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Metropolitan Police Video Training

Phil Crawley
@IsItBroke on Twitter

Video Measurement - Principals (4 days)

Course Aim

The aim of the course is to provide grounding in video fundamentals, compression and picture quality analysis for staff who work with video processing, detection and vision systems.

Course Structure

- **Day 1 - TV Fundamentals; *Scanning and Sampling, Colour Systems, Analogue Composite Coding***
- Day 2 - TV Fundamentals; *Digital Component Coding, Conversion of Film to Television, High Definition*
- Day 3 - Compression; *DCT principles, Intra-Frame vs Inter-Frame Encoding, blocks and macroblocks etc.*
- Video Tape Recording; *Magnetic recording principles, rotary recording, Simple VT maintenance.*
- Day 4 - Television Measurements; *Analogue, Digital*
- Picture Quality Analysis; *Analogue picture impairments, digital picture impairments, compression*
- TV Displays; *CRT, LCD and Plasma displays. Problems with LCD and Plasma, Projection systems.*

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Scanning and Sampling

The video signal

- It can be analogue or a digital representation of that analogue signal
- It is ***synchronous*** – the image is scanned line by line many times a second and if the flow of information is interrupted the received picture is distorted – unlike IP
- It is ***scanned*** – the picture is broken down into lines and frames that appear so rapidly as to give the illusion of a complete and moving image
- It is limited – it can't represent the world exactly as your eyes see it
- It is fragile – numerous problems in the way video is sent around facilities and recorded/played-back can cause picture distortions
- It degrades 'gracefully' – even digital video can suffer a lot of distortion and still 'light-up' a monitor – it may suffer a rejection when it comes to delivery though.

The principles apply equally to monochrome, colour and high-definition pictures.

Scanning and Sampling

For the most basic monochrome video the signal has to carry two things:

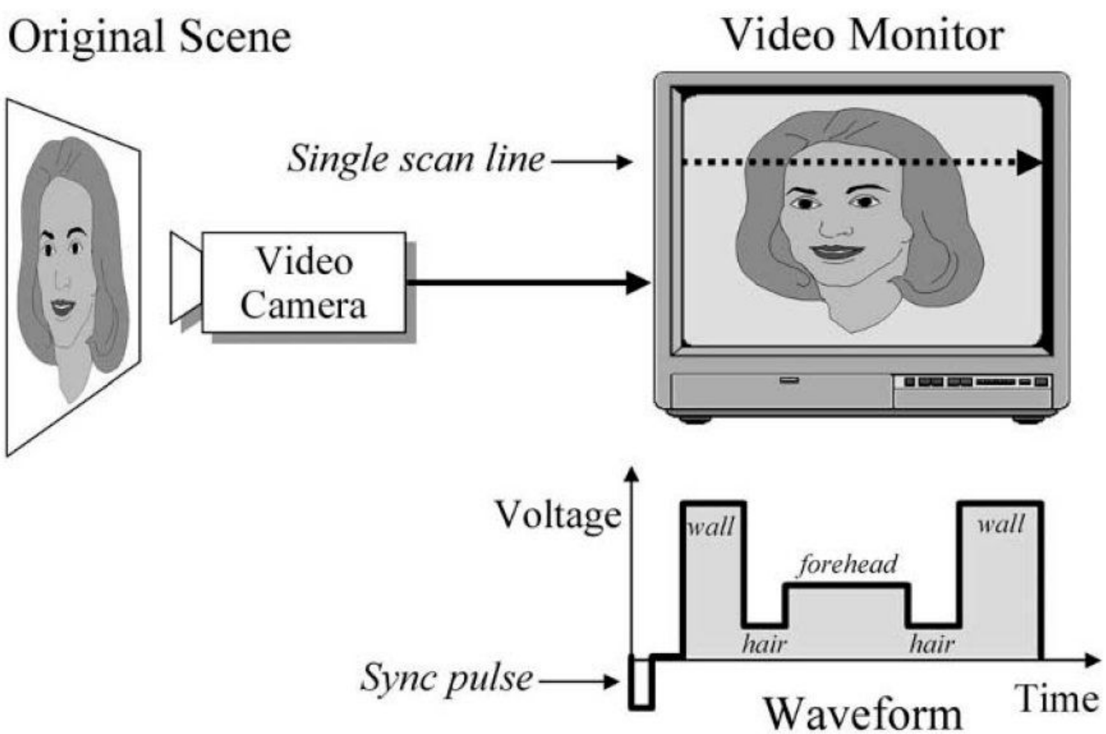
- The black and white brightness information as perceived by the *rods* in the back of your eye – often referred to as the ***luminance***
- Synchronising information – akin to the sprocket holes in film and referred to as ***syncs*** – It's how the picture monitor can lock so that the picture remains stable.

By common agreement video travels down a coaxial cable and is a 1v signal. 0.7v of the signal is devoted to the picture content (from black to peak white) with the lower 0.3v devoted to the sync pulses. Because of this widespread agreement the engineer in the OB truck can be sure that the bit of the signal he's adjusting to look like black will be the same level when it arrives at the transmitter, for example.

Should some problem or misalignment occur in the signal chain any increase or decrease in the signal level will show itself as pictures that are too bright or dark when viewed on a monitor.

Life was very simple in monochrome days!

Scanning and Sampling



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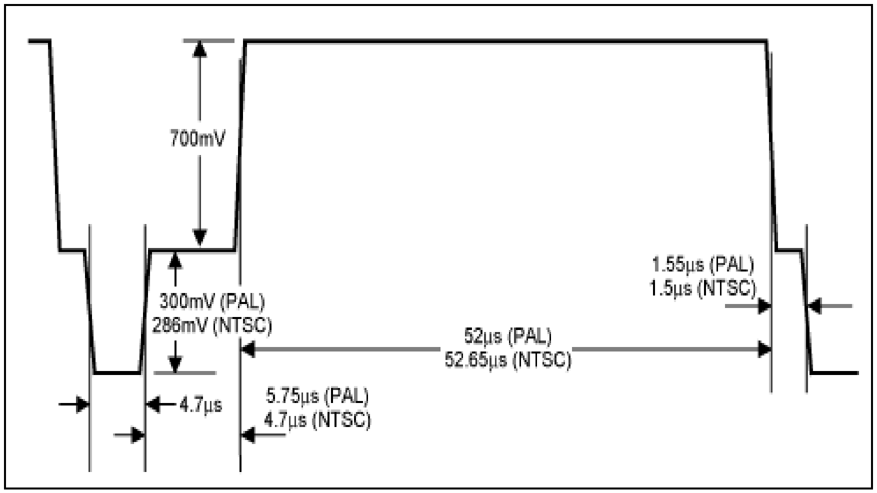
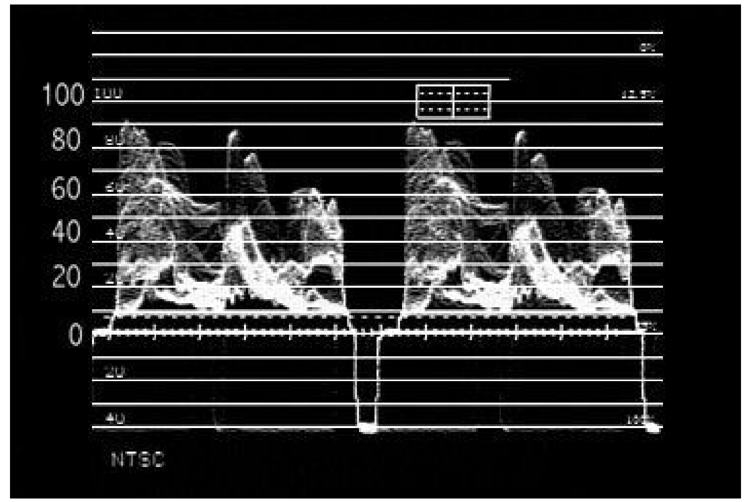
Scanning and Sampling





