REPORT 1212*

MEASUREMENTS AND TEST SIGNALS FOR DIGITALLY ENCODED COLOUR TELEVISION SIGNALS

(Question 25/11, Study Programme 25M/11)

1. Introduction (1990)

Digital television systems operate in very different ways from analogue systems with the consequence that a quite different set of picture impairments may be introduced. Impairments may occur both from the conversions to and from the digital domain (which include filtering, sampling and quantization processes, see Reports 629, 962 and Recommendation 601) and by degradations of the digital signal itself (such as individual digit errors, timing jitter or loss of frame synchronization). In the conversion processes, the impairments may be picture dependent, while errors in the digital domain may be bit-sequence dependent. In the digital domain, an increase in noise or distortion above a certain threshold level can result in a rapid increase in the number of digit errors. Before that level is reached, the error performance can be improved significantly by the use of error correction techniques.

Picture impairments may thus arise from several sources:

a) distortions in the conversion processes from analogue to digital form and from digital to analogue form;

b) errors in the digital channel;

c) distortions introduced by digital signal processing.

Test and measurement methods for the digital television system must therefore include consideration of these separate factors and of the need for both off-line (acceptance and maintenance testing) and on-line (monitoring and diagnostic) requirements.

In the case of picture impairments, either subjective or objective tests may be used. Section 2.1 of this report contains information on subjective test methods and section 2.2 considers objective testing. In either case, care must be taken to consider the effect of two- or three-dimensional signal processing techniques which render many current analogue test signals of little use (in that case because of their line-repetitive nature). Section 2.3 of this report considers the testing of signals in digitally encoded form. In this case,

* This Report should be brought to the attention of the CMTT and of the IEC.

the emphasis is on the measurement of residual bit errors (after any correction has taken place), error distributions and their relation to picture or other information. Objective tests and specialized test equipment may be required.

In digital equipment, advantage can often be taken of the self-test capability of many digital integrated circuits and the ability of the digital circuits to generate well-defined waveforms to test the analogue parts of the conversion circuits.

There is a great deal of work remaining to create adequate measurement and test methods for digital television equipment and administrations are thus invited to make contributions on this subject.

2. Assessment methods

2.1 Subjective assessment

At present subjective assessment is the only technique useful in practice for the evaluation of digital television systems and it is therefore important that the method used should be in accordance with Recommendation 500. Special attention should be paid to the choice of picture material. For example, in [CCIR, 1974-78a], the use of pictures involving either linear or rotational movement is proposed. This document also suggests that slow periodic fluctuations in picture signal amplitude may be useful.

For subjective assessment of interfield or interframe coding methods (which are important for high-efficiency bit-rate reduction of digital television signals), moving test pictures are essential. [CCIR, 1982-86a] describes the factors to be considered in the preparation of such moving test pictures and presents an example set which consists of 26 moving scenes. Report 1206 contains a suggested set of pictures, scenes and sequences for subjective assessments.

2.2 Objective measurements

2.2.1 Measurements on digital television equipments and installations

Studies have been made to define objective parameters, measurements of which could be related to the subjective impairments [CCIR, 1974-78b; Kretz, 1977]. One approach consists of considering separately the various impairments which may affect different types of picture information (e.g. plain areas, contours, fine details). Recent studies [CCIR, 1978-82a] indicate that picture-quality impairments arising from digital transmission can be classified into several categories of disturbance which are independent of each other in terms of their effects upon subjective picture quality. The physical terms to express the respective categories of disturbance for intraframe coding are defined and can be measured using well-known test signals such as the staircase and sawtooth signals. [CCIR, 1982-86b] shows a method for classifying picture quality impairments by using psychological factor analysis, in such cases where the classification procedure cannot take place *a priori*.

Combinations of analogue and digital equipments will continue to be employed in studios before all-digital studios come into operation. In this interim period the video signal will undergo a number of analogue-digital-analogue conversions. Each conversion in either direction is a potential source of picture impairments.

Present analogue test methods are suitable for many measurements of mixed analogue-digital-analogue signal paths in studios, but it is recognised that some measurements provide results which are made unreliable by digital signal processing.

