Methods for the measurement of the characteristics of CCD cameras

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CONTENTS

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Introduction

The scope of this document is the evaluation of the video performance of solid-state colour television cameras using charge-coupled device (CCD) sensors. The methods are applicable to cameras used in all areas of television programme-making: studio production, electronic field production (EFP) and electronic news-gathering (ENG). The aspect ratio considered is 4:3, but most of the methods described can easily be adapted to the aspect ratio of 16:9.

A similar document (EBU document Tech. 3238 [1]) was published in 1983 for tube cameras and certain of the methods described there remain applicable to CCD cameras. The specific characteristics of CCD cameras have, however, led to the development of a number of new measurement methods.

The document has been prepared by Specialist Group G4/SENSORS of the EBU Technical Committee with a view to the establishment of standard methods for measuring the characteristics of new generations of CCD cameras. It is designed to assist broadcasters and manufacturers with the evaluation and comparison of CCD production cameras.

Chapter 1

General conditions

1. Test charts

Most of the methods described in this document use special test charts whose reproduction by the camera under test is evaluated either by measuring the output signals, or by measuring any distortions on a high-quality monitor screen.

All the test charts presented in this document are rectangular and have an aspect ratio of 4:3 (width/height), corresponding to the proportions of conventional television displays.

In practice, the test charts can be transparent or reflective.

2. Illumination

2.1. Using transparent test charts

Two types of light box can be used for transparent test chart illumination, as shown in *Fig. 1.*

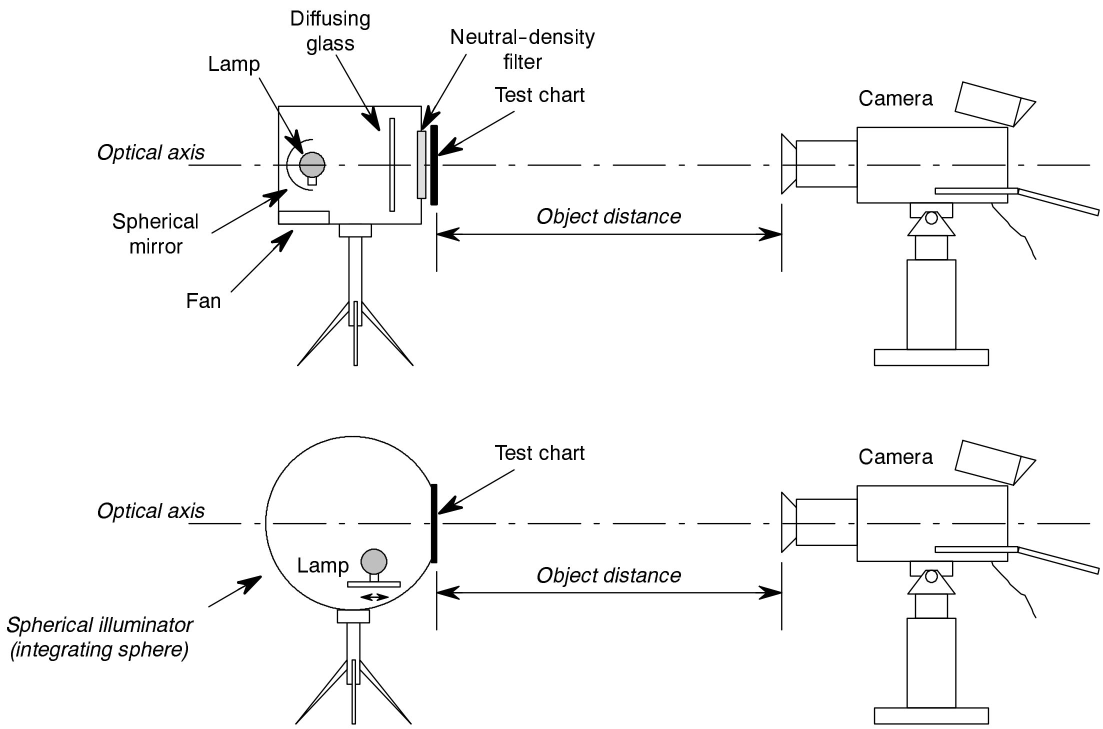


Fig. 1 - Examples of arrangements for the mounting and illumination of transparent test charts.

The first type comprises a set of fluorescent tubes mounted behind a diffusing screen. Problems may arise due to poor uniformity of test chart illumination.

The second type of light box comprises a tungsten filament light source, powered by a stabilized source, which illuminates a diffusing sphere. The luminous flux and colour temperature at the output window, where the transparencies are placed, are very uniform and easily adjusted.

2.2. Using reflective test charts

In the case of reflective test charts, illumination is by means of two quartz halogen lamps having a colour temperature of 3100 ± 100 K. They are placed on either side of the perpendicular through the centre of the test chart (*Fig. 2*).

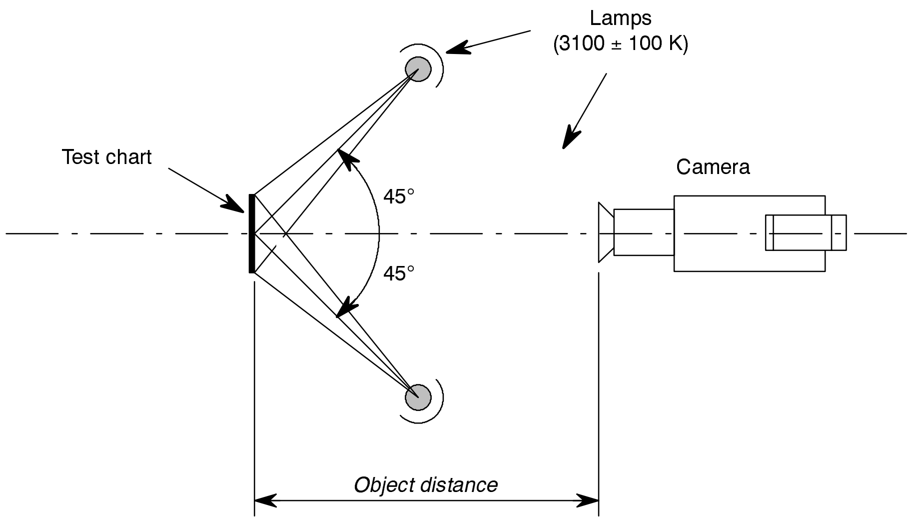


Fig. 2 - Arrangement for illumination of reflective test charts.

2.3. Precautions

Whichever form of test chart and light source is used, the colour temperature must be checked prior to each measurement.

Adequate uniformity of illumination can be achieved by adjusting the distance of the sources, or by defocussing them. Ideally, the uniformity of illumination should be within 1%, but 5% is acceptable in practice. The luminous intensity can be adjusted without changing the colour temperature.

During measurements, care must be taken to ensure that the supply voltage remains constant, otherwise changes in the colour temperature of the sources may occur.

3. Lens adjustments

The lens should be adjusted to give optimum performance. Proposed values for the various lens parameters are as follows:

Aperture: *f* /4, *f* /8 (ideally *f* /5.6).

Object distance: Typically 3m (adjusted to suit the requirements of the measurement to be done).

Focal length: a suitable focal length in the medium focal length range.

In general, settings of the parameters near the ends of the lens adjustment ranges should be avoided.

4. Test conditions

The camera is positioned in such a way that its optical axis coincides with the perpendicular through the centre of the test chart.

As the test environment is usually a television studio, which has sources at typically 3100K, the filter wheel in the camera is set at 3200K.

The camera must be lined up with the test chart so that the edges of the image, indicated by arrow-heads, match up perfectly with the normal picture area reproduced on a monitor set to under-scan.

Except where indicated otherwise, the camera controls should be set as shown in *Table 1*:

Table 1 - Basic settings of main camera and lens controls.

Control	Basic setting
Gain	0 dB
Flare corrector	ON
Black balance with lens capped	35 mV
White balance	700 mV
Colour corrector	ON
Contour corrector	ON
Noise reducer	OFF
Black and white shading correctors	ON and optimized
Gamma corrector	ON and calibrated
Dynamic knee corrector	ON
Exposure time	nominal value (= 20 ms)

For each measurement procedure described in *Chapter 2* of this document, a Table is given which indicates specific settings which are different to those of *Table 1*.

The effect of switching the correctors ON and OFF should be negligible on the white and black balance and on the white and black levels; the levels indicated correspond to the normal source levels in 75 Ω.

When making the measurements, care must be taken to ensure that the general alignment is maintained.

5. Recommended measuring equipment

The following equipment is needed in order to carry out the full range of CCD camera evaluations described in this document:

- Transparent and reflective test charts.
- Video oscilloscope with sufficient bandwidth for TV mode synchronization.
- Digital wide-band storage oscilloscope with averaging function.
- Spectrum analyzer.
- High-quality monochrome monitor.
- Grade-1 colour monitor.

- Video amplitude analyzer with marker or signal-difference video amplifier.
- Adjustable delay lines (0 to 100 ns in 5 ns steps).
- 500 kHz or 1 MHz low-pass filters
- Wide-band voltmeter or video noise meter.
- Photometer (luminance, colour temperature measurements).
- Carousel for presentation of grey samples and colour samples.
- Waveform monitor.
- Differential amplifier.

6. Presentation of test results

A clear form of presentation of the results of tests is essential, especially if comparisons are to be made with tests done in other organizations.

The measurement results obtained *must* be accompanied by details of the camera and lens used: model, type, serial number, etc...

Chapter 2 of this document indicates recommended forms of presentation of results for each type of test.

Chapter 2

Measurement methods

This Chapter gives details of measurement procedures for the following characteristics of CCD cameras:

- Sensitivity
- Maximum sensitivity
- Signal-to-noise ratio (random noise and fixed-pattern noise)
- Horizontal static resolution
- Aliasing
- Registration
- Geometry
- White shading or white level non-uniformity
- Black shading or black level non-uniformity
- Streaking
- Flare
- Transfer law or gamma correction
- Smearing
- Over-exposure headroom
- Blemishes
- Image format
- Colorimetric fidelity measurement

Each Section begins with a definition of the characteristic. This is followed by a description of the equipment used and the adjustments of the camera and lens, and the description of the measurement procedure. This includes, where necessary any equations needed to convert measurement results into a value (or series of values) quantifying the characteristic. Finally, guidance is given on the form of presentation of the results, with the aim of ensuring that results of measurements made in different organizations, or by equipment manufacturers, can be meaningfully compared.

The order of presentation of the measurement procedures in this document does not imply any order of importance of the corresponding characteristics.

1. Sensitivity

1.1. Definition

Sensitivity is measured as the illumination value required, on a test chart with a given reflection factor, to produce a nominal signal at the camera output, at a calibrated lens aperture.

1.2. Equipment used

Test chart

A reflective test chart having at least two neutral samples of suitable dimensions to avoid edge effects (streaking, diffused light, shading) is recommended. One of the surfaces has a reflection factor of at least 60% over the whole visible spectrum and the other has a spectral reflection factor uniformly equal to 0.1%.[1]

Sets of neutral samples are suitable for this test, or a "grey scale" test chart of the kind represented in *Fig. 3* may be used.

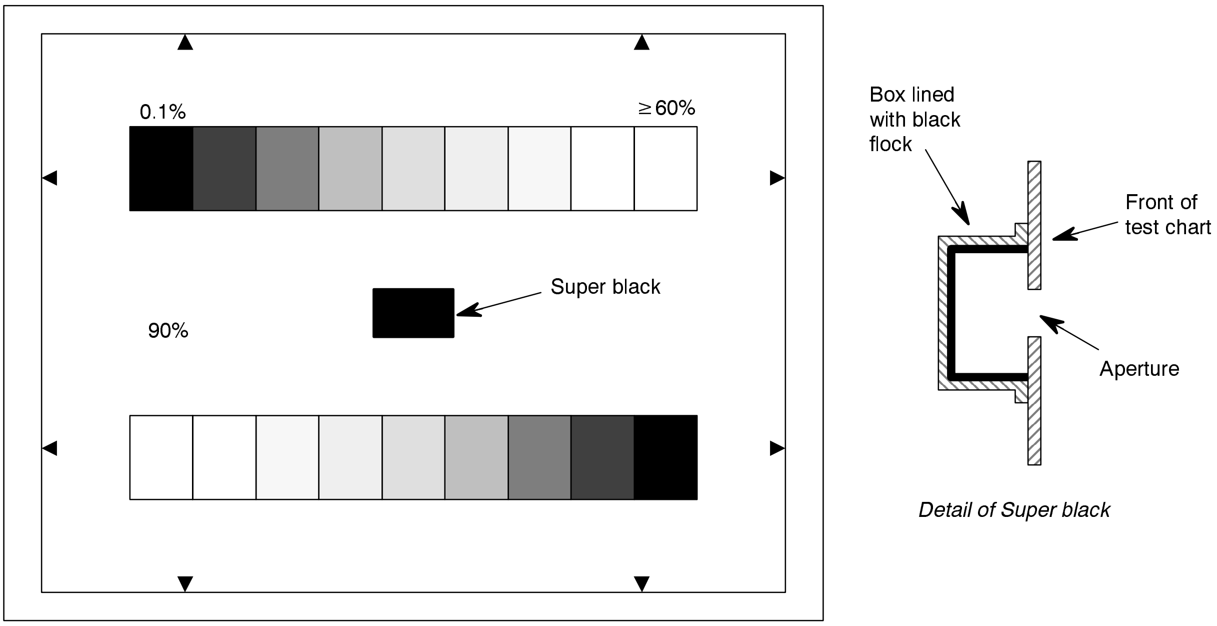


Fig. 3 - Example of a test chart for the measurement of sensitivity.

Measuring equipment

- Light meter or photometer.
- Video oscilloscope or sampling video voltmeter.

1. Two commonly-used test charts have reflection factors for "white" of 60% and 90% respectively. Either may be used.

1.3. Measurement conditions

Note: Because of the inaccuracy of *f*-stop calibration in current lenses, a calibrated lens is preferred for this measurement.

The test chart is evenly illuminated by a source having a colour temperature of 3100 ± 100K.

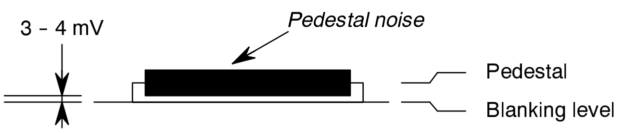
The measurement is made on the part of the video signal corresponding to the part of the test chart with 60% (or more) reflectance.

The camera and lens controls are set as follows:

Control		Setting for this measurement
Gain		0 dB
Flare corrector		ON
Black balance with lens capped		35 mV
White balance		700 mV
Colour corrector		ON
Aperture/contour corrector		ON
Noise reducer (“coring”)		OFF
Black and white shading correctors		ON and optimized
Gamma corrector		OFF
Dynamic knee corrector		OFF
Exposure time		nominal value (= 20 ms)
White clipper		OFF
Pedestal		*Note 1*
Iris	2/3-inch CCD image format 1/2-inch CCD image format	*f* /4.0 *f* /2.8
Zoom focal length		*Note 2*

Notes:

1 The pedestal is adjusted in such a way that the lower part of the noise on the black reference of the chart is just above the blanking level (normally 3 to 4 mV). See figure below:



2 Lens adjustment is optimized for satisfactory measurement (the effect of vignetting should be minimized).

1.4. Measurement procedure

The white part of the test chart, having a reflection factor 60% or more, is regarded as equivalent to a Lambert radiator. The corresponding video signal at the output of the green channel (G) is measured. If the G signal is not available (which may be the case with some portable cameras), the measurement is made on the coded signal (Y), taking care to first balance the white of the camera (minimum sub-carrier).

The illumination level incident on the test chart is adjusted until the nominal amplitude of 700 mV in 75Ω is obtained in the green channel (or coded luminance, Y).

The illumination incident on the test chart plane is then measured.

