

# TECHNICAL REPORT

# IEC TR 62251

First edition  
2003-05

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**Multimedia systems and equipment –  
Quality assessment –  
Audio-video communication systems**

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Reference number  
IEC/TR 62251:2003(E)

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## Multimedia systems and equipment – Quality assessment – Audio-video communication systems

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**MULTIMEDIA SYSTEMS AND EQUIPMENT –  
QUALITY ASSESSMENT –  
AUDIO-VIDEO COMMUNICATION SYSTEMS**

FOREWORD

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Technical reports do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful by the maintenance team.

IEC 62251, which is a Technical Report, has been prepared by IEC technical committee 100: Audio, Video and Multimedia Systems and Equipment.

The text of this technical report is based on the following documents:

|               |                  |
|---------------|------------------|
| Enquiry draft | Report on voting |
| 100/561/DTR   | 100/662/RVC      |

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

# MULTIMEDIA SYSTEMS AND EQUIPMENT – QUALITY ASSESSMENT – AUDIO-VIDEO COMMUNICATION SYSTEMS

## 1 Scope

This Technical Report specifies items to be measured by objective methods, methods of measurement together with measuring conditions, processing of the measured data and presentation of acquired information for objective assessment of end-to-end quality of audio-video communication systems over digital networks. The measurements are supposed to be conducted in a double-ended and a full reference. The systems are assumed to have electrical interface channels at the input and at the output of audio-video signals for objective assessment.

The extension for systems that do not have such channels is left for further study.

## 2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies

IEC 60268-4, *Sound system equipment – Part 4: Microphones*

IEC 60268-5, *Sound system equipment – Part 5: Loudspeakers*

IEC 61146-1:1994, *Video cameras (PAL/SECAM/NTSC) – Methods of measurement – Part 1: Non-broadcast single-sensor cameras*

IEC 61146-2:1997, *Video cameras (PAL/SECAM/NTSC) – Methods of measurement – Part 2: Two- and three-sensor professional cameras*

IEC 61966-2-1:1999, *Multimedia systems and equipment – Colour measurement and management – Part 1: Colour management – Default RGB colour space – sRGB*

Amendment 1 (2003)

IEC 61966-2-1, *Multimedia systems and equipment – Colour measurement and management – Part 2-1: Colour management – Default RGB colour space – sRGB*

IEC 61966-3:2000, *Multimedia systems and equipment – Colour measurement and management – Part 3: Equipment using cathode ray tubes*

IEC 61966-4:2000, *Multimedia systems and equipment – Colour measurement and management – Part 4: Equipment using liquid crystal display panels*

IEC 61966-5:2000, *Multimedia systems and equipment – Colour measurement and management – Part 5: Equipment using plasma display panels*

IEC 61966-9:2000, *Multimedia systems and equipment – Colour measurement and management – Part 9: Digital cameras*

CIE 15.2:1986, *Colorimetry*

ITU-R BS.1387-1 :2001, *Method for objective measurements of perceived audio quality*

ITU-R BT.601-5 :1995, *Studio encoding parameters of digital television for standard 4:3 and wide-screen 16:9 aspect ratios*

ITU-T J.144 :2001, *Objective perceptual video quality measurement techniques for digital cable television in the presence of a full reference*

ITU-T P.931 :1998, *Multimedia communications delay, synchronization and frame rate measurement*

### **3 Terms and definitions**

In order to understand this Technical Report, the following terms and definitions apply.

#### **3.1**

##### **audio-video communication system**

system that handles audio, video and optionally other data streams in a synchronized way within users' perception in order to transmit and/or exchange information, which is assumed to operate over a local- or wide-area digital network

#### **3.2**

##### **DMOS**

difference between the source and processed Mean Opinion Scores (MOS) resulting from the subjective testing experiment conducted by the Video Quality Expert Group (VQEG)

#### **3.3**

##### **PEAQ**

perceived evaluation of audio quality defined by ITU-R BS.1387-1

#### **3.4**

##### **PSNR**

objective video quality metric defined by peak-signal to noise ratio, the noise being calculated from the source and processed video frames

#### **3.5**

##### **VQR**

objective video quality rating reduced from any objective metric by being optimally correlated with the DMOS

### **4 Configuration for quality assessment**

#### **4.1 Input and output channels**

Audio signal and video signal in audio-video streams shall be captured at the input and at the output channel, respectively, of the audio-video communication system as shown in Figure 1.

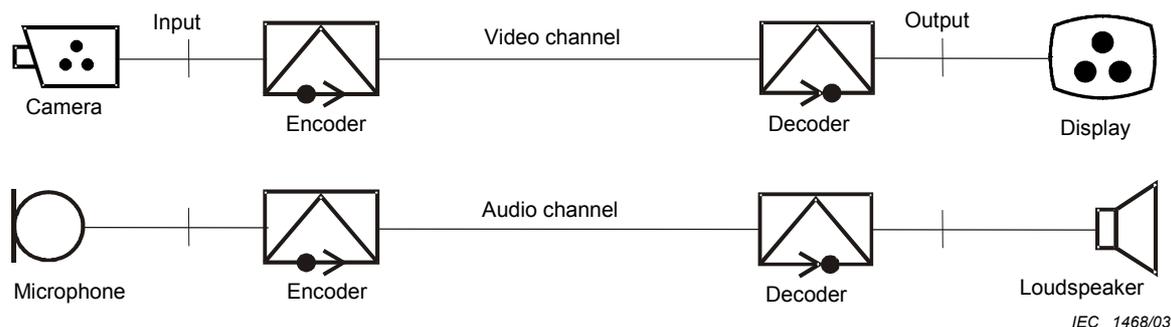
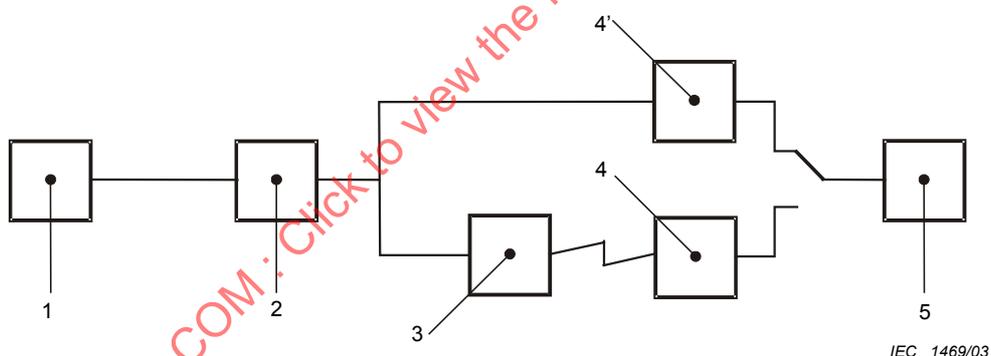


Figure 1 – Model of audio-video communication systems

#### 4.2 Points of input and output terminals

In the spirit of the end-to-end quality assessment of audio-video communication systems, the points for acquisition of raw data should be as far as ultimate end-points as possible. However, since the methods of measurement and characterization for equipment which incorporates input transducers such as video cameras and microphones have already been standardized, such as in IEC 61146-1, IEC 61146-2, IEC 61966-9 and IEC 60268-4, and the methods of measurement and characterization of equipment which incorporates output transducers such as video signal displays and loudspeakers, as in IEC 61966-3, IEC 61966-4, IEC 61966-5 and IEC 60268-5, they can be outwith the scope of the range of the end-to-end.

Figure 2 shows a schematic diagram for quality assessment under double-ended and full reference conditions.



#### Key

- 1 Original audio or video reference.
- 2 Pre-conditioner: reduced dynamic range, frequency range for audio; reduced frame size and frame rate for video to fit to the quality assessment of the audio-video communication systems, if necessary.
- 3 Encoder for network streaming with a specified bit-rate in order to fit to the bandwidth of end-to-end network connection.
- 4 Decoder and rendering for the received data to make them audible and visible.
- 4' Rendering for the preconditioned data to make them audible and visible, optional.
- 5 Data acquisition and calculation for quality assessment to provide information specified in this report.

Figure 2 – Schematic diagram for quality assessment

## 5 Video quality

### 5.1 Introduction

For the purpose of end-to-end objective assessment of video quality, two aspects have been covered in this Technical Report; one is static characteristics such as tone reproduction and colour reproduction described in 5.2 and 5.3, the other dynamic characteristics based on streaming of video frames to networks described in 5.4, 5.5 and 5.6.

It is recommended to make use of a set of commonly available video sources as reference such as the test sequences in the Canadian Research Centre (CRC) as the original video reference for the item 1 in Figure 2. Because of its high bit-rate and large frame size, the reference source should be reduced in frame size and bit-rate for use as the item 2 in Figure 2, if necessary, for actual encoding as streaming video to a network with limited bandwidth.

For the dynamic characteristics, reference video sequences currently available are listed in Table A.1. All reference video sources in Table A.1 have been adopted in this Technical Report with the permission of the owner, the Canadian Research Council (CRC), which were used by the Video Quality Expert Group (VQEG) for subject video quality tests to obtain the Difference of Mean Opinion Score (DMOS) and also object Video Quality Metric (VQR) as reported in ITU-R 10-11Q/56-E.

The format of each of the reference video sources is composed of 10 frames (for leader) + video frames for 8 s + 10 frames (for trailer). There are two video formats 525/60Hz and 625/50Hz, but only the 525/60Hz format shown in Table A.1 is adopted in this Technical Report for evaluation.

Each line is in pixel multiplexed 4:2:2 component video format as Cb Y Cr Y ... and so on, encoded in line with ITU-R BT.601-5, where 720 bytes/line for Y, 360 B/line for Cb and 360 B/line for Cr. The lines are concatenated into frames and frames are concatenated to form the sequence files.

The format contains 720 pixels (1 440 bytes) per horizontal line and has 486 active lines per frame. The frame sizes are  $1\,440 \times 486 = 699\,840$  B/frame and the sequence sizes are 240 frames file size for 8 s + 20 frames. Thus, file size is  $699\,840$  bytes/frame  $\times$  260 frames = 181 958 400 bytes. 30 frame/s will result a bit-rate of  $699\,840$  bytes/frame  $\times$  30 frame/s  $\times$  8 bits = 167 961 600 bit/s. Since it is a too high bit-rate to be handled by ordinary personal computers and to be streamed to the Internet, the original test sequences have been reduced in frame size to be  $320 \times 240$  pixels, and in format to be RGB (instead of YCC) 24-bit/pixel to fit to a typical video format (AVI) where IEC 61966-2-1 is taken into account.

NOTE 1 Pixel-by-pixel error assessment requires a very high degree of normalisation to be used with confidence. The normalisation requires both spatial and temporal alignment as well as corrections for gain and offset. For this purpose, Clause A2 of ITU-R 6Q/39-E should be referred to.

NOTE 2 Since the values of objective quality metrics largely depend on video contents, varieties of commonly available video sources should be used as far as possible.

NOTE 3 Video quality metrics obtained by objective assessment in Clause 5 should be converted to be VQR by optimum correlation with DMOS, which is under consideration within ITU-R WP 6Q.

## 5.2 End-to-end tone reproduction

### 5.2.1 Items to be assessed

End-to-end non-linearity in term of tone reproduction.

### 5.2.2 Method of assessment

An image of the grey steps chart defined in IEC 61146-1, as shown in Figure 3, should be used as the reference source for item 1 of Figure 2. The still neutral image should be prepared as a file for item 2 of Figure 2 and repeatedly encoded to be a streaming video transmitted to a network.



IEC 1470/03

**Figure 3 – The image of the grey steps defined in IEC 61146-1**

The received streaming video should be decoded and rendered by a viewer for the incoming streaming videos. The image data to be displayed should be captured at an output terminal.

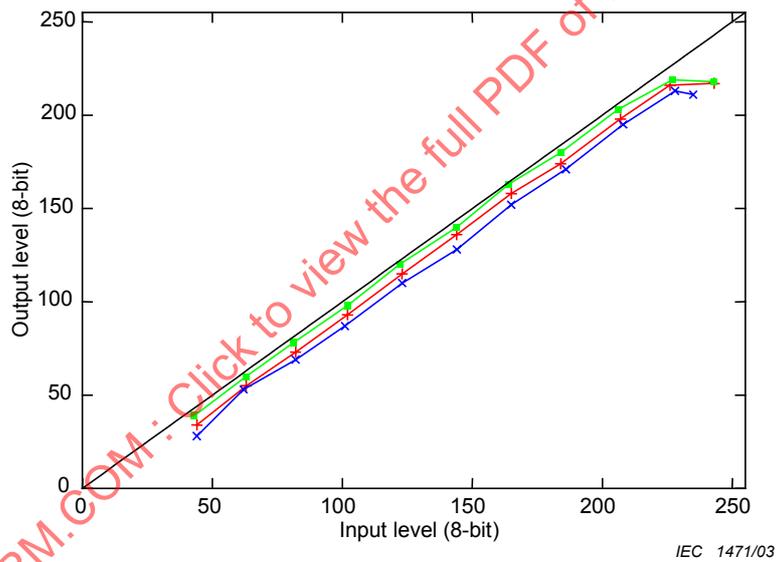
The image data should be compared in terms of three component data, R, G, and B, averaged in each of the corresponding areas.

