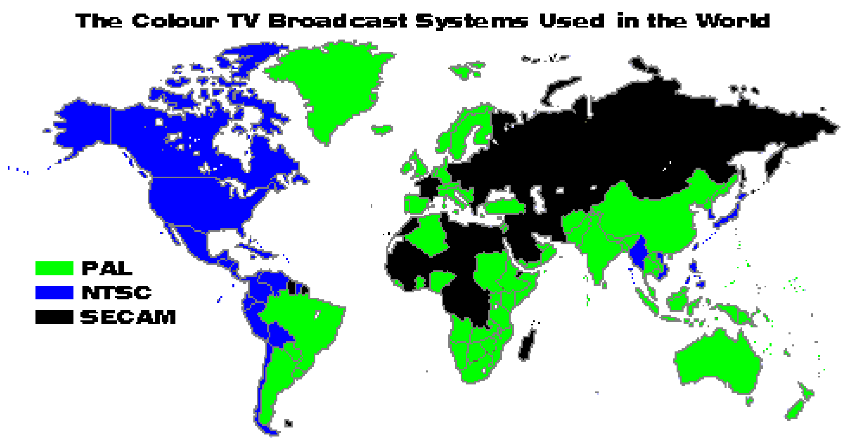
Chapter Contents

Appendix 1 - Analog Broadcast Video Standards

There are three well-established analog video broadcast formats in use today:

- NTSC [National Television Standards Committee]
- PAL [Phase Alternation Line]
- SECAM [Séquential Couleur Avec Mémoire]

WORLD TELEVISION FORMATS†



There are several different ways which each of these standards have been implemented. Besides these, there are a number of new emerging formats. Whether any of them catch on is yet to be seen.

The world's first commercial color broadcasting system went into service in the U. S. in 1954, and was based on the NTSC standard. This system was fully compatible with the existing black & white transmission facilities and receivers. In subsequent years, the European community also developed color broadcasting systems namely PAL in Germany and SECAM in France.

All of the systems derive the luminance signal from the same source:

$$E'_Y = 0.299\,E'_R + 0.587E'_G + 0.114E'_B$$

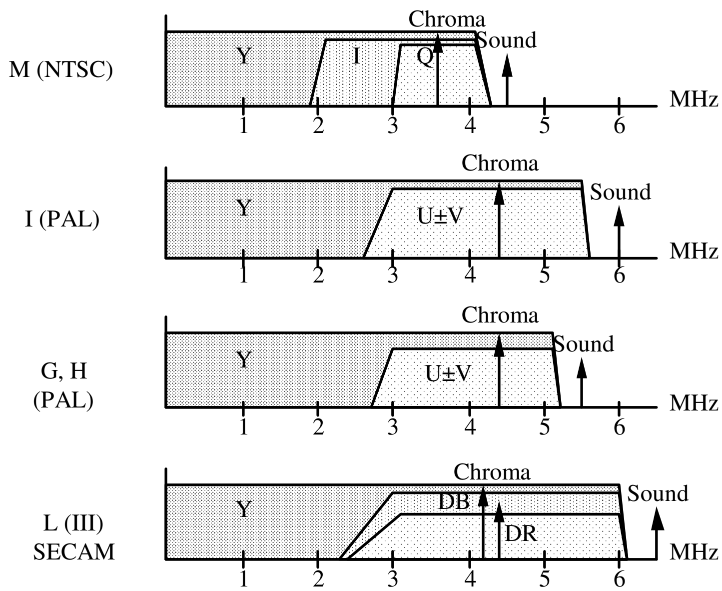
The terms E'_Y, E'_R, E'_G, E'_B denote the gamma corrected values.

† http://www.epicmultimedia.com.au/eformats.cfm

WORLD TELEVISION FORMATS[1]

	System Code						
Parameter	**M (N)**	**B**	**C**	**G (H)**	**I**	**D K (K')**	**L**
Lines per picture	525 (625)	625	625	625	625	625	625
Field Frequency [Hz]	60 (50)	50	50	50	50	50	50
Line Frequency [HZ]	15734 (15625)	15625	15625	15625	15625	15625	15625
Video Bandwidth [MHz]	4.2	5	5	5	5.5	6	6
Channel Bandwidth [MHz]	6	7	7	8	8	8	8
Audio above Video [MHz]	4.5	5.5	5.5	5.5	6	6.5	6.5
Vestigial Sideband Width [MHz]	.75	.75	.75	.75 (1.25)	1.25	.75 (1.25)	1.25
Video Modulation Polarity	-	-	+	-	-	-	+
Audio Modulation	fm±25 KHz	fm±50 KHz	am	fm±50 KHz	fm±50 KHz	fm±50 KHz	am
FM Pre-emphasis [µSec]	75	50		50	50	50	