Notice:

- This is a single line of the television signal – there are 625 in every frame of video
- Only 576 lines are displayed – the remainder make up the vertical interval – used for synchronising and other things
- Please note the signal levels – 0.7v for the picture part, 0.3v for the sync-pulses

Scanning and Sampling

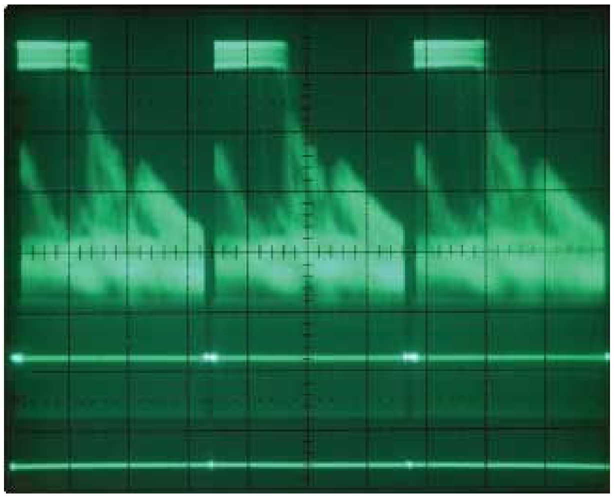
- At the end of each line, there is a portion of the waveform (horizontal blanking interval) that tells the scanning circuit in the display to retrace to the left edge of the display and then start scanning the next line.

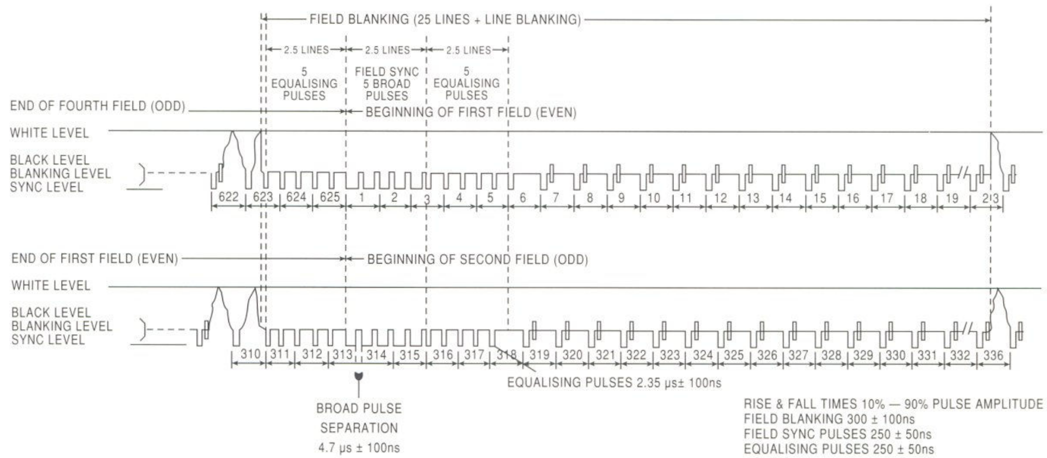
- Starting at the top, all of the lines on the display are scanned in this way. One complete set of lines makes a picture. This is called a frame. Once the first complete picture is scanned, there is another portion of the waveform (vertical blanking interval, not shown) that tells the scanning circuit to retrace to the top of the display and start scanning the next frame, or picture.

- This sequence is repeated at a fast enough rate so that the displayed images are perceived to have continuous motion.

- This is the same principle as that behind the "flip books" that you rapidly flip through to see a moving picture or cartoons that are drawn and rapidly displayed one picture at a time.

Scanning and Sampling





Field-rate waveforms are used to reveal problems and effects that occur at the rate of picture update – 50 **fields** per second in PAL systems.

Scanning and Sampling

Video frames, fields and interlaced vs. progressive pictures

- These are two different types of scanning systems. They differ in the technique used to "paint" the picture on the screen.

- Television signals and compatible displays are typically interlaced, and computer signals and compatible displays are typically progressive (non-interlaced).

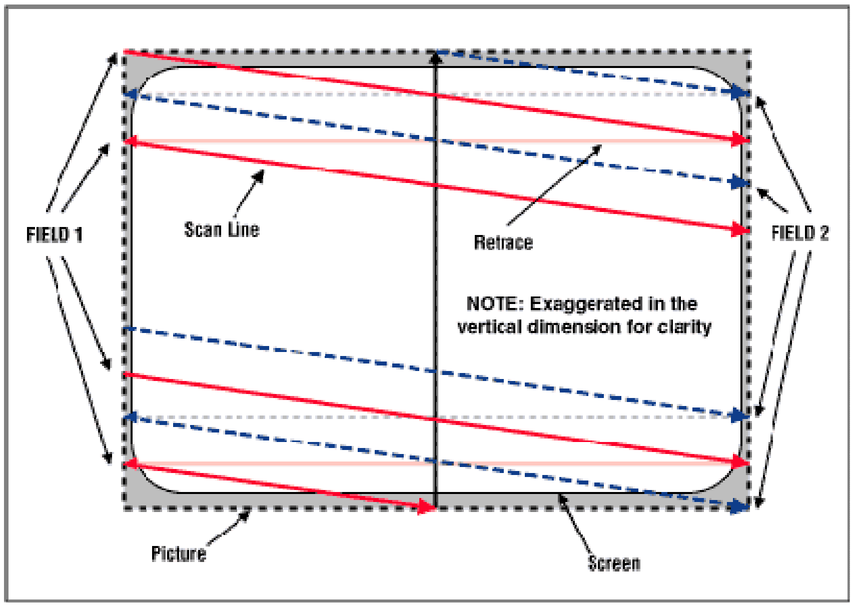
- Interlaced scanning is where each picture, referred to as a frame, is divided into two separate sub-pictures, referred to as **fields**. Two fields make up a frame.

- An interlaced picture is painted on the screen in two passes, by first scanning the horizontal lines of the first field and then retracing to the top of the screen and then scanning the horizontal lines for the second field.

http://en.wikipedia.org/wiki/Video_field

Scanning and Sampling

Video frames, fields and interlaced vs. progressive pictures



- Interlacing allows much better motion rendition at the (modest) expense of loosing vertical resolution around moving objects.
- Ideal system for CRT-based displays, problematic for solid-state (LCD, Plasma etc) display systems
- Interlaced video doesn't fare well with modern delivery systems (compressed digital video) and so although initial HD formats are interlaced (1080i video) it will fall by the wayside s we move to 1080p video.

