

# Colorimetria e TV a Cores

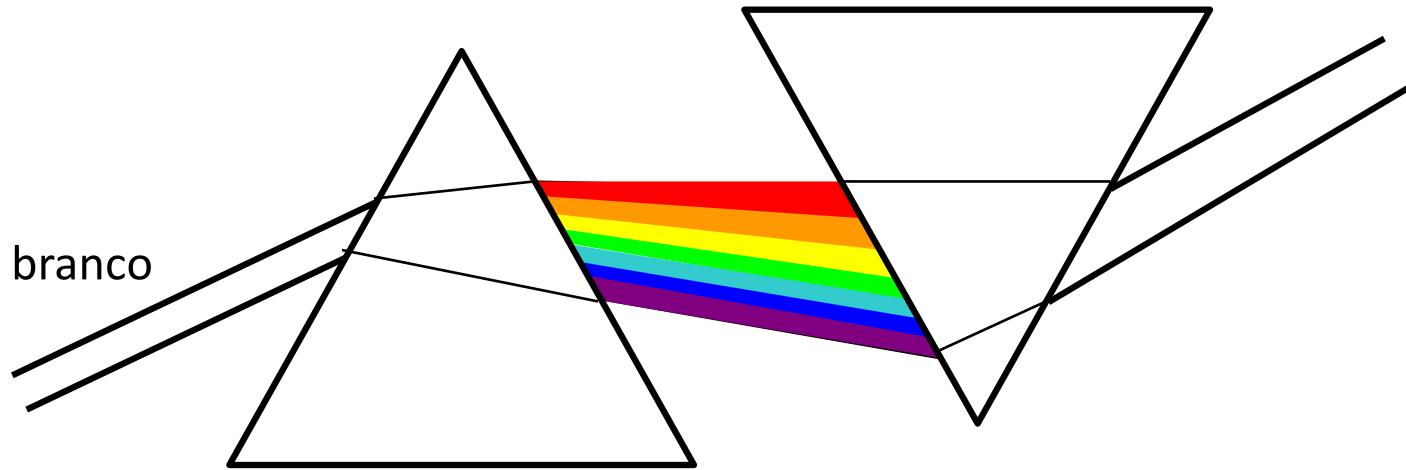
PTC3547

Codificação e Transmissão Multimídia

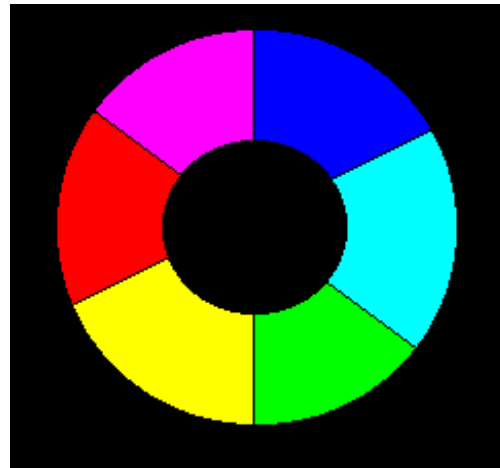
Guido Stolfi – EPUSP - 2019

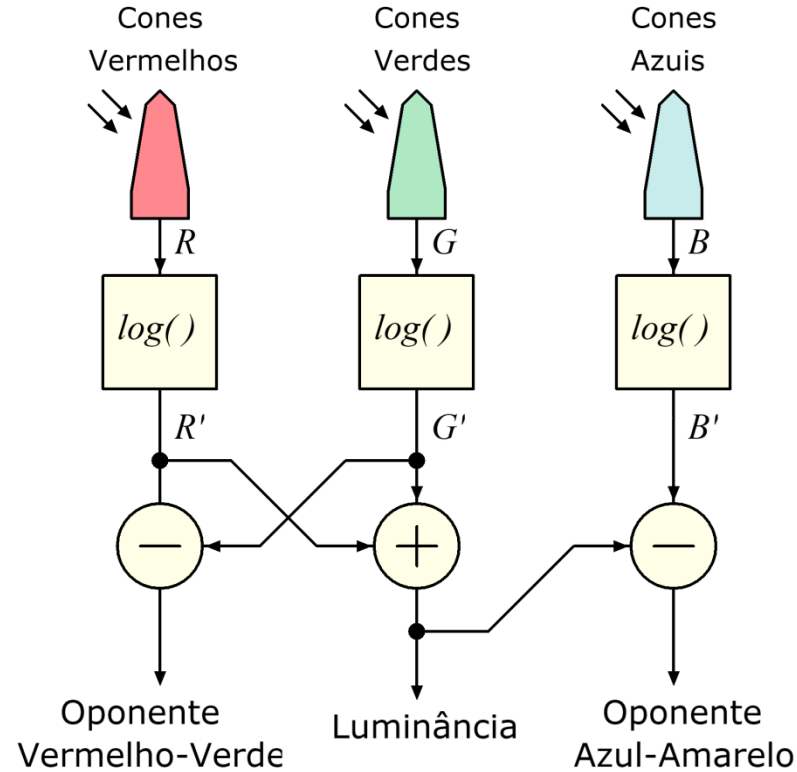


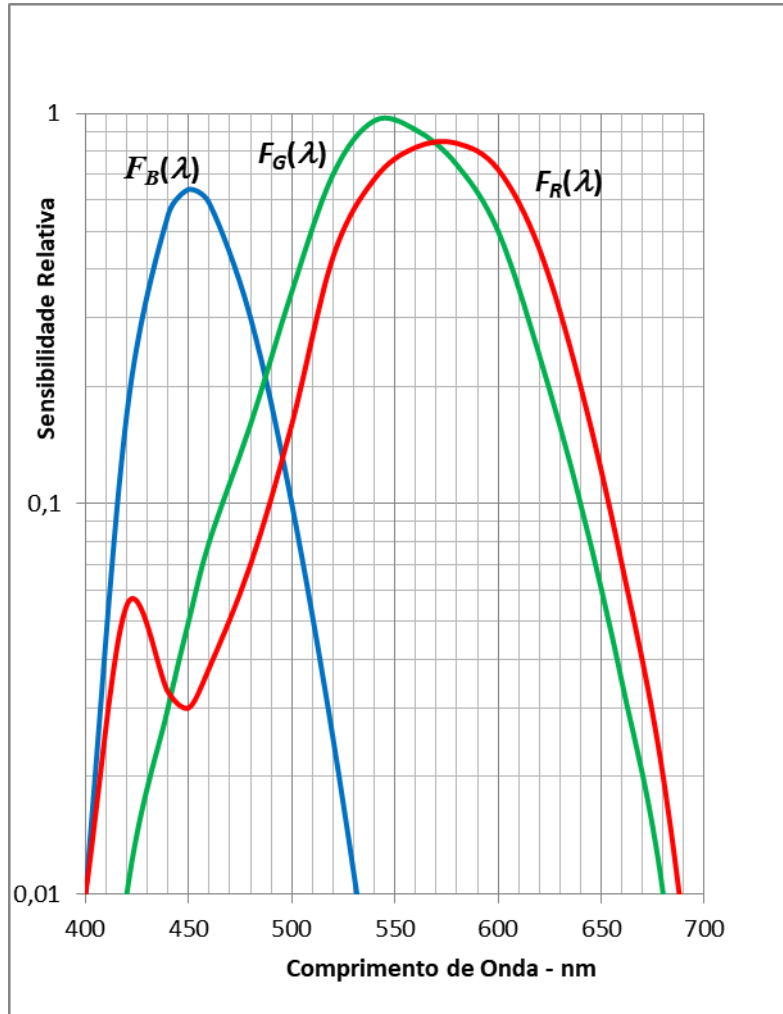
- Oponentes cromáticas
- Modelo da Percepção Cromática
- Processos de Colorimetria
- Funções de Cromaticidade
- Coordenadas  $r-g$  e  $x-y$
- Exemplos de Cálculos Colorimétricos
- Transmissão de TV a Cores
- Codificadores NTSC, PAL-M
- Outros Codificadores Analógicos
- Colorimetria para HDTV e UHDV
- Equipamentos de Teste para sinais de Vídeo



$\lambda$ (nm)	cor		$\lambda$ (nm)	cor
590-560	amarelo	$\Leftrightarrow$	470-430	Azul/violeta
605-590	laranja	$\Leftrightarrow$	430-380	azul/verde
780-605	vermelho	$\Leftrightarrow$	500-470	ciano
---	magenta	$\Leftrightarrow$	560-500	verde





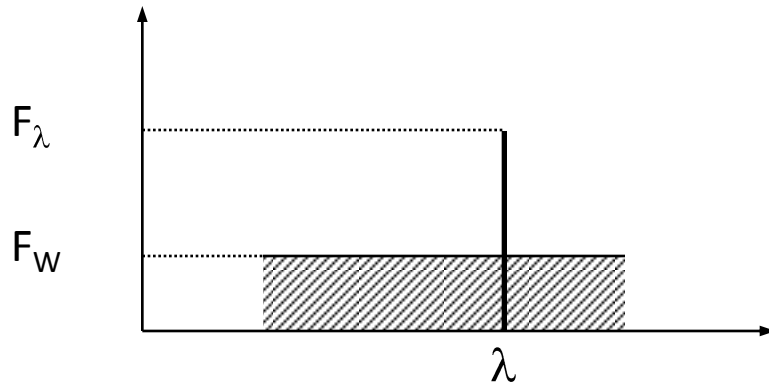


$$R = \int P(\lambda) \cdot F_R(\lambda) d\lambda$$

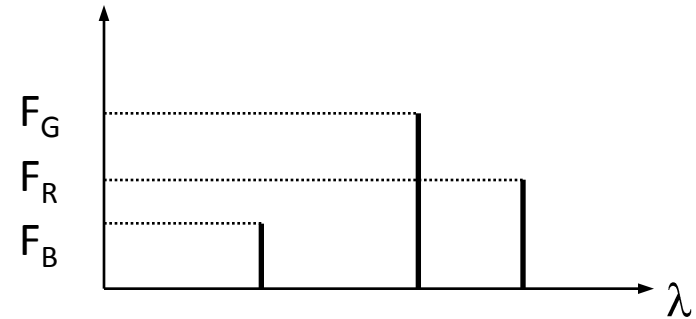
$$G = \int P(\lambda) \cdot F_G(\lambda) d\lambda$$

$$B = \int P(\lambda) \cdot F_B(\lambda) d\lambda$$

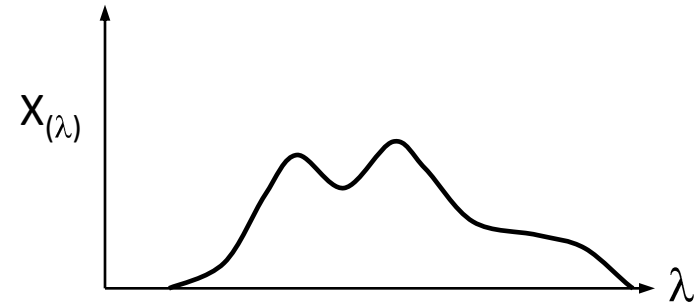
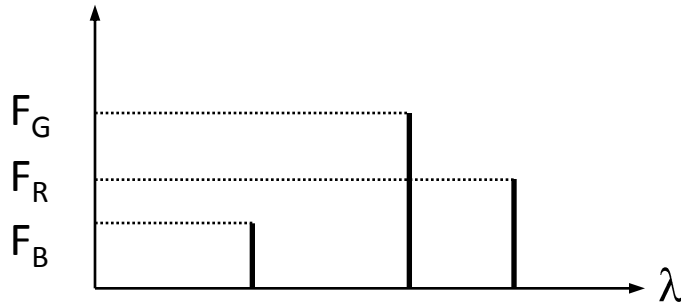
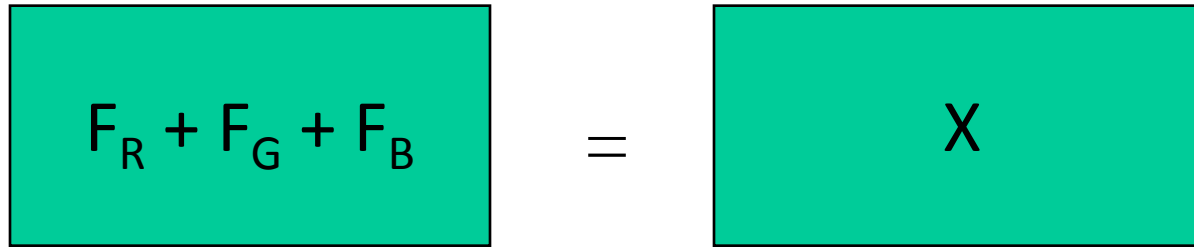
Objetivo: Reproduzir os estímulos visuais R, G e B artificialmente



(a)

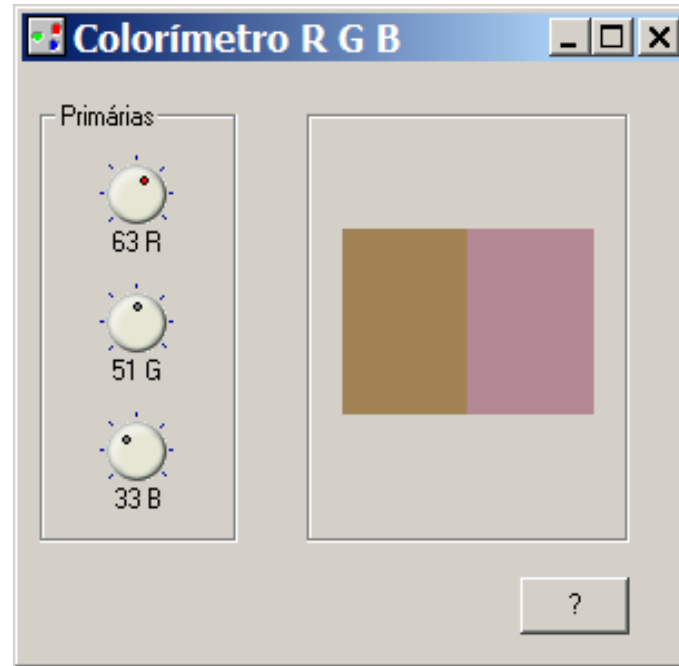


(b)

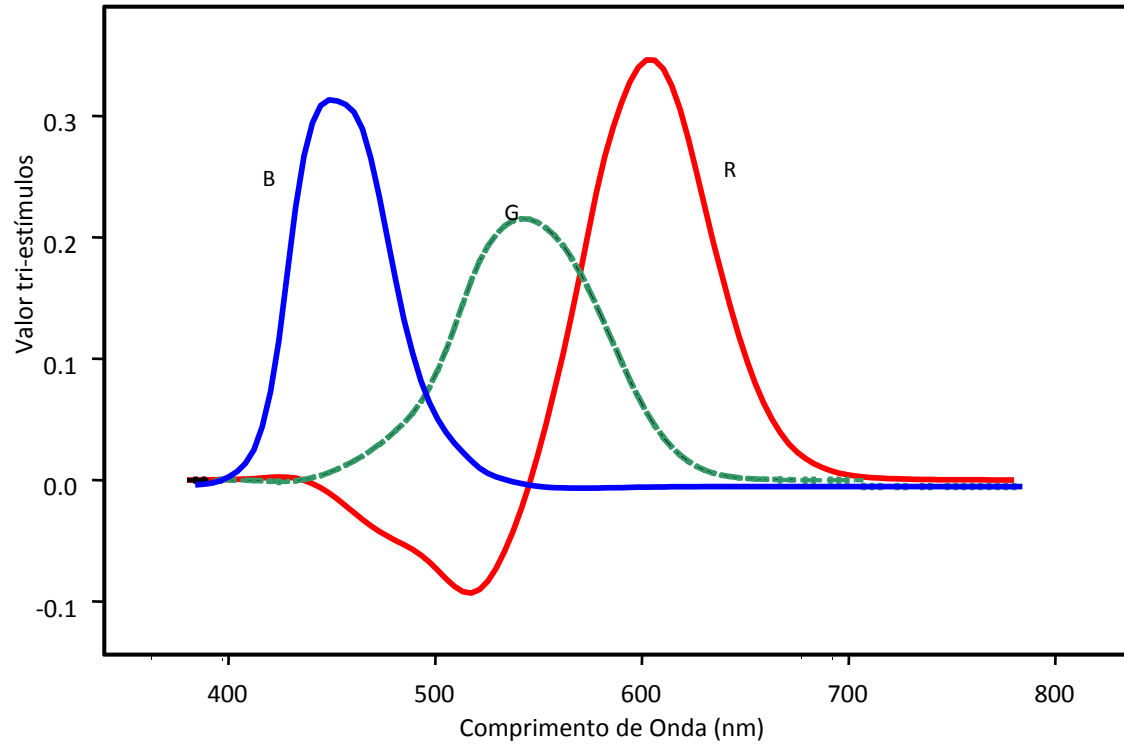


Estímulos R, G, B iguais nos dois casos





# Coordenadas Colorimétricas



Primários em 700nm (**R**), 546.1 nm (**G**) e 435.8 nm (**B**)

$$R = \int_{380}^{780} P(\lambda) \bar{r}(\lambda) d\lambda$$

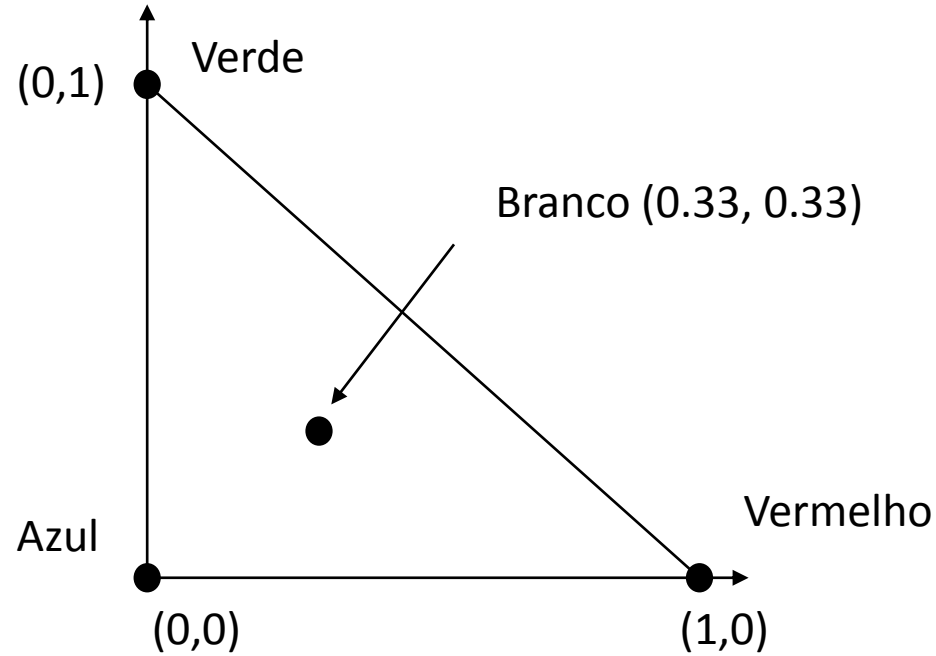
$$G = \int_{380}^{780} P(\lambda) \bar{g}(\lambda) d\lambda$$

