Recognized as an
American National Standard (ANSI)

IEEE Std 205-2001
(Revision of
IEEE Std 205-1958)

IEEE Standard on Television: Measurement of Luminance Signal Levels

Sponsor

Audio and Visual Techniques Committee
of the
Broadcast Technology Society

Approved 17 March 2001

IEEE-SA Standards Board

Abstract: A method of measuring the amplitude levels of an SMPTE 170M-1994; NTSC color or monochrome television video signal is described. It is concerned with luminance measurements at various points in transmission systems where the signals are at video frequencies. The methods described are limited to the use of waveform monitors, software video processing for amplitude assessment, or suitable oscilloscopes, and are primarily directed to specifying means of measuring television signal levels for operating purposes.
Keywords: chrominance, filter, luminance, luminance measurement filter, NTSC, SMPTE 170M, video, waveform monitor

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Print: ISBN 0-7381-2812-0 SH94914
PDF: ISBN 0-7381-2813-9 SS94914

Introduction

(This introduction is not part of IEEE Std 205-2001, IEEE Standard on Television: Measurement of Luminance Signal Levels.)

This standard is a revision of IEEE Std 205-1958 and updates portions of the standard, reflecting changes in TV practices and improvements in equipment used for measurements of television signals. This standard does not preclude automatic processing (software) or other test methods that may be in use for this purpose. This revision adds an improved version of the luminance measurement filter (LUM filter) and also documents the previous IEEE Std 205-1958 response (IRE filter). However, the IRE filter response was generally found to have insufficient rejection of chroma and may not be readily available. See 5.3 and A.2 for more information.

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IEEE Standard on Television: Measurement of Luminance Signal Levels

1. Overview

1.1 Scope

This standard describes a method of measuring the amplitude levels of an SMPTE 170M-1994,[1] NTSC color or monochrome television video signal. It is concerned with luminance measurements at various points in transmission systems where the signals are at video frequencies. The methods described in this standard are limited to the use of waveform monitors, software video processing for amplitude assessment, or suitable oscilloscopes, and are primarily directed to specifying means of measuring television signal levels for operating purposes.

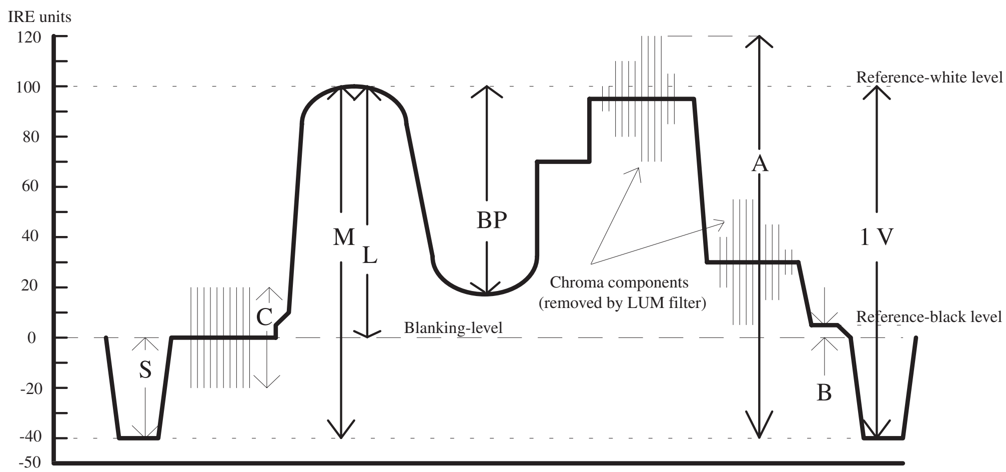
1.2 Purpose

This standard provides a uniform method to measure the luminance portion of a video signal in the possible presence of large chrominance portions. It also specifies a method of measuring video levels in a manner permitting ready correlation between measurements at different points of a system, regardless of the nominal voltages present.

