World Analogue Television Standards and Waveforms

Colour Standards

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THE INFORMATION presented in this section has been compiled from several modern and historical sources and, errors and omissions excepted, the intention is to give a summary of the various standards at the time that they were current. Nevertheless, it is hoped that present-day standards are also accurately accounted for, and to this end any corrections would gratefully received (please E-mail me with any comments). Thanks are especially due to Mark Carver, Steve Palmano and Peter Vince for help and advice. Written sources consulted include *[Electronics and] Wireless World* and *[Practical] Television* magazines, textbooks by Benson KB and Whitaker JC, Carnt PS and Townsend GB, Holm WA, Hutson GH, Kerkhov F and Werner W, and technical publications from BBC, EBU, IBA and ITU.

I am particularly indebted to Peter Vince for recently spotting certain anomolies in the ITU document BT.470-6 from which many of the details in these pages were taken. It has been superseded by BT.1700 and BT.1701, and the values quoted in these pages are now verified by those, and by SMPTE 170M-1999 in relation to the NTSC standard. Many of the NTSC parameters feature recurring decimal fractions, and I have indicated these throughout with square brackets, for example f_{SC} = 3 579 545.[45]Hz

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History of Colour Standards

THE THREE analogue colour coding standards that have been in common use are NTSC, SECAM and PAL, though several others have been proposed, including SECAM IV and MAC. John Logie Baird (of course) was the first to demonstrate colour television using a field-sequential version of his 30-line standard, but during the war he also had a hand in developing high-quality electronic systems and came up with his 'Telechrome' two-and three-gun display tubes. George Valensi, a Frenchman, was the first to propose a compatible system based on luminance and chrominance signals.

However, most of the early work on colour in the United States of America was based on field-sequential systems that were incompatible with monochrome transmissions. CBS developed a 343-line 120 fields per second system in 1940 and followed it with a 525-line 144 fields per second system that required a 12MHz vision bandwidth in 1945. This latter system was transmitted for a while in 1951, but quickly abandoned, and the search for a compatible system was intensified.

NTSC was the first compatible standard to be developed, in which the normal black-and-white picture was accompanied by colour information carried on subcarriers in the same vision passband. Other standards were later adopted in various countries, but they were all derived from NTSC and differed mainly in the way the subcarriers were modulated and incorporated into the vision signal.

The table below lists the subcarrier frequencies used around the world in experimental standards as well as those eventually used in service.

Subcarrier Summary: (= experimental standard) ([...] = recurring decimals)

NTSC		A	I	M
	f_{SC} (Hz)	2 657 812.5 2 809 687.5[1] 2 505 937.5[1]	4 429 687.5	3 579 545.[45]

SECAM		A	B, D, G, K, K1, L			M
			Original	Optimised		
		D'R and D'B	D'R and D'B	D'R	D'B	D'R and D'B

	f_{SC} (Hz)	2 600 000 Dev^n: ±250 000	4 437 500 Dev^n: ±770 000	4 406 250 Dev^n: +350 000, -506 000	4 250 000 Dev^n: +506 000, -350 000	3 579 545.[45] Dev^n: ±500 000

PAL		**A**	**B, D, G, H, I, K, K1, E-PAL, PAL-Plus**	**M**	**N**
	f_{SC} (Hz)	2 660 343.75	4 433 618.75	3 575 611.[88811 1]	3 582 056.25

Experimental colour systems:

System A/NTSC: Transmitted by BBC on Bands I and IV in London between 1955 and 1960 [1] These values were used with E'_Q signals having slightly different bandwidths during early System A/NTSC experiments.
System I/NTSC: Transmitted by BBC on Band IV in London from 1963-64
System A/SECAM: Transmitted by ITA in Band III in 1962
System M/SECAM: Considered by US and Japan for recording onto unmodified monochrome video tape recorders in 1965 (transcoded to/from NTSC)
System A/PAL: Demonstrated by BBC and ABC in London from 1965-66

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Choice of Subcarrier Frequency (f_{SC})

More information

A discussion about the visibility of sound/chroma patterning in PAL can be found in the pdf document Research Report No G-102 (1966/30) on the BBC's R&D website.

Note: In this section I use the terms NTSC, PAL and SECAM to refer to the colour standards independently of the associated line standards, which I refer to explicitly where appropriate.

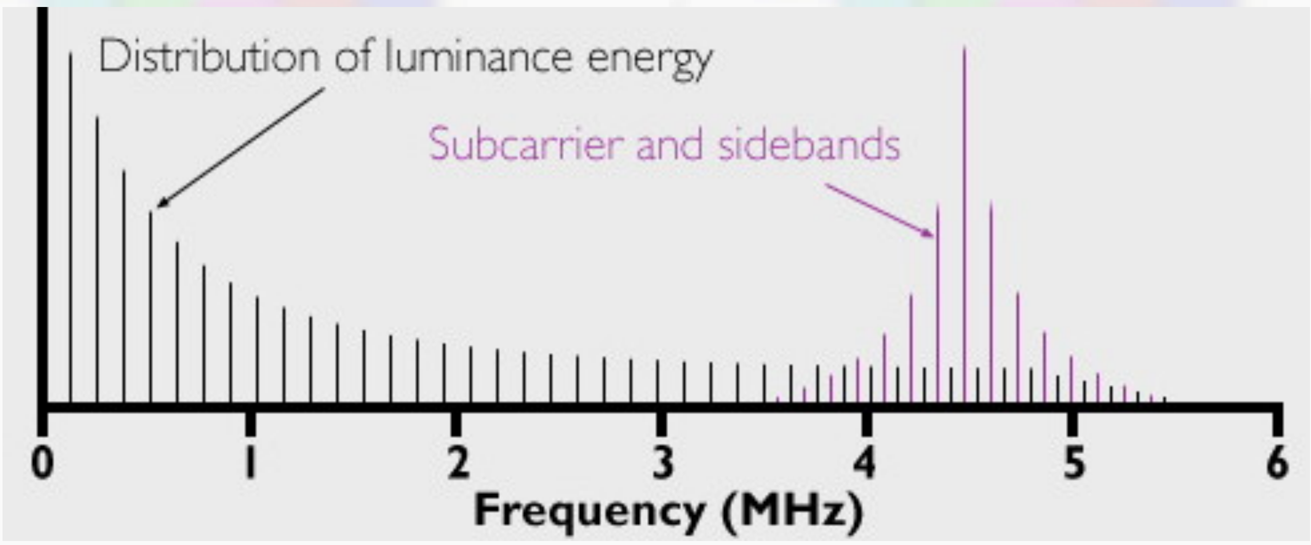
THE SUBCARRIER frequencies listed in the table above look arbitrary, yet they are specified to several significant figures. Why is this, and need they be so accurate?

You might think that the subcarrier frequency could have any one of a large number of values, but in fact the choice is quite limited. Let us look at how the choice was made for the PAL 625/50 standard (where f_{SC} can be expressed as 567 x 15625/2 + 15625/4 + 25 Hz) as that is the one that required the most stringent 'tweaking', and visit some of the other standards on the way.

How is it that we can superimpose the luminance and chrominance signals in the first place, and then separate them later?

The energy in the luminance signal is concentrated at the low-frequency end of the spectrum, but the distribution is not continuous, rather being 'spiky', with the picture (25Hz), field (50Hz) and line (15625Hz) frequencies and their harmonics predominating. This is a consequence of the way the picture is scanned. The effect on the spectrum is to have sharp peaks of energy at multiples of the line frequency accompanied above and below by little groups at multiples of picture and field frequencies, looking rather like sidebands.

The chrominance baseband spectrum is similar, but because it is amplitude modulated onto a carrier, it is shifted in frequency up the spectrum as a pair of symmetric sidebands. It is a simple matter to arrange for the subcarrier to be an odd multiple of half the line frequency, which puts these sideband clusters precisely in between the luminance clusters, hence "567 x 15625/2" (I give the reasoning behind the choice of 567 below). The main energy in the chrominance signal is concentrated around the subcarrier frequency, where luminance energy distribution is lowest (and vice versa).



Distribution of energy in an encoded colour signal, showing interleaving of luminance and chrominance signals

The vertical lines represent luminance energy at multiples of line frequency (black) and chrominance signals at odd multiples of half line frequency (magenta). For clarity, not all the lines are shown - there should me more of them and closer together - and the harmonics of the field frequency are not shown at all.

That explains how the two signals can co-exist in the same frequency band without mutual interference to a large extent. The two signals may be separated in the decoder either with simple notch and passband filters or with more complex 'comb' filters, which were expensive and rarely used in the early days, but are easier to implement with digital decoder circuitry.

The visual effect of the subcarrier on a B&W telly is to lighten and darken the luminance signal at subcarrier frequency, producing a pattern of dots along each scanning line. The dots line up to form stripes, which could look quite objectionable. The subcarrier frequency should be chosen to be high enough that the dots are so close together as to be barely visible, yet low enough to accommodate the upper sideband of the chrominance signal within the luminance bandwith.

The luminance bandwidth on 625/50 systems is between around 5 and 6MHz and the chroma bandwidth is about 1MHz, so we need a subcarrier frequency of around 4.5MHz.

This is as precise as we need to be with the SECAM standard, where the subcarrier is frequency modulated by the two colour difference signals and therefore has no fixed frequency or phase relationship with other parameters such as line or field frequency. This has unavoidable adverse effects on both the interleaving of the luminance and chrominance signals and the visibility of the subcarrier on monochrome receivers. The values chosen for the red and blue subcarriers that are transmitted on alternate lines are 4 406 250Hz and 4 250 000Hz respectively, with deviation values chosen so that the chrominance signal fits snuggly at the top of the video passband.

