SPG8000A Option PTP operation instructions

This document describes how to configure the SPG8000A to operate in your PTP network and also provides information about the basics of PTP operation. A list of known bugs and operational limitations are included.

How to configure Option PTP on the SPG8000A

General information

The operation of the instrument is intended to be primarily an SPG with the addition of PTP functionality, and the menu structure reflects this orientation.

Reference mode. The Reference mode selection restricts the possible PTP functions as follows:

- If the Reference mode is set to GPS, Genlock or Internal, the primary PTP function is a master.
- If the Reference mode is set to PTP, then the primary PTP function is restricted to Slave PTP mode.
- Automatically adapting between master and slave functions via the BMCA is not supported.

Secondary PTP engine. A secondary PTP engine is also available. This allows implementing two masters when in Internal mode or locked to GPS, and simultaneous Master and Slave operation.

The primary and secondary PTP systems must be on different domains.

Presets. Most of the PTP functions are saved in the presets. After configuring the instrument, a user can save the Power-on preset so that the desired instrument state is restored when the instrument is powered on.

Black outputs. The black outputs support a 1pps mode. This is useful for measuring timing between systems.

Firmware update. After a firmware update, the presets are often not valid and will usually be erased. Therefore, after an update please use the REF button menu to reselect either GPS or PTP as the Reference mode, and then use the PTP button menu to reselect all of the parameters. Next, use the SYSTEM button menu to resave the Power-on preset with your preferred settings.

www.tek.com

061-4417-00

Tektronix

Basic setup recommendations

1. Use the SYSTEM button menu to set the PTP network IP address using DHCP or Manual mode. (Press the SYSTEM button, and then press the down arrow twice to access the menu.)

NOTE. *Both PTP ports share the same network address. See the PTP network settings section below for information about how to configure the two PTP ports.*

2. Use the REF button menu to set the Reference mode depending on whether the SPG8000A will be a PTP master, slave or both. (Press the REF button, and then press the left or right arrow to select. Press ENTER to confirm the selection.)
   - If the SPG8000A is to be the PTP master, select either GPS, Genlock or Internal mode.
   - If the SPG8000A is to be a PTP slave, select PTP mode.
   - If the SPG8000A is to be both a PTP master and slave, select PTP mode and then configure the secondary master.
3. If Genlock mode is selected as the Reference mode, then also set the time to VITC, LTC, or Internal. In addition, select to use the ST309 data as "input" if ST309 date information is available in the input timecode. Note the limitations on Drop Frame time code in the limitations section of this document.
4. Use the PTP button menu to configure the Primary master or slave PTP profile, message rates, etc. (Press the PTP button once, and then use the arrow keys and the ENTER / BACK keys as necessary to make selections.)
5. If desired, press the PTP button a second time to access the secondary PTP engine. Select parameters as needed.
6. Configure the rest of the SPG8000A as per the online manual for the SPG8000.

SYSTEM button menu additions

PTP network settings. A new submenu in the SYSTEM button menu allows users to set the Network parameters on the PTP connection. Use this menu to set the DHCP/Manual and other network selections.

This menu also allows setting the DSCP level on the PTP messages. For most situations, the default value of 0 for noncritical General messages and 46 for the Event messages is appropriate. If you are using the AES67 profile, it may help to set both message types to the maximum value of 56. Changing these values resets all of the PTP systems and will disrupt the PTP operation for about 35 seconds.

This menu also allows control of the internal switch. The RJ45 and SFP ports can be configured as fully cross-linked, isolated or to mirror the RJ45 to the SFP. For most applications the Isolated setting is appropriate. This setting allows the two ports to both access PTP functions and not allow cross traffic. If you want the ports to work like a normal switch, use the Cross-linked setting. In this setting, all traffic into either port will echo out the other port. In Mirror mode, all the traffic in and out of the RJ45 port will be echoed to the SFP port. This is useful if you need to use Wireshark on a Unicast system. In this case, hook the Wireshark PC to the SFP port and use the internal switch to mirror the traffic.

Epoch settings. A second new submenu in the SYSTEM button menu controls the Epoch Selection, which is intended to change the timing on the Black outputs. For PTP systems, set this to the 1970 epoch.