Notes:

1. Care must be taken to ensure that the colour temperature of the light incident on the test chart remains constant when the flux is adjusted.
2. If possible, the lens should be calibrated in *T* values. It must be borne in mind that two lenses having the same *T* values give images of the same light intensity; this may not be the case for identical *f* values if the lenses have different transmission factors *t*. The relation between *T* and *f* is as follows:

$$T = \frac{f}{\sqrt{t/100}}$$

1.5. Presentation of results

The results are to be presented as follows:

Sensitivity

CCD format:	2/3-inch:	Sensitivity = **xxxx** LUX at *f* /4 or *T*/4
	1/2-inch:	Sensitivity = **xxxx** LUX at *f* /2.8 or *T*/2.8

Conditions:

White reflectance factor:	60%
Nominal G (or Y) signal:	700 mV / 75Ω
Illumination colour temperature:	3100 ± 100 K

Notes:

1. The results that are recorded should be those corresponding to 60% reflectance in the white area. If a 90% reflective test chart is used, the measurements, in lux, should be multiplied by 1.5 to present the results corresponding to 60 % reflectance.
2. These results can be used to derive the illumination required for apertures other than those specified for the measurements. The following formula should be used:

$$E_s = E_m \times (s/m)^2$$

where:

E_s is the illumination required to give an output signal of nominal amplitude with the iris setting *f* /*s*;

E_m is the illumination measured with the iris setting *f* /*m* at which the measurement is made.

2. Maximum sensitivity

2.1. Definition

Maximum sensitivity is defined as the minimum illumination value which guarantees the nominal video signal level for defined camera settings (maximum video gain).

2.2. Equipment used

The test chart and equipment are the same as for the nominal sensitivity measurement described in *Section 1*.

2.3. Measurement conditions

The measurements are made on the part of the video signal corresponding to white.

The camera and lens controls are set as follows:

Control		Setting for this measurement
Gain		Maximum
Flare corrector		ON
Black balance with lens capped		35 mV
White balance		700 mV
Colour corrector		ON
Aperture/contour corrector		ON
Noise reducer ("coring")		OFF
Black and white shading correctors		ON and optimized
Gamma corrector		OFF
Dynamic knee corrector		OFF
Exposure time		nominal value (= 20 ms)
White clipper		–
Pedestal		–
Iris	2/3-inch CCD image format 1/2-inch CCD image format	Maximum aperture *Note*
Zoom focal length		Close to minimum

Note: It should be borne in mind that the splitter may have a different aperture.

2.4. Measurement procedure.

The illumination is set in such a way that for the white part of the test chart, the level of the video signal, measured at the output of the green channel (or Y output), is above its nominal value.

To simulate a reduction in test chart illumination, without changing the colour temperature of the source, a calibrated attenuator filter is placed before the front lens of the zoom.

The attenuation is increased by adding neutral filters until the nominal video level (700 mV/75Ω) begins to decrease.

The attenuation value, corresponding to the total density of the filters, is noted.

Another way of lowering the illumination produced by a quartz studio lamp is to de-focus its luminous flux by means of its internal spherical mirror.

The maximum sensitivity is then calculated as follows. First the attenuation is determined:

$$A = 10^D$$

where: A is the total attenuation of the filters;

D is the sum of the filter densities.

After the test chart illumination E has been measured, the sensitivity S is given by the equation:

$$S = E/10^D$$

If transmission factors are given instead of densities, then:

$$D = \log\frac{100}{t}$$

where: t is the transmission factor expressed as a percentage.

2.5. Presentation of results

This measurement does not indicate the impairment of the picture quality when the camera is set to maximum gain, which will depend on the different techniques used for contour correction, bandwidth reduction, etc. A rough idea of the quality should therefore be given by a measurement of the unweighted signal-to-noise ratio and horizontal resolution under these conditions.

The results are to be presented as follows:

Maximum sensitivity

Maximum sensitivity = **xxx** LUX at *f* /1.4 (or actual maximum aperture)

Conditions:	
White reflectance factor:	60%
Gain:	+ **xx** dB
Complementary measurements:	
Signal-to-noise ratio (unweighted):	**xx** dB
Resolution:	**xx** % at **xx** MHz

3. Signal-to-noise ratio (random noise)

In a CCD image pick-up device, two types of noise affect the picture quality: random noise and fixed-pattern noise. Accordingly, two signal-to-noise ratio values have to be considered. This *Section* is concerned with the measurement of random noise; fixed-pattern noise is considered in *Section 4.*.

3.1. Definition

The various contributions to random noise can be summed up as follows:

Reset noise This noise is due essentially to uncertainty over the value of the reset potential of floating diffusion at the output.

Owing to the thermal noise generated in the recharge transistor channel, the potential at the capacity output fluctuates randomly.

Output amplifier noise This noise is associated with the amplifier transistors connected to the floating diffusion of the CCD output. This noise conforms to a $1/f$ law at low frequencies. It becomes virtually white noise at frequencies in the range from 1 MHz to 3 MHz.

Dark current The origin of this current is the thermal generation of electron-hole pairs which accumulate in the nearest potential well. This dark current fluctuates and the resulting signal is a shot noise which depends on the integration time and temperature of the device.

Signal fluctuation Detection of an optical signal is accompanied by noise due to the quantum nature of the photons absorbed (noise according to Poisson's law).

3.2. Equipment used

Test chart

Overall white reflective or transparent test chart.

Measuring equipment

- Video noise meter.

For some measurements, appropriate bandwidth limiting or noise weighting have to be placed between the camera and the measuring equipment. These standardized filters are described in document EBU Tech. 3238 [1]. (See also Part C, Annex II, para. 1 of CCIR Recommendation 567 [2])

3.3. Measurement conditions

In addition to the random noise of the CCD sensors, the overall signal-to-noise ratio is affected by noise generated in the video signal processing channel: wide-band amplifier, contour correction, colour correction (masking), non-linear corrections, encoder subcarrier balance. In order to separate the effects of these processes, it is recommended that measurements be made under three sets of conditions, listed in the table on *page 16*. It is permissible to adjust the encoder sub-carrier balance to obtain the minimum noise level in each condition.

3.4. Measurement procedure

Condition A

The camera lens is capped and the black-level control adjusted to 5% of the nominal video level to avoid clipping of noise at blanking level.

Control	Setting for Condition A	Setting for Condition B	Setting for Condition C
Gain	0 dB		Maximum
Flare corrector	ON		
Black balance with lens capped	35 mV		
White balance	700 mV		
Colour corrector	OFF	ON	
Aperture /contour corrector	OFF	4MHz, 0 dB, level dependency at lower position	
Noise reducer ("coring")	OFF		
Black and white shading correctors	ON and optimized		
Gamma corrector	OFF (gamma = 1)	ON and calibrated (gamma = 0.45)	
Dynamic knee corrector	OFF	Automatic	
Exposure time	nominal value (= 20 ms)		
White clipper	-		
Pedestal	-		
Iris 2/3-inch CCD image format 1/2-inch CCD image format	- -		
Zoom focal length	-		

Condition B

With the lens capped, the black level is adjusted to 10% of the video signal level. (It is assumed that a pedestal of 10% corresponds to a well-defined linear portion of the gamma law.) The lens cap is then removed and the camera directed at the reflective or transparent test chart. The lens is then de-focussed.

The amplitude of the video signal is adjusted, by modifying either the test chart illumination or the iris so that its value, 346 mV, corresponds to the point of unity gain (0 dB) on the transfer curve (Gamma = 0.45).

Condition C

The procedure is the same as for *Condition B*, except that the gain is set to its maximum value.

For the three sets of conditions A, B and C, the measurements are made with the noise meter, within a band extending from 100 kHz (or 200 kHz depending on the equipment) to 5 MHz. The upper frequency limit is defined by a band-pass filter with sharp cut-off, and the lower limit is defined by the low-pass filter defined in Part C, Annex II, para. 1, of [2].

Depending on the equipment used, results will be given either as the RMS value of the noise, or as a direct indication of the signal-to-noise ratio.

These measurements can be made on any of the signals at the output of the camera: luminance (Y), or coded Y luminance signal with a sub-carrier filter when the Y output is not accessible.

For luminance signal measurements, the measurement is made both with and without the weighting filter specified in Part C of [2].

For each of the measurements, the value of the signal-to-noise ratio is recorded (or calculated).

The results are expressed in decibels (dB) with reference to the nominal level (700 mV) corresponding to a white level of 100%.

The signal-to-noise value for the luminance signal is determined as follows:

$$S/N = 20 \log \frac{nominal\ signal\ level}{RMS\ noise\ level} \ \text{dB}$$

3.5. Presentation of results

The results are to be presented as follows:

Random noise

$S/N_{luminance}$ = 20 log (nominal signal/RMS noise)

Conditions	*weighted S/N*	*unweighted S/N*
A	**xx.xx** dB	**xx.xx** dB
B	**xx.xx** dB	**xx.xx** dB
C	**xx.xx** dB	**xx.xx** dB

Notes:

1. Measurements could also be made on the RGB signals; this would be helpful for checking purposes.
2. If the aperture/contour correction cannot be switched OFF for *Condition A*, this should be indicated with the results.

4. Signal-to-noise ratio (fixed-pattern noise)

4.1. Definition

Fixed-pattern noise is a static noise resulting from various parameters:

Non-uniformity of the dark current: This non-uniformity results from the thermal generation of minority carriers in the silicon. To a first approximation, the dark current has two components: a mean dark current which is relatively uniform, to which are added localized effects due to crystalline impurities which generate non-uniformities and interference peaks.

Non-uniformity of photoelement response: There are variations in the response from one pixel to the next, mainly as a result of different spatial apertures of the photoelements. This non-uniformity gives rise to the phenomenon know as the “dirty window effect”.

A few other parameters, such as differences in the anti-blooming drains, can also contribute to fixed-pattern noise.

4.2. Equipment used

Measuring equipment

- Digital oscilloscope with averaging function.
- Appropriate video filters.
- Monochrome monitor.

4.3. Measurement conditions

The camera lens is capped and the camera and lens controls are set as follows:

Control	Setting for this measurement
Gain	0 dB
Flare corrector	ON
Black balance with lens capped	35 mV
White balance	700 mV
Colour corrector	OFF
Aperture/contour corrector	OFF
Noise reducer (“coring”)	OFF
Black and white shading correctors	ON and optimized
Gamma corrector	ON and calibrated
Dynamic knee corrector	ON
Exposure time	nominal value (= 20 ms)
White clipper	–
Pedestal	70 mV
Iris 2/3-inch CCD image format 1/2-inch CCD image format	– –
Zoom focal length	–

As indicated in *Section 4.1.*, the fixed-pattern noise is dependent upon the temperature. It is therefore recommended that measurements be repeated under different environmental conditions:

a) Normal room temperature (25°C).

b) Ambient temperature of 40°C.

Measurements are made on the camera after a temperature stabilization time of at least 2 hours, and again after 8 hours.

4.4. Measurement procedure

The measurement is made on the luminance signal, but can also be made on the RGB signals for verification purposes. In the case of a composite Y output signal, the sub-carrier must be attenuated by an appropriate notch filter.

As a general rule, since the white non-uniformity is not significant, it is only necessary to measure the fixed-pattern noise at black level. However, measurements may also be made at other levels.

The signal to be measured is band-pass filtered from 100 kHz to 5 MHz using a filter as defined in Part C, Annex II, para 1 of [2]. The filtered signal is displayed using an digital storage oscilloscope having an averaging function. The oscilloscope is set so that selection of a line in a given field is possible.

The weighted noise measurement is believed to give a reasonable correlation to the perceived results, whereas the unweighted measurement can be affected by high-frequency clock noise.

The sampling oscilloscope must be set to operate at 20 Msample/s or more. The oscilloscope sampling frequency must be indicated in the measurement results.

For a given line, the oscilloscope will be required to give a mean value for at least 64 measurement readings. Care must be taken to ensure that the video signal on the chosen line is within the dynamic range of the digital-to-analogue converter at the oscilloscope input This averaging operation serves to separate the fixed-pattern noise from the total noise (which includes random noise). Since the mean value of white random noise is known to be zero, the signal obtained is therefore the fixed-pattern noise only, as represented in *Fig. 4*.

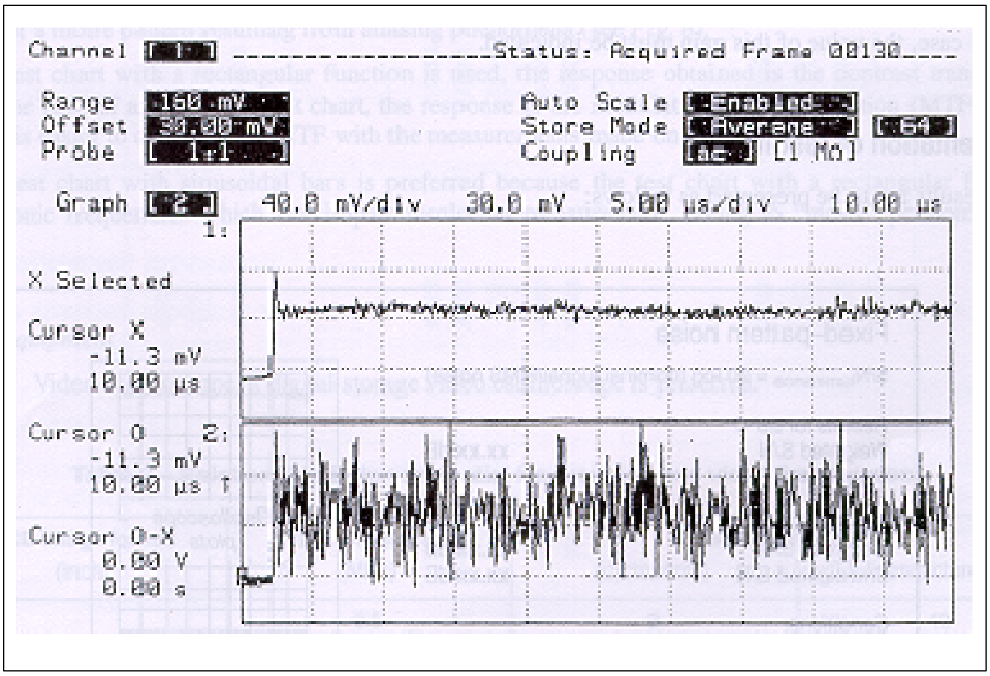


Fig. 4 - Example of the measurement of fixed-pattern noise
The bottom trace shows the total noise (random noise plus fixed-pattern noise).
The top trace shows the average value of the bottom trace, representing the fixed-pattern noise only.

Monitoring on a monochrome screen may be useful.

It is recommended that the measurements are repeated on three lines of a field at $H/4$, $H/2$ and $3H/4$, where H is the useful image height.

Measurements are made on one or more outputs, preferably in the following order:

- Luminance Y or coded Y
- RGB signals

The number of acquisitions (samples taken for for determination of average values) will be recorded.

The result is expressed in decibels (dB), as a ratio of the nominal value of the useful signal (700 mV/75Ω) and the r.m.s. value of the fixed-pattern noise.

The r.m.s value can be obtained on some oscilloscopes but it is often indicated as the standard deviation. The r.m.s indication may include the DC component.

Alternatively, the acquired waveform from the oscilloscope can be processed by a computer to obtain the r.m.s. value.

The standard deviation σ is related to the r.m.s voltage as follows:

$$V_{RMS} = \sigma \sqrt{\frac{n}{n-1}}$$

where: n is the number of samples.

Practical measurement will use more than 20 samples, so V r.m.s. is very close to the value of σ.

Unless the values measured on the three lines are very different, an overall result should be obtained by averaging the results on the three measured lines.

Note: The measurement must not take account of any peaks whose amplitudes significantly exceed the amplitude of the fixed-pattern noise.

If necessary, the measurements can be repeated with the video gain of the camera set to the maximum value. In this case, the value of this gain must be indicated.

