Encoder Testing

New Design Challenges Brought on by the Move to DTV

As broadcasters make the transition from exclusively analog video broadcasting to programming that includes compressed digital video, digital encoder designers are faced with the need to understand the MPEG-2 compression standard and the role it plays in designing robust MPEG equipment.

The MPEG-2 (ISO/IEC 13818) standard, finalized in 1994, includes several sections on the system layer (Program and Transport Stream) as well as a definition of the Elementary Streams (video, audio and data).

The standard was written for MPEG-2 decoders. There is no specification for MPEG-2 encoders. This approach allows encoder designers to implement any design they want, as long as any MPEG-2 decoder following the ISO/IEC 13818 standard can properly decode the output of that design. While encoders are typically more complicated and much more expensive than decoders, testing an encoder for compliance with the MPEG-2 standard is somewhat simpler than verifying a decoder. It is not, however, a trivial task.

This application note will focus on the particular issues encoder designers face when testing for MPEG-2 compliance and the measurement solutions Tektronix provides that streamline encoder characterization and testing.

Understanding the MPEG-2 standard

MPEG-2 is today's dominant digital compression standard because it enables the delivery of high quality transmission of multiple programs in a single digital signal, and because it paves the way for high definition TV. Its compression algorithm is based on discrete cosine transform (DCT) coding and interframe motion compensation. Today's encoders provide internal conversion from PAL or NTSC to a data stream of 270 Mb/s, and/or have a direct SDI input. Using MPEG-2 compression, spatial and temporal redundancies within the moving pictures are removed and the data stream is compressed to less than 3 Mb/s. In addition, the audio is compressed down to less than 400 kb/s.

The output stream of an MPEG-2 audio or video encoder is called an Elementary Stream (ES). An Elementary Stream can be broken into convenient-sized data blocks in a Packetized Elementary Stream (PES).

These data blocks need header information to identify the start of the packets and must include time stamps because packetizing disrupts the time axis.

Figure 1 shows that video and audio PES can be combined to form a Program Stream (PS), provided the audio and video encoders are locked to a common clock. Time stamps in each PES ensure lip-sync between the video and audio. Program streams have variable length packets with headers. They find use in data transfers to and from optical and hard disks, which are error free and in which files of arbitrary sizes are expected. DVD uses program streams.

For transmission and digital broadcasting, several programs and their associated PES can be multiplexed into a single Transport Stream (TS). A TS differs from a PS in that the PES packets are further subdivided into short fixed-size packets and in that multiple programs encoded with different clocks can be carried. This is possible because a transport stream has a program clock reference (PCR) mechanism that allows transmission of multiple clocks, one of which is selected and regenerated at the decoder. The ATSC standard, however, mandates that each picture frame be placed in a single PES.

A Single Program Transport Stream (SPTS) is also possible and may be found between an encoder and a multiplexer. Since a TS can genlock the decoder clock to the encoder clock, the SPTS is more common than the PS.

A TS is more than just a multiplex of audio and video PES. In addition to the compressed audio, video and data, a TS includes a great deal of metadata describing the bit stream. This includes the Program Association Table (PAT) that lists every program in the transport stream. Each entry in the PAT points to a Program Map Table (PMT) that lists the elementary streams making up each program. Some programs will be open, but some programs may be subject to conditional access (encryption) and this information is also carried in the metadata.

The TS consists of fixed-sized data packets, each containing 188 bytes (Figure 2). Each packet carries a packet identifier code (PID). Packets in the same elementary stream all have the same PID, so the decoder (or demultiplexer) can select the elementary stream(s) it wants and reject the remainder. Packet continuity counts ensure that every packet that is needed to decode a stream is received. An effective synchronization system is needed so that decoders can correctly identify the beginning of each packet and deserialize the bit stream into words.

