NTSC: Nice Technology, Super Color

Presentation by
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Overview

- Introduction
- Historical factors in the development of black and white television
- Description of broadcast television signals
- NTSC color encoding

Introduction: NTSC coding

- NTSC: National Television Standards committee
- Standard encoding scheme for television signals in the United States and Canada (NTSC Countries)
- NTSC is often criticized, but according to Blinn "NTSC encoding…is one of the most amazing technical achievements of our time…Done well, it can look really good"

History of NTSC coding

- The original constraints on television:
  - Wireless interface
    - Must deliver image and sound information in the form of a broadcast radio transmission
  - CRT (raster) display
    - Initial CRTs technologically limited to ~0.5 m
    - Viewing distance assumed to be ~3 m
    - Therefore the limits of human vision dictate that a “good” quality picture must have spatial resolution of at least several hundred lines per frame

History of NTSC coding

- Constraints continued:
  - 4:3 aspect ratio desired
  - Local power-line frequencies can cause undesirable artifacts
    - Vertical CRT rate set to match power-line rate (60Hz in North America, 50 Hz in Europe)

History of NTSC coding

- Transmitting a complete frame (400-500 lines) at 60 Hz requires an unacceptably wide broadcast channel
- 2:1 interlacing used instead
  - Divide a frame into *fields* containing even-numbered and odd-numbered lines
  - Refresh each field at 60 Hz
  - Human persistence of vision creates the illusion of the full vertical resolution being refreshed
  - Simple form of lossy compression!

History of NTSC coding

- North American/Japanese standard:
  - 525 lines per frame
  - 60 Hz field rate
- European standard:
  - 625 lines per frame
  - 50 Hz field rate
- We are still talking about black and white: "NTSC" and "PAL/SECAM" refer to specific methods of color encoding, so the standards above are properly referred to as "525/60" and "625/50"

History of NTSC coding

- How to transmit these images as a radio signal?
  - 485 of the original 525 lines are available for “active” video (the other 40 are vertical blanking intervals)
  - Assuming a Kell factor of 0.7, the system should deliver (485)(0.7) = 340 lines of vertical resolution
  - 4:3 ratio implies (4/3)(340) = 453 “pixels” for each horizontal line

History of NTSC coding

- Radio transmission continued:
  - Recall:
    - Lines per frame: 525
    - Lines per field (2:1 interlacing): (525)/(2) = 262.5
  - Therefore, line rate = (262.5 lines/field)(60 fields/s) = 15750 Hz
  - 20% of the line time is required for horizontal blanking/retrace
  - Recall horizontal resolution is ~453 “pixels”
    - This implies a maximum of 227 black/white cycles per line (the highest frequency image possible)

History of NTSC coding

- Radio transmission continued:

Bandwidth required for video:

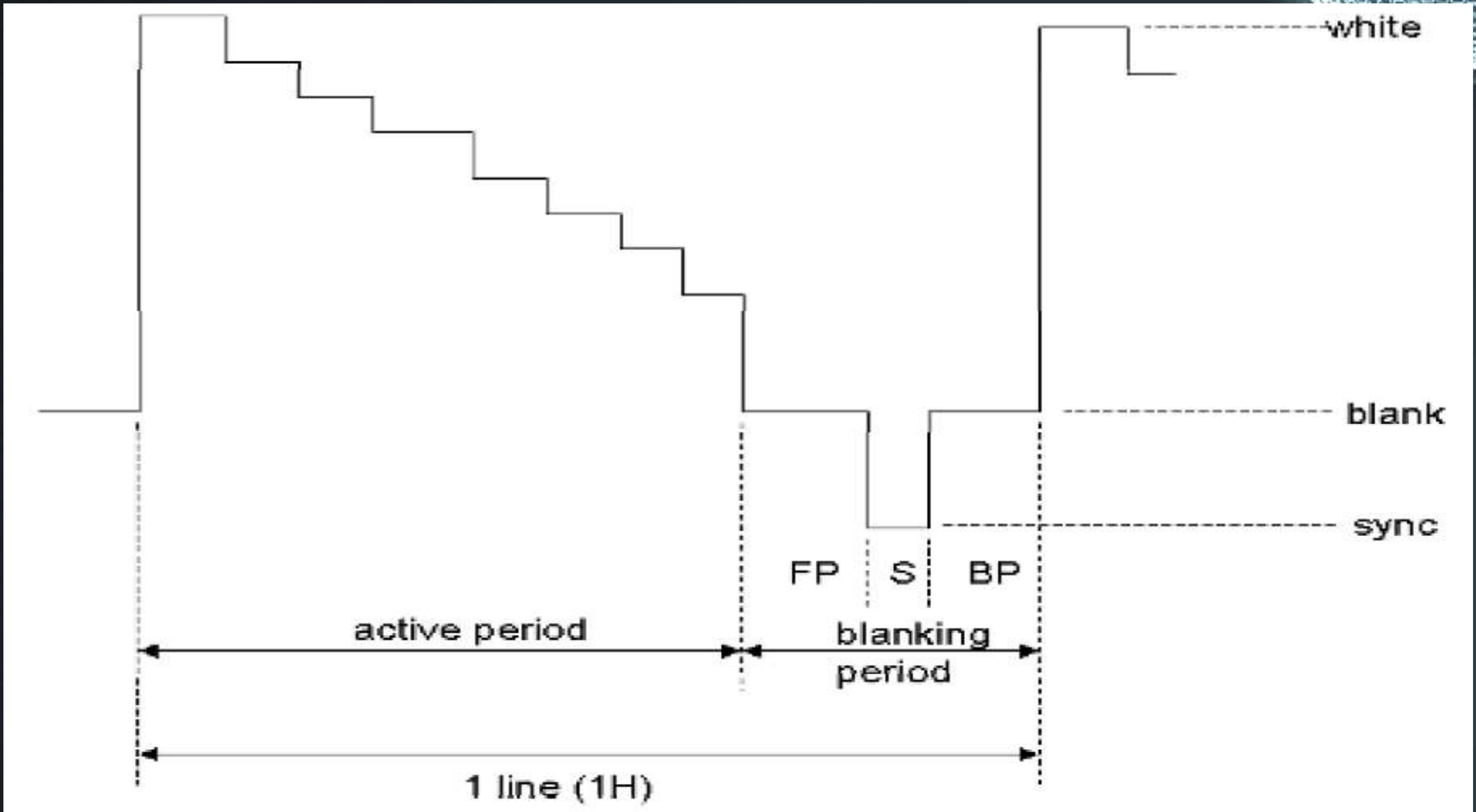
$$\frac{227(\text{cycles / line})}{(0.8/15750)(\text{s / line})} = 4.47\,\text{MHz}$$

- – Conclusion: to deliver an image of the desired resolution, using the 525/60 scanning standard, requires an ~4.5 MHz bandwidth channel (at minimum)
- – This is close to the numbers actually chosen for broadcast television
  - In the US, 525/60 standard channels each occupy 6 MHz (CCIR-M)

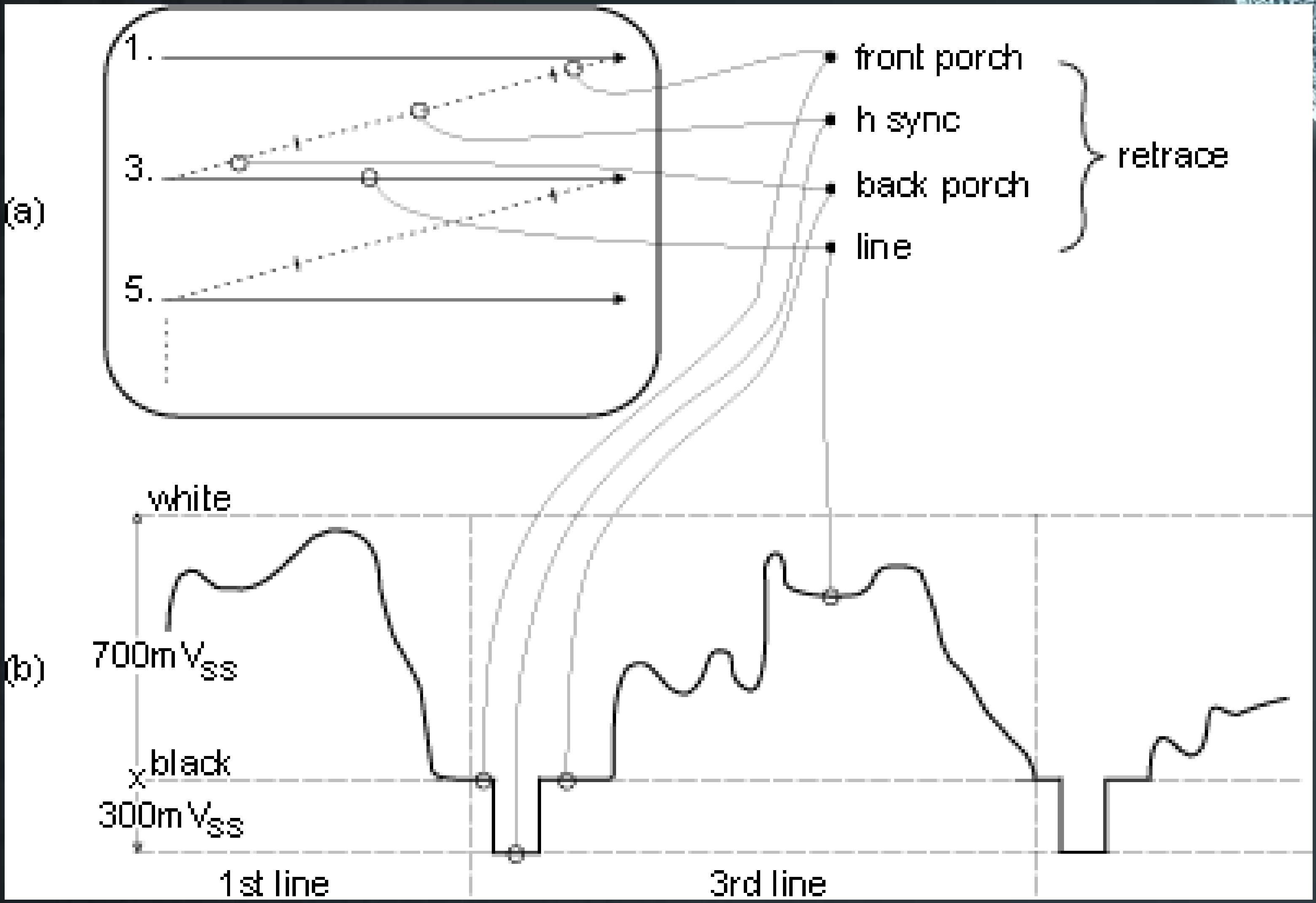
Broadcast signal modulation

- Negative modulation
  - Increase in luminance = decrease in depth of modulation
  - The “blacker” portions of the image are transmitted at a higher percentage of modulation than the “whiter” portions
  - When to start a new line, field or frame?
    - Need “sync” pulses
  - Sync pulses are excursions *below* the level established for black
    - Therefore the highest modulation occurs at the sync pulses, and the receiver is more likely to deliver good reception in the presence of noise

A television signal



Another view of the signal



History of NTSC coding

- Backwards compatibility
  - When color television was introduced, the new signals had to maintain compatibility with existing black and white TV sets
  - Also, a black and white signal fed to a new color TV had to produce a black and white picture
  - Finally, the new signal had to fit into the same bandwidth as the original black and white signal (including audio!)

Black and White Signal in Frequency Space

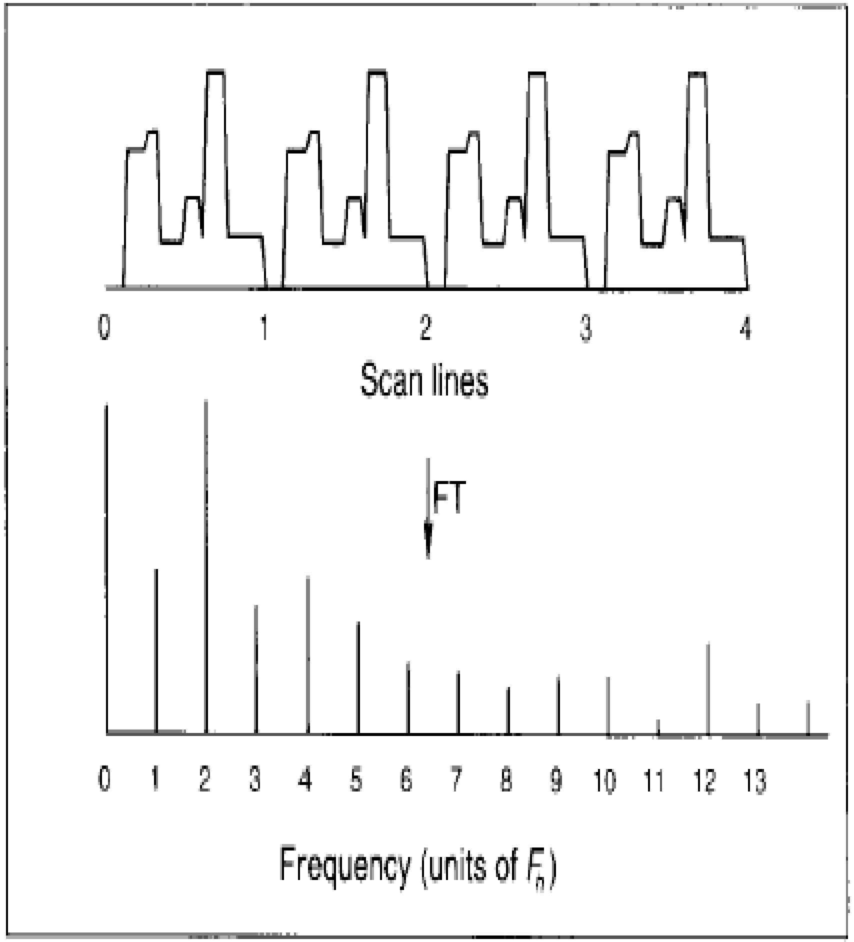
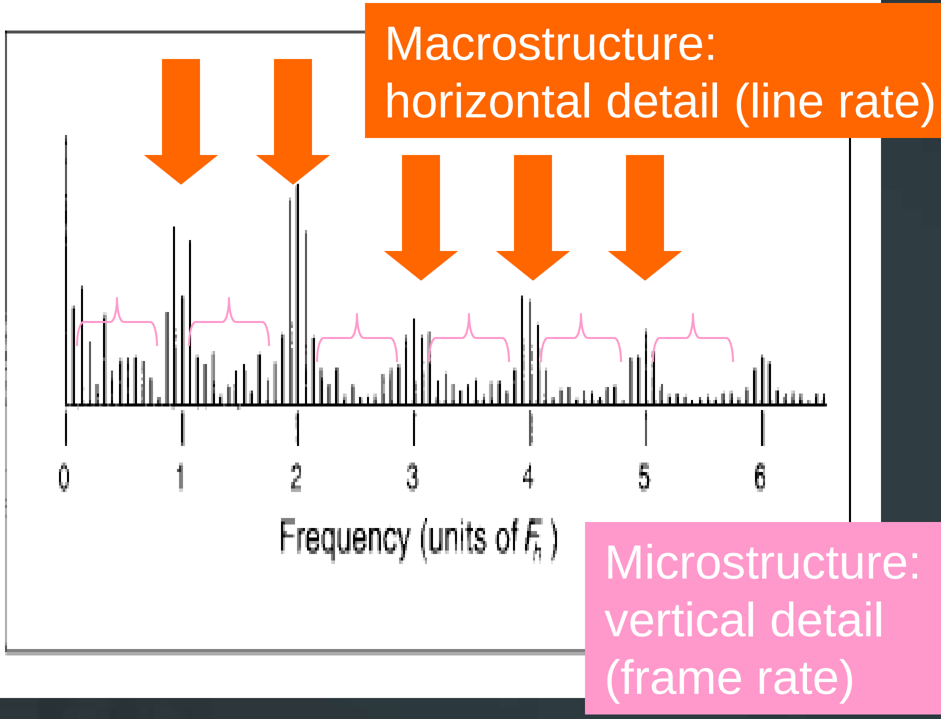


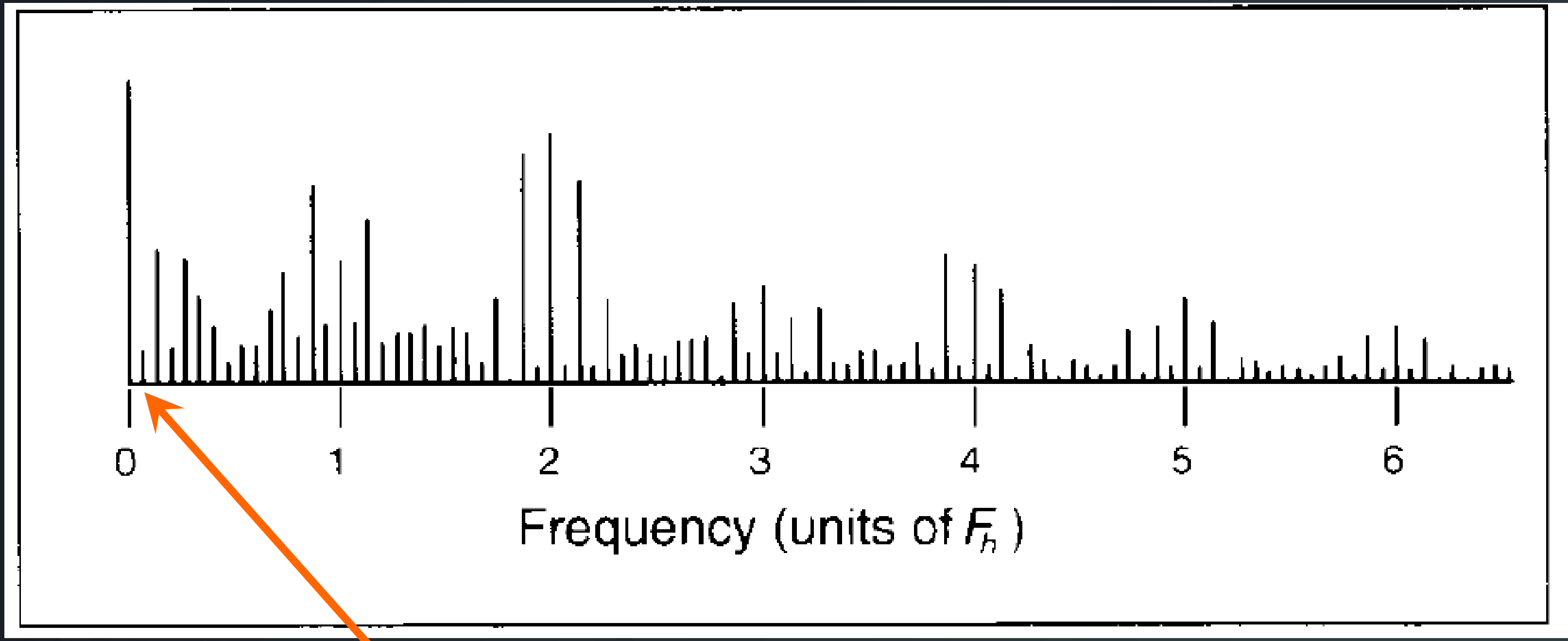
Figure 2. The spectrum of a repeated scan line.