1.3 Application

The significant levels of the luminance portion of the signal are shown in Figure 1. The peak amplitude excursion of a composite color signal may exceed, by substantial amounts, the peak amplitude of the luminance portion of the signal. Because subjective brightness is more nearly proportional to the luminance portion than to any other signal portion, it is desirable to maintain the luminance portion of the signal at a consistent level. The application of this standard will result in approximately the same brightness and contrast when the signal is viewed on either color or monochrome monitors, without requiring supplementary adjustments. Additionally, an improved LUM filter is introduced to

[1]Information on references can be found in Clause 2.



Typical Measured Levels

A: The peak-to-peak amplitude of the composite color video signal.
B: (Set-up) The difference between black, typically reference-black, and blanking level.
C: The peak-to-peak amplitude of the color burst.
L: Luminance signal white-peak value.
M: Composite monochrome video signal peak-to-peak amplitude (M=L+S).
S: Synchronizing signal-amplitude.
BP: Black peak.

Figure 1—Typical scale and level definitions.

approximate the luminance or Y portion of the decoded signal, allowing better matching of subsequent composite-to-component conversions.

2. References

This standard shall be used in conjunction with the following publication.

ANSI/SMPTE 170M-1994, Television Composite Analog Video Signal—NTSC for Studio Applications.[2]

3. Definitions

For the purposes of this standard, the following terms and definitions apply. *The Authoritative Dictionary of IEEE Standard Terms*, Seventh Edition should be referenced for terms not defined in this clause.

The significant portions of a composite video signal are defined below, and shown in Figure 1.

3.1 black peak: A maximum negative excursion of the luminance portion from reference white towards blanking.

3.2 blanking level: That level of a video signal which separates the luminance portion from the synchronizing pulses.

[2]ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA (http://www.ansi.org/).

NOTE—The chrominance portion of the video signal can extend below the blanking level.

3.3 burst portion: The portion of the video signal that is a sample of the subcarrier frequency sinusoid allowing synchronous demodulation. This gated and filtered signal derived from the subcarrier is located on the back porch (the interval between the horizontal sync pulse and active video).

3.4 chrominance portion: The chrominance portion of the video signal is the color-difference information after modulation of the color subcarrier frequency. This portion is added to the luminance portion to form the composite color signal.

3.5 luminance portion: The portion of the video signal that is intended to contain the monochrome or gray-scale information.

3.6 reference black level: The luminance signal level corresponding to a specified maximum negative excursions for black peaks, nominally 7.5 IRE units above blanking. Typically the reference black level is the setup level.

3.7 reference white level: The luminance signal level corresponding to a specified maximum limit for white peaks defined as nominally 100 IRE [B1][3] units above blanking.

3.8 sync level: The level of a video signal located below the blanking level containing the horizontal and vertical synchronizing pulses.

3.9 white peak: A maximum positive excursion of the luminance portion from blanking towards reference white.

4. Theory of measurements

The method of luminance signal level measurement in the presence of a chrominance portion prescribed in this standard is based on utilizing waveform monitors and filters with similar amplitude, frequency, and group-delay characteristics. This method can achieve an acceptable degree of accuracy when used by operators measuring a composite video signal at various locations in a transmission system.

5. Method of measurement

5.1 List of equipment

a) Display device
b) Filter
c) Calibration Signal

5.2 Display device specifications

5.2.1 Waveform monitor

A waveform monitor or oscilloscope with a luminance filter meeting the specifications of 5.3, for level measurements, shall be used.

[3]The Numbers in brackets correspond to those of the bibliography in Annex B.

NOTE—Industry practice uses waveform monitors rather than oscilloscopes for the purpose of measuring television signal levels. Whenever a waveform monitor is indicated, an oscilloscope could be substituted, provided it is equipped with an IRE scale and preceded with a luminance (LUM) filter.

5.2.2 Waveform monitor accuracy

A waveform monitor shall be capable of luminance level measurements with errors not exceeding 1% of a 1 V signal displayed with 140 IRE units on a 170 IRE unit scale. Factors that contribute to instrument measurement error include:

a) Spot size and focus
b) Brightness
c) Deflection amplitude
d) Vertical linearity
e) Display rotation
f) Readability of external scales, including a reasonable allowance for parallax
g) Calibration accuracy, and stability of calibration

5.2.3 Bandwidth

The bandwidth and group-delay characteristics of the waveform monitor shall not significantly alter the characteristics of the luminance filter. A typical waveform monitor will have a frequency response within 2% from 50 Hz to 6 MHz referenced to 50 kHz, and a 2T transient response error of 1% or less and a 75 Ω input impedance with return-loss >36 dB to 5 MHz.