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http://en.wikipedia.org/wiki/Interlaced

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Typical Frequencies for Common TV and Computer Video Formats

Video Format	NTSC	PAL	HDTV/SDTV	VGA	XGA
Description	**Television Format for North America and Japan**	**Television Format for Most of Europe and South America**	**High Definition/ Standard Definition Digital Television Format**	**Video Graphics Array (PC)**	**Extended Graphics Array (PC)**
Vertical Resolution Format (visible lines per frame)	Approx 480 (525 total lines)	Approx 575 (625 total lines)	1080 or 720 or 480; 18 different formats	480	768
Horizontal Resolution Format (visible pixels per line)	Determined by bandwidth, ranges from 320 to 650	Determined by bandwidth, ranges from 320 to 720	1920 or 704 or 640; 18 different formats	640	1024
Horizontal Rate (kHz)	15.734	15.625	33.75-45	31.5	60
Vertical Frame Rate (Hz)	29.97	25	30-60	60-80	60-80
Highest Frequency (MHz)	4.2	5.5	25	15.3	40.7

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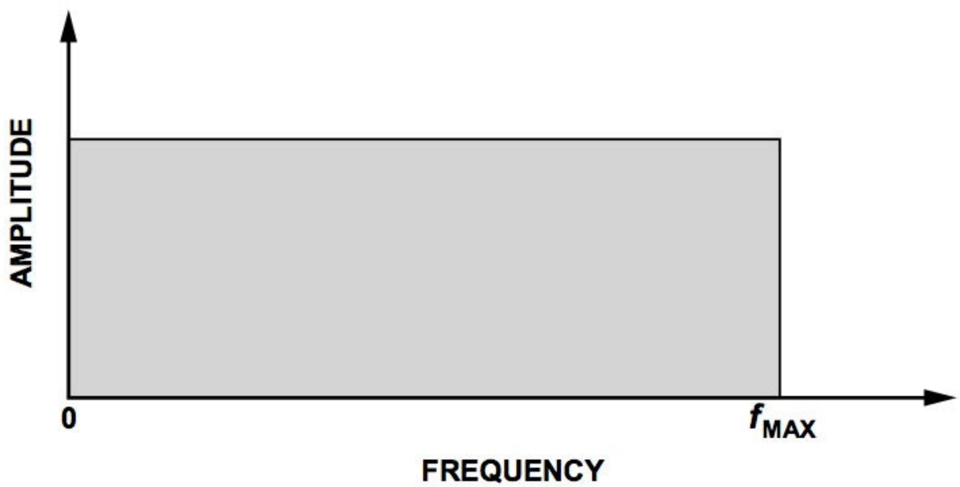
Scanning and Sampling

Signal bandwidth requirements for analogue video

Since the content of an image varies significantly in terms of bandwidth, the spectrum of a video signal can be compared to the spectrum of Gaussian noise, which is flat between dc and infinity. Because the bandwidth of the video signal is limited, the highest frequency component from its spectrum, f_{MAX}, is determined by the system's capability to capture the smallest details of the image.



Scanning and Sampling

Signal bandwidth requirements for analogue video

- The number of lines and the resolution of each line dictate how 'high' the resolution of the signal is.
- The "Kell Factor" is used to determine the required line bandwidth for a given number of TV lines
- The horizontal resolution that is required to match the vertical resolution attained by a given number of 625 scan lines means the required horizontal resolution must be 4/3 times the effective vertical resolution, or $(4/3)\times0.7\times576 = 537.6$ lines of resolution. Taken further, since 537.6 lines is equal to 268.8 cycles, and given 576i50 has an active line period of 52μs, its luminance signal requires a bandwidth of $268.8/52 = 5.17$ MHz.
- For 625-line SD video we assume an analogue bandwidth of 5.5Mhz

http://en.wikipedia.org/wiki/Kell_factor

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What is considered Hi-Def has changed over the years!

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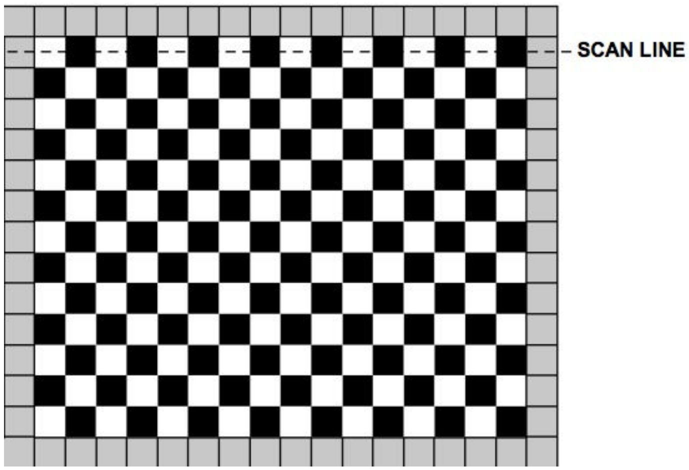
Scanning and Sampling

Other considerations – bandwidth problems and DC coupling

- The component with the highest frequency from the video signal's spectrum dictates the bandwidth of the signal. This corresponds to the smallest picture detail that can be reproduced – we've seen this is 5.5Mhz
- It is important to determine the minimum video frequency that needs to be passed by the system unattenuated. While the maximum video frequency represents the smallest detail that can be reproduced, the minimum video frequency is determined by the largest image detail. A completely white frame would be close to DC (i.e. very low frequency)



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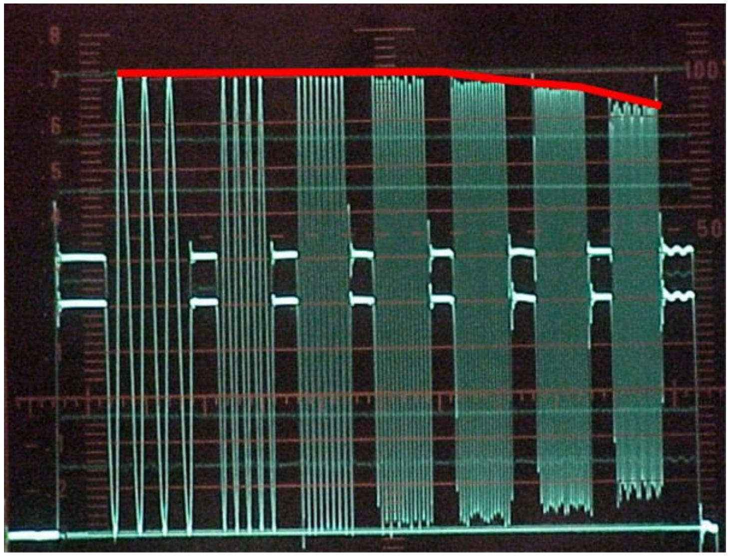
Scanning and Sampling



- If a signal has less than the required bandwidth then fine detail starts to be lost.
- The red line shows how the frequency response 'rolls off'
- This kind of 'sweep' signal is commonly used by engineers to correct equalisation is video circuits.