### 5.2.3 Presentation of assessment result

The data for display versus the input image data should be reported as a table and a plot as shown in Table 1 and Figure 4, respectively, as examples, together with the audio-video communication system under assessment and the specification of the input-output point.

**Table 1 – An example of tone reproduction**

|    | Specification |      |      | Input |     |     | Output |     |     |
|----|---------------|------|------|-------|-----|-----|--------|-----|-----|
|    | R %           | G %  | B %  | R     | G   | B   | R      | G   | B   |
| 0  | 2,0           | 2,0  | 2,0  | 44    | 43  | 44  | 34     | 39  | 28  |
| 1  | 4,5           | 4,5  | 4,5  | 63    | 63  | 62  | 55     | 60  | 53  |
| 2  | 8,1           | 8,1  | 8,1  | 82    | 81  | 82  | 73     | 78  | 69  |
| 3  | 13,0          | 13,0 | 13,0 | 102   | 102 | 101 | 93     | 98  | 87  |
| 4  | 19,8          | 19,8 | 19,8 | 123   | 122 | 123 | 115    | 120 | 110 |
| 5  | 27,9          | 27,9 | 27,9 | 144   | 144 | 144 | 136    | 140 | 128 |
| 6  | 37,8          | 37,8 | 37,8 | 165   | 164 | 165 | 158    | 163 | 152 |
| 7  | 48,6          | 48,6 | 48,6 | 184   | 184 | 186 | 174    | 180 | 171 |
| 8  | 63,0          | 63,0 | 63,0 | 207   | 206 | 208 | 198    | 203 | 195 |
| 9  | 77,3          | 77,3 | 77,3 | 226   | 227 | 228 | 216    | 219 | 213 |
| 10 | 89,9          | 89,9 | 89,9 | 243   | 243 | 235 | 217    | 218 | 211 |



**Figure 4 – An example plot of tone reproduction**

### 5.3 End-to-end colour reproduction

#### 5.3.1 Item to be assessed

End-to-end colour shifts in the CIELAB colour space for a still colour image.

#### 5.3.2 Method of assessment

An image of the colour reproduction chart defined in IEC 61146-1, as shown in Figure 5, should be used as the reference source for item 1 of Figure 2. The still colour image should be prepared as a file for item 2 of Figure 2 and repeatedly encoded to be a streaming video transmitted to a network.



IEC 1472/03

**Figure 5 – The image of the colour reproduction chart defined in IEC 61146-1**

The received streaming video should be decoded and rendered by a viewer for streaming videos. The colour image data to be displayed should be captured at an output terminal.

The image data should be acquired in terms of three component data, R, G and B, averaged in each of the corresponding areas.

#### 5.3.3 Presentation of assessment result

Input colours and output colours in R, G and B data should be regarded to be in sRGB defined in IEC 61966-2-1. They should be converted to CIE 1976 L\*a\*b\* uniform colour space. Colour differences  $\Delta E_{ab}^*$  between the reference data and the received data should be calculated and reported as shown in Table 2.

**Table 2 – An example of colour reproduction**

|    | Specification |        |        | Input (8-bit x 3) |     |     | Output (8-bit x 3) |     |     | Colour difference<br>$\Delta E_{ab}^*$ |
|----|---------------|--------|--------|-------------------|-----|-----|--------------------|-----|-----|--|
|    | R %           | G %    | B %    | R                 | G   | B   | R                  | G   | B   |  |
| 0  | 87,053        | 80,546 | 87,216 | 222               | 205 | 222 | 221                | 211 | 215 | 3,5                                    |
| 1  | 48,904        | 24,181 | 23,419 | 184               | 134 | 132 | 186                | 135 | 129 | 1,4                                    |
| 2  | 37,405        | 27,352 | 12,466 | 163               | 141 | 99  | 164                | 144 | 91  | 4,2                                    |
| 3  | 25,874        | 32,782 | 5,646  | 138               | 154 | 69  | 139                | 156 | 66  | 2,0                                    |
| 4  | 12,176        | 34,717 | 19,279 | 98                | 158 | 121 | 96                 | 158 | 123 | 0,9                                    |
| 5  | 15,414        | 34,081 | 41,443 | 109               | 156 | 171 | 109                | 158 | 166 | 2,2                                    |
| 6  | 17,982        | 29,222 | 61,449 | 117               | 146 | 204 | 119                | 145 | 196 | 1,9                                    |
| 7  | 36,893        | 24,007 | 52,231 | 164               | 130 | 190 | 163                | 137 | 187 | 3,9                                    |
| 8  | 51,332        | 22,896 | 45,507 | 188               | 130 | 178 | 187                | 132 | 162 | 5,3                                    |
| 9  | 43,311        | 3,062  | 4,885  | 174               | 52  | 65  | 172                | 56  | 54  | 8,1                                    |
| 10 | 83,988        | 56,759 | 4,964  | 236               | 197 | 65  | 219                | 201 | 62  | 4,7                                    |
| 11 | 2,426         | 25,943 | 13,965 | 47                | 138 | 104 | 45                 | 140 | 105 | 1,2                                    |
| 12 | 3,259         | 7,178  | 18,424 | 54                | 77  | 118 | 50                 | 77  | 113 | 2,7                                    |
| 13 | 82,033        | 49,052 | 37,190 | 233               | 184 | 163 | 219                | 186 | 157 | 3,7                                    |
| 14 | 10,356        | 12,908 | 4,612  | 91                | 101 | 63  | 89                 | 100 | 53  | 5,2                                    |

$$\overline{\Delta E_{ab}^*} = 3,396$$

## 5.4 End-to-end colour differences

### 5.4.1 Item to be assessed

The average of colour differences in the psychophysically uniform colour space defined in CIE 15.2 between the reference video frame and the corresponding deteriorated video frame.

### 5.4.2 Method of assessment

Reference videos in Table A.1 are used as item 1 of Figure 2. Frame size reduced videos in uncompressed AVI-format should be prepared for item 2 of Figure 2. It is necessary to embed frame numbers at this point so that they can be used to identify received frames corresponding to the transmitted frames.

Encoded and transmitted streaming videos shall be continuously captured. Pixel-by-pixel calculations should be conducted.

The average colour difference  $\overline{\Delta E_{ab_k}^*}$  in the psychophysically uniform colour space between the reference and the deteriorated frames  $k$  is defined as in equation (1).

$$\overline{\Delta E_{ab_k}^*} = \frac{1}{K} \sum_{m=M_1}^{M_2} \sum_{n=N_1}^{N_2} \Delta E_{ab_k}^* \tag{1}$$

where

$$K = \frac{1}{(M_2 - M_1 + 1)(N_2 - N_1 + 1)};$$

$L_{o_k}^*$ ,  $a_{o_k}^*$  and  $b_{o_k}^*$

are the triplets in the CIELAB colour space corresponding to each pixel of the reference video frame  $k$ ;

$L_{d_k}^*$ ,  $a_{d_k}^*$  and  $b_{d_k}^*$

are the triplet in the CIELAB colour space corresponding to each pixel of the deteriorated video frame  $k$ ;

$$\Delta E_{ab_k}^* = \sqrt{(L_{d_k}^* - L_{o_k}^*)^2 + (a_{d_k}^* - a_{o_k}^*)^2 + (b_{d_k}^* - b_{o_k}^*)^2}$$

is the CIELAB colour difference between the pixels.

The triplets in the CIELAB colour space should be deduced from the pixel values  $R$ ,  $G$  and  $B$  of the reference and the deteriorated video frames in the default RGB colour space (sRGB) defined in IEC 61966-2-1. Each pixel is positioned at row  $m$  and column  $n$  in a video frame.

#### 5.4.3 Presentation of assessment results

The colour difference between each of the corresponding frames should be plotted versus frame numbers as shown in Figure 6 together with identifications of reference video sources. The conditions of measurement such as frame size in pixels, frame rate, streaming bit-rate should also be reported.

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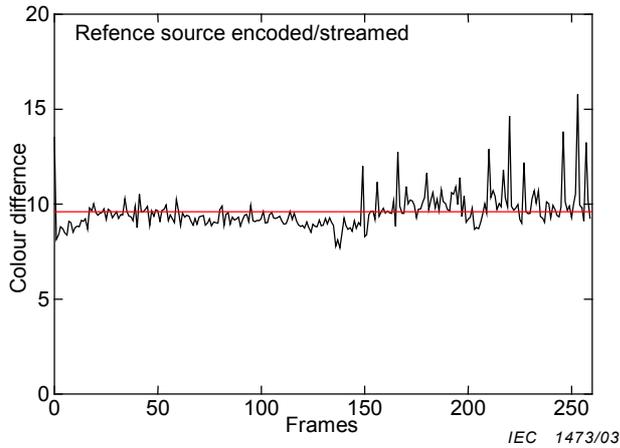


