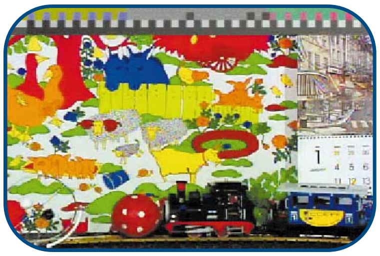
A Guide to Maintaining Video Quality of Service for Digital Television Programs



Digital Television Primer

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▶ A Guide to Maintaining Video Quality of Service for Digital Television Programs

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Video Quality of Service

The International Telecommunications Union (ITU) has defined Quality of Service (QoS) as "The collective effect of service performance which determine the degree of satisfaction of a user of the service." [1, 2, 3] They further note that QoS is a combination of aspects and requires additional description in order to be used in a quantitative sense for technical evaluations. "User" is emphasized in the definition by the use of Italics and is a key element in evaluating the system for the delivery of digital television programs.

A digital television system may be described in terms of four major components as shown in Figure 1. They are:

1) a source of the program audio and video
2) facilities that process the program in some manner
3) transmission links between components
4) the final viewer of the program for entertainment or other purposes

Digital television programs consist of video, one or more channels of audio, and potentially large amounts of data. This guide only covers the technologies relating to QoS for the video part of the program, which we will refer to as Video Quality of Service, or "VQoS." A gateway appropriate for the particular transmission link provides the connection to pass the program to each of the other system components. Facilities and transmission links may have a wide variety of configurations and degrees of complexity. VQoS and related technical parameters will be determined by requirements of the various users associated with each component of the digital television system.

Figure 2 is a simplified block diagram of a facility. Its purpose is to emphasize the fact that compressed video is now a significant factor in determining VQoS within a facility. With multiples of the blocks shown it could represent a very sophisticated program provider facility while a cable headend or network affiliate pass-through of a program may not use all of the blocks.

Digital transmission links don't lend themselves to a similar diagram due to the variety of methods employed. Examples include such things as: terrestrial consumer television, cable consumer television, satellite consumer television, satellite inter-facility transmission, microwave inter-facility transmission, fiber optic transmission of standard digital video protocols, fiber optic transmission of proprietary protocols, and various broadband network protocols. Among the latter are plesiochronous digital hierarchy (PDH), synchronous digital hierarchy (SDH, Sonet) and ATM using either of those hierarchies.

At each gateway, the user will expect to determine the VQoS for the incoming and/or outgoing programs. Within a facility or transmission system, there will be further user expectations for VQoS relating directly to the program or other parameters depending on the methods being used. Therefore, there is not just one definition of VQoS for digital television pro-

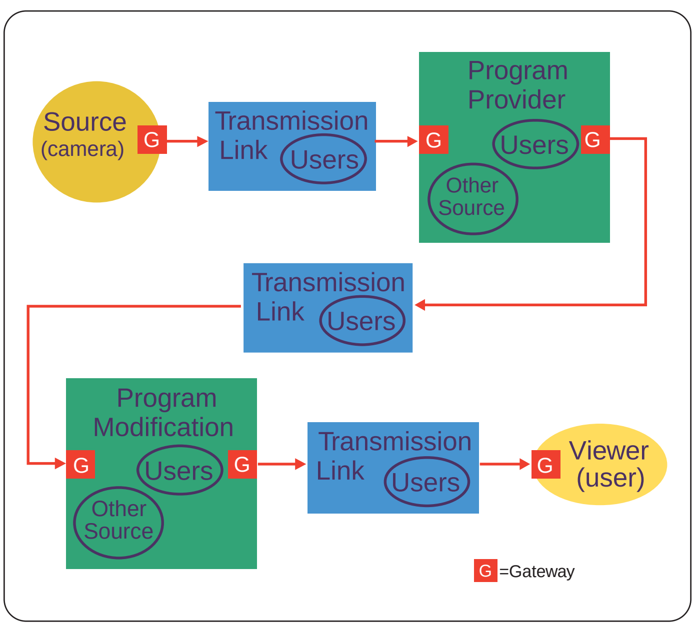


Figure 1. *Digital television system components.*

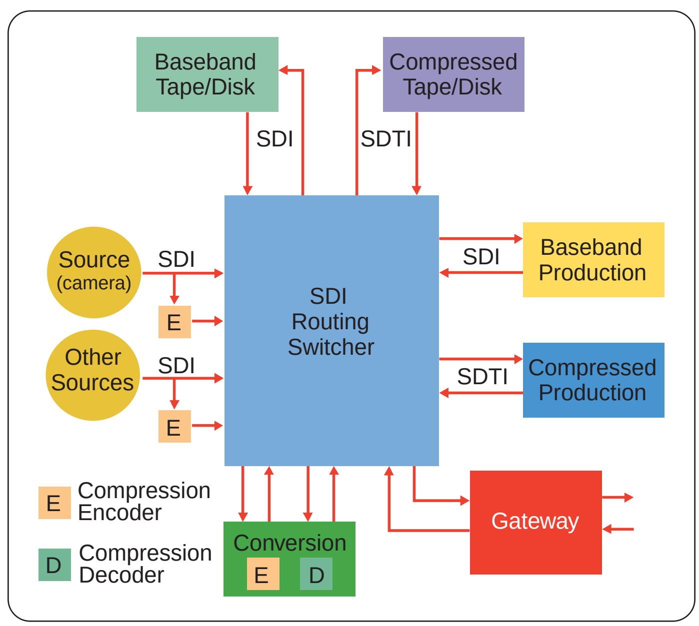


Figure 2. *Simplified block diagram of a digital television facility.*

grams. In fact there are a virtually unlimited number of parameters that might be specified. As an example, an ITU-T document covering only telephone networks and ISDN contains over 350 definitions of terms relating to QoS [1] and does not even include any definitions directly relating to transmission of digital television programs. In the following sections appropriate types and methods of testing are defined from which important VQoS parameters may be selected for testing to provide the satisfaction expected by the user.

To determine VQoS, there are a variety of technical methods that may be employed. In application of these methods, there are two basic approaches to evaluating VQoS parameters; measurement and monitoring. Measurement provides the most accurate evaluation of a parameter but may require more complex equipment and have some restrictions such as availability of the source (input) video. Measurement accuracy is important in such things as design, manufacturing, equipment selection, acceptance testing, and system installation. These are all key in providing the VQoS level expected by the user. Monitoring is used for the operational aspects of maintaining VQoS. Here continuous real time evaluation of a more limited set of parameters, often with less accuracy, is common. With the tens to hundreds of channels in some digital television systems cost effective multi-channel instruments are required.

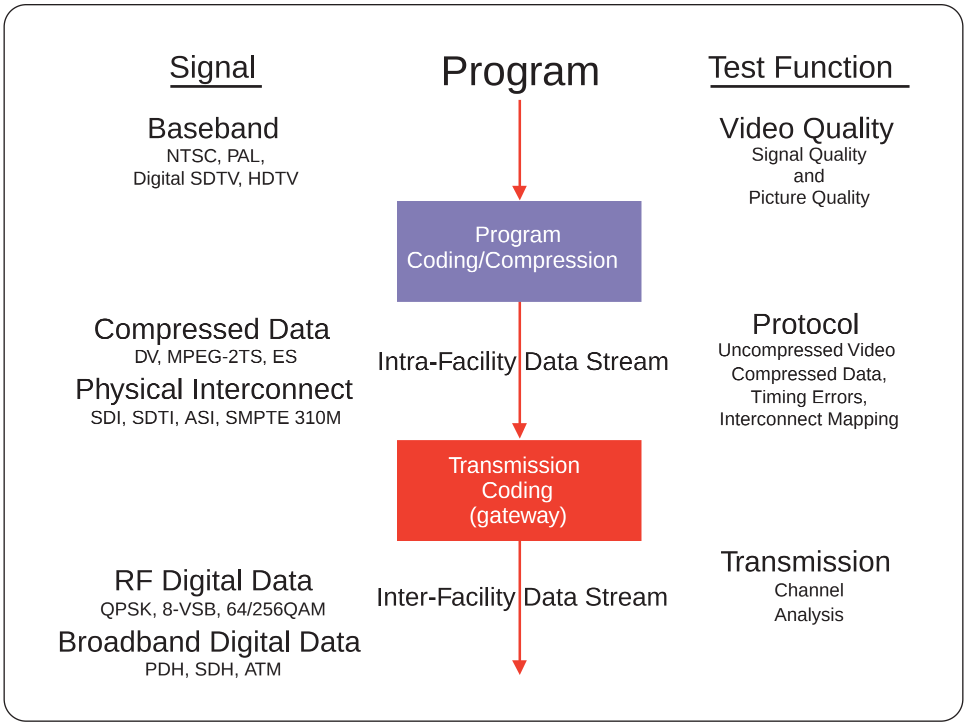


Figure 3. *Digital television testing layers.*

Testing Layers

There are three major testing layers as shown in Figure 3. Baseband video consists of such signals as traditional analog NTSC or PAL video, component digital standard definition video (SDTV) as defined by ITU-R BT.601 [5] and digital high definition video (HDTV) as defined by ITU-R BT.709. [6]

At the intra-facility level, there are two aspects to consider; compression method and physical interconnect. Although MPEG-2 [7, 8] is nominally one compression method within a program provider facility, it is commonly used in at least two forms; elementary streams, or transport streams with PES streams. Program streams are an additional possibility. DV is another common compression method for both SDTV [9] and HDTV program production.

At this layer it is the formatting protocol of the compressed data and its mapping into the physical interconnection that are most often examined to determine VQoS. Certainly the electrical operation of the interconnection must be maintained as well. However, this is usually accomplished with sufficient headroom to provide a completely error free environment for all intra-facility interconnections. Common physical interconnections are:

- Serial digital interface (SDI) for both SDTV [4] and HDTV [10]
- Serial data transfer interface (SDTI) [11] using the same physical interface as SDI
- SMPTE 310M [12] a robust synchronous serial interface for ATSC transmitters
- Asynchronous serial interface (ASI) [13] operating at the same bit rate as SDTV SDI but using a different channel code

Broadband digital networks and RF methods are used for inter-facility transmission. Traditionally, various proprietary and standard RF methods with powerful error correction have been used. More recently, mapping the compressed data through an ATM layer or directly into PDH or SDH transport protocols with or without error correction is becoming more common.

In most cases, the gateways shown in Figure 1 will be the transmission coding from intra-facility data formats to inter-facility transmission formats. However, based on the design of the terminal equipment it might well be the baseband video that is processed in a standard or proprietary manner for inter-facility transmission. This has been a common approach for analog NTSC and PAL signals. For consumer television terrestrial, satellite and cable applications the DVB [14] and ATSC [15] systems are most commonly used. They are both based on MPEG-2 data with different forms of information tables and RF modulation methods.