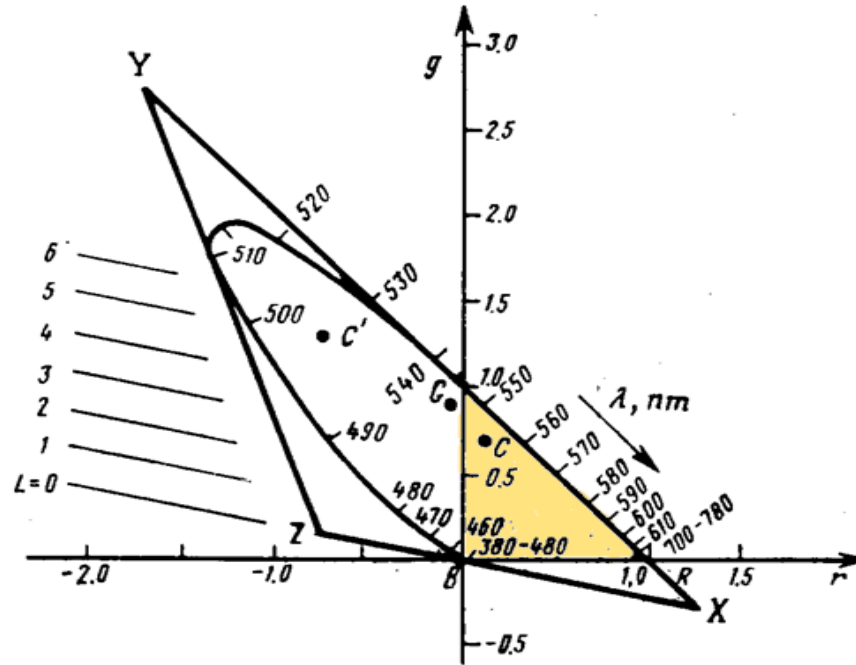
$$B = \int_{380}^{780} P(\lambda) \bar{b}(\lambda) d\lambda$$

$$r = \frac{R}{R + G + B}$$

$$g = \frac{G}{R + G + B}$$

$$b = \frac{B}{R + G + B} = 1 - r - g$$





$$X = 0.490R + 0.310G + 0.200B$$

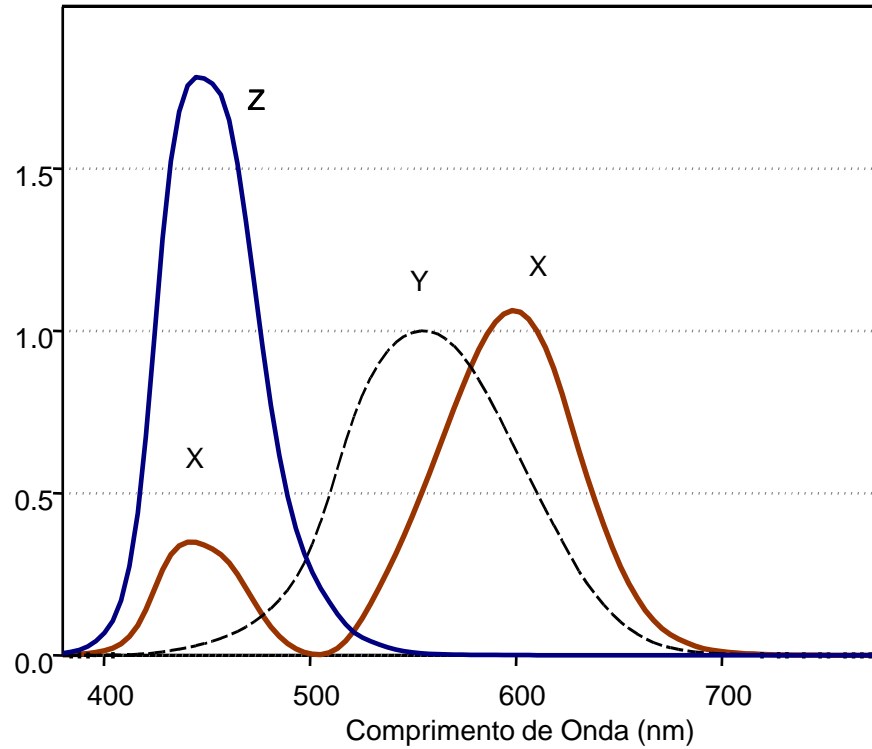
$$Y = 0.177R + 0.813G + 0.011B$$

$$Z = 0.000R + 0.010G + 0.990B$$

$$R = 2.365X - 0.897Y - 0.468Z$$

$$G = -0.515X + 1.426Y + 0.089Z$$

$$B = 0.005X - 0.014Y + 1.009Z$$

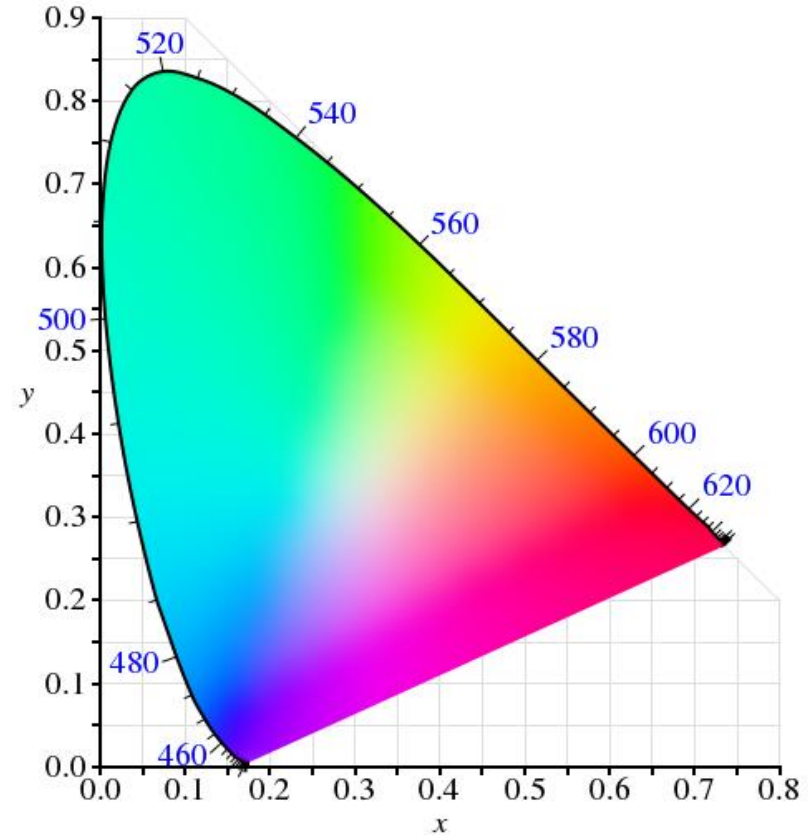
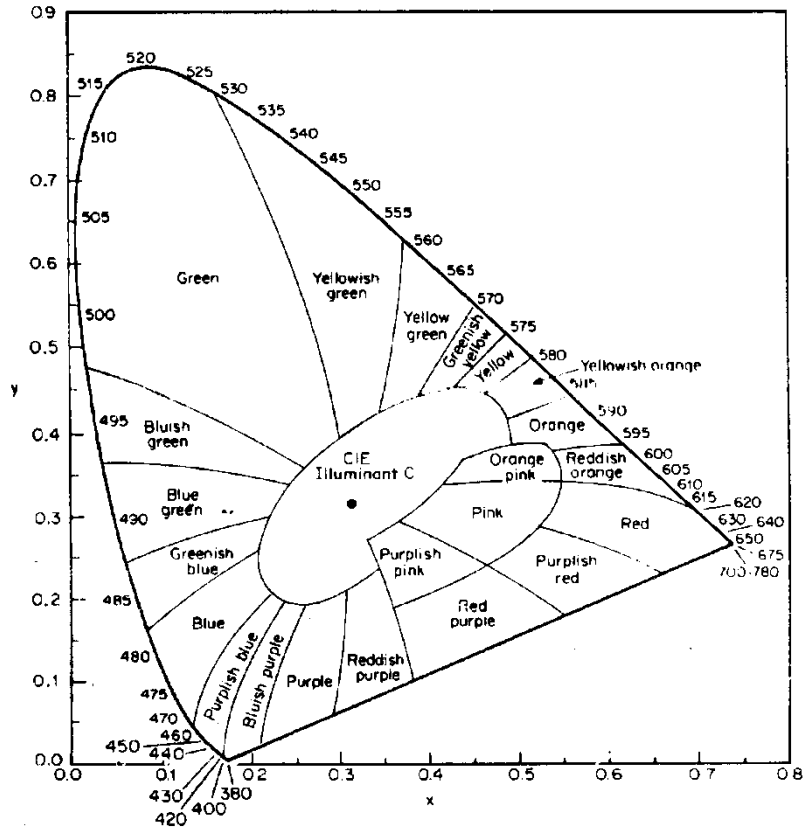


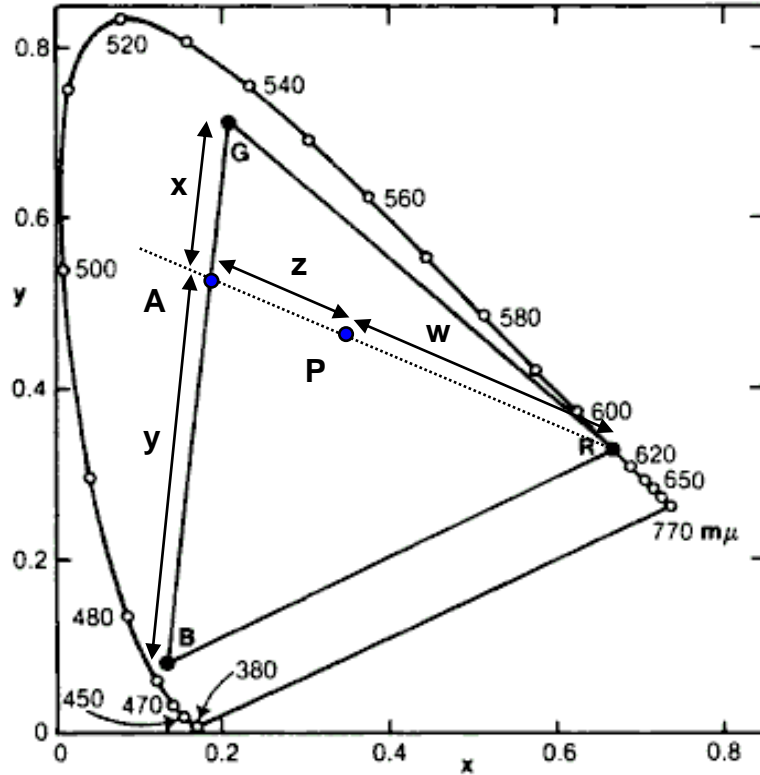


$$x = \frac{X}{X + Y + Z}$$

$$y = \frac{Y}{X + Y + Z}$$

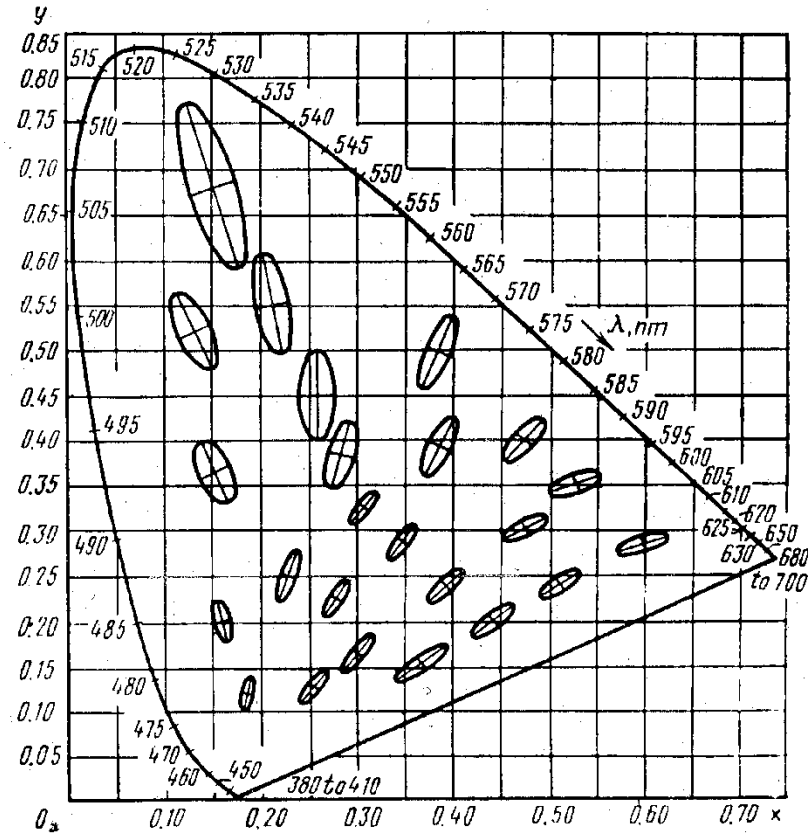
# Diagrama de Cromaticidade CIE



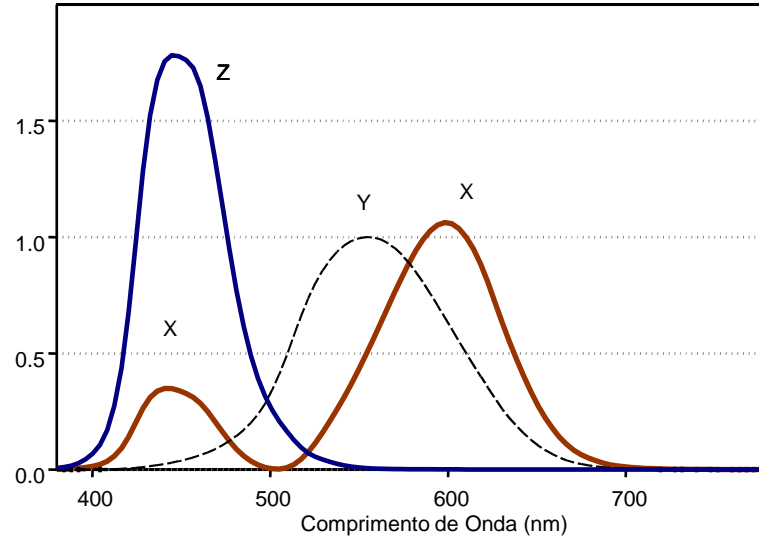
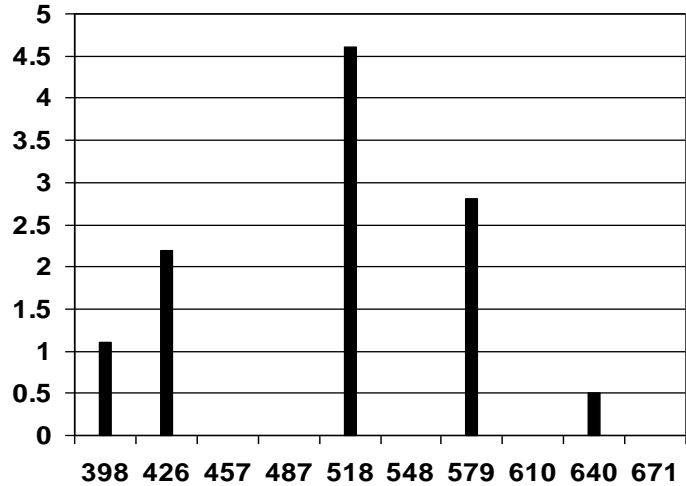


$$A = (yG + xB)/(x+y)$$

$$P = (wA + zR)/(w+z)$$



# Exemplos



$$X = \int_{380}^{780} P(\lambda)\bar{x}(\lambda)d\lambda = 1.1 \times 0.014 + 2.2 \times 0.284 + 4.6 \times 0.063 + 2.8 \times 0.916 + 0.5 \times 0.448 = 3.72$$

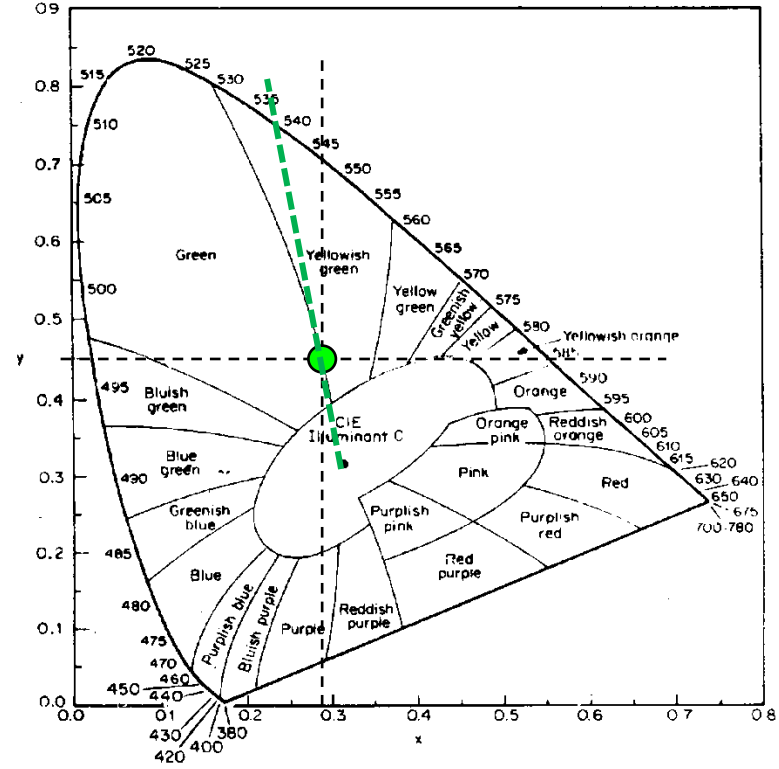
$$Y = \int_{380}^{780} P(\lambda)\bar{y}(\lambda)d\lambda = 1.1 \times 0.0004 + 2.2 \times 0.012 + 4.6 \times 0.71 + 2.8 \times 0.87 + 0.5 \times 0.175 = 5.82$$

$$Z = \int_{380}^{780} P(\lambda)\bar{z}(\lambda)d\lambda = 1.1 \times 0.068 + 2.2 \times 1.39 + 4.6 \times 0.078 + 2.8 \times 0.002 + 0.5 \times 0.0 = 3.50$$

