UNIVERSITATEA “POLITEHNICA” BUCUREŞTI
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LABORATOR TELEVIZIUNE

VIDEO SIGNALS IN DIGITAL COLOR SYSTEMS

1. Common features of the color television systems

1.1. Primary color signals

In television the colorimetric system RGB-TV is used, where initials come from the English names of primary colors, namely red (Red, with 610 nm wavelength - $\lambda_R = 610\,nm$), green (Green, 535 nm wavelength - $\lambda_G = 535\,nm$), blue (Blue, 470 nm wavelength – $\lambda_B = 470\,nm$).

The wavelengths have been chosen because these color phosphors were available at the introduction of the color television system, phosphors which are used to produce image elements on the only available display at that moment, the color Cathode Ray Tube (CRT). Note that the values in parentheses is the dominant wavelength, because the issue of a pure monochromatic radiation is impossible. The theoretical basis of this system is the first axiom of Grassmann. It states that any color in the spectrum can be decomposed into the three mentioned above, with various weights, by means of optical filters. Color information is broadcasted by the primary color signals (E_R, E_G, E_B).

1.2. Color TV systems compatible with BW TV systems

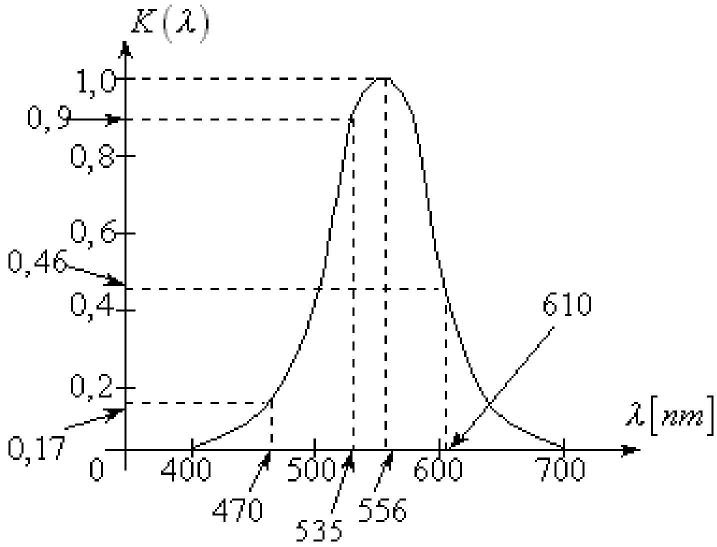
Because at the beginning of color television there was an infrastructure with black and white receivers, it was necessary to ensure a direct compatibility, namely the possibility to receive on a black and white receiver a color broadcast with unobservable impairments or hardly visible errors observable. To accomplish this goal, there must be kept for color television the analysis and synthesis parameters for BW TV, namely the aspect ratio, the frame and line frequency, the pulse durations and locations and the transmission channel parameters, such as modulation type, bandwidth, relative space frequency between sound and image carriers.
It was also necessary to ensure backward compatibility, meaning the ability to receive a color broadcast on a BW television receiver.

1.3. Signals for compatible color TV systems

There is a color television signal called the luminance signal, denoted by Y which can be processed by a black and white TV, thus ensuring direct compatibility. This signal is obtained by summing the weighted components corresponding to three primary colors and luminance is decomposed according to Grassmann's third axiom. The weighting is given by the different perception by the human visual system of the three primary colors depending on their wave length. The perception is illustrated in the human eye relative spectral sensitivity feature $K(\lambda)$, that has a maximum at $\lambda = 556nm$.
The weight corresponding to each primary color in the luminance formula are obtained by dividing their coefficient values in the spectral sensitivity curve to the sum of the three coefficients, thus generating normalized weights: $c = \frac{0{,}17}{0{,}17 + 0{,}9 + 0{,}46} = \frac{0{,}17}{1{,}53} = 0{,}11$

$b = \frac{0{,}9}{1{,}53} = 0{,}53 \qquad a = \frac{0{,}46}{1{,}53} = 0{,}3$. The luminance signal is:

$$E_Y = 0{,}3E_R + 0{,}53E_G + 0{,}11E_B$$



For a color TV receiver, the color TV compatible system sends together with the luminance signal Y, two color difference signals $E_R - E_Y$ and $E_B - E_Y$. For any gray level from black to white the three color primary signals are equal $E_R = E_G = E_B = E_Y$, which means that the color difference signals are zero. In fact, the color difference signals carry only the pure color information (hue and saturation) and no information for luminance. That makes possible the use of a reduced bandwidth (1.2 to 1.5 MHz) for the $E_R - E_Y$ and $E_R - E_Y$ signals. due to the fact that human eye resolution for color details is 3 to 4 times lower than for gray details. That is why the luminance and color difference signals combination is used also in the digital color TV systems where there was not necessary any compatibility with a previous television system, and so it was possible to broadcast directly the E_R, E_G, E_B signals.