Figure 6a – Example for SRC13\_REF\_\_525

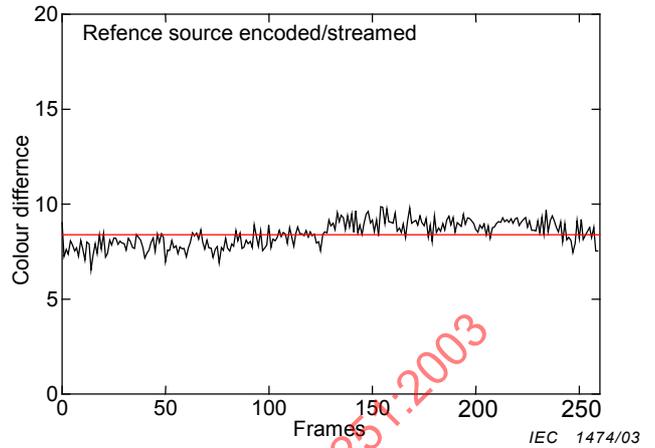


Figure 6b – Example for SRC14\_REF\_\_525

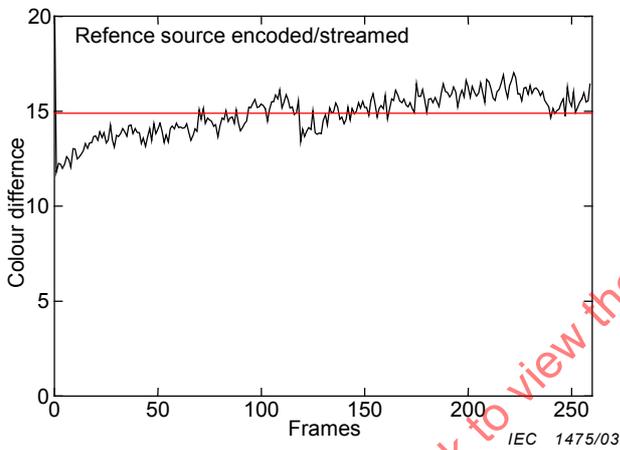


Figure 6c – Example for SRC15\_REF\_\_525

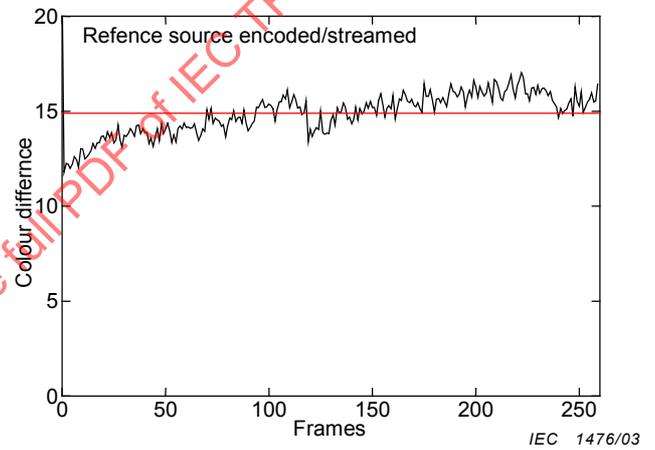


Figure 6d – Example for SRC16\_REF\_\_525

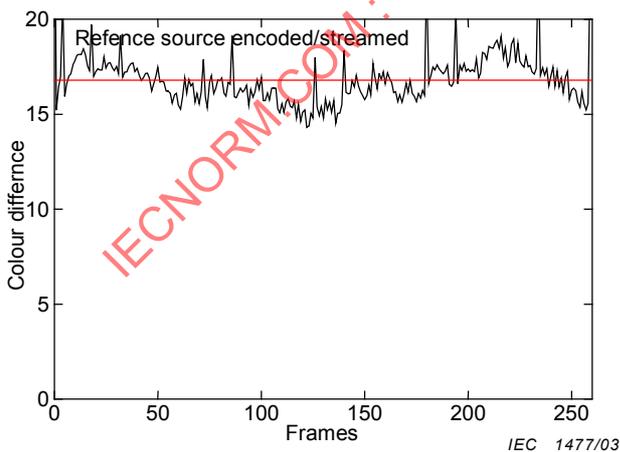


Figure 6e – Example for SRC17\_REF\_\_525

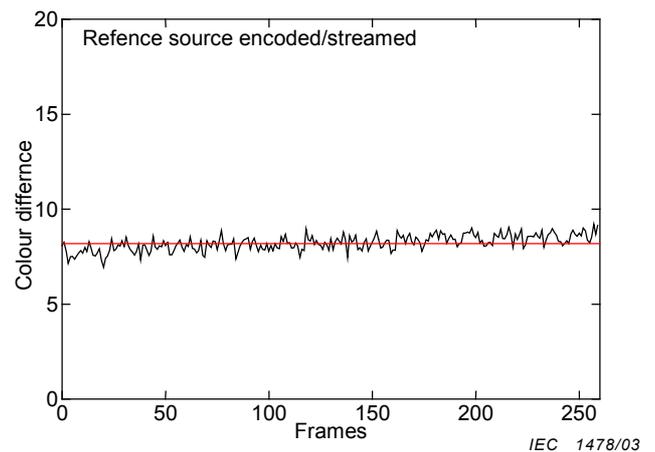


Figure 6f – Example for SRC18\_REF\_\_525

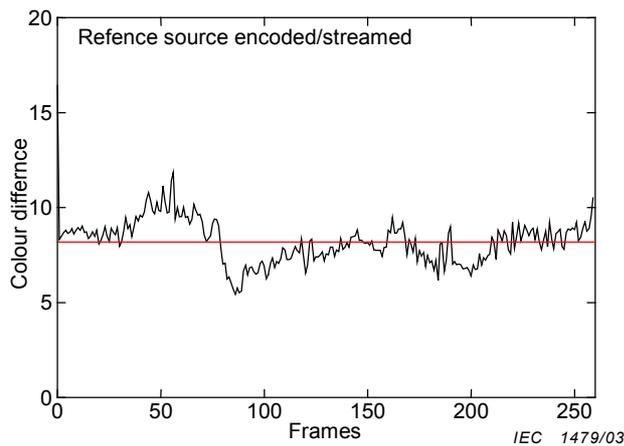


Figure 6g – Example for SRC19\_REF\_\_525

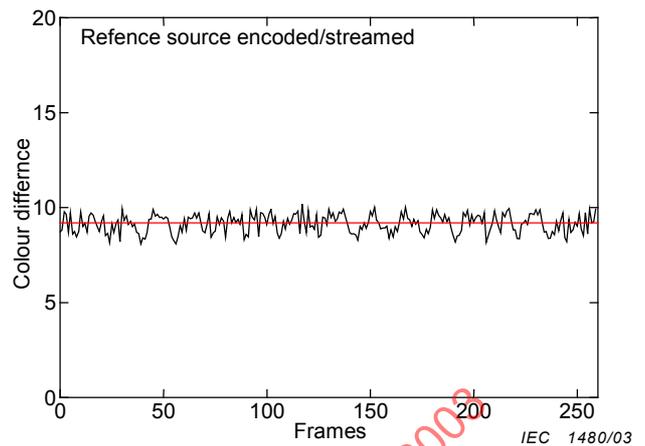


Figure 6h – Example for SRC20\_REF\_\_525

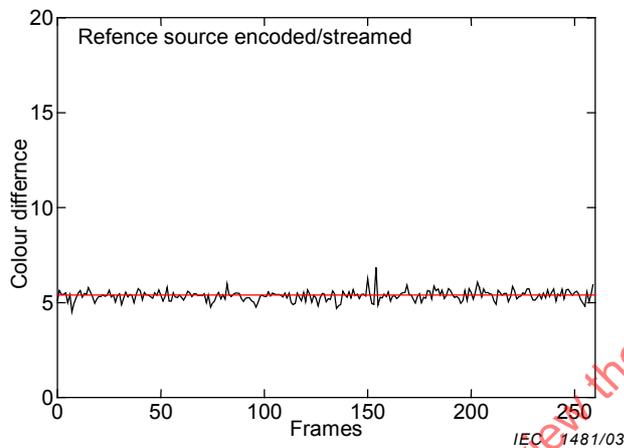


Figure 6i – Example for SRC21\_REF\_\_525

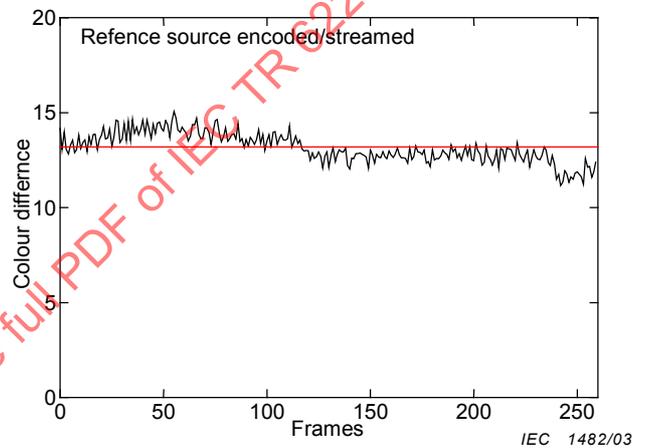


Figure 6j – Example for SRC22\_REF\_\_525

Condition of assessment:

video frame size: 320 pixels x 240 pixels

frame rate: 30 s<sup>-1</sup>

streaming bit-rate: 250 kb s<sup>-1</sup>

network bandwidth: more than 250 kb s<sup>-1</sup>

reproduction: Microsoft Media Player® version 7.1

**Figure 6 – Colour differences between reference and streamed video frames at 250 kbs<sup>-1</sup> and 30 s<sup>-1</sup>**

As a summary of the assessment, acquired data should also be averaged over frames as in equation (2) so as to provide the single metric for objective assessment as the grand average. It should be reported as in Table 3.

$$\overline{\Delta E_{ab}^*} = \frac{1}{(K_2 - K_1 + 1)} \sum_{k=K_1}^{K_2} \Delta E_{ab_k}^* \quad (2)$$

**Table 3 – Grand averages of colour differences**

| Reference video source | Grand average of colour difference |
|------------------------|------------------------------------|
| SRC13_REF__525         | 9,6                                |
| SRC14_REF__525         | 8,4                                |
| SRC15_REF__525         | 14,9                               |
| SRC16_REF__525         | 8,3                                |
| SRC17_REF__525         | 16,8                               |
| SRC18_REF__525         | 8,2                                |
| SRC19_REF__525         | 8,2                                |
| SRC20_REF__525         | 9,2                                |
| SRC21_REF__525         | 5,4                                |
| SRC22_REF__525         | 13,2                               |

**5.5 End-to-end peak-signal to noise ratio (PSNR)**

**5.5.1 Item to be assessed**

Peak-signal to noise power ratios, PSNRs, in three-dimensional coordinate systems.

**5.5.2 Method of assessment**

Reference videos in Table A.1 are used as item 1 of Figure 2. Frame size reduced videos in uncompressed AVI-format should be prepared for item 2 of Figure 2. It is necessary to embed frame numbers at this point so that they can be used to identify received frames corresponding to the transmitted frames.

Encoded and transmitted streaming videos shall be continuously captured. Pixel-by-pixel calculation should be conducted.

The peak-signal to noise ratio (PSNR) between a full reference image and a reproduced image recommended in ITU-T J.144 should be used. It defined the PSNR by the following equation (3).

$$PSNR = 10 \lg \left( \frac{S_{\max}^2}{MSE} \right) \tag{3}$$

$$MSE = \frac{1}{K} \sum_{p=P_1}^{P_2} \sum_{m=M_1}^{M_2} \sum_{n=N_1}^{N_2} (d(p, m, n) - o(p, m, n))^2$$

where

$$K = \frac{1}{(P_2 - P_1 + 1)(M_2 - M_1 + 1)(N_2 - N_1 + 1)} ;$$

$d(p, m, n)$  and  $o(p, m, n)$

represent, respectively, degraded and original pixel vectors at frame  $p$ , row  $m$  and column  $n$  ;

$S_{\max}$

is the maximum possible value of the pixel vectors.

For colour images, each picture element is normally composed of three dimensional values, red (R), green (G) and blue (B). Thus, the definition in equation (4) applies for the mean-square errors.

$$MSE_{\text{RGB}} = \frac{1}{K} \sum_{p=P_1}^{P_2} \sum_{m=M_1}^{M_2} \sum_{n=N_1}^{N_2} \left( (R_d - R_o)^2 + (G_d - G_o)^2 + (B_d - B_o)^2 \right) \quad (4)$$

where  $S_{\text{max(}(\text{RGB})} = 3 \times 2^{2(N-1)}$  for the values in  $N$ -bit encoding.

It is recommended to evaluate the PSNR in the more uniform colour space, CIE 1976 LAB, as in equation (5).

$$MSE_{\text{Lab}} = \frac{1}{K} \sum_{p=P_1}^{P_2} \sum_{m=M_1}^{M_2} \sum_{n=N_1}^{N_2} \left( \Delta E_{ab}^* \right)^2 \quad (5)$$

where  $S_{\text{max(Lab)}} = \sqrt{(L_{\text{max}}^*)^2 + (a_{\text{max}}^*)^2 + (b_{\text{max}}^*)^2}$ , actual value of which depends on a colour gamut of original RGB colour space.

It is recommended to use the default RGB colour space defined by IEC 61966-2-1, in which  $S_{\text{max(Lab)}} = 148,254$ .

NOTE It should be noted that the terms for summation in equation (5) are the square of the colour differences in the psychophysically uniform colour space described in 5.4.

Additionally, luminance signal  $Y$  and two colour difference signals  $C_b$  and  $C_r$  denoted as Ycc will also be calculated for comparison as in equation (6).

$$MSE_{\text{Ycc}} = \frac{1}{K} \sum_{p=P_1}^{P_2} \sum_{m=M_1}^{M_2} \sum_{n=N_1}^{N_2} \left( (Y_d - Y_o)^2 + (C_{b_d} - C_{b_o})^2 + (C_{r_d} - C_{r_o})^2 \right) \quad (6)$$

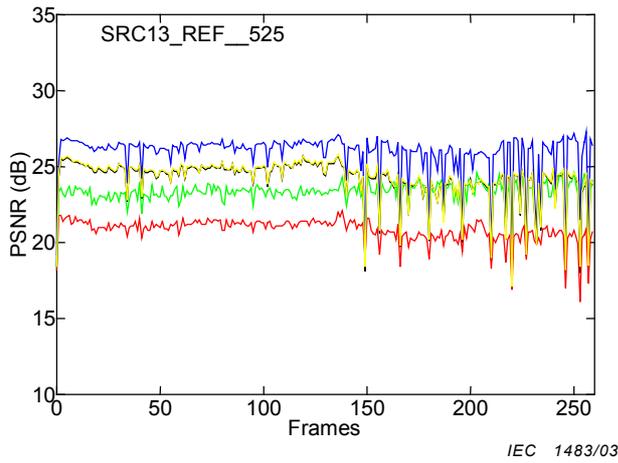
where  $S_{\text{max(Ycc)}} = 1,01659$  in YCbCr system defined in IEC 61966-2-1, Amendment 1.

### 5.5.3 Presentation of assessment results

The PSNRs in three-dimensional spaces Lab, Ycc and RGB together with one-dimensional PSNRs in  $L^*$  and  $Y$  should be reported as shown in Figure 7.

