SATEC

Phasor Measurement Unit
PMU PRO

IEEE C37.118.2 Synchrophasor Data Transfer Protocol

Reference Guide

BG0655 Rev. A5

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For further information regarding a particular installation, operation or maintenance of equipment, contact the manufacturer or your local representative or distributor.

REVISION HISTORY

A1	June 2024	Release.
A2	Aug 2024	Added second client-server TCP/UDP and spontaneous UDP data streams.
A3	Oct 2024	Detailed IEEE C37.238 PTP power profile settings.
A4	Nov 2024	Updated IEEE C37.118.2 configuration data.
A5	Dec 2024	Added PMU ID and selectable power channels units.

Table of Contents

1 General

This document describes protocol implementation features and configuring of the IEEE C37.118.2 synchrophasor data transfer protocol in the PMU phasor measurement unit (PMU).

The PMU provides commanded client-server UDP and TCP data transmission and spontaneous UDP data transmission over IP protocol.

Streaming of synchrophasor data is also available over Ethernet via the IEC 61850 protocol by mapping the IEEE C37.118.2 synchrophasor data stream to IEC 61850-9-2 sampled values service (see the PMU IEC 61850 Reference Guide for more information).

Reference documents:

IEEE Std C37.118.1-2011, IEEE Standard for Synchrophasor Measurements for Power Systems

IEEE Std C37.118.1a-2014, IEEE Standard for Synchrophasor Measurements for Power Systems, Amendment 1: Modification of Selected Performance Requirements

IEEE Std C37.118.2-2011, IEEE Standard for Synchrophasor Data Transfer for Power Systems

IEC/IEEE 60255-118-1:2018, Measuring relays and protection equipment – Part 118-1: Synchrophasor for power systems – Measurements

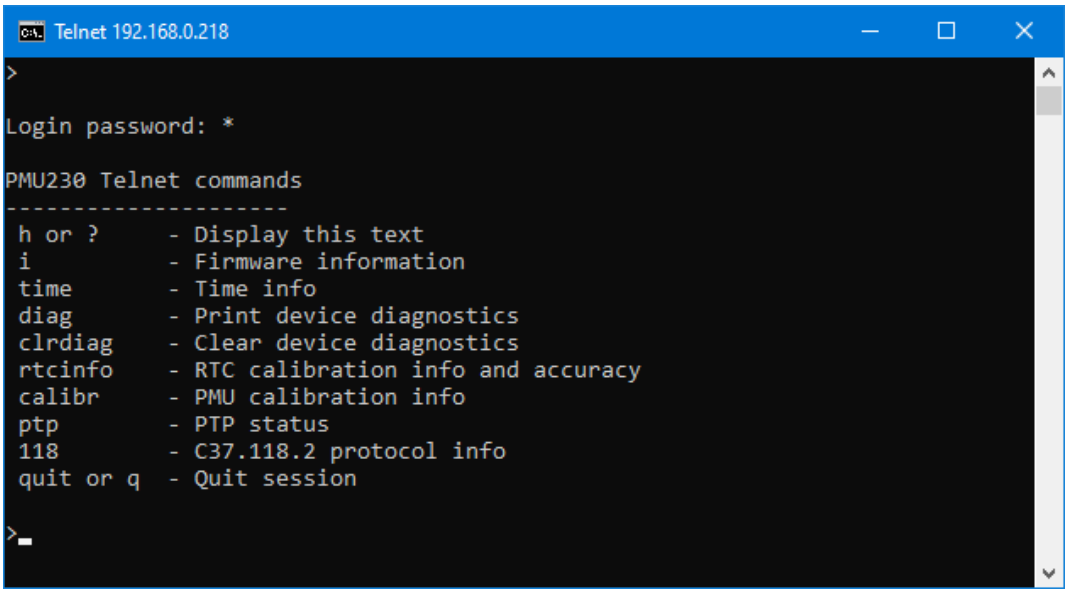
IEEE Std 1588-2008, IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems

IEEE Std C37.238-2017, IEEE Standard Profile for Use of IEEE 1588 Precision Time Protocol in Power System Applications

IEC/IEEE 61850-9-3:2016, Communication networks and systems for power utility automation - Part 9-3: Precision time protocol profile for power utility automation

NOTE

The PMU comes with a Telnet server that can be used to monitor or check the current status and operations of the device. Run a Telnet client on your PC, log into the device with your user password and enter a command from the suggested list.



2 Protocol Implementation

The PMU IEEE C37.118.2 features are user configurable, allowing it to be easily adapted for use in a variety of installations. To keep maximum interoperability with phasor data concentrators (PDC) and controlling stations, the PMU supports all standard frame types for synchrophasor data interrogation and streaming.

The PAS configuration software supplied with the PMU provides all necessary tools for remote configuration of the device.

