CinemaSource™

Understanding Human Color Vision

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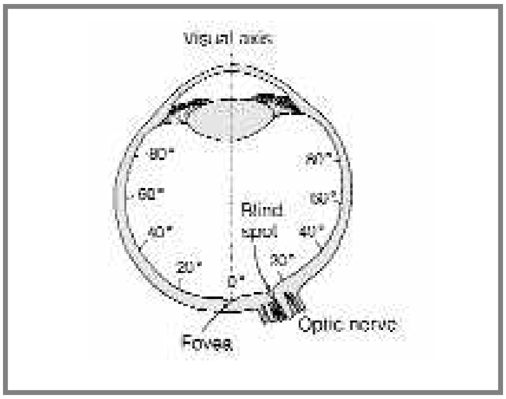
VISUAL COLOR THEORY



How The Eye Works

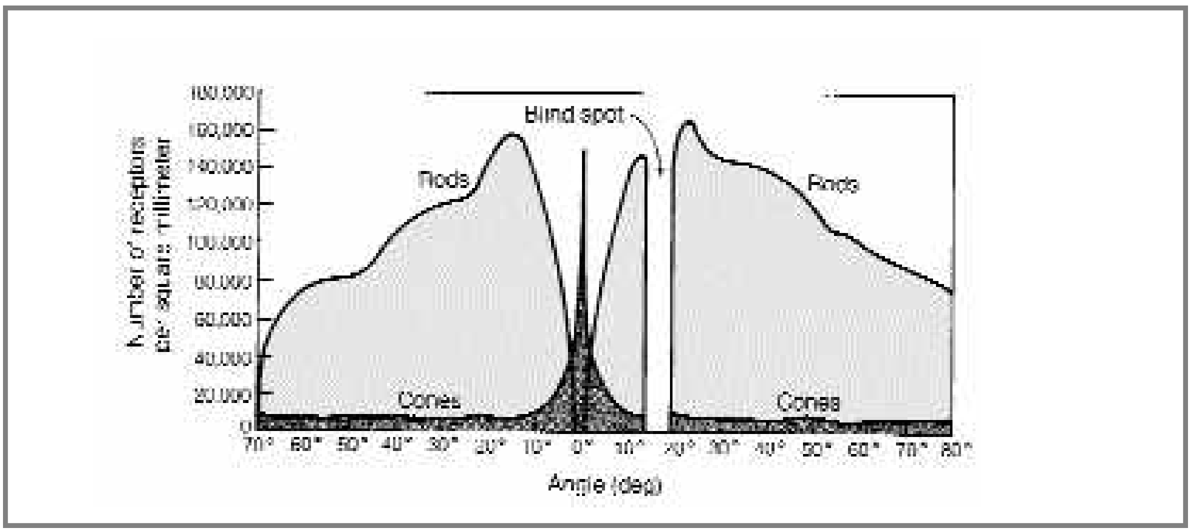
In physical terms, what we perceive as "light" constitutes a section of the electromagnetic spectrum ranging from approximately 400 to 700 nanometers in wavelength. Human vision results from the stimulation of the eye by electromagnetic radiation in this range.

At the rear of everyone's eye is a photosensitive structure called the retina. The retina is made up of a wide variety of specialized cells whose sole purpose is to turn received light into neural impulses. The actual "wiring" of the surface of the retina is very complex but for our purposes we can identify two types of cells that play a major role in the visual process; these are rods and cones. Rods are photosensitive cells specialized low level illumination and cones are cells specialized for the reception of color.

Directly in the back of the retina is a special structure called the Fovia. The Fovia is a small, dense grouping of Cone cells that is used for high resolution perception. It is in the Fovia that almost all our color perception occurs. What you might find interesting is that one aspect of the Fovia is remarkably similar to that of a color video camera; it has three types of "receptor" cells. Each type is sensitive to a different color. The diagram on the next page shows the spectral response of these different cone cells.

