Basic concepts of analog and digital video signal

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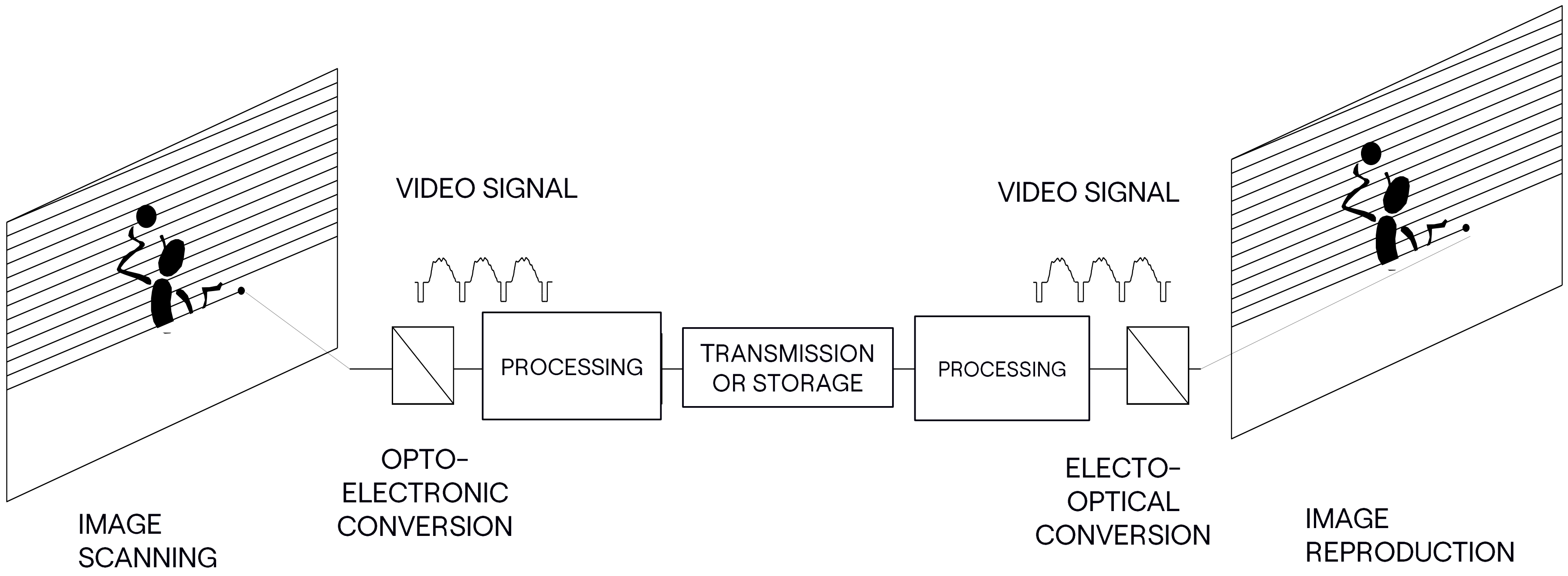
Conversion of light into electrical signal

- in order to include images and video signals in multimedia systems as media content, optical images (spatial distribution of light intensities) need to be converted into electrical signal
- electrical signal is a one-dimensional signal (occupies single value of voltage or current at a given time)
- scanning standard determines the manner in which the optical images are converted into electrical signals
  - scanning standard defines the number of lines per frame and number of frames per seconds (frame frequency or frame rate)
- the same layout is applied in the reproduction process by which electrical signals are converted into images

Video signal production

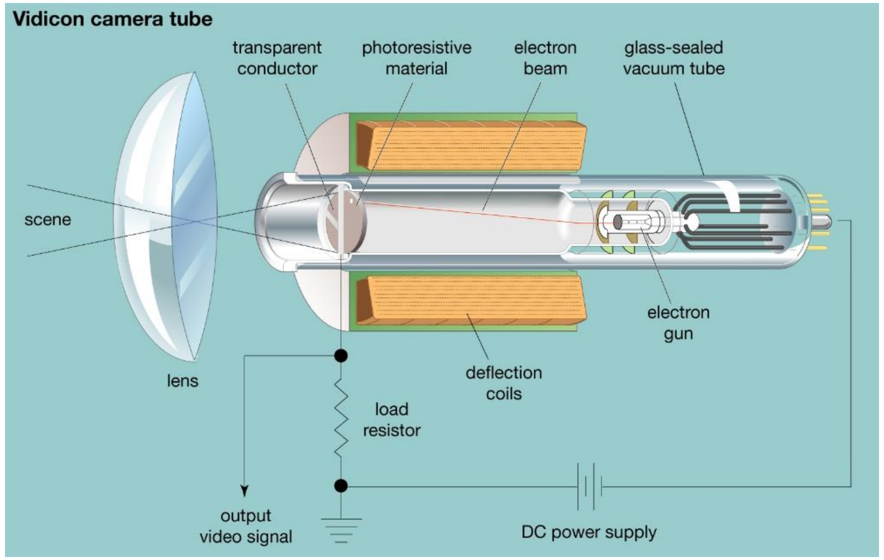


Video signal production

- image scanning process
  - carried out in video camera
  - video camera contains photosensitive sensor (active element) that performs scanning and opto-electronic conversion
    - the spatial arrangement of light intensities that represents the image is transformed into a time sequence of electrical impulses
  - sensors can be divided into two basic groups
    - pickup tubes
    - semiconductor image sensors
      - CCD - *Charge Coupled Devices*
      - CMOS - *Complementary Metal Oxide Semiconductor*
  - the amplitude of the obtained electrical signals corresponds to the light intensity of the currently analyzed surface element of the image and represents video signal

Video signal production

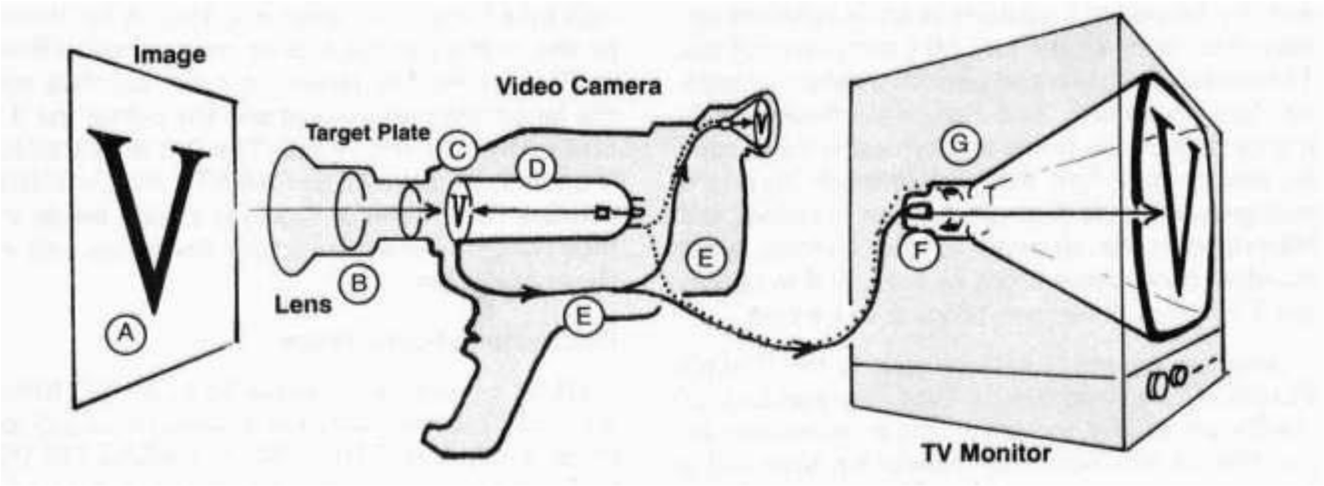
- camera sensor
  - the optical image of the scene is focused onto the photosensitive layer of the sensor
  - under the influence of light, electrical charges proportional to the optical image are created and stored on the photosensitive layer
  - cameras with pickup tubes
    - image scanning is performed by an electron beam
    - electron beam is moved horizontally and vertically using deflection coils, which are located outside the tube
    - electron beam passes over the positive charges that are stored on the on the photosensitive layer of the tube
    - electron beam neutralizes the charges what results in electrical current changes at the output (video signal)



  - cameras with semiconductor image sensors don't use electron beam
    - scanning is performed by horizontal and vertical charge transfer and reading in a specific order which depends on the type of sensor

Video signal production

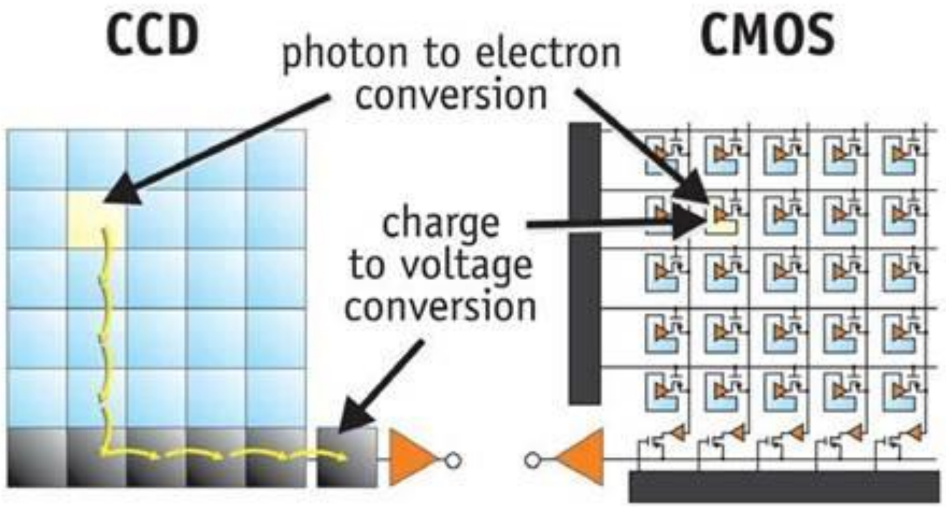
- camera with pickup tube and monitor with cathode ray tube (CRT)



- light is reflected from image (A) focused by lens (B) on photosensitive layer (C)
- this layer is scanned by the electron beam (D) produced by the tube
- charges on the C are converted into electrical signal (video signal)
- video signal (E) comes to cathode ray tube (CRT) of the monitor (F)
- the CRT scans the face of the tube in the monitor in step with the video signal supplied by the camera (G)
- the image is displayed on the light-sensitive face of the CRT, converting video signal back into optical information again

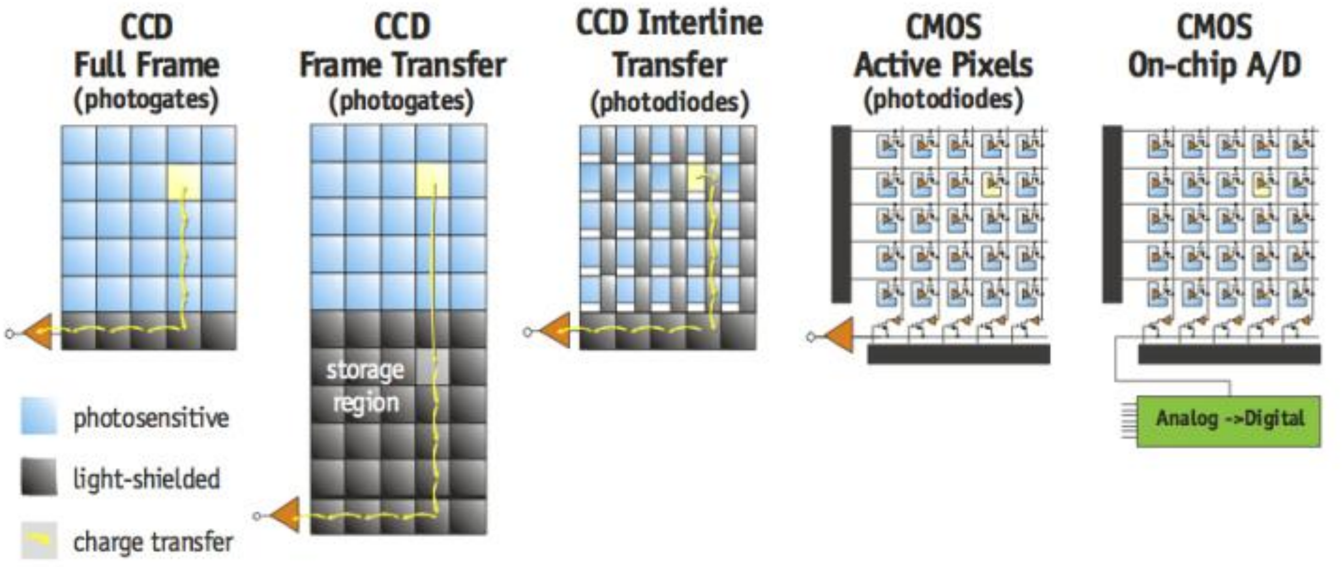
Video signal production

- CCD and CMOS sensors



- CCD transfers the charge from pixel to pixel and convert it to the voltage at the output register
- in the case of CMOS devices, the charge-to-voltage conversion is done for each pixel

Video signal production

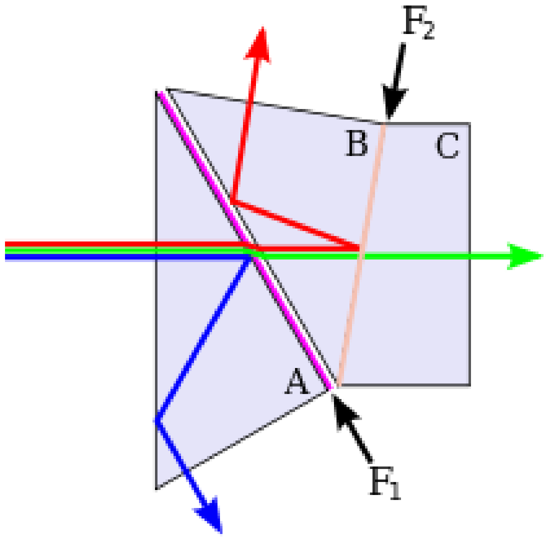


- full frame CCD sensors
  - the entire sensor area is dedicated to photosensitive cells
  - accumulated charges are shifted vertically
    row by row into the serial output register
  - during read out, image area can be masked
    using shutter to avoid smearing caused by light falling on the sensor while signal is to the readout register
- frame transfer CCD sensors
  - all charges of an image are fast shifted to storage region which is protected from light
  - the sensor is always collecting light

- interline transfer CCD sensors
  - charges are transfered for each pixel to a masked area
  - the charge for each pixel is read-out while the next image is captured
  - the interline mask reduces the light sensitive area of the sensor

Video signal production

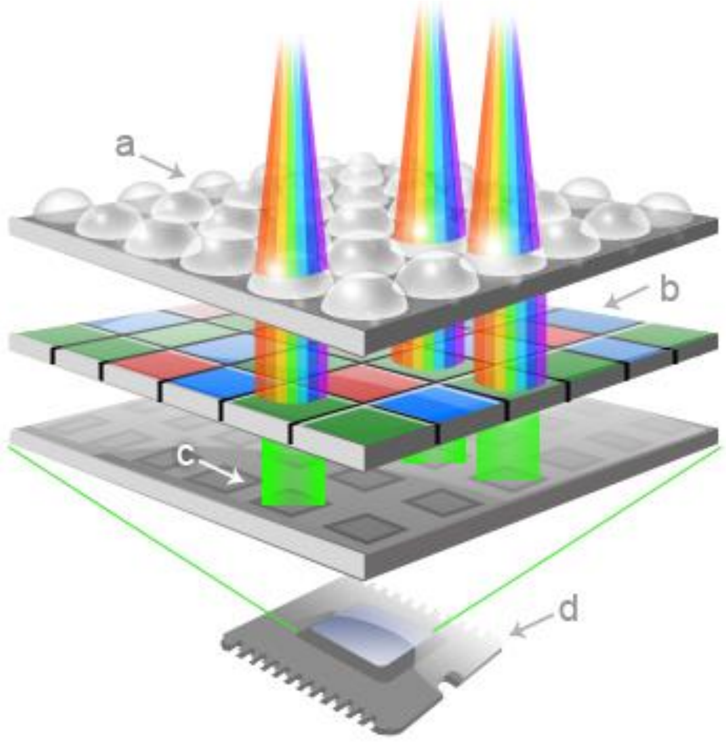
- video signal
  - in an achromatic (black and white) camera, a video signal is luminance signal (E'_Y), which transmits information about the brightness of the scene
  - in color camera three signals are generated which are called primary color signals
    - signal for red color - E'_R
    - signal for green color - E'_G
    - signal for blue color - E'_B
  - in 3-CCD camera the input light is divided into three spectral components using color separation prism
  - each component is directed to its own sensor in which the opto-electronic conversion is performed



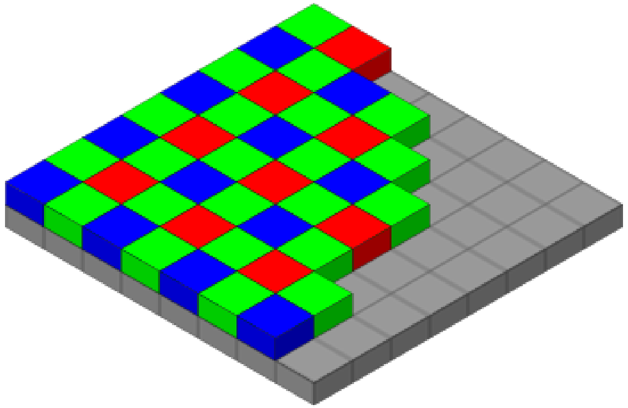
- color separation prism
  F1 – reflects blue light
  F2 – reflects red light

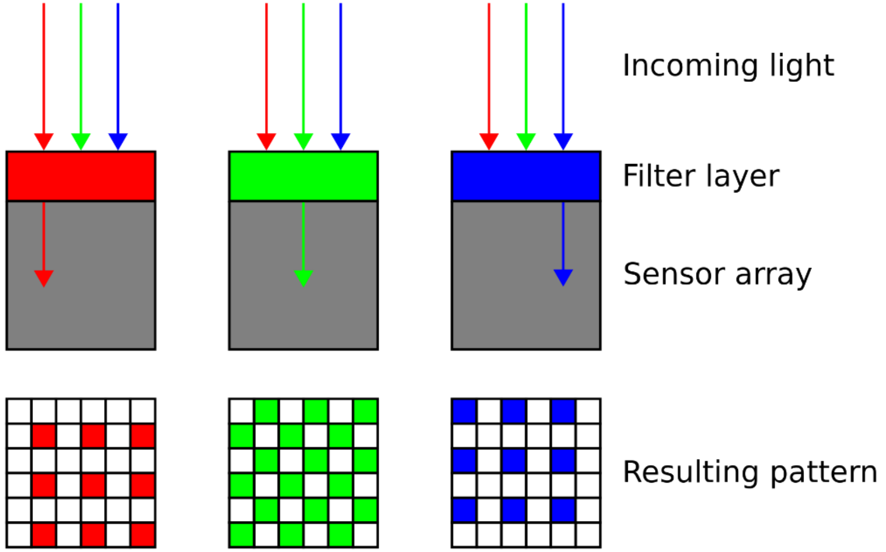
Video signal production

- single CCD camera
  - color filter (Bayer filter) is located in front of the CCD sensor
  - each cell of the filter transmits only one light component to the sensor
  - at the output of the sensor, three primary color signals are obtained



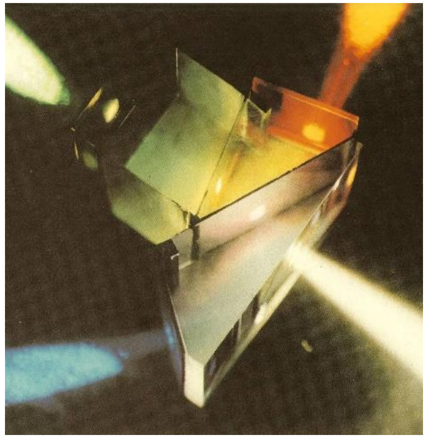
a – microlenses
b – Bayer filter
c – sensor
d – CCD chip

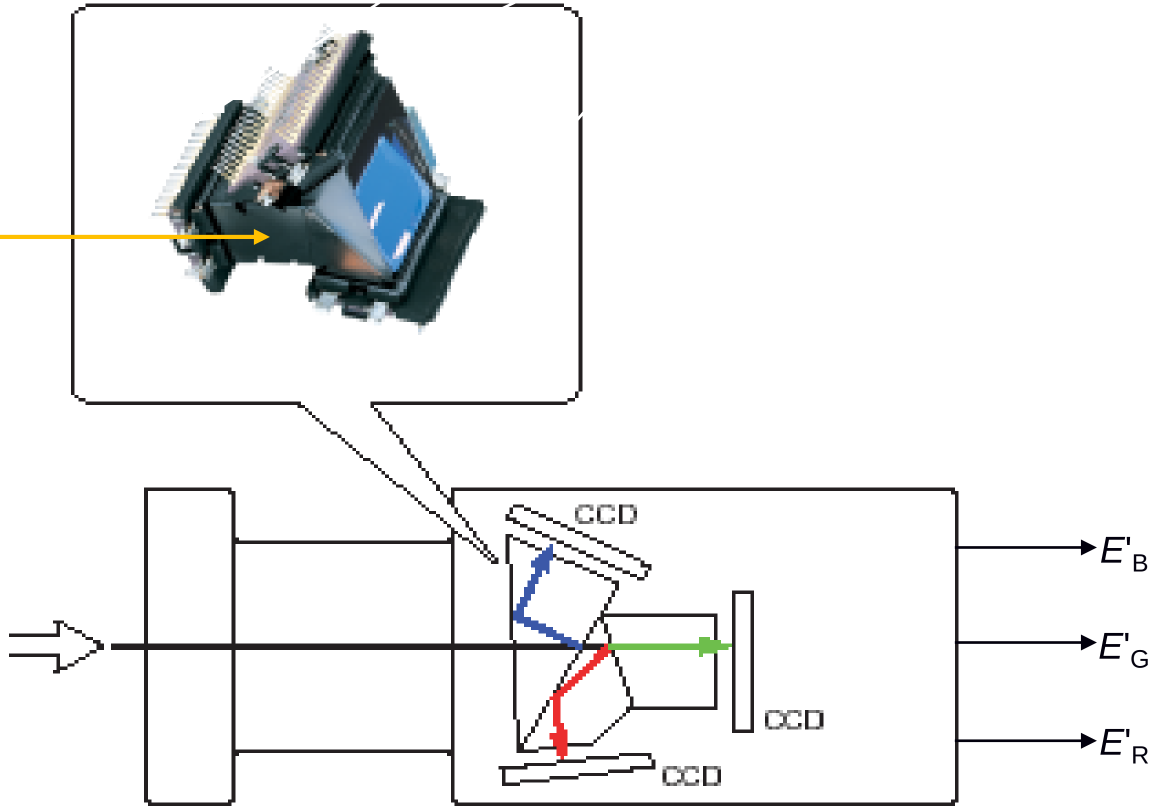




Video signal production

Prism for color separation



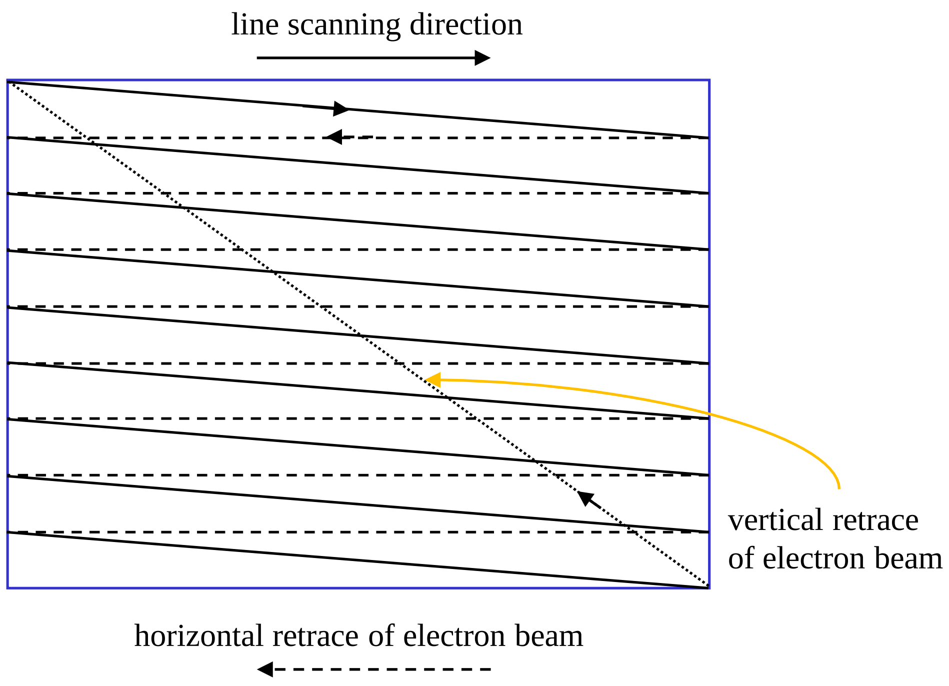


Video signal reproduction

- image reproduction
  - the video signal is converted into a light intensity distribution (electro-optical conversion) synchronously with the camera scanning process
  - image display devices
    - cathode ray tubes (CRT)
    - liquid crystal display (LCD) screens
    - plasma screens
    - video projectors

