**SMPTE EG 2059-10:2023**
**Revision of SMPTE EG 2059-10:2016**

# SMPTE ENGINEERING GUIDELINE

# Introduction to the New Synchronization System (SMPTE ST 2059)



## Table of Contents — Page

**Foreword** .......... **2**
**Introduction** .......... **2**
**1 Scope** .......... **3**
**2 Terms and Definitions** .......... **3**
**3 Concept of the New Synchronization System** .......... **3**
**4 IEEE 1588 PTP (Precision Time Protocol)** .......... **4**
4.1 Introduction to PTP .......... 4
4.2 Synchronization Overview .......... 4
4.3 Device Types .......... 6
4.4 Redundancy .......... 8
**5 Time Source** .......... **8**
5.1 Introduction to time sources .......... 8
5.2 Primary Reference Time .......... 9
5.3 Locally-generated reference time .......... 10
5.4 A/V Synchronization Signal .......... 11
5.5 A/V Synchronization Signal + Reference Time .......... 12
**6 Synchronization Ecosystem** .......... **14**
6.1 General .......... 14
6.2 System with legacy synchronization and ST 2059 PTP-based synchronization .......... 14
6.3 System with multiple PTP profiles .......... 15
**7 SMPTE ST 12-1 Time Code Generation** .......... **15**
**Bibliography (Informative)** .......... **16**


**Approved November 11, 2022**

## Foreword

SMPTE (the Society of Motion Picture and Television Engineers) is an internationally-recognized standards developing organization. Headquartered and incorporated in the United States of America, SMPTE has members in over 80 countries on six continents. SMPTE's Engineering Documents, including Standards, Recommended Practices, and Engineering Guidelines, are prepared by SMPTE's Technology Committees. Participation in these Committees is open to all with a bona fide interest in their work. SMPTE cooperates closely with other standards-developing organizations, including ISO, IEC and ITU.

SMPTE Engineering Documents are drafted in accordance with the rules given in its Standards Operations Manual. This SMPTE Engineering Document was prepared by Technology Committee TC-32NF.

This Engineering Guideline is purely informative and meant to provide tutorial information to the industry. It does not impose Conformance Requirements and avoids the use of Conformance Notation.

Engineering Guidelines frequently provide tutorial information about a Standard or Recommended Practice and when this is the case, it is advised that the user rely on the Standards and Recommended Practices referenced for interoperability information.

In this revision, terminology is adjusted to match that of SMPTE ST 2059-2:2021. Text referring to Alternate Master is deleted as this option is no longer permitted in ST 2059-2:2021. Where applicable, references are updated.

## Introduction

This clause is entirely informative and does not form an integral part of this Engineering Document.

The legacy methods of synchronization for television, audio and other moving picture signals rely on standards that have been in place for over 30 years. These standards are becoming increasingly inappropriate for the digital age with, for example, networked content sharing and the higher frame rates appropriate to HDTV, UHDTV and other image formats.

In order to solve these problems, SMPTE has specified a new synchronization system based on alignment to reference time measured from the SMPTE Epoch. SMPTE ST 2059-1 specifies how signals are aligned with respect to the SMPTE Epoch. SMPTE ST 2059-2 specifies a Profile of IEEE Std 1588-2008 Precision Time Protocol for distribution of reference time and synchronization metadata in the professional broadcast environment.

This guideline describes basic ideas, concepts and use cases of the new synchronization system, including SMPTE ST 12-1 Time Code generation.

At the time of publication, no notice had been received by SMPTE claiming patent rights essential to the implementation of this Engineering Document. However, attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. SMPTE shall not be held responsible for identifying any or all such patent rights.

 

# 1 Scope

The objective of this document is to introduce the basic concepts behind the use of the new SMPTE ST 2059 synchronization system and the IEEE-1588 Precision Time Protocol in Professional Broadcast Applications, and to describe some use cases. Detailed explanation of the technology is out of scope of this document.

# 2 Terms and Definitions

For the purposes of this document, the terms and definitions given in SMPTE ST 2059-1:2021 and SMPTE ST 2059-2:2021 apply.

# 3 Concept of the New Synchronization System

Periodic AV signals can be created deterministically if their phase and clock frequency at a particular time are known. For example, in the case of a video synchronization signal, if the start point of the video frame (phase) and the video clock frequency are known, it can be created deterministically at any given point in time.

The new synchronization system takes advantage of this characteristic and shares time information across the system rather than transferring synchronization signals themselves. As time information consists of phase (offset from the certain point in time) and frequency, if the phase relationship between time and an A/V signal has been defined, any A/V synchronization signal can be created deterministically from time information. This concept is illustrated in Figure 1.

