byte integer (0 to 32 767).	This example contains 4 phasors.	2	00 04
ANNMR	Number of analog values—2 byte integer.	This example contains 3 analog values.	2	00 03
DGNMR	Number of digital status words—2 byte integer.	This example contains 1 set of binary data.	2	00 01

Table D.2—Configuration message example *(continued)*

Field	Short description	Example	Size (bytes)	Hexadecimal value
CHNAM	Phasor and channel names—16 bytes for each phasor, analog, and digital channel in ASCII format in the same order as they are transmitted.	The first phasor name is: “VA ”	16	56 41 20 20 20 20 20 20 20 20 20 20 20 20 20 20
		The second phasor name is: “VB ”	16	56 42 20 20 20 20 20 20 20 20 20 20 20 20 20 20
		The third phasor name is: “VC ”	16	56 43 20 20 20 20 20 20 20 20 20 20 20 20 20 20
		The fourth phasor name is: “I1 ”	16	49 31 20 20 20 20 20 20 20 20 20 20 20 20 20 20
		The first analog name is: “ANALOG1 ”	16	41 4E 41 4C 4F 47 31 20 20 20 20 20 20 20 20 20
		The second analog name is: “ANALOG2 ”	16	41 4E 41 4C 4F 47 32 20 20 20 20 20 20 20 20 20
		The third analog name is: “ANALOG3 ”	16	41 4E 41 4C 4F 47 33 20 20 20 20 20 20 20 20 20
		Digital channel 1 label is: “BREAKER 1 STATUS“	16	42 52 45 41 4B 45 52 20 31 20 53 54 41 54 55 53
		Digital channel 2 label is: “BREAKER 2 STATUS”	16	42 52 45 41 4B 45 52 20 32 20 53 54 41 54 55 53
		Digital channel 3 label is: “BREAKER 3 STATUS”	16	42 52 45 41 4B 45 52 20 33 20 53 54 41 54 55 53
		Digital channel 4 label is: “BREAKER 4 STATUS”	16	42 52 45 41 4B 45 52 20 34 20 53 54 41 54 55 53
		Digital channel 5 label is: “BREAKER 5 STATUS”	16	42 52 45 41 4B 45 52 20 35 20 53 54 41 54 55 53

Table D.2—Configuration message example *(continued)*

Field	Short description	Example	Size (bytes)	Hexadecimal value
		Digital channel 6 label is: “BREAKER 6 STATUS”	16	42 52 45 41 4B 45 52 20 36 20 53 54 41 54 55 53
		Digital channel 7 label is: “BREAKER 7 STATUS”	16	42 52 45 41 4B 45 52 20 37 20 53 54 41 54 55 53
		Digital channel 8 label is: “BREAKER 8 STATUS”	16	42 52 45 41 4B 45 52 20 38 20 53 54 41 54 55 53
		Digital channel 9 label is: “BREAKER 9 STATUS”	16	42 52 45 41 4B 45 52 20 39 20 53 54 41 54 55 53
		Digital channel 10 label is: “BREAKER A STATUS”	16	42 52 45 41 4B 45 52 20 41 20 53 54 41 54 55 53
		Digital channel 11 label is: “BREAKER B STATUS”	16	42 52 45 41 4B 45 52 20 42 20 53 54 41 54 55 53
		Digital channel 12 label is: “BREAKER C STATUS”	16	42 52 45 41 4B 45 52 20 43 20 53 54 41 54 55 53
		Digital channel 13 label is: “BREAKER D STATUS”	16	42 52 45 41 4B 45 52 20 44 20 53 54 41 54 55 53
		Digital channel 14 label is: “BREAKER E STATUS”	16	42 52 45 41 4B 45 52 20 45 20 53 54 41 54 55 53
		Digital channel 15 label is: “BREAKER F STATUS”	16	42 52 45 41 4B 45 52 20 46 20 53 54 41 54 55 53
		Digital channel 16 label is: “BREAKER G STATUS”	16	42 52 45 41 4B 45 52 20 47 20 53 54 41 54 55 53
PHUNIT	Conversion factor for phasor channels. PhasorMAG = PHUNIT X× 0.00001 Voltage PHUNIT = (300 000/32768) × 10E+5 Current PHUNIT = (15 000/32768) × 10E+5	Factor = 915527	4	00 0D F8 47
		Factor = 915527	4	00 0D F8 47
		Factor = 915527	4	00 0D F8 47
		Factor = 45776	4	01 00 B2 D0