The highest priority VQoS parameters for each user in the production and distribution of digital television programs will be based on the testing layers appropriate for their part of the system. Program providers will be most interested in video quality and intra-facility interconnection operation while transmission service providers will be most interested in error conditions of the channel. However, the video VQoS parameters are important to all users as the ultimate test of providing the program to the final viewer. Although a broadband service provider might be most interested in error rates and ATM cell loss ratios, it is the effect they have on the video quality that will be the topic of discussion with the ad agency that paid for the commercial. Similarly, the program content provider will discuss guaranteed cell loss ratios when selecting a provider for inter-facility transmission for a distributed studio design.

Video Test Method Terms

Video systems are intended to display a picture that accurately represents the scene being scanned by the camera. With today's special effects capabilities, the displayed pictures may differ in an artistically defined manner from the original. Nonetheless, at some point in the processing where the artistic changes are complete, the resulting pictures are to be accurately conveyed to the user with the desired VQoS. There are a number of terms that are used to describe video test methods:

- Signal quality (indirect)
- Picture quality (direct)
- In-service
- Out-of-service
- Real-time
- Non-real-time (deferred time)
- Continuous
- Sampled (or scanned for multiple programs)

It is important to note that each pair of terms is independent of the other pairs. As an example, in-service testing could use either direct or indirect methods and it could be either real or non-real time. Real time tests may be either continuous or sampled.

Analog video and uncompressed digital video are evaluated using traditional **signal quality** tests. These are **indirect** with respect to the pictures passing through the system. That is, they measure channel response to a series of different high quality test signals. Indirect tests are based on the premise of a time invariant linear system. Video distortions produced may be accurately determined by passing suitable test signals through the same system. Such testing is well described by other publications [16, 17] and will not be covered in this guide.

Digital compression systems are non-linear, hence the resulting video quality will be a function of the picture content and other time varying attributes of the system (e.g., statistical multiplexing). Test signals are easily compressed, hence their changes through a system are not a meaningful measure of video quality. Therefore a **direct** testing of **picture quality** is required in addition to the signal quality measurements for the linear parts of the system. Direct evaluation of the system is based on quality changes between the video at the selected test point and the video at the source. The source video may be either a variety of defined (preferably standard) program-like picture sequences or general program material.

> Note: The term "picture quality" is actually picture degradation through the system and does not imply the intrinsic quality of the picture. Beauty is in the eye of the beholder and not something we can measure.

In-service tests are made while the program is being displayed, directly by evaluating the program material or indirectly, for linear systems, by including vertical interval test signals with the program material. **Out-of-service**, appropriate test scenes are used for direct tests (picture quality) and full field test signals are used for indirect tests (signal quality).

Real-time testing provides results shortly after the video has been processed by the system where "shortly" is determined by the user requirements for the test. An example would be differential phase and gain measurements averaged over several fields using a Tektronix VM700T. For many applications, such as MPEG-2 transport stream (TS) protocol verification or high accuracy picture quality measurement, **deferred-time** testing is appropriate to allow a more detailed analysis from data stored on disks.

In the application of real-time testing, it may be necessary to use a sampled approach where only certain time increments or **samples** of the data are analyzed due to the computing power required. This might also be used where several programs are scanned one after the other providing a sample of VQoS for each program. Testing methods that are less complex can be accomplished in real time, based on a **continuous** stream of data.

Picture Quality Test Methods

Television programs are produced for the enjoyment or education of human viewers, so it is the viewers' opinion of the VQoS that is important. Formal subjective tests as defined by ITU-R BT.500 [18] have been used for many years. With the advent of digital video compression, the number of different test methods in BT.500 have increased every year. Advantages of subjective testing are:

- a test may be designed to accurately represent a specific application
- valid results are produced for both conventional and compressed television systems
- a scalar mean opinion score (MOS) is obtained
- it works well over a wide range of still and motion picture applications

Weaknesses of subjective testing are:

- a wide variety of possible methods and test element parameters must be considered
- meticulous setup and control are required
- many observers must be selected and screened
- the complexity makes it very time consuming

The result is subjective tests are only applicable for development purposes. They do not lend themselves to operational monitoring, production line testing, troubleshooting, or repeatable measurements required for equipment specifications.

Subjective testing is too complex and provides too much variability in results, making clear the need for an objective testing method of picture quality. However, since it is the observer's opinion of picture quality that counts, any objective measurement system must have good correlation with subjective results for the same video system and test sequences. With a new paradigm such as compressed digital video, subjective test methods were used before objective test methods became available. Certainly subjective test methods are the starting point for evaluating objective test methods. However, it is an objective test method that provides accurate measurements, with proven correlation to subjective assessments, that will be the benchmark for development of test materials and calibrating less capable objective methods.

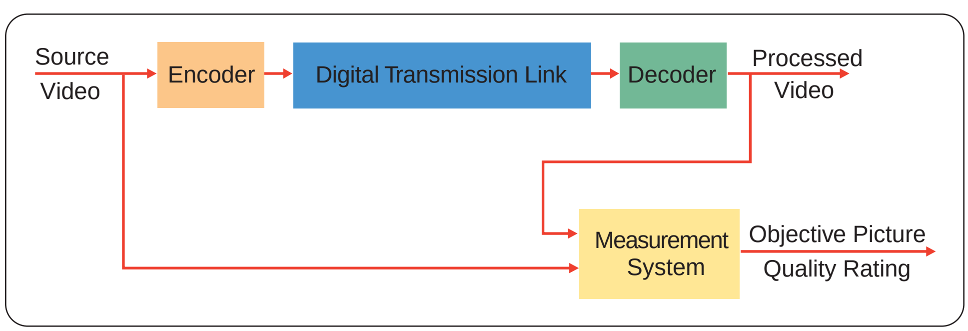
There is general agreement in the industry that there are three methodologies for objective picture quality measurement that provide three levels of measurement accuracy. [19, 20] They are identified as:

- Complete source video (also called Picture comparison)
- Reduced source video information (also called Feature extraction)
- No source video (also called Single-ended)

The first two methods are double-ended, that is, the actual source video, an exact copy of the source video, or some reduced information extracted from the source video must be available to the instrument making the picture quality calculations.

Note: Source video is sometimes called reference video. In this guide, the term "source" is used since "reference" might imply a defined video sequence, whereas VQoS will often be determined based on program video.

Picture comparison makes a measurement of picture quality (degradation) using the full source video and the video processed by the system under test as shown in Figure 4. It uses a matrix-based mathematical computation to process each picture or sequence of pictures. The resulting data represents a filtered version of the pictures containing an amount of data similar to the original pictures. Typically, the pixel-by-pixel difference between filtered versions of the source and degraded pictures is used to determine an objective quality score. This is the most accurate method because it has complete information about the changes in the pictures and generally uses a very sophisticated computation algorithm based on a model of the human vision system, which includes temporal and color response. Knowledge of the compression or other processing applied to the video is not required. Although a primary application of this measurement method is for codec evaluation using standard test sequences, it can be used in-service for monitoring of statistical multiplexer operation or at a remote location if a copy of the source material is available. Real-time con-



► ***Figure 4.*** *Picture comparison test method.*

tinuous operation is not precluded, although significant compute power is required.

It is the sophisticated processing algorithm that gives the picture comparison method an accuracy superior to the other two methods. Because the complete source video is available, another less sophisticated calculation can be made. Peak-signal-to-noise ratio (PSNR) [21] has traditionally been used for evaluating differences between a source and processed picture. Although it is known to produce inconsistent results on sequences with different complexity of spatial and temporal pictures, it is a useful benchmark and can be used to locate small differences between pictures that would not necessarily be seen by a human observer.

Feature extraction, shown in Figure 5, uses a mathematical computation to derive characteristics of a single picture (spatial features) or a sequence of pictures (temporal features). This usually results in an amount of reference data per picture that is considerably less than used to transmit the compressed picture. The calculated characteristics of the source and degraded pictures are then compared to determine changes in the pictures related to the type of features extracted. This provides a measure of picture impairments. In this low reference data mode, incorrect video, lost frames, and other types of errors not necessarily due to the compression process, can be detected. [19] To facilitate application of the feature extraction method, a special MPEG-2 TS PID (packet identification) has been defined by the DVB to carry the reference data.

By using a relatively high level of reference data, perhaps as much as the compressed picture, a useful objective picture quality calculation can be made. Knowledge of the compression or other processing applied to the video may be used to determine what features are to be extracted in order to increase the measurement accuracy of the picture quality calculation. Because bits = cost, applications for feature extraction are primarily for monitoring of inconsistencies of pictures sent and received through a transmission system as described above.

Single-ended testing, as shown in Figure 6, is the most appropriate method for VQoS monitoring. Based on a knowledge of the compression system being used, the processed video can be analyzed for artifacts and other defects. The most common artifact to be detected is blockiness, a result of the discrete cosine transform (DCT) compression system used by MPEG-2 and DV. As the compression system works harder due to either more complex program material or less bits available for data, more blockiness will be generated. The higher the level of blockiness the greater the picture degradation for a given source video sequence. Much like PSNR, this method does not provide strong correlation with subjective picture quality assessment over a variety of video sequences. None the less, it has some significant operational advantages. Since no information from the source video is required, the single-ended monitor may be placed anywhere in the system. Detection of picture defects is not limited to compression artifacts; a measure of gaussian noise would be an example of another detectable picture defect. This could be useful at a compression encoder input to increase coding efficiency and resulting picture quality. Compute power required for the test is modest, allowing an economic approach to multi-channel operation. Artifact level detection can be used as a trigger to warn of possible VQoS problems. A log of detected artifacts versus time can be a valuable system troubleshooting tool.

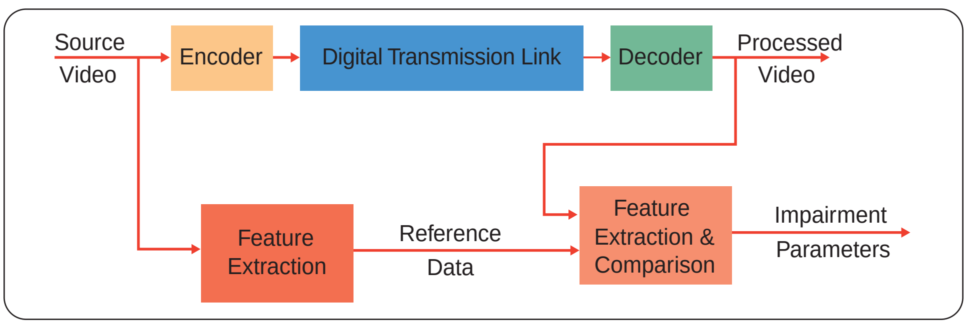


Figure 5. Feature extraction test method.