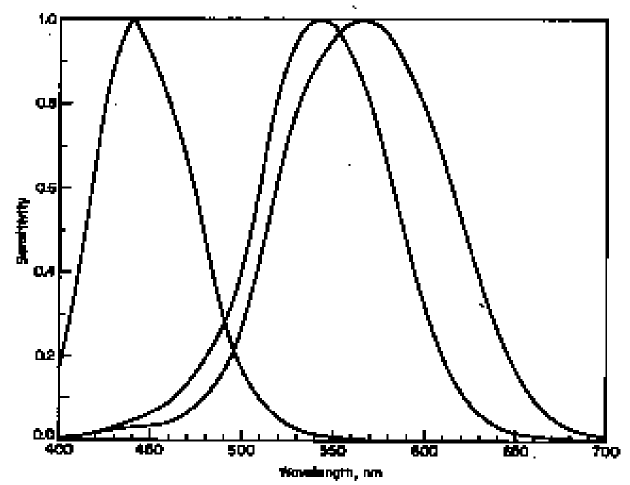
Visible Light

400 nm	Ultraviolet
450 nm	Violet
500 nm	Blue
550 nm	Green
600 nm	Yellow
650 nm	Orange
700 nm	
750 nm	Red
800 nm	Infrared



The Science Of Colorimetry

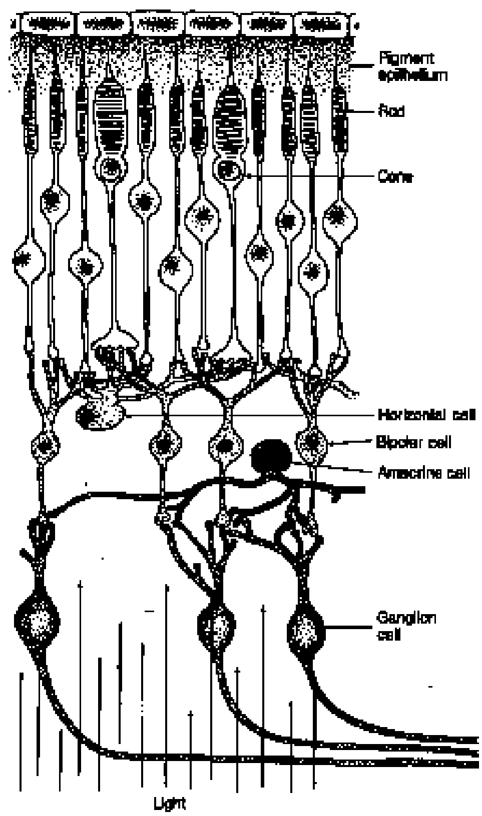
The science of color is a very complex subject. There are untold numbers of text books that deal in great detail with all the facets this science and they are stuffed with advanced mathematical concepts. What we will attempt here is the short course (very short course) of what one should know about the science of color as it applies to the video engineer.



Response Of Three Types Of Cone Cells

First, color is a phenomena that exists in our brain. As we examined previously we can identify various physiological structures that are responsible for color reception, B&W reception, etc but the bottom line is that we need to take this perception of color, whatever the physiological mechanism, and quantify it so it can be used in the design and manufacture of physical materials and display devices. The way this is done is by using the concept of “color space”.

A color space is a method by which we can specify, create and visualize color. As human beings, we may define a color by our perceptual attributes of brightness, hue and colorfulness. A computer will define a color in terms of the excitations of red, green and blue phosphors on the CRT faceplate. The printing industry defines a color in terms of the reflectance and absorbance of cyan, magenta, yellow and black inks on the paper.