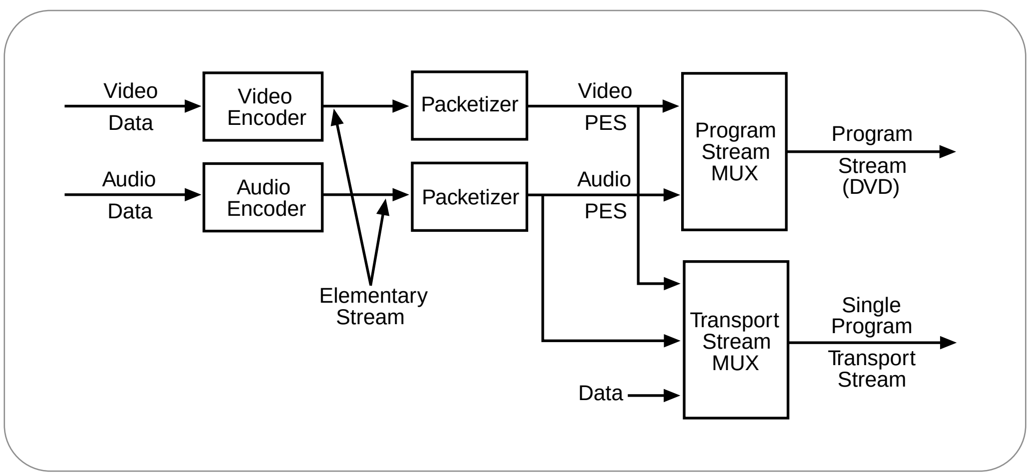


Figure 1: *Encoding, packetizing, and multiplexing data flow.*

Testing for decodability errors

The most critical error, with respect to the decodability of the encoded signal, is loss of the transport stream sync. That is, the sync byte is missing (typically, because no signal is present). The sync byte always contains a value of hexadecimal 47 (decimal 71). Whenever an unlocked MPEG-2 receiver reads its first 47h, it then expects another sync byte to arrive 188 bytes later. The number of consecutive packets with good sync bytes required to achieve lock is device dependent, but it typically ranges from two to six. Without these consecutive good sync bytes, a receiving device cannot remain locked up with (synchronized to) the transmitted signal.

The Tektronix MTS300 Multi-Standard MPEG Test System can be used for real-time monitoring and analysis of the quality of the sync byte in the transport stream. It provides status-at-a-glance display of the overall bandwidth and efficiency of the transport stream under test. And its graphic and dynamic displays show the data rates, percentage of use and global data information for each program, PID and the transport stream.

Other tests of decodability require that we take a closer look at the construction of the MPEG-2 transport stream. Referring again to Figure 2, transport stream segments of direct interest here are the packet ID (PID), the scrambling control field, the continuity counter and the payload. Because the payload of each packet is identified by its PID value, proper transmission of the PID is essential to decoding the transport stream. Other referencing information that can be contained in the payload relates PID values to specific programs in a transport stream.

