CHAPTER 13
The Color Information

13.1 Requirements for Color TV:

We live in a colored world not in a black and white one. It is only at very low intensities of light that the eye ceases to discern colors, and hence, recognizes objects in shades of gray. In the treatment of TV, we started with monochrome TV, only because it is simpler. As color TV was developed, the need for compatibility has been recognized, so that the owner of a black and white receiver could still receive a monochrome signal. Also, the color TV receiver should - as well - be able to display - in black and white - monochrome programs. To do this we must ensure that:

1- Color transmission occupies the same overall band as in monochrome transmission.
2- Color TV system must have the same line and field frequencies and the same sync pulses, and have the same sound and luminance carrier frequencies as in a monochrome signal.
3- The color information is embedded in the composite video signal, such that it appears only in a color TV set and disappears otherwise, without affecting the monochrome signal.

To see how there requirements are achieved, we must learn first more about colors.

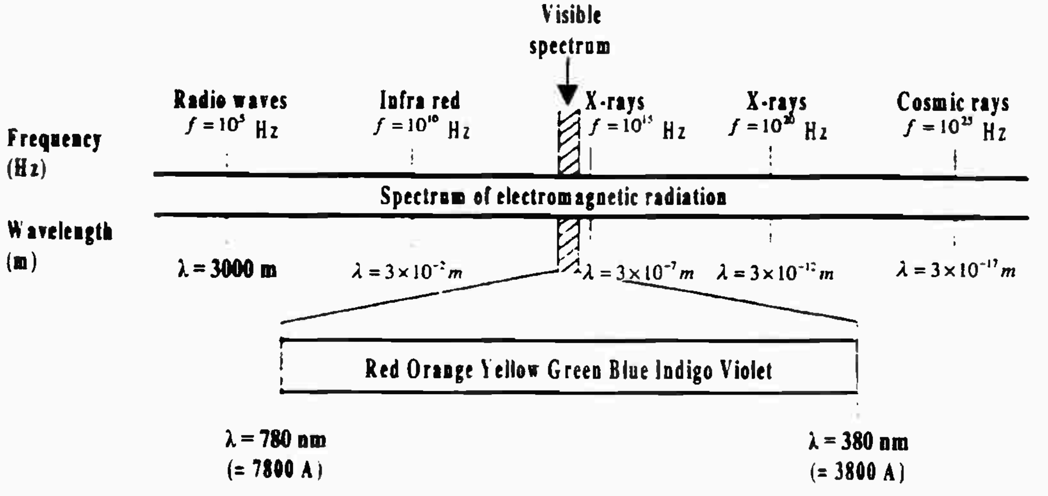


Fig. 13.1 Electromagnetic radiation spectrum

13.2 Origin of Colors:

The electromagnetic spectrum extends from 10^5 Hz to above 10^{25} Hz. The visible part of the spectrum centers around the frequency of 5 X 10^{14} Hz, and spreads from λ = 7800A° (red) to 3800A° (violet) (Fig 13.1). These are the limits set by the eye. Each light component is said to be monochromatic. When all components of the visible spectrum reach the eye, simultaneously, we see white light. But when white light passes through a medium it refracts. Each frequency component refracts differently. The shorter wavelength refracts more.

13.3 The Human Eye:

The eye is very much like a camera. Its opening (or aperture) is called the pupil. The diameter of this aperture increases under low light intensity to allow in more light, and decreases to a very small size under high light intensity. The iris is a muscular ring that controls the pupil. The sharpest image is formed when the aperture is small.

The lens focuses the image on the retina. The retina consists of a large number of light sensitive elements called receptors, which act as transducers, converting optical signals to electrical signals. These light sensitive elements are two types; rods and cones. Rods are sensitive only to the intensity of the incident light and not to color. Cones are sensitive to color. They do most of the action during day light. At night, the rods alone are active. They are 10000 times more sensitive, but they are monochrome.

Exactly opposite to the center of the lens, is the fovea (1 mm^2 diam.) It consists only of cones (about 160000 cones / mm^2). Each has a separate nerve fiber going to the brain in the optic never. The fovea is the area of maximum visual resolution not maximum sensitivity. When the eye concentrates on a small detail, it is the fovea that becomes responsible for vision. Away from the fovea, the cells no longer have individual nerve fibers, but they are arranged in groups with several cells sharing one fiber. The human eye is extraordinarily rich in the density of receptor cells. The human eye has 125 million receptors, while in TV, we have around 250,000 cells. There are 3 million cones in the eye and 1 million individual fibers in the optic nerve. The spot where the optic nerve is bunched is called the blind spot. Notice that part of the scene on the blind spot in one eye is still seen by the other eye, and small movements of the eye shift the image, so that the blind spot does not really affect seeing the scene (Fig. 13.2).

However, the eye is not uniformly sensitive over the visual spectrum. Fig 13.3 shows the relative response of the average eye to light of constant luminance at various wavelengths. The curve peaks in the green / yellow area. Incidentally, this is the same area where the luminance of sunlight peaks. Near dark condition, the peak moves more into the blue. Our ability to distinguish a variety of different colors might suggest that we have an equal number of different types of cones in the retina, with each type sensitive to a certain wavelength. In fact, creating the color impression is not only a result of shining a monochromatic light on the retina.

Almost all colors can be matched by mixing only three colored lights (red, green, and blue). These are called primaries. It is true that there are only three types of cones, each having a different response curve. But the three response curves overlap, so that the spectral colors may be produced either by only one type or by the superposition of the responses of two types (Fig. 13.4). Distribution of receptors on the retina is different for rods and for cones (Fig 13.5). The fovea has about 160000 cones/mm^2 and no rods. It is one region of high acuity and direct communication to high brain centers. Cones are of no use at night. At night, our vision is not very sharp, we see mostly excitation shades of gray due to rods. It is certain that the simultaneous excitation of red and green cones gives the same mental impression as that from monochromatic yellow.

When we see an object as green in daylight, it is only the reflected part of sunlight falling on it that is green, meaning that the remainder of the spectrum is absorbed in the object. Grass does not look green under sodium light, because such light does not contain green for grass to reflect.

There are many more colors which do not appear in the spectrum as monochromatic colors. There are called nonspectral colors, and may be obtained by mixing monochromatic colors.

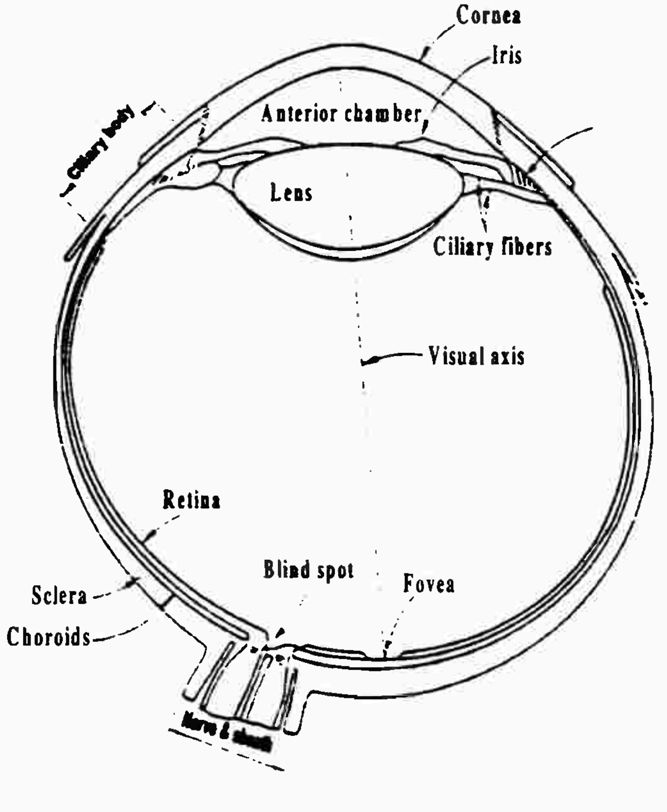


Fig. 13.2 A simplified diagram of a cross section of the human eye.