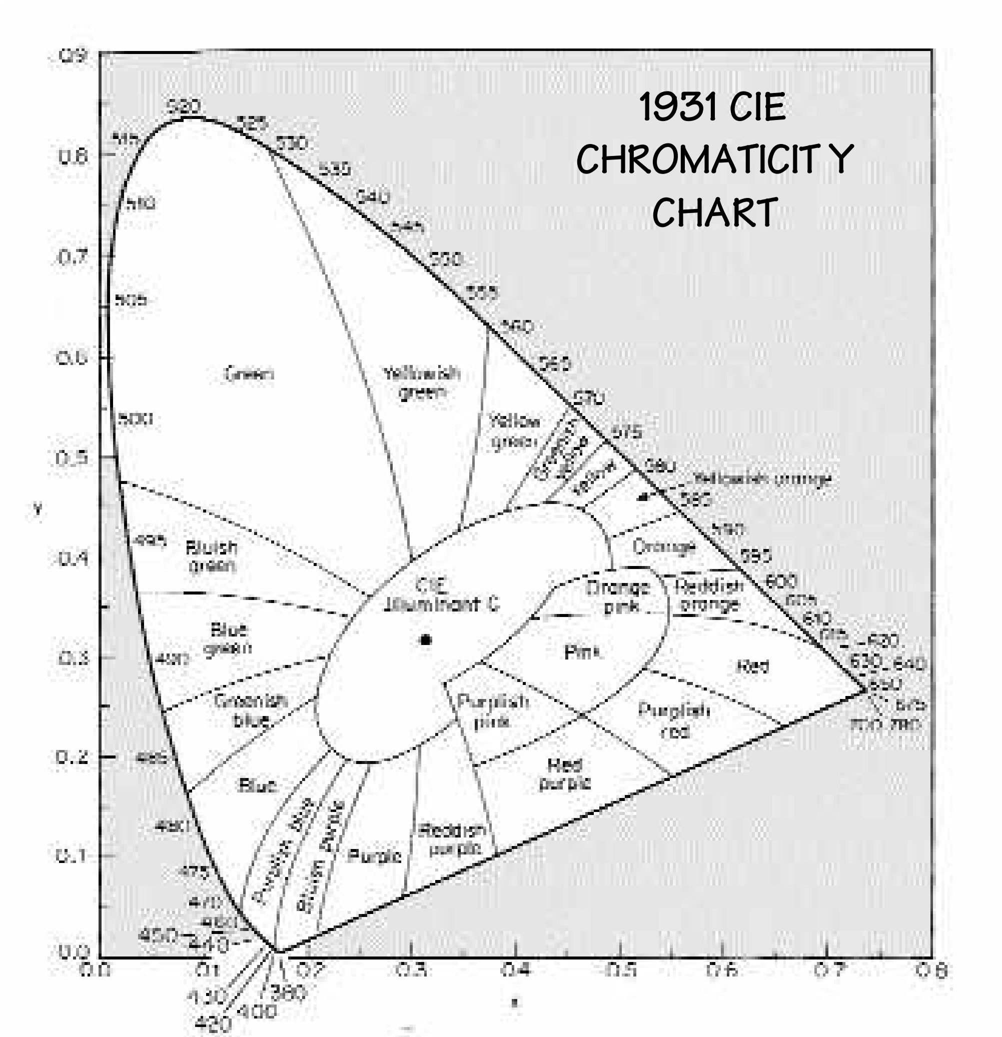


If we imagine that each of the three attributes used to describe a color are axes in a three dimensional space then this defines a color space. The colors that we can perceive can be represented by the CIE system, other color spaces are subsets of this perceptual space. For instance the RGB color space can be visualized as a cube with red, green and blue axes. This cube lies within our perceptual space, since the RGB space is smaller and represents less colors than we can see.

There actually many color spaces that are popular and several have a direct correlation with video displays. Let’s look at a few of the most common ones

1) RGB (Red, Green, Blue)

The RGB color space is an additive color system based on trichromatic theory, commonly used by CRT displays where proportions of excitation of red, green and blue emitting phosphors produce colors when visually fused.



The CIE Chromaticity Chart is a standard color space. In 1931 CIE defined a human "Standard Observer", based on measurements of the color-matching abilities of the average human eye. Using data from laboratory measurements, a system of three primaries, XYZ, was developed in which all visible colors can be represented using only positive values of X, Y and Z. The Y primary is identical to Luminance, X and Z give color (chroma) information. This forms the basis of the CIE 1931 XYZ color space, which is fundamental to all colorimetry. Values are normally assumed to lie in the range [0;1]. Colors are rarely specified in XYZ terms, it is far more common to use "chromaticity coordinates" which are independent of the Luminance (Y).

