It’s About Time

The SMPTE ST 2059
Network-Delivered Reference Standard

Paul Briscoe, Consultant
Toronto, Canada

SMPTE Standards Update Webcasts

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SMPTE Standards Update Webcast:
It’s About Time
The SMPTE ST 2059: Network-Delivered Reference Standard

Your Host

Joel E. Welch
Director of Education
SMPTE

Today’s Guest Speakers

Paul Briscoe
Consultant

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Let’s talk about synchronization

**Live television facilities operate in a synchronous manner**

- All signals are frequency locked to a reference
- All signals are phase adjusted (“timed”) according to use

**Started with the first TV transmission**

- Scanning beam on camera was tracked by receiver
- Production had to keep the beam on track when switching

**This requirement has followed us to the digital age of SDI**

- ..and got more complex

**Live IP systems have the same issues and more.**

**So we’re stuck with it. Can we make it any better?**
Synchronization analogy

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Synchronization analogy

Old-school reference signals

Legacy reference signals we know and love

- BlackBurst, TLS, DARS, Time Code
- Generate them in a central place (Master (redundant))
- Distribute them to all equipment that needs them (Slaves)
- Used to establish output timing, input windows, time of day
- Allows building synchronous facilities

Can lock master(s) to GPS (GNSS, etc.)

- (more) accurate frequency reference
- Time of day for timecode
Problem? What problem?

**Multiple signals = multiple distributions**

- **CAPEX**
  - Different distribution hardware and (maybe) cabling
- **OPEX**
  - Physical equipment maintenance / single points of failure

Inflexible – have to pull cables to evolve

Break in a path in the tree causes downstream disruption(s)

Analog signals (old analog signals!)

Technology horizon - EOL
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Loss of a path in the tree results in further downstream reference loss
All slaves beyond go freerunning
Loss of one signal may be worse than loss of all

Synchronization analogy

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Distributing fundamental signals

What we distribute are media signals posing as reference signals

- BlackBurst (or TLS) – video with no picture
- DARS – audio with no sound
- Timecode – Good ol’ ST12 (12M to some) longitudinal timecode

Why? History.

- Easy to use in slave equipment – natural frequencies (for media)
- Same interfaces and systemization technologies as media signals
- Made sense when life was simple.

———

What are we actually distributing?

Two fundamental things:

- Frequency (timebase), which ensures:
  - Signals are locked (stationary in time) wrt one another
    - Frequency of signal is correct (per SMPTE, etc. STDs)
  - Phase (“timing” or “alignment”), which ensures:
    - Signals are in a deterministic time relationship “timed”
      - made coincident (-ish) at points of use

Acid test for a system: Main breaker.

- Everything comes up the same each time.
What are we synchronizing?

Video sources feeding a production switch / mix / key environment
- Cameras, feeds, graphics, CG, replay / slomo, servers....

Facility resources feeding each other and elsewhere
- Studios, MCR

Audio sources and facilities

Router switchpoint timing

Automation systems (timecode)

What part of the signal do we use?

Frequency (timebase)
- Derived from interface signal edges
  - H (and SC) in video
  - Edges in DARS and Timecode

Phase (“timing” or “alignment”)
- Largest periodic element of signal (“alignment event”)
  - Vertical in video
  - X or Z preamble in DARS
  - Bit 0 in timecode
Meanwhile

Things are changing quickly underfoot

• Analog going away fast – no more critical timing performance
• Technologies are changing – really fast
  • Product implementation technologies – HW > SW
  • Broadcaster systemization technologies – digital > network
  • Distribution technologies – many > network
  • Consumption technologies - network
• Workflows are changing - network

IT has arrived.

Is there a better way?

Nice to have:

• meets legacy performance requirements
• one distribution infrastructure, not many
• one method to carry all references, not many
• a means of providing redundancy in the distribution
• something that would directly support new / future standards
• something that can be externally / globally referenced
• as close to plug and play as today
• something that can run over a network
A new kind of reference “signal”

IEEE1588 Precision Time Protocol (PTP)

Delivers precision time to slave devices over network
- Runs on IP (and Layer 2) networks
- Provides for a master (“Grandmaster”) and slave devices
- Offers master and distribution redundancy
- Offers external (GPS, etc.) lock to frequency and time
- Can coexist happily with other network traffic
- Network switches can participate to improve performance

So what? Where’s the frequency and phase?

What does PTP do?