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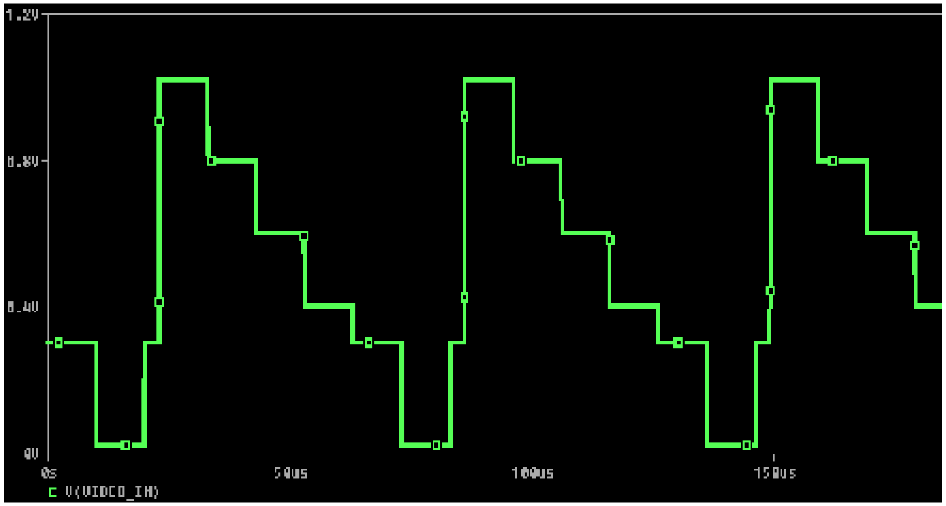

- There are two parts of our analogue video signal that depend on the DC part of the signal being faithfully carried
- The synchronising pulses have a lot of DC about them
- Big areas of white (or grey, or black) are very DC'ish
- If the video signal is not 'clamped' so that the bottom of the sync pulses is held at 0v then the video level may be mis-interpreted and the monitor (or other equipment) may not be able to 'lock'.

Because of the way video distribution amplifiers work and long cable runs a video signal often acquires a biasing voltage which requires the receiving piece of equipment to re-clamp the signal using the *coupling* switch. The clamp may work to black level or sync-tips; Sometimes called 'DC Restore'.

Scanning and Sampling

Frames, lines, and pixels – digital video.

- Real life is analogue and continuous
- We've already chopped up real life into TV frames (fields as well) and lines
- For digital TV we have to go further and chop each TV line into pixels

Video Format	NTSC	PAL	HDTV/SDTV	VGA	XGA
Description	**Television Format for North America and Japan**	**Television Format for Most of Europe and South America**	**High Definition/ Standard Definition Digital Television Format**	**Video Graphics Array (PC)**	**Extended Graphics Array (PC)**
Vertical Resolution Format (visible lines per frame)	480	576	1080 or 720 or 480; 18 different formats	480	768
Horizontal Resolution Format (visible pixels per line)	704 / 720	704 / 720	1920 or 704 or 640; 18 different formats	640	1024

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Colour Systems

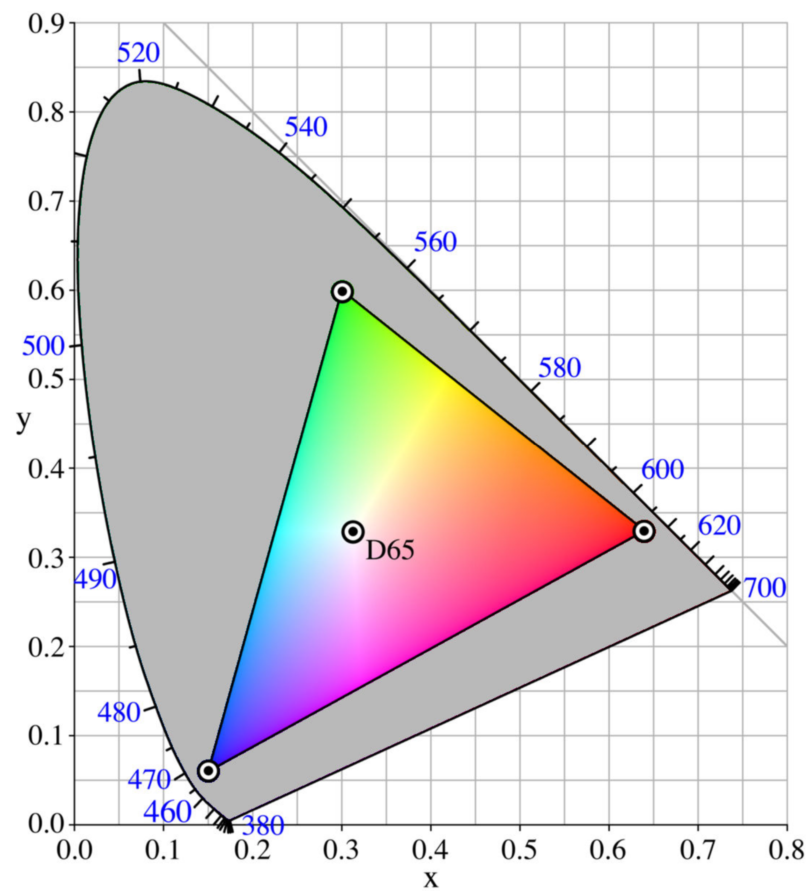
Perception

- Human vision is a 'tri-stimulus' system
- We perceive red, green and blue colour via our eye's 'cones'
- We perceive overall light level via our eye's 'rods'

The range of visible wavelengths (380 – 700nm) runs from ultra-violet through to infra-red. The much-smaller range of colours that a TV camera can capture are shown.

The range of display'able colours is referred to as the 'gamut' of the system.

D65 is the 'colour of white' that we use for TV.



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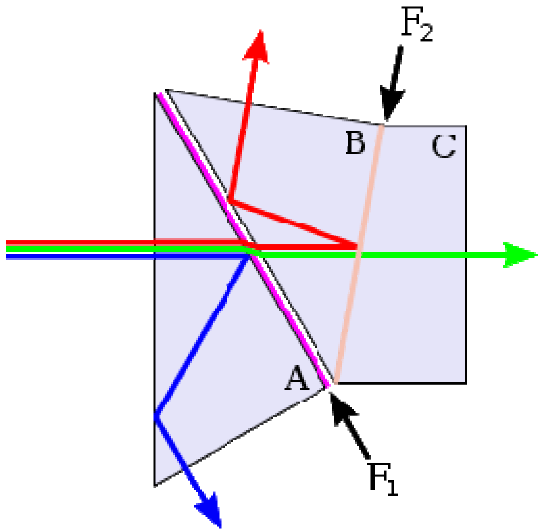
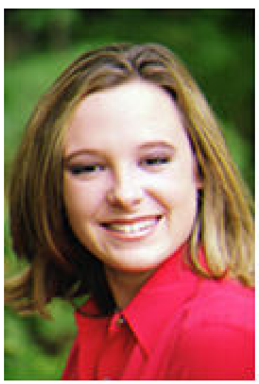
Colour Systems

Image acquisition

- All devices that make pictures (TV camera, Telecine machine, computer graphics workstation etc) make pictures as three monochrome images; Red, Green, and Blue.
- This mimics the way the eye works, 'tristimulus'
- In the case of a TV camera this is achieved with a specially designed glass component referred to as a 'dichroic block'





Original image.

Image when separated into RGB components.

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Colour Systems

Generation of colour component signals

- Although all image-generating equipment does so internally is the R, G, B colour space it has been normal (until very recently) for colour pictures to be carried in the lighter-weight component standard.
- The three R, G, & B signals each have a bandwidth of 5.5Mhz (in an SD camera)
- Component video comprises a full-bandwidth luminance signal AKA the 'Y-component'
- The colour portion of the image is 'painted in' with two half-bandwidth chrominance signals
- In component video the luminance signal is still 5.5Mhz, but the two colour-difference signals are only 2.75Mhz of bandwidth (half the resolution of the luminance)

The colour difference signals are commonly referred to as U & V or (depending on the application) Pb & Pr or Cb & Cr. If they are being carried on analogue cables then three pieces of coaxial cable are required.