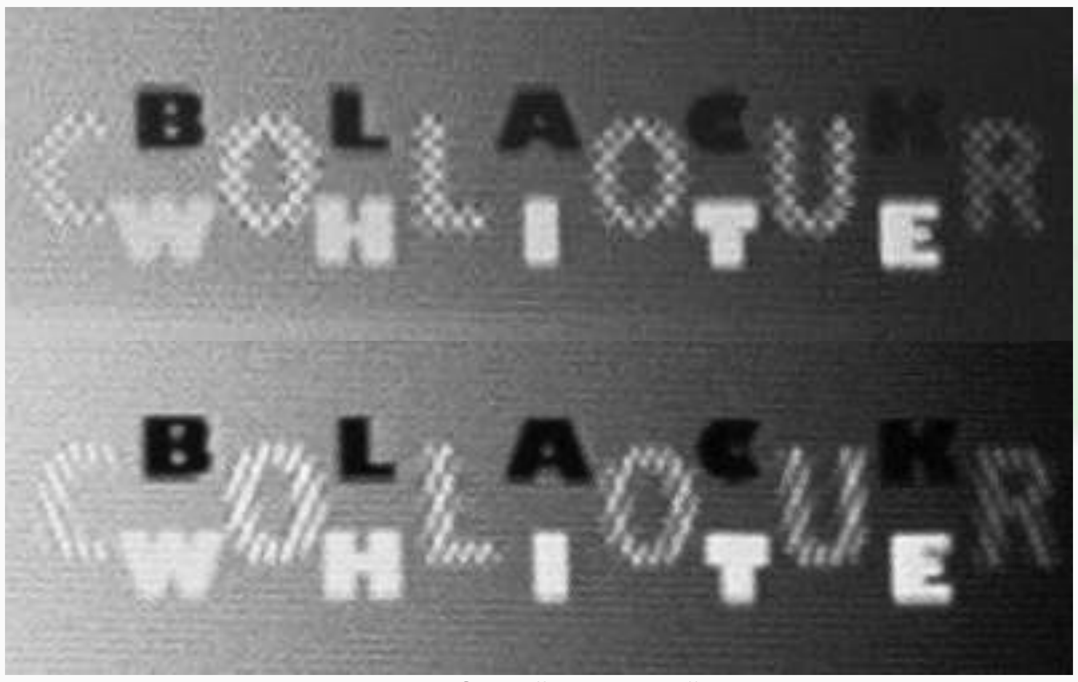
The SECAM colour standard uses a (more-or-less) constant amplitude (peaking at just less than half the black-to-white luminance amplitude) frequency-modulated subcarrier that appears as random fine herringbone lines all over the screen, and its visibility has been reduced by various means outlined in the SECAM section below. In brief, the frequencies of the two undeviated SECAM subcarriers are even multiples of the line frequency, and their sense is inverted on consecutive fields and on one line out of three in order to break up the dot pattern. The amplitude of the subcarriers is also reduced in areas of low or zero colour saturation.

Other colour standards use amplitude modulated subcarriers with the actual subcarriers supressed so that no patterning occurs on grey areas (no colour - no carrier) and is mild in areas of low saturation. On plain coloured areas the dot pattern is essentially static, (though it appears to crawl around due to the strobing effect of scanning) and is repeated line by line, frame by frame. The visibility of the dot patterns in saturated coloured areas can be reduced by careful selection of the subcarrier frequency, and thereby the positioning of the dots on the screen.

A subcarrier around 4.5MHz at an odd multiple of half the line frequency is a suitable target figure for the 625/50 standard, and 4 500 000 x 2/15625 = 576. Television engineers like figures with low prime factors so that they can be divided by means of simple circuitry to generate other frequencies. The nearest odd number to 576 is 575, which has prime factors of 5 and 23. The next nearest number with lower prime factors is 567, which has prime factors of 3 and 7, so this was the one chosen, and 567 x 15625/2 yields a subcarrier frequency of 4 429 687.5Hz.

This is within spec for the D/K and I Systems with their video bandwidths of 6.5 and 6MHz respectively, though the 1MHz bandwidth upper chrominance sideband is slightly low-pass filtered in the B/G system, which has a 5MHz video bandwidth, and therefore decoders suitable for vestigial sideband working need to be used in B/G receivers (the use of a delay line, which has been standard in all but the simplest early PAL receivers, achieves this).

To render the dots less visible, it would help if the bright dots on one line were to be spaced vertically between the dark dots on adjacent lines, yielding a diagonally staggered, or quincunx, dot pattern, like the '5' on a gambling die or playing card. Similarly a bright dot at any point on the picture ought to be followed by a dark dot at the same point in the next picture. For this to happen with an NTSC signal, we need the subcarrier to be an odd multiple of half the line frequency, and for there to be an odd number of lines per picture.



Appearance of colour subcarrier on a monochrome screen

These two close-ups show the appearance of subcarrier on coloured areas in an NTSC signal (top) and a PAL signal (bottom) displayed on a monochrome television screen. The colours of the letters are in the same order as standard colour bars. The grey background, on which the interlaced scanning lines are faintly visible, has the same luminance level as the colour of the letter it passes behind. A characteristic of the PAL colour standard is that the precise nature of the dot pattern depends on the hue.

This is precisely what we have, and so for NTSC the problem is solved. Owing to the strobe effect, the resulting dot pattern on 625 lines appears to crawl slowly vertically up the screen (and also with 405 and 525 lines - with 403, 523 or 623 lines it would crawl downwards, apparently).

A subcarrier frequency of 567 x 15625/2 = 4 429 687.5Hz therefore satisfies the all above requirements for a 625/50 NTSC colour standard. However, there is a further requirement that the difference between the frequencies of the subcarrier and the sound carrier in the transmitted signal should also be an odd multiple of half the line frequency in order that harmonics of the colour subcarrier (where the clusters of energy occur, as we have seen) do not fall near the frequency of the fm sound carrier, which could cause interference to both sound and vision.

In the 625/50 systems where the vision-sound carrier spacing is 5.5, 6 or 6.5MHz, this is the case (68.5, 100.5 and 132.5 times the line frequency respectively) but there is no suitable subcarrier frequency for the 525/60 System M with its 4.5MHz spacing. In order to avoid changing the vision-sound carrier spacing of every transmitter in the network, it was decided that the line and field frequencies at the studios would be multiplied by a factor of 1000/1001, yielding a subcarrier frequency of 3 579 545.[45]Hz, which satisfies all the criteria above.

Returning to 625-line PAL, there is the complication that the V component is inverted on alternate lines. A colour with only U present would yield a staggered dot pattern similar to the same colour in NTSC, but a V-only colour would have all the bright dots aligned vertically.

The solution is to add 1/4 of the line frequency to the NTSC value (yielding 4 433 593.75Hz). This produces a 3/4 line offset for the U signal and 1/4 line offset for the V signal. The dot pattern therefore moves diagonally up or down the screen at a steeper angle than in NTSC and in a direction depending on the proportions of U and V in the colour.

We saw earlier that in order to reduce the visibility of the dot pattern, a bright dot on one frame should be followed by a dark dot at the same position in the following frame, and that this is achieved by default with NTSC when the subcarrier is an odd multiple of half the line frequency and there is an odd number of lines per frame. The additional adjustments in the subcarrier frequency required for PAL mean that precise interlacing of the dots cannot be obtained, but an approximation is arrived at by adding another half cycle of subcarrier per field (ie by adding 25Hz to the subcarrier frequency), yielding the familiar 4 433 618.75Hz.

These final two corrections yield a sound carrier relationship of 100.24968 times the line frequency, with the nominal vision-sound carrier spacing of 6.000MHz ± 1kHz on System I. Again, because of the more complicated nature of the PAL signal, minimum patterning does not coincide with a subcarrier-to-sound carrier spacing that is an odd multiple of half the line frequency, as with NTSC, but 100.24968 is very close to the optimum ratio for 6MHz sound, producing patterning about 3dB above the minimum. In fact it turns out that minimum patterning is obtained with a negative offset of the sound carrier of 400Hz, so the System I spacing was set at 5.9996MHz with a tighter tolerance of ± 500Hz and this offset was also adopted for the nominally 5.5MHz Systems B/G in New Zealand (see CCIR Transmission Systems).

Methods of deriving the subcarrier, line and field frequencies from a single reference oscillator so that all are phase-related are necessarily complicated. HV Sims, in 1969, mentions two methods, one by Walter Bruch and the other by the BBC, but their explanations take up a page of text and two pages of diagrams.

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NTSC

"Never Twice the Same Colour"

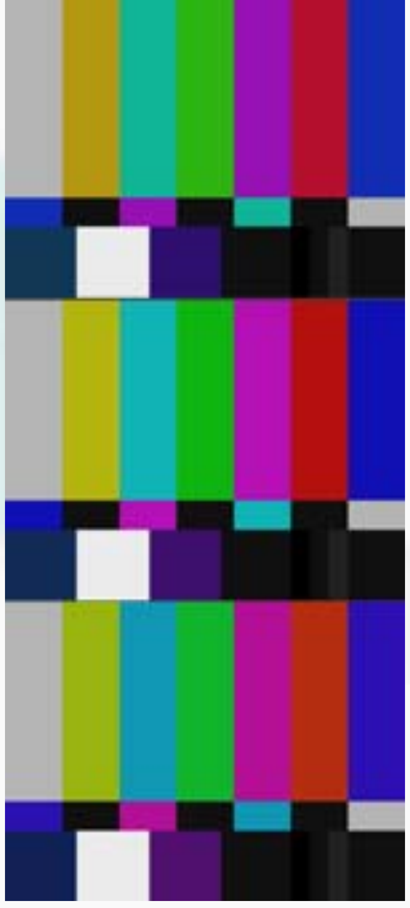
NTSC is named after the *National Television Systems Committee* which had been set up in 1940 by the RMA (Radio Manufactureres Association) and was asked in 1949 to find a compatible colour television standard for the USA to replace the incompatible field-sequential colour system that had been used since 1948. RCA took up the challenge and devised an entirely new standard from start to finish - from camera, through coder, decoder and shadowmask display tube - that could be also received in black and white on an existing receiver. It was submitted for approval on 25 June 1953 to the FCC (Federal Communications Commission) who authorised it for use on 1 January 1954, and has only ever been adopted for use (other than experimentally) on 525-line standards.

Waveforms and tables

On other pages there are Portable Document Format graphics of the Horizontal and Vertical Blanking Intervals of the 525/60 waveform and tables of the characteristics of the baseband and modulated System M NTSC 525/60 signals.

In it the two colour difference signals (see the section on colour) are amplitude modulated in quadrature (QAM) onto a subcarrier of 3 579 545.[45] ±10Hz. A burst of subcarrier is placed on the back porch (between the end of the line synchronising pulse and the start of video) in order to synchronise the local oscillator required to demodulate the signal in the receiver. Unfortunately, during propagation, the phase relationship between the burst and the picture information can drift, resulting in incorrect hues that cannot be corrected automatically, and so a manual front-panel 'hue' control is incorporated in receivers which the user adjusts for 'most natural' colours.

In addition, crosstalk between the two colour difference signals resulting from poor separation during decoding also leads to incorrect hues and the orginal RCA proposal made use of colour phase alternation (CPA) in order to reduce it. However, with no delay line available for electrical cancellation of the errors strong 'Venetian blinds' appeared as a crawling line structure on the picture and this was considered unacceptable, so the I/Q method of modulation as described below, which also reduced crosstalk, was used instead. Ironically, since the introduction of glass delay lines for PAL standards elsewhere, NTSC decoders have begun to use them in 'comb filters' which eliminate crosstalk between the luminance and chrominance signals, improving the quality of both, though without removing hue errors.