BANDWIDTH COMPARISONS



Consumer RGB & YUV Video Formats by Harris

1 *Video Techniques*, Gordon White

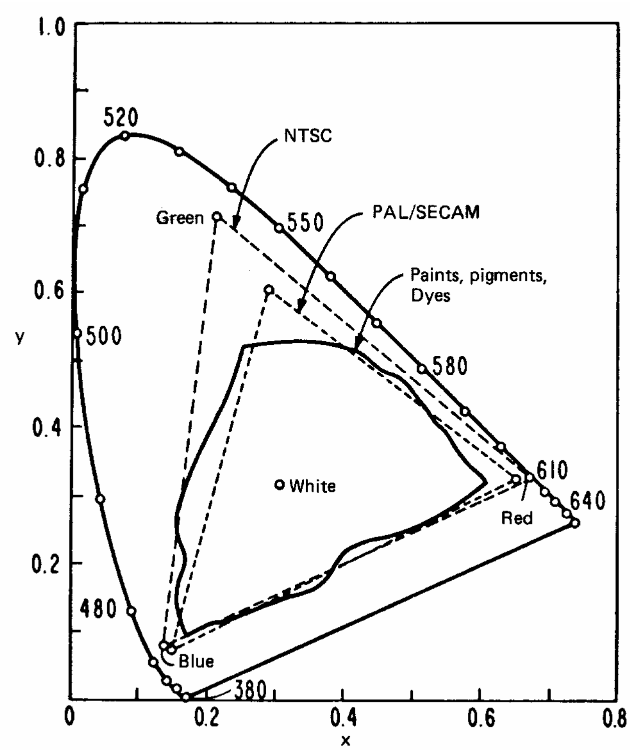
______ Notes ______

BROADCASTING SYSTEMS COMPARISON

Similarities	Use the same colorimetry principles
	Similar imaging and display technology
	Wideband luminance and narrow band chromance
	Backward compatible with older systems
Differences	Line and field rates
	Component bandwidths
	Frequency allocations
	Color encoding formats

It is also interesting to note, that each system has a slightly different choice of primary colors.

TELEVISION CHROMATICITY DIAGRAM[2]



		x	y
NTSC	R =	0.67	0.33
	G =	0.21	0.71
	B =	0.14	0.08
PAL/SECAM	R =	0.64	0.33
	G =	0.29	0.60
	B =	0.15	0.06
White: NTSC (Ill. C)	=	0.310	0.316
White: PAL/SECAM (D6500)	=	0.313	0.329

CIE chromaticity-diagram comparison of systems.

2 Television Engineering Handbook, K Blair Benson ed, FIG. 21-14

From the above colorimetery diagram, it is evident that color television can produce a greater range or colors than is possible with pigments and dyes. The main areas where color photography and cinematography still enjoy a significant lead over television imaging is in size and resolution. However, with the development of wide screen high definition television, this advantage may some day be gone.

Since all of the methods used to broadcast color had to be backward compatible with existing B&W systems, there is a certain lack of elegance in all of them. The advent of digital video and HDTV† promises to change this, but at considerable cost.

SELECTED COUNTRY LIST

Country	**Color**	**Code**
Australia	PAL	B
Brazil	PAL	M
Canada	NTSC	M
China	PAL	D
France	SECAM	L
Germany [West]	PAL	B G
Germany [East]	SECAM	B G
Hong Kong	PAL	I
Japan	NTSC	M
Switzerland	PAL	B G
United Kingdom	PAL	I
USA	NTSC	M
USSR [former]	SECAM	D K

A1.1 NTSC

Since the chroma sub-carrier is an odd multiple of 1/2 the horizontal sweep rate, the reference burst appears to alternate its phase on each scan. Consequently, any color signal passing through the video amplifier on a B&W TV set, appears to visually cancel out.

NTSC is prone to color errors due to differential gain and differential phase variations. In the early days of television, it was apparently nicknamed *Never The Same Color* since any drift or change in the chroma synchronization leads to a change in hue.

COLOR DIFFERENCE SIGNALS

Color coding is achieved by combining the outputs of three separate color camera tubes into two color difference signals, namely *B-Y* and *R-Y*. These color difference signals can be vectorially added to provide a composite signal where the magnitude and phase correspond to the hue and saturation.