2) CMYK (Cyan Magenta Yellow Black)

A subtractive color space commonly used in printing and photography. Printers often include the fourth component, black ink, to improve the color gamut (by increasing the density range), improving blacks. CMYK color spaces are difficult to transfer properly from RGB color spaces.

3) HSL (Hue Saturation and Lightness)

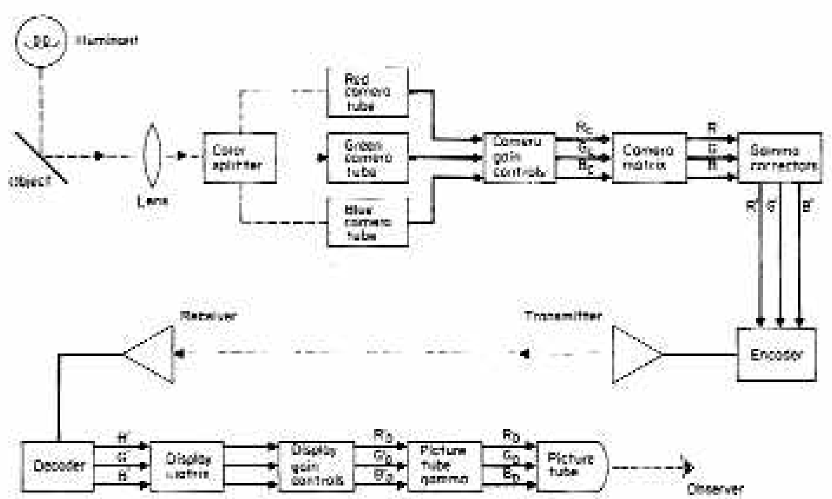
Actually there are many HSL types of color spaces, some examples are HSI (intensity), HSV (value), HCI (chroma/colorfulness/intensity), HVC, TSD (hue saturation and darkness) etc etc.

4) YIQ, YUV, YCbCr

These are the television transmission color spaces. They separate luminance from chrominance (lightness from color) and are useful
in compression and image processing applications. YIQ and YUV are, if used according to their relative specifications, linear.

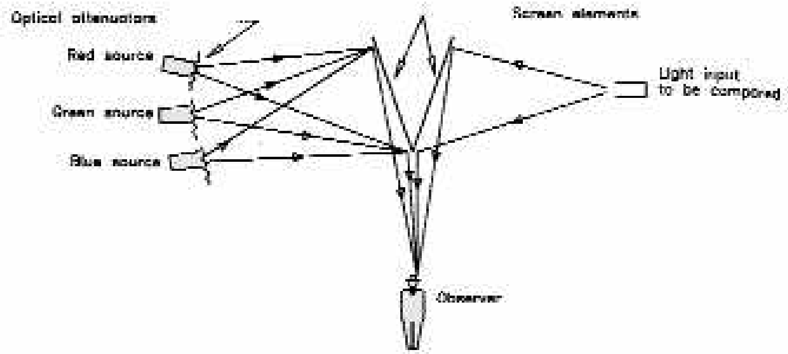
Measuring Color Spaces

There are many ways of quantifying the perception of color. For our purposes, the best method to consider is the “Tristimulus” method. The theory is actually pretty simple: By utilizing three different colored primarys thousands of other different colors can be made. It is important to note, that there is no specific uniqueness to the color of the primarys. Any three primarys can be used to create color as long as they are complementary. The way that the three primarys are combined is determined via the use of a color matching device. The way it works is that an observer views a split screen panel. (see the diagram on the next page). One side is illuminated with the color being matched and the other with a combination of the three primarys. This is done for all the colors of interest and a mathematical matrix is developed that defines how the three primarys are combined in order to produce different colors.