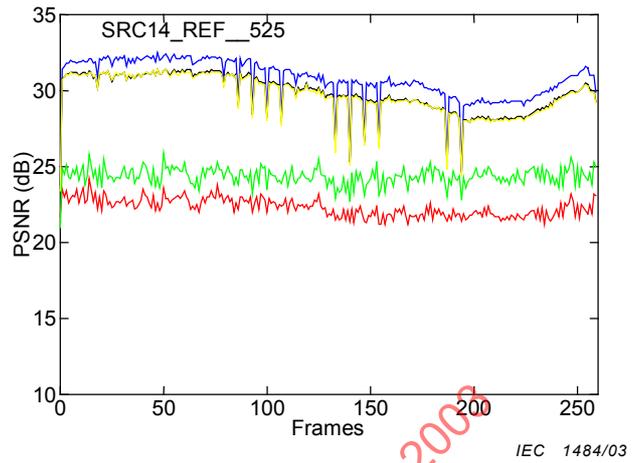
The conditions of measurement such as frame size in pixels, frame rate, streaming bit-rate should also be reported.

NOTE In order to demonstrate software developed by Chiba University in collaboration with Mitsubishi Electric Corp. for various quality metrics regarding the known hypothetical deterioration used in the Video Quality Expert Group (VQEG) in terms of three-dimensional PSNRs and one-dimensional PSNRs together with the average colour difference are attached in Annex A for information.



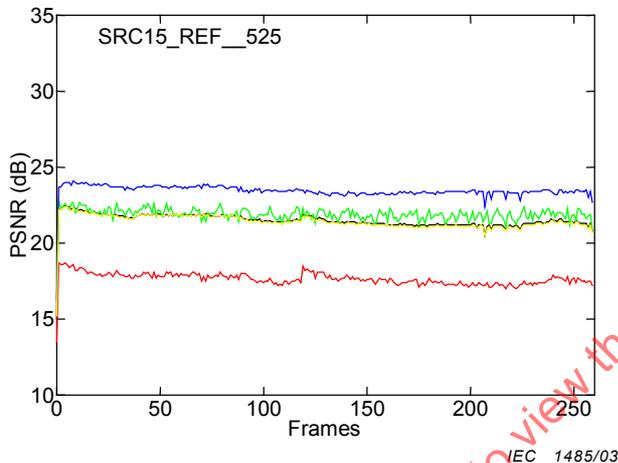
IEC 1483/03

Figure 7a – SRC13\_REF\_525



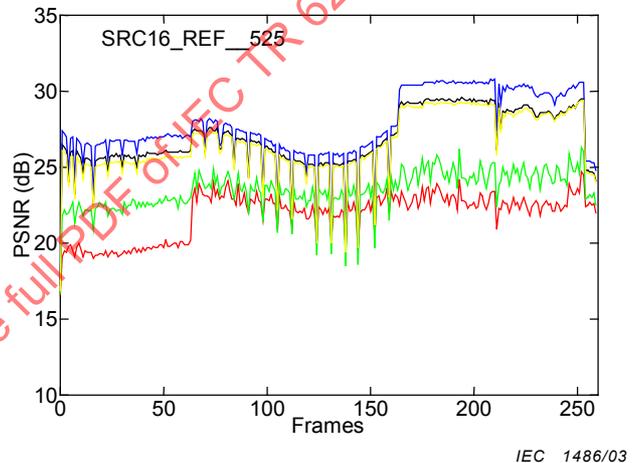
IEC 1484/03

Figure 7b – SRC14\_REF\_525



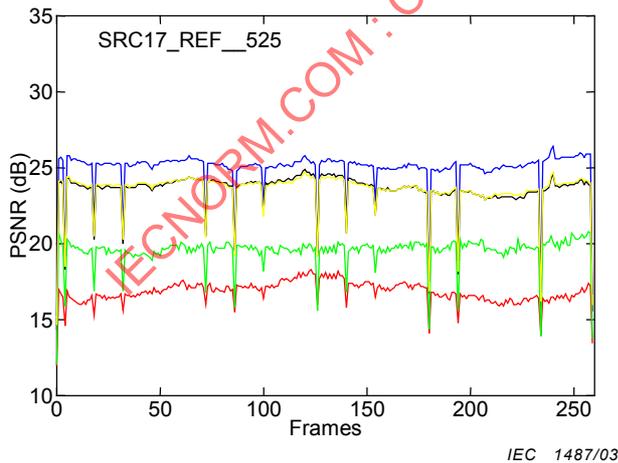
IEC 1485/03

Figure 7c – SRC15\_REF\_525



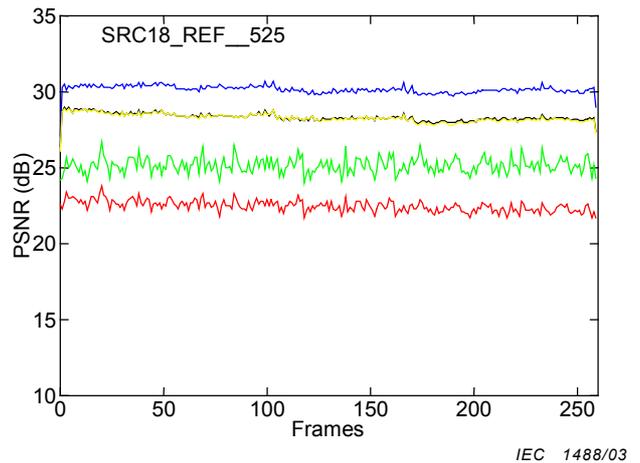
IEC 1486/03

Figure 7d – SRC16\_REF\_525



IEC 1487/03

Figure 7e – SRC17\_REF\_525



IEC 1488/03

Figure 7f – SRC18\_REF\_525

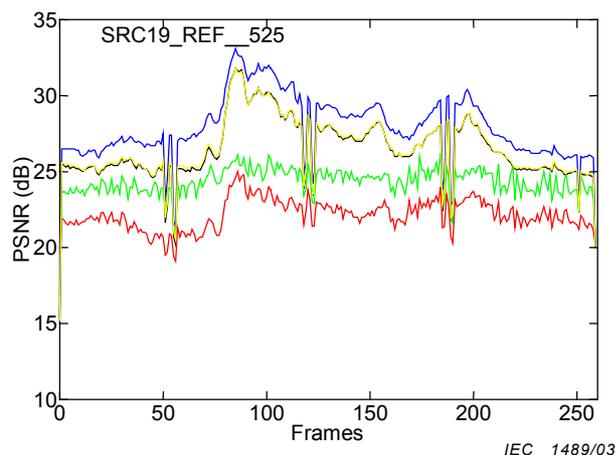


Figure 7g – SRC19\_REF\_\_525

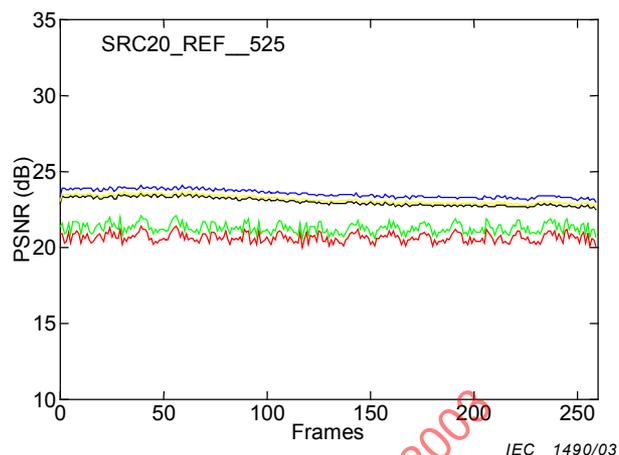


Figure 7h – SRC20\_REF\_\_525

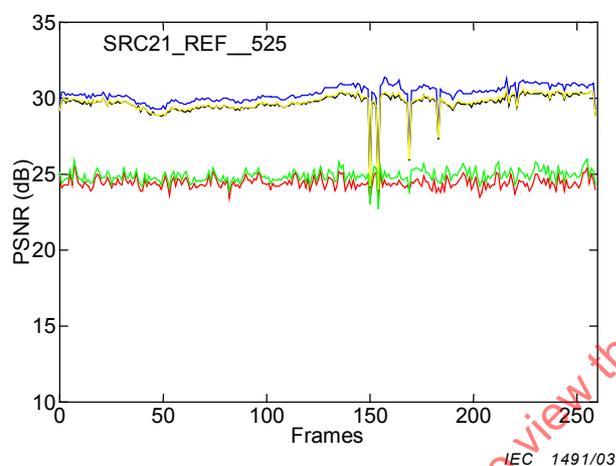


Figure 7i – SRC21\_REF\_\_525

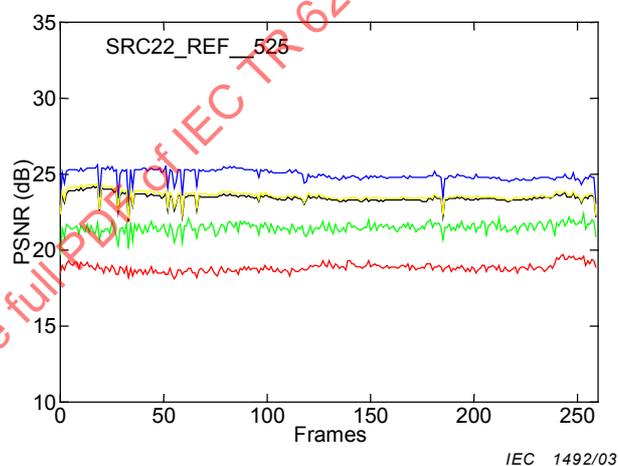


Figure 7j – SRC22\_REF\_\_525

Condition of assessment:

video frame size: 320 pixels x 240 pixels

frame rate: 30 s<sup>-1</sup>

streaming bit-rate: 250 kbs<sup>-1</sup>

network bandwidth: more than 250 kbs<sup>-1</sup>

reproduction: Microsoft Media Player® version 7.1

### Figure 7 – Examples of PSNR assessment

As a summary of the assessment, the PSNRs should also be averaged over frames so as to provide the overall metrics for objective assessment as in equation (7). It should be reported as in Table 4.

$$\overline{PSNR} = \frac{1}{(K_2 - K_1 + 1)} \sum_{k=K_1}^{K_2} PSNR_k \quad (7)$$

**Table 4 – Overall PNSRs averaged over the frames**

| Reference identification | RSNR in CIELAB | RSNR in YCC | RSNR in RGB | RSNR in L* | RSNR in Y |
|--------------------------|----------------|-------------|-------------|------------|-----------|
| SRC13_REF_525            | 20,9           | 24,4        | 24,4        | 23,3       | 26,1      |
| SRC14_REF_525            | 22,3           | 29,9        | 30,0        | 24,4       | 30,9      |
| SRC15_REF_525            | 17,7           | 21,5        | 21,5        | 21,9       | 23,5      |
| SRC16_REF_525            | 22,1           | 27,0        | 27,2        | 23,7       | 28,2      |
| SRC17_REF_525            | 16,9           | 23,7        | 23,7        | 19,6       | 25,1      |
| SRC18_REF_525            | 22,5           | 28,3        | 28,3        | 25,2       | 30,2      |
| SRC19_REF_525            | 22,3           | 27,0        | 27,0        | 24,4       | 28,4      |
| SRC20_REF_525            | 20,7           | 23,2        | 23,0        | 21,3       | 23,6      |
| SRC21_REF_525            | 24,4           | 29,8        | 29,7        | 24,9       | 30,3      |
| SRC22_REF_525            | 18,8           | 23,6        | 23,5        | 21,5       | 24,9      |

## 5.6 End-to-end objective assessment of video quality

### 5.6.1 Item to be assessed

Estimation of subjective Difference Mean Opinion Scores (DMOS) using a model emulating human visual and perceptual characteristics for digital videos.

### 5.6.2 Method of assessment

For this purpose, the VQEG in its phase 1 test studied the proposed models from ten proponents (actually 9 out of 10 were considered effective) as reported in the document ITU-R 10-11Q/56-E. They are summarized as follows:

- a) image evaluation based on segmentation that provides quality prediction over a set of predefined scenes;
- b) visual discrimination model that simulates the responses of human spatiotemporal visual mechanisms;
- c) a model to emulate human-visual characteristics using spatiotemporal 3-dimensional filters;
- d) Mean Square Error (MSE) weighted by human visual filters such as pixel-based, block-based and sequence-based filters;
- e) perceptual distortion metric based on a spatiotemporal model of the human visual system;
- f) a model composed of a perceptual model and a feature extractor specifically tuned to certain type of distortions;
- g) digital video quality incorporating many aspects of human visual sensitivity in a simple image processing;
- h) perceptual video quality measure using the same approach in measuring video quality as the perceptual speech quality measure in measuring speech quality;
- i) a model using reduced bandwidth features extracted from spatial-temporal regions and linear combination of parameters to estimate the subjective quality rating.

Performance of all the models was tested in terms of feature extraction capability against the conventional peaksignal-to-noise ratio method.

The VQEG is under the phase 2 test for full reference television among new proponents. A feasible method of assessment (model) is still under consideration.