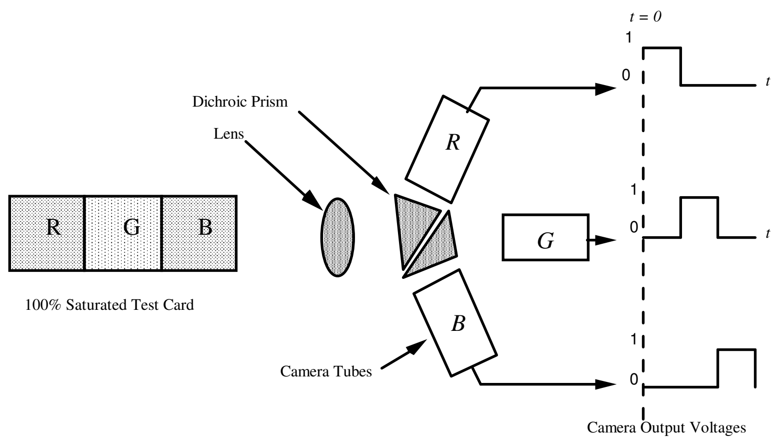
† High Definition TV

Notes

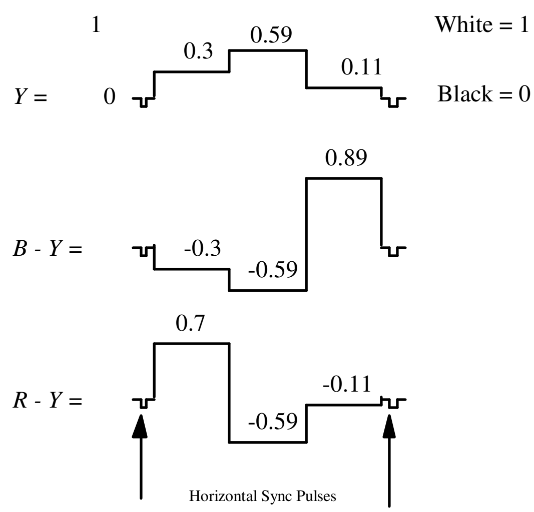
The *G - Y* color difference signal is not used since it has a smaller magnitude in comparison to the other two difference signals, and is therefor more susceptible to noise.

The circuit that generates the difference signal is generally referred to as the matrix. The matrix signals are then combined as shown next:

CAMERA SCANNING A TEST CARD

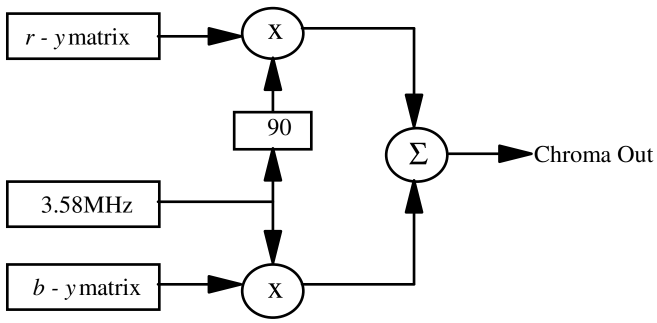


The signals from the camera tubes is sent to a matrix to generate the color difference signals. The matrix output resembles:

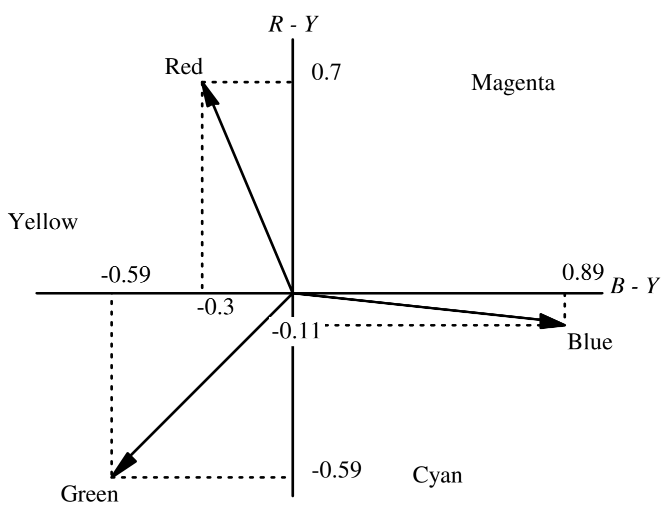


The matrix color difference signals are then applied to a chroma modulator.

CHROMA MODULATOR



Summing the color difference signals in the above modulator translates the chroma signals into polar quantities.



$$\text{Magnitude} = \sqrt{(R-Y)^2 + (B-Y)^2} \qquad \text{Phase Angle} = \tan^{-1}\left(\frac{R-Y}{B-Y}\right)$$

		Color Difference Signals			
	Y	B-Y	R-Y	Magnitude	Phase
Red	0.3	-0.3	0.7	0.76518	113.2
Green	0.59	-0.59	-0.59	0.83439	225
Blue	0.11	0.89	-0.11	0.89677	353

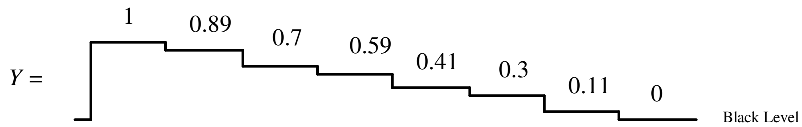
The complementary colors are 180^{o} out of phase with the primary colors, but have the same magnitude. The *Y* value for the complementary colors is 1 - primary value.