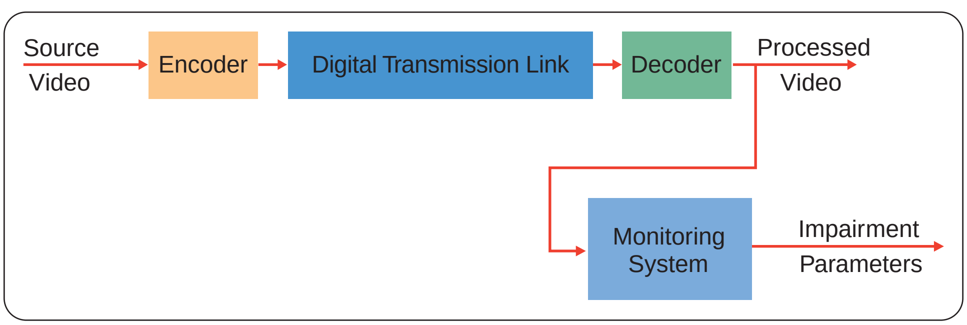


Figure 6. Single-ended test method.

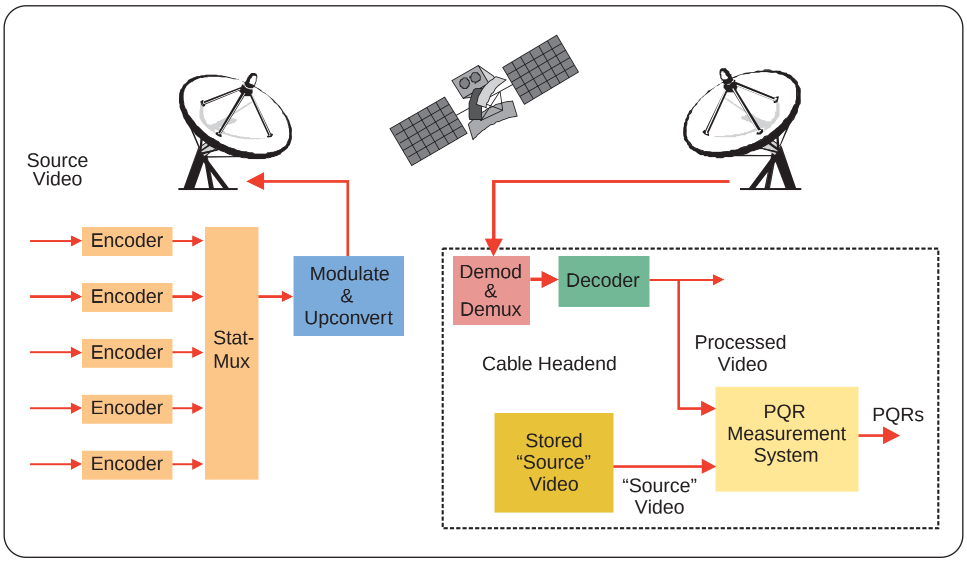
Video Quality of Service

Maintenance of VQoS for a digital television system requires attention to all three testing levels (Figure 3). In this section of the guide only the baseband video is covered. The following steps are key to maintaining video VQoS:

- Maintain baseband quality: This is important both for the control of such traditional parameters as levels, bandwidths and timing, but also because the compression encoder will provide better results with good quality input. Baseband test methods are not covered in this guide.
- Select compression equipment: This is a system design function that requires a measurement-grade picture quality analysis instrument such as the Tektronix PQA200 to evaluate available codecs.
- Select operating data rates: Economy of transmission link operation requires careful selection of constant bit rate values or average bit rates for statistical multiplexer operation. Although rates may be adjusted on an operational basis, this is basically a system design function that requires a measurement-grade picture quality analysis instrument such as the Tektronix PQA200.
- Monitor program defects to indicate potential problems: Multi-channel continuous monitoring using a defect detection instrument such as the Tektronix PQM300 is essential to maintaining design level VQoS. Remote reporting of defects and operation of the monitoring equipment is important to maintaining the VQoS for the entire digital television system.
- Resolve operational or equipment failure problems: The multi-channel monitoring system will alert operators to potential problem areas. System analysis or trouble-shooting may require isolation of one of the blocks, encoder, transmission link, and decoder. Since the picture quality measurements are made on the baseband video, it is appropriate to replace any of those blocks with a reference block of known quality. For compression codec evaluation, the transmission link might be entirely eliminated. For encoder evaluation, a reference decoder could be used.

Unfortunately, the convenience of performing measurement level VQoS evaluation anywhere in the system, albeit by indirect means, is not available for compressed systems as it is for uncompressed linear systems. There are two approaches to this situation. First, since the video is being carried throughout the system as digital data, if the bits don't change, and the timing of the transmission is held within given limits, the video and its quality will not change either. Intra-facility transmission links are error free if operating properly. For broadcast applications, inter-facility transmission links will use forward error correction (FEC) to provide the same error free operation. Even video conferencing transmission links are expected to have quite low error rates and use sophisticated error concealment. [22] In this case, measurement of picture quality at the original encoding location provides the necessary VQoS information. For satellite transmission, the link can be included in the measurement by providing the picture comparison measurement instrument with downlink video as the processed video at the uplink location.

The second approach is the use of known video sequences. Application of standardized reference video test sequences [22] allows out-of-service picture comparison evaluation of system performance at a location remote from the input video source. The standardized video sequences or any predetermined video sequence of the user's choice (perhaps a show opening moving graphic) can also be used as the "source" video for the measurement. An example is measurement of picture quality rating (PQR) for a cable headend is shown in Figure 7. Another very important benefit of using standardized reference video sequences is that it enables the manufacturer and purchaser of equipment for compressed digital television to understand and measure performance specifications using common material.



► ***Figure 7.*** *Example of remote PQR measurement.*

Tektronix PQA200

PQR objective picture quality ratings are now widely used in the industry to specify compressed digital television system performance. The Tektronix PQA200 is a self-contained, picture comparison type test set providing reference test sequences as the source video and a powerful human vision system (HVS) model algorithm to compute the PQR values for the processed video. In addition to measurement of the overall PQR value for a 2-second sequence, the PQA200 displays and stores on disk field-by-field PQR maps, PQR values, PSNR values, normalization values, and signal quality measurements.

The basis for the Tektronix PQA200 picture comparison calculation is the Sarnoff/Tektronix HVS model. This is a method of predicting the perceptual ratings human viewers will assign to a degraded color-image sequence relative to its non-degraded counterpart. The model takes in two image sequences and produces several difference estimates, including a single metric of perceptual differences between the sequences based on Sarnoff Corporation's patented JNDmetrix algorithm.

Figure 8 shows an overview of the algorithm. The inputs are two image sequences of arbitrary length. For each field of each input sequence, there are three data sets, labeled Y', C'_b, and C'_r at the top of Figure 8 derived, for example, from a D1 tape. Y, C_b, C_r data are then transformed to R', G', and B' electron-gun voltages that give rise to the displayed pixel values. In the front-end processing section of the model, R', G', B' voltages undergo further processing to transform them to a luminance and two chromatic images that are passed to subsequent stages.

The purpose of the front-end processing is to transform video input signals to light outputs, and then to transform these light outputs to psychophysically defined quantities that separately characterize luma and chroma.

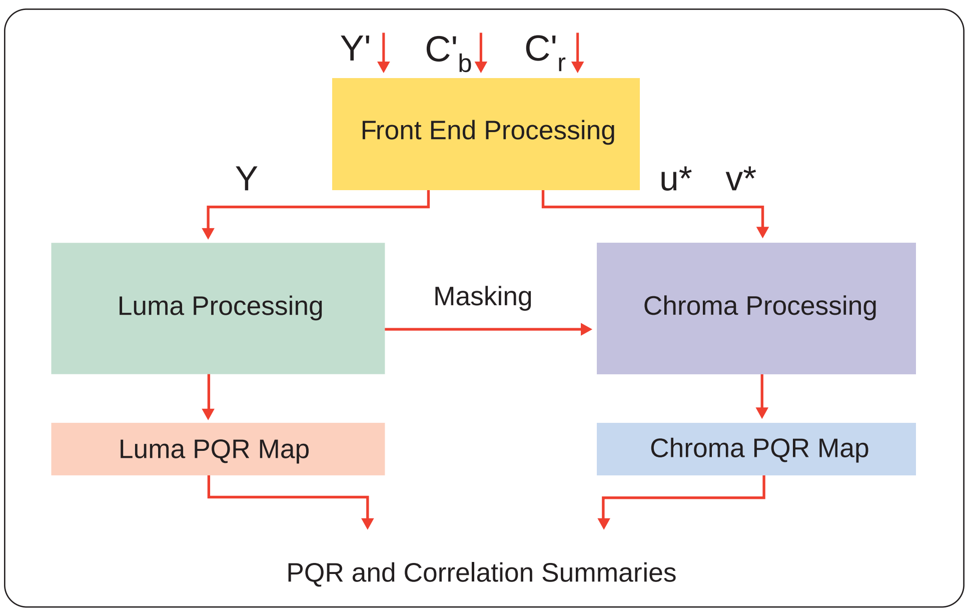


Figure 8. *Sarnoff/Tektronix human vision model flow chart.*

A luma-processing stage accepts two images (processed and source) of luminance Y, expressed as fractions of the maximum luminance of the display. From these inputs, the luma-processing stage generates a luma PQR map. This map is an image whose gray levels are proportional to the noticeable difference between the processed and source image at the corresponding pixel location. (Note: PQR calculations are based on the JNDmetrix™ algorithm (JND = just noticeable difference)).

Similar processing, based on the CIE L*u*v* uniform-color space, occurs for each of the chroma images u* and v*. Outputs of u* and v* (chroma) processing are combined to produce the chroma PQR map. Both chroma and luma processing are influenced by an input from the luma channel called masking, which perceived render differences more or less visible depending on the structure of the luma images.

Luma, chroma, and combined luma-chroma PQR maps are each available as output, together with a small number of summary measures derived from these maps. Single PQR value summaries model an observer's overall rating of distortions in a test sequence. PQR maps give a more detailed view of the location and severity of artifacts.

Application of the PQR objective picture quality rating method to any video system requires normalization of the processed video. Normalization means that time-invariant systematic changes in the video from reference input to processed video output are removed prior to performing the human vision system (HVS) based measurement. As the most sensitive and accurate objective picture quality measurement method, the PQR method is based on HVS filters that compare reference and processed pictures on what is effectively a pixel-by-pixel basis. Separation of the measurement into two parts, normalization and PQR-calculation, is necessary to obtain the most meaningful results.