Figure 3. The spectrum of a whole frame.



The Frequency effects of Interlacing

Interlacing changes values at microstructure frequencies:



Also reduces flicker (29.97 Hz component)

Another clever exploitation of human perception

- The human eye perceives abrupt transitions in brightness better than changes in hue
- Also, the eye is more sensitive to the orange-blue (flesh tone) range than to purple-green
- To take advantage of these characteristics, NTSC transforms RGB into YIQ color space
- Y= luminance (This is the only signal used by black and white TV)

$$Y = 0.299R + 0.587G + 0.114B$$
$$I = 0.596R - 0.275G - 0.321B$$
$$Q = 0.212R - 0.523G + 0.311B$$

(Current NTSC color TV actually uses YUV)

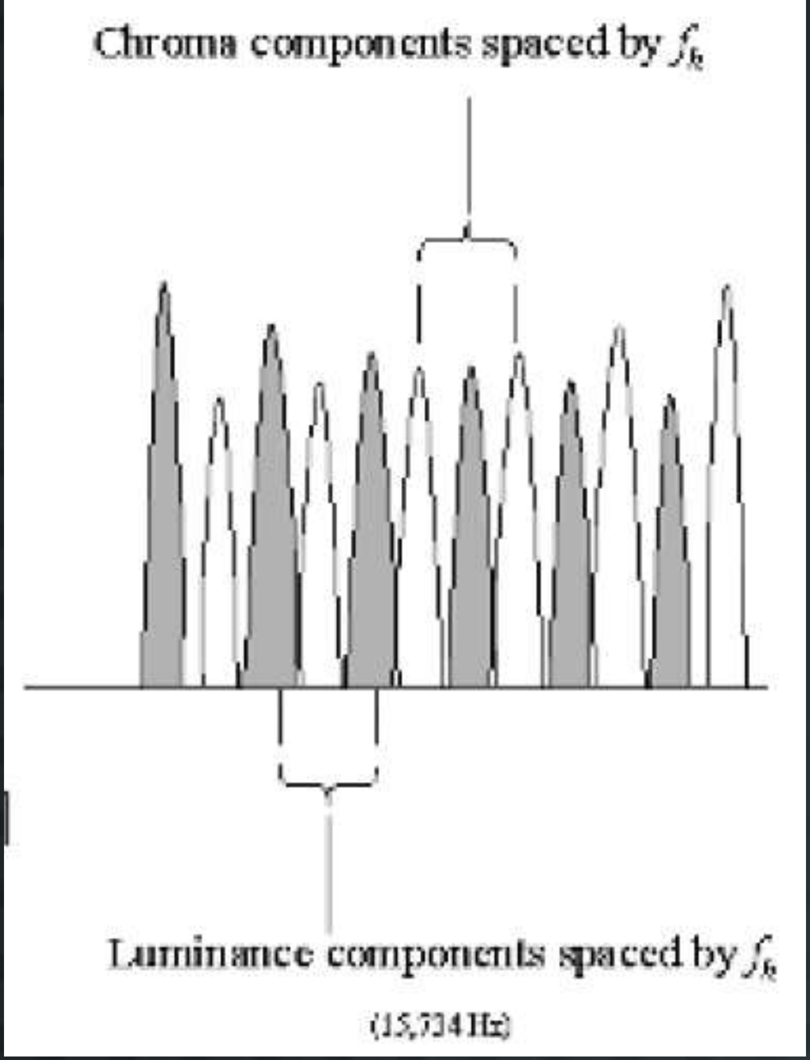
Bandlimiting for compression

- Changing coordinate systems from RGB to YIQ does not do any data compression
- The NTSC standard band-limits YIQ, with I and Q much more constrained (Because of humans' reduced spatial color vision acuity, as mentioned earlier)

Table 2. Bandwidth of NTSC primaries.

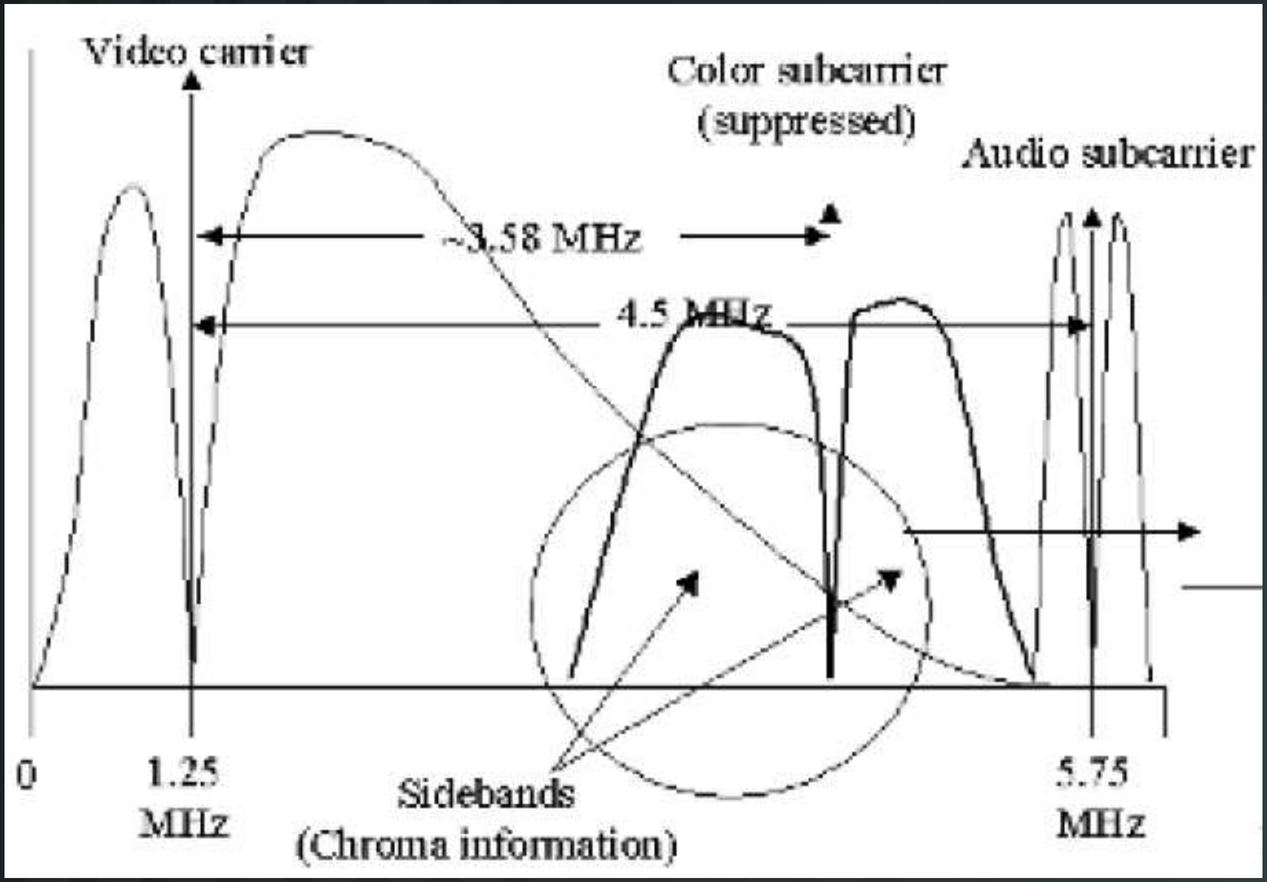
Signal	Maximum frequency		
	MHz	Cycles/pixel	Cycles/line
Y	4.2	1/3.4	267
I	1.5	1/9.5	96
Q	0.55	1/26	35

How to add color information?



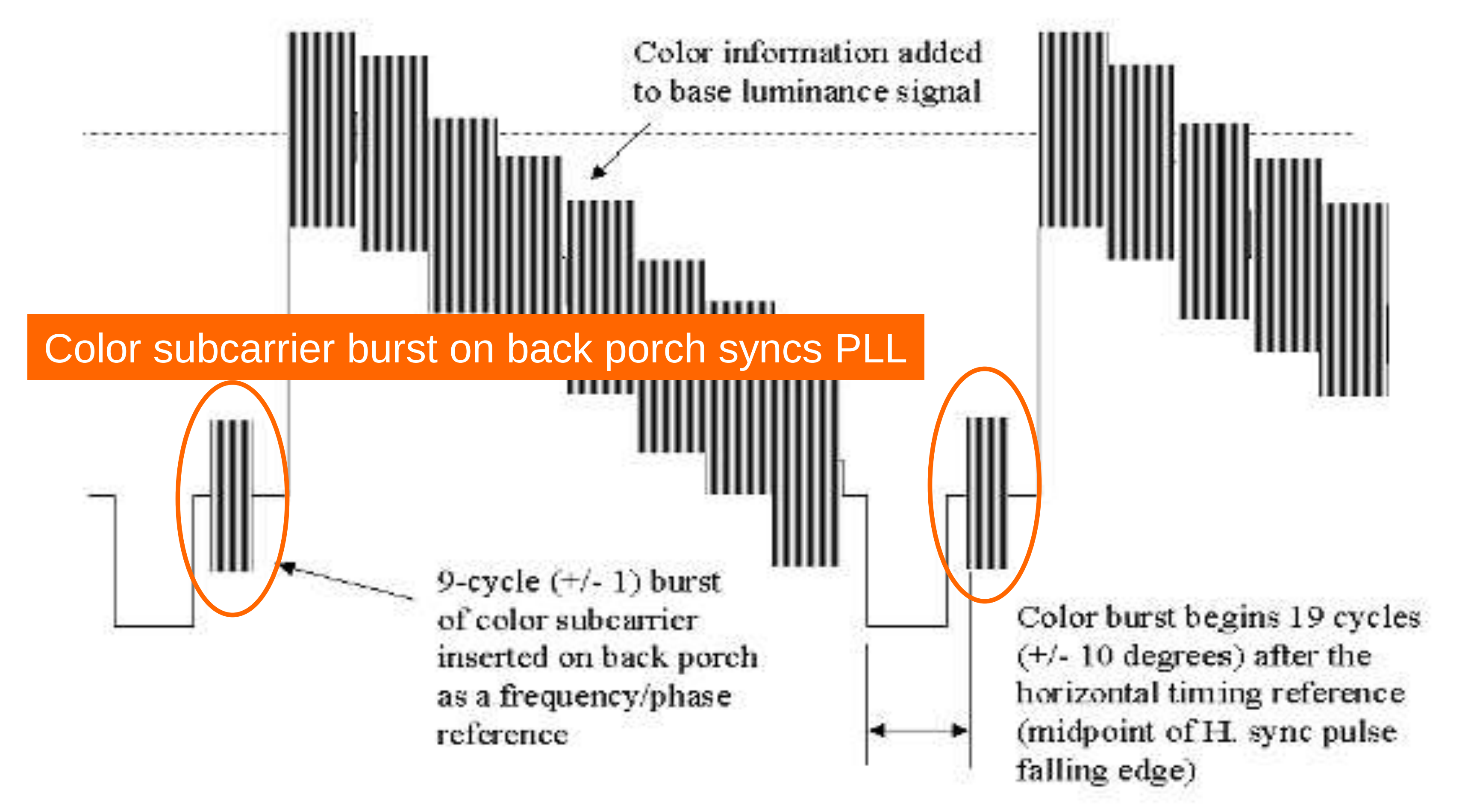
- Due to the regular line and field structure of raster-scan transmission, the spectral components appear clustered around multiples of the line and field rate.
- Put color signal components into the space between the "pickets" of luminance information!

A Color signal



- Add a color subcarrier at a frequency which is an odd multiple of one-half the line rate

Addition of the color subcarrier

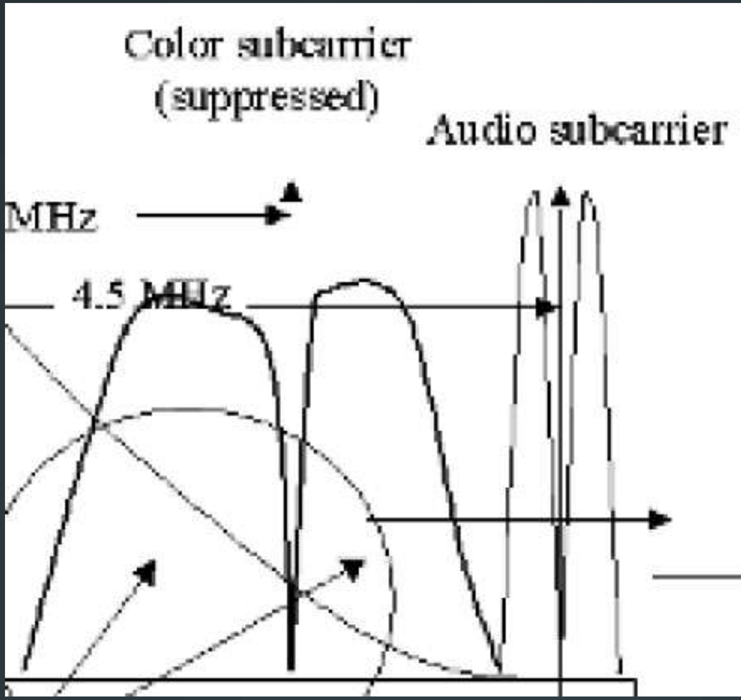


Combining I & Q

- The color components I (interphase) and Q (quadriphase) are combined into one signal using quadrature modulation
- Multiplying I and Q by a sine wave in the time domain is the same as convolving the Fourier transform with two impulses at +/- the subcarrier frequency $F_{subcarrier}$
- This makes copies of I & Q centered around the subcarrier
- I & Q must be bandlimited for accurate demodulation (computer generated signals often violate this)

Color and Audio

- Note that the new color information comes very close to the audio components at the upper end of the channel
- To avoid mutual interference, the chroma subcarrier was shifted down by a factor of 1000/1001



Decoding NTSC

- Cheapest method: low pass filter with 3MHz cutoff to get rid of chroma
  - But also removes some of the high frequency luminance data, and blurs the image
- If some color signal remains in the recovered Y values, it will look like dots crawling up vertical edges – “chroma crawl”
- If some luminance signal remains in the separated chroma values, it will appear that rainbows are superimposed on what should be monochrome

Decoding NTSC

- A better method: a comb filter at the line rate
  - Improvement over low-pass method, but can still lead to vertical chroma detail being misinterpreted as horizontal brightness detail if the color changes quickly from one scan line to the next
  - Equivalent to averaging each scan line with the previous one
    - Unless the color changes dramatically between lines, the color signals will cancel because the chroma signal switches sign from one scan line to the next (227.5 color carrier cycles/line)

Decoding NTSC

- Best separation of Y and C: a comb filter at the frame rate
  - Equivalent to averaging each pixel with the same pixel from the previous and subsequent frames (chroma changes sign from frame to frame as well as line to line)
  - Expensive monitors switch between comb filters at the line and frame rates as needed

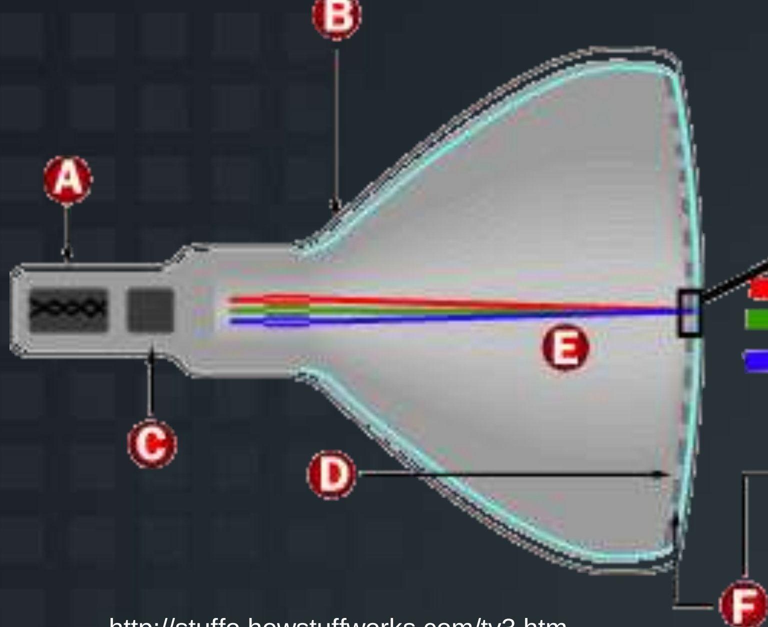
Conclusion

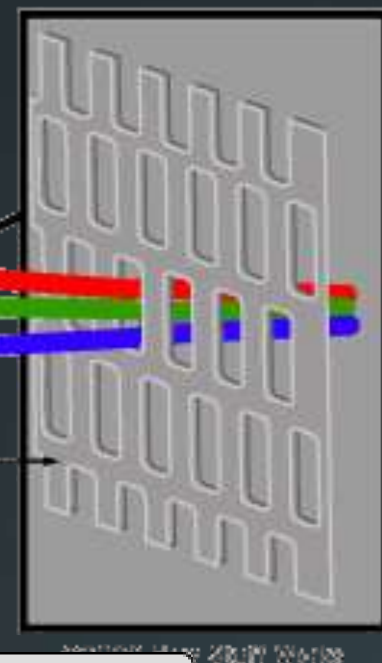
- NTSC color TV is a system that utilizes many clever methods to deal with the constraints imposed upon it
- When preparing artificial computer images for NTSC presentation, an awareness of the standard can help ensure good results
  - Filter out high frequencies before encoding!

