# Configuring IEEE C37.118 Synchrophasors for an SEL-400G by Using PTP Power Profile on an SEL-2740S Software-Defined Network Switch

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## Introduction

You can use the IEEE C37.118 protocol to transport time-aligned power system measurements for analytics, compliance, islanding schemes, and other applications. As this protocol becomes more commonly used, the need to quickly configure relays and peripheral devices becomes more urgent.

Precision Time Protocol (PTP) is an accurate, Ethernet-based time protocol that allows for time synchronization of phasor measurement units (PMUs) without running additional cabling for conventional time distribution with IRIG-B004. This saves money and time when commissioning.

Software-defined networking (SDN) is a networking option that allows for an engineered deny-by-default network that is intrinsically secure and fast. There is an ever-growing need for better cybersecurity, and the SEL-2740S and SEL-2742S Software-Defined Network Switches provide a secure solution for substations. SDN increases the cybersecurity of a system by eliminating attack-prone networking features like media access control (MAC) tables, the Rapid Spanning Tree Protocol (RSTP), and cast types.

This application guide leverages these concepts to create a secure system by using an SEL-400G Advanced Generator Protection System as a PMU to stream data back to an SEL-3555 Real-Time Automation Controller (RTAC), which acts as a phasor data concentrator (PDC). Additionally, an SEL-2488 Satellite-Synchronized Network Clock is used as a PTP Grandmaster to transmit time to the PDC, PMU, and SDN switch. For more information on configuring the SEL-2488 to distribute PTP to an RTAC, see [1].

You can use this application guide even if you do not use PTP or SDN. If you use IRIG-B000/004, connect the satellite-synchronized clock to the IRIG-B input of the SEL-400G and RTAC. If you use a traditional Ethernet switch, such as the SEL-2730M Managed 24-Port Ethernet Switch, you can skip the SDN steps.

## Time Synchronization

All devices in a synchrophasor network must be time-synchronized to ensure IEEE C37.118 communications function properly. This level of accuracy mandates that an external time source be used. For the example presented in this application guide, we use a PTP Power Profile timing source from an SEL-2488.

PTP is a broad Ethernet-based protocol that was originally created by IEEE and is the core of [2]. PTP is used to time-synchronize clocks across a network. Both the IEC and the IEEE committees released a Power Profile standard that is tailored for the electrical power systems called ([2] [3]). We will use this standard for our network clocks synchronization. In this example, the SEL-2488 determines that it is the sole Grandmaster clock in this network via the Best Master Clock Algorithm (BMCA). The BMCA is the process by which PTP clocks determine the master and, subsequently, the Grandmaster clock of the domain. Thus, all other clocks in the network will be timed via the Grandmaster clock [4].

Before configuring your SEL-2488, ensure that the firmware has been updated to R107-V0 or later to include the PTP Power System Profile (IEEE C37.238-2017) support. If your SEL-2488 does not support PTP, contact SEL Technical Support.

See *Figure 1* for the topology of the SEL-2488 to SEL-2740S that communicates the PTP Power Profile between devices.

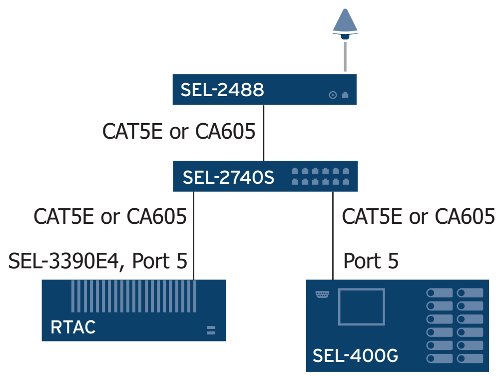



**Figure 1 Network Topology for PTP and Connectivity**

# Part 1: SEL-2488 Configuration

## SEL-2488 Settings

The IEEE C37.118.1-2011 standard requires time-stamping and synchronizing with an accuracy of 1 µs or better. GPS is commonly used in power utilities and industrial environments to provide a stable, high-accuracy, distributed time source. Commercially available GPS receivers can vary in time accuracy from 50 ns to 1 ms depending on the vendor. For this application, we are using the SEL-2488 and SEL-9524B GPS/GLONASS GNSS Antenna to receive time signals from GPS satellites with ±40 ns precise-time accuracy corresponding to PTP ±100 ns peak accuracy [4]. The SEL-2488 continuously transmits PTP messages from enabled Ethernet interfaces to determine initial time source selection and qualification and maintains a 1 µs accuracy.

If the SEL-2488 and the SEL-9524B have not been installed and commissioned, see the *SEL-2488 Quick-Start Guide* (available at selinc.com) for installation instructions. To configure the SEL-2488 for outputting time, perform the following steps in the SEL-2488 web interface.

Step 1. Navigate to **Precision Time Protocol** under Time Management.

The SEL-2488 has four configurable Ethernet ports that can provide various time code formats. For this application complete the following:

a. Select the box next to **ETH 2** to enable PTP.

b. Select **IEEE C37.238-2017** from the Profile dropdown menu, as shown in *Figure 2*.

This preset profile automatically configures the Domain, Priority 1, Priority 2, and the rest of the pertinent settings associated with the Power Profile.

c. Select **Submit**.

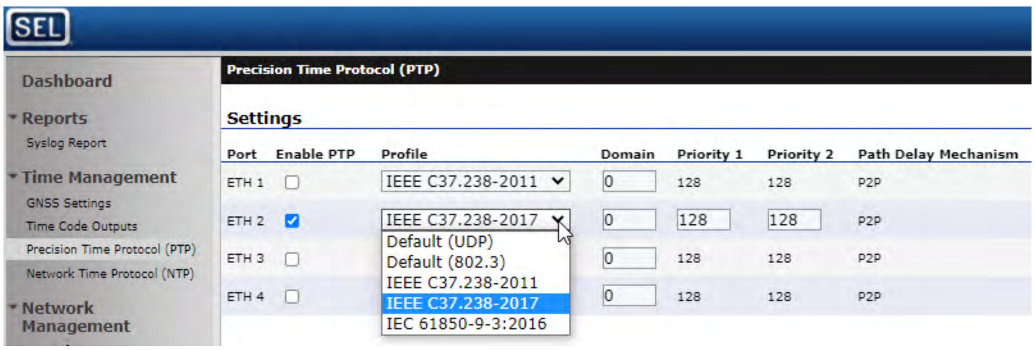



**Figure 2 Configuring PTP Port Settings by Using the IEEE C37.238-2017 Preset Profile**

Step 2. Enable the checkbox for port **ETH 2** and configure a valid IPv4 address corresponding with the network.

*Figure 3* shows the IP Configuration section of the SEL-2488 that is found in Network Management. In this application, we are using the IPv4 address **192.168.70.71** with a **/24** CIDR.

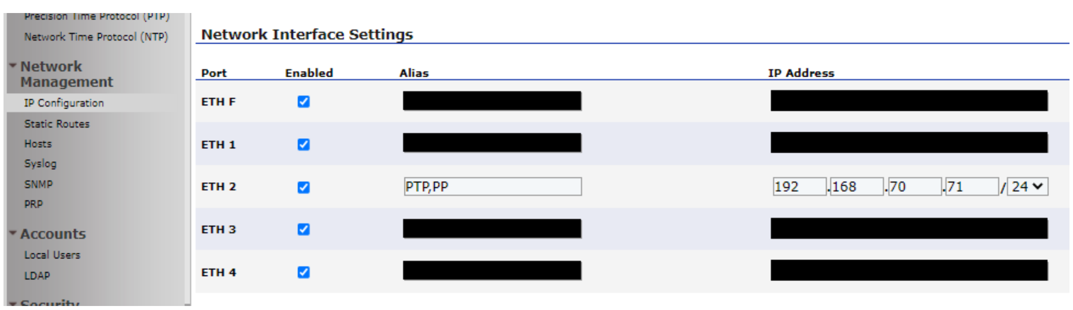



**Figure 3 Configuring the IP Address Under Network Management**

Step 3. Navigate to the SEL-2488 Dashboard to verify the status and GNSS settings (See *Figure 4*).

