

# ANALOGUE TELEVISION



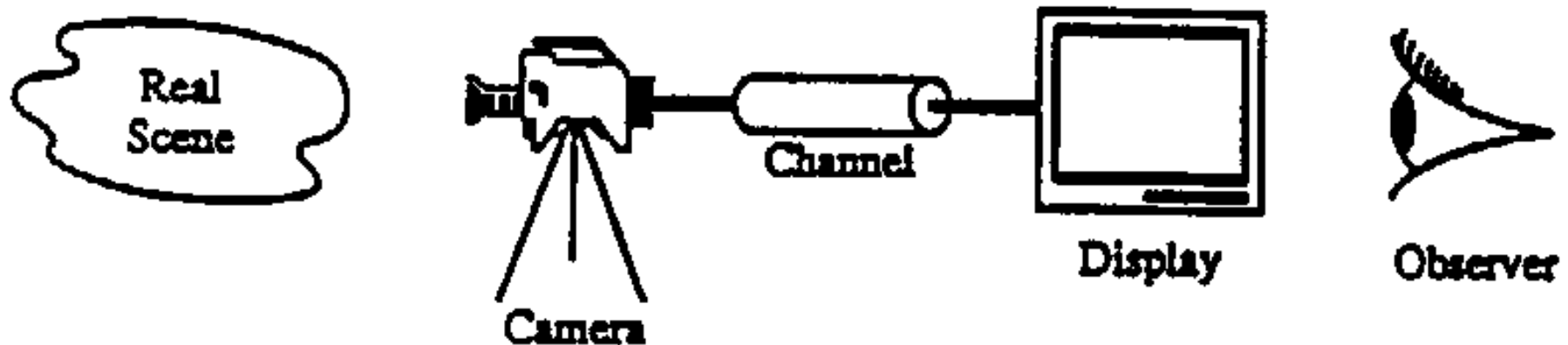
*Fernando Pereira*

*Instituto Superior Técnico*

# The box that changed the World ... or A picture is worth a thousand words !

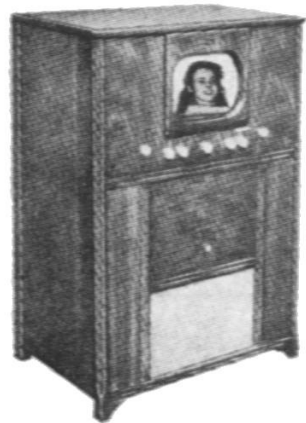


# Television: the Objective



**Transference at distance of audiovisual information using electrical/optical signals where many users (?) simultaneously (?) consume the same content.**

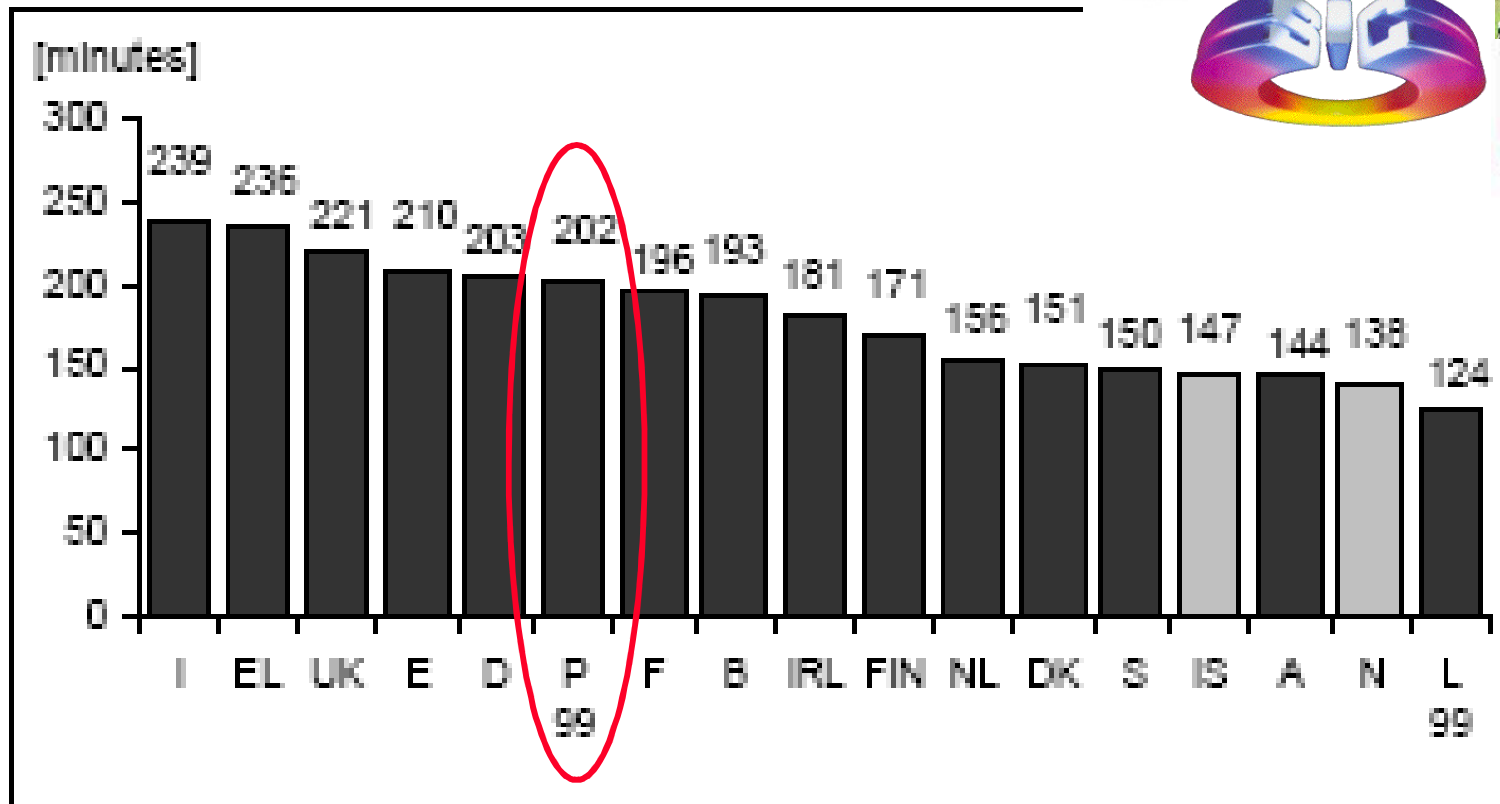
# The Final Target: Telepresence



Growing sensation of immersion

At

# Minutes of TV per Day ...

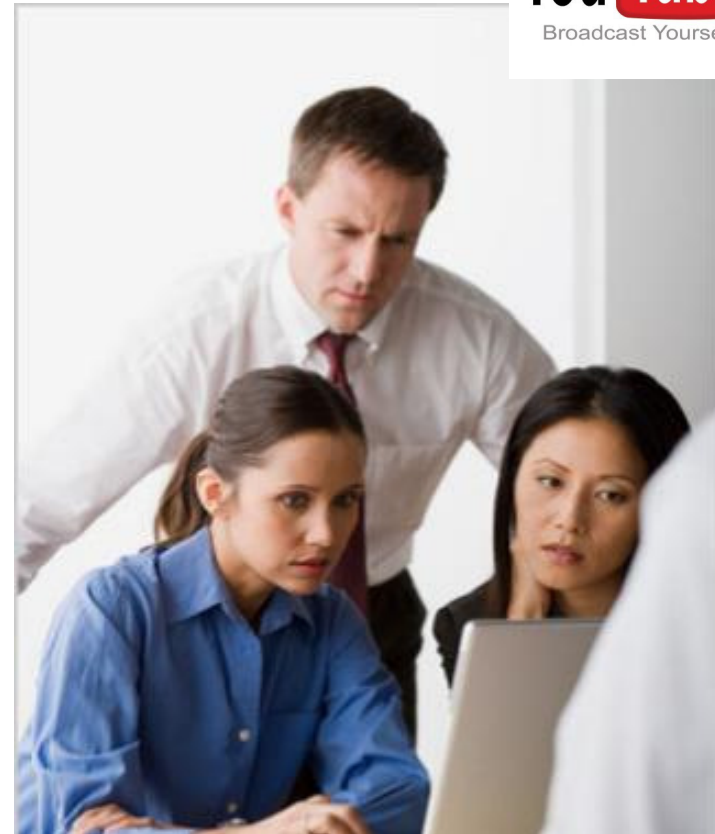


**Year 2000**

# Lean Backward versus Lean Forward



**You Tube**  
Broadcast Yourself





# History of Television: First Phase

- ★ 1925 - John Baird shows the possibility to transmit shapes of simple objects.
- ★ 1926 - John Baird shows the first monochrome TV system.
- ★ 1928 - John Baird shows the first colour TV system.
- ★ 1929 - Bell Labs show the first colour TV system where colours are transmitted in parallel.
- ★ 1936 – Olympic Games in Berlin – First TV transmission with great power.
- ★ 1937 – France, UK, Germany and USA start regular services of monochrome TV (low definition).
- ★ 1941 – FCC (USA) standardizes the monochrome TV system with 525 lines.
- ★ 1951 - CCIR does not reach agreement on a single standard for monochrome TV systems.
- ★ 1951/52 – Starts in Europe the monochrome TV system with 625 lines.
- ★ 1953 - FCC (USA) standardizes the NTSC TV colour system.
- ★ March 1957 – Starting in Portugal of monochrome TV regular transmissions.
- ★ 1957 – Crowning of Queen Elisabeth II – First European direct transmission.
- ★ 1960 – In Germany, appears the PAL TV colour system.
- ★ 1960 – In France, appears the SECAM TV colour system.
- ★ 1964 – Olympic Games in Tokyo – First satellite direct transmission of monochrome TV.



## History of Television: Second Phase

- ★ 1970 – Start in Japan the studies towards high definition TV.
- ★ 1977 – Allocation by WARC of 27 MHz channels for satellite TV.
- ★ **March 1980 – Starting in Portugal of colour TV (PAL) regular transmissions.**
- ★ 1981 – First public demonstration of the Japanese high definition TV system - MUSE.
- ★ 1983 – Specification in Europe of the MAC system for satellite TV transmissions.
- ★ 1985 – Europe decides to develop its own high definition TV system (HD-MAC) in reaction to the Japanese system (MUSE).
- ★ 1986 – First MUSE prototype for the MUSE high definition TV system.
- ★ 1988 – Olympic Games in Seoul – Direct satellite transmission with the MUSE system.
- ★ 1989 – Starting in Japan of high definition (MUSE) regular transmissions.
- ★ 1990 – Football World Cup in Italy – First demonstration of the European high definition system (HD-MAC).
- ★ 1992- Olympic Games in Barcelona – Large scale demonstration of the HD-MAC system.
- ★ 1993 – USA select the first TV system fully digital.
- ★ 1993 – Digital TV gains supporters ... digital TV technology develops very quickly ...
- ★ 1993 - MPEG-2 standard is finished.
- ★ 1998 - DVB develops technical specifications complementing the MPEG-2 standard for a full digital TV chain.
- ★ 200X –TV digital grows in many forms, cable, copper wires (ADSL), IPTV, DVB-H, ...

# Classification of Television Systems

## ★ Type of information

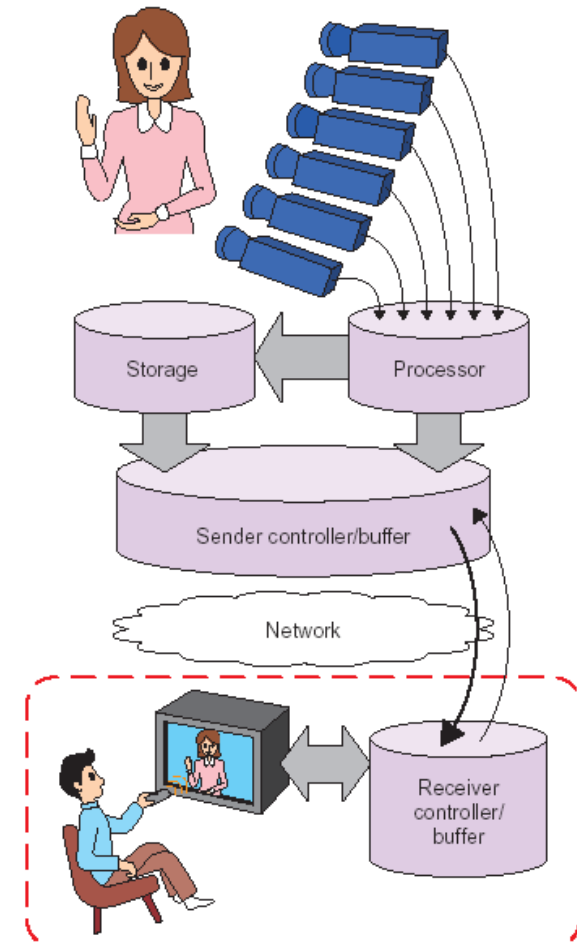
- Black and white (Y)
- Colour (YUV)
- Stereo ( $2 \times$  YUV)
- Multiview ( $N \times$  YUV)

## ★ Image definition

- Low definition,  $< 300$ - $400$  lines/image
- Medium definition,  $\approx 500$ - $600$  lines/image
- High definition,  $> 1000$  lines/image

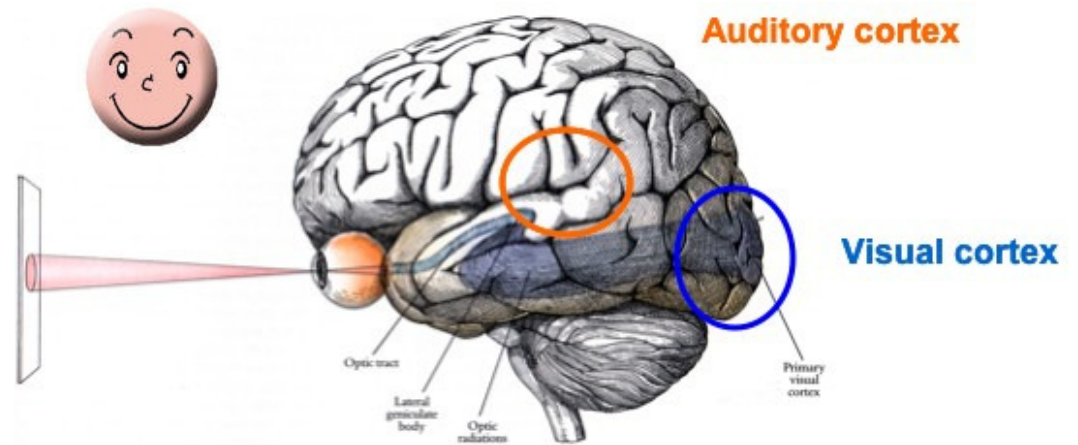
## ★ Transmission

- Radio (terrestrial)
- Cable
- Satellite
- Telephone line (XDSL)
- Mobile (UMTS)



## We, the Users ...

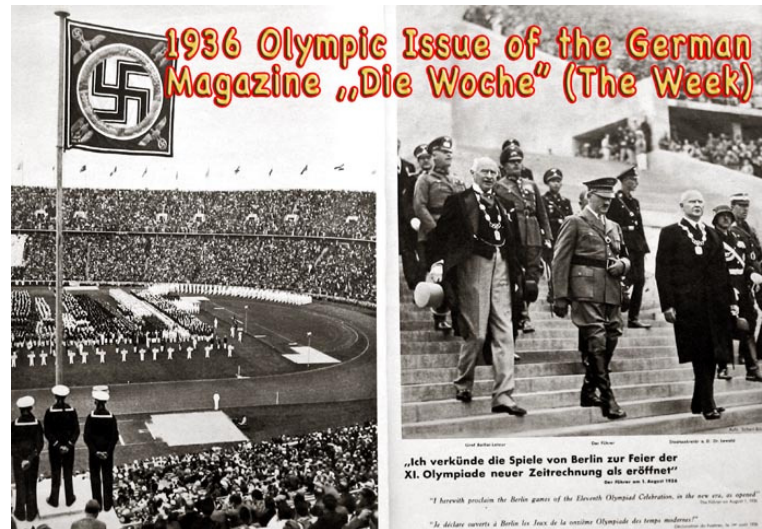
**Audiovisual communication services must, above everything, satisfy the final user needs, maximizing the user experience !**



**For this, it is essential to take consider the characteristics of the Human Visual and Auditory Systems. For video data, it is essential to account in the system design:**

- ★ **The limited capacity to see spatial detail**
- ★ **The conditions under which it reaches the ‘illusion of motion’**
- ★ **The lower sensibility to color in comparison with luminance/brightness**

# MONOCHROME TELEVISION

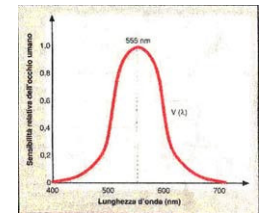


# What do we See in BW TV ? ... Luminance

- ★ The luminous flux radiated by a luminous source with a power spectrum  $G(\lambda)$  is given by:

$$\Phi = k \int G(\lambda) y(\lambda) d\lambda \quad [\text{lm or lumen}] \quad \text{with } k=680 \text{ lm/W}$$

where  $y(\lambda)$  is the average sensibility function of the human eye



- ★ The way the radiated power is distributed by the various directions is given by the luminous intensity:

$$J_L = d\Phi / d\Omega \quad [\text{lm/sr or vela (cd)}]$$

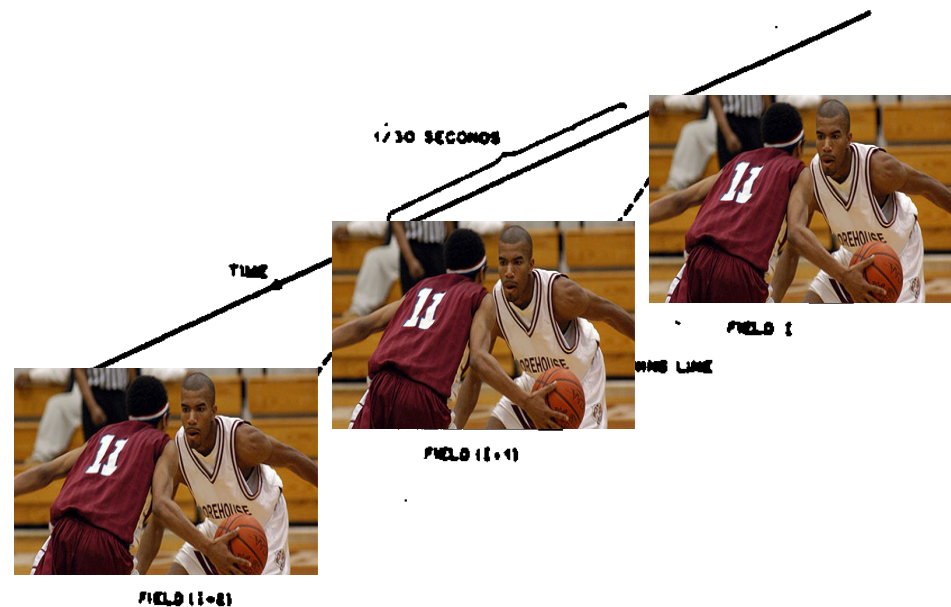
- ★ In television, the relevant quantity is the luminance of a surface element  $dS$  when it is observed with an angle  $\theta$  such that the surface orthogonal to the observation direction is  $dS_n$

$$Y = dJ_L / dS_n \quad [\text{lm/sr/m}^2]$$

which corresponds to the luminous flux, per solid angle, per unit of area.

# Illusion of Motion: Temporal Resolution

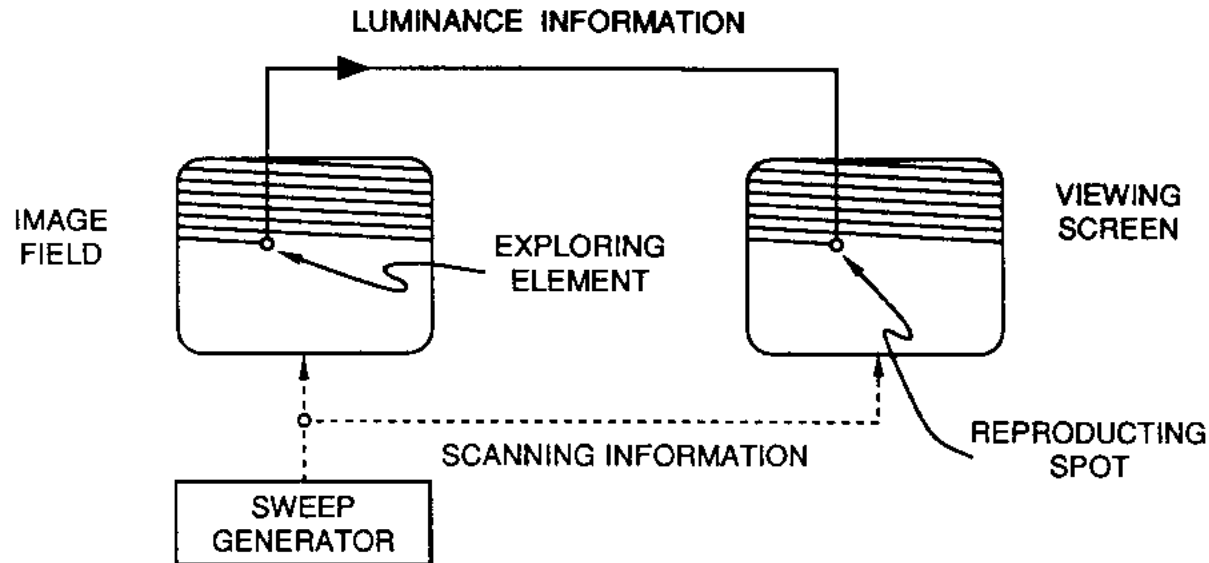
- ★ Visual information corresponds to a time varying 3D signal which has to be transformed into a time varying 1D signal to be transmitted using the available channels.
- ★ At the reception, the information is visualized in a 2D space resulting from the projection (during acquisition) into the camera plane.
- ★ The 2D signal is sampled in time at a rate that guarantees the illusion of motion; this illusion improves with the image rate.



Experience shows that it is possible to get a good illusion of motion up from 16-18 image/s, depending on the image content.

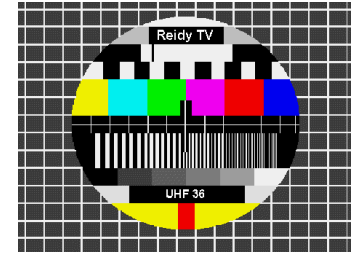
For CRT TV, the frame rate is 25 Hz (Europe) and 30 Hz (US and Japan) due to the electromagnetic interference with the electric network at 50/60 Hz.

# From 2D to 1D: the Scanning Process



- ★ The transformation of the 2D signal in the camera plan into a 1D signal to be transmitted is made through a line scanning process of the image, from top to bottom and left to right (such as when reading a book).
- ★ The scanning sequence is *a priori* determined and, thus, it is known by the sender and the receiver.
- ★ Initially, as there were no memory capabilities available, the acquisition, transmission and visualization processes were practically simultaneous.