Effect of positive and negative phase errors on NTSC colour bars (correct at centre)

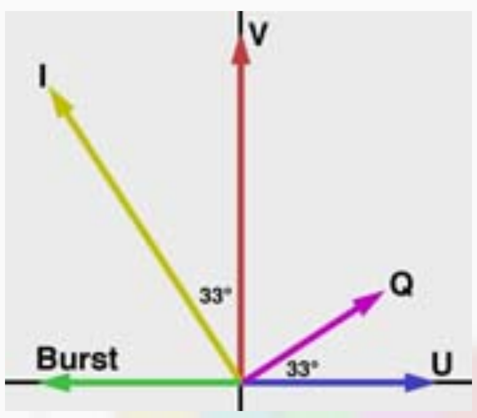
Because of the relatively low vision bandwidth (4.2MHz) of the 525-line NTSC standard, the choice of colour subcarrier frequency is a compromise. It would be impracticable to transmit the U and V signals [$E'_U = 0.493(E'_B - E'_Y)$ and $E'_V = 0.877(E'_R - E'_Y)$] without seriously distorting them due to restriction of the upper sideband, so instead a further property of human vision is exploited. Green-magenta vision is less acute than orange-cyan, so it was arranged for the axes of the chrominance information to be rotated by 33° in order that the orange-cyan (I) signal may be assigned about twice the bandwidth of the green-magenta (Q) one. Therefore, the Q signal is transmitted with equal sidebands, while the upper sideband of the I signal is truncated.

There are several options available to the designer of the NTSC decoder. The chrominance signal may be filtered so that both I and Q have the same bandwidth and then either the I and Q or U and V signals may be demodulated using suitably phased referenced oscillators, or the the wider lower sideband of the I signal may be exploited by using single-sideband demodulation. The green colour-difference signal may be obtained from either the I and Q or U and V signals, whereby:
(G-Y) = -0.28I - 0.54Q = -0.575U - 3.94V = -0.509(R-Y) - 0.194(B-Y)
or it may be demodulated directly using a reference subcarrier signal having a phase angle of 55.8° wrt the +(B-Y) axis. The resultant is then attentuated to 70% of its level to obtain the correct (G-Y) value.

Also, since the phosphor colours are not identical to the camera colours, many designers change the values of the coefficients in the matrixing circuits in order to improve (or otherwise change) the colour rendition. Often there is a menu of various settings to choose from. Add to that the ubiqitous 'hue' control that allows the viewer to set the reference oscillator phase to what he thinks is the correct value and it becomes easy to see how the NTSC standard acquired its soubriquet of 'never twice the same colour'.

Although never used in service, experimental 405-line colour transmissions were made in the 1950s and 1960s by the BBC using NTSC coding. The subcarrier frequency was 2 657 812.5Hz. Tests were also made with E'_Q signals of slightly higher and lower bandwidths than the one finally used. These necessitated subcarrier frequencies of 2 809 687.5Hz and 2 505 937.5Hz. The BBC also made tests with 625-line NTSC, in which the subcarrier frequency was 4 429 687.5Hz.

NTSC coding is used on System M only.



The instantaneous voltage E_{NTSC} of the complete encoded NTSC signal is given by:
$E_{NTSC} = E'_Y + E'_Q \sin(wt + 33°) + E'_I \cos(wt + 33°)$
where:
w (omega) = 2 pi times the subcarrier frequency f_{SC}
E'_R, E'_G and E'_B are the gamma corrected primary colour signals
$E'_Y = 0.299E'_R + 0.587E'_G + 0.114E'_B$
$E'_Q = 0.74(E'_R - E'_Y) - 0.27(E'_B - E'_Y)$
$E'_I = 0.48(E'_R - E'_Y) + 0.41(E'_B - E'_Y)$

The modulation mode of the colour subcarrier is suppressed-carrier amplitude-modulation of two subcarriers in quadrature (QAM).

Colour synchronisation of the oscillator in the NTSC decoder is by reference to a burst of nine cycles of subcarrier inserted into the back porch of the line blanking period. The p-p amplitude of the burst is 4/10 of the luminance (blanking to peak white) amplitude and the phase is 180° relative to the $(E'_B - E'_Y)$ axis. It is important that the burst amplitude remains in the correct proportion to the chrominance amplitude, since the burst amplitude is used as a reference for automatic gain control in the receiver and errors would affect the saturation of the displayed picture.

Subcarrier frequency and chrominance bandwidth

For M/NTSC the field frequency f_V and line frequency f_H (nominally 60Hz and 15.750kHz for monochrome transmissions) are derived from the subcarrier frequency f_{SC} = 3 579 545.
[45] ±10Hz as follows:
$f_H = 2f_{SC} / 5x7x13$ Conversely, $f_{SC} = (455/2) f_H$
$f_V = 2f_H / 3x5x5x7$
These values may also be expressed as follows:
f_{SC} = 5 000 000 x 63 / 88 = 3 579 545.[45]Hz
f_H = (5 000 000 x 63 / 88) / 227.5 = 15 734.[26573 4]Hz
f_V = 60 x 1000 / 1001 = 59.94[005 994]Hz

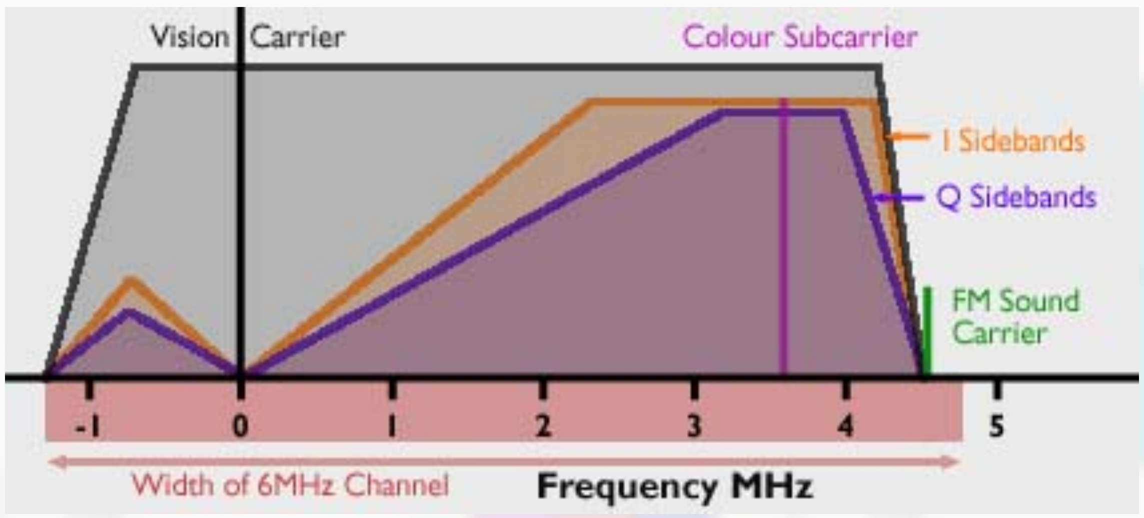
The attenuation of the colour difference signals before modulation in System M/NTSC is as follows:
E'_I - <3dB @ 1.3MHz, >20dB @ 3.6MHz
E'_Q - <2dB @ 0.4MHz, <6dB @ 0.6MHz, >6dB @ 0.6MHz

For the experimental System A/NTSC transmissions radiated by the BBC between 1956 and 1963 the field frequency f_V and line frequency f_H (nominally 50Hz and 10.125kHz for monochrome transmissions) were derived from the subcarrier frequency f_{SC} = 2 657 812.5Hz as follows:
$f_H = 2f_{SC} / 3x5x5x7$ Conversely, $f_{SC} = (525/2) f_H$
$f_V = 2f_H / 3x3x5x7$

The attenuation of the colour difference signals before modulation in System A/NTSC was as follows:
E'_I - <3dB @ 1MHz
E'_Q - <3dB @ 0.34MHz

In addition, two other values for the bandwidth of the E'_Q signal were tested by the BBC. Each required a different subcarrier frequency.
E'_Q - <3dB @ 0.22MHz, f_{SC} = 2 809 687.5Hz
E'_Q - <3dB @ 0.46MHz, f_{SC} = 2 505 937.5Hz

For the experimental System I/NTSC transmissions the field frequency f_V and line frequency f_H (nominally 50Hz and 15.625kHz for monochrome transmissions) were derived from the subcarrier frequency f_{SC} = 4 429 687.5Hz as follows:
$f_H = 2f_{SC} / 3x3x3x3x7$ Conversely, $f_{SC} = (567/2) f_H$
$f_V = 2f_H / 5x5x5x5$



Frequency spectrum of a System M/NTSC vestigial sideband transmission

The frequencies marked are relative to the vision carrier. The levels and slopes of the curves are stylised for clarity. The attenuation on the 'plateaux' is <3dB and is >20dB where the curves meet the x-axis. The colour subcarrier is supressed - the vertical magenta line indicates its frequency.

Colorimetry

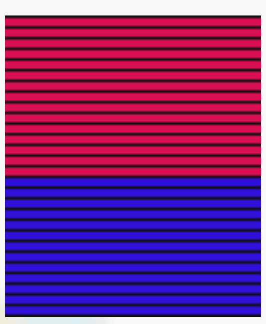
In 1953 the CIE coefficients for the primary colours, and for the reference white of colour display devices (where $E'_R = E'_G = E'_B$), of the NTSC standard were chosen as follows:

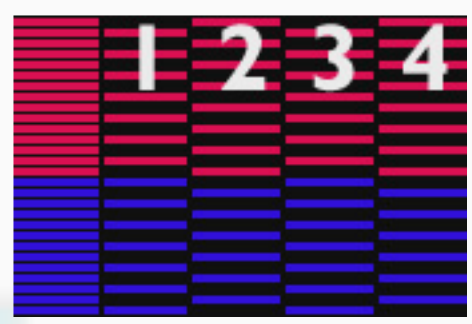
Red:	x = 0.67	y = 0.33
Green:	x = 0.21	y = 0.71
Blue:	x = 0.14	y = 0.08
White Illuminant C:	x = 0.310	y = 0.316

However, over the years the phosphors used in colour display tubes have changed, and they no longer match those for which the coefficients were chosen. Nevertheless, the same primaries continue to be used in coding NTSC signals in the United States of America, and correction circuits are now in use in studio monitors and domestic receivers in order to improve the colorimetry of the display. The white reference for monitors is now specified as Illuminant D_{65} (x = 0.313, y = 0.329). In Japan, studio monitors are adjusted to display Illuminant D, 9 300K.