1.4. The chrominance signal and the color composite video signal

Since the analysis is similar to that of black-and-white, the television signals spectrum will have the same characteristics: small bandwidths at multiples of line frequency, field frequency and their linear combinations. In the free spaces that are in the luminance signal spectrum, it will be possible to place the color difference signals spectrum components, modulated on a color subcarrier. The color subcarrier has a value around 3 to 4 MHz and is modulated with the two color difference signals in amplitude in quadrature QAM (in NTSC and PAL systems) or in frequency FM (in SECAM).

The modulated color subcarrier is called the chrominance signal. If the luminance signal Y is summed with the chrominance signal, with the horizontal and vertical sync and blanking pulses, and with additional signals necessary to demodulate the chrominance signal, the color composite video signal is obtained.

2. PAL System

2.1. QAM modulation

Quadrature amplitude modulation is used in NTSC and PAL systems. The chrominance signal formula is:

$$E'_C(t) = E'_{B-Y}(t)\sin\omega_{sp}t + E'_{R-Y}(t)\cos\omega_{sp}t = \left|E'_C(t)\right|\sin\left[\omega_{sp}t + \varphi_C(t)\right]$$

where $\left|E'_C(t)\right| = \sqrt{E'^2_{R-Y}(t) + E'^2_{B-Y}(t)}$ and $\varphi_C(t) = \operatorname{arctg}\dfrac{E'_{R-Y}(t)}{E'_{B-Y}(t)}$

Reducing peak to peak amplitude of the chrominance signal before summation with the luminance and auxiliary signals is through a weighting operation in order to maintain the composite color video signal in the range between the sync and white level (1 Vpp).

The weighting coefficients are calculated from the condition that for the two color bars (yellow and cyan) that follow white in the 8 bars standard color test pattern, $E'_Y + E'_C$ is equal with 1 V (white level):

$$\left[E'_Y + \sqrt{\left(a\cdot E'_{R-Y}\right)^2 + \left(b\cdot E'_{B-Y}\right)^2}\right]\Big|_{\text{GALBEN}} = 1$$

$$\left[E'_Y + \sqrt{\left(a\cdot E'_{R-Y}\right)^2 + \left(b\cdot E'_{B-Y}\right)^2}\right]\Big|_{\text{TURCOAZ}} = 1$$

By solving the equations system, the weighting coefficients for the color difference signals are obtained:

$$a = \frac{1}{1{,}14} = 0{,}877$$

$$b = \frac{1}{2{,}03} = 0{,}493$$

A specific signal in PAL and NTSC color systems is the color synchronizing signal (or burst). Its presence can be detected on the posterior level of the blanking pulse and is need to synchronous demodulate the chrominance signal at the reception, where the carrier generated should be with the same frequency and phase as that of the transmitter. This signal consists of 10 periods of a sinusoid of the same amplitude peak to peak as the sync pulses, with a frequency equal to the color subcarrier frequency.

2.2 PAL signals

The luminance signal:

$$E_Y = 0{,}3E'_R + 0{,}59E'_G + 0{,}11E'_B.$$

The weighted color difference signals:

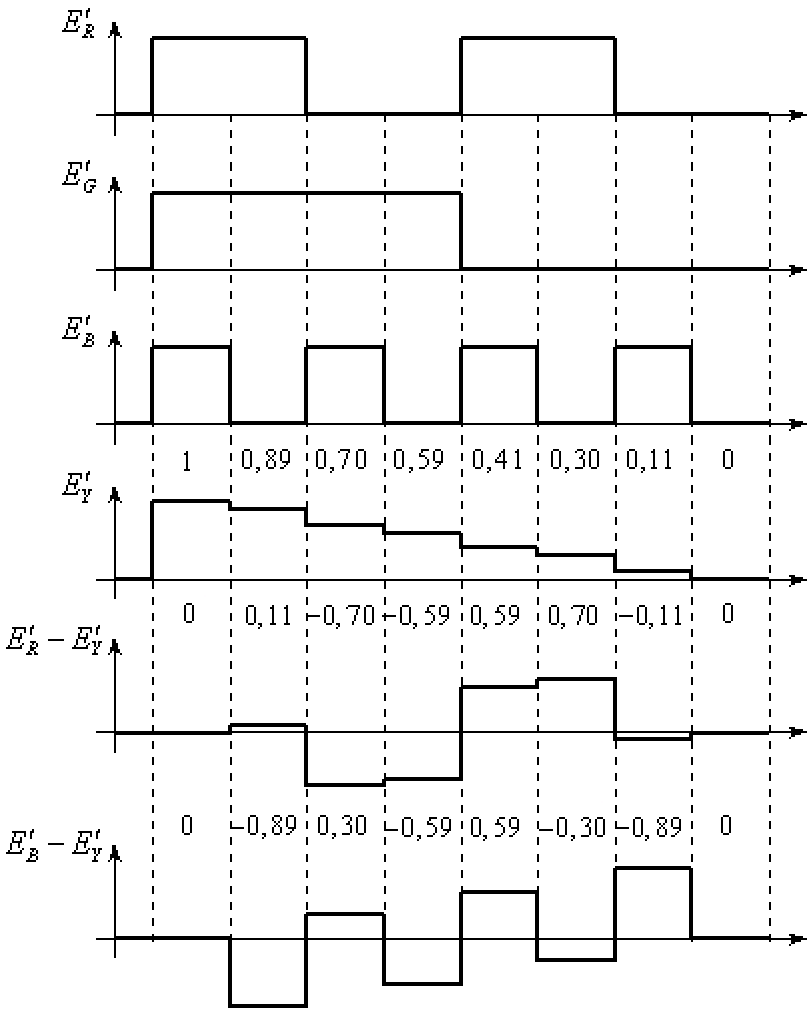
$$E'_U = \frac{E'_{B-Y}}{2{,}03}$$

$$E'_V = \frac{E'_{R-Y}}{1{,}14}$$

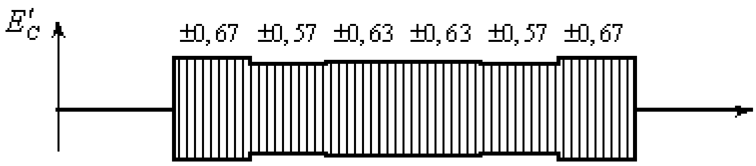
The standard color bars test pattern has 8 color vertical bars in the decreasing order of the luminance. It contains white, black, the primary colors (red, green and blue) and their corresponding complementary colors (cyan, purple and yellow). Two colors are complementary if white is obtained by mixing them in equal quantities. The colors in the standard color bars test pattern are with 100% saturation (pure colors) and with 75% brightness (except white which has 100% brightness). If the correct transmission of the three primary colors is verified, all the other colors will be correctly displayed since they are linear combinations of the primary colors. In the table below, the signals corresponding to the standard color bars test pattern are calculated.

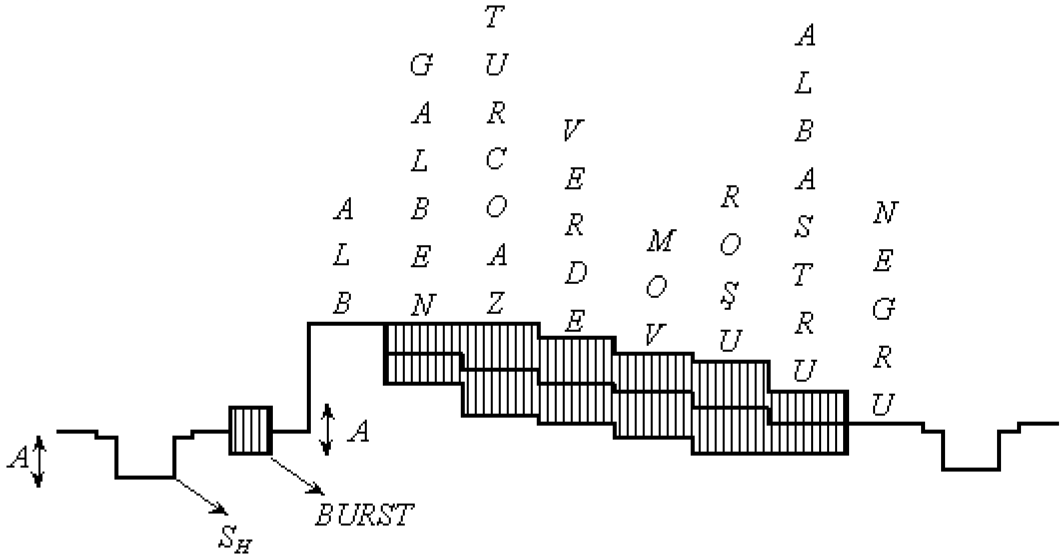
Color	E_R	E_G	E_B	E_Y	$E_R - E_Y$	$E_B - E_Y$	E_C	$\varphi \circ$
White	1	1	1	1	0	0	0	0
Yellow	1	1	0	0,89	0,11	-0,89	0,89	173
Cyan	0	1	1	0,70	-0,7	0,30	0,76	307
Green	0	1	0	0,59	-0,59	-0,59	0,83	225
Purple	1	0	1	0,41	0,59	0,59	0,83	45
Red	1	0	0	0,30	0,70	-0,30	0,76	127
Blue	0	0	1	0,11	-0,11	0,89	0,89	353
Black	0	0	0	0	0	0	0	0