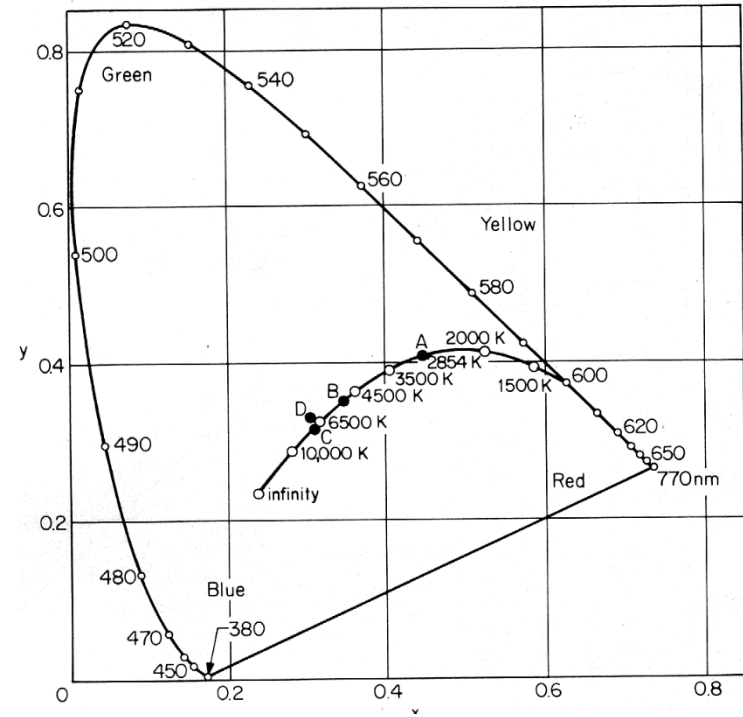
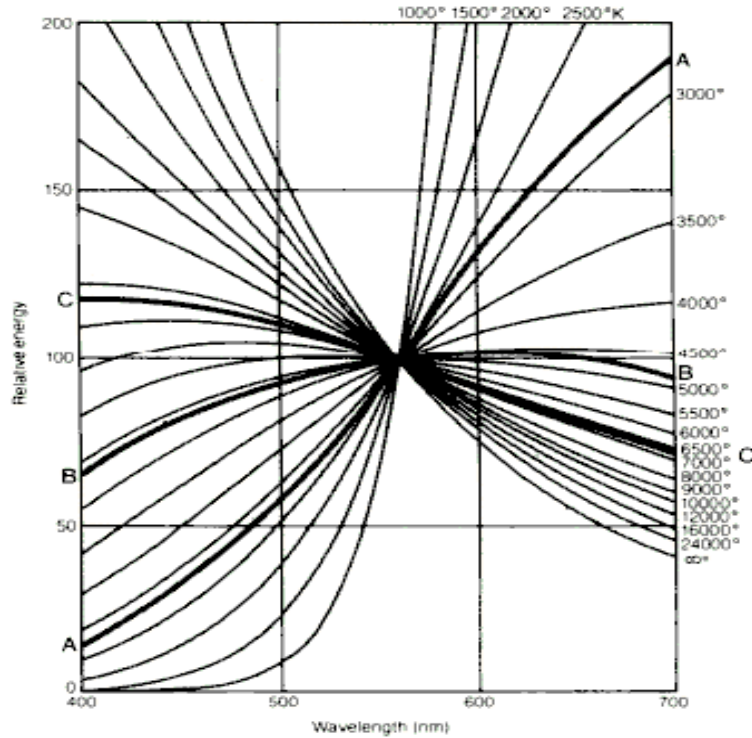
$$x = \frac{X}{X + Y + Z} = \frac{3.72}{13.04} = 0.285$$

$$y = \frac{Y}{X + Y + Z} = \frac{5.82}{13.04} = 0.446$$

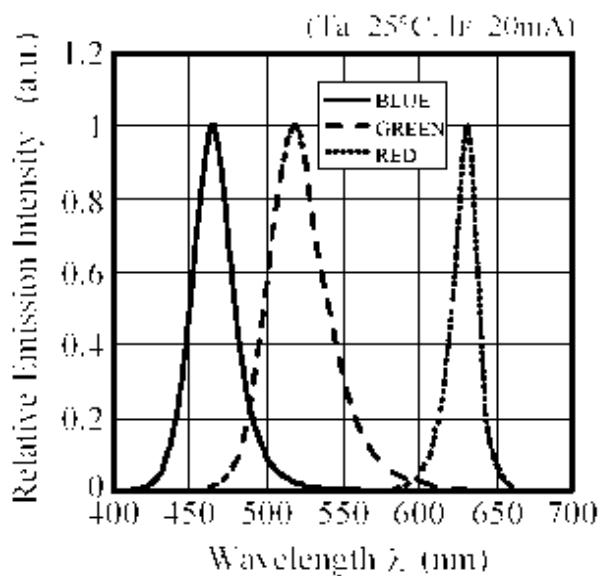
Comprimento de onda dominante: ~538 nm



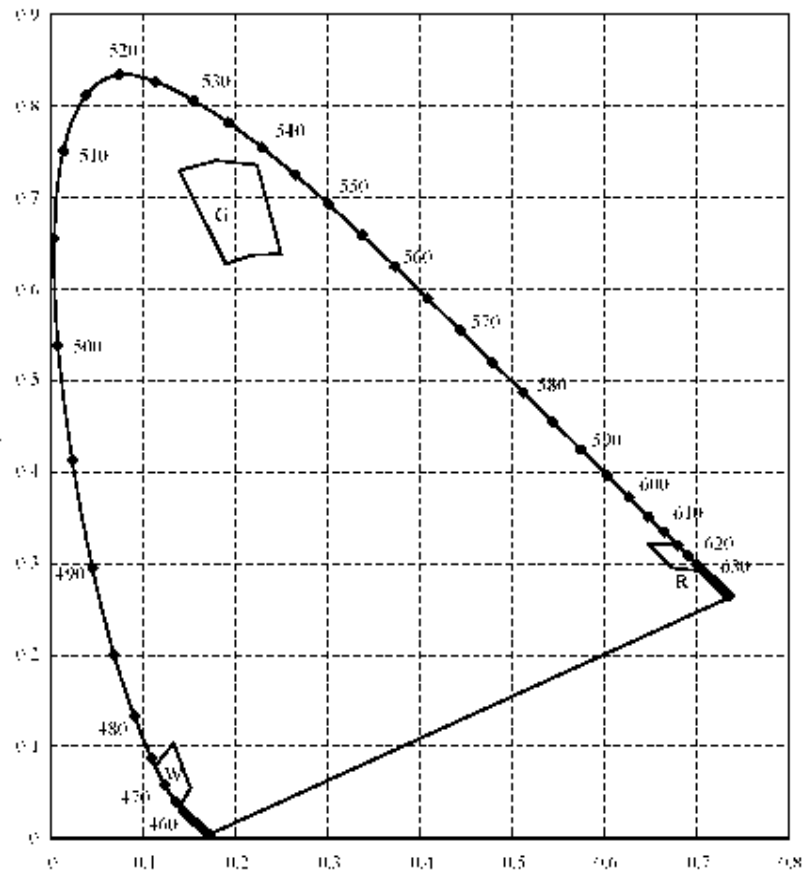
# Exemplo: Colorimetria de um Corpo Negro Aquecido







LED Nichia NSCM315C



Características dos LED's:

LED	Comprimento de Onda	Intensidade Luminosa a 20 mA
Vermelho	640 nm	80 mcd
Verde	570 nm	130 mcd
Azul	470 nm	25 mcd

Aplicando a função de luminância:

	$\lambda$	$F(\lambda)$	Pot	X	Y	Z
R	640	0.175	457	204	80	0
G	570	0.952	137	104	130	0.3
B	470	0.091	274	53	25	353

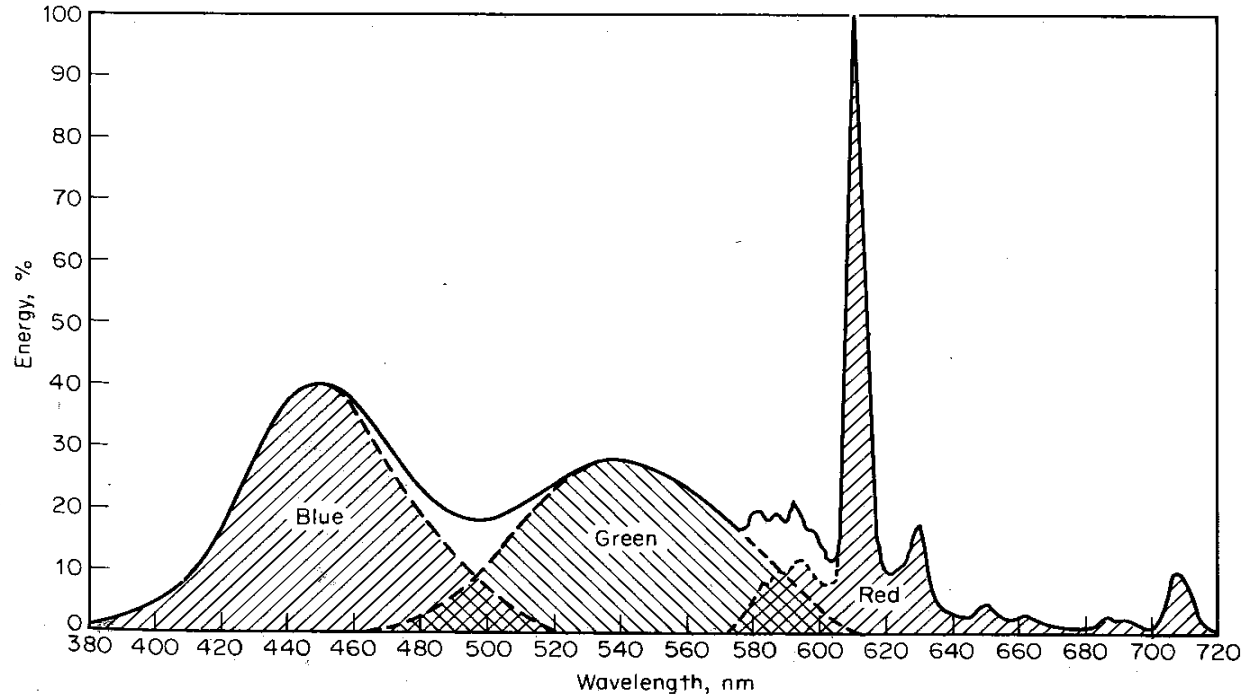
$$\begin{aligned} & r (204 X + 80 Y + 0 Z) + \\ & + g (104 X + 130 Y + 0.3 Z) + \\ & + b (53 X + 25 Y + 353 Z) = \\ \\ & = 1000 X + 1000 Y + 1000 Z \end{aligned}$$

Resolvendo, temos:

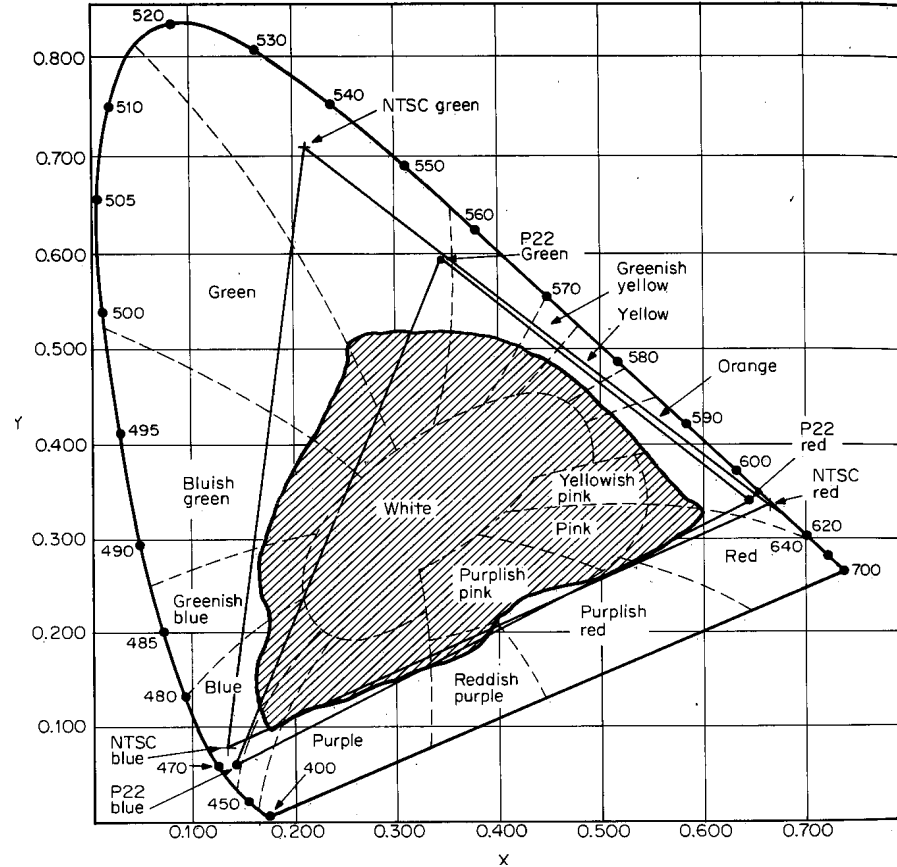
$$\begin{aligned} r &= 0,745 \Rightarrow 0,112 \Rightarrow 2,23 \text{ mA} \\ g &= 6,68 \Rightarrow 1,00 \Rightarrow 20 \text{ mA} \\ b &= 2,83 \Rightarrow 0,423 \Rightarrow 8,47 \text{ mA} \end{aligned}$$

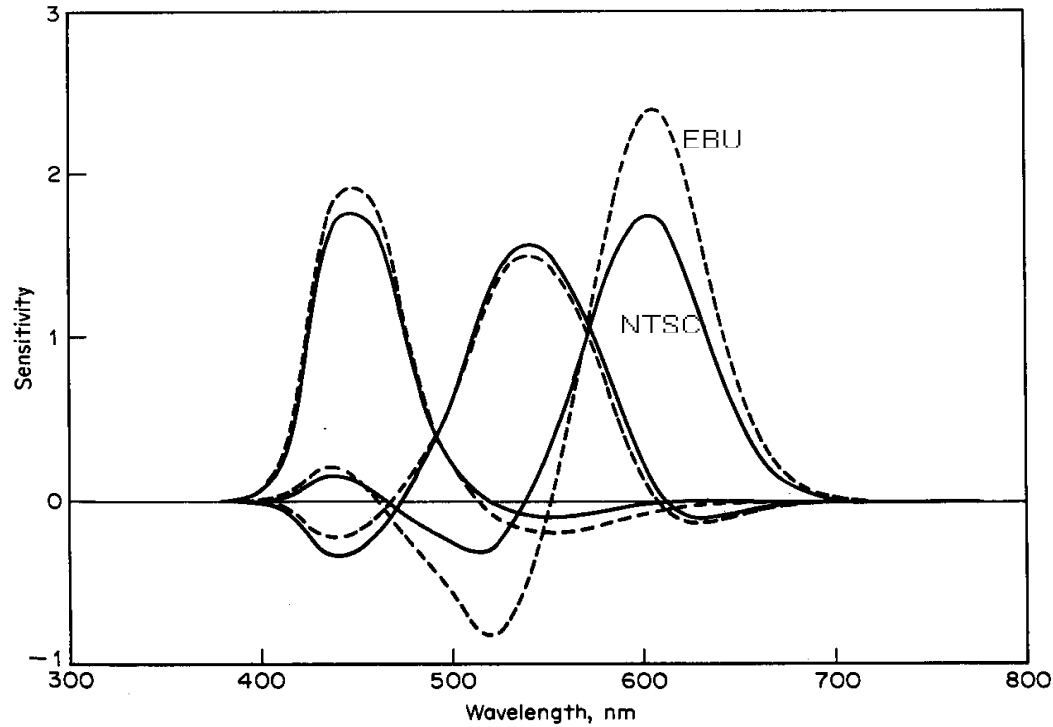
Intensidade luminosa de R + G + B = branco:  
 $0,112 \times 80 + 1 \times 130 + 0,423 \times 25 = 150 \text{ mcd}$

# Primários de um Cinescópio (NTSC)



# Coordenadas de Cromaticidade dos Primários (NTSC e P22)



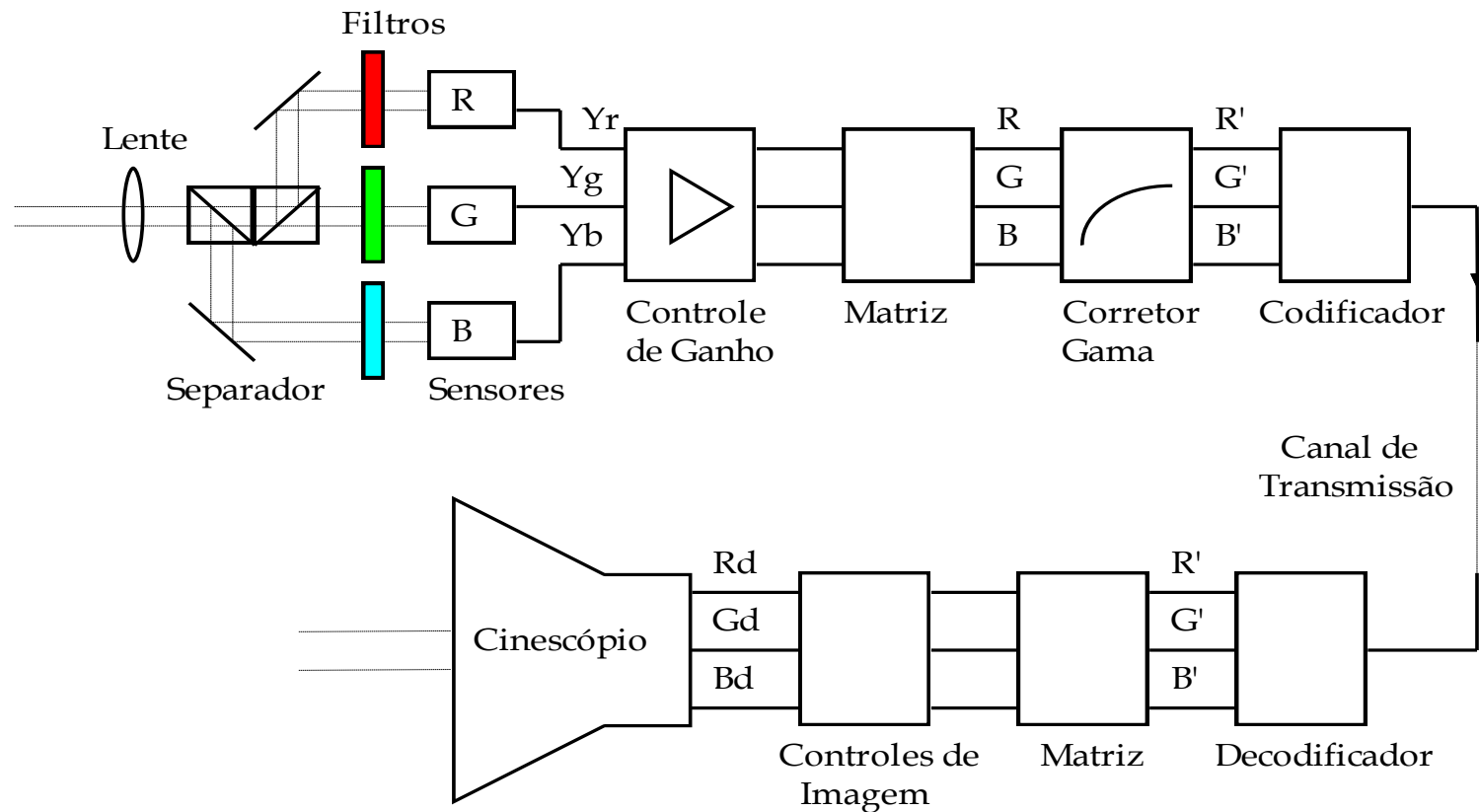


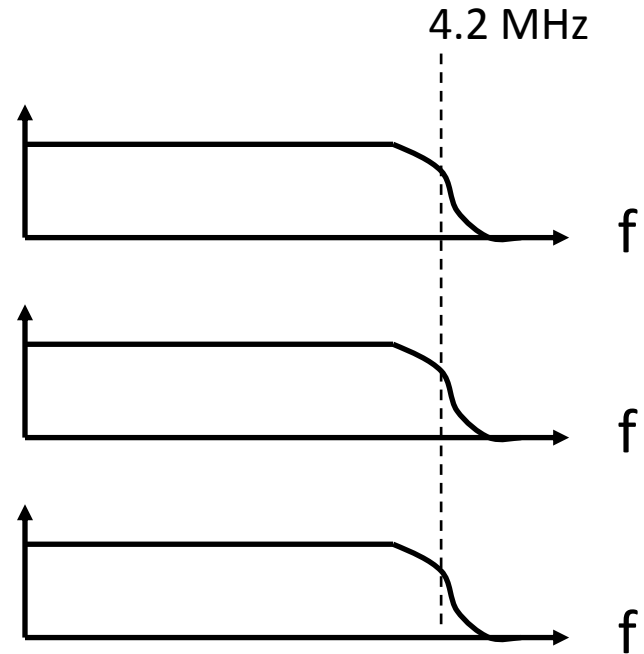
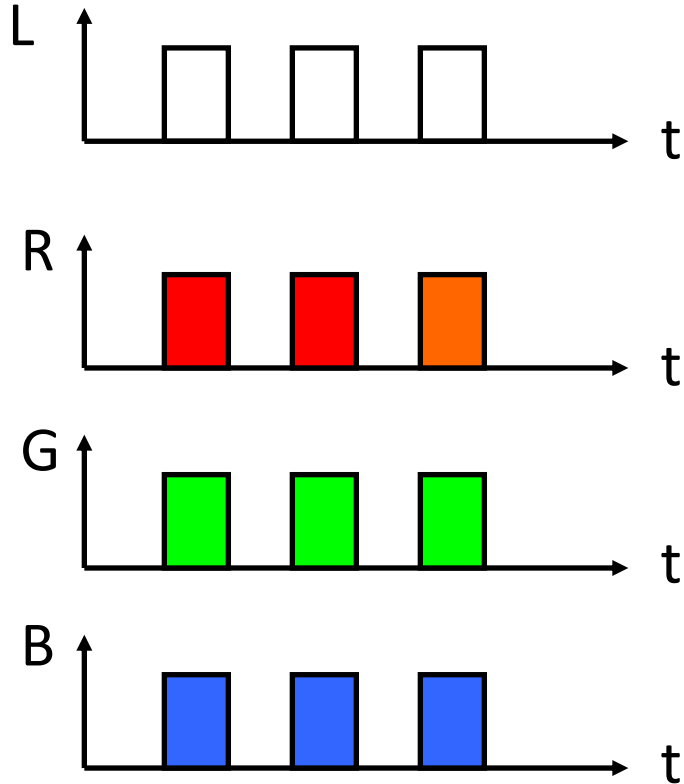
# Transmissão de TV a Cores