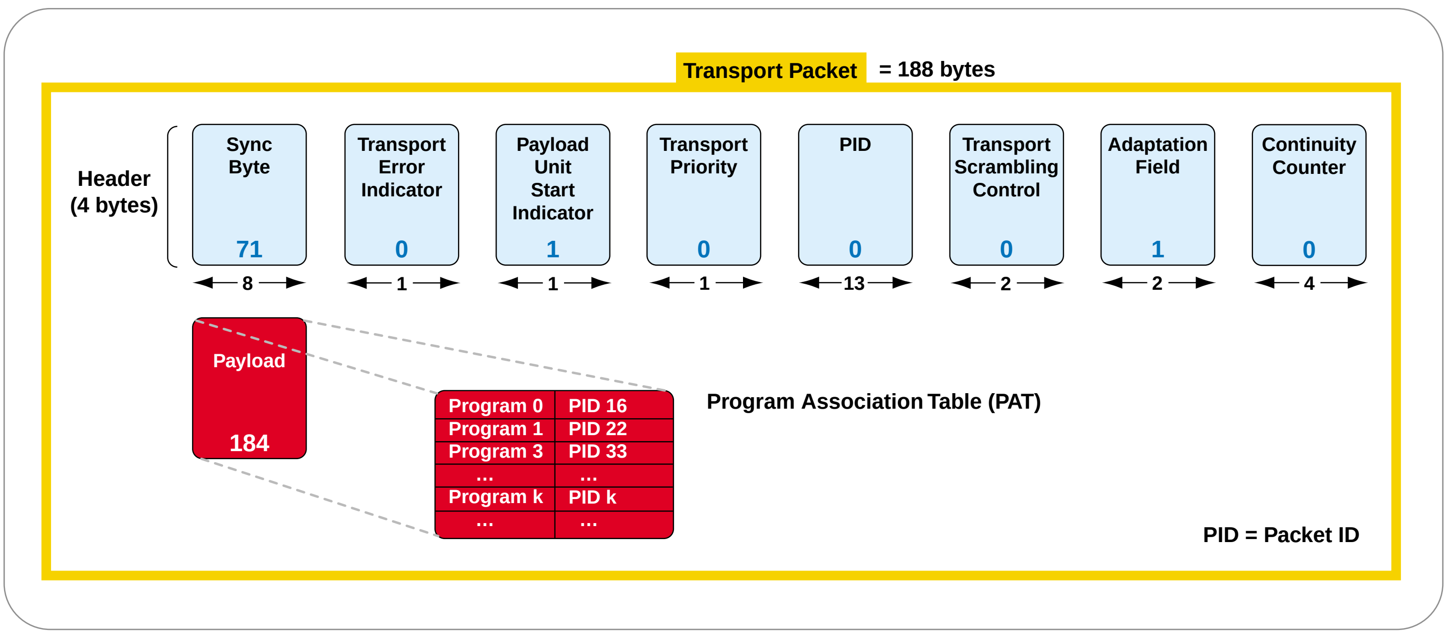


Figure 2: An MPEG-2 transport stream.

In Figure 3, which continues in greater detail the referencing begun in Figure 2, we see that PIDs can identify ("point to") further sets of PIDs.

Program specific information is usually sent every 100 ms or so to ensure that any consumer can access any desired program as swiftly as possible after switching on, or after switching to a new TS. It also ensures that consumer receivers are updated with any program changes. An example of such a program change would be when a channel switches from showing shopping-club programming to local-area programming late at night. This information is indicated in the program association table (PAT), which in fact is the top level of the MPEG-2 transport stream hierarchy, and whose packet ID is always 0. This table lists all the programs in the transport stream and associates each program with another PID, that of a packet with a program map table (PMT) as its payload.

Here, at the low level of reference that is the program map table, are the PIDs of the audio, video and data packets of that program (data packets traditionally comprised teletext but now also include web access information for internet access applications like WebTV). In Figure 3, the program association table indicates that the PMT of program 3 will arrive in a PID 33 packet. Upon consulting the table of PID 33, the decoder sees that the video content for program 3 is in all the packets with a PID value of 19, and the audio is in all the packets with PID values of 81 and 82. Figure 3 shows how all these differently functioning packets are carried in the transport stream by a time division multiplexing process.