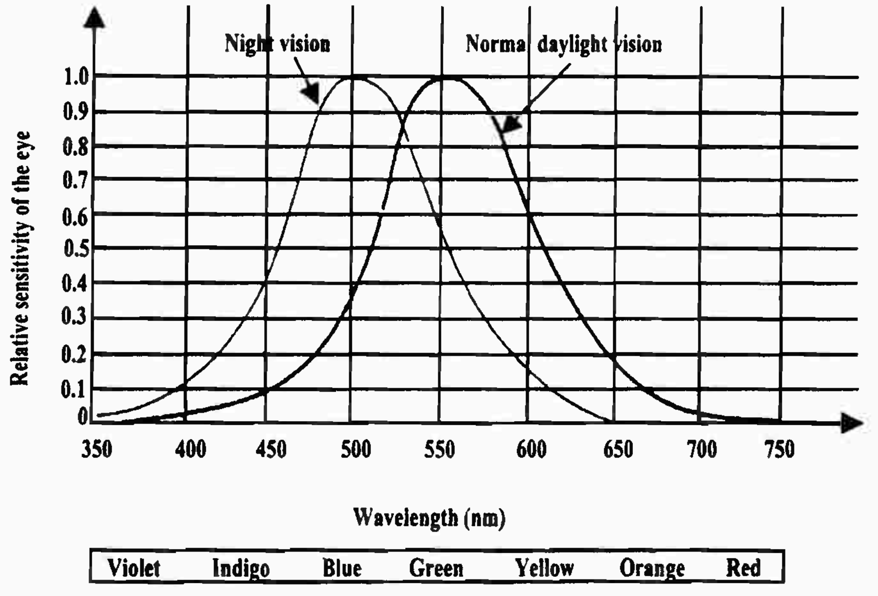


Fig. 13.3 Relative sensitivity of an average human eye to different wavelengths

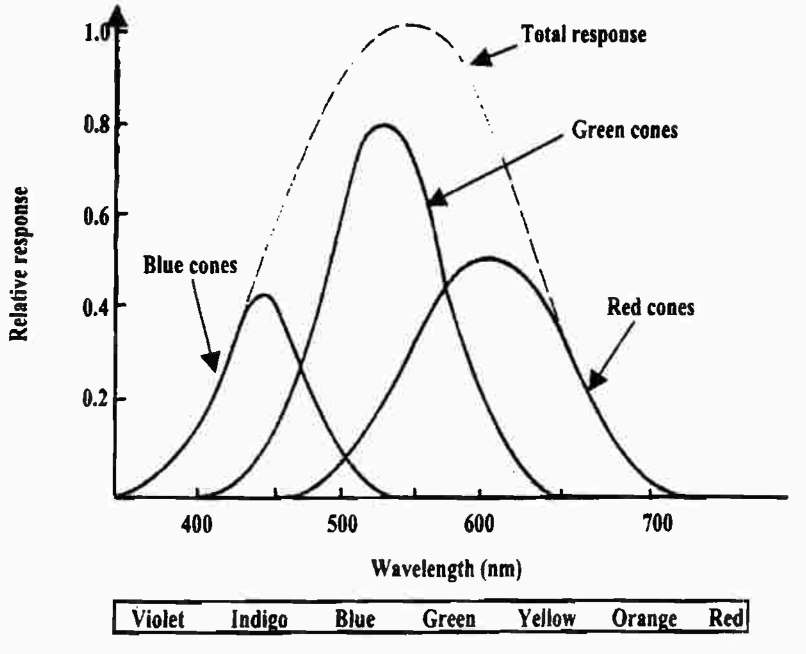


Fig. 13.4 Relative sensitivity of cones in the retina

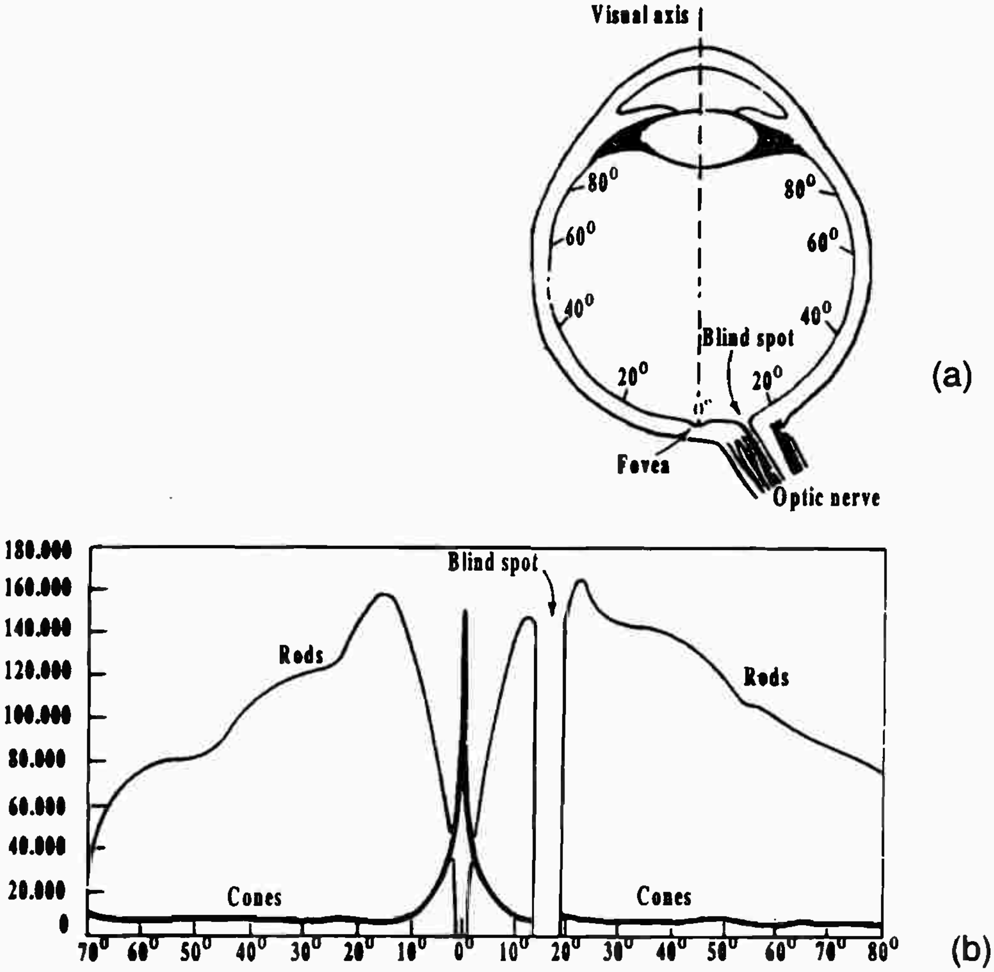


Fig. 13.5 Distribution of receptor cells in the human eye
a) cross section showing fovea and blind spot
b) angular distribution of rods and cones

13.4 The Eye of the Mind:

Let us do a simple experiment. We bring a slide projector which projects a slide onto a wall or a screen. Let us bring a white stick and put it in the way of the light beam. We move the stick slowly. the stick intercepts on its surface a line of the image. Let us move the stick fast up and down. We see the image formed in full in space, without the need for a wall or a screen. But we know all too well that there is no way that the stick could form the image in full at once on its surface. It forms the image, though, line by line. However, somehow, we are led to believe that we see a full image in front of us. This is the same principle of TV, where raster is performed line by line, and the image is, thus, constructed line by line. The eye - being just a camera - transmits the image formed on the retina onto the brain, where the actual sensation of vision takes place. Actually, it is the brain that processes the information, and is responsible for seeing, recognizing and comprehending the scene. Understanding exactly how this is done eludes us. But we can gather some information that will give us a very sketchy idea about the very complex mechanism of perception, concerning how the brain processes information from the sensory organs, taking as a special case here the visual system.

The two eyes collect information from the visual environment with a total of 250 million individual receptors, and send the information to the brain over 1.6 million nerve fibers. The two different types of receptor systems complement one another. The cone system is a high resolution system responsible for color information. The rod system is sensitive to light intensity with limited resolution, and insensitive response to color. The neural cells that process the information and communicate with one another are called neurons.

A neuron consists of a cell body and an axon (or nerve fiber) that connects the cells to one another. Junctions between neurons occur on the cell body or on spine-like dendrites. The retina might be considered as a network of neurons. There are cells that function to interconnect adjoining areas. These cells are called horizontal organization of the retina. Some cells carry signals produced at the retinal detectors toward the brain. These cells are called vertical organization of the retina which end up with ganglion cells. There are about 800000 of them. Their axons are several inches long, and they travel from the eye to the brain. The axons of the ganglion cells make up the optic nerve. Signals from the receptor cells go vertically up through two synapses, first between the receptor itself and a bipolar cell, and then between the bipolar and a ganglion cell. At the same time, horizontal cells make connections among the receptors themselves and modify the activity at the junction between the receptors and the bipolar cells. A second level of horizontal processing is performed by amacrine cells which modify the activity of the junction between bipolar cells and ganglion cells.

The density of interconnections varies in different parts of the retina. In the periphery, a single ganglion cell may receive information from thousands of rods. At the central fovea region, an individual cone may connect directly through a single bipolar cell to an individual ganglion cell (Fig. 13.6). Each ganglion cell of the retina contributes a fiber to the optic nerve. The 800,000 fiber cable has the thickness of a pencil. The nerve fiber leaving each eye crosses without interruption at a location called the optic chiasma. All the fibers from the left half of each retina go to the left hemisphere of the brain. All the fibers from the right half of each retina group together and go to the right hemisphere of the brain. This regrouping at the optic chiasma splits the visual scene into two halves. The parts of the visual scene to the left half of the fovea end up at the right half of the brain. Note that the lens reverses the visual image. Thus, an object on the left is focused on the right half of the retina, and consequently, to the right hemisphere of the brain (Fig 13.7).

