Video is now following the path that voice communications has already traveled—the path from analog to digital. Bits that represent voices have traveled through telecom networks for years, and those bits have required digital, rather than analog, test equipment. Now it's video's turn.

A popular technique for encoding digital video and audio programs is based on the MPEG-2 standard (ISO/IEC 13818). (See Footnote 1 below.) Encoders compress digitized video and audio signals into packets for transport to an MPEG-2 compliant decoder. The decoder will decode the video and audio programs and convert them back to analog for use with traditional TV sets. Most decoders will be set-top boxes that receive MPEG-2 data-called transport streams—and produce standard NTSC analog outputs. Other decoders used in video servers will convert a stored encoded program to analog for distribution over a cable-TV network.

The MPEG-2 test equipment available today is designed for testing bits, packets, and protocols, but it doesn't test for video or audio quality. So, you can have a perfectly delivered transport stream that carries unacceptable video and audio. The next generation of test equipment will have to measure the quality of compressed digital video and audio programs. In the meantime, you'll have to settle for testing the quality of data transmissions and the MPEG-2 transport stream.

**How Does Data Get There?**

*Figure 1* shows the path that digitized data take from a signal source to a delivery system. After a complex spatial and temporal compression process, encoded video and audio elementary streams (ESs) are packetized into packetized ESs (PESs). If the program is headed for an editing workstation, perhaps one in a TV studio, then the program's audio and video PESs are multiplexed into a program stream. For broadcast, PESs from many programs are packetized into 188-byte packets; that's the transport stream. These packets may then be encoded for transport over a fiber-optic delivery system such as an ATM network or RF modulated for broadcast over a satellite network or a cable-TV system.
Figure 1. Digitized video and audio is compressed, packetized, and multiplexed into MPEG-2 program streams or transport streams.

Figure 2 shows the structure of a transport-stream packet. Each header and its payload occupy 188 bytes. An important field in the header is the program ID (PID). The PID is a 13-bit field that tells the decoder to which program each packet belongs. Every audio, video, and data PES in a transport stream has a unique PID.

MPEG-2 analyzers are test systems that monitor the PIDs; you can program the analyzers to capture data from any or all PIDs. The screen in Figure 3 shows how MPEG-2 analyzers give you a picture of a transport stream’s structure and contents. Companies that manufacture MPEG-2 analyzers are Digital Transport Systems (San Diego, CA), Hewlett-Packard (Santa Clara, CA), Symbionics (Cambridge, UK), and Tektronix (Beaverton, OR).
Figure 3. MPEG-2 analyzers show the contents of multiplexed programs in a transport stream delivered over an ATM network. (VPI, VCI, UNI, NNI, and AAL-5 refer to ATM networks.)
MPEG-2 analyzers can verify that the PIDs in a transport stream are consistent with those presented in the transport stream’s program association table (PAT). As programs begin and end, a transport stream’s PIDs will change. Therefore, an encoder transmitting a stream must update the stream’s PAT on a regular basis, typically once every 0.5 s. (See Footnote 2 below.) MPEG-2 analyzers measure the frequency of the table updates from an encoder’s output. A PAT containing illegal PIDs or PIDs from a program that has ended will consume unnecessary processing time at the decoder, as will an encoder that sends table updates too frequently.

A transport stream’s PAT, which is always located in PID 0, contains a listing of which PIDs contain the program map tables (PMTs). The PMTs describe the programs in the transport stream by providing a listing of the video and audio PIDs that make up a particular program—such as 1431 and 1432 in Figure 3. The PMT also tells the decoder which PID contains the program clock reference (PCR) for each program.

The transport stream’s adaptation field (see Fig. 2) contains 42 PCR bits. These bits synchronize data transmissions between an encoder and a decoder and compensate for the varying delays in delivery. Without that synchronization, viewers will see choppy video or out-of-sync audio and video. Encoders and decoders have 27-MHz clocks that require synchronizing. The PCR field periodically transmits time information that the decoder uses as a software PLL to keep its clock synchronized to the sender’s clock.

The amount of PCR jitter is an indication of a system’s overall multiplex jitter; multiplex jitter can produce video that is unacceptable to viewers. Pearse Ffrench, vice president of Digital Transport Systems, notes that the MPEG-2 specs (ISO/IEC 13818-9) call for low-jitter applications to have jitter that is less than 25 ms. According to Ffrench, the jitter introduced by satellite transmission is typically a few microseconds, while transmission through an ATM network can create jitter as high as 2-3 ms. The transport stream analyzed in Figure 4 shows an average jitter of 90 ms (0.00009 ms) and a maximum PCR jitter of 270 ms.