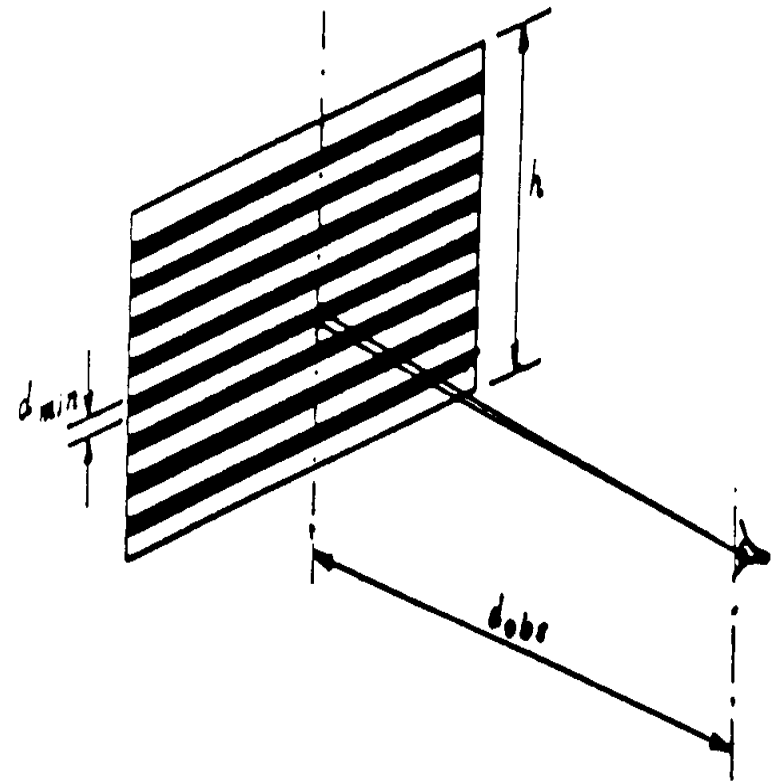
# Visual Acuity versus Number of Lines



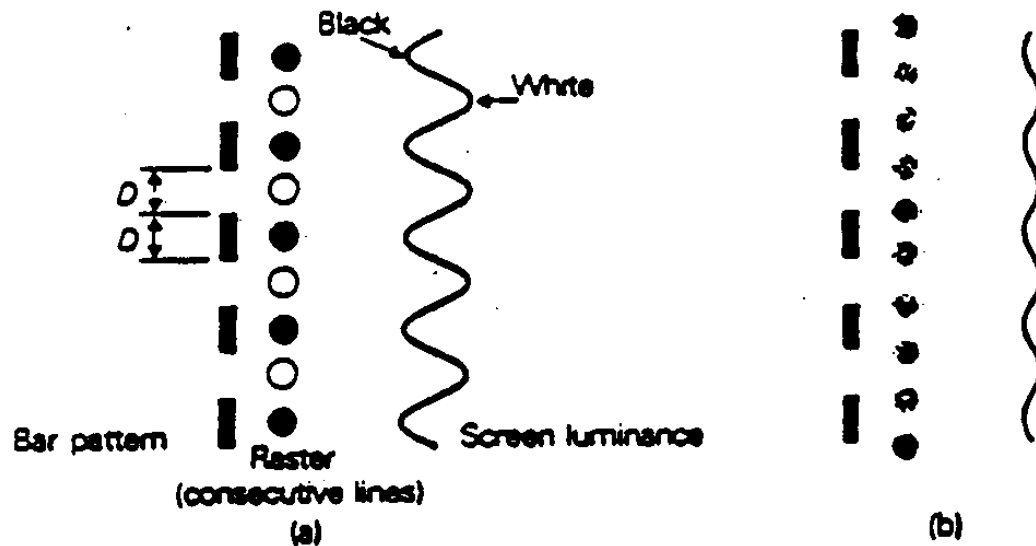
- ★ Visual acuity regards the eye capability of distinguishing (resolving) spatial detail; it is measured with the help of special images called *Foucault bars images*.
- ★ The visual acuity determines the minimum number of lines in the image in order the user located at a certain distance does not ‘see’ the lines and gains the sensation of spatial continuity.
- ★ The maximum number of lines that the Human Visual System manages to distinguish in a Foucault bars image is given by

$$N_{\max} \sim 3400 h / d_{\text{obs}}$$

for  $d_{\text{obs}}/h \sim 8$ ,  $N_{\max} \sim 425$  lines.



## The Kell Factor: Why and Impact ...



The phenomena associated to the Kell factor only happens for the vertical direction because this is where the visual information is discretized.

- ★ Kell factor is a parameter used to determine the effective resolution of a discrete display device.
- ★ If a horizontal line in a Foucault bars image were to fall exactly between two adjacent scan lines, it would not show well.
- ★ The empirically determined relationship between the number of visually resolvable lines and the number of scan lines is called the Kell factor and is about 0.7.
- ★ This means the number of scan lines must be  $(N_{\max} / 0.7) \sim (3400 h / d_{\text{obs}} / 0.7) \sim 600$

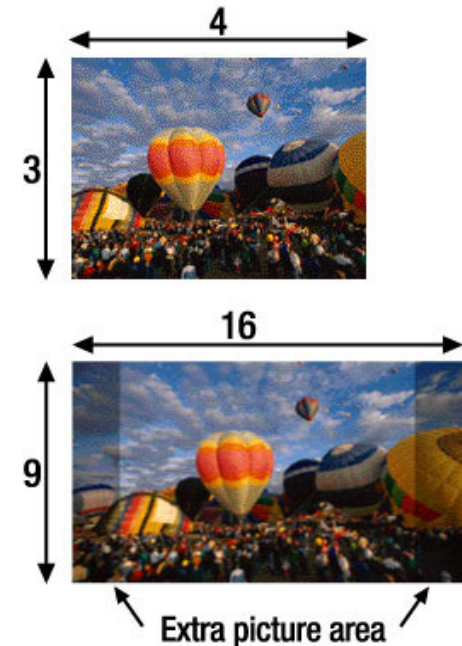
## Analogue TV Design ...

The temporal evolution is characterized by:

- ★ **Number of images/second** – Depends on the frequency needed to create the illusion of motion and the frequency of the electrical power network

Each 2D image is characterized by:

- ★ **Number of lines/image** – Depends on the visual acuity and the Kell factor.
- ★ **Aspect ratio** – To give the user a more intense sensation of involvement, the image is longer in the horizontal direction since this is the ‘format’ of our eyes and most real life action is performed along the horizontal axis ( $4/3 \Rightarrow 16/9$ )
- ★ **Bandwidth** – Determines the maximum detail per line.

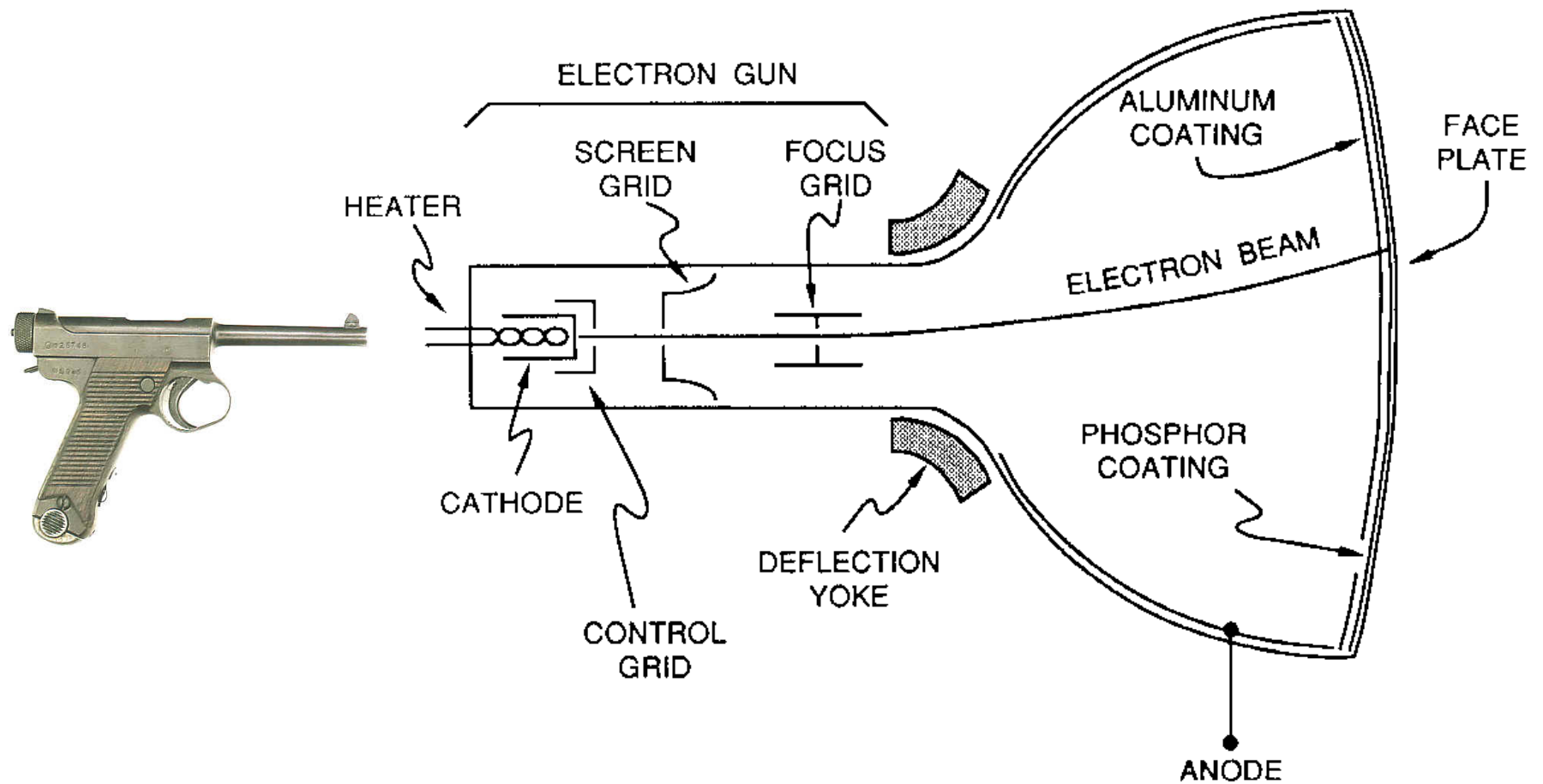


# Cathodic Ray Tubes (CRT): the First Displays



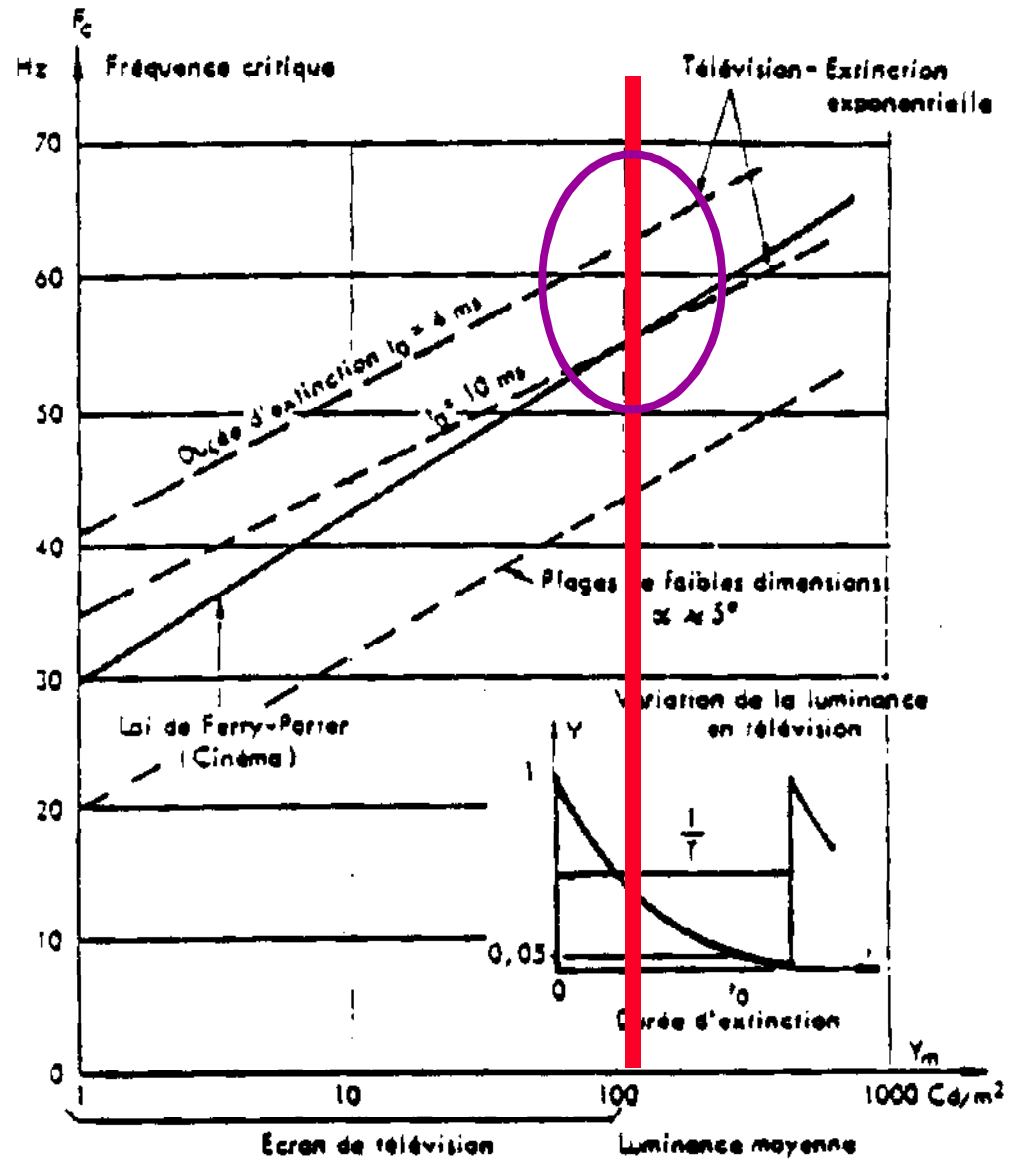
- ★ The cathode ray tube (CRT) is a vacuum tube containing an electron gun (a source of electrons) and a fluorescent screen, with internal or external means to accelerate and deflect the electron beam, used to create images in the form of light emitted from the fluorescent screen.
- ★ The image may represent electrical waveforms (oscilloscope), pictures (television, computer monitor), radar targets and others.
- ★ The CRT uses an evacuated glass envelope which is large, deep, heavy, and relatively fragile.

# Image Synthesis in a Cathodic Ray Tube (CRT)

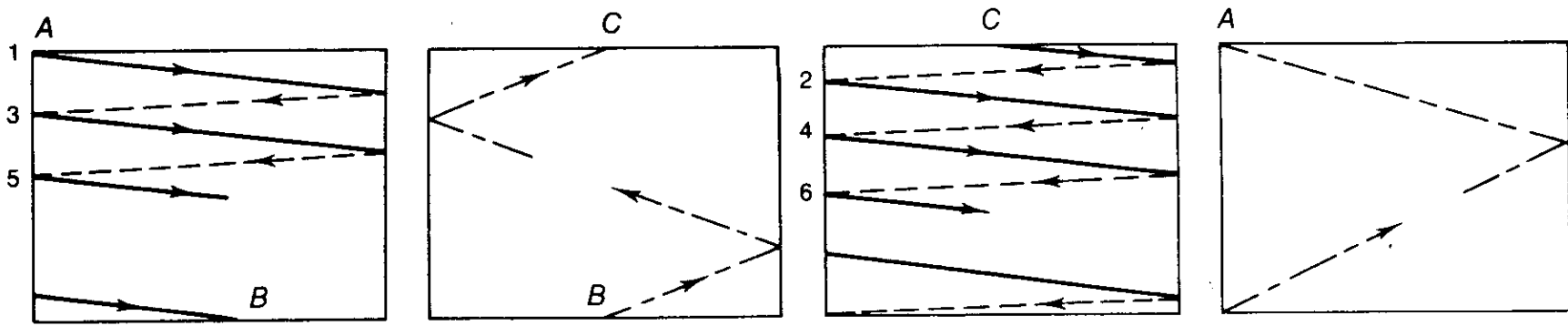


# Flicker

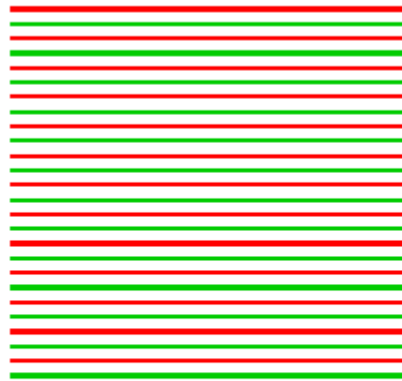
- ★ Flicker mandates the use of a image rate significantly higher than the rate necessary for the illusion of motion.
- ★ For Cathode Ray Tubes (CRTs), the luminance variation in time is exponentially decreasing, with time constants between 3 and 5 ms.



## Against Flicker, Interlacing ...



- ★ In order to have each zone of the image enough refreshed, each image is represented as 2 fields (this means two half-images): one with the odd and another with the even lines.
- ★ Interlacing resolves the flicker problem avoiding to increase the signal bandwidth by simply doubling the number of images/second.



**1 frame**

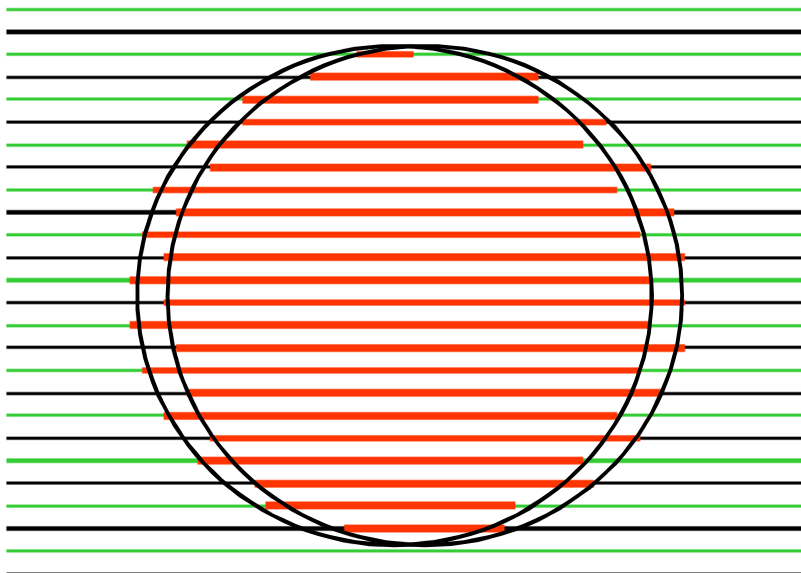
=



+



**2 fields**



field 1  
+  
field 2  
=  
complete  
frame

**25 images/s  $\Rightarrow$  50 fields/s**

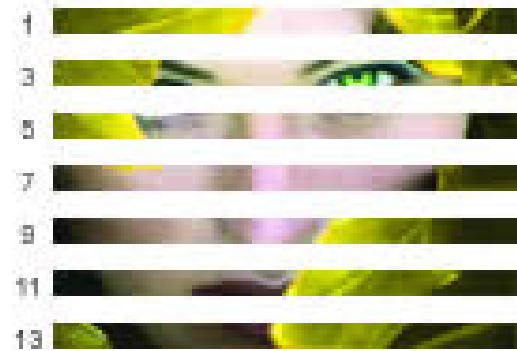
**Nº images/s does not change !**

**Nº lines /image does not change !**

**Bandwidth does not change !**

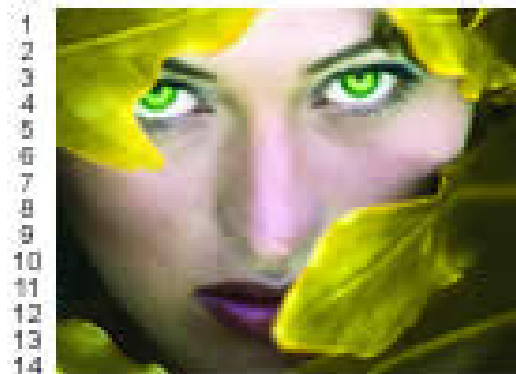
# Frames and Fields ...

## Interlaced

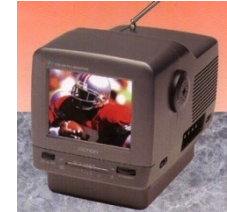


Odd lines  
Field 1

Even lines  
Field 2



# Gamma Correction



The gamma correction is introduced to compensate the fact that cameras and CRTs are non-linear devices.

- ★ Being  $Y_{orig}$  the luminance of the original scene, the camera produces a luminance signal  $Y_c$

$$Y_c = K_1 Y_{orig}^{\gamma_1} \quad (\gamma_1 \sim 0.3 - 1)$$

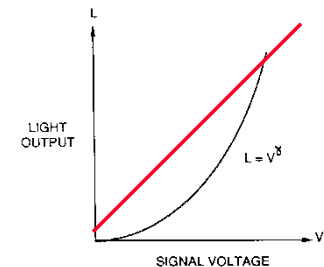
- ★ At the receiving CRT, the luminance as a similar variation

$$Y_{trc} = K_2 Y_c^{\gamma_2} \quad (\gamma_2 \sim 2 - 3)$$

this means the original and the reproduced luminances relate as

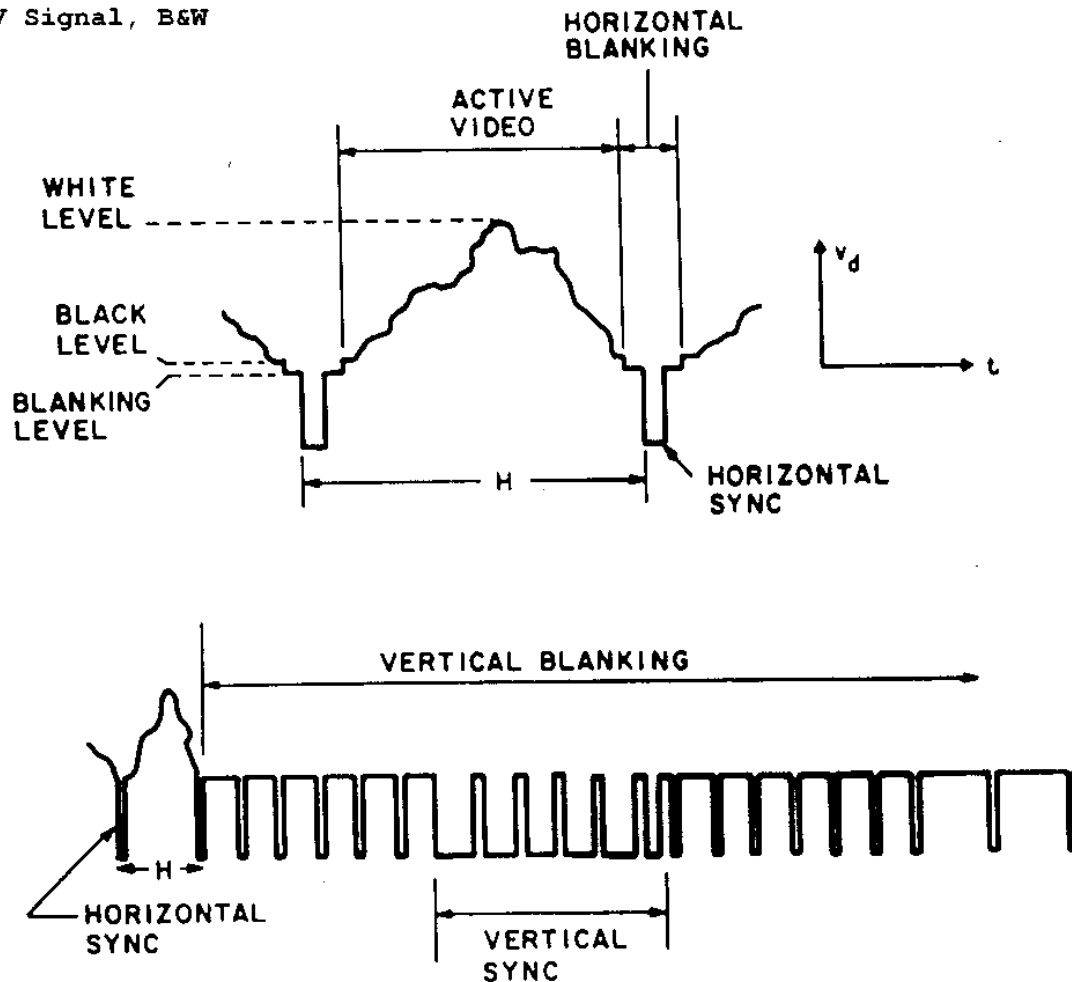
$$Y_{trc} = K_2 K_1^{\gamma_2} Y_{orig}^{\gamma_1 \gamma_2}$$

- ★ To obtain a total gamma ( $\gamma_1 \gamma_2$ ) between 1 and 1.3, a non-linear device is introduced at the camera output which makes the gamma correction with  $\gamma_1 \gamma_2 \gamma_{cor} \sim 1.3$ .