Ensure that the **PTP**, **Time Quality**, **Antenna**, and **Satellite Lock** LEDs are illuminated green. Verify the **ETH 2** port settings by selecting the port. This indicates that the port Services/Protocols is set to PTP and the IP address is set to 192.168.70.71/24.

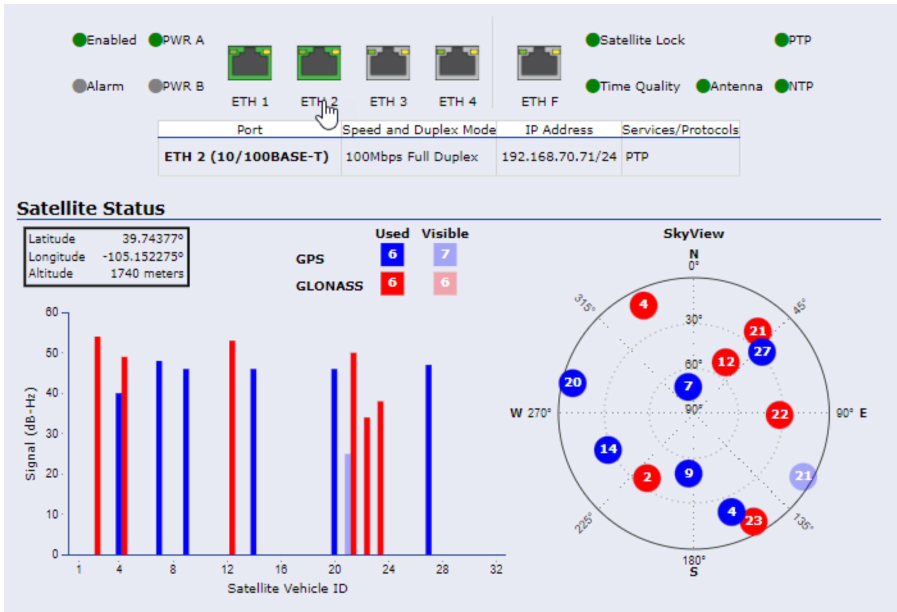



**Figure 4 Status Indicators on the Web Interface Dashboard**

## Part 2: Configuring the SEL-2740S SDN Network

The SEL-2740S provides secure Ethernet connectivity for this specific application. This section describes how to configure the necessary logical connections (LCs) by using the SEL-5056 Software-Defined Network (SDN) Flow Controller. Before creating LCs to facilitate traffic between these devices, ensure that the following prerequisites are met:

1. The SEL-5056 must be commissioned.
2. The SEL-2740S must be adopted.
3. All hosts (IED, clocks, etc.) must be adopted.
4. All links between the hosts and the SEL-2740S must be adopted.

Refer to [5] for instructions on how to adopt hosts and SDN switches by using the SEL-5056. This reference also describes the architectural Ethernet network model and how to commission and adopt devices into an SDN network [5]. *Figure 1* shows the topology of the network and devices. This represents the physical connectivity of the SEL-2488, the RTAC, the SEL-2740S, and the SEL-400G.

**Table 1 Associated Configuration for Devices**

| SEL Device | Alias | Port | IPv4 Address |
|---|---|---|---|
| SEL-2740S | C37.118 SDN | N/A | 192.168.70.3 |
| SEL-2488 | SEL 2488 | B4 | 192.168.70.71 |
| RTAC | 3555 RTAC | B3 | 192.168.70.75 |
| SEL-400G | SEL 400G | B2 | 192.168.70.70 |
| SEL-5056 | Controller | B1 | 192.168.70.2 |

## Creating PTP Traffic Flows

The SEL-2488 sends PTP traffic to the network to provide time synchronization to all end devices, including the SEL-2740S. Before you create the necessary PTP traffic flow, you must enable PTP on the adopted and configured SEL-2740S devices that are discussed in this application guide.

Step 1. Navigate to **Configuration Objects** under the Configuration view of the SEL-5056.

a. Select **Nodes** to show all device settings found in the network.

For this application guide, the name of the SEL-2740S is **C37.118 SDN** and the Enable PTP checkbox is selected, as shown in *Figure 5*.

b. Select **Submit**.


**Figure 5 SDN Switch Settings With PTP Enabled**

Step 2. Create a LC by selecting the master clock (**SEL 2488**) from the topology screen.

Select **PTP Power Profile** from the Select CST dropdown menu, as shown in *Figure 6*.

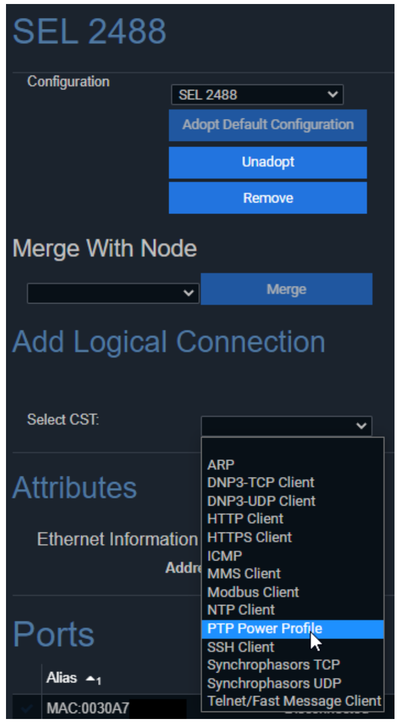



**Figure 6 Select CST for PTP Power Profile of the SEL-2488**

Step 3. For each device requiring PTP time synchronization (including all SDN switches), select the device from the Select Endpoint dropdown menu.

a. Select **Add Endpoint**.

b. Once this is done for all devices, select **Create Multicast**.

c. Select **Submit**.

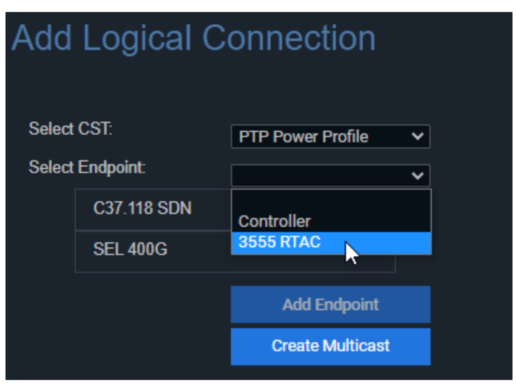



**Figure 7 PTP Power Profile for Endpoints**

Step 4. From the topology screen, review individual traffic flows by selecting the green LC arch to the right of the associated devices.

Verify that there is a multicast PTP Power Profile CST from the SEL-2488 to the selected end device, as shown in *Figure 8*. Note that ARP is not required for PTP communications. However, it is necessary for IP Ethernet-based communications protocols, i.e., Network Time Protocol (NTP).

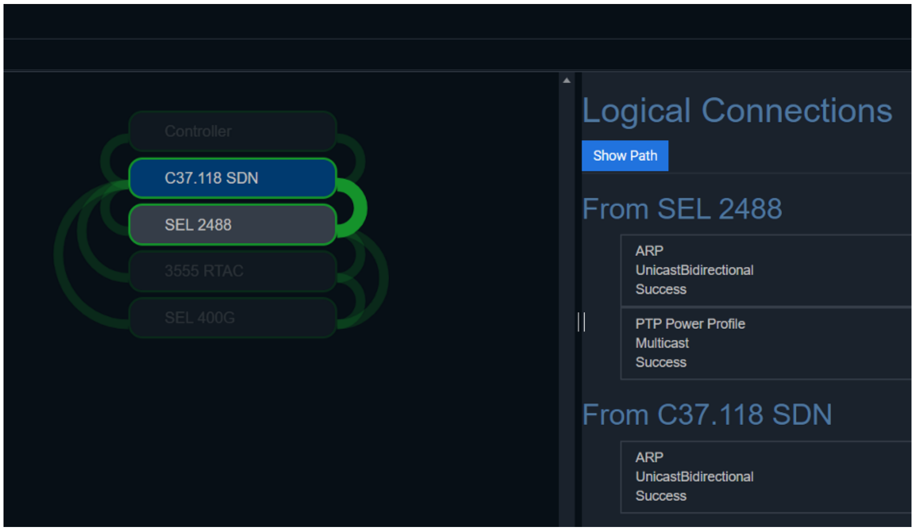



**Figure 8 Traffic Flow Verification From the SEL-2488 to C37.118 SDN**

### Create Synchrophasor TCP Traffic Flows

Step 1. To create the LC between the RTAC and the SEL-400G for PMU data, select the RTAC device (**3555 RTAC**) from the topology screen.