New PTP button menu

There are two PTP functions: Primary and Secondary. Press the PTP button repeatedly to toggle between the two functions.

The Primary PTP function will be either Master or Slave depending on the Reference selection. Adaptive mode between master and slave is not supported.

The Secondary PTP function is only a master. The primary and secondary PTP functions cannot be on the same domain. The SPG8000A will display an error message if an attempt is made to set them to the same domain.

The entries in the PTP menu vary depending on modes of the instrument. Master and Slave modes need different settings. Multicast, Unicast and Mixed modes have different settings. Different profiles allow different ranges for some parameters. The possible PTP menu entries are listed below with a basic description of their function:

- Master can be enabled or disabled. Slave is always on.
- Profile Type. The following profile types are available: General, ST2059, AVB and AES67. Since each profile retains unique settings, each parameter must be set for each profile type.
- Press ENTER to set defaults for the selected profile. The defaults will set a nominal value given the selected profile.

- Domain. Defaults to a reasonable setting for each profile. Users are not allowed to set both PTP engines to the same domain.
- Communication mode. All of the master and slave devices on a given domain must use compatible communication modes. For most profiles, this means the master and slave communication modes need to match exactly. On the SMPTE profile, the Multicast and Mixed modes are compatible, so a master in any of these modes will work with a slave in any of those modes.

  Unicast is separate and the master and slave must match. Note that the Unicast, and Mixed without negotiation modes require that the IP address of all the masters be entered into the Acceptable Master Table (AMT) of the slave.
- Announce interval allows setting the rate at which the master will send announce messages. For Unicast mode there are two settings: Desired and Required. The slave will start by requesting the Desired rate. If the master refuses that rate, the slave will request a slower rate. This continues down to the Required setting. If the master cannot support the Required setting, the communication will not start. The default for the Required setting is the minimum rate / maximum interval allowed in the profile.
- Sync interval allows setting the rate at which the master will send sync messages. For Unicast mode there are two settings: Desired and Required. The slave will start by requesting the Desired rate. If the master refuses that rate, the slave will request a slower rate. This continues down to the Required setting. If the master cannot support the Required setting, the communication will not start. The default for the Required setting is the minimum rate / maximum interval allowed in the profile.
- Delay Message allows setting the rate at which the master will send delay request messages. For Unicast mode there are two settings: Desired and Required. The slave will start by requesting the Desired rate. If the master refuses that rate, the slave will request a slower rate. This continues down to the Required setting. If the master cannot support the Required setting, the communication will not start. The default for the Required setting is the minimum rate / maximum interval allowed in the profile.
- Announce timeout count sets the number of announce messages which can be missed before the device will assume the master is no longer present. After that time, all the devices on the domain will start the process of selecting a new master.
- Priority 1 and 2 are used in the BMCA to select the active master. Typically, all the masters should have the Priority 1 parameter set to the same value, and then use the Priority 2 parameter to select the primary master if all have the same clock quality. A lower value is preferred. For example, if you set the Priority 2 parameter of the primary master to 127, then set the Priority 2 parameter of all other masters to 128.

- One-step and two-step communication mode controls whether the timestamp for the sync message is sent in the sync (one-step mode) or sent in a follow-up message (two-step mode). Some devices, such as transparent clocks, only work on two-step messages. All slaves are required to work in both one-step and two-step modes.
- Delay Mechanism. Two delay modes are available: Peer-to-Peer and End-to-End.
  - In Peer-to-Peer mode, the Pdelay request and Pdelay response messages are local to each link in the network. Each device determines the local link and device delays. The sync message from the master then collects the corrections as it propagates from the master to slave. Peer-to-Peer mode is useful in PTP networks where the routing configuration changes. For Peer-to-Peer mode to work well, all of the devices need to be PTP aware.
  - In End-to-End mode, the sync, follow up, delay request and delay response messages go through the network all the way between the master and slave. End-to-End mode is useful in PTP networks where some or all devices are not PTP aware.
- Acceptable Master Table is required in Unicast and Mixed without Negotiation modes. Enter the IP address of all masters into the AMT of the slaves. The AMT can support up to eight IP addresses.
- Asymmetric delay allows correcting the slave timing for any asymmetric delay in the network. Use the 1 pps or other timing signal to determine the required delay. This should not be necessary if the network is PTP aware.