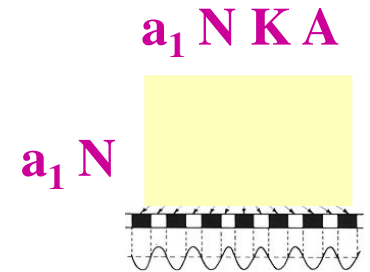
# Composite Video Signal in Time ...

TV Signal, B&W



Due to equipment limitations, there was a need to take a certain amount of time between the end of a line and the starting of the next line as well as the end of a field and the starting of the next field – called horizontal and vertical retraces – which may be useful, e.g. for teletext ...

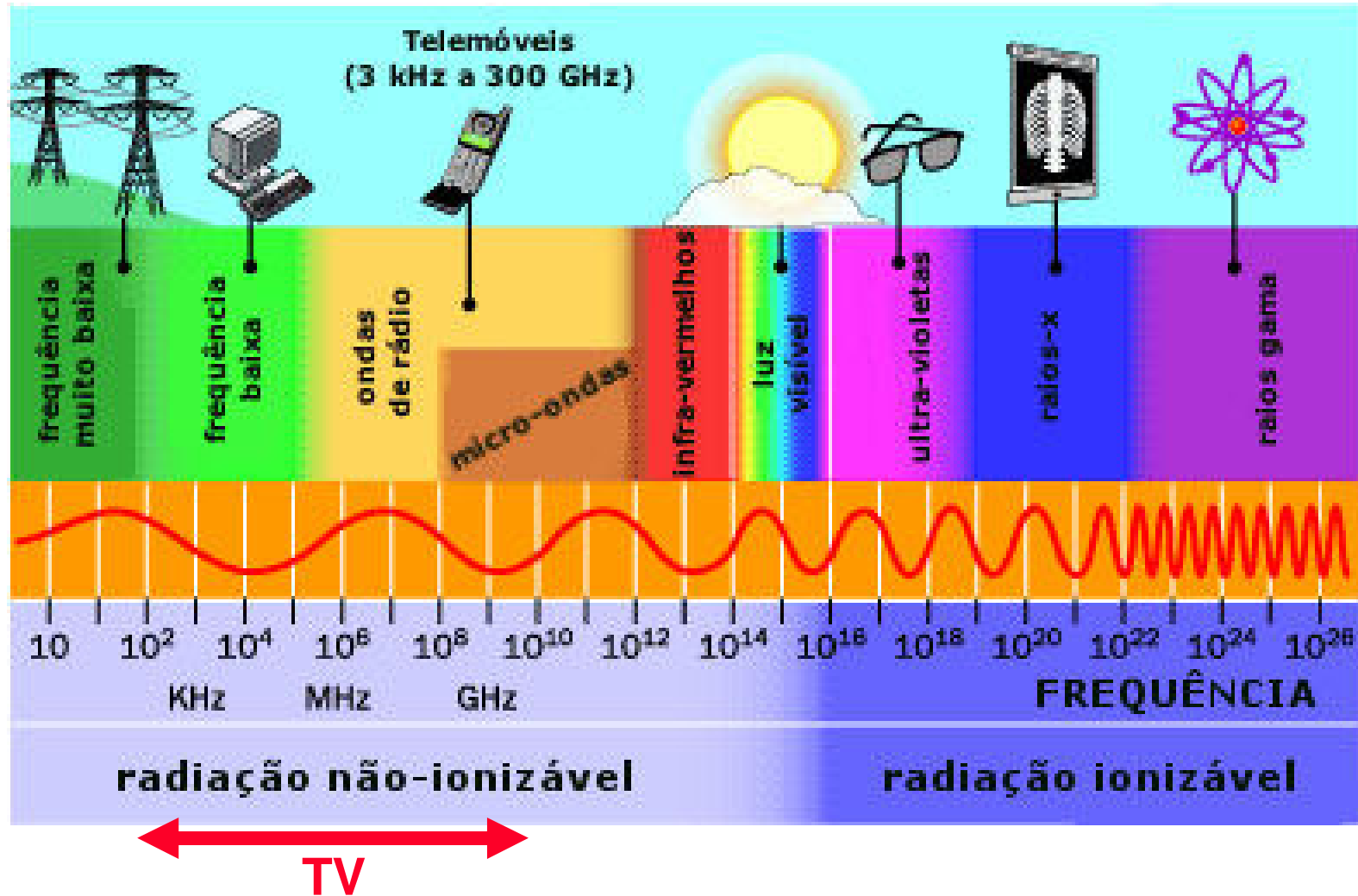
## Video Signal Bandwidth ...



Assuming that similar vertical and horizontal image elements densities are desired ( $a_1 \sim 0.92$  and  $a_2 \sim 0.8$ ):

- ★ Number of vertical scan image elements:  $N_v = a_1 N$
- ★ Number of vertical resolvable image elements:  $N_r = a_1 N K$
- ★ N° of horizontal image elements (for same density):  $N_h = a_1 N K A$
- ★ Number of image elements in the image:  $N_v N_h = a_1^2 N^2 K A$
- ★ Frequency of image elements (line):  $f_{ele} = a_1 N K A / (a_2 / N F)$
- ★ Frequency of image elements (image):  $f_{ele} = a_1^2 N^2 K A / (a_1 a_2 / F)$
- ★ Maximum frequency present in the video signal:  $f_{max} = a_1 N^2 F K A / 2 a_2$
- ★ Video bandwidth:  $LB \sim f_{max} = a_1 N^2 F K A / 2 a_2$

# How is the Spectrum Used ?



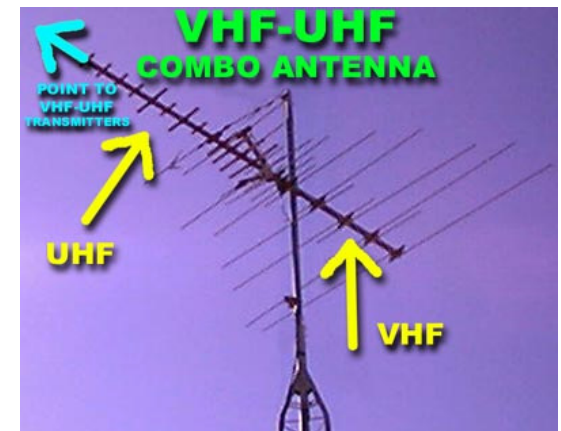
# Terrestrial TV: VHF and UHF Bands

## VHF

- ★ VHF is the acronym for *Very High Frequency*.
- ★ It refers to the radio frequencies from 30 MHz to 300 MHz. This bandwidth range is commonly used for radio and TV transmissions.

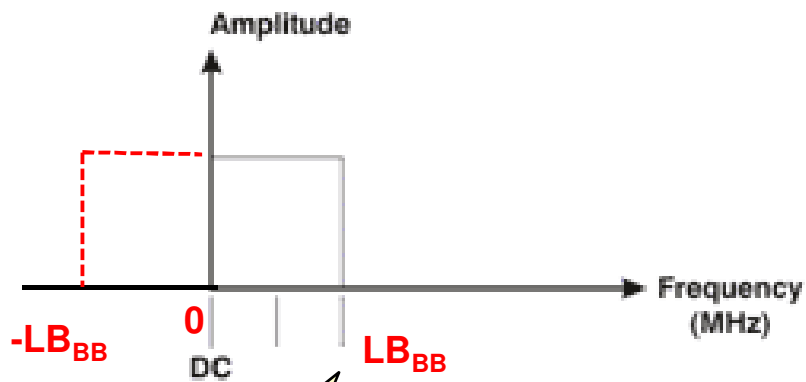
## UHF

- ★ UHF is the acronym for *Ultra High Frequency*.
- ★ It refers to the radio frequencies from 300 MHz to 3 GHz. This bandwidth range is commonly used for radio and TV transmissions.
- ★ Electromagnetic waves in this band have higher atmospheric attenuation and lower ionosphere reflection than VHF waves.

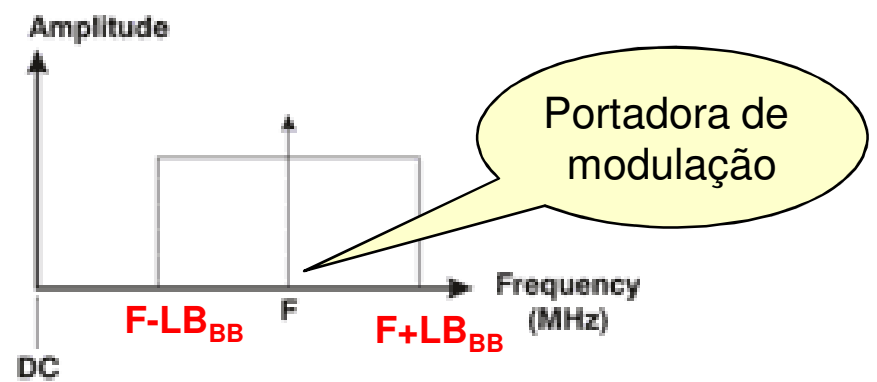


# Amplitude Modulation...

**Baseband**

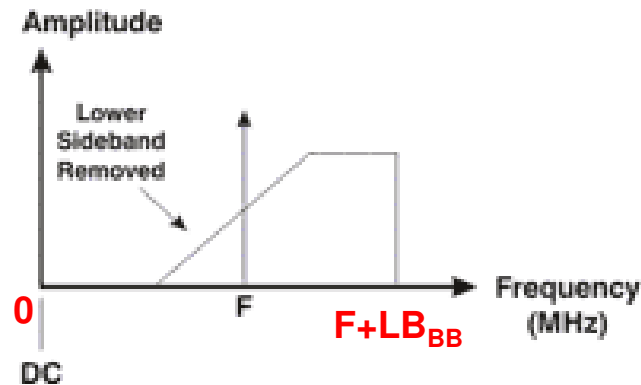


**Double Side Band (DSB)**

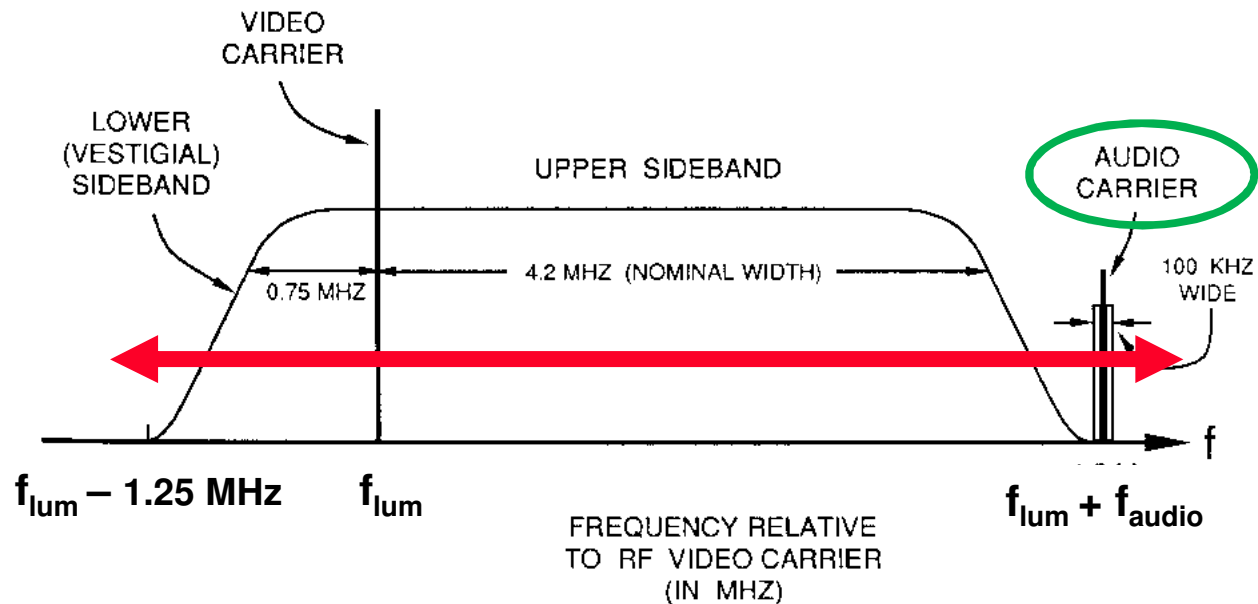


Typically, around 4-5 MHz for analogue TV signals

**Vestigial Side Band (VSB) = DSB+filter**



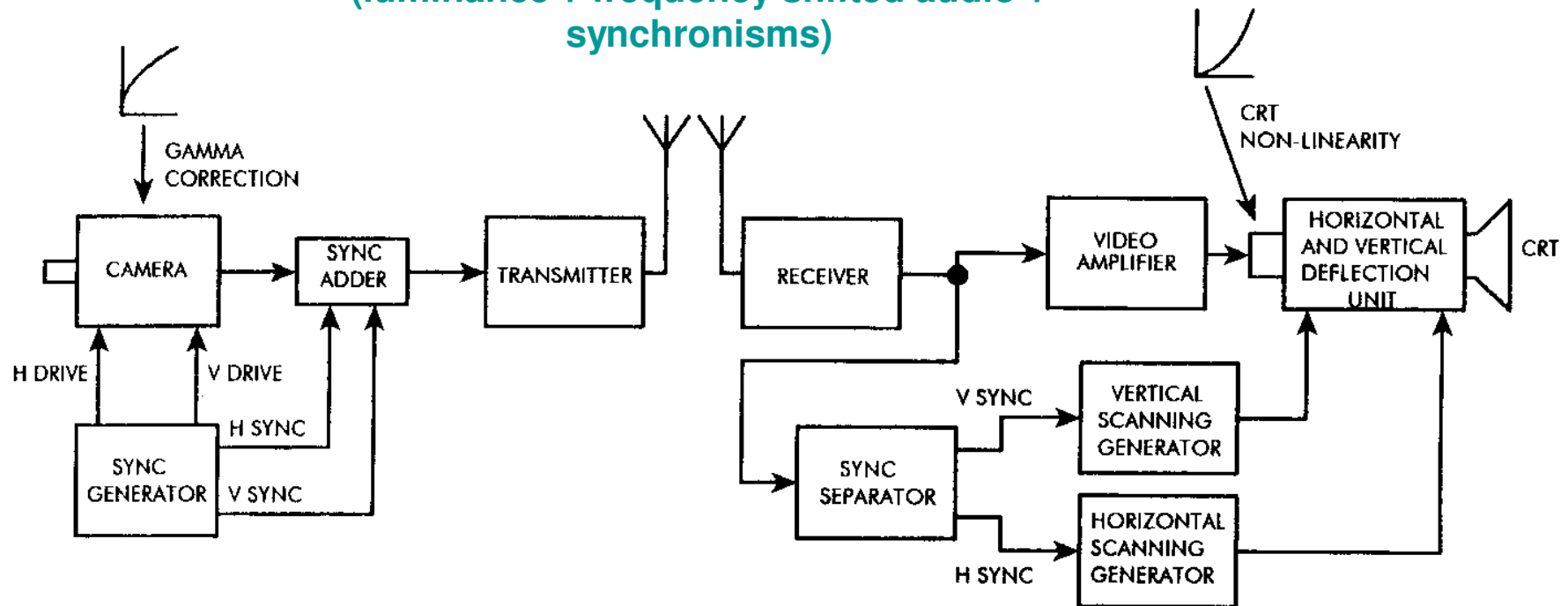
## TV Signal in Modulated Frequency ...



- ★ The modulation selected for the luminance is *Vestigial Side Band* (VSB) since it is spectrally rather efficient (lower bandwidth) and allows to use relatively simple demodulating systems.
- ★ The VBS signal is obtained at the sender from the Double Side Band (DSB) signal using adequate vestigial filtering.
- ★ The audio signal is treated separately and modulated in a different carrier, using amplitude or frequency modulation (typically FM).

# Monochrome TV System

**Modulated**  
(luminance + frequency shifted audio +  
synchronisms)



# COLOUR TELEVISION





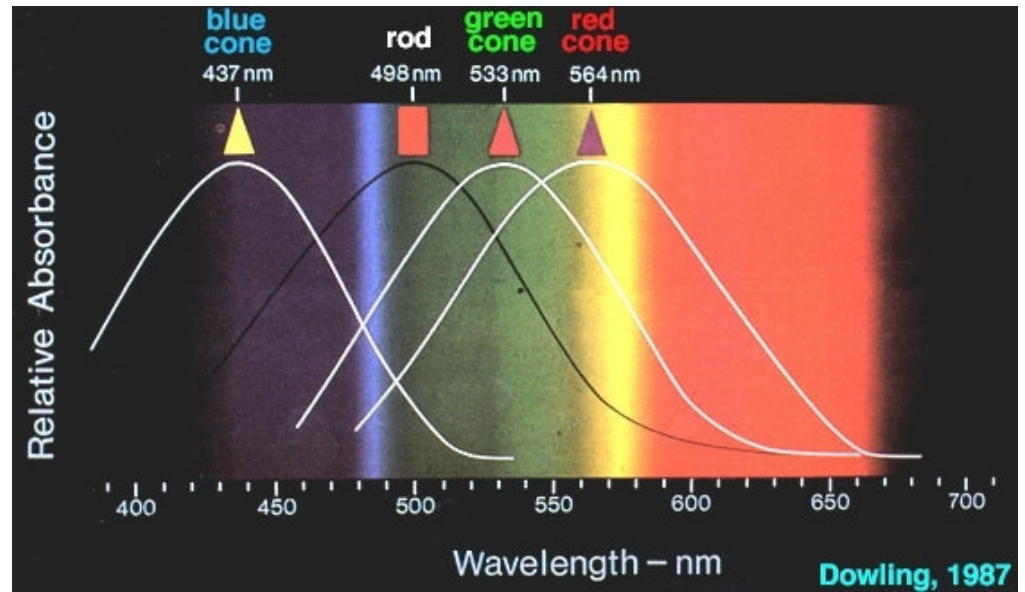
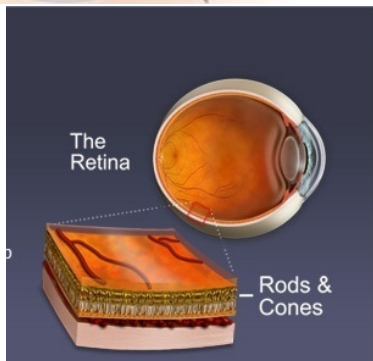
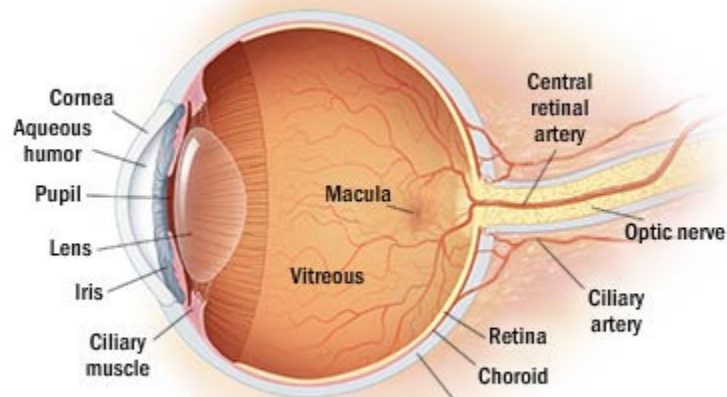
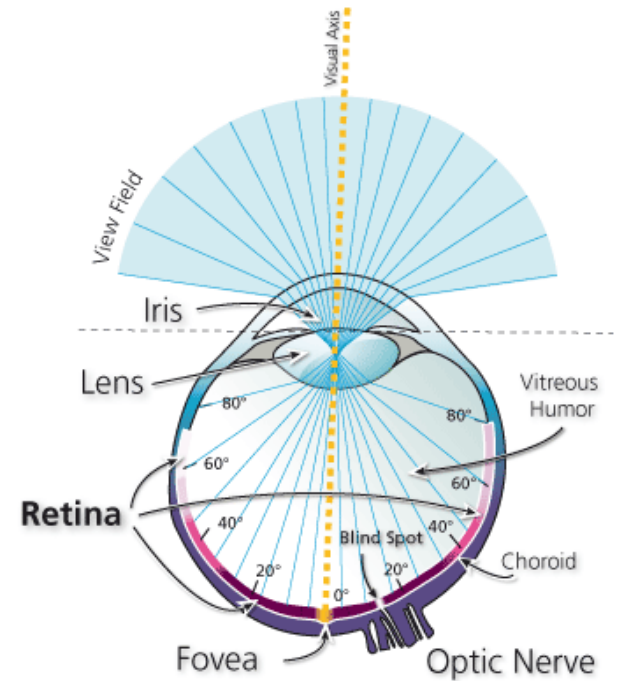
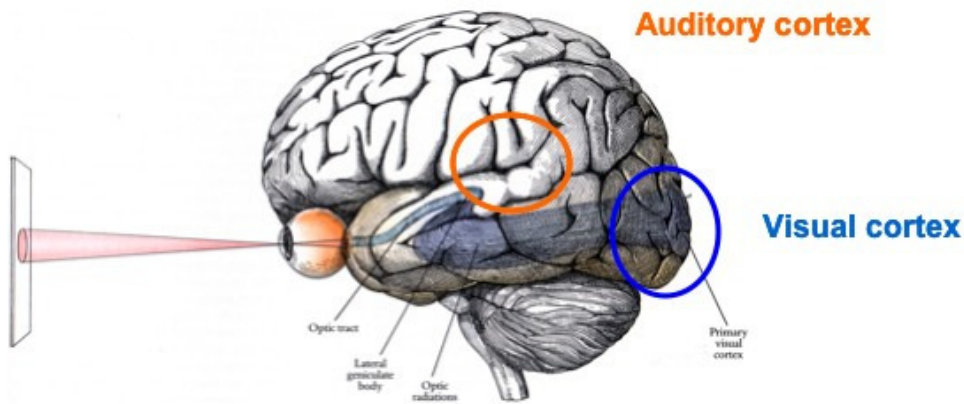
# About TV Compatibilities

Colour TV is another natural development in the emulation of human capabilities by Telecommunications.

Colour TV takes benefit of technological developments and must guarantee compatibility without using more bandwidth than black and white TV !!!



- ★ **BACKWARD COMPATIBILITY (directa)** – A colour TV emission must be able to be received by a black and white TV receiver (of course, in black and white).
- ★ **FORWARD COMPATIBILITY (inversa)** – A colour TV receiver must be able to receive (in black and white) a black and white emission.