5.2.4 Scale

An appropriate scale is shown in the left-hand portion of Figure 1, together with an illustrative video signal showing the relation between the scale and the waveform presentation. The zero or reference point of the scale is located at the blanking level. The upper part of this linear scale is marked from 0 to 120 IRE units. The luminance portion of the video signal is measured on this portion of the scale. The lower part of the scale is marked in linear steps from 0 to −50 units and is where levels of the sync signal can be measured.

5.2.5 Time-base

The waveform monitor time-base shall be synchronized at both line and field rates and may be switchable to multiples and submultiples of those rates to provide a convenient display of portions of lines and fields, or two lines or two fields.

5.2.6 DC restoration

A dc restoration circuit, preferably referenced to reference blanking or back porch and capable of being disabled, shall be employed to prevent vertical shifts of the displayed waveform in the presence of low-frequency disturbances [average picture level (APL), hum, etc.]. The time constants of the dc restoration circuit shall be short enough so that the above disruptions are prevented or significantly reduced.

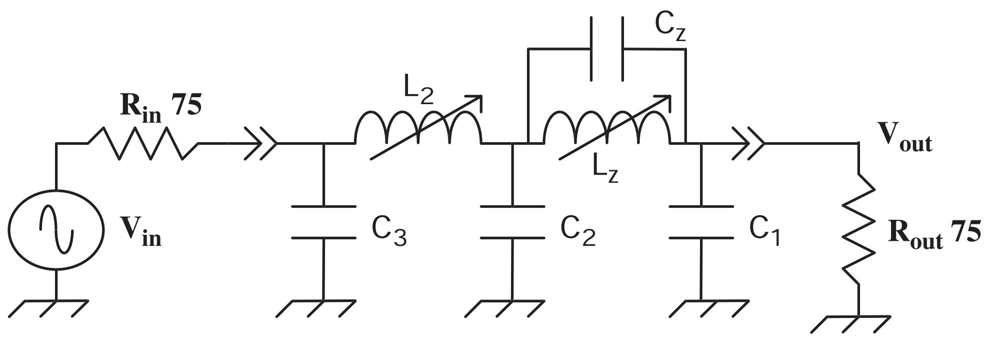
5.2.7 Vertical and horizontal centering

A suitable means shall be provided for the alignment of the displayed image with the graticule containing the IRE scale.

5.3 Specifications of the luminance (LUM) measurement filter

5.3.1 Luminance measurement-filter frequency response magnitude mask

See Figure 2 and Figure 3 for more information.



L_z and L_2 are tuned for best step-response (minimum overshoot/undershoot)

$C_1 = 4050\,\text{pF}$ $L_z = 8.31\,\mu\text{H}$ $R_{in} = 75\,\Omega$
$C_2 = 1200\,\text{pF}$ $C_z = 217\,\text{pF}$ $R_1 = 75\,\Omega$
$C_3 = 494\,\text{pF}$ $L_2 = 6.04\,\mu\text{H}$

Detailed specification of luminance (LUM) filter:

$$H(s) = V_{out}/V_{in}, \qquad H(s) = \frac{n_2 s^2 + n_0}{d_5 s^5 + d_4 s^4 + d_3 s^3 + d_2 s^2 + d_1 s + d_0}$$