NTSC Countries

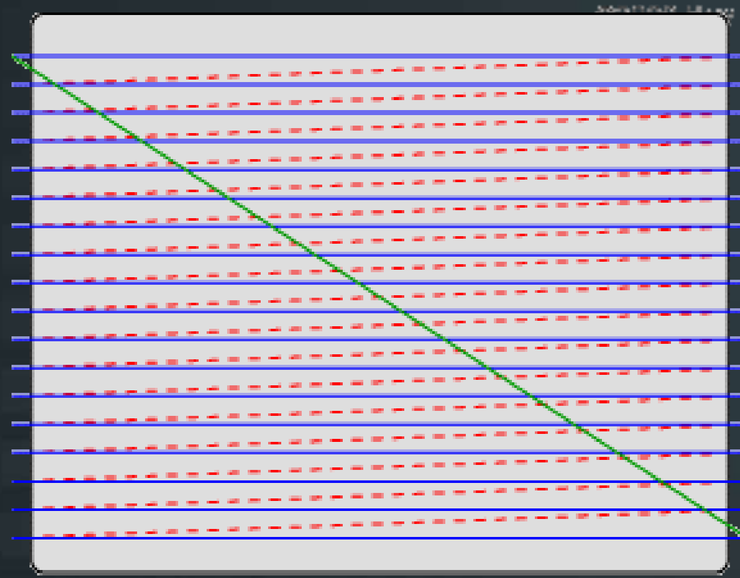
- USA, Antigua, Bahamas, Barbados, Belize, Bermuda, Bolivia, Burma, Canada, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Greenland, Guam, Guatemala, Guyana, Honduras, Jamaica, Japan, South Korea, Mexico, Netherlands Antilles, Nicaragua, Panama, Peru, Philippines, Puerto Rico, St. Vincent & the Grenadines, St. Kitts, Saipan, Samoa, Surinam, Taiwan, Tobago, Trinidad, Venezuela, Virgin Islands (back)

CRT Display





http://stuffo.howstuffworks.com/tv3.htm



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http://stuffo.howstuffworks.com/tv7.htm

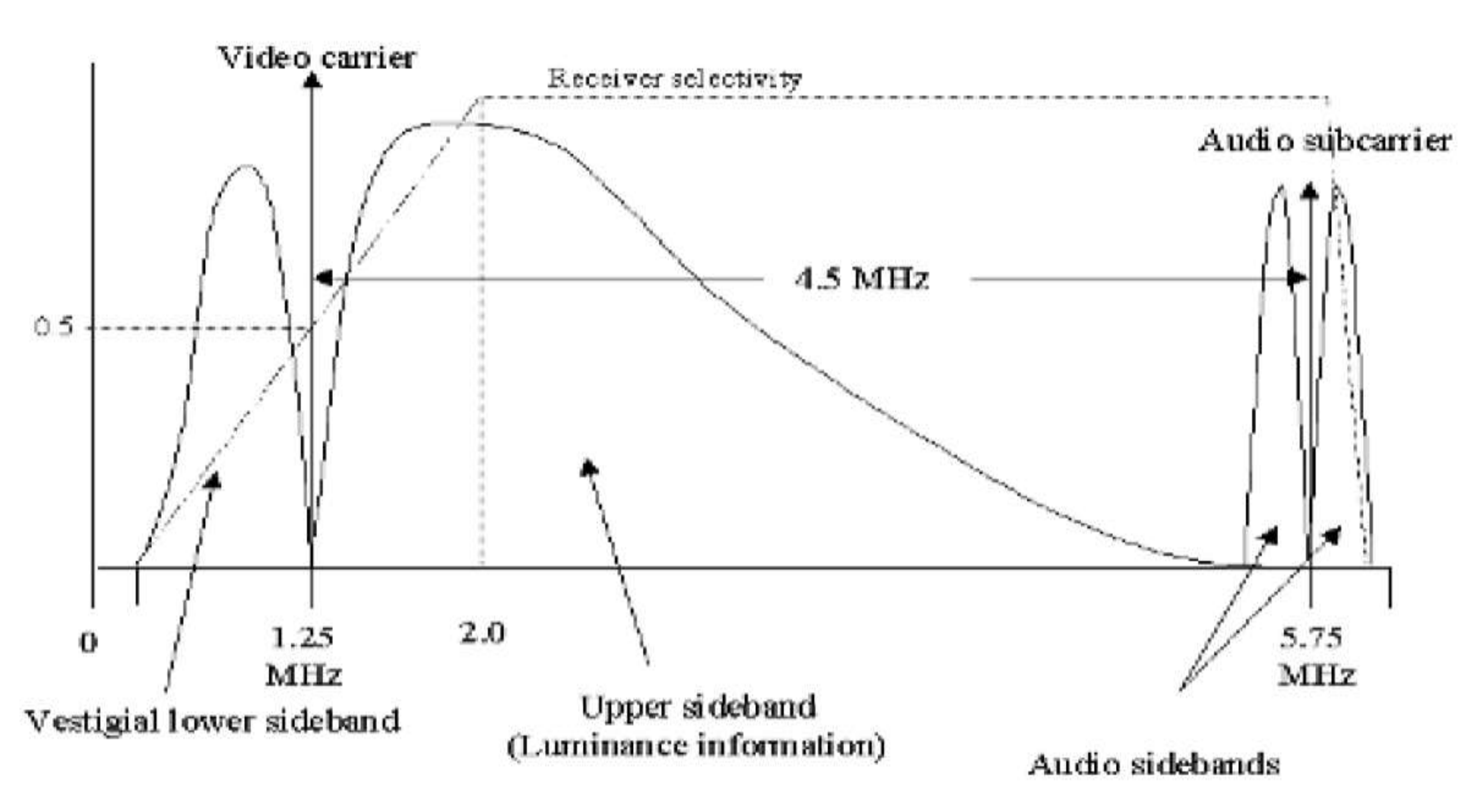
Definition: Kell factor

- The effects of interlacing and device constraints reduce the quality of the image that is actually delivered
- The *Kell factor* is the ratio between actual delivered resolution (under ideal conditions) and the number of lines transmitted per frame
- Television systems are assumed to operate at a Kell factor of ~0.7

(back to History of NTSC)

CCIR-M channelization

Video: Vestigial-sideband amplitude modulation (VSB)
Audio: Frequency modulation (FM)



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Television Broadcasting into the Digital Era

Overview of Topics

1 - Basic Concepts of Television Systems

2 - Digital Video Sampling & Standards

3 - Digital Audio/Video Stream Compression

4 - Digital Modulation Systems

5 - Transmission System Error Protection

6 - Digital System Parameters, Planning and SI

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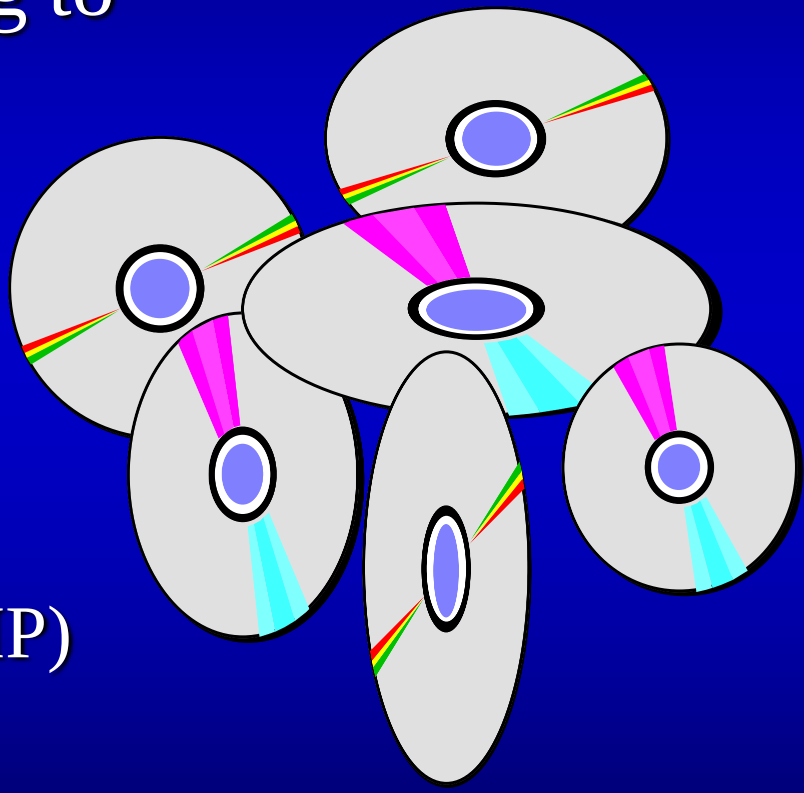
Digital Media

- First media systems were analog
- Most media are converting to digital
  - Computer storage
  - Music (LP-CD)
  - Telecommunications
  - Multimedia
  - Internet Networking (TCPIP)
  - Radio (DAB)
  - Television (DTTB)



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What is Television

- Images - Black and White Shades of Grey
- Colour - Hue & Saturation
- Sound - Audio Information
- Data - Teletext & Other Data
- Synchronisation - Specifies the Timing
- Transport System - Gets the Above to your TV

History - Ferdinand Braun - CRT

- 1890 Ferdinand Braun developed the Cathode Ray Tube.
- 1897 developed the Cathode Ray Oscillograph, the precursor to the radar screen and the television tube
- 1907 First use of cathode ray tube to produce the rudiments of television images.
- He shared the Nobel Prize for physics in 1909 with Guglielmo Marconi for his contributions to the development of wireless telegraphy.

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John Logie Baird - Basic TV

- Oct 1923 John Logie Baird was the first person anywhere in the world to demonstrate true television in the form of recognisable images, instantaneous movement and correct gradations in light and shade. Scanning was done mechanically with a Nipkow disc. The first 30 line picture transmitted was a Maltese cross.
- 1927 he also demonstrated video recording
- 1928 transatlantic television
- 1937 the broadcast of high definition colour pictures
- 1941 stereoscopic television in colour
- 1944 the multi-gun colour television tube, the forerunner of the type used in most homes today.

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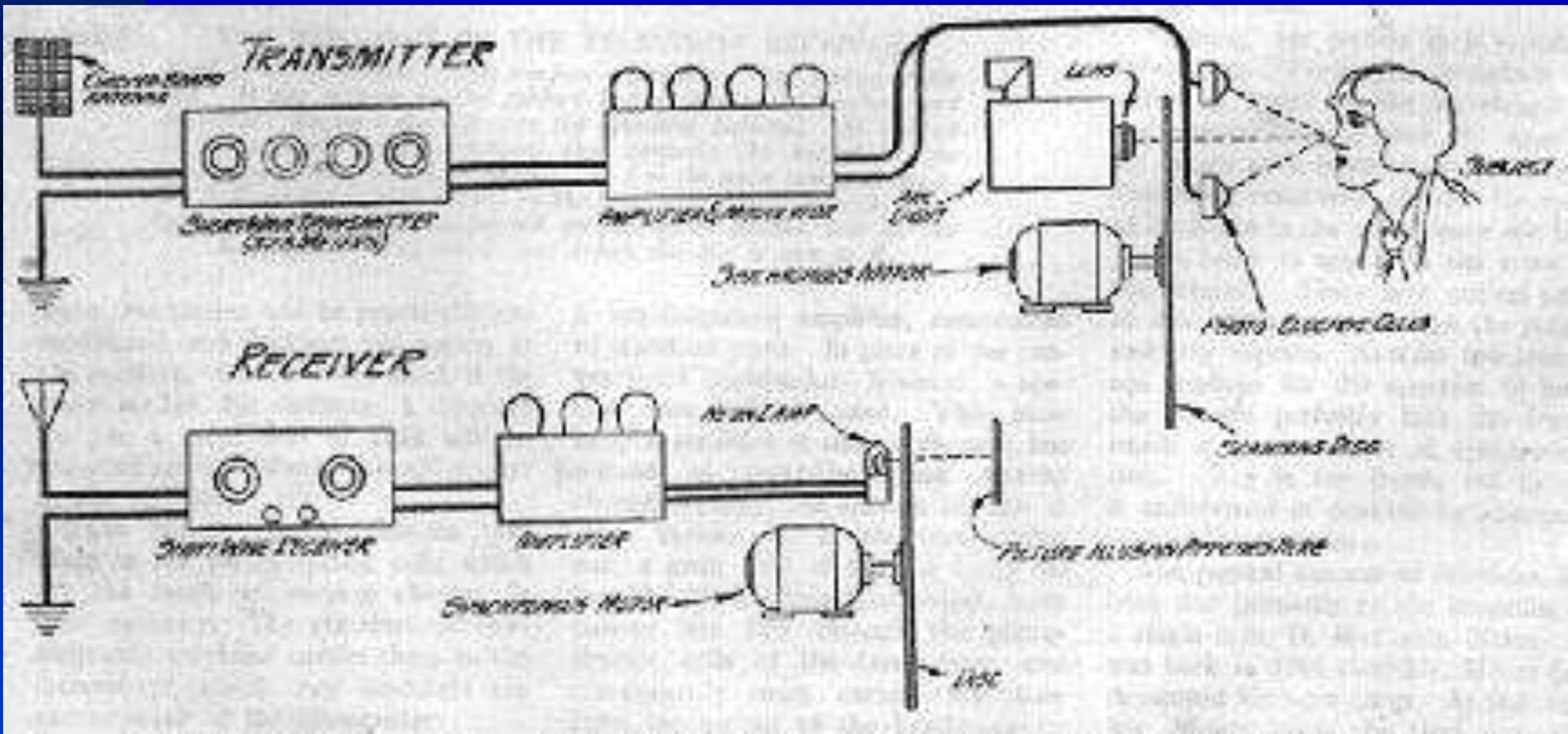
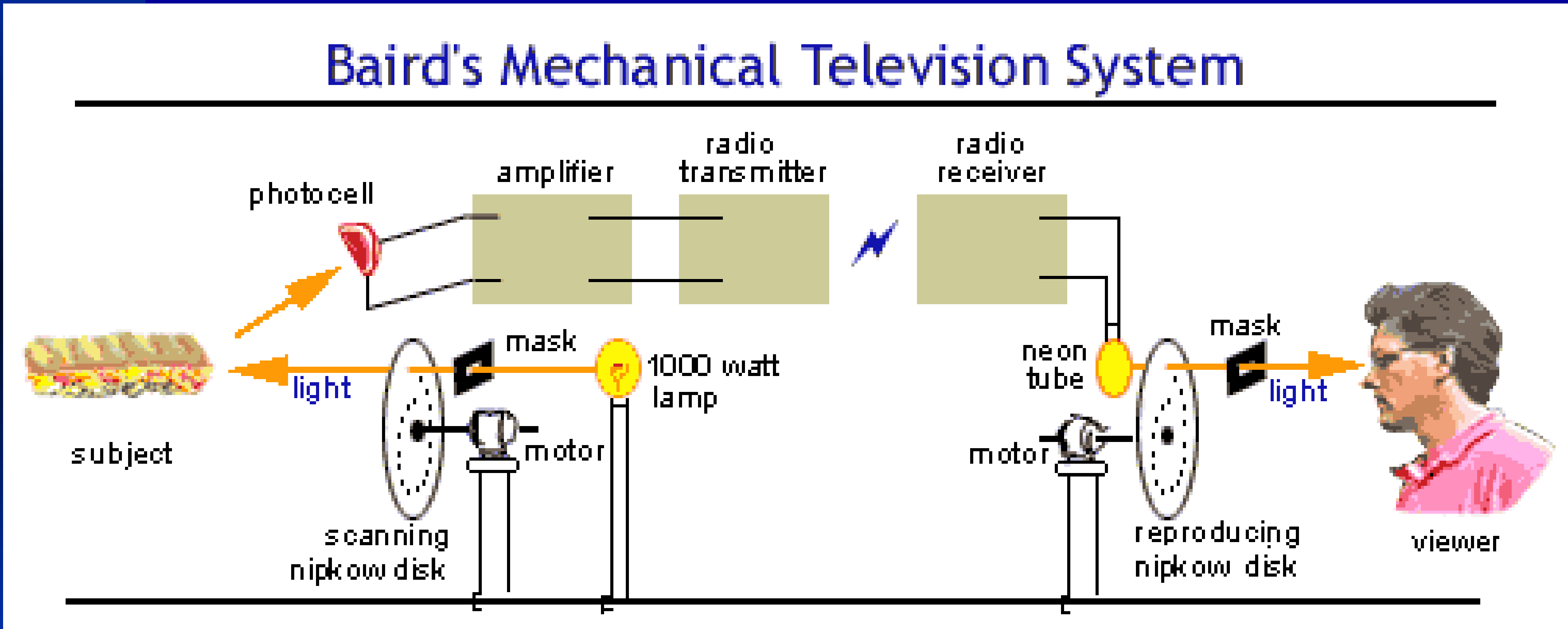
Early Mechanical Approach to TV

Mechanical Nipkow discs were used to scan the image and reconstitute the image at the receiver. PE cells were used to capture the image. The problem was synchronising the disks.