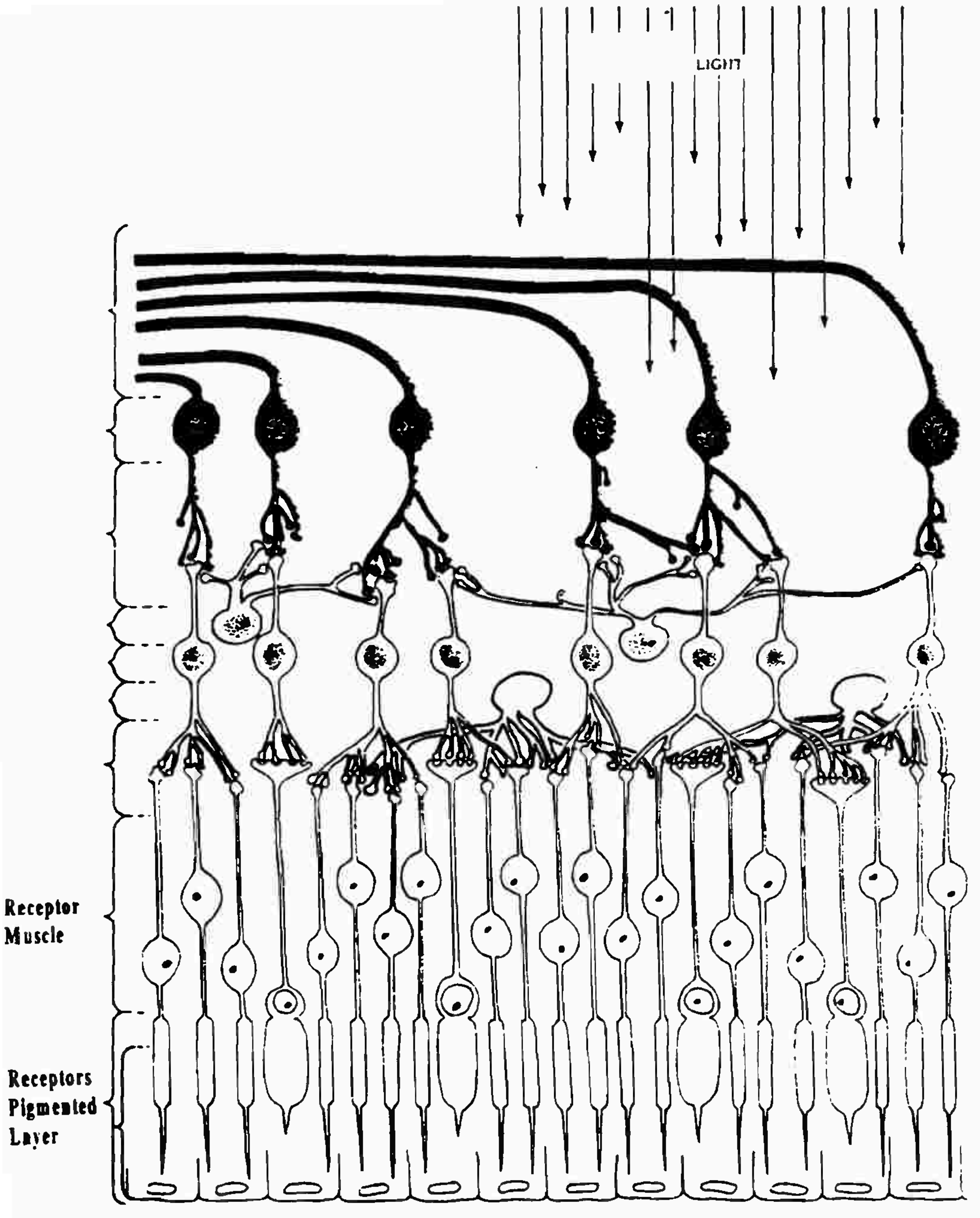


Fig. 13.6 Cell networking at the retina

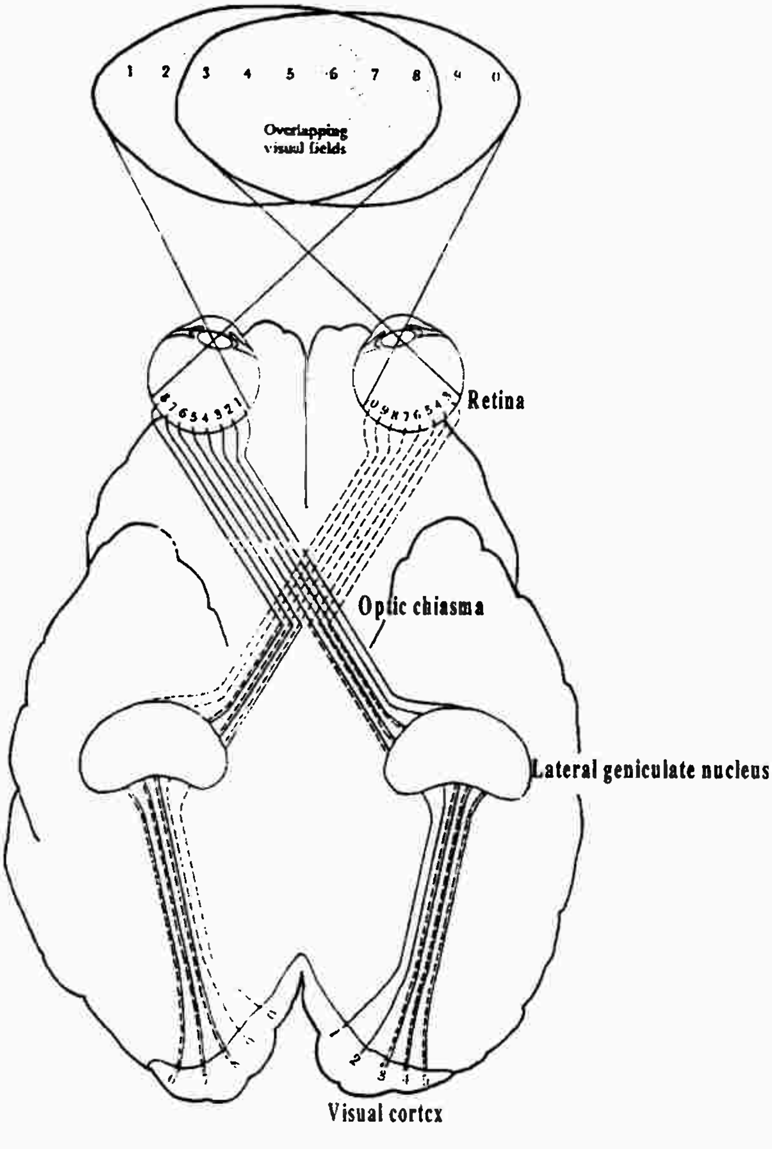


Fig 13.7 Pathway to the brain

The primary emphasis in the processing of the visual image is concentrated upon the central part of the visual field. In the visual cortex, more than 50% of the neurons appear to be concerned with the central 10% of the visual field, i.e., only a small part of the visual scene is analyzed in great detail. The periphery of the eye is more sensitive to light intensity than in the center, but it is not as responsive to the fine details of the scene - or to color information - as the fovea. There seem to be two distinct channels.

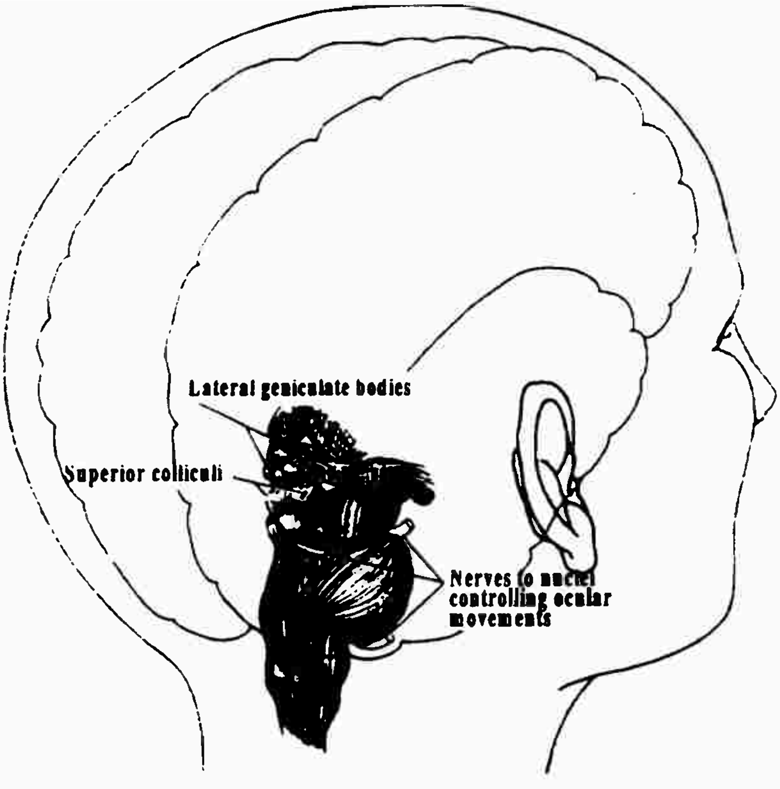


Fig 13.8 Localization and pattern recognition

One set of nerve fibers travel from the eye to the brain, then breaks away from its neighbors and - rather than going to the lateral geniculate nucleus with the rest - ends up at the superior calliculus. The super calliculus seems to allow for information about corresponding spatial location, hence, is responsible for localization. The visual cortex seems to be responsible for pattern recognition (Fig 13.8).

The direct flow of information in the retina is from photosensors to bipolar cells to the ganglion cells. Ganglion cells fire action potentials (electrical signals), which travel along the optic nerve to the brain. The horizontal cells and the amacrine cells communicate laterally across the retina. Horizontal cells connect neighboring pairs of photosensors and bipolar cells. Thus, communication between photosensors and bipolar cells can be influenced by the amount of light absorbed by neighboring photosensors. This lateral flow of information sharpens the perception of contrast between light and dark patterns falling on the retina. Amacrine cells connect neighboring pairs of bipolar cells and ganglion cells. One role of amacrine cells is to adjust the sensitivity of the eyes according to the overall level of light falling on the retina. When light levels change, amacrine cell connections to the ganglion cells help the ganglion cells remain sensitive to temporal changes in stimulation.

Thus, even with large changes in background illumination, the eyes are sensitive to smaller more rapid changes in the pattern of light falling on the retina. What does the eye tell the brain in response to a pattern of light falling on the retina? One aspect of information processing in the retina is convergence of information. There are more than 100 million photosensors in each retina, but only about 1 million ganglion cells sending messages to the brain. How is the information from all those photosensors integrated to form the messages sent to the brain by the ganglion cells? It is found that each ganglion cell has a well defined receptive field that consists of a specific group of photosensors. Stimulating these photosensors with light activates the ganglion cell. Information from many photosensors is integrated in this way to produce a single message.

The receptive field of each ganglion cell is divided into two concentric areas, called the center and the surround. There are two kinds of receptive fields, on-center and off-center. Stimulating the center of an on-center receptive field excites the ganglion cell, and stimulation of the surround inhibits it.

Meanwhile, stimulation of the center of an off - center receptive field inhibits the ganglion cell, and stimulating the surround excites it. Center effects are stronger than surround effects. The response of a ganglion cell to stimulation of the center of its receptive field depends on how much of the surround area is also stimulated. A small dot of light directly on the center has the maximum effect.

Ganglion cells communicate to the brain information about contrast between light and dark that fall on their receptive fields. The photosensors in the center of the receptive field of a ganglion cell are connected to that ganglion cell by bipolar cells. The photosensors in the surround send information to the center photosensors and thus, to the ganglion cell through the lateral connections of horizontal cells. Thus, the receptive field of a ganglion cell consists of a pattern of synapses among photosensors, horizontal cells, bipolar cells and ganglion cells. The receptive fields of neighboring ganglion cells can overlap greatly. A given photosensor can be connected to several ganglion cells. The eye sends to the brain simple messages about the pattern of light intensities falling on small circular patches of the retina. Cortical cells - called simple cells - are maximally stimulated by bars of light that have specific orientations. So, simple cells probably receive input from several ganglion cells whose circular receptive fields are lined up in a row. Complex cells seem to receive input from several simple cells that share a certain stimulus orientation, but they have receptive fields in different places on the retina. It seems that the brain assembles a mental image of the visual world by analyzing edges of patterns of light falling on the retina. This analysis is conducted in a parallel fashion. Each retina sends 1 million axons to the brain, but there are at least 200 million neurons in the visual cortex.

Each bit of information from a retinal ganglion cell is received by hundreds of cortical cells, each responsive to a different combination of orientation, position and even movement of contrasting lines in the pattern of light falling on the retina.

How do we see objects in 3D? Our two eyes see overlapping - yet slightly different - fields, i.e., we have binocular vision. The result of the division of axons in the optic chiasm is that all visual information from the left visual field goes to the right side of the brain. All visual information from the right visual field goes to the left side of the brain. Cells in the visual cortex are organized in columns. These columns alternate; left eye, right eye, left eye, right eye and so on. Cells closest to the border between two columns receive input from both eyes and are binocular cells. These cells interpret distance by measuring the disparity between locations where the same stimulus falls on the two retinas. When we look at an object, we can detect its shape, color, depth and movement. Where does all this information come together? A specific visual experience comes from the simultaneous activity in a larger collection of cells. In addition, most visual experiences are enhanced from other senses, and from memory as well. This explains why about 75% of the cerebral cortex is association cortex.

13.4 Color Models:

There are two types of mixing of colors. In TV, the color mixing is called additive. Colors may be created by mixing red, green and blue lights, such that:

Red	+	green	=	yellow
Red	+	blue	=	magenta
Blue	+	green	=	cyan
Red	+ blue	+ green	=	white

Red, green and blue are called primary colors. Yellow, magenta and cyan are known as complementary colors. If a complementary is added in appropriate proportions to one primary – which is not contained in that complementary color - (e.g. yellow + blue), white is produced.

Alternatively, color mixing may be done in a different mode. When white light is shining down on pigments which absorb parts of the spectrum and reflect the rest, we may express the following:

yellow	=	white	–	blue
magenta	=	white	–	green
cyan	=	white	–	red

Thus, we see the colors that are not absorbed by the pigments. When we add colors in this way, we have

yellow	+	magenta	=	white – blue – green = red
yellow	+	cyan	=	white – blue – red = green
magenta	+	cyan	=	white – green – red = blue

yellow + magenta + cyan = white – blue – green – red = black

This is called color mixing by subtraction. Yellow - for example- appears as such, because the pigment subtracts blue, leaving the red and green parts of the spectrum. Together, they look yellow. Magenta appears so, because green is absorbed, leaving red and blue. When the two pigments yellow and magenta are added, there is only one color which they both reflect, i.e., red. That is why it appears red. Primary colors in this case become yellow, cyan and magenta that are called pigments (or artists' primaries) to distinguish them from red, green and blue (TV and light mixing).

It is found that the eye behaves as though the outputs of the three types of cones are additive. Luminance is numerically equal to the sum of the luminance values of the three primaries. The property of the eye of producing a response which depends on the algebraic sum of the red, green and blue inputs is called Grassman's law. The luminous flux is measured in lumens, while the illumination is measured in lux (which is lumens /m^2).

The following luminance equation expresses the approximate quantities of the other color TV primaries, which are necessary to produce one lumen of white light,

$$1 lm\ of\ white = 0.30\ lm\ of\ red + 0.59\ lm\ of\ green + 0.11\ lm\ of\ blue \quad (13-1)$$

We define trichromatic units T such that eqn. (13-1) becomes:

$$1 lumen\ of\ white = 1T\ unit\ of\ red + 1T\ unit\ of\ green + 1T\ unit\ of\ blue \quad (13-2)$$

or

$$1 lm\ of\ white = 1T(R) + 1T(G) + 1T(B) \quad (13-3)$$

$1T$ unit of red = 0.3 lumens of red
$1T$ unit of green = 0.59 lumens of green
$1T$ unit of blue = 0.11 lumens of blue

Thus,

$3T$ units of white = $1T(R) + 1T(G) + 1T(B)$

or

$$1T(W) = \tfrac{1}{3}T(R) + \tfrac{1}{3}T(G) + \tfrac{1}{3}T(B) \quad (13-4)$$

This is a direct application of Grassman's law.