Twitter

Thanks to interlace, the overall flicker rate of 525/60 pictures is 60Hz. However, along horizontal edges there is 'twitter' at frame rate - ie 30Hz - which can be very noticeable when the adjacent areas have significantly different luminance values. The same frame-rate twitter pattern is visible on a monochrome receiver displaying any colour signal, but the effects on a colour receiver depend on the encoding standard. Here is what happens in the NTSC colour standard across four fields of video:





Let us take as an example a transition between a red area and a blue area, as in the detail shown on the left, which shows both fields superimposed (or a non-interlaced 'progressive' version, if you like). The colours chosen lie precisely along the (R-Y) and (B-Y) axes for ease of calculation. When scanned in the 525/60i NTSC colour standard the transition would appear as in the diagram on the right, over four successive fields of video. Since the two colour difference signals are transmitted simultaneously on each line and the decoder derives both colour difference signals from the current line, there is red/blue twitter at 30Hz, as with monochrome.

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SECAM

"Something Essentially Contrary to the American Method"

SECAM, *Système en Couleur à Mémoire,* sometimes known as

Waveforms and tables

On other pages there are Portable Document Format graphics of the Horizontal and Vertical

Séquentielle Couleur à Mémoire, or *Sequential Colour avec Mémoire*, is used on 625-line standards in some Francophone and former USSR countries, though many of the latter began to change to PAL following the fall of communism in the nineteen nineties. It was a French development (by Henri de France) of NTSC in which the colour difference signals are separately frequency modulated on two subcarriers of frequencies 4 406.25 ±2kHz and 4 250.0 ±2kHz [1] and transmitted on alternate lines and stored in a steel or glass acoustic delay line in the receiver. Its advantages in robustness and immunity to phase-shift errors are outweighed by its higher visibility on monochrome receivers, poorer colour quality and greater complexity at the broadcasting end of the chain. A different system, technically similar to an abandoned BBC proposal of 1963, NIR or SECAM IV, was developed in the USSR and then the USSR and France worked together to develop SECAM III which was tested during 1966/67 and launched simultaneously in both countries on 1 October 1967.

Blanking Intervals of the 625/50 waveform and tables of the characteristics of the baseband and modulated System B, D, G, K, K1 and L SECAM 625/50 signals.

[1] Originally both subcarriers had the same undeviated frequency of 4 437.5kHz with a symmetrical deviation of ±770kHz, but like many of the characteristics this was later 'optimised' in order to improve some of the shortcomings of the system.

In the autumn of 1962 the Independent Television Authority (ITA) in the UK made tests using System A/SECAM in order to assess monochrome receiver compatibility. The subcarrier frequency was 2 660kHz with a deviation of ±250kHz. From 1963 the ITA made 625-line SECAM colour tests, as did the BBC.

SECAM coding is used on Systems B, D, G, K, K1 and L.

The instantaneous voltage E_{SECAM} of the complete encoded SECAM signal is given by:
$E_{SECAM(R)} = E'_Y + G \cos 2pi\ (f'_{0R} + df_{0R}\ f'_0\ D'_R{}^*\ dt)$
$E_{SECAM(B)} = E'_Y + G \cos 2pi\ (f'_{0B} + df_{0B}\ f'_0\ D'_B{}^*\ dt)$
where:
(R) refers to the lines carrying (R-Y) information
(B) refers to the lines carrying (B-Y) information
E'_R, E'_G and E'_B are the gamma corrected primary colour signals
$E'_Y = 0.299E'_R + 0.587E'_G + 0.114E'_B$
It is permitted to attenuate E'_Y within the chrominance passband (as a function of its amplitude) in order to reduce interference distortions between the luminance and chrominance signals.

The chrominance signals are built up as follows:

Firstly the two colour difference signals are scaled and signed:
$D'_R = -1.902(E'_R - E'_Y)$
$D'_B = 1.505(E'_B - E'_Y)$

Next, the two colour difference signals are low-pass filtered, with attenuation as follows:
D'_R and D'_B - <3dB @ 1.3MHz, >30dB @ 3.5MHz

Then low-frequency pre-correction ('video pre-emphasis') is applied, with a frequency response rising from 0dB at 10kHz to a peak of 9dB at 750kHz and falling to 0dB at 1.5MHz:
$D'_R{}^* = A_{BF}(f)\ D'_R$
$D'_B{}^* = A'_{BF}(f)\ D'_B$
where:
$A_{BF}(f) = (1 + j\ (f / f_1)) / (1 + j\ (f / 3f_1))$
f = signal frequency (kHz)
$f_1 = 85$kHz

The two chrominance components are then frequency-modulated onto the two colour subcarriers, whose instantaneous amplitudes are given by:

$\cos 2pi\ (f'_{0R} + df_{\ 0R}\ f'_0\ D'_{\ R}{*}\ dt)$

and

$\cos 2pi\ (f'_{0B} + df_{\ 0B}\ f'_0\ D'_{\ B}{*}\ dt)$

where:

f_{0R} = 4 406 260 ±2 000Hz [B-Y subcarrier rest frequency]

f_{0B} = 4 250 000 ±2 000Hz [B-Y subcarrier rest frequency]

df_{0R} = 280 ±9kHz [nominal deviation of R-Y subcarrier]

df_{0B} = 230 ±7kHz [nominal deviation of B-Y subcarrier]

The amplitude of each subcarrier is frequency-weighted by a factor G by means of a 'bell filter' (rf pre-emphasis) before being added to the luminance component:

$G = M_0\ (1 + j\ 16F) / (1 + j\ 1.26F)$

where:

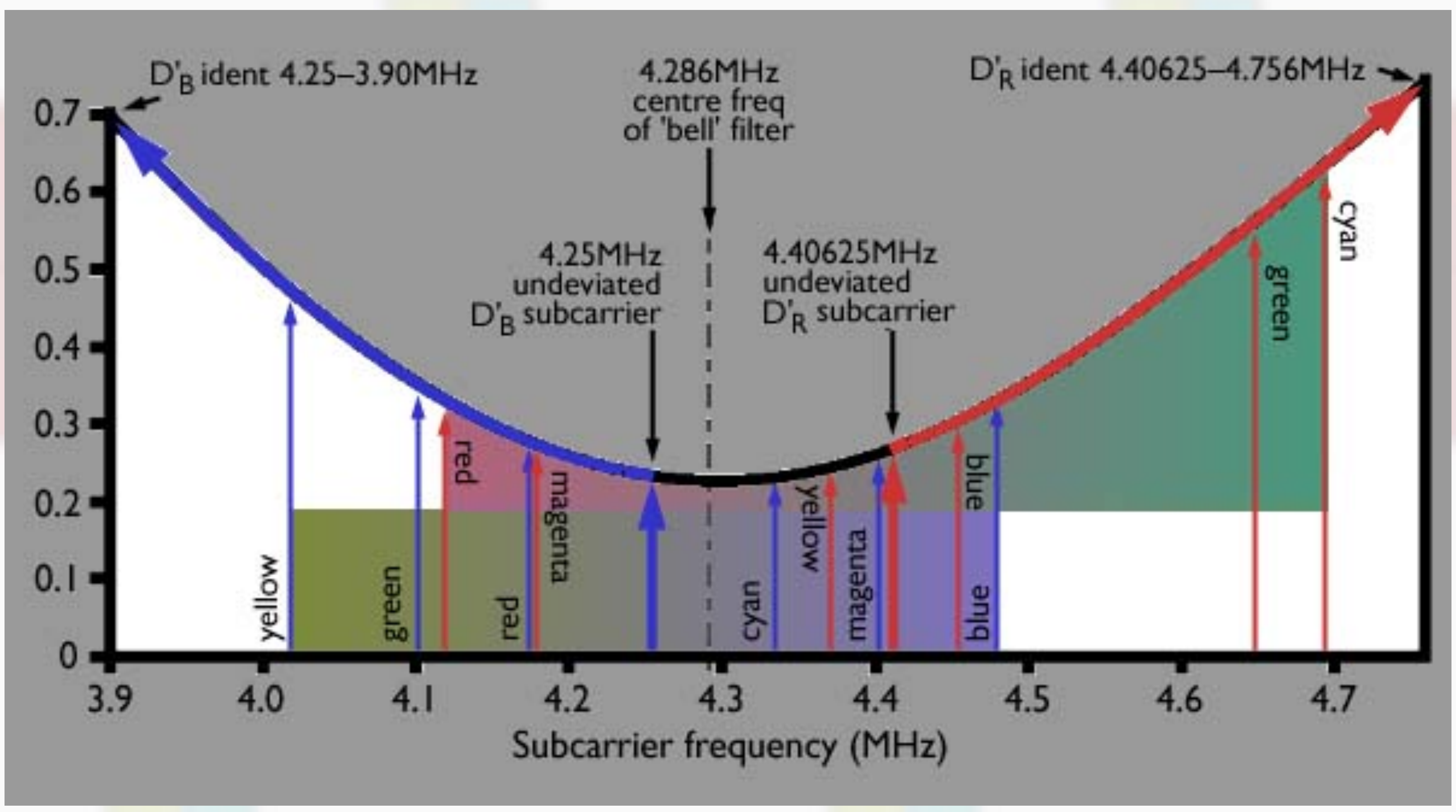
$2M_0$, the p-p subcarrier amplitude, is 23 ±2.5% of the luminance (blanking level to peak white) amplitude

$F = f / f_0 - f_{\ 0} / f$

f_0 = 4 286kHz

f is the instantaneous subcarrier frequency

By this means, the p-p amplitude of the subcarriers is maintained at 23% of peak white at the centre frequency of the bell filter (4.286MHz) around which most of the low-luminance colours are found, and 70% of peak white at the limits of modulation (3.9MHz and 4.756MHz) which are only reached during colour transients. Thereby the visibility of the subcarriers on monochrome receivers is reduced somewhat. In the receiver a reciprocal bell, or 'remise-en-forme' filter, giving an attenuation of 0dB at 4.286MHz and 12dB at 3.750 and 4.822MHz (the tolerance at all points is ±0.5dB) restores the correct amplitudes before passing the signal through the 64µs delay line.



This diagram from the SECAM colour bars section of the Test Cards page shows the frequencies and amplitudes (relative to peak white) of the two subcarriers for a set of 75% colour bars, and also shows the locus of the subcarriers during the field interval 'green bottles' ident signals, where each starts with undeviated carrier during the back porch of line blanking and progresses in a linear fashion to its respective limit of modulation.

The two coloured areas under the curve represent the deviation of the two subcarriers during period of constant colour (D'_B at the bottom and D'_R at the top). The white areas are those occupied by 'overshoot' of the subcarriers on colour transients due to the video pre-emphasis applied to the colour difference signals before modulation. The colour bar names reading upwards refer to lines carrying D'_B and those reading downwards to lines carrying D'_R.