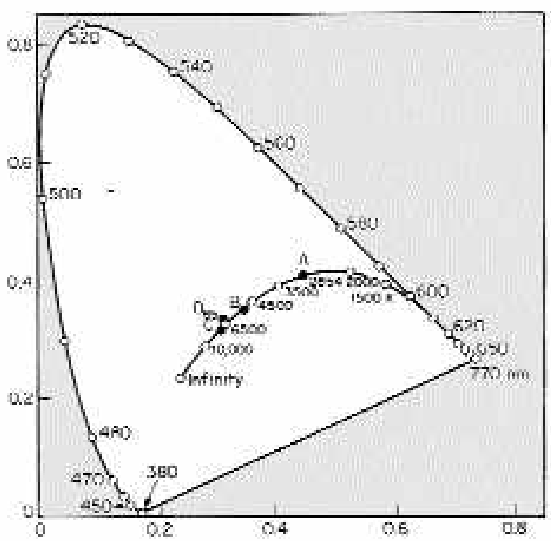
Camera encoding and receiver decoding matrixes all deal with the transformation of color spaces

Measuring the matching functions of three primary illuminating colors is done with a half field matching device . One on half of the field the obser ver sees a color to be matched. They then adjust the amounts of the three primarys until they see a match

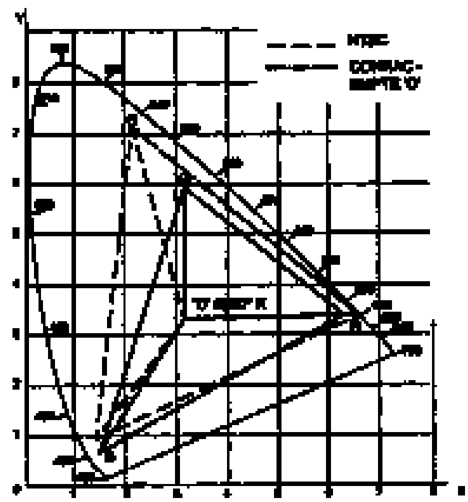


What is White?

In colorimetry, we say that the white point of a system is the color at which all three of the tristimuli (RGB or XYZ etc) are equal to each other. The white point color does not have to be perceptually white, it is only the balance color for the system. You can think of the white point as being the color of the illuminant for any scene represented by that system but there is no reason why all color systems should use exactly the same white point. The TV system in Europe uses D65 as its white point while the original NTSC used Illuminant C. Both are equally valid as white points, they are only 10.34 dC* CIELuv units apart. Below we show the position on the 1931 CIE chromaticity chart the position of illuminant C and D6500. As you can see they are very close to each other.

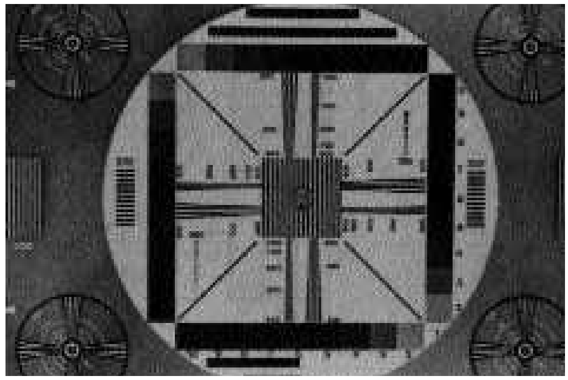


Position Of White Illuminants



Phosphor Gamuts

UNDERSTANDING VIDEO RESOLUTION



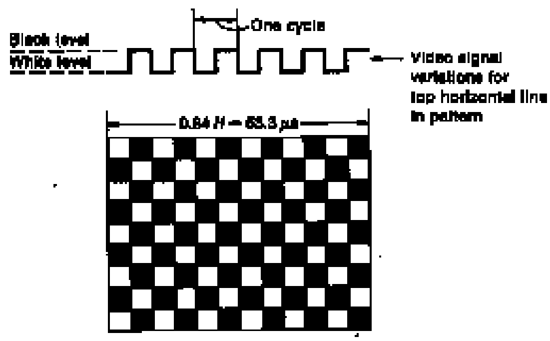
The term resolution is used to quantify a display device's ability to reproduce fine detail in a video image. In a raster scanned CRT-based device, there is a significant difference between horizontal and vertical resolution.