Step 2. From the Select CST dropdown menu, select **Synchrophasors TCP**.

Step 3. Under Select Endpoint, select the SEL-400G (**SEL 400G**).

Step 4. Select **Create Unicast** to review the LC.

Step 5. Select **Submit**.

Step 6. Repeat this process by using the ARP CST (see *Figure 9*).

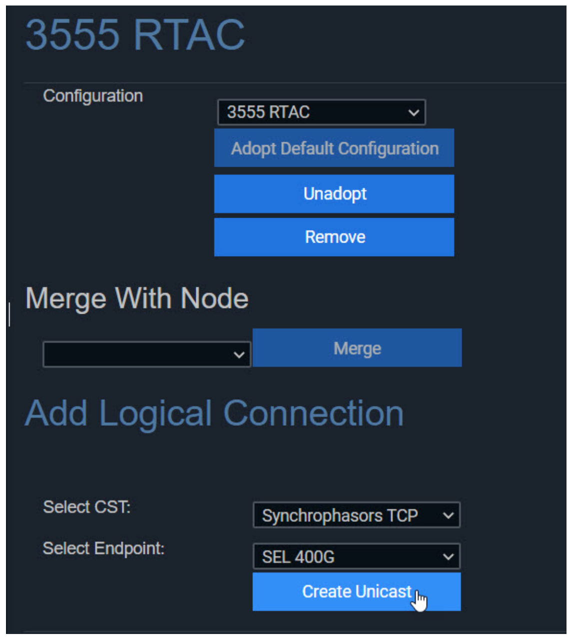



**Figure 9 Synchrophasor TCP Connection Between the SEL-400G and the RTAC**

At this point, the topology of the SDN configuration, end devices, LCs for PTP Power Profile, and PMU Synchrophasor TCP communications is as shown in *Figure 10*.

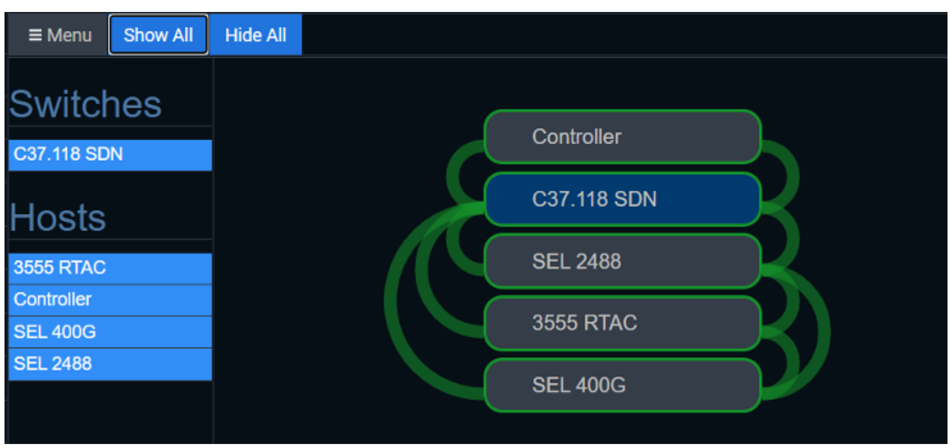



**Figure 10 Final Topology of This SDN Configuration**

NOTE: If the user desires, they can configure other logical connections for other services, such as PING, ACSELERATOR RTAC, Telnet, etc.

## PART 3: QUICKSET SETTINGS FOR THE SEL-400G

The SEL-400G is an option for PMU applications that allows for multiple current and voltage inputs. The ACSELERATOR QuickSet® SEL-5030 Software settings that are discussed in this application guide allow the SEL-400G to stream IEEE C37.118 protocol data to a PDC by using an Ethernet network.

Step 1. Enable the SEL-400G synchrophasor options by selecting **Global > Synchrophasor Settings**. Change EPMU to **Y** to enable C37.118 data in the relay, as shown in *Figure 11*.

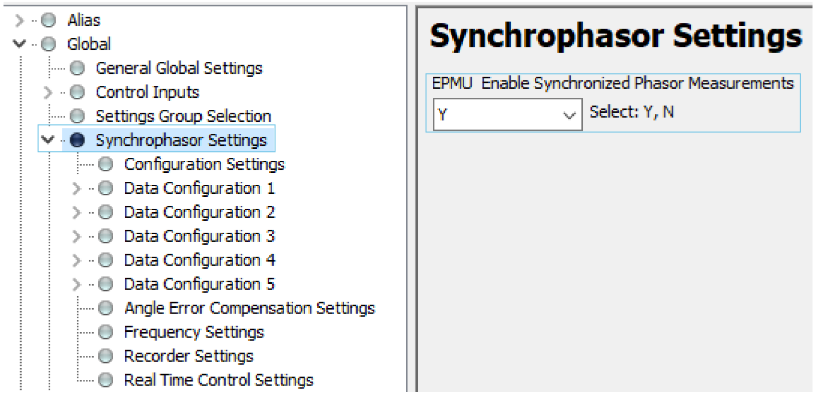



**Figure 11 Enabling SEL-400G Synchrophasor Options**

Step 2. Select **Configuration Settings** under Syncrophaser Settings, as shown in *Figure 12*. Enable the necessary number of separate configurations. The SEL-400G can send out five different user-configurable streams. In this application guide we are using one.

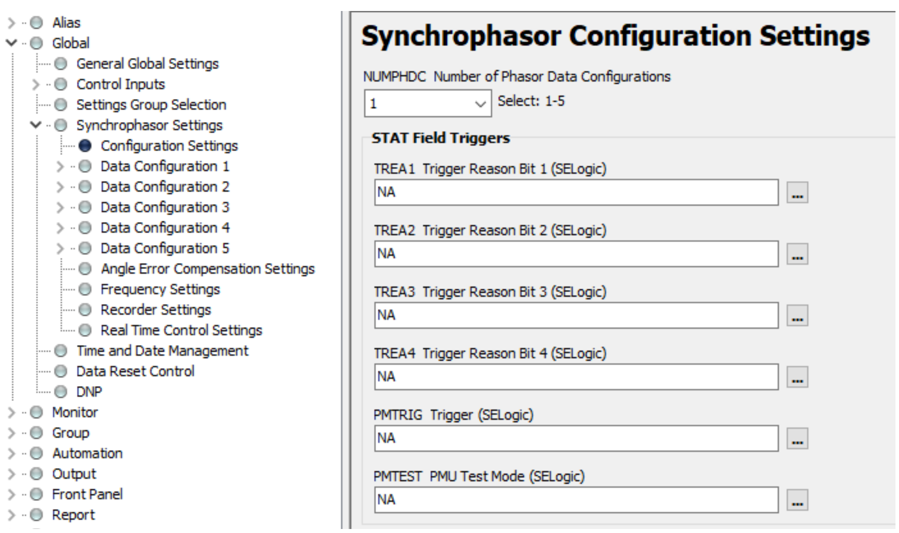



**Figure 12 SEL-400G Synchrophasor Configuration Settings**

The STAT Field Triggers are not being used in this application guide. The purpose of these settings is to stream back the result of a SELOGIC control equation. Setting this does not impact the traditional stream of C37.118 data. Therefore, for the purposes of this application guide, we are not setting the TREA or PMTRIG settings.