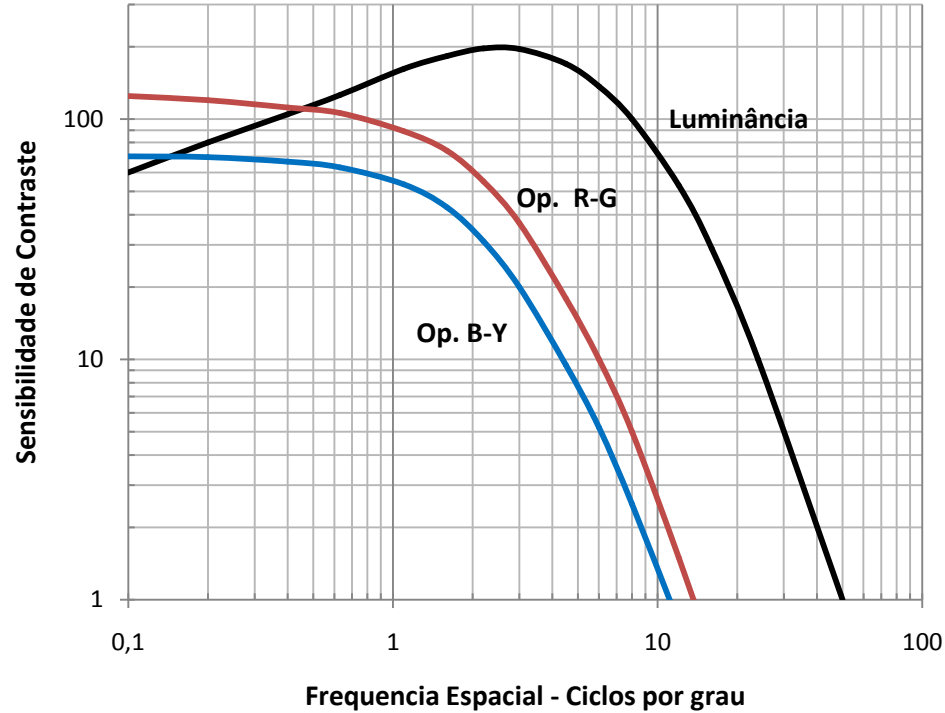
- Fidelidade Física (espectral)
- Fidelidade de Valores Tri-estímulos (R, G, B)
- Fidelidade Colorimétrica (x, y)
- Reprodução Correspondente (mesma iluminação)
- Fidelidade Subjetiva (ao gosto do usuário)

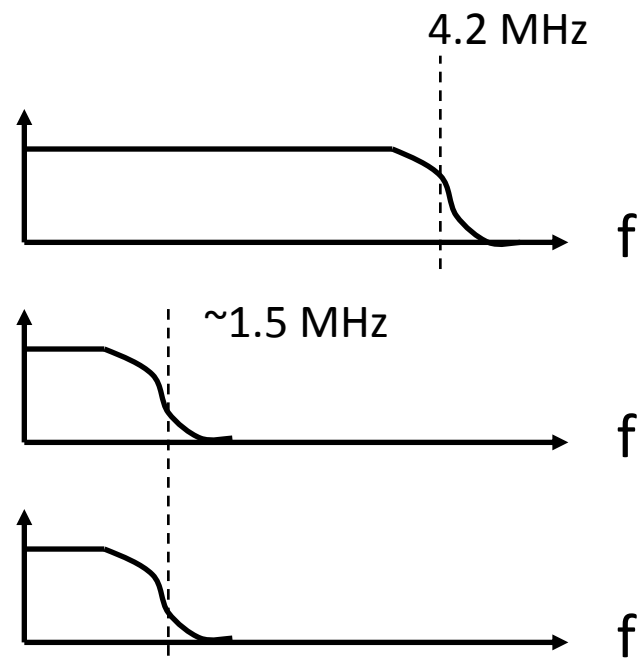
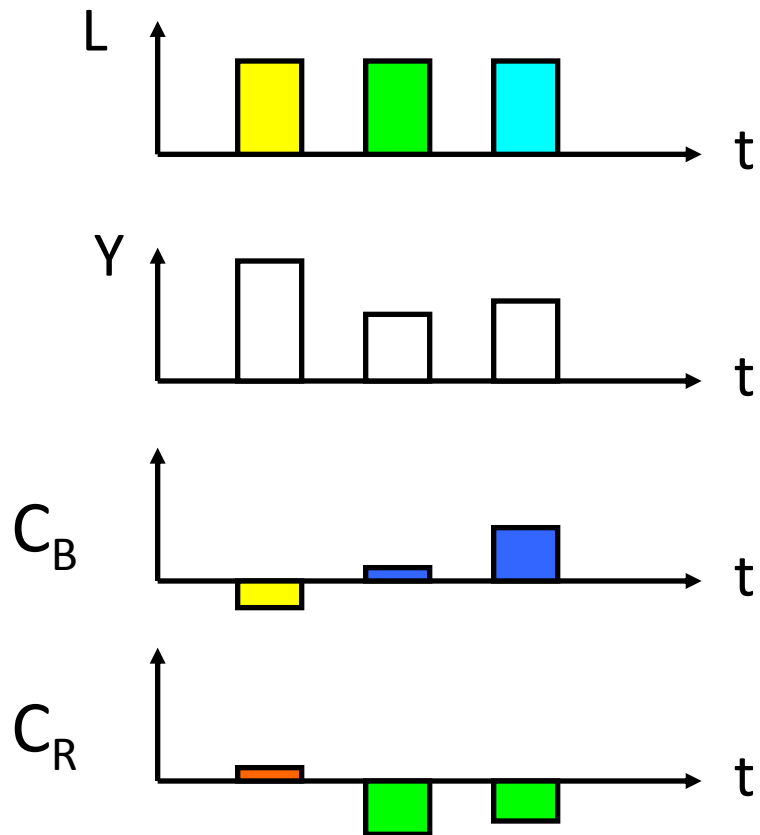


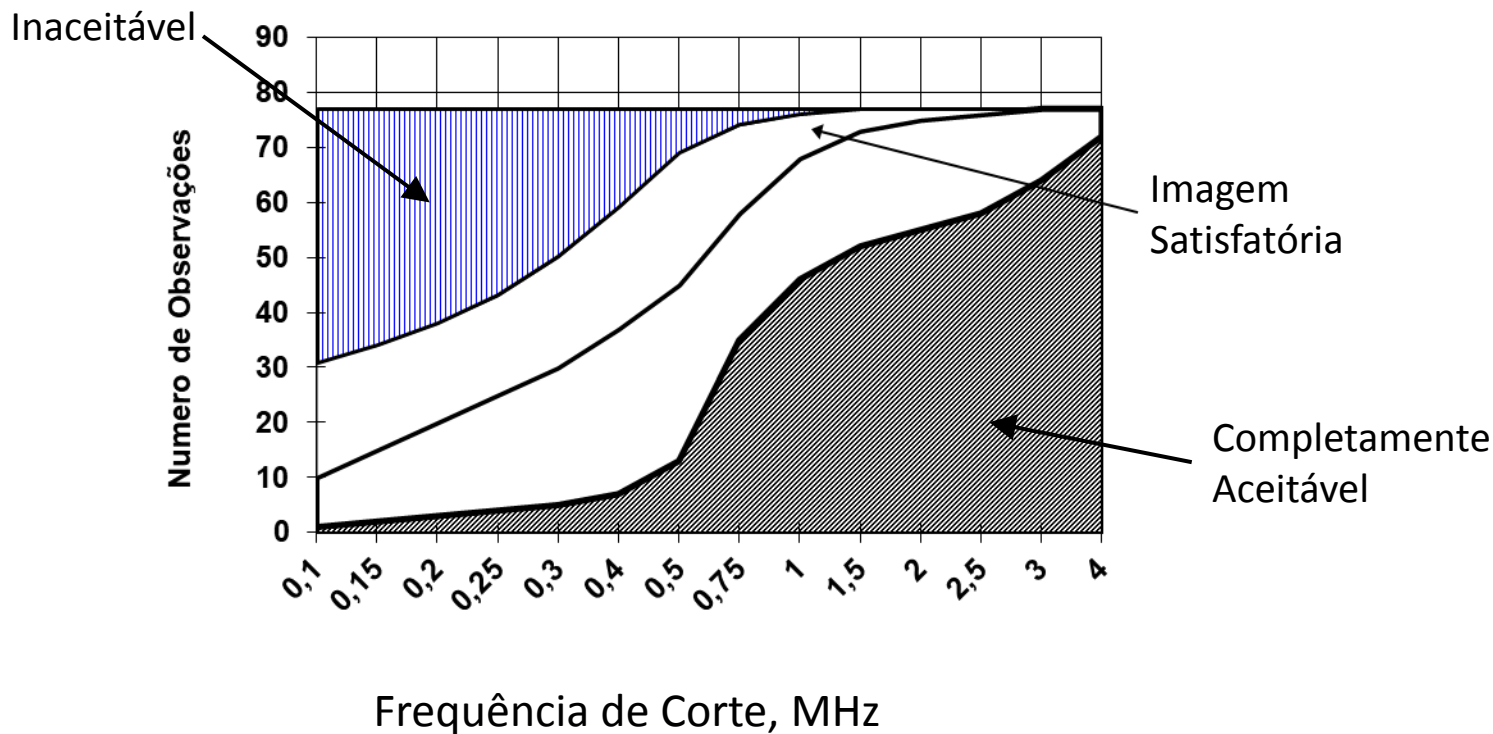
# Diagrama de um Sistema de TV a Cores











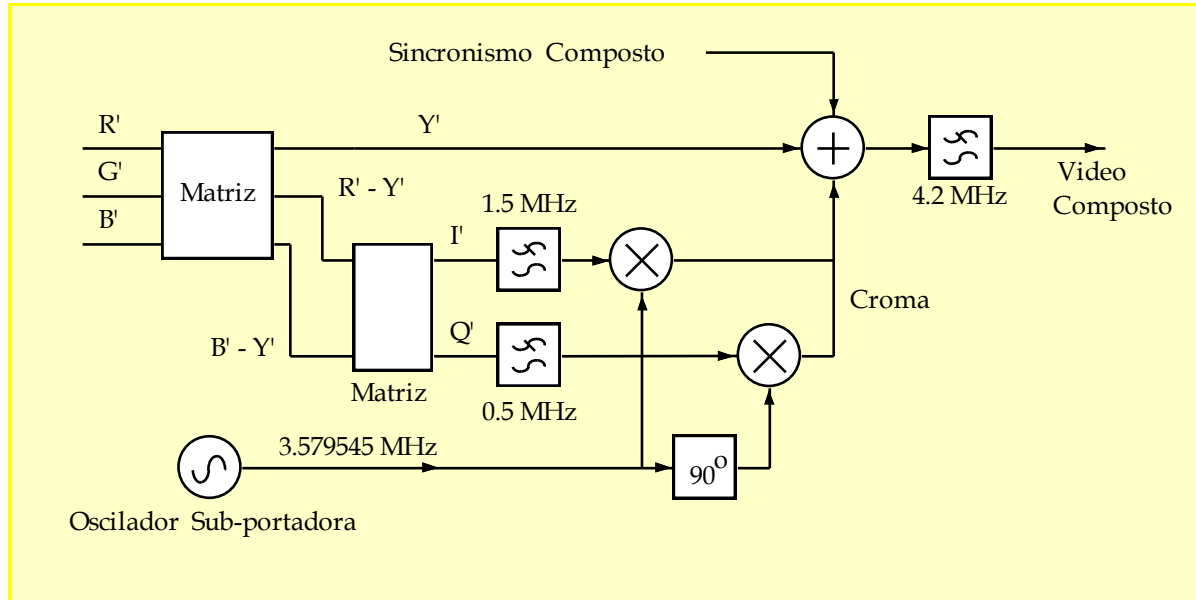
$$Y' = 0.299 R' + 0.587 G' + 0.114 B' \quad (4.2 \text{ MHz})$$

$$(R' - Y') = 0.701 R' - 0.587 G' - 0.114 B'$$

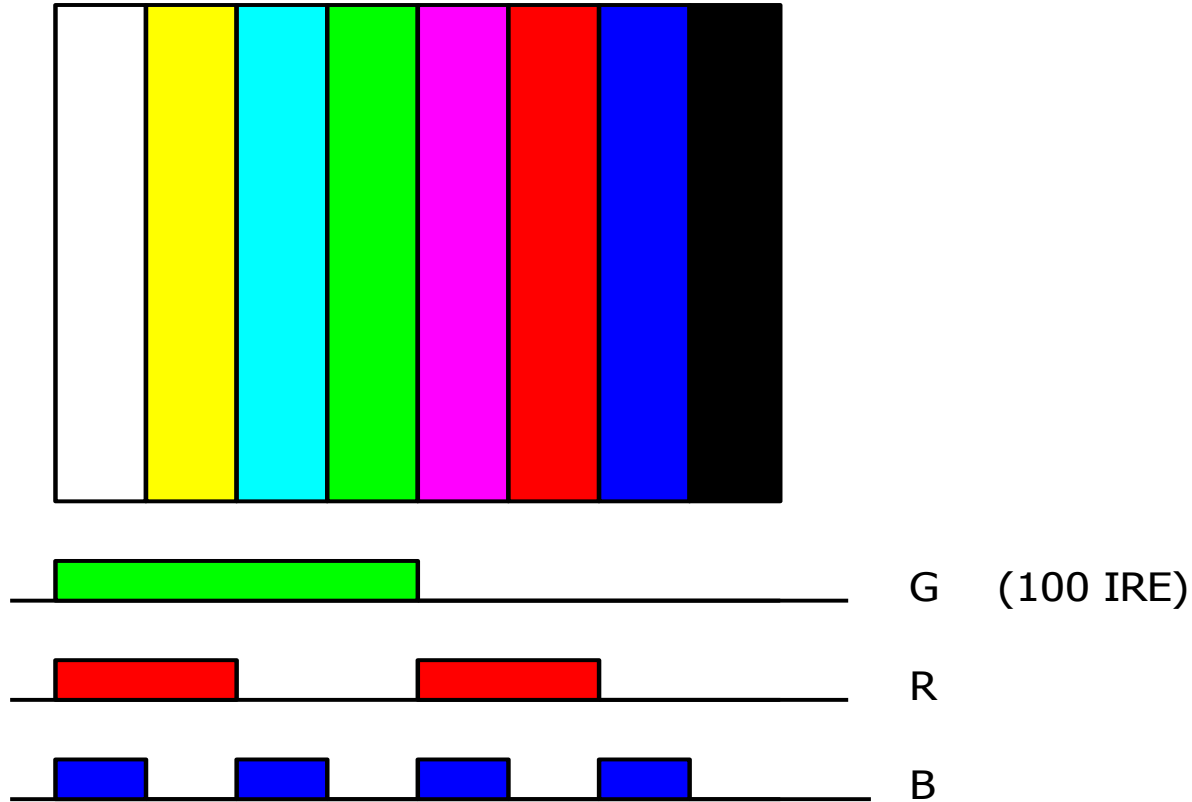
$$(B' - Y') = -0.299 R' - 0.587 G' + 0.886 B'$$

$$\begin{aligned} I' &= 0.74 (R' - Y') - 0.27 (B' - Y') = \\ &= 0.60 R' - 0.28 G' - 0.32 B' \quad (1.5 \text{ MHz}) \end{aligned}$$

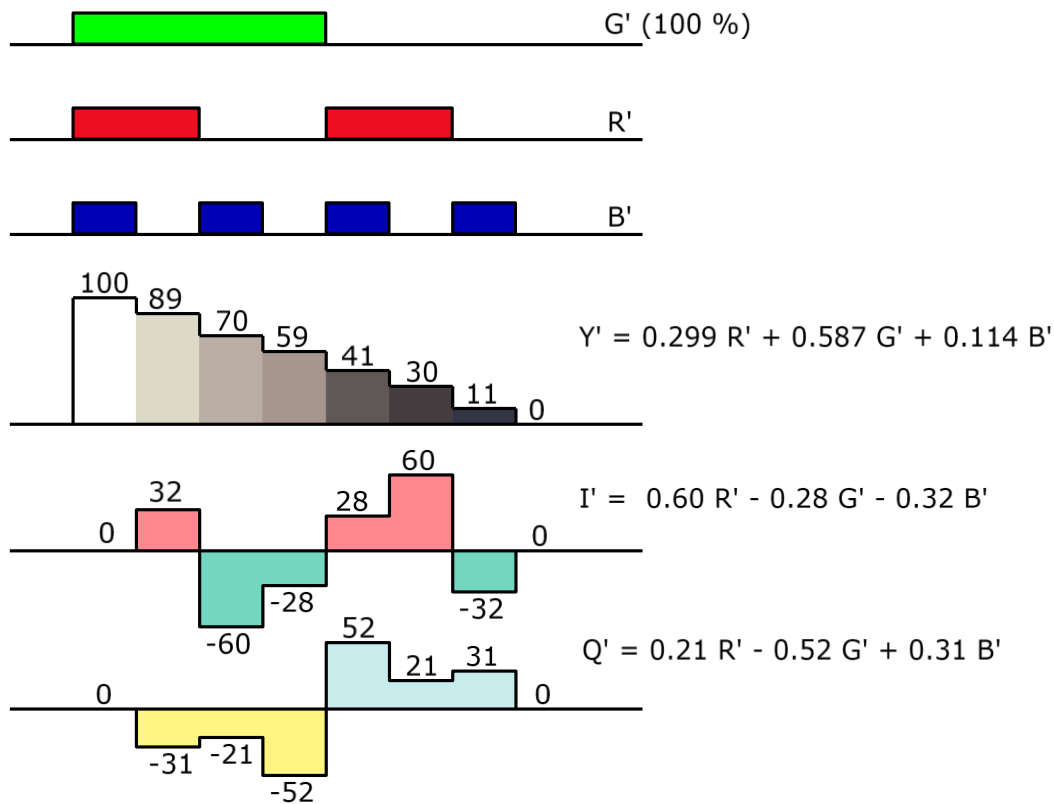
$$\begin{aligned} Q' &= 0.48 (R' - Y') + 0.41 (B' - Y') = \\ &= 0.21 R' - 0.52 G' + 0.31 B' \quad (0.5 \text{ MHz}) \end{aligned}$$