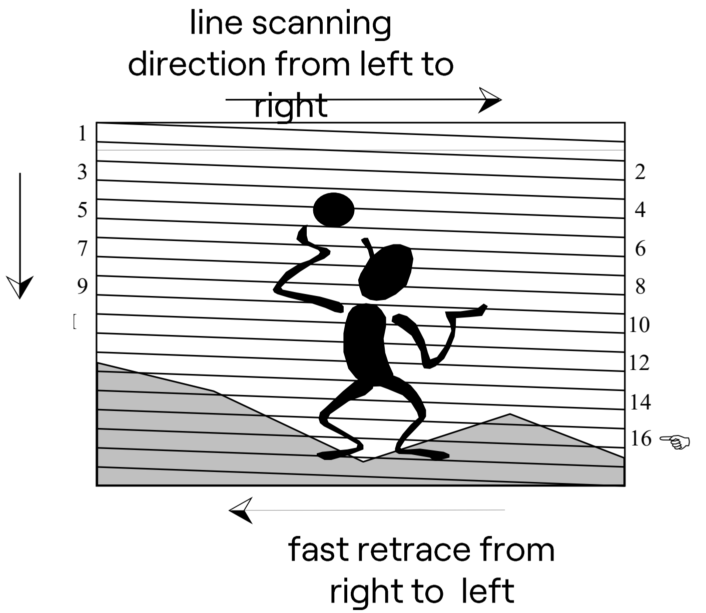
Scanning process

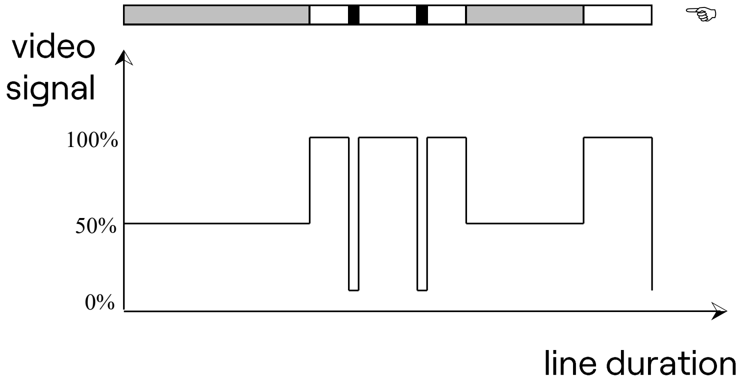
- scanning process in a camera with pickup tubes
  - starting at the top, the electron beam moves across the image from left to right, then returns to the beginning of the next line and starts to scan the next line
  - the scanning process continues until the end of the image, when the electron beam returns upwards and starts to scan the new image
  - scanning speed must be high enough so that the whole image be scanned before changes of its contents



Scanning process

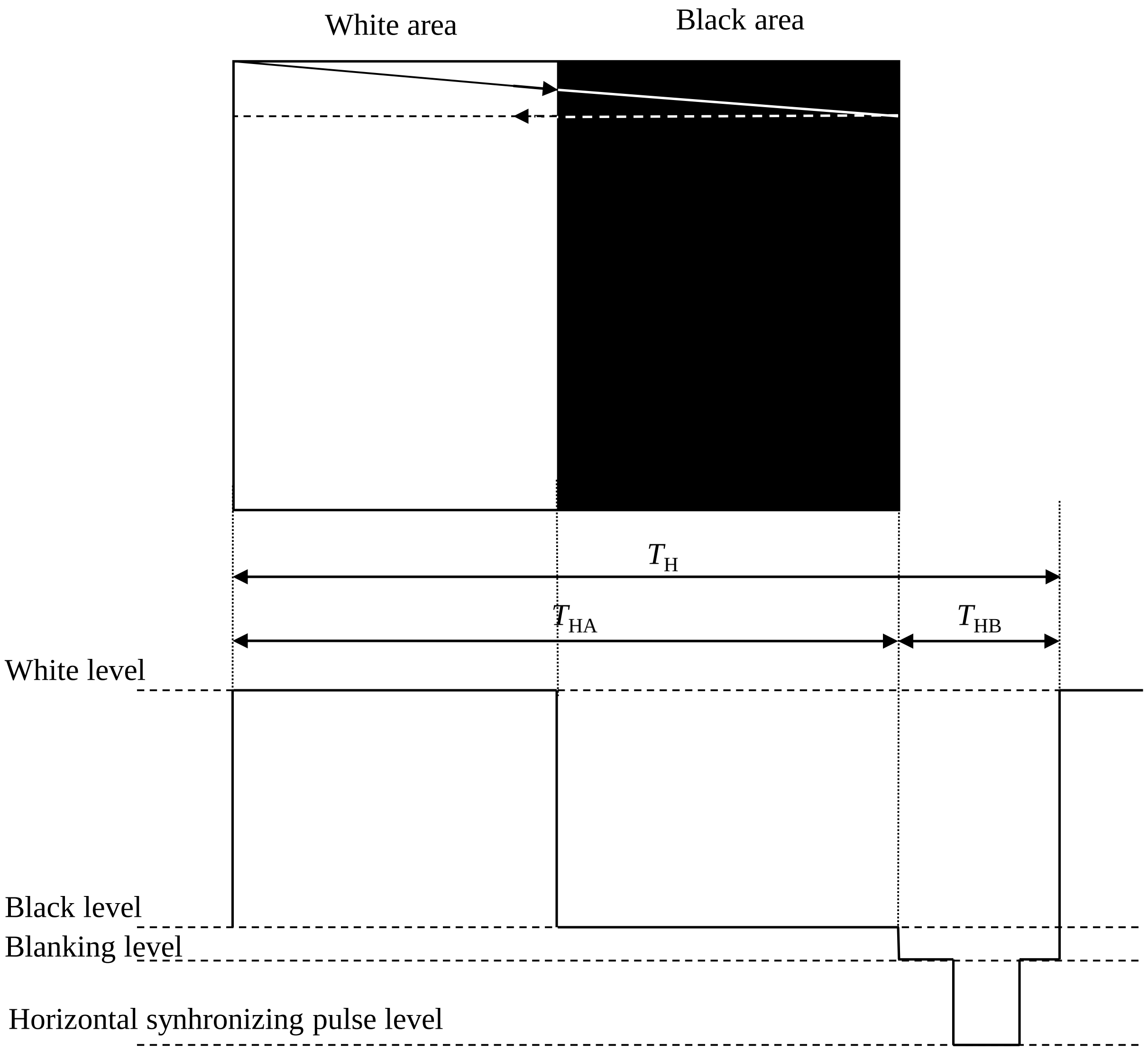
- by scanning the image from left to right, the active part of one scanning line is created (visible on the screen)
  - a high level of light intensity (white and bright parts of the image) corresponds to a higher amplitude of the electrical signal
  - a low level of light intensity (black and dark parts of the image) corresponds to a lower amplitude of the video signal
- the retrace of the electron beam from the end of one line to the beginning of the next line must not be visible and occurs during the horizontal blanking interval (HBI)





Video signal

- timing values
  - T_H – total line duration
  - T_{HA} – active line duration
  - T_{HB} – horizontal blanking interval (HBI)

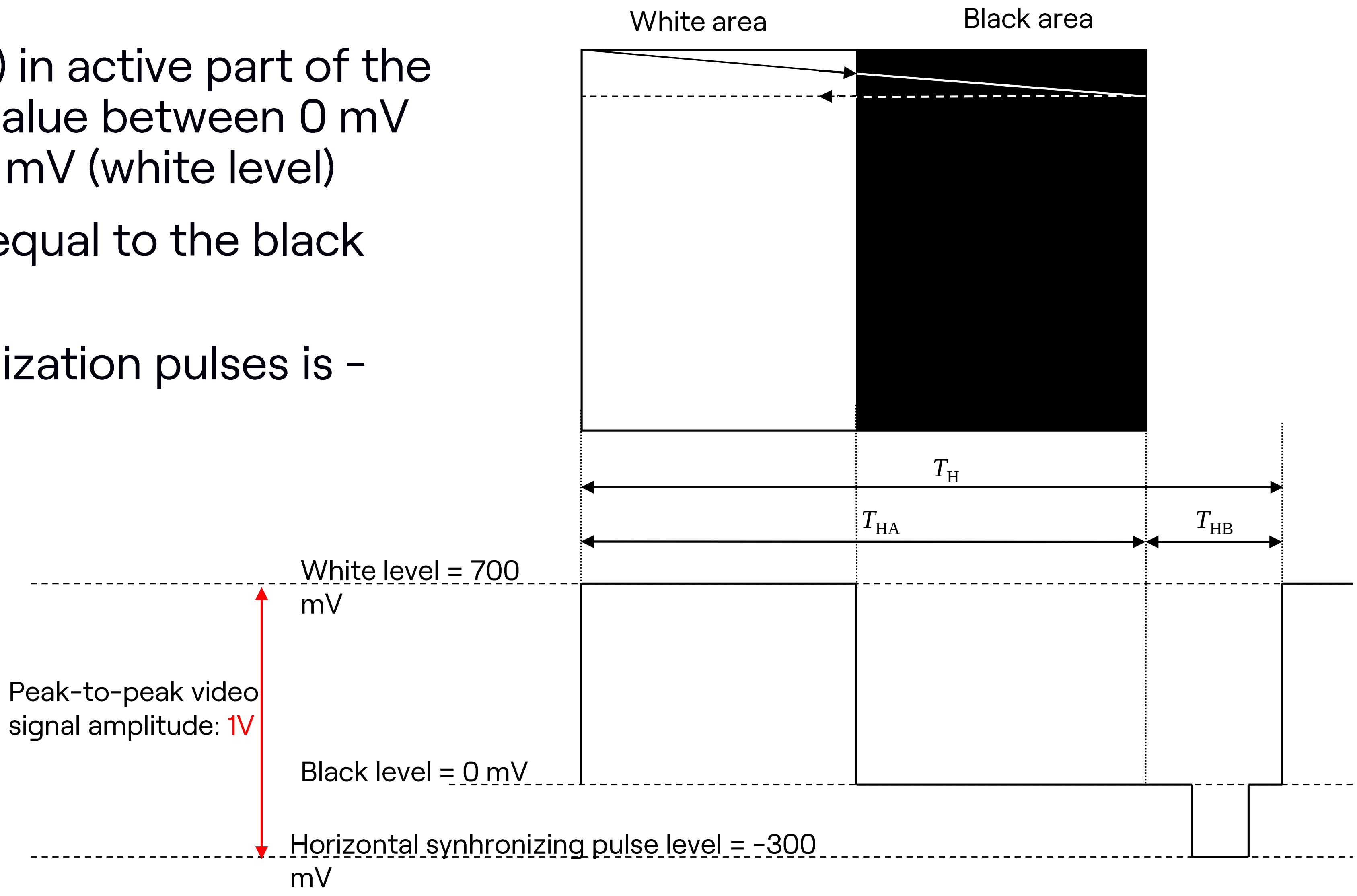


Video signal

- horizontal blanking interval
  - added after the active part of the line
    - ensures the suppression of the electron beam (the electron beam is switched off or blanked) in the pickup tube and the cathode ray tube during the horizontal retrace
  - HBI contains horizontal sync pulses (HSP)
    - the sync pulse level is in the "blacker than black" area (not visible on the screen)
    - allow synchronization of the transmitting and receiving side
- vertical blanking interval (VBI)
  - added after active part of the image (in the context of video signal image is often called „frame”)
    - ensures that the electron beam is switched off or blanked during the vertical retrace
  - VBI contains vertical sync pulses (VSP)
    - allow synchronization of the transmitting and receiving side

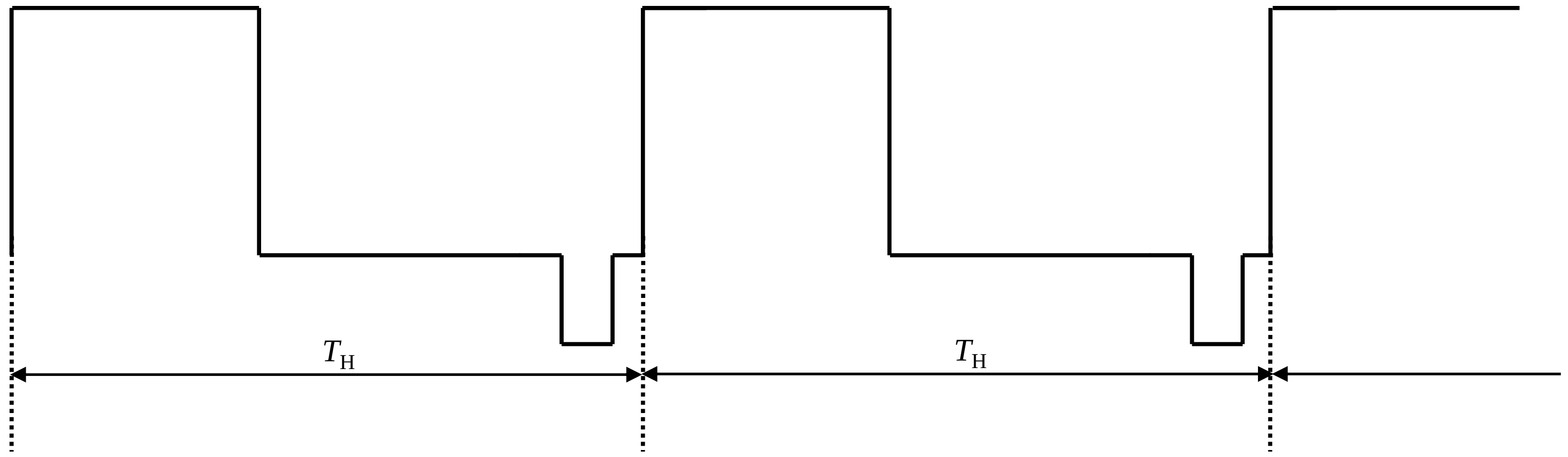
Amplitude values in video signal

- luminance signal (E'_Y) in active part of the frame can take any value between 0 mV (black level) and 700 mV (white level)
- the blanking level is equal to the black level
- the level of synchronization pulses is -300 mV



Horizontal frequency

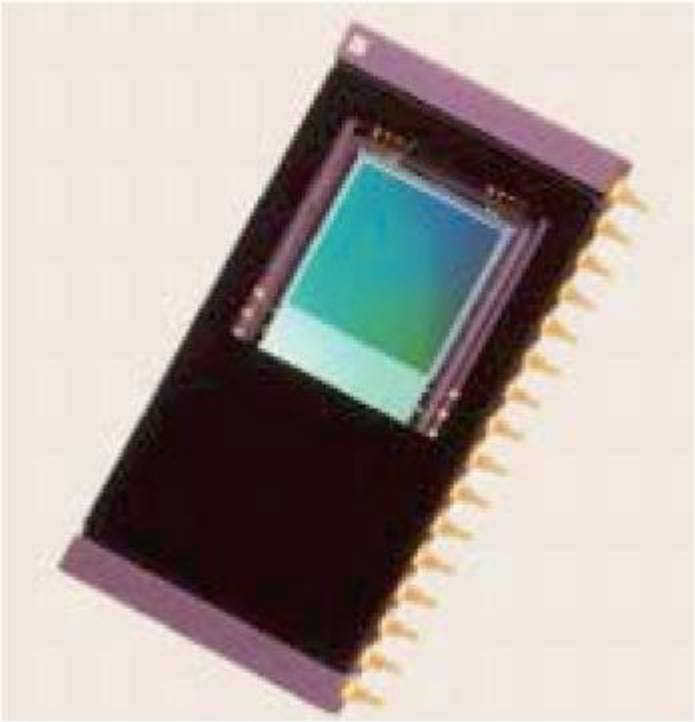
- the scanning process gets repeated till the whole frame is scanned
  - scanning in the horizontal direction is performed with horizontal scan rate or horizontal frequency f_H ($f_H=1/T_H$)
  - the horizontal frequency is the number of times per second that a raster-scan video system transmits or displays a complete horizontal line
    - by increasing the number of horizontal scanning lines, the image quality increases but the complexity of the transmission system also increases because a larger bandwidth is required to transmit the video signal



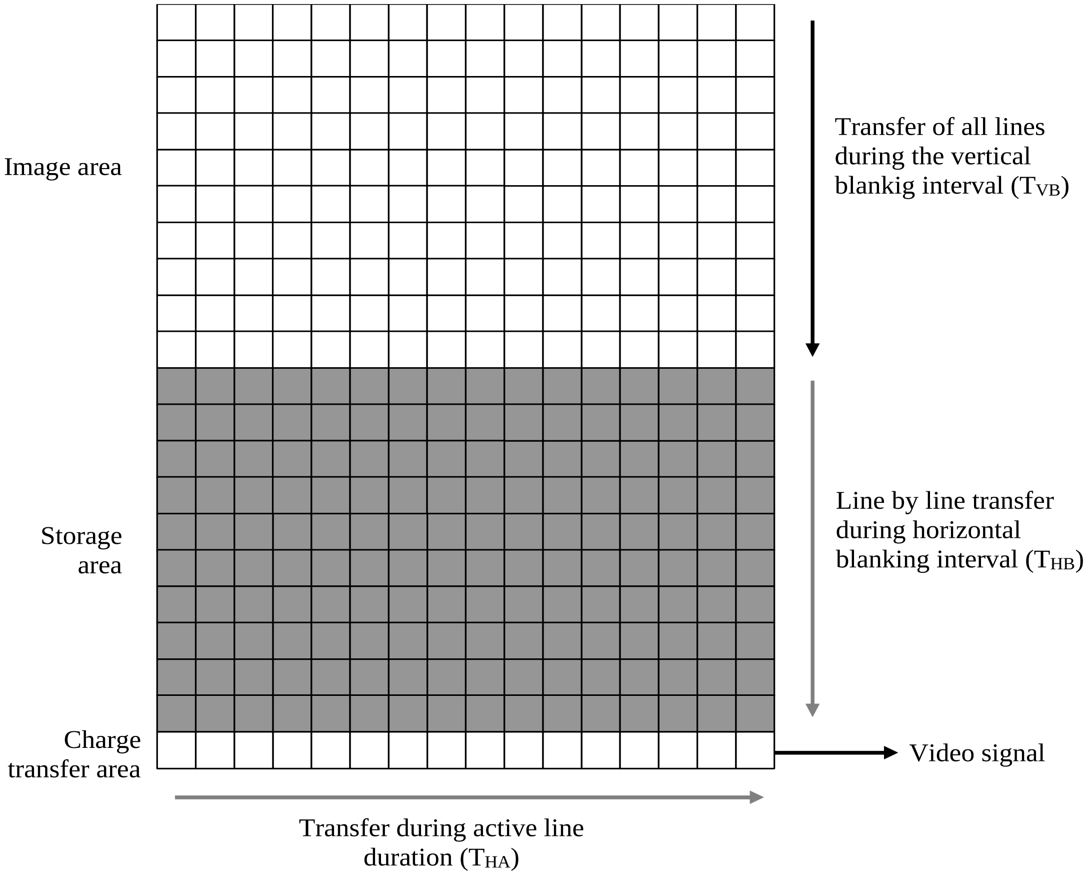
$f_H=1/T_H$

Video signal production

- example of using video time intervals inside a CCD sensor



FT (*Frame Transfer*) CCD senzor

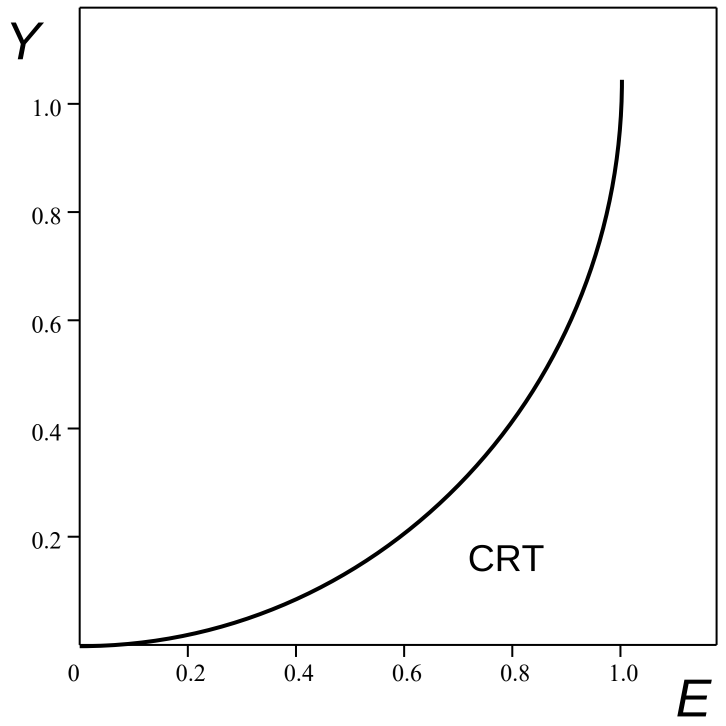


Non-linearity in image reproduction

- when reproducing an image in a cathode ray tube, the voltage of the video signal modulates the current of the electron beam
  - the electron beam current fluctuates depending on the voltage levels of the video signal
  - the front of the cathode ray tube is made of a layer composed of special types of phosphor that glow when they are hitted by electron beam
  - in the phosphor layer, the kinetic energy of the electron beam is converted into light intensity
  - the luminance of the surface hitted by the electron beam is proportional to the current of the electron beam
- the relationship between the electron beam current and the video signal voltage is nonlinear, which causes incorrect reproduction of luminant levels and colors
  - in order to correct the nonlinearity of the conversion of the electrical signal into light, gamma correction is introduced

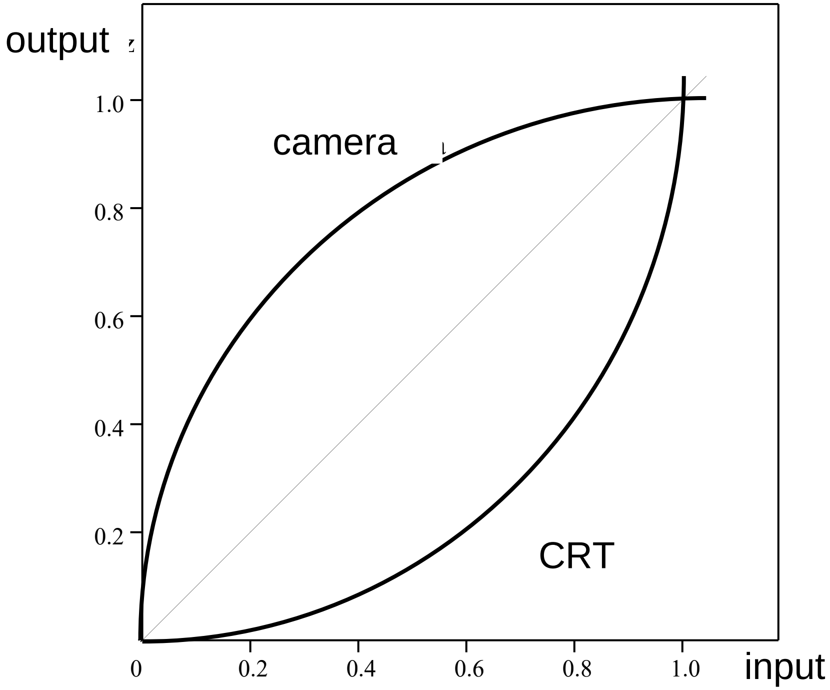
Gamma correction

- the nonlinear relationship between the voltage E, at the input of CRT and the luminance of the image Y can be represented as : $Y=k(E)^{\gamma}$
  - factor γ (gamma factor) shows the degree of nonlinearity that occurs when converting a video signal into light
- the standardized value of the gamma factor for television receivers in European TV systems is $\gamma = 2.8$ and $\gamma = 2.2$ in the American TV system
  - response of CRT monitors
    - $Y=kE^{2,8}$ (Europe)
    - $Y=kE^{2,2}$ (America)



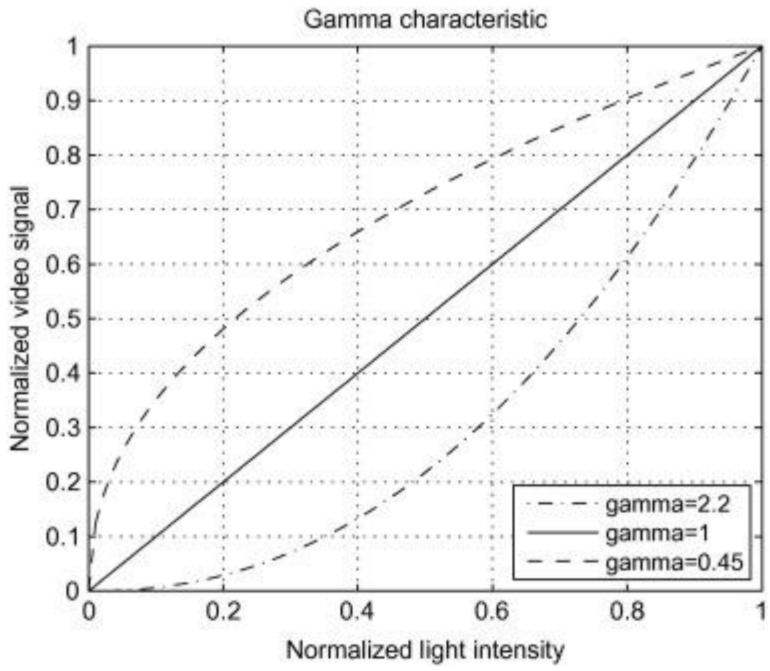
Gamma correction

- gamma correction is not performed in monitors
  - gamma correction performed in monitors is inefficient solution (each monitor should contain a complex nonlinear amplifier)
- gamma correction is performed in cameras
  - the video signal generated in the camera (E) is passed through a nonlinear amplifier and signal E’ is generated
  - the amplifier has a reciprocal characteristic of the cathode ray tube characteristic
  - the gamma factor of that amplifier is
    - γ = 1/2,8=0,3571 (Europe)
    - γ = 1/2,2=0,4545 (America)