Define coefficients for numerator: $n_2 = 1, \quad n_0 = \dfrac{1}{L_z C_z}$

Define coefficients for denominator: $d_0 = \dfrac{R_{in}}{L_z C_z R_1} + \dfrac{1}{L_z C_z}, \quad R_1 = R_{out} = 75\,\Omega$

$$d_5 = L_2 C_3 \left(C_1 + C_2 + \frac{C_1 C_2}{C_z}\right) R_{in}, \qquad d_4 = \left(\frac{L_2}{R_1}\right)\left(C_1 + C_2 + \frac{C_1 C_2}{C_z}\right) R_{in} + \left[L_2 C_3 \left(1 + \frac{C_2}{C_z}\right)\right],$$

$$d_3 = \left[C_1 + C_2 + C_3 + \frac{C_1 C_2}{C_z} + \frac{C_1 C_3}{C_z} + \frac{C_3 L_2}{L_z C_z}(C_1 + C_2)\right] R_{in} + \frac{L_2}{R_1}\left(1 + \frac{C_2}{C_z}\right),$$

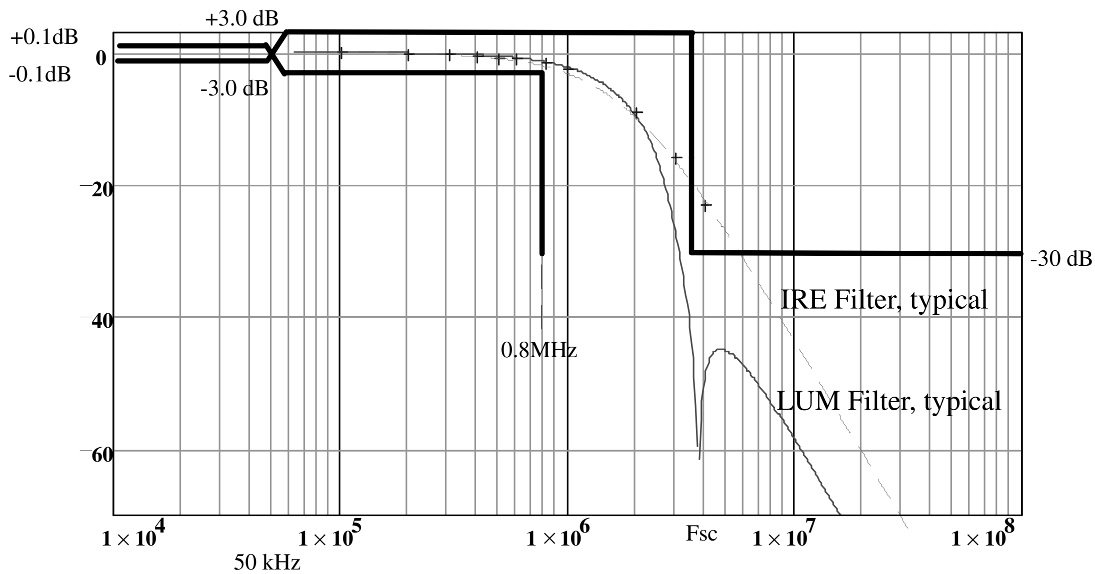
$$d_2 = \frac{R_{in}}{R_1}\left(1 + \frac{C_1}{C_z} + L_2 \frac{C_1 + C_2}{L_z C_z}\right) + \left(1 + \frac{C_2 + C_3}{C_z} + \frac{L_2 C_3}{L_z C_z}\right),$$

$$d_1 = \frac{R_{in}}{L_z C_z}(C_1 + C_2 + C_3) + \frac{L_z + L_2}{R_1}\frac{1}{L_z C_z}$$

Pole–zero values:

$$\text{Poles:} \quad P = \begin{bmatrix} -7.132 \times 10^6 \\ -6.655 \times 10^6 + 7.524 \times 10^6\,J \\ -6.655 \times 10^6 - 7.524 \times 10^6\,J \\ -4.849 \times 10^6 - 1.502 \times 10^7\,J \\ -4.849 \times 10^6 + 1.502 \times 10^7\,J \end{bmatrix} \text{rad/s}, \qquad \text{Zero:} \quad z = \sqrt{\frac{n_0}{n_2}} \qquad z = 2.355 \times 10^7 \text{ rad/s}$$

Figure 2—Schematic diagram of recommended passive luminance-measurement filter (LUM filter) for conformance to response mask of 5.3



+ IEEE 205-1958 IRE response points, see A.2

Figure 3—Luminance measurement filter-frequency response magnitude mask

5.3.2 Filter transient response

The purpose of this filter is to allow reasonably accurate and consistent setting of luminance amplitudes that are independent of the chroma portions of a composite signal. The transient response of this filter should not contain overshoot and/or ringing that detracts from this purpose whether it is implemented totally in software, firmware, or as a hardware prefilter (internal or external to a waveform monitor). Therefore, it is expected that the filter's response to a sine-squared, T-rise (or faster) step or bar signal should have less than 1% peak overshoot, undershoot, and/or ringing. [A T-rise step is defined as the integral of a sine-squared pulse with a half-amplitude duration (HAD) of 125 ns.]