30 Line Mechanical TV



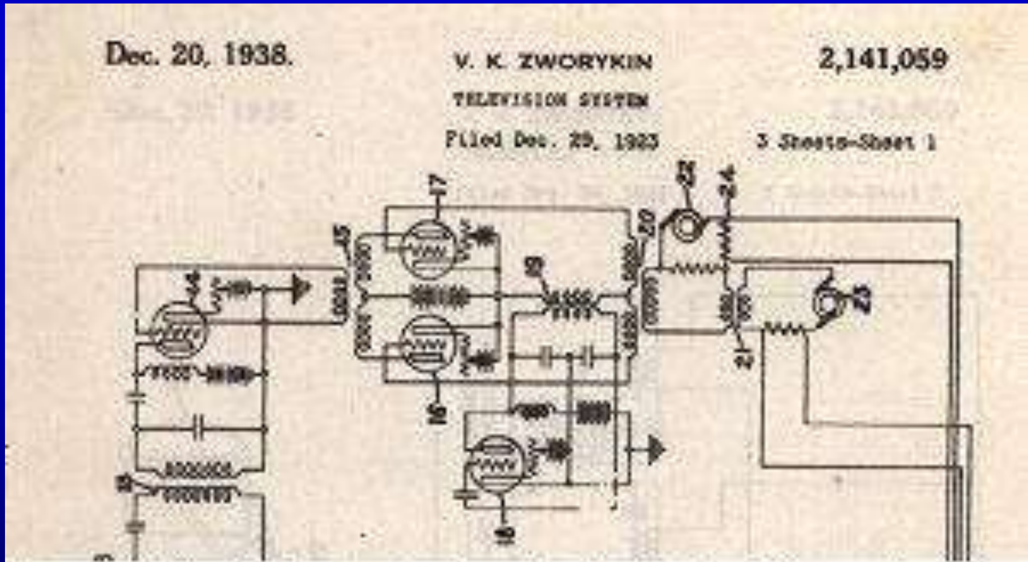
Electronic Television - Farnsworth

- In 1922 at Age 14 Philo Farnsworth had the idea of how to make Electronic Television possible.
- Sept. 7, 1927, Farnsworth painted a square of glass black and scratched a straight line on the centre. The slide was dropped between the Image Dissector (the camera tube that Farnsworth had invented earlier that year) and a hot, bright, carbon arc lamp. On the receiver they saw the straight-line image and then, as the slide was turned 90 degrees, they saw it move. This was the first all-electronic television picture ever transmitted.

The Recreated Image Dissector, in the same hands that built the original 50 years earlier

Vladimir Zworykin - Iconoscope

- In 1923 Vladimir Zworykin of RCA made a patent application for a camera device, and by 1933 had developed a camera tube he called an Iconoscope. Although Zworykin submitted his patent application first after many years of legal battle Farnsworth was acknowledged as the inventor of electronic television.
- By the end of 1923 he had also produced a picture display tube, the "Kinescope"



Zworkykin's 1938 patent - bearing the date of the application that was ruled "inoperative" by the patent office in 1934

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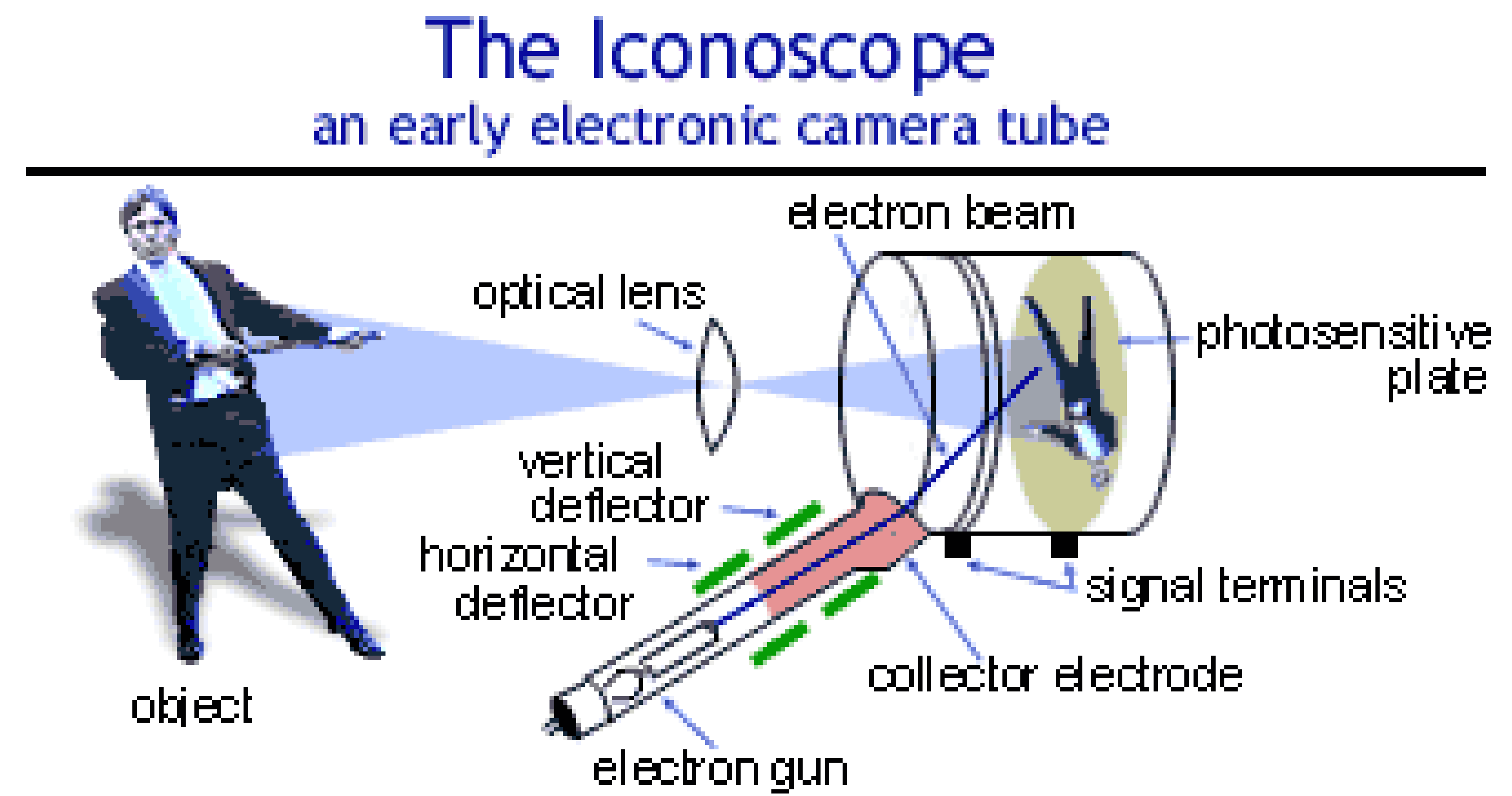
Significant Television Inventions

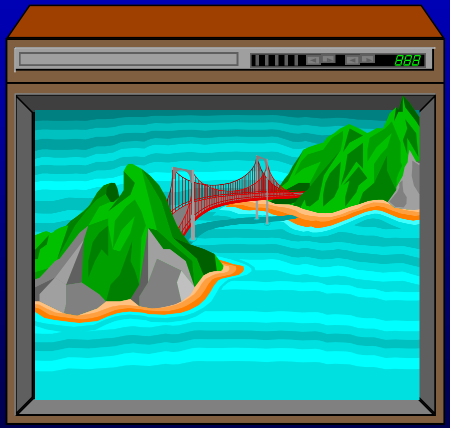


- These inventions were the underlying basis of the development of Television as we know it today

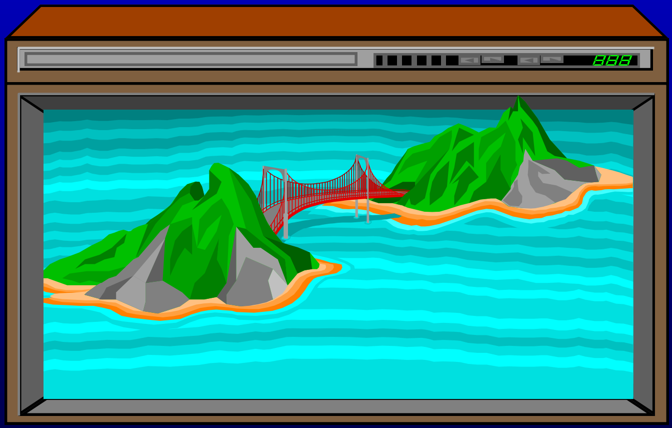
Aspect ratio

- First TV displays were Round
- Rectangular Rasters easier to Generate
- Television Developed a 4:3 Aspect Ratio
- Cinematic formats are much wider
- World now moving to 16:9 Aspect Ratio

4:3 (12:9)



16:9



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Film

- Has been the highest Resolution storage format.
- Various frame sizes used. 16mm, 35mm & 70mm
- Difficult to produce, store, handle and display.
- Easily degraded due to contamination and scratches.
- Generally recorded at 24 fps.
- Generally displayed at 72 fps (each frame 3x) to reduce flicker
- Use a device called a Telecine to convert to television formats

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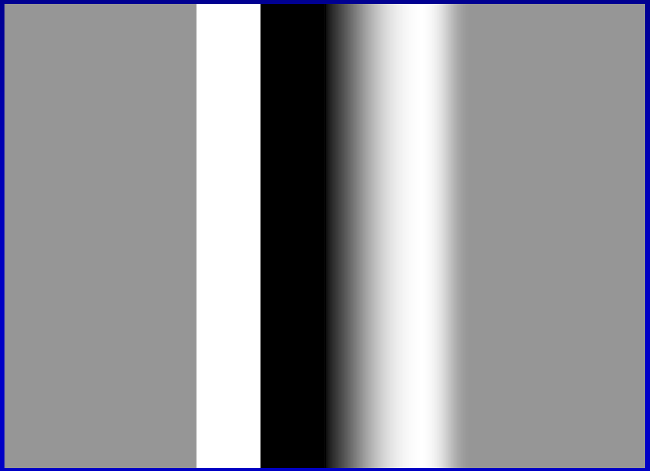
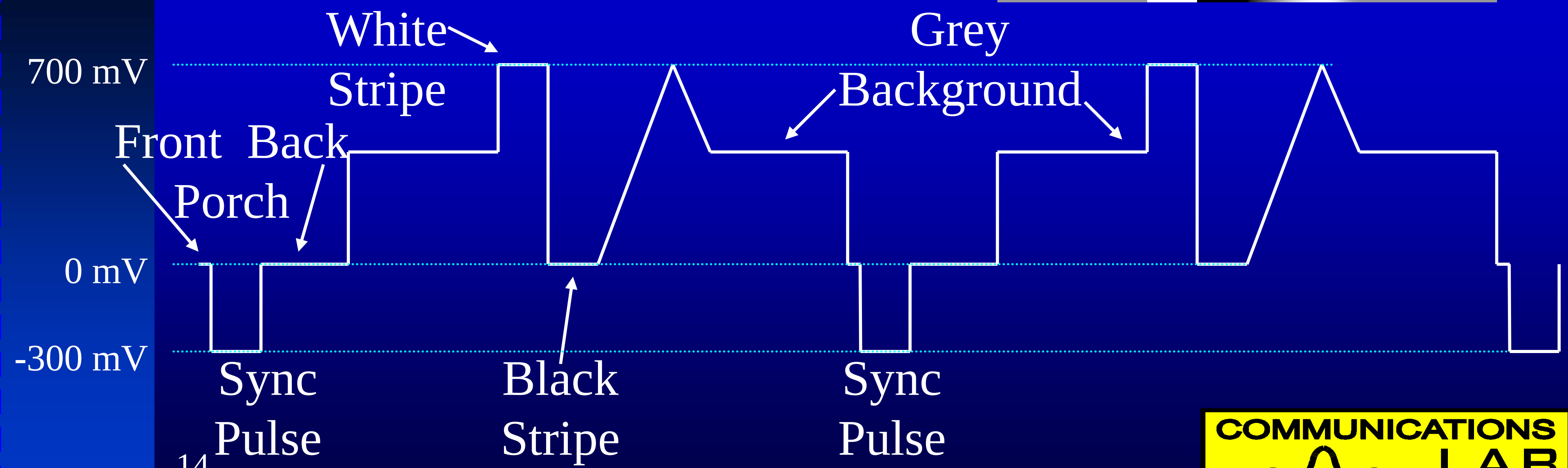
The Video Signal

- First Television Pictures were Black & White Referred to as Luminance
- Video refers to the linear base-band signal that contains the image information





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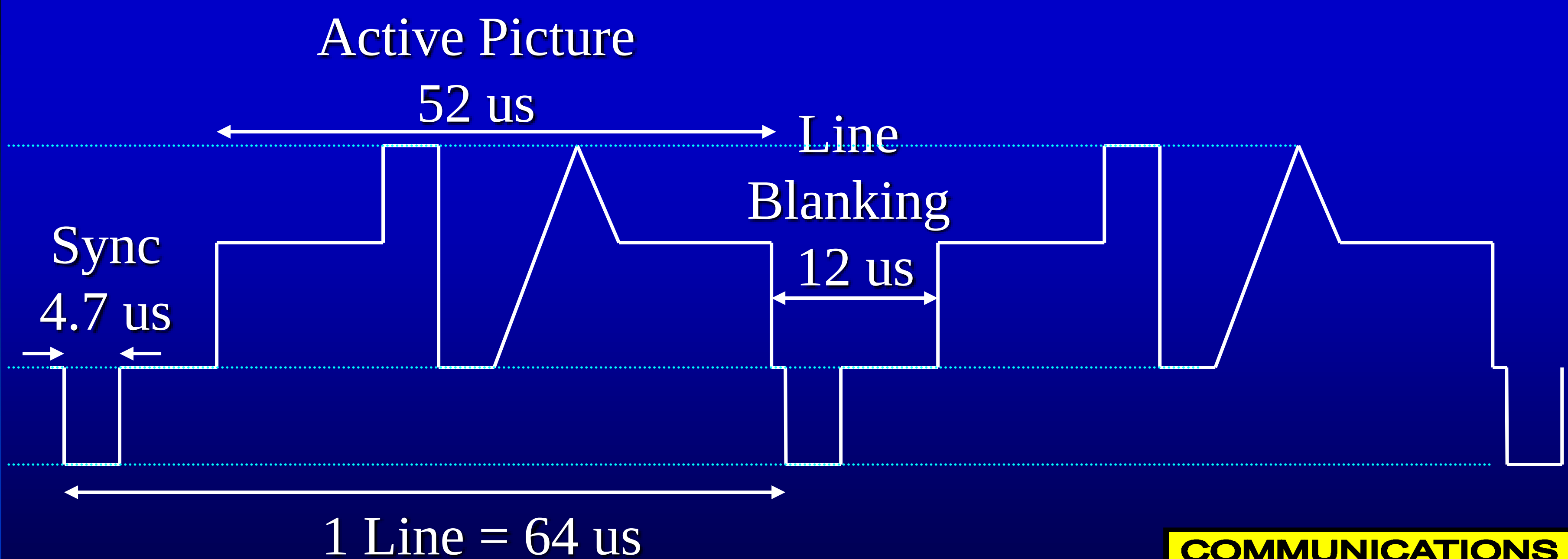
Video Timing

- SDTV
  - 64 us for each line (15.625 kHz)
  - 52 us Active Picture Area
  - 12 us Blanking and Synchronisation
- Two level sync pulse 300 mV below blanking



Frame Rate

- A Frame represents a complete TV picture
- Our analog TV Frame consists of 625 lines.
- A Frame is usually comprised of 2 Fields each containing 1/2 the picture information
- Our system has a Frame rate of 25 Hz
- The Field rate is 50 Hz
- Pictures displayed at 25 Hz exhibit obvious flicker
- Interleaving the Fields reduces flicker.