Parameters to be adjusted by the normalization process are horizontal and vertical picture shifts, luminance and color gain changes, luminance and color DC level changes, and component or luminance to color channel-to-channel delay offset. Because these changes could produce changes in perceived picture quality, they are reported as part of the results of the measurement method. It is necessary to separate these changes from the PQR calculation for two reasons. The main reason is to provide the most accurate PQR value. Second, such normalization corresponds closely with typical system operation for the gain and DC level parameters where appropriate adjustments are generally available and routinely made. Small values of picture shift, horizontally or vertically, are generally not considered to change perceived picture quality. However, their presence is indeed a picture error and will produce significant problems in multi-generation applications. They must also be removed to provide accurate picture comparison calculations.

Figure 9 shows the PQR measurement system operation with respect to normalization. Processed video is normalized on a field-by-field basis by comparison with the reference video or by measurement of calibrated test signals embedded in the reference sequence. Only time-invariant static changes in video are removed, dynamic changes due to the compression and decompression processes are measured as part of the PQR calculation. To ensure accuracy and speed of calculation of the normalization values, the PQA200 inserts special calibration stripes in the reference video sequences. The reference video sequences are derived from a set of ITU-R standard sequences. [23] More flexibility in choice of video sequences is provided by use of the video capture and striping feature.

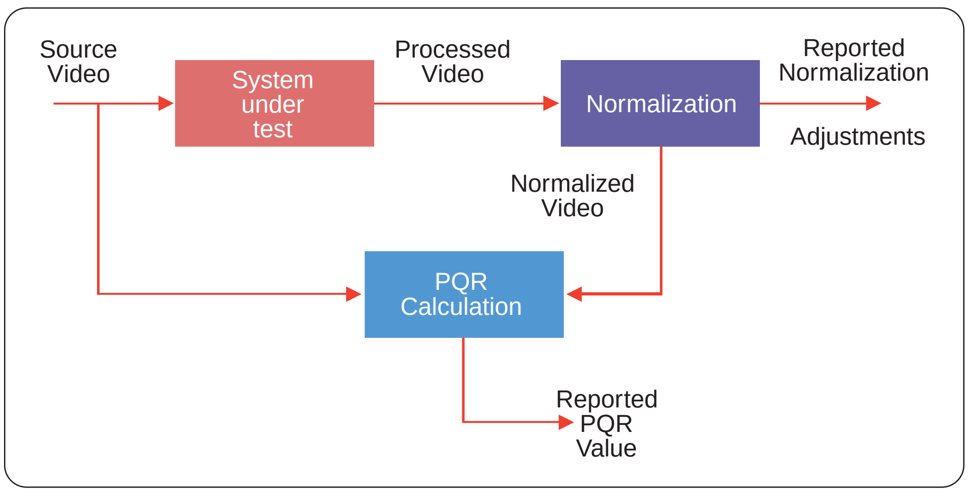


Figure 9. *PQR measurement system operation.*

Good correlation with subjective assessments is a requirement for any picture quality measurement instrument. The IRT (Institut fuer Rundfunktechnik GmbH, of Munich, Germany) and Tektronix have completed an investigation into the performance of the PQR method. The investigation consisted of a blind test comparing the PQR picture quality metric and the subjective mean opinion scores (MOS) of viewers. A data set of 60 video scenes was used in the experiment. It was generated by IRT from six different video sequences passed through two different MPEG-2 encoders at compressed rates of 2, 3, 4.5, 7, and 10 Mb/s. Subjective scoring procedure used panels of 25 assessors. Strict BT.500 [18] double stimulus continuous quality scale (DSCQS) method procedures were followed. No model parameters were adjusted to fit the IRT data set. Given the absence of any adjustments to the model parameters, which are based on human vision science, the agreement between subjective and objective results displays a strong correlation of 0.88. Using the same data but eliminating the values in the upper right-hand corner of Figure 10, which shows results of the test, correlation over typical broadcast quality is 0.91.

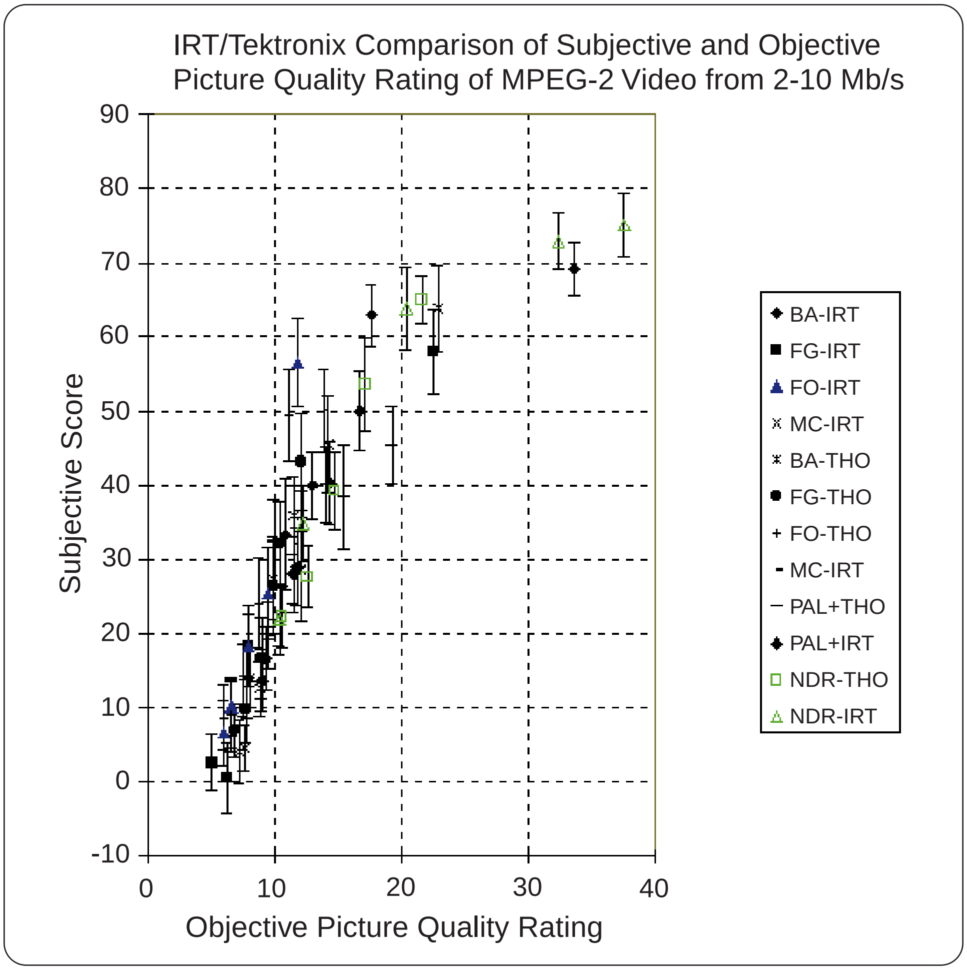
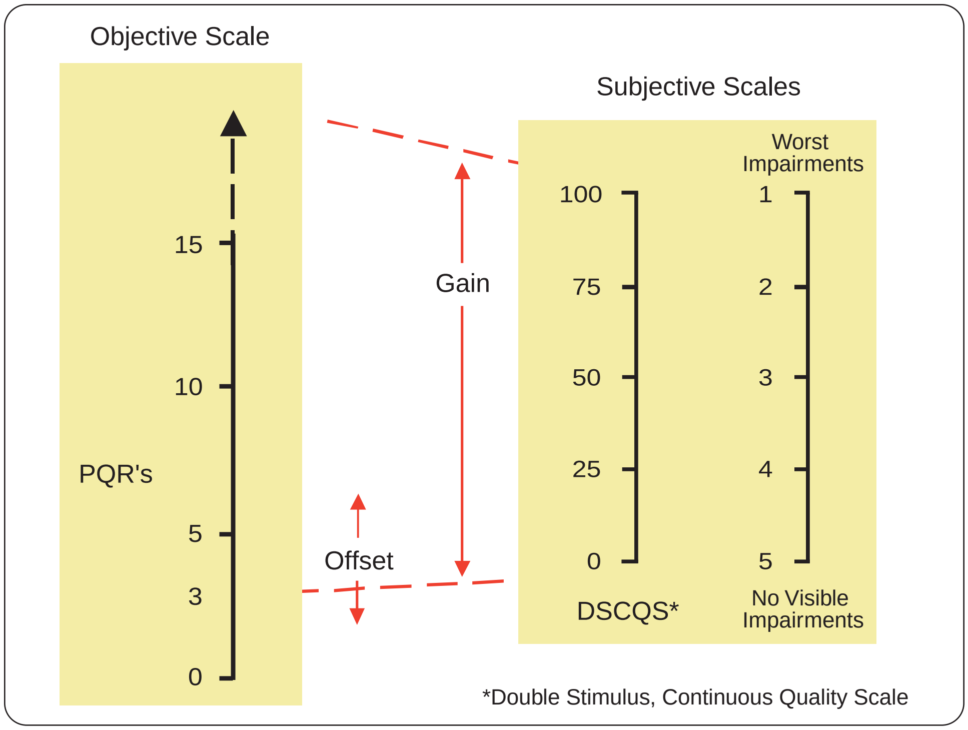


Figure 10. *PQR correlation with subjective assessment.*

One of the strengths of the picture comparison method is that the PQR values for a given sequence and a given codec at a given bit rate will remain constant. Subjective assessment scores will vary depending on the choice of test conditions and also the group of people selected to perform the test. While this does not change the correlation, it does alter the slope of the graphs. In other words, the variation in subjective scores has the effect of altering the vertical scaling on the graph shown in Figure 10. This makes it difficult to establish a constant relationship between PQR values and different sets of subjective scores. Note also that the PQR scale can be seen to have a zero offset. This is due to the ability of the PQA200 to measure picture impairments that are below the visible threshold. Subjective measurements are obviously limited to measurement of visible impairments.

It is possible to define a general relationship between PQR values and subjective assessment scales as shown in Figure 11. PQR values are shown on the left-hand scale. On the right are the two scales associated with subjective measurements. [18] The first of these is the DSCQS scale with values between 0 and 100, and the second the five-grade impairment scale with values between 1 and 5. While PQR values can be related directly to subjective results for a specific set of subjective tests using gain and offset values, this is not particularly useful since the values would be different for each new design of the subjective test. A broad general relationship can be defined between the three scales. A DSCQS result of 0 indicates no visible impairments and may be equated to a 5 on the five-grade impairment scale. This corresponds to PQR values in the range of 3 to 5. A value of 100 on the DSCQS scale representing worst impairment may be equated to a 1 on the five-grade impairment scale and corresponds to PQR values higher than 15 or 20.