It is recognized that the transient response of similar low-pass filters is often indirectly specified via a flat group (envelope)-delay mask. It should be remembered that, in a broad sense, a flat group-delay only guarantees an even-symmetric impulse-response (odd-symmetric step-response). It does not eliminate or limit overshoot and ringing. For example, the recommended 75 Ω, LC passive LUM filter shown in Figure 2 has a slightly larger 2T response and more chroma rejection than the flat group-delay optimized version of the same filter. However, both versions have virtually no ringing or overshoot in response to a step input.

5.4 Calibration signal

A suitable amplitude-reference signal shall be used for establishing the waveform monitor amplitude calibration to within 1.0% when measuring 1000 mV (140 IRE) or 714 mV (100 IRE) input signals.

NOTE—A variety of low-frequency square or sine-wave sources of 1 V peak-to-peak amplitude would allow the calibration of the waveform monitor. However, the advantage of using a 100 kHz square-wave signal derived from an accurate frequency source is that it allows calibration of the horizontal time-base as well, since this waveform provides identifiable 10 μs markers.

5.5 Measurement procedure

Refer to Figure 4 for a diagram of the test setup.

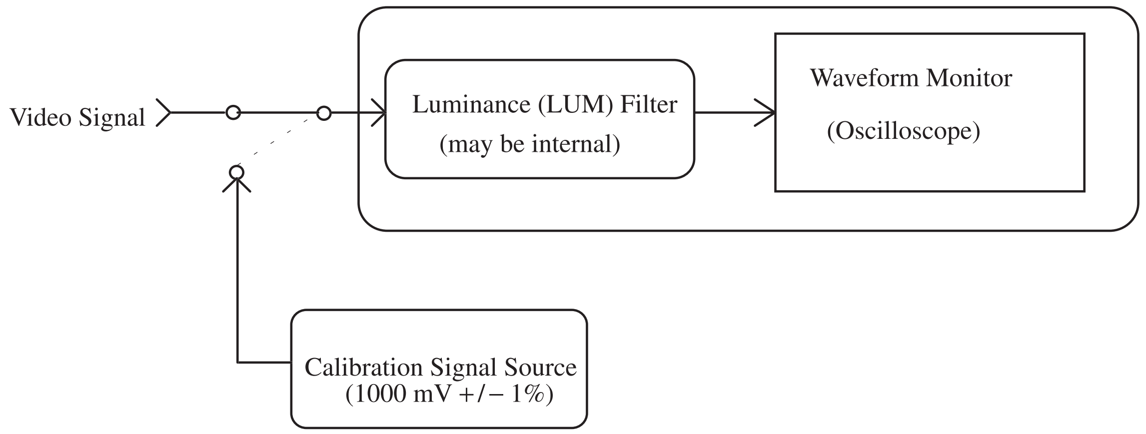


Figure 4—Test setup

5.5.1 Calibration

Apply the calibration signal to the test setup as shown in Figure 4 and adjust the vertical gain of the waveform monitor so that the display indicates 140 IRE units with a 1V peak-to-peak input signal. If the calibration signal is internal to the waveform monitor, switch the calibration signal on, and adjust for the proper display.

5.5.2 Measurement of the signal under test

Apply the video signal to the input of the luminance measurement filter (LUM filter) and connect the output of the filter to the calibrated waveform monitor. Adjust the centering to place blanking on the 0-line of the IRE scale. The various levels of the luminance signal can now be read directly from the IRE scale. If the filter is internal to the waveform monitor, switch the filter on and proceed as above without an external filter.