Gamma correction

- the implementation of gamma correction in the camera cancels the nonlinearity of the cathode ray tube
- the total transfer characteristic is linear
- in achromatic cameras, gamma correction is performed on a luminant signal
  $Y \rightarrow E_Y^{1/\gamma} = E'_Y; \ (E'_Y)^\gamma \rightarrow Y$
- in color cameras gamma correction is performed on primary color signals
  - $R \rightarrow E_R^{1/\gamma} = E'_R; (E'_R)^\gamma \rightarrow R$
  - $G \rightarrow E_G^{1/\gamma} = E'_G; (E'_G)^\gamma \rightarrow G$
  - $B \rightarrow E_B^{1/\gamma} = E'_B; (E'_B)^\gamma \rightarrow B$



Gamma correction

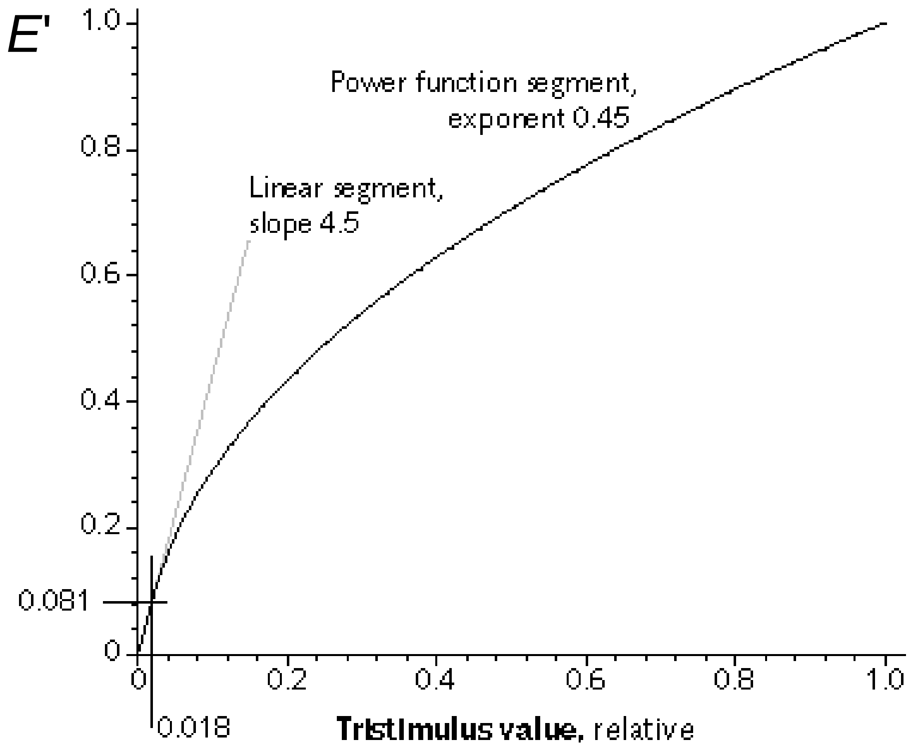
- the opto-electronic conversion characteristic of cameras recommended by SMPTE-170M * and ITU-R BT.709

$E' = 1{,}099\ Y^{1/2{,}2} - 0{,}099$

za $0{,}018 \le Y \le 1$

$E' = 4{,}500\ Y$

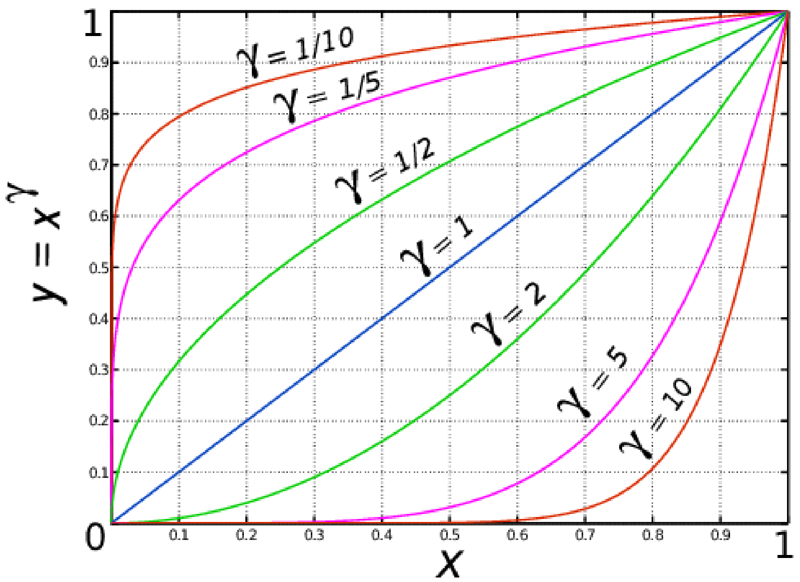
za $Y < 0{,}018$

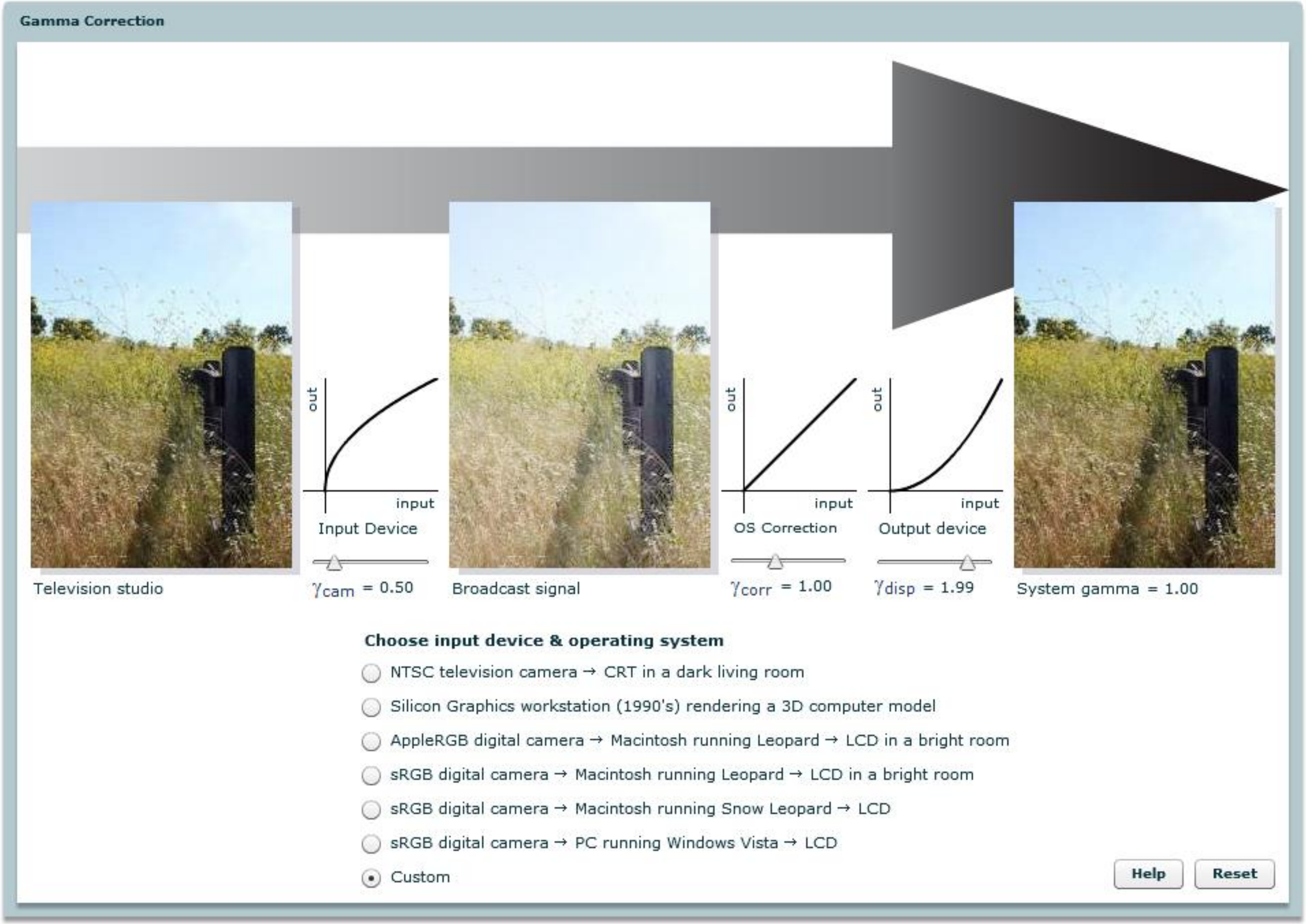


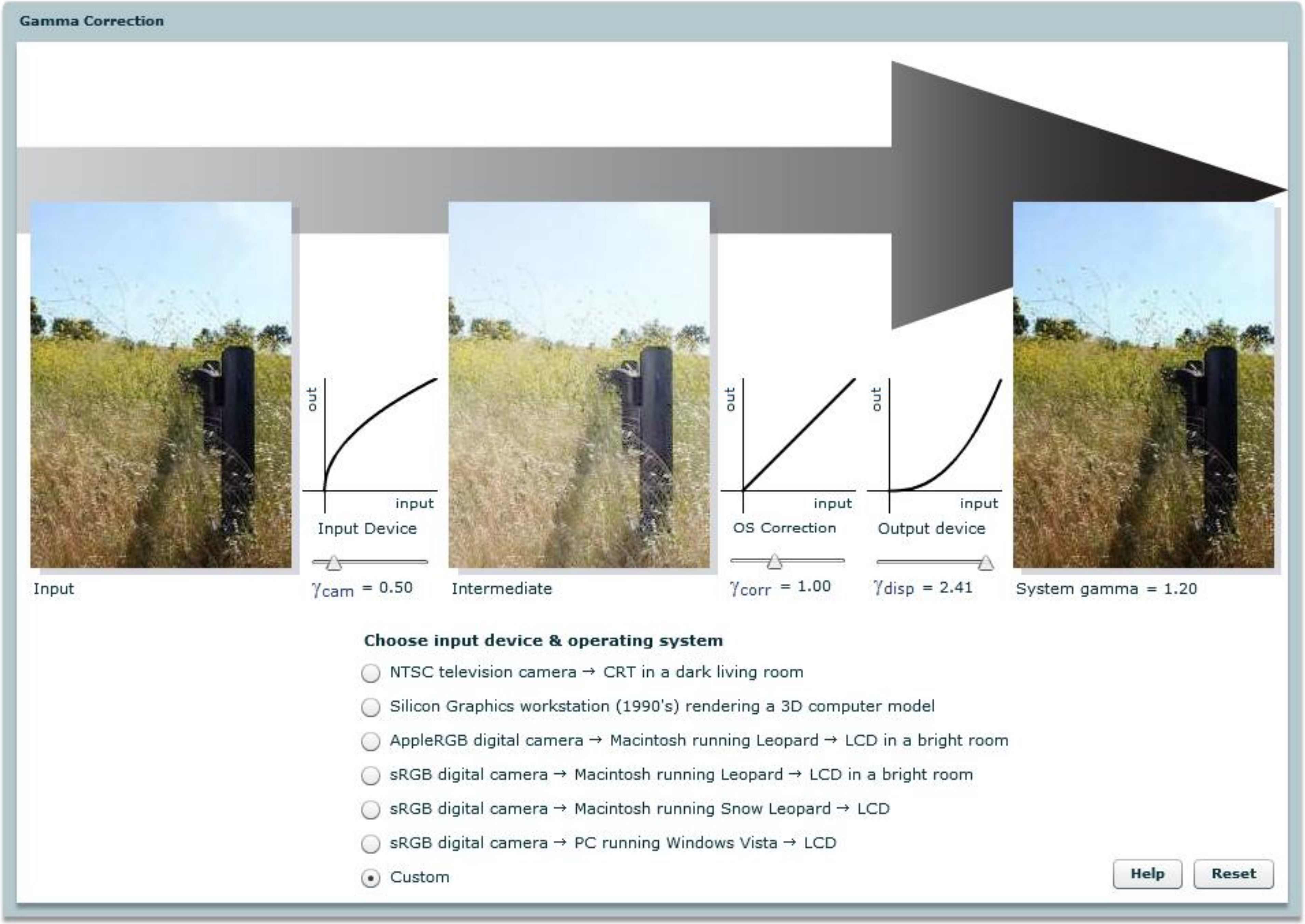
* *Society for Motion Pictures and Television Engineers*

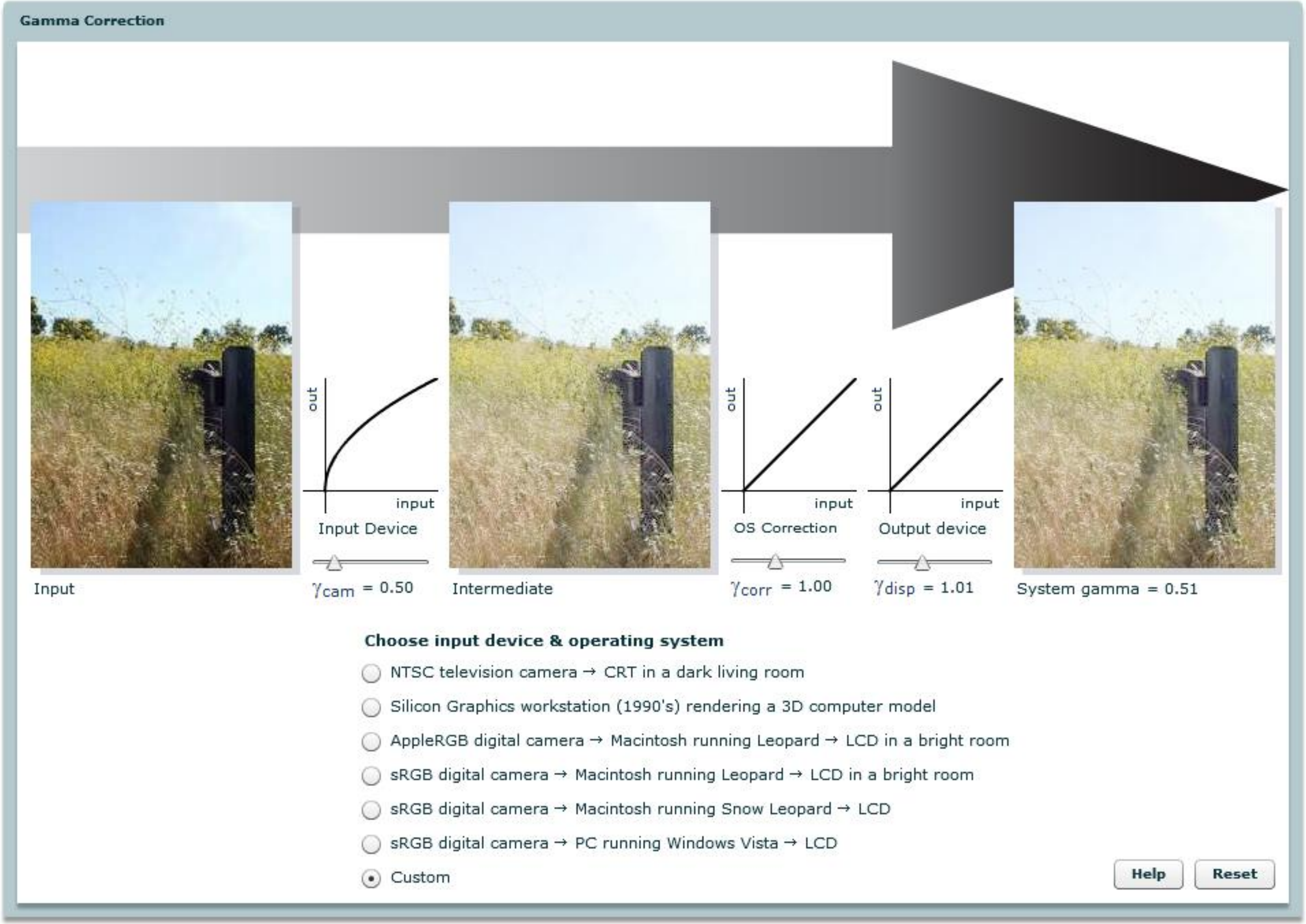
Gamma correction

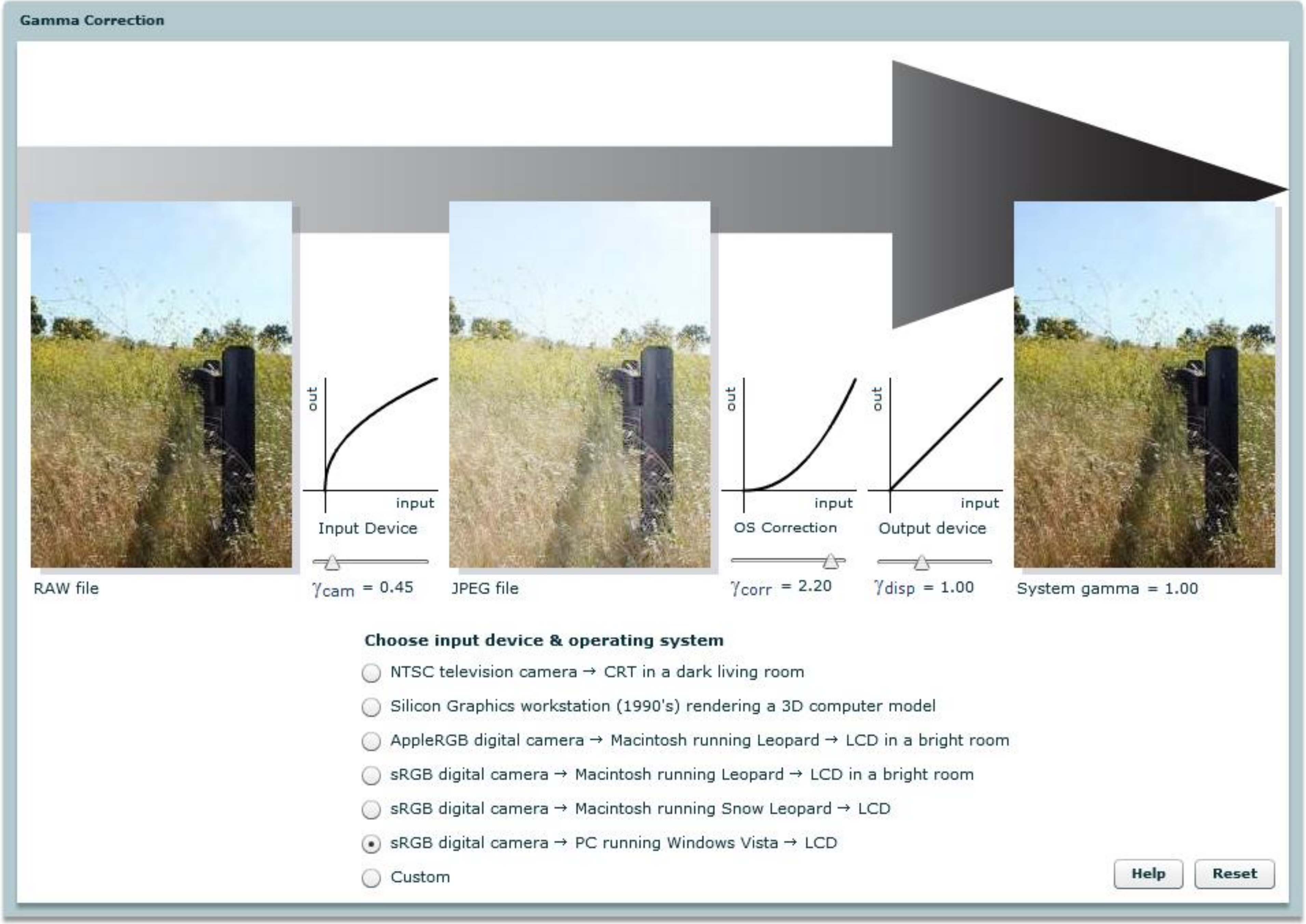
- in multimedia systems, where computer monitors are used to reproduce the image, gamma correction becomes a complex issue
- cameras may or may not have a fixed or variable gamma factor
- image processing, encoding, and storage software may include gamma correction with one factor, and image decoding and display software may expect a different gamma factor
- LCD monitors have a linear characteristic of electro-optical conversion
- the same picture looks different in different systems




Gamma Correction
out
input
Input Device
out
input
OS Correction
out
input
Output device
Television studio
γ_{cam} = 0.50
Broadcast signal
γ_{corr} = 1.00
γ_{disp} = 1.99
System gamma = 1.00
Choose input device & operating system
NTSC television camera → CRT in a dark living room
Silicon Graphics workstation (1990's) rendering a 3D computer model
AppleRGB digital camera → Macintosh running Leopard → LCD in a bright room
sRGB digital camera → Macintosh running Leopard → LCD in a bright room
sRGB digital camera → Macintosh running Snow Leopard → LCD
sRGB digital camera → PC running Windows Vista → LCD
Custom
Help
Reset


Gamma Correction
out
input
Input Device
out
input
OS Correction
out
input
Output device
Input
γ_{cam} = 0.50
Intermediate
γ_{corr} = 1.00
γ_{disp} = 2.41
System gamma = 1.20
Choose input device & operating system
NTSC television camera → CRT in a dark living room
Silicon Graphics workstation (1990's) rendering a 3D computer model
AppleRGB digital camera → Macintosh running Leopard → LCD in a bright room
sRGB digital camera → Macintosh running Leopard → LCD in a bright room
sRGB digital camera → Macintosh running Snow Leopard → LCD
sRGB digital camera → PC running Windows Vista → LCD
Custom
Help
Reset


Gamma Correction
out
input
Input Device
γcam = 0.50
Input
Intermediate
out
input
OS Correction
γcorr = 1.00
out
input
Output device
γdisp = 1.01
System gamma = 0.51
Choose input device & operating system
NTSC television camera → CRT in a dark living room
Silicon Graphics workstation (1990's) rendering a 3D computer model
AppleRGB digital camera → Macintosh running Leopard → LCD in a bright room
sRGB digital camera → Macintosh running Leopard → LCD in a bright room
sRGB digital camera → Macintosh running Snow Leopard → LCD
sRGB digital camera → PC running Windows Vista → LCD
Custom
Help
Reset

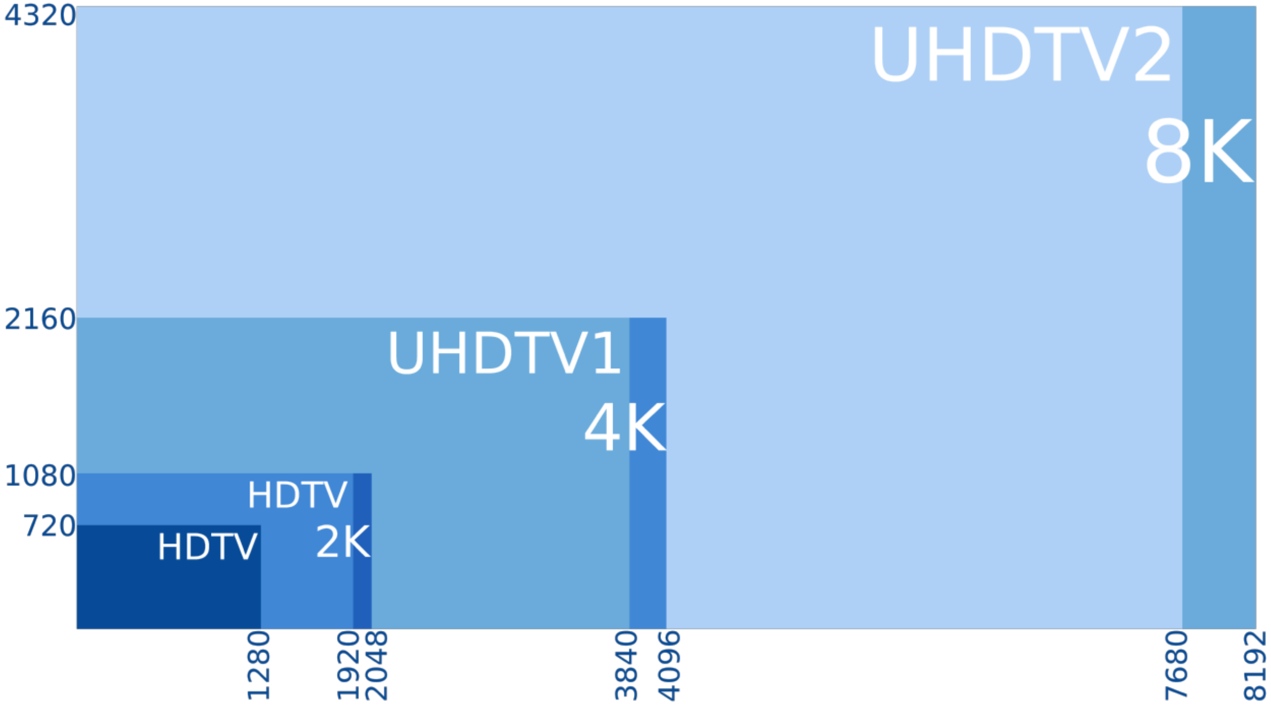

Gamma Correction
out
input
Input Device
out
input
OS Correction
out
input
Output device
RAW file
γ_{cam} = 0.45
JPEG file
γ_{corr} = 2.20
γ_{disp} = 1.00
System gamma = 1.00
Choose input device & operating system
NTSC television camera → CRT in a dark living room
Silicon Graphics workstation (1990's) rendering a 3D computer model
AppleRGB digital camera → Macintosh running Leopard → LCD in a bright room
sRGB digital camera → Macintosh running Leopard → LCD in a bright room
sRGB digital camera → Macintosh running Snow Leopard → LCD
sRGB digital camera → PC running Windows Vista → LCD
Custom
Help
Reset