ST2059 profile menu selections. When ST2059 is the selected profile and the SPG8000A is configured as a PTP master, these additional menu selections appear. These settings only drive the Synchronization Metadata message content and have no effect on the operation of the master. Each of these menu selections can be set to "Auto" to ensure that the metadata bits are sent in a valid state.

- ST2059 SM Default Frame. Sets the metadata message fields to indicate the selected frame rate: 23.98, 24, 25, 29.97, 30, 47.95, 48, 50, 59.94, 60, 71.92, 72, 100, 119.9, or 120.
- ST2059 SM Drop Frame Flag. Sets the metadata message bit for the Drop Frame Flag to enabled or disabled.
- ST2059 SM CFID. Sets the metadata message bit for the Color Frame ID to enabled or disabled.

Status menu

Press the STATUS button then use the down arrow to select different types of status. The PTP master and PTP slave status sections have multiple pages that can be displayed using the left and right arrow.

- The master status reports the clock quality and some of the ST2059-2 metadata parameters it is sending.
- The slave status reports the clock quality and some of the ST2059-2 metadata parameters it is receiving.

Web UI and SNMP

The Web UI and SNMP allow users to control of most of the instrument functions that are available from the front panel. See the *SPG8000A User Manual* for more information on the SNMP command set.

Known bugs and limitations

The following is a list of known bugs and operational limitations:

- Genlock to PAL with VITC or 25 Hz LTC is fully functional. Genlock to NTSC with VITC or 30 Hz Drop Frame LTC basically works but is not fully accounting for the drop frame compensation. Therefore, there may be a few frames of error until the scheduled jam sync had occurred.
- The Peer-to-Peer delay mode has had limited testing. The basic messages are present but a full system has not been demonstrated.
- ST2059-2 SM leap seconds are not fully implemented. The other messages should be working.
- Slave Lock takes about 2.5 minutes.
- The AVB and AES67 profiles have had limited testing.

PTP operational overview

PTP introduction

Option PTP for the SPG8000A adds two Precision Time Protocol (PTP) engines to the SPG system. The primary PTP engine has the capability to be a master PTP source or lock the SPG to the PTP as a slave. The secondary PTP engine can only be a master.

PTP operating modes. The basic operating mode of the SPG is set in the Reference Select menu. The reference selection drives the allowed function of the primary PTP engine as follows:

- If the SPG reference selection is set to internal, or to lock to an external GPS, NTSC, PAL, Tri-level or CW signal, then the primary PTP engine can only be a master.
- If the SPG reference selection is set to lock to an external PTP signal, then the primary PTP engine can only be a slave.

PTP master selection. In a PTP network, all the masters on the network are evaluated by the Best Master Clock Algorithm (BMCA). The BMCA runs on all devices, and chooses a master based on several parameters. Some of the parameters relate to clock quality; conversely the Priority 1 and Priority 2 parameters are set by the user to influence the choice of a master:

- Priority 1. This parameter defines which clocks are allowed to be considered as masters. To be considered as a master, the value should be set to 128 or less. Priority 1 is the first criteria in the BMCA, so if Priority 1 is set to a lower value than other devices on the system, then it will be chosen even if the clock quality is poor. Typically, all the masters in a domain should have the same value for the Priority 1 parameter.
- Priority 2. This parameter is used to break the tie between masters that have the same clock quality. Several values may be used to define a hierarchy of devices. Most profiles use 128 as a default, so a value of 127 or lower would indicate a preferred master.
- The final tie-breaker in the BMCA is the clock ID. This is usually the MAC address so it provides a unique value by which the BMCA can choose.

Network topology. In a typical IEEE1588 PTP network, many devices may be either masters or slaves. If the current master stops working, all the devices that are capably of being a master broadcast their clock quality and a new master is selected.