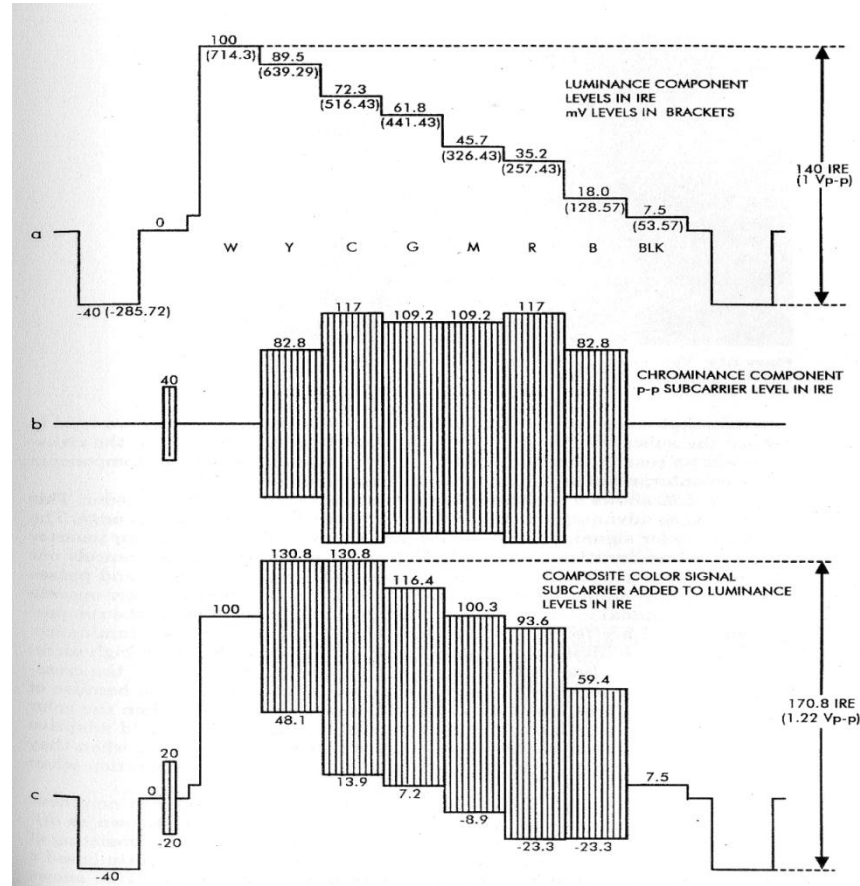
# Exemplo: Padrão de Barras Coloridas (RGB)

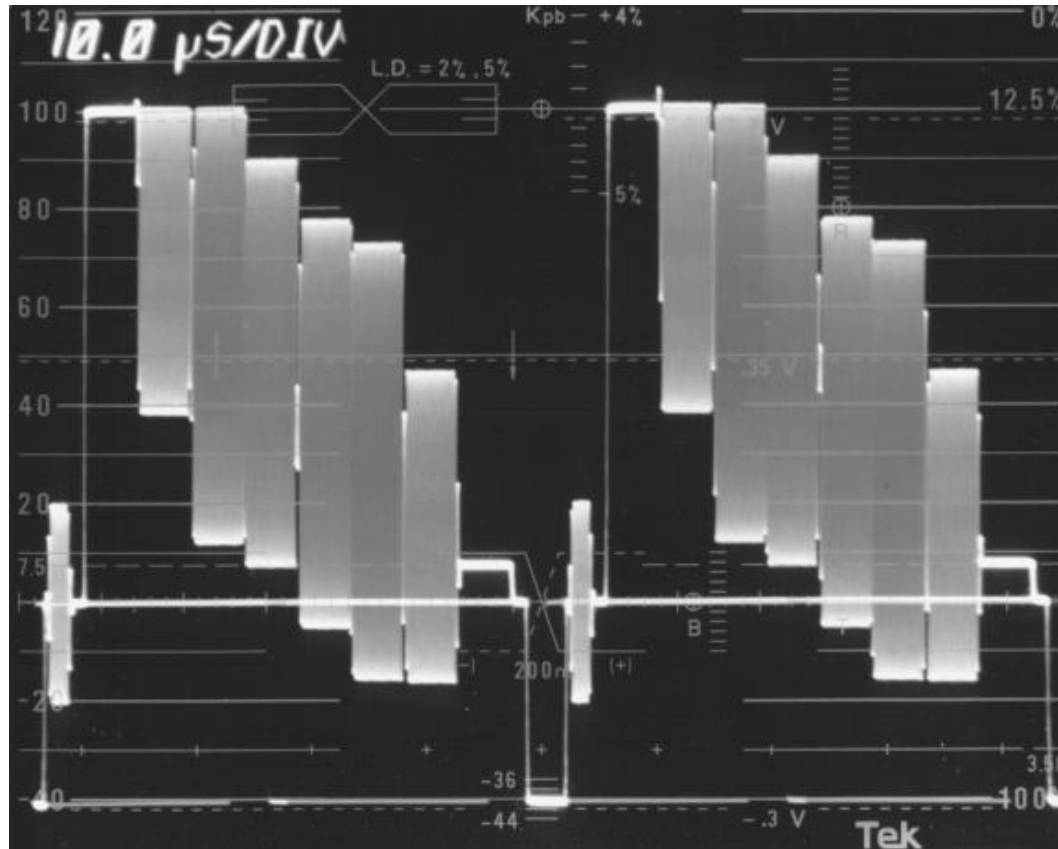


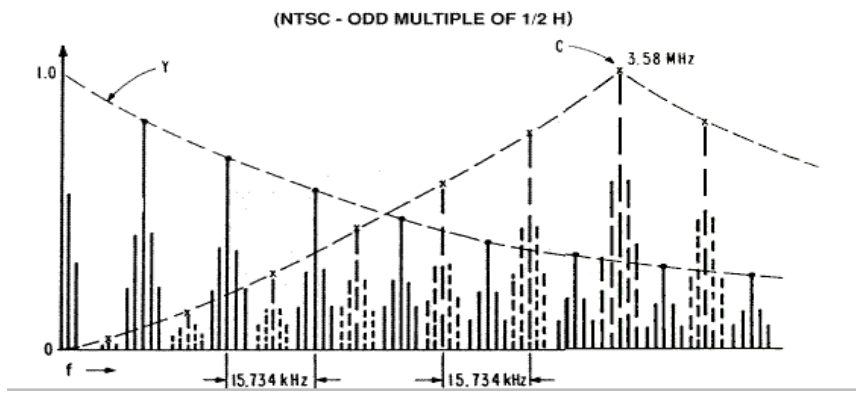
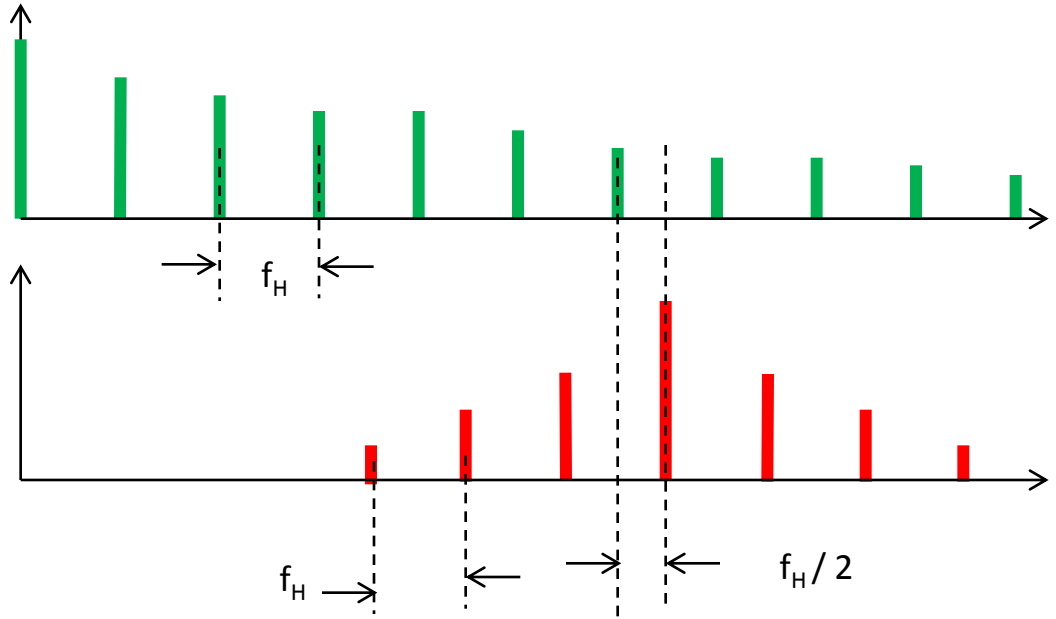


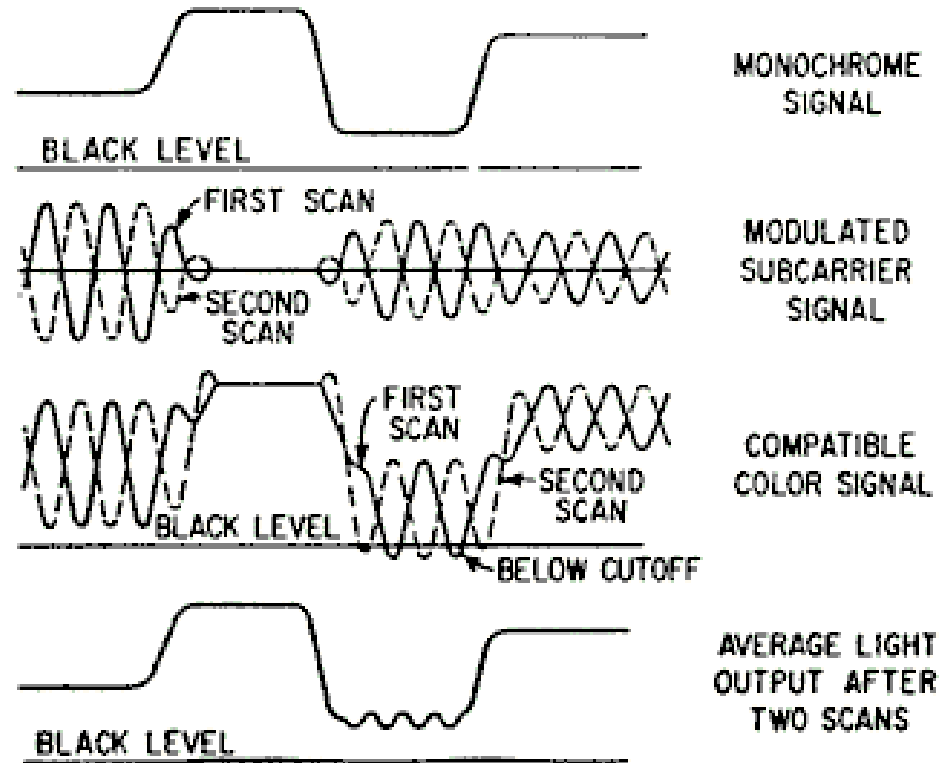


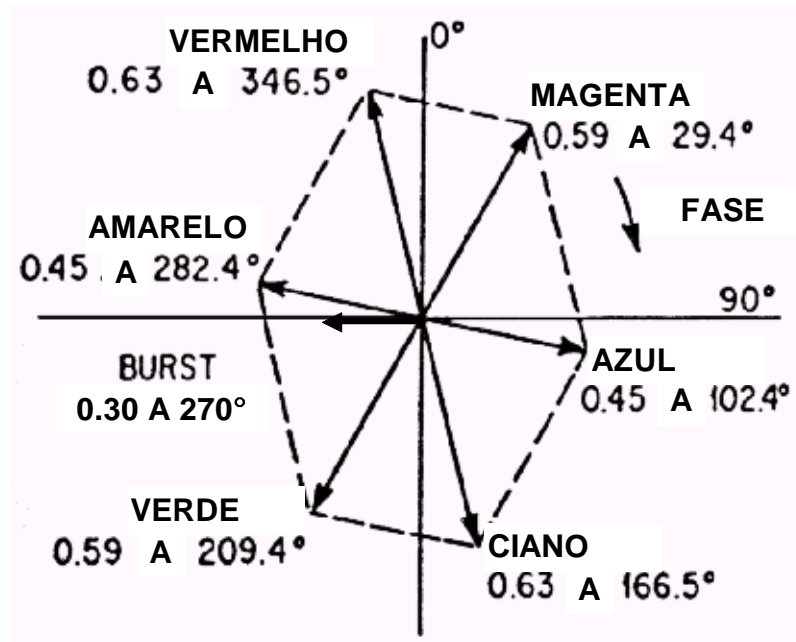
# Formas de Onda na Modulação NTSC

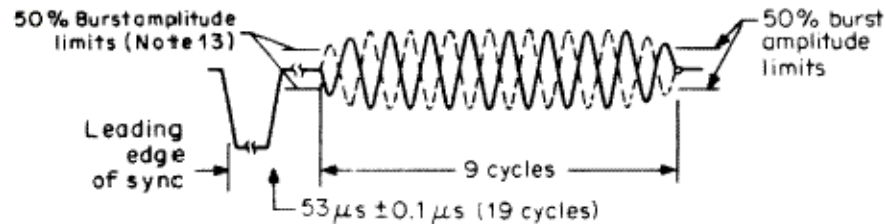
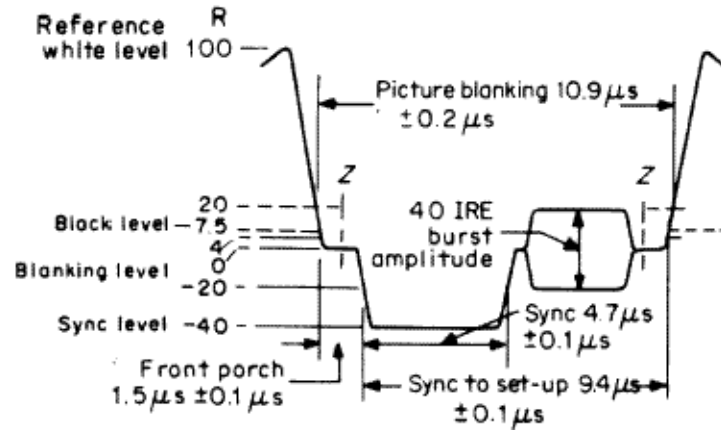












Intercalamento Espectral:

$$f_{SC} = (2n+1)/2 \times f_H$$

$$f_{SC} - 4.5 \text{ MHz} = (2p+1)/2 \times f_H$$

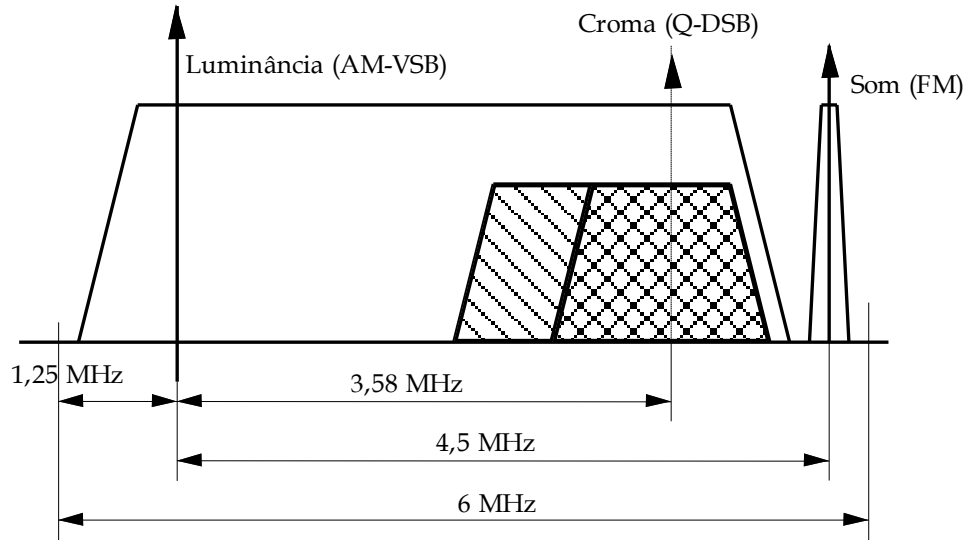
frequências multiplicadas por 1000/1001  $\Rightarrow$

$$f_H = 15734,265... \text{ Hz} \Rightarrow f_V = 59.94 \text{ Hz}$$

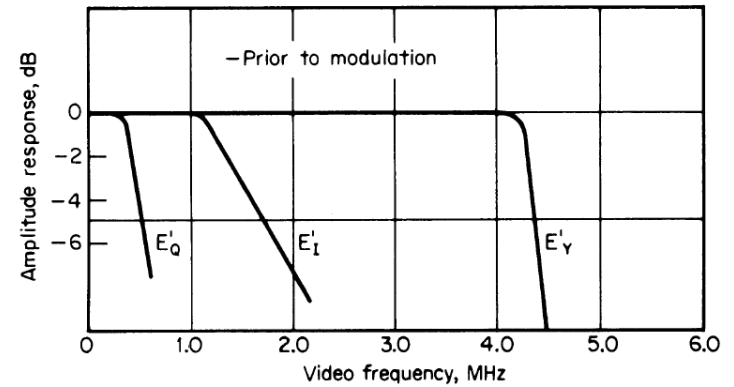
$$f_{SC} = 455/2 f_H = 5 \times 7 \times 13 / 2 f_H = 3.579545 \text{ MHz}$$

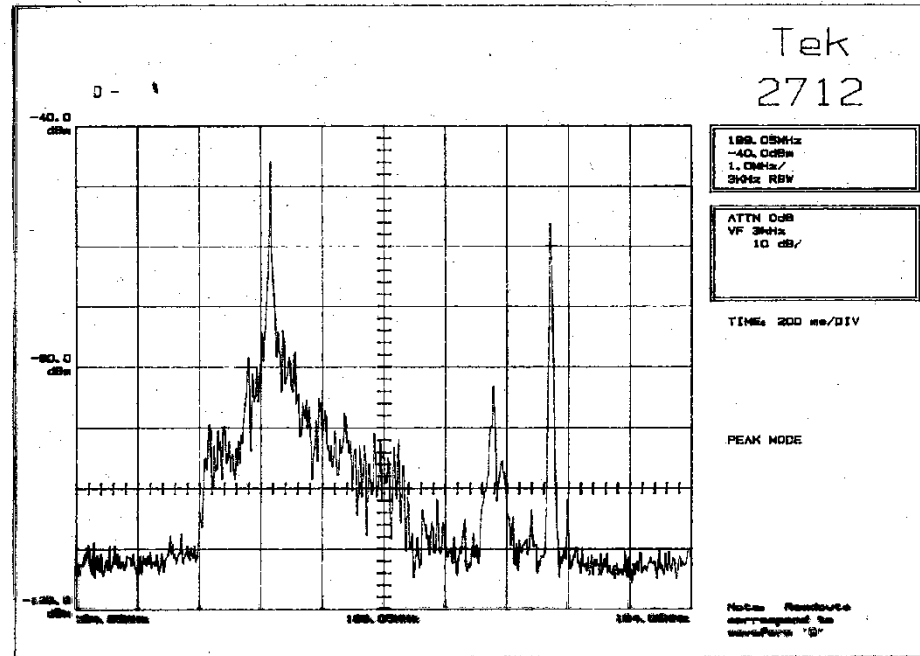
$$f_Q = \frac{1}{2} f_V = 29.97 \text{ Hz}$$