4.5. Presentation of results

The results are to be presented as follows:

Fixed-pattern noise

$S/N_{luminance}$ = 20 log (nominal signal/RMS noise)

Results for 25°C

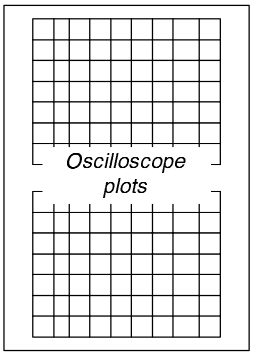
Weighted S/N	**xx.xx** dB
Unweighted S/N	**xx.xx** dB

Results for 40°C

Weighted S/N	**xx.xx** dB
Unweighted S/N	**xx.xx** dB

Conditions:

Number of acquisitions:	**xxx**
Sampling frequency:	**xxx** sample/s



5. Horizontal static resolution

5.1. Definition

Static resolution is measured as the variation in camera response over a range of spatial frequencies. Very often, only one typical high frequency is considered. The measurement of static resolution is a way of characterizing response of a camera to fine details of a picture.

5.2. Equipment used

Test charts

Two different types of test charts can be used, the fundamental difference between them being the form of the transitions between the white and black levels.

A *sinusoidal test chart* contains vertical bars, the density variation of which, in the horizontal direction, gives a sinusoidal video waveform. An example of a sinusoidal test chart is given in *Fig. 5*.

A *rectangular function test chart* has alternating black and white vertical bars with sharp transitions. The horizontal variation of the density of the bars is a periodic "rectangular" function with a mark-space ratio of 1.

These charts usually contain two groups of bars with a known spatial frequency, distributed at nine positions within the picture, as indicated in *Fig. 6*. The groups correspond, after analysis by the camera, to video frequencies of 0.5 MHz and 5 MHz.

Table 2 shows the approximate correspondence between spatial frequencies and video frequencies.

The test charts for CCDs of the two most common image formats have bars representing the following spatial frequencies:

- test chart for 2/3-inch image format: 1 period at 2.95 c/mm, 35 periods at 29.5 c/mm.
- test chart for 1/2-inch image format: 1 period at 4.06 c/mm, 35 periods at 40.6 c/mm.

Note: The groups of 35 periods are useful for a better evaluation of any spurious modulation on the 5 MHz burst in the form of a moiré pattern resulting from aliasing phenomena (see *Fig. 8*).

If a test chart with a rectangular function is used, the response obtained is the contrast transfer function (CTF). In the case of a sinusoidal test chart, the response is the modulation transfer function (MTF). It may be noted that it is easier to compare the MTF with the measurements made on lenses.

The test chart with sinusoidal bars is preferred because the test chart with a rectangular function may create harmonic frequencies which can impair resolution measurement, owing to "moiré" phenomena in CCD cameras.

Measuring equipment

- Video oscilloscope; a digital storage video oscilloscope is preferred.

Table 2 - Relationship between spatial frequencies and video frequencies.

CCD image format (inch)	Video frequency (MHz)	Spatial frequency (cycles/mm)	Spatial frequency (TV lines/picture height)
2/3	0.5	3	40
	5	30	400
1/2	0.5	4	40
	5	40	400

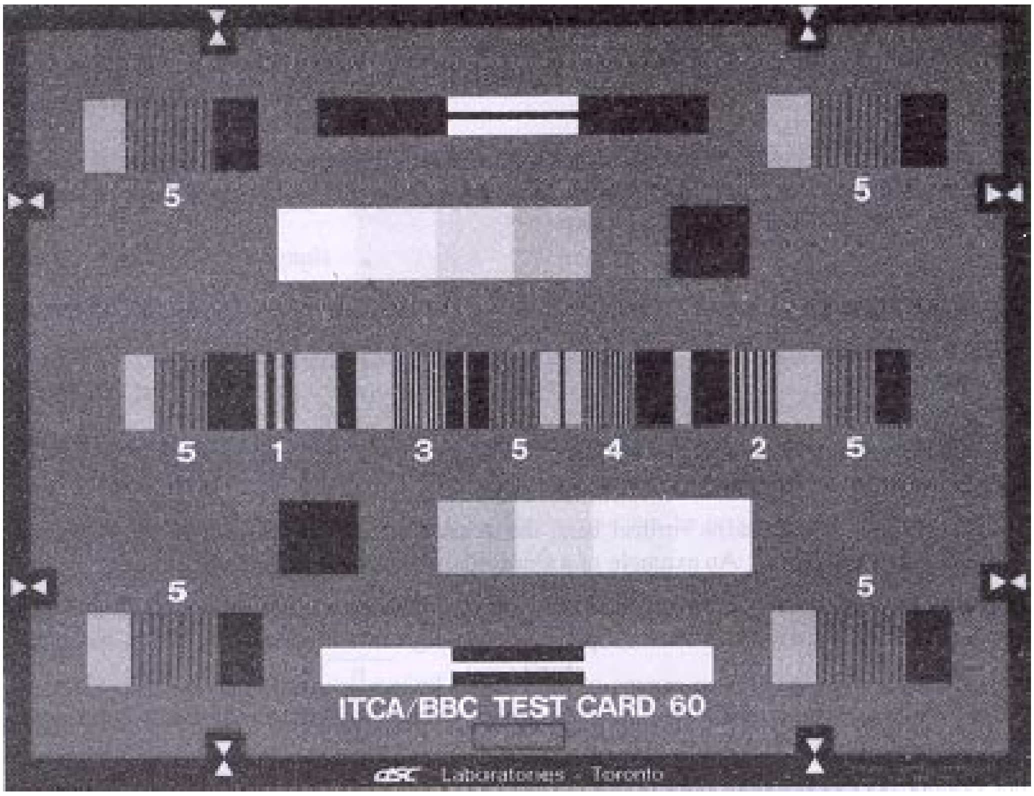


Fig. 5 - Test chart for resolution measurements, with a sinusoidal response.

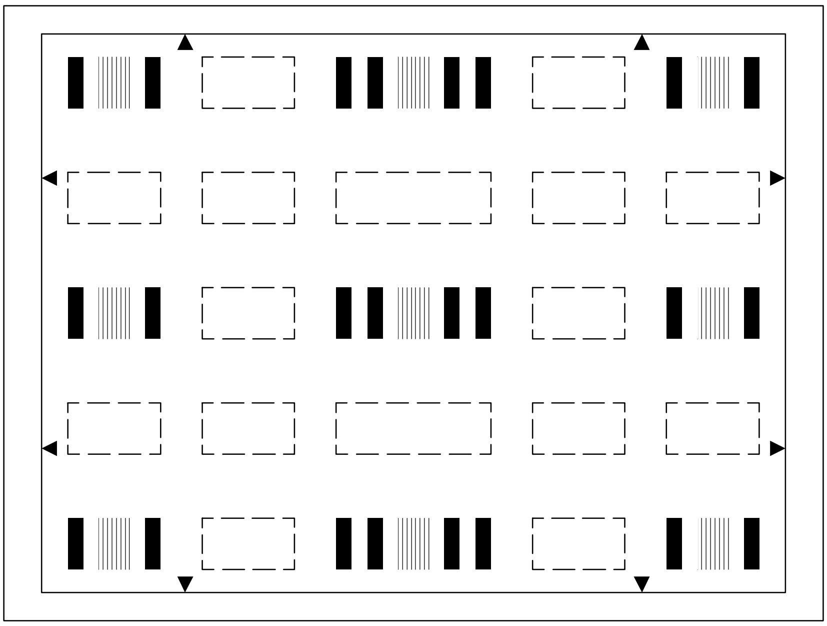


Fig. 6 - Test chart for resolution measurements, with a rectangular response.

5.3. Measurement conditions

Irrespective of the type of test chart used, the camera settings must be as shown in the table below.

Control		Setting for this measurement
Gain		0 dB
Flare corrector		ON
Black balance with lens capped		35 mV
White balance		700 mV
Colour corrector		OFF
Aperture/contour corrector		OFF
Noise reducer ("coring")		OFF
Black and white shading correctors		ON and optimized
Gamma corrector		OFF (gamma = 1)
Dynamic knee corrector		ON
Exposure time		nominal value (= 20 ms)
White clipper		–
Pedestal		–
Iris	2/3-inch CCD image format 1/2-inch CCD image format	*f*/5.6 *f*/4
Zoom focal length		mid-range

The amplitude of the part of the video signal displayed on the oscilloscope corresponding to the lowest frequency is normalized to 100%.

Care must be taken to avoid clipping of the signal to be measured at the black and white levels.

5.4. Measurement procedure

For a given test chart, measurements can be made on the various camera output signals, but preferably on the Y luminance signal (or coded Y with perfect black and white balance).

The measurement is made at the centre of the image, but also at the sides and at the corners so that account is taken of the lateral chromatic aberration of the lens.

In addition to determining response of the camera at the particular frequency of 5 MHz, measurements of the response at other frequencies could serve to plot a curve giving contrast loss (or modulation) according to the spatial frequency of the test chart. Frequency bursts of 0.5, 2, 3, 5, 6, 7, 8 MHz are recommended for this measurement.

5.4.1. Special considerations

a) Impact of "beat" frequencies on resolution measurements

When measuring the static resolution, it is probable that a "beat" will affect the camera response at a specific spatial frequency, and under certain conditions only. If this occurs, the measured signal resembles an amplitude-modulated carrier signal, as shown in *Fig. 7.*

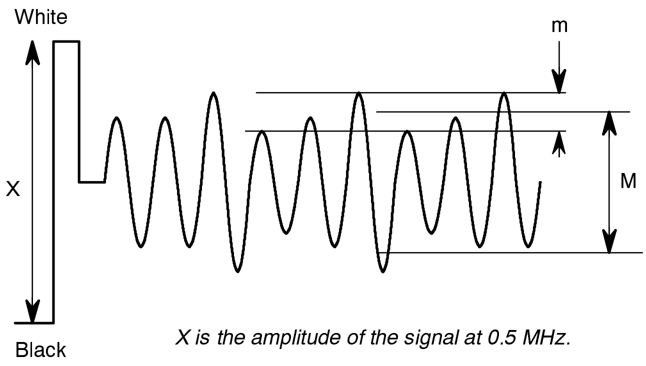


Fig. 7 - Determination of the percentage modulation when measuring static resolution.

The percentage of modulation is then defined by the relationship:

$$\textit{modulation}\ (\%) = \frac{M}{X} \times 100$$

The interference ripple at this frequency is given by:

$$\textit{ripple}\ (\%) = \frac{m}{M} \times 100$$

The signal level to be recorded in the test results is that corresponding to the value *M*.

b) *Contrast and modulation transfer functions*

The following equations can be used to convert between the MTF the CTF:

$$\mathrm{MTF}(N) = \frac{\Pi}{4}\left[\mathrm{CTF}(N) + \frac{\mathrm{CTF}(3N)}{3} + \frac{\mathrm{CTF}(5N)}{5} + \frac{\mathrm{CTF}(7N)}{7} + \frac{\mathrm{CTF}(9N)}{9} + \ldots\right]$$

$$CTF(N) = \frac{4}{\pi}\left[\mathrm{MTF}(N) + \frac{\mathrm{MTF}(3N)}{3} + \frac{\mathrm{MTF}(5N)}{5} + \frac{\mathrm{MTF}(7N)}{7} + \frac{\mathrm{MTF}(9N)}{9} + \ldots\right]$$

where: *N* is the spatial frequency of the test chart, expressed in television lines/picture height.

5.5. Presentation of results

Where only the modulation value at 5 MHz is required, the modulation percentage is obtained by defining the ratio of the response at 5 MHz to that at 0.5 MHz.

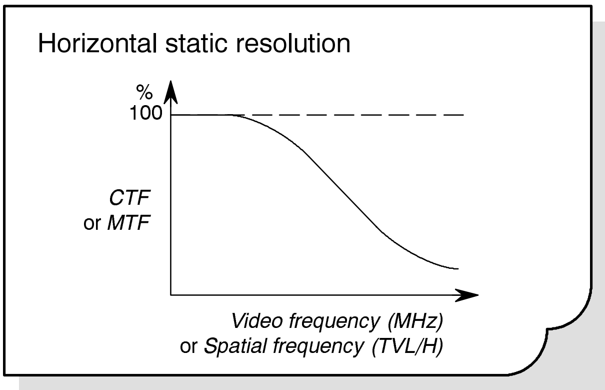
The results are presented in the form of a table representing the various areas of the image measured.

Horizontal static resolution

CTF / MTF values at 5 MHz at nine image positions:

xxx %	xxx %	xxx %
xxx %	xxx %	xxx %
xxx %	xxx %	xxx %

In the case of measurements made at a range of spatial frequencies, the curve giving the percentage of modulation in relation to the spatial frequency must be plotted:



6. Aliasing

6.1. Definition

Aliasing is caused by unwanted frequency components, generated as a result of sub-Nyquist sampling of the wanted image, which fall in the wanted video bandwidth

6.1.1. Generation of aliasing components

Image pick-up in a CCD sensor takes the form of a spatial sampling process. The spectrum of the signal obtained at the output of such a process comprises a basic spectrum, which is repeated around multiples of the sampling frequency. Above a certain high spatial frequency in the image signal, the condition dictated by the Nyquist criterion, which states that the sampling frequency should be at least twice the highest frequency in the original signal ($f_{sampling} > 2f_{max}$), is not met; under these conditions the basic spectrum and the first repeat spectrum can overlap and give rise to "beats". These beats are seen as moiré on the picture.

The frequency components resulting from the overlap between the basic and repeat spectra are called "aliasing" components.

Fig. 8 depicts the sampling process in the X-domain (i.e. horizontally in the television picture) and in the spatial frequency domain for a CCD sensor.

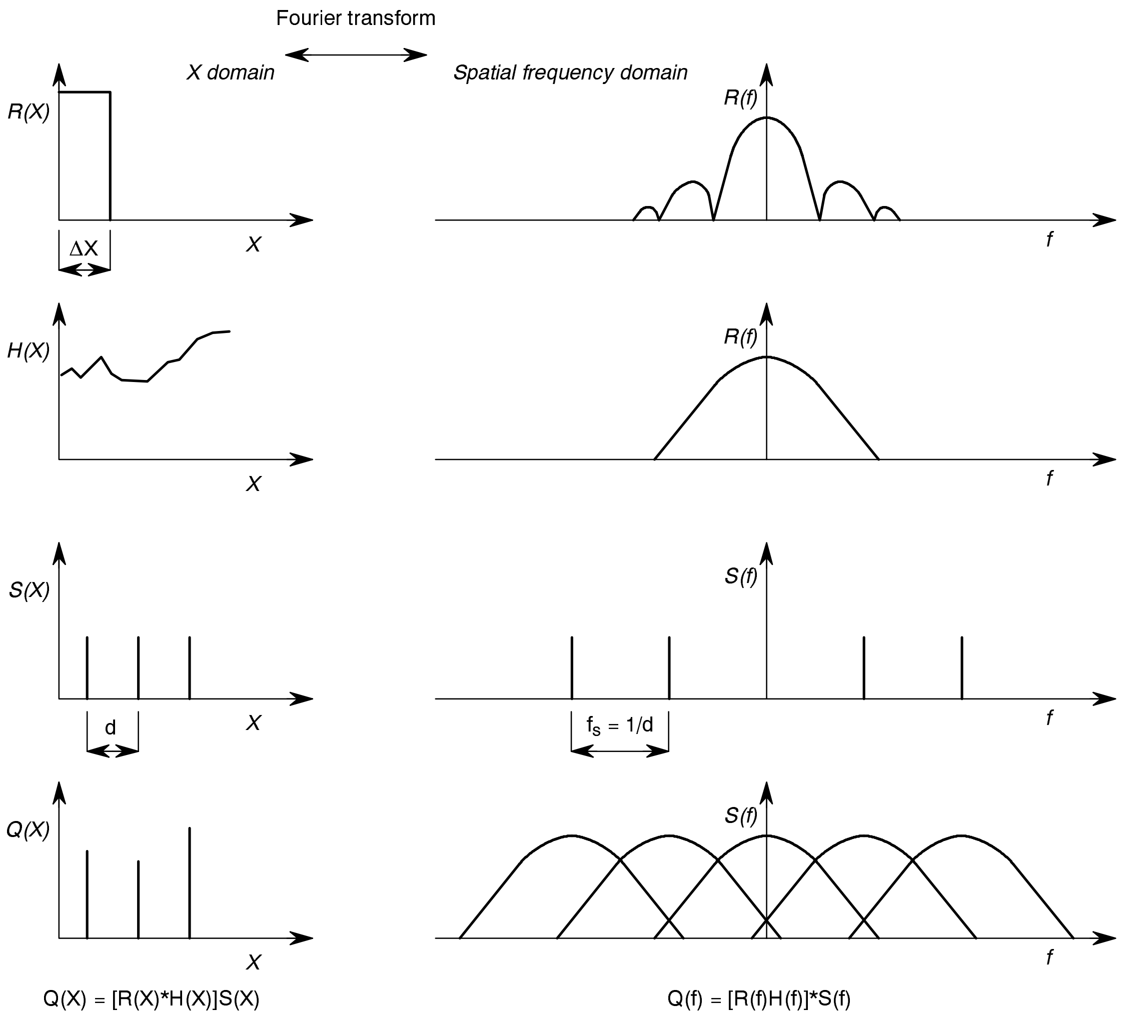


Fig. 8 - Illustration of the image sampling process in the X domain and spatial frequency domain.