Step 3. Select **Data Configuration 1**. This is where you set the MRATE1 (message rate), as shown in *Figure 13*. The station name (PMSTN1) and hardware identifier (PMID1) are also set here. All three of these settings must match the RTAC settings in *Part 4: RTAC Settings* in *Step 4* (Station Name) and *Step 7* (Data Rate).

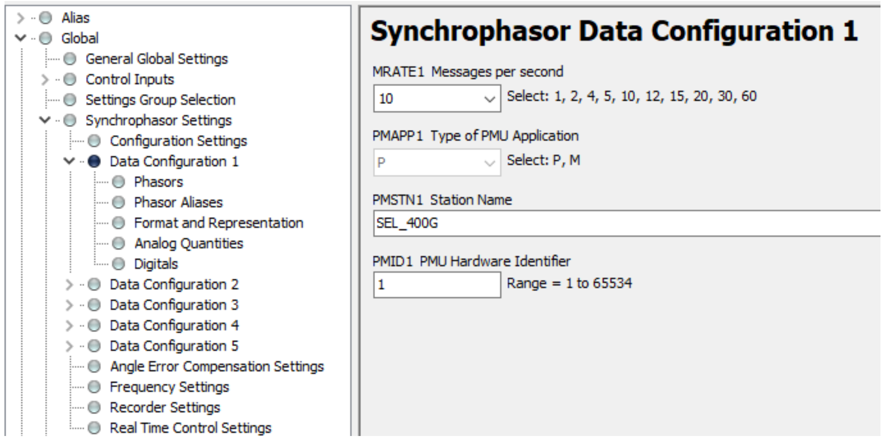



**Figure 13 SEL-400G Data Configuration Settings**

Step 4. Select **Phasors** under the Data Configuration 1 dropdown menu, as shown in *Figure 14*. Select the current and voltage terminals that are connected. For this application guide, current is set to Terminal X and voltage is set to Terminal Z.

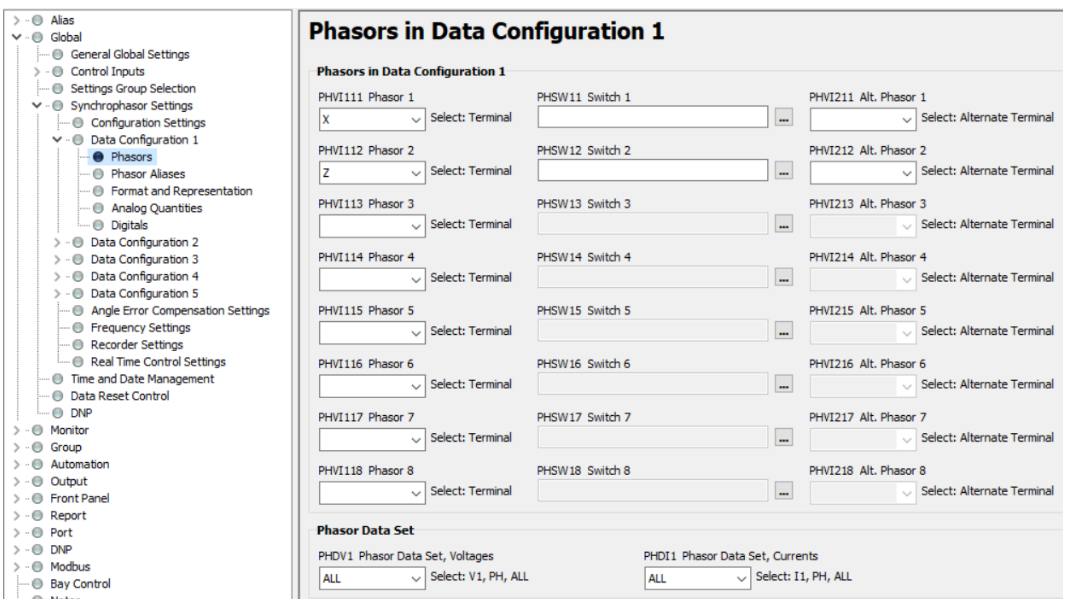



**Figure 14 SEL-400G Phasor Configuration Settings**

Settings PHSW11 and PHVI211 allow the relay to switch the terminals that are being used for the synchrophasor stream back to the RTAC. For this application guide, alternate terminals are not used. The Phasor Alias section is also not addressed, which is the tab that allows you to create your own naming convention for the phasors streaming back (we use the default names in this application guide). If you use aliases, you must edit the Channel Name in the RTAC settings. The concepts of aliasing and channel names are important in *Part 3: QuickSet Settings for the SEL-400G* in *Step 6* and in *Part 4: RTAC Settings* in *Step 5*, *Step 6*, and *Step 7*.

Step 5. Select **Format and Representation** under the Data Configuration 1 dropdown menu, as shown in *Figure 15*.

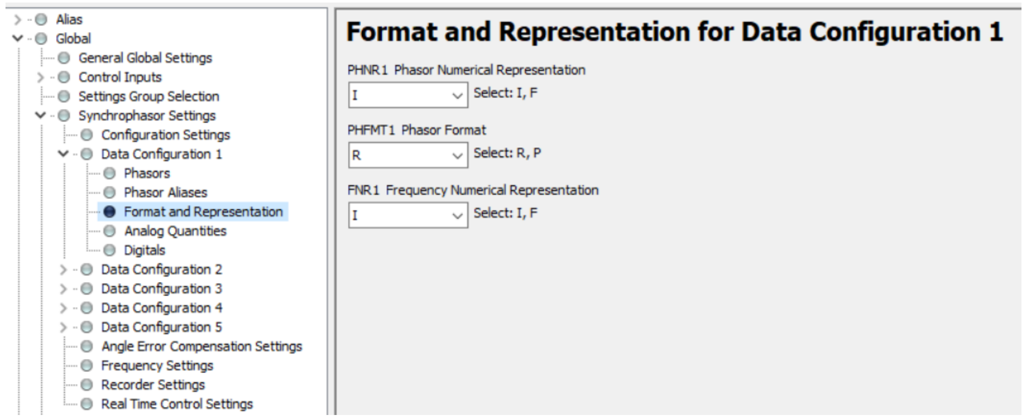



**Figure 15 SEL-400G Format and Representation Settings**

This is where you configure how the phasor data are formatted. Set PHNR 1 to **I**, PHFMT 1 to **R**, and FNR 1 to **I**. These settings are explained in *Table 2*.

**Table 2 Format and Representation Options**

| Setting | Prompt |
|---|---|
| PHNR*q* | Phasor Num. Representation (I = Integer, F = Float) |
| PHFMT*q* | Phasor Format (R = Rectangular, P = Polar) |
| FNR*q* | Freq. Num. Representation (I = Integer, F = Float) |

Step 6. The Analog Quantities page allows for user-configurable analog values in the SEL-400G. You can enter any quantity into this page that is listed in *Section 12: Analog Quantities* of [6] and it will be part of the stream of data leaving the relay. For this application guide, select analog quantities **RA001** and **RA002**, as shown in *Figure 16*.

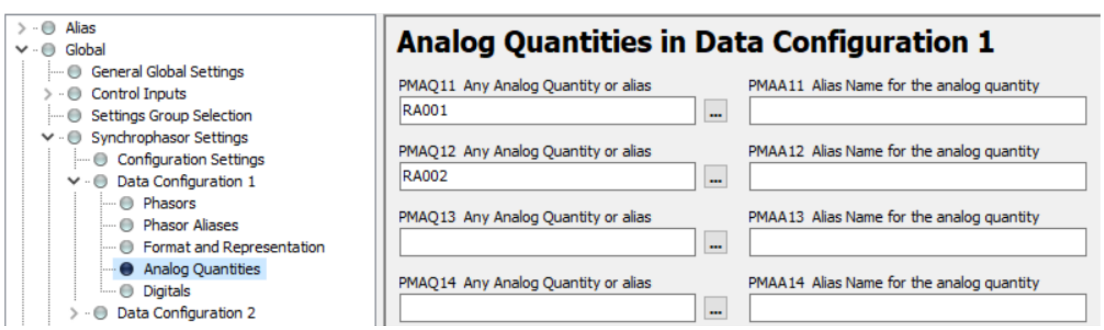



**Figure 16 SEL-400G Analog Quantities Settings**

When you configure the RTAC to receive these data, the Channel Name must match exactly the PMAQ11 name or the Alias Name. If you use an alias, the RTAC Channel Name must match the alias. This is discussed further in *Part 4: RTAC Settings*, *Step 6*.