For video networks it may make sense to depart from the telecom-style PTP topology and dedicate devices to be only masters or slaves. This is the approach supported by the SPG8000A, which allows for a more traditional primary and backup master structure controlling a range of slave devices. The BMCA is still used to select the active master and the network still takes the place of the ECO in the legacy Black-burst/Tri-level network. See the *SPG8000A User Manual* for suggestions on possible network topologies.

The five basic PTP timing messages

There are five basic timing messages in a PTP system: Announce, Sync, Follow-up, Delay request, and Delay response. Other messages are present in some instances. For example, grant requests and responses appear in unicast systems, and Type Length Value (TLV) management messages appear in SMPTE ST2059 profile systems.

Announce message. The Announce message is sent by the master to advertise its capability. This message contains the clock quality and priority settings needed for the BMCA to evaluate which device is the best master.

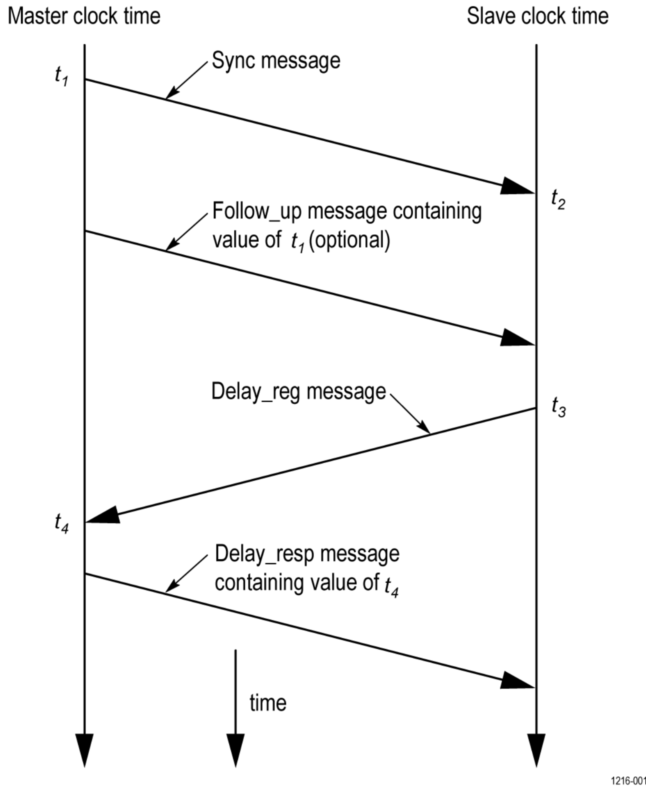
Sync message. The Sync message is sent by the master and is used to measure the propagation delay from the master to slave. The sync message may contain the timestamp indicating when it was sent, or that time may be in the Follow-up message. The receiver must timestamp the sync message upon receipt. These two timestamps are usually called "t1" and "t2" and provide the first delay measurement.

Follow-up message. The Follow-up message is sent only in cases where the PTP network hardware is not capable of inserting the timestamp into the Sync message. (See page 10, *One-step and two-step operation*.)

Delay request message. The Delay request is sent by the slave. The time at which it is sent is noted by the slave, but is not included in the message. This time is usually called "t3." When the delay request is received by the master, the master timestamps the receive time. This timestamp is usually called "t4."

Delay response message. The delay response is sent from the master to the slave. The response contains the t4 time stamp from when the master received the delay request. Once the slave receives the delay response, it has the second pair of timestamps needed to calculate the second delay measurement of the slave to master delay.

Message timing. The following figure show the relationships between the five PTP timing messages.



Profiles

The IEEE1588 standard defines multiple parameters, such as the rates for Sync and Announce messages, and optional functions such as grandmaster clusters. Specific industries wanting to use PTP are encouraged to define their own “profile,” which allows the PTP standard to be tuned for specific applications. The profile defines the default and range of each parameter, and defines with options are required, allowed or prohibited.

In the SPG8000A, the profile can be initialized to the default value for a given profile and mode. After setting the reference mode, the user should go to the PTP menu and select the profile. The user then has the options to initialize the profile parameters to the default value for both the selected profile and operating mode (Master, Slave or Adaptive). After initialization, the user can modify the profile parameters and save as part of an instrument preset. The allowed range of the parameters is restricted to that which is allowed for the given profile type.