Number of lines

- SDTV - *Standard Definition Television*
  - 525-line standard (number of active lines per frame is L_V=485, 40 lines in VBI)
  - 625-line standard (L_V=575, 50 lines in VBI)
- HDTV – *High Definition Television*
  - spatial format
    - number of samples per active line (N_V) x number of active lines per frame (L_V)
    - 1920 x 1080 (N_V=1920, L_V=1080)
      - total number of lines per frame (L_U) is 1125, and total number of samples per line (N_U) is 2640
    - 1280 x 720 (N_V=1280, L_V=720)
      - L_U=750, N_U=1980

Number of lines

- UHDTV – *Ultra High Definition Television*
  - the parameters are derived from the 1920 x 1080 HDTV format
  - image formats:
    - UHDTV-1: 3840 × 2160
      - L_U = 2250 (2x1125)
      - N_U = 5280 (2x2640)
    - UHDTV-2: 7680 × 4320
      - L_U = 4500 (4x1125)
      - N_U = 10560 (4x2640)

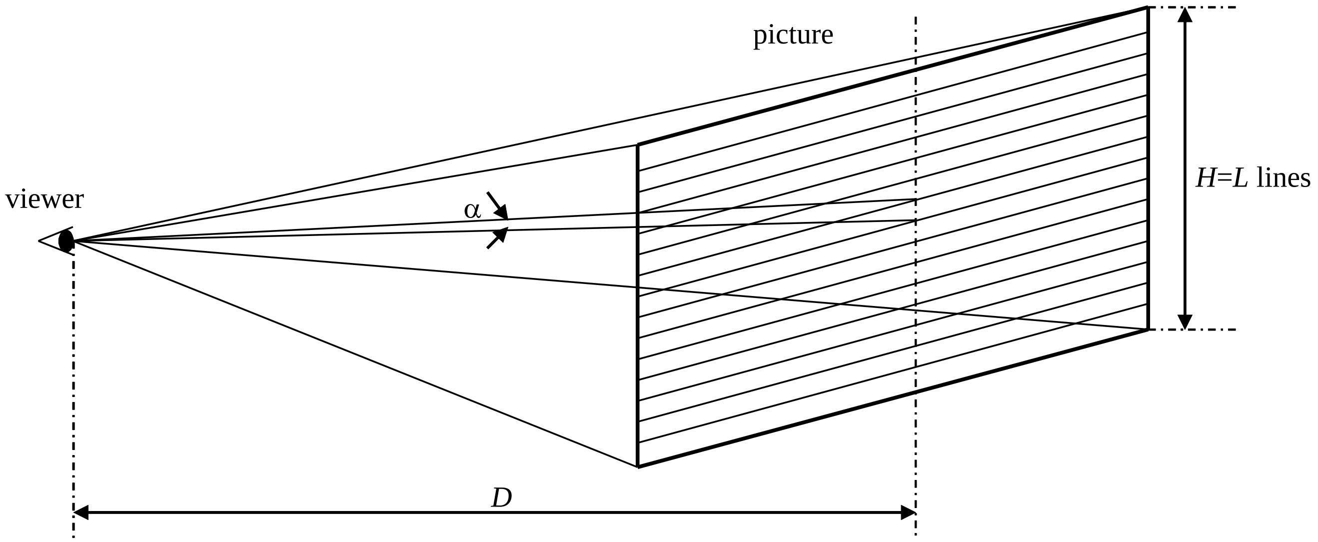


Number of lines

- standardization of the number of lines in video systems was based on the properties of the human visual system
  - L should be large enough to prevent scan line visibility
  - L should not be too large (details that human eye cannot resolve should not be captured)
- in SDTV systems, it is assumed that the visual acuity angle is 1.5’
  - for a certain distance (D) from the picture, the viewer perceives the adjacent lines at angle approximately equal to 1.5’
  - in SDTV systems the optimal distance from the picture is 4-6 picture height (D = 4-6H)

Number of lines

- number of lines in SDTV



$$\operatorname{tg}\frac{\alpha}{2}=\frac{\frac{H}{2L}}{D}$$

$$\alpha=1{,}5'\Rightarrow\operatorname{tg}\frac{1{,}5'}{2}\approx 2\cdot 10^{-4}$$

$$L=\frac{H}{2D\operatorname{tg}\frac{\alpha}{2}}=\frac{1}{2\frac{D}{H}\operatorname{tg}\frac{\alpha}{2}}$$

$$L=\frac{1}{2\frac{D}{H}2\cdot 10^{-4}}\approx\frac{2500}{\frac{D}{H}}$$

$$\frac{D}{H}=4-6\Rightarrow L=625-417$$

- number of visible lines in SDTV should be between 417 and 625
- SDTV standards
  - 525-line standard (L_V=485, 40 lines in VBI)
  - 625-line standard (L_V=575, 50 lines in VBI)

Number of lines

Number of lines

- in the design of HDTV, visual acuity angle of 1’ is assumed
- in HDTV systems the optimal distance of the viewer from the picture is 3 picture heights (D = 3H)

$$\alpha = 1' \Rightarrow \mathrm{tg}\frac{1'}{2} \approx 1{,}45 \cdot 10^{-4}$$

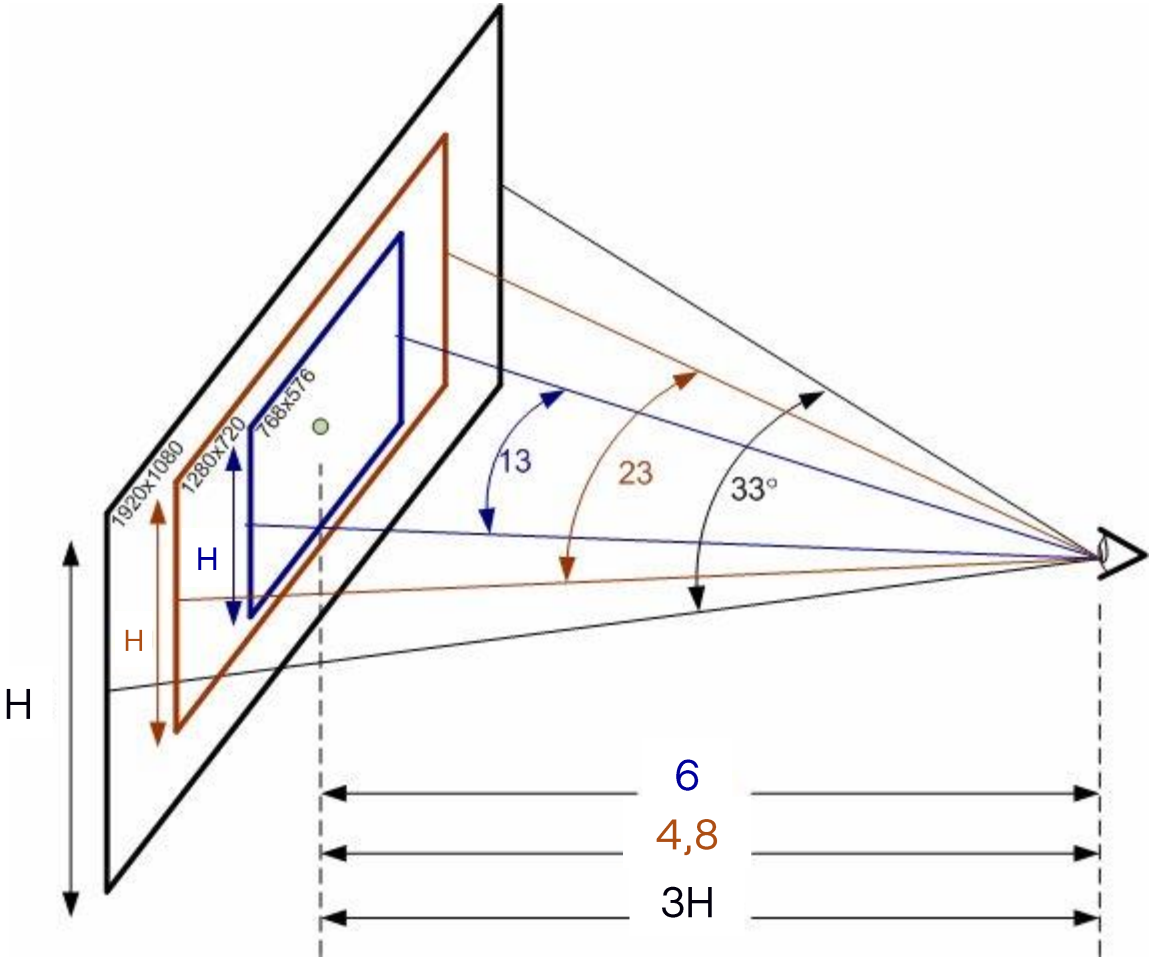
$$L = \frac{1}{2\frac{D}{H}1{,}45 \cdot 10^{-4}} \approx \frac{3448}{\frac{D}{H}}$$

$$\frac{D}{H} = 3 \Rightarrow L = 1149$$

- number of visible lines in HDTV is L_V=1080
- total number of lines is L_U= 1125

Number of lines

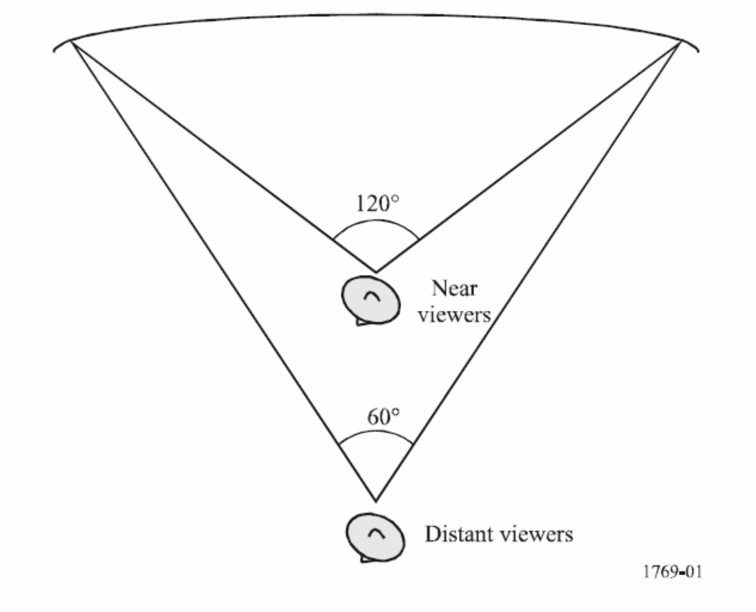
- the horizontal viewing angle depends on the distance of the viewer from the picture



Number of lines

- in UHDTV-1 the optimal distance of the viewer from the picture is 1.5 picture heights (*D*=1,5*H*)
- in UHDTV-2 the optimal distance of the viewer from the picture is 0.75 picture heights (*D*=0,75*H*)

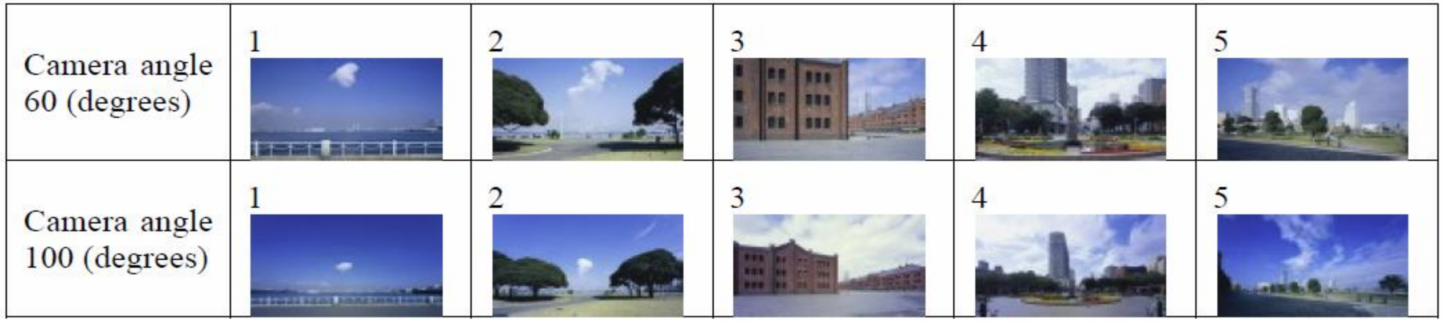
System	1920×1080	3840× 2160	7680×4320
Distance of the viewer (*D*)	3*H*	1,5*H*	0,75*H*
Horizontal vieweing angle	31º	58º	96º
The values are determined assuming that an observer with a visual acuity angle of 1' will not see the line structure of the image (the observer does not perceive the scanning lines as separate).			

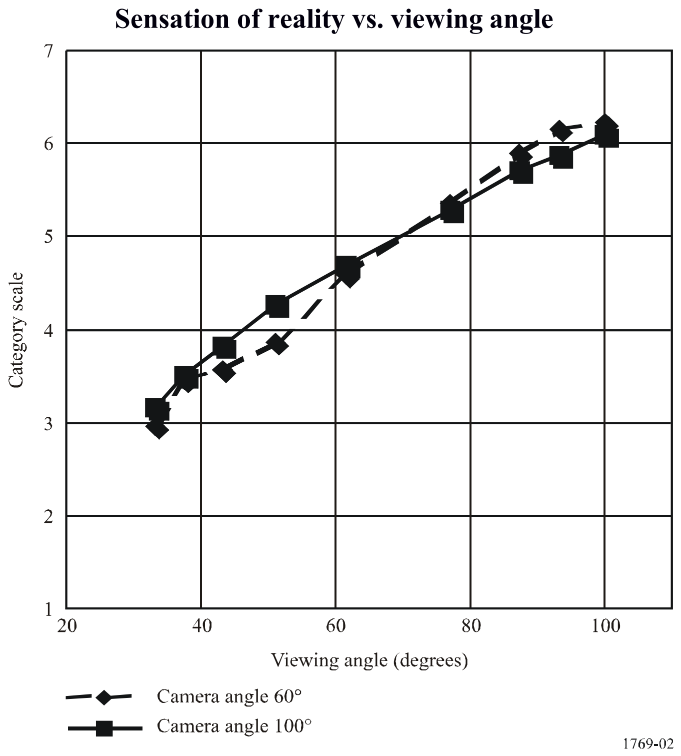


Number of lines

- results of subjective evaluation of "sensation of reality" (taken from ITU-R BT.1769)
  - the results confirm that wider viewing angle generates higher sensation of reality

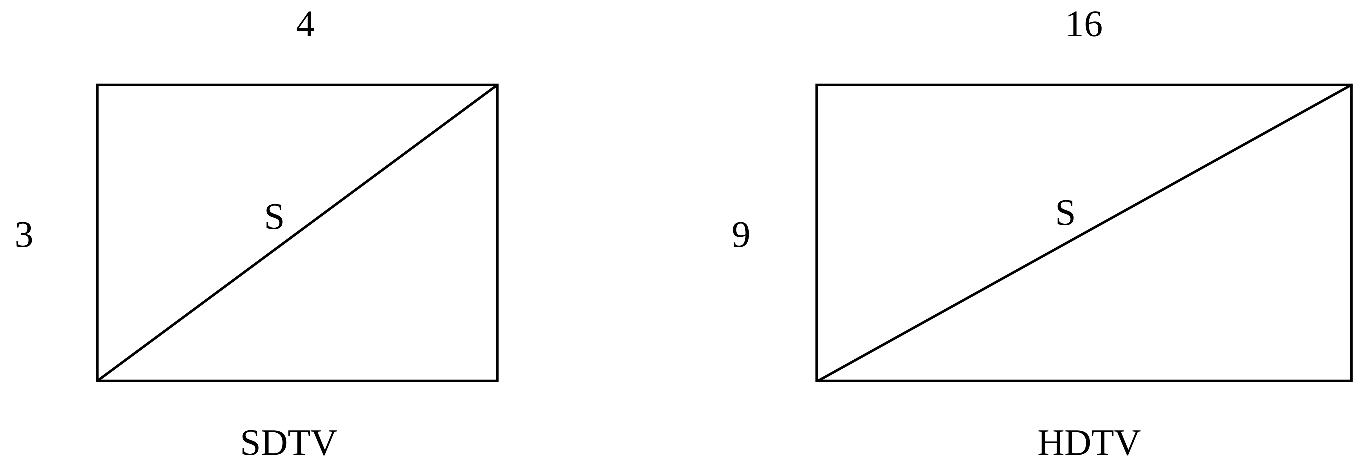
Scanning lines		1 000	1 143	1 333	1 600	2 000	2 667	3 200	3 556	4 000
Picture aspect ratio		16:9								
Picture size diagonally (inch)		75	86	100	120	150	200	240	267	300
Viewing distance	(m)	2.8								
	(H)	3.0	2.6	2.2	1.9	1.5	1.1	0.93	0.84	0.75
Horizontal viewing angle (degrees)		33.2	37.6	43.3	51.0	61.6	76.9	87.3	93.3	100.0





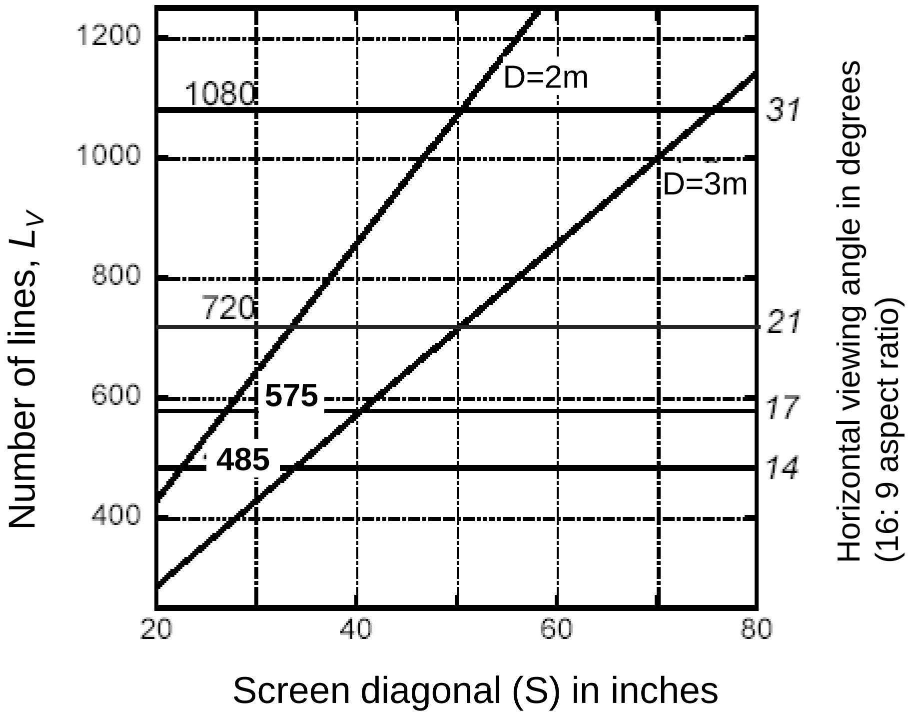
Aspect ratio

- aspect ratio (AR) is defined as the aspect ratio of width (W) and height (H)
- in SDTV systems the aspect ratio is 4: 3 (1.33: 1)
- in HDTV systems the aspect ratio is 16: 9 (1.78: 1)
- screen sizes are measured on the diagonal (S), typically in inches



Size of screen

- ovisnost udaljenosti promatranja i veličine ekrana



Number of frames per second

- object in motion are displayed in the video signal using a sequence of frames each showing one phase of movement
- the minimum required number of frames per second to experience the continuity of movement is $f_S = 10$ frames/s (f_S is the frame frequency or frame rate)
- for fast movements there is an impression of blur and 10 frames/s is too low
- additional problem is disappearance of the image during VBI that can cause a flicker effect
  - flicker effect - the viewer perceive vertical blanking interval inserted between two frames
  - flicker effect disappears at a sufficiently high frame frequency (f_S)
  - flicker effect disappears for most people at frame frequencies higher than 50 Hz (50 frames per second)
- the term of vertical frequency (f_V) is introduced
  - it is the frequency of VBI occurrence
  - in SDTV systems $f_V \neq f_S$

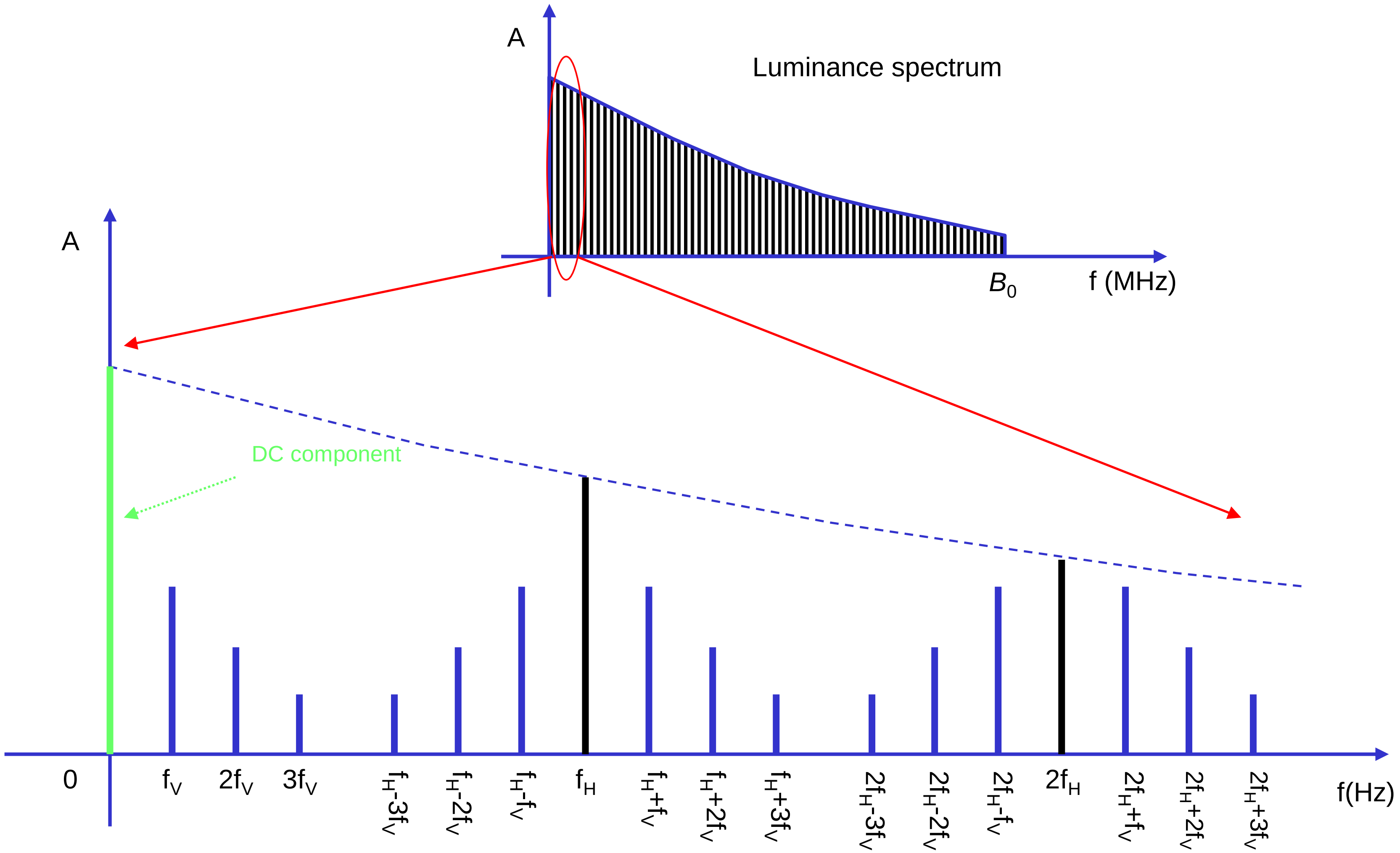
Number of frames per second

- European SDTV standard (625/50)
  - total number of lines per frame: L_U=625
  - number of active lines per frame: L_V=575
  - vertical frequency: f_V=50 Hz
  - number of frames per second: f_S=25 Hz
  - horizontal frequency: $f_H = L_U \cdot f_S = 625 \cdot 25 = 15\,625$ Hz
  - line duration: $T_H = 1/f_H = 64$ μs
- North-american SDTV standard for black and white TV (525/60)
  - total number of lines per frame: L_U=525
  - number of active lines per frame: L_V=485
  - vertical frequency: f_V=60 Hz
  - number of frames per second: f_S=30 Hz
  - horizontal frequency: $f_H = L_U \cdot f_S = 525 \cdot 30 = 15\,750$ Hz
  - line duration: $T_H = 1/f_H = 63{,}49$ μs
  - in the color TV f_H is changed, and the consequence is change of vertical frequency (f_V=59,94 Hz, f_S=29,97 Hz)

Spectrum of video signal

- the spectral components produced by the scanning of a stationary scene are determined by multiples of f_H and f_V
  - the spectrum is shaped by nf_H components whose amplitudes decrease by increasing frequency
  - harmonics of f_V appear around each nf_H ($nf_H \pm mf_V$)
- the spectrum of video signal theoretically expands to infinity
  - in practice, the spectrum is limited by determining the nominal bandwidth of the video signal (B_0), which differs in different systems
    - high-frequency (HF) components for most pictures have small amplitudes and neglecting them will not significantly reduce picture quality
    - the sensitivity of the human visual system decreases with increasing frequency
  - 625/50 → B_0=5 MHz
  - 525/60 → B_0=4,2 MHz
  - 1125/50P, 1125/60P → B_0=60 MHz
  - 1125/50I, 1125/60I → B_0=30 MHz

Spectrum of video signal



Spectrum of video signal

- How many harmonics of f_H are transmitted in 625/50 and 525/60 systems if progressive scanning is used (f_S = f_V)?
  - 625/50 system (B_0= 5 MHz)
    $f_H = L_U \cdot f_S = 625 \cdot 50 = 31\,250$ Hz
    number of harmonics of f_H is: 5 MHz/31 250=160
  - 525/60 system (B_0= 4,2 MHz)
    $f_H = L_U \cdot f_S = 525 \cdot 60 = 31\,500$ Hz
    number of harmonics of f_H is: 4,2 MHz/31 500=133

Too small number of frequency components!