New test signals to ease these difficulties have been proposed. [CCIR, 1974-78a] suggests the use of a sine-squared pulse of half-amplitude duration somewhat less than half the active line period, with superimposed colour sub-carrier, as a test signal for the measurement of quantization noise [Krivosheev, 1976].

[CCIR, 1974-78c] proposes a line-duration sawtooth signal with superimposed colour sub-carrier for the measurement of differential gain and differential phase.

In [CCIR, 1978-82b] a method is suggested for the measurement of distortion introduced by digital processes wherein the processed signal in digital form is subtracted from the original signal also in digital form, thereby providing greater accuracy. Analysis can then be performed on either digital measuring equipments or existing analogue measuring equipments.

Weston [1982] describes a digital test-signal generator for testing equipments and systems using two and three-dimensional signal processing. It produces, *inter alia*, electronic zone plate test patterns which may be stationary (two dimensional) or moving (three-dimensional). The zone plate signals form a powerful diagnostic aid for studying the properties of such processes as spatial and temporal filtering, sub-sampling, interpolation etc., and for optimizing the algorithms used. As in other types of frequency-responses measurements, the results are most useful qualitatively; the quantitative results are difficult to relate to a subjective assessment using real pictures. Nevertheless, tests with zone plate patterns can be used distinctively to reveal particular impairment modes and thus critical real pictures.

[CCIR 1986-1990a] describes the application of a pseudorandom data sequence, generated by a feedback shift register to check the operation of bit-parallel video interfaces corresponding to CCIR Recommendation 656 and the transmission paths between them within the studio. The ranges of values of the quantization levels, in the application described, correspond to the defined range given in CCIR Recommendation 601, however quantization values will occur which lie outside of the RGB signal range.

Although the statistical characteristics (e.g. correlation) of the proposed pseudorandom sequence are not typical of digitized broadcast television, the method described has been used to determine the pulse crosstalk between circuit elements and transmission lines. Results obtained from such determinations should however be interpreted accordingly. The method has also been used to measure bit error rates in, and unwanted radiation from, intrastudio links and the time response of linear and non-linear circuit components, again subject to the reservations of the statistics of the pseudorandom data.

[CCIR 1986-1990b], suggests that conformity tests on the 4-2-2 interfaces must be based on the use of real-time measurement techniques suitable for checking the parameters specified in Recommendation 656 for each item of data transmitted.

In [Lebrat-Fouillet, 1989], it is explained measuring methods based on the use of 4-2-2 test signals:

- The clock jitter on a parallel interface can be measured by producing a signal whose amplitude is proportional to the phase difference between the interface clock and a stable clock obtained by appropriate filtering. Oscilloscopic observation of this signal after calibration provides the amplitude and distribution of the jitter in relation to the structure of the video signal (line, field, etc.).

- The differential transmission delay on a parallel interface can be measured by comparing the data detected by the interface clock with those detected by a number of clock signals obtained by means of a fixed phase shift (gain or lag) in relation to the interface clock. This comparison yields for each item of data the maximum clock gain and lag possible if correct detection is to be maintained, and by combining these results we can measure the differential transmission delay.

2.2.2 Measurements on digital television codecs

Meiseles [1988] describes a method of measurement for objectively determining the effects of the motion prediction algorithms used in some bit rate reduction video codecs. Using the method described, the static performance of the coding system is first measured to find the attributes of frequency response, gain, 2T pulse response, short time waveform distortion (IEEE 511 - 1979 method) and non-linear gain. The results of these tests provide the performance reference for the dynamic tests. The dynamic test pattern with the appropriate test signals, used to measure the static responses, are used to measure the previously described attributes. The differences between the static results and the dynamic results are those caused by the prediction process. By using this method the processing artifacts of slope overload, edge jitter, quantizing error, prediction error, and signal-to-noise ratio can be measured accurately and with repeatability.

Objective measurements of codec quality are also discussed in Report 1206.