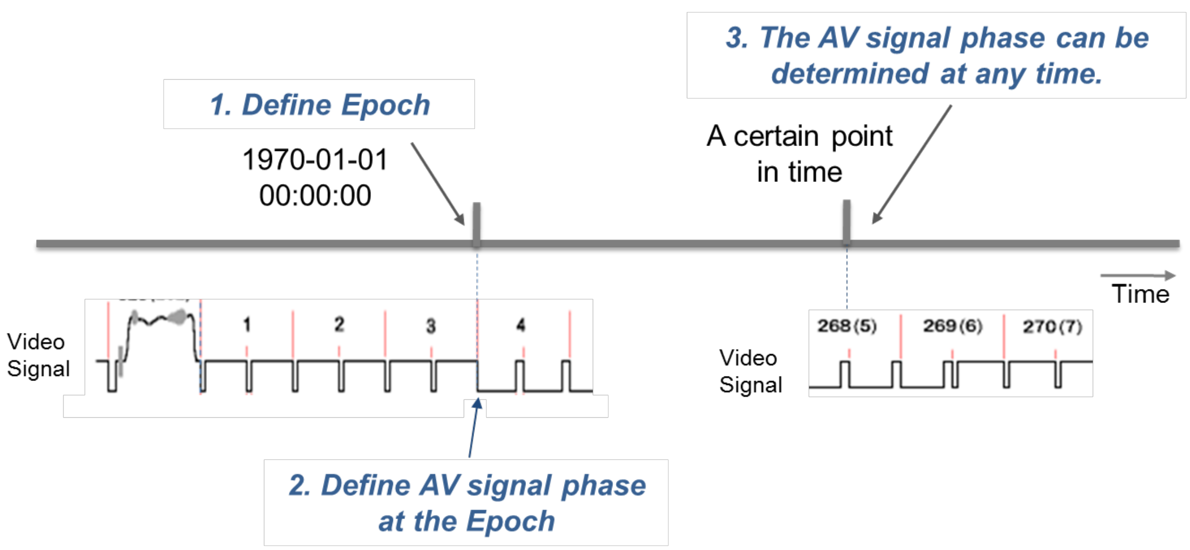


**Figure 1 — Concept of the New Synchronization System.**

SMPTE ST 2059-1 defines a reference point in time (the 'SMPTE Epoch') and the alignment of A/V signals to the Epoch.

The phase of the video signal is given by time since the Epoch modulo video frame period.

 

# 4 IEEE 1588 PTP (Precision Time Protocol)

## 4.1 Introduction to PTP

The new synchronization system uses PTP, as specified in IEEE Std 1588-2008, as a means of sharing precision time across a network. PTP is a time distribution protocol which runs on a network, such as a LAN. It allows for time synchronization with sub-microsecond accuracy. The same approach to synchronization is used in IEEE Std 1588-2019.

The PTP defined in IEEE 1588 has many possible parameters and options. A ‘Profile’ is used to define sets of attributes and their values in order to optimize its application to specific industries or for particular purposes. SMPTE ST 2059-2 specifies the SMPTE PTP profile which is optimized for professional broadcast applications.

The following is a simple explanation of the PTP operation. See IEEE Std 1588 and SMPTE ST 2059-2 for further detail.

## 4.2 Synchronization Overview

As illustrated in Figure 2, PTP performs time synchronization by exchanging PTP messages periodically between a PTP leader and PTP followers. These messages include timestamps corresponding to time of transmission or reception of the message or a related one. PTP followers perform time synchronization using the timestamps.

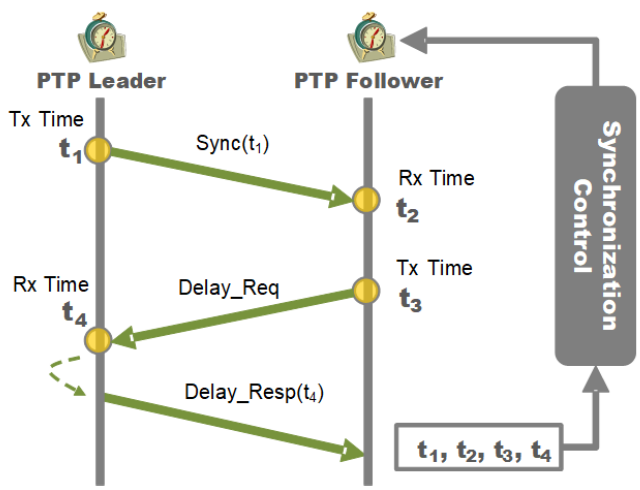


**Figure 2 — Concept Diagram of the PTP Synchronization Control.**

In order to synchronize time at the PTP follower to the PTP leader, both the frequency and phase of the time information have to be controlled. The principle is shown in Figure 3.

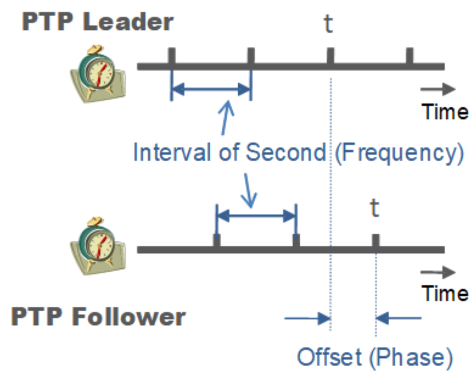


**Figure 3 — Time Synchronization: Frequency and Phase.**

The PTP follower extracts frequency and phase information from PTP messages.