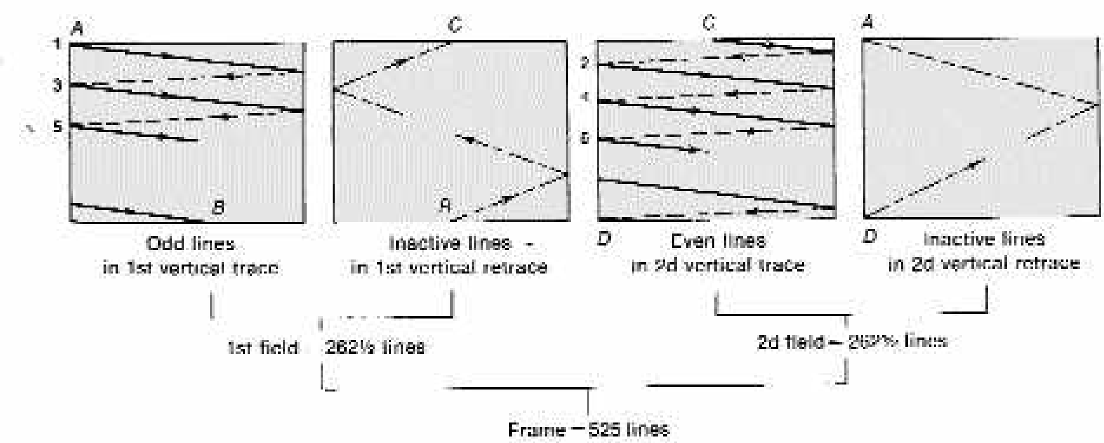
Vertical Resolution:

Below we have a diagram that shows how an electron beam is "scanned" across a picture tube faceplate to form a NTSC video image. The technique of interlacing the images was developed to minimize that bandwidth of the signal and reduce flicker in the display. The maximum vertical resolution is simply the number of scan lines visible in the display. This number is the number of horizontal scan lines (525) minus the retrace lines (43). Thus the maximum vertical resolution of a NTSC display is 525 -43 = 482 lines.

Horizontal Resolution:

Horizontal resolution is a completely different mechanism. The horizontal resolution of a CRT-based display is limited by how faster you can turn the electron beam on and off to form alternating horizontal line pairs