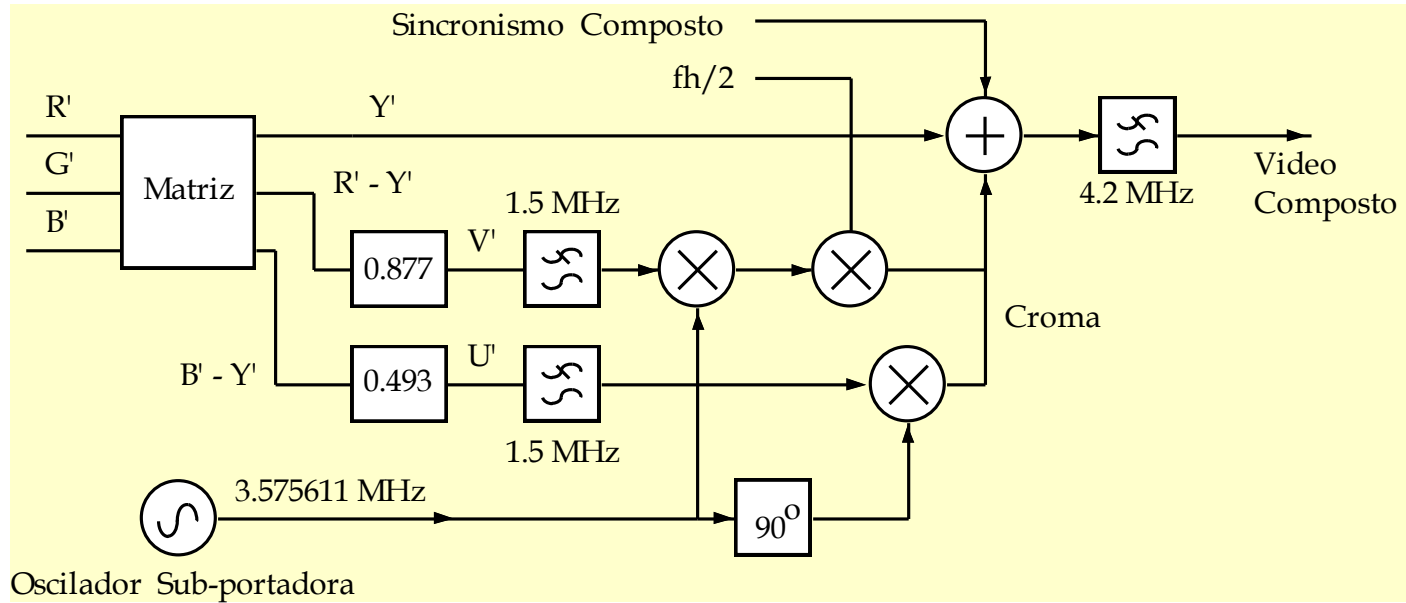


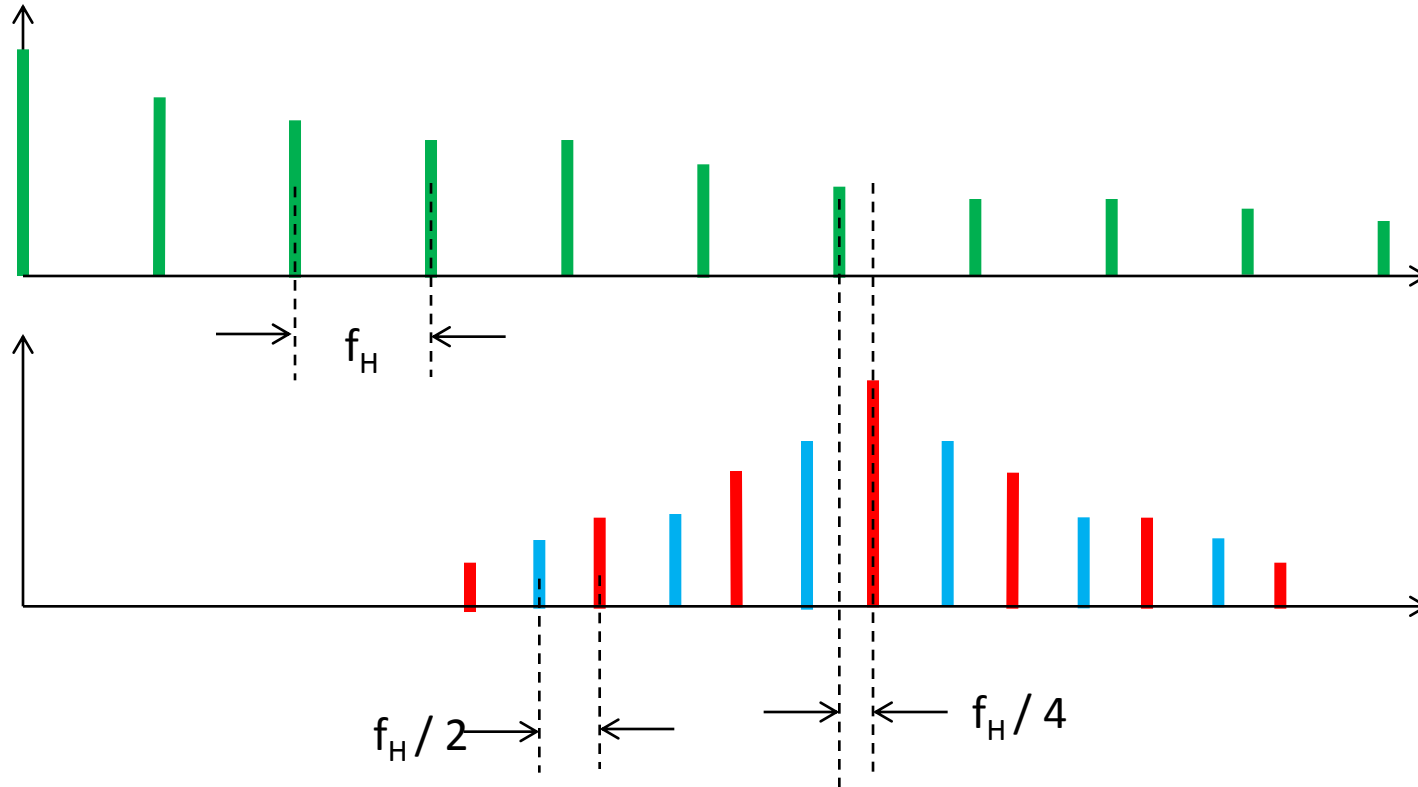


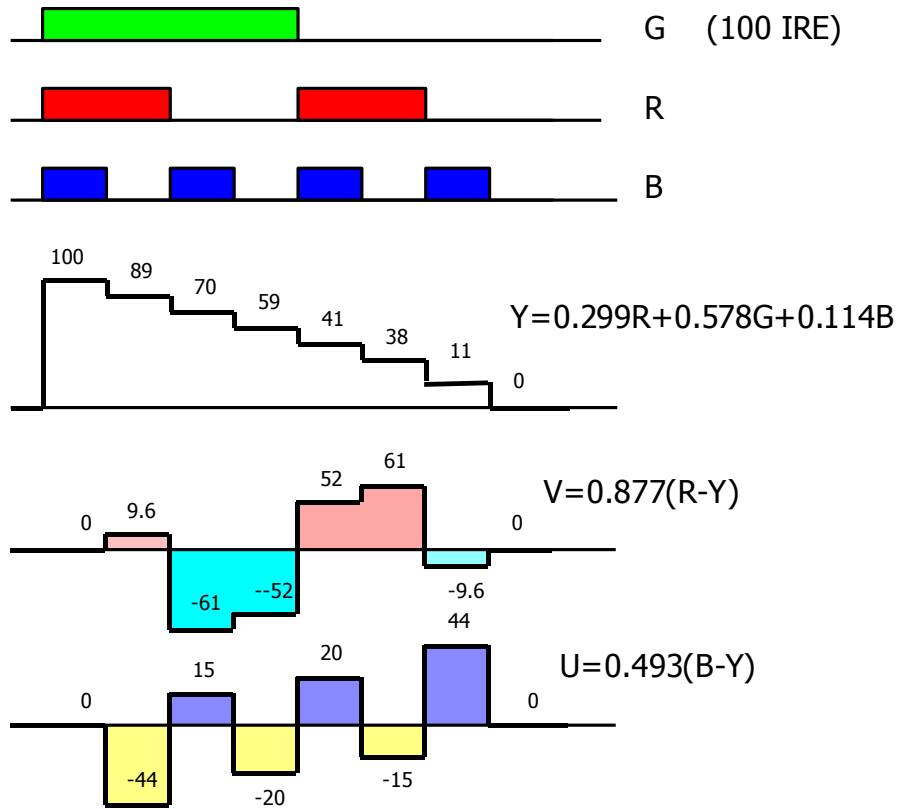
Limitação de Banda dos sinais Y, I e Q



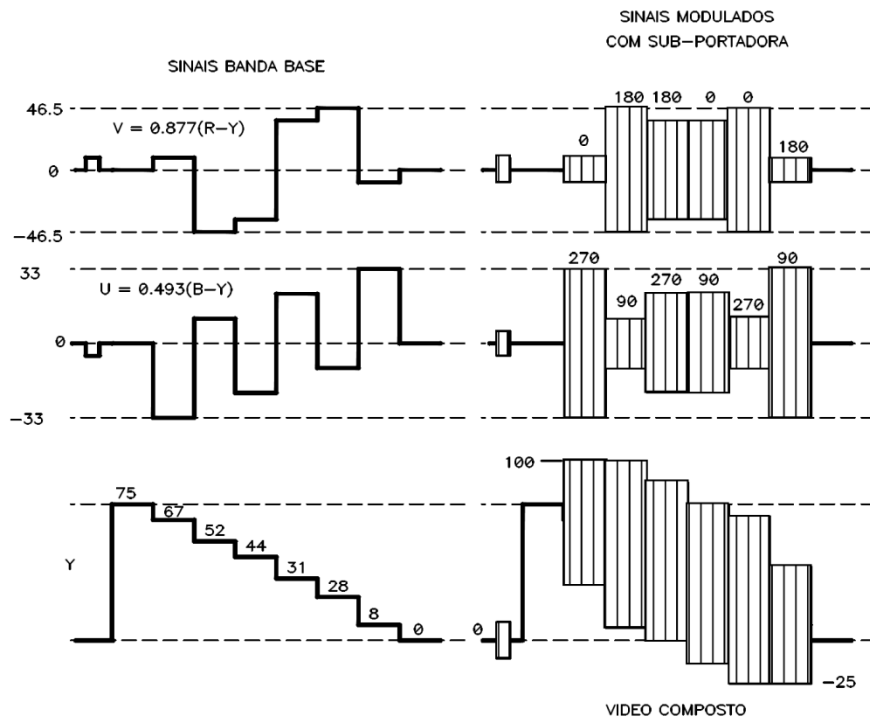








# Formas de Onda na Modulação PAL-M



(Padrão de Barras com 75% do Fundo de Escala)

## **PAL-B/G/H/I (Europa)**

50 Hz / 625 linhas

$$f_{sc} = 4,433618 \text{ MHz}$$

$$B_w(Y) = 5 \text{ MHz (padrões B/G/H)}$$

ou 5,5 MHz (padrão I)

$$B_w(\text{canal}) = 7 \text{ MHz (B) ou } 8 \text{ MHz (G/H/I)}$$

$$f_{sc} = \frac{1135}{4} f_H + \frac{1}{2} f_V$$

## **PAL-N** (Argentina, Paraguai, Uruguai)

50 Hz / 625 linhas

$f_{sc} = 3,582056$  MHz

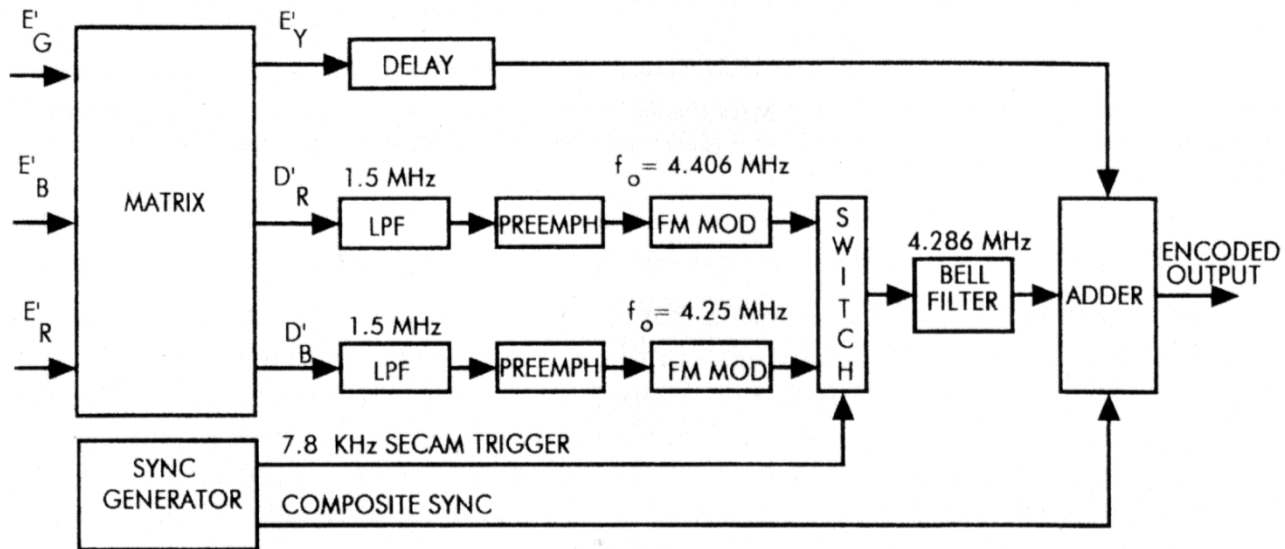
$B_w(Y) = 4,2$  MHz

$B_w(\text{canal}) = 6$  MHz

(Resolução diferente na Vertical e Horizontal)



## SECAM (França, URSS)



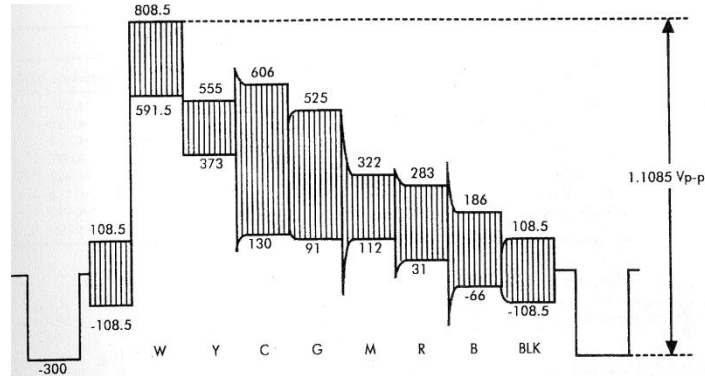
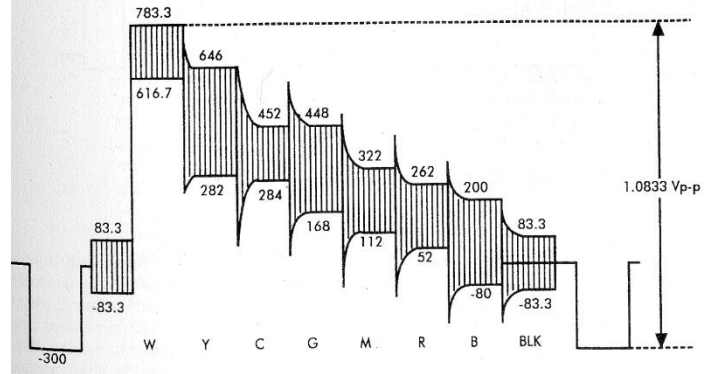


Figure 2.48 SECAM 100/0/75/0 color bars red line signal waveform.



## **S-VHS** (Super-Video)

Sinais separados para Luminância ( $Y'$  + Sync) e crominância ( $I'$ ,  $Q'$  e “burst” modulados em 3,58 MHz)

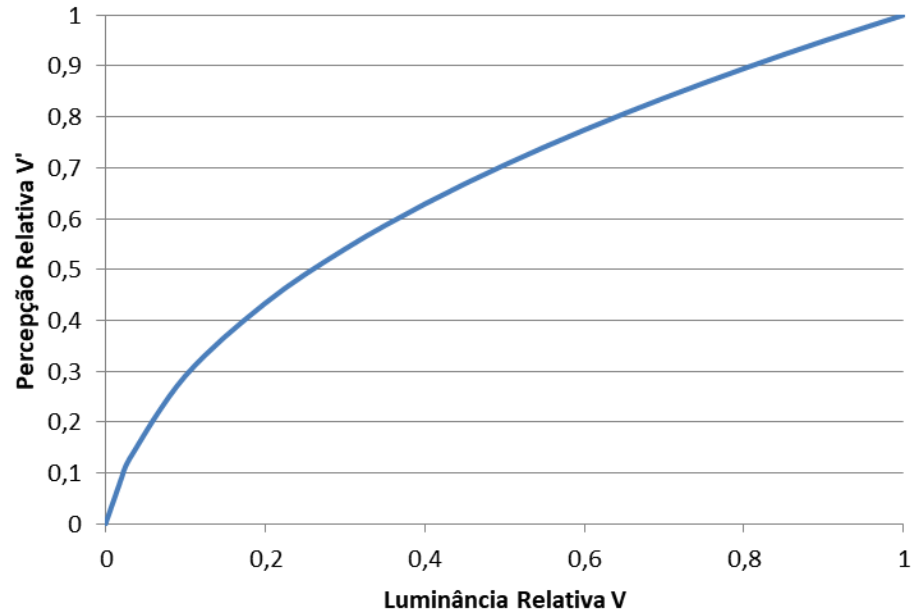
## **Componentes** (YUV)

Sinais  $Y'$ ,  $(R'-Y')$  e  $(B'-Y')$  separados  
Aplicação profissional, DVD, Blu-Ray etc.