Transfers precision time to many slave devices over a network

PTP transfers frequency via running time:
- 1 GHz virtual clock (timebase) (typically a submultiple)

PTP transfers phase via running time:
- A count value since the time the counter was zero (“Epoch”)
  - High span (~136 years) / high granularity (1 ns)

When locked to an external authoritative source, multiple independent masters will have same time and frequency.
- Global locking possible via GNSS (e.g. GPS)
Who uses PTP?
Time-locked loop theory

Algorithm for a human time-locked-loop

- You have a running pendulum clock
- Tune in radio time signal
- “at the tone, the time is…” - set your clock
- Wait a day (or longer if clock keeps OK time)
- Tune in radio time signal
- “at the tone, the time is…” - set your clock, note the error
- Adjust your pendulum slightly according to magnitude and direction of error
- GOTO “Wait a day”.

- Eventually your clock will maintain correct time (phase)
- Your pendulum period is accurate (frequency)

PTP protocol takes care of network latency

- PTP time counter runs in the master
- Clocked by a very good timebase
- Time can be arbitrary (start from zero at powerup)
  - Time can be set locally to approximately the right time (manual)
- Time and frequency can be authoritative (from GNSS)

PTP time counter runs in the master
- Clocked by a very good timebase
- Time can be arbitrary (start from zero at powerup)
  - Time can be set locally to approximately the right time (manual)
- Time and frequency can be authoritative (from GNSS)
PTP Range and Granularity

- 1 Year
- 1 Month
- 1 Day
- 1 Hour
- 1 Minute
- 1 Second
- 1 Millisecond
- 1 Microsecond
- 1 Nanosecond

12M Timecode

- SDI Video
- Composite Video
- AES Audio

Calendar

- NTP

IEEE1588

- GPS Native

Time Counter

- Whole Seconds - 32 bits (~136 years)
- Nanoseconds – 32 bits (1 ns)

1 Hz (PPS)

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PTP vs. you

- 1 Year
- 1 Month
- 1 Day
- 1 Hour
- 1 Minute
- 1 Second
- 1 Millisecond
- 1 Microsecond
- 1 Nanosecond

12M Timecode

- SDI Video
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- AES Audio

Calendar

- NTP

IEEE1588

- GPS Native

Time Counter

- Whole Seconds - 32 bits (~136 years)
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1 Hz (PPS)

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PTP on the network

Transmits very small packets
Can be all of either or a mix of unicast and multicast messaging
  • Reserved addresses
  • Specific network domains

Very robust in the presence of traffic
IP switches can provide PTP-specific services to improve performance
  • Boundary Clock switches provide unique master on each port
  • Transparent Clock switches process timestamps

PTP high accuracy
PTP-specific switch types

PTP delay measurement

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So what?

We need:

- Special SMPTE frequencies, not 1 GHz submultiples
- Specific phase information related to our signals (events)
- A way to establish deterministic phase relationships

Timecode!

Getting the funny frequencies

Media frequencies are unusual
PTP is based on integer frequency
Today, cross-synthesis is trivial
  - FPGA-based logic
  - COTS components
Source oscillator performance is transferred
We do this all the time today inside equipment.
Not a big deal.
Phase as events

Phase is conveyed in legacy signals as alignment events

Events used to reset signal generator
Combined with frequency, this is how we lock signals

Phase via PTP

PTP knows nothing about our requirements – it's just time
Consider a video signal and a PTP counter
For each event, there will be a corresponding PTP time value
Next event can be calculated from current event
Phase anchoring in PTP

We need to have an anchor so all slaves are event-synchronous
PTP defines 1970.01.01 00:00:00 as the “Epoch”

Count value was
00000000000000000000000000000000000000000000000000000000

We (SMPTE) define that all signals had their events at the epoch
Knowing this, slaves can calculate future events
Because events occurred at a known time (epoch), all slaves calculate the same event times.

This concept is central to the ST-2059 standard.

Locking to time

Cross-synthesis of required media frequency
Calculation of next event based on epoch
Same signal generation bits as legacy gear
Does it actually work?

Very early tests done with PTP locking a video generator
Master generated one signal
Two slaves generated two more signals

So what about the network?