Step 7. The Digitals tab allows for user-configurable digital values for any of the available Relay Word bits in the SEL-400G. As shown in *Figure 17*, enter **EN_RLY** (Relay Enable), **IN208**, and **IN209**. As previously mentioned, the naming conventions come into play when you configure the RTAC as the PDC.

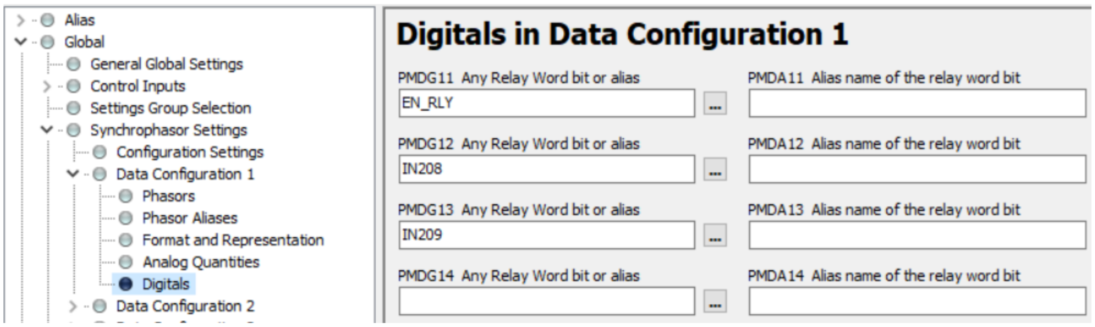



**Figure 17 SEL-400G Digitals Settings**

Step 8. The last setting that you need to review under the Global section is Time and Date Management. As seen in *Figure 18*, this is where you configure the local time offset. The IRIGC setting is forced to C37.118 when EPMU is set to Y (as shown in *Figure 11*).

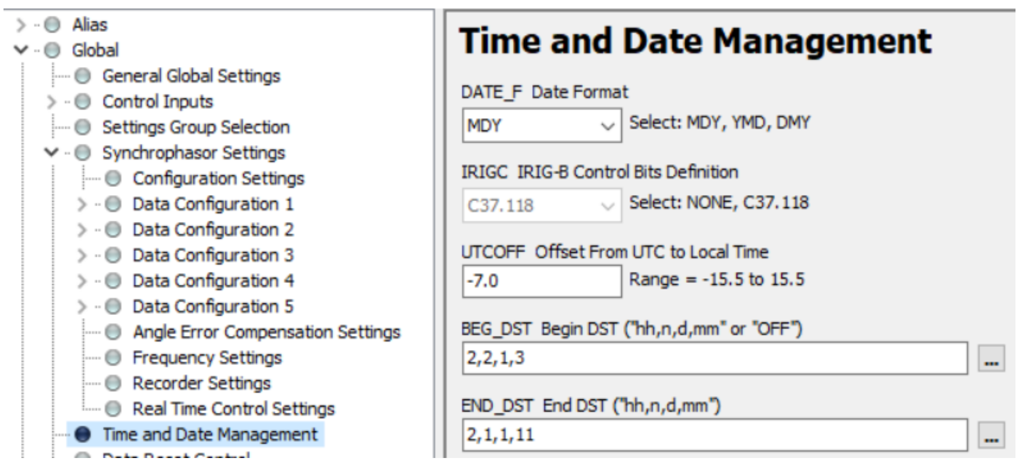



**Figure 18 SEL-400G Time and Date Management Settings**

Step 9. Next, you must configure the SEL-400G Ethernet Port 5. As shown in *Figure 19*, set the SEL-400G to be in the same network as the SEL-2488 and the RTAC by using **192.168.70.70/24** as the IPADDR.

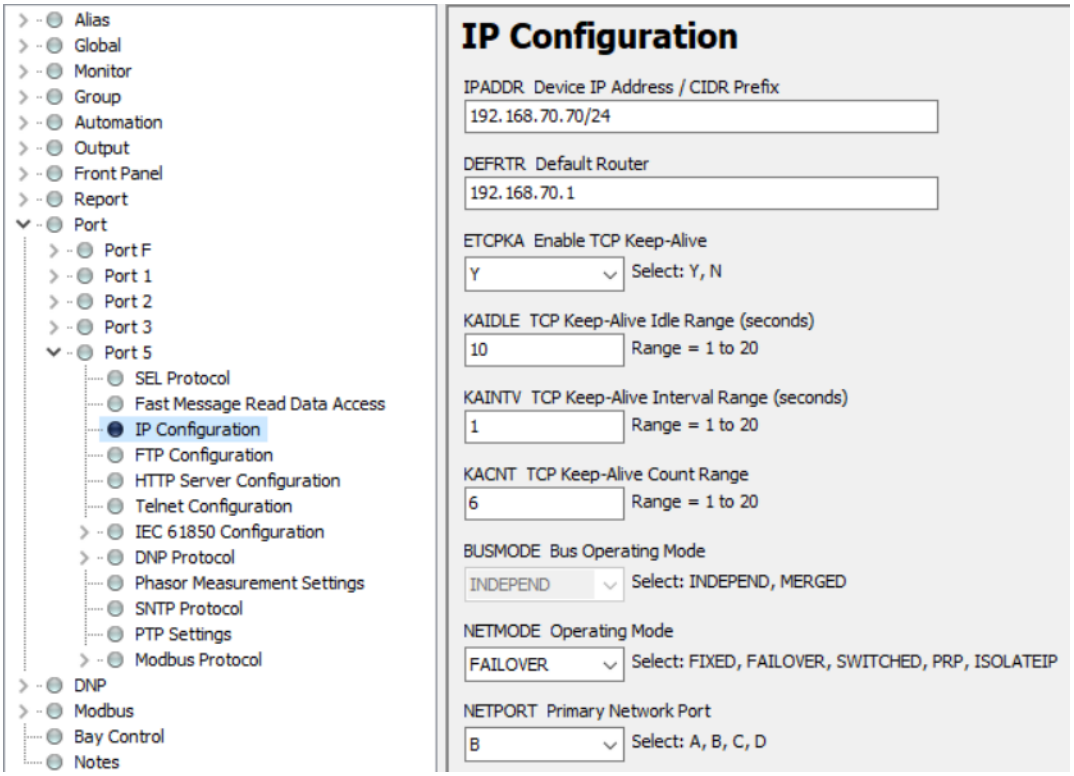



**Figure 19 SEL-400G IP Configuration Settings**

Step 10. For the Port 5 settings, select **Phasor Measurement Settings**, as shown in *Figure 20*. Enable the C37.118 protocol by setting EPMIP to **Y**. PMOTS1 is TCP by default. This must match the RTAC settings in *Part 4: RTAC Settings*, *Step 1*. Setting PMODC1 allows for selection of which data configuration to send from this port; configure Data Set 1 in *Step 3*. Set PMOIPA1 as the IP address of the RTAC (192.168.70.75), and use the default C37.118 port (4712).