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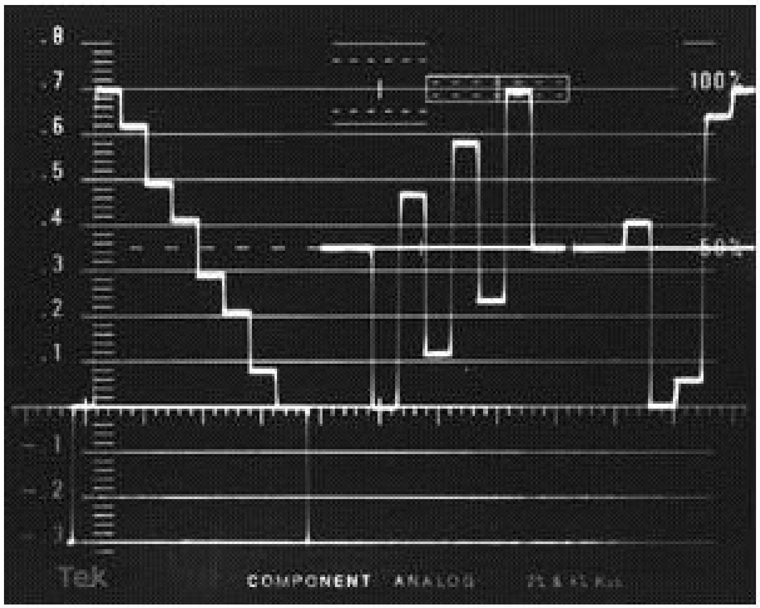
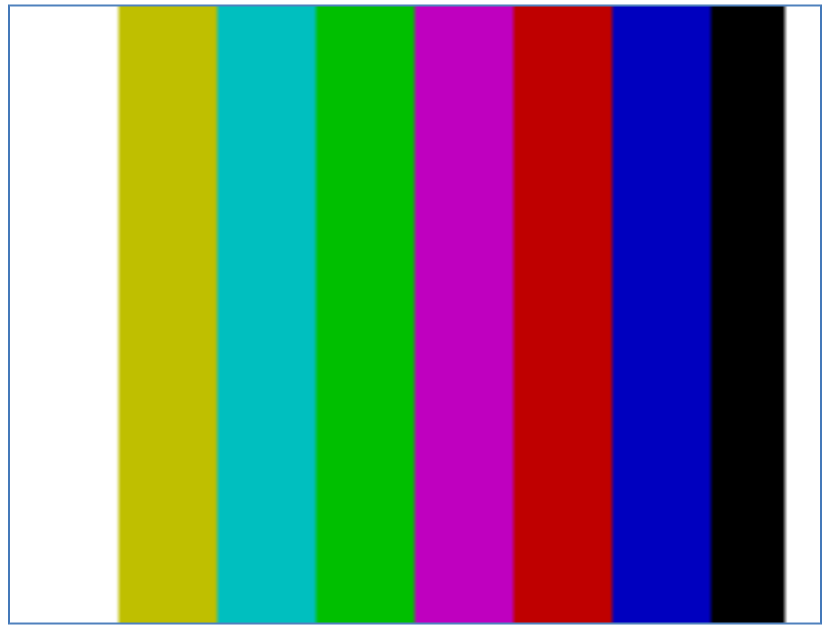
Colour Systems

Generation of colour component signals





Count the number of bars (white through black) and match them to the colour bars on the monitor.

Colour Systems

Generation of colour component signals

$$Y = 0.299R + 0.587G + 0.114B$$
$$Cb = 0.564(B-Y) + 350mV$$
$$Cr = 0.713(R-Y) + 350mV$$

These equations define how we go from RGB to Y, Cr, Cb (and the reverse would be true).

Visually it is hard to tell the difference between RGB and component, but the advantage is that R,G,B requires 3 x 5.5Mhz of bandwidth against component's 5.5 + 2x 2.75Mhz which means VTRs need only record 2/3s as much signal.

The disadvantage is that certain video effects don't work so well due to less colour resolution (chroma key etc).

Like old-school monochrome video all of these signals have 0.7v of range for the picture part and 0.3v of range for the sync-pulses.

In RGB the green signal may carry the syncs, in component the Y-signal has the syncs.

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Composite video overview

Back in the 1950s engineers knew they couldn't even record component video on VTRs or transmit it over the air. Consequently they needed a system that was compatible the existing monochrome video. The transition to all-colour TV took twenty years.

- New colour TVs had to be able to display the existing monochrome channels
- Old TVs had to be able to display the new colour signals without much interference

With all this in mind three systems that shoe-horned a 'colour sub-carrier' signal into the monochrome 'luminance' picture.

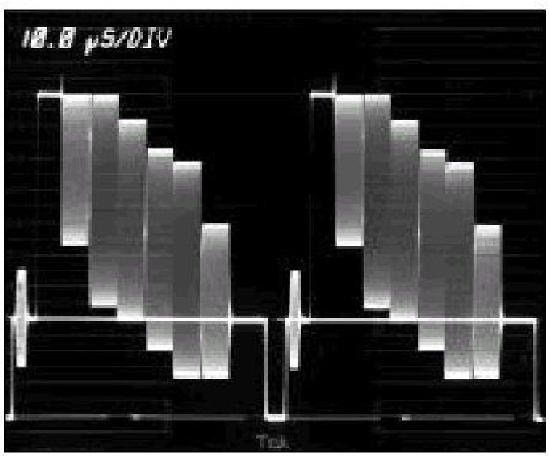
- NTSC – the American standard, the BBC tested it in the early sixties before;
- PAL – the European standard, eventually used throughout the EU except;
- SECAM – French system also used in Russia.

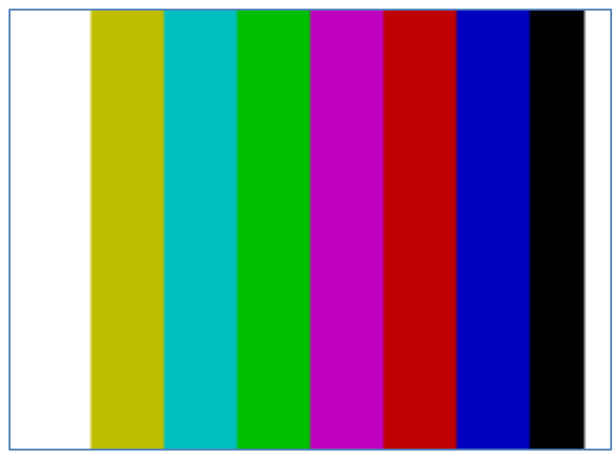
This is the order that the systems arrived and they largely build on the advantages of the earlier standards.

