CHAPTER 3

COLOR TELEVISION SYSTEMS

3.1 Introduction

3.1.1 Color signals

The color RGB-TV system has three primary colours: Red, with wavelength \( \lambda_r = 610\, nm \), Green, wavelength \( \lambda_g = 535\, nm \), Blue, wavelength \( \lambda_b = 470\, nm \). The color image is decomposed in the optical system of the camera in three spatial distributions that corresponds to the red, green and blue content of the original image. Each of these three spatial distributions are delivered to three image sensors. The image sensors generate at their outputs the primary colour signals \( E_R, E_G, E_B \).

3.1.2 Compatibility

When color television systems were designed, the black and white television systems were already in use and it was necessary to find a solution in order to use as much as possible the black and white television infrastructure (radio transmitters, bandwidth and channel allocation) and to allow the black and white receivers to display (in black and white) images broadcasted in one of the new colour television systems. For the color receivers it was also necessary to display (in black and white) images broadcasted in old still working black and white systems.

3.2 Signals in compatible television systems

It is compulsory to use a signal that carries the luminance information in order to be used by a black and white television receiver. This signal is called luminance signal, \( E_Y \). This signal is generated by a sum of the three primary colour signals (red, green and blue) weighted according to their relative perception by the human eye. This is the relative spectral eye response \( K(\lambda) \), with a maximum at \( \lambda = 556\, nm \). If the sum of the weighted coefficients has to be 1 (in that case if each of the primary colour signal has an amplitude between 0V and 1V, then luminance signal has also the same amplitude), then:
Together with the luminance signal, $E_Y$, two other signals (linear combination of the primary colour signals) must be sent in order to reconstruct from these 3 signals the primary color signals at the receiver and to apply these to the display device in order to obtain a color image. These signals are the color difference signals $E_R - E_Y$ and $E_B - E_Y$. For any grey level between black and white $E = E_R = E_G = E_B = E_Y$ and the colour difference signals $E_R - E_Y$ and $E_B - E_Y$ are zero. In this way, the color difference signals $E_R - E_Y$ and $E_B - E_Y$ carry only the hue and saturation information from the color, and the luminance signal $E_Y$ carries the luminance information of the color.

Because the CRT (Cathode Ray Tube) transfer function (displayed colour brightness versus input signal voltage on each cathode) is nonlinear, $B_{R,G,B} = k \cdot E_{R,G,B}^\gamma$ ($\gamma$ value 2.2), it is necessary to have a gamma correction on each primary colour signal. This is done by the gamma correction circuit in videocameras: $E_{R,G,B}' = \left(E_{R,G,B}\right)^{\frac{1}{\gamma}}$. This gamma correction is valid also for other display devices for example for LCD (Liquid Crystal Display) devices that have a similar transfer function (displayed colour brightness versus input primary color signal voltage) as the CRT.

### 3.3 Chrominance signal and color video complex signal

The two color difference signals are transmitted by using a color subcarrier. This color subcarrier is amplitude or frequency modulated (depending on the TV colour system). Colour difference signal bandwidth is $1.2 - 1.5 MHz$, that is 3 to 4 times lower than the luminance bandwidth, because the eye resolution for colour details is 3 to 4 times lower than the eye resolution for black and white details.

The subcarrier frequency is chosen in order to allow the spectrum interlace of the subcarrier modulated signal (the chrominance signal) in the free spaces present in the luminance signal spectrum.
By adding this chrominance signal with the luminance signal and other auxiliary signals the color complex video signal is generated SVCC.

Direct compatibility is not complete because the modulated subcarrier frequency is visible on the black and white TV receivers as a high frequency structure superimposed on the black and white image. This effect is called subcarrier visibility.