► ***Figure 11.*** *Relationship between PQR values and subjective scales.*

Tektronix PQM300

Continuous real-time monitoring of multiple channels is key to maintaining operational VQoS for digital television programs. Single-ended detection of compression artifacts and other properties of the processed video are the most effective ways to provide such a monitoring capability. The Tektronix PQM300 provides an extensive set of monitoring and logging features in a multi-channel configuration. Up to eight component digital video channels or four composite analog channels may be simultaneously monitored. This is full, every frame, every pixel monitoring of all channels. No sampling (analysis of discrete time increments) or scanning (sampling of one channel, then the next and so on) are used, as this would allow defects to go undetected.

Picture defect detection features of the PQM300 are:

- Blockiness artifact detection: This is the basic defect created by the DCT-based MPEG-2 and DV compression methods. Blockiness will be present even if not visible and increased blockiness always indicates less picture quality for a given type and complexity of scene. Since block size will vary depending on the pixel resolution of the compression system, the block size parameter may be set either manually or by automatic detection. Just as the PQA200 provides a picture quality rating (PQR) the PQM300 provides a picture defect indicator (PDI) metric based on the blockiness calculation.
- Uncorrelated (gaussian) noise detection: Noise is primarily an analog system defect although it can occur in digital systems due to quantizing with too few bits per sample. The hybrid analog and digital systems used for program production and distribution are susceptible to such defects. By examining flat picture areas over a number of fields, a useful measure of signal-to-noise ratio can be derived.
- Repeated frame detection: Typical operational problems with digital video programs are frozen frames due to loss of data somewhere in the system or complete loss of program. Continuous detection and logging of repeated frames along with user-set parameters for number of repeats and number of occurrences of groups of repeats provides useful troubleshooting information.

A separate alarm trigger level may be set for each defect and each channel providing a real-time warning of potential problems. For system troubleshooting and long-term trend analysis, a complete history file of alarms is maintained. Raw data files are also saved allowing complete review and further analysis of the monitoring information.

One of the most important advantages of the single-ended method is the capability of placing the monitor anywhere in the system that baseband video is available. Of course this could be in widely varying locations, perhaps thousands of miles apart. The PQM300 has two remote operational features that add to its flexibility as a monitoring tool. The user interface is software running on a Windows NT/98 computer with IP connection to the instrument. This means that the PQM300 may be operated from any remote location based on an IP connection such as the Internet. This operation may be browser based using a Java applet or run from software installed on the user's computer, the latter being most convenient for modem connection since it eliminates applet download time. Using the standard SNMP protocol over an IP network such as the Internet, alarm trigger events from any number of instruments at any number of locations can be monitored at a central location. Simultaneously available on the display are indications for each channel of no-alarm, past-alarm, or alarm-now.

Single-ended picture quality testing does not provide the measurement level capability of PQR values. In order to understand how best to use the alarm triggers, it is important to know the relative accuracy of the PDI values. For a given complexity and type of scene, PDI values correlate very well with changes in picture quality. PSNR (the reciprocal of mean square error, MSE) has a similar characteristic as shown in the right-hand graph of Figure 12 using data from an early report on the effectiveness of JNDmetrix algorithm. [24]

For an individual scene, the right-hand graph shows good subjective to MSE correlation while there is poor correlation over all scenes. The left-hand graph shows excellent correlation between subjective assessment and PQR values for all scenes. This data was one of the early indicators that subjective assessment scores.

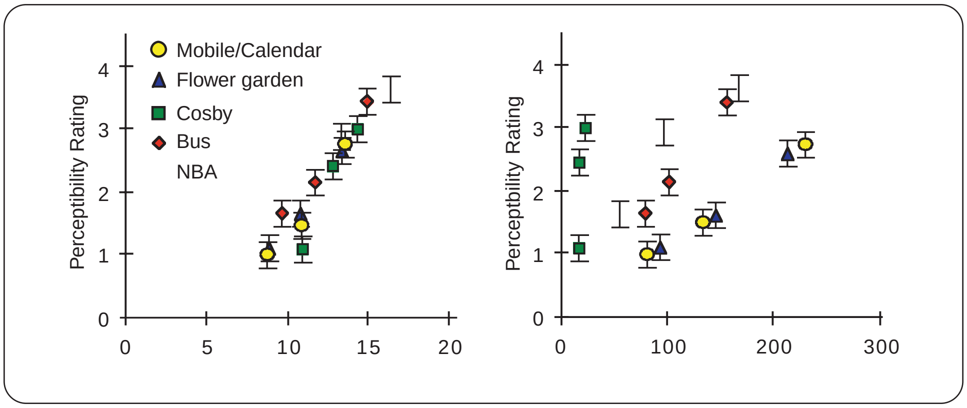


Figure 12. Comparison of PQR and MSE values with subjective assessment scores.

A useful computation using the Figure 12 data is to compare the two objective measures, PQR and MSE. Since PQR is a good indicator of subjective results for this variety of scenes and MSE is not, one would expect a poor correlation between the two over the variety of scenes but good correlation for individual scenes. This is verified by the following data.

Scene	PQR-MSE Correlation
Cosby	0.993
Mobile	0.992
Bus	0.997
Flower	0.999
NBA	0.998
All Scenes	0.311

Although subjective test methods are the starting point for evaluating objective test methods, it is an accurate measurement quality objective test method that will be the benchmark for development of test materials and calibrating less capable objective methods. Therefore, a comparison of PDI to PQR values is of interest. This is meaningful for two reasons. First, and most important, PQR has been shown to be well correlated with subjective assessments. Therefore, if PDI correlates well with PQR this implies a reasonable correlation with subjective assessment. Second, PDI will be differentiated from, and shown to be more useful than, PSNR if the correlation with PQR is good over a wide variety of scenes. A graph of the PQR versus PDI data is shown in Figure 13.

PQR to PDI correlation for individual scenes is very high similar to that in the PQR/MSE chart. Using all the data, the correlation between PQR and PDI is 0.907. While this gives support for the use of PDI as an objective picture quality test method, the scatter of the data from scene to scene makes it clear that it is not a replacement for the more capable PQR measurements. Two vertical lines have been added to the chart to emphasize this situation. For a maximum PQR rating of 3 (just visible defects), a PDI monitoring alarm would have a possible range of settings from 2 to 3. At a PQR rating of 4 (slightly more visible defects), the PDI monitor settings would range from 3 to 6 to trigger an alarm.

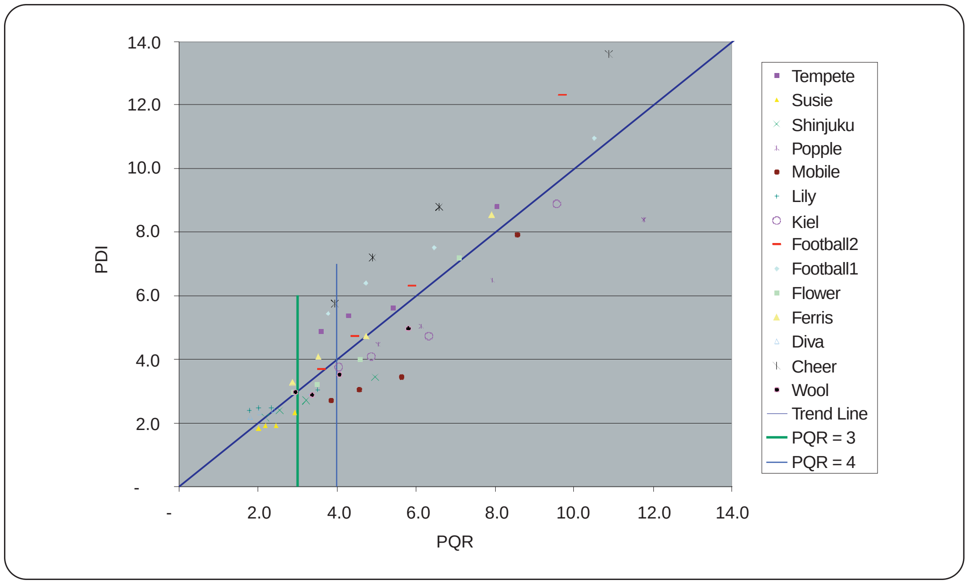


__Figure 13.__ Correlation of PQR and PDI values.

Correlation calculation results for the individual scenes and for all scenes are:

Scene	**PQR-PDI Correlation**
Wool	0.984
Tempete	0.970
Susie	0.940
Shinjuku	0.997
Popple	0.995
Mobile	0.971
Lily	0.977
Kiel	0.973
Football2	0.997
Football1	0.999
Flower	0.987
Ferris	0.993
Diva	0.991
Cheerleaders	0.999
All Scenes	**0.907**

The conclusion is that the PDI method is an excellent monitoring tool for two reasons. First, it is very adaptable to use anywhere in a DTV system because it is single-ended. That is, no information from the source video is required. Second, it has a reasonable correlation with the PQR method that has proven to provide consistent results in a wide variety of applications. However, the sensitivity to type of scene, while not nearly as poor as PSNR, still limits the PDI method to monitoring applications. It serves as a very useful system alarm and warning indicating that more accurate measurements may be necessary.

Protocol Test Methods

For intra-facility transmission links, maintenance of VQoS involves several different sub-layers of testing and the extended application of digital analysis techniques. Although there are a variety of interconnection methods and types of data to be carried, each is defined in specifications developed by standards organizations. While protocol testing is the primary type of analysis to be performed, there are other sub-layers to be considered as well. Although Figure 3 only shows the transmitting path, the receiver path merely reverses the arrows to complete the system. Expanding on the intra-facility layer explanation, the types of tests to be included to insure VQoS are outlined below.

1. Protocol analysis of formatting and compliance to standards of

   Uncompressed video [4, 5] and included ancillary data

   Compressed programs in such formats as

      MPEG-2 elementary streams
      (ES) [8]
      MPEG-2 transport streams
      (TS) [7]
      MPEG-2 program streams
      (PS) [7]
      DV-based data streams [9]

   Physical layer data mapping of

      SDTI [11]
      ASI [13]

2. Physical layer electrical characteristics, waveform type specifications for

   SDI [4]
   ASI [13]
   SMPTE 310M [12]

3. Timing errors due to inter-facility transmission links

   Jitter and wander in received data timing information

   Jitter and wander in baseband video resulting from the timing information

4. Response to custom data streams

There are a number of terms that are used to define the test methods. They are similar to those used for video testing but are restated here as applicable for protocol testing.

- Real-time
- Non-real-time (deferred time)
- Continuous
- Sampled (or scanned for multiple programs)
- In-service
- Out-of-service

Real-time testing is primarily a monitoring function where key characteristics of one or more data streams are analyzed to determine if they meet the required specifications. **Deferred-time** testing is implemented by storing a data stream and generally performing an extensive in-depth protocol analysis. Real-time testing may include timing analysis whereas the storage of the data for deferred-time testing usually does not provide any timing information.