Figure 4 shows one example of how frequency information can be extracted and calculated. The Sync message is a PTP message which the PTP leader sends to PTP followers periodically. Assuming that the network delay is consistent between the PTP leader and a PTP follower, the difference between Sync message intervals measured by the PTP leader (Δl) and the Sync message intervals measured by PTP follower (Δf) is the frequency difference. Therefore frequency can be synchronized by a control system in the PTP follower to remove the difference (Δl - Δf). In order to achieve precise synchronization, it is essential to minimize the impact of variations in the network delay. Also, in order to speed up the synchronization time, it is effective to reduce the Sync message intervals.

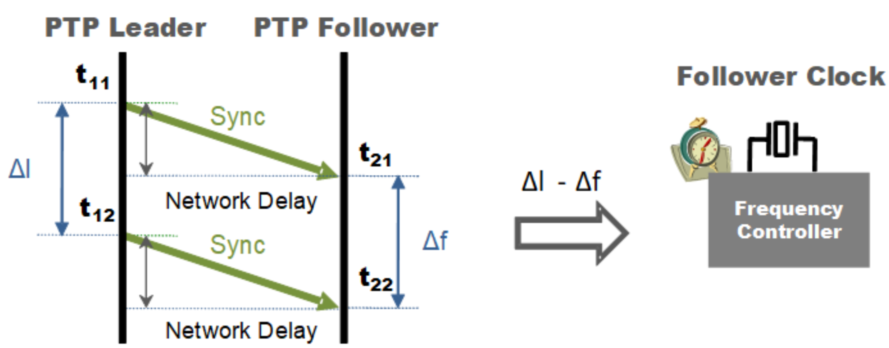


**Figure 4 — Example of Frequency Control.**

Phase control is also needed, and Figure 5 shows an example of how this can be achieved. The Delay_Req message is a PTP message that a PTP follower sends periodically to the PTP leader. Assuming that the network delay between the PTP leader and the PTP follower is consistent and is the same in each direction, the time difference between when the Sync message is sent and when the Sync message is received $(t_2 - t_1)$ = Network Delay + Time difference (between PTP leader clock and PTP follower clock) and time difference between when Delay_Req message is sent and when Delay_Req message is received $(t_4 - t_3)$ = Network Delay - Time difference. Therefore, the time difference (phase) can be calculated as follows:

$$\text{Time Difference} = \frac{(t_2 - t_1) - (t_4 - t_3)}{2}$$

 

Again, as it is assumed the network delay is consistent and in order to achieve precise synchronization, it is essential to minimize the impact of variations in network delay. Also, in order to speed up the synchronization time, it is effective to reduce the Delay_Req message intervals.

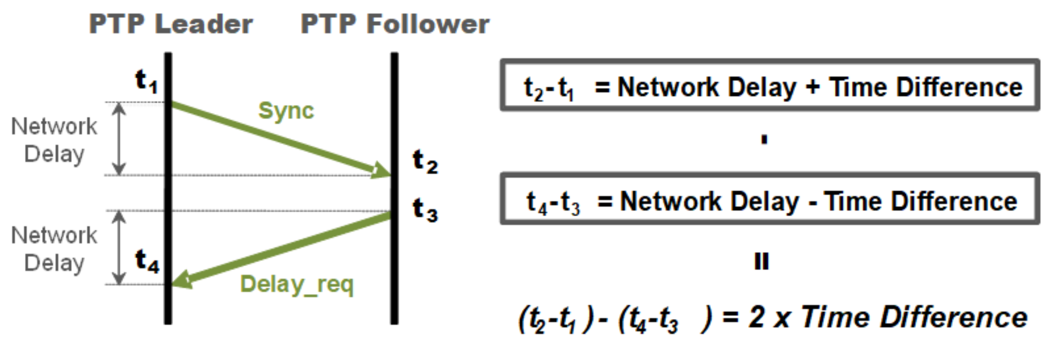


**Figure 5 — Example of Time Phase Control.**

## 4.3 Device Types

PTP is a distributed protocol that specifies how the real-time clocks in the system synchronize with each other. These clocks are organized into a leader-follower synchronization hierarchy.

PTP executes within a logical scope called a 'domain'. All PTP messages are always associated with a particular domain.

IEEE Std 1588 defines three kinds of clock: an ordinary clock which is an end device with one port on the network described above; a transparent clock, and a boundary clock, both of which have more than one port on the network.

NOTE More precisely, there are two types of transparent clocks: an end-to-end transparent clock and a peer-to-peer transparent clock. In this document, only the end-to-end transparent clock is described.

*1. Ordinary Clock*

The ordinary clock can be a grandmaster clock (PTP GM) in a system, or it can be a follower clock (PTP follower). The PTP GM is at the top of the leader-follower hierarchy and determines the reference time for the entire system within a domain.

*2. Transparent Clock*

As described above, reducing the effect of network delay variation is essential in order to perform precision time synchronization. One option to reduce the impact is to use a transparent clock.

The transparent clock, illustrated in Figure 6, is a special switch for PTP and embeds the time taken to pass through the switch (residence time) into PTP event messages. PTP followers can compensate for varying network delay by subtracting residence time and thereby reduce its impact.