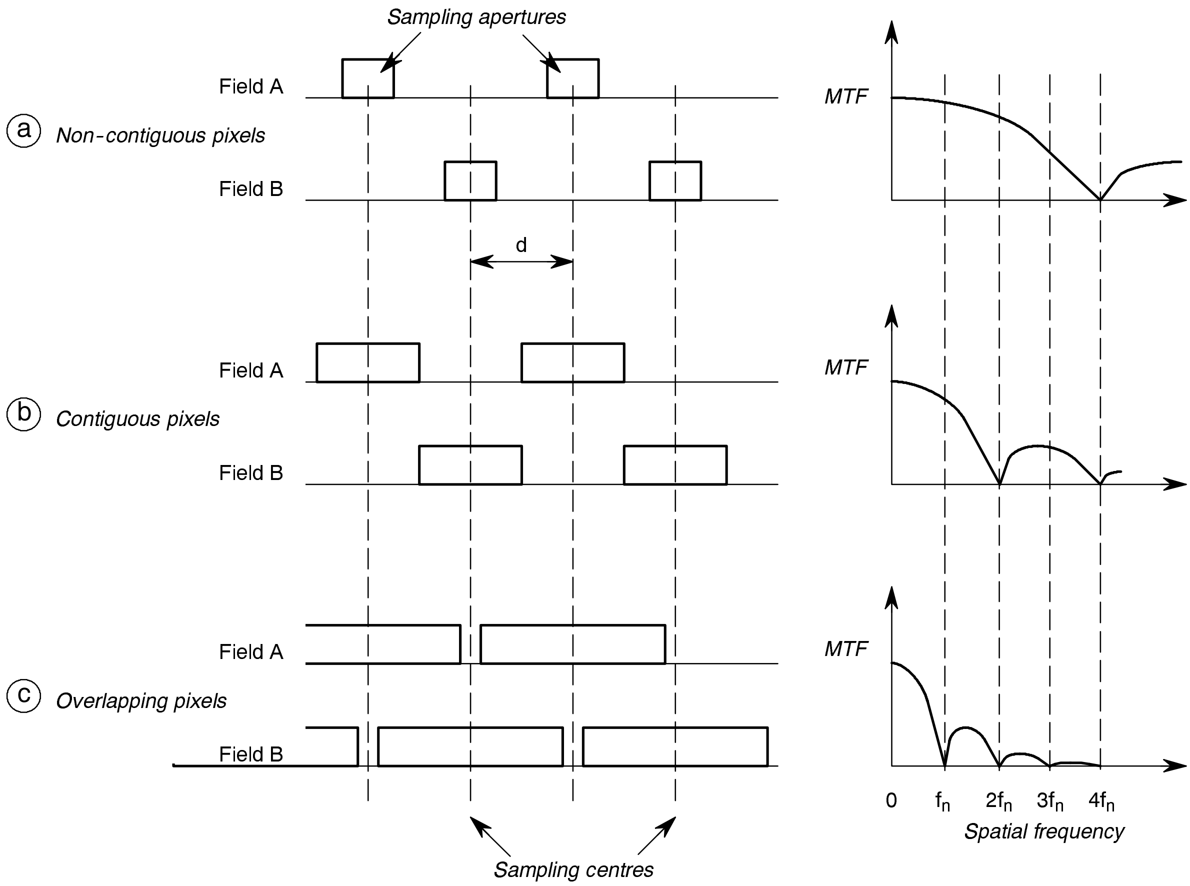


Fig. 9 - Responses of three types of CCD sensors.

One technique used to alleviate aliasing involves the insertion of an optical low-pass filter in the light path; this reduces the level of information above the Nyquist frequency which reaches the sensors.

The visibility of moiré patterns depends on the type of sensor, on the low-pass optical filtering and on the spatial frequency of the test pattern which is analyzed.

The trade-off between resolution and aliasing is also dependent upon the CCD architecture. The situations are different for frame transfer and interline transfer devices. *Fig. 9* shows the responses of sensors having non-contiguous pixels (interline transfer CCD) and contiguous or overlapping pixels (frame transfer CCD).

6.1.2. Some considerations on aliasing measurement.

It is not at present possible to express the severity of aliasing as a single, meaningful figure. It is well known that low frequency alias components are much more noticeable than the higher frequencies; consequently, simple aliasing measurements lead to a graph rather than to a single number.

A further problem, of a more practical nature, is that to measure the alias curve in an unambiguous way, a sinusoidal test chart is needed which is large enough to permit easy measurement with a spectrum analyzer. The only available sinusoidal test chart, the BBC TC 60 (*Fig. 5*), does not meet this criterion.

In other applications outside the field of video, the most common solution to the first problem is to state that all alias frequencies should be below a certain level which does not influence the baseband.

Until this criterion can be met in CCD cameras, and to avoid requirement for a specific form of weighting curve, an indication of the severity of aliasing in the range of most disturbing frequencies can be found by the measuring procedure described below.

6.2. Equipment used

Test charts

The ideal solution would be a set of test charts with vertical black and white bars of different spatial frequencies. These would have a rectangular or, preferably,a sinusoidal density variation.

Another possibility is to use a single test chart with a known spatial frequency when framed across its overall width. At the top of the test chart, outside the area framed by the camera, a horizontal line is been drawn on which are marked the framings corresponding to specific spatial frequencies seen by the camera; framing for each spatial frequency can be adjusted by zooming in or out, or by changing the distance to the camera.

A range of frequencies from 3 to 30 MHz is appropriate for current cameras.

An example of a test chart with different framing markers is given in *Fig. 10*.

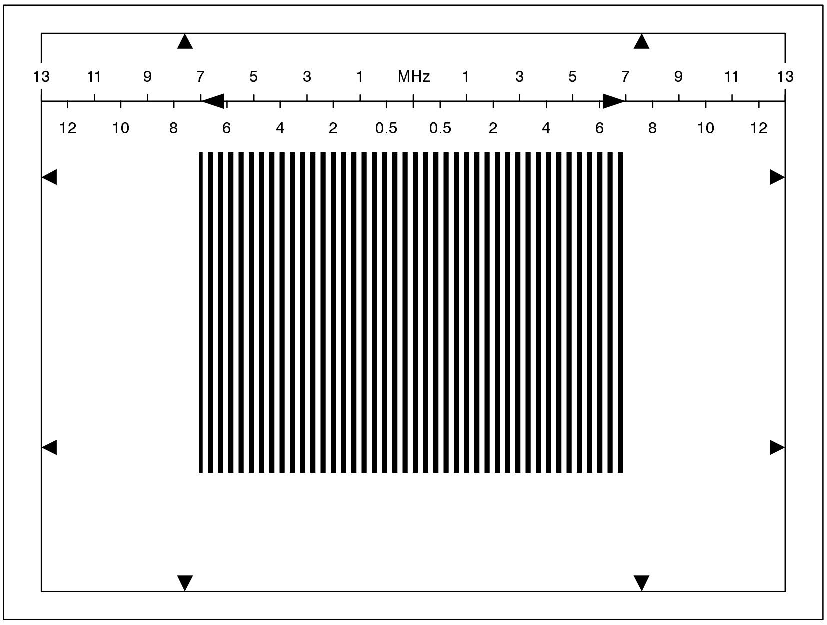


Fig. 10 - Example of a test chart for the measurement of aliasing.

Measuring equipment

- Monochrome monitor
- Spectrum analyzer
- Video filters

It is important to ensure that only those components of aliasing which can be transmitted through downstream video equipment, and detected when viewing the pictures, are measured. An appropriate video band-pass filter is required.

6.3. Measurement conditions

The camera is aligned with a test chart of a given spatial frequency, and its selected output is connected to the input of a spectrum analyzer or a waveform monitor. The camera and lens settings should be as shown in the table on *page 29*.

Control		Setting for this measurement
Gain		0 dB
Flare corrector		ON
Black balance with lens capped		35 mV
White balance		700 mV
Colour corrector		ON
Aperture/contour corrector		ON
Noise reducer (“coring”)		OFF
Black and white shading correctors		ON and optimized
Gamma corrector		OFF (gamma = 1)
Dynamic knee corrector		ON
Exposure time		nominal value (= 20 ms)
White clipper		–
Pedestal		0 mV (*Note*)
Iris	2/3-inch CCD image format 1/2-inch CCD image format	Set to give 700 mV/75Ω for peak white
Zoom focal length		–

Note: If the signal includes mixed sync pulses, it is recommended that these pulses are suppressed, because they render interpretation of the spectrum analyzer curves more difficult.

6.4. Measurement procedure

The procedure involves two steps:

- Subjective investigation of the performance of the camera by changing the test chart spatial modulation frequency and noting the conditions which cause the largest and most noticeable alias (moiré) pattern.
- Objective measurement of the alias signal and the test pattern parameters.

6.4.1. Investigation of performance

A grating with a single horizontal spatial frequency should be used (see *Fig. 10*).

The camera-to-chart distance or the zoom setting are varied to investigate the alias performance.

With a knowledge of the number of CCD pixels per row, the image frequencies which are likely to cause aliasing can be predicted. Some additional products may be generated in the gamma processor, as a consequence of non-linear mixing of harmonics to produce another frequency.

6.4.2. Measurement of the aliasing

Measurements are taken on the luminance (Y) signal and also on the colour-difference signals (R-Y) and (B-Y) if this is necessary or if these signals are subject to a greater aliasing disturbance.

The selected signal is displayed on a waveform monitor or on a spectrum analyzer; a line strobe is used if the test pattern image is only a small part of the picture.

With the knowledge gained from this investigation using the single-frequency test pattern, the image size is adjusted to obtain alias products at 1 MHz.

If the image spatial frequency required to produce 1 MHz alias coincides with a zero in the anti-alias filter characteristic, then an alternative frequency of 500 kHz should be chosen (the actual frequency used should be noted with the results).

Having determined these conditions, the signal level measured with the zoom and iris adjusted to give a 1 MHz input frequency is adopted as a reference amplitude.

A record should be made of the image spatial frequency, the peak-to-peak 1 MHz alias amplitude, the lens focal length, aperture, and object distance for each of the settings required to produce alias products in the range of 0.5 MHz to 1 MHz.

Measurements at other alias frequencies within the pass-band can be made if considered necessary.

The amplitude of the alias component is read directly, in decibels, on the display of the spectrum analyzer.

6.5. Presentation of results

The worst alias component will be recorded as a percentage of the input signal amplitude. Several results may be recorded if it is difficult to choose the worst alias. The reason for the presentation of additional results must then be stated. The difference in decibels between the 1 MHz reference signal and the alias component must be recorded.

The results and a list of measurement conditions are to be presented as follows:

Aliasing	
Difference in levels between alias product and 1 MHz reference	**xx dB**
Conditions	
Type of test chart	. . . . .
Type of grating (sine/square)	. . . . .
Input frequency (test chart)	. . . . .
Type of output signal (Y, R-Y, B-Y)	. . . . .
Alias frequency (if not 1 MHz)	. . . . .
Lens focal length	. . . . .
Lens aperture	. . . . .
Video low-pass filter (if used)	. . . . .

A print-out from the spectrum analyzer may be provided (an example is given in *Fig. 11*).

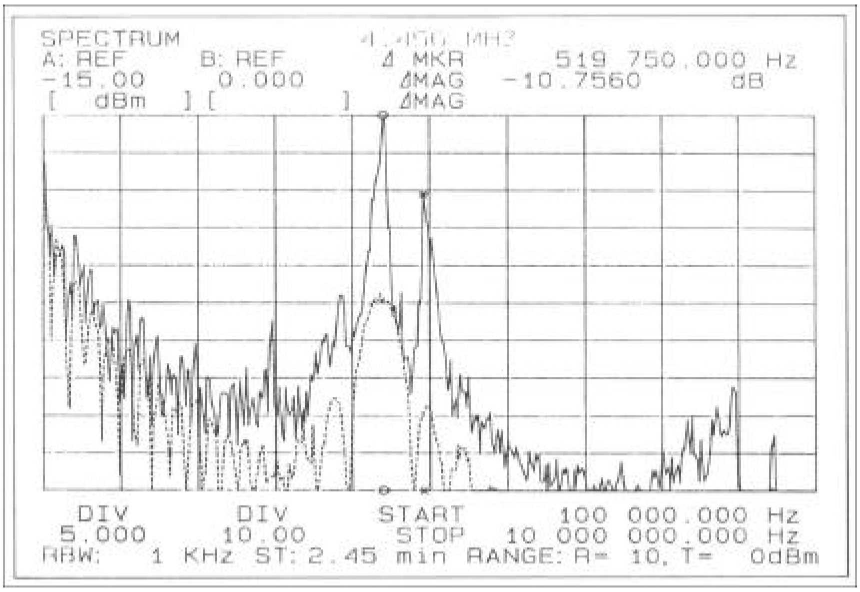


Fig 11 - Example of the measurement of aliasing, using a spectrum analyser

7. Registration

7.1. Definition

Registration is measured as the maximum relative displacement between the red (R) and green (G) signals, and the blue (B) and green (G) signals.

In CCD cameras, any offsets which may exist are mainly due to lateral chromatic aberrations in the lens. The sensors themselves are positioned with great precision by means of a master lens and introduce no significant offset.

7.2. Equipment used

Test chart

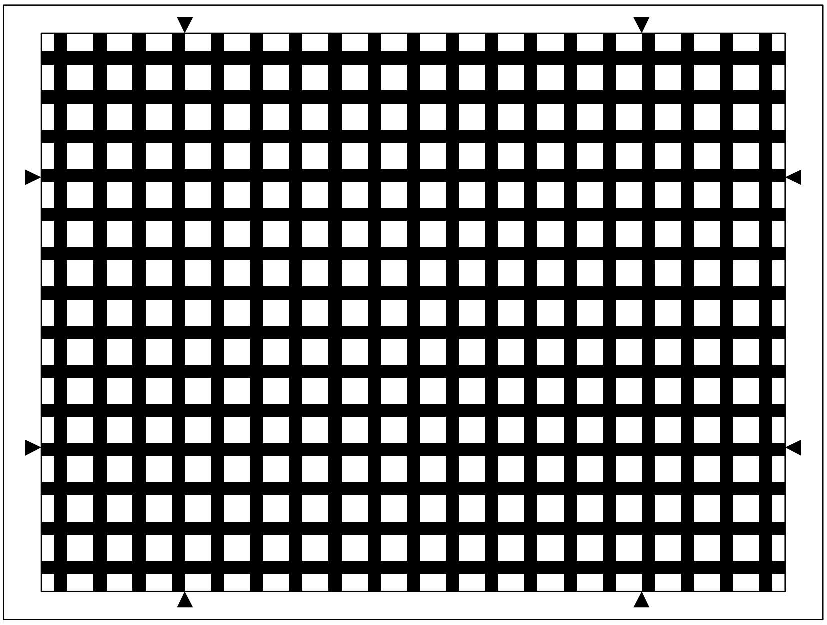
A test chart with black horizontal and vertical lines on a white background is recommended.