Continuous testing is the preferred method for real-time monitoring. This means that every set of data, such as TS packets, are analyzed to a level of detail allowed by the compute power available. Sampled testing would only analyze a selected subset of data. This could be due to a lack of compute power to analyze every packet or due to scanning of multiple channels where increments of time for analysis are allocated to each channel.

In-service tests have no specific limitations as are incurred with video quality testing. The data may be analyzed while programs are being transmitted at any location in the system and in a single-ended manner. The only limits relate to compute power for real-time and continuous monitoring as discussed above. **Out-of-service** testing is also an important aspect for maintaining VQoS but the emphasis is on custom streams, such as transport streams, to determine system response to known valid or specifically invalid data sets.

The number of different types of testing and possible instrument features related to maintaining VQoS at the intra-facility transmission link layer is virtually unlimited. No one instrument does it all. In this guide the emphasis is on MPEG-2 TS analysis including timing errors potentially added by inter-facility links. Although other compression methods are used in the studio, it is the MPEG-2 TS that is used throughout the industry for delivery of programs to the home viewer and for many applications internal to the program production process. Protocol analysis is based on accepted standards. In the case of MPEG-2 TS, the key standards are the MPEG-2 system standard [7], ATSC standards [15] and DVB standards. [14] A working knowledge of these standards is helpful in understanding the protocol and timing test methods discussed in this guide. An excellent source of this information is contained in a separate Tektronix publication. [25]

Real-Time MPEG-2 Transport Stream Analysis

There are over 25 different fields of anywhere from 1-byte to 42-bytes in the MPEG-2 TS header. An example of the more important fields is shown in Figure 14. (Not shown are those in the adaptation field extension.) While the minimum header is a 4-byte block with nine fields, the maximum header could use the entire 188-byte packet. VQoS monitoring for TS requires more than just analyzing the headers. In addition, there are a number of required and optional tables that are different in basic-MPEG, DVB and ATSC systems. To facilitate practical real-time monitoring of MPEG-2 TS, the DVB Measurements Group has specified items to be analyzed in three priority groups. [26] Each item is specified in detail in the reference.

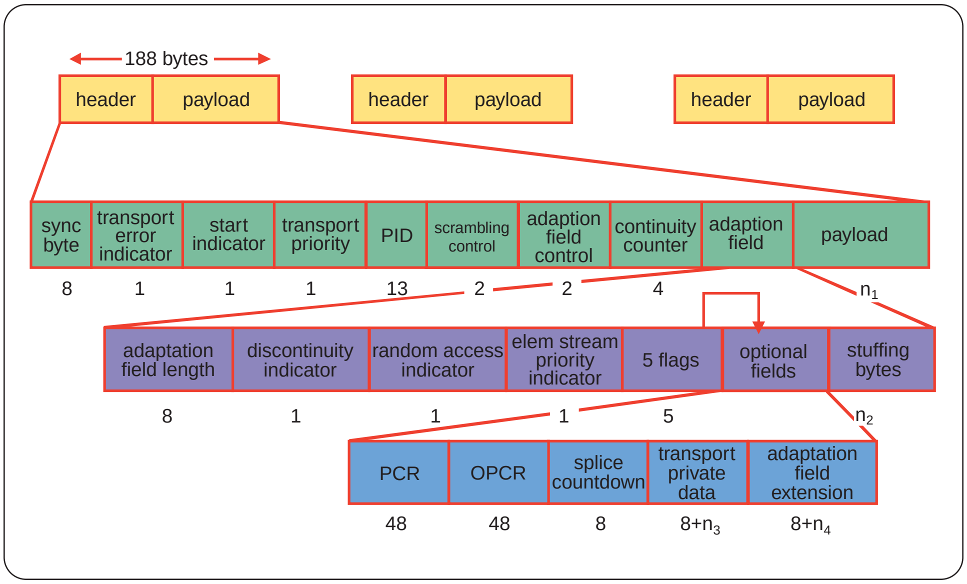


Figure 14. *Transport stream packet header, required and optional fields.*

- First Priority: Necessary for decoding

  TS_sync_loss
  Sync_byte_error
  PAT_error
  Continuity_ count_error
  PMT_error
  PID_error

- Second Priority: Recommended for monitoring

  Transport_error
  CRC_error
  PCR_error
  PCR_accuracy_error
  PTS_error
  CAT_error

- Third Priority: Application dependent monitoring

  NIT_error
  SI_repetition_error
  Buffer_error
  Unreferenced_PID
  SDT_error
  EIT_error
  RST_error
  TDT_error
  Empty_buffer_error
  Data_delay_error

Many of the items in the third priority group are DVB-specific. VQoS monitoring instruments will include a user selection for basic-MPEG-2 and ATSC versions of the items. The two buffer error items and the delay error item are often not included in monitoring equipment due to the complexity of hardware and software to do the test.

Another important aspect of real-time monitoring for TS is measurement of the jitter and wander present in the received program clock reference (PCR) data. This is discussed in a later section since it also relates to deferred-time testing.

Deferred-Time MPEG-2 Transport and Elementary Stream Analysis

With so much information carried in TS packet headers and the many tables, deferred-time analysis is a must for system design, installation, and maintenance. VQoS matters that are not resolved by real-time monitoring techniques may require extensive in-depth analysis. The basic principle is to capture the TS data in a storage device. This could be tens of megabytes in memory to many gigabytes on hard disk. Key requirements for deferred-time analysis are completeness and automatic operation. Every packet and table is analyzed for those parameters checked in the measurement instrument and selected by the user. Typical categories of analysis are:

- Syntax: determines that the formatting of all TS header, PES header, and table data meets the appropriate standards. A simple example would be that each TS packet starts with the correct, 47H, sync byte. A more complex example would be that the correct reserved bits are inserted in the correct locations in a 42-bit PCR value.
- Semantic: values are within the allowable range per the appropriate standards. An example would be the 2-bit adaptation field control. The value 00 is not allowed.
- Consistency: compares data in the various tables to determine that there is no conflicting data. This includes comparing the required MPEG-2 tables to the DVB SI or ATSC PSIP tables as well as checking the consistency among the tables required by each system.
- PSI/SI/PSIP Rates: the frequency of occurrence and time between tables meet the appropriate standards.
- PTS/DTS Timing: time stamp values are within the allowable range with respect to each other and the associated PCR values.
- PCR Accuracy: MPEG-2 allows PCR values to be no more than 500 ns different from the true value for the TS. See the discussion below regarding accuracy, jitter, and wander.
- Dynamic: a series of hypothetical buffers are defined by the MPEG-2 system decoder standard to control packet occurrence in the TS due to the not-standardized system encoder. Analysis includes the transport stream system target decoder (T-SDT), the legal time window (LTW), and buffer smoothing.

Based on the above list and the fact that captured files may be gigabytes in size, it is clear that automatic analysis and error location is required for deferred-time analysis. Once the TS is captured, analysis of the even more complex elementary stream (ES) is possible. Syntax and semantic analysis for ES will cover video sequence, group of pictures, and pictures.

Reference Frequency and Timing Error Analysis

An important aspect of the MPEG-2 system is accurate regeneration of the system clock at the receiving site. While this was certainly considered by the engineers who designed and standardized the MPEG-2 system, all issues were not completely resolved. The timing error that may be present in the TS received from a transmission link has become a key VQoS issue.

Operation of the MPEG-2 reference clock system is shown in Figure 15. A 27 MHz clock is derived from the input video to the encoder (generally locked to a plant reference) and used to place program clock reference (PCR) data in to the headers of some TS packets. PCR values are a specific

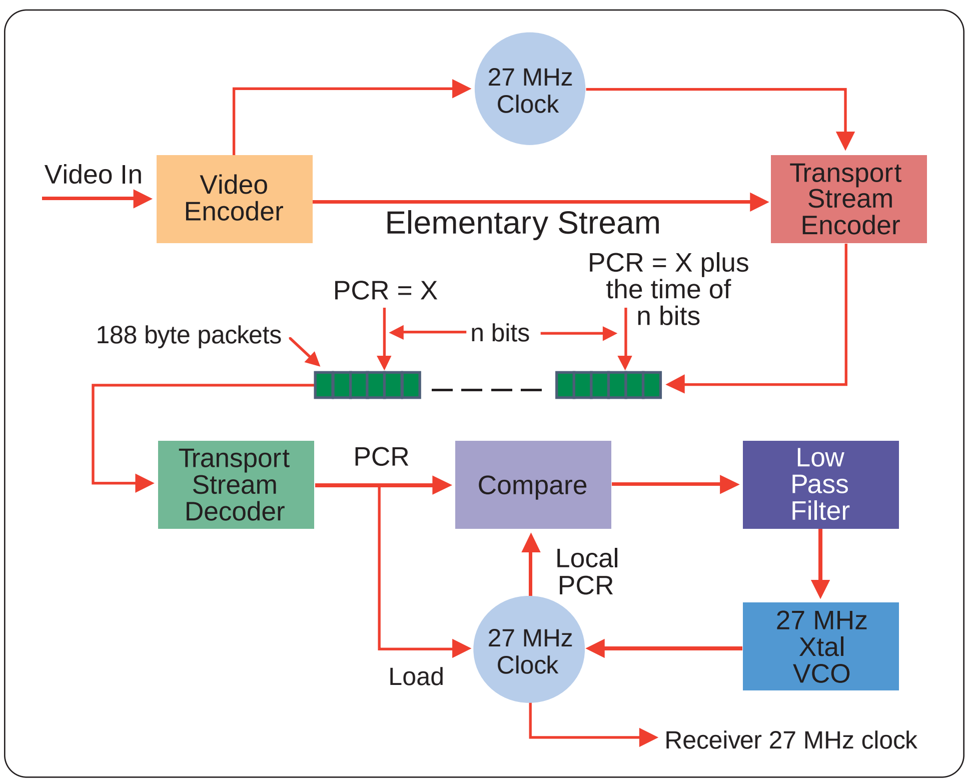


Figure 15. *MPEG-2 reference clock system.*

number, not frequency information. Their values are binary in increments of 38 ns with a maximum value of slightly more than 24 hours. At the time a TS packet with a PCR is transmitted, the instantaneous value of the clock is placed in the packet header, say value X. The next PCR value will be inserted many TS packets later. Its value will be X plus the time it took for all of the bits of the intervening packets to be transmitted. At the receiver, the first PCR seen is used to set the local 27 MHz clock. Subsequent PCR values are used in a phase locked loop (PLL) to adjust the frequency of the local clock. On the average, the local clock is running at exactly the same frequency as the encoder clock.