Domains

The IEEE1588 standard defines "domains," which allow multiple PTP services to coexist simultaneously on one physical Ethernet connection. For example, on a given network one master and several slaves can be using domain 0 while a second master and other slaves are using domain 1. These two PTP services are independent. One use for this is to have masters on different domains provide PTP on different profiles. For example, domain 0 might be an AES67 profile, domain 1 could be a master using the AVB (802.1AS) profile, and domain 127 could be a master on the SMPTE ST2059 profile.

Since the SPG8000A has two PTP engines, the instrument can provide PTP mastering on two domains and two profiles simultaneously. With multiple SPGs, more domains and profiles can coexist on the same network.

One-step and two-step operation

Some PTP messages have a time stamp associated with them. This time stamp indicates the time of the local clock when the message was sent or received. In some cases, the hardware is capable of embedding the time stamp in the message as it is sent. This is known as "one-step" mode since the message and its associated time are sent together.

In other cases, the hardware is not capable of inserting the time into the message, so instead it is sent in a second follow-up message. This is called "two-step" mode since there are two messages.

It is interesting to note that in End-to-End mode, only the Sync message is effected by the one-step and two-step setting since it is the only message that needs the transmit time stamp inserted. This means that other than masters, all devices should be able to process either one-step or two-step message types. In a similar fashion, Peer-to-Peer mode has some messages that may require follow-up support.

Multicast, Unicast, and Mixed Communication modes

There are three basic message modes for PTP: Multicast, Unicast, and mixed Multicast and Unicast. For full Multicast or Unicast modes, all of the PTP messages are sent in the selected mode type.

For some profiles, such as some telecom profiles and the SMPTE ST2059 profile, a mixture of Multicast and Unicast are allowed. On the SMPTE profile unique mixed mode, the Announce and Sync messages are sent as multicast. However, the Delay request and Delay Response messages are sent as Unicast.

Some points to understand about communication modes:

- Whatever mode is chosen, the master and slave must match or be compatible
- Multicast and Mixed mode may need IGMP joins and leaves
- Full Unicast must have the master address in all slave AMTs
- Unicast without negotiation does not allow master to regulate load
- Two masters can be used on different domains to serve slaves on different communication modes

Multicast system messages. Multicast messages are broadcast and so they can be received without knowing the address of the sender. This allows a slave to hook up to the network, receive the announce messages and discover the identity of the master. Multicast in some networks requires the devices to use IGMP to join and leave the multicast group.

In Multicast PTP systems, the master sets the rate of the announce and sync messages. The master also sends the maximum allowed delay request rate in the delay response message. Ideally, the slave will use that value to set the delay request rate although some slave set this rate independently. The delay request rate is typically the same as the sync rate, but may be higher or lower.

Unicast system messages. Unicast messages require the address of the master be entered into the Acceptable Master Table (AMT) in each slave. If there are multiple masters, the IP address for each master must be entered in the AMTs of all the slaves.

In Unicast PTP systems, the slave must have the address of the master in its acceptable master table. The slave sends several grant requests to the master requesting specific rates for each message type. If the master accepts the grant requests, it will send grant acknowledges. If the master denies the grant, the slave may send a new grant request at a lower rate. This process may continue for several iterations until the master and slave agree on a rate. The master and slave will then start exchanging the PTP messages. If the master cannot support any of the rates requested by the slave, then the slave will not be able to lock to the master.

Mixed mode system messages. In Mixed Mode systems, some messages are Multicast and some are Unicast. For the SMPTE ST2059 profile, the Announce and Sync messages are sent as Multicast. This allows devices to discover the active master. The Delay Request rate is configured for Unicast, so the slave and master must exchange grant messages before the system will start the full range of messages.

In Mixed mode without negotiation, the delay request rate set by the slave must be equal to or less than the Sync rate set by the master. Otherwise, the slave will not be able to connect to the master.

SMPTE profile system messages. For SMPTE profile systems, a given domain must use one type of message for all Announce, Sync and Follow up messages. Therefore, all masters and slaves on that domain must be configured for either Multicast or they all must be configured for Unicast.

