EBU Technical Information I15-1998 Testing for conformity with ITU-R Recommendations BT.601 and BT.656

EBU Committee	*First Issued*	*Revised*	*Re-issued*
PMC	1989	1998	

Keywords: Video (digital), Measurements/Alignment

1. Introduction

This document was originally produced by EBU Specialist Group G/DIAG in 1989 at the request of the Steering Committee of EBU Working Party G. It was a response to the widespread introduction of digital video signal processing equipment that claimed to be operating in accordance with ITU-R Recommendations BT.601[2] and BT.656[3]. This document outlines suitable conformity tests that EBU Members can use to verify for these claims. These tests relate to both type-acceptance and installation testing.

The Recommendation BT.601 is not sufficient to specify fully the performance of digital video equipment. It defines only the essential parameters for the sampling of a video signal. Other factors, not defined in the Recommendation, play an important part in the performance of equipment. Where possible, these parameters have been included in this document.

In this revised edition, only those parts have been changed which need to be updated following amendments of the Recommendations BT.601 and BT.656. The remainder of the text has been left without modifications because the test methods described are still useful and still in use today. The original Appendix 2 “Test instruments for component systems” has been withdrawn because the list is out of date and no longer comprehensive. The bibliography has also been updated.

This document contains a list of those parameters which is necessary to check if operations of “601” equipment is to be assured, and suggests methods by which this can be carried out. It is limited to consideration of the 4:2:2 level of ITU-R 601. It also does not include the additional special tests necessary for specific items of equipment, such as a digital VTR.

Appendix 1 contains details of test signals employed for the measurements described in this document. This list of test signals varies from the one described in the ITU-R Recommendation BT. 801[7].

In this document, all the signal levels described are considering to have 8-bit sampling. ITU-R Recommendation BT.601 permits an option of 10 bits, which is widely used in television production. This should be borne in mind when reading the document.

2. Performance parameters

Many of the parameters in the following list are additional to those strictly required for testing for conformity with Recommendation BT.601. However, it is considered necessary to check these parameters when evaluating or accepting equipment. Such parameters are marked with an asterisk (*).

2.1. ADC/DAC performance parameters

- Filtering of luminance signal and colour-difference signals (conformity with gain and delay templates)
- Luminance and colour-difference coding ranges
- Accuracy of R, G, B - to - Y, C_r, C_b and Y, C_r, C_b - to - R, G, B, matrices*
- Relative delays between the component signals*
- Co-siting of colour-difference samples
- Co-siting of colour-difference samples with the correct luminance samples
- Differential delays between the component signals*
- Black-level accuracy*
- Response to excessive amplitude signals*
- Monotonicity and linearity of converters*
- Relationship between digital and analogue active lines (position and length)
- Noise*

* This parameter is not included in ITU-R Recommendations BT.601 and BT.656

2.2. Signal processing

- Use of adequate word sizes within equipment*
- Rounding/truncation operation at interfaces*
- Generation of "illegal" Y, C_r, C_b combinations (resulting in negative values of R, G, B)*
- Transparency of digital signal processing*

2.3. Interfaces

- Correct operation of timing reference signals (TRS)
- Electrical characteristics of the interface
- Suppression of spurious 00/FF words

3. Possible test methods

3.1. ADC and DAC parameters

Recommendation BT.601 states only that the form of signal coding is uniformly-quantized PCM with eight bits per sample. For the luminance signal there are 220 quantization levels, with black corresponding to level 16 and peak white to level 235. For the colour-difference signals there are 225 quantization levels centred on level 128, which corresponds to zero analogue signal. Parameters such as linearity, monotonicity, gain accuracy, relative gain and delay inequalities and clamp performance are not specified; they are, however, vital to the overall performance of a system and should be measured.

3.1.1. Filtering

Annex III of ITU-R Recommendation BT.601 gives the templates for the sampling filters for luminance and colour-difference signals. The tolerances required are very narrow and measurement of filter responses to the accuracy required by the template is difficult. Consequently, it is not proposed that broadcasters should attempt to measure the filter characteristics precisely. Instead, when evaluating equipment, it should be verified that filters are of an appropriate type from a recognized competent manufacturer.