i.e. for cyan: $Y = 1 - \text{Red} = 1 - 0.3 = 0.7$

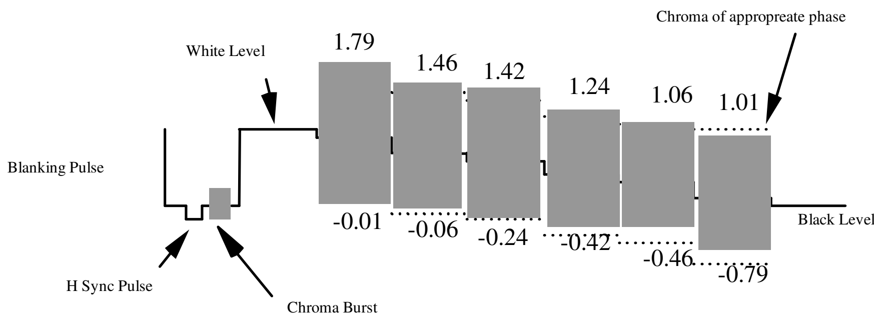
Notes

W	Y	C	G	M	R	B	Blk

Color Bar



The magnitude and phase of the chroma signal is superimposed on the Y signal.



ADJUSTED COLOR

These chroma signals exceed the maximum sync tip and white levels. This causes over modulation and distorts the colors. Therefor the chroma signals are reduced.

The luminance signal is amplitude modulated on the picture carrier, with a maximum modulation index of 0.7. A 33% peak overload due to the chroma signals is considered acceptable, since this would result in a peak modulation index of 0.93 (0.7 x 133% = 93%)

This implies that the sum of the color difference signal and luminance signal must be limited to 1.33. The amount of reduction can be calculated by solving the following equation for the coefficients *a* and *b*:

$$Y + \sqrt{a^2(R-Y)^2 + b^2(B-Y)^2} = 1.33$$

Since the largest overloads are due to yellow (magnitude 1.78) and cyan (magnitude 1.46), we can write the following equations:

For Yellow: $0.89 + \sqrt{a^2(0.11)^2 + b^2(0.89)^2} = 1.33$

For Cyan: $0.7 + \sqrt{a^2(0.7)^2 + b^2(0.3)^2} = 1.33$

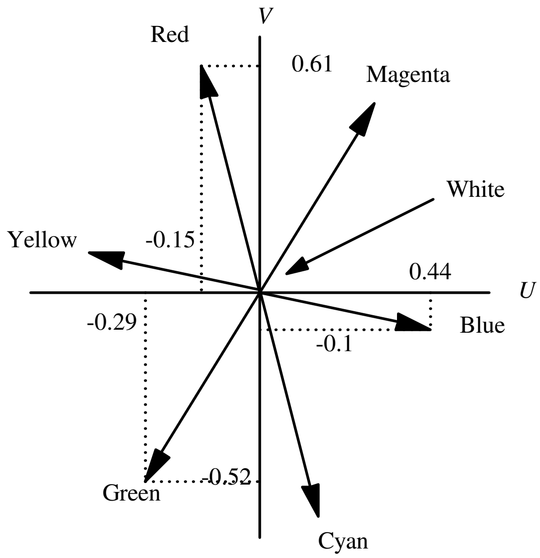
Solving for *a* and *b*, we obtain: $a = 0.877$ and $b = 0.493$

Notes

Over modulation can still occur with these adjusted chroma levels, but seldom does because the saturation of natural or staged scenes is usually less than 75%.

The adjusted chroma signals are redesignated as *U* & *V*.

$$E'_U = 0.493(E'_B - E'_Y) = -0.148E'_R - 0.291E'_G + 0.493E'_B$$
$$E'_V = 0.877(E'_R - E'_Y) = 0.614E'_R - 0.519E'_G - 0.097E'_B$$



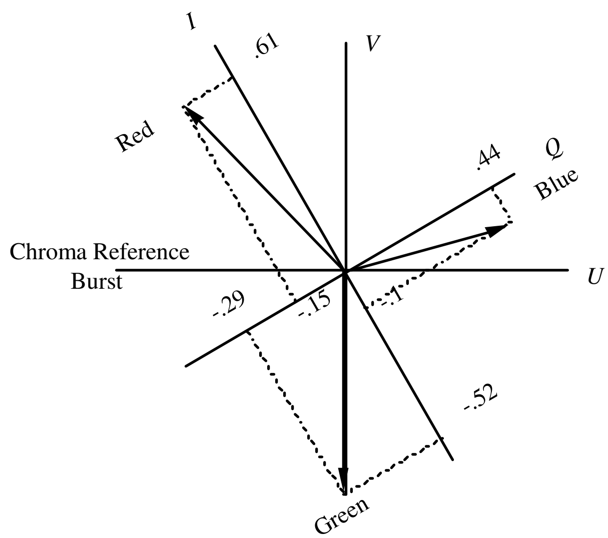
BROADCAST COLOR

Since the eye can resolve finer chromance detail in orange and cyan hues than in green and magenta, the chromance signals are advance by 33^{o} from the *U* & *V* axis before being broadcast. These new signals are designated *I* & *Q*.