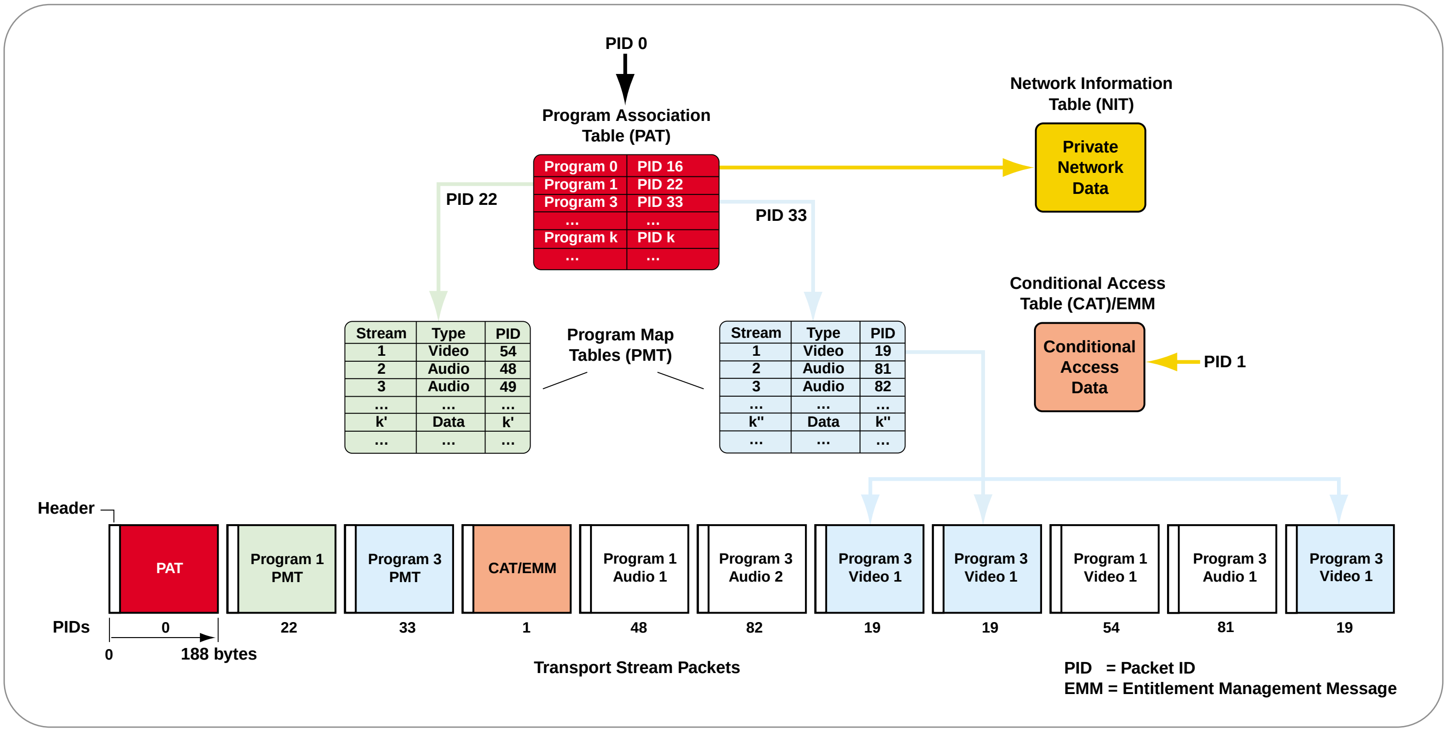


Figure 3: *Audio, video, and data packets of an MPEG-2 transport stream.*

Figure 4 is a screen shot from the MTS300 MPEG-2 analyzer that summarizes some of the elements of Figures 2 and 3.

The hierarchical view on the top left presents a graphic view of every component in the transport stream. It contains an icon for every stream component, enabling the designer to easily see how many program streams are present as well as the video and audio content of each. Each icon represents the top layer of a number of lower analysis and information layers. The analyzer creates the hierarchical view using the program association table (PAT) and the program map table in the program specific information (PSI) data of the transport stream.

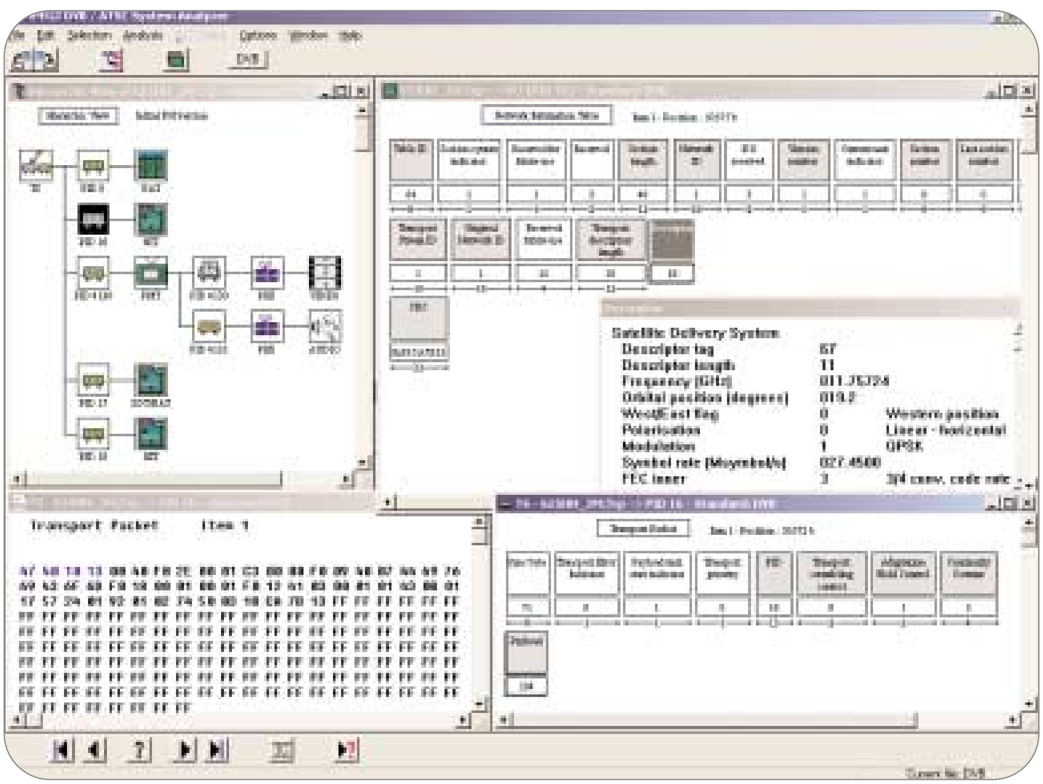
A check for PAT error is called for in our example. Recall that, once synchronized, decoders first look for PID 0, which the MPEG-2 standard reserves for the program association table. But if PID 0 fails to occur often enough (at least every half second), or is missing the table in its payload, or indicates that its contents are scrambled, a PAT error is flagged and the decoder will not be able to process the stream. (Scrambling for each packet is indicated in the 2-bit scrambling control field shown in Figure 2.)