If it is desired to test a filter, suitable test signals are line-repetitive frequency sweeps covering 0.5-7 MHz for the luminance channel and 0.5-3.5 MHz for the colour-difference channels. It should be noted that bipolar signals may be required for the colour-difference channels if associated analogue circuits are included. The sweep can be observed with a high-quality oscilloscope or waveform monitor. (A suitable network analyser should be used if available, as it results in more-precise measurements. Its use is limited to cases where direct access to the filter is possible.)

The resolution of 8-bit sampling is insufficient to permit highly accurate filter testing by examination of the signal in the digital domain, but adequate results can probably be obtained. Use can be made of a high-quality DAC (taking account of any filtering that may take place in the DAC) or the digital data can be stored and then analysed.

If direct access to the DAC filter is not available, a digital test signal will be required if the effects of the ADC filter are to be avoided or if the DAC module has only digital inputs. The limitation of 8-bit sampling will restrict the accuracy of this measurement.

In addition, the output of the DAC module should be checked, using a spectrum analyser. No out-of-band signal below 80 MHz should exceed -40 dB with respect to the peak video level. This test should also be made with no video input signal, to show possible cross-talk from the clock signal and its harmonics.

The filter group-delay characteristic is also included in Annex III to ITU-R Recommendation BT.601. It can be measured sufficiently accurately by applying a pulse signal (1T for luminance channel and 2T for colour-difference channels) or a multipulse signal and checking the pulse symmetry.

3.1.2. Coding ranges

The DAC gain should be checked first, by injecting a known digital code into the DAC input; 16/235 or 128/240 are suitable values, corresponding to black level/peak-white in the luminance channel and zero/peak value in the colour-difference channels. Having calibrated the DAC, the ADC gain can now be checked by using the aligned DAC to restore an analogue test signal to analogue form for measurement: the combination of ADC and DAC should produce unity gain and no DC offset. To set the ADC gain, it is recommended that a differencing technique be used, employing a test signal such as colour bars or staircase.

3.1.3. Matrix accuracy

Matrixing can take place in the analogue or digital domain.

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* This parameter is not included in ITU-R Recommendations BT.601 and BT.656

A suitable test signal is the RGB colour-bar signal. The accuracy of this signal should first be checked with a video level meter. It can be used to check the corresponding signal levels on the luminance and colour difference channels, which should be within ~ 0.5% of the theoretical value. These limits assume that the input terminations are accurate to within ± 0.5%.

3.1.4. Sampling jitter

No figure is given in ITU-R Recommendation BT.601 for the stability, long-term or short-term, of the sampling clock. Since the clock frequency is usually locked to an external reference [5], e.g. a colour-black signal, a measurement of the clock frequency is meaningless, except as a check that the clock oscillator is indeed locked to the reference. Jitter, however, should be checked.

Before attempting to measure sampling clock signal jitter, the stability of the external reference, if used, must be checked.

Practical experience suggests that the short-term jitter of the sampling clock should be less that 3 ns peak-peak (Note that this is not related to the specification for clock jitter at a digital video output interface in ITU-R Recommendation BT.656).

Techniques for observing jitter on the sampling clock signal include that of combining the clock signal with a stable reference at the clock frequency (e.g. from a synthesizer), using the A + B mode on an oscilloscope (this requires the stable reference frequency to be adjusted for not observable drift and the display to be calibrated by adding a small calibrated delay to one signal path; the amplitude change is then related to the delay introduced). Alternatively, the clock signal and stable reference can be combined in a mixer and the low-frequency jitter component extracted by filtering.

3.1.5. Relative delays between the component signals

The maximum timing difference between components should not exceed 10 ns.

Three test methods have been evaluated, using modified bow-tie, pulse and lightning (colour-bar) display. The necessary signals are already in use for measuring delay differences between analogue component signals.

For reasons explained in *Section 3.1.6.*, the frequencies used for the bow-tie signal were changed to 2.5 MHz and 2.49 MHz in the luminance and chrominance channels respectively. Bow-tie test signals are more sensitive than pulse-type test signals.

Figs. 1, 4 and 7 show displays of bow-tie, pulse and colour-bar test-signals in the presence of a 10 ns relative delay between components.