2.3 Testing of signals in digitally encoded form

Some information on the assessment of digital circuits is in Report 1206.

3. Examples of 4:2:2 test signals

[CCIR, 1986-90b and c] describe some test signals and procedures for 4:2:2 digital equipment. Such digital signals are defined below. However, further signals are required to provide a more complete assessment of performance.

Administrations are encouraged to carry out studies to define further test signals.

3.1 Explanatory notes

Each of sub-paragraphs 3.2 to 3.9 describes a 4:2:2 test signal, giving:

- a number and a description for each test signal (in the title of the sub-paragraph);
- the composition of digital active signal lines. Y (i) stands for the value of the luminance signal Y for sample number i of the digital active video line, with samples numbered from 1 to 720 in chronological order. When i is odd C_B (i) and C_R (i) stand for the values taken on by colour difference signals C_R and C_B;
- the use of signal in 4:2:2 digital video equipment tests.

Table I defines six 720-sample digital waveforms, referred to as A1, A2, A3, A4, A5 and A6.

These digital waveforms are made up of pulses in uniform ranges, ramps between two uniform ranges, and transitions between two uniform ranges, shaped by a filter whose impulse response R(t) is defined as a function of time t as follows:

- for $-3T < t < 3T$, $R(t) = 0.42 + 0.50 \cos(\pi t/3T) + 0.08 \cos(2\pi t/3T)$
- otherwise $R(t) = 0$

(R(t) is a Blackman window)

The value of T is 74 ns for digital waveforms A1, A2, A3 and A4 and 148 ns for A5 and A6.

3.2 Test signal No. 1: GREY

The active video lines of this signal are defined by : Y(i) = A1 (i), $C_R = C_B = 128$

This signal is critical for transmission via a parallel interface, since each of the 8 interface data binary signals then contains a succession of bits 0, 1, 0, 1, 0, 1 ... and attains maximum power concentration at high frequencies (multiples of 13.5 MHz) which often prove difficult to preserve in practical transmission links.

3.3 Test signal No. 2: ALTERNATING WHITE/BLACK at 0.1 Hz

This signal produces alternately:

- for 5 seconds, pictures containing "white" digital active video lines defined by Y(i) = A2(i), $C_R = C_B = 128$;
- for 5 seconds, pictures containing "black" digital active video lines defined by Y = 16, $C_R = C_B = 128$.

This signal produces a variation of the black level in the corresponding analogue video signals, owing to the suppression of continuous components and very low frequencies by the analogue transmission links. It provides a means of checking the compensation for this variation, as well as black stability and accuracy in digital coding.

3.4 Test signal No. 3: END-OF-LINE PULSES

The signal's digital active video lines are defined by:

Y(i) = A3 (i), $C_R = C_B = 128$

This four-pulse signal can be used to check the position of the digital active line in relation to the analogue reference, as well as the activity of samples situated at the end of the digital active line.

The outside edges of the two internal pulses coincide with the ends of the line displayed in the 625/50 system.

3.5 Test signal No. 4: BLACK/WHITE RAMP

The digital active video lines of this signal are defined by:

$Y(i) = int (A_4(i)); C_R = C_B = 128$

This signal may be used to test the existence and position of quantization levels 1 to 254 of the luminance signal.

3.6 Test signal No. 5: YELLOW/GREY RAMP

The digital active lines of this signal are defined by:

$C_B(i) = int (A_5(i))$

$C_R(i) = int (128.5 -(0.114/0.701) (A_5(i)-128))$

$Y(i) = int (126 - (169/224) (A_5(i)-128))$

This signal can be used to test the existence and position of quantization levels 1 to 128 of the colour difference signal C_B.