 

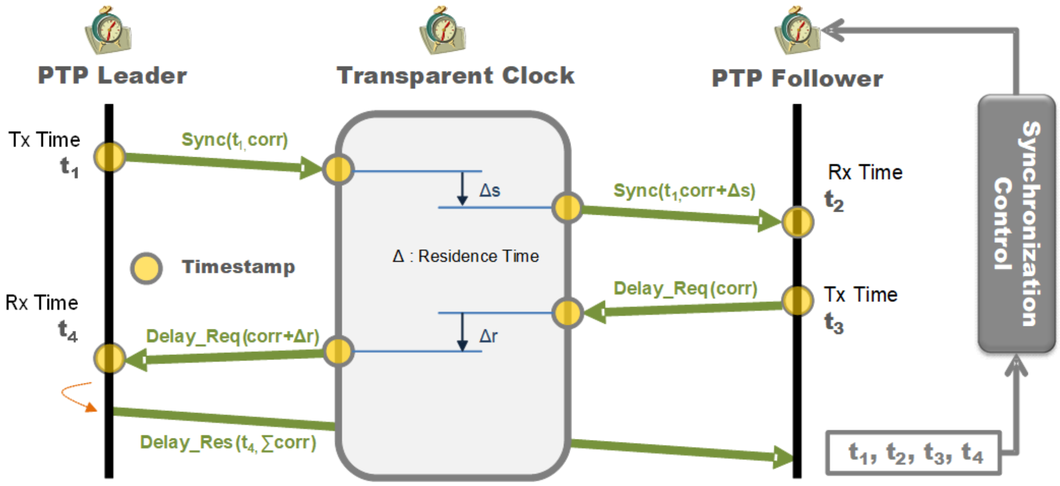


**Figure 6 — Concept of Transparent Clock.**

3. *Boundary Clock*

The maximum number of PTP followers that a PTP GM can control is limited by several conditions, including the rate at which it can process and respond to Delay_Req messages. A boundary clock is designed to increase the maximum number of PTP followers connected to the same PTP GM by establishing hierarchical structure.

Figure 7 illustrates a boundary clock. This includes both a PTP leader (L) and a PTP follower (F), and conveys the time synchronized by the PTP follower to the downstream PTP followers as a PTP leader.

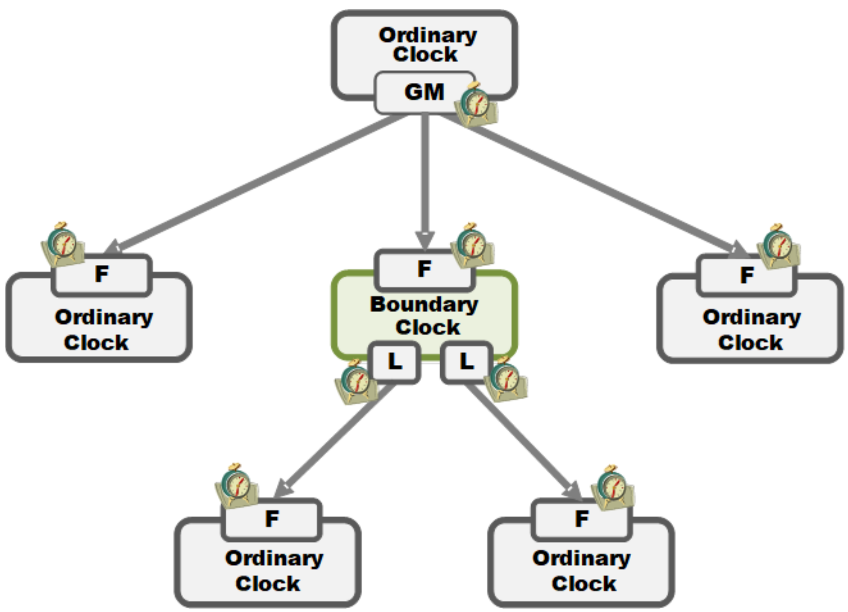


**Figure 7 — Concept of Boundary Clock.**

 

### 4.4 Redundancy

IEEE Std 1588 defines the BMCA as the default PTP redundancy mechanism.

The BMCA is used to determine what state, e.g., LEAD or FOLLOW, a particular port is intended to be in. If the current PTP leader fails, the BMCA will be executed on all other clock ports and will result in one of them becoming the new leader (assuming not all the devices are follower-only clocks).

When using a BMCA, SMPTE ST 2059-2 specifies use of the IEEE 1588 default BMCA mechanism.

Other PTP redundancy options are also defined in IEEE Std 1588 but are not permitted to be used by SMPTE ST 2059-2.

## 5 Time Source

### 5.1 Introduction to time sources

The new synchronization system can be applied to various use cases according to system requirements. The essential point is that in each case, PTP followers create a synchronization signal using exactly the same mechanism.

Aside from use cases related to the network configuration such as inclusion of transparent clocks or boundary clocks, the main distinguishing factor between use cases is the type of time source used by the PTP GM.

There are two types of timescales supported by IEEE Std 1588: ‘PTP’ and ‘ARB’ (arbitrary). With the PTP timescale, the Epoch is the SMPTE Epoch. In the case of timescale ARB, the Epoch is set by an administrative procedure, might be reset during normal operation, and does not necessarily correspond to the SMPTE Epoch.