The defining equations are:

$$E'_I = -0.27(E'_B - E'_Y) + 0.74(E'_R - E'_Y) = 0.596E'_R - 0.274E'_G - 0.322E'_B$$
$$E'_Q = 0.41(E'_B - E'_Y) + 0.48(E'_R - E'_Y) = 0.211E'_R - 0.522E'_G + 0.311E'_B$$

Since these signals are still linear combinations of *R, G,* and *B*, the entire process can be performed by adjusting the resistor values in the camera color matrix circuits.



The chroma reference burst is set to 180° or yellow instead of 0° or blue to reduce the cross coupling between the chromance and luminance signals.

		Broadcast Chroma Signals			
	Y	I	Q	Magnitude	Phase
White	1.0	0	0	0	0
Yellow	0.89	0.322	-0.312	0.448	134.132
Cyan	0.7	-0.599	-0.213	0.636	250.425
Green	0.59	-0.277	-0.525	0.594	207.838
Magenta	0.41	0.277	0.525	0.594	27.838
Red	0.3	0.599	0.213	0.636	70.425
Blue	0.11	-0.322	0.312	0.448	314.132
Black	0	0	0	0	0

The PAL system uses the *U* & *V* signals, while the NTSC system uses the *I* & *Q* signals.

Although it is possible to decode the color information directly from the *I*, *Q*, & *Y* signals:

$$R = 0.62E'_Q + 0.95E'_I + E'_Y$$
$$G = -0.64E'_Q - 0.28E'_I + E'_Y$$
$$B = 1.73E'_Q - 1.11E'_I + E'_Y$$

Generally the *I* & *Q* signals are restored to the *B-Y* and *R-Y* axis before decoding the colors.

Chroma Carrier Frequency

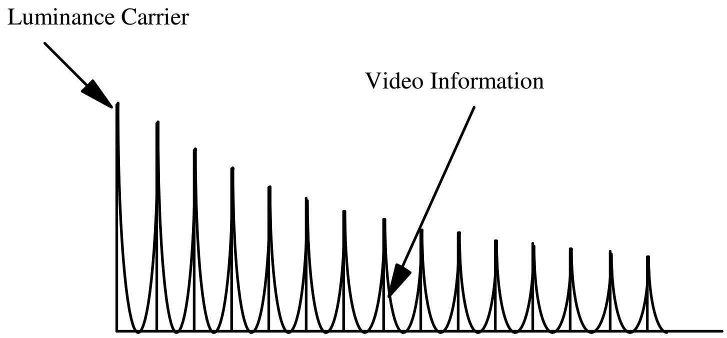
If the chroma carrier frequency is too low, it interferes with the luminance signal, and if it is too high, it interferes with the audio signal. In both cases unacceptable beat frequencies are created.

A compromise of about 3.5 MHz seems reasonable. The difficulty arises in selecting the exact frequency.

The video and audio carriers are fixed exactly 4.5 MHz apart. There can be no adjustment of this relationship since the two signals are heterodyned together to create the audio IF at 4.5 MHz.

The ideal solution to this problem requires that all three video carriers be frequency locked to each other.

In examining the luminance spectrum, it becomes clear that the video information is not uniformly spread across the entire spectrum. Rather, the Y signal is clustered at frequencies that are multiples of the horizontal and vertical sync rates away from the carrier.



Multiples of 15750 Hz

From this, it becomes evident that it would be desirable to interleave the chroma signal between the spectral lines of the luminance signal.

The easiest way to frequency lock all the carriers together, and provide interleaving, is to fix them to some multiple of the H sync rate.

The values closest to those used in B&W TV is obtained by making the FM carrier the 286 harmonic of the H sync rate. Since this does not come out exactly to 4.5 MHz, it becomes necessary to make a slight adjustment in the H sync rate:

$$\frac{4.5\text{ MHz}}{286} = 15,734.26\text{ Hz}$$

Since there are 262.5 lines per field, the new V sync rate is:

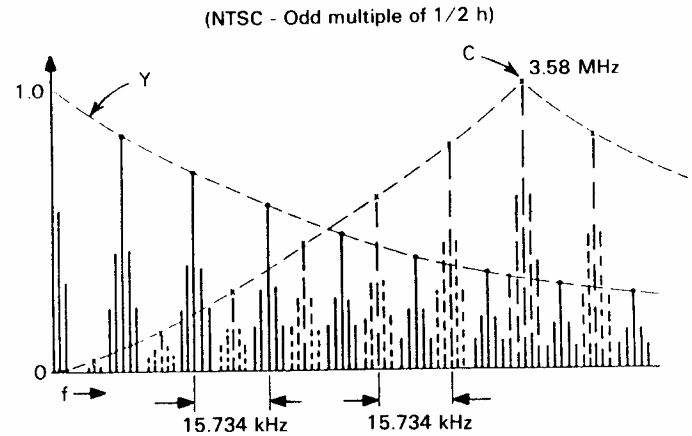
$$\frac{15,734.26}{262.5} = 59.94\text{ Hz}$$

These necessary changes are small enough that a B&W set would never know the difference.