NOTE "A new method" was submitted by the Republic of Korea that incorporates spatiotemporal wavelet transform as described in ITU-R 6Q/42-E. In this Technical Report, it was examined in the sRGB domain as shown in Annex B.

### 5.6.3 Presentation of assessment results

Video quality rating as an estimation of difference mean opinion scores should be reported together with the model used and the conditions.

NOTE An example of the presentation is under consideration.

## 6 Audio quality

### 6.1 Perceived audio quality with full reference signals

#### 6.1.1 Item to be assessed

Objective Difference Grade (ODG) values, measured by PEAQ (Perceived Evaluation of Audio Quality) method recommended in ITU-R BS.1387-1.

#### 6.1.2 Justification

Perceived audio quality (PEAQ) is one of the key factors when designing digital audio-video communication systems. Formal listening tests have been the relevant method for judging audio quality. However, subjective quality assessments are both time consuming and expensive. It was desirable to develop an objective measurement method in order to produce an estimate of the audio quality. Traditional objective measurement methods, like signal-to-noise-ratio (SNR) or total-harmonic-distortion (THD) have never really been shown to relate reliably to the perceived audio quality. The problems become even more evident when the methods are applied modern codecs, which are both non-linear and non-stationary. After thorough verification, ITU-R recommends an objective measurement method, known as PEAQ (Perceived Evaluation of Audio Quality), to estimate the perceived audio quality of equipment under test, for example a low bit-rate codec. This method is specified in ITU-R BS.1387-1 and described briefly in Annex B.

The output variable from the PEAQ objective measurement method is the objective difference grade (ODG) and distortion index (DI). The ODG corresponds to the subjective difference grade (SDG) in the subjective domain. The resolution of the ODG is limited to one decimal. One should however be cautious and not generally expect that a difference between any pair of ODGs of a tenth of a grade is significant. The DI has the same meaning as the ODG. However, DI and ODG can only be compared quantitatively but not qualitatively. As a general rule, the ODG should be used as the quality measure for ODG values greater than approximately  $-3,6$ . The ODG correlates very well with subjective assessment in this range. When ODG value is less than  $-3,6$ , the DI should be used. Therefore, both ODG or DI variables shall be measured.

#### 6.1.3 Method of assessment and algorithm of PEAQ

The basic concept for the PEAQ objective measurement method is illustrated in Figure 8. It consists of two inputs, one for the (unprocessed) reference audio signal, corresponding to item 2 of Figure 2, and the other for the audio signal under the test. The latter may, for example, be the output signal of digital audio-video communication systems, corresponding to the output of item 4 of Figure 2, that is stimulated by the reference signal.

This measurement method is applicable to most types of audio signal processing equipment, both digital and analogue. It is, however, applied by focusing on digital audio communication channels in this document. The block “device under test” corresponds to items 2 and 3 of Figure 2.

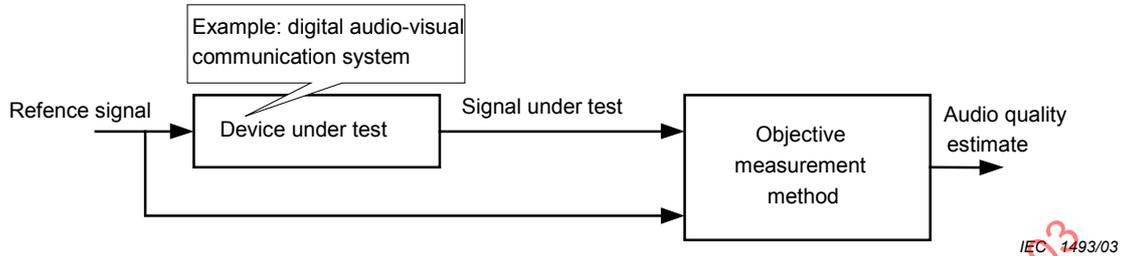


Figure 8 – Basic concept for making objective measurements

A representation of the PEAQ model is shown in Figure 9. The PEAQ method is based on generally accepted psychoacoustic principles. In general, it compares a signal that has been processed in some way with the corresponding time-aligned reference signal. In the first step of signal processing, the peripheral ear is modelled as known as “perceptual model”, or “ear model.” Concurrent frames of the reference and the processed signals are each transformed to the outputs of ear models. In a consecutive step, algorithm models the audible distortion present in the signal under test by comparing the outputs of the ear models. The information obtained by these processes results in several values, so called MOVs (model output variables) and may be useful for detailed analysis of the signal.

The final goal is to drive a quality metric, consisting of a single number that indicates the audibility of the distortions present in the signal under test. In order to archive this, some further processing of the MOVs is required which simulates the cognitive part of the human auditory system. Therefore, the PEAQ algorithm incorporates an artificial neural network.

There are two versions of the PEAQ; a “Basic” version, featuring a low complexity approach, and an “Advanced” version for higher accuracy at the trade off of higher complexity. The structure of both versions is very similar, and fits exactly into the PEAQ model shown in figure 9. The major difference between the basic and the advanced version is hidden in the respective ear models and the set of MOVs used. Annex C provides more information about PEAQ, which helps readers to understand the measurement results.

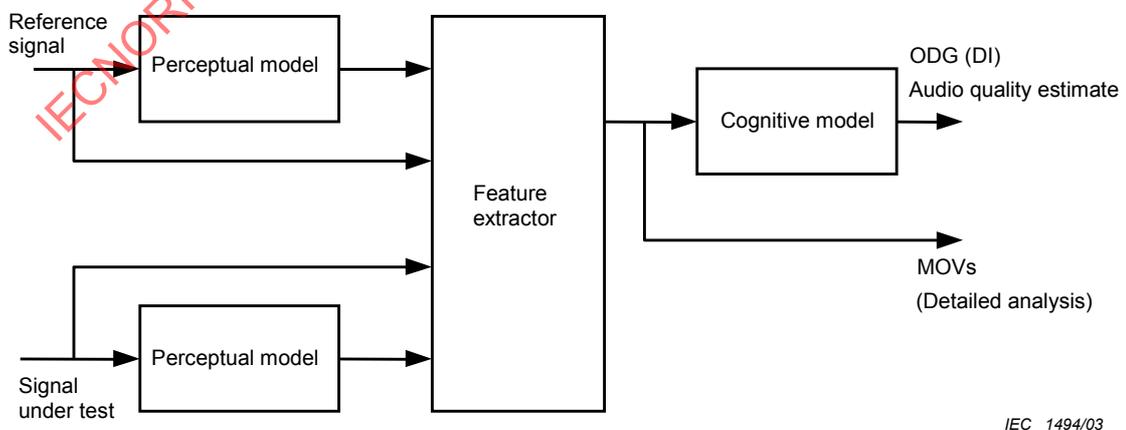


Figure 9 – Representation of the PEAQ model

It is recommended to use the reference items available from the ITU as WAV-files (Microsoft RIFF format) on a CD-ROM. All reference items have been sampled at 48 kHz in 16-bit PCM. The reference and test signals provided by the ITU have already been time and level adapted to each other, so that no additional gain or delay compensation is required.

The measurement algorithm must be adjusted to a listening level of 92 dB SPL.

#### 6.1.4 Presentation of assessment results

PEAQ measurement results should be reported in terms of the names of the reference and signal under test items<sup>2</sup>, and the resulting DI and ODG values in a table.

Table 5 is related to the basic version, and Table 6 contains the values for the advanced version.

**Table 5 – Test items and resulting DI and ODG values for the basic version**

| Item        | DI    | ODG    | Item        | DI     | ODG    | Item        | DI     | ODG    |
|-------------|-------|--------|-------------|--------|--------|-------------|--------|--------|
| Acodsna.wav | 1,304 | -0,676 | Fcodtr2.wav | -0,045 | -1,927 | lcodhrp.wav | 1,041  | -0,876 |
| Bcodtri.wav | 1,949 | -0,304 | fcodtr3.wav | -0,715 | -2,601 | lcodpip.wav | 1,973  | -0,293 |
| Ccodsax.wav | 0,048 | -1,829 | gcodcla.wav | 1,781  | -0,386 | mcodcla.wav | -0,436 | -2,331 |
| Dcodryc.wav | 1,648 | -0,458 | hcodryc.wav | 2,291  | -0,166 | ncodsfe.wav | 3,135  | 0,045  |
| Ecodsmg.wav | 1,731 | -0,412 | Hcodstr.wav | 2,403  | -0,128 | scodclv.wav | 1,689  | -0,435 |
| Fcodsb1.wav | 0,677 | -1,195 | lcodsna.wav | -3,029 | -3,786 |             |        |        |
| Fcodtr1.wav | 1,419 | -0,598 | kcodsme.wav | 3,093  | 0,038  |             |        |        |

**Table 6 – Test items and resulting DI and ODG values for the advanced version**

| Item        | DI    | ODG    | Item        | DI     | ODG    | Item        | DI    | ODG    |
|-------------|-------|--------|-------------|--------|--------|-------------|-------|--------|
| Acodsna.wav | 1,632 | -0,467 | Fcodtr2.wav | 0,162  | -1,711 | Lcodhrp.wav | 1,538 | -0,523 |
| Bcodtri.wav | 2,000 | -0,281 | Fcodtr3.wav | -0,783 | -2,662 | Lcodpip.wav | 2,149 | -0,219 |
| Ccodsax.wav | 0,567 | -1,300 | Gcodcla.wav | 1,457  | -0,573 | Mcodcla.wav | 0,430 | -1,435 |
| Dcodryc.wav | 1,725 | -0,415 | Hcodryc.wav | 2,410  | -0,126 | Ncodsfe.wav | 3,163 | 0,050  |
| Ecodsmg.wav | 1,594 | -0,489 | Hcodstr.wav | 2,232  | -0,187 | Scodclv.wav | 1,972 | -0,293 |
| Fcodsb1.wav | 1,039 | -0,877 | lcodsna.wav | -2,510 | -3,664 |             |       |        |
| Fcodtr1.wav | 1,555 | -0,512 | Kcodsme.wav | 2,765  | -0,029 |             |       |        |

## 6.2 Sampling rate and quantization resolution

### 6.2.1 Item to be assessed

Sampling rate and bandwidth of the reference and the processed audio signals.

### 6.2.2 Method of assessment

Sampling rate is relevant to the bandwidth of audio signals. For high-quality audio signals, the sampling rate 48 kHz is used. The sampling rate and bandwidth of the reference and processed audio signals should be extracted.

<sup>2</sup> The names of the corresponding reference items are derived by replacing the substring “cod” in the names of the test items by “ref”, e.g. the reference item for “bcodtri.wav” is “breftri.wav”.

Resolution of quantization relates to the dynamic range of audio signals or quantization noise. For high-quality audio signals, the linear (or uniform) quantization method, which have 16-bit quantization resolution, are used. The resolution and quantization method should be identified.

### 6.2.3 Presentation of assessment results

Extracted and identified values should be reported.

## 6.3 Delay

### 6.3.1 Item to be assessed

Delay time in seconds from audio inputs to an encoder and received digital audio signals.

### 6.3.2 Method of assessment

Pulsed audio signals should be used as input in terms of item 2 of Figure 2. Lap time between the input of item 3 and the output of item 4 of Figure 2 should be measured in seconds.

NOTE In most audio communication systems over the digital networks, a buffering scheme is incorporated. Therefore, buffering time is also taken into account in the measurement.

### 6.3.3 Presentation of assessment result

The measured delay time should be reported in seconds.

## 7 Total quality

### 7.1 Synchronization of audio and video (lip sync)

#### 7.1.1 Item to be assessed

Temporal synchronization between audio and video channels.

#### 7.1.2 Method of assessment

The raison d'être of true multimedia systems, in contrast to a mere collection of unrelated media channels, is the ability to keep temporal synchronization among different channels. It is therefore vitally important to include a temporal synchronization quality measurement in the quality assessment items of audio-video communication systems.

The framework for measurement of temporal synchronization among media channels is given in ITU-T Recommendation P.931. Its basic assumption is that media signal can be captured at such interfaces as the camera output and the display input for the visual channel and the microphone output and the loudspeaker input for the audio channel. This assumption is shown in Figure 1.

Media signals at those interfaces are digitized, if necessary, broken into fixed sized frames, and given timestamps. For the details of this procedure, refer to ITU-T Recommendation P.931.

The audio and the video media streams being considered, digitized frames of these media streams are given sequence numbers as follows:

- $A(m)$  and  $V(n)$  are the input audio and the video frames, respectively ( $m$  and  $n$  are the sequence numbers for each stream). It is assumed that they are associated in the sense that they correspond to the same event.