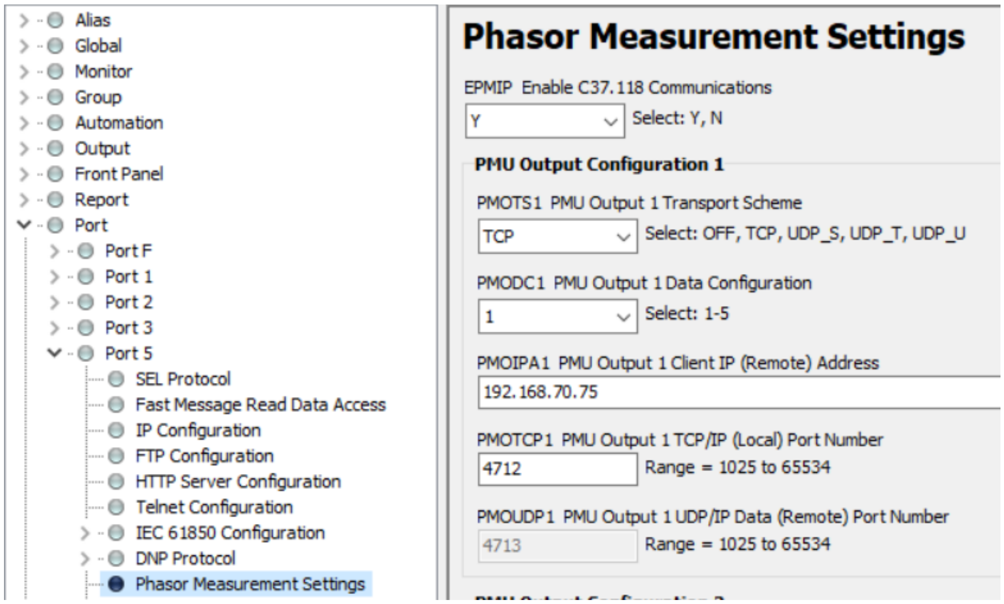



**Figure 20 SEL-400G Phasor Measurement Settings**

Step 11. In the SEL-400G, configure the PTP settings. Under the Port 5 settings, select **PTP Settings**, as shown in *Figure 21*.

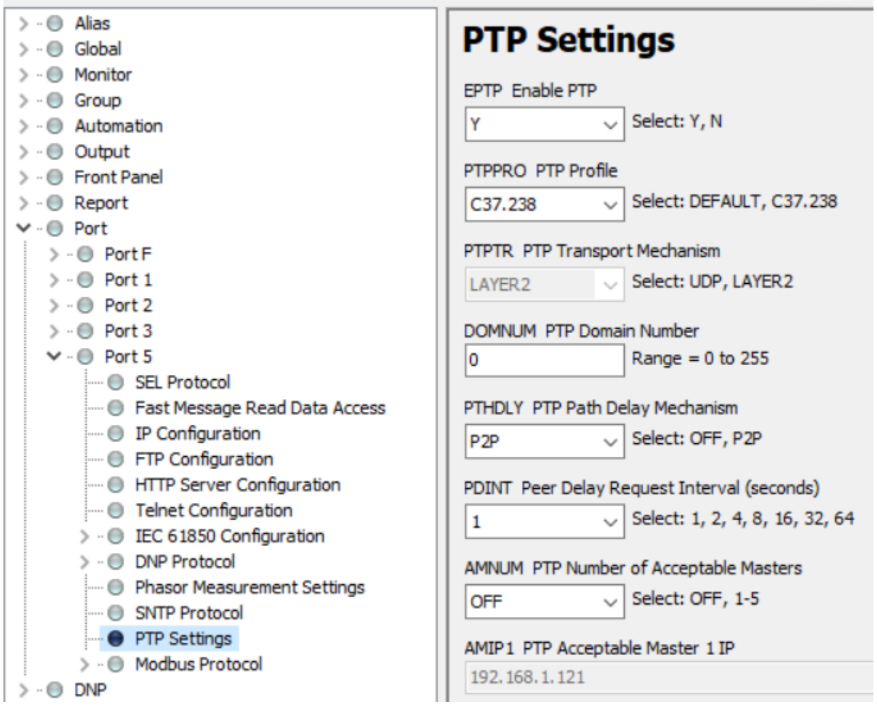



**Figure 21 SEL-400G PTP Settings**

Step 12. To enable PTP, change the EPTP setting to **Y**.

The Power Profile causes PTPPRO to be set to C37.238. The PTP domain must match the SEL-2488 settings from *Part 1: SEL-2488 Configuration*, *Step 1*. In this application guide, we set DOMNUM to **0**. The rest of the settings are default. AMNUM is set to OFF because that setting allows the SEL-400G to access any Grandmaster PTP clock on the network.

## PART 4: RTAC SETTINGS

The RTAC acts as a PDC for the SEL-400G. As discussed in [7], there is no loss of capacity in the RTAC by using this protocol.

Step 1. Set the RTAC Ethernet Port 5 to have an IP Address of **192.168.70.75**.

Step 2. In a new ACSELERATOR RTAC® SEL-5033 Software project, add an SEL-400G with IEEE C37.118 protocol and set the Connection Type to **Client - Ethernet**.

Step 3. In the Settings tab, leave the Transport Scheme setting at its default value of TCP, as shown in *Figure 22*. This must match the PMOTS1 setting of the SEL-400G configured in *Part 3: QuickSet Settings for the SEL-400G*, *Step 9*. Enter the Server IP Address of the SEL-400G PMU (in this example, 192.168.70.70). The Server IP Port was left at the default value (4712). The PDC Id setting is a unique identifier for the SEL-400G PMU. For this application, the PDC Id is 1. This must match the PMID 1 setting from *Part 3: QuickSet Settings for the SEL-400G*, *Step 3*.

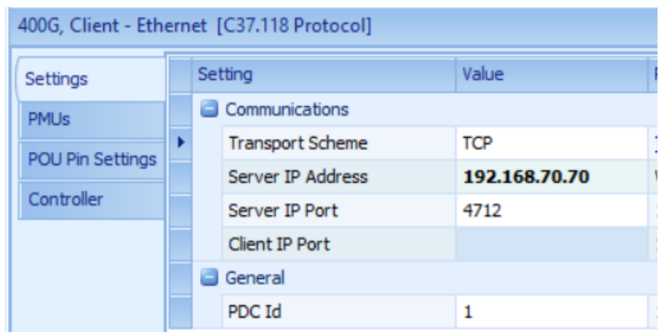



**Figure 22 SEL-400G Ethernet Settings for IEEE C37.118**

Step 4. Select the PMUs tab, as shown in *Figure 23*, and enter a Station Name (SEL_400G for this example). The Station Name in the RTAC must be the same as the PMSTN1 setting in *Part 3: QuickSet Settings for the SEL-400G*, *Step 3*. The Station Name must be unique for multiple PMUs on a single IEEE C37.118 client RTAC project. The Pmu Id must match the PDC Id parameter configured in *Step 3*.

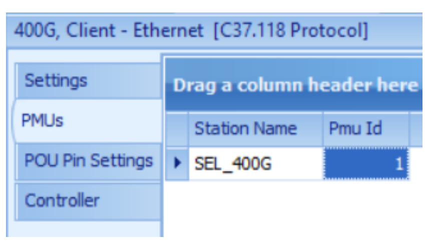


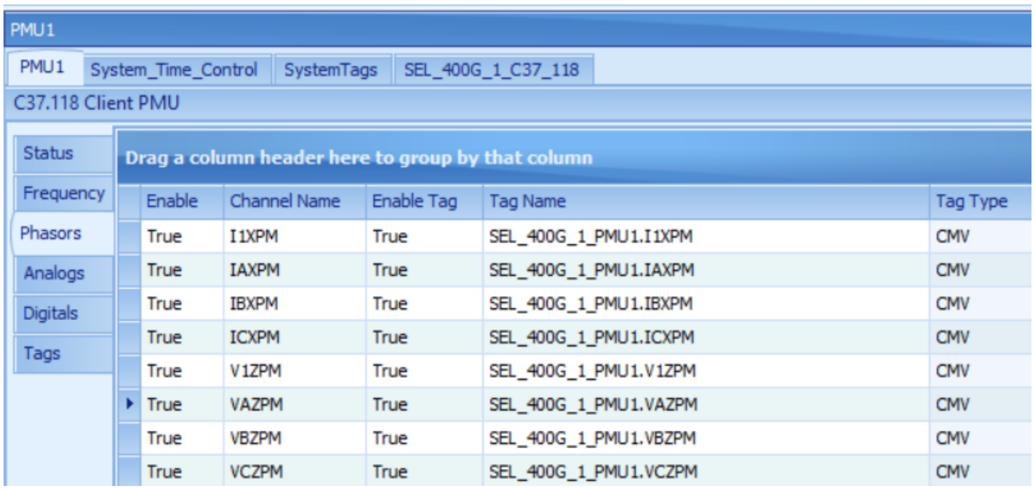

**Figure 23 PMU Station Name**

Step 5. After the IEEE C37.118 client device is added, add a subitem representing a single PMU directly below it.

a. Select the green arrow to show the PMU data available from the SEL-400G. On the various tag tabs on this subitem there are two options for enabling PMU data: the Enable column, which allows the RTAC to bring the phasor data back from the PMU (SEL-400G), and the Enable Tag column, which allows for the data to be used internally by the Logic Engine of the RTAC.

b. For this application, select the **Phasors** tab to enable the currents and voltages for all phases the SEL-400G is using, as shown in *Figure 24*. These values will be enabled for both collection (Enable) and logic engine (Enable Tag) use.