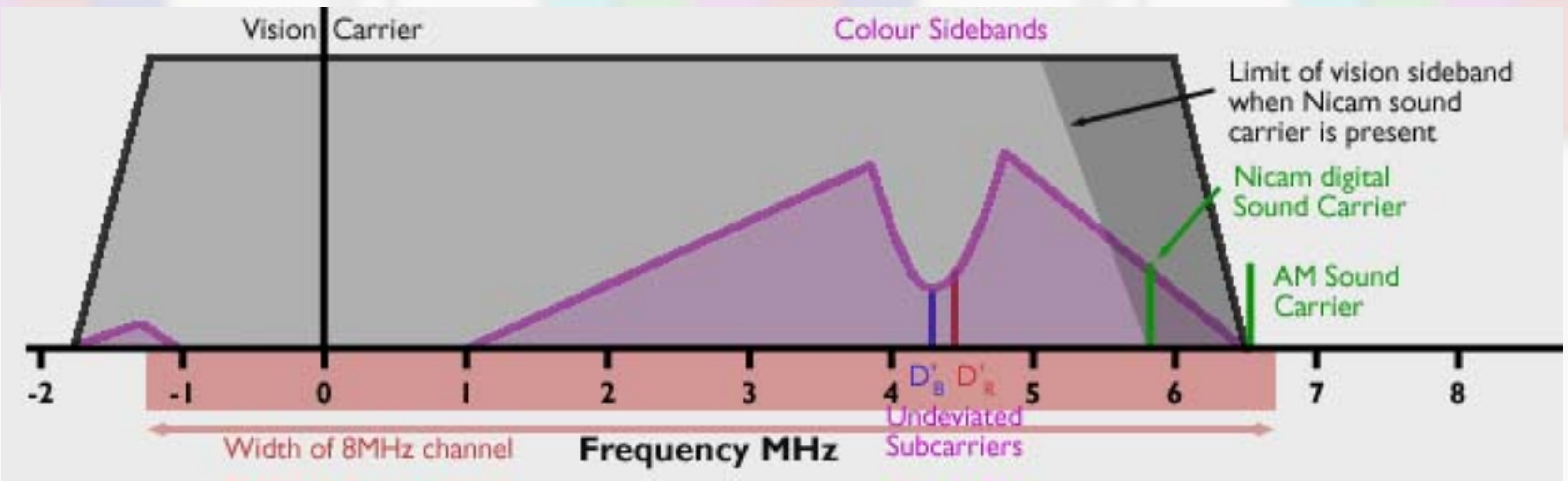
The field frequency f_V and line frequency f_H (nominally 50Hz and 15.625kHz for monochrome transmissions) are derived from the unmodulated subcarrier frequencies

f_{0R} = 4 406 260 ±2 000Hz and f_{0B} = 4 250 000 ±2 000Hz at the beginning of each line as follows:

$f_H = f_{0R} / 2x3x47 = f_{\ 0B} / 2x2x2x2x17$ Conversely, $f_{0R} = 282\ f_H$ and $f_{0B} = 272\ f_H$

$f_V = 2f_H / 5x5x5x5$

The attenuation of the colour difference signals before modulation and before low frequency pre-emphasis is applied is as follows:
D'_R and D'_B - <3dB @ 1.3MHz, >30dB @ 3.5MHz



Frequency spectrum of a System L/SECAM vestigial sideband transmission

The frequencies marked are relative to the vision carrier. The levels and slopes of the curves are stylised for clarity. The attenuation on the 'plateaux' is <3dB and is >20dB where the curves meet the x-axis.

Colorimetry

Originally, the same CIE coefficients for the primary colours, and for the reference white of colour display devices, as for the NTSC standard were chosen. However, over the years the phosphors used in colour display tubes have changed, and they no longer match those for which the coefficients were chosen. For that reason, the following CIE coordinates are now used in SECAM countries (though the older NTSC coordinates are also permitted):

Red:	x = 0.64	y = 0.33
Green:	x = 0.29	y = 0.60
Blue:	x = 0.16	y = 0.06
White Illuminant D_{65}:	x = 0.313	y = 0.329

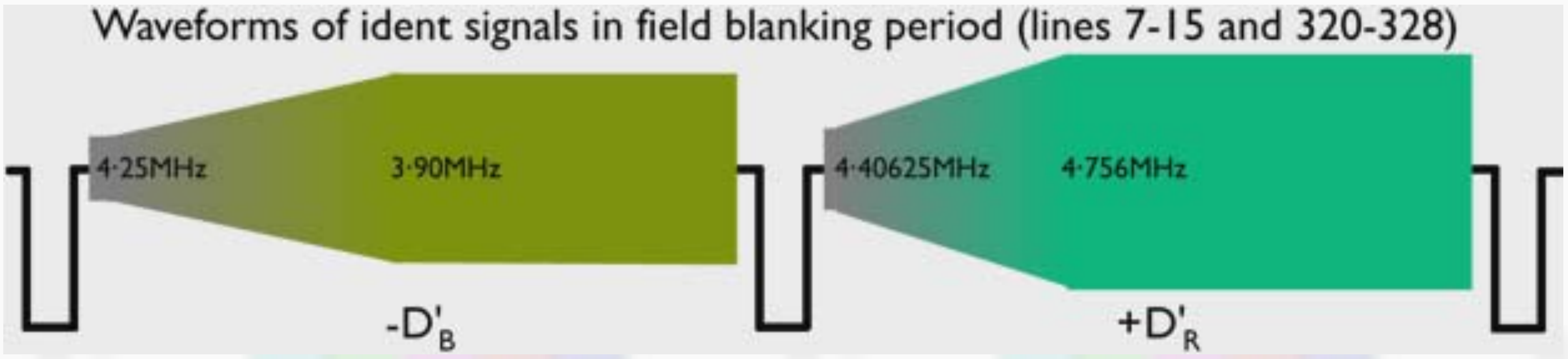
Synchronisation of SECAM colour transmissions

SECAM decoders do not have a crystal reference oscillator, nor do they require an accurate amplitude reference, but there is a line-by-line commutating switch which needs to be set correctly so that the D'_R and D'_B signals may be sent to the appropriate demodulators. Either of two colour synchronisation methods may be used:

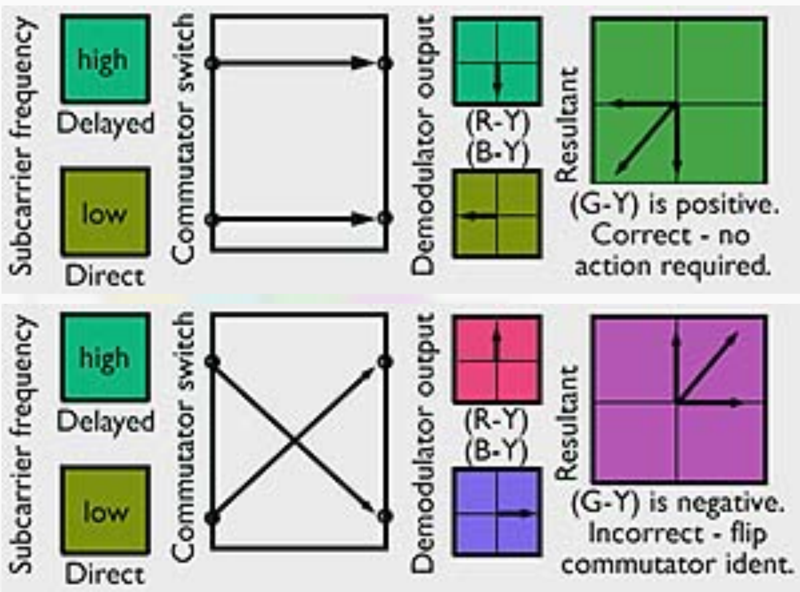
- *Line identification:* by chrominance subcarrier reference signals inserted into the back porch of the line blanking period, or
- *Field identification:* by chrominance subcarrier reference signals occupying nine lines of field-blanking period on Lines 7 to 15 in Fields 1 & 3 and Lines 320 to 328 in Fields 2 & 4

In both methods these identification signals comprise subcarrier of deviation +350kHz on D'_R lines and -350kHz on D'_B lines of 500mV p-p amplitude, where the luminance (blanking level to peak white) amplitude is 700mV. When decoded, these signals give a particular polarity of (G-Y). This is compared by the decoder with the expected polarity, and if it is incorrect, the commutating switch is held up for a line to re-establish correct synchronisation.

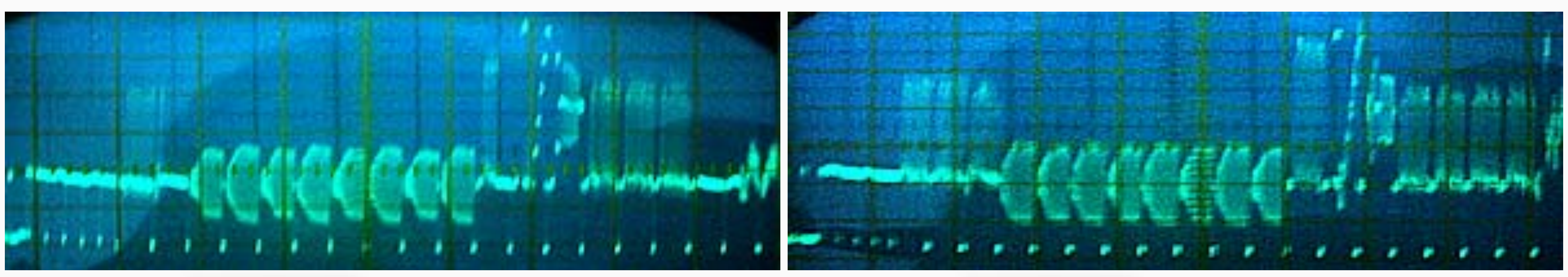
Line identification is now the preferred method, and in France all receivers manufactured from 1 December 1979 had to be able to use this method of synchronisation. The so-called 'green bottles', however, are still used on certain transmissions, for example the French first, second and third programme analogue satellite transmissions from 5.0°W.