TABLE I - Table of values used for defining digital test signals

i	1 ≤ i ≤ 20	21	22	23	24	25	26 ≤ i ≤ 694	695	696	697	698	699	700 ≤ i ≤ 720
A1(i)	16	18	33	72	110	125	127	125	110	72	33	18	16

i	1 ≤ i ≤ 20	21	22	23	24	25	26 ≤ i ≤ 694	695	696	697	698	699	700 ≤ i ≤ 720
A2(i)	16	19	50	126	201	232	235	232	201	126	50	19	16

i	1	2	3	4	5	6	7 ≤ i ≤ 10	11	12	13	14	15	16	17 ≤ i ≤ 706	707	708	709	710	711	712	713	714	715	716	717	718	719	720
A3(i)	16	44	154	235	154	44	16	17	64	185	229	121	31	16	17	64	185	229	121	31	16	16	44	154	235	154	44	16

i	1 ≤ i ≤ 21	22	23	24	25 ≤ i ≤ 60	61 ≤ i ≤ 88	89 ≤ i ≤ 100	101 ≤ i ≤ 536	537 ≤ i ≤ 550	551 ≤ i ≤ 586	587 ≤ i ≤ 600	601	602	603	604	605	606 ≤ i ≤ 720
A4(i)	16	14	9	3	1	((i-57)/2)	16	((i-67)/2)	235	((i-79)/2)	254	250	217	135	53	20	16

i	1 ≤ i ≤ 20	21	22	23	24	25	26	27	28	29	30 ≤ i ≤ 40	41 ≤ i ≤ 96	97 ≤ i ≤ 120	121 ≤ i ≤ 564	565 ≤ i ≤ 720
A5(i)	128	126	120	108	89	65	40	21	9	3	1	((i-33)/4)	16	((i-53)/4)	128

i	1 ≤ i ≤ 120	121 ≤ i ≤ 564	565 ≤ i ≤ 580	581 ≤ i ≤ 632	633 ≤ i ≤ 660	660	661	662	663	664	665	666	667	668	669	670 ≤ i ≤ 720
A6(i)	128	((i+395)/4)	240	((i+383)/4)	254		252	246	234	215	191	167	148	136	130	128

i is the sample number and takes on values from 1 to 720.

TABLE I - Table of values used for defining digital test signals (continued)

i	1 to 254	255 to 508	509 to 762	763 to 1016	1017 to 1270	1271 to 1440
A7(i)	i	509-i	i-508	1017-i	i-1016	1525-i

i	1 to 47	48	49	50	51	52	53	54	55	56 to 668
A8(i)	235	232	218	187	139	86	46	24	17	16

i	669	670	671	672	673	674	675	676	677 to 720
A8(i)	19	33	64	112	165	205	227	234	235

i	1 to 24	25	26	27	28 to 334	335	336	337	338	339 to 360
A9(i)	240	232	191	143	128	130	152	204	236	240

i	1 to 24	25	26	27	28 to 334	335	336	337	338	339 to 360
A10(i)	16	24	65	113	128	126	104	52	20	16

3.7 Test signal No. 6: GREY/BLUE RAMP

The digital active video lines of this signal are defined by the same formulae as in § 3.6, replacing A_5 by A_6.

This signal can be used to test the existence and position of quantization levels 128 to 254 of the colour difference signal C_B.

3.8 Test signal No. 7: CYAN/GREY RAMP

The digital active video lines of this signal are defined by:

$C_B(i) = \text{int}\,(128.5 - (0.299/0.886)\,(A_5(i) - 128))$

$C_R(i) = \text{int}(A_5(i))$

$Y(i) = \text{int}\,(126 - (88/224)\,(A_5(i) - 128))$

This signal may be used to test the existence and position of quantization levels 1 to 128 of the colour difference signal C_R.

3.9 Test signal No. 8: GREY/RED RAMP

The digital active video lines of this signal are defined by the same formulae as in § 3.8, replacing A_5 by A_6.

This signal may be used to test the existence and position of quantization levels 128 to 254 of the colour difference signal C_R.

3.10 Test signal No. 9: CB, Y, CR, Y ramp

The active video lines of this signal are defined by Table $A_7(i)$ for 1440 samples of the digital active line multiplex.

This signal is useful for testing the conformity of the digital video signal format at the output of the digital processing equipment carrying out demultiplexing and remultiplexing operations on the components of the digital video signal.

Note - This signal produces spurious colours in the R, G, B field.