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Flicker and Judder

- Flicker and Judder are terms used to describe visual interruptions between successive fields of a displayed image. It affects both Film & TV.
- If the update rate is too low, persistence of vision is unable to give illusion of continuous motion.
- Flicker is caused by:
  - Slow update of motion Information
  - Refresh rate of the Display device
  - Phosphor persistence Vs Motion Blur
- Judder usually results from Aliasing between Sampling rates, Display rates and Scene motion

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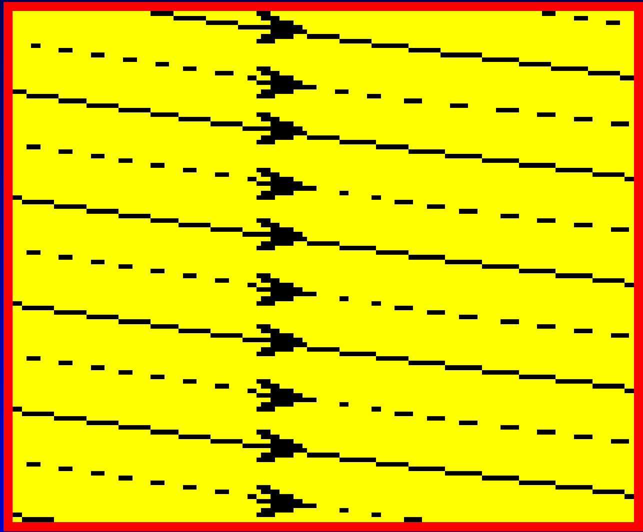
Interlace



- To reduce the perceived screen flicker (25 Hz) on a television, a technique called 'interlacing' is employed.
- Interlacing divides each video frame into two fields; the first field consists of the odd scan lines of the image, and the second field of each frame consists even scan lines.
- Interlace was also used to decrease the requirement for video bandwidth.
  It is a form of Compression

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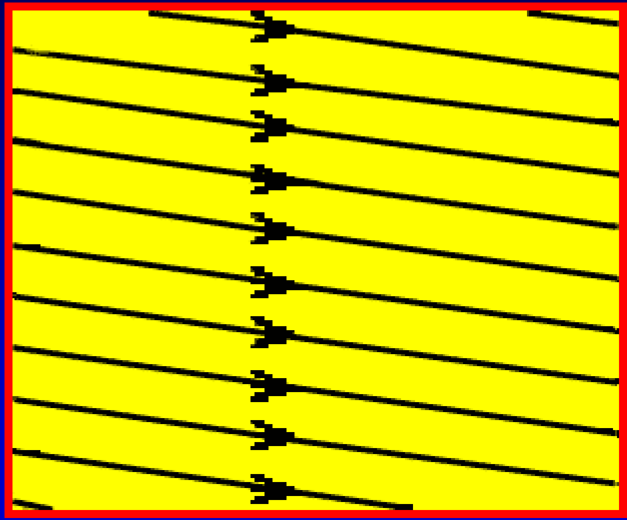
Interlaced Vs Progressive Scan

- Interlaced pictures. - 1/2 the lines presented each scan
  1,3,5,7,9,11,13...............623,625 field 1
  2,4,6,8,10,12,14.............622,624 field 2
- Because the fields are recorded at separate times this leads to picture twitter & judder
- Progressive pictures - all the lines sent in the one scan.
  1,2,3,4,5,6,7,8................623,624,625 picture
- No twitter or judder.
- But twice the information rate.

Progressive Scan



- Simplifies the interpolation and filtering of images
- Allows MPEG-2 compression to work more efficiently by processing complete pictures
- Direct processing of progressively-scanned sources
- 24 frame/second progressive film mode can be provided.
- Assists video conversions with different:
  - numbers of scan lines
  - numbers of samples per line
  - temporal sampling (i.e., picture rate)

Progressive Doubles Raw Data Requirement

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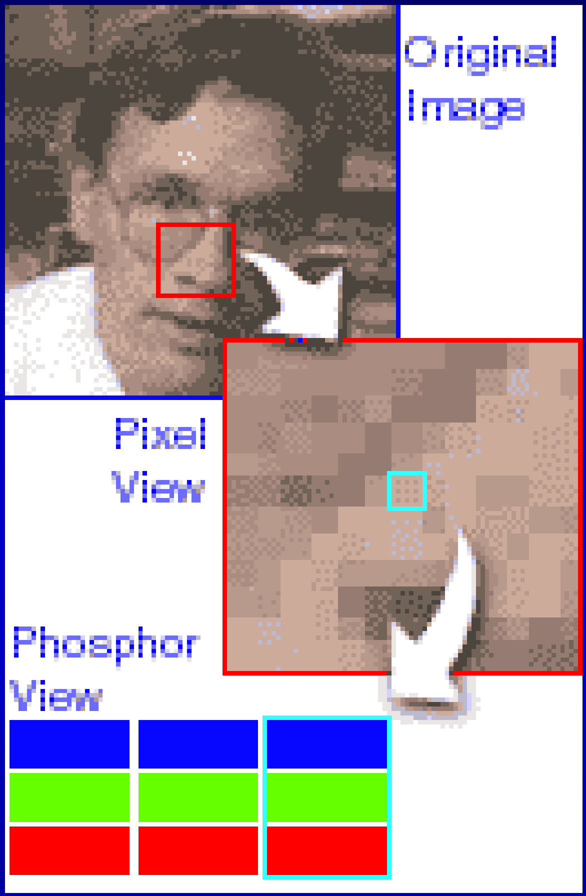
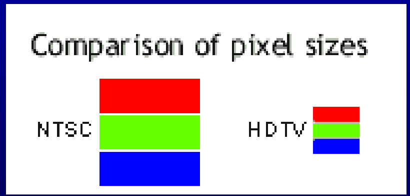
Resolution

- The number of picture elements resolved on the display
- Resolution in TV is limited by:
  - Capture device
  - Sampling Rate
  - Transmission System / Bandwidth
  - Display Device
    - Dot Pitch, Phosphor
    - Focus & Convergence
  - Viewing distance / Display size
  - Human Eye
- Typical SDTV systems attempt to transfer 720 pixels per line





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Colour Equations for PAL

- For B&W only had to transmit Luminance (Y)
- A Colour Image has Red, Green & Blue Components which need to be transmitted.
- We already have the Y signal.
- To remain compatible with Monochrome sets use Y, U & V to represent the Full Colour Picture

$$Y = 0.299\,R + 0.587\,G + 0.114\,B$$

Colour Difference Signals

$$U = 0.564\,(B - Y)$$

$$V = 0.713\,(R - Y)$$

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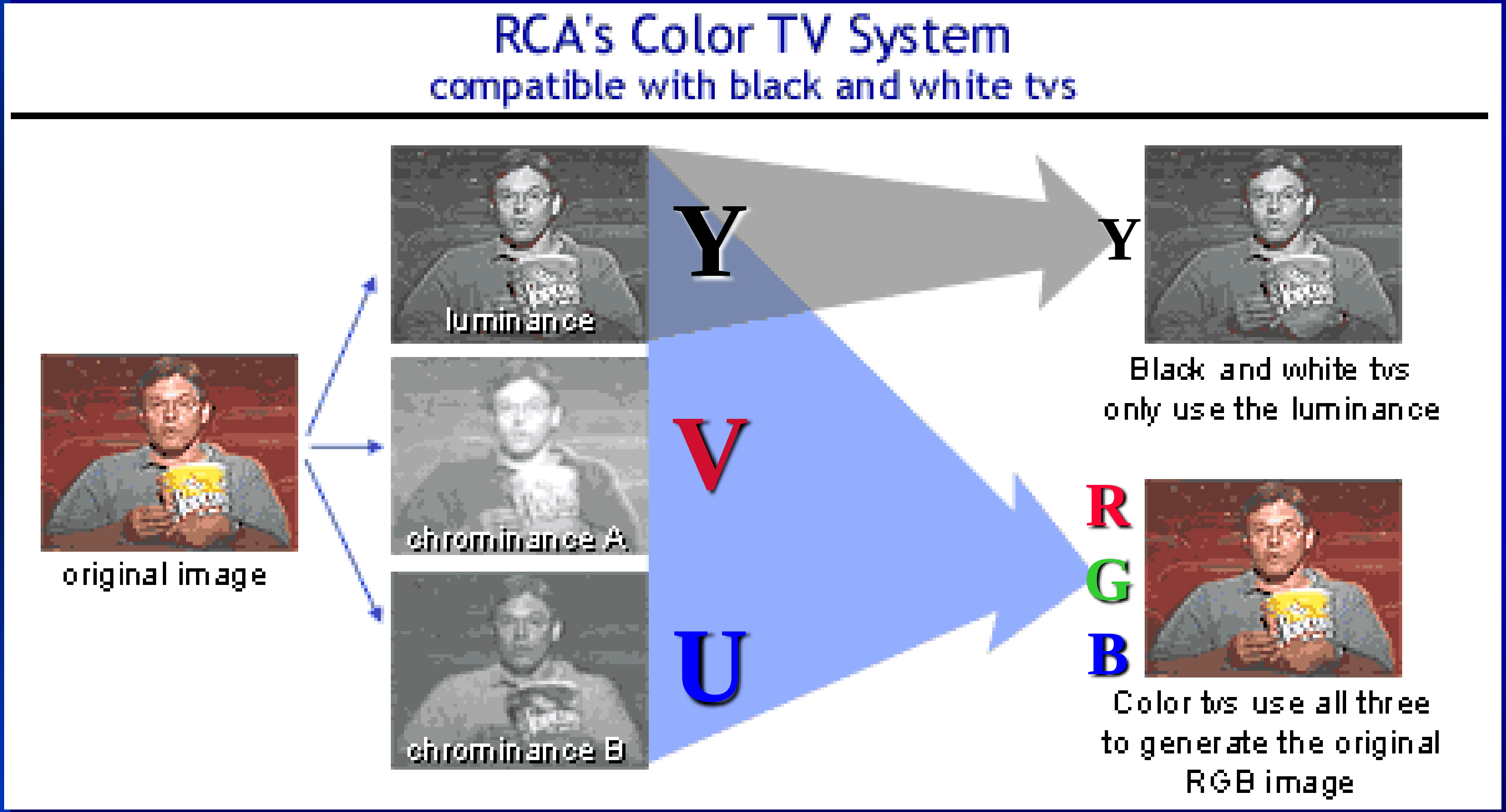
A Compatible Colour System



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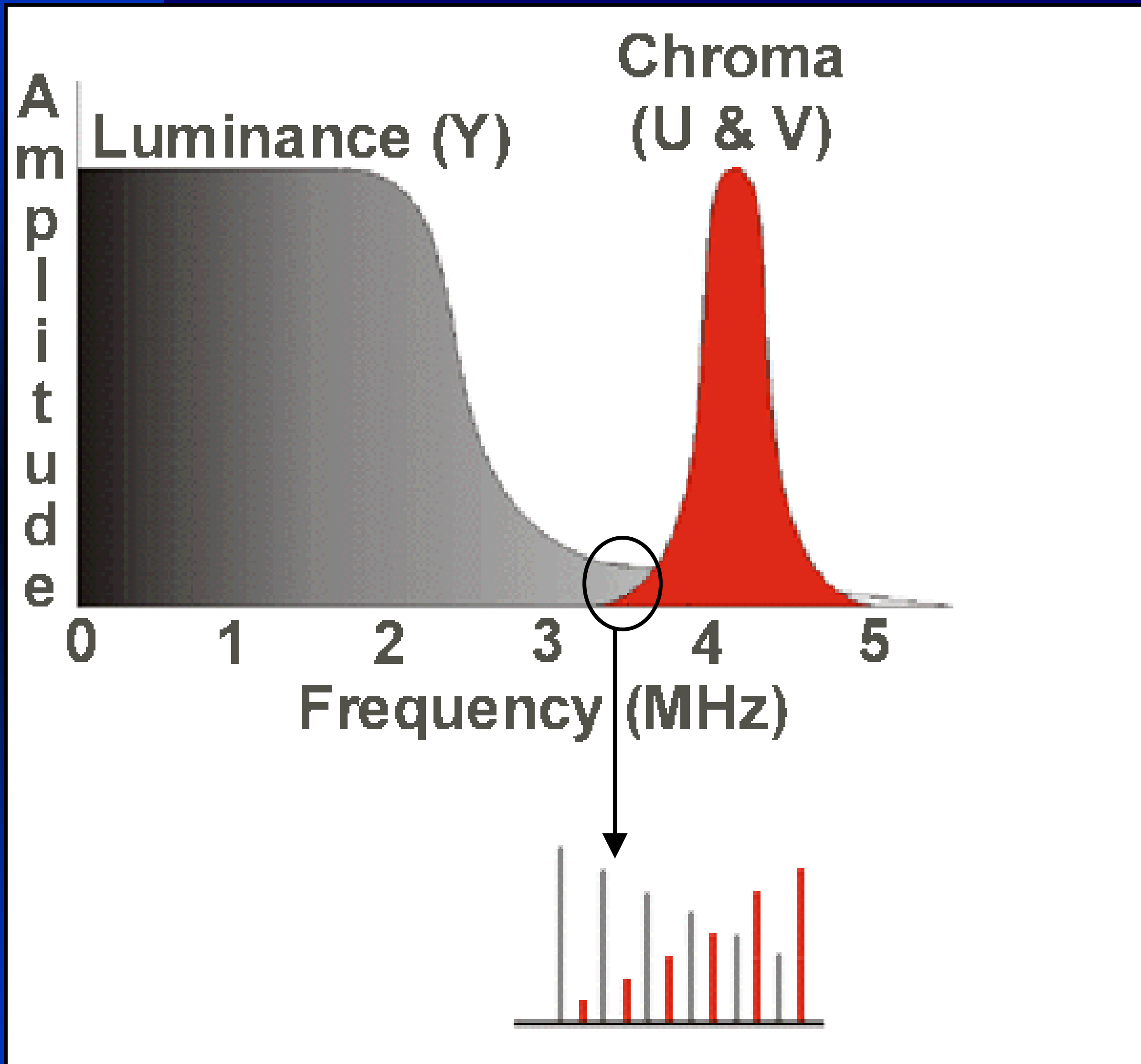
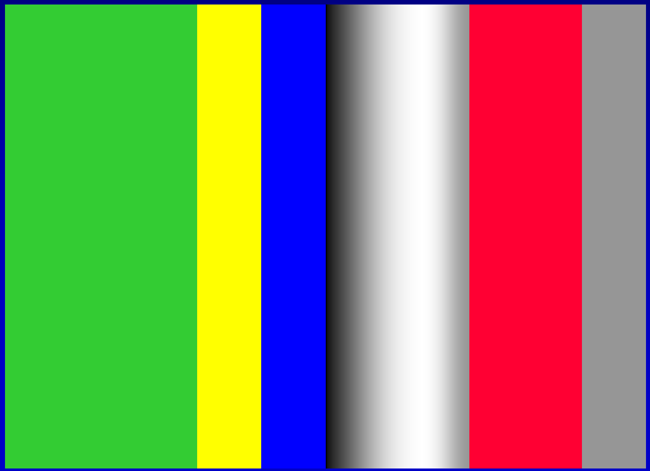
Colour Sub Carrier



- Colour Sub-Carrier is added at 4.43361875 MHz
- Frequency selected to interleave colour information spectra with Luma spectrum
- More efficient use of spectrum.