The type of time source used by the PTP GM is indicated by the attribute timeSource. In the case of the SMPTE ST 2059-2 profile, two additional values for timeSource have been added for cases when the frequency reference is derived from a legacy synchronization signal.

The following four types of time source are assumed, and the features and typical use cases of each are described.

1. *Primary reference time*

The PTP GM is synchronized to a primary reference time, for example, by means of Global Positioning System (GPS) reception. The timescale is PTP.

2. *Locally-generated reference time*

The PTP GM is synchronized to a locally-generated time source that is not necessarily referenced to a primary reference time. The timescale is ARB or PTP.

3. *A/V synchronization signal*

A/V synchronization signal such as black burst. Timescale is ARB.

4. *A/V synchronization signal + reference time*

Combination of A/V synchronization signal such as black burst and reference time. Timescale is ARB or PTP.

 

## 5.2 Primary Reference Time

Figure 8 illustrates an example of a use case where GPS is used as a time source.

By sharing a primary reference time, synchronization can be achieved between PTP followers that are not necessarily connected to the same PTP GM. Synchronization can even be achieved for devices not connected to the PTP GM if the primary reference time can be obtained independently.

Also, as illustrated in Figure 8 as Facility 1, a legacy synchronization signal based facility can also coexist if the legacy sync generator is locked to the primary reference time and as a result, the output legacy synchronization signals are Epoch aligned.

Therefore, a distributed synchronization environment can be easily established. This could be the optimum solution for new 'green field' facilities.

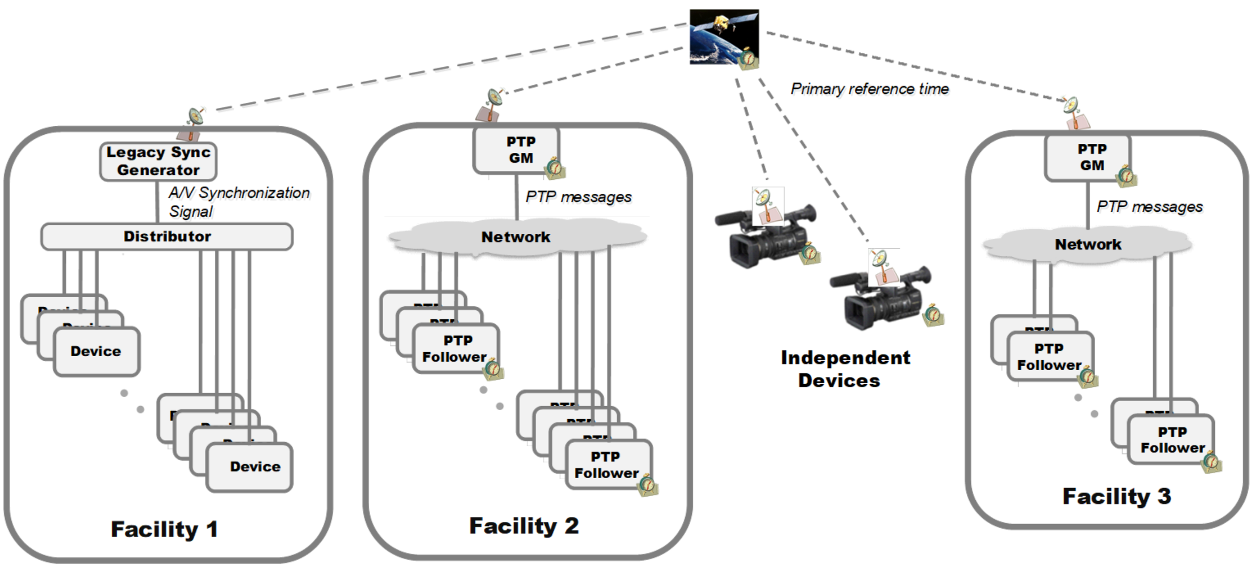


**Figure 8 — Use case where time source is a Global Reference Time.**

## 5.3 Locally-generated reference time

Figure 9 illustrates an example of use case where a locally-generated reference time, such as a wall clock, is not necessarily locked to a primary reference. As with current conventional operation using a legacy sync generator, synchronization can be achieved between PTP followers connected to the same PTP GM. The precision of the shared time depends on the precision of the GM time reference. This could be the solution for a closed ‘island’ system.

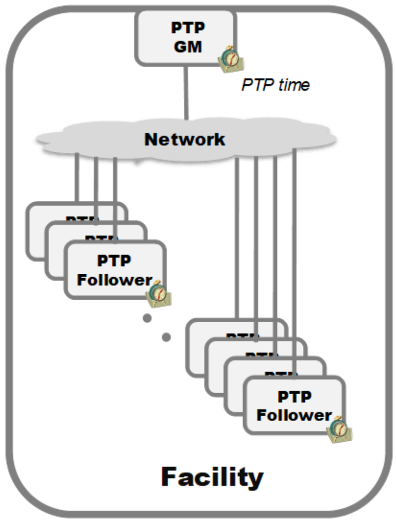


**Figure 9 — Use case where a time source is not necessarily locked to a primary reference time.**

## 5.4 A/V Synchronization Signal

Figure 10 illustrates an example of use case where a free-running legacy A/V synchronization signal such as color black alone is used as a source of PTP time, without any reference to an actual time source. An example of such an application is where it is wished to replace a small part of an established system based on a legacy synchronization signal such as black burst.