- $A'(p)$  and  $V'(q)$  are the output audio and the video frames, respectively.
- $T_A(m)$  and  $T'_A(n)$  are the timestamps for  $A(m)$  and  $A'(n)$ , respectively. Timestamps for other frames are defined in the same way.

For each input frame, however not all the input frames are to be used as described in ITU-T P.931, the corresponding output frame is to be found. Since the media stream data is modified, distorted, dropped and reshaped, the matching process is non-trivial. For video frames, the method which utilizes the metrics of PSNRs assessed in Clause 5 will be used. For audio frames, a two-stage process, which employs the audio envelopes for a coarse stage and the power spectral densities for a fine stage, will be used. For details, refer to ITU-T P.931.

It is assumed here that the matching relationships between  $A(m)$  and  $A'(p)$ ,  $A'(p)$ , and  $V'(n)$  and  $V'(q)$  are established. Under this assumption, the time skew between the audio and video frames is given by the following equation (8):

$$S_{AV}(p,q) = O'_{AV}(p,q) - O_{AV}(m,n) \quad (8)$$

where  $Q_{AV}(m,n) = T_A(m) - T_V(n)$  and  $Q'_{AV}(p,q) = T'_A(p) - T'_V(q)$ .

NOTE 1 It is important to choose appropriate input audio signals to obtain a valid and meaningful assessment result. If the video signal contains still or almost-still scenes, the process for matching the input and the output frames will become difficult or even impossible. A similar caution is to be applied to the assessment of the audio channel.

NOTE 2 Modern video compression schemes give fluctuating compression, transmission (when variable bit-rate encoding is employed) and decompression times, depending on the input properties. Therefore, the appropriate input signals suited for the assumed application should be used for assessment.

NOTE 3 For systems with a low video frame rate, it is sometimes natural and desirable to have a larger temporal skew between the video and the audio streams, because the video delay fluctuates while the audio data generally flows isochronously.

Selection of standard audio-video input streams suited for common usage is left for future study.

### 7.1.3 Presentation of assessment results

The report from the measurement should be expressed so that any variation between individual measurement is clearly illustrated. Classical summary statistics (for example, minimum, maximum, average and standard deviation) may also be reported.

## 7.2 Scalability

### 7.2.1 Item to be assessed

Autonomous function to tune frame rate dynamically depending on available bandwidth between the sender and the receiver.

### 7.2.2 Method of assessment

The method for measurement of scalability is left for future study.

### 7.2.3 Presentation of assessment results

Under consideration.

### 7.3 Overall quality

#### 7.3.1 Item to be assessed

Overall quality factor in terms of audio and video interaction.

#### 7.3.2 Method of assessment

Overall quality of audio-video communication systems  $OQ_{AV}$  should be defined as in equation (9).

$$OQ_{AV} = aQ_V + bQ_A + cQ_{V\&A} \quad (9)$$

where  $Q_V$  is the objective quality metric assessed in clause 5,  $Q_A$  is the objective quality metric assessed in clause 6,  $Q_{V\&A}$  is the objective quality metric assessed in this clause; the coefficients  $a$ ,  $b$  and  $c$  are the weighting factors, which depend on actual applications of the audio-video communication system.

#### 7.3.3 Presentation of assessment results

The overall quality factor should be reported with sufficient information on the audio-video communication system under assessment.

## Annex A (informative)

### PSNRs defined in three-dimensional spaces applied to hypothetical deterioration over the reference video sources

#### A.1 Introduction

This annex is intended to demonstrate the definitions PSNRs in three-dimensional vector space for each pixel that consists of a frame of videos. The definition of PSNR in the CIELAB is given in equation (5), PSNR in sYCC in equation (6), PSNR in sRGB in equation (4). The average colour difference defined in equation (1) is also included in this annex for comparison together with one-dimensional PSNRs in  $L^*$  and  $Y$ .

The values of the objective quality measures will be easily compared with other possible future measures and the results of subjective assessment of video quality.

#### A.2 Test sources and hypothetical deterioration

In this annex, 16 known different hypothetical deteriorations over the digital video files prepared in ITU-R BT.601-5 format and used in the Video Quality Expert Group (VQEG) are indicated. The source videos are labelled from SRC13\_REF\_\_525.yuv to SRC22\_REF\_\_525.yuv as shown in table A.1. They are made use of by the permission of the VQEG.

Software for varieties of objective measures have been developed in Chiba University, Japan, in collaboration with Mitsubishi Electric Corp. The values have been obtained for reduced frame size of 320 x 240 pixels per frame over 260 frames. In other words  $P1=1$ ,  $P2=260$ ,  $M1=1$ ,  $M2=240$  and  $N1=1$ ,  $N2=320$  in equation (B.4). Numerical results are shown in Tables A.2 to A.6.

**Table A.1 – Reference video sources available for objective assessment**

| Designation    | Name              | Contents   |
|----------------|-------------------|--|
| SRC13_REF__525 | Balloon-pops      | Film, saturated colour, movement                     |
| SRC14_REF__525 | New York 2        | Masking effect, movement                             |
| SRC15_REF__525 | Mobile & Calendar | Colour, movement                                     |
| SRC16_REF__525 | Betes_pas_betes   | Colour, synthetic, movement, scene cut               |
| SRC17_REF__525 | Le_point          | Colour, transparency, movement in all the directions |
| SRC18_REF__525 | Autumn leaves     | Colour, landscape, zooming, water fall movement      |
| SRC19_REF__525 | Football          | Colour, movement                                     |
| SRC20_REF__525 | Sailboat          | Almost still   |
| SRC21_REF__525 | Susie             | Skin colour  |
| SRC22_REF__525 | Tempete           | Colour, movement                                     |

**Table A.2 – PSNRs in various colour spaces and the colour difference for SRC13 and SRC14**

|                    | Lab  | sYCC | sRGB | L*   | Y    | ΔE  |                    | Lab  | SYCC | sRGB | L*   | Y    | ΔE  |
|--------------------|------|------|------|------|------|-----|--------------------|------|------|------|------|------|-----|
| <b>hrc1/src13</b>  | 20,5 | 23,2 | 23,6 | 26,3 | 26,3 | 8,3 | <b>hrc1/src14</b>  | 22,4 | 25,8 | 25,9 | 26,6 | 28,1 | 7,5 |
| <b>hrc2/src13</b>  | 23,6 | 23,5 | 23,2 | 25,9 | 25,0 | 5,4 | <b>hrc2/src14</b>  | 25,7 | 24,3 | 24,5 | 25,4 | 24,3 | 4,9 |
| <b>hrc3/src13</b>  | 22,2 | 22,7 | 22,3 | 25,6 | 24,6 | 5,8 | <b>hrc3/src14</b>  | 24,9 | 23,8 | 24,0 | 25,1 | 24,1 | 4,7 |
| <b>hrc4/src13</b>  | 21,4 | 22,1 | 21,7 | 25,6 | 24,7 | 7,4 | <b>hrc4/src14</b>  | 24,6 | 23,9 | 24,0 | 25,4 | 24,3 | 5,5 |
| <b>hrc5/src13</b>  | 20,4 | 19,3 | 19,0 | 21,2 | 20,3 | 8,0 | <b>hrc5/src14</b>  | 22,5 | 19,7 | 20,0 | 20,7 | 19,6 | 5,9 |
| <b>hrc6/src13</b>  | 22,2 | 22,6 | 22,1 | 25,9 | 24,9 | 6,2 | <b>hrc6/src14</b>  | 24,5 | 23,6 | 23,8 | 25,3 | 24,1 | 5,0 |
| <b>hrc7/src13</b>  | 22,2 | 21,1 | 20,7 | 23,0 | 22,1 | 5,9 | <b>hrc7/src14</b>  | 24,5 | 21,5 | 21,7 | 22,5 | 21,4 | 4,1 |
| <b>hrc8/src13</b>  | 21,9 | 22,3 | 21,9 | 25,3 | 24,5 | 6,7 | <b>hrc8/src14</b>  | 24,3 | 23,5 | 23,7 | 24,9 | 24,0 | 5,3 |
| <b>hrc9/src13</b>  | 21,6 | 20,6 | 20,3 | 22,8 | 21,8 | 6,9 | <b>hrc9/src14</b>  | 24,3 | 21,4 | 21,7 | 22,4 | 21,4 | 4,5 |
| <b>hrc10/src13</b> | 22,1 | 20,9 | 20,6 | 23,0 | 22,0 | 6,3 | <b>Hrc10/src14</b> | 24,3 | 21,4 | 21,6 | 22,5 | 21,4 | 4,4 |
| <b>hrc11/src13</b> | 21,7 | 22,8 | 22,5 | 24,5 | 25,3 | 6,9 | <b>Hrc11/src14</b> | 25,5 | 26,0 | 26,1 | 24,6 | 26,3 | 4,1 |
| <b>hrc12/src13</b> | 22,4 | 23,6 | 23,3 | 24,8 | 26,0 | 5,9 | <b>Hrc12/src14</b> | 26,0 | 26,2 | 26,4 | 24,8 | 26,4 | 3,7 |
| <b>hrc13/src13</b> | 21,3 | 20,7 | 20,6 | 23,4 | 22,2 | 6,8 | <b>Hrc13/src14</b> | 21,5 | 20,8 | 21,7 | 23,2 | 21,7 | 5,4 |
| <b>hrc14/src13</b> | 21,2 | 20,3 | 20,0 | 22,7 | 21,6 | 7,9 | <b>Hrc14/src14</b> | 23,9 | 21,3 | 21,6 | 22,4 | 21,3 | 5,3 |
| <b>hrc15/src13</b> | 21,9 | 22,1 | 21,7 | 25,3 | 24,4 | 7,6 | <b>Hrc15/src14</b> | 25,8 | 25,8 | 26,0 | 27,2 | 26,3 | 5,6 |
| <b>hrc16/src13</b> | 22,1 | 22,8 | 22,3 | 25,8 | 25,2 | 7,0 | <b>Hrc16/src14</b> | 26,0 | 26,0 | 26,2 | 27,4 | 26,5 | 5,3 |

NOTE 1 hrc16/src14 and so on correspond to hypothetically degraded video (hrc16) from the reference source video (src14), respectively.

NOTE 2 All videos are in the size of 320 pixels x 240 pixels, each of which has a 24-bit colour depth.

**Table A.3 – PSNRs in various colour spaces and the colour difference for SRC15 and SRC16**

|                    | Lab  | sYCC | sRGB | L*   | Y    | ΔE   |                    | Lab  | SYCC | sRGB | L*   | Y    | ΔE  |
|--------------------|------|------|------|------|------|------|--------------------|------|------|------|------|------|-----|
| <b>hrc1/src15</b>  | 11,8 | 13,6 | 13,1 | 20,7 | 19,5 | 24,8 | <b>hrc1/src16</b>  | 20,3 | 21,6 | 21,8 | 23,8 | 25,7 | 9,5 |
| <b>hrc2/src15</b>  | 17,0 | 18,5 | 18,4 | 24,2 | 23,1 | 10,8 | <b>hrc2/src16</b>  | 27,1 | 28,1 | 28,0 | 31,1 | 32,0 | 4,4 |
| <b>hrc3/src15</b>  | 15,1 | 16,7 | 16,5 | 23,1 | 21,7 | 13,2 | <b>hrc3/src16</b>  | 29,2 | 29,0 | 28,9 | 31,0 | 31,9 | 2,4 |
| <b>hrc4/src15</b>  | 13,6 | 15,0 | 14,5 | 23,0 | 21,2 | 18,7 | <b>hrc4/src16</b>  | 22,9 | 23,7 | 23,6 | 28,3 | 28,3 | 6,0 |
| <b>hrc5/src15</b>  | 14,6 | 15,4 | 15,2 | 19,8 | 18,9 | 15,9 | <b>hrc5/src16</b>  | 21,7 | 22,0 | 21,9 | 24,8 | 25,5 | 6,0 |
| <b>hrc6/src15</b>  | 14,0 | 15,4 | 15,0 | 23,0 | 21,3 | 17,3 | <b>hrc6/src16</b>  | 23,5 | 24,2 | 24,0 | 28,7 | 28,7 | 5,1 |
| <b>hrc7/src15</b>  | 16,1 | 17,0 | 16,9 | 21,1 | 20,3 | 12,1 | <b>hrc7/src16</b>  | 22,8 | 22,9 | 22,8 | 25,7 | 26,4 | 4,4 |
| <b>hrc8/src15</b>  | 14,0 | 15,3 | 15,0 | 22,6 | 20,9 | 17,6 | <b>hrc8/src16</b>  | 23,4 | 24,2 | 24,0 | 28,4 | 28,5 | 5,2 |
| <b>hrc9/src15</b>  | 15,9 | 16,6 | 16,5 | 20,7 | 19,7 | 13,1 | <b>hrc9/src16</b>  | 22,8 | 22,7 | 22,7 | 25,5 | 26,1 | 4,6 |
| <b>hrc10/src15</b> | 16,4 | 17,3 | 17,2 | 22,1 | 21,0 | 11,9 | <b>hrc10/src16</b> | 24,9 | 25,8 | 25,4 | 28,9 | 30,3 | 3,8 |
| <b>hrc11/src15</b> | 15,8 | 17,2 | 17,0 | 22,9 | 22,0 | 12,8 | <b>hrc11/src16</b> | 25,4 | 27,5 | 27,3 | 27,8 | 31,6 | 3,8 |
| <b>hrc12/src15</b> | 16,0 | 17,5 | 17,3 | 23,3 | 22,7 | 12,0 | <b>hrc12/src16</b> | 25,7 | 27,9 | 27,6 | 28,0 | 32,2 | 3,5 |
| <b>hrc13/src15</b> | 15,4 | 16,2 | 16,1 | 21,5 | 19,7 | 14,6 | <b>hrc13/src16</b> | 23,3 | 23,5 | 23,6 | 29,1 | 29,5 | 4,3 |
| <b>hrc14/src15</b> | 15,6 | 16,1 | 16,0 | 20,6 | 19,2 | 14,3 | <b>hrc14/src16</b> | 22,9 | 22,6 | 22,6 | 25,2 | 25,4 | 5,2 |
| <b>hrc15/src15</b> | 15,7 | 16,1 | 16,0 | 21,1 | 19,3 | 15,4 | <b>hrc15/src16</b> | 23,7 | 23,3 | 23,5 | 26,0 | 26,2 | 5,8 |
| <b>hrc16/src15</b> | 15,7 | 16,3 | 16,2 | 21,6 | 19,9 | 14,9 | <b>hrc16/src16</b> | 23,9 | 23,5 | 23,7 | 26,2 | 26,5 | 5,6 |