3.1.6. Co-siting of colour-difference samples with each other and with the correct luminance samples

ITU-R Recommendation BT.601 states that the colour-difference samples are co-sited with each other and with alternate (i.e. first, third, fifth, etc.) luminance samples. There may exist relative delays between the components at the sampling instants, arising from filter and other delays and compensating delays may exist at the ADC and DAC.

Three methods have been evaluated, using modified bow-tie signals, pulse signals and colour-bar signals.

The bow-tie signal is already in use for measuring delay differences between analogue component signals, although the frequencies currently used for the application are not ideal for use in digital component testing. By changing the frequencies to 2.5 MHz and 2.49 MHz in the luminance and chrominance channels respectively, a delay difference of one clock period will produce a very characteristic display which indicates both the channel in which the error exists and its sense, i.e. early or late. This is illustrated in Fig. 2. The same test can be used to verify that the colour-difference signals are co-sited with the correct luminance samples (Fig. 3.)

The modification of the bow-tie signal frequencies increases the sensitivity of the technique to relative delays. In the case of siting errors, the indication will be of an error related to the clock period (74 ns), whereas relative delays will be of smaller magnitude and will not be related to the clock period. Both types of error can, of course, co-exist.

A pulse test signal can also be used, of a duration appropriate to the channel bandwidths. 8T or 10T luminance pulse signals are also suitable, combined with a pedestal in the case of the colour-difference channels, as shown in *Fig 4*. The channel outputs can then be viewed on alternate scans of an oscilloscope triggered at line rate or using the A-B facility. This is illustrated in *Figs. 5* and *6.*

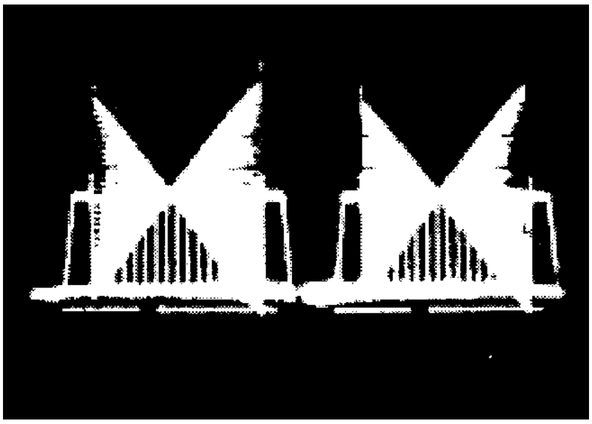

Fig. 1 - Bow tie display for correct siting of samples but with a small relative delay of 10 ns

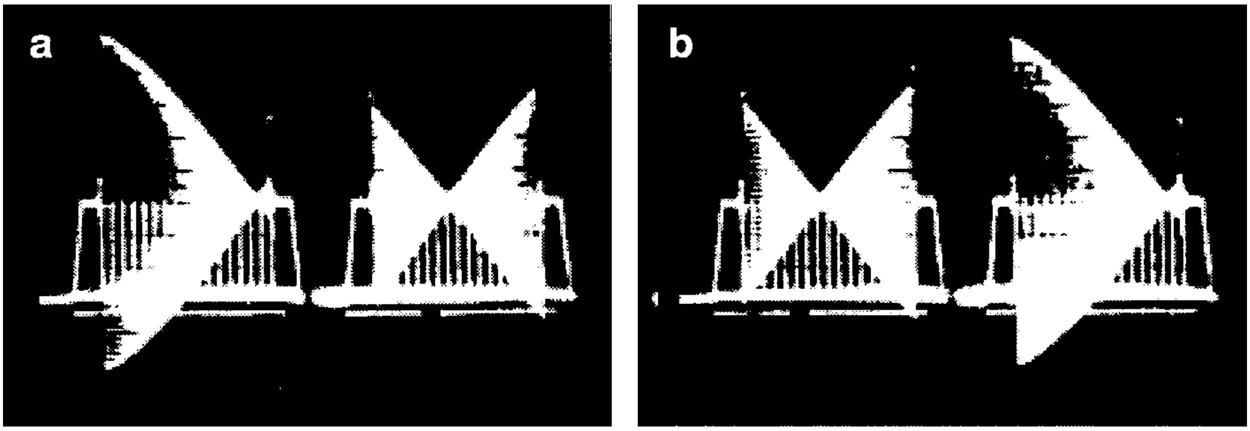

Fig. 2 - Bow-tie displays for chrominance samples not co-sited with each other:

(a) C_b early with respect to C_r

(b) C_r early with respect to C_b

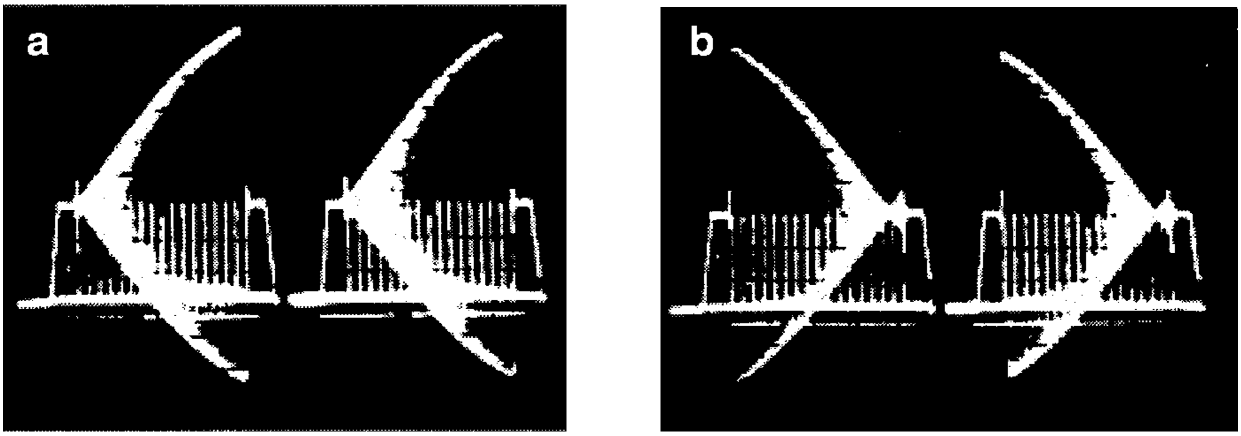

Fig. 3 - Bow-tie displays for chrominance samples not co-sited with the correct luminance samples:

(a) Late site (b) Early site

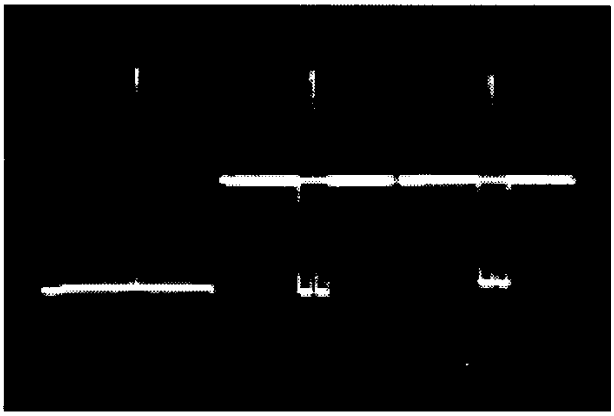

Fig 4 - 10T pulse signal used to check co- siting

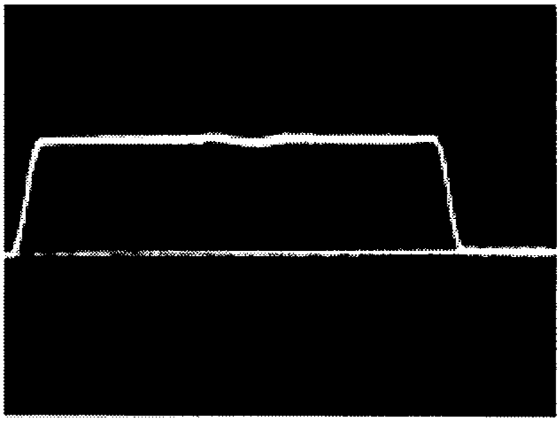

Fig 5 - Pulse display for correctly co-sited samples but with a small relative delay of about 10 ns