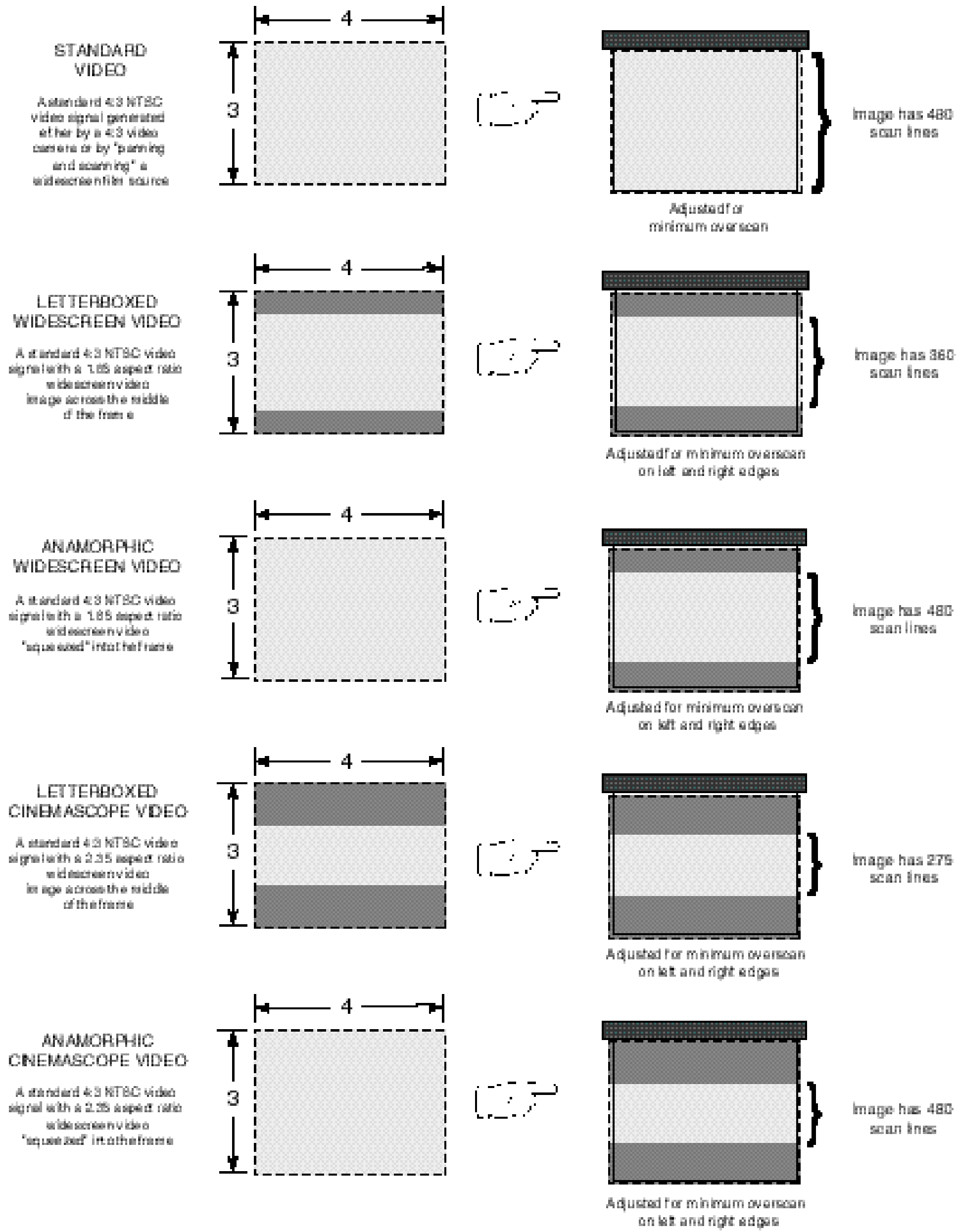


Horizontal Resolution of Various Video Sources

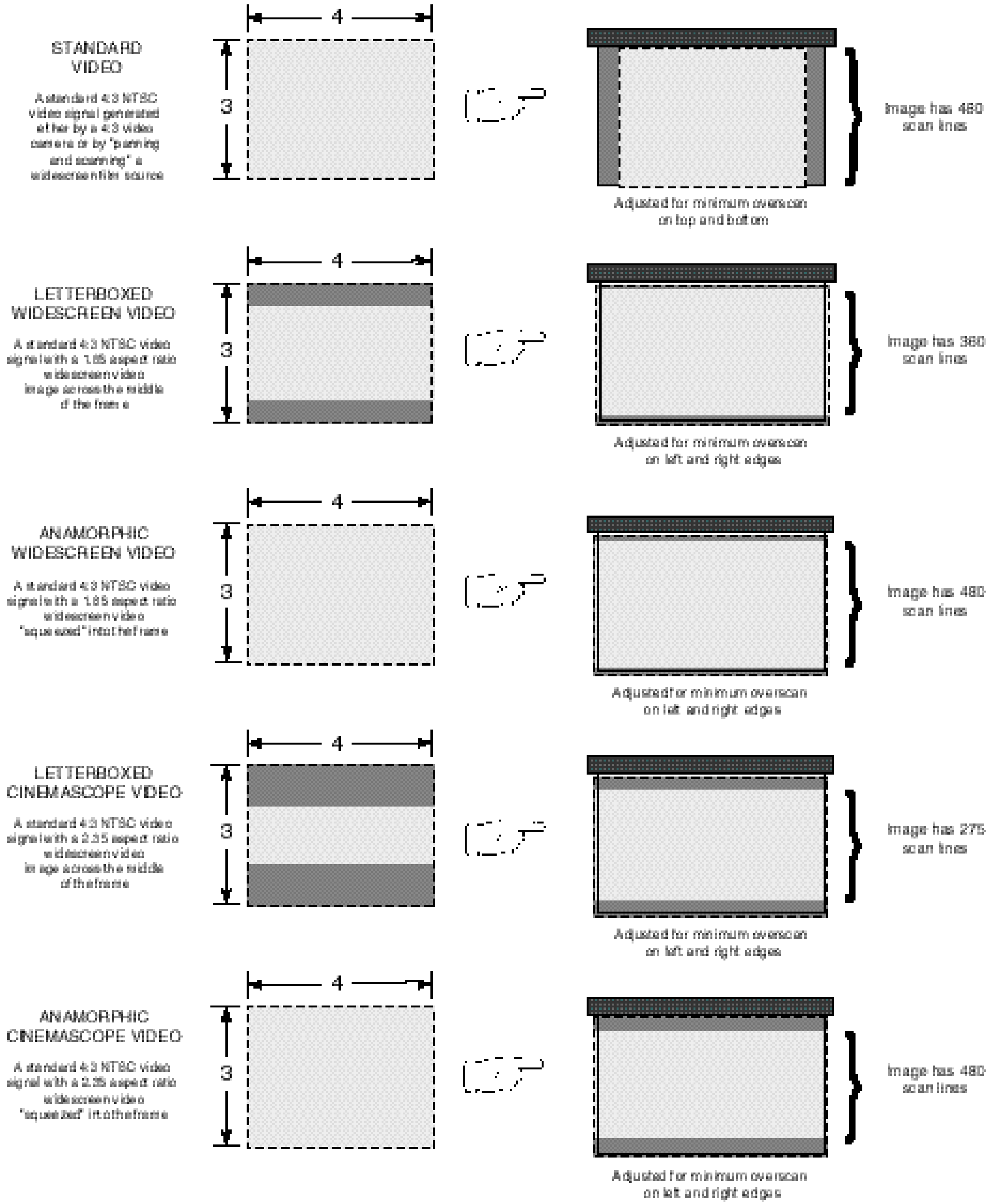
Signal Source	Horiz Resolution
VHS Tape	240
Terrestrial Broadcast	330
Laserdisc	425
DVD	480
Satellite	500

COMPUTER/GRAPHICS ADAPTER		RESOLUTION (H/V)	HORIZONTAL FREQUENCY	VERTICAL FREQUENCY
	VGA	640/480 - 640/400	31.5 Khz	60/72 hz
	SVGA	800/600	35.5 Khz	60/72/76 hz
	XGA	1024 x 768	39.4 Khz	60/72/76 hz
	SXGA	1280 x 1024	37.9/48.4/61 Khz	60/72/76 hz

THE GRAND ALLIANCE DIGITAL TELEVISION FORMATS	Horizontal Pixels Across Screen Width (Horizontal Resolution)	Viewable Scan Lines (Vertical Resolution)	Image Aspect Ratio	Picture Refresh Rates
High Definition Television (HDTV) 1080P/1080I	1920	1080	16:9	24/30Hz - Progressive 60Hz - Interlaced
High Definition Television (HDTV) 720P/720I	1280	720	16:9	24/30/60Hz - Progressive
480P/480I and Others	704	480	4:3-16:9	24/30/60 Hz - Progressive 60Hz - Interlaced
Standard Definition Television (SDTV)	640	480	4:3	24/30/60Hz - Progressive 60 Hz - Interlaced



Projecting different aspect ratio video sources on a 4:3 screen with a front projector operating at standard video rate (15.75 kHz)



Projecting different aspect ratio video sources on a 16:9 screen with a front projector operating at standard video rate (15.75 kHz)