The VQoS issue is implied in the words "on the average." Variations in reference frequency at the decoder and video output may be measured as jitter, drift rate, and frequency offset. Professional users will expect tight tolerances for these parameters to be consistent with studio standards. [28, 29, 30, 31] Consumer products such as VCRs and TV sets are more forgiving and operate correctly with somewhat less stringent tolerances.

There are two design values specified by the MPEG-2 standard that affect operation of the clock recovery system. First, the PCR values are transmitted only 10 to 30 times per second depending on the system (basic MPEG, DVB, or ATSC.) This is equivalent to using vertical sync to genlock a 27 MHz-based reference – not impossible but difficult. Good PLL design can handle this situation and provide reasonably fast lock-up when changing channels. Second, the PCR values may be inaccurate by as much as ±500 ns. When horizontal sync edges are expected to have an accuracy of +2 ns measured over at least one field, this could be a real problem. Again, good PLL design can help. With a potential phase shift of the expected PCR value of almost a microsecond, it might be difficult to meet the sync accuracy specification. In general, the PCR accuracy is much better than the specification allowed by the standard. PCR accuracy is measured using deferred-time analysis, thereby eliminating transmission channel latency variations.

The timing model for the MPEG-2 system standard expects a constant delay between the system encoder and the system decoder. [7 annex D] Of course transmission links do have variable latency, especially the broadband digital network. For ATM applications, the variable latency can be on the order of milliseconds. Design of a receiver with buffering and appropriate PLL operation can eliminate these timing variations.

VQoS monitoring is accomplished at two layers. Testing methods for PCR timing variations are being defined by the DVB Measurements Group and will be added to the ETSI standard [26] when complete. Test methods for jitter and wander in baseband analog and digital video are being defined by the IEEE. A standard will be published in late 1999 or early 2000. [32]

Real-time testing is used to monitor the total PCR value timing error. This includes both the accuracy variation allowed by the MPEG-2 standard and the packet latency variation produced in the transmission link. Deferred-time testing eliminates the packet latency variations by storing the packets in a contiguous manner; therefore, it measures just the PCR accuracy. By using both PCR-related methods in conjunction with the baseband measurement, it is possible to provide a complete VQoS analysis of the reference clock system.

Tektronix MTS200 Series

A laboratory instrument providing the full range of MPEG-2 protocol analysis capabilities is required for design, manufacturing, equipment selection, system installation, and system evaluation. The Tektronix MTS200 series provides both the full range of analysis tools and flexible TS generation capability. Beyond the laboratory applications, the MTS200 series also provides real-time monitoring of VQoS parameters as described in the previous sections. Brief descriptions of some of the key features are given below.

To ease the analysis of real-time test results, the MTS200 Series provides a hierarchical display of the elements that make up the transport stream. Shown in Figure 16, color is used to indicate the status of each element under test within the transport stream. Green indicates that the element under test passes; Red indicates that there is a current error; and Orange indicates that an error has occurred but is no longer present. The Real-time Analyzer also offers message logging that can be viewed either from the master log or on an individual PID basis. A statistical view provides a status-at-a-glance display of the overall bandwidth and efficiency of the transport stream under test. Graphic and dynamic displays show the data rates, percentage of use, and global data information for each program, PID, and the transport stream.

PCR Analysis with frequency offset and drift information (see Figure 17) are displayed in real-time. The real-time analyzer enables you to use MPEG, DVB, ATSC, or user-defined limits. Errors are graphically displayed in red and added to the message log with time of day and date information. The real-time system also provides multiple PCR views simultaneously to assist in identifying multiplexer or encoder problems.

The PID Allocation view enables you to view all PIDs associated with either PSI/SI/PSIP or program tables and monitor their rates. High and low limits can be set to alert the user with error messages when these limits have been exceeded. This is especially important when monitoring the output of a statistical multiplexer and trying to identify a program that may be using too much bandwidth. DVB ETR290 measurements can be monitored in either overview or detailed views.

One of the most powerful features of the MTS200 series is the capability to combine real-time monitoring and deferred-time analysis in one instrument. The MTS215 MPEG Test System addresses this by incorporating a trigger/capture function that enables the user to specify an error or event to be monitored. When the designated error or event occurs, the system automatically captures the event so that it can be analyzed at a later time. The system can capture a minimum of 35 minutes of data running at 60 Mb/s. Deferred-time analysis is based on a hierarchical presentation similar to that in Figure 16 displaying the structure of the transport stream and identifying all of the

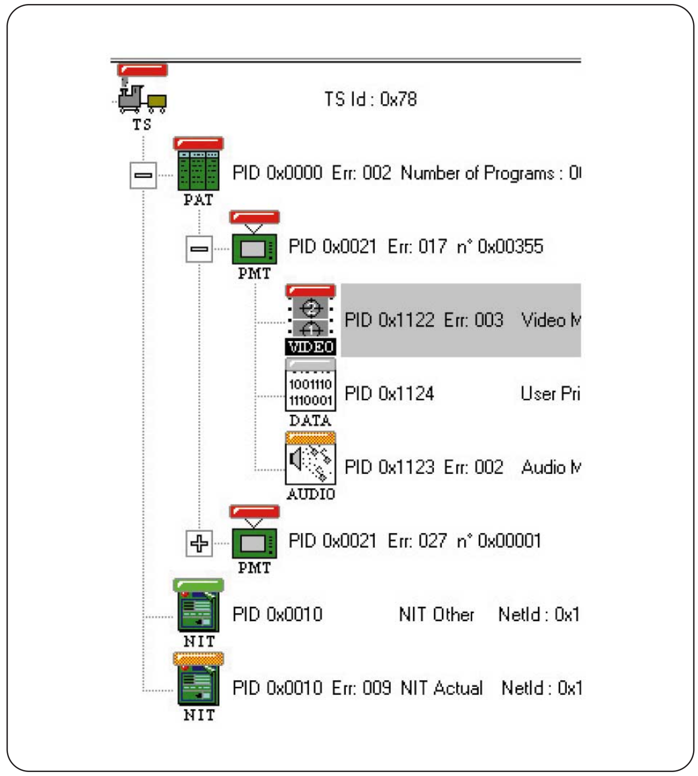


Figure 16. Transport stream real-time hierarchical display.

components. Headers for TS, PES, and tables may be shown in an interpreted display providing details of the definition of each field, indicating incorrect values and showing the meaning of correct values. Graphical displays are used to show PCR accuracy analysis (not jitter), multiplex allocation rate analysis, and a PID map for viewing distribution of the data. Optional software for deferred-time analysis of AC-3™ and MPEG audio and video elementary streams is available.

Another important function for design, system installation and system evaluation is the capability to generate custom transport streams. User-definable parameters include: Timing offsets, Data rates, PES packet size,

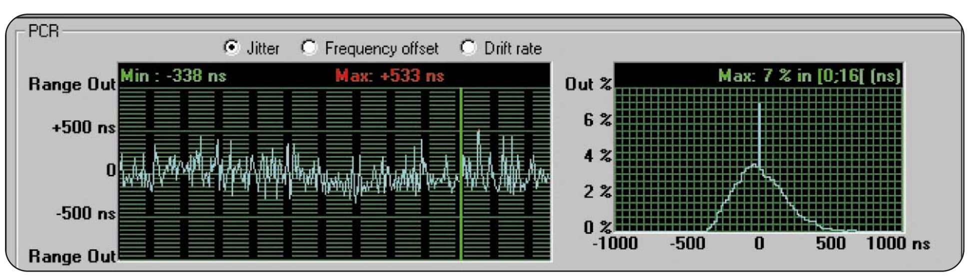


Figure 17. PCR jitter display.

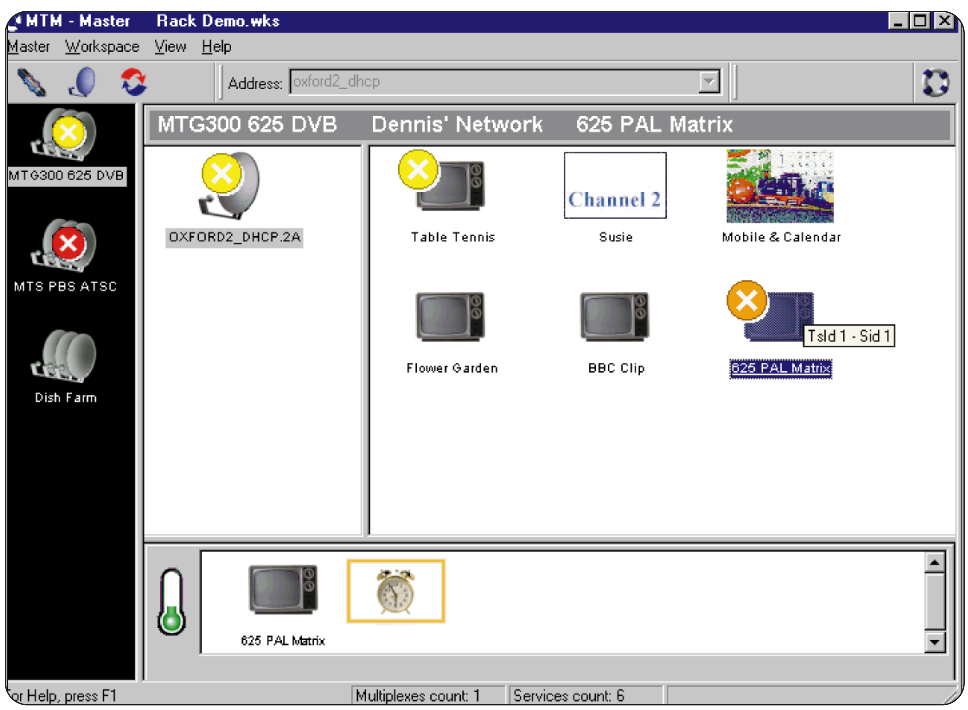
PCR accuracy errors, Channel coding, DVB SI table information, and ATSC PSIP Table information (Terrestrial or Cable). Generation of a "known good" transport stream accommodates testing the performance of the entire system or an individual component under ideal conditions. Because there is control over various parameters, the user can create a custom transport stream with variations to stress performance at or near operational limits. CD-ROMs with elementary streams are included with all MTS200 Series systems having generation capability. The video elementary streams contain both motion sequences and traditional television test patterns. Another generator option is real-time multiplexing of transport streams. This application can quickly process many input streams and output a valid MPEG-2 stream. The input transport streams can represent a single program transport stream (SPTS) or multi-program transport streams (MPTS), elementary streams, private data, PSI tables, DVB-SI tables, or ATSC-PSIP tables. Some of the important characteristics are Dynamic management of MPEG2 PSI, DVB SI and ATSC PSIP tables, SPTS and MPTS file multiplexing, Allocation and dynamic filtering of PIDs, and Re-stamping of PCRs.