For SMPTE mixed mode, the Announce, Sync, and Follow up messages are configured as Multicast so that the delay requests can be Multicast, Unicast, or Unicast without negotiation. To use this combination, set the master and slave to any of the modes: Multicast, Mixed, or Mixed without negotiation. The masters will support all of the slave modes simultaneously.

BMCA

The Best Master Clock Algorithm (BMCA) is used to choose the active master on the domain. This is partially explained in the introduction to this document. The BMCA operation varies somewhat as function of communication mode.

Multicast mode. In Multicast mode, the active master sends announce messages that all other masters and slaves can receive. So all devices can evaluate the BMCA and decide on the best master. If any device detects that its BMCA rating is better than the current master, it will send an announce and take over as the active master.

Unicast mode. In Unicast mode, slaves only get Announce messages if they establish a grant from the master. Therefore, each slave must set up a grant with every device in its AMT. Since the masters do not set up grants from other masters, they do not have the information to evaluate the BMCA and know if they are the active master. It is up to the slaves to evaluate the BMCA based on the announce message they get from each master in their AMT. Each slave then decides which master is the best and then set up grants for the other message types. If slaves on a given network have a different list of masters in their AMT, then they may choose a different master.

Mixed mode. In a SMPTE ST2059 mixed environment, the announce message is Multicast. Therefore, the BMCA can follow the Multicast conventions.

Compensating for causes of asymmetric delay

Several factors can cause the PTP message delay to be different for the messages sent from the master to slave as opposed to the messages the other direction from the slave to master. Unless corrected, this propagation delay asymmetry will cause an offset in the clock phase equal to ½ the difference in the two path delays. There are 4 main causes of asymmetric delay: Rate mismatch in the ports on a switch, Traffic mismatch on the two paths, message type mismatch, and cable delay variation. The paragraphs below contain hints on how to design the system to minimize the delay asymmetry. Alternatively, the SPG8000A provides a way to manually enter a correction value to cancel the delay error.

Rate mismatch. Rate mismatch in a switch causes a delay asymmetry due to the fact that the switch does a “store and forward” on messages. This means the entire message must be stored in the buffer before it starts to be “forwarded” or sent out. For example, for a 100 Mb input and 1 Gb output, the switch must wait for the entire message to clock in at the slow rate before it can start outputting the message at the high rate. Conversely for a 1 Gb/s input and 100 Mb/s output, the entire packet is quickly read in at the faster rate, so then the output can start sooner, albeit at a lower rate.

While the total time is the same for both directions, the delay on the fast-in, slow-out direction is shorter on the packets which contain the PTP timestamps. This effect is significant on a 100 Mb/1 Gb rate mismatch, but much less significant on a 1 G/10 G switch since the message time at 1 Gb/s is quite short. If the switch supports Transparent Clock (TC) mode, then this rate mismatch delay effect is corrected by the TC delay correction.

Traffic mismatch. Another cause of asymmetric delay is traffic mismatch on the two paths. If there is a high percentage of traffic utilization on the master to slave path, then most of the PTP messages may be delayed significantly. If the traffic on the other direction is significantly different, then the messages on the path may not suffer the same delay.

This effect can be quite large depending on the traffic, the quality of the switch, and the number of switches in the network. To reduce this effect, a user should avoid large loading on the PTP network, use high-quality switches that avoid this delay variance, or use PTP Transparent mode switches which will insert residence time information to allow the slave to correct for this delay.

Message type mismatch. Another cause of delay asymmetry is message type mismatch. For example, if the sync message is Multicast and the delay request is Unicast, then some switches may process the messages differently and cause a differential delay. Since the SMPTE profile allows a mixed mode operation, switches should be evaluated to ensure they do not have this effect. If transparent mode switches are used, then this effect should be corrected by the slave.

Cable delay variation. The actual propagation delay through Cat 5 cable can be significantly different in one direction versus the other direction. This can be due to the twist rate on the pairs, routing inside the sheath, material differences, etc. The PTP system is incapable of removing this effect, so the best way to prevent this is to use high-quality cable with a minimum variation in the physical propagation delay.