Solution:
decreasing f_H
or
increasing B_0

- solution – *interlaced scanning*
  - it is a technique for doubling the perceived frame rate of a video display without consuming extra bandwidth
  - *frame* is divided into two *fields*
  - the number of lines per field is twice less than the number of lines per frame

Interlaced scanning

- vertical frequency (f_V) of is the frequency of field changes, ie the frequency of occurrence of VBI (vertical blanking interval)
  - f_V is twice the frame frequency ($f_v = 2 \cdot f_S$)
  - f_H is twice lower than the f_H of the system with progressive scanning

Interlaced scanning

- $f_H = L_U \cdot f_S = (L_U/2) \cdot f_v$
  - 625/50 system → $f_H = 625 \cdot 25$ Hz $= 312{,}5 \cdot 50 = 15\,625$ Hz
- line duration: $T_H = 1/f_H$
  - 625/50 system → $T_H = 1/15\,625$ Hz $= 64$ µs
- field duration: $T_V = 1/f_V$
  - 625/50 system → $T_V = 1/50$ Hz $= 20$ ms
- frame duration: $T_S = 2 \cdot T_V$
  - 625/50 system → $T_S = 2 \cdot 20$ ms $= 40$ ms
- frame frequency: $f_S = 1/T_S$
  - 625/50 system → $f_S = 1/40$ ms $= 25$ Hz

Interlaced scanning

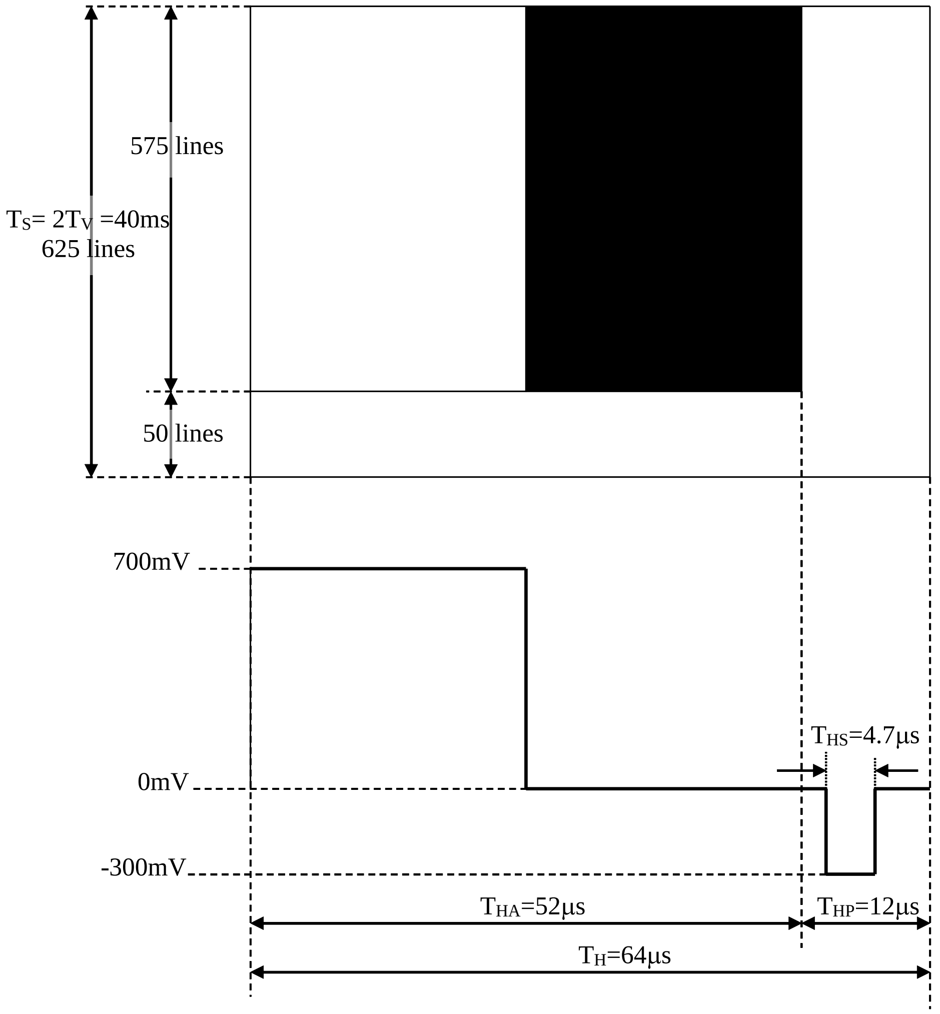
Progressive scanning

Interlaced scanning

FER

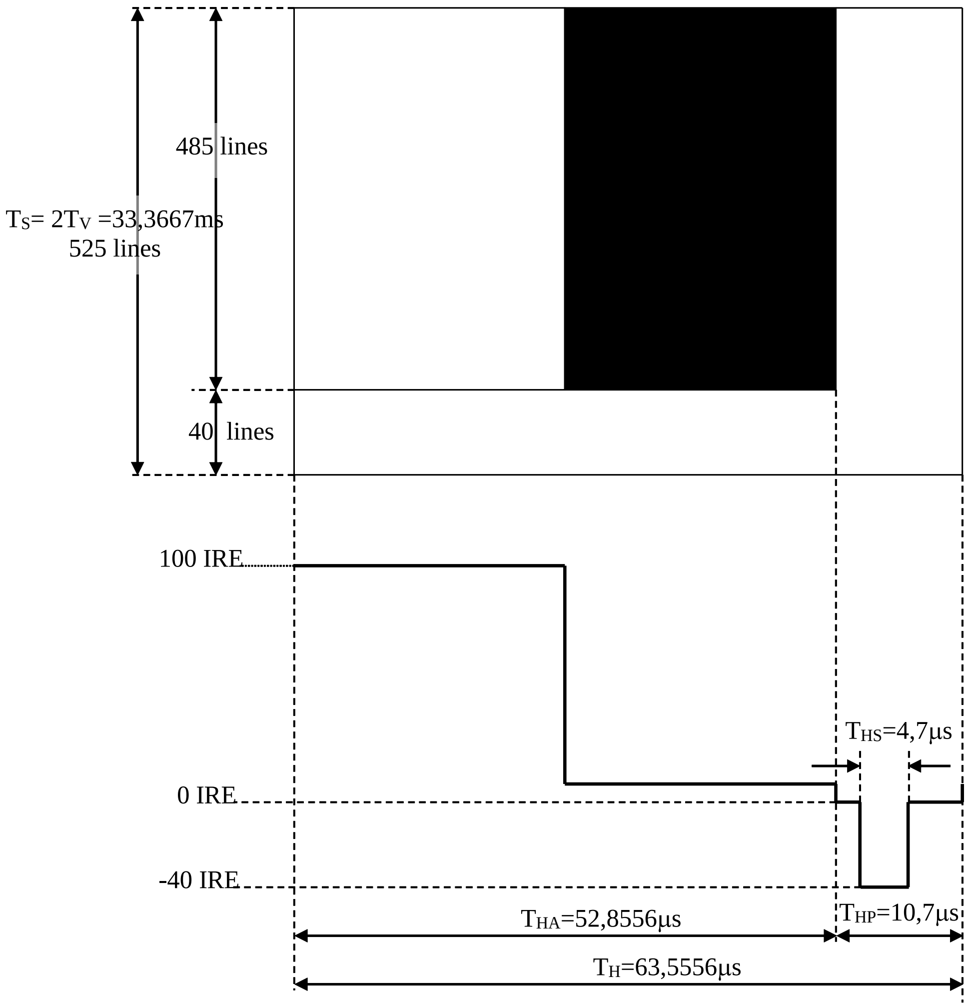
Video signal parameters

- 625/50
  - total line duration
    T_H = 64 μs
  - active line duration
    T_{HA}= 52 μs
  - horizontal blanking interval (HBI)
    T_{HP}= 12 μs
  - frame duration
    T_S = 625 · 64 μs = 40 ms
  - active time of picture scanning
    T_{SA} = 575 · 52 μs = 29,9 ms



Video signal parameters

- 525/60
  - f_V = 59,94 Hz (60/1,001 Hz)
  - $f_H = f_V \cdot L_U/2$ = 59,94·262,5 =15734,25 Hz
  - total line duration
    T_H = 63,5556 μs
  - active line duration
    T_{HA}= 52,8556 μs
  - horizontal blanking interval (HBI)
    T_{HP}= 10,7 μs
  - field duration
    $T_V = 1/f_V$ = 1/59,94 = 16,68335 ms
  - frame duration
    $T_S = 2 \cdot T_V$ = 33,3667 ms
  - frame frequency
    f_S = 1/ 33,3667 = 29,97 Hz

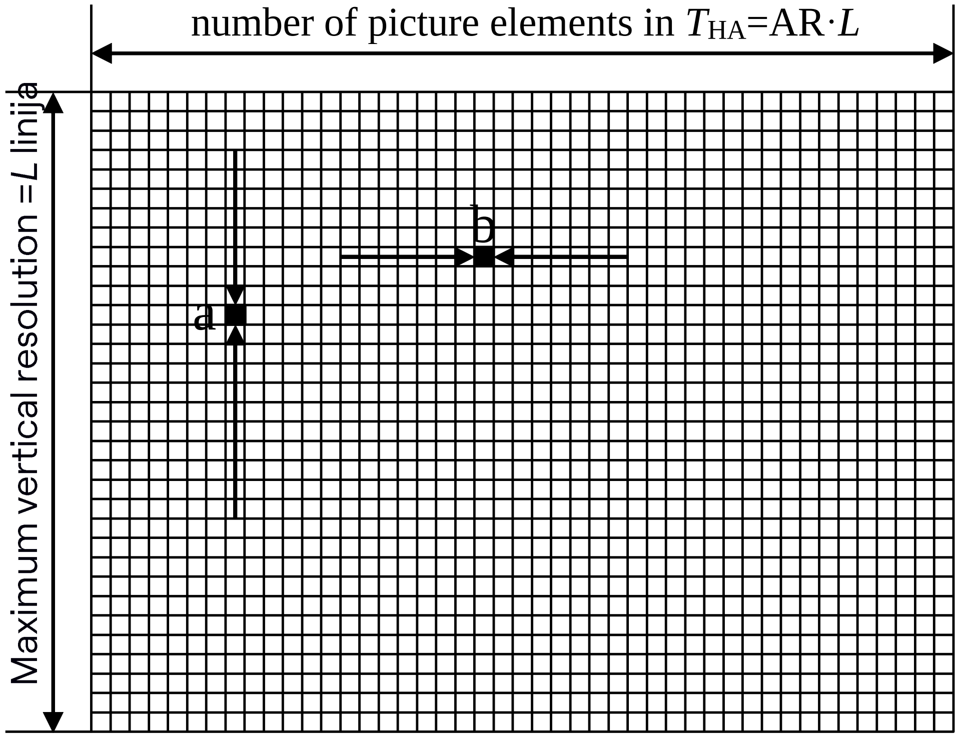


Resolution

- vertical resolution
  - the number of black and white horizontal lines that alternate over the height of the image, and can be distinguished by the human visual system
  - depends on the number of scanning lines (L) and opto-electronic and electro-optical conversion
- horizontal resolution
  - the number of black and white vertical lines that alternate over the width of the image (W)
  - the width of the image on which the resolution is measured must be equal to the height of the image
  - in SDTV the aspect ratio of the picture is 4:3
    - to determine the resolution, the width of the image should be multiplied by 3/4
  - in HDTV aspect ratio of the picture is 16:9
    - to determine the resolution the width of the image should be multiplied by 9/16

Resolution

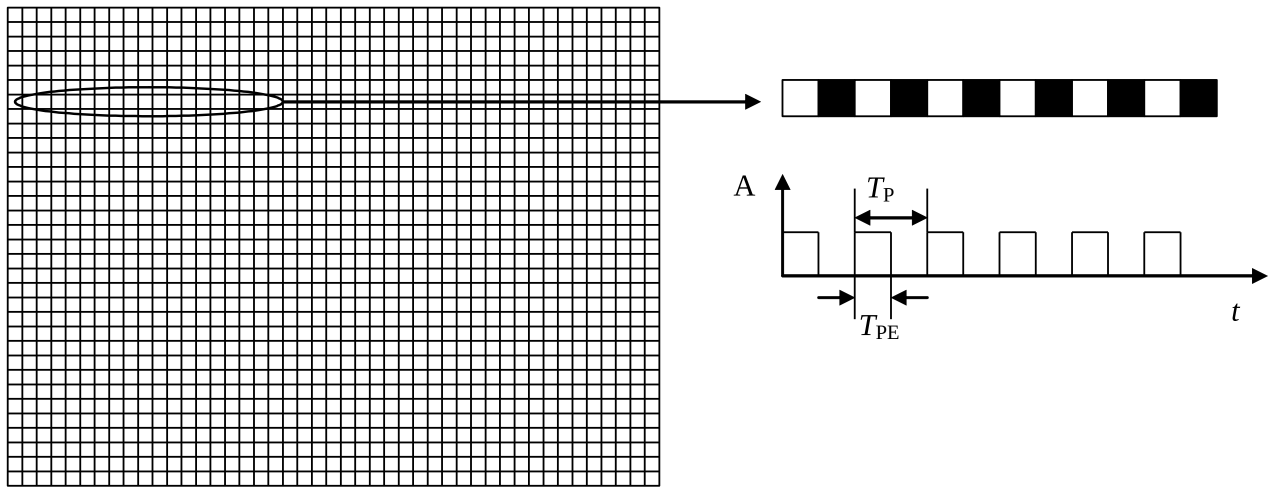
- assumption: the resolutions in the horizontal and vertical directions are equal
  - the distance between the scanning lines (a) determines the width of the picture element (b)
  - the number of picture elements in T_{HA} is (AR · L)



a=b
picture
elements are
quadratic

Resolution

- to measure the resolution the adjacent picture elements should have different luminances
  - assumption: the white and black picture elements alternate in the image



The total number of picture elements in the active part of the image T_{SA}: (AR $\cdot L$) $\cdot L$
The duration of one picture element: $T_{PE}=T_{SA}/(AR\cdot L\ \cdot L)=(T_{HA}\cdot L\ )/(AR\ \cdot L\ \cdot L)=T_{HA}/(AR\ \cdot L)$
Signal period: $T_P=2\cdot T_{PE}$
Frequency of the signal: $f_P=1/T_P=(AR\cdot L)/(2\cdot T_{HA})$

Resolution

- 625/50 sustav
  - total number of picture elements in the active part of the image $4/3 \cdot 575 \cdot 575 \approx 440\,833$
  - duration of one picture element
  - T_{PE}=29,9 ms/440 833= 0,0678 μs
  - signal period T_P=2·0,0678 = 0,1356 μs
  - frequency of the signal f_P=1/0,1356 μs = 7,37 MHz
  - frequency bandwidth of video signal is B = 7,37 MHz
- vertical resolution is limited
  - all lines in the active part of the image are not visible
  - the vertical resolution constraint is expressed by the Kell factor (K)
    - K is the ratio of the number of visible lines and the number of lines in the active part of the picture
  - the Kell factor for some system is determined by visual tests under strictly controlled conditions

Resolution

- SDTV system – Kell faktor is K=0,7 (for HDTV K=0,9)
  - vertical resolution is not L_V lines, but it is ($L_V \cdot$ 0,7) lines
- when K is taken into account vertical resolution is

  625/50 → $575 \cdot 0{,}7 \approx 402$ lines

  525/60 → $485 \cdot 0{,}7 \approx 339$ lines
- due to the introduction of the Kell factor, the required bandwidth of the video signal is reduced so that it is $B = 0{,}7 \cdot f_P$
- the formula for determining the frequency bandwidth of a video signal is

$$B = K \cdot f_P = \frac{K \cdot AR \cdot L}{2 \cdot T_{HA}}$$

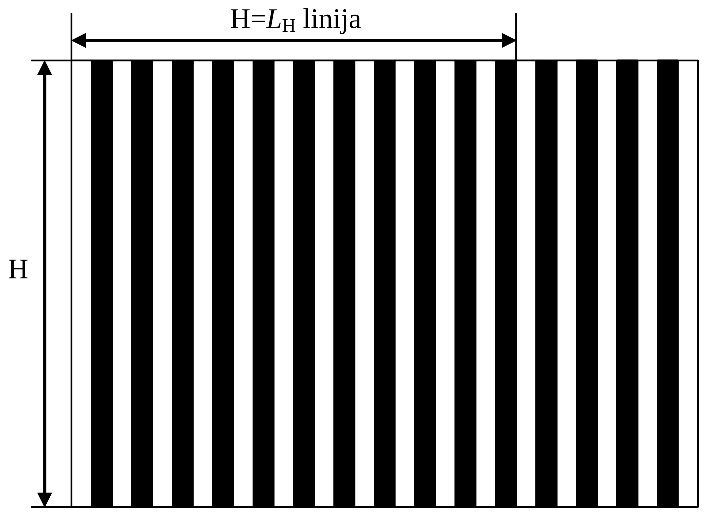
  - 625/50

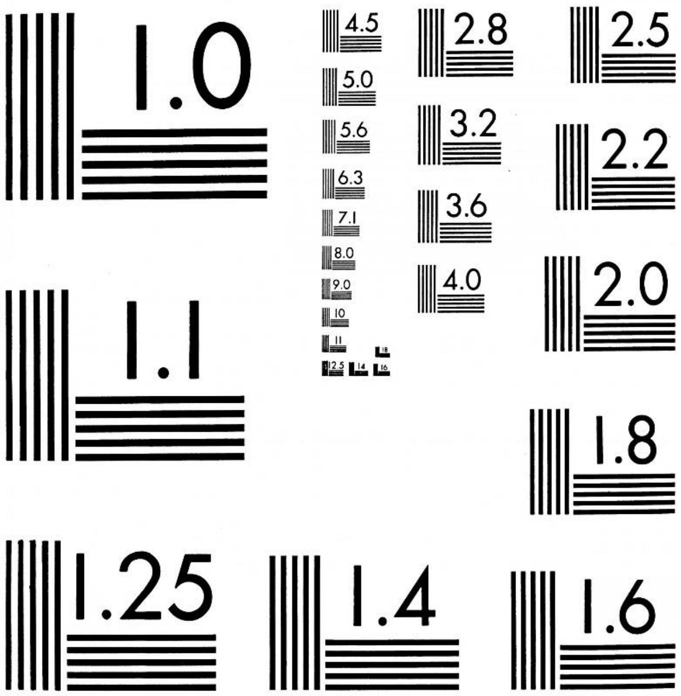
    $B = 0{,}7 \cdot f_P = 0{,}7 \cdot 7{,}37\ \text{MHz} = 5{,}159\ \text{MHz}$

    The nominal (standard) bandwidth of the video signal is B_0=5 MHz!
  - HDTV – K=0,9

Horizontal resolution

- a measure of the quality of a video system or device
  - defined at a width equal to the height of the image (H)
  - active part of the line (T_{HA}) is taken into account
- is expressed through
  - the number of black and white vertical lines (L_H) of equal width that can be resolved on the screen
  - video frequency B_V generated by an image that contains black and white vertical lines of equal width, that can still be resolved one from another on the screen



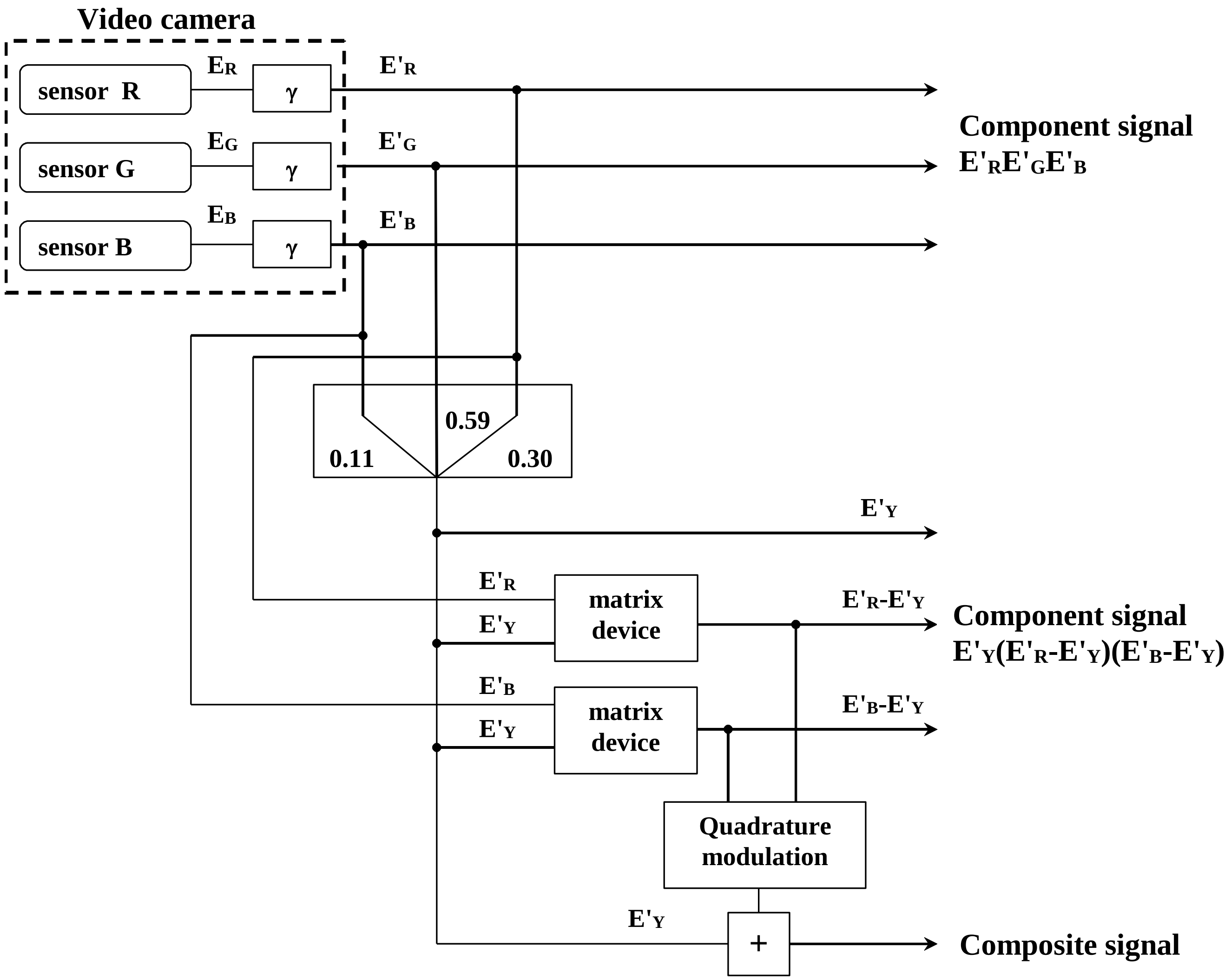


$$L_H = \frac{2 B_V T_{HA}}{AR} \qquad B_V = \frac{1}{2} \frac{AR \cdot L_H}{T_{HA}}$$

- 625/50 → T_{HA}=52 μs → $L_H = 78 \cdot B_V$ (B_V is in MHz)
- the maximum horizontal resolution in the 625/50 system is obtained for $B_V = B_0$ = 5 MHz
  - $L_{Hmaks} = 78 \cdot B_V = 78 \cdot 5\text{MHz} \approx 390$ lines

Color signal components

- composite and component video signal



Component video

- output signals from camera are gama-corrected signals of primary colors: red (E'_R), green (E'_G) i blue (E'_B), which represents the first form of component video
- reshaping the signals of primary colors gives
  - the second form of component video
    - luminanace signal (E'_Y) + two chrominance signals (red color-difference signal (E'_R–E'_Y) i blue color-difference signal (E'_B–E'_Y))
  - composite systems – three components share the same bandwidth
    - NTSC – *National Television Systems Committee*
    - PAL – *Phase Alternation Line*
    - SECAM – *Séquentiel Couleur avec Mémoire*