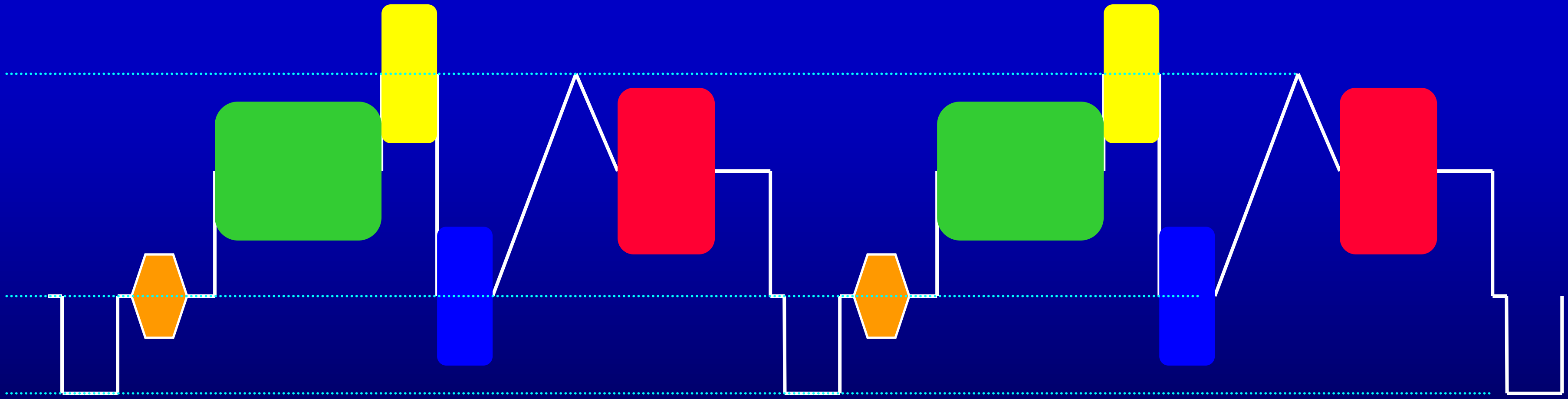
Adding Colour to B&W Video



First TV signals were only Luminance

In 1975 we added PAL Colour System

- **A Colour Reference Burst on Back Porch**
- **And IQ modulated Colour Information**



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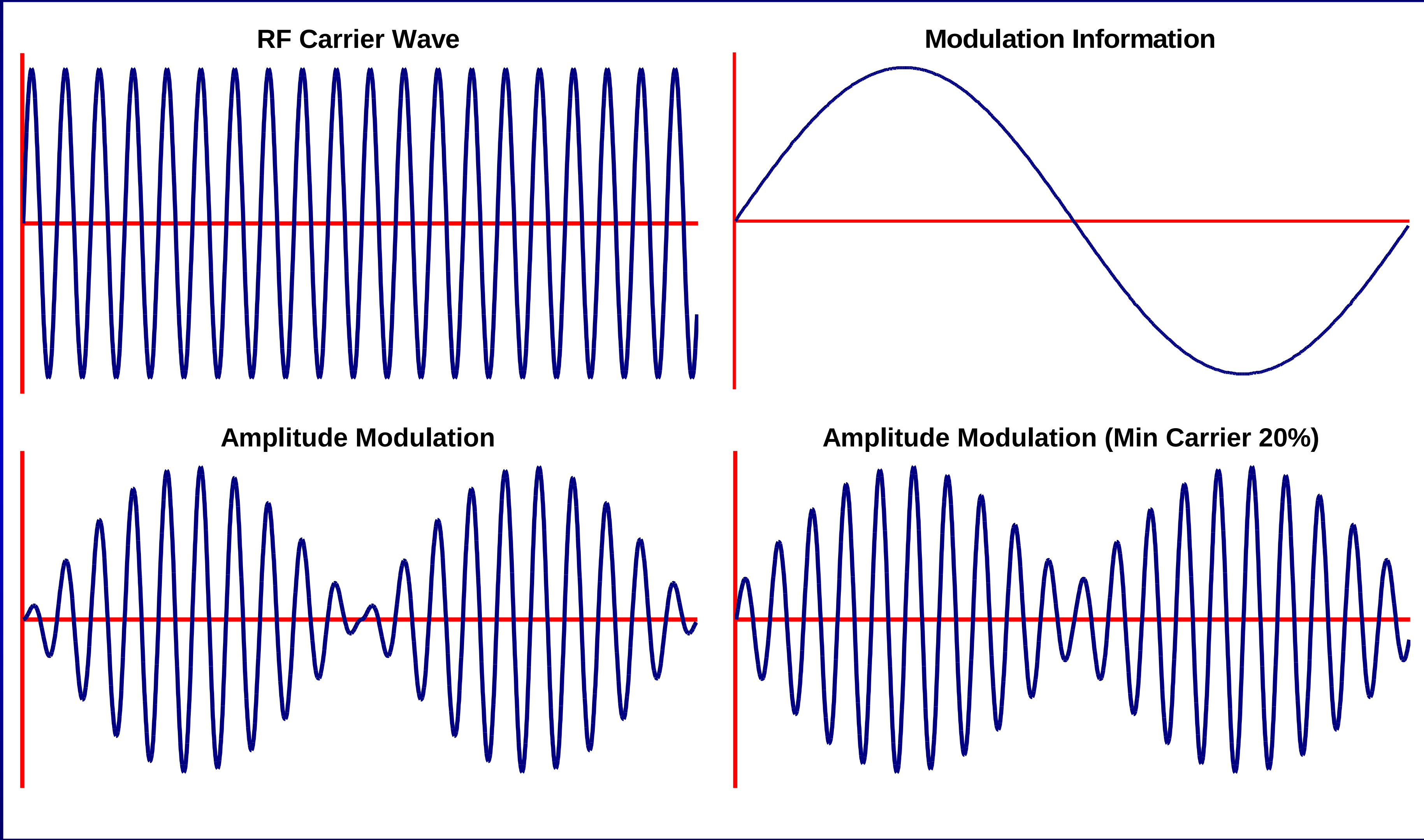
Amplitude Modulation



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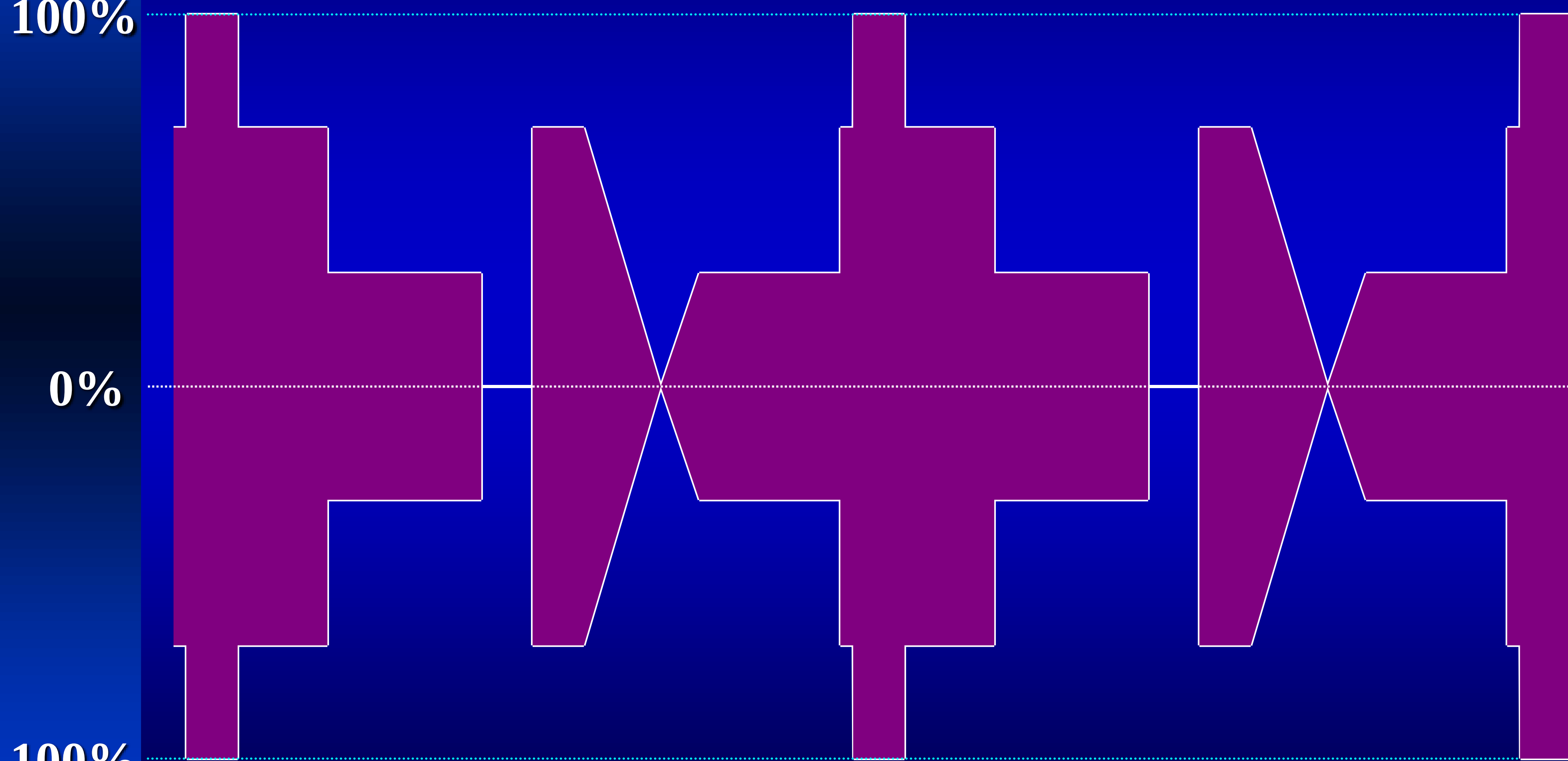
Television Modulation - AM

- TV uses Negative AM Modulation



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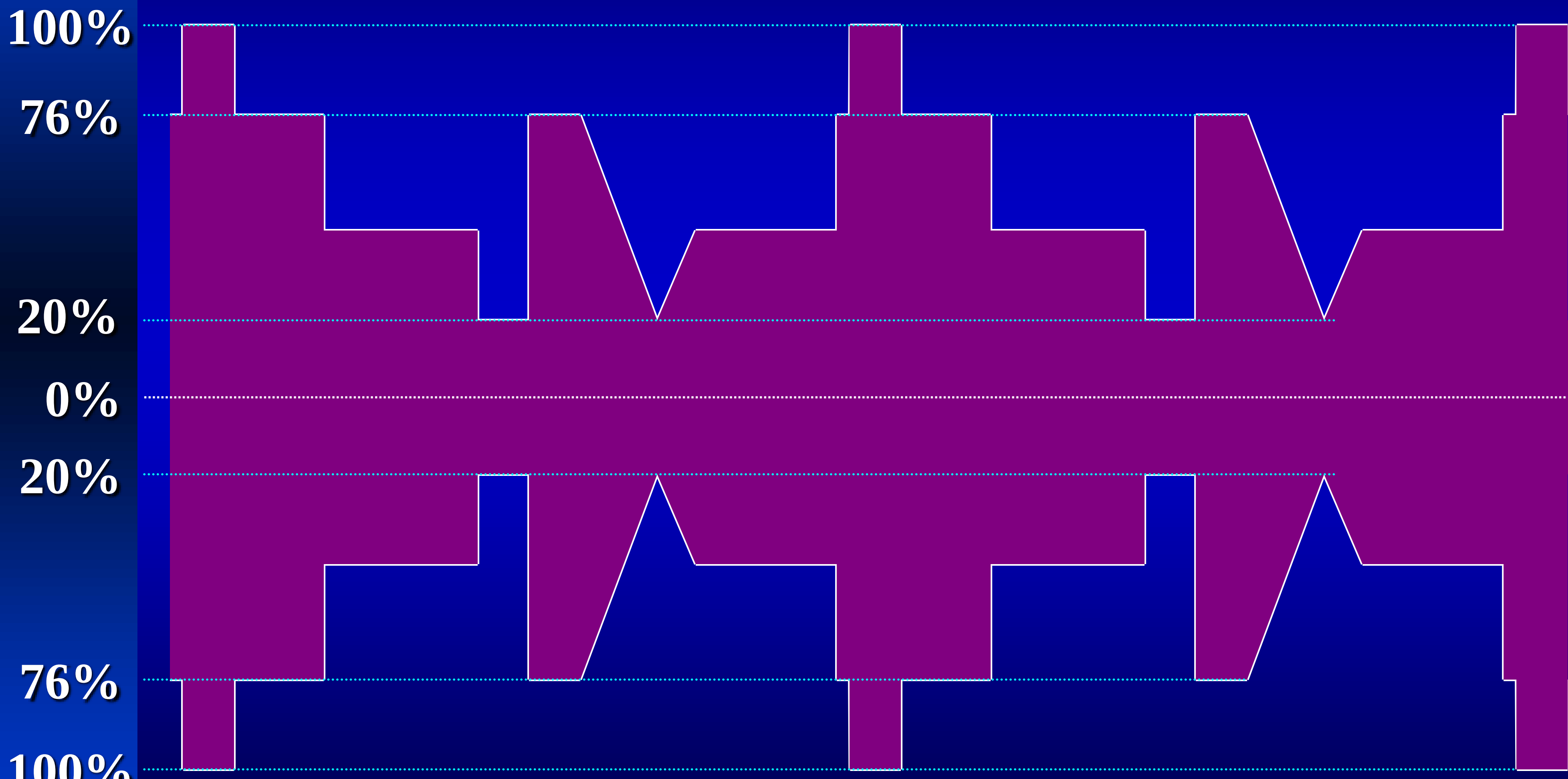
TV Modulation - AM Min 20%

- Peak White 20% Black 76% Syncs 100%



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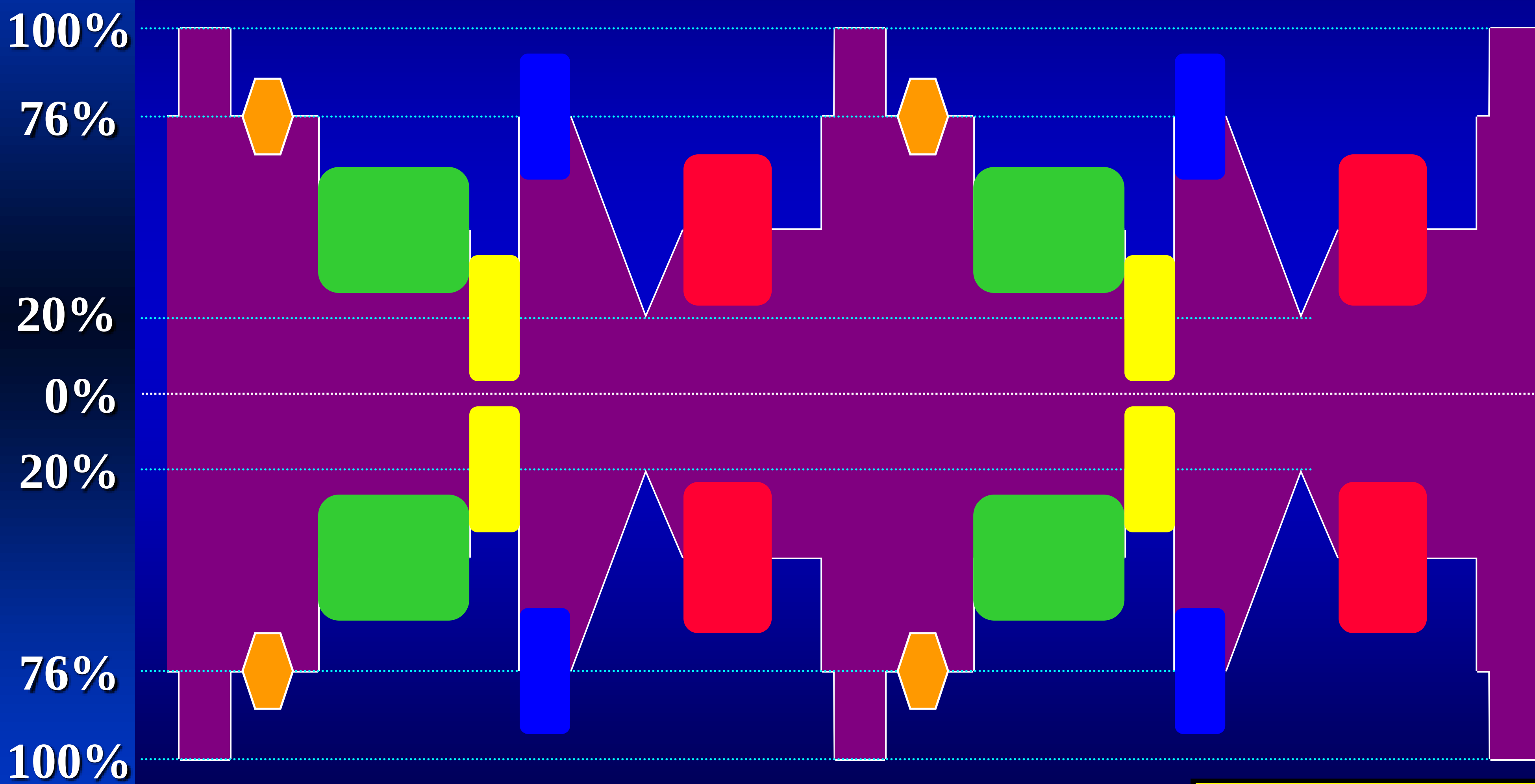
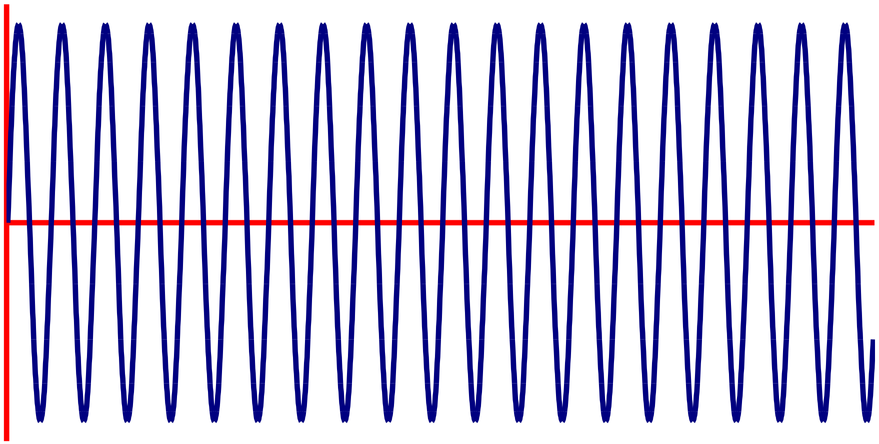
TV Modulation - PAL AM