See Chapter 3 for instructions on how to configure IEEE C37.118.2 options in the device for your particular installation.

See the PMU Installation and Operation Manual for more information on configuring the device via PAS.

The protocol implementation details are explained in the following sections.

2.1 IEEE C37.118.2 Data Communications

The PMU provides commanded unicast client-server UDP and TCP data transmission and spontaneous multicast or unicast UDP data transmission using two data streams with programmable data rates. The data stream ID number assigned to PMU streams uniquely identifies each data stream. Only requests with matching data stream ID numbers are responded by the PMU.

The synchrophasor measurement data reporting rate can be configured in submultiples or multiples of the nominal power line frequency from 1 to 240 frames per second.

PMU reporting rates at 50 Hz system frequency:

Reporting rates (frames/s)	1	2	5	10	25	50	100	200

PMU reporting rates at 60 Hz system frequency:

Reporting rates (frames/s)	1	2	3	4	5	6	10	12	15	20	30	60	120	240

Each data stream can be individually configured to any data rate that is submultiple of the PMU reporting rate.

2.1.1 Commanded Unicast UDP and TCP Data Transmission

Commanded unicast data transfer is controlled by commands sent by the client over a unicast TCP or UDP connection to the PMU's local TCP or UDP port, respectively.

Configuration and header frames are always sent to the IP address and port from which the corresponding command was received, while data frames are sent to the IP address and port from which the start command was sent. This does not necessarily have to be the same port.

Streaming Data Slots

The PMU provides up to 5 simultaneous unicast TCP and/or UDP connections for streaming synchrophasor data at a user-programmable data rate using one of two commanded data streams. The transmission start command should indicate the selected stream identifier.

The stream data rate must be a submultiple of the PMU reporting rate. If it is not, the device will set it to the PMU reporting rate.

Although the UDP server responds to commands from unlimited number of UDP clients and the TCP server can support more client connections, commands to turn on data transmission for new connections after all 5 data streams have started will be ignored.

TCP Connection Timeouts

The PMU uses the TCP keepalive probes to detect dead connections and prevent resource leaks. If the connection is idle longer than 20 seconds, the device sends a keepalive request to check if the connection is alive. If no response is received after 5 successive keepalive retransmissions, the connection is considered dead and will be closed.

The client connection idle timeout can be used to terminate a connection if it has been inactive for too long. The idle timeout can be configured from 30 to 300 seconds or set to 0 to disable it via the device Network Setup (see the PMU Installation and Operation Manual for details). It is disabled by default, and when enabled will be automatically deactivated while streaming data.

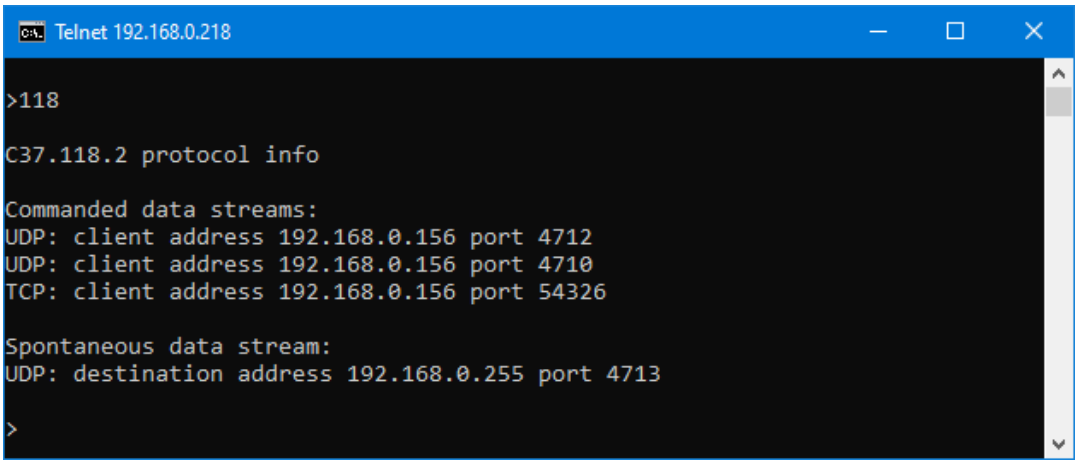
Uncontrollable UDP Data Flow

In case of the commanded UDP transmission, IEEE C37.118.2 does not provide tools for probing whether a client who initiated transmission is still alive and listening to the synchrophasor data stream.

Abnormal termination of client operations without explicit turning off the data transmission may leave the streaming slot active forever and thus limit the number of slots available for new data streams.

The PMU provides a command you can send to the device via the IEEE C37.118.2 setup dialog (see Section 3) that stops all active commanded UDP streams and releases the corresponding data streaming slots.