Color models have been developed to illustrate additive color mixing. One of these models is the color triangle. It is a diagram which allows the relationship between given primaries and the colors which may be obtained by mixing them to be illustrated in a simple form, so that any color may be exactly specified in terms of coordinates on the diagram. Fig.13-9 shows one equilateral triangle with the three primaries in the corners. The colors formed by mixing red and green are shown along the side RG. Yellow falls midway between red and green, with orange on one side of it and yellowish green on the other. Similarly, magenta falls between red and blue, and cyan is between blue and green. Contributions from all three primaries are needed to create all shades of color within the triangle. At the center of the triangle, the contributions of the three primaries are equal, so that this is the position of white (W). The two colors connected to any straight line drawn diametrically across the triangle to pass through W are complementary colors,i.e., together they form white (e.g. red and cyan or blue and yellow).

We must introduce here two more definitions. In Fig. 13.9, the point R represents pure red and is said to be fully saturated. On moving toward W along RW line, the red becomes diluted with white, so that pure red changes to pale pink (point P), and finally the red tint disappears altogether at W. A color is said to be desaturated when white is added to it. The word saturation expresses how much white is added to the color, while the word hue is used to describe the characteristic of color. Thus, to describe a given color impression, three quantities have to be considered. These are brightness (luminance), hue and saturation. A color triangle is two dimensional and shows only hue and saturation but not brightness. In Fig 13.9, point P represents a red hue of low saturation. Another dimension, i.e., out of the paper along a line perpendicular at point P would be needed to show the brightness of the red hue at P.

In a TV signal, the brightness is transmitted as the luminance signal. It is these other two properties (hue and saturation) which need to be specified in color TV signal. This is called the chrominance (color – bearing) signal, which has to be transmitted along side the luminance signal. That is how the color at a point in the scene may be specified in totality in terms of brightness, hue and saturation. In monochrome TV signal, brightness and saturation are needed to give all shades of gray in the scene.

It is often more convenient to use a right – angled triangle (Fig.13.10). Red is plotted along the X axis and green along the Y axis. The amount of blue present in a given hue is deduced by a simple calculation of Grassman's law. Since $1T$ unit of each hue has been specified, the sum of the red, green and blue components of a given hue is unity. Hence, the number of T units of blue is found by subtracting the sum of the red and green T units from 1 .

Referring to Fig. 13.10, the hue at point Q is specified by quoting the coordinates $R = 0.5$, $G = 0.2$. Thus, $1T$ unit of hue, at Q contains $0.5T$ (red) and $0.2T$ (green). The amount of blue is

$$1-(0.5+0.2)=0.3T$$

Thus, $1T$ unit of Q is given by

$$1T(Q)=0.5T(R)+0.2T(G)+0.3T(B)) \qquad (13-5)$$

At point P, the hue is located at the X axis, i.e., $x = 0.25$, $y = 0$. Thus, $1T$ unit of hue at P consists of $0.25T(R)$ and $0T(G)$, and the amount of blue is $(1-0.25)T = 0.75T(B)$

Thus, we note that the coordinates x, y, z represent

$$x = \frac{X}{X+Y+Z} \qquad (13-6)$$

$$y = \frac{Y}{X+Y+Z} \qquad (13-7)$$

$$z = \frac{Z}{X+Y+Z}, \qquad (13-8)$$

where X is the luminosity of red, Y is the luminosity of green and Z is the luminosity of blue.

The triangles discussed so far are useful, but are limited in application, since they only show the hues obtainable from the specified primaries. No three parameters exist from which all colors of the spectrum and all the non-spectral colors (the purples) can be produced. The CIE diagram (Fig 13.11) has hypothetical primaries. This allows an all-embracing color model. The fictitious primaries in this horse shoe shaped chromaticity diagram are situated at the corners of the triangle and all the spectral colors fall along the curved part of the diagram which lies within the triangle.

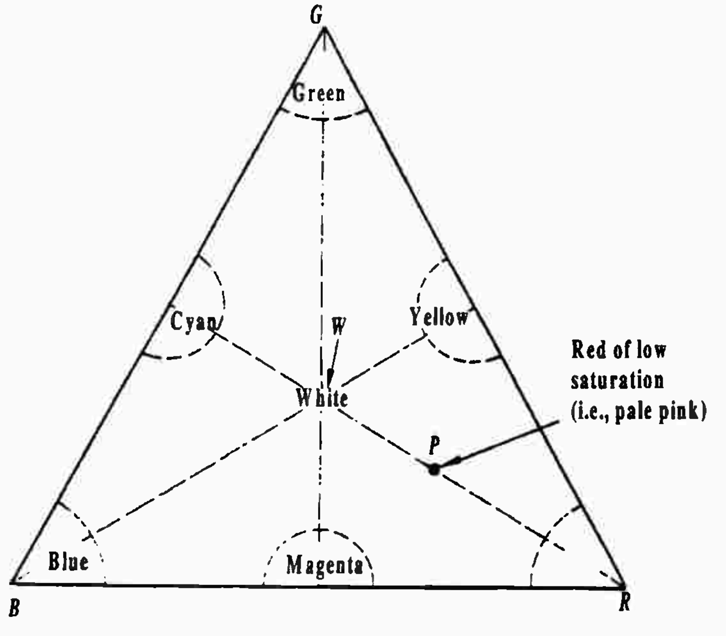


Fig. 13.9 Additive mixing color triangle

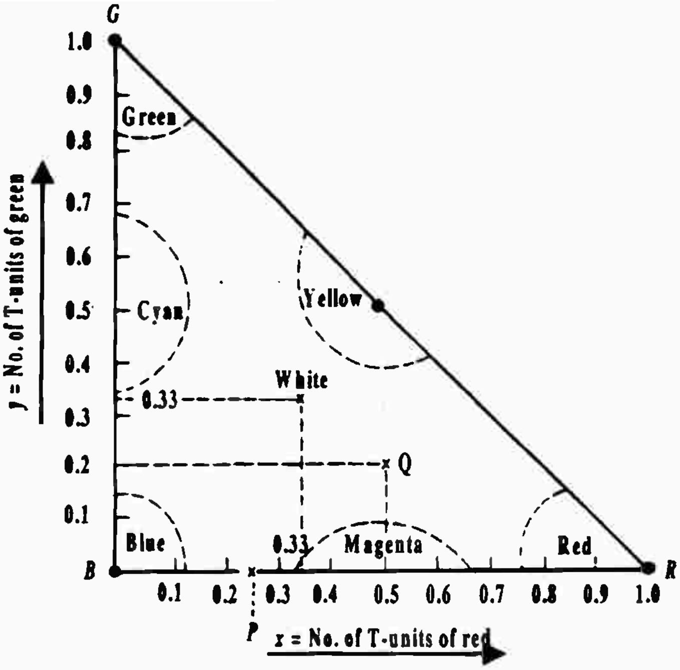


Fig 13.10 Right angled color triangle

This curved part is marked in nanometers to allow monochromatic colors to be identified by reference to their wavelengths. No such calibration appears on the base of horse shoe, because it is there that the non-spectral purple colors are situated, and for these non-monochromatic colors, wavelength has of course no meaning. The full line triangle RGB shows the range of hues which can be produced by a color TV system using the primaries in use (UK) and the dotted triangle shows NTSC primaries. The coordinates are given in table 13.1

Table 13.1 CIE coordinates

Color	Present primaries used in UK and EBU			Primaries in traditional NTSC		
	x	y	Fig. 13.10 reference	x	y	Fig. 13.11 reference
Red	0.64	0.33	R	0.67	0.33	r
Green	0.29	0.60	G	0.21	0.71	g
Blue	0.15	0.06	B	0.14	0.08	b

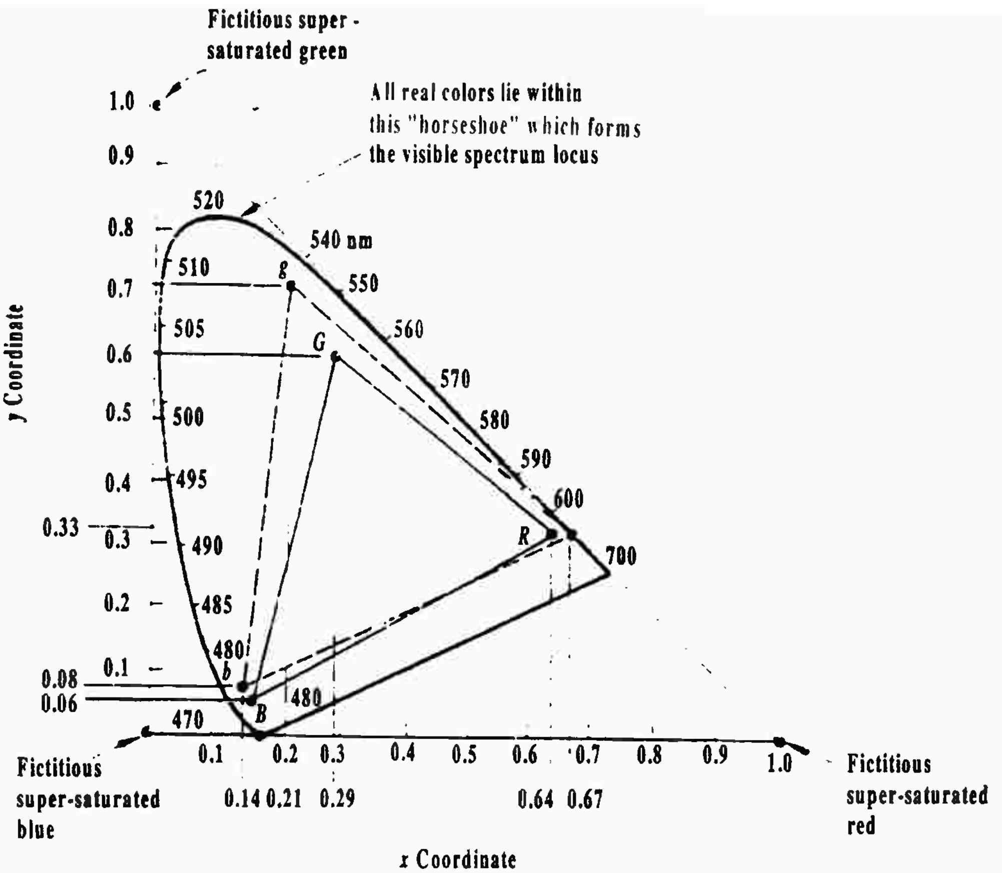


Fig 13.11 CIE Chromaticity diagram

Fig. 13.12 shows the CIE diagram divided in regions of recognizable hues. Fig. 13.13 shows a 3D model which includes brightness. This is called the double coned model. It describes all parameters of saturation, hue and brightness.

13.6 The TV color signal:

A complete color signal in color TV consists of two components: a monochrome signal (Y) (called luminance or brightness signal) and a signal which carries color information. The monochrome signal is equivalent to a conventional monochrome TV signal, and is given as in eqn. (13-1).

The variations in the monochrome signal reflect the variations in amplitude of the picture signal, and hence, the changes in light intensity on the CRT screen. The second component of the color TV signal is the color signal (called chrominance or chroma signal). The color signal takes the form of a subcarrier and an associated set of side bands. The subcarrier frequency is nearly 3.58 MHz. Next, we modulate this color carrier (called color subcarrier) with the proper signal. This would mean the need to transmit R, G, B components of each pixel. Modulating the subcarrier with three different signals might prove to be an uneasy task. We must, however, remember from eqn. (13-10) that R, G, B are not independent. In fact, we need to know only two components and with the knowledge of Y – which is transmitted anyway for luminance information - we can deduce the third. In fact, what needs to be transmitted is the difference between any two of three signals $B-Y$, $R-Y$ or $G-Y$. The monochrome signal Y is passed through LPF (Fig. 13.14) since the color signals are concerned with low frequencies. The Y signal is then amplified and inverted and added to G, R, B signals. At the receiver, the original R, G and B can be obtained by adding noninverted Y to $G-Y$ to get G, to $R-Y$ to get R, and to $B-Y$ to get B.