# Colorimetria para HDTV e UHDV

$$V' = \begin{cases} 4,5 \times V & 0 \leq V < 0,018 \\ 1,099 \times V^{0,45} - 0,099 & 0,018 \leq V \leq 1 \end{cases}$$

Recomendação  
ITU-R BT.709



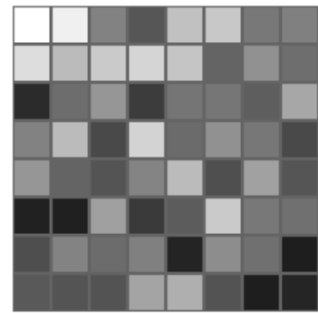
## SMPTE 274M / ITU-R BT.709

Primário	x (CIE)	y (CIE)
R	0.640	0.330
G	0.300	0.600
B	0.150	0.060
Branco	0.3127	0.3290

$$Y' = 0.2126 R' + 0.7152 G' + 0.0722 B'$$

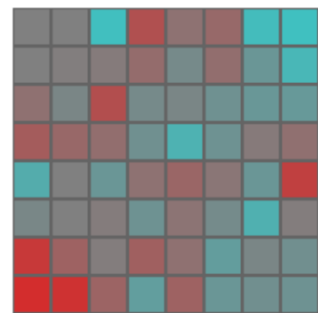
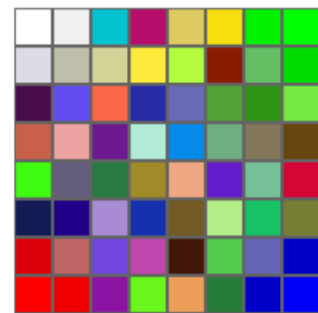
$$P_B' = \frac{1}{1.8556} (B' - Y')$$

$$P_R' = \frac{1}{1.5748} (R' - Y')$$



Luminância:

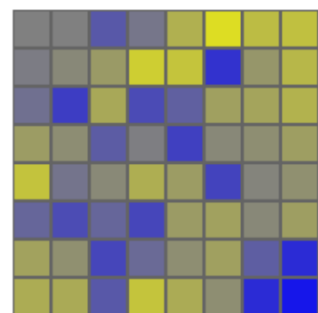
$$Y' = 0.2627 R' + 0.6780 G' + 0.0593 B'$$



Crominância:

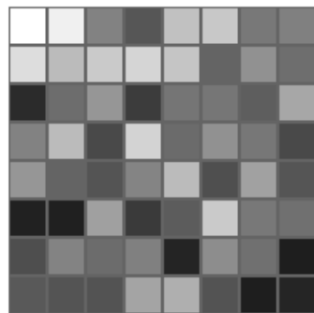
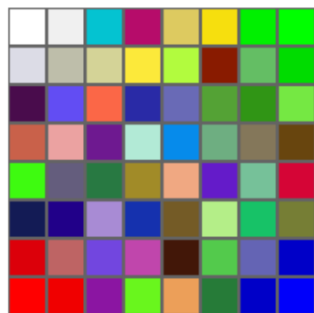
$$P_R' = \frac{1}{1.4746} (R' - Y')$$

Recomendação  
ITU-R BT.709

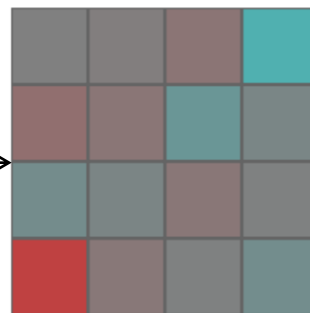
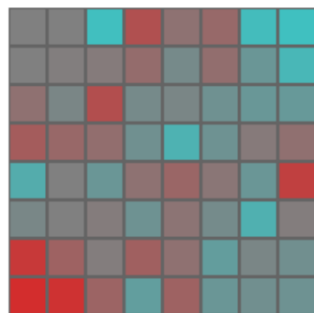


$$P_B' = \frac{1}{1.8814} (B' - Y')$$

64 pixels

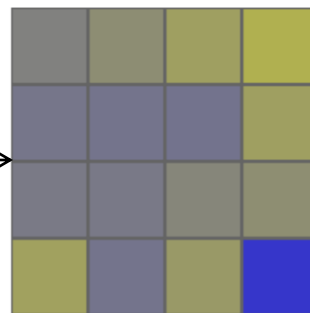
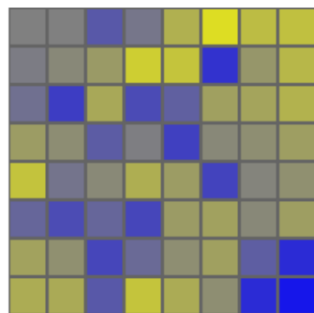


64 amostras de Luminância



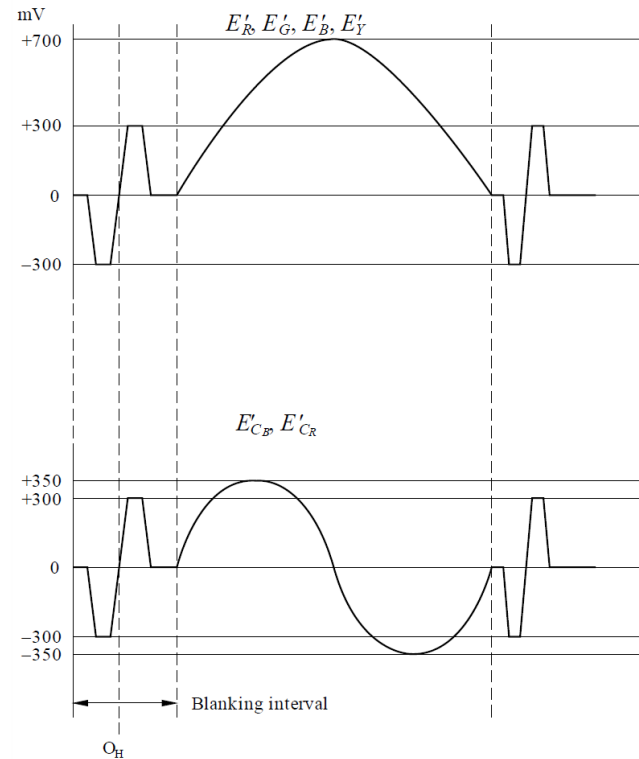
16 + 16  
amostras de  
Crominância

Recomendação  
ITU-R BT.709





## SMPTE 274M / ITU-R BT.709



BT.0709-02B

## ITU-R BT.2020

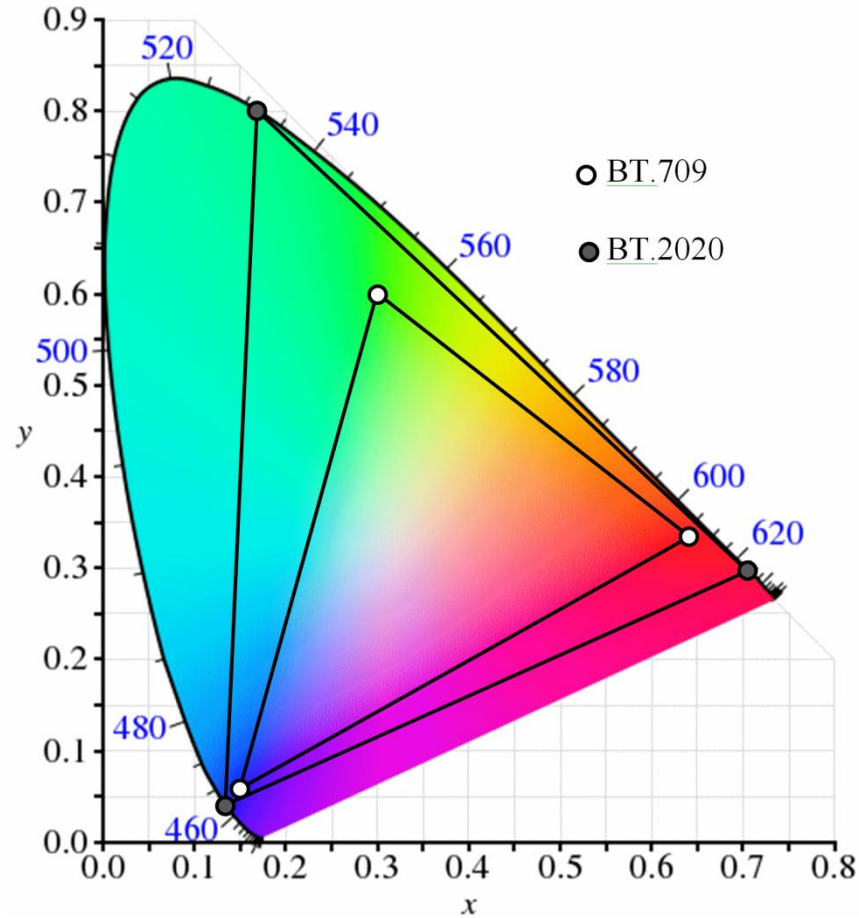
Primário	x (CIE)	y (CIE)
R	0.708	0.292
G	0.170	0.797
B	0.131	0.046
Branco	0.3127	0.3290

$$V' = \begin{cases} 4.5 \cdot V & 0 \leq V \leq 0.0181 \\ 1.0993 \cdot V^{0.45} - 0.0993 & 0.0181 \leq V \leq 1 \end{cases}$$

$$C_B' = \frac{1}{1.8814} (B' - Y')$$

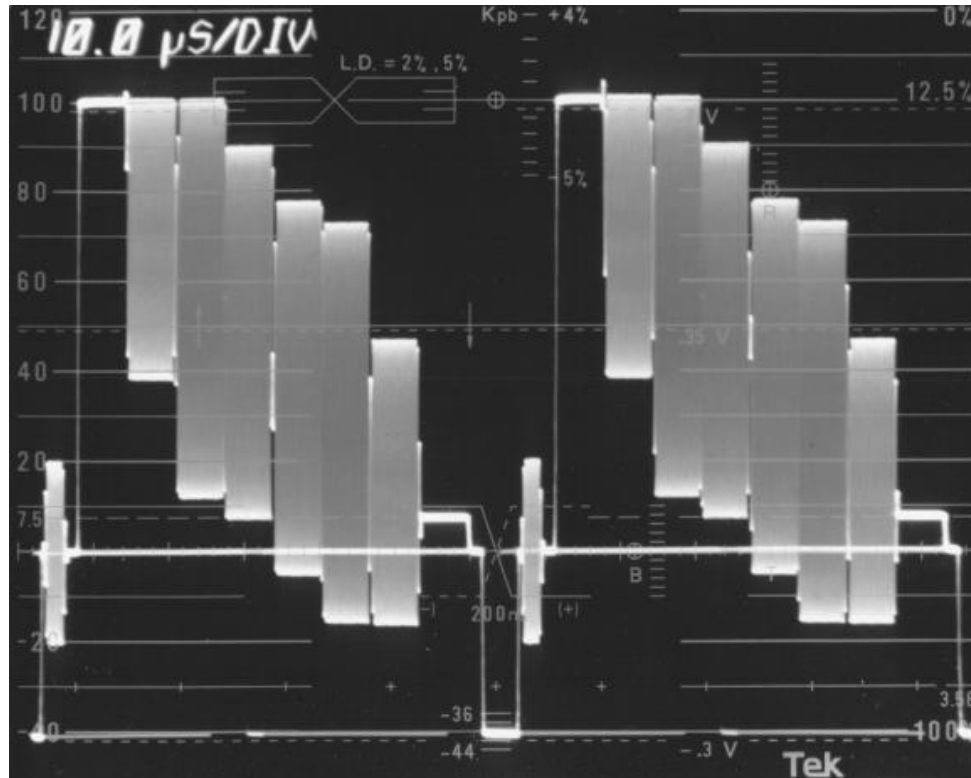
$$C_R' = \frac{1}{1.4746} (R' - Y')$$

$$Y' = 0.2627 R' + 0.6780 G' + 0.0593 B'$$



# Equipamentos e Sinais de Teste para TV

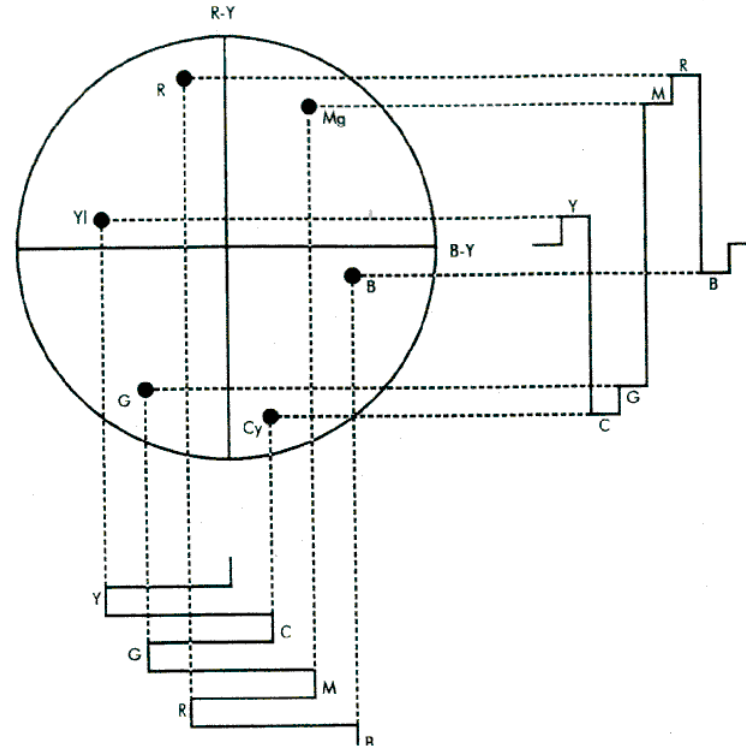
## Monitor de Forma de Onda

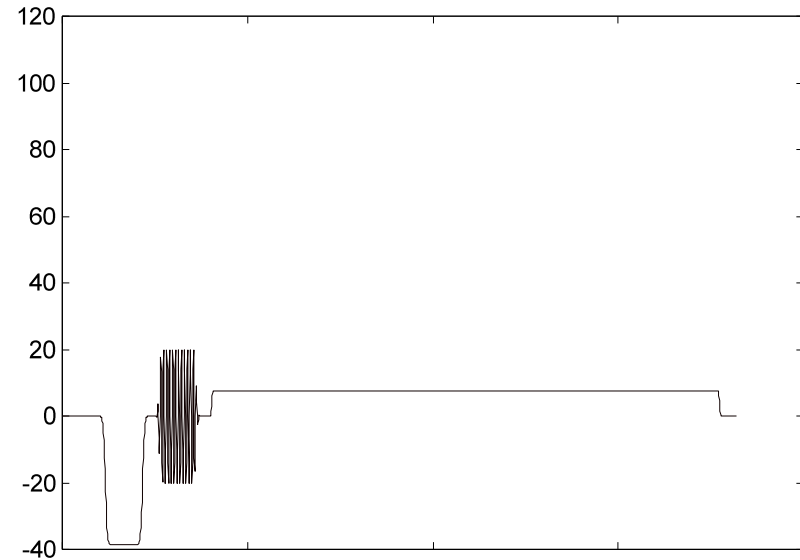


2H

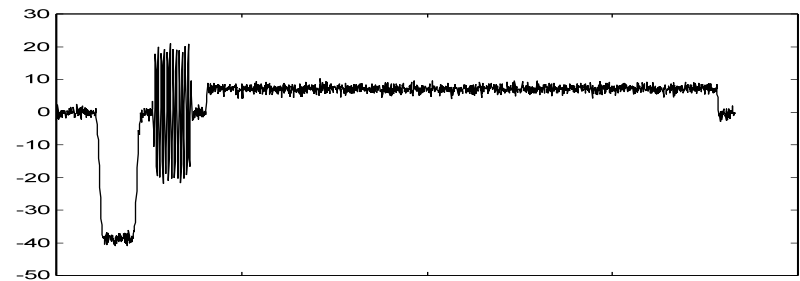
## Vetorscópio



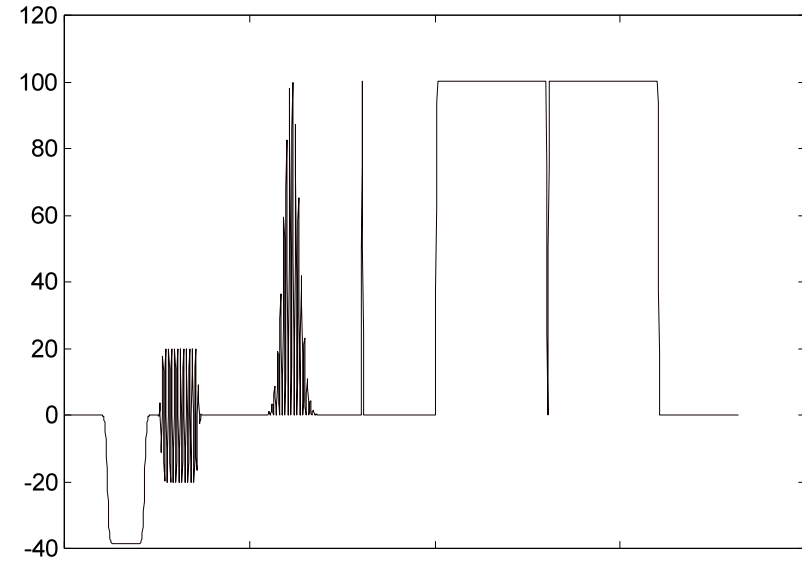




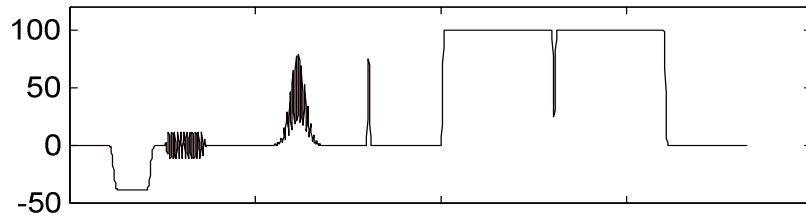
Sinal com presença de ruído aditivo



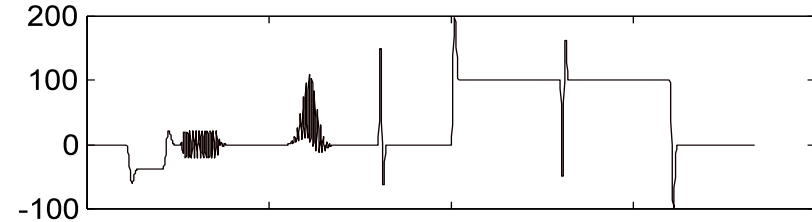




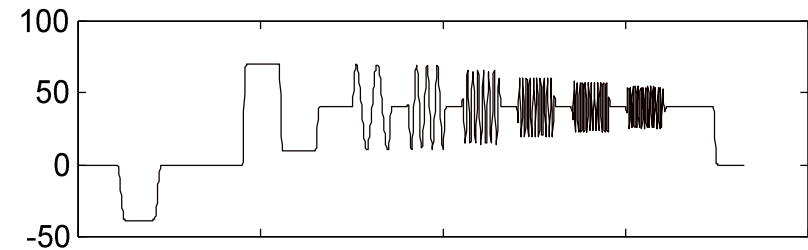
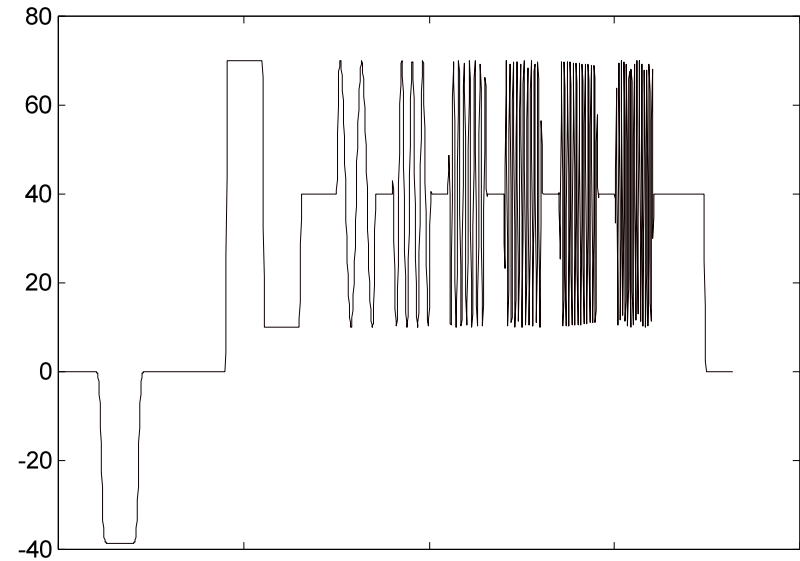
Atenuação do sinal de croma:



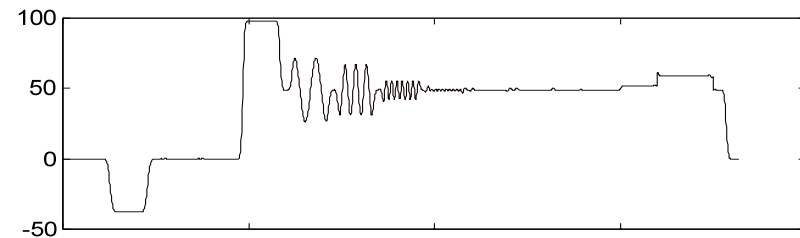
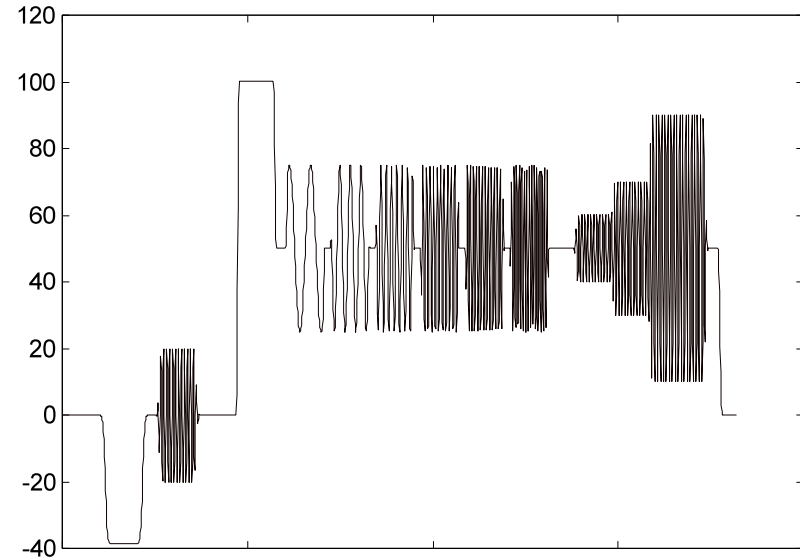
Atraso do sinal de croma:



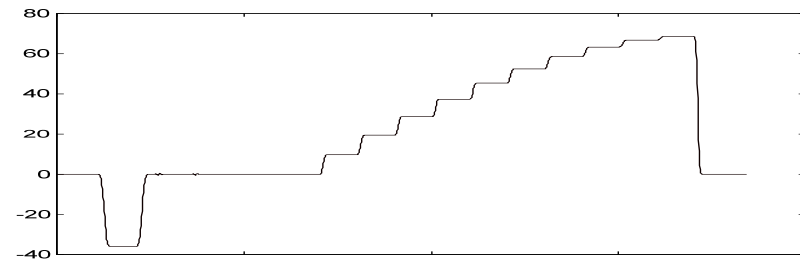
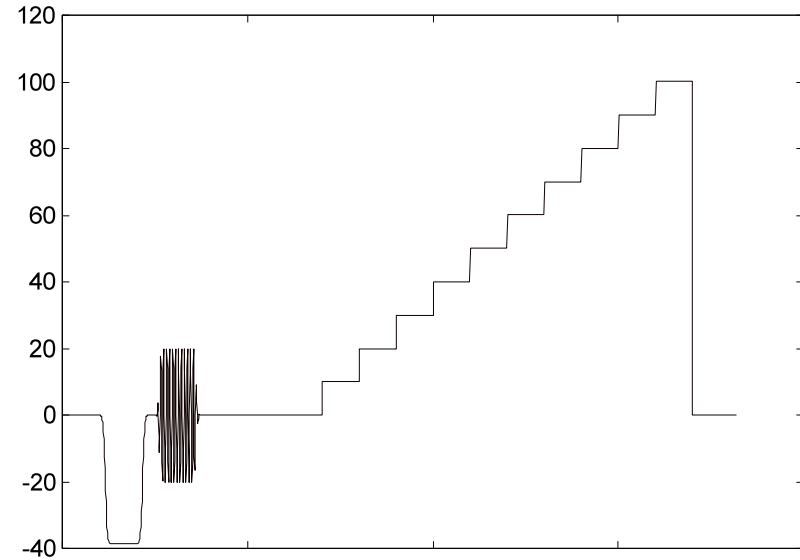
Efeito da limitação da  
resposta em frequência:



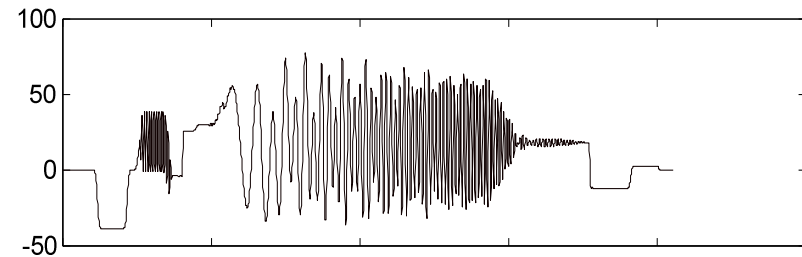
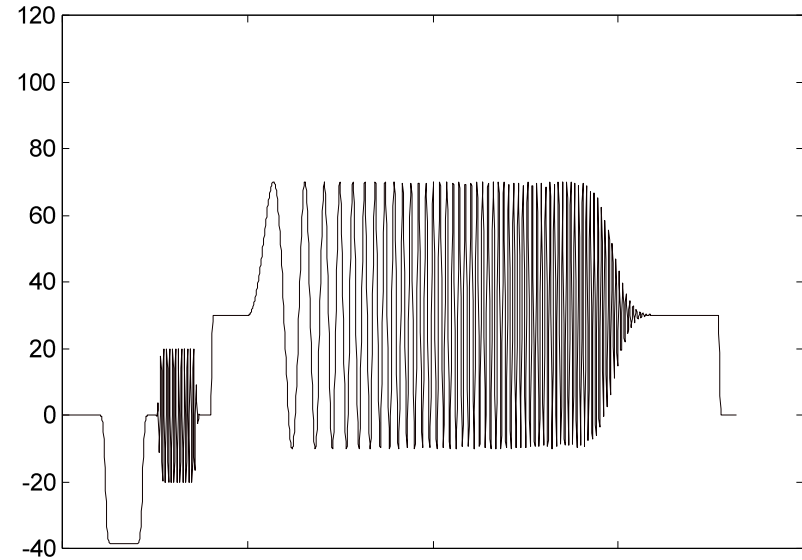
Efeito de intermodulação  
luma-croma  
(Filtro de rejeição de croma ativado):



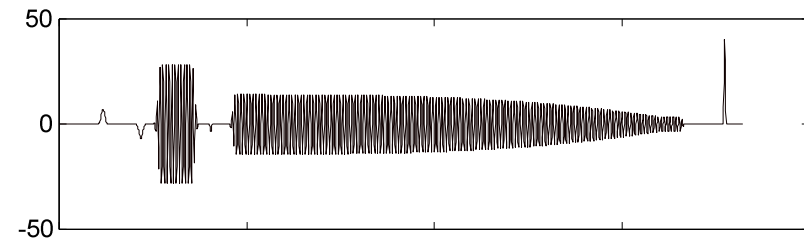
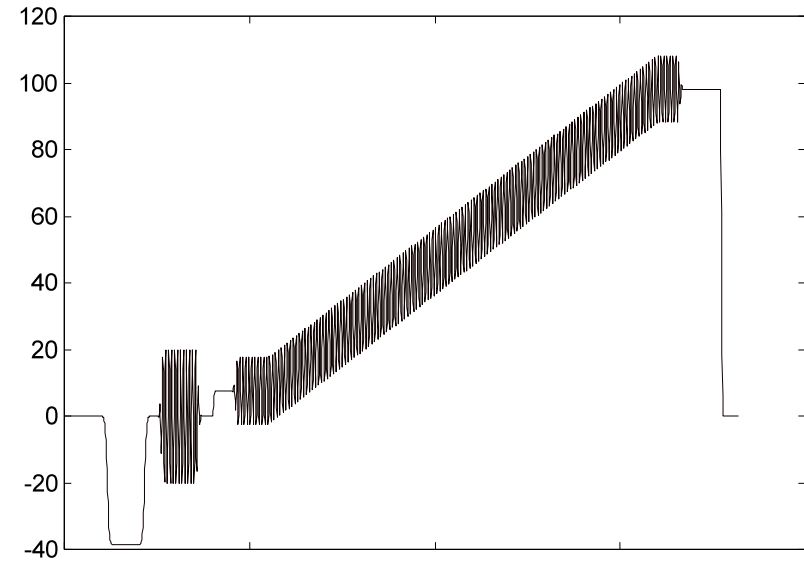
Efeito de não-linearidade  
(Filtro de rejeição de croma ativado):



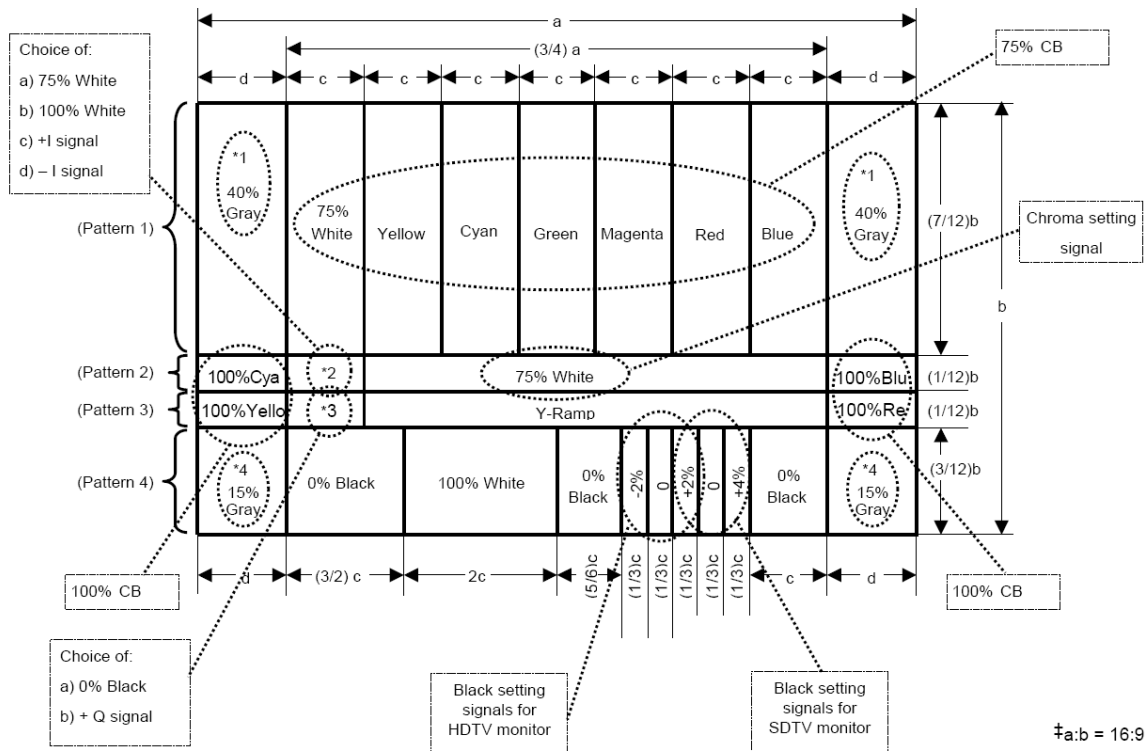
Efeito de multipercurso na recepção do GCR:



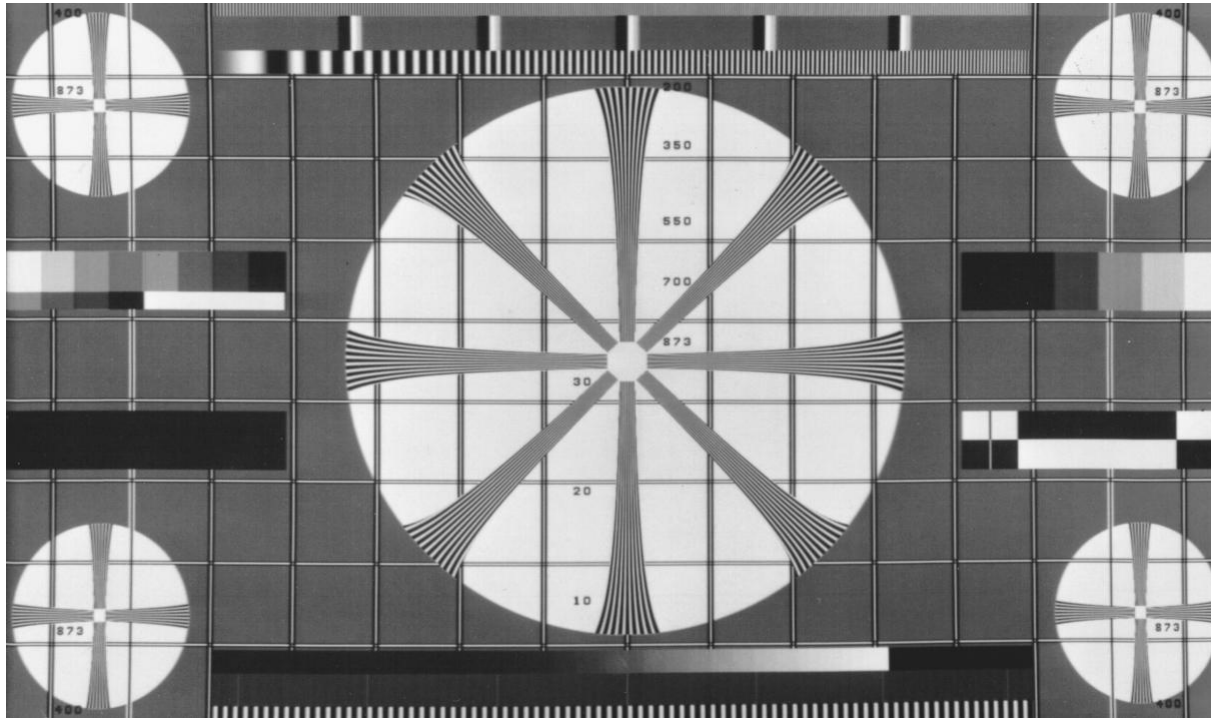
Efeito de não-linearidade  
(filtro de croma ativado):



## Padrão de barras SMPTE RP219 / ARIB STD-B28



## Padrão de Teste de Resolução





Padrão “Zone Plate” com varredura de frequência vertical e horizontal

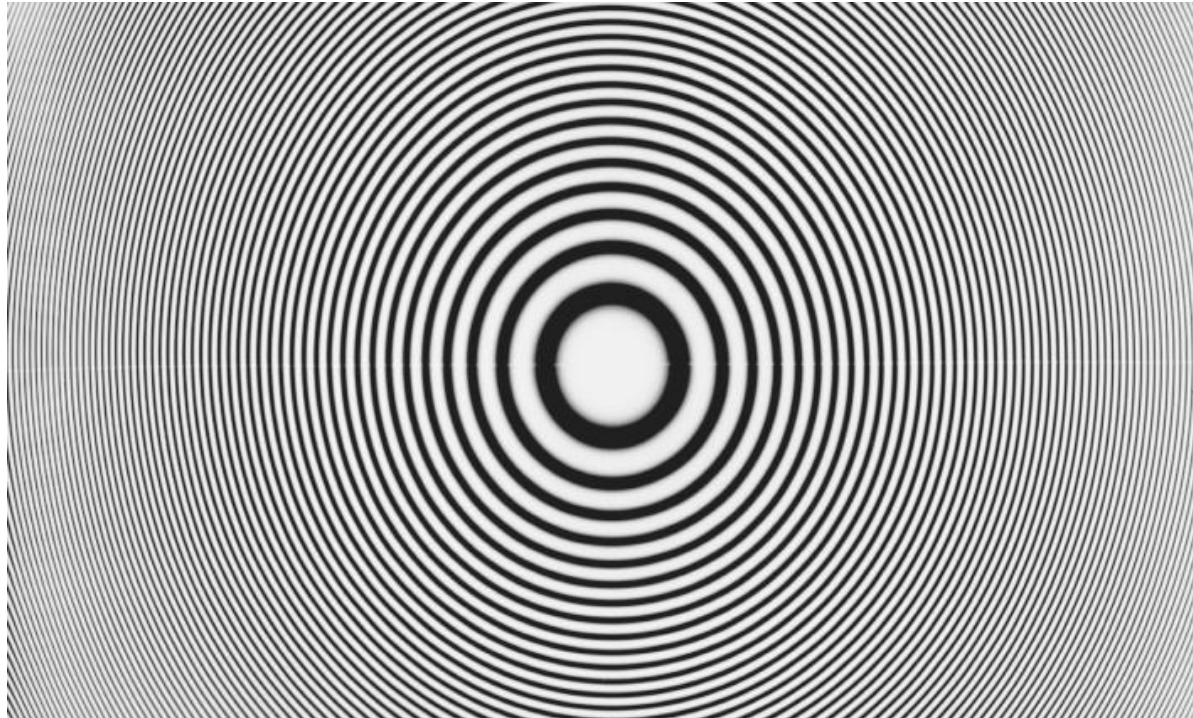
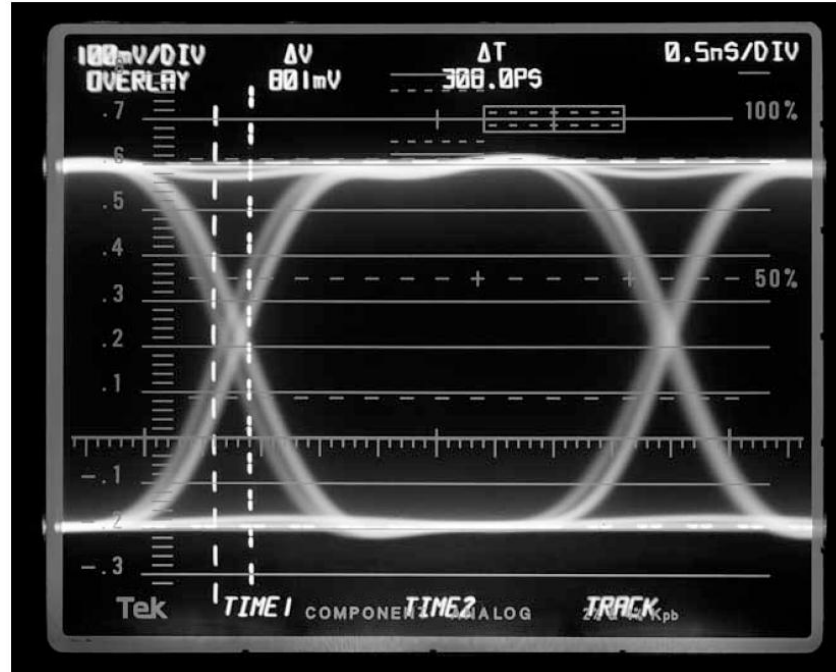


Diagrama de Olho para interfaces digitais



NTSC = Never Twice the Same Color

SECAM = System Essentially Contrary to American Methods

PAL = Peace, At Last

PAL-M = Pay a Little More