NOTE 1 hrc16/src14 and so on correspond to hypothetically degraded video (hrc16) from the reference source video (src14), respectively.

NOTE 2 All videos are in the size of 320 pixels x 240 pixels, each of which has a 24-bit colour depth.

**Table A.4 – PSNRs in various colour spaces and the colour difference for SRC17 and SRC18**

|                    | Lab  | sYCC | sRGB | L*   | Y    | ΔE   |                    | Lab  | sYCC | sRGB | L*   | Y    | ΔE   |
|--------------------|------|------|------|------|------|------|--------------------|------|------|------|------|------|------|
| <b>hrc1/src17</b>  | 15,8 | 19,2 | 19,2 | 20,8 | 23,3 | 16,7 | <b>hrc1/src18</b>  | 18,3 | 21,0 | 20,7 | 23,2 | 25,6 | 10,2 |
| <b>hrc2/src17</b>  | 20,2 | 23,2 | 23,6 | 26,6 | 26,9 | 9,2  | <b>hrc2/src18</b>  | 22,8 | 24,8 | 24,5 | 28,0 | 28,7 | 6,0  |
| <b>hrc3/src17</b>  | 20,2 | 23,2 | 23,3 | 26,2 | 27,1 | 8,3  | <b>hrc3/src18</b>  | 22,4 | 24,2 | 23,8 | 27,7 | 28,0 | 6,5  |
| <b>hrc4/src17</b>  | 18,6 | 21,2 | 21,6 | 25,2 | 25,0 | 11,1 | <b>hrc4/src18</b>  | 18,1 | 20,4 | 19,7 | 26,6 | 26,9 | 9,9  |
| <b>hrc5/src17</b>  | 18,0 | 20,1 | 20,5 | 22,7 | 23,0 | 11,8 | <b>hrc5/src18</b>  | 18,9 | 20,1 | 20,0 | 21,7 | 22,6 | 9,0  |
| <b>hrc6/src17</b>  | 18,5 | 20,8 | 21,1 | 24,9 | 24,7 | 10,0 | <b>hrc6/src18</b>  | 19,3 | 21,6 | 21,0 | 27,2 | 27,4 | 8,4  |
| <b>hrc7/src17</b>  | 19,8 | 21,8 | 22,1 | 24,5 | 24,9 | 8,6  | <b>hrc7/src18</b>  | 20,3 | 21,5 | 21,5 | 22,8 | 23,7 | 7,2  |
| <b>hrc8/src17</b>  | 18,1 | 20,5 | 20,8 | 24,3 | 24,2 | 10,9 | <b>hrc8/src18</b>  | 19,5 | 21,7 | 21,2 | 26,8 | 27,2 | 8,4  |
| <b>hrc9/src17</b>  | 18,6 | 20,6 | 20,9 | 23,4 | 23,7 | 10,3 | <b>hrc9/src18</b>  | 20,4 | 21,5 | 21,6 | 22,8 | 23,6 | 7,4  |
| <b>hrc10/src17</b> | 19,7 | 21,9 | 22,2 | 24,8 | 25,2 | 8,9  | <b>hrc10/src18</b> | 21,6 | 23,0 | 22,8 | 25,3 | 26,0 | 6,5  |
| <b>hrc11/src17</b> | 18,1 | 20,4 | 20,7 | 23,2 | 23,9 | 10,8 | <b>hrc11/src18</b> | 21,5 | 24,4 | 24,0 | 26,7 | 29,8 | 6,4  |
| <b>hrc12/src17</b> | 19,0 | 21,4 | 21,8 | 24,1 | 25,1 | 9,3  | <b>hrc12/src18</b> | 21,7 | 24,5 | 24,1 | 26,7 | 30,1 | 6,1  |
| <b>hrc13/src17</b> | 16,9 | 18,6 | 19,0 | 22,0 | 22,0 | 13,2 | <b>hrc13/src18</b> | 21,9 | 24,0 | 23,6 | 27,7 | 27,9 | 6,9  |
| <b>hrc14/src17</b> | 18,2 | 20,3 | 20,6 | 23,4 | 23,4 | 11,6 | <b>hrc14/src18</b> | 21,3 | 22,8 | 22,6 | 25,2 | 25,7 | 7,2  |
| <b>hrc15/src17</b> | 17,8 | 20,0 | 20,4 | 23,0 | 23,0 | 13,4 | <b>hrc15/src18</b> | 21,6 | 23,7 | 23,3 | 29,0 | 28,5 | 7,8  |
| <b>hrc16/src17</b> | 18,2 | 20,7 | 21,2 | 23,8 | 24,0 | 12,5 | <b>hrc16/src18</b> | 21,7 | 23,9 | 23,4 | 29,4 | 29,2 | 7,4  |

NOTE 1 hrc16/src14 and so on correspond to hypothetically degraded video (hrc16) from the reference source video (src14), respectively.

NOTE 2 All videos are in the size of 320 pixels x 240 pixels, each of which has a 24-bit colour depth.

**Table A.5 – PSNRs in various colour spaces and the colour difference for SRC19 and SRC20**

|                    | Lab  | sYCC | sRGB | L*   | Y    | ΔE  |                    | Lab  | sYCC | sRGB | L*   | Y    | ΔE   |
|--------------------|------|------|------|------|------|-----|--------------------|------|------|------|------|------|------|
| <b>hrc1/src19</b>  | 20,0 | 22,6 | 22,6 | 23,2 | 25,6 | 7,8 | <b>hrc1/src20</b>  | 15,8 | 17,4 | 17,2 | 20,1 | 20,2 | 12,7 |
| <b>hrc2/src19</b>  | 23,6 | 25,1 | 24,9 | 27,9 | 28,6 | 4,8 | <b>hrc2/src20</b>  | 20,6 | 20,8 | 20,7 | 23,7 | 22,1 | 6,9  |
| <b>hrc3/src19</b>  | 23,1 | 24,6 | 24,4 | 27,7 | 28,0 | 5,8 | <b>hrc3/src20</b>  | 18,7 | 19,3 | 19,3 | 22,6 | 21,3 | 8,2  |
| <b>hrc4/src19</b>  | 20,3 | 22,5 | 22,1 | 26,6 | 27,1 | 6,9 | <b>hrc4/src20</b>  | 18,7 | 19,2 | 19,0 | 22,6 | 21,0 | 8,8  |
| <b>hrc5/src19</b>  | 19,8 | 20,8 | 20,7 | 22,5 | 23,3 | 7,4 | <b>hrc5/src20</b>  | 18,7 | 16,2 | 16,0 | 18,5 | 16,6 | 8,3  |
| <b>hrc6/src19</b>  | 20,6 | 22,7 | 22,3 | 27,0 | 27,2 | 6,6 | <b>hrc6/src20</b>  | 18,8 | 19,4 | 19,2 | 23,1 | 21,4 | 8,1  |
| <b>hrc7/src19</b>  | 21,0 | 21,7 | 21,7 | 22,8 | 23,5 | 5,9 | <b>hrc7/src20</b>  | 19,4 | 17,5 | 17,3 | 19,6 | 18,1 | 7,2  |
| <b>hrc8/src19</b>  | 20,7 | 22,6 | 22,3 | 26,6 | 26,9 | 6,8 | <b>hrc8/src20</b>  | 18,6 | 19,2 | 19,0 | 22,8 | 21,2 | 8,4  |
| <b>hrc9/src19</b>  | 21,2 | 23,1 | 22,7 | 27,2 | 27,2 | 6,2 | <b>hrc9/src20</b>  | 20,0 | 20,3 | 20,1 | 23,5 | 22,0 | 6,4  |
| <b>hrc10/src19</b> | 20,0 | 21,3 | 21,1 | 24,4 | 24,7 | 7,8 | <b>Hrc10/src20</b> | 20,3 | 18,8 | 18,6 | 21,3 | 19,5 | 6,5  |
| <b>hrc11/src19</b> | 21,4 | 23,6 | 23,3 | 25,6 | 27,7 | 6,3 | <b>Hrc11/src20</b> | 19,9 | 21,5 | 21,4 | 23,3 | 23,8 | 6,6  |
| <b>hrc12/src19</b> | 22,4 | 24,7 | 24,4 | 25,9 | 28,8 | 5,4 | <b>Hrc12/src20</b> | 20,3 | 21,9 | 21,7 | 23,4 | 24,1 | 6,2  |
| <b>hrc13/src19</b> | 20,8 | 21,8 | 21,7 | 24,2 | 24,3 | 6,9 | <b>Hrc13/src20</b> | 19,8 | 18,8 | 18,7 | 21,4 | 19,8 | 7,8  |
| <b>hrc14/src19</b> | 21,1 | 22,1 | 22,0 | 24,8 | 25,1 | 7,1 | <b>Hrc14/src20</b> | 19,6 | 18,4 | 18,2 | 21,1 | 19,3 | 7,6  |
| <b>hrc15/src19</b> | 23,3 | 24,6 | 24,4 | 28,8 | 28,5 | 5,9 | <b>Hrc15/src20</b> | 19,5 | 20,3 | 20,2 | 23,5 | 22,2 | 8,4  |
| <b>hrc16/src19</b> | 23,6 | 25,1 | 24,8 | 29,4 | 29,4 | 5,4 | <b>Hrc16/src20</b> | 19,6 | 20,4 | 20,4 | 23,7 | 22,4 | 8,3  |

NOTE 1 hrc16/src14 and so on correspond to hypothetically degraded video (hrc16) from the reference source video (src14), respectively.

NOTE 2 All videos are in the size of 320 pixels x 240 pixels, each of which has a 24-bit colour depth.