## A Bit of Colorimetry ...

- ★ In additive colour systems, the sum of all colours gives white and the subtraction of all colours gives black.
- ★ Colorimetry studies show that it is possible to reproduce a high number of colours through the addition of only 3 primary colours, carefully chosen.
- ★ The primary colours used in television to generate all the other colours are

- Vermelho (RED)
- Verde (Green)
- Azul (Blue)

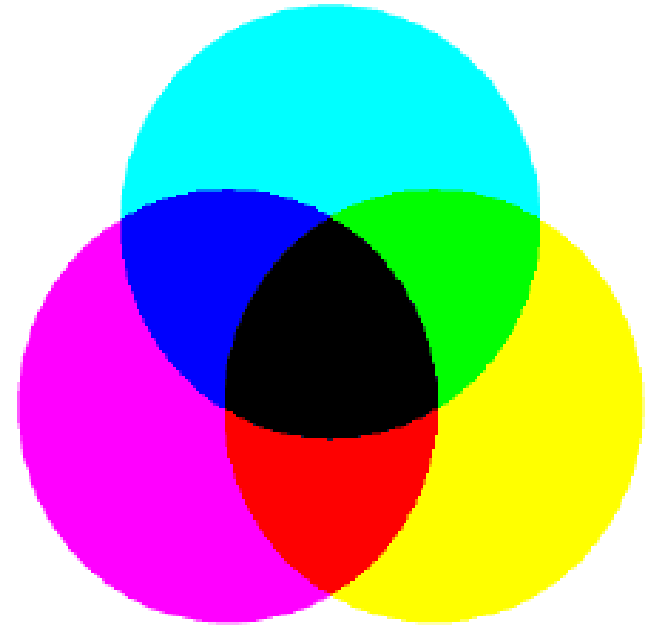
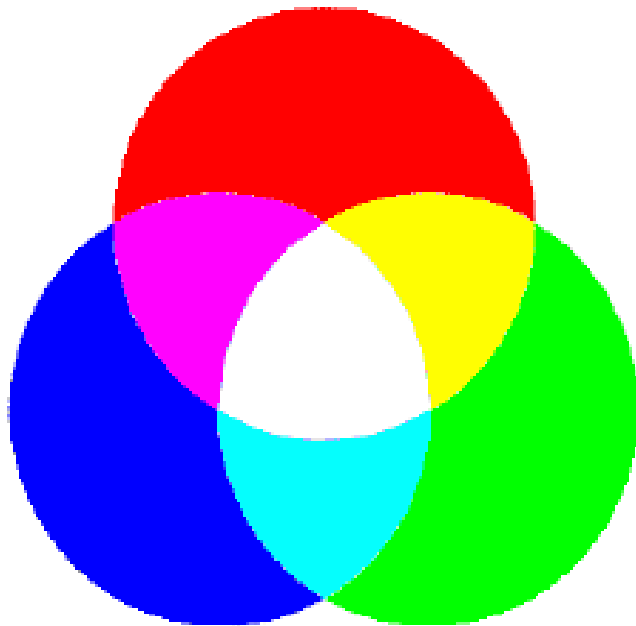


- ★ Luminance, Y, may be obtained from the primary colours as

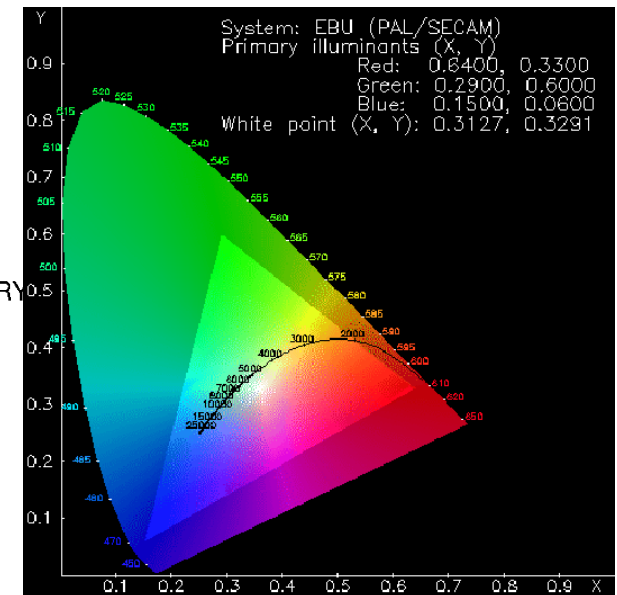
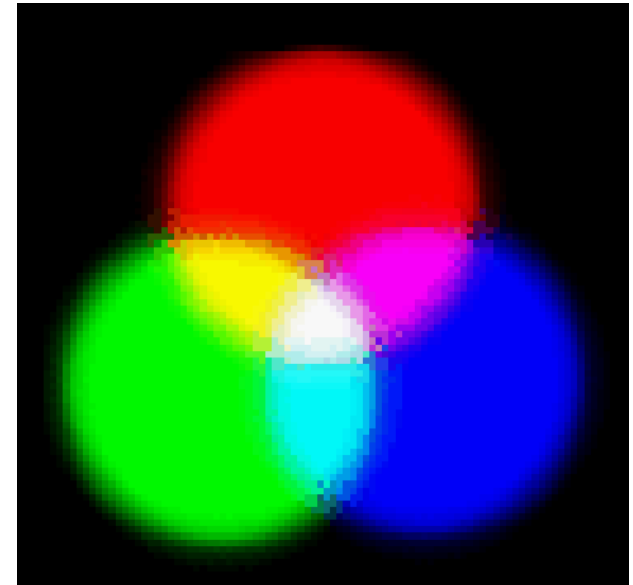
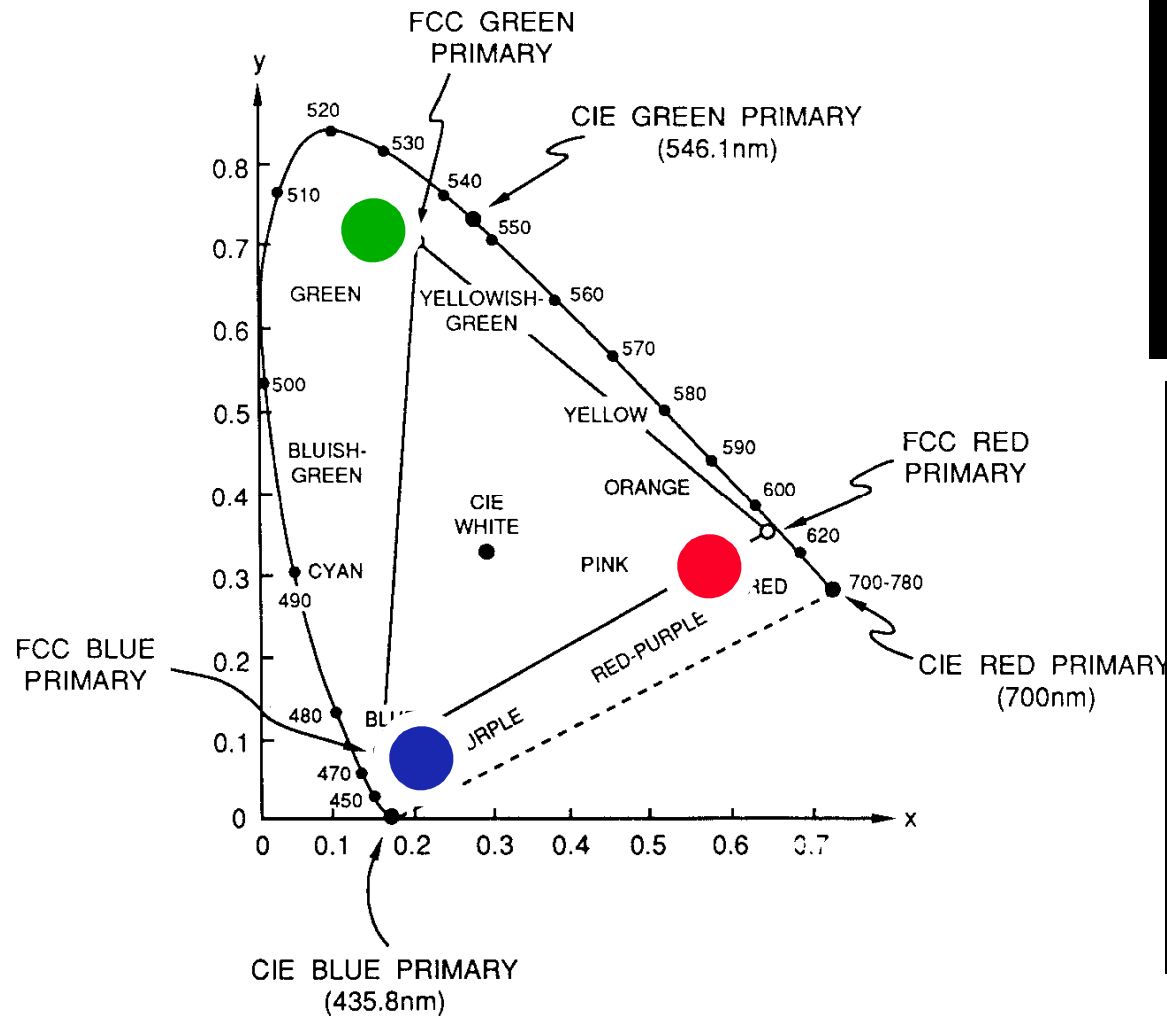
$$Y = 0.3 R + 0.59 G + 0.11 B$$

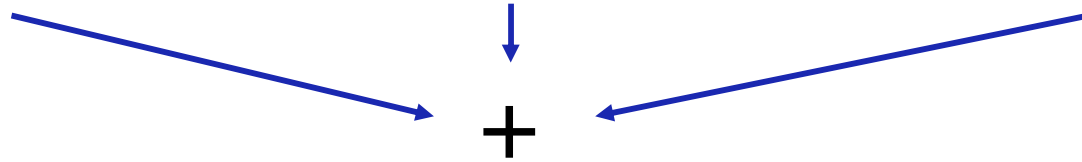
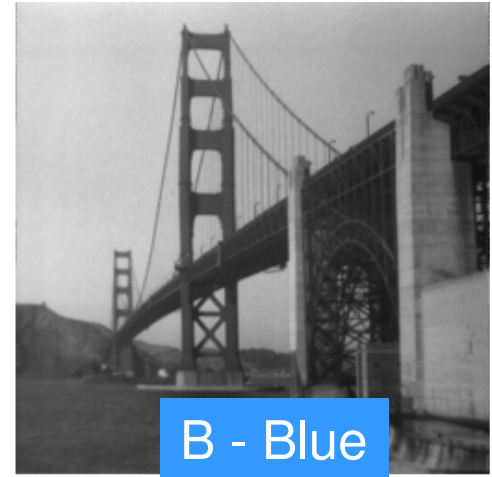
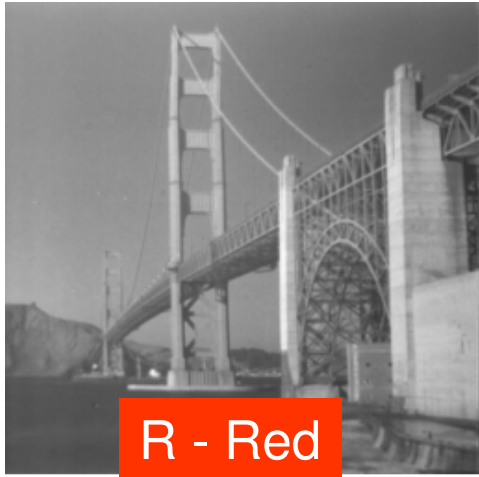


# Additive and Subtractive Color Synthesis



# Chromaticity Diagram ...







# Colour TV: Selecting the Signals ...

## ★ BACKWARD COMPATIBILITY (Y signal):

- RGB signals are not selected for colour TV transmission because they cannot guarantee backward compatibility and would ask, at least, in principle, three times the bandwidth of the luminance signal.
- Backward compatibility mandates the transmission of the **LUMINANCE SIGNAL, Y**, which may be obtained from the primary colours as  **$Y = 0.3R + 0.59G + 0.11B$** .

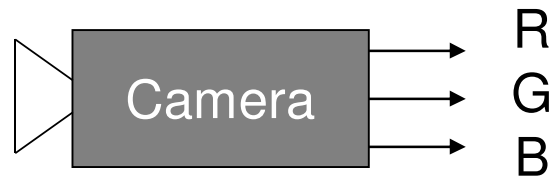
## ★ ADDING COLOUR (2 filtered signals more):

- Colour transmission requires the selection of 2 other signals which together with Y allow to easily recover the RGB signals in colour receivers.
- These signals must use the smallest possible bandwidth by exploiting the lower human sensibility to colour information.

## ★ FORWARD COMPATIBILITY (2 chrominance signals, R-Y and B-Y):

- The **R-Y, B-Y and G-Y CHROMINANCE SIGNALS** allow to recover the R,G,B signals in a simple way, provide forward compatibility and need less bandwidth (than R,G,B); R-Y and B-Y are selected because they provide higher SNR.

# Luminance and 2 Chrominances ...



$$\begin{aligned}
 Y &= 0.30R + 0.59G + 0.11B && \sim 5 \text{ MHz} \\
 B - Y &= U && \sim 1-2 \text{ MHz} \\
 R - Y &= V && \sim 1-2 \text{ MHz}
 \end{aligned}$$



Y - Luminance

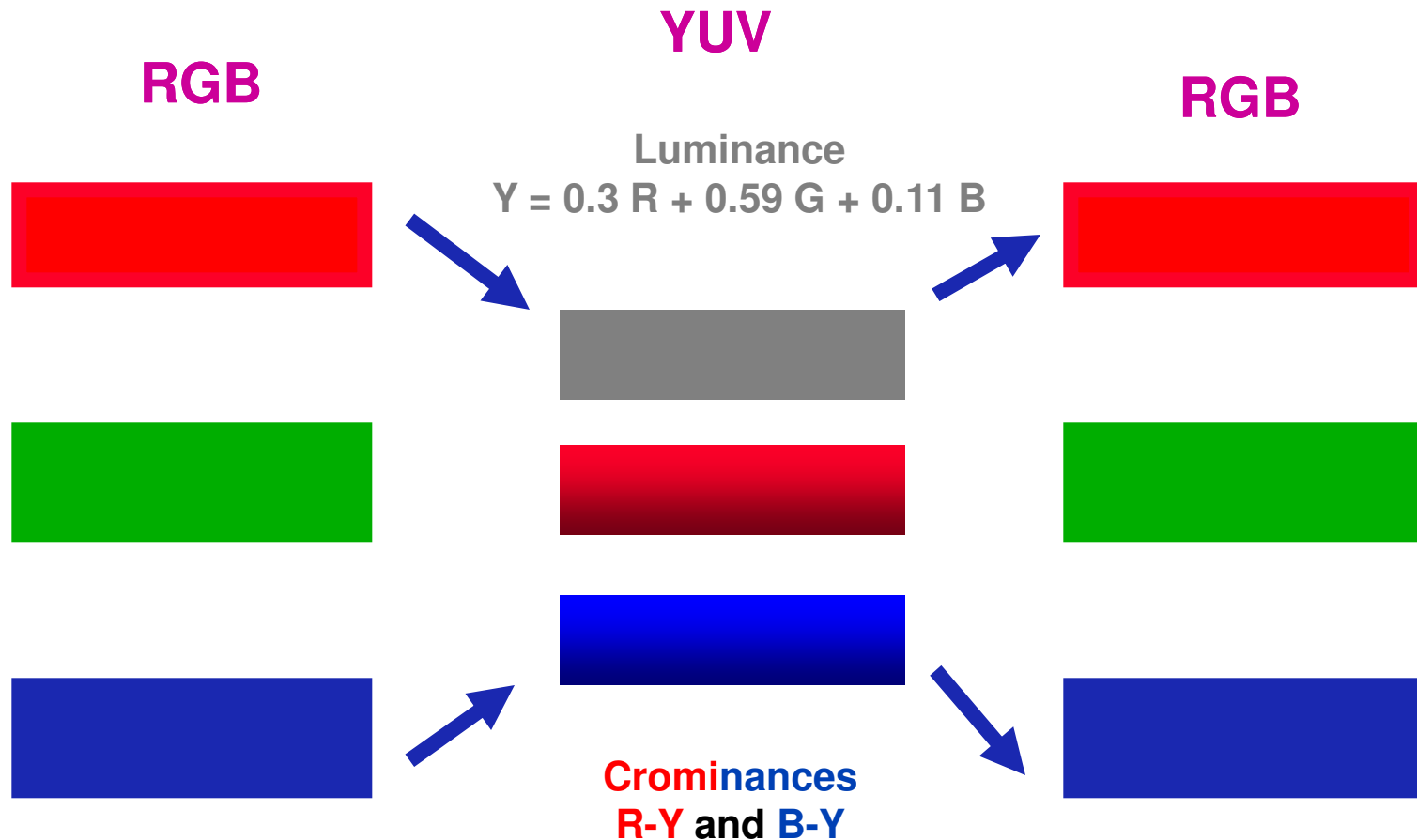


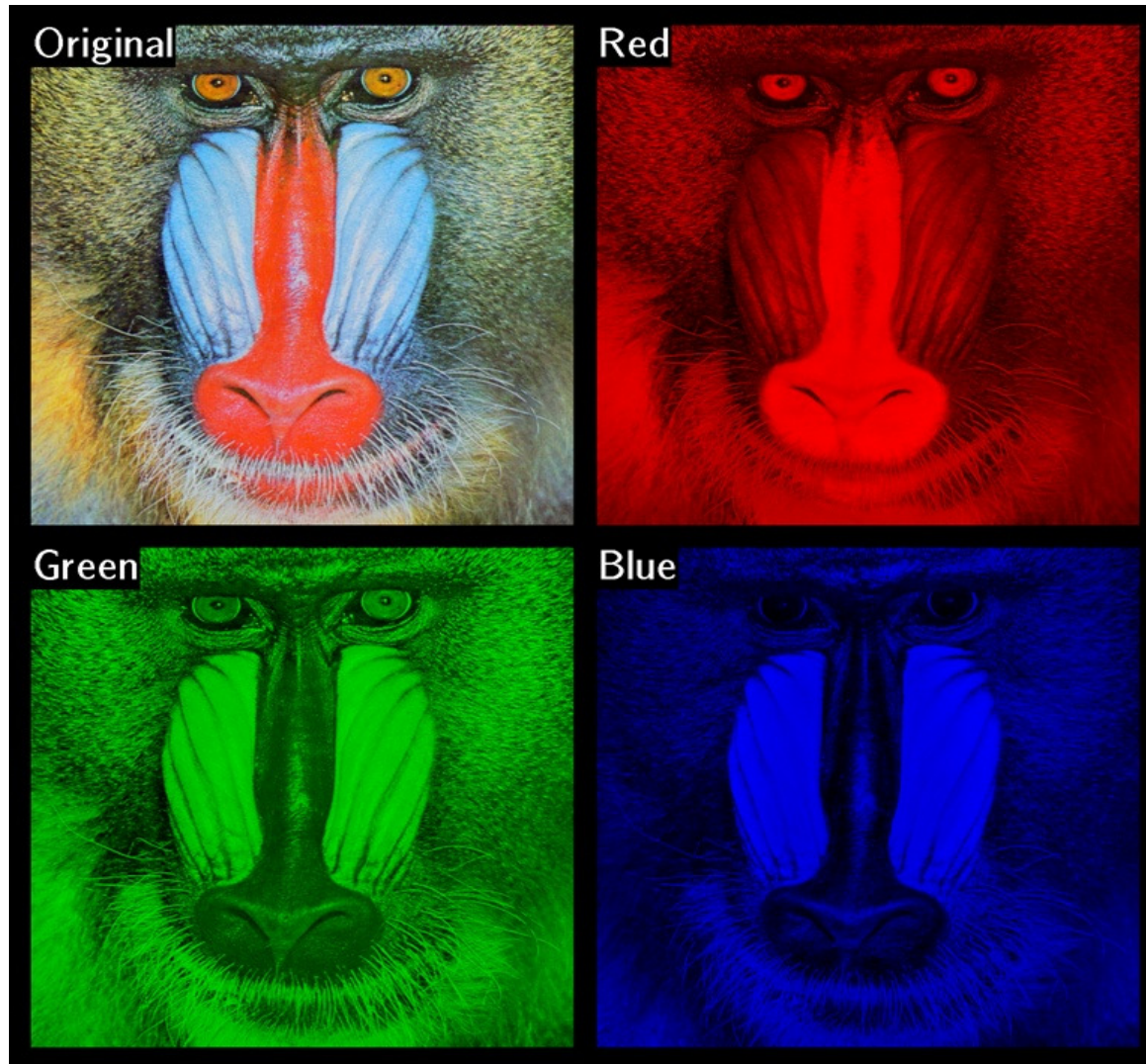
B - Y = U

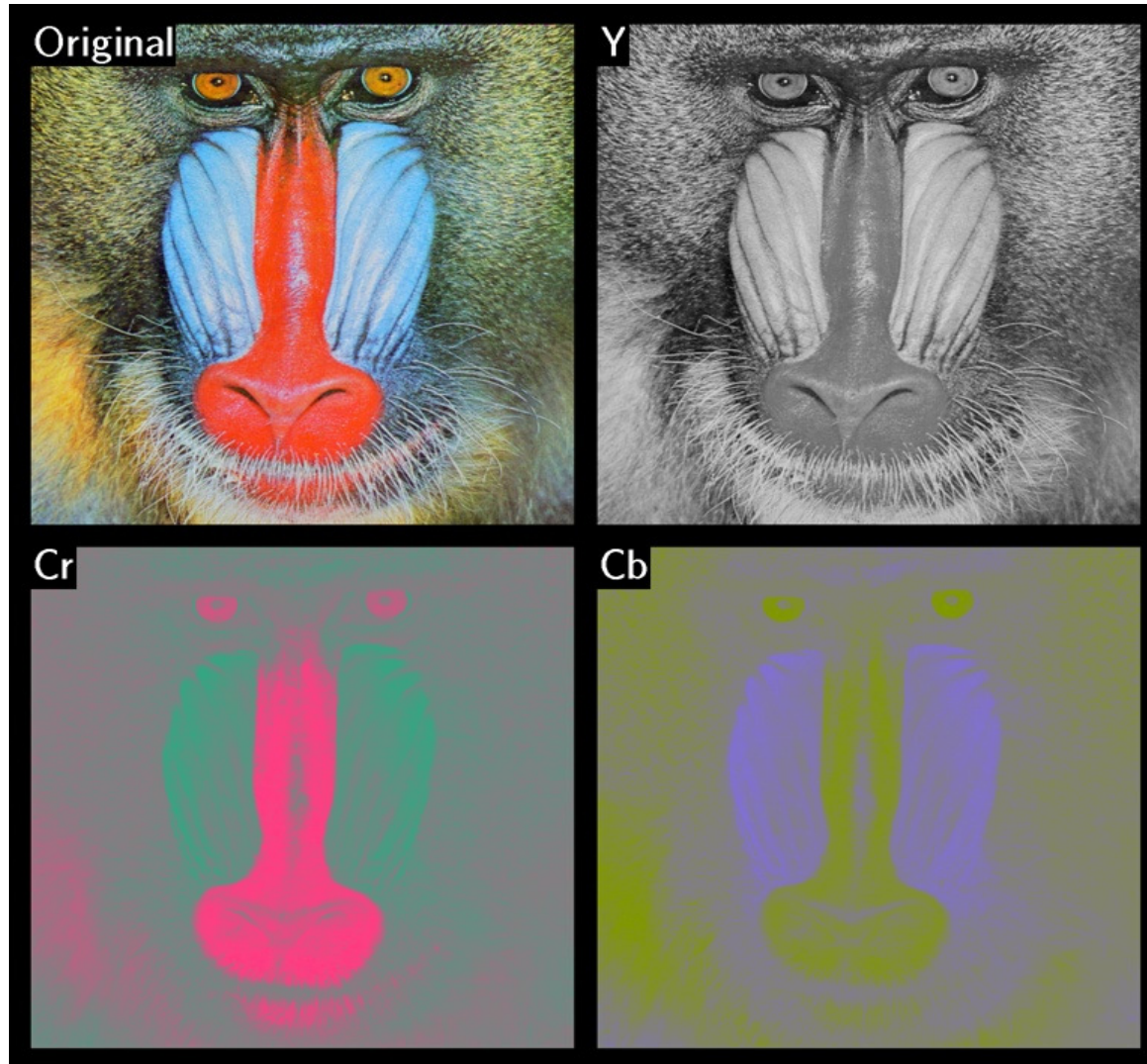


R - Y = V

# Acquisition, Transmission and Synthesis Signals ...

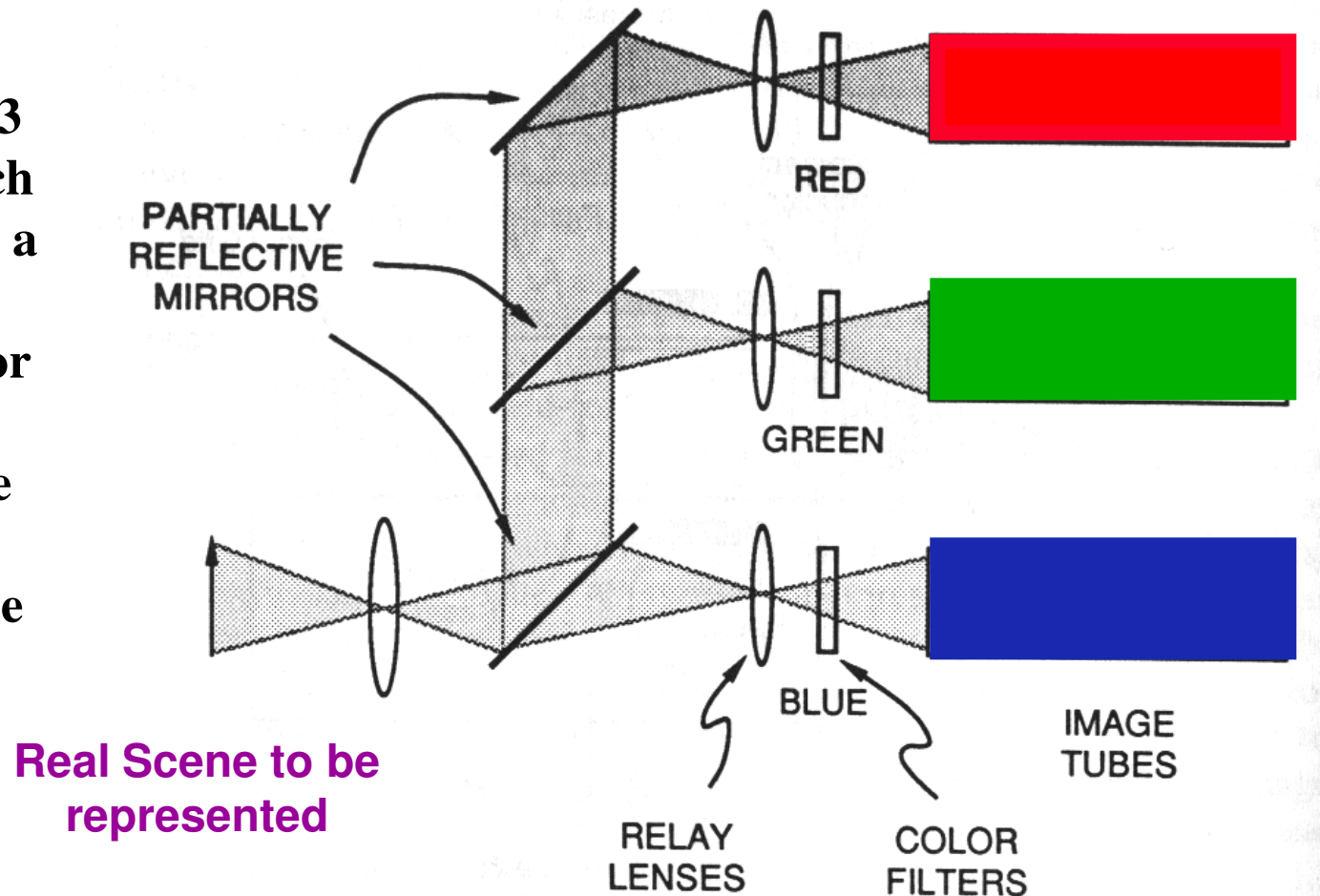






# Image Analysis

The image is analyzed using 3 image tubes, each one preceded by a filter with a spectral behavior adapted to the spectrum of the corresponding phosphors in the CRT.