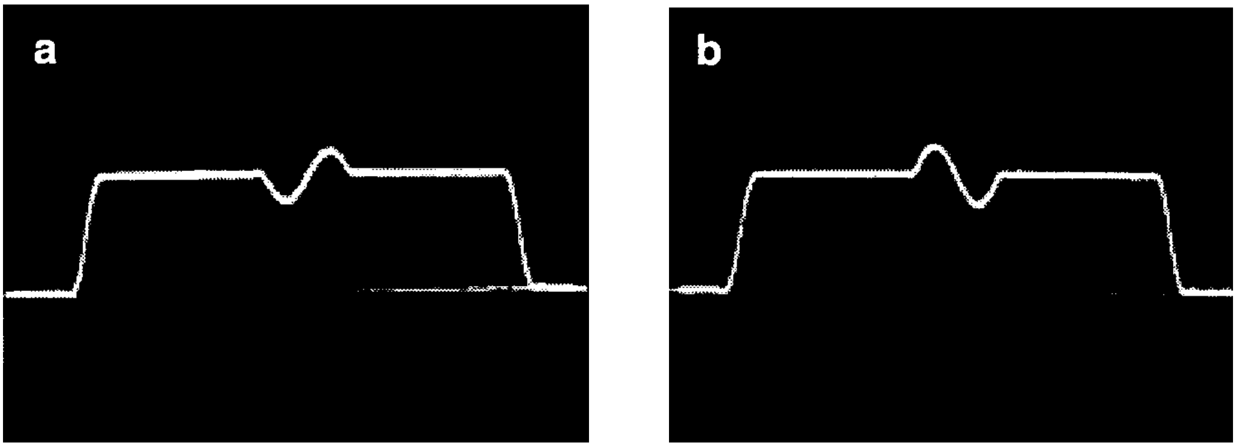

Fig 6. -Pulse display for chrominace samples not co-sited with each other,
(a) C_b early with respect to C_r (b) C_b late with respect to C_r.

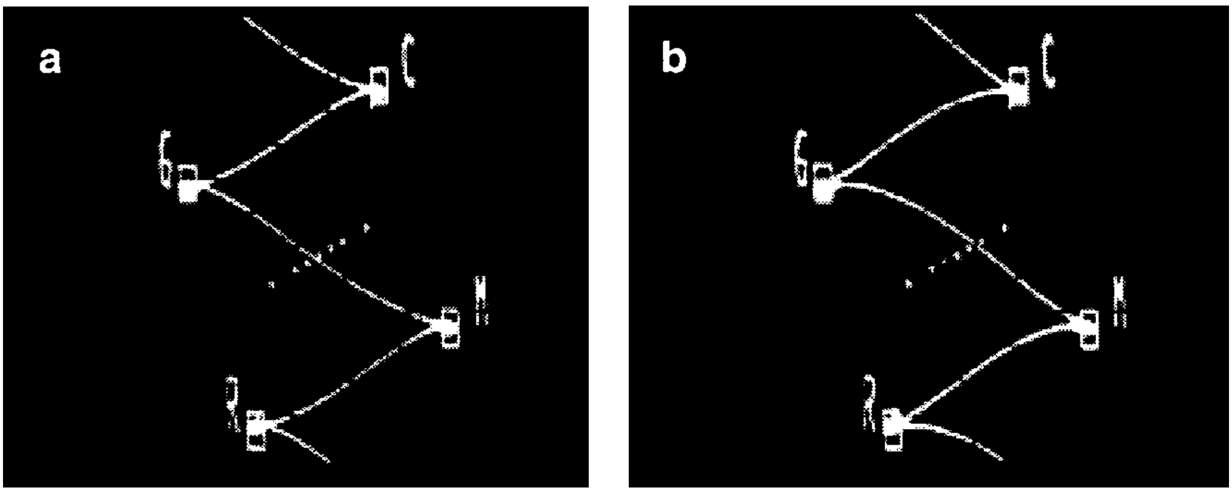

Fig 7 - Use of lightening isplay to check timing,
(a) correct sampling site but with a small relative delay of about 10 ns between channels
(b) chrominace sample on incorrect site

It is also possible to use a component colour-bar signal, viewing the results on a lightning display. The centre portion of the display contains information about timing differences between the components. This is a less convenient test than the bow-tie or pulse methods, since it requires a special waveform display unit. The display is illustrated in *Fig. 7*.