Table D.2—Configuration message example *(continued)*

Field	Short description	Example	Size (bytes)	Hexadecimal value
ANUNIT	Conversion factor for analog channels. Because the analogs are represented by floating-point conversion factor is unity (or simply not used).	This analog is an "instantaneous" sample of a point on the input waveform	4	00 00 00 01
		This analog is an rms calculation	4	01 00 00 01
		This analog is a peak calculation	4	02 00 00 01
DIGUNIT	Mask words for digital status words.	First mask: Normal state is 0 for all bits Second mask: All 16 bits are valid	4	00 00 FF FF
FNOM	Nominal line frequency code and flags.	Nominal 60 Hz	2	00 00
CFGCNT	Configuration change count.	22 changes	2	00 16
DATA_RATE	Rate of phasor data transmissions.	30 messages per second	2	00 1E
CHK	CRC-CCITT.	—	2	D5 D1

D.4 Command message

Command messages affect the behavior of the PMU. They control the transmission of data, configuration, and header messages. The example shown in Table D.3 causes a PMU to begin transmission of data messages. The fields shown are described in 6.2 and 6.6 of the standard.

Table D.3—Command message example

Field	Short description	Example	Size (bytes)	Hexadecimal value
SYNC	Synchronization byte and version number.	Command Message, Version 1	2	AA 41
FRAMESIZE	Number of bytes in frame.	18	2	00 12
IDCODE	Data stream ID number, 16-bit integer, 1–65534.	7734	2	1E 36
SOC	SOC time stamp.	12:00 AM on 6/6/2006 = 1 149 591 600	4	44 85 60 30
FRACSEC	Fraction of second with Time Quality.	No leap second pending or past, clock never locked, fractional time 0.77 s	4	0F 0B BF D0
CMD	Defined commands are data on, data off, send header, send configuration, extended frame.	Turn on the data stream	2	00 02
CHK	CRC-CCITT.	—	2	CE 00

Annex E

(normative)

Synchrophasor message mapping into communications

E.1 Serial communications

The messages specified in Clause 6 shall be mapped in their entirety into the serial communication interface. RS-232 is commonly sent byte by byte with various functions that access the serial interface. The entire message as described in Clause 6 shall be written in the order described to the serial interface. Likewise, when received, it shall be read in its entirety from the serial interface. The serial communication system may apply ordering or encoding within the communication system, but as long as compatible devices are used at both ends, the data written into and read from the serial interface will be the same and in the same order. Figure E.1 illustrates this process.

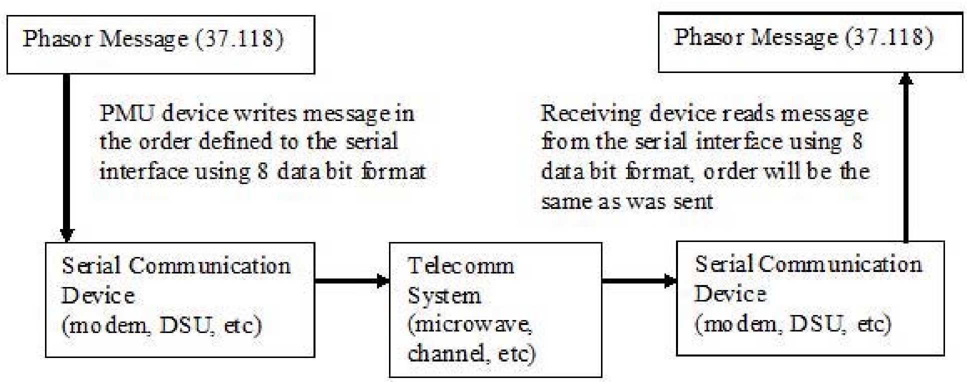


Figure E.1—Phasor message transmission over serial communications

E.2 Network communications using Internet protocol (IP)

Phasor messages shall also be mapped in their entirety into TCP (as defined in RFC 793) or UDP (as defined in RFC 768). They shall be written to and read from using standard IP input-output functions. Default port numbers shall be 4712 for TCP and 4713 for UDP, but in all cases, the user shall be provided the means to set port numbers as desired. The IP may be carried over Ethernet or another transport means. With a stacked protocol like IP, each message layer is encapsulated in the next one down to the transport layer where the message is sent. This process is illustrated in Figure E.2.