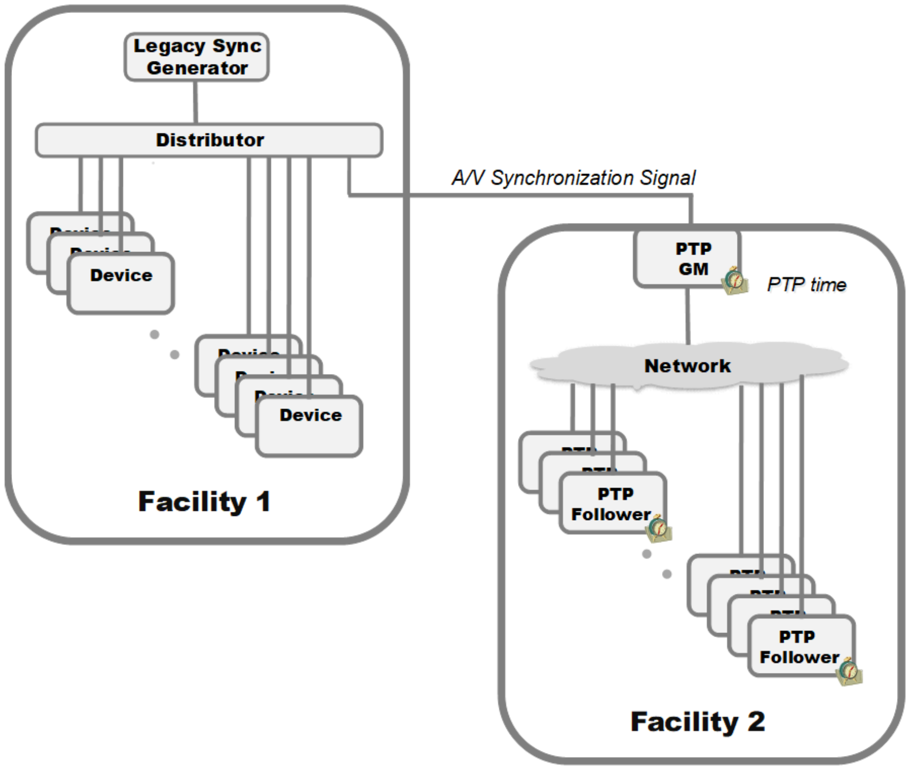


**Figure 10 — Use case where time source is A/V synchronization signal.**

Figure 11 shows the concept. In this case, the PTP GM extracts frequency and phase information from the A/V synchronization signal and this is used to create a source of time starting from an Epoch that is related to the synchronization signal. As an A/V synchronization signal has only time periodicity, and no absolute relationship with real time, conversion to real time (TOD) is not possible and so PTP time at initialization always starts from an administratively set A/V synchronization-related Epoch.

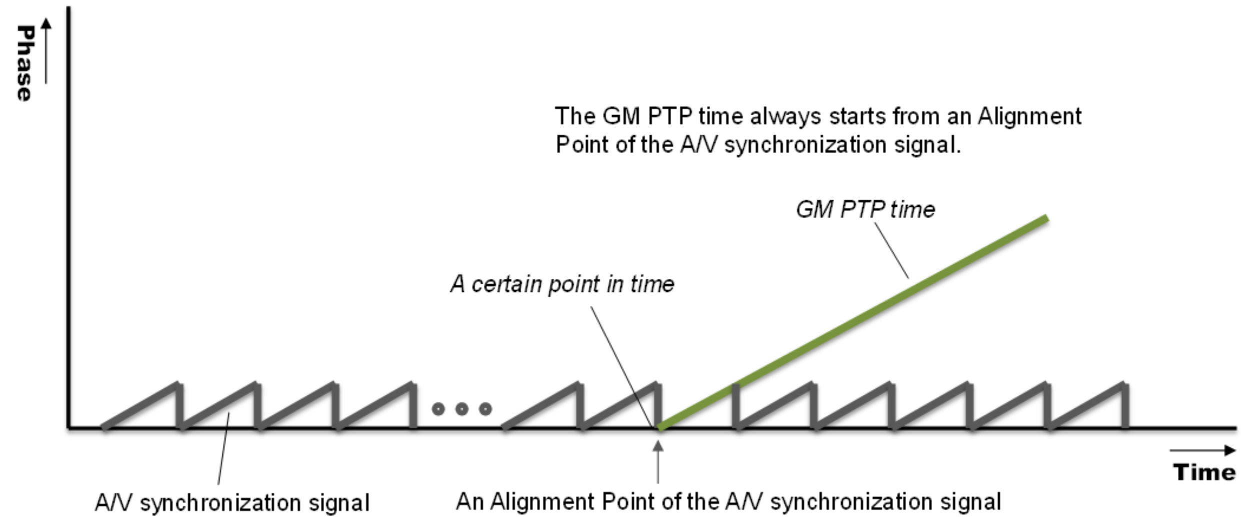


**Figure 11 — Example of conversion from A/V synchronization signal to PTP time.**

If it is required to share real time, the configuration described in Clause 5.5 can be chosen.