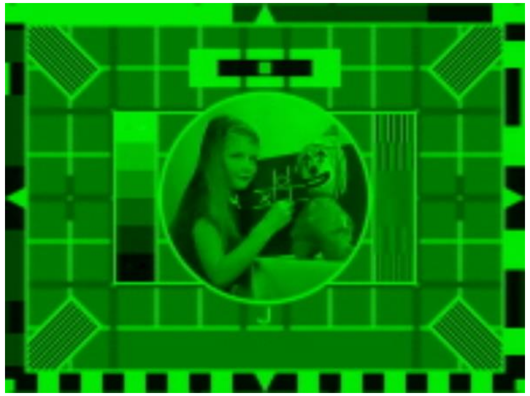
Component video

Signal levels



E'_R E'_G E'_B

Display on monitor

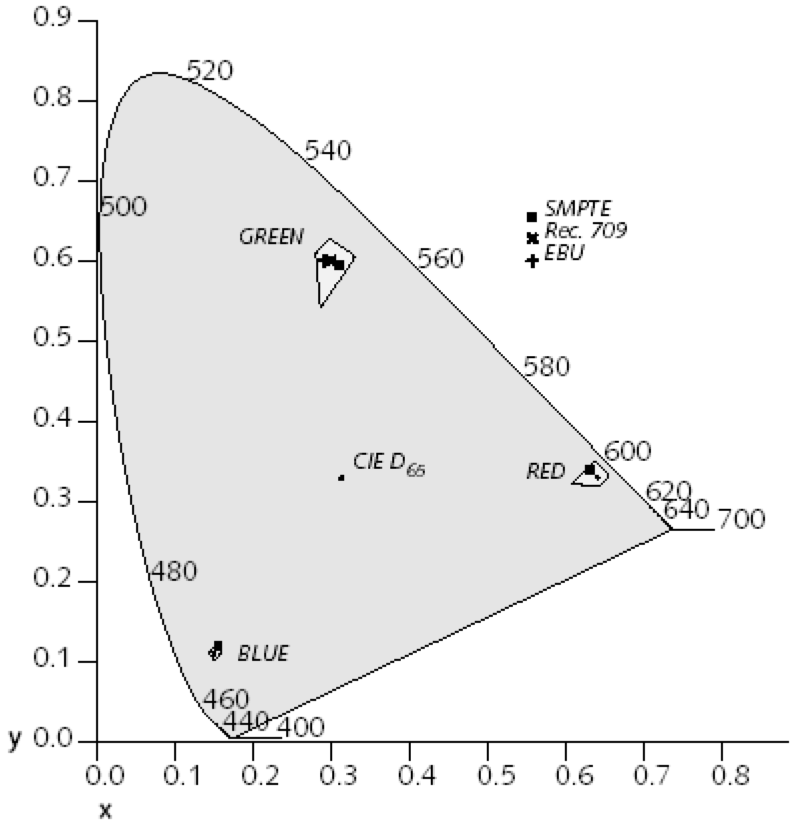

E'_R E'_G E'_B

Primary colors in video systems

- video primary colors ≠ CIE primary colors
  - in the past they depended on phosphors in the monitors and TV receivers (r - receiver) which should produce light of primary colors with sufficient intensity
    - $\lambda(Rr)$ = 610 nm
    - $\lambda(Gr)$ = 540 nm
    - $\lambda(Br)$ = 465 nm

    EBU (*European Broadcasting Union*) primary colors
- in achromatic systems the luminant E'_Y signal creates a black and white picture
  - for white image $E'_Y = 1$, for black image $E'_Y = 0$
- in color video systems the luminant E'_Y signal is produced by combining E'_R , E'_G and E'_B
  - for white image $E'_R=1$, $E'_G=1$ and $E'_B=1$
  - if $E'_Y=E'_R+E'_G+E'_B$, for white image luminance signal will be $E'_Y=3$
- signal strengths for red E'_R, green E'_G and blue E'_B in color systems are determined according to the properties of the human visual system

Primary colors in video systems



NTSC primary colors (white-C)

R:	xr=0.67	yr=0.33
G:	xg=0.21	yg=0.71
B:	xb=0.14	yb=0.08

SMPTE primary colors (white-D65)

R:	xr=0.630	yr=0.340
G:	xg=0.310	yg=0.595
B:	xb=0.155	yb=0.070

EBU primary colors (white-D65)

R:	xr=0.64	yr=0.33
G:	xg=0.29	yg=0.60
B:	xb=0.15	yb=0.06

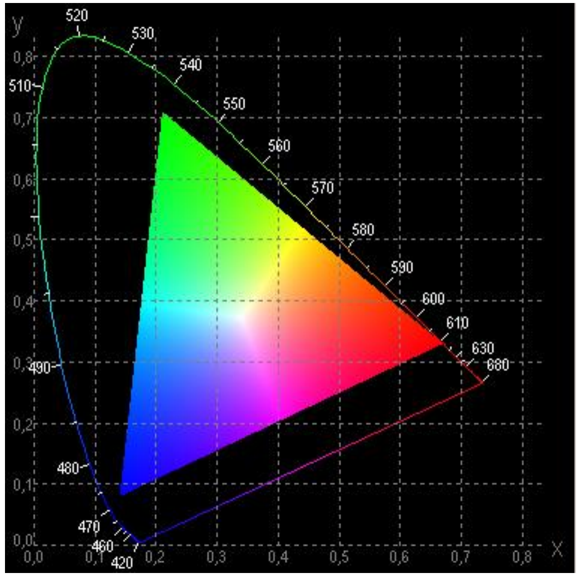
ITU-R BT.709 primary colors (white-D65)

R:	xr=0.64	yr=0.33
G:	xg=0.30	yg=0.60
B:	xb=0.15	yb=0.06

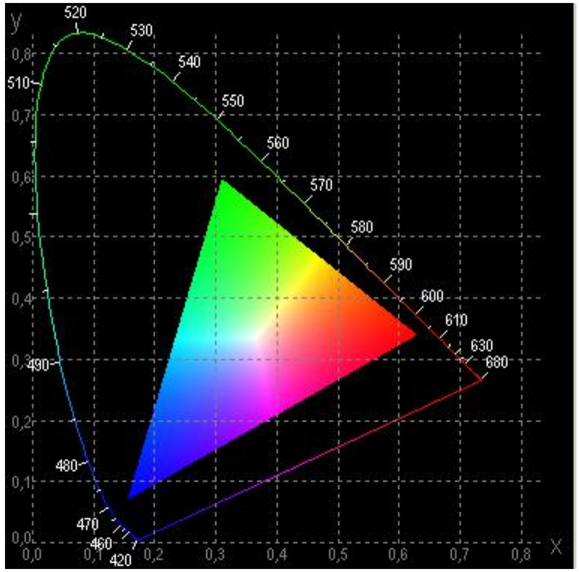
Primary colors in video systems

- color triangles in chromaticity diagram for different systems

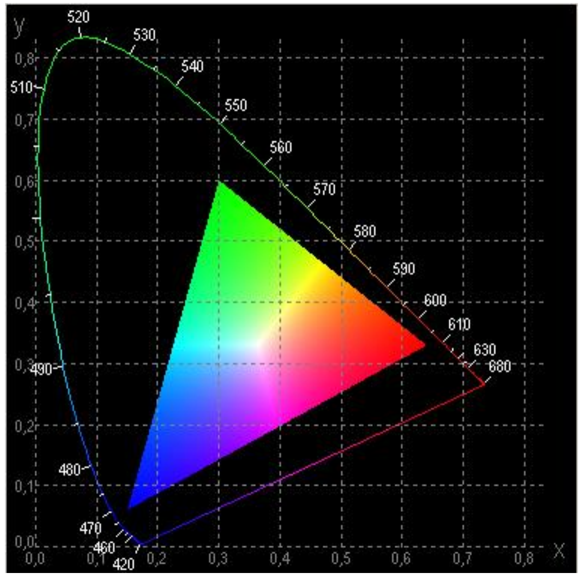
NTSC



SMPTE

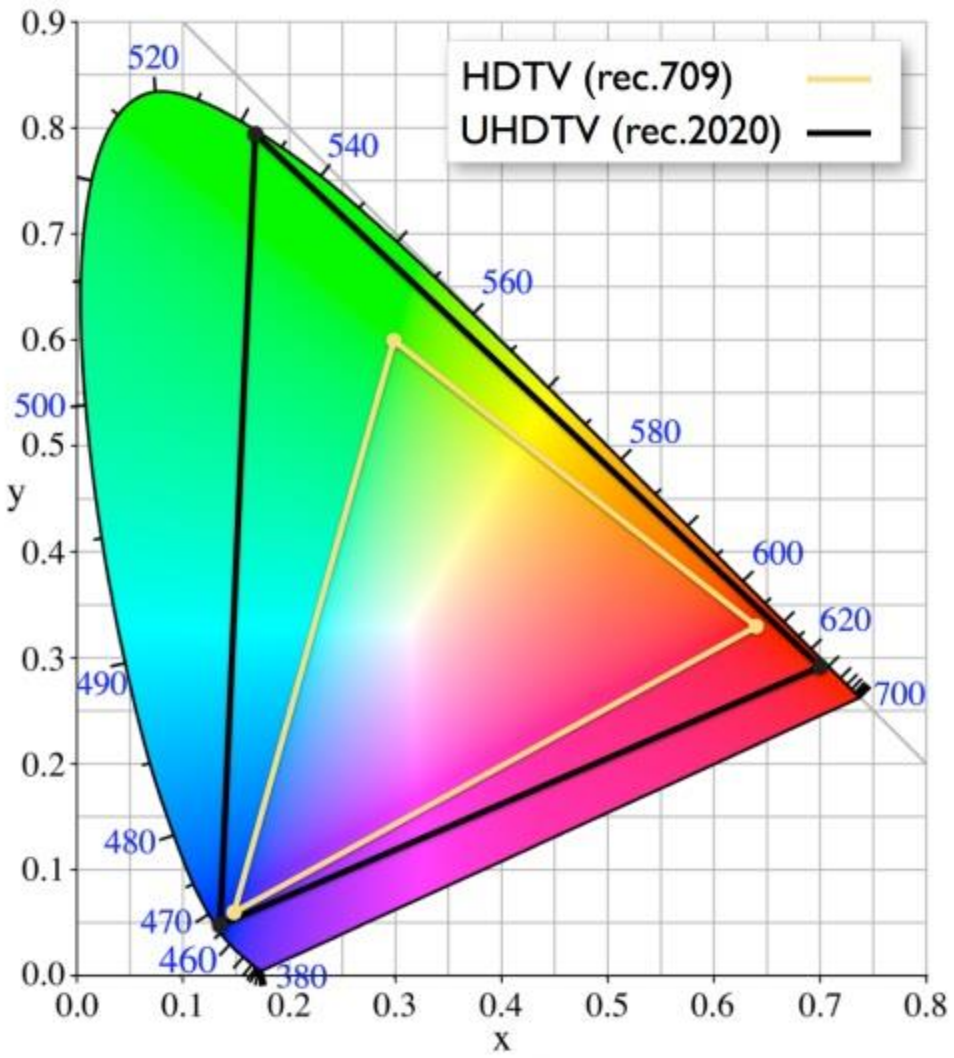


EBU



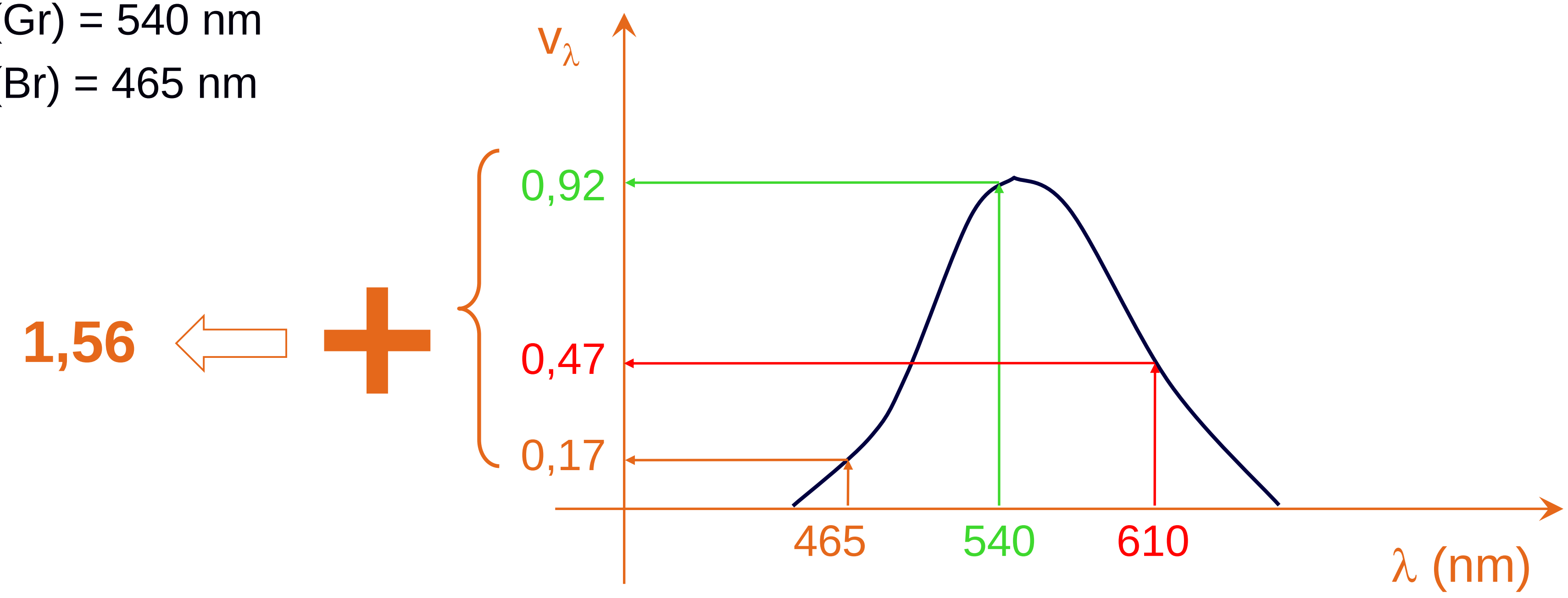
Primary colors in video systems

- color triangles for HDTV i UHDTV



Luminance signal

- luminosity curve
  - enables obtaining luminance signal from the signals for primary colors (in one phase of television development it enabled the compatibility of achromatic and color television)
  - EBU primary colors (European systems)
    - λ(Rr) = 610 nm
    - λ(Gr) = 540 nm
    - λ(Br) = 465 nm



Luminance signal

$v_\lambda(Rr) = 0{,}47$

$v_\lambda(Gr) = 0{,}92$

$v_\lambda(Br) = 0{,}17$

1,56

- relative luminosity coefficients:

$$\overline{v_\lambda}(\mathrm{Rr}) = \frac{0.47}{1.56} = 0.30$$

$$\overline{v_\lambda}(\mathrm{Gr}) = \frac{0.92}{1.56} = 0.59$$

$$\overline{v_\lambda}(\mathrm{Br}) = \frac{0.17}{1.56} = 0.11$$

$$E'_Y = 0{,}3 \cdot E'_R + 0{,}59 \cdot E'_G + 0{,}11 \cdot E'_B$$

Luminance signal

- white picture
  - $E'_R = E'_G = E'_B = 1$
  - $E'_Y = 0{,}3 \cdot 1 + 0{,}59 \cdot 1 + 0{,}11 \cdot 1 = 1$
- black picture
  - $E'_R = E'_G = E'_B = 0$
  - $E'_Y = 0$
- red picture
  - $E'_R = 1$, $E'_G = E'_B = 0$
  - $E'_Y = 0{,}3$
- yellow picture
  - $E'_R = 1$, $E'_G = 1$, $E'_B = 0$
  - $E'_Y = 0{,}3 + 0{,}59 = 0{,}89$

YUV model of component video

- signals E'_R, E'_G i E'_B can be used to obtain E'_Y

$$E'_Y = 0{,}30 \cdot E'_R + 0{,}59 \cdot E'_G + 0{,}11 \cdot E'_B$$

- it is sufficient to transmit two signals for the primary colors from which E'_Y is subtracted and signal E'_Y
- color-difference signals (signals of primary colors from which E'_Y is subtracted)

$$(E'_R - E'_Y) = E'_R - 0{,}30 \cdot E'_R - 0{,}59 \cdot E'_G - 0{,}11 \cdot E'_B = 0{,}70 \cdot E'_R - 0{,}59 \cdot E'_G - 0{,}11 \cdot E'_B$$
$$(E'_B - E'_Y) = E'_B - 0{,}30 \cdot E'_R - 0{,}59 \cdot E'_G - 0{,}11 \cdot E'_B = -0{,}30 \cdot E'_R - 0{,}59 \cdot E'_G + 0{,}89 \cdot E'_B$$
$$(E'_G - E'_Y) = E'_G - 0{,}30 \cdot E'_R - 0{,}59 \cdot E'_G - 0{,}11 \cdot E'_B = -0{,}30 \cdot E'_R + 0{,}41 \cdot E'_G - 0{,}11 \cdot E'_B$$

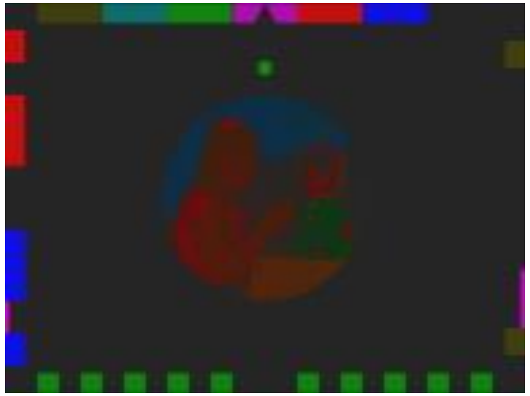
- color difference signals are low frequency signals by which the bandwidth can be limited

YUV model of component video

Input picture

E'_Y

Input piture - E'_Y



YUV model of component video

Signal levels

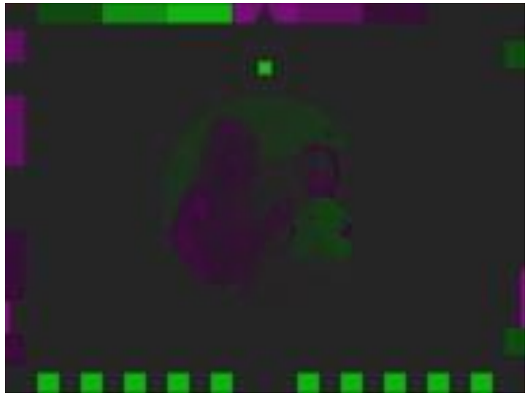
$E'_R - E'_Y$

$E'_G - E'_Y$

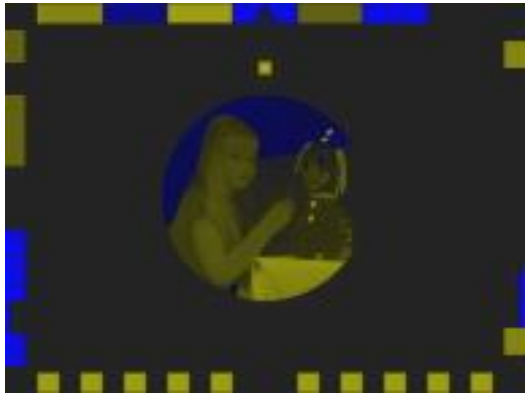
$E'_B - E'_Y$

Display on monitor

$E'_R - E'_Y$



$E'_G - E'_Y$



$E'_B - E'_Y$

YUV model of component video

Color	E'_R	E'_G	E'_B	E'_Y	$E'_R - E'_Y$	$E'_B - E'_Y$	$E'_G - E'_Y$
white	1	1	1	1	0	0	0
yellow	1	1	0	0,89	0,11	-0,89	0,11
cian	0	1	1	0,70	-0,70	0,30	0,30
green	0	1	0	0,59	-0,59	-0,59	0,41
purple	1	0	1	0,41	0,59	0,59	-0,41
red	1	0	0	0,30	0,70	-0,30	-0,30
blue	0	0	1	0,11	-0,11	0,89	-0,11
black	0	0	0	0	0	0	0

[-0,70 to 0,70]

[-0,89 to 0,89]

[-0,41 to 0,41]

Color-bar (maximally saturated primary colors and complementary colors + white + black)

YUV model of component video

- signals $(E'_R - E'_Y)$ and $(E'_B - E'_Y)$ are selected for transmission because the signal $(E'_G - E'_Y)$ has the smallest amplitude range (–0.41 to 0.41)

$$E'_Y = 0{,}30 \cdot E'_R + 0{,}59 \cdot E'_G + 0{,}11 \cdot E'_B$$
$$(E'_B - E'_Y) = -0{,}30 \cdot E'_R - 0{,}59 \cdot E'_G + 0{,}89 \cdot E'_B$$
$$(E'_R - E'_Y) = 0{,}70 \cdot E'_R - 0{,}59 \cdot E'_G - 0{,}11 \cdot E'_B$$

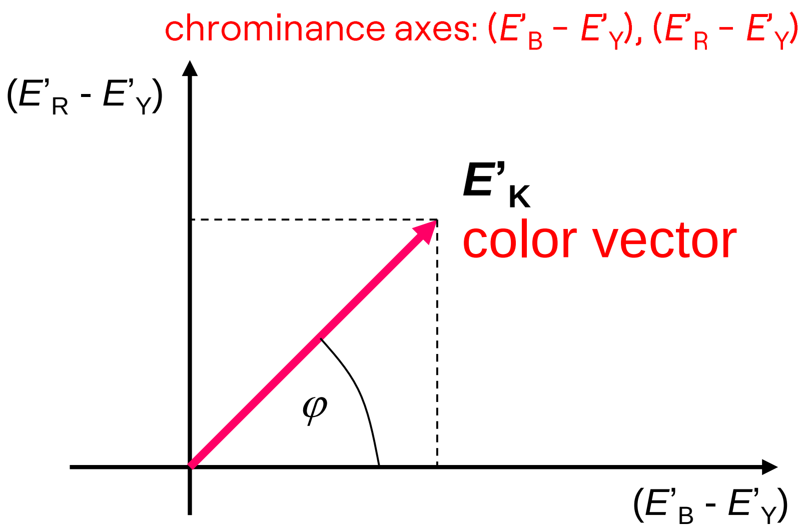
- in real system amplitudes of $(E'_R - E'_Y)$ and $(E'_B - E'_Y)$ are reduced (the degree of reduction depends on the system)
- in PAL system, reduced color-difference signals are E'_U i E'_V

$$E'_U = 0{,}493(E'_B - E'_Y)$$
$$E'_V = 0{,}877(E'_R - E'_Y)$$

- the component video model in which the luminance signal and the two color-difference signals E'_U i E'_V are transmitted is called the YUV model

Color vector display

E'$_{K}$ - chrominance signal



AMPLITUDE CORRESPONDS TO COLOR SATURATION :

$$E'_{KA} = \sqrt{(E'_R - E'_Y)^2 + (E'_B - E'_Y)^2}$$

PHASE CORRESPONDS TO COLOR HUE:

$$tg\varphi = \frac{(E'_R - E'_Y)}{E'_B - E'_Y)}$$

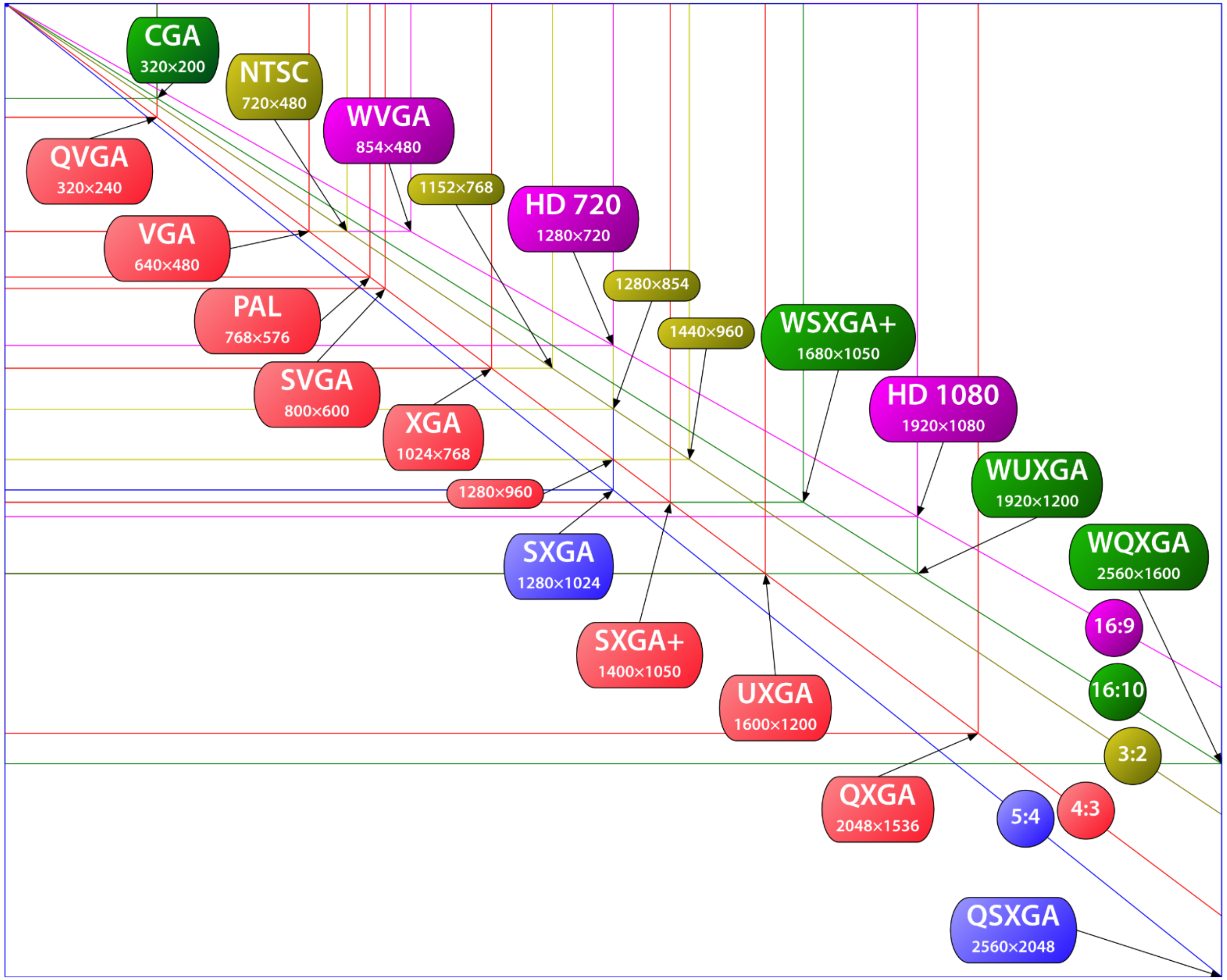
Digital image formats

- digital video signal formats are derived from analog video signal
  - the sampling frequency is determined in relation to the horizontal frequency
- Recommendation ITU-R BT.601 (1986)
  - *Studio encoding parameters of digital television for standard 4:3 and wide-screen 16:9 aspect ratios*
  - defines parameters for analog-to-digital video signal conversion in 525/60 and 625/50 systems (4: 3 and 16: 9 systems)
  - the sampling frequency for the luminance component is 13.5 MHz
  - image formats are 720x576 for 625/50, and 720x480 for 525/59.94