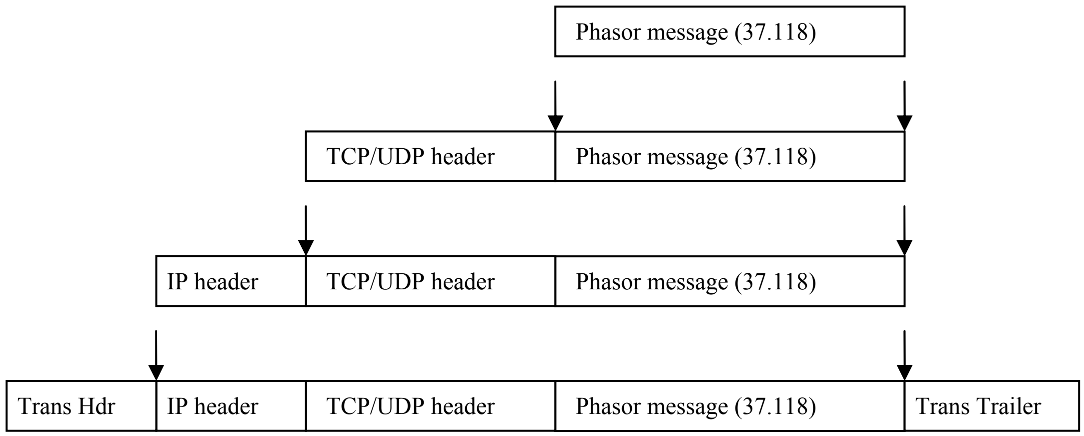


Figure E.2—Mapping of IEEE C37.118 data into a TCP or UDP packet—A transport layer header and trailer are shown, as it would be when using Ethernet

Annex F

(informative)

Synchrophasor communication methods for IP

F.1 Communication introduction

Data transmission using this standard is a real-time method, where data is sent immediately after measurement using a predefined constant interval. Data transmission for non-real-time uses and other protocols will have different requirements that are not discussed here. Using this standard, synchrophasor data can be carried over any communication system that has sufficient bandwidth and allows using this message structure. The required bandwidth will be dictated by the reporting rate and the message size. Originally, only RS-232 serial communications were used and the data was mapped directly into the serial API. As communications have evolved into network methods, synchrophasor communication has moved as well. While not proscribed by the standard, several common methods using IP have evolved. These methods have been followed by vendors and implementers. IP is widely used and commonly available, so these methods are easy to implement with standard equipment and easy to operate by IT personnel. These methods are described in the following subclauses.

Cyber security must be addressed with the communications used to transport synchrophasor data. This annex describes only methods that have been implemented to date and does not attempt to prescribe measures that may be applied in the future. Users of these methods need to be aware of the risks of unsecured communications and should consider adopting more secure methods.

F.2 Transmission using IP over Ethernet

Phasor measurement systems most commonly use the IP over network communications. The previous standard, IEEE Std C37.118-2005 [B6], as well as this standard require that if a stacked protocol such as IP is used for transmitting the messages, that they are included in their entirety (all parts of the defined message is included). It further prescribes default ports for using communication by both TCP and UDP, though the user can specify any port assignment they prefer.