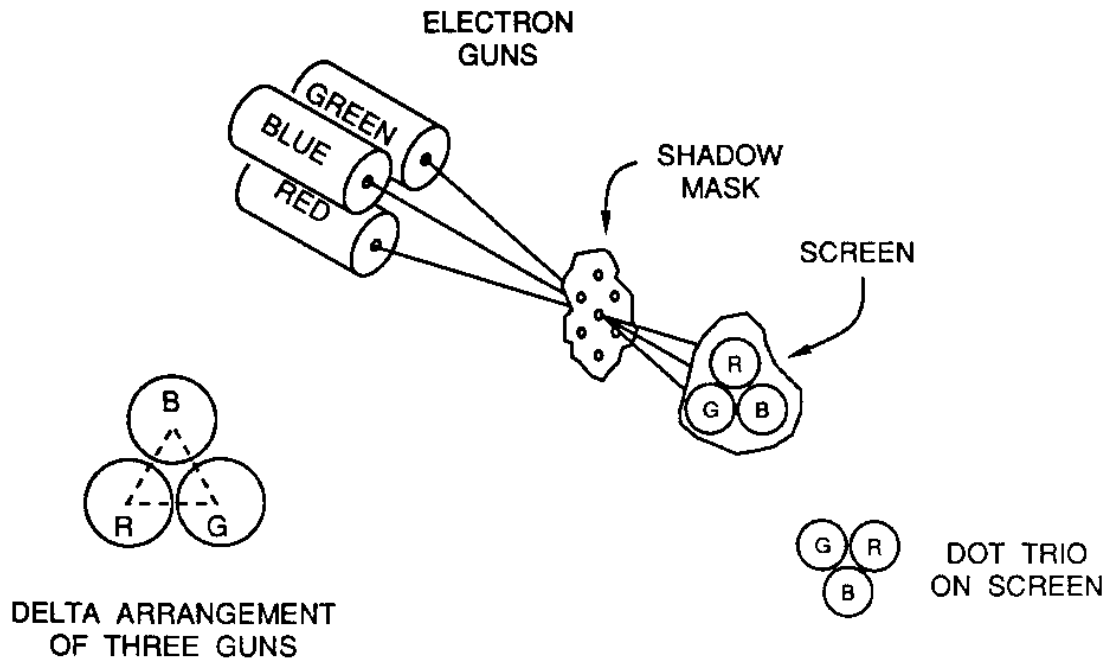
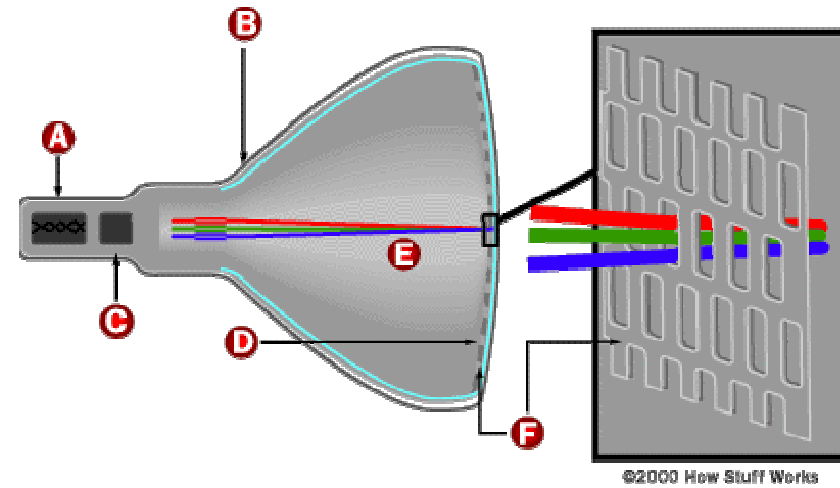


# Cathodic Ray Tubes (CRT): the First Displays



- ★ The cathode ray tube (CRT) is a vacuum tube containing an electron gun (a source of electrons) and a fluorescent screen, with internal or external means to accelerate and deflect the electron beam, used to create images in the form of light emitted from the fluorescent screen.
- ★ In colour CRTs, there are three electron guns, and three fluorescent materials in the screen, one for each primary colour (R,G,B).
- ★ The CRT uses an evacuated glass envelope which is large, deep, heavy, and relatively fragile.

# Image Synthesis





## Gamma Correction ...

**YUV  $\Rightarrow$  RGB  
at reception !**

- ★ To compensate the luminance conversion non-linearities at the camera and display, gamma correction is needed in the luminance signal like in black and white TV; this means

$$Y^{1/\gamma} = (0.3 R + 0.59 G + 0.11 B)^{1/\gamma}$$

should be transmitted with  $1/\gamma$  being the transmitted gamma.

- ★ As each of the primary colour tubes has a characteristic similar to the one for the monochrome CRTs, it is essential to make also the gamma correction for each primary component; this means the colour receiver must be able to obtain

$$R^{1/\gamma}, B^{1/\gamma} \text{ e } G^{1/\gamma}$$

- ★ To avoid the resolution of non-linear equations at the colour receivers, an approximation of the luminance signal is transmitted

$$Y' = 0.3 R^{1/\gamma} + 0.59 B^{1/\gamma} + 0.11 G^{1/\gamma}$$

which prevents to reach perfect backward compatibility since  $Y^{1/\gamma} \neq Y'$ .

## Gamma Correction ... in Detail ...

Should send

1.  $Y^{1/\gamma} = (0.3 R + 0.59 G + 0.11 B)^{1/\gamma}$
2.  $R^{1/\gamma} - Y^{1/\gamma}$
3.  $B^{1/\gamma} - Y^{1/\gamma}$

Difficult equation system to be solved by colour TVs!

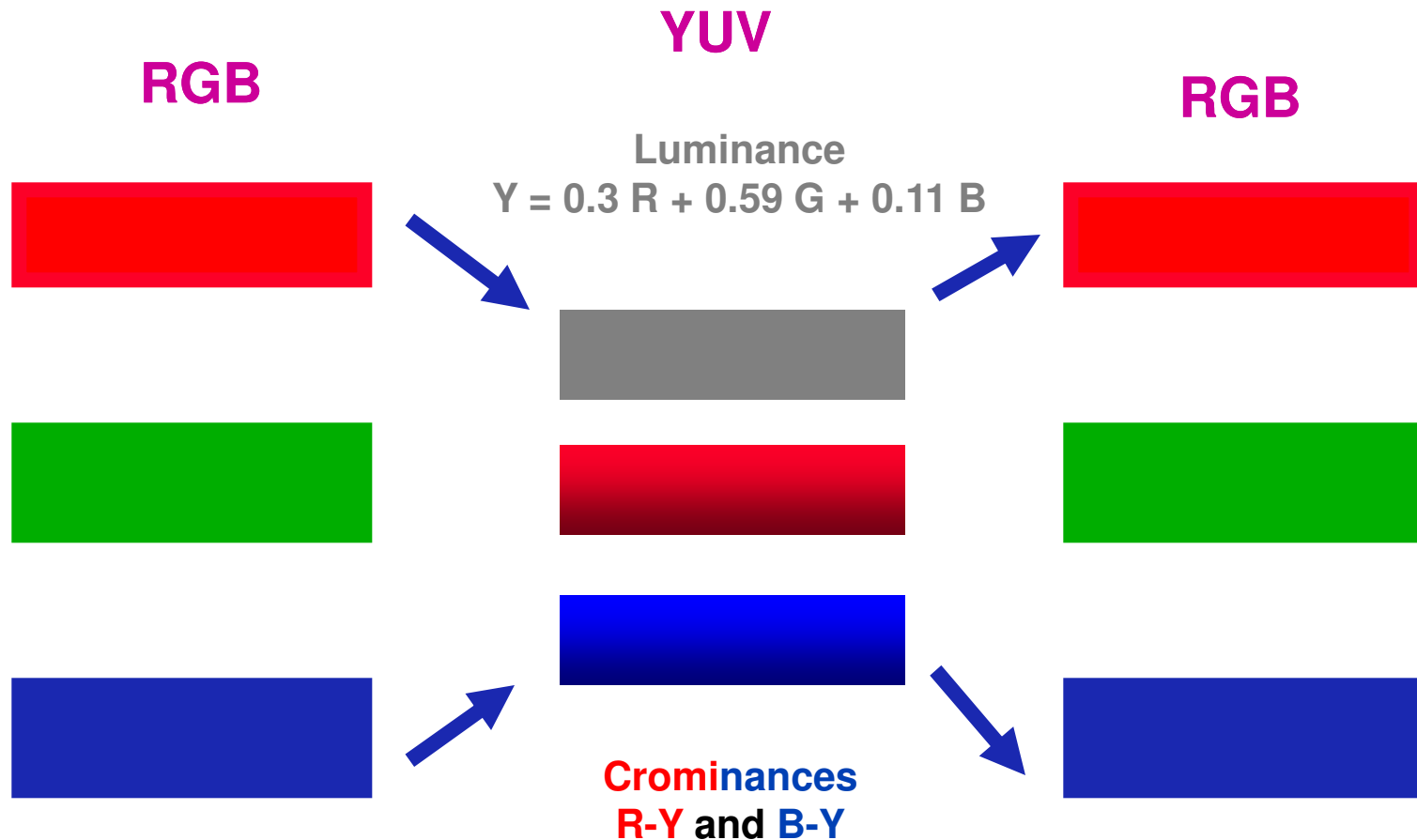
But sends

1.  $Y' = 0.3 R^{1/\gamma} + 0.59 G^{1/\gamma} + 0.11 B^{1/\gamma}$
2.  $R^{1/\gamma} - Y'$
3.  $B^{1/\gamma} - Y'$

Linear (easier) equation system to be solved by colour TVs!

Because it is easier to recover the  $R^{1/\gamma}$ ,  $B^{1/\gamma}$  and  $G^{1/\gamma}$  signals at the colour receivers.

# Acquisition, Transmission and Synthesis Signals ...



# Bandwidth: How do you Fit Big in Small ?



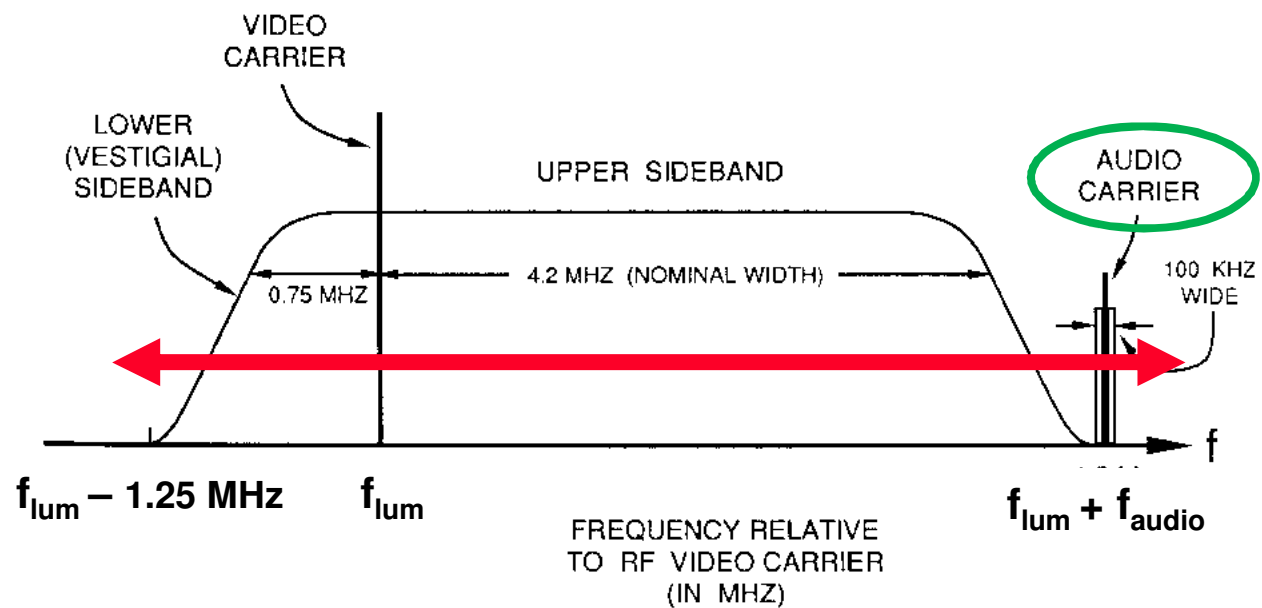
## CONDITION 1

- ★ **The total available bandwidth for a colour TV channel is the same as for a monochrome TV channel (8 MHz in Europe and 6 MHz in US).**

## CONDITION 2

- ★ **Instead of transmitting only the luminance signal, it is now necessary to transmit (in the same bandwidth) the luminance signal and two chrominance signals.**

# TV Signal in Modulated Frequency ...



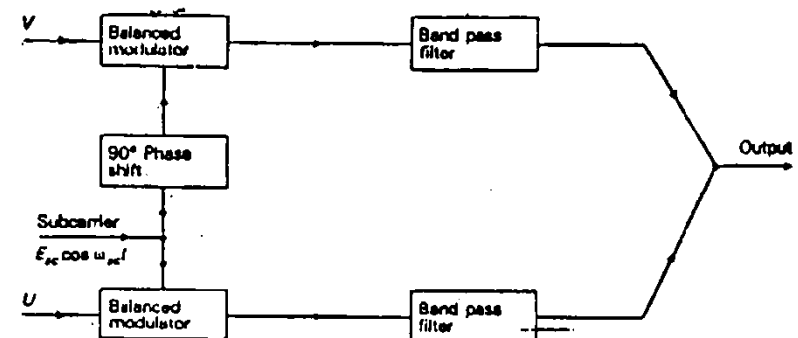
# Chrominance Transmission: Quadrature Modulation

- ★ The 2 chrominance signals modulate 2 carriers with the same frequency but with a phase difference of 90°.
- ★ To limit saturation, the following signals are used
  - $V' = 0.877 (R' - Y')$
  - $U' = 0.493 (B' - Y')$  (both gamma corrected)

which have lower amplitude and are filtered to have a bandwidth much inferior to the luminance bandwidth.

- ★ The chrominance modulated signal comes

$$U' \cos \omega_c t + V' \sin \omega_c t$$



# Chrominance Transmission: Quadrature Demodulation

★ To recover the 2 chrominances, the modulated signal is multiplied by

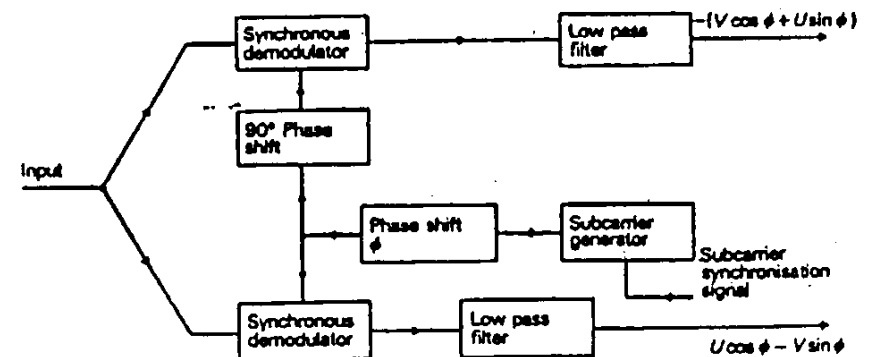
$$\cos \omega_c t \text{ e } \sin \omega_c t$$

and the result is adequately filtered.

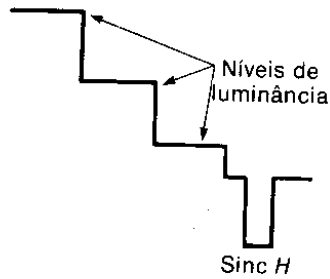
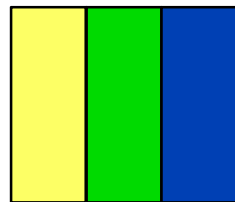
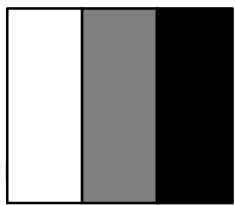
★ With quadrature amplitude modulation, a phase error in the demodulation carrier leads to undesirable mixtures of the 2 modulating signals

instead of  $\underline{U}'$ , it comes  $\underline{U}' \cos \phi - \underline{V}' \sin \phi$

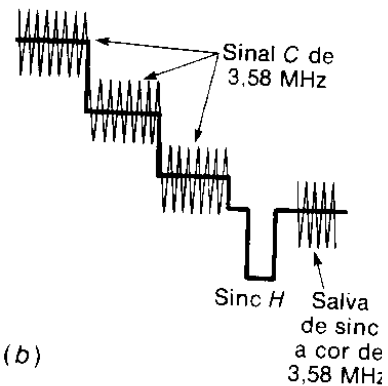
instead of  $\underline{V}'$ , it comes  $-\underline{V}' \cos \phi - \underline{U}' \sin \phi$



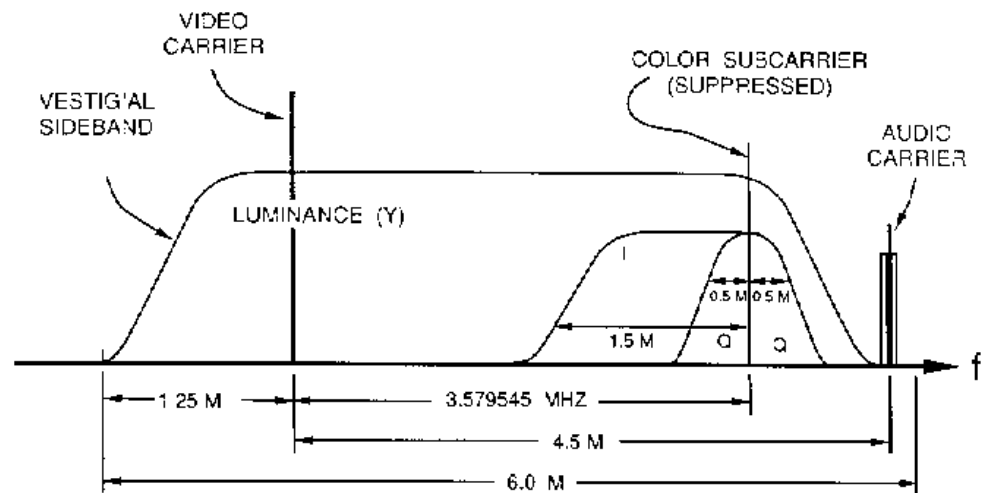
# Colour TV Signals: in Time and in Frequency ...