Digital image formats

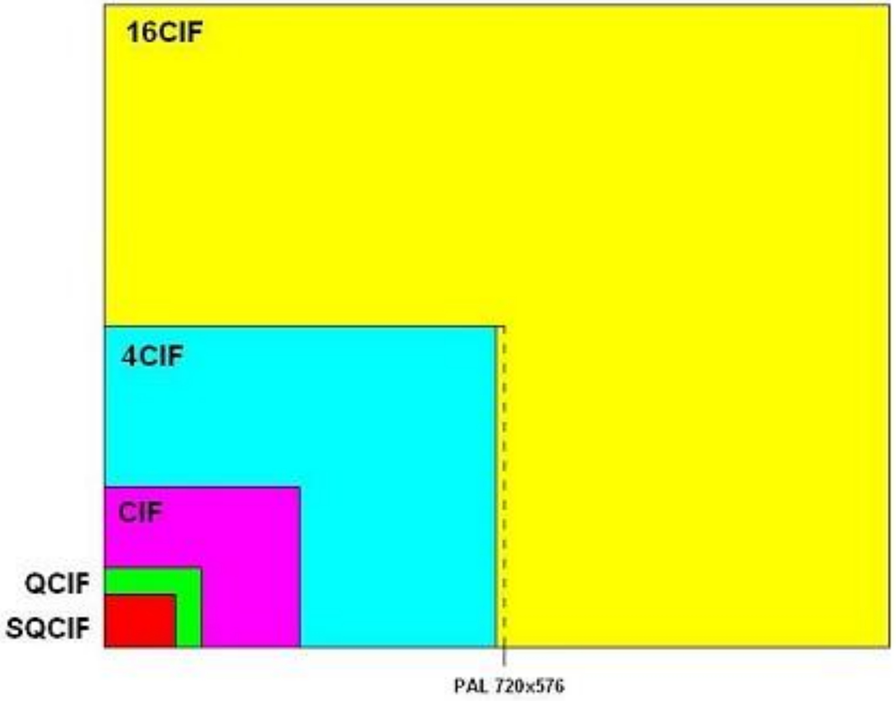
- image formats for display on computer monitors
  - the basic format is VGA (*Video Graphics Array*) - 640x480 pixels (picture elements)
  - more about formats:

https://www.gearbest.com/blog/how-to/17-types-of-common-screen-resolutions-2883



Digital image formats

- image formats used in ITU-T recommendations
  - basic format is CIF (*Common Interchange Format*)
    - is derived from image formats produced by analog-to-digital conversion in accordance with ITU-R BT.601



Format	16CIF	4CIF	CIF	QCIF	SQCIF
Image size	1408 × 1152	704 × 576	352 × 288	176 × 144	128 × 96
Number of pixels	1 622 016	405 504	101 376	25 344	12 288

ITU-R recommendation BT.601

- sampling frequency for luminance signal is 13,5 MHz set
- two sampling structure
  - 4:4:4
    - signal components are [E'_Y, (E'_R–E'_Y), (E'_B–E'_Y)] or [E'_R, E'_G, E'_B]
    - sampling frequency is 13,5 MHz for each component
  - 4:2:2
    - signal components are [E'_Y, (E'_R–E'_Y), (E'_B–E'_Y)]
    - sampling frequency for E'_Y is 13,5 MHz
    - sampling frequency for (E'_R–E'_Y) and (E'_B–E'_Y) is 6,75 MHz (subsampling with factor 2)

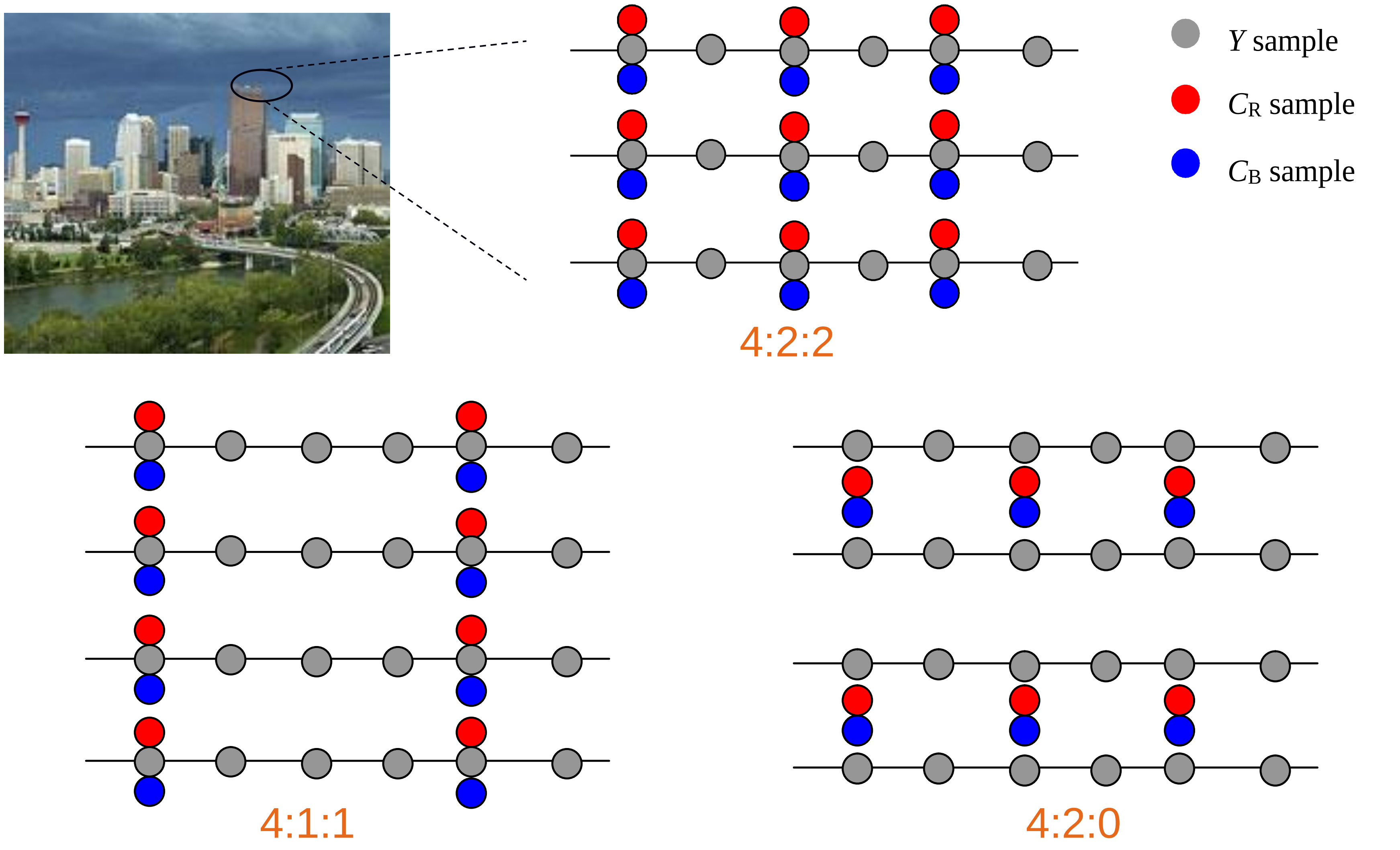
ITU-R recommendation BT.601

- 13,5 MHz, 4:2:2 sampling structure

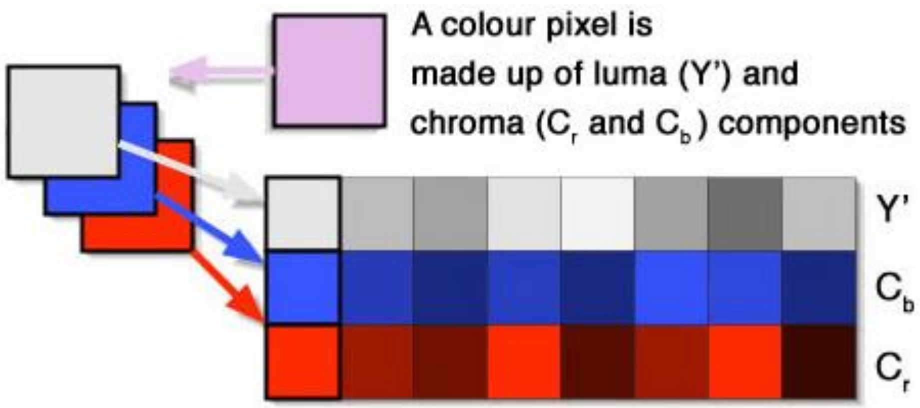
Parameters	525-line, 60/1.001, field/s systems	625-line, 50 field/s systems
1) Coded signals: Y, C_R, C_B	These signals are obtained from gamma pre-corrected signals, namely: E'_Y, $E'_R - E'_Y$, $E'_B - E'_Y$	
2) Number of samples per total line: – luminance signal (Y) – each colour-difference signal (C_R, C_B)	858 429	864 432
3) Sampling structure	Orthogonal, line, field and frame repetitive. C_R and C_B samples co-sited with odd (1st, 3rd, 5th, etc.) Y samples in each line	
4) Sampling frequency: – luminance signal – each colour-difference signal	13.5 MHz 6.75 MHz The tolerance for the sampling frequencies should coincide with the tolerance for the line frequency of the relevant colour television standard	
5) Form of coding	Uniformly quantized PCM, 8 or 10 bits per sample, for the luminance signal and each colour-difference signal	
6) Number of samples per digital active line: – luminance signal – each colour-difference signal	720 360	
7) Analogue-to-digital horizontal timing relationship: – from end of digital active line to O_H	16 luminance clock periods	12 luminance clock periods

ITU-R recommendation BT.601

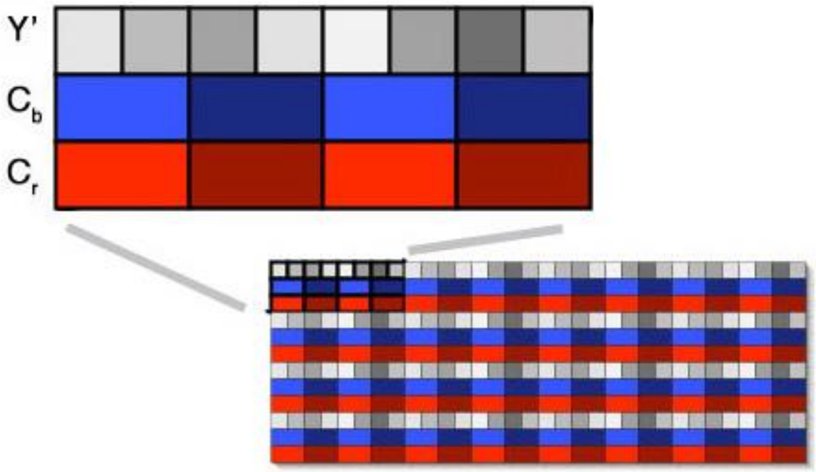
- sampling structure



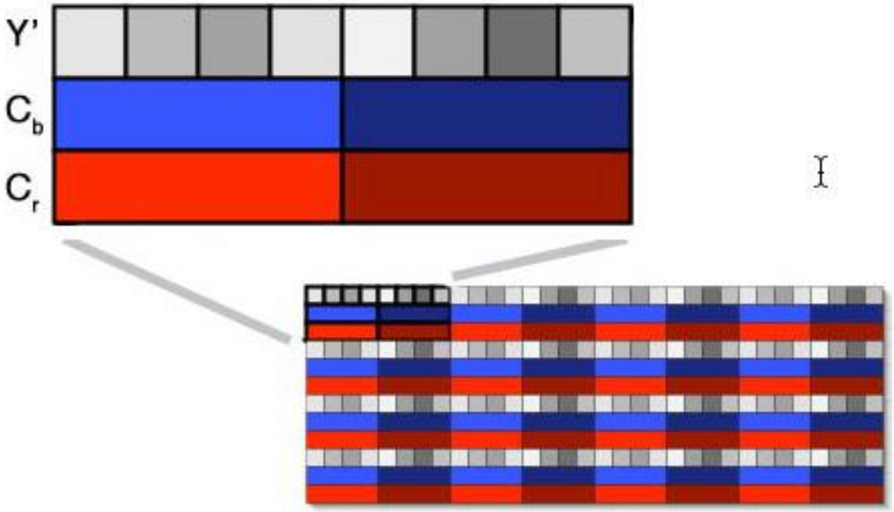
ITU-R recommendation BT.601



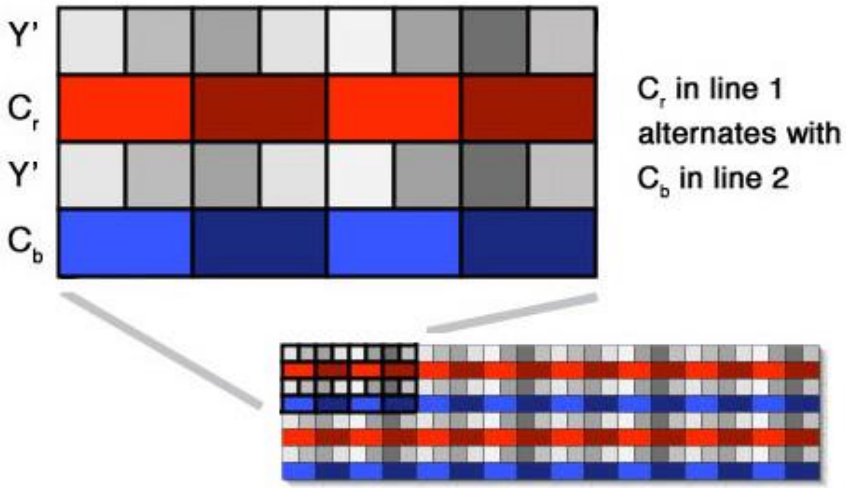
4:4:4 Chroma Sampling



4:2:2 Chroma Sampling



4:1:1 Chroma Sampling



4:2:0 Chroma Sampling

ITU-R recommendation BT.601

- spatial format
    - 525-line standard
        - spatial format: 720 x 480 [number of Y samples in active line (N_V) x number of active lines per frame (L_V)]
    - 625-line standard
        - spatial format: 720 x 576
- interlaced scanning (I)
    - frame is divided into two fields
    - vertical frequency (f_v) = field frequency ≠ frame frequency (f_s)
        - f_v=50 Hz (50 fields per second, 25 frames per second → f_s=25 Hz)
        - f_v=60 Hz (60 fields per second, 30 frames per second → f_s=30 Hz)
- recommended sampling structure: 4:2:2, 4:2:0
- number of bits per sample: 10 bits/sample

ITU-R recommendation BT.601

- the resolution for the color components are expressed relative to the resolution of the luminance signal

Sampling structure	Horizontal [%]	Vertical [%]
4:4:4	100	100
4:2:2	50	100
4:2:0	50	50
4:1:1	25	100

Bit-rate

- **gross bit-rate** after analog-digital conversion of component video signal is $R=(f_s n)_Y+(f_s n)_{CR}+(f_s n)_{CB}$

Format	f_S, MHz	n	R, Mbit/s
4:4:4	13,5	8	324
4:4:4	13,5	10	405
4:4:4	18	8	432
4:4:4	18	10	540
4:2:2	13,5/6,75	8	216
4:2:2	13,5/6,75	10	270
4:2:2	18/9	8	288
4:2:2	18/9	10	360
4:1:1	13,5/3,375	8	162

  – if only the active part of the frame is observed, the bit-rates are reduced (**useful bit-rate**):
    - for 13,5 MHz, 625/50, 4:2:2
      – R=720 x 576 x 25 x 8 + 360 x 576 x 25 x (8 + 8) = 166 Mbit/s
    - for 13,5 MHz, 625/50, 4:1:1
      – R=720 x 576 x 25 x 8 + 180 x 576 x 25 x (8 + 8) = 124 Mbit/s

Bit-rate

- example: video signal in digital form generated by the recommendation of ITU-R BT.601 with 8-bit/sample coding for each component in 4: 2: 2 format and for frame rate of 25 Hz
  - required number of bits to encode the active part of an image:

  (720 x 576) x8 bits + (360 x 288) x8 + (360 x 288) x8 = 6,635,520 bits
  - bit-rate for the active part of the image: 6,635,520 bits x 25 = 165.88 Mbit/s = 20.736 MB/s
  - it is possible to store 4 minutes of uncompressed digital video signal on a 5 GB hard disk

Video signal compression is required!

HDTV

- ITU-R standard for HDTV
    - ITU-R BT.709: *Parameter Values for the HDTV Standards for Production and International Programme Exchange - PART 2: HDTV SYSTEMS WITH SQUARE PIXEL COMMON IMAGE FORMAT*
- SMPTE (*Society for Motion Pictures and Television Engineers*) standards:
    - SMPTE 296M: *1280 x 720 Progressive Image Sample Structure – Analogue and Digital Representation and Analogue Interface*
    - SMPTE 274M: *1920 x 1080 Image Sample Structure, Digital Representation and Digital Timing Reference Sequences for Multiple Picture Rates*
- the parameters for HDTV that appear in the SMPTE 274M standard are equal to the parameters from the ITU-R recommendation BT.709

HDTV

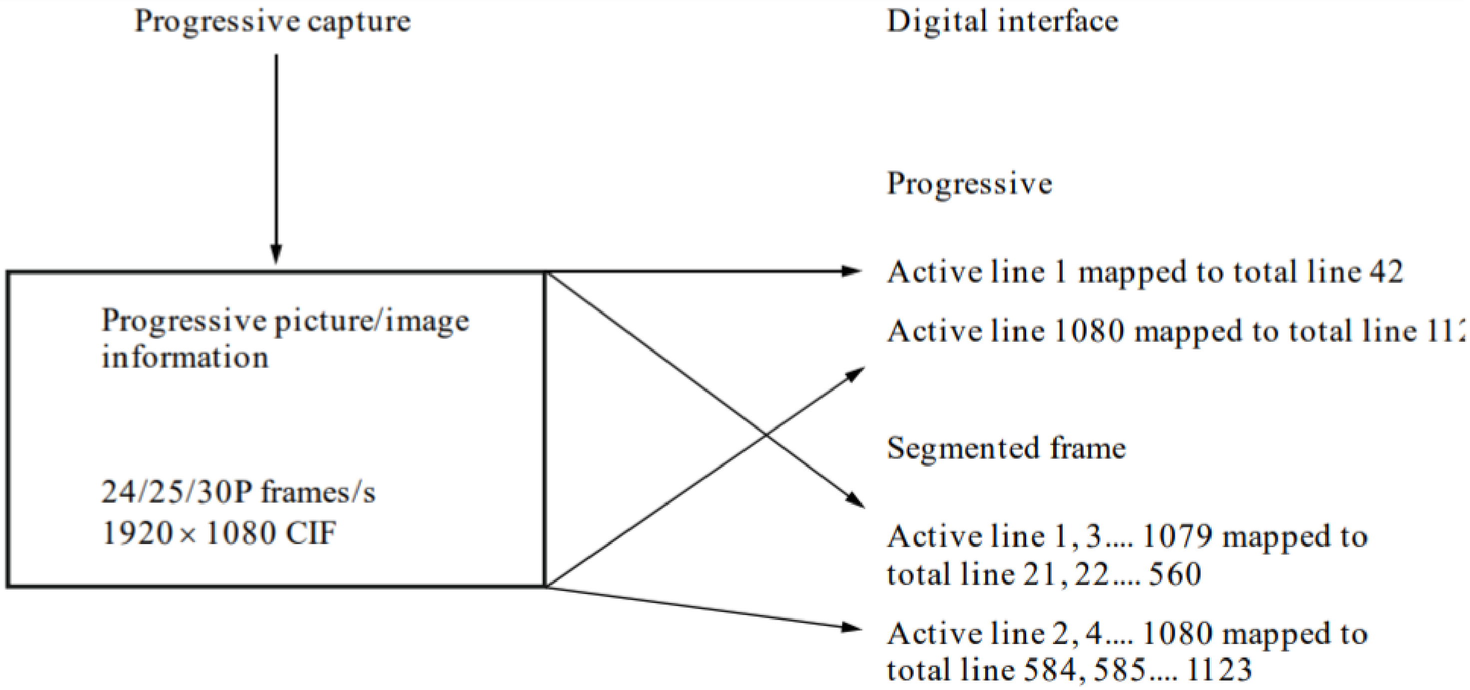
- HDTV parameters in accordance with ITU-R recommendation BT.709 and SMPTE 274M

Parametar	Vertical frequency/scanning type									
	60/P	30/P	30/PsF	60/I	50/P	25/P	25/PsF	50/I	24/P	24/PsF
Aspect ratio	16:9									
Samples per active line	1 920									
Sampling structure	Ortogonalna									
Active lines per frame	1080									
Pixel aspect ratio	1:1 (square pixels)									

HDTV

- PsF - *Progressive Segmented Frame*

Mapping of progressive images into progressive and segmented frame transport interfaces



HDTV

- HDTV ITU-R BT.709 parameters

<table>
<tr><th rowspan="2">Parameter</th><th colspan="10">Parameter values</th></tr>
<tr><th>60/P</th><th>30/P</th><th>30/PsF</th><th>60/I</th><th>50/P</th><th>25/P</th><th>25/PsF</th><th>50/I</th><th>24/P</th><th>24/PsF</th></tr>
<tr><td>Number of lines</td><td colspan="10">1125</td></tr>
<tr><td>Vertical frequency (Hz)</td><td>60
(60/1,001)</td><td>30
(30/1,001)</td><td colspan="2">60
(60/1,001)</td><td>50</td><td>25</td><td colspan="2">50</td><td>24
(24/1,001)</td><td>48
(48/1,001)</td></tr>
<tr><td>Scanning type</td><td colspan="3">1:1</td><td>2:1</td><td colspan="3">1:1</td><td>2:1</td><td colspan="2">1:1</td></tr>
<tr><td>Frame frequency (Hz)</td><td>60
(60/1,001)</td><td colspan="3">30
(30/1,001)</td><td>50</td><td colspan="3">25</td><td colspan="2">24
(24/1,001)</td></tr>
<tr><td>Line frequency (Hz)</td><td>67 500
(67 500/1,001)</td><td colspan="3">33 750
(33 750/1,001)</td><td>56 25
0</td><td colspan="3">28 125</td><td colspan="2">27 000
(27 000/1,001)</td></tr>
<tr><td>Number of sample per line
– R, G, B, Y
– CB, CR</td><td colspan="4">2 200
1 100</td><td colspan="4">2 640
1 320</td><td colspan="2">2 750
1 375</td></tr>
<tr><td>Nominal bandwidth of E'_Y in analog domain (MHz)</td><td>60</td><td colspan="3">30</td><td>60</td><td colspan="5">30</td></tr>
<tr><td>Sampling frequency
– R, G, B, Y (MHz)</td><td>148,5
(148,5/1,001)</td><td colspan="3">74,25
(74,25/1,001)</td><td>148,5</td><td colspan="3">74,25</td><td colspan="2">74,25
(74,25/1,001)</td></tr>
<tr><td>Sampling frequency
– CB, CR (MHz)</td><td>74,25
(74,25/1,001)</td><td colspan="3">37,125
(37,125/1,001)</td><td>74,25</td><td colspan="3">37,125</td><td colspan="2">37,125
(37,125/1,001)</td></tr>
</table>