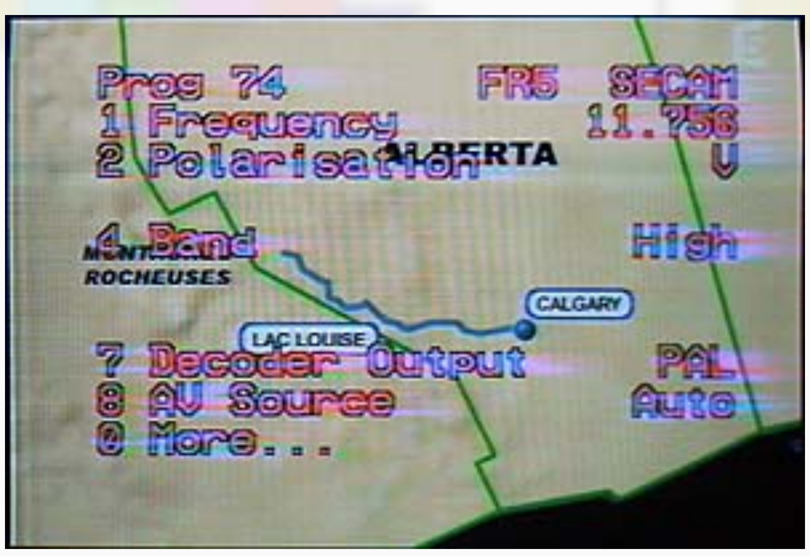
The 'green bottles' comprise subcarrier that starts undeviated and moves to the maximum deviation for -D'$_B$ and +D'$_R$. The amplitude of the subcarrier also increases according to the bell curve above. The line ident signals are similar, but are compressed into a few cycles during the back porch of the line blanking period.



During normal picture lines the subcarrier from the current line together with that from the previous line (from the output of the ultrasonic delay line) is fed to the (R-Y) and (B-Y) demodulators via a commutating switch that changes state after every line. The recovered (R-Y) and (B-Y) signals are then matrixed to give the (G-Y) signal. In the case of the ident signals, if the commutating switch is correct, the resultant will be in the third quadrant and the (G-Y) signal will be positive. If the ident is incorrect, the (G-Y) signal will be negative. Thus the polarity of the (G-Y) pulse may be used to reset the ident if required. This process is the same for line ident signals during the back porch of the line blanking period as well as the full-line 'green bottles' in the field blanking period.



These two oscilloscope traces show eight 'green bottles' (lines 8-15 and 321-328) sharing the vertical blanking interval with teletext (6, 19-21, 318-320 and 332-335) and VITS (vertical interval test signals, 16-18 and 329-331) on odd and even fields in a recent French SECAM analogue satellite transmission.

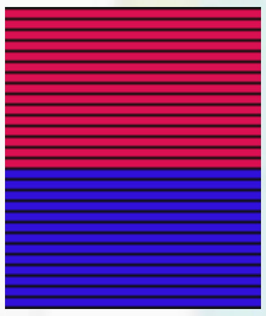


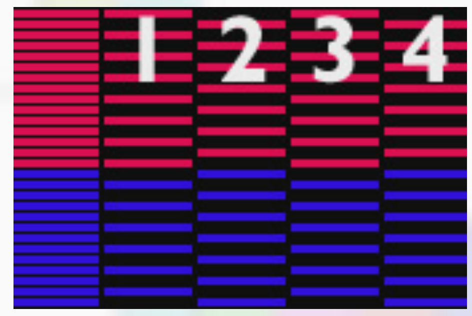
Correct SECAM decoding requires that the subcarrier be present throughout the active line, and not just in coloured areas. If an attempt is made to inlay text, as illustrated here where an analogue satellite receiver's menu is being displayed, the loss of subcarrier during the white characters causes the automatic gain control on the decoder to set the colour gain to maximum with the result that severe coloured noise is present on the text and for a short while afterwards until the gain has settled back to the correct value.

It is partly for this reason that the French devised the SCART, or Peritel, interconnection system in which inlaid text from decoders or video recorders is carried as separate red, green, blue and keying signals rather than encoded SECAM. Similar problems occur in production studios and so component (YPbPr) or PAL encoded pictures are used, the SECAM transcoding taking place either at the station output, or at the transmitter.

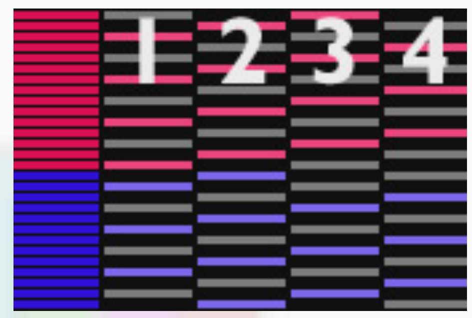
Twitter

Thanks to interlace, the overall flicker rate of 625/50 pictures is 50Hz. However, along horizontal edges there is 'twitter' at frame rate - ie 25Hz - which can be very noticeable when the adjacent areas have significantly different luminance values. The same frame-rate twitter pattern is visible on a monochrome receiver displaying any colour signal, but the effects on a colour receiver depend on the encoding standard. Here is what happens in the SECAM colour standard across four fields of video:

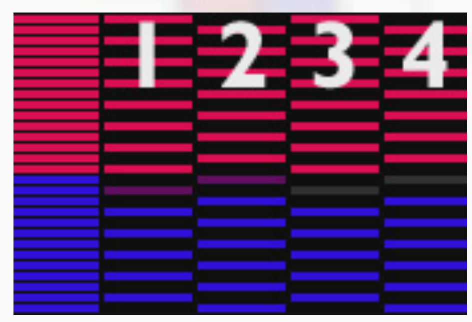




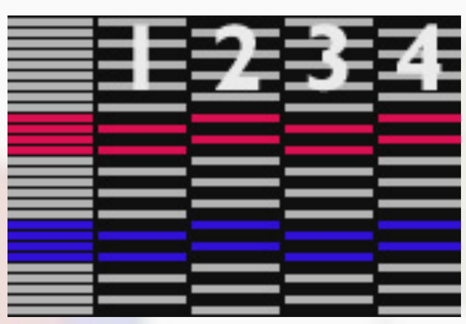
Let us take as an example a transition between a red area and a blue area, as in the detail shown on the left, which shows both fields superimposed (or a non-interlaced 'progressive' version, if you like). The colours chosen lie precisely along the (R-Y) and (B-Y) axes for ease of calculation. When scanned in the 625/50i standard the transition would appear on an RGB monitor as in the diagram on the right, over four successive fields of video. Since the two colour difference signals are transmitted sequentially on alternate lines and the decoder derives one colour difference signals from the current line, and the other from the previous line via a delay line, there are inaccuracies at the horizontal transition.

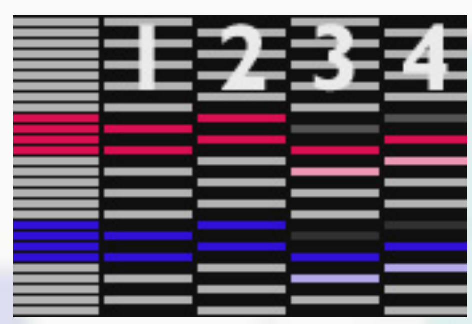


The diagram on the right shows the actual chroma signals being transmitted, superimposed upon a grey pedestal for clarity. As the shade of red chosen has no (B-Y) content, lines of (B-Y) subcarrier show as grey during the lines of the red colour. The same is true of the (R-Y) signal during the lines of the blue colour. Notice that during two fields there are adjacent lines of full red and full blue chroma, while in the other two fields there are adjacent lines of no chroma. The decoder interprets the former as red + blue = magenta, and the latter as grey.



In the decoded display shown on the right, there is twitter at 12.5Hz comprising two fields of magenta and two fields of grey at the colour transition. This is in addition to the 25Hz luminance and red/blue twitter.





Although I have chosen a saturated red/blue transition, the effect happens wherever one or other of the colours appears, and is particularly noticeable with text on a white background, as in this example (far right) where the SECAM display is compared to an RGB display (near right). Between them is an animated sequence illustrating the SECAM 12.5Hz twitter in slow motion.

| Top | Contents | History | Choice of f_{SC} | NTSC | SECAM | PAL | SECAM IV | MAC | Extended PAL | PAL Plus | Equations | Bookmarks |

PAL

"Peace At Last"

PAL, *Phase Alternation by Line,* is used on 625-line standards and was

Waveforms and tables

On other pages there are Portable Document Format graphics of the Horizontal and Vertical

developed in 1962 by Dr Walter Bruch of Telefunken in West Germany as an offspring of NTSC and SECAM. The QAM subcarrier frequency is 4 433 618.75 ±5Hz (±1Hz for I/PAL), and the sense of the (R-Y) colour difference signal is inverted on alternate lines. When this signal is re-inverted in the receiver and averaged with the signal from the previous line, which has been stored in a glass acoustic delay line, phase errors are cancelled out so that hue errors are eliminated and appear instead as less-noticeable amplitude (saturation) errors. The two colour difference signals are recovered simply by adding and subtracting the 'live' signal and that from the delay line:
$(E_{PAL(Line\ n)} + E_{PAL(Line\ n+1)})/2 = E'_U$; $(E_{PAL(Line\ n)} - E_{PAL(Line\ n+1)})/2 = E'_V$.
A secondary advantage of adding and subtracting the direct and line-delayed signals electrically is that a comb filter action is produced, resulting in excellent separation of the two colour difference signals.

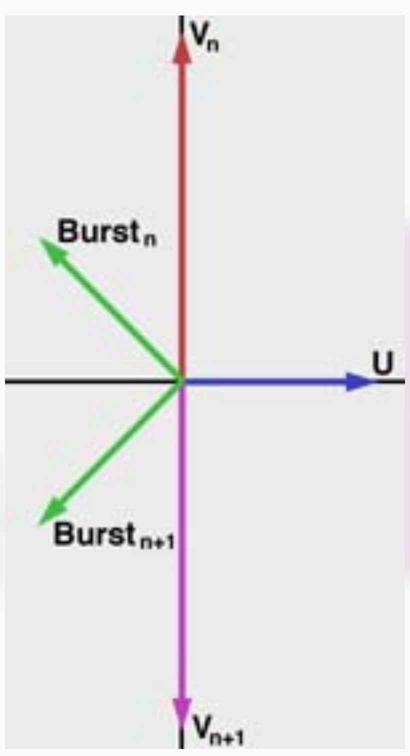
Blanking Intervals of the 625/50 waveform and tables of the characteristics of the baseband and modulated System B, D, G, H, I, K, K1, M and N PAL 625/50 signals.

The hue of a given point on the screen is defined by the phase of the subcarrier at that point with reference to the phase of the carrrier insertion oscillator which is synchronised to a burst of subcarrier at the start of each line. Hue errors occur when the phase of the picture subcarrier has shifted during transmission with respect to the phase of the reference burst. On the phasor diagram, this shows up as a rotation of the phasors with respect to the burst and the (R-Y) and (B-Y) axes. Because the (R-Y) signal is inverted on alternate lines, the resultant phasors of one line are a mirror image of those from the previous one, reflected about the (B-Y) axis. A clockwise rotation on one line becomes an anti-clockwise rotation on the next, following re-inversion of the (R-Y) signal and so the hue error can be cancelled out electrically by means of a delay line, or optically in the case of a PAL-S (simple PAL) receiver that does not use a delay line.