## 5.5 A/V Synchronization Signal + Reference Time

Figure 12 illustrates an example of use case where a free-running legacy A/V synchronization signal and reference time are used as a source of PTP time.

An A/V synchronization signal has its own inherent time period and is not necessarily Epoch aligned. On the other hand, reference time increments monotonically from the Epoch.

The objective is to create the GM PTP time from which the identical AV synchronization signal can be reconstructed at a PTP follower together with approximately the correct time.

Figure 13 illustrates the concept. There is an offset between the Epoch of the reference and Epoch′, the phase zero point in time of an A/V synchronization signal which is the closest to the Epoch. The phase of the GM PTP time is set by shifting the reference by 'Offset' so that the A/V synchronization signal uses Epoch′. This adjustment affects the PTP time accuracy which would be in error by up to plus or minus half the inherent time period of the A/V signal.

If the A/V synchronization signal contains embedded time code representing the time of day and optionally date (with Daily Jam applied as appropriate), this could be used as a source of time.

NOTE Even if primary reference time is used for this use case, the output PTP time from followers is no longer primary reference time.

 

The frequency of the GM PTP time is synchronized to the A/V synchronization signal. Because the frequency of the A/V synchronization signal might be slightly different from that of the correct time period, it is possible that the GM PTP time will gradually deviate from the correct real time. For example, if the input video clock frequency is 1ppm different from the nominal frequency, the GM PTP time will deviate by 84ms in a day. Therefore, if the application requires a closer approximation to the correct time, it might be necessary to make occasional adjustments to either GM PTP time or follower time.

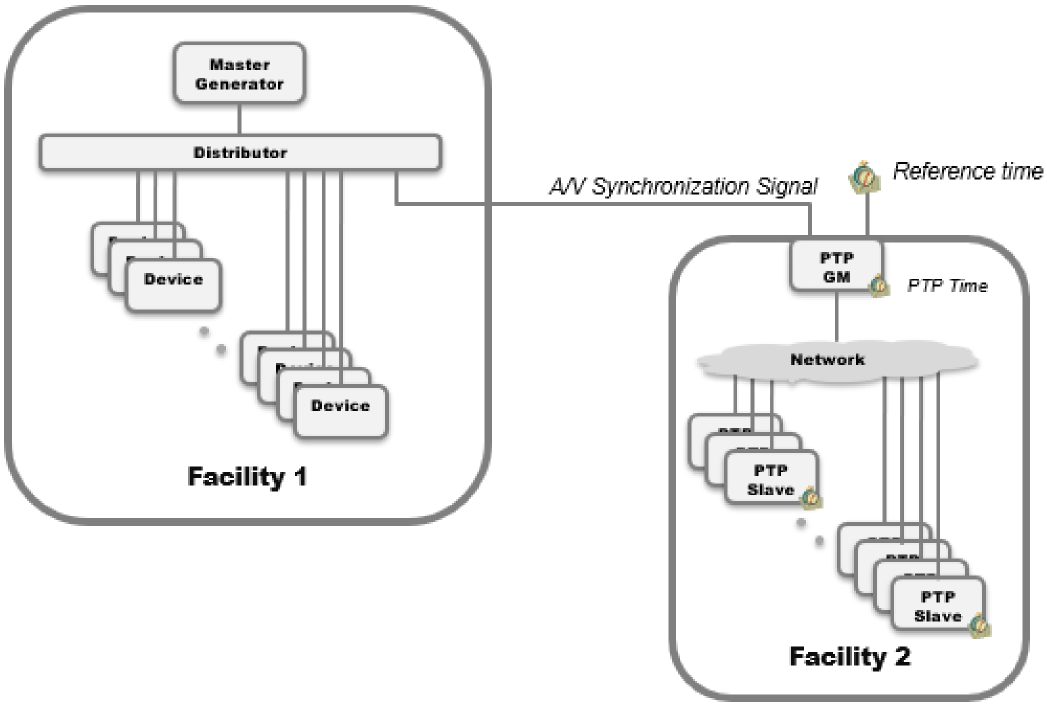


**Figure 12 — Use case where time source is A/V synchronization signal + reference time.**

 