Continuity-count errors are the next to be checked. Each packet of audio, video and data in a transport stream has its own continuity counter, which increments with each successive packet for a particular program. A continuity-count error occurs when successive counter words contain the same count (indicating a repeated packet) more than twice, or the count is out of order, or packets are lost.

To test for PMT errors, recall that the program map table carries the PID values of the packets containing the actual audio, video and data for a particular program. Like the PAT error, a PMT error occurs if the program map table comes too infrequently or its scrambling control field indicates that the table is scrambled (is not 0). This is not to say that the program cannot be scrambled – only that the table listing the PID values of the audio and video elements may not be, by the rules of MPEG-2.

PID errors are the last of the critical decodability errors to test. When a PID referred to in the program association table or program map table does not occur within an expected, user-definable time interval, a PID error is flagged.

As should be apparent, any one of these decodability error conditions is likely to prevent programs within a transport stream from being decoded at all, and therefore warrants continuous monitoring in operational settings.



▶ ***Figure 4:*** *Hierarchical views of the packets in Figure 3 displayed on an MPEG-2 analyzer.*

Data monitoring

Due to the increase in demand on accessing Internet services through cable and satellite communications, IP data monitoring has become an important issue. The Tektronix MTS300 real-time analyzer performs IP monitoring with detailed viewing of EN 301 192 (DVB Data Broadcasting) tables, syntactic control of the tables with error reporting and the ability to monitor data flow of the broadcast session.

Analyses performed include:

- Intra-PSI analysis
- Inter SI/PSI analysis (data broadcast descriptors)
- Consistence of data carousel
- TCP/IP session monitoring

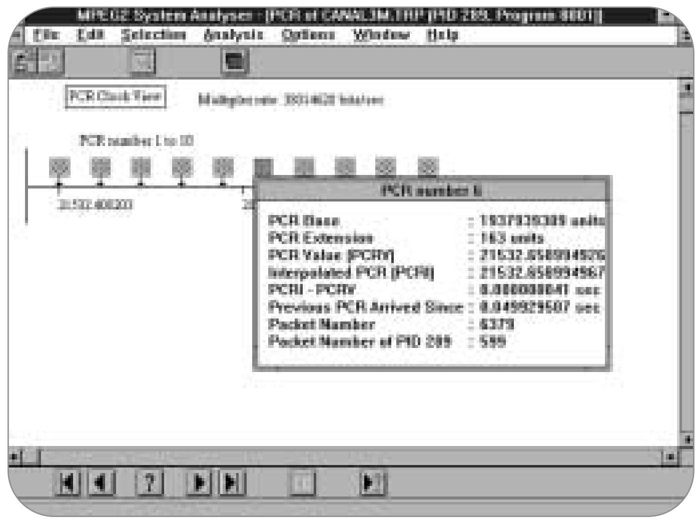
Several new tables are now available within the hierarchical display. Digital Storage Media Command and Control (DSM-CC) from ISO/IEC 13818-6 defines the following types: Multiprotocol encapsulation, U-N messages, and Stream descriptors. EN 301 192 defines the following tables: 1-layer Data carousel, Multi-protocol encapsulation, 2-layer Data carousel, Data Piping, and Data Streaming. Figure 5 shows multiple DSM-CC elements along with their IP traffic sessions.