When used on System N, in which 625-line signals are fitted into narrower 525-Line Standard M channels, the subcarrier frequency used is 3 582 056.25 ±5Hz. Uniquely, in Brazil, PAL is used on System M and the subcarrier frequency is 3 579 611.[88811 1] ±10Hz.

In 1965-66 ABC Television undertook colour television demonstrations using System A/PAL at its Teddington, Middlesex, studios. The BBC is also understood to have made similar tests. The subcarrier frequency was 2 660 343.75Hz.

PAL coding is used on Systems B, D, G, H, I, K, K1, M and N.



The instantaneous voltage E_{PAL} of the complete encoded PAL signal is given by:
$E_{PAL(Line\ n)} = E'_Y + E'_U \sin wt + E'_V \cos wt$
$E_{PAL(Line\ n+1)} = E'_Y + E'_U \sin wt - E'_V \cos wt$
where:
Line n refers to the odd lines of Fields 1 & 2 and the even lines of Fields 3 & 4
Line n+1 refers to the even lines of Fields 1 & 2 and the odd lines of Fields 3 & 4
w (omega) = 2 pi times the subcarrier frequency f_{SC}
E'_R, E'_G and E'_B are the gamma corrected primary colour signals
$E'_Y = 0.299E'_R + 0.587E'_G + 0.114E'_B$
$E'_U = 0.493(E'_B - E'_Y)$
$E'_V = 0.877(E'_R - E'_Y)$

The modulation mode of the colour subcarrier is suppressed-carrier amplitude-modulation of two subcarriers in quadrature (QAM) with the sign of the E'_V component inverted on alternate lines.

Colour synchronisation of the oscillator in the PAL decoder is by reference to a burst of ten cycles of subcarrier inserted into the back porch of the line blanking period. The p-p amplitude of the burst is 3/7 of the luminance (blanking to peak white) amplitude and the phase is ±135° relative to the $(E'_B - E'_Y)$ axis, alternating line by line, the sign being the same as that of the $(E'_R - E'_Y)$ signal on the same line. It is important that the burst amplitude remains in the correct proportion to the chrominance amplitude, since the burst amplitude is used as a reference for automatic gain control in the receiver and errors would affect the saturation of the displayed picture.

Subcarrier frequency and chrominance bandwidth

For all standards except M/PAL and N/PAL the field frequency f_V and line frequency f_H (nominally 50Hz and 15.625kHz for monochrome transmissions) are derived from the subcarrier frequency f_{SC} = 4 433 618.75Hz as follows:
$f_H = 4f_{SC} / (5x227 + 4 / 5x5x5x5)$ Conversely, $f_{SC} = (1135/4 + 1/625) f_H$
$f_V = 2f_H / 5x5x5x5$

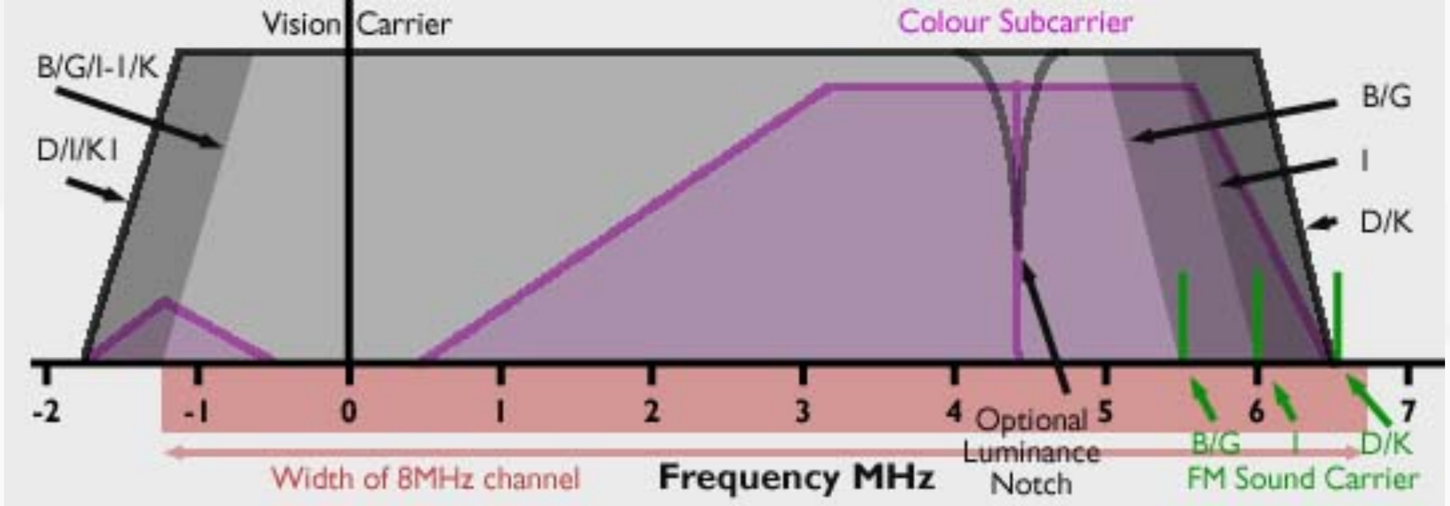
For A/PAL the field frequency f_V and line frequency f_H (nominally 50Hz and 10.125kHz for monochrome transmissions) were derived from the subcarrier frequency f_{SC} = 2 660 343.75Hz as follows:
$f_H = f_{SC} (3x5x5x7/2 + 1/4)$ Conversely, $f_{SC} = (1051/4) f_H$
$f_V = 2f_H / 3x3x3x5$

For M/PAL the field frequency f_V and line frequency f_H (nominally 60Hz and 15.750kHz for monochrome transmissions) are derived from the subcarrier frequency f_{SC} = 3 579 611.
[88811 1] ±10Hz as follows:
$f_H = 4f_{SC} / 3x3x101$ Conversely, $f_{SC} = (909/4) f_H$
$f_V = 2f_H / 3x5x5x7$
These values may also be expressed as follows:
f_{SC} = 5 000 000 x 63 / 88 x 909 / 910 = 3 579 611.[88811 1]Hz
f_H = 4 / 910 x 5 000 000 x 63 / 88 = 15 734.[26573 4]Hz
f_V = 2 / 525 x 4 / 910 x 5 000 000 x 63 / 88 = 59.94[005 994]Hz

For N/PAL the field frequency f_V and line frequency f_H (nominally 50Hz and 15.625kHz for monochrome transmissions) are derived from the subcarrier frequency f_{SC} = 3 520 562.5 ±5Hz as follows:
$f_H = 4f_{SC} / (7x131 + 4 / 5x5x5x5)$ Conversely, $f_{SC} = (917/4 + 1/625) f_H$
$f_V = 2f_H / 5x5x5x5$

The attenuation of the colour difference signals before modulation is as follows:
M/PAL: E'_U and E'_V - <2dB @ 1.3MHz, >20dB @ 3.6MHz
N/PAL: E'_U and E'_V - <3dB @ 1.3MHz, >20dB @ 3.6MHz
All other systems: E'_U and E'_V - <3dB @ 1.3MHz, >20dB @ 4.0MHz

The bandwidth (-3dB points) of the modulated chrominance signal prior to modulation on the vision carrier is as follows:
Lower sideband:
All systems: f_{SC} - 1.300MHz
Upper sideband:
D/PAL and K/PAL (in People's Republic of China only): f_{SC} + 1.300MHz
I/PAL: f_{SC} + 1.066MHz
M/PAL: f_{SC} + 0.600MHz
N/PAL: f_{SC} + 0.620MHz
Other systems/territories: f_{SC} + 0.570MHz



Frequency spectrum of a PAL vestigial sideband transmission

The frequencies marked are relative to the vision carrier. The levels and slopes of the curves are stylised for clarity. The attenuation on the 'plateaux' is <3dB and is >20dB where the curves meet the x-axis. The colour subcarrier is supressed - the vertical magenta line indicates its frequency. The attenuation of the luminance signal by the optional notch filter is 6dB maximum at frequencies near f_{SC}. The width of the notch at the 3dB points is 400kHz.

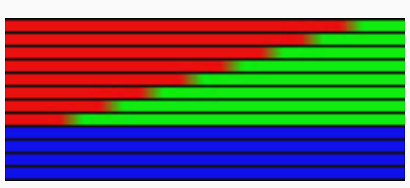
Colorimetry

Originally, the same CIE coefficients for the primary colours, and for the reference white of colour display devices, as for the NTSC standard were chosen. However, over the years the phosphors used in colour display tubes have changed, and they no longer match those for which the coefficients were chosen. For that reason, the following CIE coordinates are now used in PAL countries:

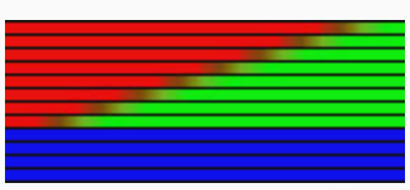
Red: x = 0.64   y = 0.33
Green: x = 0.29   y = 0.60
Blue: x = 0.16   y = 0.06
White Illuminant D_{65}: x = 0.313   y = 0.329

Resolution of PAL colour signals

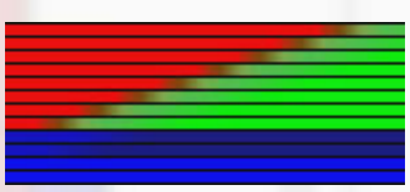
The diagrams below emulate various ways of displaying a small portion of an electronically generated colour signal comprising saturated red, green and blue areas in close proximity. If you switch your monitor to greyscale you will see that each diagram is identical in luminance.



Here is the signal displayed on an RGB monitor where the R, G and B signals have the same high bandwidth as the encoded Y or luminance signal.



Here it is displayed on an NTSC or PAL-S (Simple PAL, with no delay line) monitor where the (R-Y) and (B-Y) signals have about a quarter of the bandwidth of the Y signal, resulting in a smearing of the coloured transitions, although they are still defined by the high-bandwidth Y signal.