You can check which data streams are currently active via Telnet using the "188" command as shown in the following picture.



2.1.2 Spontaneous UDP Data Transmission

Unlike commanded data transfer, spontaneous data frames are sent to a user-configured IP address and destination port. The PMU provides two data streams for simultaneous transmission of synchrophasor data frames to two different destinations at user-programmable data rates.

Spontaneous data transfer must be enabled or disabled explicitly by the user through the IEEE C37.118.2 settings (see Section 3 for details) or over an alternate client-server TCP or UDP connection to a local PMU TCP or UDP port, respectively, by referring to the appropriate spontaneous data stream identifier. Regardless of how the data stream is enabled, its state is stored in non-volatile memory, so that if it is enabled, data transfer is automatically started after the device reboots.

Configuration and header frames can be requested and received over an alternate TCP or UDP connection by referencing the appropriate data stream identifier, just as in a regular client-server connection. Configuration frames can also be sent spontaneously to a user-configured destination port without an explicit command, like spontaneous data frames are sent (see Spontaneous Configuration Frames below).

Spontaneous UDP data transmission can operate in unicast, multicast or broadcast mode depending on the destination IP address the user specified. If the UDP clients have an ability to join a multicast group, you can select one from the multicast address range of 225.0.0.0 through 239.255.255.255.

For broadcast transmission within your local network, set the host part of the network address to 255. Use a routable broadcast address to expand the broadcast transmission beyond your local network.

2.2 IEEE C37.118.2 Message Frames

2.2.1 Data Frames

Synchrophasor data frames transmit a time stamped set of measurements that include phasor estimates, frequency deviation from the nominal power line frequency or actual frequency, and the rate of change of frequency. In addition, the data frame can be expanded to contain analog data (total active, reactive and apparent power, and power factor) and digital input status information.

Phasor components can include three voltage and three current phasors, positive sequence voltage and current phasors, negative sequence voltage and current phasors, or all of them in one frame.

Complex phasor values can be sent in a rectangular coordinates format (real and imaginary) or in polar coordinates (magnitude and angle). Phasor and frequency data can be represented in 32-bit IEEE floating-point format or as 16-bit scaled integer numbers. When using the integer format, the data conversion factors are provided in IEEE C37.118.2 configuration frames.

See Section 3 for information on configuring IEEE C37.118.2 data frames.

2.2.2 Configuration Frames

IEEE C37.118.2 configuration frames provide information about the synchrophasor data stream in binary format. The PMU supports CFG-1, CFG-2 and CFG-3 configuration frames.

The configuration frame contents correspond to the specification given by IEEE C37.118.2-2011. In CFG-3 frames, the PMU GUID is not supported and is transmitted as a null string.

Channel Names

The names of the phasor, analog data and digital status channels are user configurable. The channel name can be up to 16 characters long. The default channel names are listed in the following table.

Channel name	Description
VA	V1 voltage phasor
VB	V2 voltage phasor
VC	V3 voltage phasor
IA	I1 current phasor
IB	I2 current phasor
IC	I3 current phasor
V1	Positive sequence voltage phasor
I1	Positive sequence current phasor
V2	Negative sequence voltage phasor
I2	Negative sequence current phasor
P	Fundamental total active power (analog channel)
Q	Fundamental total reactive power (analog channel)
S	Fundamental total apparent power (analog channel
PF	Displacement power factor (analog channel)
DI1	Digital status channel 1

Channel name	Description
…	
DI25	Digital status channel 25

Conversion Factors

When transmitting data in 16-bit integer format, the conversion factors for phasor channels in CFG-2 frames are represented as an unsigned 24-bit word in 10^{-5} volts or amperes per bit to scale.

Conversion factors for analog channels in CFG-2 frames are represented as an unsigned 24-bit word in 10^{-3} per bit to scale. Power readings are transmitted in kW/kvar/kVA units.

If transmitted data is in floating-point format, this 24-bit value will represent a unity scale factor and shall be ignored.

Spontaneous Configuration Frames

In spontaneous UDP data transmission mode, CFG-2 or CFG-3 configuration frames can be sent spontaneously without an explicit client command. When enabled, a configuration frame is sent periodically every 30 seconds.

2.2.3 Header Frame

A header frame gives information about a synchrophasor data stream in human-readable format. An example header frame is shown below.