This test chart must have 19 vertical lines and 14 horizontal lines, of a width equal to at least 1.3% of the picture height to minimize any aliasing problem.

An example of such a test chart is shown in *Fig. 12*.

Measuring equipment

- Monochrome monitor.
- Video delay lines, switchable in 5ns steps with a total delay of more than 200 ns.
- Differential video amplifier.
- Waveform monitor.



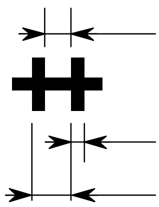


Fig. 12 - Test chart for the measurement of registration.

7.3. Measurement conditions

The camera and lens settings should be as shown in the table below:

Control		Basic setting
Gain		0 dB
Flare corrector		ON
Black balance with lens capped		35 mV
White balance		700 mV
Colour corrector		OFF
Aperture/contour corrector		OFF
Noise reducer ("coring")		OFF
Black and white shading correctors		ON and optimized
Gamma corrector		ON and calibrated
Dynamic knee corrector		ON
Exposure time		nominal value (= 20 ms)
White clipper		–
Pedestal		–
Iris	2/3-inch CCD image format 1/2-inch CCD image format	*f*/4 *f*/2.8
Zoom focal length		*Note*

Note: Minimum and intermediate positions obtained by successively doubling the minimum focal length until the maximum focal length is reached.
If range extenders or other focal length attachments are fitted, the test shall be repeated at the extreme focal lengths.

7.4. Measurement procedure

The measurement equipment is connected as shown in *Fig. 13*.

Measurements are made on the RGB outputs.

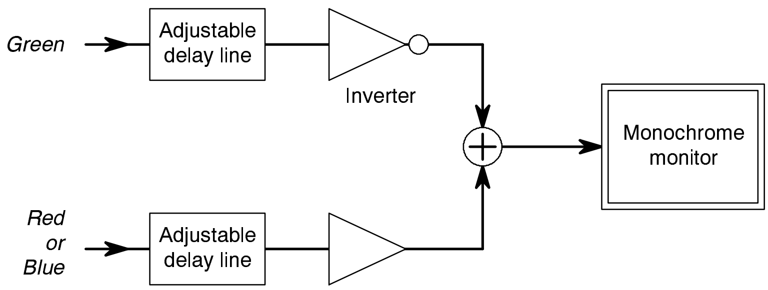


Fig. 13 - Arrangements for the measurement of registration.

The RGB signal levels are set at between 50% and 100% of their nominal peak level.

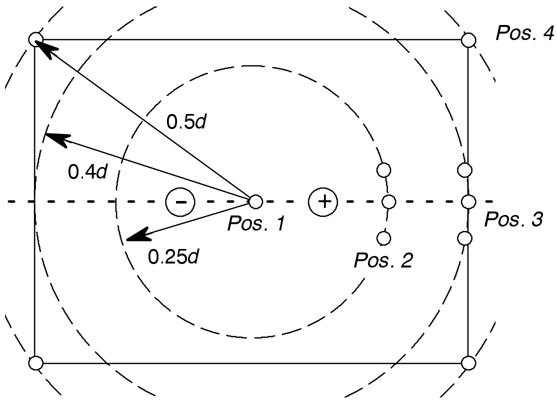
It is suggested that the measurements are made with the lens setting in the extreme end.

With the wide angle setting, the test pattern dimensions will for example be: 800 x 600 mm, with the "tele" setting: 400 x 300 mm.

With the camera correctly focussed on the test chart, and for a given zoom setting, the image is observed on a monochrome monitor.

By adjustment of the delay lines, two vertical lines of the R-G (or B-G) image are superimposed in a given area of the picture. The convergence error (in nanoseconds) is then read out directly from the delay line settings.

The vertical registration error is measured by comparison with a horizontal distortion of the same amplitude. The measurements are repeated in three positions of the image defined as follows: (see *Fig. 14*).



Note: *d* is the length of the image diagonal.

Fig. 14 - Positions for the measurement of registration.

Before taking measurements at positions 2 and 3, the CCD positioning should be verified at position 1.

Then, for the different focal lengths (minimum, intermediate, maximum) the maximum errors are recorded for positions 2 and 3.

7.5. Presentation of results

The maximum errors are given as percentages of the image height[2].

The results are to be presented as follows:

Registration

Position	*R-G*	*B-G*
2	xx %	xx%
3	xx%	xx%

2. A vertical registration error of 0.1% of the image height is equivalent to an error of 39 ns in the horizontal direction, for the ITU-R 625-line television standard.

8. Geometry

8.1. Definition

The characteristic known as geometry is a measure of the ability of a camera to faithfully reproduce the shape and relative dimensions of a scene.

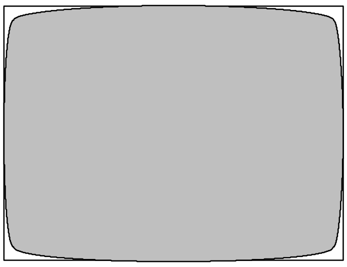
8.1.1. Types of geometry error

Geometry is measured as the "mapping" error between a 4:3 rectangular test pattern and its reproduction by the camera. Geometric picture distortions in CCD cameras are due primarily to lens-related distortions, as there are no scanning errors in CCD sensors.

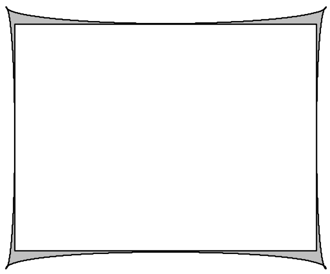
Optical distortion, in general, is a caused by a variation in the magnification of the image, which is dependent on the distance from the the optical axis. Its effect is to cause straight lines in the object to appear curved in the image.

Two forms of geometric errors can be determined on a rectangular object (*Fig. 15*):

- a negative distortion, in which the points of the object are displaced from their theoretical position in a direction towards the optical axis (barrel distortion).
- a positive distortion, in which the points are displaced in a direction away from the optical axis (pincushion distortion).



Barrel distortion (negative)



Pin-cushion distortion (positive)

Fig. 15 - Illustration of geometry errors.

8.2. Equipment used

Test charts

a) A commonly-used test chart is the geometry test chart shown in *Fig. 16a*. This chart features concentric rings, the external and internal diameters of which are calibrated as percentages of the picture height; these rings determine the tolerances.

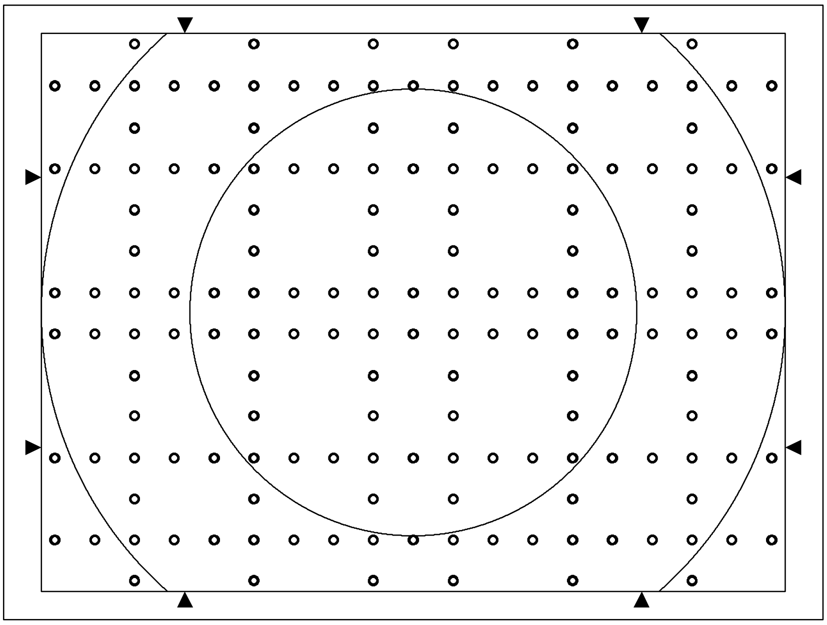
   An electronically-generated test pattern with a grille comprising 14 horizontal lines and 19 vertical lines, in a rectangle of format 4:3, can be used as a reference (see *Fig. 16b*).

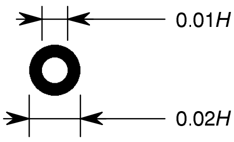
b) An alternative test chart comprising 20 columns x 15 rows of concentric circles as shown in *Fig. 16d* can also be used. In this case, it is used in conjunction with an electronic dot generator.

Measuring equipment

- Electronic test pattern generator (cross hatch or dots).
- High-quality monochrome monitor.
- Analogue mixer with two inputs.

(a) *Test chart for geometry measurement.*





Notes: The diameter of the outer circle is equal to the picture width.
The diameter of the inner circle is 0.8 times picture width.
H = picture height.

(b) *Electronically-generated grid pattern.*

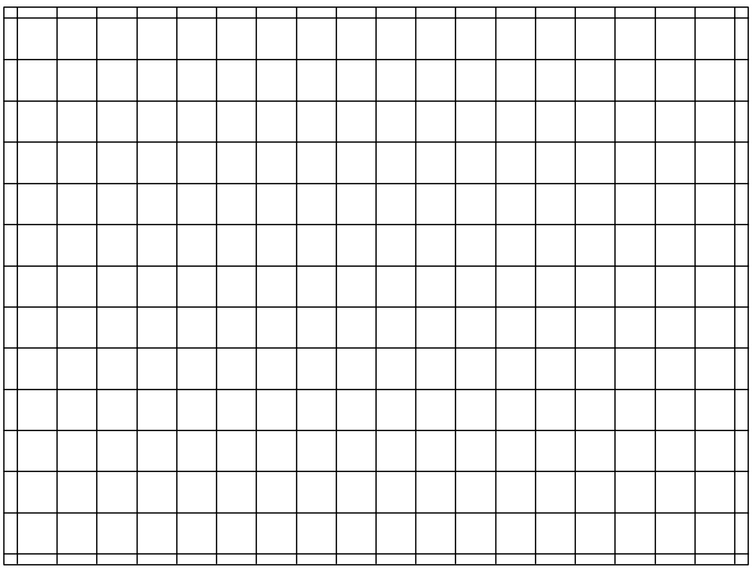
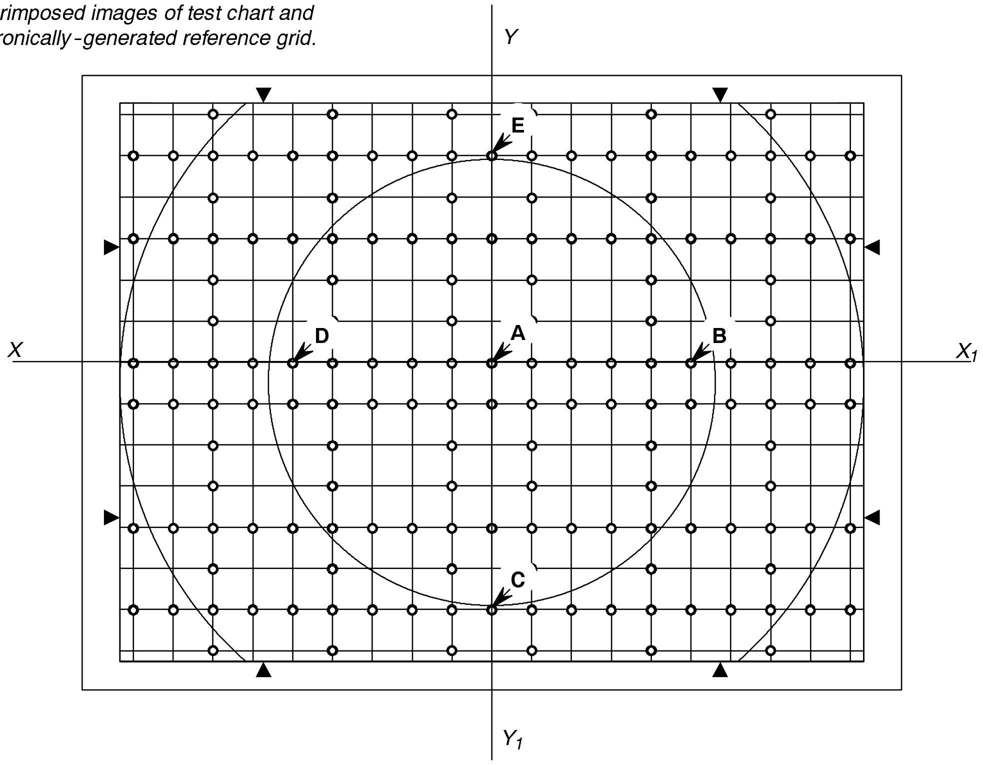
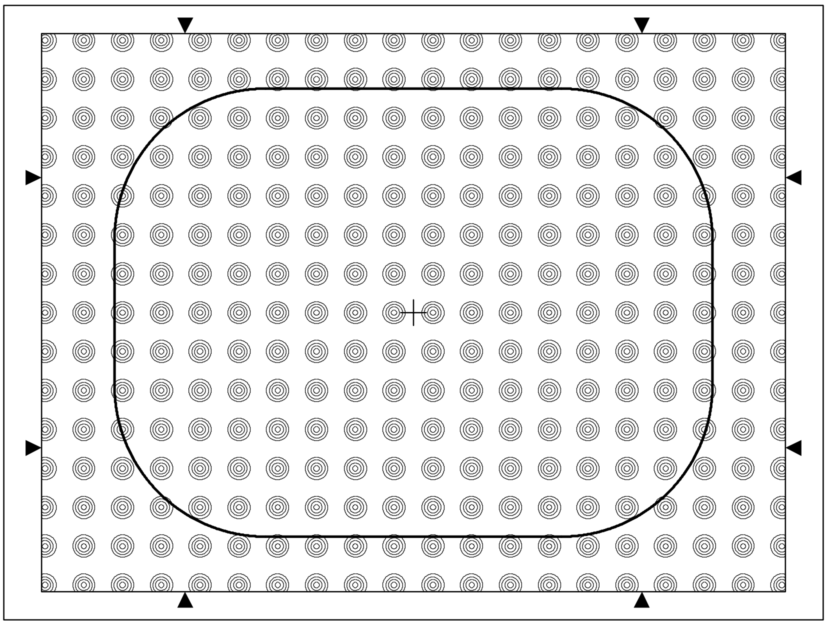


Fig. 16 - Test charts for the measurement of geometry.

ⓒ *Superimposed images of test chart and electronically-generated reference grid.*



ⓓ *Alternative form of test chart, for use with an electronic dot-pattern generator.*



Notes: The circle radii are 0.5, 1.0, 1.5 and 2.0 % of picture height
The width of the inner zone is 0.8 times the image width.
The height of the inner zone is 0.8 times the image height.
The corner radius of the inner zone is 0.21 times the image height.

Fig. 16 - Test charts for the measurement of geometry.

8.3. Measurement conditions

The camera and lens settings should be as shown below.

Control		Basic setting
Gain		0 dB
Flare corrector		ON
Black balance with lens capped		35 mV
White balance		700 mV
Colour corrector		ON
Aperture/contour corrector		ON
Noise reducer (“coring”)		OFF
Black and white shading correctors		ON and optimized
Gamma corrector		ON and calibrated
Dynamic knee corrector		ON
Exposure time		nominal value (= 20 ms)
White clipper		–
Pedestal		–
Iris	2/3-inch CCD image format 1/2-inch CCD image format	maximum maximum
Zoom focal length		–

The camera must be perfectly centred on the test pattern and perpendicular to it, and the actual height of the image is adjusted to be equal to the height of the final image format.