4 PAL System

4.1 Quadrature Amplitude Modulation

This type of modulation (QAM) is used in NTSC and PAL systems. The chrominance signal is:

\[ E'_c(t) = E'_{b-y}(t) \sin \omega_p t + E'_{r-y}(t) \cos \omega_p t = \left| E'_c(t) \right| \sin \left[ \omega_p t + \phi_c(t) \right], \]

where \( \left| E'_c(t) \right| = \sqrt{E'^2_{r-y}(t) + E'^2_{b-y}(t)} \), \( \phi_c(t) = \arctg \frac{E'_{b-y}(t)}{E'_{r-y}(t)} \). It is not allowed for the modulated color subcarrier superimposed on the luminance signal for a specific color to be above the white level or below the sync level. The condition to be fulfilled by color difference weighting:

\[
\left[ E'_r + \sqrt{(a \cdot E'_{b-y})^2 + (b \cdot E'_{r-y})^2} \right]_{\text{GALBEN}} = 1 \quad \text{si} \quad \left[ E'_y + \sqrt{(a \cdot E'_{r-y})^2 + (b \cdot E'_{b-y})^2} \right]_{\text{TURCOAZ}} = 1.
\]

By solving this equation system the resulting values are \( a = \frac{1}{1,14} = 0,877 \) and \( b = \frac{1}{2,03} = 0,493 \).

In order to demodulate the QAM signal it is necessary to rebuild the subcarrier frequency with correct frequency and phase. For this purpose in PAL and NTSC systems a burst is used. It is a signal consisting of 10 subcarrier periods with a fixed phase and peak to peak amplitude equal to the sync pulse amplitude. Burst amplitude is used in the colour decoder for automatic gain control (AGC) in the chrominance amplifier. This burst signal is transmitted on the return horizontal time interval.

4.2 Signals

In PAL system the luminance signal is used (as in the other TV color systems):

\[ E_y = 0,3E'_r + 0,59E'_b + 0,11E'_y. \]

The weighted color difference signals are:

\[ E'_u = \frac{E'_{b-y}}{2,03} \quad \text{and} \quad E'_v = \frac{E'_{r-y}}{1,14}. \]

For the colors used in standard test pattern signal values before gamma correction are presented in the table below.

<table>
<thead>
<tr>
<th>Color</th>
<th>( E_r )</th>
<th>( E_g )</th>
<th>( E_b )</th>
<th>( E_y )</th>
<th>( E_r - E_y )</th>
<th>( E_b - E_y )</th>
<th>( E_c )</th>
<th>( \phi^\circ )</th>
</tr>
</thead>
<tbody>
<tr>
<td>White</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
After gamma correction the resulting signals are $E'_r$, $E'_g$, $E'_b$. Color difference signals are weighted $\frac{E'_b - E'_y}{1,14}$ and $\frac{E'_r - E'_y}{2,03}$. After the lowpass filter (1,2 MHz bandwidth) the signals are $E'_u = \frac{E'_b - E'_y}{2,03}$ and $E'_v = \frac{E'_r - E'_y}{1,14}$.

For the color standard test pattern whith 8 vertical color bars: white, black, red, green and blue (the primary color signals) cyan, mauve and yellow (their complementary colors). Two complementary colors have the property that by mixing them the result is white.

The 8 color bars are placed in the standard test pattern in decreasing order of their luminance.

The signals are presented below.

<table>
<thead>
<tr>
<th></th>
<th>$E_x$</th>
<th>$E_y$</th>
<th>$E_z$</th>
<th>$E'_x$</th>
<th>$E'_y$</th>
<th>$E'_z$</th>
<th>$E''_x$</th>
<th>$E''_y$</th>
<th>$E''_z$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0,89</td>
<td>0,11</td>
<td>-0,89</td>
<td>0,89</td>
<td>173</td>
<td></td>
</tr>
<tr>
<td>Cyan</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0,70</td>
<td>-0,7</td>
<td>0,30</td>
<td>0,76</td>
<td>307</td>
<td></td>
</tr>
<tr>
<td>Green</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0,59</td>
<td>-0,59</td>
<td>-0,59</td>
<td>0,83</td>
<td>225</td>
<td></td>
</tr>
<tr>
<td>Mauve</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0,41</td>
<td>0,59</td>
<td>0,59</td>
<td>0,83</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>Red</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0,30</td>
<td>0,70</td>
<td>-0,30</td>
<td>0,76</td>
<td>127</td>
<td></td>
</tr>
<tr>
<td>Blue</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0,11</td>
<td>-0,11</td>
<td>0,89</td>
<td>0,89</td>
<td>353</td>
<td></td>
</tr>
<tr>
<td>Black</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>