- Headroom prevents Colour Over/Under Modulating

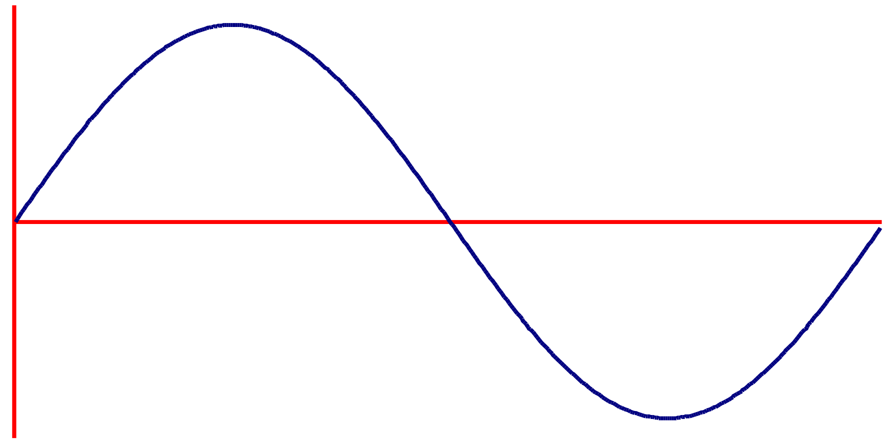


Frequency Modulation

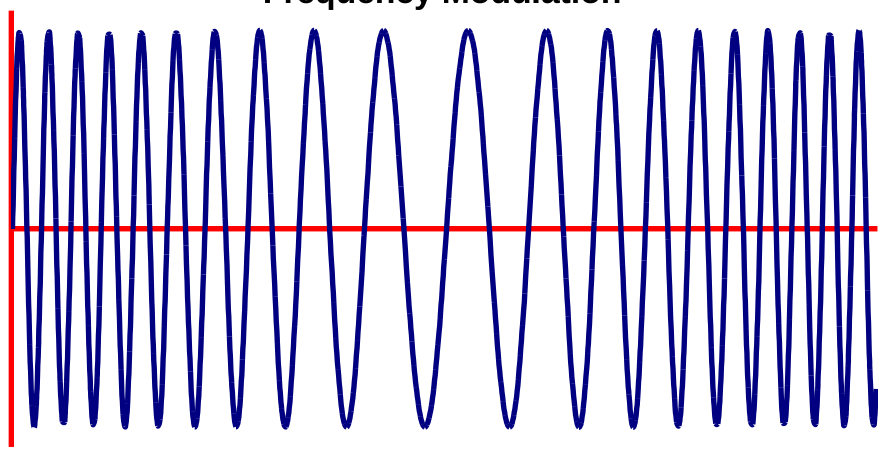
RF Carrier Wave



Modulation Information



Frequency Modulation



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Intercarrier Sound

- A FM subcarrier is added to the AM picture to carry the Audio information
- FM Deviation 50 kHz used with 50 us Emphasis
- PAL-B uses 5.5 MHz Sound subcarrier (L+R)
  - -10 dB wrt Vision for mono single carrier mode
  - -13 dB wrt Vision for Stereo & Dual mode
- 2nd Sound subcarrier for Stereo (R)
  - 5.7421875 MHz (242.1875 kHz above main sound)
  - -20 dB wrt Vision carrier
  - 54.7 kHz Subcarrier Pilot tone added to indicate: Stereo (117.5 Hz) or Dual mode (274.1 Hz)

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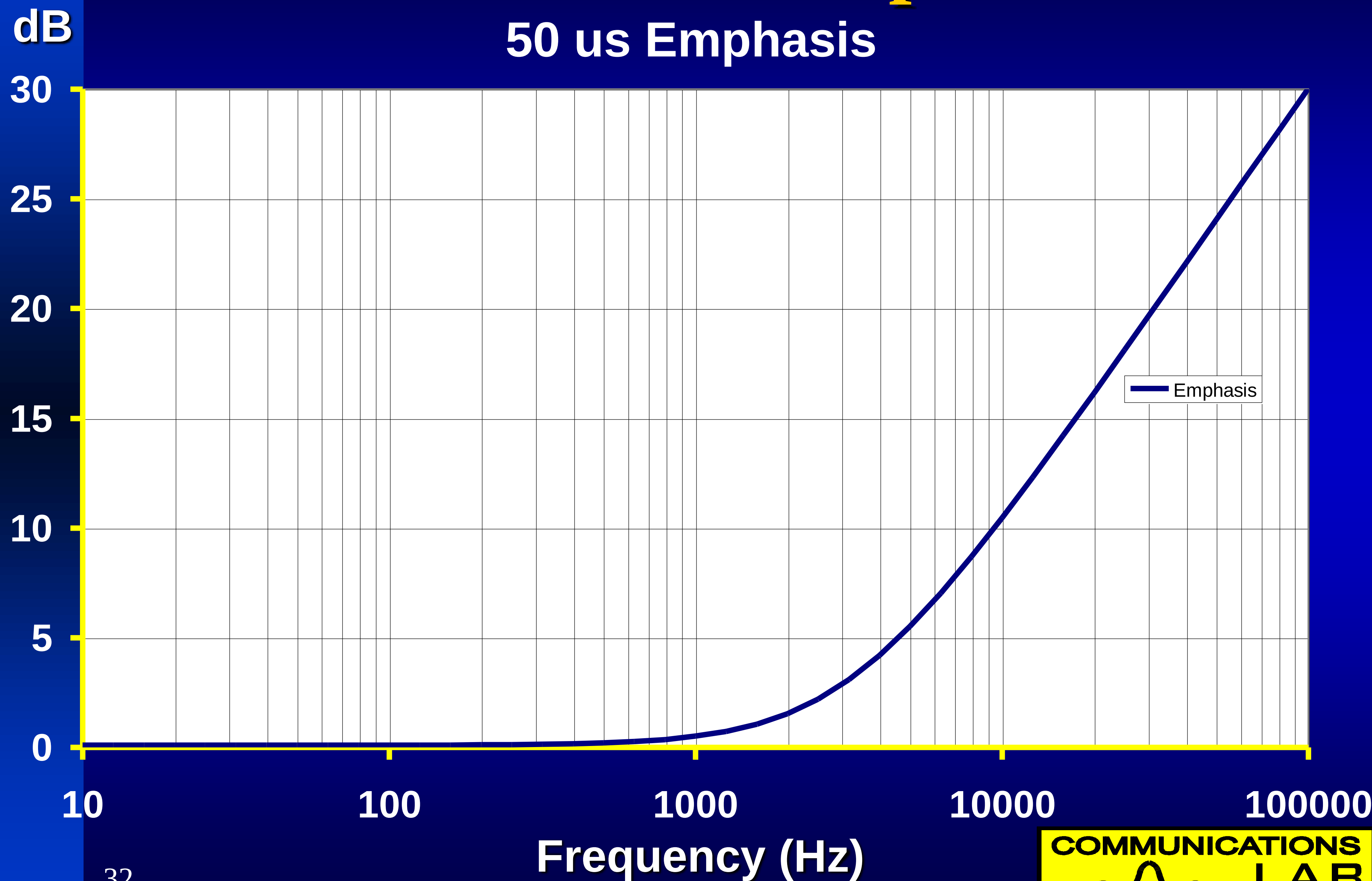
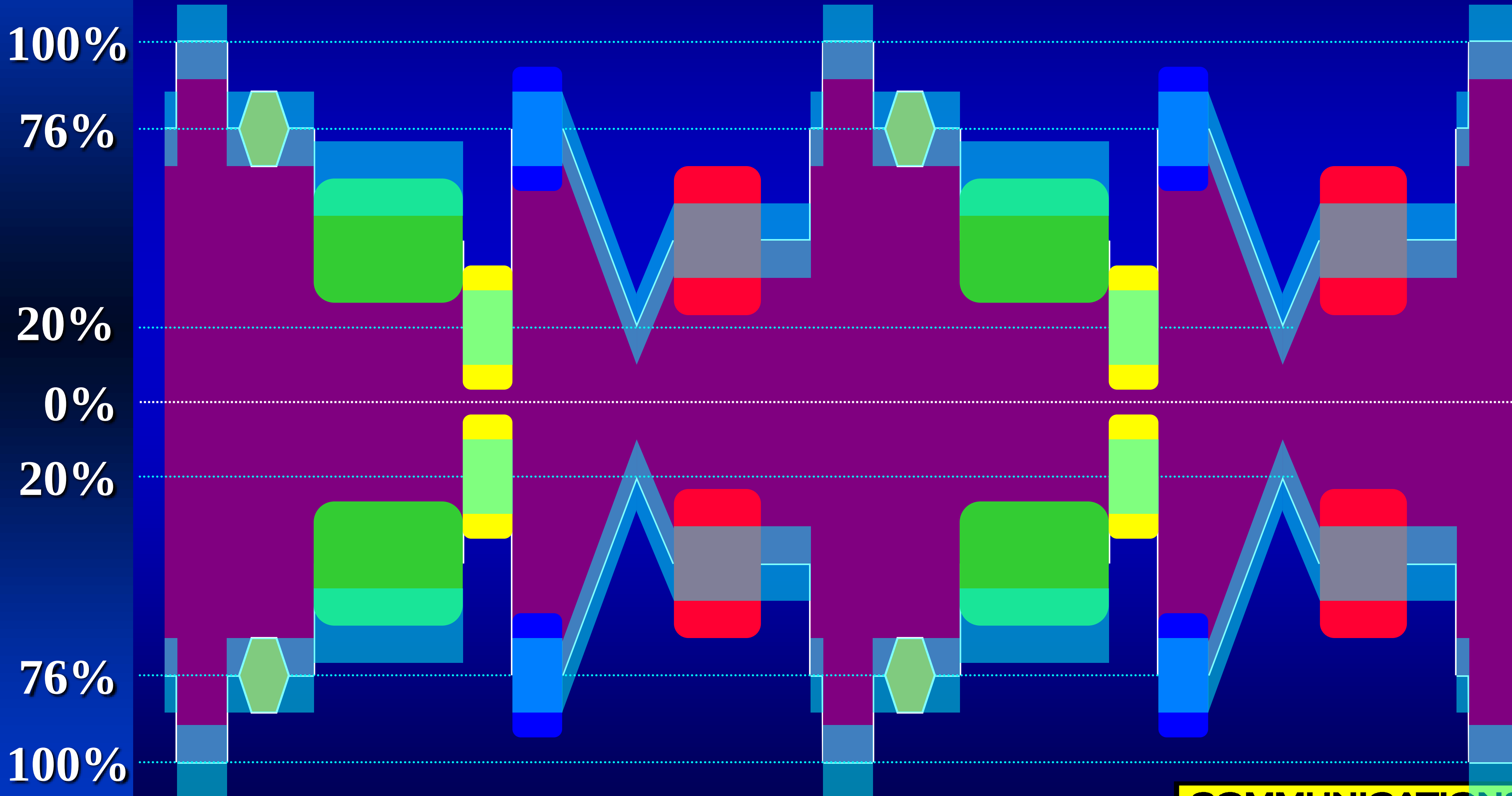
FM Sound Emphasis



TV Modulation - Sound

- FM Sound Subcarriers Superimpose over the AM



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NTSC

- National Television Systems Committee (NTSC)
- First world wide Colour system Adopted (1966)
- Generally used in 60 Hz countries
- Predominantly 525 line TV systems
- AM modulation of Luma & Syncs (4.2 MHz)
- U & V Chroma AM Quadrature Modulated (IQ)
- Chroma Subcarrier 3.579545 MHz
- FM or Digital subcarrier modulation of Sound

SECAM

- Sequentiel Couleur Avec Memoire (SECAM)
- Developed by France before PAL
- 625 Line 50 Hz Colour system
- Uses AM modulation for Luminance & Sync
- Line sequentially sends U & V Chroma components on alternate lines
- Receiver requires a 1H chroma delay line
- Uses FM for Colour subcarrier 4.43361875 MHz
- Uses FM for sound subcarrier

PAL

- Phase Alternation Line-rate (PAL) Colour System
- Developed in Europe after NTSC & SECAM
- Generally associated with 50 Hz Countries
- Predominantly 625 Line system
- AM modulation of Luma & Syncs (5 MHz)
- U & V Chroma AM Quadrature Modulated with V (R-Y) component inverted on alternate lines
- Chroma Subcarrier 4.43361875 MHz
- FM or Digital subcarrier modulation of Sound

Vestigial Side Band - VSB

- AM Modulation gives a Double Side Band signal
  - Each sideband contains identical information
  - 5 MHz of information means required BW > 10 MHz
  - Only one sideband is required for demodulation
- To conserve spectrum Analog TV uses VSB
  - Only 1.25 MHz of the lower sideband is retained
  - VSB truncates the high frequency part of the lower sideband.
- To implement Analog TV with no lower sideband would have been very expensive because of the filtering required.

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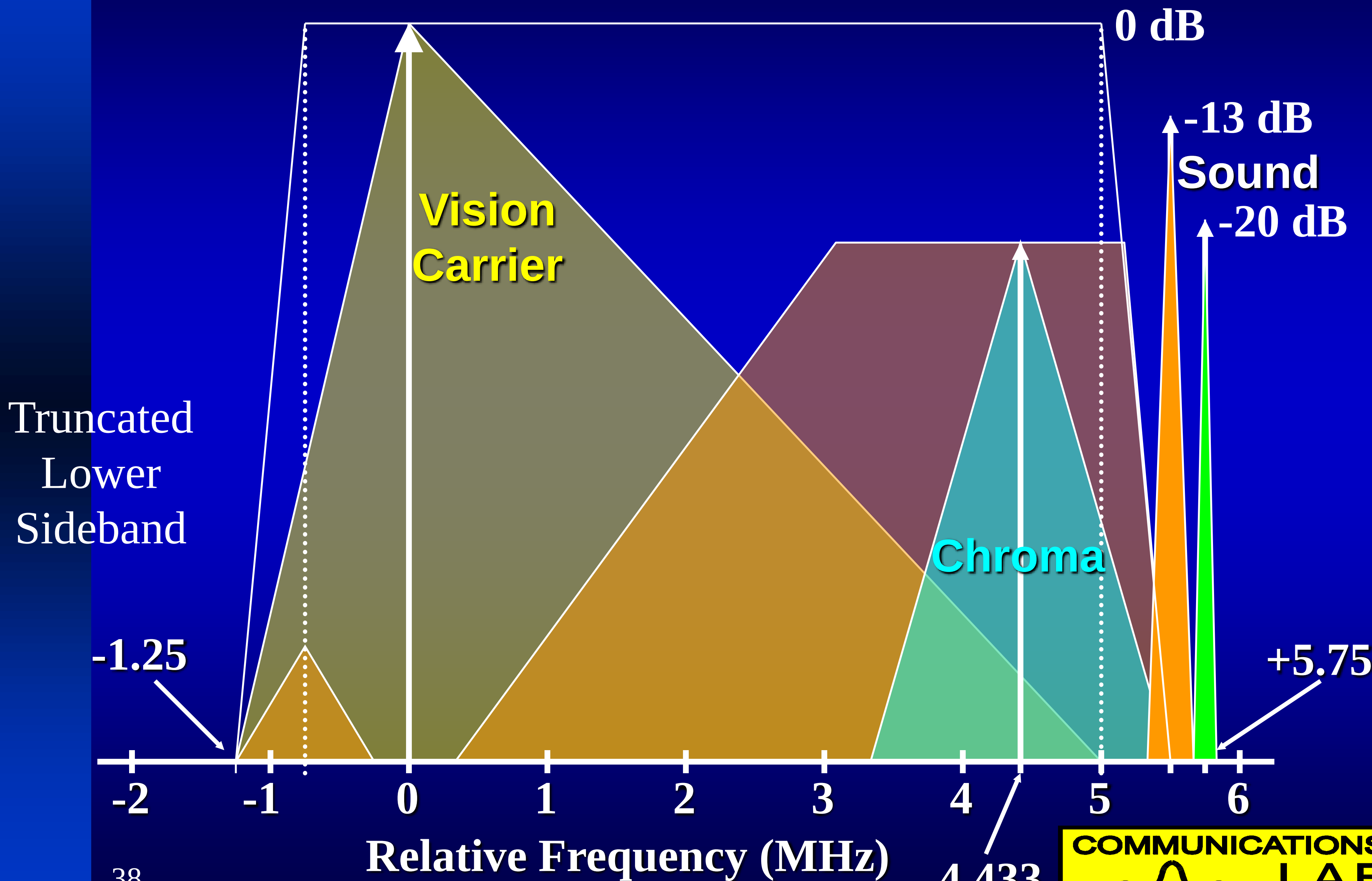
PAL-B Spectrum