For zoom lenses, the picture height distortion should be determined as a function of focal length. Zoom lenses usually have negative (barrel) distortion at their shortest focal lengths and positive (pincushion) distortion at their longest focal lengths. Measurements are therefore taken with a focal length corresponding to “wide angle” in order to determine the barrel distortion and with a focal length which is twice as long as the first, to determine the pincushion distortion. A further doubling of the focal length will ensure that the maximum pincushion distortion is obtained. Most zoom lenses have maximum distortions for these two settings, as illustrated in *Fig. 17.*

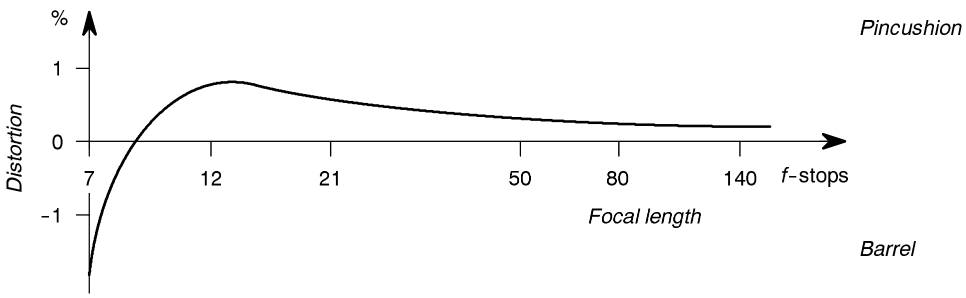


Fig. 17 - Typical variations of geometric distortion as a function of focal length.

When the focal distance is increased by a factor of 2, and if the same field angle is to be preserved, the test pattern dimensions must be multiplied by 2; it is therefore helpful to have two geometric test patterns with a dimensional ratio of 2. This avoids having to move the camera in relation to the test pattern and repeating the positional settings which are usually fairly time-consuming.

8.4. Measurement procedure

The monitor is set in the low-scan (underscan) mode.

One of the test charts shown in *Fig. 16* is used, with an electronic test pattern generator (lines or dots, as appropriate).

The measurement is made on the monochrome monitor screen which displays the camera output picture superimposed over the electronically-generated reference test pattern.

The amplitude and alignment settings of the electronic test pattern must be such that the cross-points of the lines (or the dots) coincide perfectly with the corresponding points of the geometry test pattern analyzed by the camera (*Fig. 16*).

For the focal lengths defined previously, the displacement ΔH of each corner in the vertical direction is measured. The distortion is then calculated as a percentage of picture height by the formula:

$$D = \frac{\Delta H}{H} \times 100$$

where: ΔH is the displacement
H is the displayed picture height

The average of the distortions for the four corners is then calculated.

8.5. Presentation of results

A tabular for of presentation of the results is recommended, as follows:

Geometry

Focal length		*Average distortion*	
Minimum	(.....)	**xx**%	(barrel)
2 x minimum	(.....)	**xx**%	(pin-cushion)
4 x minimum	(.....)	**xx**%	

9. White shading or white level non-uniformity

9.1. Definition

White shading or non-uniformity is measured as the maximum extent of white level variations, in different areas of the picture, when the camera is directed at an evenly-illuminated test chart.

9.2. Equipment used

Test chart

Uniformly reflective neutral test chart.

Measuring equipment

- Oscilloscope.
- Video amplitude meter.

9.3. Measurement conditions

The camera and lens settings should be as shown below.

Control		Basic setting
Gain		0 dB
Flare corrector		ON
Black balance with lens capped		35 mV
White balance		700 mV
Colour corrector		ON
Aperture/contour corrector		ON
Noise reducer ("coring")		OFF
Black and white shading correctors		ON and optimized
Gamma corrector		ON and calibrated
Dynamic knee corrector		ON
Exposure time		nominal value (= 20 ms)
White clipper		–
Pedestal		–
Iris	2/3-inch CCD image format 1/2-inch CCD image format	See *Section 9.4.* See *Section 9.4.*
Zoom focal length		–

The test chart illumination is adjusted so that the RGB output signals are equal to 700 mV/75Ω (nominal amplitude).

The lens is initially focussed on the test chart and then de-focussed.

9.4. Measurement procedure

The first step is to set up the alignment of shading correction. The lens is adjusted as follows:

Iris	2/3-inch CCD image format 1/2-inch CCD image format	*f* /5.6 *f* /4
Zoom focal length		normal operating position

The shading corrector is set to the position giving the best results.

Then, it is recommended to take measurements in two sets of conditions.

Condition A

The lens is adjusted as follows:

Iris	2/3-inch CCD image format 1/2-inch CCD image format	fully open
Zoom focal length		no change

In this case, the distortion is mainly introduced by vignetting in the optical system.

Measurements are made on the RGB output signals and the distortions are recorded for two picture zones defined in *Fig. 18*):

Condition B

The lens is adjusted as follows:

Iris	2/3-inch CCD image format 1/2-inch CCD image format	fully open
Zoom focal length		change to obtain worst result

In this case the distortions are the result of vignetting and vertical shading.

The focal length adjustment which gives the worst result may be wide-angle position.

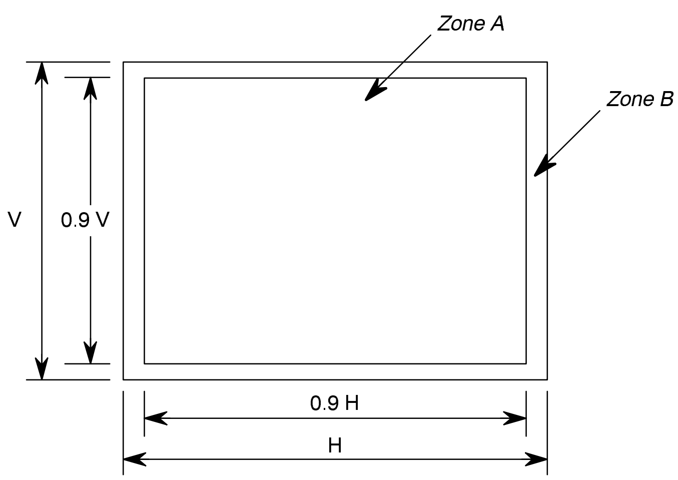


Fig. 18 - Measurement zones for white shading.

The measurements of *Condition A* are then repeated.

On the basis of these measurements, the differences R-G, R-B and B-G are calculated and the maximum peak-to-peak variations are recorded for each zone.

9.5. Presentation of results

For the two sets of conditions *A* and *B*, the results are recorded in a table giving the amount of non-uniformity as a percentage of the nominal signal level. The following presentation is recommended:

White shading (non-uniformity)

Focal length: *Normal operating conditions*
Iris: *Fully open*

Signal	*Zone A*	*Zone B*
R	**xx**%	**xx**%
G	**xx**%	**xx**%
B	**xx**%	**xx**%
R-G	**xx**%	**xx**%
B-G	**xx**%	**xx**%
R-B	**xx**%	**xx**%

Focal length: *Wide angle (or worst conditions)*
Iris: *Fully open*

Signal	*Zone A*	*Zone B*
R	**xx**%	**xx**%
G	**xx**%	**xx**%
B	**xx**%	**xx**%
R-G	**xx**%	**xx**%
B-G	**xx**%	**xx**%
R-B	**xx**%	**xx**%

10. Black shading or black level non-uniformity

10.1. Definition

Black shading or non-uniformity is measured as the maximum extent of variations of the black level, in different areas of the picture, when the camera is receiving no luminous stimulation.

10.2. Equipment used

Measuring equipment

- Oscilloscope.
- Video amplifier.

10.3. Measurement conditions

The camera and lens settings should be as shown in the table below:

Control	Basic setting
Gain	0 dB
Flare corrector	ON
Black balance with lens capped	35 mV
White balance	700 mV
Colour corrector	ON
Aperture/contour corrector	ON
Noise reducer (“coring”)	OFF
Black and white shading correctors	ON and optimized
Gamma corrector	ON and calibrated
Dynamic knee corrector	ON
Exposure time	nominal value (= 20 ms)
White clipper	–
Pedestal	35 mV
Iris 2/3-inch CCD image format 1/2-inch CCD image format	– –
Zoom focal length	–

10.4. Measurement procedure

The camera lens is capped.

Measurements are made on the RGB output signals from the camera and the distortions are recorded for the two picture zones defined in *Fig. 18*.

On the basis of these measurements, the differences R-G, R-B and B-G are calculated and the maximum peak-to-peak variations are recorded for each zone.

10.5. Presentation of results

The results are recorded in a table giving the amount of non-uniformity as a percentage of the nominal signal level. The following presentation is recommended:

Black shading (non-uniformity)

Signal	*Zone A*	*Zone B*
R	**xx**%	**xx**%
G	**xx**%	**xx**%
B	**xx**%	**xx**%
R-G	**xx**%	**xx**%
B-G	**xx**%	**xx**%
R-B	**xx**%	**xx**%

11. Streaking

11.1. Definition

Streaking is measured as the disturbance caused by white patches on a black background to the video level corresponding to the adjacent black areas.

This disturbance appears to the right of, and below, the white areas.

11.2. Equipment

Test chart

It is preferable to use a transparent test chart showing, on a black background, a series of horizontal (white) bars of differing lengths. An example of a suitable chart is shown in *Fig. 19*.

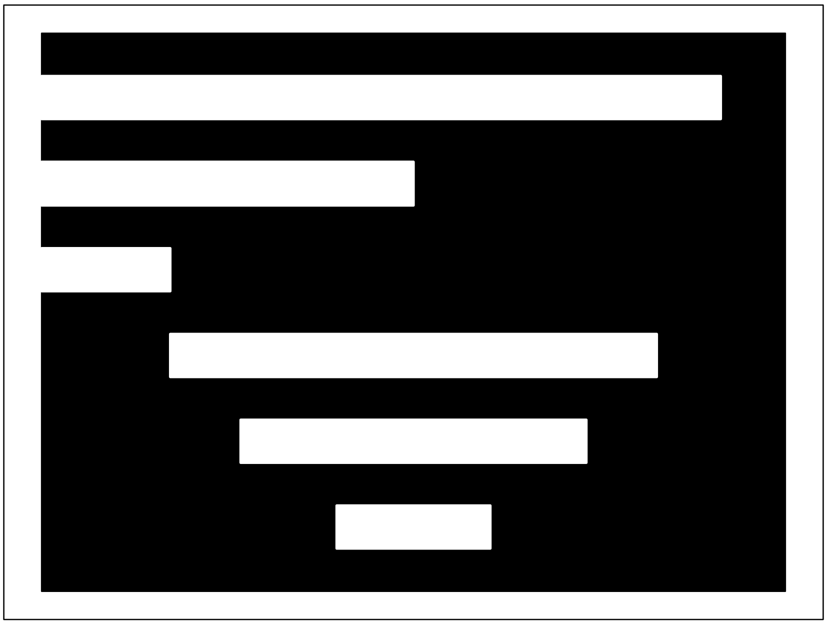


Fig. 19 - Test chart for measurement of streaking.

Measuring equipment

- Video level meter.
- Monochrome monitor.
- Oscilloscope.
- 500 kHz low-pass filter.

11.3. Measurement conditions

The camera and lens settings should be as shown on *page 45*.

The test chart illumination must be adjusted so that the white bars give a signal of 100% with an average iris setting.

Control		Basic setting
Gain		0 dB
Flare corrector		ON
Black balance with lens capped		35 mV
White balance		700 mV
Colour corrector		ON
Aperture/contour corrector		OFF
Noise reducer (“coring”)		OFF
Black and white shading correctors		ON and optimized
Gamma corrector		ON and calibrated
Dynamic knee corrector		OFF
Exposure time		nominal value (= 20 ms)
White clipper		–
Pedestal		35 mV
Iris	2/3-inch CCD image format 1/2-inch CCD image format	mid-range mid-range
Zoom focal length		–

11.4. Measurement procedure

The television lines which scan through the horizontal white bars of the test chart are displayed on the oscilloscope. Measurements are made at the RGB outputs (or luminance Y if RGB are not available).

The first microsecond following the transition from white to black is ignored.

The measurement is repeated at various points, taking account of the nature of the streaking observed on a control monitor.

Care must be taken to avoid the effect of flare from the white bar.

Note: In order to distinguish the effects of flare (see *Section 12.*) from the effects of streaking, a differential measurement may be made taking as reference one of the lines which do not cross the white bars (these lines will be affected by flare only).

11.5. Presentation of results

The worst value of peak deviation of the black level in the streak, compared with an adjacent black area which is unaffected by the streak, should be recorded. The result is given as a percentage of the nominal amplitude (700 mV/75Ω).

The following presentation is recommended:

Streaking	
Streaking	**xx** %

12. Flare

12.1. Definition

Flare (veiling glare) is defined as the ratio of the illuminance in the image of a black area and the illumance in a surrounding bright field.

12.1.1. Considerations on the causes and measurement of flare

Flare is caused by the diffusion of light in the optical path (zoom lens, dichroic beam splitter) and inside the CCD itself. It impairs the picture, either by throwing a uniform white veil over the picture (veiling glare), or by blurring transitions.

It is essential that a distinction be made between these two effects.

Flare is measured by determining the variations of the black level as compared to its nominal level. Flare depends on the average picture level (APL) (as shown in *Fig. 20*), so these variations should be determined when the APL varies between 0% to 50% on the one hand, and from 0% to 99% on the other hand.

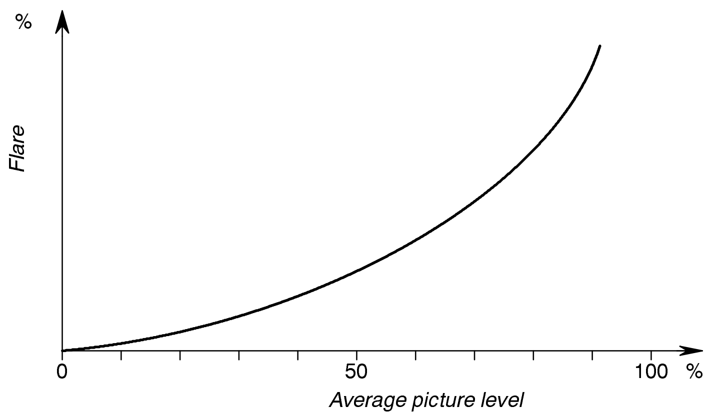


Fig. 20 - Variation of flare as a function of the average picture level (APL).

12.2. Equipment used

Test charts

Several special test charts can be used:

a) To measure overall flare, the appropriate test chart has in its centre a black rectangle of format 4/3. This rectangle is surrounded by a white zone of equal area, thus giving an APL of 50%.

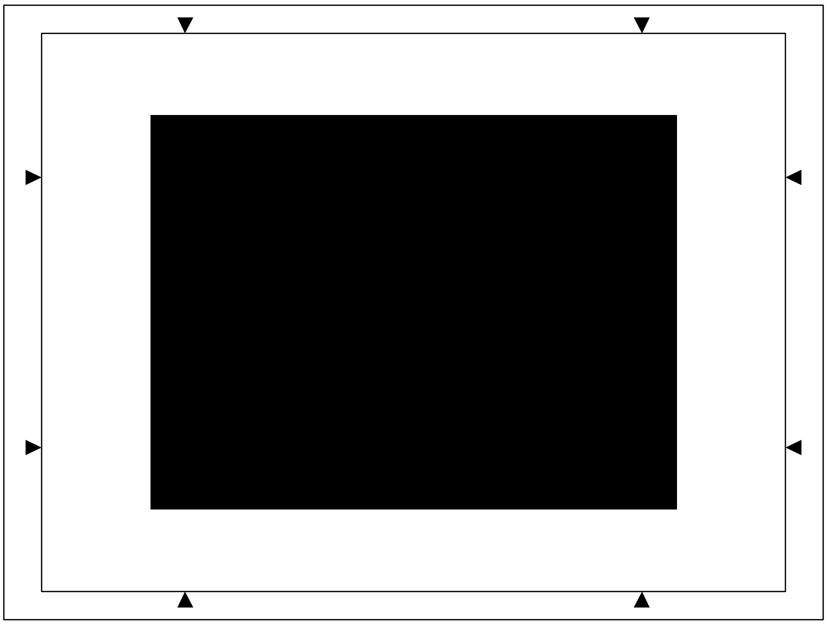
An example of such a test chart is shown in *Fig. 21*.

b) To measure localized flare, the appropriate test chart has a central black rectangle of format 4/3 surrounded by a white zone of an area sufficient to give an APL of 99%.