IP networks profuse media systems today
Touch most equipment already

Non-time-sensitive networks:
  • Configuration and software upgrade
  • Monitoring and Control

Time-sensitive networks:
  • Live media transport

PTP can live on any / all networks
The new opportunity

Masters provide native redundancy (2+)
Autochangeover is virtual between masters (PTP BMCA)
With external reference, they lock to that, one ‘drives’ the network
Without external reference, one becomes master, other(s) lock to it.
With failure of master, another picks up the role
The ‘greenfield’ problem

Most people will evolve to network equipment and infrastructure

How to deploy PTP references with legacy systems?
- Both systems need to have same timebase
- Both systems need to provide the same signal alignment
- Facilities / equipment can pick and choose which to use
- User can evolve from old to new at their will

Will require a new kind of master generator scheme
- GrandMaster + legacy SPG master

Legacy Master contains PTP slave functionality
Legacy signals generated same as any slave
Distributed via tree structure as before
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**Equipment with a choice**

- **Black Burst**
- **Sync Separator**
- **Logic**
- **Phase-locked loop**
- **TCXO**
- **Compare**
- **Local Running Time Count**
- **Live Running Time**
- **Calculate Next Event**
- **PTP Slave**
- **Local Timebase Oscillator**
- **10 MHz**
- **Cross-synthesis**
- **V Reset**
- **Signal Generator Clock**
- **SDI**

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What about live IP?

**Live IP uses PTP as its native timing infrastructure**

- Live media and PTP live on same network
- Live media transport is by RTP protocol
  - RTP uses timestamps for payload synchronization
- Network senders use PTP to create media timestamps
- Network receivers use timestamps to align media streams
  - also use PTP for internal and legacy output timing
- PTP used for timecode generation
- PTP can be used for locking non-IP media equipment

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**RTP Timestamp**

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<tr>
<th>V</th>
<th>P</th>
<th>X</th>
<th>CSRC count</th>
<th>M</th>
<th>Payload type</th>
<th>Sequence number (16 bits)</th>
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<td>Payload (real time data)</td>
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<td>Padding (size x 8 bits)</td>
<td>Padding size (8bits)</td>
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</table>
SMPTE ST2059

SMPTE Standard suite for network-delivered references

- 2059-1 “Epoch and Signal Generation”
  - Alignment points for interface signals (that exist today)
  - Formulae for direct calculation of signals from PTP time
  - Formulae and algorithms for deterministically calculating ST12 time-address and ST309 date
- 2059-2 “SMPTE PTP Profile”
  - Specific PTP rules required by SMPTE application
  - SMPTE-specific helper metadata
    - Network and SMPTE parameters

ST 2059-1 Scope

This Standard defines:

- A point in time, the SMPTE Epoch, which is used for alignment of all signals referenced in this Standard;
- The alignment of these signals to the SMPTE Epoch;
- Formulae which specify the ongoing alignment of these signals to SMPTE ST 2059-2 Profile IEEE 1588-2008 PTP time;
- Formulae which specify the calculation of SMPTE ST 12-1 Time-Address values and SMPTE ST 309 date values from SMPTE Profile IEEE 1588-2008 PTP data.
ST 2059-2 Scope and Introduction

This standard specifies a Precision Time Protocol profile specifically for the synchronization of audio/video equipment in a professional broadcast environment.

The profile is based on IEEE Std 1588-2008 and includes a self-contained description of parameters, their default values, and permitted ranges.

This profile is designed with the following purposes in mind:

- To permit a slave to be synchronized within 5 seconds of its connection to the operational PTP network. While there are many factors that will in practice influence the synchronization time, the default values of configurable attributes have been chosen to help achieve this target.
- Having achieved initial synchronization, to maintain network-based time accuracy between any two slave devices with respect to the master reference within 1 microsecond.
- To convey Synchronization Metadata (SM) required for synchronization and time labeling of audio/video signals.

The SMPTE Epoch

Specific origin Epoch for SMPTE 2059 use

The SMPTE Epoch shall be January 1st, 1970 00:00:00 TAI, which is the same as the PTP Epoch specified in IEEE Std 1588-2008.

Periodic signals in scope of this standard shall have a defined temporal reference point and shall be aligned such that the reference point occurred at the SMPTE Epoch and the signal subsequently maintained its specified frequency.
Signal Generation

ST 2059-1 specifies the alignment of all common media signals and formats to the Epoch including AES-3 and timecode.

Tables convey specific alignment point definitions

Formulae convert PTP time value into specific media elements
- lines, pixels, bits, edges, blocks, samples

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<th>Television System and Reference Standard</th>
<th>Frame Rate [Hz]</th>
<th>Reference Standard System Number</th>
<th>Horizontal Alignment (Y Sample)</th>
<th>Y samples per total line H</th>
<th>Y Samples per active line HA</th>
<th>Total Lines V</th>
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</table>
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### SMPTE ST2059-1 formulae

\[ T = \frac{1}{SR} \]

\[ \text{NextAlignmentPoint} = \left( \text{int} \left( \frac{t}{H \times V \times T} + 1 \right) \times (H \times V \times T) \right) \]

\[ \text{SampleWordNumber} = \left( \text{int} \left( \frac{t}{T} + P \right) \right) \% H \]

\[ \text{LineNumber} = \left( \text{int} \left( \frac{t}{T} + P - \frac{HA}{H} \right) \% V \right) + 1 \]

