Time synchronization and media streams for content production using SMPTE ST 2110 standards

SMPTE ST 2110 standards is a set of standards for the IP-based transport of audio, video and data in a television production network. Initially ST 2110 was concerned with the transport of uncompressed media, but compressed media types have been added.

ST 2110 standards are a progression from the ST 2022 standards for the transport of multiplexed audio, video and data video, which in turn were a progression from the SMPTE 259M standard for the Serial Digital Interface (SDI) transport of digital media over a coax cable.

The ST 2022 standards essentially described the IP transport of an SDI stream consisting of multiplexed audio, video and data. The audio, video and data in the multiplex were co-timed, so it was easy to maintain the audio and video synchronization, but it was harder to process the audio and video elements separately.

In a ST 2110 network, the audio, video and data are carried as separate elemental streams, where the encapsulation, timing (e.g. timestamping), frame synchronisation and transmission is described by the ST 2110 set of standards.

The suite of ST 2110 standards consists of the documents summarized in the following sections.

Contents

1. ST 2110-10:2017 System Timing and Definitions

This standard references SMPTE ST 2059-2 [13] PTP Profile of IEEE 1588 Precision Clock Synchronization Protocol. IEEE 1588-2008 is now superseded by IEEE 1588-2019, referred to as PTPv2 [14]. ST 2059-2 also specifies that the synchronization of device reference clocks when there are multiple audio and video devices at the same location should be < 1 µs, achieved within 5 s of connection. The Reference Architecture in the Joint Task Force on Networked Media Phase 2 Report [15] is also relevant to this, as it recommends that for multi-channel audio and image synchronization, time synchronization between media streams should be < 10 µs.

ST 2110-10 describes a system timing model based on RTP timestamp values in the RTP packet headers and a common reference clock that can be distributed to all participating devices via IEEE 1588-2008 Precision Time Protocol.

The RTP timestamps are tied to the media:

- For video, RTP timestamps of all packets for a video frames are the same.
- For real-time sources, this should represent the Image Capture Time.
- For SDI converters, the RTP timestamp is the moment when the video frame alignment point arrives at the device input (as defined by the alignment points in SMPTE ST 2059-1 [16])
- All media clocks must have an offset of zero.

A media clock is generated from the RTP timestamps, local time and media type, where timing is the Epoch as specified in SMPTE ST 2059-1. Unlike in other RFC 3550 compliant streams, where the initial RTP timestamp should be a random value, RTP streams employed for broadcast streaming use a wall clock time as initial RTP timestamp. The media clock shall have a value of zero at the SMPTE Epoch.

This standard provides examples of the Session Description Protocol (SDP) data used to describe the media stream and its reference clock parameters.

ST 2110-10 also refences the use of redundant streams, as defined in SMPTE ST 2022-7 [17], allowing the seamless reconstruction of a stream of SMPTE ST 2022 RTP datagrams based on the transmission of two streams of identical content.

2. ST 2110-20:2022 Uncompressed Active Video

This standard specifies the real-time, RTP-based transport of uncompressed active video essence over IP networks. An SDP-based signalling method is also described providing the metadata necessary to receive and interpret the stream.

Video essence is transported using RTP, as described in IETF RFC 3550 [18], subject to the constraints and payload definition. Specifically, this involves employing the RTP timestamps and media clock configuration described in ST 2110-10. Some RTP payload header extensions are employed, with the definition of specific video sample types. An example of the video-specific SDP metadata is also provided. ST 2110-20 allows signalling of video formats, including:

Width and Height of image	Up to 32767 x 32767
Chroma sampling	4:4:4, 4:2:2, and 4:2:0

Sample Component Systems	Y'C'BC'R, Y'CC'BCC'RC, ICTCP, RGB, R'B'G', X'Y'Z', RP 157 key signals
Bit Depth	8-bit, 10-bit, 12-bit, 16-bit integer, 16-bit floating point
Colorimetry	ITU-R BT.601-7, ITU-R BT.709-6, ITU-R BT.2020-2, ITU-R BT.2100-0, ST 2065-1 ("ACES"), ST 2065-3 ("ADX"), ISO 11664-1
Transfer Characteristics	ITU-R BT.709, ITU-R BT.2100-0 (including "PQ", "HLG"), linear, ST 2065-1 ("ACES"), ST 2065-3 ("ADX")

3. SMPTE ST 2110-21:2022 Traffic Shaping and Delivery Timing for Video

ST 2110-21:2022 supersedes ST 2110-21:2017, with some modifications to read times for interlaced video streams. The standard specifies a timing model for SMPTE ST 2110-20 streams as measured leaving the sender, and defines the sender SDP parameters used to signal the timing properties of the streams.

ST 2110-21 defines a Packet Read Schedule (PRS) as either linear or gapped. These schedules define the latest time a packet can be emitted. The gapped PRS has values that loosely approximate the delivery of samples in the SDI signal. The linear PRS has values that are evenly spaced throughout the frame period. The timing of the first packet of a frame is referenced to an integer number of frames since the Epoch.

ST 2110-21 also defines two Transmission Traffic Shape Models, a Network Compatibility Model and a Virtual Receiver Buffer Model. Both models are based on 'leaky bucket' style buffers.