The luminance signal-weighted in the same proportion as the response of the human eye-is given by

$$Y = 0.30R + 0.59G + 0.11B \qquad (13-9)$$

The chrominance signal $\upsilon_{ch}(t)$ can be written as

$$\upsilon_{ch}(t) = (R - Y)\cos\omega_{cs}t + (B - Y)\sin\omega_{cs}t\,, \qquad (13-10)$$

where ω_{cs} is the color subcarrier

Thus, $R-Y$ and $B-Y$ voltages are used to modulate separate carriers each at 3.58 MHz, but 90^{o} out of phase. If we represent each modulated carrier by a phasor (Fig. 13.15), the phase angle of the resultant will be governed by the color or hue of the picture, whereas the amplitude or length of the resultant phasor will determine the saturation of the colors. Hence, special phase control circuits must be incorporated to compensate for any phase shift, which might introduce errors in the color in the receiver.

We note that while the Y signal extends over the entire video frequency range (0-4 MHz), the color subcarrier is 3.58 MHz with a series of sidebands, since the two carriers are amplitude modulated by the color difference signals. These sidebands contain the color information and extend above and below 3.58 MHz, depending on the band of frequencies contained in the $R-Y$ and $B-Y$ modulating voltages. It has been determined that the eye responds to the color signal within a frequency range up to 1.5 MHz. Thus, the portion of the range from 1.5-4 MHz is monochrome, while the sideband frequencies of the color modulating voltages $R-Y$ and $B-Y$ extend from 0 to 1.5 MHz, the 0 being taken at the color subcarrier of course.

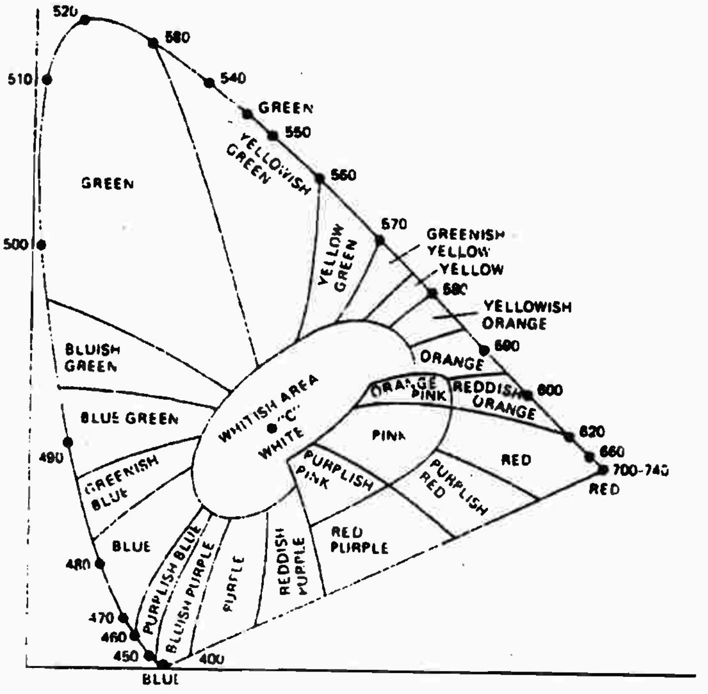


Fig 13.12 CIE chromaticity diagram with color regions shown

It has been found that the human eye sees a full color range only when the area of the object being viewed is relatively large. As the size of the area or object decreases, it becomes more difficult for the eye to discern colors. We can safely say that the eye needs three primary colors for viewing large objects or areas, but it can get along very well with only two when viewing a medium size area. When the area is very small, the eye can discern only changes in brightness, i.e., shades of gray. In effect, the eye becomes color-blind.

We may then modify our conditions for the color signal accordingly. Large objects require the three primary colors. Such an object may be produced by low video frequencies - say up to 0.5 MHz. Medium size objects require video frequencies ranging from 0.5 1.5 MHz. In this case, only two colors are needed. We, therefore, need two color signals, one that has a bandpass only up to 0.5 MHz and one that has a bandpass from 0 to 1.5 MHz.

We note from eqn. (13-9) that

$$R - Y = R - 0.59\ G - 0.30\ R - 0.11\ B$$
$$= 0.70\ R - 0.59\ G - 0.11\ B \qquad (13-11a)$$

while

$$B - Y = R - 0.59\ G - 0.30\ R - 0.11\ B$$
$$= 0.89\ B - 0.59\ G - 0.30\ R \qquad (13-11b)$$

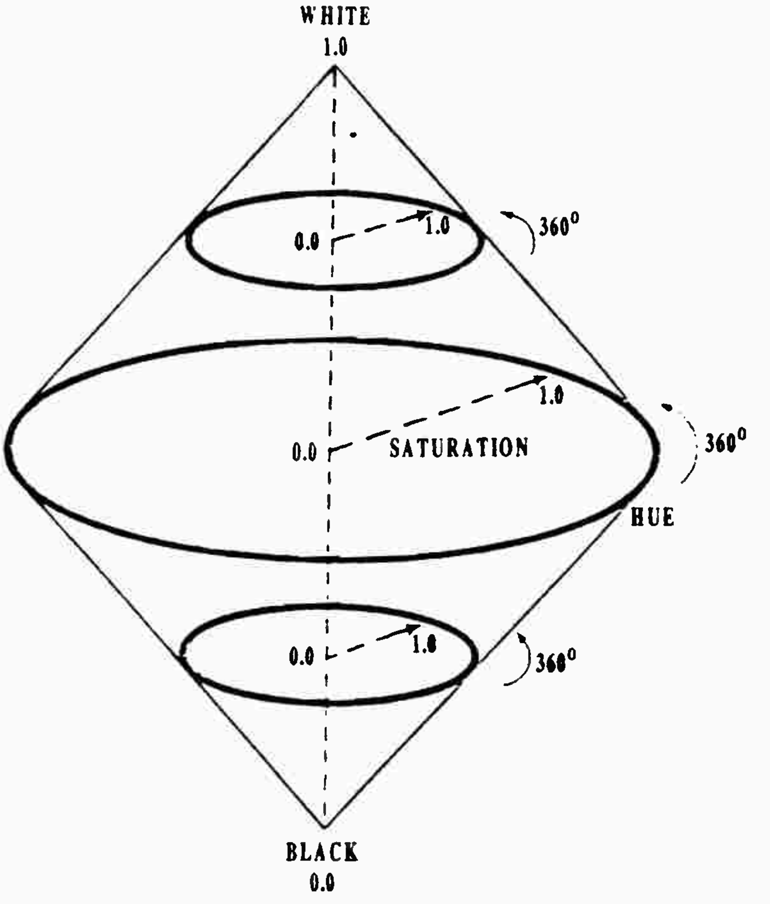


Fig 13.13 Double-coned color model

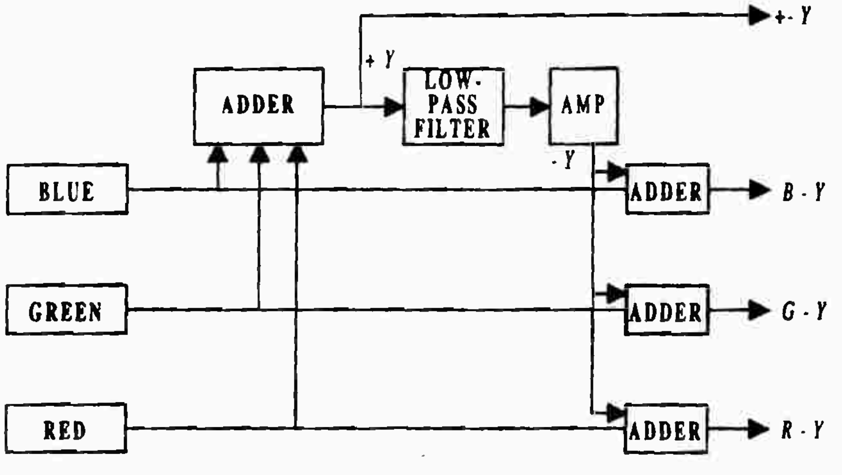


Fig. 13.14 Block diagram for obtaining color difference signals

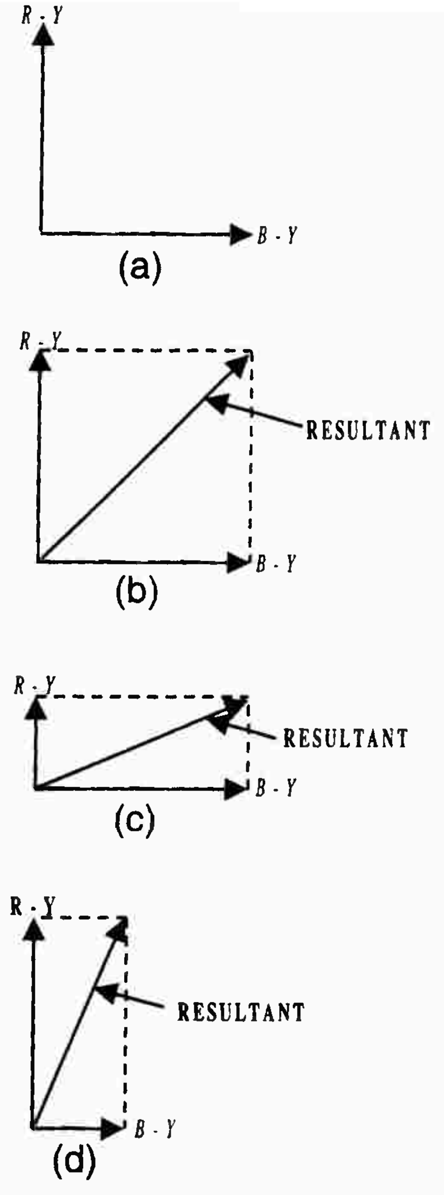


Fig. 13.15 Phasor representation of color difference signals

a) $R - Y$ and $B - Y$ vectors

b) the resultant when $R - Y = B - Y$

c) the resultant when $B - Y > R - Y$

d) the resultant when $R - Y > B - Y$

Let us for now assume that the color camera is scanning a scene containing only red, $R-Y$ signal becomes $0.70R$ and the $B-Y$ signal becomes $-0.30R$. Fig. 13.16 shows the resultant phasor when only red signal is being sent. By following the same procedure, the position of the resultant phasor may be obtained for different colors. The result is shown (Fig. 13.17). We see how the phase of the color subcarrier changes as the color to be transmitted varies. Note that the phase angle of the resultant phasor is governed by the hue of the picture, while the amplitude (length of the resultant phasor) is governed by the saturation of the colors.

The designers of the NTSC system found that it would be better to use color signals I and Q in place of $R-Y$ and $B-Y$. The I (in-phase) and Q (quadrature) are shown (Fig. 13.18). Thus, instead of $R-Y$ and $B-Y$ signals modulating the 3.58 MHz color subcarrier, we now have I and Q signals. The Q signal has sidebands up to 0.5 MHz and the I signal has sidebands up to 1.5 MHz. For all color signal frequencies up to 0.5 MHz, both I and Q are active. Note that all colors in Fig 13.18 may be obtained for frequencies up to 0.5 MHz, whether we use $R-Y/B-Y$ or I/Q systems.

For color signal frequencies from 0.5 1.5 MHz, the Q signal drops out, and only the I signal produces color on the CRT screen. Note from Fig. 13.18, when I is active the colors produced on the screen will vary from reddish (positive I) to bluish green (negative I). Note that for medium size objects (produced by video signal from 0.5 MHz to 1.5 MHz) the sensitivity of the eye for color is reduced.