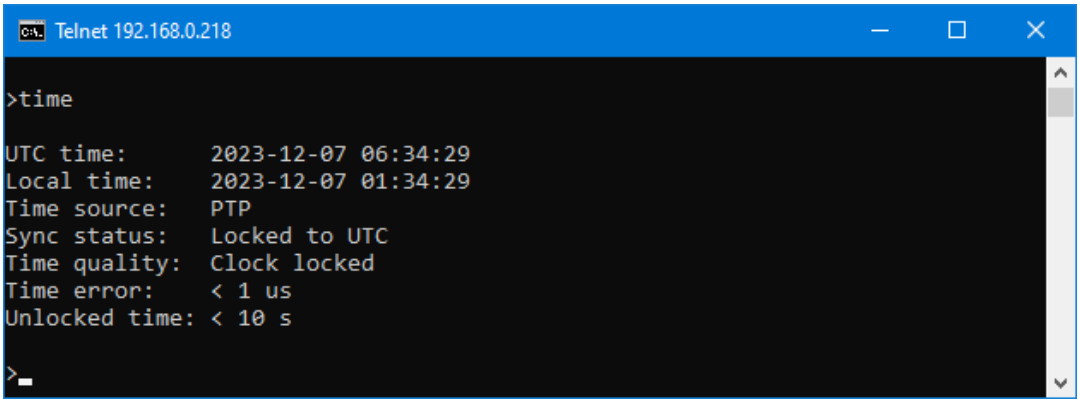
```
Station Name: MMF92_21kV
ID Code: 7000
UTC Time: 2024-02-28 06:39:11.617
Time Quality: Locked
Time Base: 1000000
Revision Count: 1
Data Rate: 50 frames/s
Total Phasors: 6
Total Analogs: 0
Total Digitals: 0
Phasor Coordinate Format: Rectangular
Phasor Data Format: Floating Point
Frequency Data Format: Floating Point
V Conversion Factor: 1.0 V
I Conversion Factor: 1.0 A
Angle Conversion Factor: 1.0000
Frequency Conversion Factor: 1.000 Hz
df/dt Conversion Factor: 1.00 Hz/s
Nominal Frequency: 50 Hz
```

2.3 UTC Time Synchronization

The PMU clock must be synchronized to UTC time using an external IRIG-B timecode source or from an IEEE 1588 PTPv2 master clock.

NOTE: The ⚠ warning LED on the front panel of the PMU flashes red ones a second when the PMU clock is not synchronized with the UTC time source.

You can check the clock status and time accuracy via Telnet using the "time" command as shown in the following picture.



You can also see the clock status in the status bar on the PMU front display and check the time quality on the Monitor/Clock Status page (see the PMU Installation and Operation Manual).

2.3.1 IRIG-B Time Synchronization

Connect the IRIG-B signal wires to the PMU IRIG-B terminals.

To enable the IRIG-B port as a UTC source, select the IRIG-B time synchronization option in the IEEE C37.118.2 setup (see Section 3 for details) or in the Local Settings setup (see the PMU Installation and Operation Manual).

The PMU IRIG-B port uses an unmodulated (pulse-width coded) timecode signal (unbalanced 5V level) according to the IRIG 200-04 standard. It supports B004/B005 timecode formats with time code extensions specified for the IRIG-B profile in Annex D of IEEE Std C37.118.1-2011.

The PMU IRIG-B port can synchronize to the IRIG-B timecode source with sub-microsecond accuracy.

2.3.2 IEEE 1588 PTP Time Synchronization

The PMU Ethernet port must be connected to an IEEE 1588 grandmaster clock through a 1588 PTPv2 peer-to-peer transparent clock switch compliant with IEEE Std 1588-2008.

To enable the IEEE 1588 port as a UTC source, select the IEEE 1588 time synchronization option in the IEEE C37.118.2 setup (see Section 3 for details) or in the Local Settings setup (see the PMU Installation and Operation Manual).