Timing analysis

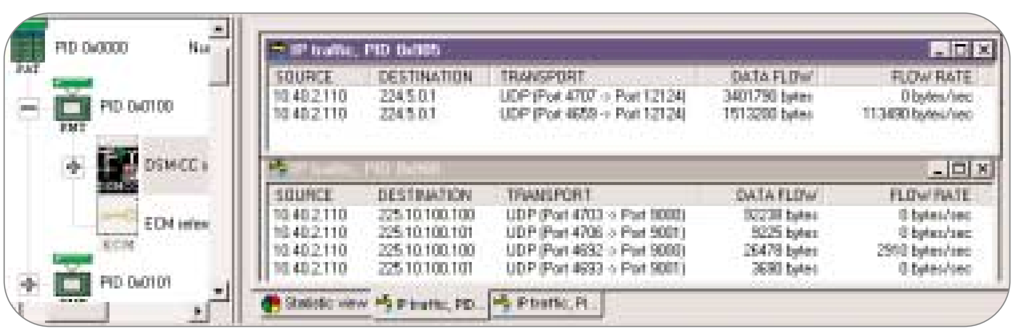
To display real-time video and audio correctly, the transport stream must also deliver accurate timing to the decoders. Correct transfer of program clock data is critical because this data controls the entire timing of the decoding process. This task can be confirmed by analyzing the PCR (program clock reference) and time-stamp data.

PCR data from a multiplexer may be precise, but demultiplexing may put the packets of a given program at a different place on the time axis, requiring that the remultiplexer update the PCR data. Consequently, it is important to test for PCR jitter after the data is remultiplexed. The system graphically indicates the times at which PCRs were received.

Further, each PCR can be opened to display the PCR data, as shown in Figure 6. To measure jitter, the analyzer predicts the PCR value by using the previous PCR and the bit rate to produce interpolated PCR, or PCRI. The actual PCR value is subtracted from PCRI to give an estimate of the jitter. The figure also shows the time since the previous PCR arrived.



▶ ***Figure 6:*** *Graphical representation of PCR data, overlaid with specific information on one PCR.*



▶ ***Figure 5:*** *Multiple DSM-CC elements along with their IP traffic or information.*

An alternate approach, shown in Figure 7, provides a graphical display of PCR jitter and PCR repetition rate, which is updated in real time. (For more information on PCR jitter, see Tektronix' PCR Jitter Primer, Literature Number 25W-14617-0.)

Once PCR data is known to be correct, the video and audio time stamps can be analyzed. Figure 8 shows a time-stamp display for a selected elementary stream. The time of arrival, the presentation time, and, where appropriate, the decode times are all shown.