In fact, for medium size objects, the eye is sensitive mostly to the bluish greens and the reddish oranges. That is why the designers of the NTSC system preferred the I/Q system over $R-Y/B-Y$. The I component produces mostly bluish greens and reddish oranges, which correspond to the sensitivity of the eye for medium size objects. In other words, the information is simply contained in the value of I varying from positive to negative values along the I axis.

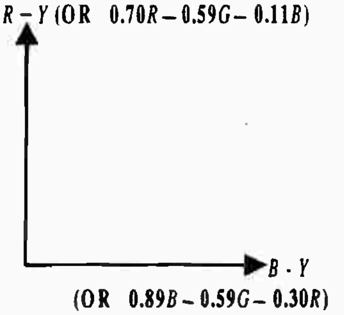
We may now analyze the spectrum of the color signal (Fig. 13.19). The Y signal extends from 0 to 4.2 MHz. The color subcarrier (3.58 MHz) is modulated by the I and Q signals (Prob. 13.1) where:

$$I = 0.60\ R - 0.28\ G - 0.32\ B \qquad (13-12a)$$

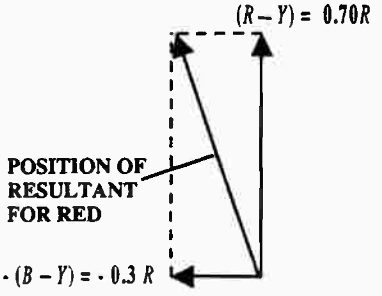
$$Q = 0.21\ R - 0.52\ G + 0.31\ B \qquad (13-12b)$$

Since the Q signal has color frequencies that extend from 0 to 0.5 MHz, the upper Q sideband extends from 3.58 MHz to 3.58+0.5=4.08 MHz. The lower Q sideband extends from 3.58 MHz down to 3.58-0.5=3.08 MHz.

The I signal has color frequencies that extend from 0 to 1.5 MHz. The lower sideband extends from 3.58 MHz down to 3.58-1.5 or 2.08 MHz. If there were a full upper sideband, it would extend to 3.58+1.5=5.08 MHz. But since the upper video limit is 4.2 MHz, the upper sideband of the I signal is limited to 0.6 MHz. This brings the upper sideband of the I signal to 4.18 MHz, in order to maintain the overall channel bandwidth to 6 MHz and prevent interference (spill over) with neighboring channels.



(a)



(b)

Fig. 13.16 Determination of the resultant vector when the scene is red

a) vectors $R-Y$ and $B-Y$.

b) position of the signal vector (when only red color is scanned)

13.7 The Color Subcarrier:

In the NTSC system, the 3.58 MHz carrier is suppressed. This has two advantages. First, it reduces the beat frequency of 0.92 MHz, which results from beating with the 4.2 MHz sound subcarrier. Second, when monochrome transmission is underway, both I and Q are zero. Since the carrier is suppressed, then the entire color signal will then be removed, therefore, it must be reinstated in the receiver for detection.

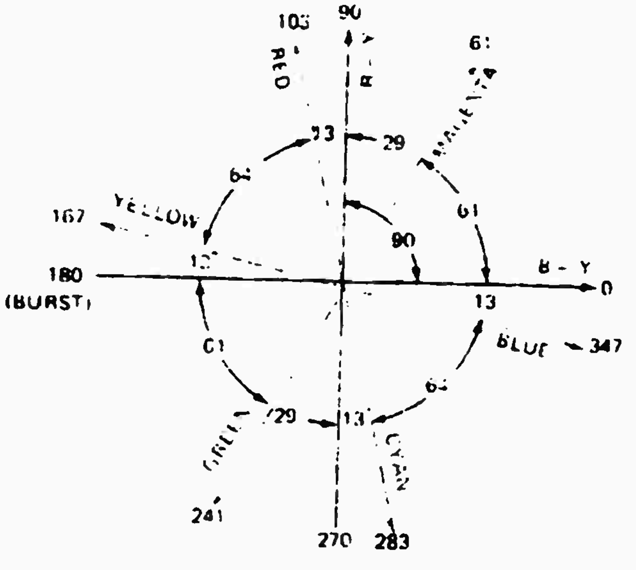


Fig. 13.17 Phase of the color subcarrier for different colors

An oscillator at 3.58 MHz must be present in the receiver to regenerate the needed carrier. This oscillator must, however, be synchronized. A phase shift will produce a shift in hues. Fig. 13.20 shows the pattern produced by a color bar generator for corresponding phase angles (Fig. 13.18). To maintain the correct phase relation, a short burst sample of the carrier must be transmitted along with the signal following each horizontal pulse in the back porch of each blanking pedestal (Fig 13.21). It contains a minimum of 8 cycles of the subcarrier. In the receiver, this burst is used to lock in the frequency and phase of the 3.58 MHz oscillator. The color burst does not interfere with horizontal synchronization, because it is lower in amplitude and follows the horizontal synchronizing pulse.

It must be noted that the color signals – unless minimized -might appear on the screen as a spurious dot pattern. To solve this problem, the color subcarrier must be chosen to be an odd multiple of half the horizontal scan frequency. Thus, the color information on a horizontal scan line is guaranteed to be 180° out of phase with the color information on the same horizontal scan line one frame later.

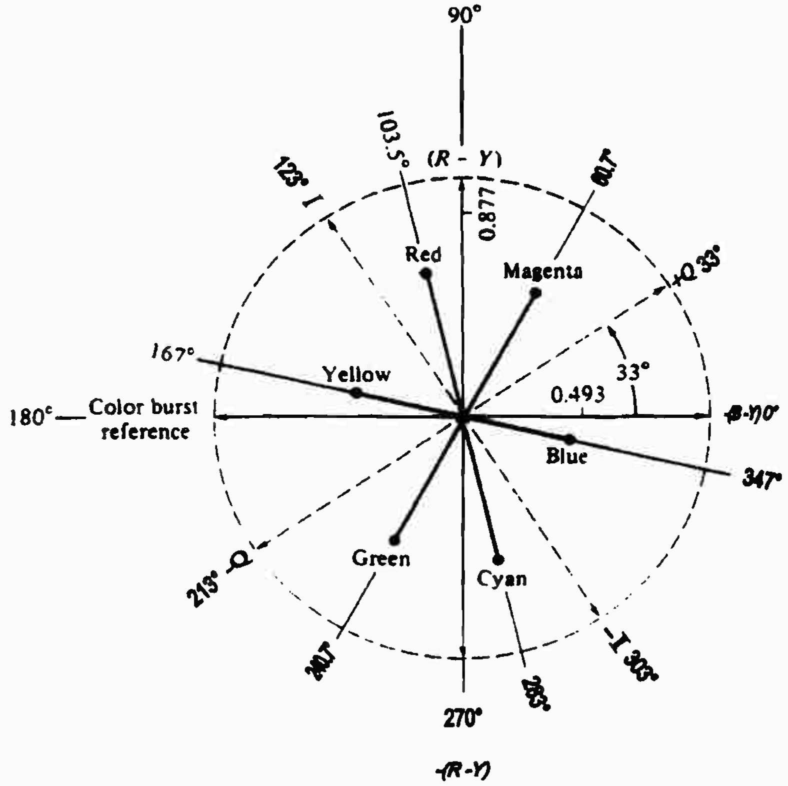


Fig. 13.18 I and Q signals

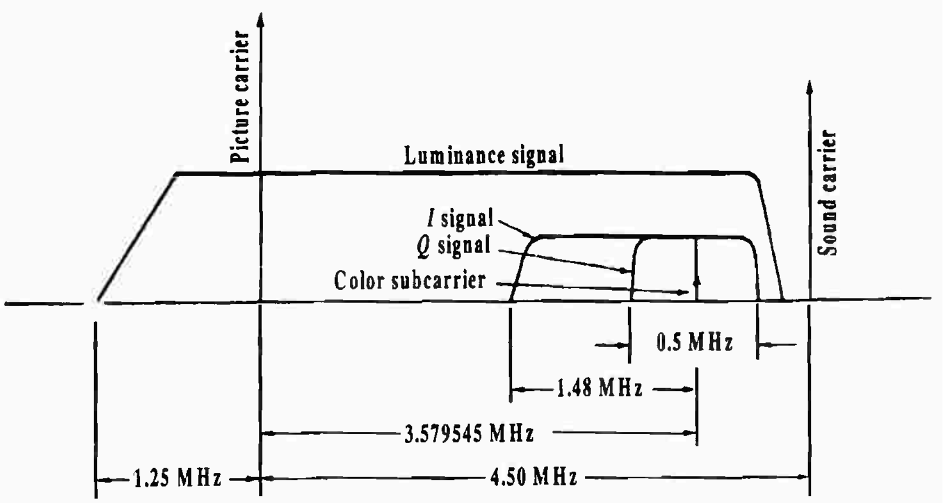


Fig. 13.19 Color TV spectrum (NTSC)

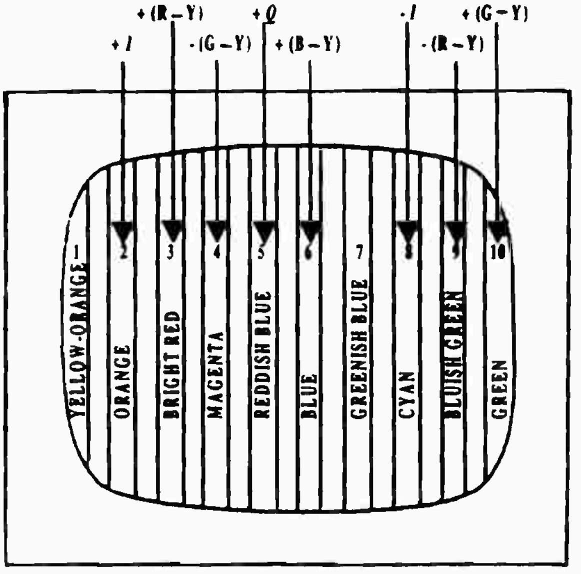


Fig. 13.20 Bar pattern developed by a color bar generator

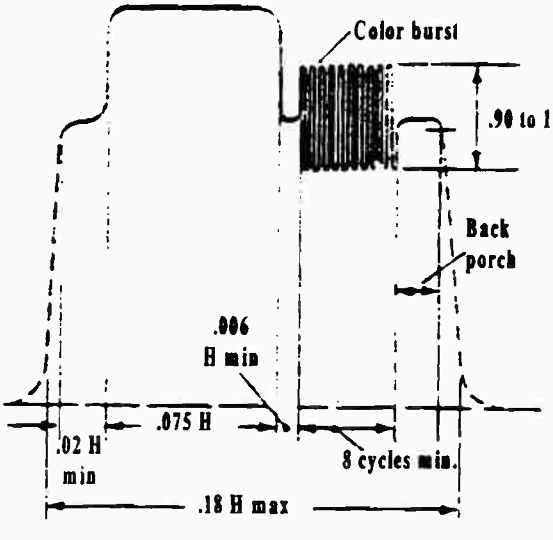


Fig 13.21 Color burst

This is because the number of cycles the signal passes through each frame is equal to a whole number of cycles plus one half of a cycle. Fig 13.22 shows a portion of one horizontal scan line for a monochrome video signal. A portion of one modulated horizontal scan line is shown. One frame later, this modulation is inverted 180°. Since the two signals are nearly equal in amplitude and opposite in polarity they cancel out. The eye does not discern the color signal which might, otherwise, cause interference in the scene. At the same time, it is desirable to have the color subcarrier frequency as high above the picture carrier frequency as possible, in order to minimize interference with the monochrome video information.