The signals from the table are displayed in the diagram below.



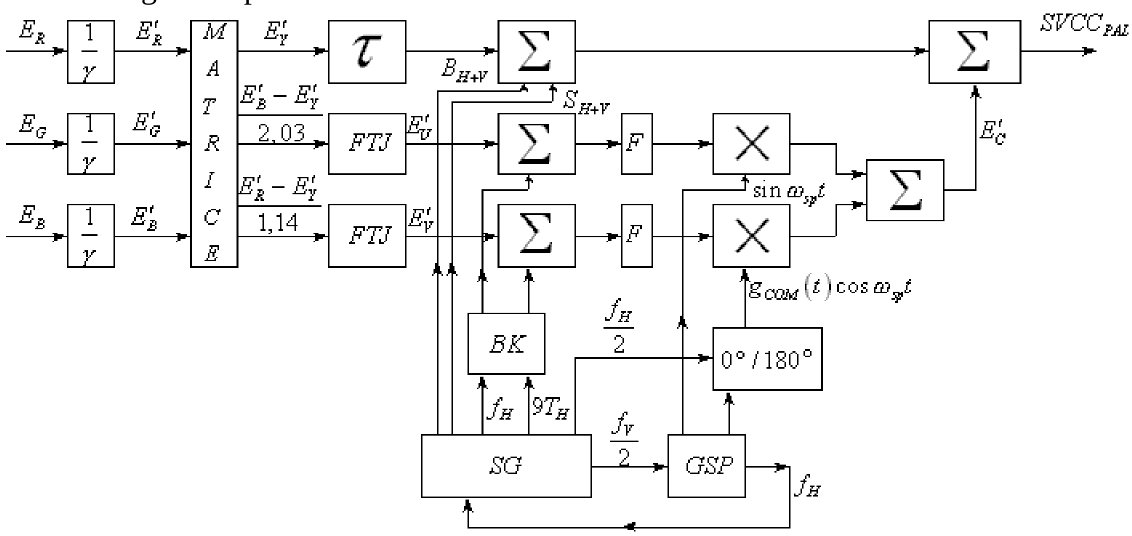
The chrominance signal and the composite PAL video signal are presented below:



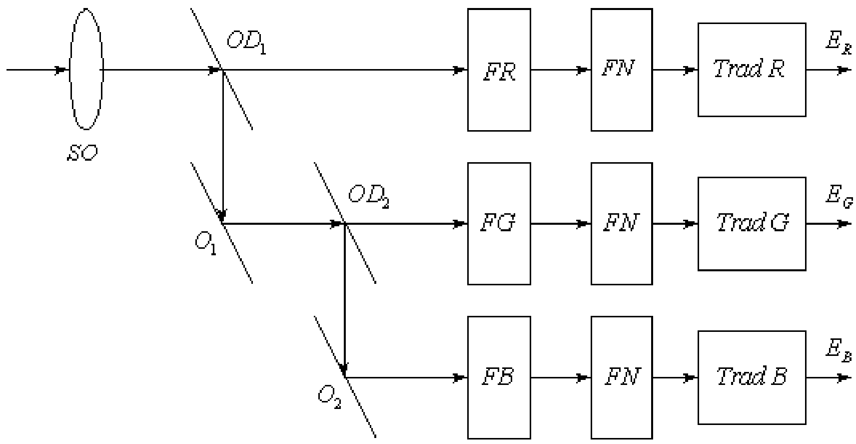


2.3 PAL Coder

The block diagram is presented below:



There are two processing paths in this diagram: the luminance and the chrominance path, as defined by the signals that it processes. Input signals are the three primary color signals received from the optoelectronic transmitter (camera), and has the following scheme.