(a)



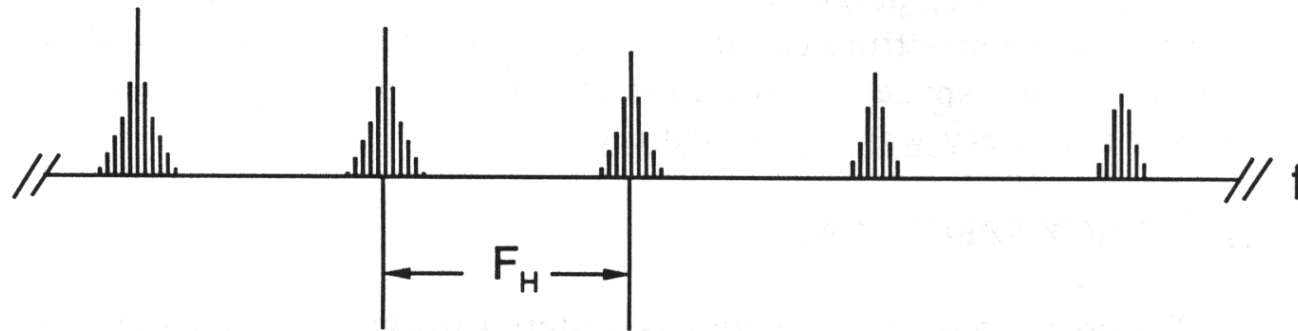
(b)



# Mixing but not Too Much ...

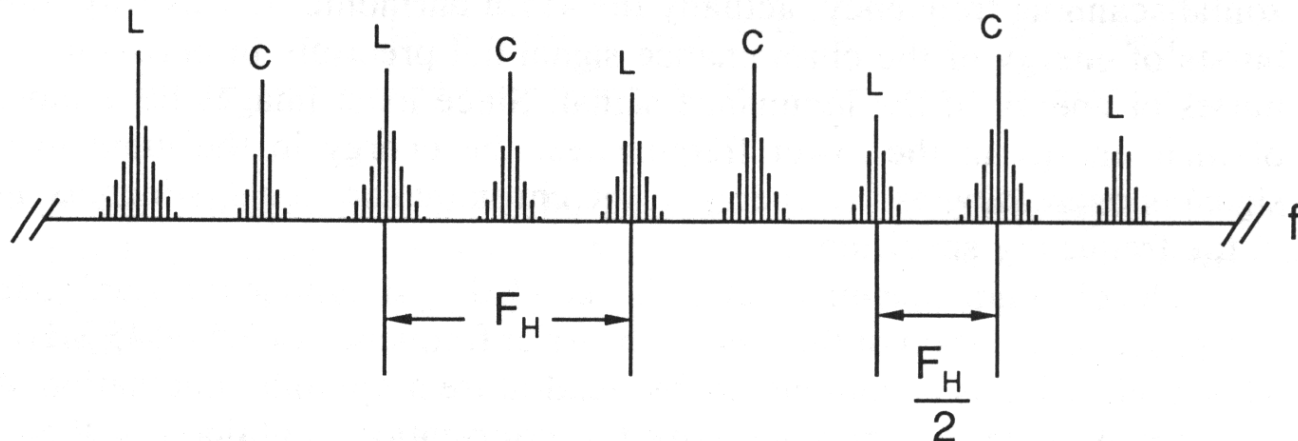
**Before**

MONOCHROME SPECTRAL DETAIL



**After**

COLOR TELEVISION SPECTRAL DETAIL



# Vector Diagram

The quadrature modulated signal comes

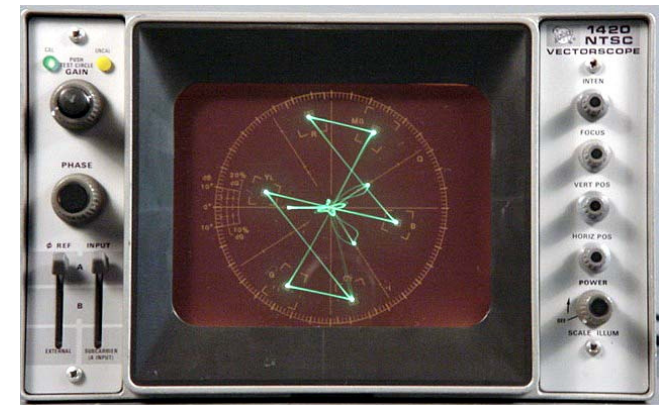
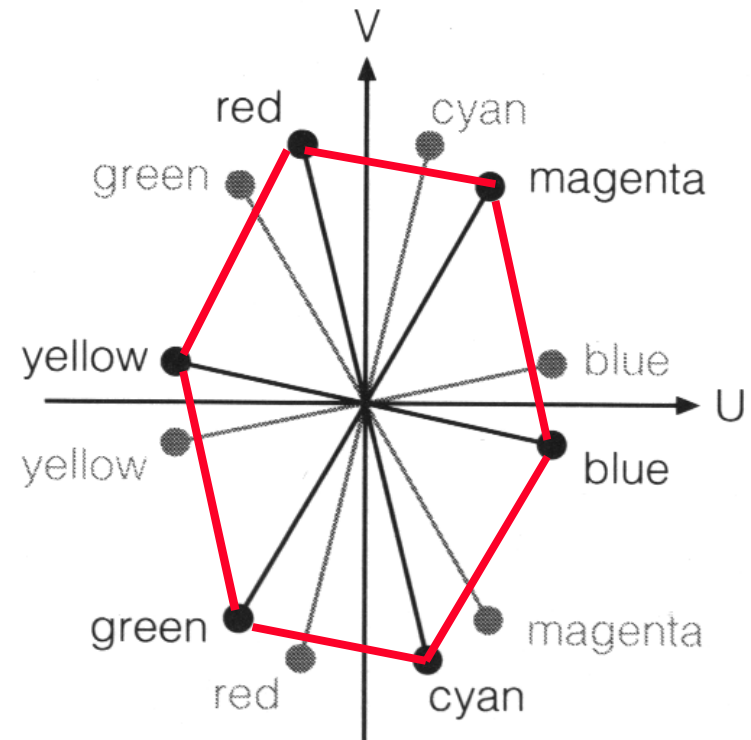
$$U' \cos \omega_c t + V' \sin \omega_c t =$$

$$A \cos (2 \pi f \omega_c t + \phi)$$

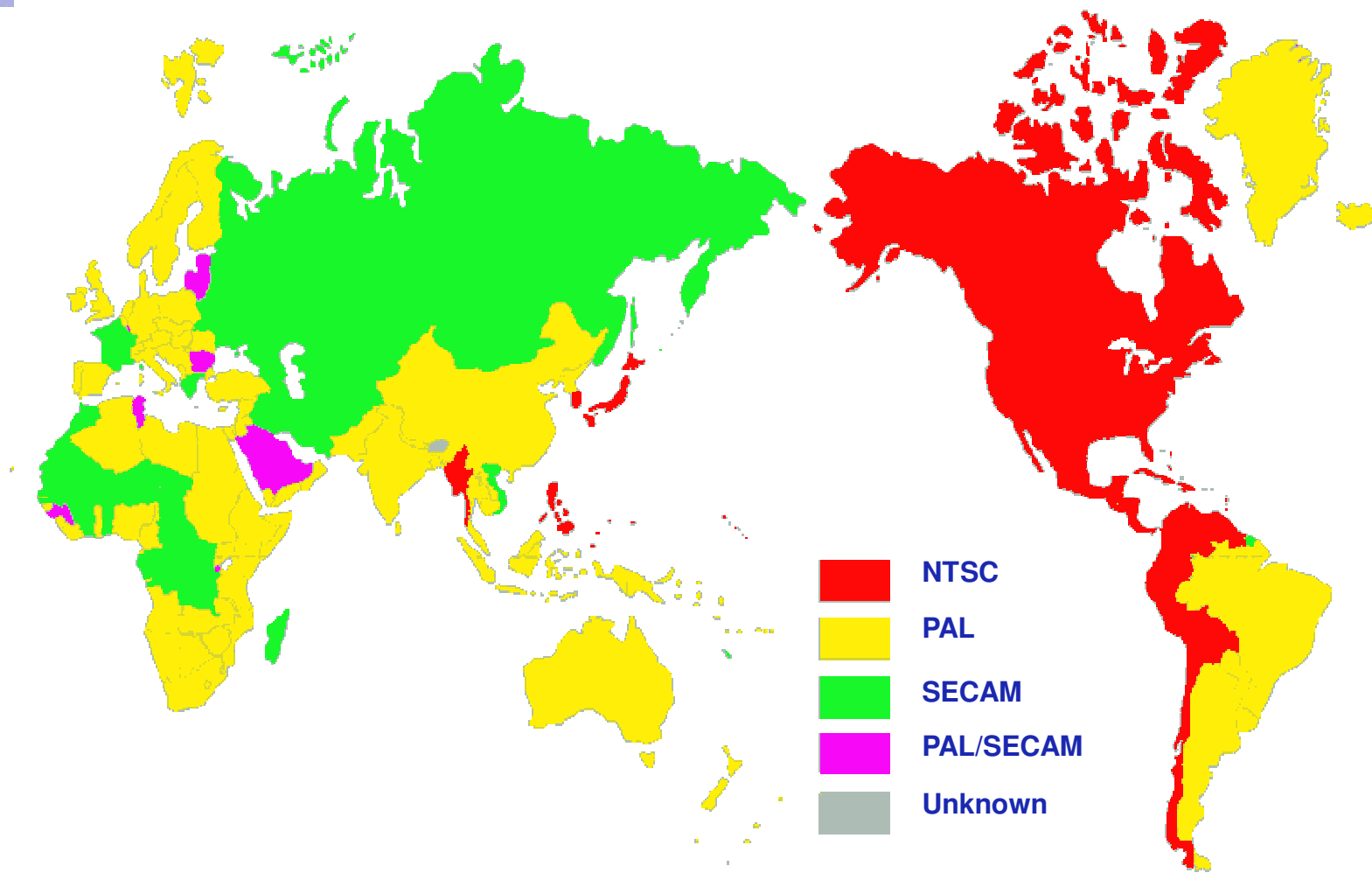
where  $A$  and  $\phi$  are the amplitude and phase of the colour carrier

$$A = (U'^2 + V'^2)^{1/2}$$

$$\phi = \arctg (V' / U')$$



# The World of Analogue TV





# NTSC SYSTEM



## The NTSC System (*National Television Standards Committee*)



- ★ In the NTSC system, the radio frequency TV slots are 6 MHz wide.
- ★ For the NTSC system, the signals transmitted are

$$I' = -0,27 (B'-Y') + 0,74 (R'-Y') = \cos 33^\circ V' - \text{sen } 33^\circ U'$$

$$Q' = 0,41 (B'-Y') + 0,48 (R'-Y') = \cos 33^\circ U' + \text{sen } 33^\circ V'$$

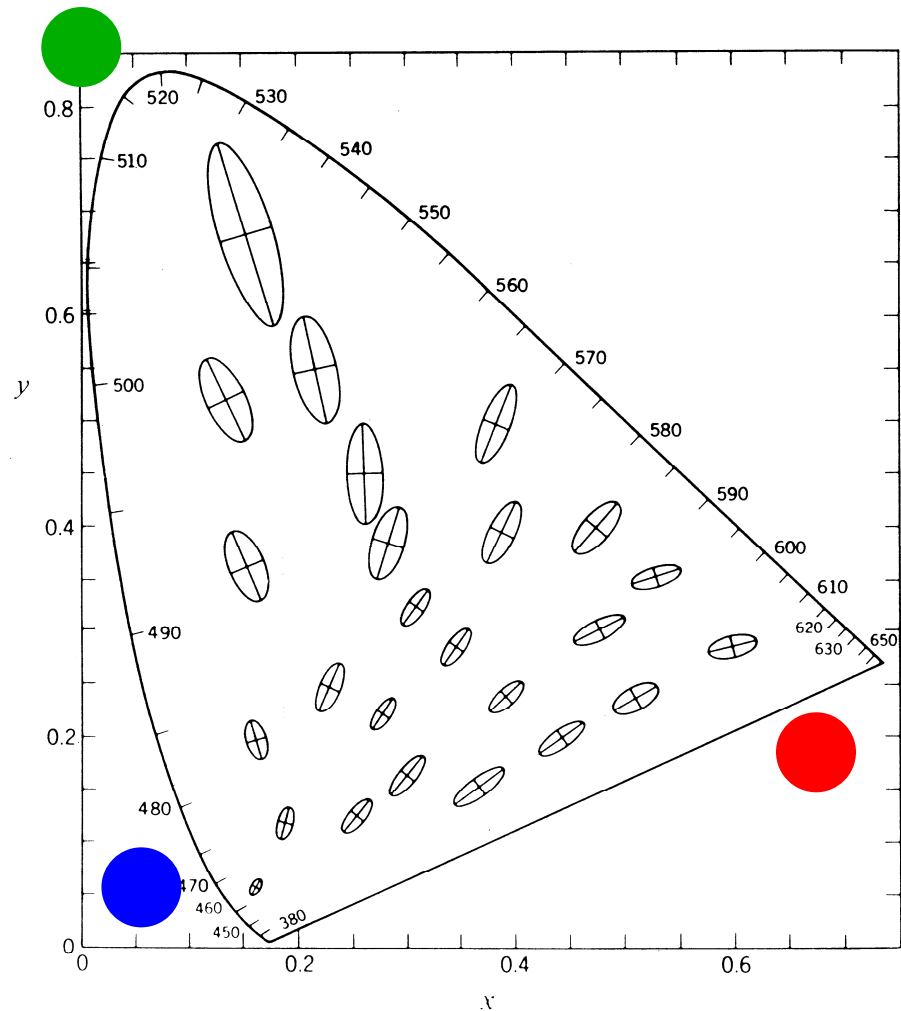
obtained by linear transformation of the U' and V' signals.

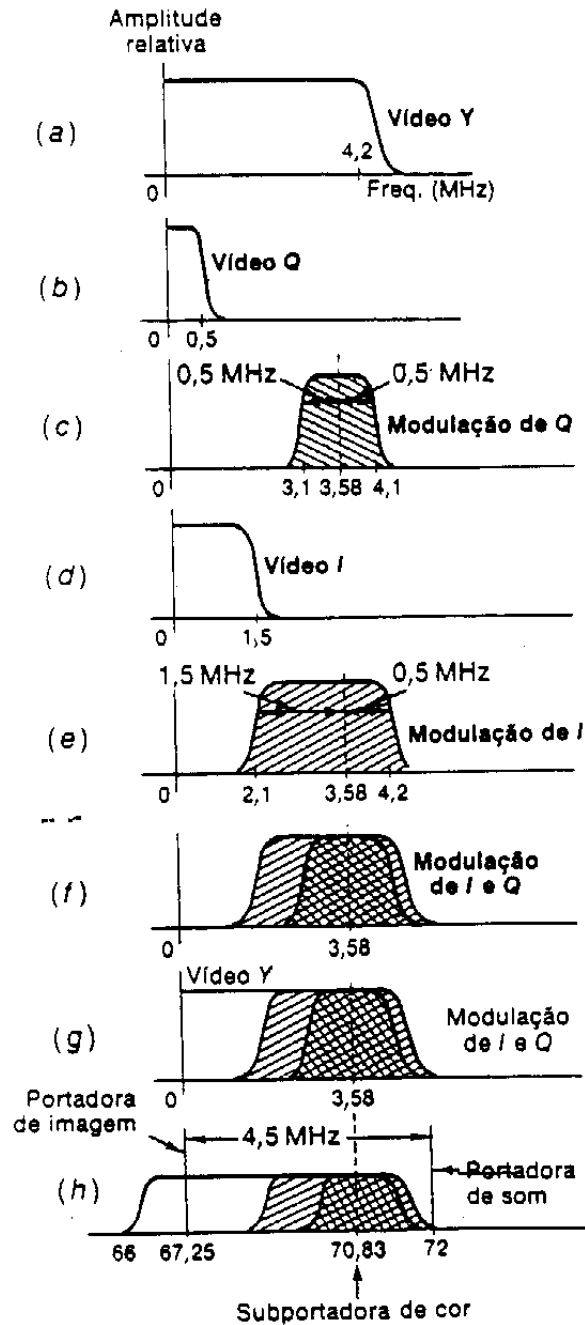
- ★ The NTSC system takes benefit from the fact that the human sensibility to colour variations depends on the direction the colour is varying in a chromaticity diagram.
- ★ If the chrominance signals express colour variations along directions to which humans are differently sensitive, it is acceptable that the bandwidth for these signals is also different.

# Colour Variation Sensibility: MacAdam Ellipses

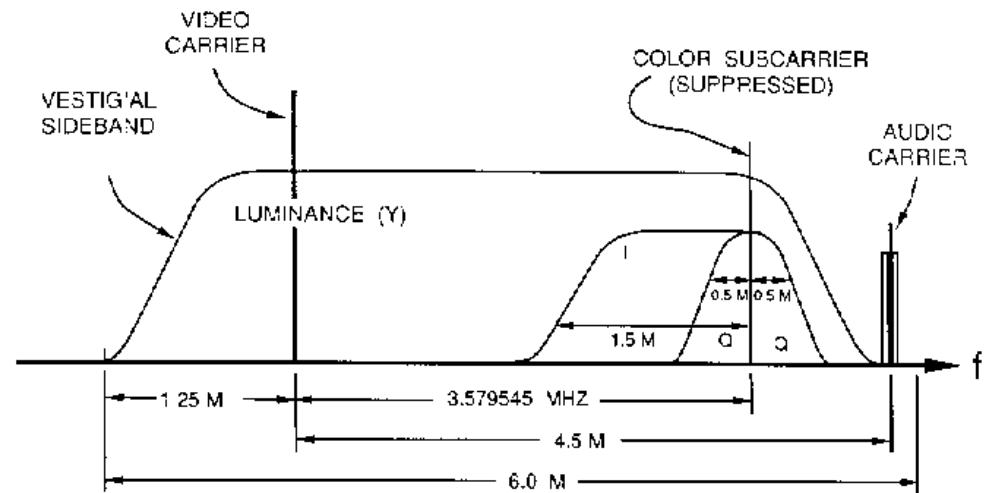
**MacAdam ellipses refer to the region on a chromaticity diagram which contains all colors which are indistinguishable, to the average human eye, from the color at the center of the ellipse. Therefore, the contour of the ellipse represents the just noticeable differences of chromaticity.**

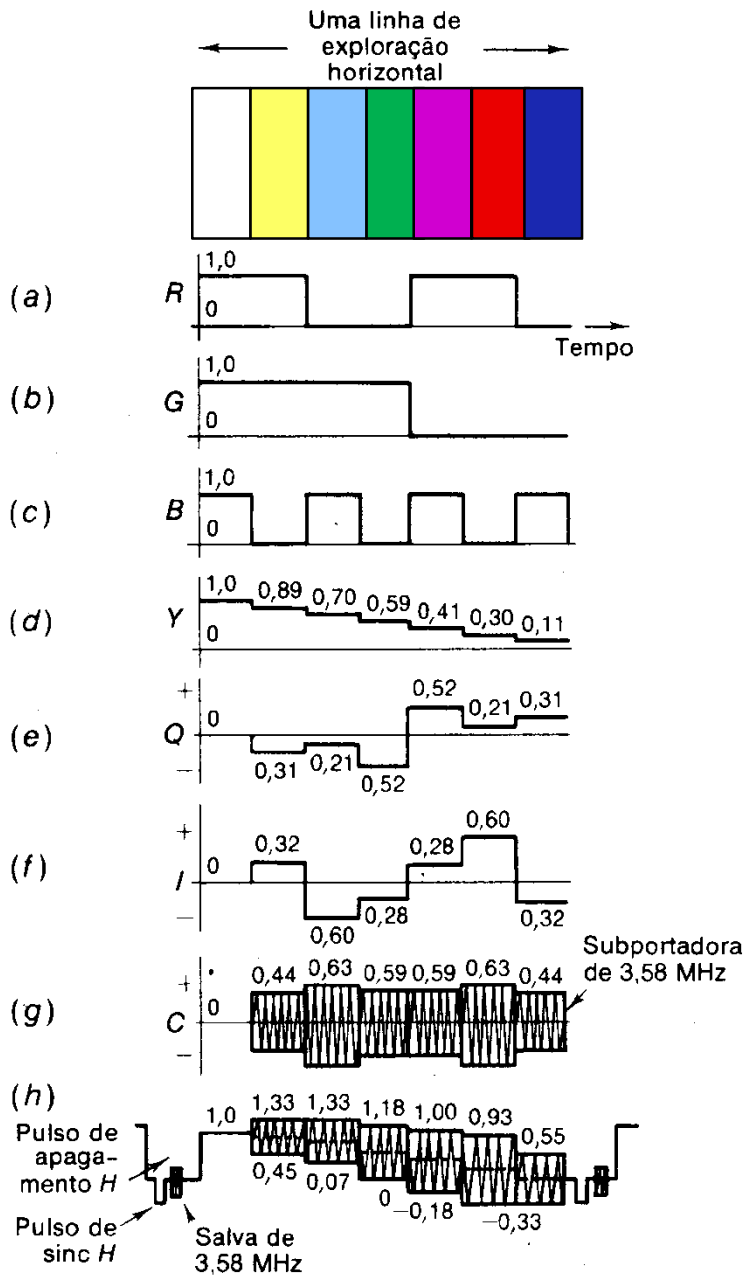
**The human visual system is not equally sensitive to colour variations along all directions.**





# NTSC Signal in Frequency





# NTSC Composite Signal in Time

$$c(t) = I' \cos(360^\circ f_c t + 33^\circ) + Q' \sin(360^\circ f_c t + 33^\circ)$$

$$c(t) = A_{NTSC} \cos(2\pi f_c t + \phi)$$

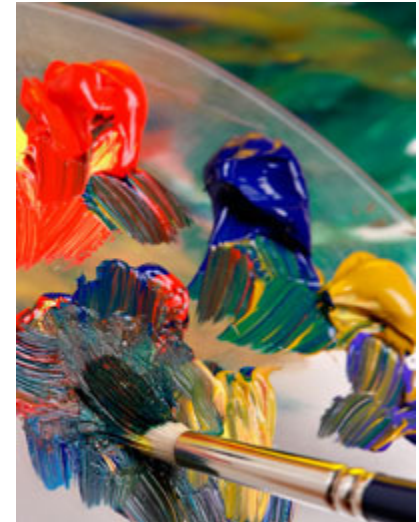
with

$$A_{NTSC} = (I'^2 + Q'^2)^{1/2}$$

$$\phi_{NTSC} = 123^\circ - \arctg(Q'/I')$$

(in relation to U)

# Separation of NTSC Chrominances



- ★ To recover the quadrature modulating chrominance signals, the modulated signal is multiplied by

$$\cos \omega_c t \quad \text{and} \quad \sin \omega_c t$$

and the result is adequately filtered.

- ★ The perfect quadrature demodulation is only possible if the modulated signal does not suffer any interference and the equipment is perfectly tuned. This is, in practise, impossible !

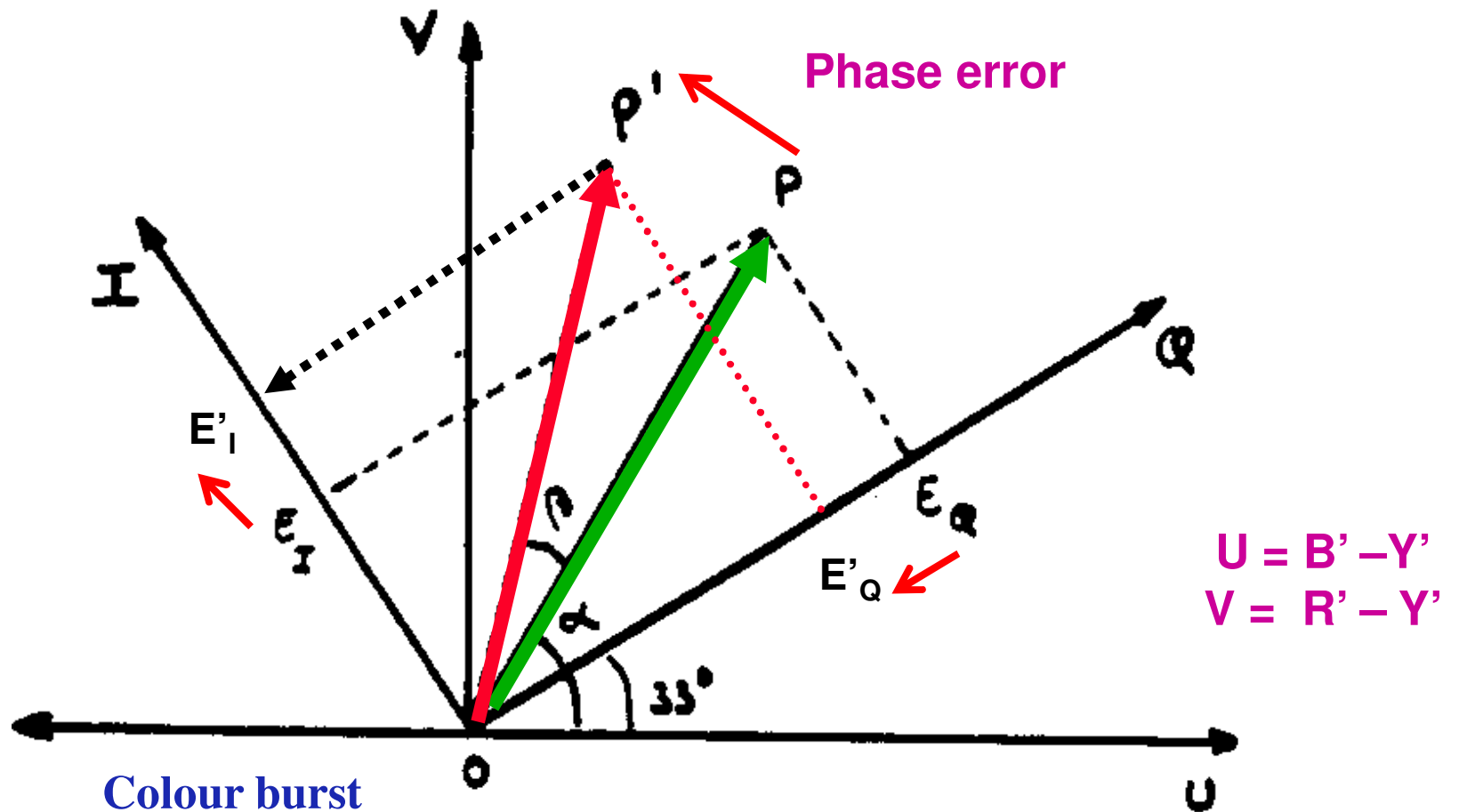


- ★ Since

- there are small frequency or phase shifts in the demodulating carrier
- transmission channels introduce differential amplitude or phase gains

it is not possible to perfectly recover the quadrature modulated signals (U and V) which means there are colour mixtures and, thus, colour errors.