The chroma carrier frequency can now be defined as the 227.5 harmonic of the H sync rate:

$$227.5 \times 15,734.26 = 3.579545 \text{ MHz}$$

This interleaves the chroma frequency components between the luminance components. The signal is transmitted as DSBSC to reduce the possibility of beating with the *Y* signal.



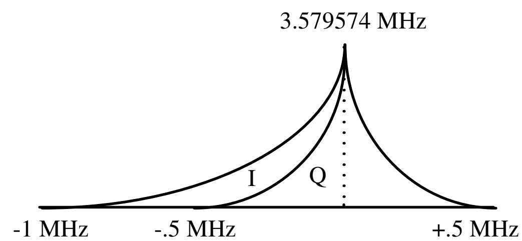
The video baseband frequency spectrum

A color burst used to provide a reference phase, is transmitted on the back porch of the H sync pulse. This burst is not transmitted during B&W broadcasts.

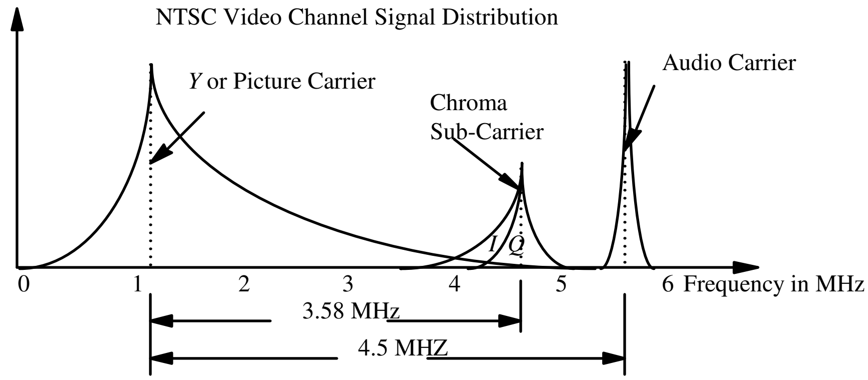
Since there is less detail in color than luminance, the *I* & *Q* channels are allocated much less bandwidth than the *Y* signal. The *Q* axis represents colors that the eye cannot readily distinguish. Therefor the *Q* signal is somewhat band limited. The positive *Q* axis corresponds to magenta or purplish hues, and the negative to green. The eye can more readily discern the colors associated with the *I* axis where positive corresponds to orange, and negative to cyan.

Q is band limited to ±0.5 MHz

I is band limited to -1 to +0.5 MHz



Notes



Frequencies	Sound	4.5 MHz above the picture carrier
	H Sync	15734.264 ± 0.044 Hz
	V Sync	59.94 Hz
	Chroma carrier	3.57954506 MHz
% Mod	H pulse peak	100%
	Blanking	75%
	Black	70%
	White	12.5%

Gamma Correction

The gamma correction performed in the camera tube has some affect on the nature of the video signal. The following inequality:

$$E_Y = .3E_R^{1/\gamma} + .59E_G^{1/\gamma} + .11E_B^{1/\gamma} \leq \left(.3E_R + .59E_G + .11E_B\right)^{1/\gamma}$$

holds in a B&W picture since $E_R = E_G = E_G$, but does not hold true in a color picture. Consequently, the luminance signal is slightly smaller than it should be in highly saturated color scenes. This results in a slightly lower luminance signal and a reduction in definition. This amounts to cross coupling between the luminance and chromance signals. To reduce this interference, the chroma burst is referenced to 180° (yellow) rather than 0° (blue).

A1.2 PAL

This system was developed in Germany and adopted in most European countries including Great Britain. Broadcasting started in 1967. This technique overcame the very strict requirement for phase and amplitude integrity required in the NTSC system. The line-by-line alternation of color information on one of the chroma signals results in a visual self-cancellation of transmission irregularities.

The chroma signal is generated in a similar way as the NTSC system, but the phase of one of the chroma signals is reversed on alternate lines, both spatially and temporally.

- The color burst is +135° on odd lines of the 1st & 2nd fields, and even lines of the 3rd & 4th fields

- The color burst is +225^o on even lines of the 1st & 2nd fields, and odd lines of the 3rd & 4th fields
- Any phase distortion tends to cause alternate lines to deviate in opposite directions, and is visually canceled out by the eye

The average phase of the burst is held to 180^o ± 2^o, thus allowing the system to tolerate a phase differential of 40^o.