NTSC system Overview

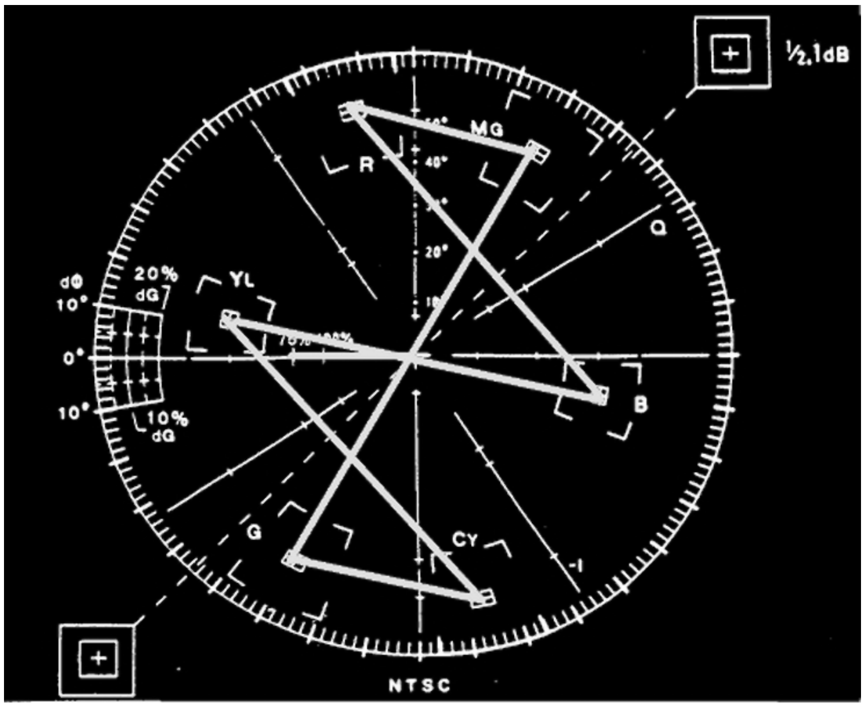
"Never Two Similar Colours"!

- The two colour difference signals get scaled and called I & Q
- I & Q are bandwidth limited to less than 1Mhz – not much colour detail!
- They are then quadrature-modulated onto a subcarrier at 3.579545 MHz
- The resulting subcarrier signal is mixed in with the luminance signal.
- A small burst of the 3.5Mhz subcarrier is added at the start of each video line – the phase of that burst is locked to the phase of the subcarrier and is always the same colour; mid-yellow.





NTSC system Overview

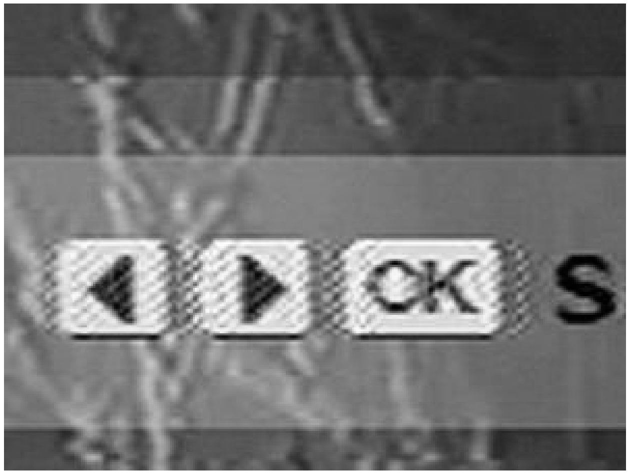


- Where is the green colour difference?!

- This is the display of a different kind of test-set called a 'vector-scope' which displays just the chrominance part of the signal
- Notice the colour burst reference along the negative horizontal – always a yellow colour reference for the decoder
- The I portion of the signal shows along the horizontal axis and the Q portion along the vertical
- The I component can also be considered the blue colour-difference signal, the Q is the red colour-difference.

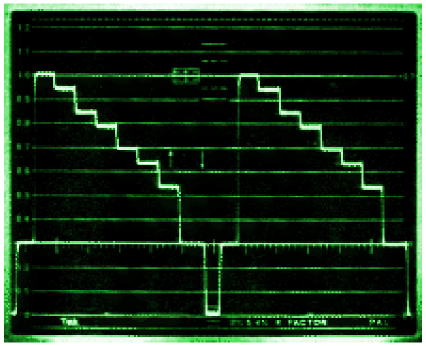
NTSC system Overview

- The amplitude of the colour subcarrier dictates how saturated a colour is
- The phase of the colour subcarrier (WRT the colour burst) dictates the colour
- The size of the colour burst and the sync pulse are both 0.3v
- The signal still displays properly on a black and white display
- If a newer display doesn't see the colour burst it turns off its colour decoder



You have to look closely at a colour image displayed on a B&W display to see the effect of the subcarrier signal.

NTSC system Overview



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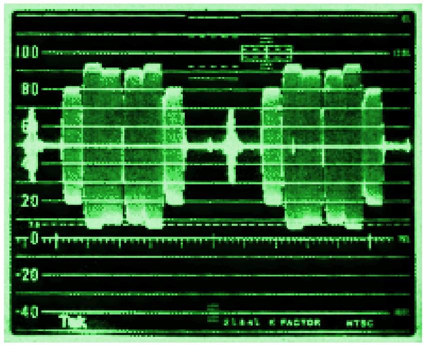

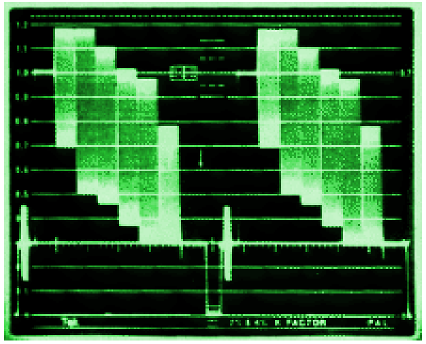

Monochrome signal colour subcarrier signal composite video

Notice;

- Although the luminance and the chrominance don't go over 1v the combined signal does
- This can be problematic and led to the use of "75% bars"

NTSC system Overview

Frame rates, subcarrier frequency

- 29.97 frames/sec = 59.94 fields/sec
- Why such a crazy number? Isn't it best to lock to mains frequency?
- f_{csc} = n +0.5 (where n= number of lines); this minimised colour-line interference
- n=15750 in B&W 30 frames/sec, **but** there is audio at 4.5Mhz **which can't change**
- n can change a small amount – to 15734 lines in NTSC
- All this gives a CSC frequency of 3.579545 MHz and a frame rate of 29.97
- This need for B&W compatibility has been biting us in the backside ever since!
- HD digital film work is done at 23.976fps (rather than 24fps) for this reason.

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NTSC system Overview

Decoder considerations, cross colour

- Once the NTSC signal gets to a monitor it needs decoding to RGB to be displayed
- The hardest part of the process is to filter off the CSC leaving luminance and chrominance
- Even modern digital decoders have difficulty in getting this 100% correct
- Swirling colour in areas of high-detail – ***cross-colour***