3.1.7. Black-level accuracy

It is necessary to check that the ADC clamp, if present, does not introduce a DC offset (static error).

The absence of a black-level reference in the digital data-stream means that the black-level accuracy of the ADC is of great importance. Black level is defined as corresponding to level 16 (luminance) or level 128 (colour-difference).

Clamp alignment accuracy can be checked by applying a black-level signal to the ADC and checking for level 16 at the ADC output and "black" at the DAC output.

Low-frequency effects can be observed by applying a 700 mV bar-on/bar-off test signal to the ADC and checking that the error is less than one quantum level in both the bar-on and bar-off conditions. This is the normal clamp test; since it will produce overshoots, a check should be made that spurious 00/FF codes are not produced.

3.1.8. Response of the ADC to out-of-range signals

In the luminance channel, signal levels going more positive than 760 mV must result in the coder output remaining at level FE (decimal 254). Similarly, for input signals going more negative than -48 mV the output must remain at level 01. Levels FF and 00 are reserved for synchronization purposes.

In the colour-difference channel, input signal levels exceeding +394 mV or -397 mV must result in the output of the coder remaining at levels FE or 01 respectively.

Suitable test signals are an adjustable pedestal signal or an over-range line-rate ramp. If the inputs to the encoder are in RGB from, the Y, C_r, C_b channels can be tested by applying an over-range RGB colour-bar signal (to the same limits as defined above for the luminance channel).

3.1.9. Linearity and monotonicity

This can be checked by applying a line-rate ramp at full amplitude to each channel and observing the result of subtracting the input signal (suitably delayed) from the output of a DAC. The residual error should be less than one least-significant bit (LSB).

3.1.10. Relationship between digital and analogue active lines

It is necessary to check that the digital active line is of the correct length and is correctly timed relative to the input analogue active line. Similarly, the timing relationship between the decoded analogue signal and the associated analogue synchronizing signal should be checked.

To test the length and position of the digital active line, a suitable test waveform has been proposed to the ITU-R by TDF. It comprises band-limited pulses marking the ends of the analogue and digital active lines, as illustrated in Fig. 8.

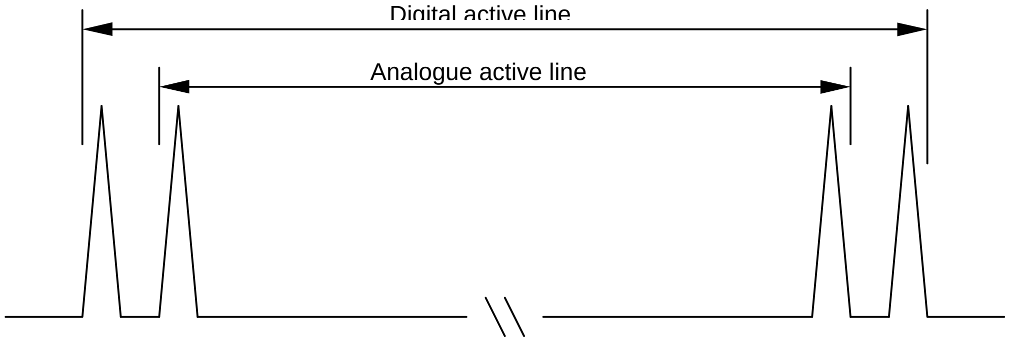

Fig. 8 - Test signal to check the timing relationship between analogue and digital active lines

In order to explore the full digital active line, a test signal extending beyond the normal analogue active line is required. Analogue component test signal generators capable of generating such signals are becoming available and these could be programmed to produce the proposed test waveform.

There have been instances of equipment that inserted spurious data into the digital active line outside the area of the analogue active line, and then relied on blanking in the DAC to conceal it. Whilst this may not cause problems in an equipment with analogue inputs and outputs, it could be serious if any digital filtering or picture compression were to be applied. If the output blanking can be disabled, the presence of spurious data can be revealed. Alternatively, a DAC connected to a digital output with a known input (e.g. black level) will also show this defect.

3.1.11. Quantization noise

The usual method employed for the measurement of quantization noise is to apply a shallow line-repetitive ramp signal to the ADC. This is then removed by high-pass filtering at the output of the DAC, the residual signal being the quantization noise.