# NTSC Mixtures or *Never Twice the Same Colour*





# PAL SYSTEM



# The PAL System (Phase Alternate Line)



★ In the PAL system, the radio frequency TV slots are 8 MHz wide.

★ The chrominance signals selected are

- $U' = 0.493 (B' - Y')$
- $V' = 0.877 (R' - Y')$

in order to limit the saturation at the emitter.

★ The chrominances are sent in quadrature, modulating a colour subcarrier with the  $U'$  and  $V'$  signals; the signal of  $V'$  is alternated (+ and -) for every image line.

**N lines:**  $c_N(t) = U' \sin(2\pi f_c t) + V' \cos(2\pi f_c t) = A_{PAL} \cos(2\pi f_c t + \phi_{PAL})$

**P lines:**  $c_P(t) = U' \sin(2\pi f_c t) - V' \cos(2\pi f_c t) = A_{PAL} \cos(2\pi f_c t - \phi_{PAL})$

with

$$A_{PAL} = (U'^2 + V'^2)^{1/2} \quad \text{and} \quad \phi_{PAL} = \arctg(V'/U') \quad (\text{em relação a } V)$$

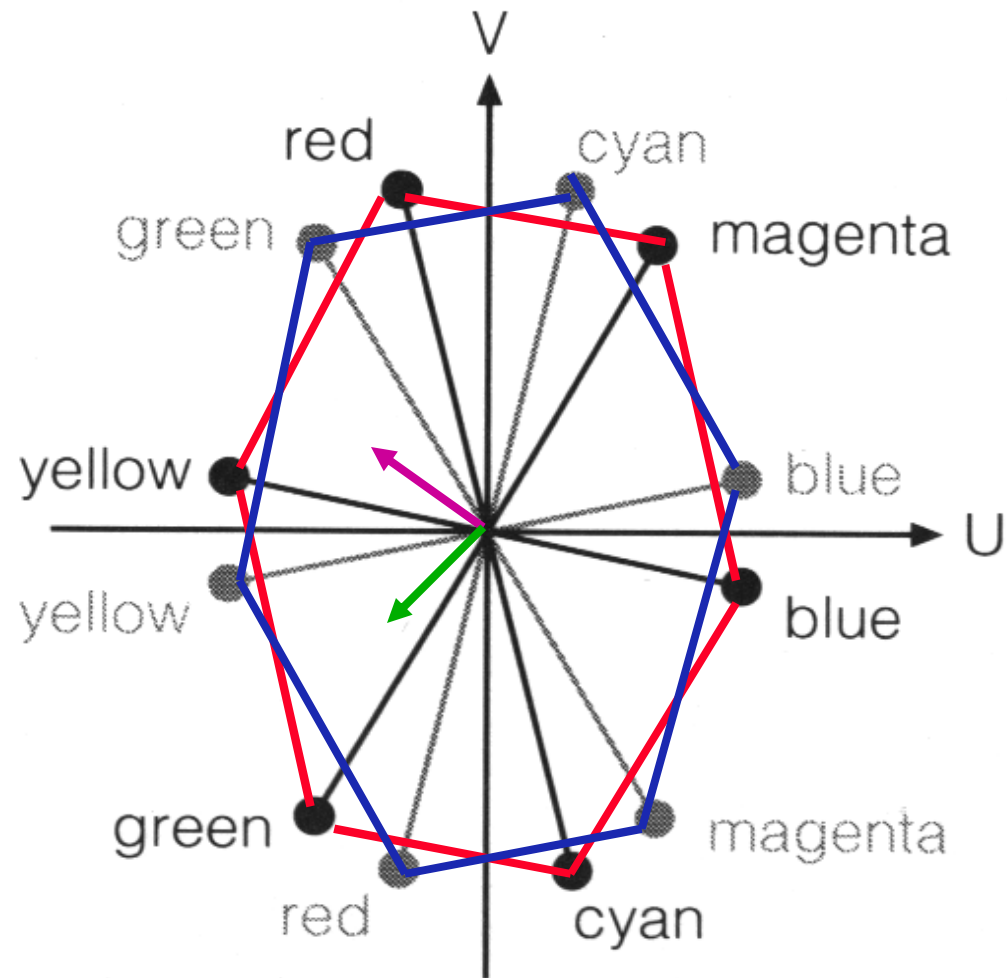
# PAL Vector Diagram

**N Lines**

**P Lines**

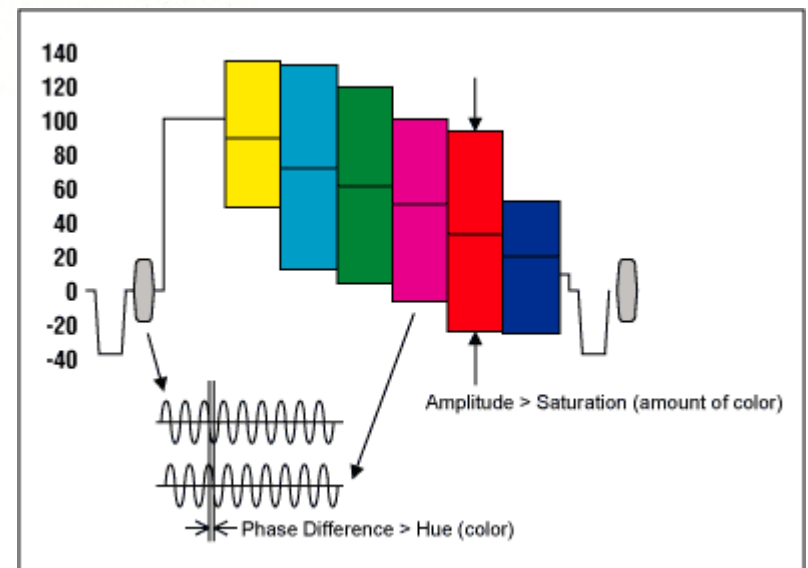
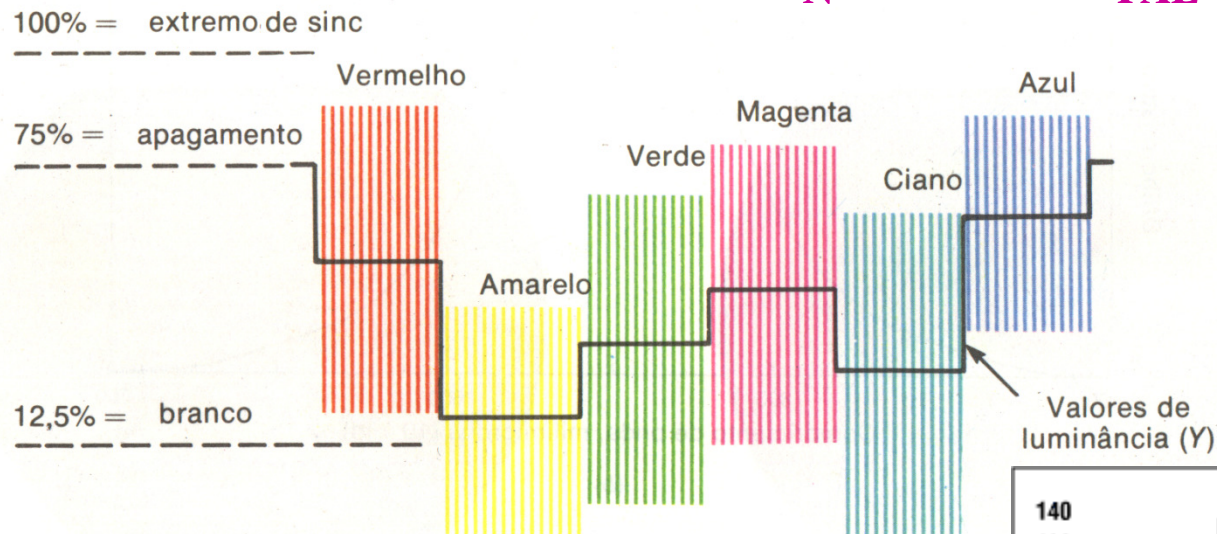
**N Burst**

**P Burst**

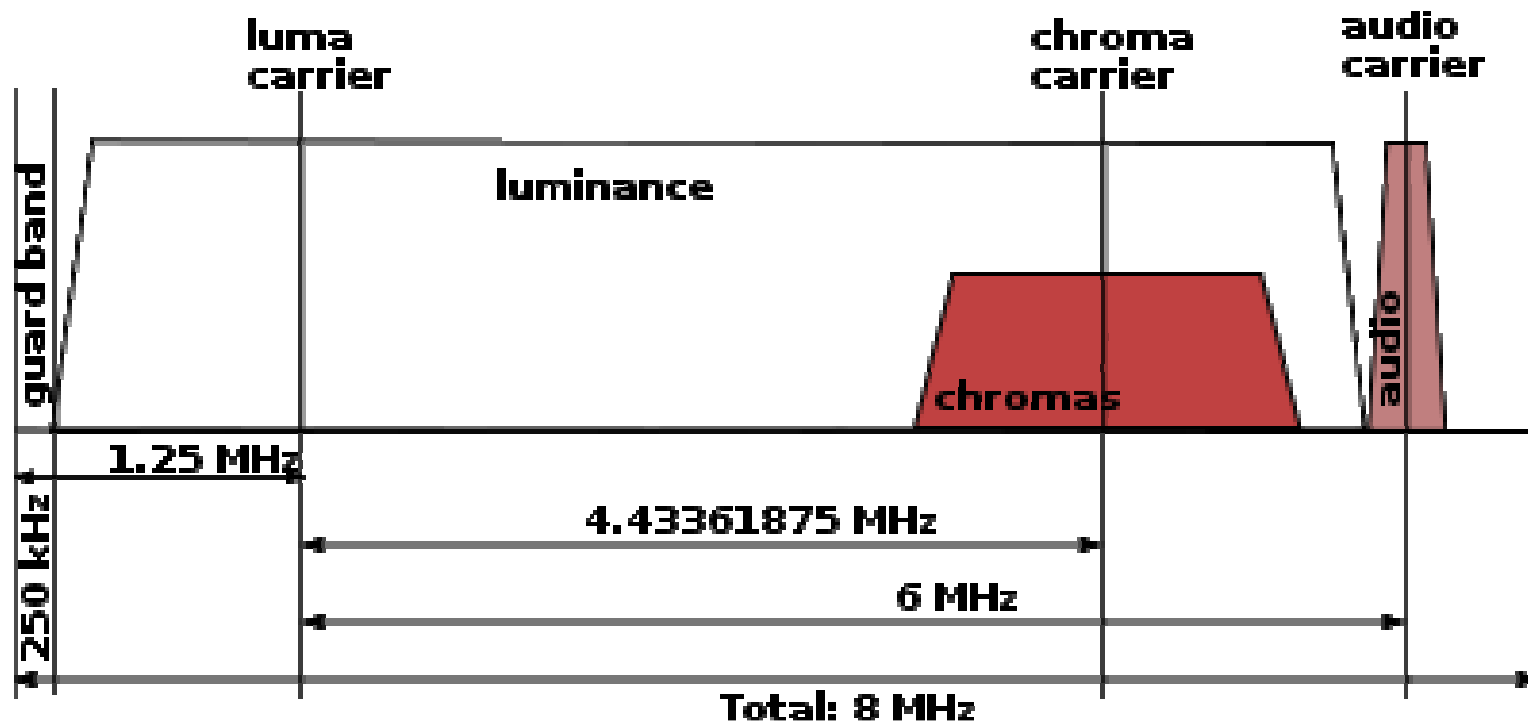


# PAL Video Signal in Time

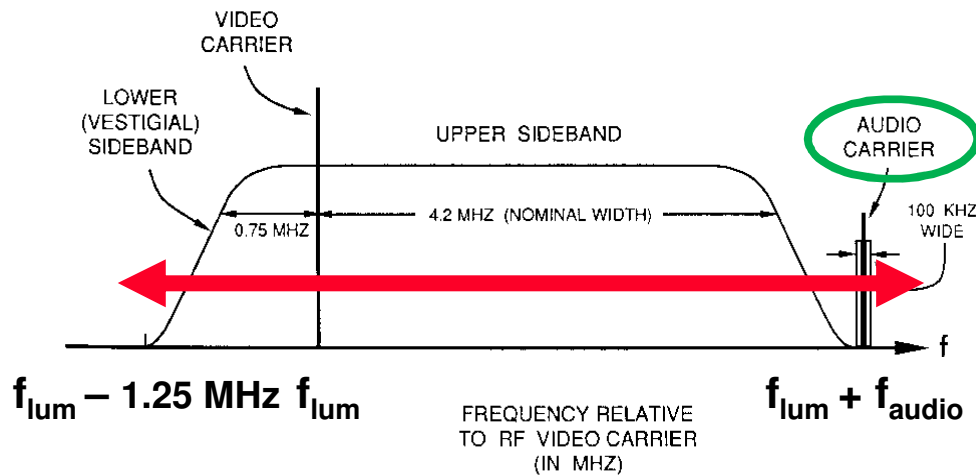
$$c_N(t) = Y + A_{PAL} \cos(2\pi f_c t + \phi_{PAL})$$



# PAL Signal in Frequency

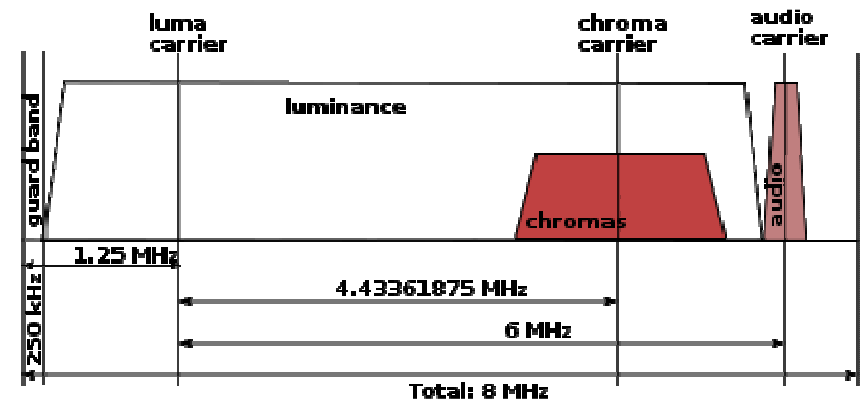
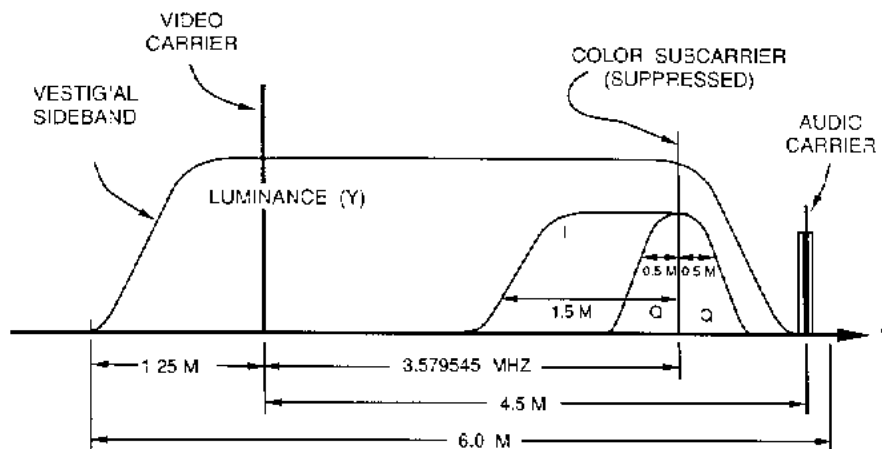


# From BW to Colour in Frequency ...



## NTSC

## PAL





# PAL Demodulation

★ Assuming that the chrominance information is similar for 2 consecutive lines, if the receiver stores the modulated chrominance signal for each line, than it is possible for the next line to recover the modulated U' and V' signals by adding and subtracting the received and stored chrominance signals (using a delay line).

★ If the stored line is N:

$$U' \sin (2 \pi f_c t) = (c_N (t) + c_P (t)) / 2$$

$$V' \cos (2 \pi f_c t) = (c_N (t) - c_P (t)) / 2$$

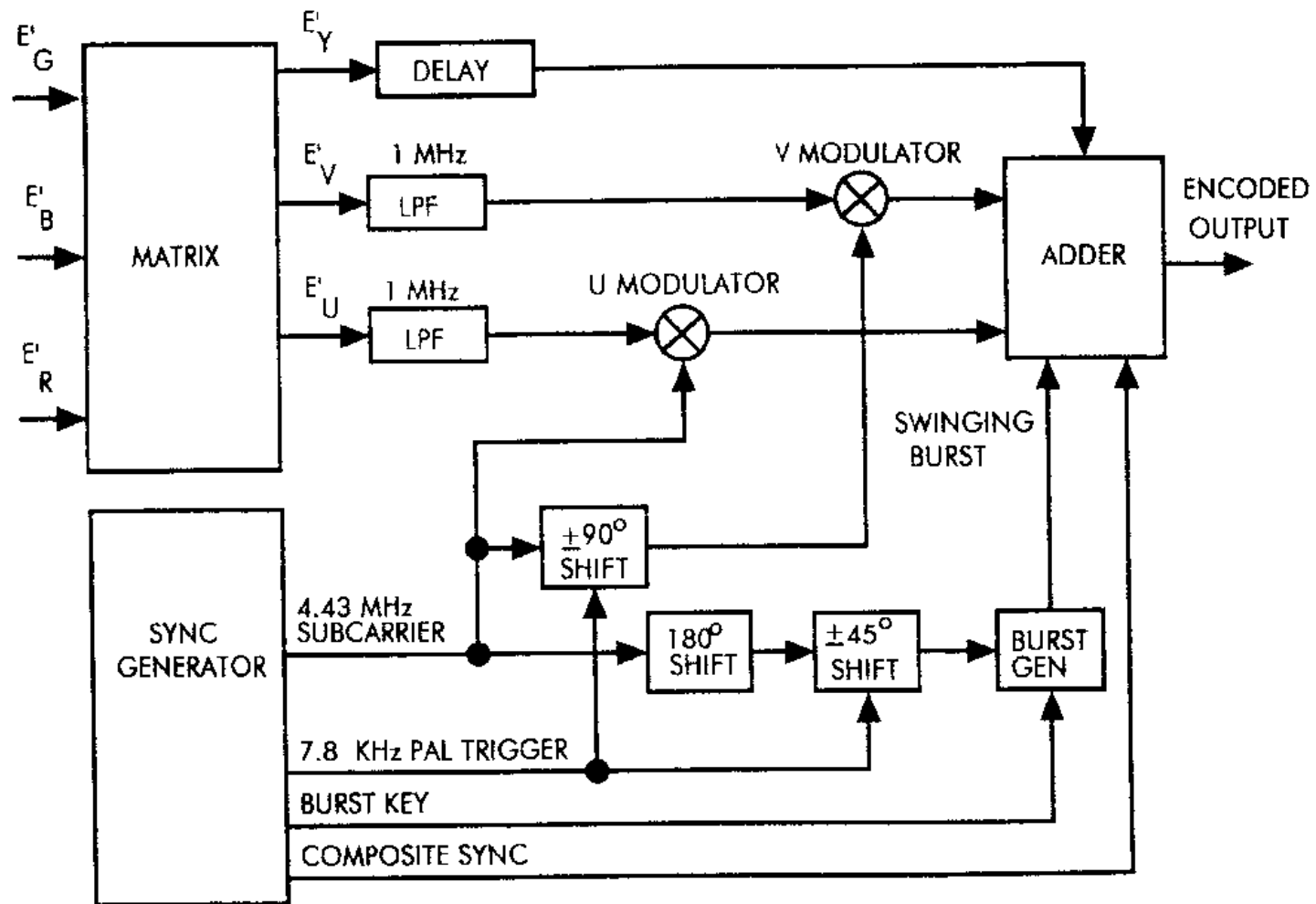
★ If the stored line is P:

$$U' \sin (2 \pi f_c t) = (c_N (t) + c_P (t)) / 2$$

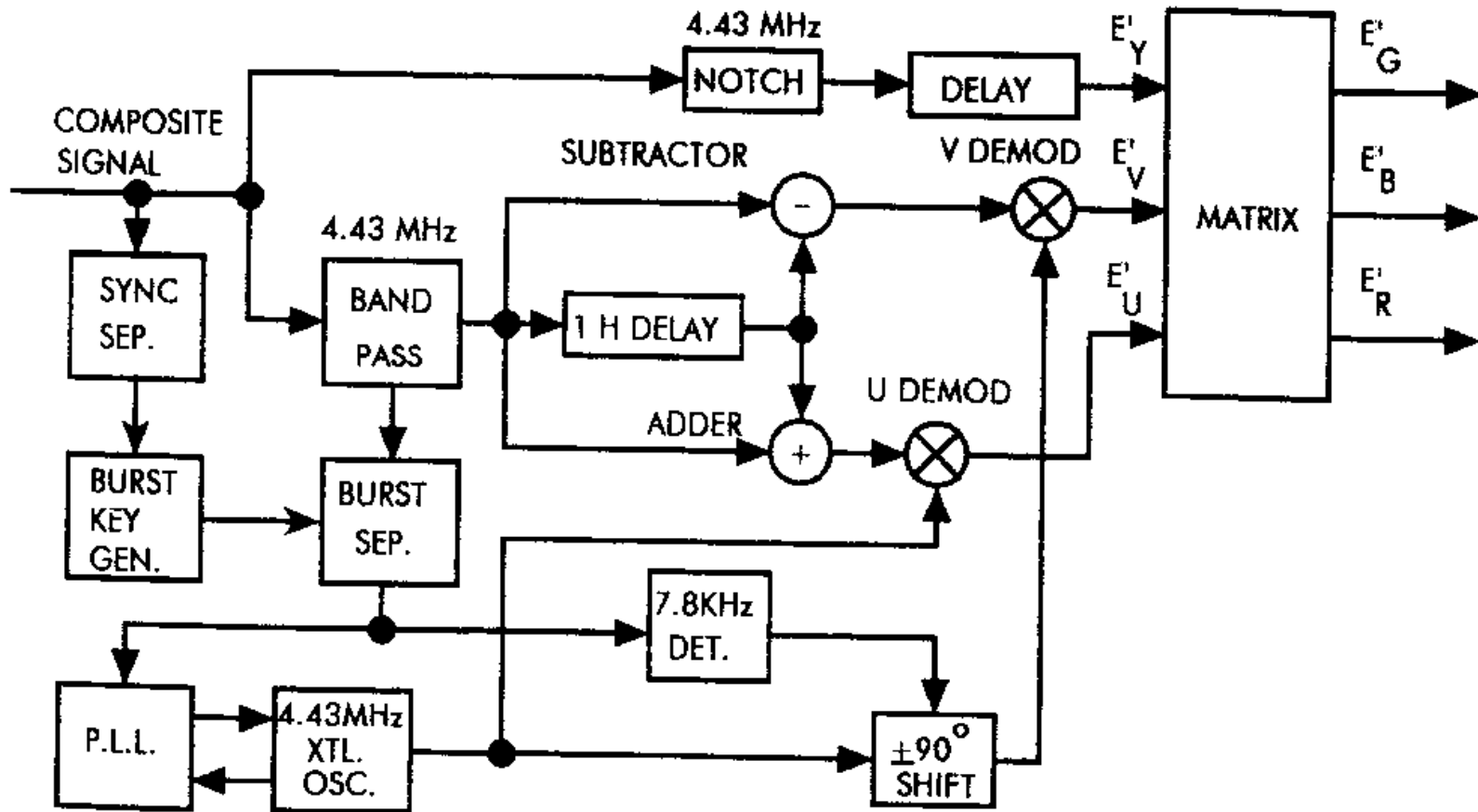
$$V' \cos (2 \pi f_c t) = (c_N (t) - c_P (t)) / 2 = - (c_P (t) - c_N (t)) / 2$$