Cure the Jitters
Because delivery systems can introduce PCR jitter into a transport stream, MPEG-2 decoders need buffers to hold incoming data until the decoder IC is ready to decode the data. The buffers in Figure 4 send data to the decoder IC at a constant data rate, usually negating any PCR jitter. Buffers must not lose data because an overflow condition in any of the video buffers will produce artifacts in a picture. According to Bob Titus, product marketing manager at Tektronix, all of the buffers in Figure 4 are equally important when testing MPEG-2 decoders because any buffer can overflow. To minimize the overflow in a video program, MPEG added the middle buffer to the MPEG-2 specification.
Figure 4. MPEG-2 analyzers show the contents of multiplexed programs in a transport stream delivered over an ATM network. (VPI, VCI, UNI, NNI, and AAL-5 refer to ATM networks.)
Transport buffers are fixed at 512 bytes, depending on the spacing of the packets and the clock rate, they can quickly overflow. The size of other buffers is up to the decoder designer and can vary depending on the intended use of the decoder. When verifying a decoder design, you should ensure the status of each buffer to be sure that the buffer size is adequate for your intended use. The MPEG-2 specification defines a method for calculating buffer sizes (see Footnote 3 below). If the MPEG-2 decoder correctly aligns the output of the transport stream, it will cause buffer overruns that produce artifacts in the picture.

In addition to testing decoders and encoders, an MPEG-2 decoder or analyzer can also test delivery systems. Testing at the system level will help you verify that the transmitted packets arrive at their destinations. To test delivery systems and decoders, you need to test them against MPEG-2 transport streams. To store these test patterns and play them, you need a transport stream player (sometimes called a generator). With a transport stream player, you can use this new transport stream to a decoder and store the received video or audio on a monitor or tape to measure the decoder’s output signal. Transport stream analyzers from Synthetics and Tektronix double as transport stream generators. A transport stream generator is also available from Logic Innovations (San Diego, CA).

To test a delivery system, feed it a known MPEG-2 transport stream, and analyze the system’s outgoing stream. Some analyzers let you analyze the transport stream in real time, while others require you to record the stream and analyze it offline. Because you can start with a known transport stream, you can introduce impairments into the delivery system and analyze their impact on the delivery of the data.

**Standard Test Streams**

Standard test streams have been developed for testing MPEG-2 decoders and delivery systems, and they are available over the Internet (see “Learn More About MPEG Technology & Test Equipment,” below). These streams let you test decoders for compliance with MPEG-2 specifications. Typical test patterns include video sequences with sharp, contrasting edges and images with high-spatial frequency, such as a set of alternating black-and-white concentric circles. Other difficult test images include those with multiple motions (see Footnote 4 below).

While testing with standard bit streams is useful, you really want to be sure that a decoder can decode streams created with any encoder. The MPEG-2 specification defines decoders, not encoders. But, decoder users expect their decoder to decode any program.


**Footnotes**

Although test methods such as the “just-noticeable-difference” test are still in their infancy, they will soon be essential. Many consumers won’t tolerate a degradation in video quality to get the higher channel count that digital video promises. By starting to develop your MPEG-2 test strategy now, you’ll be better prepared to meet your customers’ needs.

### Video Quality Still Not Tested

While test equipment can measure video quality in analog TV, there’s no equivalent digital video test equipment. MPEG-2 transport stream analyzers can measure a perfect good transport stream, yet the video carried on that stream may be unpalatable to viewers. So, program quality testing is still an important exercise. Methods to automate video-quality testing exist, but they don’t yet enable a person’s reaction to video quality. The mean-squared-error method computes the areas of the squares of the differences between an uncorrupted image and a compressed image. In theory, the lower the mean-squared error, the better the picture. Unfortunately, pictures with a higher mean-squared error can look better to people than those with lower results do.

Test systems for video quality may one day be based on visual systems rather than electronic measurements. These visual systems will have to evaluate how the human eye perceives TV pictures. Once such a system is developed, engineers will have a way to test video quality that people can rate with more repeatable test results.

A vision-based test method called “just noticeable difference” is already in use. This method uses a visual system that enables a person’s ability to distinguish between a reference image—one with no compression impairments—and an impaired image. The method will assign a numerical value to the test result. A value of 0.1 indicates that there is a 75% probability that a person will correctly identify which of two images is the original and which is the impaired copy. Test results of less than 1 indicate that the probability is less than 75%. If a person can tell the difference, then enough video quality was lost in the encoding, or the image was uncorrupted and the original signal was impaired.

Although test methods such as the “just-noticeable-difference” test are useful, they will be essential. Many consumers won’t tolerate a degradation in video quality in general. Digital video promises to bring a new era of entertainment opportunity. To bring a new era of entertainment opportunity.