3.11 Test signal No. 10: white, end-of-line porches

The active video lines of this signal are defined by:

$Y(i) = A_8(i)$, $C_B = C_R = 128$

This signal has no shaping of the transitions on Y at the ends of the digital active line and is useful for observing the analogue shaping of the line blankings by the 4-2-2 decoders.

Two integral transitions of the Blackman pulse with a rise time of 300 ns are placed 3 μs from the leading and trailing edges of analogue line blankings for 625-line systems, permitting comparative observation of the transitions and verification of the conformity of the digital-analogue time correspondence on Y.

3.12 Test signal No. 11: blue, end-of-line porches

The active video lines of this signal are defined by:

$Y = 41$, $C_B(i) = A_9(i)$, $C_R = 110$

This signal can be used to make the observations described in section 3.11) for high transitions on C_B.

3.13 Test signal No. 12: red, end-of-line porches

The active video lines of this signal are defined by:

$Y = 81$, $C_B = 90$, $C_R = A_9(i)$

This signal can be used to make the observations described in section 3.11) for high transitions on C_R.

3.14 Test signal No. 13: yellow, end-of-line porches

The active video lines of this signal are defined by:

$Y = 210$, $C_B(i) = A_{10}(i)$, $C_R = 146$

This signal can be used to make the observations described in section 3.11) for low transitions on C_B.

3.15 Test signal No. 14: cyan, end-of-line porches

The active video lines of this signal are defined by:

$Y = 170$, $C_B = 166$, $C_R(i) = A_{10}(i)$

This signal can be used to make the observations described in section 3.11) for low transitions on C_R.

3.16 Test signal No. 15: serial 1010

The active video lines of this signal are defined by:

$Y = 128$, $C_B = C_R = 129$

This signal produces, after parallel-to-serial conversion, the bit sequence ..., 1, 0, 1, 0, ... on the serial multiplex and concentrates the power at the frequency 121.5 MHz.

It is useful for monitoring the 9-bit clock phase recovery performance of the serial-to-parallel converters and assessing the receiver equalization quality.

3.17 Test signal No. 16: serial 11001100

The active video lines of this signal are defined by:

C_B = 192 Y(i uneven) = 218 C_R = 191 Y(i even) = 215

After parallel-to-serial conversion, this signal produces the bit sequence ..., 1, 1, 0, 0, 1, 1, 0, 0, ... on the serial multiplex and concentrates the power at the frequency 60.75 MHz.

It is useful for monitoring the bit clock and 9-bit clock phase recovery performance of the serial-to-parallel converters and assessing the receiver equalization quality.

Note - This signal produces spurious colours in the R, G, B field.

3.18 Test signal No. 17: serial 111000111000

The active video lines of this signal are defined by:

Y = 245, C_B = C_R = 248

After parallel-to-serial conversion, this signal produces the bit sequence ..., 1, 1, 1, 0, 0, 0, 1, 1, 1, 0, 0, 0, ... on the serial multiplex and concentrates the power at frequency 40.5 MHz.

It is useful for monitoring the bit clock and 9-bit clock phase recovery performance of the serial-to-parallel converters and for assessing the receiver equalization quality.

Note - This signal produces spurious colours in the R, G, B field.

4. Digital colour bar signals

The frequent use of colour bar signals in analogue television suggests the need to define such encoded signals for digital, in order to monitor levels and phasing between components after 4-2-2 decoding.

Tables IIa and b give a description of 100/0/100/0 and 100/0/75/0 colour bars calculated by means of mathematical equations with the following characteristics:

- shaping of transitions by integral of the Blackman impulse;
- rise time 10% to 90% for Y: 150 ns;
- rise time 10% to 90% for C_B and C_R: 300 ns.