An example of such a test chart is shown in *Fig. 22*.

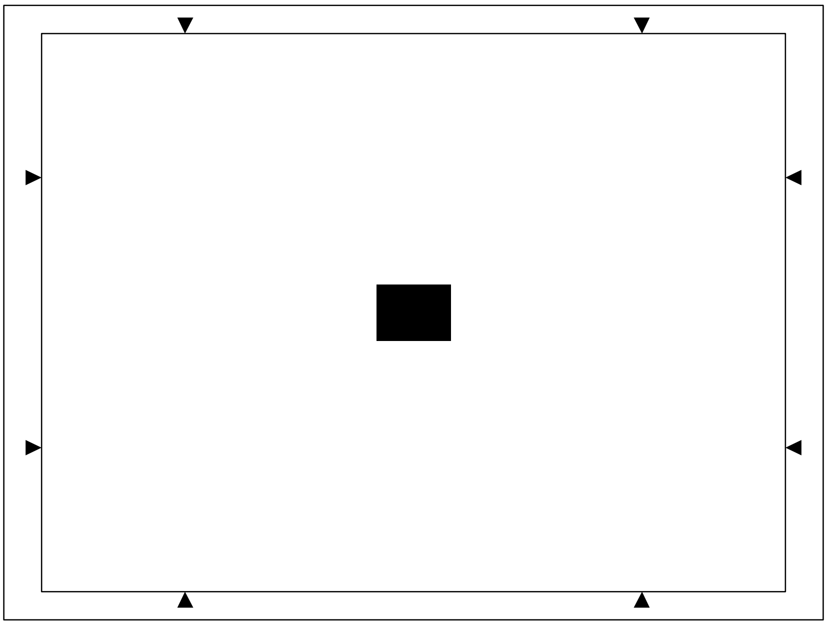
Measuring equipment

- Oscilloscope.
- Video amplitude meter.



Notes: The width of the black area is 0.707 times the width of the image.
The height of the black area is 0.707 times the height of the image.

Fig. 21 - Overall flare measurement.



Notes: The width of the black area is 0.1 times the width of the image.
The height of the black area is 0.1 times the height of the image.

Fig. 22 - Localized flare measurement.

12.3. Measurement conditions

The camera and lens settings should be as shown on *page 48*.

The test chart illumination is adjusted so that a white level of 100% is obtained with the iris aperture indicated.

Control	Basic setting
Gain	0 dB
Flare corrector	ON
Black balance with lens capped	35 mV
White balance	700 mV
Colour corrector	ON
Aperture/contour corrector	OFF
Noise reducer (“coring”)	OFF
Black and white shading correctors	ON and optimized
Gamma corrector	ON and calibrated
Dynamic knee corrector	OFF
Exposure time	nominal value (= 20 ms)
White clipper	–
Pedestal	35 mV
Iris 2/3-inch CCD image format 1/2-inch CCD image format	f/4 f/2.8
Zoom focal length	–

12.4. Measurement procedure

The focal length and aperture of the lens are not changed during the measurements.

The camera is centred on the test chart with an APL of 50%. The change in black level, at the centre of the image, is then measured for each of the RGB channels.

The test chart with an APL of 50% is then replaced by the test chart with an APL of 99% and the change in black level, at the centre of the image, is measured for each of the RGB channels.

The measurements are repeated for the corners of the image using the test chart with an APL of 99%; the the black square is placed in a position 10% from the horizontal side and 10% from the vertical side of the chart.

12.5. Presentation of results

The results are expressed as percentages of the nominal level: (700 mV/75Ω).

The following presentation is recommended:

Flare

Signal

R	**xx** %
G	**xx** %
B	**xx** %
R-G	**xx** %
B-G	**xx** %

Conditions:

Gamma:	0.45
Focal length:	......
Iris aperture:	......

13. Transfer law or gamma correction

13.1. Definition

The measured transfer law is the opto-electrical transfer curve of the camera.

13.2. Equipment used

Test charts

The transfer curve is measured using either a set of neutral glossy samples with reflectance factors of:

0.1, 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5, 5.5, 6, 6.5, 7, 7.5, 8, 8.5, 9, 9.5, 10, 20, 30, 40, 50, 60, 70, 80, 90 %.

or set of transparent neutral density filters.

Measuring equipment

- Light box with 45° illumination. A sample presentation equipment of the kind used for colorimetric fidelity measurements according to the "real samples" method is recommended (see EBU document Tech. 3237 [3]).
- Oscilloscope.
- Video amplitude meter.

13.3. Measurement conditions

The camera and lens settings should be as follows:

Control		Basic setting
Gain		0 dB
Flare corrector		ON
Black balance with lens capped		35 mV
White balance		700 mV
Colour corrector		ON
Aperture/contour corrector		ON
Noise reducer ("coring")		OFF
Black and white shading correctors		ON and optimized
Gamma corrector		ON and calibrated
Dynamic knee corrector		OFF
Exposure time		nominal value (= 20 ms)
White clipper		–
Pedestal		–
Iris	2/3-inch CCD image format 1/2-inch CCD image format	– –
Zoom focal length		–

13.4. Measurement procedure

The procedure is described for measurements using a set of reflective samples; however, the same measurements can be made with a set of transparent neutral density filters.

The procedure is in two parts:

a) Determination of the slope of the first segment of transfer law (initial gain)

The green channel of the camera is considered first. The camera is focussed on the sample with a reflectance factor of 90% and the output signal of the green channel is adjusted to 700 mV (iris setting).

The camera is then directed at the sample with a 20% reflectance factor and the gamma corrector is set so that the level in the green channel is 356 mV.

Note: For the gamma corrector, the output video signal versus input video signal can be derived as follows:

$$V_{out} = \left(\frac{V_{in}}{700}\right)^{0.45} \times 700$$

The camera is then directed at the sample with a reflectance factor of 0.1% and the black level is adjusted so that the green channel voltage is 14 mV.

The three settings are repeated to obtain a better precision.

For each sample with reflectance factors of 1% to 5%, the values of the green channel output signal are recorded. Then the arithmetic average of the differences in levels is calculated, starting with the value for the sample with reflectance factor of 0.5%.

An increment of 0.5% in the reflectance factor gives an increment of 3.88 mV in the output signal, for a linear response. The slope (or gain) of the first segment of the transfer law is obtained by dividing the calculated average value by 3.88 mV.

Examples:

If	gain = 3	then green output = 3.88 mV x 3	=	11.6 mV
	gain = 4	then green output = 3.88 mV x 4	=	15.6 mV
	gain = 5	then green output = 3.88 mV x 5	=	19.4 mV

b) Determination of the transfer law

The camera is focussed on the sample with a 90% reflectance factor and the output level of the green channel is set at 700 mV (iris setting).

The procedure is repeated for the sample with a 20% reflectance factor and the output level of the green channel is set to 356 mV (gamma setting).

Then the pedestal value is then checked.

These operations are repeated to check that the values have not been affected by the successive adjustments.

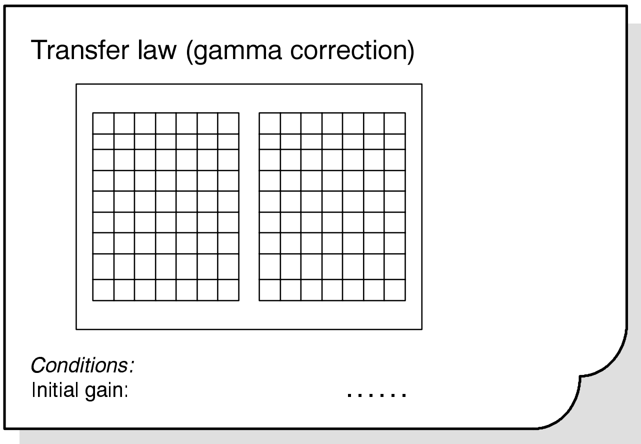
The output level of the green channel is measured for all samples from 0.1 to 90% reflectance. The values obtained are then used to plot the transfer law point by point.

The same procedure is repeated for the red and blue channels.

13.5. Presentation of results

The three sets of results are plotted on the same graph so that any transfer law differences can be highlighted. The original gain value must be indicated

The following presentation is recommended:



Examples of the overall gamma curve and details of the linear portion are shown in *Fig. 23* and *Fig. 24* respectively.

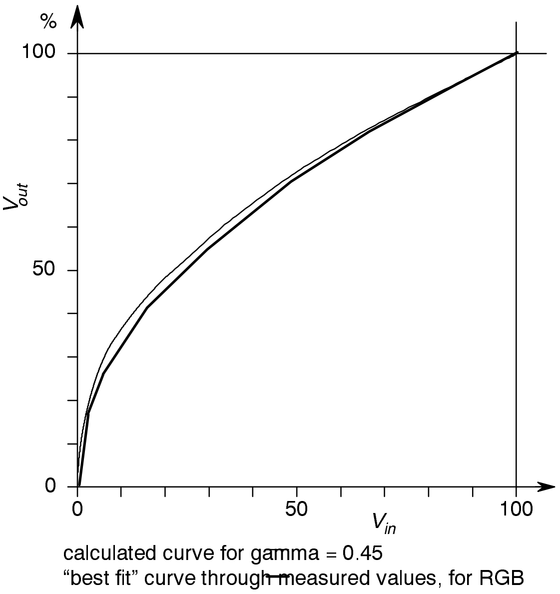


Fig. 23 - Example of a transfer (gamma) curve.

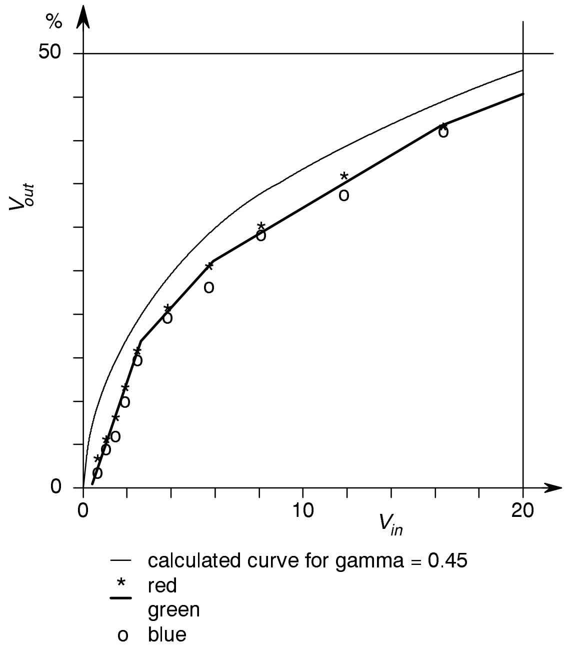


Fig. 24 - Example of the linear part of a transfer (gamma) curve.

14. Smearing

14.1. Definition

Smearing is the presence of a vertical bar in the picture, related to the presence of an over-illuminated part of the scene.

14.1.1. Considerations on smearing and its measurement

A continued build-up of photocharge can occur during the time it takes to shift out the integrated charge from a CCD sensor. This is due to the relative photosensitivity of vertical CCD registers in an interline transfer structure, and to further integration of charges during transfer, in a frame transfer structure.

The effect on the image is a vertical bar above and beneath an over-illuminated area, as illustrated in *Fig. 25*.

Fig. 25 - Illustration of smearing.

Smearing and is measured by inserting discrete attenuation steps in the optical path of the camera.

14.2. Equipment used

Test chart

A test chart illuminated from the rear, as shown in *Fig. 26*, is recommended. This test chart has a square opening on a black background; the dimensions of the opening are 1/10 of the height of the picture, and it is placed 1/10 H below the top edge of the test chart.

The position of the square opening has not been chosen at the centre of the pattern in order to minimize lens related flare phenomenon.

Measuring equipment

- Video amplitude meter.
- Monochrome monitor.
- 500 kHz or 1 MHz low-pass filter.

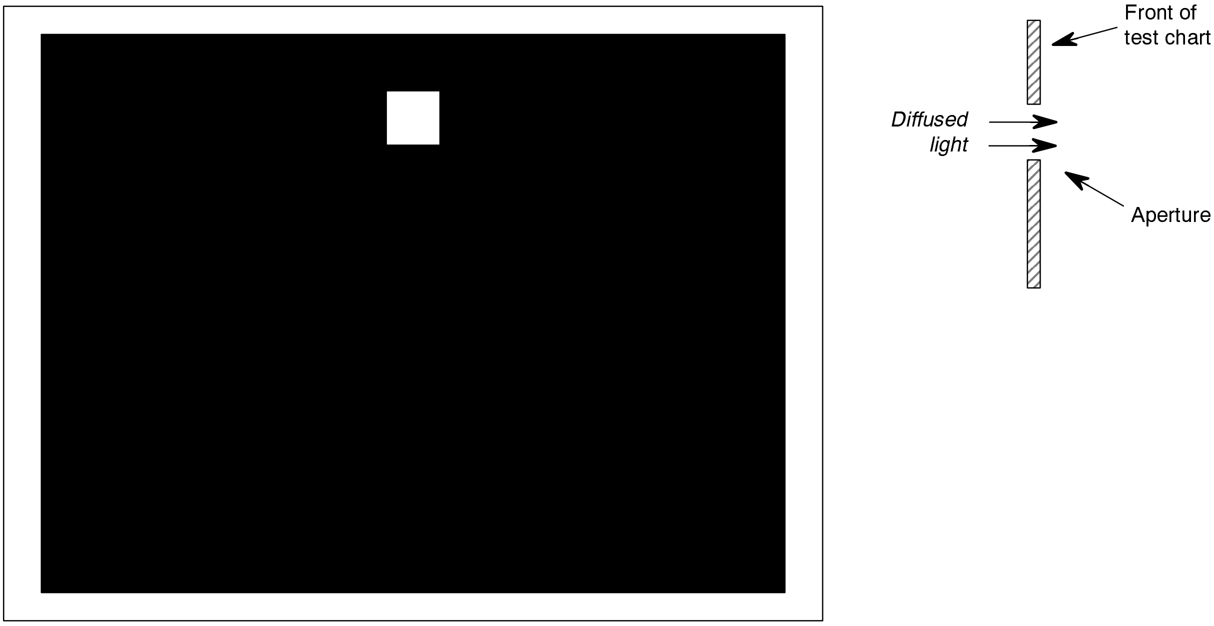


Fig. 26 - Test chart for the measurement of smearing.

14.3. Measurement conditions

Two sets of conditions are recommended, as shown in the table below:

<table>
<tr><th>Control</th><th>Setting for
Condition A</th><th>Setting for
Condition B</th></tr>
<tr><td>Gain</td><td colspan="2">0 dB</td></tr>
<tr><td>Flare corrector</td><td colspan="2">ON</td></tr>
<tr><td>Black balance with lens capped</td><td colspan="2">35 mV</td></tr>
<tr><td>White balance</td><td colspan="2">700 mV</td></tr>
<tr><td>Colour corrector</td><td>OFF</td><td>ON</td></tr>
<tr><td>Aperture /contour corrector</td><td colspan="2">ON</td></tr>
<tr><td>Noise reducer (“coring”)</td><td colspan="2">OFF</td></tr>
<tr><td>Black and white shading correctors</td><td colspan="2">ON and optimized</td></tr>
<tr><td>Gamma corrector</td><td colspan="2">ON and calibrated</td></tr>
<tr><td>Dynamic knee corrector</td><td>OFF</td><td>OFF (Note)</td></tr>
<tr><td>Exposure time</td><td>shutter OFF</td><td>nominal value (= 20 ms)</td></tr>
<tr><td>White clipper</td><td colspan="2">-</td></tr>
<tr><td>Pedestal</td><td colspan="2">70 mV</td></tr>
<tr><td>Iris 2/3-inch CCD image format
1/2-inch CCD image format</td><td colspan="2">See Section 14.4.
See Section 14.4.</td></tr>
<tr><td>Zoom focal length</td><td colspan="2">-</td></tr>
</table>

Note: If the knee corrector is ON, smear will probably occur about 2.5 f-stops earlier).