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### ST 2059-2 Profile elements

A PTP Profile contains application-specific constraints on PTP operation

- Which of the best master clock algorithm options is to be implemented.
- Which of the configuration management options is to be implemented.
- Which of the path delay mechanisms, delay request-response or peer delay is to be implemented.
- The range and default values of all PTP configurable attributes and data set members.
- The transport mechanisms required, permitted, or prohibited.
- The node types required, permitted, or prohibited.
- The options required, permitted, or prohibited.
Synchronization Metadata

Helper data for:

- Generation of date and local time of day
- Generation of timecode
  - Dropframe is not straightforward – daily jam
  - ST2059 makes this better – specifies jam time
    - Slaves can figure out what the right timecode is
- Un-obvious items
  - System primary frame rate
  - Master locking status
  - Timecode Flags

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<tr>
<th>Item</th>
<th>Octets (Bytes)</th>
<th>Offset</th>
<th>Description</th>
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</thead>
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<tr>
<td>currentLocalOffset</td>
<td>4 (int32)</td>
<td>20</td>
<td>Offset in seconds of Local Time from grandmaster PTP time(^1). See Section 5.14.</td>
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<tr>
<td>jumpSeconds</td>
<td>4 (int32)</td>
<td>24</td>
<td>The size of the next discontinuity, in seconds, of Local Time. A value of zero indicates that no discontinuity is expected. A positive value indicates that the discontinuity will cause the currentLocalOffset to increase.</td>
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<tr>
<td>timeOfNextJump</td>
<td>6 (uint48)</td>
<td>28</td>
<td>The value of the seconds portion of the grandmaster PTP time at the time that the next discontinuity of the currentLocalOffset will occur. The discontinuity occurs at the start of the second indicated. See Section 5.14.</td>
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<tr>
<td>timeOfNextJam</td>
<td>6 (uint48)</td>
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<td>The value of the seconds portion of the PTP time corresponding to the next scheduled occurrence of the Daily Jam. If no Daily Jam is scheduled, the value of timeOfNextJam shall be zero. See Section 5.14.</td>
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<td>timeOfPreviousJam</td>
<td>6 (uint48)</td>
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<td>The value of the seconds portion of the PTP time corresponding to the previous occurrence of the Daily Jam. See Section 5.14.</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

The value of `currentLocalOffset` at the time of the previous Daily Jam event. If a discontinuity of Local Time occurs at the jam time, this parameter reflects the offset after the discontinuity. The default value shall be the current value of `currentLocalOffset`.

See Section 5.14.

<table>
<thead>
<tr>
<th>daylightSaving</th>
<th>1</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Bit 0: Current Daylight Saving
- 0: Not in effect
- 1: In effect

Bit 1: Daylight Saving at next discontinuity
- 0: Not in effect
- 1: In effect

Bit 2: Daylight Saving at previous Daily Jam event
- 0: Not in effect
- 1: In effect

Bits 3-7: Reserved

See Section 5.14.

---

### Timecode in a nutshell

The SMPTE ST 12-1 Time Address value payload shall be calculated using the following steps (or equivalents which produce the identical results) that are expanded in detail in the subsections below:

1. **Step 1:** (Startup) Calculate exact date, time, and Time Address value of the previous Daily Jam event.
2. **Step 2:** (Increment time) Determine time of next codeword (`NextAlignmentPoint`).
3. **Step 3:** (Test Daily Jam) Check if Daily Jam event has occurred.
4. **Step 4:** (Update Daily Jam Values) If Daily Jam event has occurred, calculate exact date, time, and Time Address value of the local Daily Jam event.
5. **Step 5:** (Output) Calculate the SMPTE ST 12-1 Time Address value and the SMPTE ST 309 date using exact date, time, and Time Address value of the previous Daily Jam event.
6. **Step 6:** (Continue) Go back to Step 2.
9.4.3.4 30 / 1.001 frames-per-second, Drop Frame

The following formulae (or an alternative method yielding the identical results) shall be used for these calculations:

\[ \text{dropFrameMode} \text{ shall be set to Drop frame} \]
\[ \overline{F_f} = 30 \text{ Hz} \]

1. Calculate Time Address of previous Daily Jam Event as frames since midnight:

\[
\text{framecount} = \overline{F_f} \text{pdjam} \]
\[
+ (30 \times \overline{S_S} \text{pdjam}) + (1798 \times \overline{M_M} \text{pdjam}) + \left( 2 \times \text{int}\left( \frac{\overline{M_M} \text{pdjam}}{10} \right) \right) 
\]
\[
+ (107892 \times \overline{H_H} \text{pdjam}) 
\]