The chrominance (unweighted) is:

\[
E'_c = \pm 0.67, \pm 0.57, \pm 0.63, \pm 0.63, \pm 0.57, \pm 0.67
\]
After weighting and adding all the components, the PAL video complex color signal for one active line is:

The three primary colors are generated in the videocamera as shown in the diagram below.

4.3 PAL color coder

The three primary colors are generated in the videocamera as shown in the diagram below.
The symbols are:
- **SO** - optic system (the lens)
- **OD_1,2** - dichroic mirrors (one part of the visible spectrum is reflected and the other part is transmitted)
- **O_1,2** - mirrors
- **FR, FG, FB** - Coloured filters
- **FN** - neutral filters
- **Trad R, G, B** - image sensors (transducers)

The three primary color signals are gamma corrected and are used to generate in the first stage of the PAL coder (matrix) the luminance and the weighted colour difference signals. For the luminance signal the operation can be done by the diagram:

\[
\frac{R_3}{R_1 + R_3} = 0.3, \quad \frac{R_5}{R_4 + R_5} = 0.59, \quad \frac{R_8}{R_7 + R_8} = 0.11, \quad R_3 = R_6 = R_9 = R_{16}.
\]

For color difference signal generation the diagram below is used:

Because of the delay introduced on the chrominance path by the lowpass filters, an additional delay is necessary on the luminance path.
After adding pulses from the BK (Burst Key) block, the two colour difference signals are introduced in the DC component fixing blocks F. After QAM subcarrier modulation chrominance signal $E'_c$ is generated together with burst signal on the return horizontal time interval. These signals are added to the luminance and sync and blanking pulses (horizontal and vertical) generated on the luminance path and the PAL complex video signal. Phase alternation of the $E'_c$ signal at each line is obtained by a phase shift circuit with 0 or $\pi$ phase shift at each line for the cosine subcarrier signal. This is the phase error compensation in PAL.

### 4.4 Phase error compensation in PAL

The mediation done in the PAL decoder for the chrominance signal on two successive lines (possible because of the use of a delay line equal to the horizontal scan period) and phase alternation of the $E'_c$ signal (PAL = Phase Alternation Line), transform a possible phase error in the communication channel into a saturation error on the colour image. In NTSC the effect of a phase error is a hue error on the image which is most annoying for the human eye. The phase error compensation in PAL is presented in the vector diagram below:

The chrominance signal on line $K$ is the vector $E'_{c_k}$. It is assumed that on two successive lines we have the same colour. Only $E'_c$ polarity will change from line K-1 to line K. If there is a phase error $-\Delta \varphi$, $E'_{c_k}$ vector will be received instead of $E'_{c_k}$. After mediation between $E'_{c_k}$ and $E'_{c_{k+1}}$ the resulting vector is $E'_{c_{KD}}$ with the same phase as the correct vector $E'_{c_k}$ and with lower amplitude. So, in the displayed image, colour hue will be correct and
colour saturation will be lower, which is less annoying for the human eye. The human eye can tolerate a colour de-saturation of 70%, corresponding to a phase error of 40°.

4.5 Burst signal

It is necessary for color subcarrier reconstruction in the decoder. It is also used in the decoder to recover the correct polarity of $E'_r$. The burst phase is $+135^\circ$ for a line with positive $E'_r$, and $+225^\circ$ for a line with negative $E'_r$:

\[
S_c(t) = -S \sin \omega_{sp} t + S g_{com}(t) \cos \omega_{sp} t = S \sqrt{2} \sin \left[ \omega_{sp} t + 180^\circ - g_{com}(t) \cdot 45^\circ \right]
\]