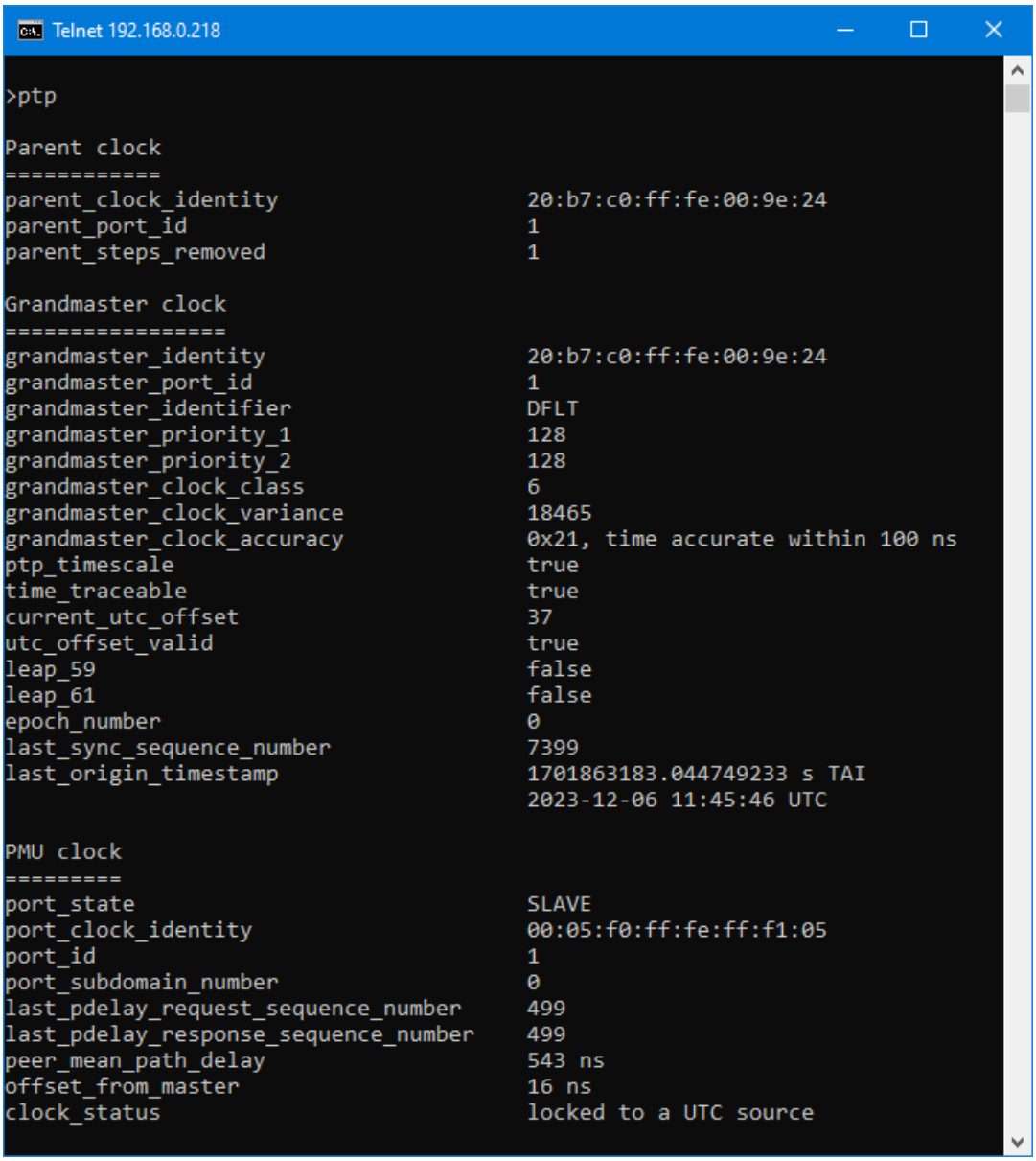
Both PMU Ethernet ports can be connected to the same or two different 1588 switches. The device will obtain UTC time from one of the available sources and automatically switch to the other port whenever the signal is lost for any reason.

Each PMU port implements an ordinary PTPv2 clock complying with IEEE Std 1588-2008 and uses the IEEE C37.238 power profile per IEEE C37.238-2011 and IEC/IEEE 61850-9-3 as follows:

1. PTP version 2.
2. PTP transport over Layer 2 Ethernet (IEEE 802.3), IEEE 1588-2008, Annex F.
3. Multicast addressing.
4. Peer-to-peer (P2P) path delay measurement mechanism.
5. Announce interval = 1 s
6. Sync interval = 1 s
7. Capable of working with one-step and two-step master clocks.
8. Responds to peer path delay requests with two-step peer delay responses (Pdelay_Resp, Pdelay_Resp_Follow_Up messages).

The IEEE 1588 PMU port can synchronize to the PTP grandmaster clock with sub-microsecond accuracy, which can be degraded by network topology, PTP switch accuracy, or transmission media asymmetry.

To troubleshoot connectivity issues with 1588 switches, you can monitor the PTP clock status and time accuracy via Telnet using the "ptp" command, as shown in the following picture.