On signals of changing average picture level (APL), it may be desirable to use the dc coupling or the dc restoration mode of the waveform monitor, if available.

Annex A

(informative)

Comments on IRE response and frequency response mask

A.1 Interpretation

Standardizing the response characteristic of the waveform monitor or luminance measurement filter serves to minimize possible differences in interpretation of signal levels. To further insure uniformity in interpreting the waveform monitor indication, test signals, such as SMPTE color bars, are very helpful for luminance measurements.

During programming, test signals, located in the vertical blanking interval (VBI), provide standardized signals for measurement purposes.

A.2 IRE Response from IEEE Std 205-1958

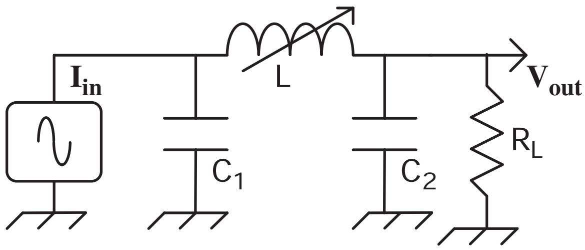
From Figure 2 of IEEE Std 205-1958 and corrected chart dated July 1958:

Table A.1—Nominal response table

f (MHz)	IRE dB
0.1	0
0.2	−0.1
0.3	−0.3
0.4	−0.45
0.5	−0.75
0.6	−1.0
0.8	−1.6
1	−2.5
2	−9
3	−16
4	−23

NOTE—This response does not reduce chroma below 10% and for this reason and lack of availability, it is generally not used for luminance measurements.

A schematic diagram of a recommended passive filter (IRE filter) that has good match to IEEE Std 205-1958 table values is shown in Figure A.1.



Element values: $C_1 = 390\,\text{pF}$ $C_2 = 85\,\text{pF}$ $RL = 500\,\Omega$ $L = 54\,\mu\text{H}$

L is tuned for best transient response

Transfer function: $H(s) - V_{out}/I_{in}$, $H(s) = SF \dfrac{N_0}{D_3 s^3 + D_2 s^2 + D_1 s + D_0}$

Define coefficients for numerator: $N_0 = RL$, $SF = \dfrac{1}{RL}$,

SF = Scale factor to normalize to unity gain

Define coefficients for denominator:

$$D_3 = RL\ C_1 C_2 L, \quad D_2 = L\,C_1, \quad D_1 = RL(C_2 + C_1), \quad D_0 = 1,$$

$$\frac{D_2}{D_3} = 2.353 \times 10^7, \quad \frac{D_1}{D_3} = 2.653 \times 10^{14}, \quad \frac{D_0}{D_3} = 1.117 \times 10^{21}$$

Figure A.1—Recommended passive filter for IRE frequency response (1958)

A.3 Comments on frequency response mask

As shown in Figure 3, the frequency response mask allows a moderate variation in filter bandwidth and shape factor. As can be seen, the minimum half-power bandwidth allowed is 0.8 MHz. Maximum half-power bandwidths approaching 1.3 MHz are possible with reasonable transition bandwidths below the 30 dB attenuation requirement at Fsc and $< 1\%$ overshoot on the step response.

Simulations were carried out on fifth-order, minimum-phase filters at these two extremes of the frequency response mask of Figure 3. The results are in Table A.2.

Table A.2—Minimum and maximum frequency response of luminance measurement filter

Simulation→	Minimum bandwidth	Typical bandwidth (see Figure 3)	Maximum-bandwidth
Bandwidth	0.8 MHz	1.1 MHz	1.3 MHz
Rise-time	430 ns	310 ns	265 ns
2T pulse response	52%	65%	70%
Attenuation at Fsc	> 40 dB	> 40 dB	30 dB

Note—All filters have < 1% overshoot and the 2T, sine-squared pulse responses are between 52% and 70% (65% using the recommended filter).

Annex B

(informative)

Bibliography

[B1] IRE Definitions, "IRE Standards on Television: Definitions of Television Signal Measurement Terms, 1955 (55 IRE 23.S1)," *Proc. IRE*, vol. 43, pp. 619–622: May, 1955.