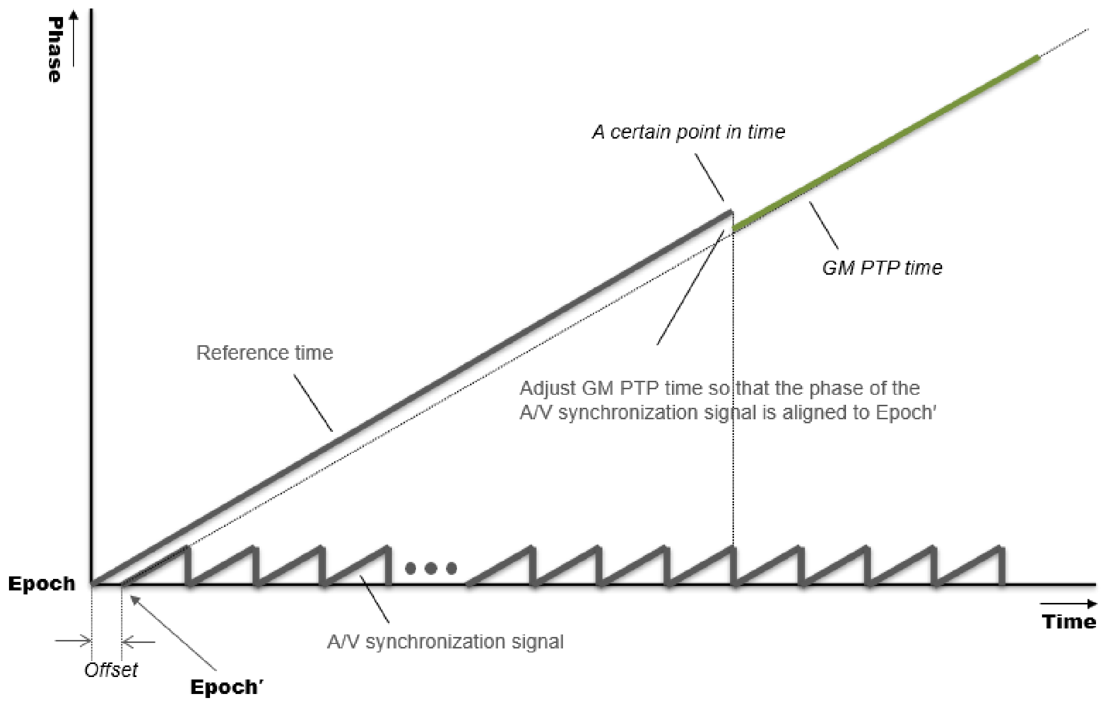


**Figure 13 — Example of conversion from a combination of A/V sync signal and reference time to PTP time.**

# 6 Synchronization Ecosystem

## 6.1 General

A simple system using only SMPTE ST 2059-based synchronization is described in Clause 6.2. However, there can be cases where several different synchronization mechanisms are employed in a system.

Clause 6 describes use cases with multiple synchronization mechanisms.

## 6.2 System with legacy synchronization and ST 2059 PTP-based synchronization

This could be the case where it is wished to replace a small part of an established system based on a legacy synchronization signal such as black burst with SMPTE ST 2059 PTP-based synchronization.

Possible solutions are described in Clause 5.4 (illustrated in Figure 10) and Clause 5.5 (illustrated in Figure 12).

 

### 6.3 System with multiple PTP profiles

As described in Clause 4, SMPTE ST 2059-2 is a PTP profile optimized for professional broadcast applications. However, other PTP profiles exist and the application scope of some might overlap with that of SMPTE ST 2059-2.

In particular, AES 67 is designed for synchronization of audio systems and is closely related to the scope of SMPTE ST 2059-2. For example, if both IP-mapped HD-SDI streams and IP-mapped audio streams are present in a system, there can be the following options in terms of their synchronization:

- Use both the SMPTE ST 2059-2 profile and the AES 67 profile with different PTP domains. PTP has a concept of 'domain' and PTP followers are able to choose the relevant profile's PTP messages distinguished by PTP domain. If the messages of two PTP profiles are synchronized, two PTP followers using the different PTP profiles will be synchronized to each other.
- Use a single PTP profile. As SMPTE ST 2059-2 conveys synchronization metadata using PTP Management messages that are not defined in AES 67, most probably SMPTE ST 2059-2 would be chosen. In this case, audio devices would need to make use of the SMPTE ST 2059-2 profile for their synchronization. In order to make this possible, only PTP attribute values common between SMPTE ST 2059-2 and AES 67 can be used. AES-R16 proposes attribute values for interoperability.

## 7 SMPTE ST 12-1 Time Code Generation

In addition to generating an A/V synchronization signal, SMPTE ST 12-1 Time Code can also be generated from PTP time. The PTP leader sends a Management Message periodically which contains Synchronization Metadata. This metadata can be used by PTP followers when generating time-of-day SMPTE ST 12-1 Time Code.

In current conventional operational practice, SMPTE ST 12-1 Time Code is distributed to each device from a central Time Code generator. The biggest change in the new scheme is that SMPTE ST 12-1 Time Code can be generated by each individual PTP follower using PTP time provided by the PTP leader, and this can be achieved and maintained deterministically whenever a follower connects to the network. PTP followers also are able to support user configured Daily Jam where this is in use.

NOTE The Daily Jam is an optional daily procedure carried out within a facility that uses SMPTE ST 12-1 time code in which the time address value is adjusted to correspond to Local Time at the chosen time of the Daily Jam. It is usually carried out in the early hours of the morning at a non-sensitive time as determined by the operator of the facility.

For details, see SMPTE ST 2059-1 and SMPTE ST 2059-2.

## Bibliography (Informative)

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

IEEE Std 1588-2019, IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems

SMPTE ST 2059-1:2021, Generation and Alignment of Interface Signals to the SMPTE Epoch

SMPTE ST 2059-2:2021, SMPTE Profile for use of IEEE-1588 Precision Time Protocol in Professional Broadcast Applications

AES-R16-2021: AES Standards Report - PTP parameters for AES67 and SMPTE ST 2059-2 interoperability

AES67-2018: AES standard for audio applications of networks - High-performance streaming audio-over-IP interoperability

 