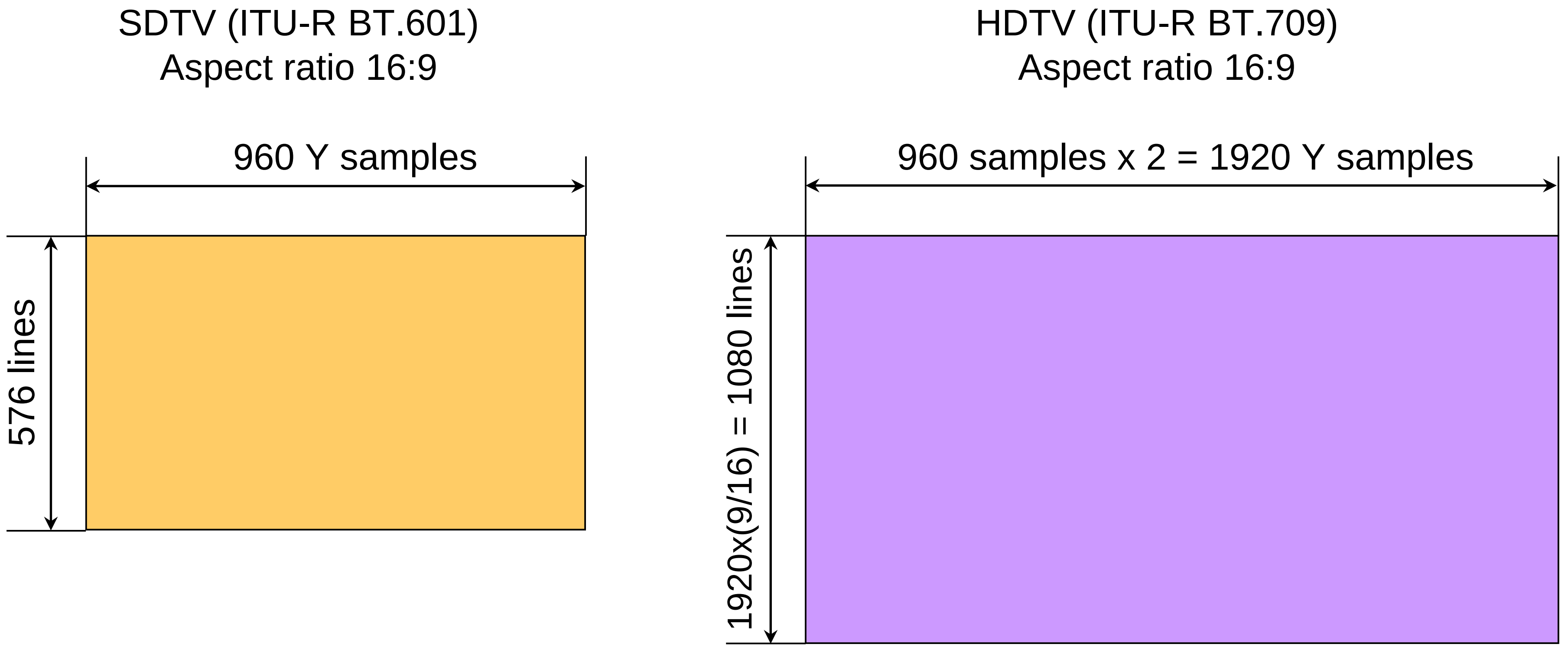
HDTV

- spatial format
  - 1920 x 1080 ($N_V=1920$, $L_V=1080$)
    - $L_U=1125$, $N_U=2640$ (for luminance signal)
  - 1280 x 720 ($N_V=1280$, $L_V=720$)
    - $L_U=750$, $N_U=1980$ (for luminance signal)
- sampling structure: 4:2:2, 4:2:0
- number of bits per sample: 10 bits/sample

HDTV

- HDTV formats are derived from analog-to-digital conversion parameters according to recommendation ITU-R BT.601 for SDTV
- the number of samples in the active line for 4: 3 format according to ITU-R BT.601 is 720
    - HDTV format 1280x720 is made so that the number of samples in the active line from the ITU-R BT.601, which is 720, is equal to the number of lines in active frame of HDTV format
    - with the screen extended to a 16: 9 aspect ratio, the number of samples in the active line (to maintain the same horizontal resolution) is $(720 \cdot 16/9) = 1280$
- the number of samples in the active line for 16: 9 format according to ITU-R BT.601 is $720x\ [(16/9) / (4/3)] = 960$
    - HDTV format 1920x1080 is made so that the number of samples in the active line from ITU-R BT.601 is doubled, ie it is $960x2 = 1920$
    - the number of samples in the active line is divided by the reciprocal value of the aspect ratio: $(1920 \cdot 9/16) = 1080$

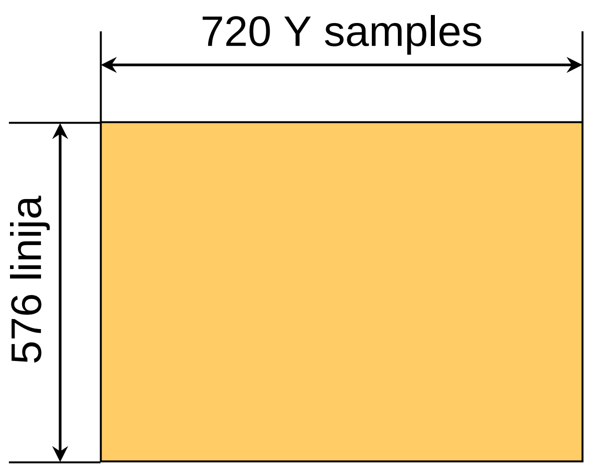
HDTV



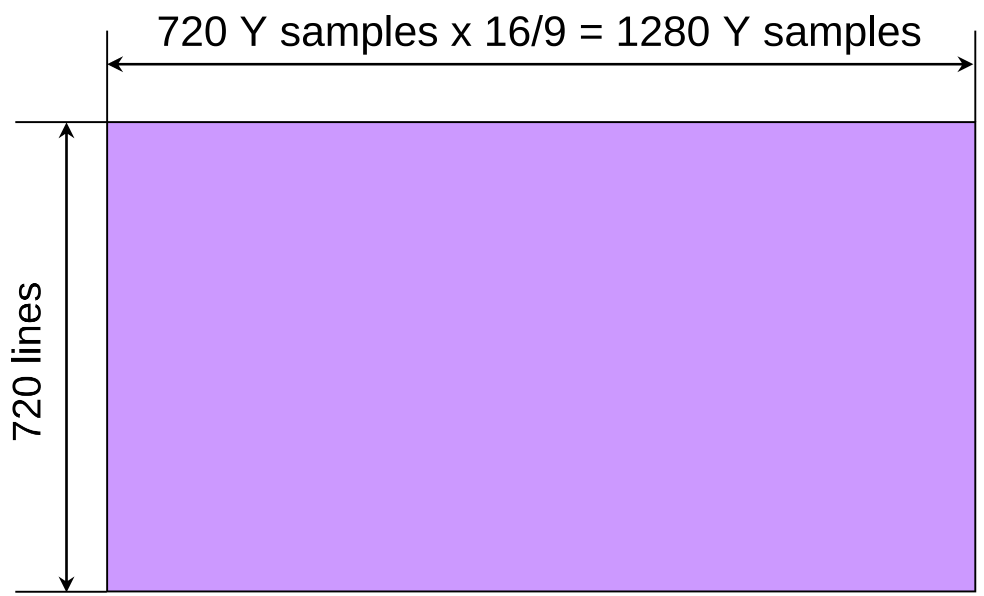
SDTV (ITU-R BT.601)
Aspect ratio 16:9
960 Y samples
576 lines
HDTV (ITU-R BT.709)
Aspect ratio 16:9
960 samples x 2 = 1920 Y samples
1920x(9/16) = 1080 lines

HDTV

SDTV (ITU-R BT.601)
Aspect ratio 4:3



HDTV (SMPTE 296M)
Aspect ratio16:9

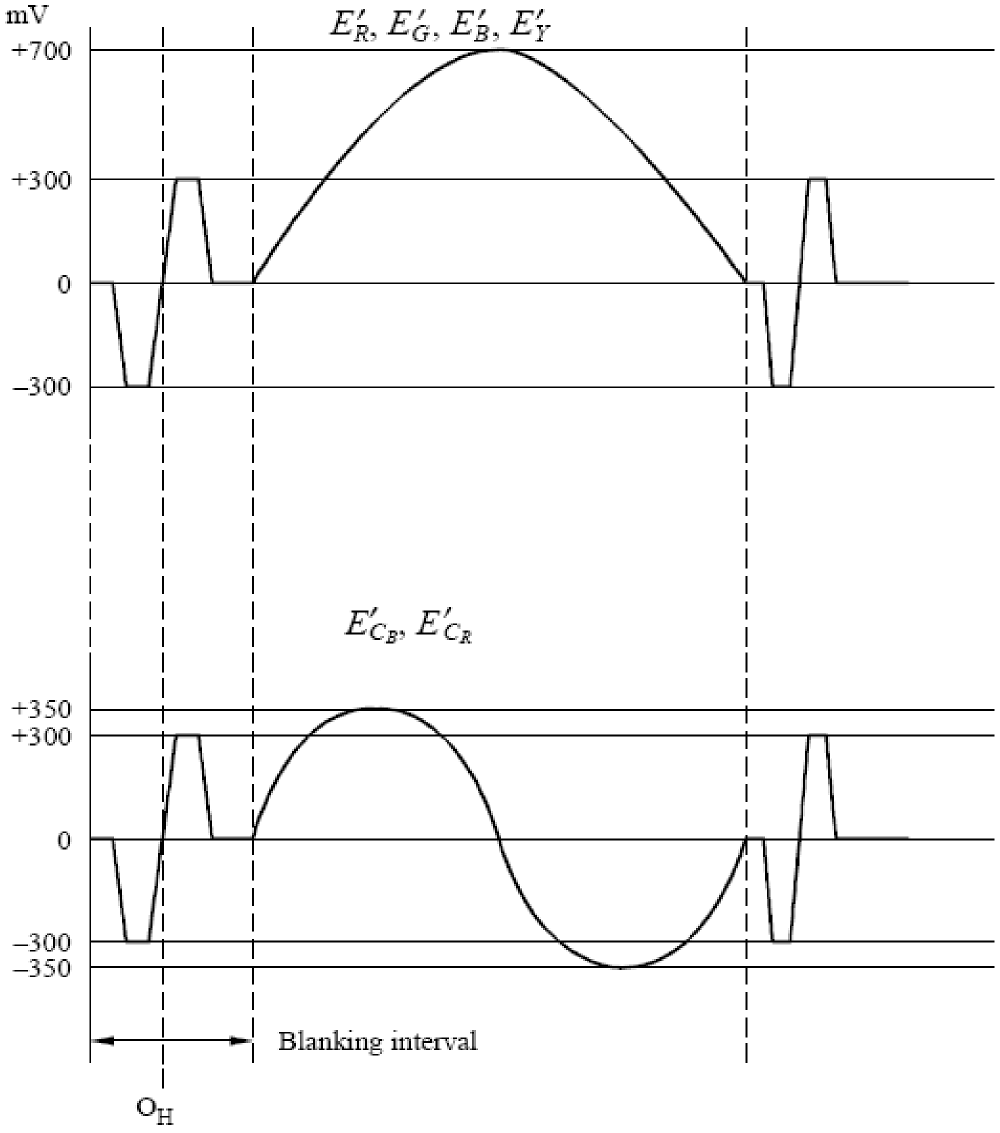


Video components

System parameters	SDTV	HDTV
CIE chromaticity coordinates for primary colors (white: D65, x=0.313, y=0.329	**EBU** | *x* | *y* Red (R) | 0,640 | 0,330 Green(G) | 0,290 | 0,600 Blue (B) | 0,150 | 0,060 **SMPTE** | *x* | *y* Red (R) | 0,630 | 0,340 Green(G) | 0,310 | 0,595 Blue (B) | 0,155 | 0,070	**ITU-R BT.709** | *x* | *y* Red (R) | 0,640 | 0,330 Green(G) | 0,300 | 0,600 Blue (B) | 0,150 | 0,060
Luminance signal	$E_Y'=0,299E_R'+0,587E_G'+0,114E_B'$	$E_Y'=0,2126E_R'+0,7152E_G'+0,0722E_B'$
Color signal components	$E'_U = 0,493(E_B' - E_Y')$ $E'_V = 0,877(E_R' - E_Y')$ $E'_{CB} = 0,564(E'_B - E'_Y)$ $E'_{CR} = 0,713(E'_R - E'_Y)$	$E'_{C_B} = 0,539(E_B' - E_Y')$ $E'_{C_R} = 0,635(E_R' - E_Y')$

Component video

- voltage levels for analog signal components



HDTV

- the possible formats of HDTV signals for the production of TV programs in European countries are determined by the document EBU Tech 3299: *High Definition (HD) Image Formats for Television Production*
  - System 1 (S1)
    - 1280 horizontal samples and 720 lines in active frame, progressive scanning with frame rate 50 Hz
  - System 2 (S2)
    - 1920 horizontal samples and 1080 lines in active frame, interlaced scanning with frame rate 25 Hz
  - System 3 (S3)
    - 1920 horizontal samples and 1080 lines in active frame, progressive scanning with frame rate 25 Hz
  - System 4 (S4)
    - 1920 horizontal samples and 1080 linija lines in active frame, progressive scanning with frame rate 50 Hz

HDTV

- sampling frequencies and bandwidth

Parameter	Video components	Systems 1, 2, 3	System 4
Bandwidth	R,G,B	30 MHz	60 MHz
	Y	30 MHz	60 MHz
	C_R, C_B	15 MHz	35 MHz
Sampling frequency	R,G,B	74,25 MHz	148,5 MHz
	Y	74,25 MHz	148,5 MHz
	C_R, C_B	37,125 MHz	74,25 MHz

HDTV

- bit-rates

System	Parameters	Number of Y samples per line	Number of lines per frame	Gross bit-rate (4:2:2, n=10)	Useful bit-rate (4:2:2, n=10)
1	1280x720/P/50	1980	750	1,485 Gbit/s	921,6 Mbit/s
2	1920x1080/I/25	2640	1125	1,485 Gbit/s	1036,8Mbit/s
3	1920x1080/P/25	2640	1125	1,485 Gbit/s	1036,8Mbit/s
4	1920x1080/P/50	2640	1125	2,970 Gbit/s	2073,6Mbit/s

- bit-rates are too high for efficient transmission by any type of communication medium

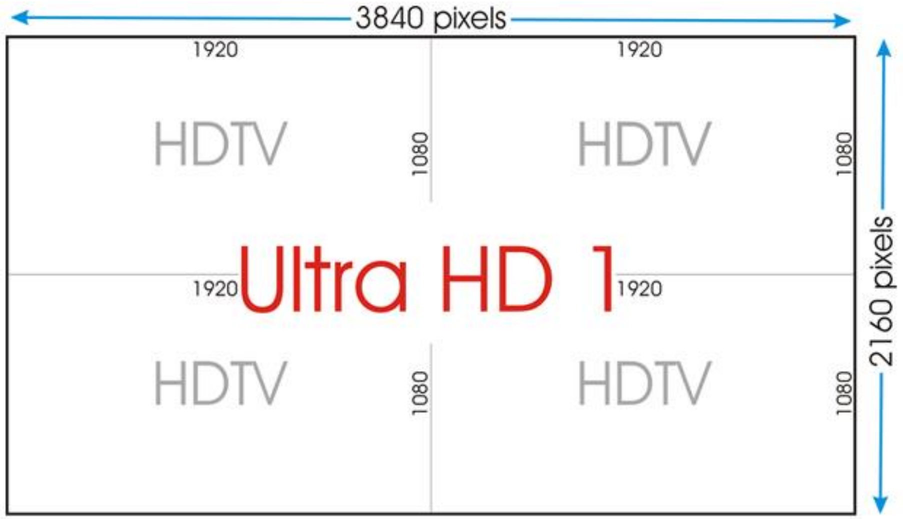
Video signal compression is required!

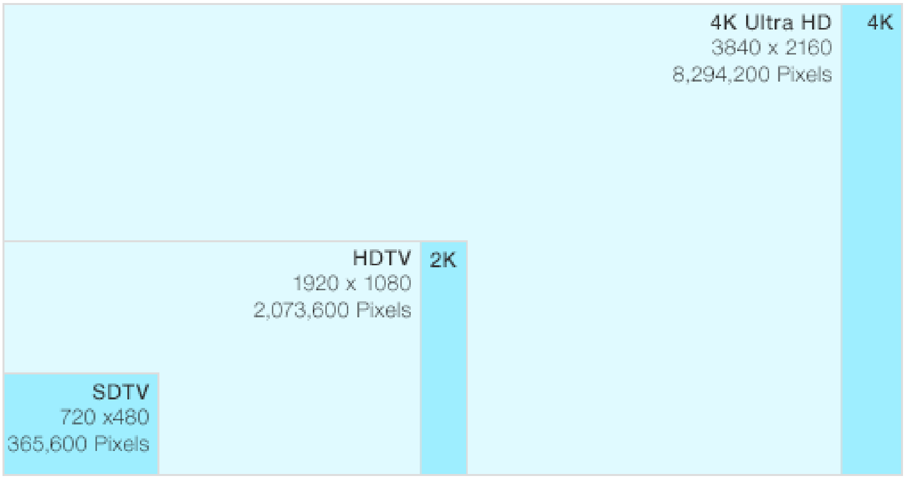
UHDTV

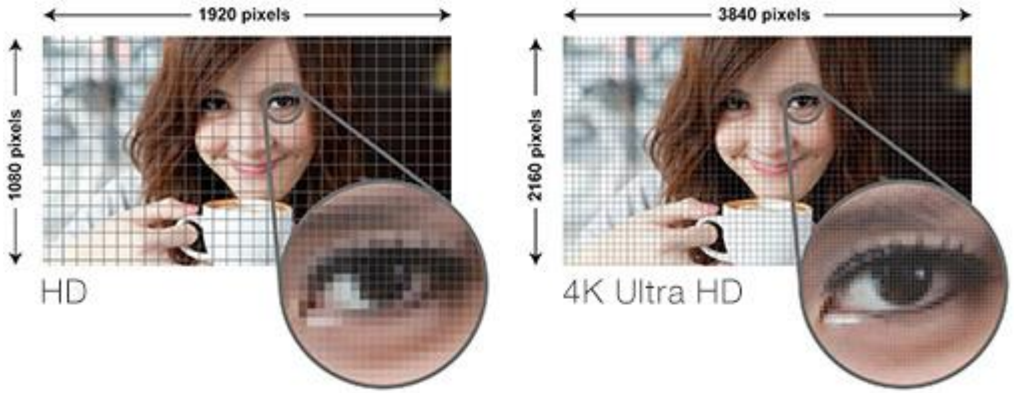
- UHDTV formats are derived from HDTV format 1920 x 1080
- parameters are defined by ITU-R BT.2020: *Parameter values for ultra-high definition television systems for production and international programme exchange)*
  - frame formats:
    - UHDTV-1: 3840 × 2160
      - L_U = 2250 (2x1125)
      - N_U = 5280 (2x2640)
    - UHDTV-2: 7680 × 4320
      - L_U = 4500 (4x1125)
      - N_U = 10560 (4x2640)
  - scanning type
    - progressive
    - frame rates in Hz: 120, 60, 60/1,001, 50, 30, 30/1,001, 25, 24, 24/1,001
  - sampling structure: 4:4:4, 4:2:2, 4:2:0
  - number of bits per sample: 10 bits/sample, 12 bits/sample

UHDTV

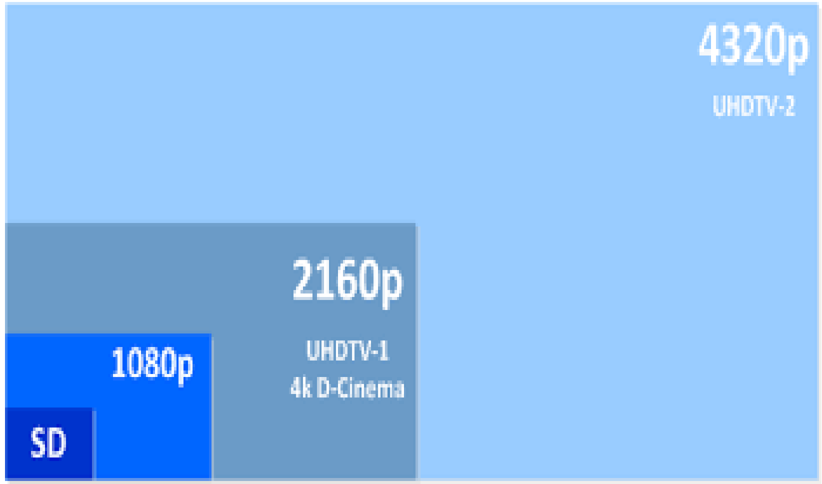
- comparison of HDTV i UHDTV-1

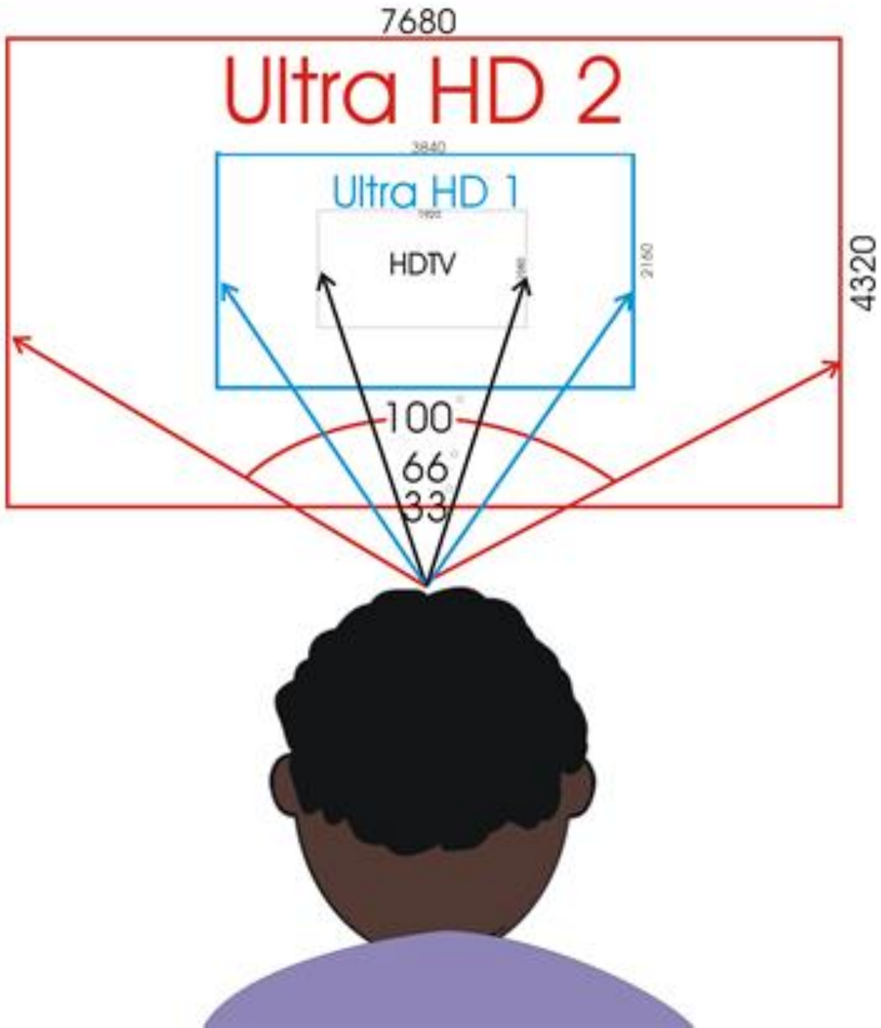






UHDTV


4320p
UHDTV-2
2160p
UHDTV-1
4k D-Cinema
1080p
SD


7680
Ultra HD 2
Ultra HD 1
HDTV
4320
100
66
33

Video components

System parameters	UHDTV
CIE chromaticity coordinates for primary colors (white: D65, x=0.327, y=0.329	<table><tr><th>ITU-R BT.2020</th><th>x</th><th>y</th></tr><tr><td>Red (R)</td><td>0,708</td><td>0,292</td></tr><tr><td>Green(G)</td><td>0,170</td><td>0,797</td></tr><tr><td>Blue (B)</td><td>0,131</td><td>0,046</td></tr></table>
Luminance signal	$E'_Y = 0{,}2627E'_R + 0{,}678E'_G + 0{,}0593E'_B$
Color signal components	$E'_{C_B} = 0{,}532(E'_B - E'_Y)$ $E'_{C_R} = 0{,}678(E'_R - E'_Y)$

UHDTV

- sampling frequency: $f_S = L_U \cdot N_U \cdot f_s$

Parameters	Number of Y samples per line	Number of lines per frame	Gross bit-rate (4:2:2, n=10)
3840x2160/P/50	5280	2250	11,88 Gbit/s
7680x4320/P/50	10560	4500	47,52 Gbit/s
3840x2160/P/120	5280	2250	28,512 Gbit/s
7680x4320/P/120	10560	4500	114,048 Gbit/s

Video signal compression is required!

Digital film formats

- 2K format
  - 2048 x 1080
  - the aspect ratio can be defined differently
  - frame rate is usually 24 frames per second
- 4K format
  - native: 4096 x 2160
  - the aspect ratio can be defined differently
    - 1.90:1 (256:135, approximately 17:9)
    - flat cropped: 1.85:1 (3996x2160)
    - CinemaScope cropped: 2.39:1 (4096x1716)
  - frame rate can be defined differently