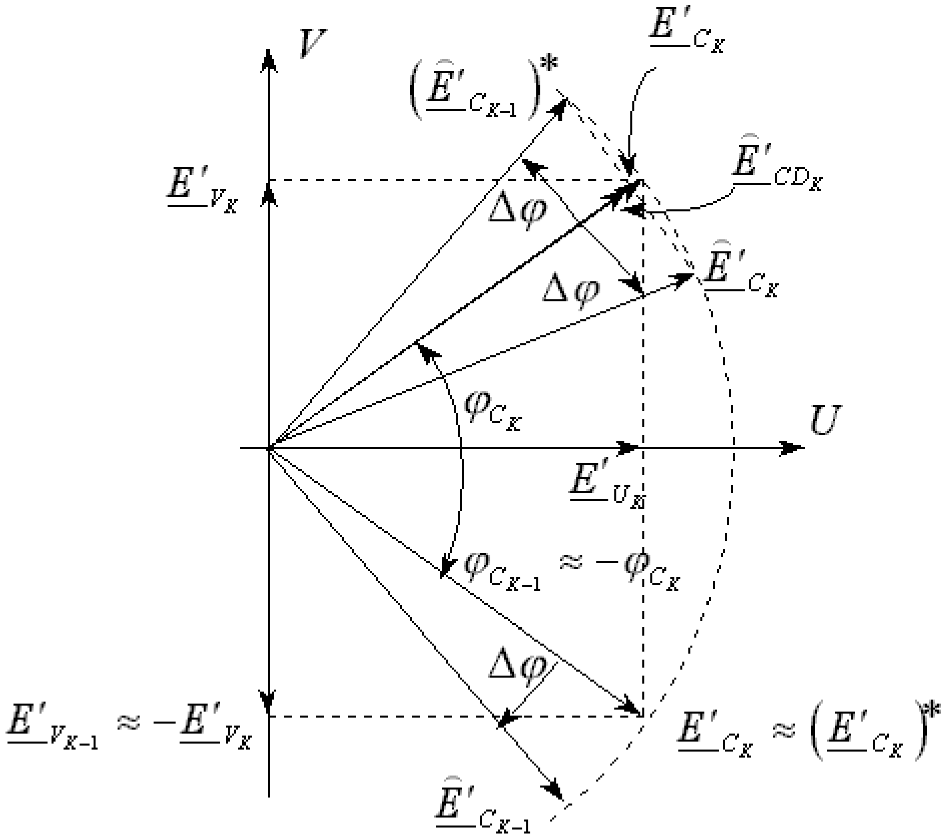


The significance of the notation is:

- SO - optical separator, lens that take the picture and sends it to the floor filter;
- $OD_{1,2}$ - dichroic mirrors; designed to let through only a part of the spectrum, reflecting the remaining part; OD_1 passes red and OD_2 green;
- $O_{1,2}$ - semitransparent mirrors, reflecting light wave on;
- , FR, FG, FB - colored optical bandpass filters;
- FN - neutral filters, equalizing the spectral response on each track;
- $Trad\, R,G,B$ - image sensors (CCD or CMOS) that converts the light signal into an electrical signal.

2.4 The phase error correction in PAL

If there is a phase error during the transmission, it will not be converted into a hue error like in NTSC. In PAL, by using a delay line equal to a line period (64 micro-seconds), it is possible to make an average of the chrominance signals on two consecutive lines; the phase error appears on the next line with the sign reversed. After reversing the phase in the PAL decoder and averaging two consecutive lines, a phase error generates an amplitude reduction of the chrominance signal, that means on the display device a reduce in color saturation which has a lower impact on the viewer than the hue error in NTSC. This type of transmission gives the system name (Phase Alternation Line). The principle is illustrated in the following figure:



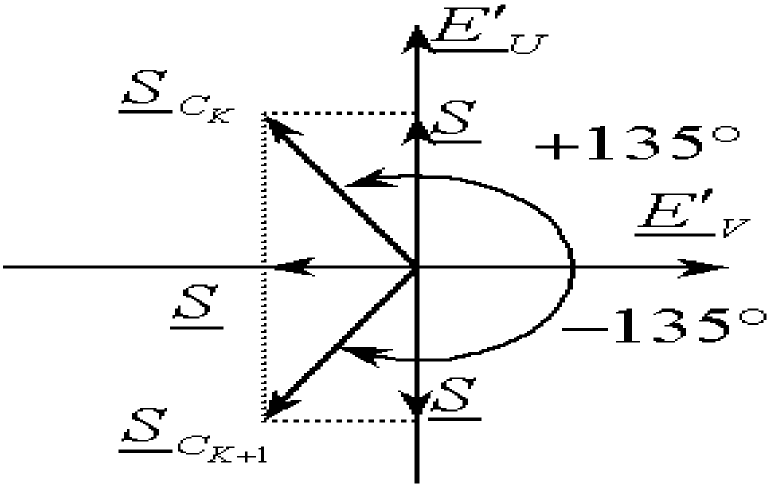
The chrominance signal on line K is represented by the vector $\underline{E'}_{C_K}$. The polarity of E'_V is changed from one line to another. At the reception, if there is a phase error, the vector will be $\underline{\hat{E}'}_{C_K}$, with phase error $-\Delta\varphi$. The average value of vector $\underline{\hat{E}'}_{C_K}$ (chrominance signal on line K) and vector $\left(\underline{\hat{E}'}_{C_{K-1}}\right)^*$ (chrominance symmetrical signal on line K-1) is vector $\underline{\hat{E}'}_{CD_K}$ with correct phase and reduced amplitude that produce a lower color saturation on the image. Since the human eye ca tolerate a 70% reduction in saturation, it results that a 40° phase error can be tolerated in PAL system.

2.5 Burst signal

It is necessary for the subcarrier frequency and phase synchronization at the reception point in the PAL decoder. It is also used for the automatic adjustment of saturation (as amplitude reference). To transmit information on the line type (E'_V with or without polarity inversion) the burst phase is $+135^\circ$ for lines with $+E'_V$ and $+225^\circ$ for the lines with - E'_V. The PAL burst signal is also used by a multi-system decoder to identify the signal that is present at its input. The burst signal is:

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

The vector representation of the burst signal on two successive lines is presented in the figure below.



3. Measurements

- Identify the platform equipment: test pattern generator (test signals corresponding to various images), oscilloscope with video / audio sync and video monitor
- Connect the composite video output of the PAL test pattern generator to the color receiver composite video input and to the oscilloscope. Draw the connection scheme
- Select from the oscilloscope TRIG menu the options VIDEO, PAL/SECAM, LINE NUMBER, and from the DISPLAY menu the option VECTORS to see steep fronts of the video signal (given the high frequency band of 5 MHz thereof)
- View the PAL composite video signal for one active line for the standard color bars test pattern.
- View the video on all active lines for all the other available test patterns from the generator.

- Draw or are store on a memory stick inserted into the USB port on the oscilloscope the measured PAL composite video signals
- Fix the function MATH on oscilloscope and FFT, view the video spectrum and for various types of test patterns
- From the options available on the PAL coder in the test pattern generator select the BURST OFF mode. Explain the image displayed in this situation on the TV receiver
- From the options available on the PAL coder in the test pattern generator select the 50% BURST mode. Explain the image displayed in this situation on the TV receiver
- From the options available on the PAL coder in the test pattern generator select the CHR OFF mode. Explain the image displayed in this situation on the TV receiver
- From the options available on the PAL coder in the test pattern generator select the Y OFF mode. Explain the image displayed in this situation on the TV receiver
- From the options available on the PAL coder in the test pattern generator select the U OFF mode. Explain the image displayed in this situation on the TV receiver
- From the options available on the PAL coder in the test pattern generator select the V OFF mode. Explain the image displayed in this situation on the TV receiver
- From the options available on the PAL coder in the test pattern generator select the BURST PHASE ROTATE mode. Explain the image displayed in this situation on the TV receiver
- For the standard color bars test pattern switch off the R, G or B signal. Explain the image displayed in this situation on the TV receiver
- Switch off the oscilloscope time base and insert the Y – R signal on the CH 1 input of the oscilloscope and the Y – B signal on the CH 2 input of the oscilloscope. Selecy the CH1 versus CH2 option. Explain the constellation displayed on the oscilloscope and compare it to the PAL vectorscope principle