14.4. Measurement procedure

The camera is focussed on the test chart, the window of which is evenly illuminated through a diffuser.

The iris aperture is initially set at its lowest value: f/22 or f/16 and any neutral filter (filters inside the camera or additional filters) are inserted in the optical path of the camera. The illumination is adjusted so that, with maximum attenuation, the video level at the RGB outputs is equal to 700 mV

The measurement is first made in the low-pass filtered red channel to which a monochrome monitor, an oscilloscope and a video amplitude meter are connected.

The oscilloscope is switched to "line frequency" mode and the reading is taken on the last line of the raster.

Note: It may be easier to measure the smear if the integration time is reduced.

The filters are gradually removed and the iris aperture is adjusted, one setting at a time, until smearing begins to appear on the monitor (the monitor should be placed in the dark). Smearing will take the form of a slight shift in black level. Experiments show that smear becomes visible when the smearing level is around 0.5% of the nominal video level (i.e. 3.5 mV).

The iris aperture value and peak value of the corresponding signal at the over-illuminated window are then recorded.

The measurements are repeated in the G and B channels.

The level of over-illumination giving rise to a smearing level of 3.5 mV is then calculated.

This level is determined taking account of the attenuations of the filters that were removed, as well as the number of aperture setting changes made before smearing occurred. (Note: a change of the iris setting of one f-stop corresponds to a multiplication of the illumination by 2.)

The product of the corresponding gains can then be used to calculate the level of over-illumination, in decibels (dB), corresponding to the emergence of smearing having a level of 3.5 mV.

14.5. Presentation of results

The following presentation is recommended:

Smearing

	R	*G*	*B*
Attenuation of filters removed:	**xx**	**xx**	**xx**
Number of iris stops:	**xx**	**xx**	**xx**
Possible over-illumination for smearing of 3.5 mV	**xx**	**xx**	**xx**

If the beginning of smearing visibility corresponds to a value other than 0.5% of the nominal signal, this value must be indicated.

15. Over-exposure headroom

15.1. Definition

The over-exposure headroom is the increase in exposure which is possible without any significant change in the output video signal being observed.

15.1.1. Considerations on the concept of over-exposure headroom

Fig. 27 shows the transfer characteristic of a CCD. The part of the curve close to saturation is sometimes called “static knee”. It is seen that the dynamic range of a camera is less than the intrinsic dynamic range of the CCD image sensor itself.

Electronic circuits in the camera allow a higher dynamic range to be obtained before saturation of the CCD; an increase of some 20 dB may be possible.

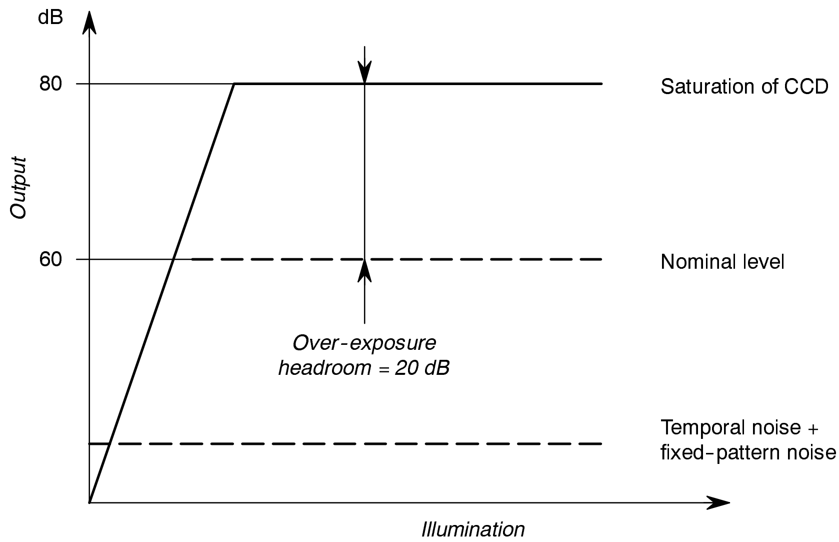


Fig. 27 - Illustration of over-exposure headroom.

15.2. Equipment used

Test chart

EIA grey scale chart (see *Fig. 3*).

Measuring equipment

- Video oscilloscope.
- Colour monitor.

15.3. Measurement conditions

Measurements are taken in two sets of conditions, shown in the table on *page 56*.

Control	Setting for Condition A	Setting for Condition B
Gain	0 dB	
Flare corrector	ON	
Black balance with lens capped	35 mV	
White balance	700 mV	
Colour corrector	ON	
Aperture /contour corrector	ON	
Noise reducer ("coring")	OFF	
Black and white shading correctors	ON and optimized	
Gamma corrector	ON and calibrated	
Dynamic knee corrector	OFF	ON
Exposure time	nominal value (= 20 ms)	
White clipper	OFF	
Pedestal	–	
Iris 2/3-inch CCD image format 1/2-inch CCD image format	See *Section 15.4.* See *Section 15.4.*	
Zoom focal length	–	

15.4. Measurement procedure

Measurements are taken on the RGB or coded luminance (Y) signals.

This measurement only considers the static knee characteristics. The procedure is in two parts:

Condition A

With the camera directed at the grey scale test chart, the iris setting is adjusted so that the white level corresponds to 700 mV. The aperture setting is then noted.

Condition B

In this case, the white level decreases. The iris is opened until the white level reaches 700 mV.

The change of iris settings (number of *f*-stops) between the two previously-noted settings gives the over-exposure headroom.

Note: If the white balance, observed on a colour monitor, alters when the iris setting is increased, the position at which the error occurs is recorded.

15.5. Presentation of results

The following presentation is recommended:

Over-exposure headroom

Over-exposure headroom = *N* x *f*-stop = **xx** dB

16. Blemishes

16.1. Definition

Process-induced defects of all kinds, both in the surface layers and in the substrate of the CCD sensor, can contribute to randomly distributed, spurious impairments of the picture, which affect only a very small number of pixels at a time. These impairments are called “blemishes”. The most visible blemishes are essentially white dots on a black background.

16.2. Equipment used

Measuring equipment

- Monochrome monitor.
- Digital storage oscilloscope with averaging function.

16.3. Measurement conditions

The camera and lens settings should be as shown in the table below:

Control	Basic setting
Gain	0 dB
Flare corrector	ON
Black balance with lens capped	35 mV
White balance	700 mV
Colour corrector	ON
Aperture/contour corrector	OFF
Noise reducer (“coring”)	OFF
Black and white shading correctors	ON and optimized
Gamma corrector	ON and calibrated
Dynamic knee corrector	ON
Exposure time	nominal value (= 20 ms)
White clipper	–
Pedestal	35 mV
Iris 2/3-inch CCD image format 1/2-inch CCD image format	– –
Zoom focal length	–

It is recommended that measurements be repeated under different environmental conditions:

a) Normal room temperature (25°C).

b) Ambient temperature of 40°C.

16.4. Measurement procedure

Measurements are made in the Y, R, G, B channels.

The camera is measured after a minimum of one hour at the test temperature, to allow for thermal stabilization (2 hours is recommended); a further measurement is made after 8 hours of operation.

For the two zones defined in *Fig. 28*, the white dots are observed on the monochrome monitor adjusted under normal conditions.

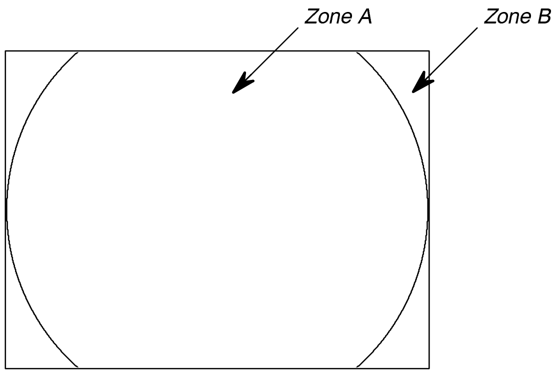


Fig. 28 - Image zones for the measurement of blemishes.

When a blemish is detected, it is localized using the video analyzer marker and its width and amplitude are measured. The oscilloscope serves to determine the number of pixels affected by the blemish.

16.5. Presentation of results

The blemishes are classified, for the two zones, according to their amplitude *A* expressed as a percentage of the nominal level (700 mV). The number of blemishes are given in a table as shown below:

Blemishes

Time after start-up: ..... hours

Amplitude ratios (A %)	*Zone 1*	*Zone 2*
1.5 < A < 3	**xx**	**xx**
3 < A < 5	**xx**	**xx**
5 < A <10	**xx**	**xx**
A >10	**xx**	**xx**

17. Image format

17.1. Definition

The width/height ratio of the image reproduced by the CCD sensor should be 4/3. Some CCD sensors do not strictly conform to that ratio because the horizontal or vertical dimensions of the image zone differ from the standard dimensions for the 2/3-inch and 1/2-inch formats.

17.2. Equipment used

Test charts

A test chart of the type shown in *Fig. 29* gives a quick indication on the accuracy of the image format.

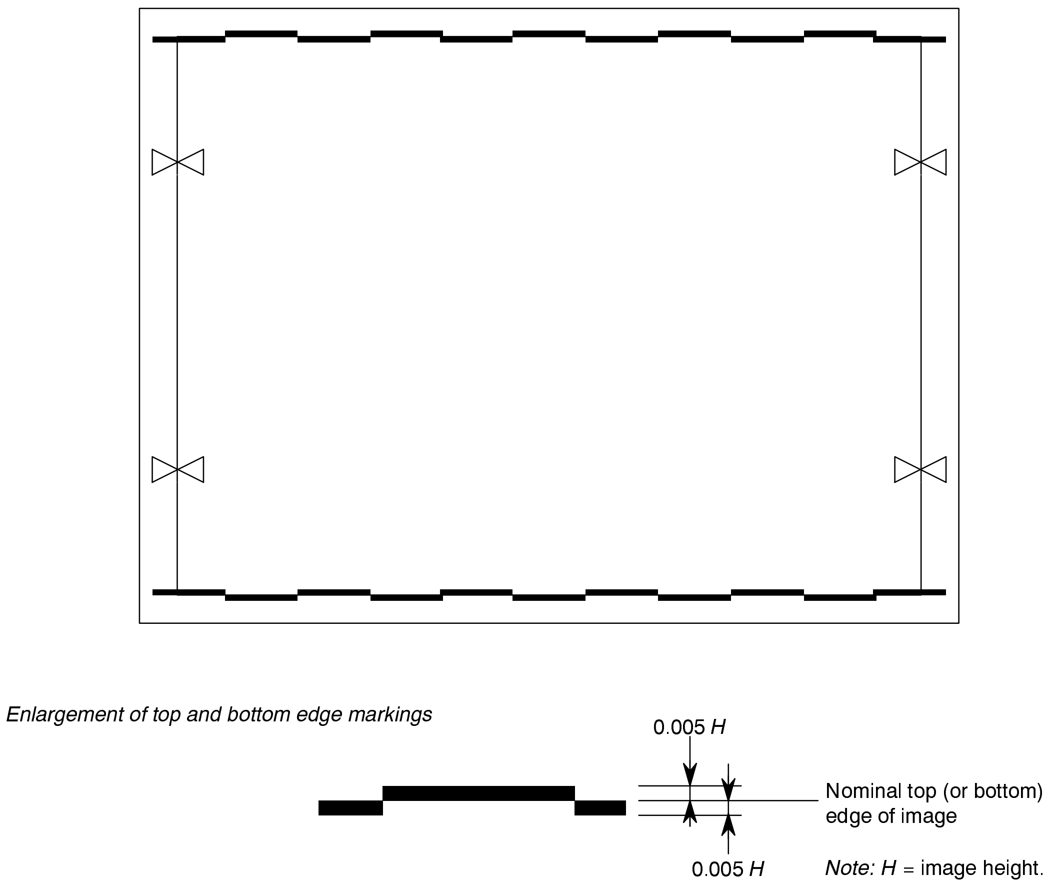


Fig. 29 - Test chart for the measurement of image format.

The maximum tolerances, as defined by the EBU, are:

± 0.5% of the height of the picture.

Measuring equipment

- Monochrome monitor.

17.3. Measurement conditions

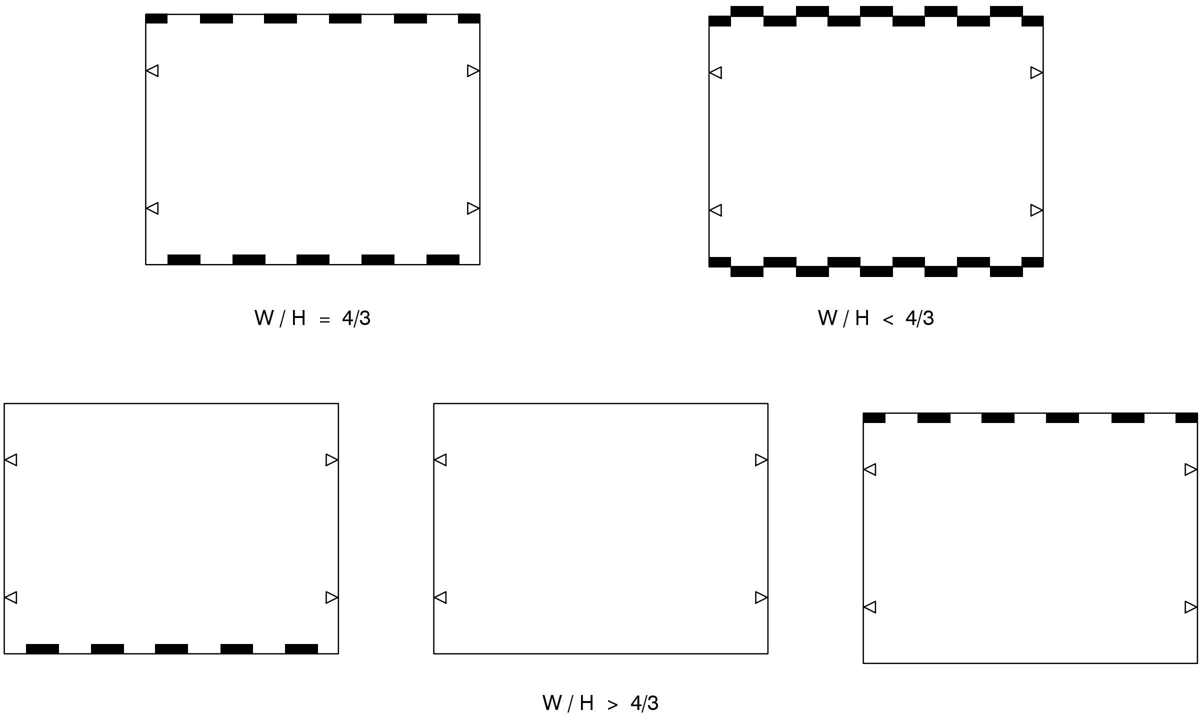
This measurement is not dependent on the settings of the camera.

17.4. Measurement procedure

Measurements are taken in the RGB channels.

The camera is directed at the test chart so that the left- and right-hand markers exactly match the active line period.

Depending on the format accuracy, the following observations can be summarized as shown in *Fig. 30*.



Note: For clarity, the vertical scale of the castellations has been exaggerated in these diagrams.

Fig. 30 - Indications given by the test chart shown in *Fig. 29.*

17.5. Presentation of results

The error, expressed a percentage of the height of the picture, is recorded.

The following presentation is recommended:

Image format

Error in height of picture = **xx** %

18. Colorimetric fidelity measurement

For colorimetric fidelity measurements, the procedure to be followed is as described in EBU document Tech. 3237 [3].

Bibliography

[1] EBU document Tech. 3238 (1983): *Methods for measuring the characteristics of television cameras*

[2] ITU-T Recommendation J.61 (formerly CCIR Recommendation 567): *Transmission performance of television circuits designed for use in international connections*

[3] EBU document Tech. 3237 (1983): *Methods of measurement of the colorimetric fidelity of television cameras*

EBU document Tech. 3237, Supplement 1 (2nd. edition, 1989): *Measurement procedures*

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