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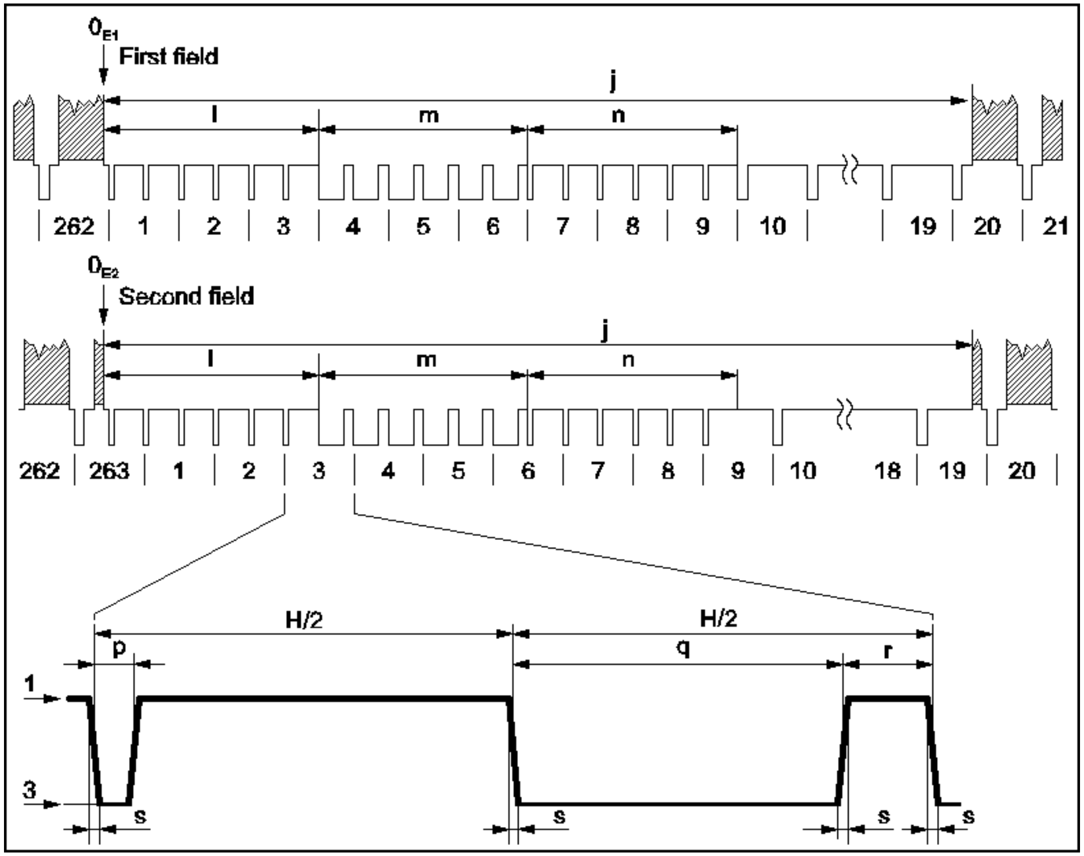
NTSC system Overview



The vertical interval

- 525-line signal, only 480 are displayed
- Various things live in the vertical interval
- Frame-sync pulses, broad-pulses, metadata, VITC, closed-captions, etc

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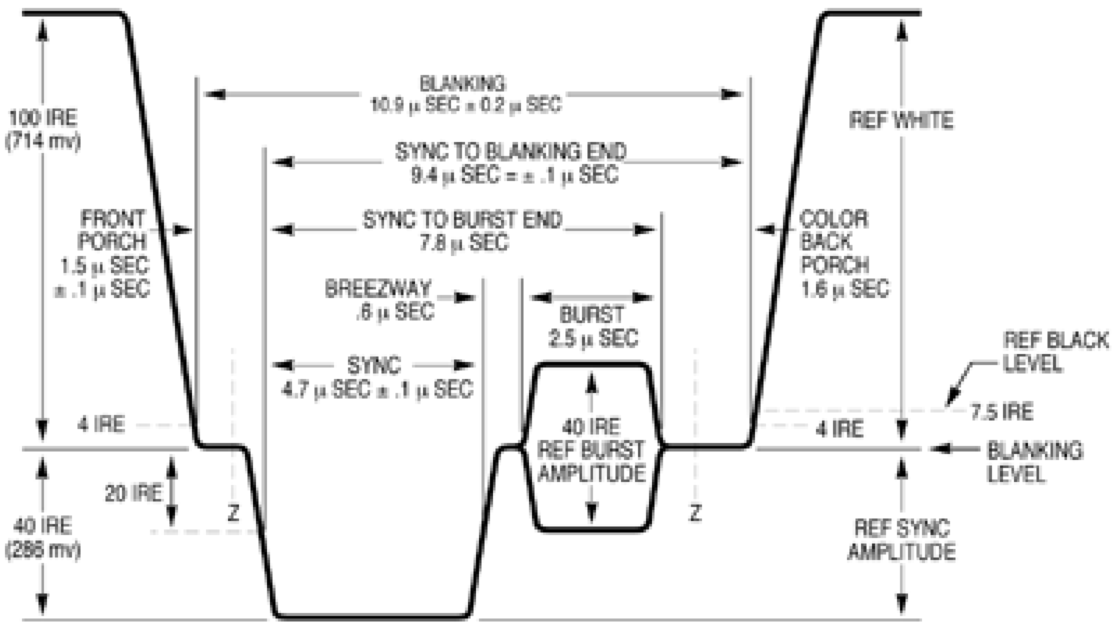
NTSC system Overview



The horizontal interval

- In NTSC black level is 7.5 IRE above blanking (unlike PAL)
- Syncs, the burst, etc all have rise/fall times – analogue!
- Burst and sync pulse the same size – helps the decoder

The last note about NTSC – there can be variation between the phase of the colour-burst and the CSC in the active line. This leads to bad colour rendition and is why NTSC TVs have a TINT control. – “**N**ever **T**wo **S**imilar **C**olours”!

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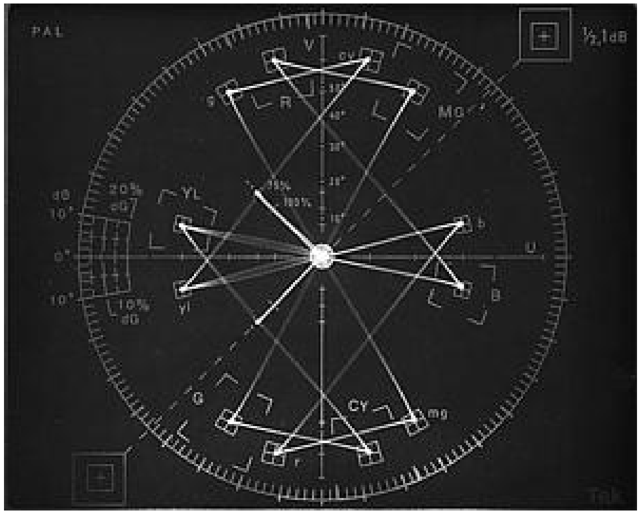
PAL system overview

'And now I will show you the most excellent way.' (!) 1 Corinthians 13 vs 1

The EBU and the BBC had ten years to see the problems with NTSC before they proposed the system that was adopted throughout most of Europe and the Commonwealth.

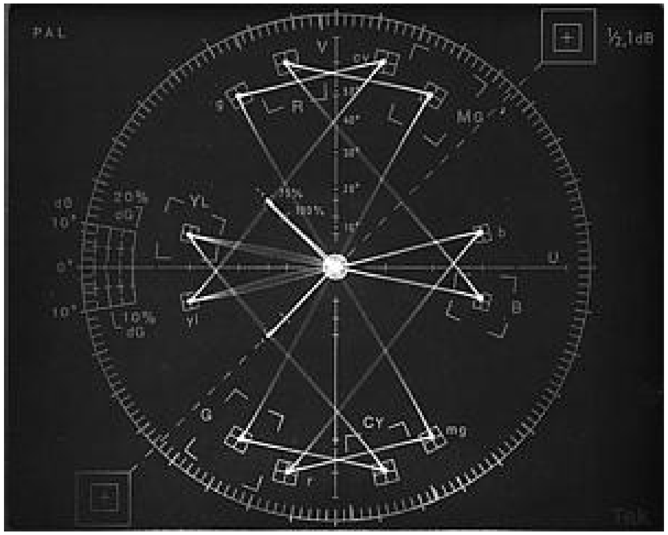
- 50 fields/sec vs 60 (actually 59.97 fields/sec!)
- 625 lines of resolution vs 525 lines
- PAL's killer feature is the **V-axis switch**
- PAL TV don't have a TINT knob to correct burst-colour errors
- 4.43Mhz (approx.) CSC frequency vs 3.58Mhz



http://en.wikipedia.org/wiki/PAL

PAL system overview

- The two colour difference signals get scaled and called U & V
- U & V are bandwidth limited to less than 1Mhz – not much colour detail!
- The V-signal is inverted every alternate TV line
- They are then quadrature-modulated onto a subcarrier at 4.43361875 MHz
- The resulting subcarrier signal is mixed in with the luminance signal.
- A small burst of the 4.43Mhz subcarrier is added at the start of each video line – the phase of that burst is locked to the phase of the subcarrier (remembering to invert the V-portion every line) and is always the same colour; muddy-brown.
- Same deal as NTSC – length of vectors=saturation, angle of vectors = colour.