Three types of senders are defined, Narrow Senders, Narrow Linear Senders, and Wide Senders. Each type of sender has specific requirements for the Transmission Traffic Shape Models. The standard further defines different types of receivers, including Narrow or Wide Synchronous Receivers, and Asynchronous Receivers.

The three sender model types are: N = Narrow, NL = Narrow Linear, W = Wide

- Type N is designed for real-time capture and processing (live events)
- Type NL is linear version of N – no gaps corresponding to SDI with vertical blanking
- Type W is designed to support software-based video sources, including graphics.

4. ST 2110-22 Constant Bit-Rate Compressed Video

The standard specifies parameters for the real-time, RTP-based transport of constant bit-rate compressed video over IP networks, referenced to a common clock. This is essentially the same as ST 2110-20, but with a constant bit rate compressed video payload. The standard does not specify compression types but does provide an example of the SDP metadata.

5. RP 2110-23 Single Video Essence Transport over Multiple ST 2110-20 Streams

This recommended practice document describes a method to split high bandwidth single video essence streams into several lower bandwidth SMPTE ST 2110-20 tributary streams. As recommended practice, the document describes existing approaches.

RP 2110-23 also provides a method to describe the appropriate grouping and signalling of these multiple SMPTE ST 2110-20 streams in the forms of:

- SDP declarations,
- Addressing conventions,
- RTP time stamp constraints.

Three decomposition methods to split a video stream into separate tributary streams are also described. These are Phased, Multi-2SI and Multi-SD decomposition.

6. RP 2110-24 Special Considerations for Standard Definition Video

This recommendation specifies the relationship between the Sample Rows of SMPTE ST 2110-20 signals and the line numbering employed by standard definition video. RP 2110-24 also provides guidance on values for certain Media Type Parameters, such as signalling the number of Sample Rows per frame and video height parameters.

7. RP 2110-25 Professional Media over Managed IP Networks: Measurement Practices

This Recommended Practice specifies recommended nomenclature for measurements on SMPTE 2110 systems, together with their associated formulae, for consistency in implementation and reporting of measurements.

RP 2110-25 also describes referencing the timing of measurements to the common reference clock and some possible methods for implementing the ST 2110-21 buffer measurements. For buffer measurement methods their characteristics and differences are described along with ways to report the results so that users understand the differences.

8. ST 2110-30 Uncompressed Audio

This standard specifies the real-time, RTP-based transport of PCM digital audio streams over IP networks by reference to AES67 [19]. An SDP-based signalling method is defined for metadata necessary to receive and interpret the stream. Non-PCM digital audio signals including compressed audio signals are outside the scope of this standard.

ST 2110-30 defines a Channel Order Convention for the identification of channel types within multi-channel audio groups. The standard also defines a set of conformance levels based on number of channels, sampling frequencies, and packet times.

The Media Clock and RTP Clock shall comply with SMPTE ST 2110-10 and rate of the Media Clock and RTP Clock shall be the same as the digital audio sampling rate. The RTP timestamp shall comply with SMPTE ST 2110-10. All senders and receivers of PCM digital audio conforming to this

standard shall support a digital audio sampling rate of 48 kHz, and should support digital audio sampling rates of 44.1 kHz and/or 96 kHz. Other sampling rates are out of scope.

9. SMPTE ST 2110-31 AES3 Transparent Transport

ST 2110-31:2022 supersedes ST 2110-31:2018, with modifications mostly concerning updates to references and normative language applying to Protocol Implementation Conformance Statement (PICS) development.

The standard specifies the real-time, RTP-based transport of AES3 [20] signals over IP networks. The modern television ecosystem has leveraged the prevalence of AES3 signal transport to encapsulate many different data items. SMPTE ST 337 [21] defines a general method for the encapsulation of various payloads into the AES3 transport, and SMPTE ST 338 [22] manages the growing namespace of the payloads.

Similar RTP header constraints are imposed, as with ST 2110-20, with an RTP payload definition where an AES3 Subframe is transported in one AM824 Subframe [23]. For AES3 Subframes containing PCM audio, senders may signal the channel order in the SDP using the Channel Order Convention specified in SMPTE ST 2110-30.

10. SMPTE ST 2110-40 Ancillary Data

ST 2110-40:2023 supersedes ST 2110-40:2018, with modification mostly updating the normative references but also the addition of a model designed for use in lower-latency systems.

The Standard specifies the real-time, RTP-based transport of SMPTE ST 291 [24] Ancillary (ANC) Data packets over IP networks. It normatively references IETF RFC 8331, which is an RTP payload definition for SMPTE ST 291-1 Ancillary Data. Similar RTP constraints are applied as in ST 2110-10, employing a 90KHz RTP clock. Traffic shaping is applied as per ST 2110-21. As with other stream types, SDP-based signalling is defined for metadata.

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Published by 5G-MAG | December 2023

www.5g-mag.com

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This is a report produced by the 5G-MAG Workgroup CP (Content Production - Standards and Architecture).

Version of the report: v.1.0

Date of publication: 22nd December 2023

This 5G-MAG Report can be downloaded from www.5g-mag.com/reports

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