The sub carrier burst is suppressed during the vertical sync pulses. To ensure that all fields start and stop with the burst in the same phase, the blanking is advanced by 1/2 a line for each field for 4 fields, and then returned to its original starting position.

PAL CHROMANCE

$$E_U = .493(E_B - E_Y)$$
$$E_V = \pm .877(E_R - E_Y)$$
$$C_{PAL} = E_U \sin\omega_c t \pm E_V \cos\omega_c t$$

The *U* and *V* signals are of equal bandwidths. The *V* signal alternates phase on alternate lines. The receiver can identify which line has the phase reversal by means of a swinging burst. The phase of this burst is switched ±45^o at the line rate. This burst signal is not present during the vertical sync period.

To prevent visual artifacts in the picture, the chroma sub-carrier must have a fixed relationship to the horizontal and vertical sync rates. This relationship is defines as:

$$f_c = \frac{1135}{4} f_{horizontal} + \frac{1}{2} f_{vertical}$$

The swinging chroma sub-carrier repeats itself after 8 fields. Therefore when a PAL waveform signal is edited or mixed, the signals must be synchronized to this pattern or random phase changes, hence color changes would occur.

Pal Plus Overview

A1.3 SECAM

SECAM, usually a 625-line system, was developed in France and went into service in 1967. It has gone through at least three versions, and the one currently in use is known as *optimized* or SECAM III.

SECAM separates the hue and saturation signals, and transmits them on alternate lines. As a result, the television set must contain a one-line memory element, so that the RGB signals can be recovered though a linear matrix. The delay line is more tolerant than in the other systems

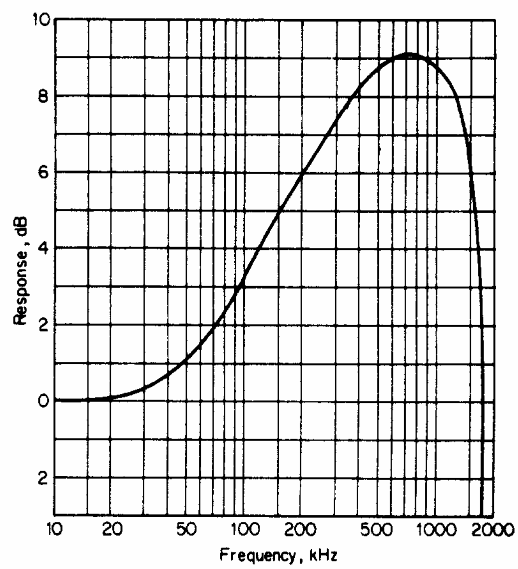
The *R-Y* and *B-Y* color difference signals frequency modulate two different sub-carriers.

Color Signal	Frequency [MHz]	Characteristics
R-Y	4.406250	odd lines 282 x the horizontal rate
B-Y	4.425000	even lines 272 x the horizontal rate

The vertical color resolution is 1/2 of the NTSC and PAL systems, but this is not very significant. The chroma signals are FM, and therefore immune to amplitude variations. However, this tends to cause interference patterns during B&W transmission.

As in any FM system, pre-emphasis is used to improve the S/N. However, the sub carrier amplitude is also increased if the luminance signal contains components near the chroma carrier.

SECAM PRE-EMPHASIS[3]



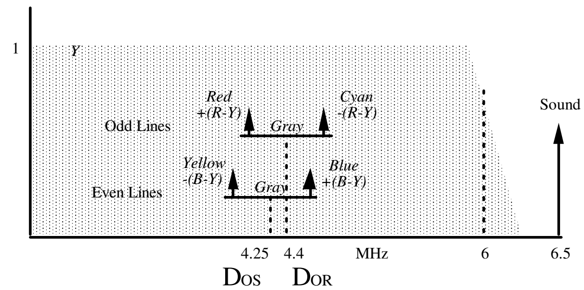
SECAM color-signal low-frequency preemphasis. ***(CCIR Rep. 624-2.)***

Two frames or 4 fields are required for the system to complete its chroma swing cycle. There are two different ways the receiver can determine what the chroma phase burst should be at the beginning of a frame. The first approach known as SECAM V, transmits what are known as bottle signals during 9 lines of the vertical blanking period.

A second approach, known as SECAM H, uses the two chroma sub carrier bursts on the horizontal sync pulse to derive the sequence information. The chroma sub-carrier is reversed on every 3rd line and between each field.