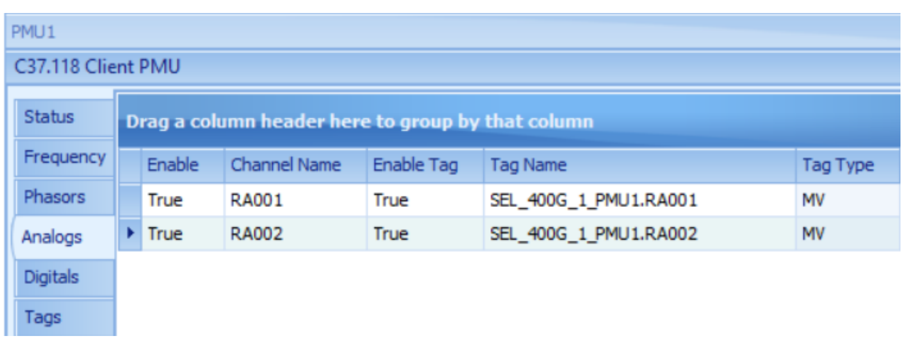
c. Delete all unused rows from the tab. To delete a row, select the blue box to the left of the Enable column to highlight the entire row and select the **–** button. If the unused channels are not deleted, the RTAC displays an “Unresolved Tag Reference” error and shows an invalid quality for other phasors while it communicates with the SEL-400G.




| Enable | Channel Name | Enable Tag | Tag Name | Tag Type |
|---|---|---|---|---|
| True | I1XPM | True | SEL_400G_1_PMU1.I1XPM | CMV |
| True | IAXPM | True | SEL_400G_1_PMU1.IAXPM | CMV |
| True | IBXPM | True | SEL_400G_1_PMU1.IBXPM | CMV |
| True | ICXPM | True | SEL_400G_1_PMU1.ICXPM | CMV |
| True | V1ZPM | True | SEL_400G_1_PMU1.V1ZPM | CMV |
| True | VAZPM | True | SEL_400G_1_PMU1.VAZPM | CMV |
| True | VBZPM | True | SEL_400G_1_PMU1.VBZPM | CMV |
| True | VCZPM | True | SEL_400G_1_PMU1.VCZPM | CMV |

**Figure 24 SEL-400G PMU Phasor Data**

Step 6. Use the Analogs and Digitals tabs to create the values that are being streamed by the SEL-400G. Because the SEL-400G has user-configurable analog and digital points, these are blank when you first open them. To add the desired channels, select the **+** button and add the points that you created in *Part 3: QuickSet Settings for the SEL-400G*, *Step 6* and *Step 7*, as shown in *Figure 25* and *Figure 26*. In the Channel Name column, the value must exactly match the SEL-400G settings or the “Unresolved Tag Reference” error will occur. If an alias was configured at the relay, that alias is used as the Channel Name. A caveat to this is EN and EN_RLY. In the SEL-400G, the relay enable bit is called EN_RLY. However, that bit is passed back via the protocol as EN.




| Enable | Channel Name | Enable Tag | Tag Name | Tag Type |
|---|---|---|---|---|
| True | RA001 | True | SEL_400G_1_PMU1.RA001 | MV |
| True | RA002 | True | SEL_400G_1_PMU1.RA002 | MV |

**Figure 25 SEL-400G PMU Analog Data**

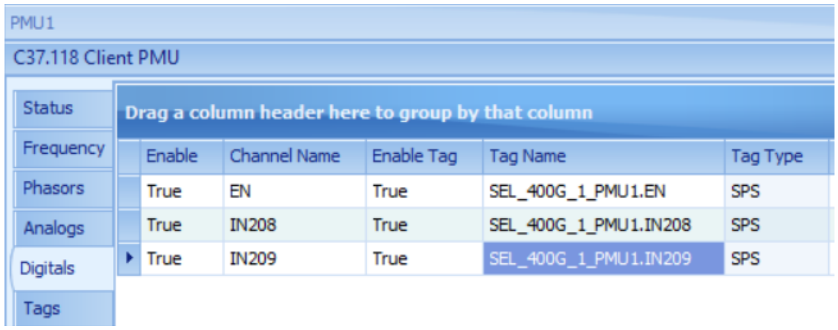



**Figure 26 SEL-400G PMU Digital Data**

Step 7. Under the System folder in the project tree, select **SystemTags**, as shown in *Figure 27*. The RTAC uses a single data rate for all attached PMUs. Set Data_Rate to **10**. This setting reflects how many messages per second the RTAC expects from the SEL-400G PMU stream. This value can be higher depending on the specific application you are using. For this application guide, a relatively slow message rate is used.

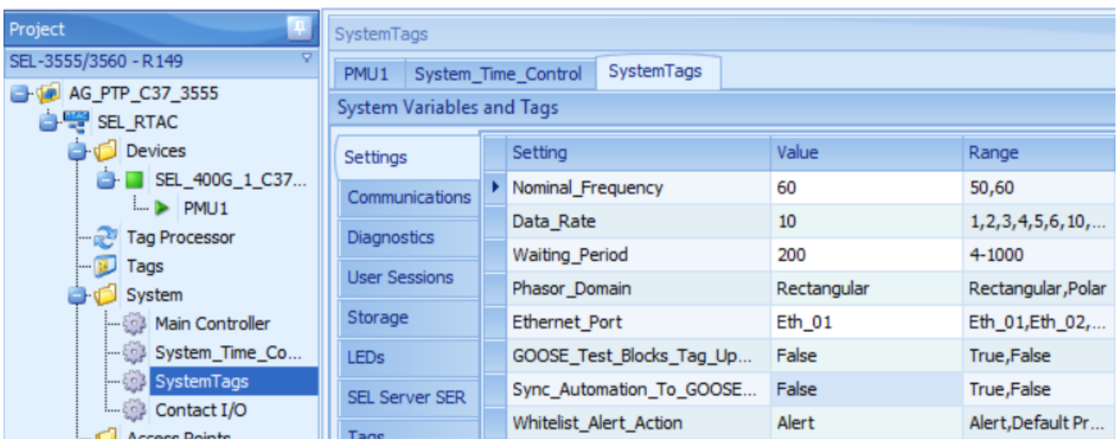



**Figure 27 RTAC Data Rate**

Step 8. Go to the **System_Time_Controller** under the System folder, as shown in *Figure 28*.

Step 9. Set the UTC offset to Mountain Standard Time (–420 as shown in *Figure 28*).

Step 10. Select the Ethernet port into which the PTP is received.

Step 11. On the Set_PTP_Interface_1 setting, select **Eth_05**.

This is the SEL-3390E4 card port where the PTP signal comes to the RTAC.