TABLE II - Description of encoded colour-bar signals for digital

a) Designation: 100/0/100/0 colour bars

Definition of Y for digital active line with rise time = 150 ns

i	1 to 14	15	16	17	18	19	20 to 100	101	102	103	104	105	106 to 186	187	188	189	190	191
Y(i)	16	16	39	126	212	235	235	235	232	223	213	210	210	210	206	190	174	170

i	192 to 272	273	274	275	276	277	278 to 358	359	360	361	362	363	364 to 444	445	446	447	448	449
Y(i)	170	169	167	157	147	145	145	144	141	126	110	107	106	106	104	94	84	82

i	450 to 530	531	532	533	534	535	536 to 616	617	618	619	620	621	622 to 720
Y(i)	81	81	77	61	45	41	41	41	38	28	19	16	16

Definition of C_R for digital active line with rise time = 300 ns

i	1 to 6	7	8	9	10	11	12 to 49	50	51	52	53	54	55 to 92	93	94	95	96	97
CR(i)	128	128	128	128	128	128	128	128	130	137	144	146	146	146	133	81	29	16

i	98 to 135	136	137	138	139	140	141 to 178	179	180	181	182	183	184 to 221	222	223	224	225	226
CR(i)	16	16	18	25	32	34	34	35	54	128	202	221	222	222	224	231	238	240

i	227 to 264	265	266	267	268	269	270 to 307	308	309	310	311	312	313 to 360
CR(i)	240	240	227	175	123	110	110	110	112	119	126	128	128

Definition of C_B for digital active line with rise time = 300 ns

i	1 to 6	7	8	9	10	11	12 to 49	50	51	52	53	54	55 to 92	93	94	95	96	97
CB(i)	128	128	128	128	128	128	128	128	116	72	28	16	16	16	31	91	150	166

i	98 to 135	136	137	138	139	140	141 to 178	179	180	181	182	183	184 to 221	222	223	224	225	226
CB(i)	166	166	154	110	65	54	54	54	69	128	187	202	202	202	191	146	102	90

i	227 to 264	265	266	267	268	269	270 to 307	308	309	310	311	312	313 to 360
CB(i)	90	90	106	165	225	240	240	240	228	184	140	128	128

b) **Designation:** 100/0/75/0 colour bars

Definition of Y for digital active line with rise time = 150 ns

i	1 to 14	15	16	17	18	19	20 to 100	101	102	103	104	105	106 to 186	187	188	189	190	191
Y(i)	16	16	39	126	212	235	235	235	227	198	169	162	162	161	158	146	134	131

i	192 to 272	273	274	275	276	277	278 to 358	359	360	361	362	363	364 to 444	445	446	447	448	449
Y(i)	131	131	129	122	114	112	112	112	109	98	87	84	84	84	82	74	67	65

i	450 to 530	531	532	533	534	535	536 to 616	617	618	619	620	621	622 to 720
Y(i)	65	65	62	50	38	35	35	35	33	25	18	16	16

Definition of C_R for digital active line with rise time = 300 ns

i	1 to 6	7	8	9	10	11	12 to 49	50	51	52	53	54	55 to 92	93	94	95	96	97
CR(i)	128	128	128	128	128	128	128	128	129	135	140	142	142	141	132	93	54	44

i	98 to 135	136	137	138	139	140	141 to 178	179	180	181	182	183	184 to 221	222	223	224	225	226
CR(i)	44	44	45	51	56	58	58	58	72	128	184	198	198	198	200	205	211	212

i	227 to 264	265	266	267	268	269	270 to 307	308	309	310	311	312	313 to 360
CR(i)	212	212	202	163	124	115	114	114	116	121	127	128	128

Definition of C_B for digital active line with rise time = 300 ns

i	1 to 6	7	8	9	10	11	12 to 49	50	51	52	53	54	55 to 92	93	94	95	96	97
CB(i)	128	128	128	128	128	128	128	128	119	86	53	44	44	44	56	100	145	156

i	98 to 135	136	137	138	139	140	141 to 178	179	180	181	182	183	184 to 221	222	223	224	225	226
CB(i)	156	156	148	114	81	73	72	73	84	128	172	183	184	183	175	142	108	100

i	227 to 264	265	266	267	268	269	270 to 307	308	309	310	311	312	313 to 360
CB(i)	100	100	111	156	200	212	212	212	203	170	137	128	128

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