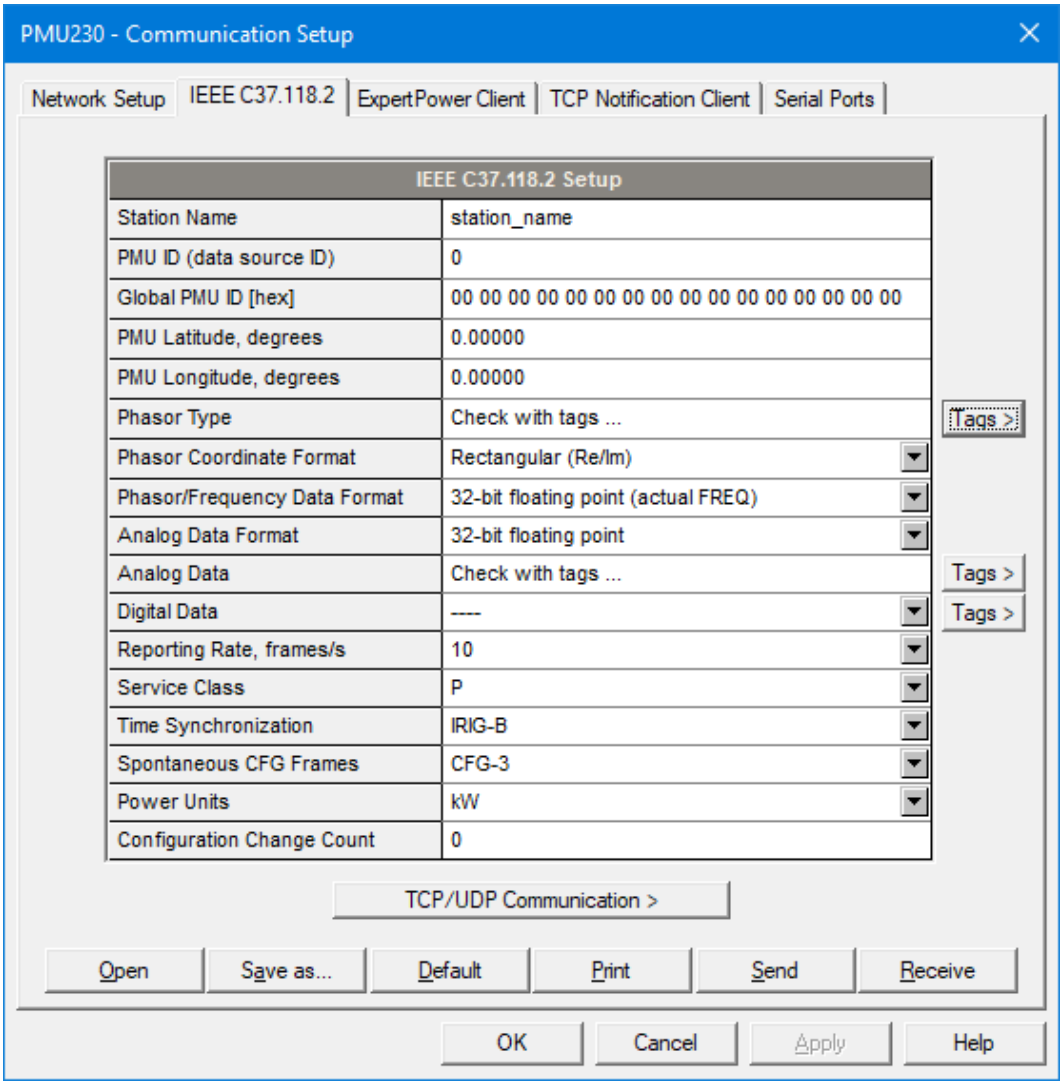


3 Configuring IEEE C37.118.2

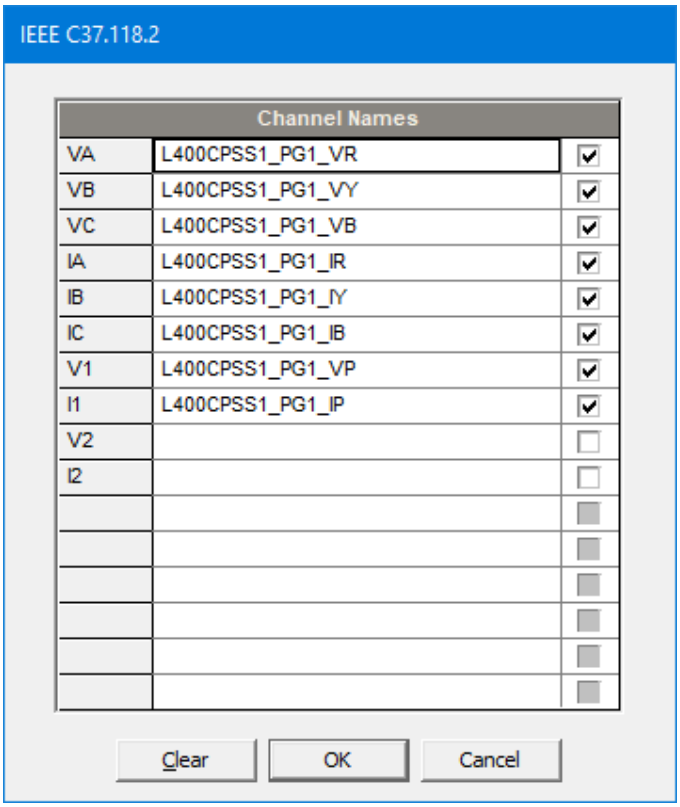
Use the PAS configuration software provided with your device to configure IEEE C37.118.2 options. See the PMU Operation Manual for more information on installation and operating PAS on your computer.