The theoretical signal-to-noise ratio for an 8-bit converter conforming to Recommendation BT.601 or BT.656 is 57.6 dB (peak-peak signal to RMS quantization noise) and the measured quantization noise should not degrade this figure by more than 2 dB.

3.2. Signal processing parameters

3.2.1. Use of adequate word sizes

This is not a requirement of Recommendation BT.601 or BT.656. However, the use of word sizes within an equipment which are too small for the necessary signal resolution will degrade the performance of the equipment, and this should be checked.

The effect of an inadequate internal word size in fading and mixing operations is to produce coherent, visible quantizing effects on line-repetitive test signals such as shallow ramps. These are the most critical test signals, although for design the headroom in a digital filter an impulse signal such as a 2T pulse can be used. Suitable tests for the adequacy of word size have yet to be devised.

3.2.2. Transparency of digital signal processing

A common defect of some special effects equipment is that, in the "straight-through" mode when no effect is in use, there is a residual distortion of the input signal. Examples of such distortions would be picture-size differences, timing shifts and changes in blanking or gain.

Although the variety of forms of these distortions precludes specific tests, those evaluating digital equipment should be mindful of the possibility of their existence.

3.2.3. Rounding/truncation

Several methods exist whereby a data word of a given size can be reduced to a smaller size, as may be required for passing through an interface between equipment. Simple truncation or rounding produces visible impairments (contouring) on critical picture material. Alternative methods exist to increase the apparent word size, and thus the subjective quality. However, these methods tend to increase, or alter the spectrum of, quantization noise on some samples. A shallow blue ramp is a particularly critical test signal for revealing these kinds of impairments.

3.2.4. Generation of illegal colours

Equipment should not generate values of Y, C_r, C_b which correspond to negative or excessive values of R, G or B, except as transients. These could be generated, for example, as a result of incorrect operation of a limiter in the Y, C_r C_b domain.

Some equipment incorporates circuits to restrict the Y, C_r, C_b signal values to conform with legal RGB signals. Consequently, test signals containing illegal values will be modified.

Test instruments are available which indicate "illegal" colour generation. [*]

3.3. Interface parameters

ITU-R Recommendation BT.656 specifies the digital video interfaces, both parallel and serial, for use in digital video studios. Equipment for use in digital television studios should employ interfaces which conform to this Recommendation in terms of signal format and electrical characteristics.

3.3.1. Correct operation of timing reference signals (TRS)

Correct operation of the timing reference signal is essential to downstream equipment and should be checked. This can be achieved by the use of a high-speed logic analyser or dedicated test instrument. [**]

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[*] For example. Tektronix WFM300, WFM601

[**] For example: Rohde & Schwarz VCA; AAVS DSA 309; Philips PT 5474; Synthesys DVA 184.

3.3.2. Electrical parameters

The most important of the electrical parameters is probably the ability of the line receiver to operate under the worst-case input conditions. These are specified in terms of eye width and height in Recommendation BT.656 and the most straightforward way of creating these conditions is to use a suitable length of appropriate cable driven from a known good source. It is largely cable loss that will control the eye height and width, although the latter will also be affected by clock-to-data jitter and crosstalk between signal pairs. A critical signal for testing interfaces is digital grey, which has Y = 127 (7F), $C_r = C_b$ = 128 (80).

The other parameters can be measured using conventional test instruments.

3.3.3. Suppression of spurious 00/FF words

Digital words 00 and FF are reserved for synchronization purposes. They must not appear in the data-stream except as part of the timing reference signal or the ancillary identification preambles, but could be created as a result of signal processing, in which case they must be suppressed.

The occurrence of words 00 and FF can be detected by a high-speed logic analyser or by instruments designed for operation on digital video systems [**]

4. Recommendation

It is recommended that the following parameters should be checked when accepting equipment claimed to conform to ITU-R Recommendations BT.601 and/or BT.656.

- ADC amplitude-vs.-frequency response
- ADC filter group delay
- ADC coding range (gain)
- Matrix accuracy
- Sampling jitter
- Black-level accuracy
- ADC linearity and montonicity
- Correct digital line length/timing.