The common methods for communication are as follows:

a) Client-server. The device providing data is the server and the device receiving data is the client. The device providing data can be a PMU, a PDC, or any other device that will output synchrophasor data. The device receiving data can be a PDC or any or other device that receives synchrophasor data. In cases where data transmission is initiated by command, the client initiates contact and controls data flow with commands

b) Basic modes of operation: spontaneous and commanded. With spontaneous, the server sends data by UDP to a designated destination without stopping, whether a receiving device is present or not. The stream is initiated by a function in the device accessed separately from data operations. With commanded operation, the server only sends data when a client requests it using the standard Start and Stop commands. Both modes may support commands to retrieve configuration and header data.

c) TCP, UDP, and multicast communication. All modes are supported in various appropriate configurations.

F.2.1 TCP-only method

This method has a single TCP connection over which commands, data, header, and configuration frames are passed. The client needs to know only the server address and port. The usual TCP data management advantages and benefits apply to all data. The link is easy to administer, troubleshoot, and manage. The main disadvantage is that with the high rate and continuous data transmission, a single dropped data packet can cause data backup in the TCP mechanism that causes an interval of data loss. If the data is recovered, all data will be delayed, which is often much worse for real-time applications than the loss of one packet. There is also more traffic generated by the return acknowledgements. TCP is a connection based protocol, thus is strictly a 1-to-1 connection, so if data is required for more than one client, it has to be sent separately to each destination. This increases traffic and requires the PMU to support multiple TCP connections. Another TCP disadvantage comes from the fact it requires two-way communication to make a connection; if security measures block incoming traffic from a protected zone, a TCP client will be unable to connect. Spontaneous UDP can operate with outgoing messages only and avoids this problem.

F.2.2 UDP-only method

This method uses straight UDP for communication in both directions for PMU messages, including commands, data, header, and configuration. The client must know the server address and port number. The server can respond to the client port or a different port by prior arrangement. The advantages of using UDP are reduced bandwidth requirements and elimination of a backup delay, due to dropouts as described for TCP in F.2.1. The disadvantage is that server-client communications are not confirmed so it is difficult to locate problems if the communications do not proceed as expected. With UDP, data is not retransmitted in case of error, so errored packets are permanently lost (unless a suitable recovery system is provided by the user). There also can be difficulty with controlling data streams since more than one client can access the connectionless control port. If data is sent to a unicast IP address, it then must be sent to each client separately. Alternatively, data can be sent to a multicast IP address, allowing numerous clients to receive it, thus minimizing network traffic. However, the user will need to set the multicast address and port separately since the command does not do this. The drawbacks to this method are real but mostly academic, and seem to cause no problems in operational systems.

F.2.3 TCP/UDP method

This method uses TCP for commands, header, and configuration communications, and UDP for sending data. The server address and port must be known to the client, and the client port UDP port must be known to the server (PMU). If the UDP is sent by multicast, that address must be known to the server as well. The commands, header, and configuration communication is secured through the TCP link and the data is sent by UDP. This minimizes data transmission delay and does not risk backup, though data will not be replaced if corrupted. This method has the advantage of more secure transmission on the critical data portions, and minimal delay or backup risk on the streaming data. It can also use multicast to reduce traffic and can support retrieving configuration information without interrupting the data transmission. It is probably the most complete of the phasor communication methods. The disadvantage is that the server must know the destination port in advance

F.2.4 Spontaneous data transmission method

With this method, a PMU, PDC, or other data serving device sends out data in the IEEE C37.118 format to a preset destination continuously. The data is sent by UDP and can be unicast, multicast, or broadcast. The output is initiated by a device setting or device interface—not through the IEEE C37.118 command set. To be compliant with the standard, command functionality must be provided. While this will make the device technically non-compliant, the user may prefer the benefits of this operation. Since the data is sent by UDP, a destination device does not have to be present. This mode is useful for sending data using multicast to many clients that may be coming online and offline randomly. It allows a steady supply of data without interruption, and can be used where two way communication is prohibited, such as through a firewall. Header and configuration information retrieval may be allowed on the same or a different channel.. In some cases, a configuration frame is sent spontaneously at a preset interval, such as once a minute, along with the data. The drawback to this method is lack of ability to turn the data stream on and off, and possibly limited ability for a client to retrieve configuration information using normal IEEE C37.118 methods. Accountability can be difficult to implement, as there is no way to tell who is listening to the data stream. This method is generally used over a small private or secured network.