**Table A.6 – PSNR's in various colour spaces and the colour difference for SRC21 and SRC22**

|             | Lab  | sYCC | sRGB | L*   | Y    | ΔE  |             | Lab  | sYCC | sRGB | L*   | Y    | ΔE   |
|-------------|------|------|------|------|------|-----|-------------|------|------|------|------|------|------|
| Hrc1/src21  | 23,1 | 25,3 | 25,8 | 22,8 | 25,8 | 5,9 | hrc1/src22  | 14,6 | 18,0 | 17,6 | 22,3 | 24,1 | 16,8 |
| Hrc2/src21  | 29,3 | 29,1 | 29,2 | 28,5 | 29,6 | 3,2 | hrc2/src22  | 18,9 | 21,7 | 21,0 | 26,3 | 26,5 | 9,3  |
| Hrc3/src21  | 29,4 | 28,8 | 28,8 | 28,4 | 29,3 | 2,9 | hrc3/src22  | 17,0 | 19,9 | 19,3 | 24,8 | 24,9 | 11,0 |
| Hrc4/src21  | 28,4 | 27,7 | 27,9 | 27,3 | 28,2 | 3,5 | hrc4/src22  | 17,4 | 20,1 | 19,4 | 25,4 | 25,6 | 11,2 |
| Hrc5/src21  | 25,7 | 24,0 | 24,1 | 22,8 | 24,0 | 3,5 | hrc5/src22  | 17,4 | 18,9 | 18,0 | 21,5 | 21,9 | 11,2 |
| Hrc6/src21  | 29,5 | 28,3 | 28,5 | 27,9 | 28,6 | 2,8 | hrc6/src22  | 17,2 | 20,0 | 19,3 | 25,7 | 25,8 | 10,8 |
| Hrc7/src21  | 26,0 | 24,4 | 24,5 | 23,1 | 24,4 | 3,0 | hrc7/src22  | 18,0 | 19,9 | 19,2 | 22,8 | 23,3 | 9,8  |
| Hrc8/src21  | 29,1 | 28,1 | 28,3 | 27,5 | 28,4 | 3,0 | hrc8/src22  | 17,2 | 19,9 | 19,2 | 25,1 | 25,2 | 11,1 |
| Hrc9/src21  | 30,7 | 29,4 | 29,5 | 28,5 | 29,6 | 2,0 | hrc9/src22  | 17,9 | 20,5 | 19,8 | 25,4 | 25,5 | 9,7  |
| hrc10/src21 | 28,5 | 26,9 | 27,0 | 25,8 | 26,9 | 2,5 | hrc10/src22 | 18,2 | 20,3 | 19,5 | 23,9 | 24,2 | 9,7  |
| hrc11/src21 | 28,8 | 30,6 | 30,7 | 26,7 | 31,0 | 2,4 | hrc11/src22 | 18,0 | 20,8 | 20,3 | 24,4 | 25,6 | 10,0 |
| hrc12/src21 | 28,9 | 30,8 | 30,9 | 26,7 | 31,2 | 2,2 | hrc12/src22 | 18,3 | 21,3 | 20,7 | 24,9 | 26,5 | 9,3  |
| hrc13/src21 | 27,4 | 25,8 | 25,9 | 25,0 | 25,9 | 3,2 | hrc13/src22 | 16,9 | 18,9 | 18,5 | 22,7 | 22,6 | 12,2 |
| hrc14/src21 | 28,2 | 26,7 | 26,8 | 25,7 | 26,8 | 2,9 | hrc14/src22 | 17,8 | 19,7 | 19,0 | 23,2 | 23,2 | 11,0 |
| hrc15/src21 | 30,5 | 30,4 | 30,5 | 30,3 | 31,1 | 3,2 | hrc15/src22 | 17,8 | 20,2 | 19,8 | 24,4 | 23,9 | 12,0 |
| hrc16/src21 | 30,6 | 30,5 | 30,6 | 30,4 | 31,2 | 3,2 | hrc16/src22 | 18,1 | 20,8 | 20,3 | 25,4 | 25,1 | 11,3 |

NOTE 1 hrc16/src14 and so on correspond to hypothetically degraded video (hrc16) from the reference source video (src14), respectively.

NOTE 2 All videos are in the size of 320 pixels x 240 pixels, each of which has a 24-bit colour depth.

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## Annex B (informative)

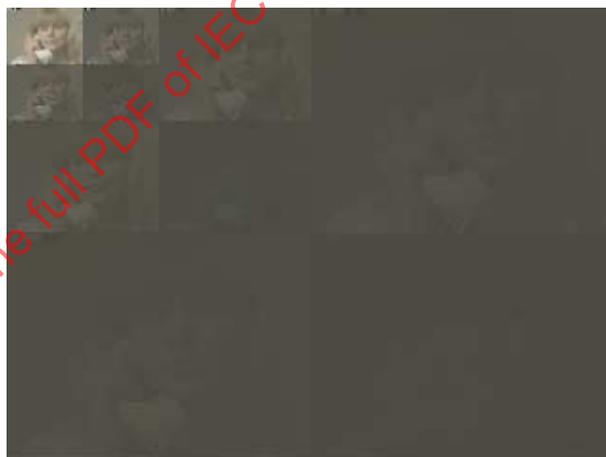
### End-to-end objective assessment of video quality in the spatial frequency domain

#### B.1 Item to be assessed

The root mean square errors between corresponding blocks in the wavelet transformed domain corresponding to the reference video and the deteriorated video, which has been proposed in ITU-R 6Q/42-E.

Three-level wavelet transform is assumed. Therefore, there are 10 blocks as shown in Figure B.1 and Figure B.2.

1  
2  
5  
8  
  
3  
4  
  
6  
7  
  
9  
10



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**Figure B.1 – Assignment of the block numbers**

**Figure B.2 – Example of wavelet decomposition visualized**

#### B.2 Method of assessment

Reference videos in Table A.1 are used as item 1 of Figure 2. Frame size reduced videos in uncompressed AVI-format should be prepared for item 2 of Figure 2. It is necessary to embed frame numbers at this point so that they can be used to identify received frames corresponding to the transmitted frames.

Encoded and transmitted streaming videos shall be continuously captured. Pixel-by-pixel calculations should be conducted.

The root mean square errors between each of corresponding blocks  $p = 1...10$  to the original video frame and the deteriorated video frame  $k$  should be acquired as the following.

Let coefficients in the wavelet domain be  $c_{R_{o,ijpk}}$ ,  $c_{G_{o,ijpk}}$  and  $c_{B_{o,ijpk}}$  for the position  $(i, j)$  of the block  $p$  of reference red, green, and blue pixel data, respectively;  $c_{R_{d,ijpk}}$ ,  $c_{G_{d,ijpk}}$  and  $c_{B_{det,ijpk}}$  for the position  $(i, j)$  of the block  $p$  of deteriorated red, green, and blue pixel data, respectively.

Deterioration  $d_{pk}$  at the block  $p$  of the frame  $k$  in the wavelet domain should be evaluated by the sum square error as in equations (B.1) and (B.2).

$$d_{pk} = \sum_i \sum_j \left( \Delta c_{R_{ijpk}}^2 + \Delta c_{G_{ijpk}}^2 + \Delta c_{B_{ijpk}}^2 \right) \quad (B.1)$$

where

$$\begin{aligned} \Delta c_{R_{ijpk}} &= c_{R_{d,ijpk}} - c_{R_{o,ijpk}} \\ \Delta c_{G_{ijpk}} &= c_{G_{d,ijpk}} - c_{G_{o,ijpk}} \\ \Delta c_{B_{ijpk}} &= c_{B_{d,ijpk}} - c_{B_{o,ijpk}} \end{aligned} \quad (B.2)$$

### B.3 Presentation of assessment results

The metric of the sum of square errors between blocks corresponding to the wavelet transformed frames should be plotted versus frame numbers as shown in Figure B.3 together with identifications of reference video sources. The conditions of measurement such as frame size in pixels, frame rate, streaming bit-rate should also be reported.

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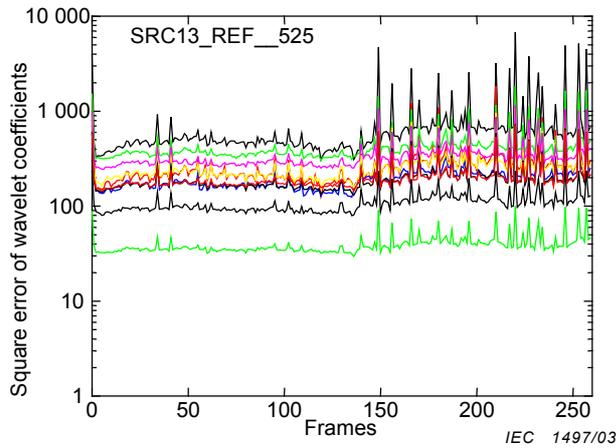


Figure B.3a – Example for SRC13\_REF\_525

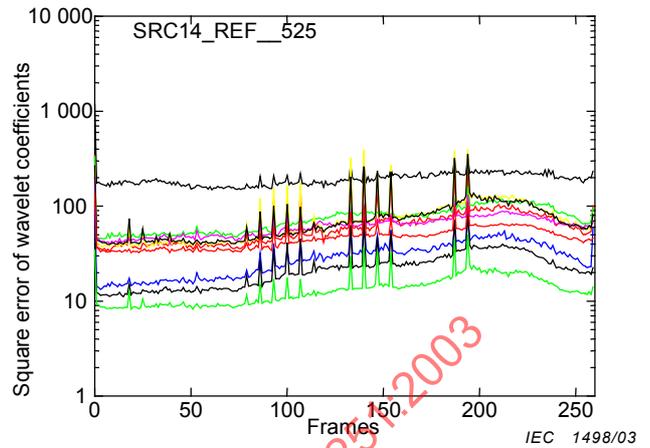


Figure B.3b – Example for SRC14\_REF\_525

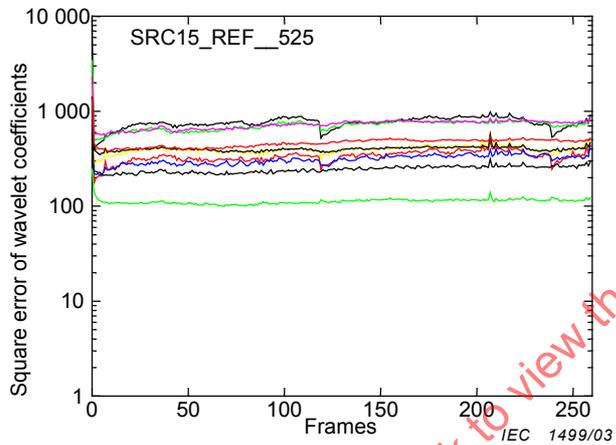


Figure B.3c – Example for SRC15\_REF\_525

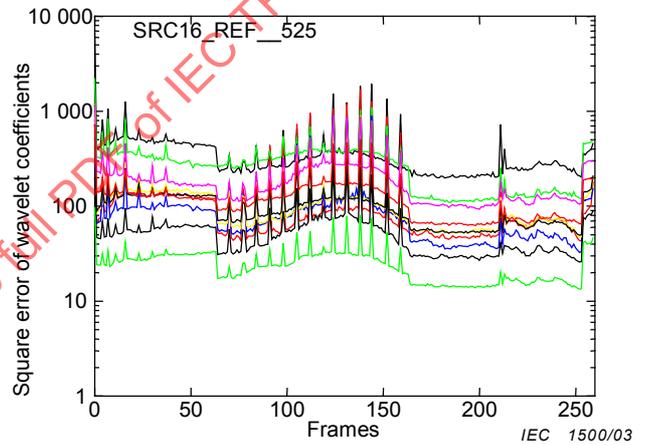


Figure B.3d – Example for SRC16\_REF\_525

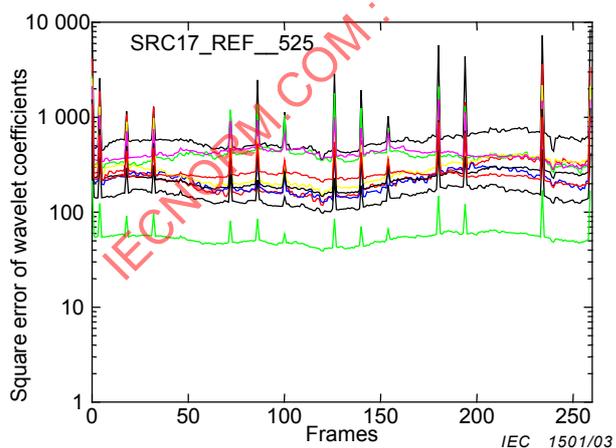


Figure B.3e – Example for SRC17\_REF\_525

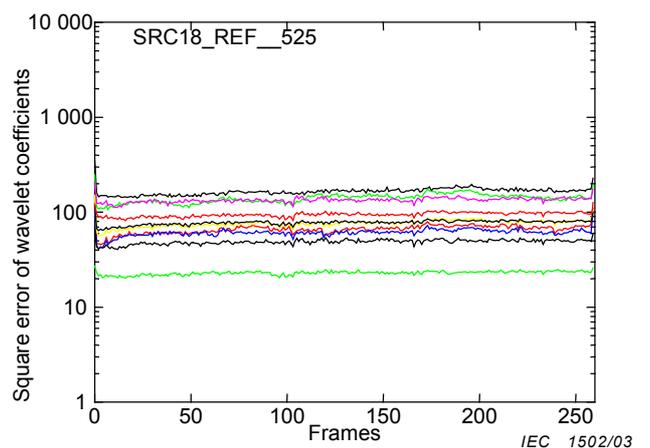


Figure B.3f – Example for SRC18\_REF\_525