When evaluating a new type of equipment, the following parameters should be checked, in addition to those listed above:

- Co-siting of samples
- Differential delays
- Response to out-of-range signals
- Use of adequate word sizes
- Quality of word size reduction (rounding)
- Correct operation of Recommendation BT.656 interfaces.
- In order to perform the checks, the following test signals should be available.
- Modified bow-tie (or 8T (or 10T) pulses)
- Frequency sweep
- Colour bars
- lT and 2T pulses (or multipulse signal)
- Line-rate ramp
- Line length/timing test signal
- Adjustable pedestal
- Bar on/off
- Digital grey.

Details of these signals are given in *Appendix 1*.

[**] For example: Rohde & Schwarz VCA; AAVS DSA 309; Philips PT 5474; Synthesys DVA 184.

Appendix 1: Test signals

It should be noted that some of the following test signals will produce "illegal" values of R, G or B signals if dematrixed.

1. Modified bow-tie signal

Comprises line-repetitive sinusoids on pedestals, with frequencies of 2.5 MHz in the luminance channel and 2.49 MHz in the colour-difference channels and phased to produce cancellation at the mid-point of the active line when either colour-difference is subtracted from the luminance signal.

Ideally, the signal should incorporate markers on a few lines in the luminance channel, indicating 10 ns intervals.

2. 8T (or 10T) pulse

May be used for checking timing errors between channels and co-siting errors. For this purpose the luminance channel carries a full-amplitude pulse and both colour-difference channels carry a full-range positive-going pulse on a peak-amplitude negative pedestal.

3. Frequency sweep

Luminance channel: 0.5 - 7 MHz

Colour-difference channels: 0.5 - 3.5 MHz

4. Colour bars

Both RGB and component versions are required, with correctly timed transitions (if lightning display is used).

5. 1T and 2T pulses

Used to check filter group delay distortion.

6. Multipulse signal

A sequence of 20T pulses modulating sinusoids at 1, 2, 3, 4 and 5 MHz in the luminance channel and at 0.5, 1, 1.5, 2 and 2.5 MHz in the colour-difference channels (the 0.5 MHz modulation is by a 40T pulse).

7. Line-rate ramps

Ideally, these should be available at both normal amplitude and high amplitude, to check ADC over-range performance and the production of spurious 00 and FF codes.

8. Shallow ramp

A 70 mV peak-to-peak signal on an adjustable pedestal, required for checking quantization noise and rounding effects.

9. Line timing and line-length test signal

This signal comprises parts of shaped pulses at each end of the television line. The outer pair indicate the position of the start and finish of the digital active line and the inner pair perform the same function for the analogue active line. It is fully defined as signal No. 3 in [7].

10. Adjustable pedestal

Should be adjustable to include out-of-range values.

11. Bar on/off signal

Used for clamp performance checks. The signal should have a period of 2 seconds for low-frequency checks, to allow time for the black level to settle for measurement.

12. Digital grey

Used to check the operation of parallel digital interfaces. The data words 127 in the luminance channel and 128 in the colour difference channels result in the signal energy being concentrated at high frequencies, which are least well transmitted by the transmission medium. Sample values are defined as signal No. 1 in [7].

Bibliography

[1] EBU Technical Recommendation R57-1998: **Testing for conformity with ITU-R Recommendations BT.601 and BT.656**.

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

[3] ITU-R Recommendation BT.656-4: **Interfaces for digital component video signals in 525-line and 625-line television systems operating at the 4:2:2 level of Recommendation 601**.

[4] EBU document Tech. 3267 (1992): **EBU interfaces for 625-line digital video signals at the 4:2:2 level of CCIR Recommendation 601**.

[5] EBU Technical Standard N14-1998**: Specification of a reference signal for the synchronization of 625-line component digital equipment**.

[6] ITU-R Recommendation BT. 711-1: **Synchronizing reference signals for the component digital studio**

[7] ITU-R Recommendation BT.801-1: **Test signals for digitally encoded colour television signals conforming with Recommendations ITU-R BT.601 (Part A) and ITU-R BT.656**

[8] EBU document Tech. 3283 (1996): **Measurements in digital component television studios. 625-line systems at the 4:2:2 and 4:4:4 levels using parallel and serial interfaces (SDI).**