To configure IEEE C37.118.2 options:

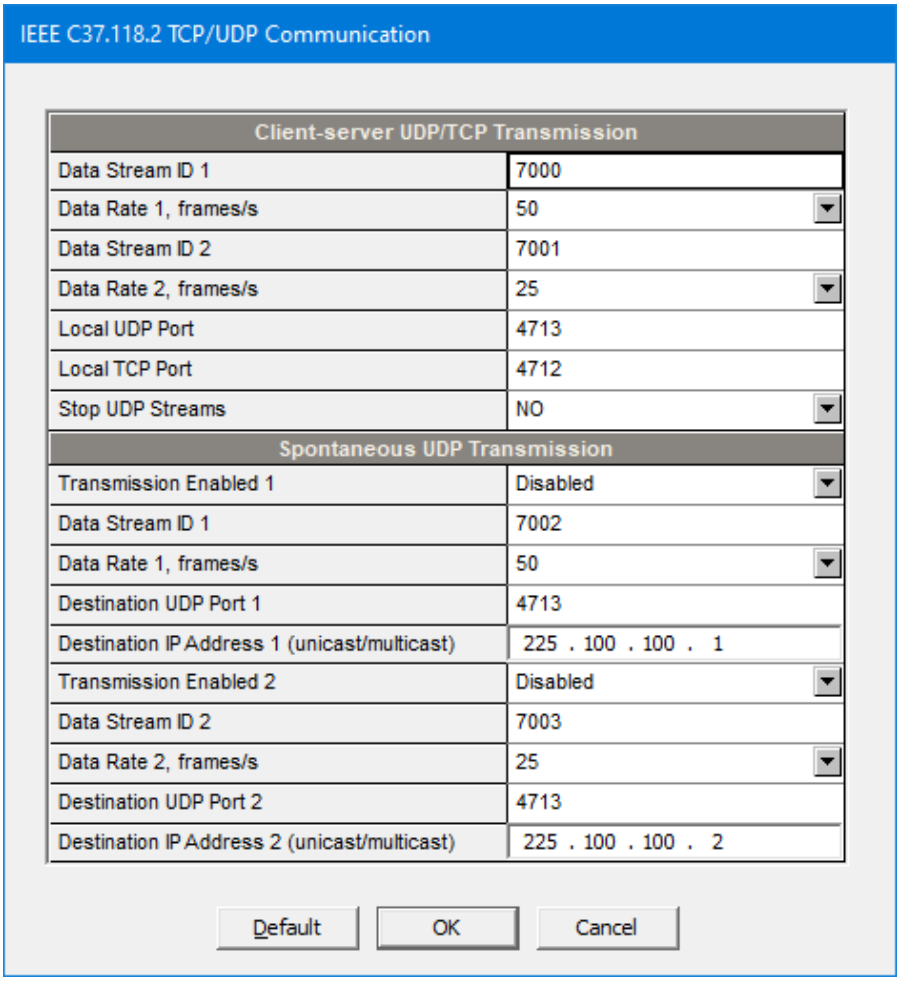
1. Make sure that the selected connection protocol for communication with your device is set to Modbus RTU or Modbus ASCII.
2. Select Communications Setup from the Meter Setup menu and then click on the IEEE C37.118.2 tab.



3. Select the desired PMU and data frame parameters. See the table below for the available options and their explanations.
4. To select phasor and analog data components and/or change the default phasor, analog, and digital channel names, click the appropriate Tags button on the right, check the channels you want to include in the data frames and enter custom channel names, then click OK. Channel names can be up to 16 characters long.



5. Click the TCP/UDP Communication button to configure IEEE C37.118.2 data streams.



6. Configure device's local TCP and UDP port numbers for client connections, and the destination addresses and ports for spontaneous transmission as desired. The default port numbers are set to the values recommended by IEEE C37.118.2.
7. Configure the data stream parameters as required for your application. **Avoid assigning the same identifier to multiple streams, as this will make streams following the first one unavailable to client commands.**
8. Click Save as… to store your setup in the device site database, and click Send to send the setup to the device.

The following table provides information on the available options.