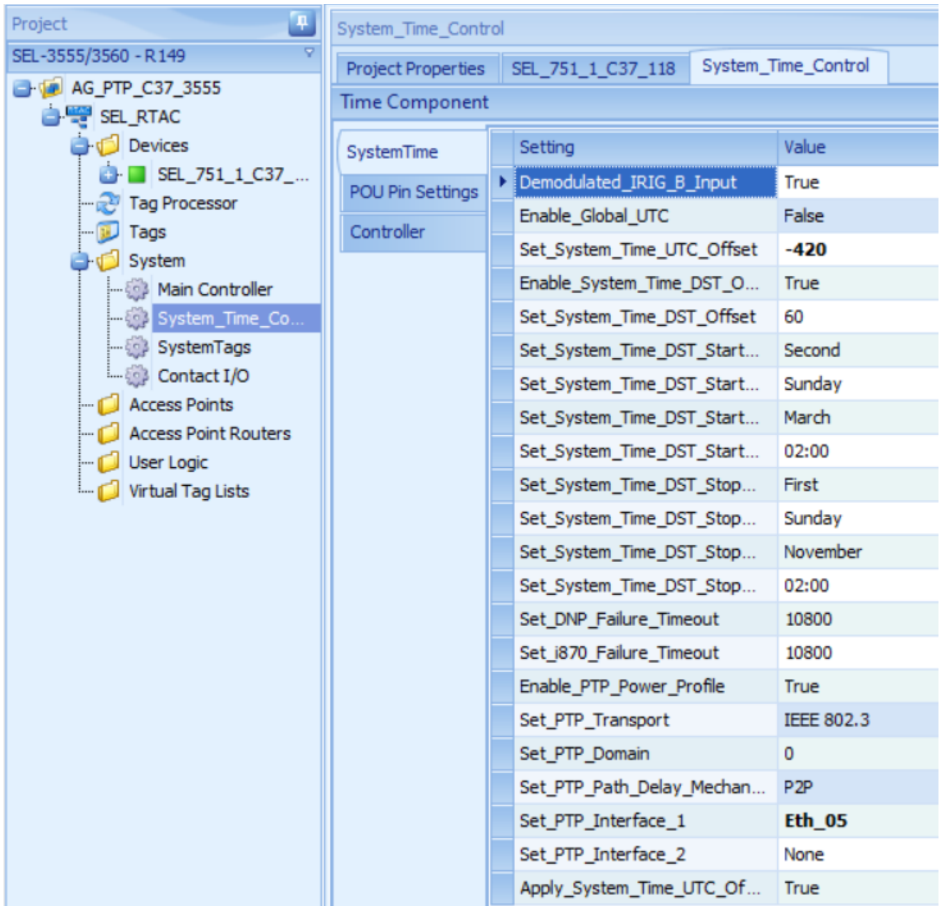



**Figure 28 RTAC SystemTime Settings**

Step 12. Select the **POU Pin Settings** tab, as shown in *Figure 29*.

This is where you configure your time source preference in the RTAC.

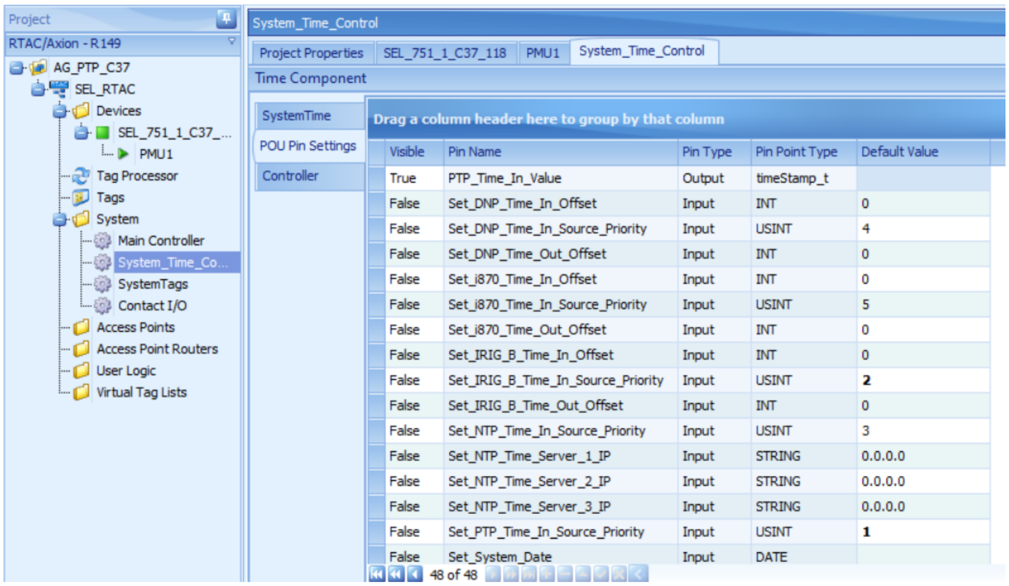



**Figure 29 RTAC System Time POU Pin Settings**

The number one selection is set to IRIG-B as the default priority. We adjusted the default values associated with the Set_IRIG_B_Time_In_Source_Priority and Set_PTP_Time_In_Source_Priority pins to recognize PTP as the primary time source. At this point the RTAC can have PTP as a primary time source and still have IRIG-B connected as a backup.

Once this is set, send the project to the RTAC by selecting the **Go Online** button in ACSELERATOR RTAC.

## TROUBLESHOOTING

With this configuration, the primary troubleshooting tool verifies that the PTP is successfully processed by your relay. From the SEL-400G terminal window, type the command **COM PTP**. This provides detailed information about the PTP signal being processed, as shown in *Figure 30*.

```
=>>com ptp

Relay 1                                    Date: 12/07/2021  Time: 11:44:25.982
Station A                                  Serial Number: 1202250095


PTP offset statistics previously cleared on 12/07/2021 18:01:30.710 (UTC)

Settings Data Set
  PTP Profile : C37.238
  Transport Mechanism : Layer2
  Path Delay : P2P


Default Data Set
  Two Step : true
  Clock Identity : 00 30 A7 FF FE 24 60 93
  Number of Ports : 1
  Clock Quality
    Clock Class : 255
    Clock Accuracy : 254
    Offset Log Variance : 0
  Priority1 : 255
  Priority2 : 255
  Domain Number : 0
  Slave Only : true


Current Data Set
  Steps Removed : 1
  Offset from Master : -16 ns
  Mean Path Delay : 0 ns


Parent Data Set
  Parent Port Identity
    Clock Identity : 00 30 A7 FF FE 0A F9 81
    Port Number : 2
  Grandmaster Clock Identity : 00 30 A7 FF FE 0A F9 81
  Grandmaster Clock Quality
    Clock Class : Synchronized with PTP timescale (6)
    Clock Accuracy : Within 100 ns
    Offset Log Variance : 18867
  Grandmaster Priority1 : 128
  Grandmaster Priority2 : 128
  C37.238 TLV Information
    GM ID : 5
    GM Time Inaccuracy : 23 ns
    Network Time Inaccuracy : 49 ns


Time Properties Data Set
  Current UTC Offset : 37
  Current UTC Offset Valid : true
  Leap59 : false
  Leap61 : false
  Time Traceable : true
  Frequency Traceable : true
  PTP Timescale : true
  Time Source : GPS
  Local Time Offset
    Offset Valid : true
    Name : UTC-07:00
    Current Offset : -25237
    Jump Seconds : 3600
    Time of Next Jump : 1647162037
```

**Figure 30 COM PTP Example**

For more troubleshooting steps and techniques, see Part 4 and Part 5 of [7].

## CONCLUSION

This application guide provides instructions for creating an IEEE C37.118 (synchrophasor) stream from an SEL-400G to an RTAC through an SEL-2740S. Specifically, it explains how to use PTP for time synchronization to minimize cabling between the SEL-400G and RTAC.

## References

[1] J. Beach and C. Garrison, "Understanding Fundamental SEL Relay Settings That Are Needed for Implementing IEEE C37.118 (Synchrophasors) Protocol on an SEL RTAC," SEL Application Guide (AG2021-33), 2021. Available: selinc.com.

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## Technical Support

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