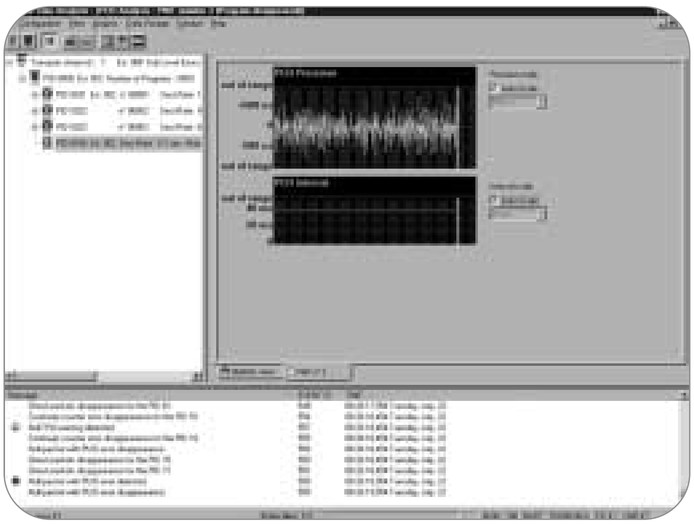


Figure 7: *Real-time graphical display of PCR jitter and repetition.*

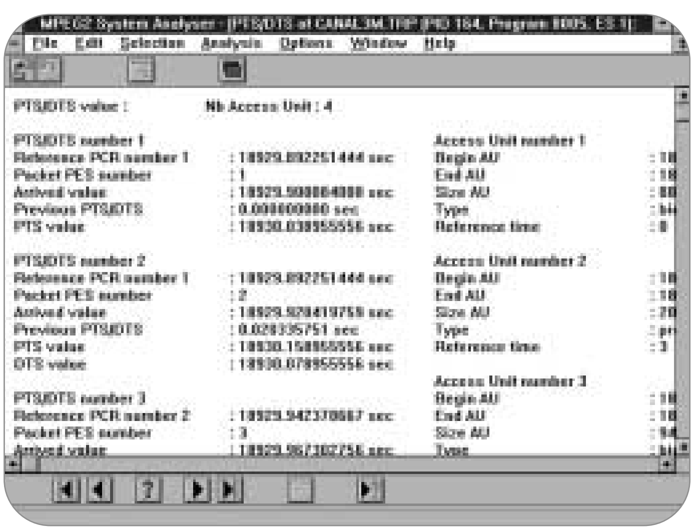


Figure 8: *Details of time stamp information for a selected ES.*

Audio-to-video delay

Problems such as audio-to-video delay and non-unity gain through systems can seriously compromise the final image and sound of a TV broadcast and indicate interoperability issues may exist between MPEG-compliant equipment from different manufacturers. Testing for either of these problems at the system level can be performed with standard analog or digital baseband audio and video test gear. End-to-end system testing will not, however, indicate whether the encoder or the decoder is the source of the problem.

To isolate the source of audio-to-video delay or I/O amplitude inequality, an MPEG-2 test generator like the Tektronix MTS300, MTG100 or MTG300 must serve as the transport stream source. These instruments replace the baseband audio/video generators routing the regular programming through the encoder. Injecting test signals with known characteristics at various points in the stream helps to determine which system components are operating correctly and which are not.

Conclusion

Pioneering work in MPEG test and picture quality analysis makes Tektronix the obvious choice when testing and evaluating MPEG-2 based encoder designs. As communications standards converge – with audio, data, images and video merging in new networks – innovative test equipment from Tektronix will ensure the integrity of the overall information system. The powerful MTS300 Multi-Standard MPEG Test System, MTG 100 and 300 MPEG Test Signal Generators, and the PQA300 Picture Quality Analysis System make the characterization, test and analysis task much more manageable for the digital designer, while delivering the finest test performance available.

Contact Tektronix:

ASEAN Countries (65) 356-3900

Australia & New Zealand 61 (2) 9888-0100

Austria, Central Eastern Europe, Greece,
Turkey, Malta & Cyprus +43 2236 8092 0

Belgium +32 (2) 715 89 70

Brazil and South America 55 (11) 3741-8360

Canada 1 (800) 661-5625

Denmark +45 (44) 850 700

Finland +358 (9) 4783 400

France & North Africa +33 1 69 86 81 81

Germany +49 (221) 94 77 400

Hong Kong (852) 2585-6688

India (91) 80-2275577

Italy +39 (2) 25086 501

Japan (Sony/Tektronix Corporation) 81 (3) 3448-3111

Mexico, Central America & Caribbean 52 (5) 666-6333

The Netherlands +31 23 56 95555

Norway +47 22 07 07 00

People's Republic of China 86 (10) 6235 1230

Republic of Korea 82 (2) 528-5299

South Africa (27 11) 254-8360

Spain & Portugal +34 91 372 6000

Sweden +46 8 477 65 00

Switzerland +41 (41) 729 36 40

Taiwan 886 (2) 2722-9622

United Kingdom & Eire +44 (0)1344 392000

USA 1 (800) 426-2200

For other areas, contact: Tektronix, Inc. at 1 (503) 627-1924

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