Tektronix MTM300

Monitoring VQoS at the protocol level for a large system requires multi-channel local monitoring, remote monitoring and control capabilities. The Tektronix MTM300 provides real-time monitoring of up to eight MPEG-2 transport streams in one instrument with a sophisticated set of warning alarms and detailed analysis of each program. Multiple instruments can transmit alarm information from up to 40 transport streams to a central monitor using the SNMP protocol over any IP network such as the Internet or point-to-point modem connections. Full remote control and display of monitoring data of multiple instruments is accomplished using a proprietary protocol over an IP network. The number of transport streams (40 maximum) to be operated in this manner is only limited by the bandwidth of the network.

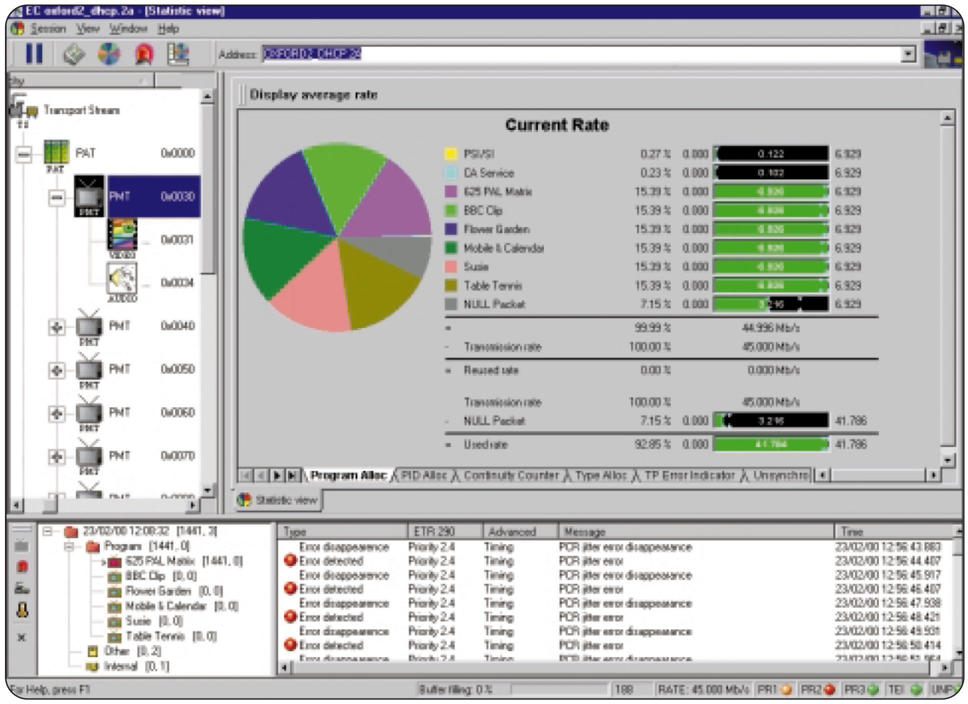
Three major levels of monitoring detail are provided for multiple transport streams: warning indicators, real-time protocol analysis, and deferred-time protocol analysis. The real-time protocol analysis is similar to that of the MTS200 series but configured for combined local and multi-user remote application. Deferred-time analysis is identical to that of the MTS200 series but limited to a 128-MB file size.

Figure 18 shows the high-level Master Client display for either local or remote status monitoring. There are three display panels with increasing level of detail. On the left is the Bouquet Panel that shows groups of TS. (Note: this is not the "bouquet" that is a group of services as defined by DVB.) The specific TS for each bouquet are pre-selected in a set-up menu from those available in a grouping appropriate for the VQoS application. To the right of the Bouquet Panel is the Multiplex Panel that displays an icon for each of the TS in the selected bouquet. On the right is the Service Panel that shows an icon for each of the programs in the TS. Where available, the icon is the logo for that service providing the user with quick program identification. On the bottom of this display is the Detail Panel that shows the type of errors, if any, occurring in the selected multiplex or service as well as an indication of the severity of the error type. Error information for the multiplex is for those items not specifically associated with an individual program, such as the Program Association Table (PAT). All of the information for this display is available at a remote location based on low bandwidth SNMP protocol communication.



► ***Figure 18.*** *Master Client display.*

Alarm indications displayed by the Master Client are based on continuous real-time analysis of every TS being monitored by the system. The Expert Client view provides local or remote access to control and display of the real-time protocol analysis. Figure 19 shows the Expert Client display for the selected TS. On the top right is a hierarchical view of the TS with icons for each of the tables, programs and program elements. To the left is the Program Allocation display showing the data rates for each of the programs and packets not associated with a specific program. On the bottom left is a window showing the history of program availability. To its right is a list of errors detected and time of occurrence. The Expert Client display and other available displays, such as PID allocation and jitter analysis, are similar to those of the MTS200 series (see Figures 16 and 17).



▶ ***Figure 19.*** *Expert Client display RF Digital Transmission VQoS.*

RF Digital Transmission VQoS

Digital transmission is the key enabling technology that allows terrestrial, satellite, and cable systems to deliver a multitude of services. Its spectral efficiency and robust resistance to interference provides subscribers with a high Video Quality of Service. Digital transmission formats include COFDM, QPSK, 8-VSB, and QAM. These formats share common characteristics, such as how the data corresponds to carrier phase and amplitude.

Ensuring the video quality of service requires testing digitally modulated signals. As with analog systems, power and interference measurements are essential to maintaining digital services. Although the effects from impairments are different than on an analog television signal, spurious interference and amplifier compression will degrade digital signals.

In addition to power and interference tests, digital transmissions require unique new measurements of transmission quality. Digital modulation formats employ adaptive equalization, forward error correction, data interleaving, and other techniques to preserve the clarity of the data. When these techniques fail, digital services abruptly fail. New tests that spot performance trends before they become customer complaints include modulation error ratio (MER), estimated noise margin (ENM), and bit error rate (BER).

MER is the best overall figure-of-merit measurement to check for non-transient impairments affecting a digital transmission. It is analogous to signal-to-noise ratio of the baseband digitally modulated signal. MER is a comparison of modulation error power to the average transmission power in decibels. The measurement can be made in-service, and uses the data derived from the signal.

ENM is also an in-service measurement. It is expressed in decibels, and indicates how much degradation can occur before the signal is at critical pre-forward error correction. Visible picture impairment will begin when transmission quality degrades beyond this critical point.

BER is an overall measure of the quality of the received bit stream and may be measured before or after error correction. BER is the ratio of the number of bit errors to the total number of bits sent in a given time interval. BER reflects only modulation impairments severe enough to cause bit errors, and remains insensitive to subtle trends in the digital modulation. A good BER indicates proper service delivery, while a bad BER highlights impaired service. At critical BER, severe impairments, such as freeze-frame of the received video, will occur.

Video quality of service is a top concern for those responsible for the operation of digital video and data services. Operators cannot afford to be plagued by signal degradation or the threat of failure. Using a balanced set of metrics will help assess overall system health, and troubleshoot modulation and data delivery performance issues.

System Approach to VQoS

Maintaining video quality of service for digital television programs requires measurement and monitoring equipment placed at various locations within the system. At each location, the test equipment will provide specific information required by the users at that location. Referring again to Figure 1, the type of testing for each block can be summarized as follows. It is assumed that video compression is used in all blocks. Where it is not used the monitoring and measurement methods to maintain VQoS are described elsewhere and not specifically included in this guide.

Source: Picture quality measurement to ensure the highest quality original. Monitoring of the protocol and mapping into the transmission link.

Transmission Link: Most important are the physical layer, digital, and analog parameters as well as the many VQoS parameters defined by ITU standards. If all the bits pass through the transmission link without error, the video quality will not change. However, the service provider will wish to test the baseband layer because that is most important to the user who receives the video. When all the bits don't arrive correctly it's the picture that will be the first topic of discussion. Monitoring of picture defects can be very useful in pointing to other problems in the system that may not be due to the compression process. In some cases, the service provider also supplies the complete gateway from baseband to transmission physical layer and is responsible for the video quality.

Program Provider: All forms of measurement and monitoring of baseband video and compressed data protocol are useful in the program provider facility. Picture quality measurement is the most important in facilities that incorporate multiple generations of video processing combined with compression. An example would be developing a very complex commercial with many artistic layers using a videodisk to store the intermediate layers. The picture quality measurement system should not be specific to one compression method since both DV and MPEG-2 are commonly used in the studio. Picture quality monitoring is useful at the inputs to the facility and may be appropriate at the output if a statistical multiplexer is used to combine programs into one transport stream. Protocol measurements and monitoring are most appropriate at the facility output to ensure fully valid data streams are being sent to the transmission link.

Program Modification: Monitoring is emphasized in this application since there are likely to be multiple channels with only minor video processing changes (such as logo insertion) to some of the programs. Simple cut-edits become a complex matter when done in the compressed domain; hence, protocol measurement as well as monitoring are important. Multi-channel picture defect monitoring is key to detecting problems in multiple input programs and very important to the optimum operation of the statistical multiplexer at the facility output.

Viewer: The actual viewer is unlikely to do testing of the received video; however, those responsible for producing and delivering the program need to ensure that VQoS meets both the viewer's expectations and the requirements of those providing the program. This may mean on-site measurement of the compressed-layer protocol and out-of-service measurement of picture quality. If there are intermittent problems, monitoring and logging of both the compressed data protocol and picture defects will aid in locating and resolving the problem. Remote monitoring capability will be particularly important for this situation.

To provide and maintain full VQoS for digital television programs, monitoring of picture defects and protocol compliance to standards at many points in the system is required. Within a facility, local area networks (LAN) are common providing a wideband Internet protocol (IP) connection. External to a facility, Internet connections at various bandwidths are available as well as point-to-point modem connections by telephone. This worldwide interconnectivity combined with the remote operation and alarm warning capabilities of the Tektronix PQM300 and MTM300 provides a powerful method to monitor and maintain the VQoS required by the many users from video source to the final viewer of the program.

References

[1] **Recommendation ITU-T E.800**, Terms and Definitions Related to Video Quality of Service and Network Performance Including Dependability.

[2] **Recommendation ITU-T M.60**, Maintenance: Introduction and General Principles of Maintenance and Maintenance Organization.

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[4] **Recommendation ITU-R BT.656-4**, Interfaces For Digital Component Video Signals in 525-line and 625-line Television Systems Operating at the 4:2:2 Level of Recommendation ITU-R BT.601 (Part A).

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[6] **Recommendation ITU-R BT.709-3**, Parameter Values for the HDTV Standards for Production and International Programme Exchange.

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