3 Television Engineering Handbook, K Blair Benson ed, FIG. 21-24

SECAM FM COLOR MODULATION[4]



SECAM LINE SWITCHING SEQUENCE[5]

Line	Field	Color Carrier	Subcarrier Phase
n	Odd	D_{OR}	0^o
n + 313	Even	D_{OB}	180^o
n + 1	Odd	D_{OB}	0^o
n + 314	Even	D_{OR}	0^o
n + 2	Odd	D_{OR}	180^o
n + 315	Even	D_{OB}	180^o
n + 3	Odd	D_{OB}	0^o
n + 316	Even	D_{OR}	180^o
n + 4	Odd	D_{OR}	0^o
n + 317	Even	D_{OB}	0^o
n + 5	Odd	D_{OB}	180^o
n + 318	Even	D_{OR}	180^o

SECAM CHROMANCE

$$D_R = -1.9(E_R - E_Y)$$

$$D_B = 1.5(E_B - E_Y)$$

The principle counties using this system are: Egypt, France, Gabon, Iran, Iraq, Ivory Coast, Lebanon, Morocco, Saudi Arabia, Senegal, Tunisia, USSR, & Zaire. A 525 line version of SECAM is used in Cuba, Haiti, & French Guinea.

4 Based on fig. 21-23 Television Engineering Handbook, K Blair Benson ed

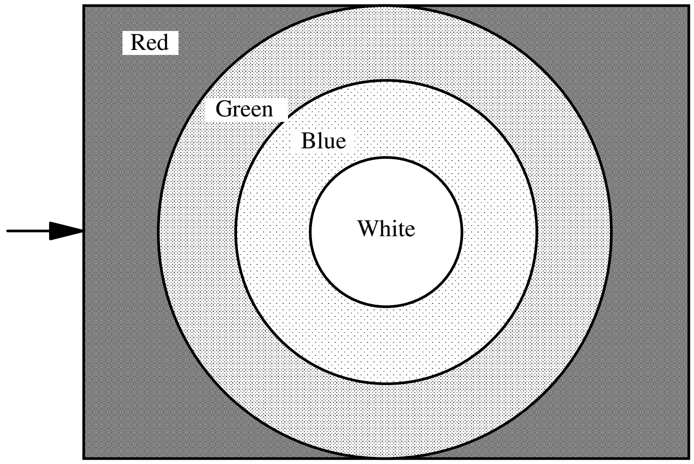
5 Television Engineering Handbook, K Blair Benson ed, FIG. 21-26

Assignment Questions

1. Why are chromance signals band limited?
2. When the carriers for color TV were chosen, the parameter which remained fixed was the (H sync rate, V sync rate, audio IF).
3. In a B&W set, the sound takeoff may occur anywhere in the video section, but in a color set, it must come before the video detector. (True, False)
4. Define luminance, hue, and saturation.
5. What is gamma correction?
6. Gamma correction (does, does not) affect the definition of highly saturated scenes.
7. Why are the color difference signals [R-Y & B-Y] adjusted to create the U & V signals?
8. Draw the block diagram of a color TV set and sketch the video waveforms throughout.
9. Sketch and discuss the block diagram of a circuit which will change the color difference signals into the I & Q chroma signal.
10. If a standard NTSC color TV camera scans the following test card, stating any and all assumptions:

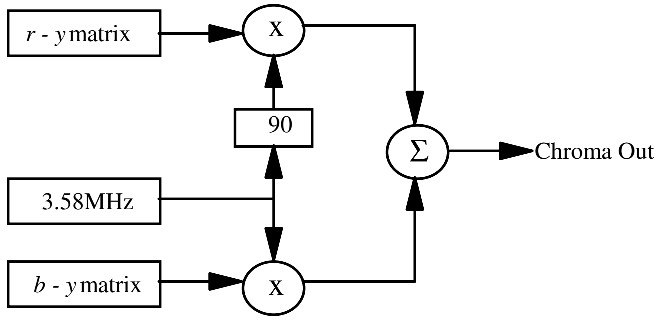
    a) Sketch the complete composite video signal for the center, horizontal scan

    b) Indicate the magnitude and phase of the chroma signal



11. Locate 100% Red, Green, & Blue on an I & Q plot.

12. What is the purpose of the following circuit?



13. Why is the luminance signal defined as: $Y = 0.3R + 0.59G + 0.11B$?
14. What is the magnitude and phase angle relationship between the primary and complementary colors?
15. Why were the vertical and horizontal rates adjusted when color broadcast was introduced?
16. The (PAL, SECAM) system switches between the two chroma signals on alternate lines.
17. The vertical color resolution of the SECAM system is [1/2, 2] times that of the PAL system.
18. The former USSR uses the [NTSC, PAL, SECAM] video signal format.
19. List all of the basic characteristics of the chroma signals used in the following video broadcast systems:

    a) NTSC

    b) PAL

    c) SECAM

For Further Research

http://www.nab.org/

http://www.ww-radio.ch/bmc_index.htm

http://www.cemacity.org/mall/product/video/hdtv.htm

http://www.smpte.org/

http://www.videointernational.com/Standards.html

http://www.ee.surrey.ac.uk/Contrib/WorldTV/index.html