2. Add number of LTC codewords since previous Daily Jam Event

\[ \text{framecount}^t = \text{framecount} + f_e \]

3. Calculate new Time Address:

\[
\overline{H_H} = \text{int}\left( \frac{\text{framecount}^t}{107892} \right) \]
\[
\overline{H_H \text{notmod}24} = \overline{H_H} 
\]
\[
\overline{M_M} = \text{int}\left( \frac{1}{1800} \right) \times \left( \text{framecount} - 2 \times \text{int}\left( \frac{\text{framecount} - 107892 \times \overline{H_H}}{1800} \right) \right) 
\]
\[
- 2 \times \text{int}\left( \frac{\overline{M_M}}{10} - 107892 \times \overline{H_H} \right) \]
\[
\overline{S_S} = \text{int}\left( \frac{1}{30} \times \left( \text{framecount} - 1798 \times \overline{M_M} \right) \right) 
\]
\[
- 2 \times \text{int}\left( \frac{\overline{M_M}}{10} - 107892 \times \overline{H_H} \right) \]
\[
\overline{F_f} = \text{framecount}^t - 30 \times \overline{S_S} - 1798 \times \overline{M_M} - 2 \times \text{int}\left( \frac{\overline{M_M}}{10} \right) 
\]
\[
- 107892 \times \overline{H_H} \]
\[
\overline{H_H \text{notmod}24} \% 24 
\]

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Back to the big picture

Which will come first, chicken or egg?

- Multiple island evolution scenarios available
- Which kind of island? Which kind of reference?

Dual-reference equipment – when and for how long?
Will it really play nicely on media networks?
Will users trust everything on one interface?
How long is the ramp?

So many questions.

First Interop tests – Fox NE&O
Tests conducted at interop

- Transport Mechanism
  - Multicast
  - Unicast
  - Mixed Mode
- BMCA
  - Clock Identity
  - Clock Accuracy
  - Clock Class
  - Priority 1 & 2
- Master TLV
  - Lengthfield
  - OrganizationID
  - OrganizationSubType
  - DefaultSystemFrameRate
  - MasterLockingStatus
  - TimeAddressFlags
  - DaylightSaving
- Slave TLV
  - Cold Start, 25Hz
  - Daily Jam, 25Hz
  - Daily Jam, 25Hz, ST to DST
- BMCA
  - Clock Identity
  - Clock Accuracy
  - Clock Class
  - Priority 1 & 2
- Master TLV
  - Lengthfield
  - OrganizationID
  - OrganizationSubType
  - DefaultSystemFrameRate
  - MasterLockingStatus
  - TimeAddressFlags
  - DaylightSaving
- Slave TLV
  - Cold Start, 25Hz
  - Daily Jam, 25Hz
  - Daily Jam, 25Hz, ST to DST

Conclusions from first interop

- **ST2059-1/2 fundamentally works as intended**
  - Based on the testing that was performed, the standards need only minor clarifications.
- **ST2059 Performance goals for Lock Time and Accuracy are achievable.**
- **Tested all of the areas that we planned to test during this interop**
  - Future interops – expand the areas of testing especially the time code math verification.
- **Highlighted that EGs need to be published**
  - EGs help to provide the background context.
- **Identified some clarifications that need to be made in ST2059-1/2**
  - Communication Mode is one area of the standard that would benefit from clarification.
- **Helped to improve vendors’ products**
SMPTE Activity

2059 WG is developing EG documents

2059 Interop group is conducting ongoing interoperability tests
  • collaborating with AES to harmonize PTP Profiles

Documents are at the one-year review point
  • small clarifications resulting from interop will be made

SMPTE SVIP (ST2110) group using 2059 for IP Standard

Demos planned for SMPTE Conference and IBC

In summary

  • Will work happily alongside legacy systems
  • Will enable new workflows
  • Higher confidence system building
  • Reduced CAPEX
  • Reduced OPEX
  • Can be evolutionary or revolutionary as appropriate
  • Can support any foreseeable future standard / format
  • Reference distribution – coming soon to a network near you!
Special Thanks

The SMPTE / EBU TPTS Team
The SMPTE ST 2059 Team
Special shout out to those who did the full tour!

Peter Symes
Leigh Whitcomb
Michel Poulin
Richard Kupnicki

Thank-you!

ST2059
It’s About Time.

Paul Briscoe, Consultant
Toronto, Canada
Q&A – Verbal Questions Encouraged!

Paul Briscoe
Consultant