PAL system overview

Advantages of PAL (V-axis switch encoder/decoder)

- In NTSC any burst-colour errors show as a colour error (faces go green etc!)
- In PAL any burst-colour errors are equally wrong either way on alternate lines and your eye tends to smooth-out the differences – this is a PAL-S (simple) decoder)
- More modern PAL decoders have a 1-line delay and they average the CSC across two lines
- The effect of burst-colour errors is that the overall colour desaturates which is visually better.
- The next two slides show the effect of Hanover bars in a simple PAL decoder and the slight desaturation with a delay-line PAL decoder.
- This doesn't stop PAL decoders mistaking high-frequency luminance for CSC; the swirly patterns on the presenter's jacket etc.

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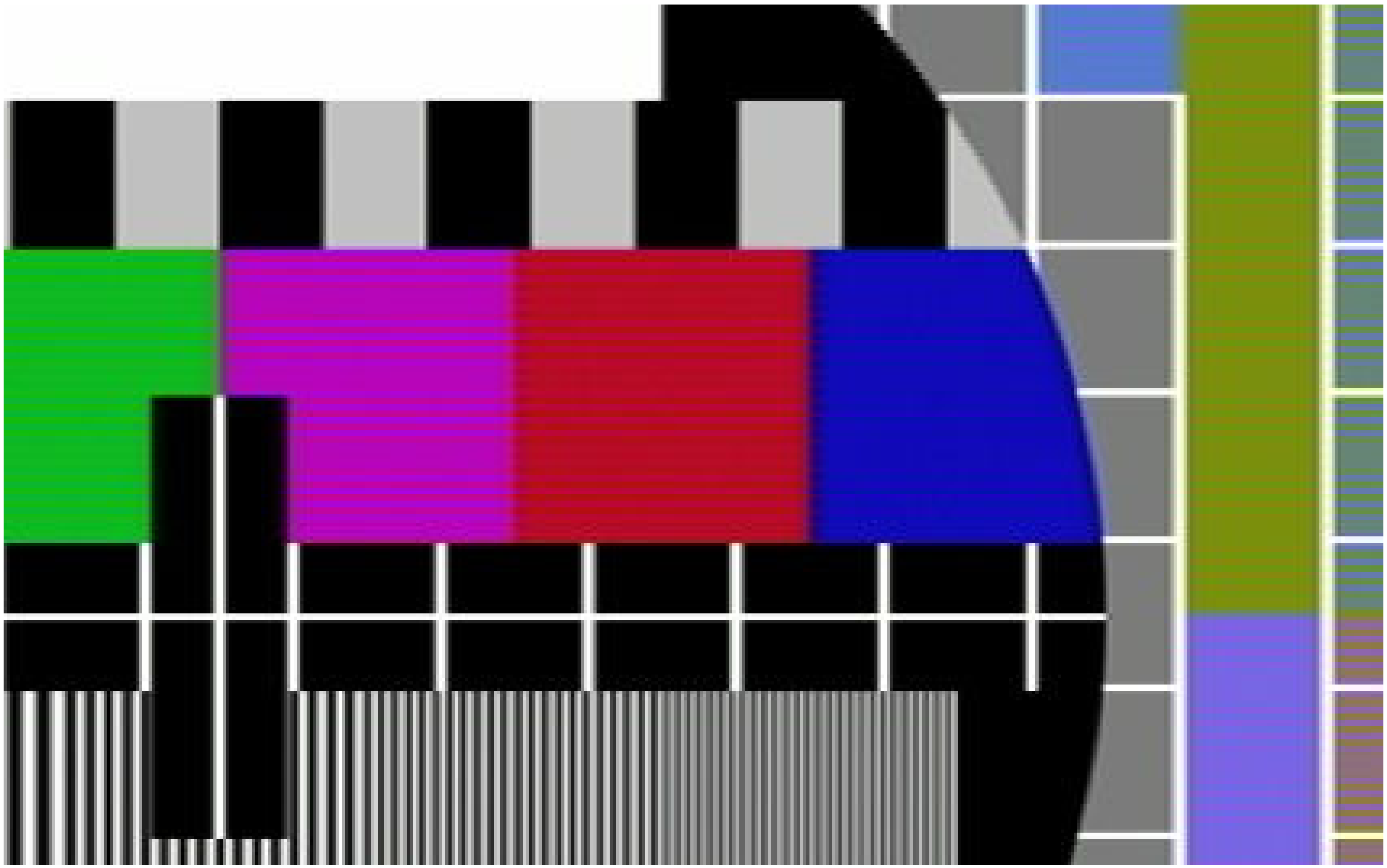

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PAL system overview

How the CSC frequency is calculated and the 8-field sequence

- 283.75 clock cycles/line +25hz offset to stop interference
- 15625 lines/sec; 625 lines x 50hz /2 (fields)
- 283.75 x 15625 +25hz = **4.43361875 Mhz**

Due to the 25hz offset of the CSC frequency the phase of the burst is the same on line 1 every four frames (eight fields). This means PAL has an 'eight field sequence'

- When editing PAL signals on VTR you have to maintain the CSC sequence
- The phase of the subcarrier and the line number is well defined; referred to as ScH phase
- This is why VTRs have an **8 field lock** switch
- NTSC only has a 4 field sequence

technology for the creative

SECAM system overview

Political reasons caused the French to develop their own system for colour television in the early 1960s. SECAM – *Séquentiel electronique couleur avec mémoire* is a system that doesn't suffer from the burst-colour errors of NTSC of the cross-colour problems of PAL & NTSC but once a signal is encoded to SECAM it can really only be decoded for display. It is a delivery-only format rather than something that can be used for post-production etc.

- 625-line & 50 fields/sec (like PAL)
- FM-encoding is used to put the U & V colour signals onto alternate TV lines
- Most French studios & facilities work in PAL and transcode to SECAM for transmission
- Better looking colour pictures than PAL and NTSC
- No CSC means no dot-crawl on B&W displays
- Better luminance/chrominance discrimination in the decoder

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Analogue video – review

- TV cameras etc produce three signals – Red, Green, Blue – three wires
- This is often converted to component video – Y, Cr, Cb (or Y, Pr, Pb or Y, U, V) – three wires
- Those two colour difference signals can then be modulated onto a sub-carrier signal; "C"
- The monochrome Y and C signals are sometimes referred to as S-Video; two wires
- The Y and C can be combined onto a single composite video signal for transmission, recording, etc – one wire

This was the state of play at the end of the eighties before the widespread adoption of digital video; this allowed much better quality in the post-production process (many passes of video with no degradation) and effects based on picture content (chroma key etc).