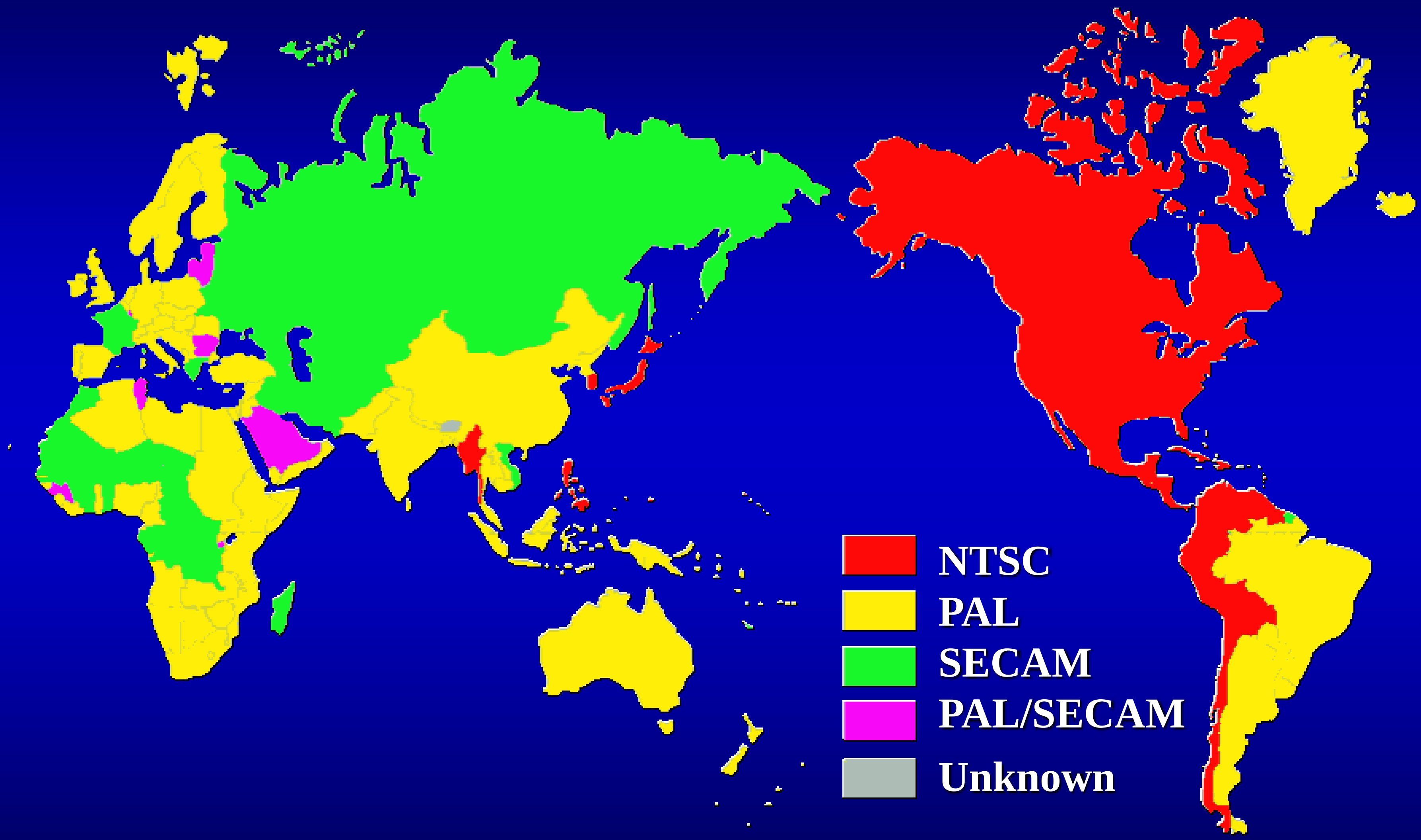


Frequencies Used

- Australia uses 7 MHz Channels

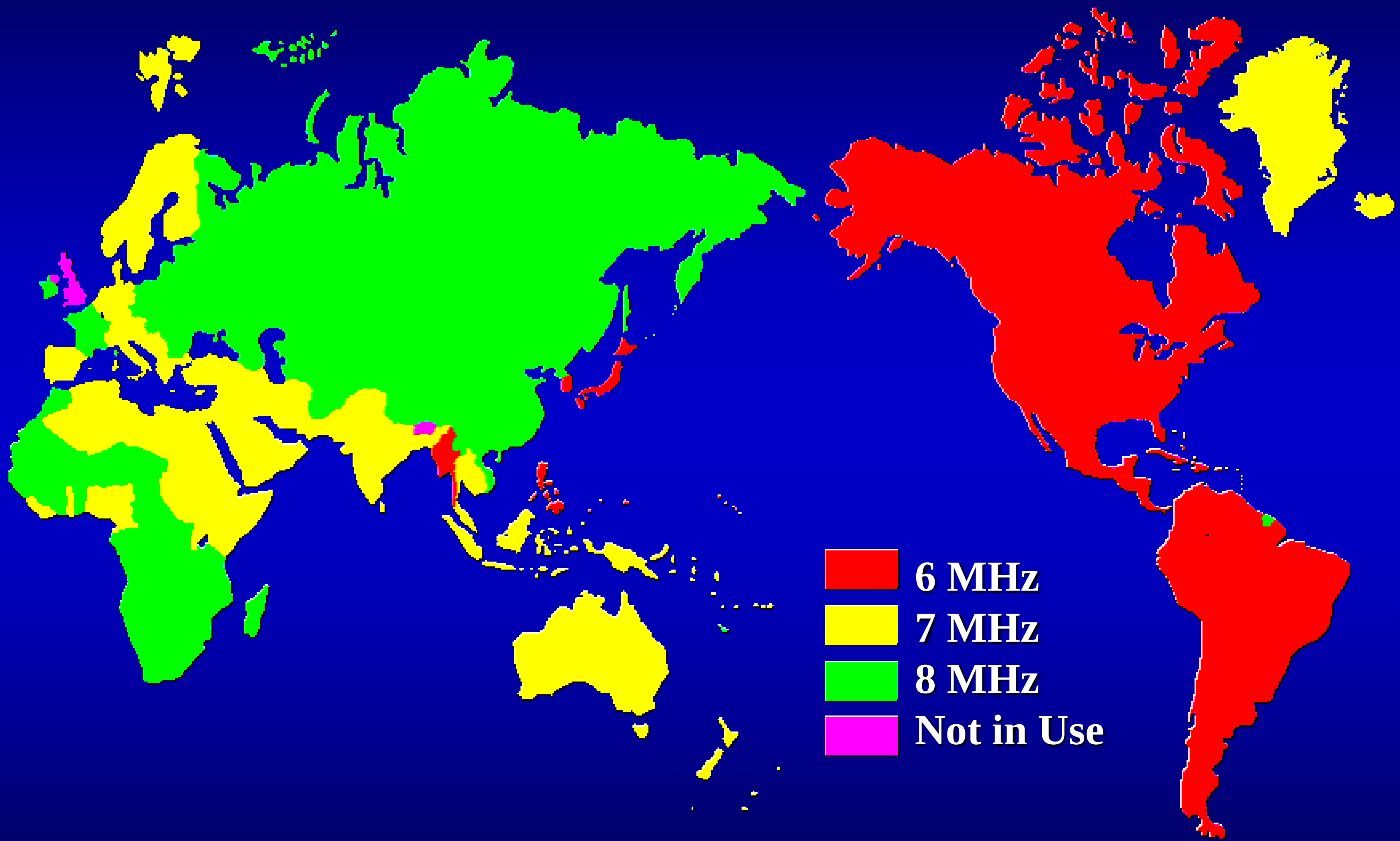
VHF Band I	Ch	0-2	45 - 70 MHz
VHF Band III	Ch	6-12	174 - 230 MHz
UHF Band IV	Ch	27-35	520 - 582 MHz
UHF Band V	Ch	36-69	582 - 820 MHz

World TV Standards



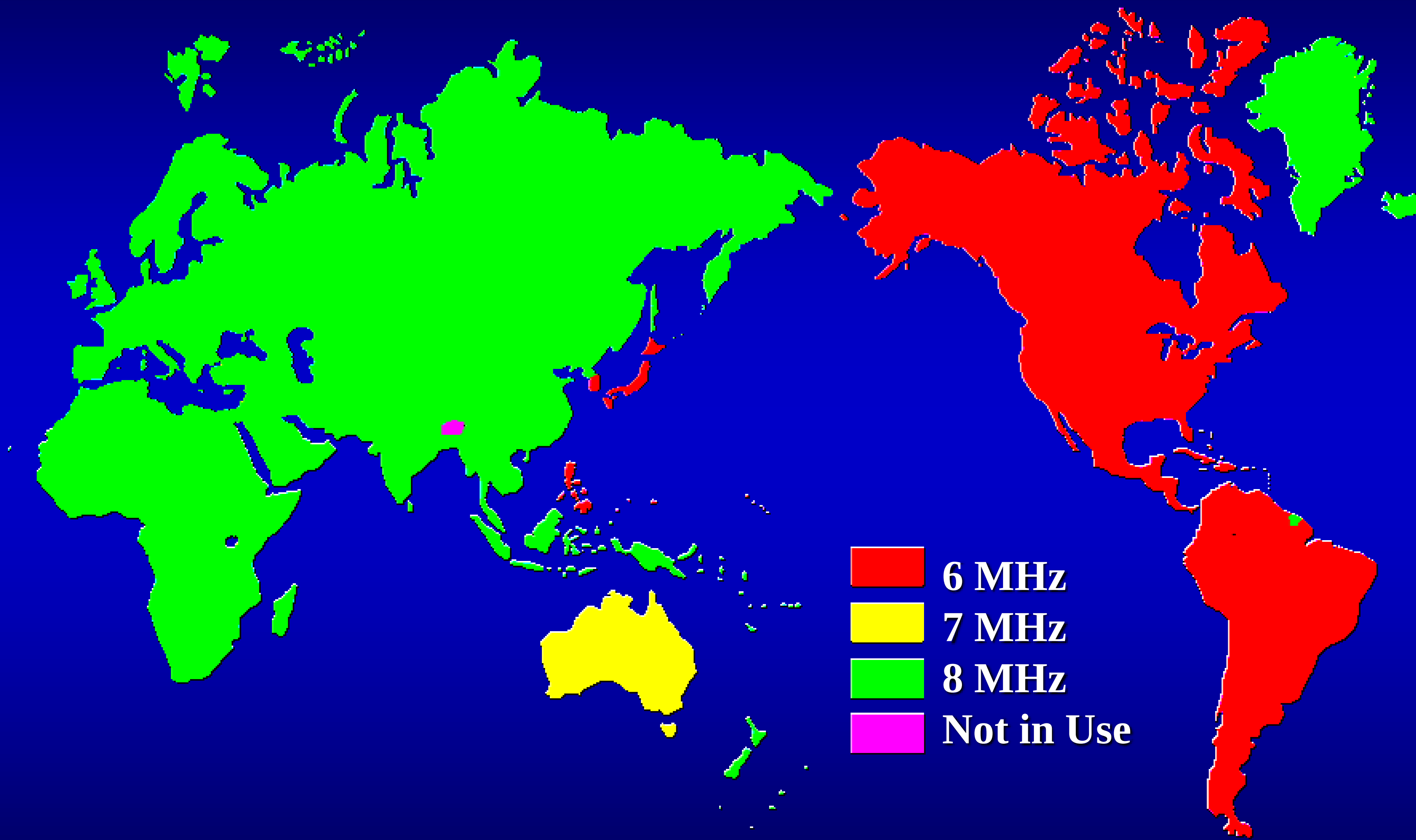
Australia is PAL

Transmission Bandwidth - VHF



Australia is one of a few countries with 7 MHz VHF TV

Transmission Bandwidth - UHF



Australia is Alone using 7 MHz on UHF

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U & V Components

$$Y = 0.299\,R + 0.587\,G + 0.114\,B$$

$$B\text{-}Y = -0.299R - 0.587G + 0.866B$$

$$U' = B\text{-}Y$$

$$R\text{-}Y = 0.701R - 0.587G + 0.114B$$

$$V' = R\text{-}Y$$

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Y, B-Y & R-Y Values

$$B\text{-}Y = -0.299R - 0.587G + 0.866B$$

Condition	R	G	B	Y	B-Y	R-Y
White	1	1	1	1	0	0
Black	0	0	0	0	0	0
Red	1	0	0	0.299	-0.299	0.701
Green	0	1	0	0.587	-0.587	-0.587
Blue	0	0	1	0.114	0.886	-0.114
Yellow	1	1	0	0.886	-0.886	0.114
Cyan	0	1	1	0.701	0.299	-0.701
Magenta	1	0	1	0.413	0.587	0.587

B-Y Range is too large

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Y, B-Y & R-Y Values

$$R-Y = 0.701R - 0.587G + 0.114B$$

Condition	R	G	B	Y	B-Y	R-Y
White	1	1	1	1	0	0
Black	0	0	0	0	0	0
Red	1	0	0	0.299	-0.299	0.701
Green	0	1	0	0.587	-0.587	-0.587
Blue	0	0	1	0.114	0.886	-0.114
Yellow	1	1	0	0.886	-0.886	0.114
Cyan	0	1	1	0.701	0.299	-0.701
Magenta	1	0	1	0.413	0.587	0.587

R-Y Range is too large

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Y, U & V Values

$U = 0.564\,(B-Y) \quad V = 0.713\,(R-Y)$

Condition	R	G	B	Y	U	V
White	1	1	1	1	0	0
Black	0	0	0	0	0	0
Red	1	0	0	0.299	-0.169	0.500
Green	0	1	0	0.587	-0.331	-0.419
Blue	0	0	1	0.114	0.500	-0.081
Yellow	1	1	0	0.886	-0.500	0.081
Cyan	0	1	1	0.701	0.169	-0.500
Magenta	1	0	1	0.413	0.331	0.419

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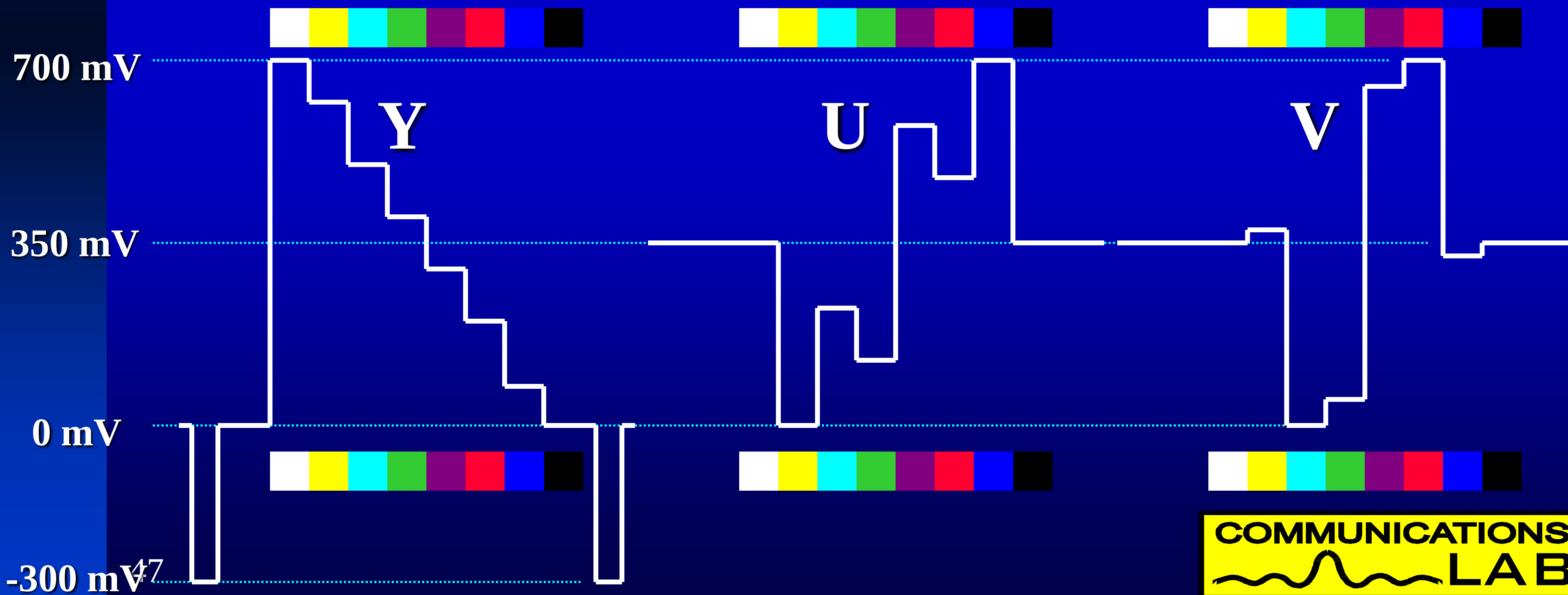
Component Video

- Video distributed as separate Y U V Components
- Y signal is 700 mV for Video Black-White
- Y Signal carries Sync at -300 mV
- U & V signals are 700 mV pk-pk. 350 mV at 0



Coax

- Video Signals are transmitted on Coaxial Cable
- 75 Ohm Coax - RG-59 or RG-178
- Video is usually 1 Volt Peak to Peak
- Terminated with 75 Ohms at end of run
- High impedance loop through taps are used
- To split video must us a Distribution Amplifier
- For Component signals all coax's must be the same length otherwise mistiming of the video components will occur

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Standard Definition Television SDTV

- The current television display system
- 4:3 aspect ratio picture, interlace scan
- Australia/Europe
  - 625 lines - 720 pixels x 576 lines displayed
  - 50 frames/sec   25 pictures/sec
  - 414720 pixels total
- USA/Japan
  - 525 lines - 704 pixels x 480 lines displayed
  - 60 frames/sec   30 pictures/sec
  - 337920 pixels total

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Enhanced Definition Television
EDTV

- Intermediate step to HDTV
- Doubled scan rate - reduce flicker
- Double lines on picture - calculated
- Image processing - ghost cancelling
- Wider aspect ratio - 16:9
- Multi-channel sound

High Definition Television - HDTV

- Not exactly defined - number of systems
- System with a higher picture resolution
- Greater than 1000 lines resolution
- Picture with less artefacts or distortions
- Bigger picture to give a viewing experience
- Wider aspect ratio to use peripheral vision
- Progressive instead of interlaced pictures

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