The average energy of monochrome video signal falls off very rapidly with increasing video frequencies (Fig 13.23). By placing the color subcarrier as high as possible, the difference in energy levels minimizes possible interference. There is an objectionable 0.92 MHz signal generated from the beat between the sound carrier (4.5 MHz) and the color subcarrier at 3.58 MHz (4.5 3.58=0.92 MHz). This beat is much less objectionable if the difference between the sound carrier frequency and the video carrier frequency is some multiple of the horizontal scan frequency.

In standard monochrome TV, the 285th and 286th harmonics of 15750 Hz are at 4.48875 MHz and 4.50450 MHz. Working backwards, the line frequency whose 286th harmonic is 4.5 MHz is 15743.26 Hz. This is what the horizontal line frequency should, be and it is within limits of the NTSC standards. With this horizontal scan frequency set, the color subcarrier must be chosen to interleave. It must be an odd multiple of one half the horizontal scan frequency. To find the value of the color subcarrier as close to 3.6 MHz as possible we note the:

$$f_{color\ subcarrier} = \frac{455 \times 15734.26}{2} = 3.579545\ \text{MHz}$$

which is the approximated 3.58 MHz. Since there are 525 lines, and for 2:1 interlace,

$$f_{vertical} = \frac{2}{525} \times 15734.26 = 59.94\ \text{Hz}$$

This is the field frequency, which is approximated by 60 Hz. Note that the sound carrier 4.5 MHz is now a multiple of whole cycles of horizontal scan, and the color subcarrier 3.58 MHz is an odd multiple of half horizontal scans. Hence, the interference effect of the beat frequency 0.92 MHz tends to cancel out.

We remember that a monochrome video signal of 4 MHz does not occupy every cycle of MHz assigned to [illegible], [illegible] signal appears in clusters of energy located at harmonics of 15750 Hz line scanning frequency, with relatively wide gaps between the clusters. Since these gaps are not needed, they may be employed for color information. This is called interleaving or color multiplexing (Fig 13.24). We see now clearly why the color subcarrier must be odd multiple of half the horizontal scan line. Further, this odd multiple serves color cancellation, and beat frequency cancellation purposes.

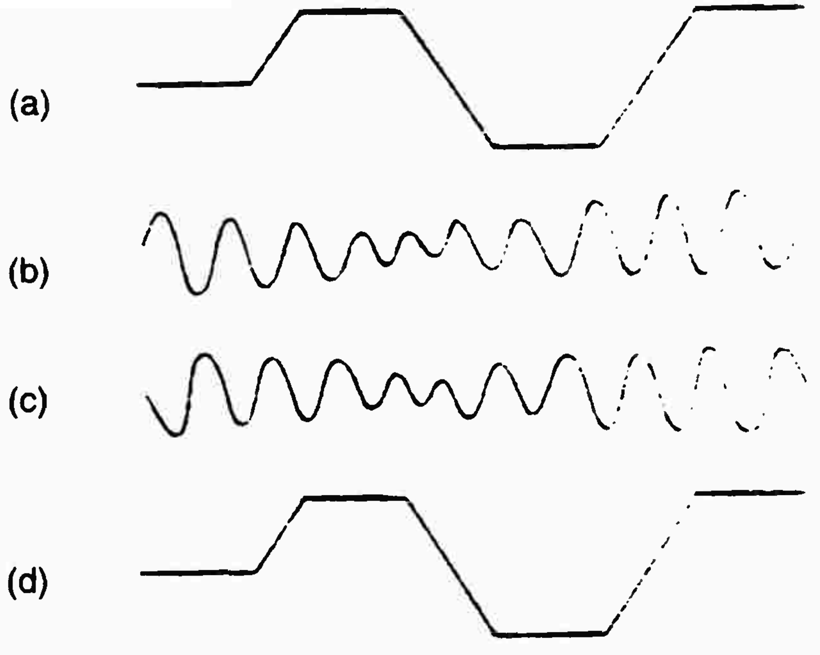


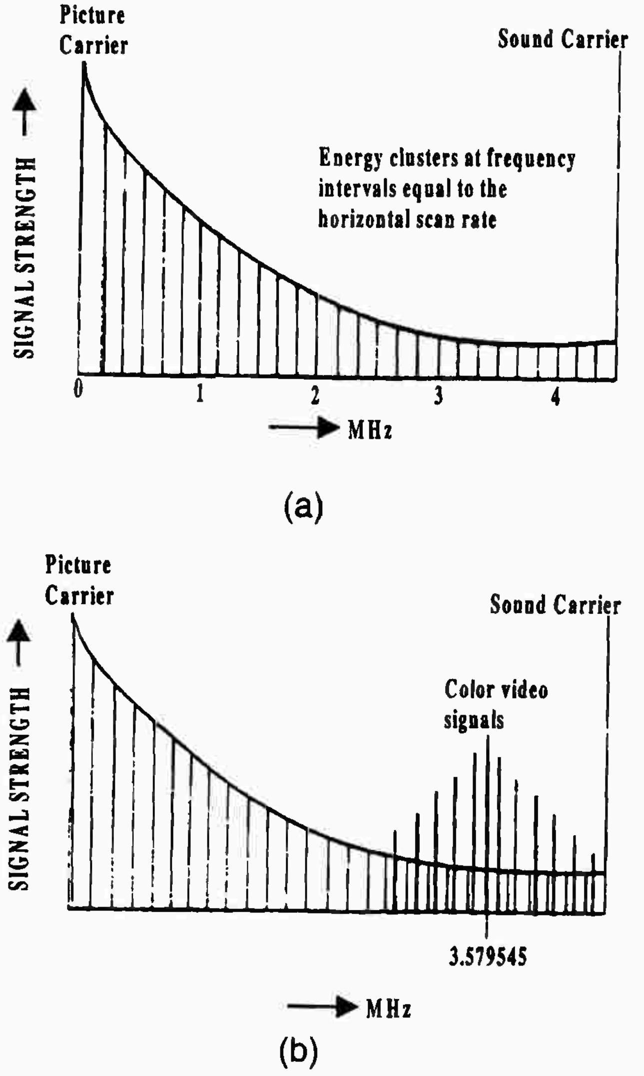
Fig 13.22 Chroma interference cancellation in frequency interleaving
a) black and white video during one scan line
b) chroma video signal during one scan line
c) chroma video signal for the same scan line one frame later(180° out of phase with b)
d) visual addition of waveforms a, b, c (chroma video signals are eliminated)

Ex. 13.1:

A horizontal scan line crosses the test pattern shown (Fig 13.25). The pattern consists of the three primary colors (red, green, blue), the three two - color combinations of primary colors (cyan, yellow, magenta) and one three - color combination of the three primary colors (white). Assume fully saturated primary colors, obtain Y, I, Q waveforms as well as the colorplexed composite video signal.

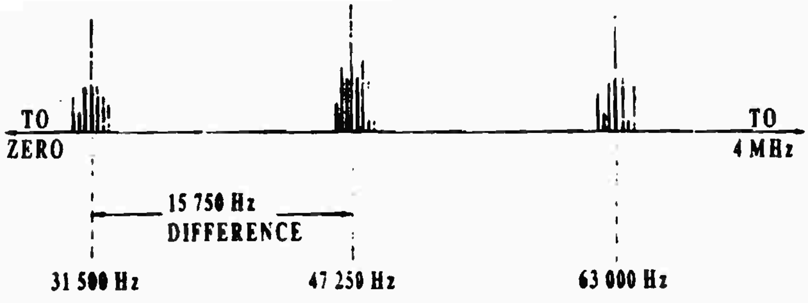
Solution:

Waveforms B, C, D (Fig. 13.25), give primary color variations for 100% saturation. Part E gives the luminance Y according to eqn. (13-9). for each color bar in the pattern. The I and Q signals are illustrated in parts F and G according to eqns. (13-13) and (13-14). Note that I and Q can have positive or negative values. Fig. 13.26 shows the color processing prior to transmission. The I and Q video signals are passed to the modulators to generate the 3.58 MHz sidebands. This is shown is Fig. 13.25H, where the carrier is modulated by I and Q in quadrature. The values are obtained by the vector addition of I and Q signals for each bar of the test pattern.

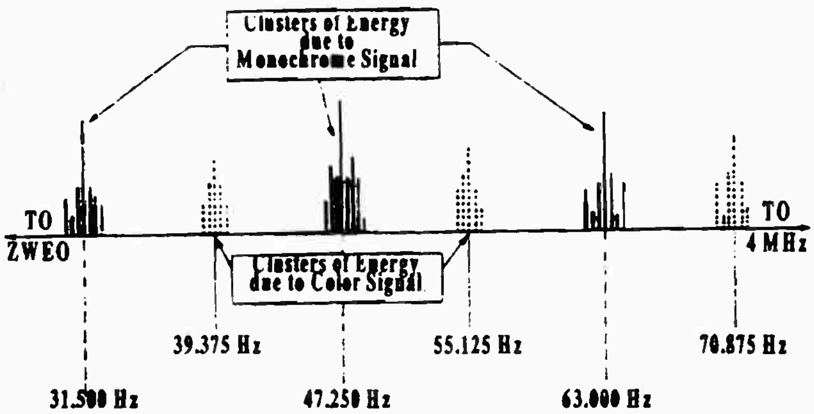


13.23 Energy distribution for color TV signal compared with monochrome TV signal
a) monochrome b) color

For example, the blue color bar I value is -0.32 and Q is 0.31, so the vector addition in part H for the blue is $\sqrt{(0.32)^2+(0.31)^2}=0.44$.
The complementary colors such as yellow and blue have the same peak amplitude, but are 180° out of phase in the 3.58 MHz subcarrier signal. At the transmitter, the 3.58HMz chrominance information is combined with the luminance signal and with color synchronizing, vertical synchronizing and blanking pulses to produce the composite colorplexed signal (Fig 13.25l).



(a)



(b)

Fig 13.24 Energy clusters
a) monochrome TV signal b) color interleaving

Adding the Y luminance signal in part E causes a shift of the 3.58 MHz chrominance information from a zero reference to a new level equal to the luminance value of the corresponding colors. This average dc level must be recovered at the receiver for correct color recovery. The representative composite video signal waveform is shown (Fig 13.27). A color bar generator uses a similar arrangement for a group of color burst signals produced in the color bar generator. Fig 13.28 shows a typical example of the output from such a generator. Each burst block contains roughly 8 cycles of subcarrier signal. Only the burst block immediately following the horizontal synchronizing pulse is used for color synchronization. The remaining ten blocks generate a series of test pattern.