# PAL Modulator



# PAL Demodulator



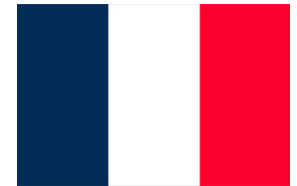


# SECAM SYSTEM



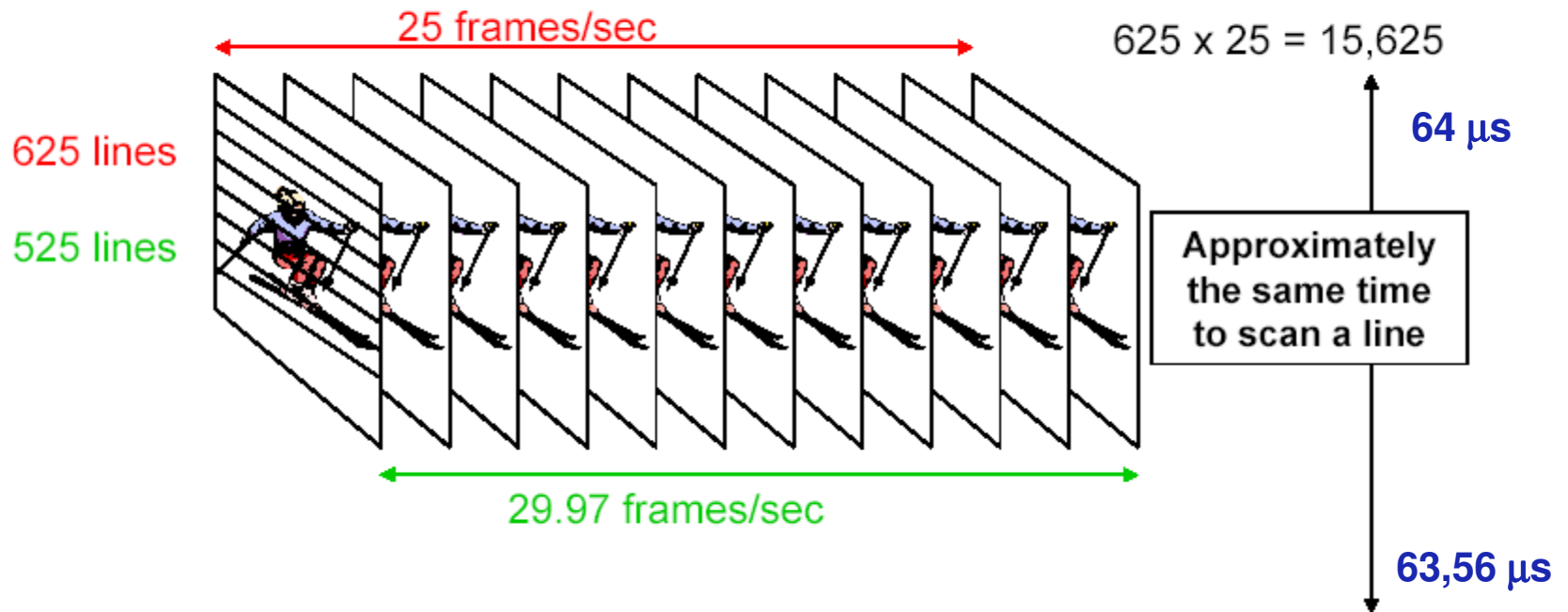
## The SECAM System (*Sequentiel Couleur a Memoire*)

- ★ In the SECAM system, the radio frequency TV slots are 8 MHz wide.
- ★ The SECAM chrominance signals are
  - $DR' = -1.9(R'-Y')$
  - $DB' = 1.5(B'-Y')$
- ★ The two chrominance signals are frequency modulated and alternately transmitted, line by line (reducing the colour spatial resolution).
- ★ There are no colour mixtures with SECAM since the two chrominance signals never coexist in time.
- ★ Although the SECAM vertical resolution for the chrominances is about half of the PAL/NTSC resolution, there is no evident reduction of the subjective quality.
- ★ As PAL (but not NTSC), also SECAM needs a delay line.



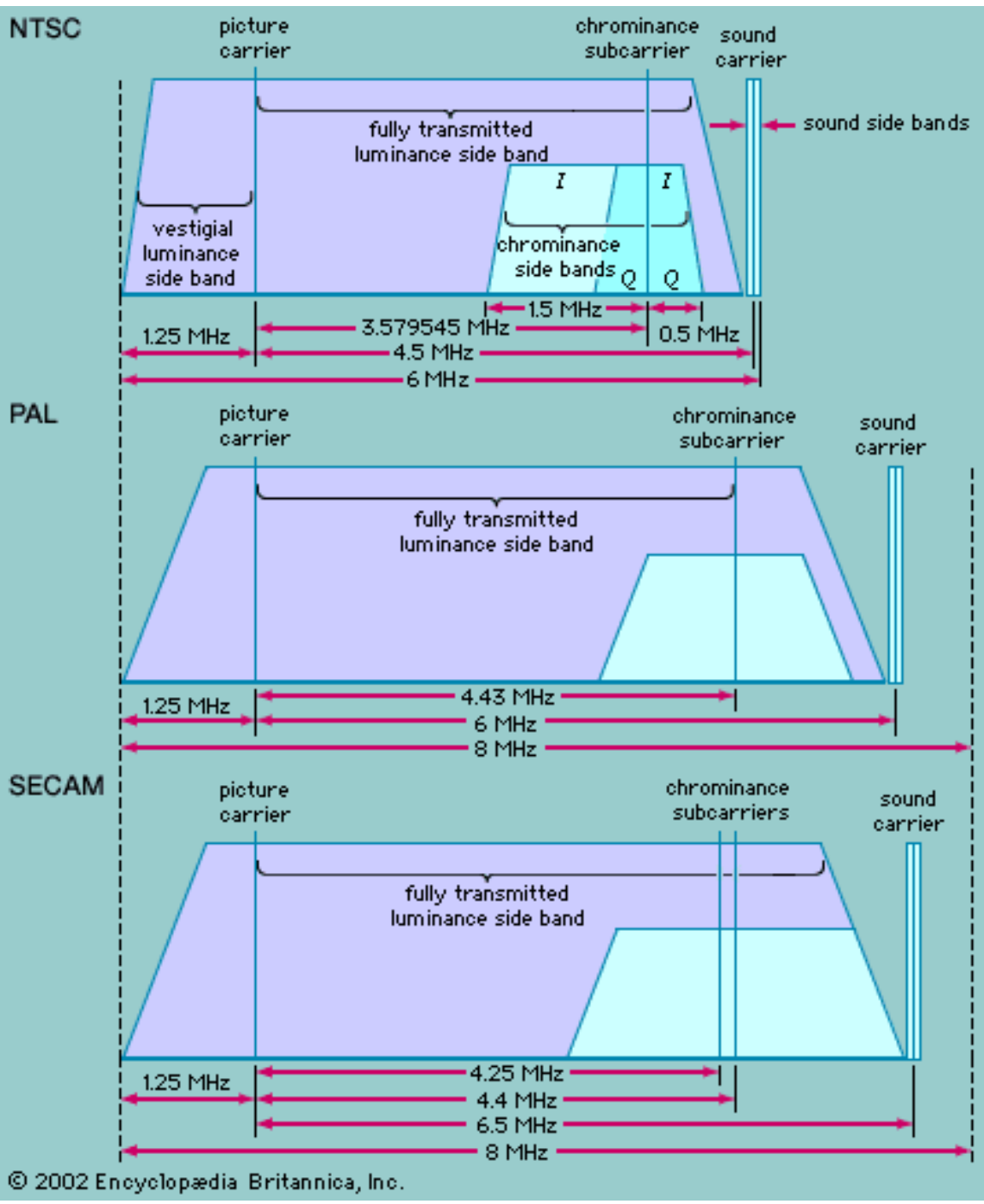
## Different but so Similar after all ...

- 625/50 television (PAL, SECAM)



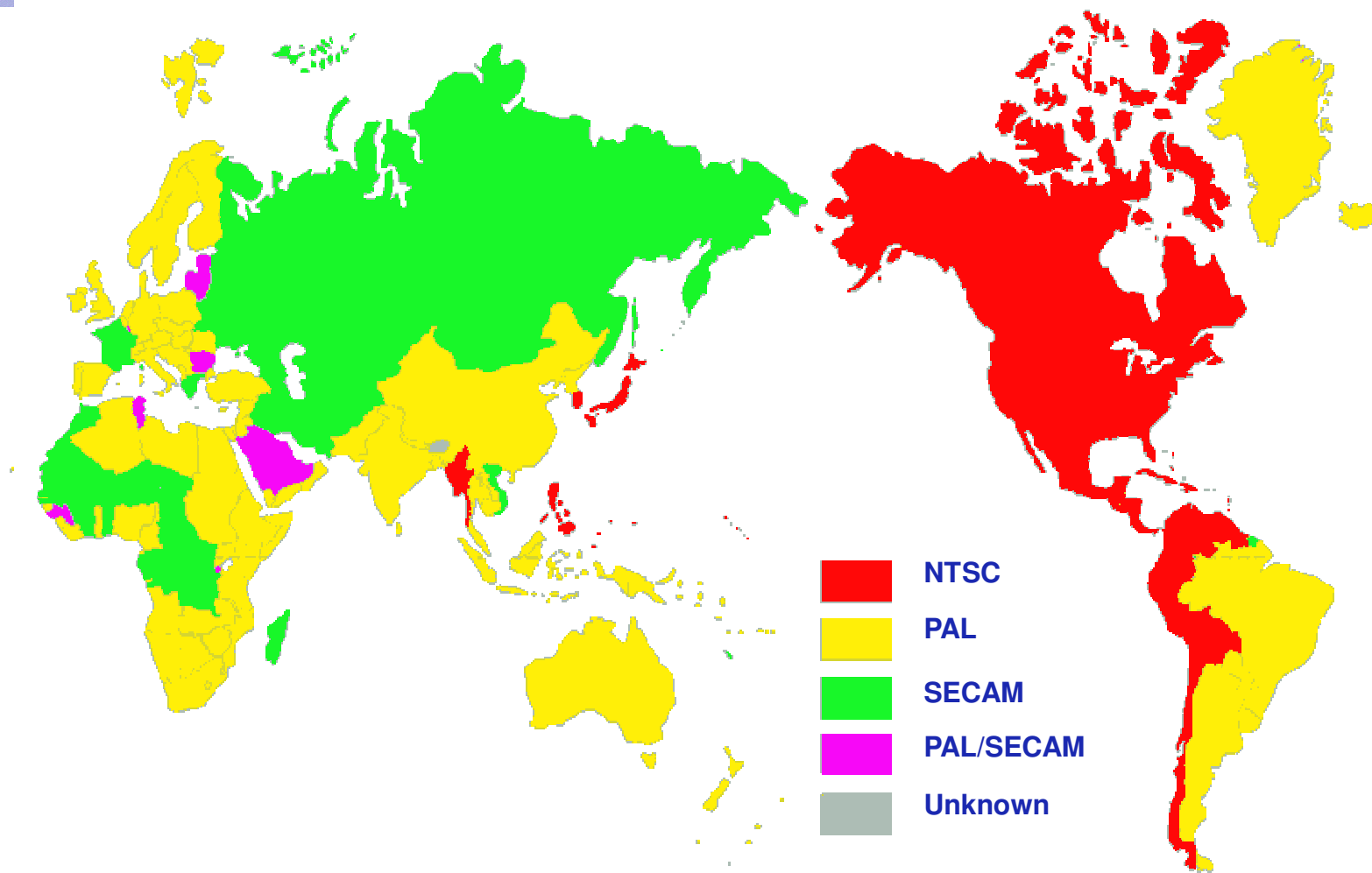
- 525/60 television (NTSC)

$$525 \times 29.97 = 15,734$$



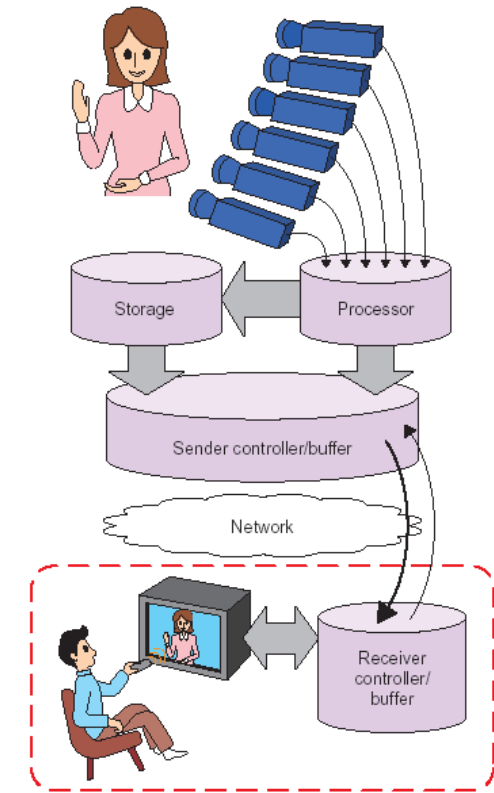
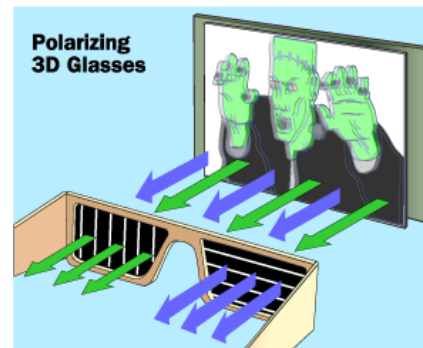
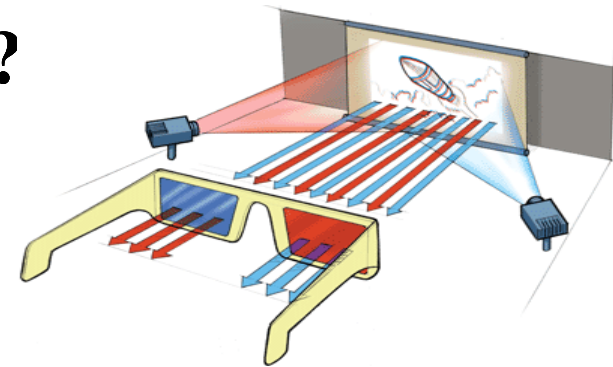
# NTSC, PAL and SECAM Spectrum Allocations for TV Channels

# The World of Analogue TV



# Television: Where is it Going ?

- ★ Analogue Monochrome TV
- ★ Analogue Colour TV
- ★ Digital TV
- ★ High Definition TV
- ★ Interactive TV
- ★ 3D Stereoscopic TV
- ★ 3D Multiview TV
- ★ 3D Free viewpoint TV
- ★ ...



in which transmission systems ?



# DISPLAY REVOLUTION



# CRT Weaknesses

- ★ **Big**
- ★ **Heavy**
- ★ **Fragile**
- ★ **High power consumption**
- ★ **Limited contrast (about 50:1)**
- ★ **Limited maximum brightness (50-100 cd/m<sup>2</sup>)**
- ★ **Colour variations due to poor 3 (RGB) gun convergence**
- ★ ...



# The New Displays: LCDs and Plasmas



FPS commercial photo





# **TERRESTRIAL TV IN PORTUGAL**

## 7 March 1957 (Thursday), 21:30: Starting of Monochrome TV Regular Transmissions



1957, 17-23 February -  
"Reportagens da Rainha",  
transmitted during the visit  
to Portugal of Queen  
Elisabeth II pre-announced  
the start of regular  
transmissions.



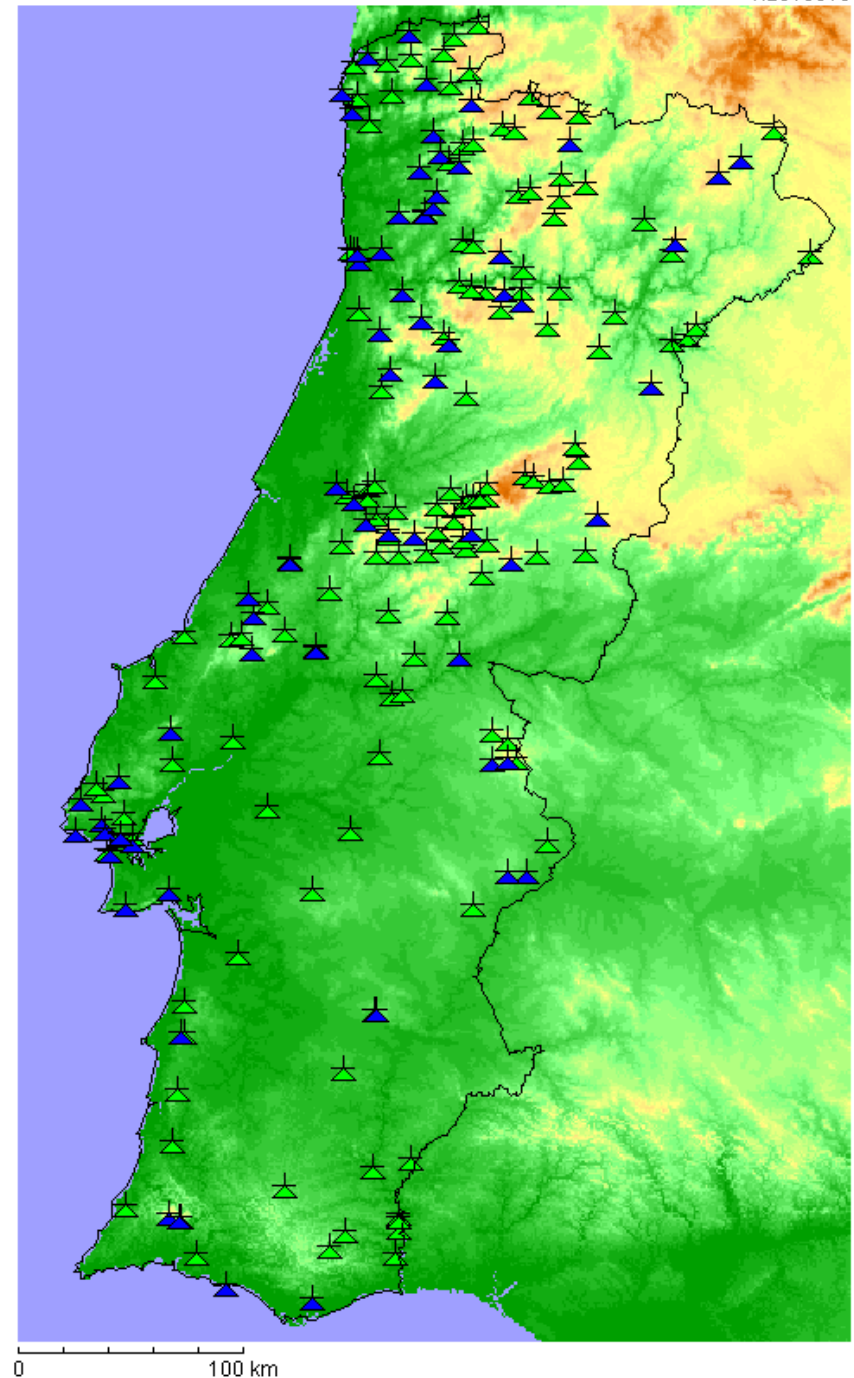
1957, 7 March - 21:30 – Start of  
regular transmissions from  
Estúdios do Lumiar in Lisbon,  
with a small emitter provisionally  
installed in Monsanto.

## Current Situation: Transmission Networks

1:2910910

Until 2008, there were two  
terrestrial broadcasting networks  
in Portugal:

- ★ PT Comunicações (green in the map) network which has the network that was initially from RTP and TDP
- ★ RETI, Rede Teledifusora Independente, (blue in the map) network which developed from the radio network from Rádio Renascença (bought by PT in 2008)





# Business Models



## Public Broadcasters (RTP) – Public & private sponsorship + Publicity

- *“A concessão geral do serviço público de televisão é atribuída à Rádio e Televisão de Portugal, SGPS, S. A., pelo prazo de 16 anos, nos termos de contrato de concessão a celebrar entre o Estado e essa sociedade.”*
- *“O Estado assegura o financiamento do serviço público de televisão, nos termos estabelecidos na lei e nos contratos de concessão.”*
- *“Os operadores que actuem ao abrigo de concessão do serviço público de televisão devem assegurar uma programação de qualidade, equilibrada e diversificada, que contribua para a formação cultural e cívica dos telespectadores, promovendo o pluralismo político, religioso, social e cultural, e o acesso de todos os telespectadores à informação, à cultura, à educação e ao entretenimento de qualidade.”*

*Lei da Televisão, 2003*



## Private Broadcasters (SIC and TVI) – Private sponsorship + Publicity

- Sociedade Independente de Comunicação (SIC) has been the first private television network in Portugal, starting the 6<sup>th</sup> October 1992; it uses the PT broadcasting network.
- Televisão Independente (TVI) was the second private network in Portugal, starting the 20<sup>th</sup> February 1993; it used his own broadcasting network until 2008.



*Audiovisual Communications, Fernando Pereira, 2011*



## Curiosity: Time for Ads (*Lei da Televisão, 2003*)

- ★ *Nos serviços de programas televisivos de cobertura nacional e acesso não condicionado, o tempo reservado às mensagens publicitárias não pode exceder 15% do período diário de emissão, salvo quando inclua outras formas de publicidade ou mensagens de televenda, caso em que esse limite pode elevar-se a 20%.*
- ★ *Nos serviços de programas televisivos de cobertura nacional e acesso condicionado, a difusão de publicidade ou de mensagens de televenda não deve exceder 10% do período diário de emissão.*
- ★ *Nos serviços de programas televisivos temáticos de televenda ou de autopromoção, o tempo destinado à publicidade não deve exceder 10% do período diário de emissão.*
- ★ *O tempo de emissão destinado às mensagens publicitárias e de televenda, em cada período compreendido entre duas unidades de hora, não pode exceder 10% ou 20%, consoante se trate ou não de serviços de programas televisivos de acesso condicionado.*
- ★ *Excluem-se dos limites fixados no presente artigo as mensagens difundidas pelos operadores de televisão relacionadas com os seus próprios programas e produtos directamente deles derivados, os patrocínios, os blocos de televenda a que se refere o artigo seguinte, bem como as que digam respeito a serviços públicos ou fins de interesse público e apelos de teor humanitário, transmitidas gratuitamente.*

# Digital Terrestrial TV in Portugal

- ★ **2002: First tentative to deploy digital terrestrial TV in Portugal failed ....**
- ★ **2007: Models for and launching of digital terrestrial TV continued to be discussed ...**
- ★ ***17 Feb 2009 (delayed to 12 June 2009) – US analogue switch off***
- ★ **April 2009 – Digital terrestrial TV starts in Portugal with PT-Comunicações (service is free but not the boxes ...)**
- ★ **26 April 2012: Deployment of digital terrestrial TV should be finished; for security, 12 more months of simulcasting ...**





# Bibliography

- ★ **Television Technology: Fundamentals and Future Prospects,** Michael Noll, Artech House, 1988
  
- ★ **Broadcast Television Fundamentals,** Michael Tancock, Pentech Press, 1991