Parameter	Options	Default	Description
IEEE C37.118.2 Setup			
Station Name	Up to 19 ASCII characters	station_name	Identifies the station
PMU ID (data source ID)	0, 1-65534	0 (Note 4)	Data source ID number
Global PMU ID [hex]	128-bit string (16 raw bytes in hexadecimal notation)		Identifies the PMU in a system that has more than 65535 PMUs.
PMU Latitude, degrees	-90.00000 to 90.00000	0.00000	PMU latitude (WGS84)
PMU Longitude, degrees	-180.00000 to 180.00000	0.00000	PMU longitude (WGS84)
Phasor Type	Phasor components	VA,VB,VC,IA,IB, IC	See Channel Names in Section 2.2.2.
Phasor Coordinate Format	Rectangular (Re/Im) Polar (Mag/Ang)	Rectangular	Phasor data format: Rectangular – real and imaginary, Polar – magnitude and angle
Phasor/Frequency Data Format	16-bit integer, 32-bit floating point, 32-bit floating point (actual FREQ)	32-bit floating point with actual frequency	Data type for phasor and frequency data (Note 1)
Analog Data Format	16-bit integer, 32-bit floating point	32-bit floating point	Data type for analog data
Analog Data	Analog components	None	See Channel Names in Section 2.2.2.
Digital Data	None, 16 DI, 32 DI	None	Digital status words to be included in data frames (Note 5)
Reporting Rate, frames/s	1-6,10,12,15,20, 25,30,50,60,100, 120,200,240	10	Synchrophasor measurement rate (Note 2)
Service Class	P, M	P	PMU performance class
Time Synchronization	IRIG-B, IEEE 1588 (PTPv2)	IRIG-B	UTC time source
Spontaneous CFG Frames	NO, CFG-2, CFG-3	CFG-3	Enables spontaneous configuration frames
Power Units	kW, W, MW	kW	Analog power channels units
Configuration Change Count	0-65535	0	Configuration change count. Maintained by the device
Client-server UDP/TCP Transmission			
Data Stream ID 1	1-65534	7000	Commanded data stream 1 ID number
Data Rate 1, frames/s	Submultiple of the PMU reporting rate	10	Commanded data stream 1 transmission rate
Data Stream ID 2	1-65534	7001	Commanded data stream 2 ID number

Parameter	Options	Default	Description
Data Rate 2, frames/s	Submultiple of the PMU reporting rate	10	Commanded data stream 2 transmission rate
Local UDP Port	1024-49151	4713	Device UDP port number for client-server connections
Local TCP Port	1024-49151	4712	Device TCP port number for client-server connections
Stop UDP Streams	NO, YES	NO	Stops all active controlled UDP streams
Spontaneous UDP Transmission			
Transmission Enabled 1	Disabled, Enabled	Disabled	Enables spontaneous data stream 1 transmission
Data Stream ID 1	1-65534	7002	Spontaneous data stream 1 ID number
Data Rate 1, frames/s	Submultiple of the PMU reporting rate	10	Spontaneous data stream 1 transmission rate
Destination UDP Port 1	1024-49151	4713	Destination port number for spontaneous data stream 1 transmission
Destination IP Address 1 (unicast/multicast)		225.100.100.1	Destination IP address for spontaneous data stream 1 transmission
Transmission Enabled 2	Disabled, Enabled	Disabled	Enables spontaneous data stream 2 transmission
Data Stream ID 2	1-65534	7003	Spontaneous data stream 2 ID number
Data Rate 2, frames/s	Submultiple of the PMU reporting rate	10	Spontaneous data stream 2 transmission rate
Destination UDP Port 2	1024-49151	4713	Destination port number for spontaneous data stream 2 transmission
Destination IP Address 2 (unicast/multicast)		225.100.100.2	Destination IP address for spontaneous data stream 2 transmission

NOTES:

1. When 32-bit floating point phasor/frequency format with actual frequency is selected, the measured frequency is transmitted as the actual frequency, otherwise it is transmitted as the deviation from the nominal frequency.
2. The selected PMU reporting rate is automatically rounded up to the nearest submultiple or multiple of the nominal frequency. In case of using both IEEE C37.118.2 and IEC 61850 synchrophasor data communications, the new reporting rate is applied to both protocols.
3. A stream data rate must be a submultiple of the PMU reporting rate, otherwise it will be automatically set to the PMU reporting rate.
4. If the PMU data source ID number is set to 0 (default), the PMU ID repeats the data stream ID number in configuration messages.
5. When custom digital channel names are used, only channels with assigned custom names are indicated as valid inputs in configuration frames.
6. Configure the synchrophasor data frame properties and local port settings before turning on the data transmission. Changing either invalidates all active data streams and stops data transmission in progress.
7. Changing the local TCP port causes closing all active connections and restarting the network services. If you make changes via an Internet connection, wait a couple of seconds until the network is ready for operation before sending a new connection request.

8. Changing the synchrophasor data frame properties advances the configuration change count. You can set it to any desired number by explicit writing the count value.
9. If you are using a TCP connection as an alternate channel for spontaneous stream control rather than for streaming synchrophasor data and want to keep the connection open, disable the TCP connection idle timeout via the device's network setup.