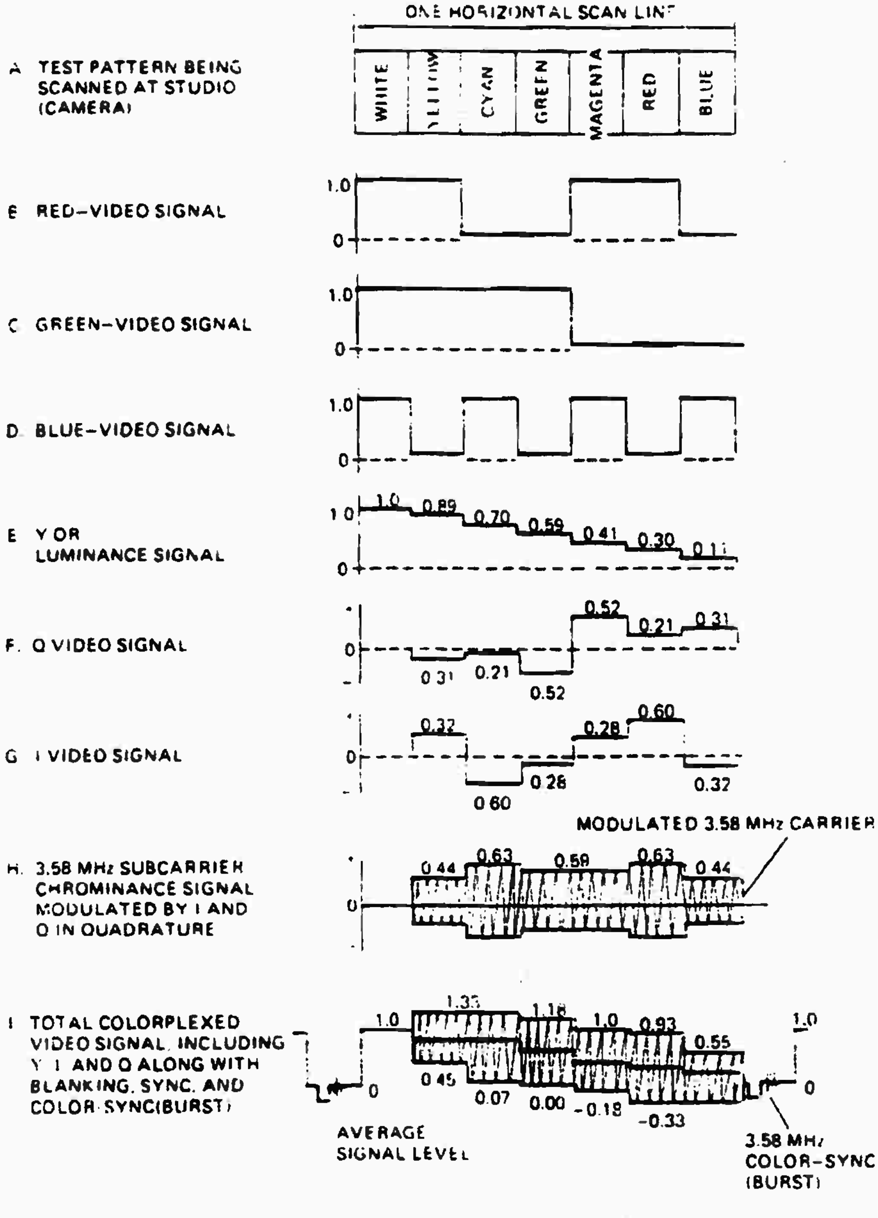


Fig. 13.25 Colorplexed composite video signal

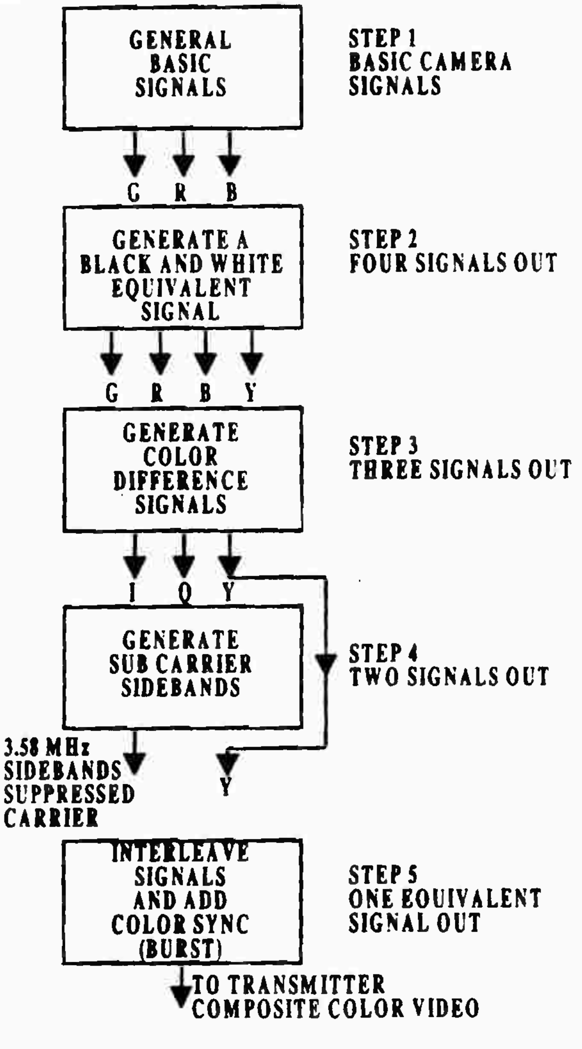


Fig. 13.26 Summary of color processing prior to actual transmission

13.8 TV Systems:

The NTSC TV system described above was the first system adopted for commercial use. In the PAL (Phase Alternating Line) color TV system, the color difference signals $R-Y$ and $B-Y$ are each transmitted within a bandwidth of 1MHz, using quadrature multiplexing. The $R-Y$ channel is reversed in polarity on successive lines at the transmitter. The correct phase is restored by a synchronous polarity reversing switch in the receiver.

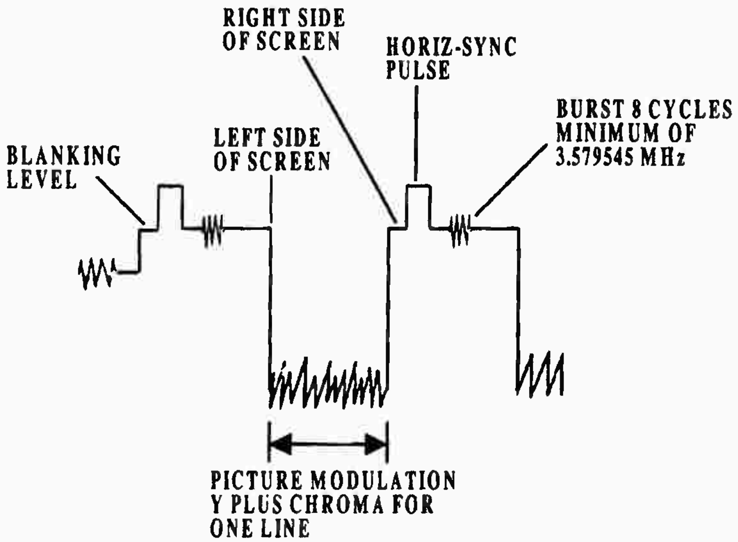


Fig. 13.27 Composite video signal

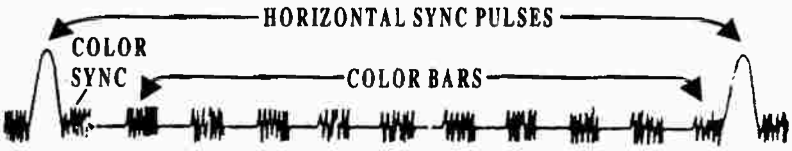


Fig. 13.28 Color bar generator signal

By this means, the effect of differential phase errors occurring in transmission (or in video recording) may be partially recorded by an averaging effect over several lines. It is to be noted that the definition of the eye along the $R-Y$ axis is better than along the $B-Y$ axis. The phase of the color burst alternates between 135° and 225° to synchronize the polarity reversing switch. The spectrum of PAL TV signal is shown (Fig 13.29).

The color system used in France is SECAM (Squential Couleur , the $R-Y$ and $B-Y$ signals are sent separately on alternate lines. Frequency modulation of the color subcarrier is used to transmit the color information.

In the SECAM receiver, a delay line and switch arrangement is used to allow a comparison of the previous line of color information with the present one. Thus, the color resolution in the vertical dimension is reduced by one half, but the quadrature multiplexing and its possible cross coupling between color signals is avoided. The use of FM for color information makes the SECAM system immune to color distortion due to amplitude variations.

A major drawback of the SECAM system is that the use of FM for the color information tends to cause some video interference pattern effects in monochrome transmission, resulting in a poorer degree of compatibility.

13.9 Compatibility:

Compatibility means transmitting color broadcast signals, so that they may be received on a monochrome receiver as monochrome. To properly reproduce color broadcasts in monochrome on monochrome receivers, the color broadcast signals must provide a Y signal used to produce the monochrome signal. This requires that color broadcasts include the normal monochrome synchronizing and blanking signals. The additional color signals that are required to produce color picture on a color set are picked up by the tuner of a monochrome set. However, monochrome sets will not pass the 3.58 MHz color subcarrier and its adjacent sidebands.

In addition, the monochrome set does not possess the various color processing circuits of a color set, hence, the chrominance signal will not affect the monochrome set.

Compatibility means also that a monochrome broadcast can be reproduced in monochrome in a color set. During monochrome broadcast, the color circuits of a color receiver are disabled by a circuit called the color killer. If such circuits were not disabled, colored snow (confetti) might appear on the screen during monochrome reception.

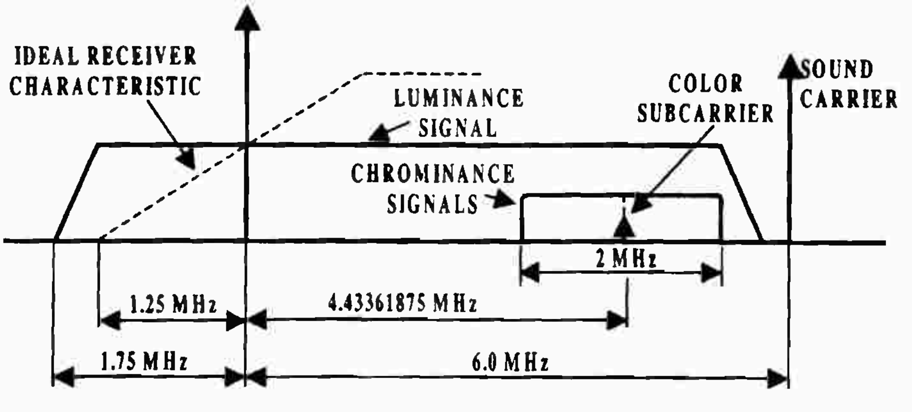


Fig 13.29 Spectrum of PAL system

Problems:

1- Obtain relations for I and Q [eqn. (13-13) and eqn. (13-14)].

2- Obtain the phasor digram for
   a) Only red
   b) Only green
   c) Only blue

3- Obtain the phasor diagram of Fig. 13.17

4- Repeat Ex 13.1 for the case
   - White 100%
   - Yellow 90%
   - Cyan 75%
   - Green 80%
   - Magenta 60%
   - Red 10%
   - Blue 20%

5- Considering the standard sensitivity curve for the human eye for normal daylight (Fig 13.3), derive eqn. (13.10)

6- The chrominance signal may be written as :
   $(R-Y)\cos\omega_{cs}t+(B-Y)\sin\omega_{cs}t$, obtain expressions for saturation and hue. Then find an expression for the total maximum magnitude. What does it signify?

7- Using the result in the problem above, find the total maximum magnitude for the following saturated colors.
   Blue-Red Magenta-Green-Cyan-Yellow.

8- Compare the results of the problem above with those of monochrome transmission, when $R=B=G$ and $Y=1$. Show that a fully saturated color requires maximum peak of 78% higher than monochrome.

9- Repeat problem 7 if the axes are rotated by 33° (for I and Q).

10- In Prob. 8, we want to limit the overload peak due to the two color difference signals to a maximum of 33%. This may be done by scaling the color difference signals by factors a_1, and a_2. Obtain a_1 and a_2 for yellow and cyan. Then write down the total corrected video signals.

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