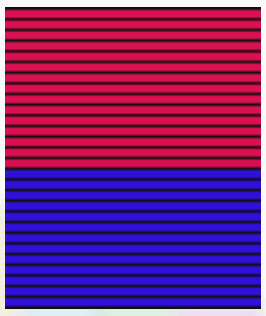


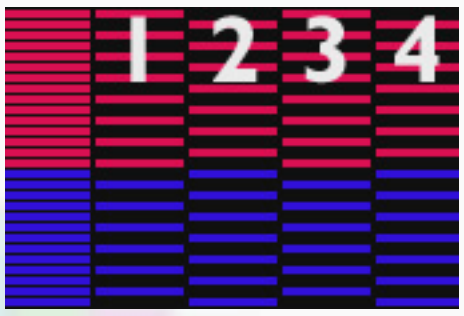
A PAL-D decoder averages the chroma from adjacent lines, though these are adjacent in time, not in position on the screen. The diagram represents two interlaced fields. If the lines are lettered A, B, C, etc from the top, the lines pairs that are averaged are A/C, B/D, C/E, D/F, etc. There is further smearing of the coloured boundaries because in this test signal the content of the adjacent lines is significantly different. Note that the first pair of blue lines is not only coloured incorrectly because it is mixed with the green of the previous lines, but that the shape of the 'point' of the green area is repeated in the blue lines, resulting in a visible loss of vertical resolution.

Here is a Simple PAL (PAL-S) display fed with a signal containing a large phase error. The error appears as different hues on adjacent pairs of lines, known as 'Hanover' or 'Venetian' blinds. With a PAL-D decoder employing a delay line, the colours would be the correct hue, but uniformly desaturated.

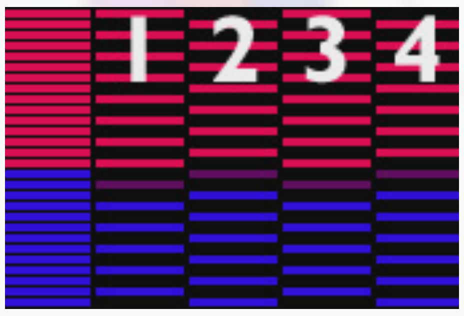
Twitter

Thanks to interlace, the overall flicker rate of 625/50 pictures is 50Hz. However, along horizontal edges there is 'twitter' at frame rate - ie 25Hz - which can be very noticeable when the adjacent areas have significantly different luminance values. The same frame-rate twitter pattern is visible on a monochrome receiver displaying any colour signal, but the effects on a colour receiver depend on the encoding standard. Here is what happens in the PAL colour standard across four fields of video:

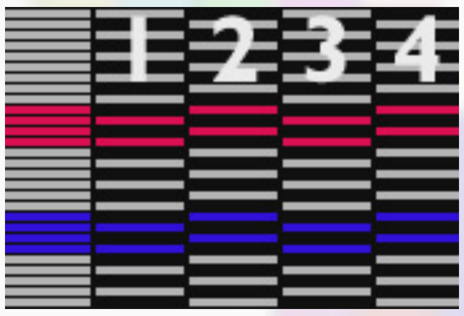


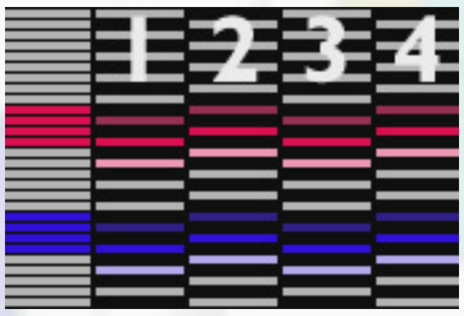


Let us take as an example a transition between a red area and a blue area, as in the detail shown on the left, which shows both fields superimposed (or a non-interlaced 'progressive' version, if you like). The colours chosen lie precisely along the (R-Y) and (B-Y) axes for ease of calculation. When scanned in the 625/50i standard the transition would appear on an RGB monitor as in the diagram on the right, over four successive fields of video. Since the two colour difference signals are transmitted simultaneously on each line but the PAL-D decoder averages colour difference signals from the current line and the previous line via a delay line, there are inaccuracies at the horizontal transition.



The actual chroma signals being transmitted are as shown in the RGB diagram (above right). Notice that at the transition there are adjacent lines of red and blue chroma. The decoder interprets this as a gross phase error and averages it as (red + blue)/2 = magenta/2; that is, desaturated magenta. In the decoded display shown on the right, there is twitter at 25Hz comprising a line of magenta at the colour transition, in addition to the 25Hz luminance and red/blue twitter.





Although I have chosen a saturated red/blue transition, the effect happens wherever saturated colour transitions appear, and is particularly noticeable with text on a white background, as in this example (far right) where the PAL-D display is compared to an RGB display (near right).

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SECAM-IV

Linear NIR

SECAM IV was a colour standard developed by the Russian research institute NIR (Nautschnuiu Issledowatelskaya Rabota). In fact two standards were developed: *Non-linear NIR* in which the square root of the amplitude of the chroma signals is transmitted (in a process analogous to gamma correction) and *Linear NIR* which omits this process. SECAM-IV as described below is the Linear version of NIR.

The USSR subsequently entered into an agreement with the French to produce an improved common SECAM standard from their two individual ones. However, the one chosen was the present standard described above (sometimes called SECAM III or SECAM Opt (optimised). Colour test transmissions began in 1963 from Moscow on System D, probably using SECAM IV, or something similar, before changing to SECAM III in a simultaneous launch with France on 1 October 1967.

News of the new Soviet colour system arrived in the west around 1966 at which time the BBC were quoted as saying "It is of interest to note that this proposal appears identical with one made by Mr. B. W. B. Pethers, a BBC engineer, in April 1963, but which was not pursued because at the time it was thought its advantages, with respect to the other systems, were not sufficiently attractive." Pethers' original system was similar to Non-linear NIR, and he also developed two variants.

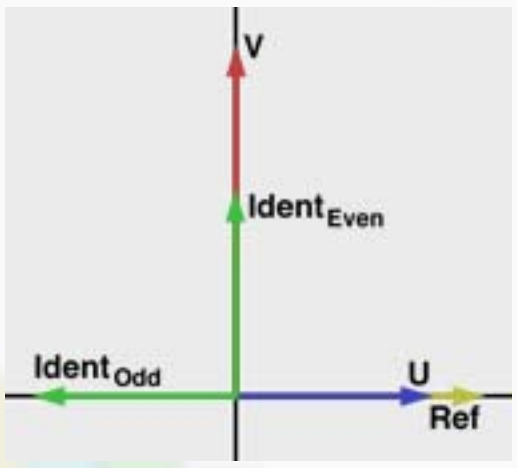
Tests were made using NIR by the ITA in the UK, and there was a strong lobby for adopting the standard throughout Europe before the various nations polarized into a PAL-SECAM split.

Although derived from NTSC, SECAM IV is quite unlike either PAL or SECAM. It uses a 'third way' to reduce hue errors.

On one line a PAL-like supressed-carrier quadrature amplitude modulated subcarrier is transmitted, and on alternate lines a similar signal is sent, but this time with a constant phase as a reference. Thus both the information and the reference carriers undergo similar phase shifts in transmission and the demodulated signals are free of phase errors. A similar idea is used in the 'colour-under' system found in domestic videotape recorders. The high-frequency chrominance signal is heterodyned to a much lower frequency range and along with it a reference signal is recorded. On playback this reference is used as a beat frequency oscillator to restore the chrominance to its proper frequency and since both suffer the same variations in tape speed the recovered chrominance is jitter-free.

SECAM-IV/Linear NIR has two deficiencies that are absent from the other standards (NTSC, PAL and SECAM III) and which arise from the use of the transmitted reference signal in its raw wideband form rather than a locally generated reference signal. Firstly, because both the picture chroma and the reference signal from adjacent lines are applied to a ring demodulator, any interfering signal which is present on both inputs will demodulate itself, producing a dc component on the output. Depending on the frequency of the interfering signal this gives either an overall colour cast or a coloured venetian blind pattern. Secondly, the effect of noise on the chroma signal is to reduce its demodulated amplitude, resulting in desaturation which is particularly noticeable on flesh tones.

The subcarrier frequency used in 625/50 SECAM IV is 4 433 618.75Hz as in the PAL standard.



The instantaneous voltage $E_{SECAM-IV}$ of the complete encoded SECAM IV signal is given by:

$E_{SECAM-IV(Line\ n)} = E'_Y + E_{S1}$

$E_{SECAM-IV(Line\ n+1)} = E'_Y + E_{S2}$

where:

Line n refers to the lines carrying S1 (chrominance) information

Line n+1 refers to the lines carrying S2 (reference) information

E'_R, E'_G and E'_B are the gamma corrected primary colour signals

$E'_Y = 0.299E'_R + 0.587E'_G + 0.114E'_B$

E_{S1} and E_{S2} are the instantaneous amplitudes of the subcarrier contained on alternate lines.

The modulation mode of the colour subcarrier is suppressed-carrier amplitude-modulation of two subcarriers in quadrature (QAM).

The chrominance signals are built up as follows:

Firstly the two colour difference signals are scaled:
$D'_R = (E'_R - E'_Y) / 1.14$
$D'_B = (E'_B - E'_Y) / 2.03$
These baseband colour difference signals have a bandwidth of >1.5MHz

Then the colour difference signals are modulated onto a subcarrier whose instantaneous amplitude on alternate lines is given by:
$E_{S1} = ((D'_R{}^2 + D'_B{}^2)^{1/2} + E_p) \cos (w_0 t + \text{phi}(t))$
$E_{S2} = ((D'_R{}^2 + D'_B{}^2)^{1/2} + E_p) \cos (w_0 t + \text{phi}_0)$
where:
E_p is a DC voltage equal to 10% of the maximum signal
$\text{phi}(t) = \arctan (D'_B / D'_R)$
phi_0 is the positive (B-Y) axis
w_0 is 2 pi times the subcarrier frequency.

In the receiver the ident switch is synchronised by 40µs trains of chrominance subcarrier occupying six lines of field-blanking period on Lines 6 to 11 in Field 1 and Lines 319 to 324 in Field 2. The p-p amplitude of the subcarrier trains is 30% of the luminance (blanking to peak white) amplitude and their phase is 180° on odd lines and 90° on even lines (relative to the (B-Y) axis. The colour difference signals D'_R and D'_B are recovered by multiplying the chrominance signal from the current line with that from the previous line which has been stored in an acoustic glass delay line (whose tolerance has to be twice as tight as that of a PAL delay line). The E_{S2} signal is used as a reference oscillator for the E_{S1} signal which contains the chrominance phase information and so a reference crystal oscillator is not required in the receiver. The E_p component of the modulated chrominance signals ensures that the subcarrier never falls below 10% amplitude, so that the reference signal is always present. The E_{S2} signal should have an amplitude 10 - 20 times that of the E_{S1} signal when applied to the demodulator.

For SECAM IV the field frequency f_V and line frequency f_H (nominally 50Hz and 15.625kHz for monochrome transmissions) are derived from the subcarrier frequency f_{SC} = 4 433 618.75Hz as follows:
$f_H = 4f_{SC} / (1135 + 4/625)$ Conversely, $f_{SC} = (1135/4 + 1/625) f_H$
$f_V = 2f_H / 625$

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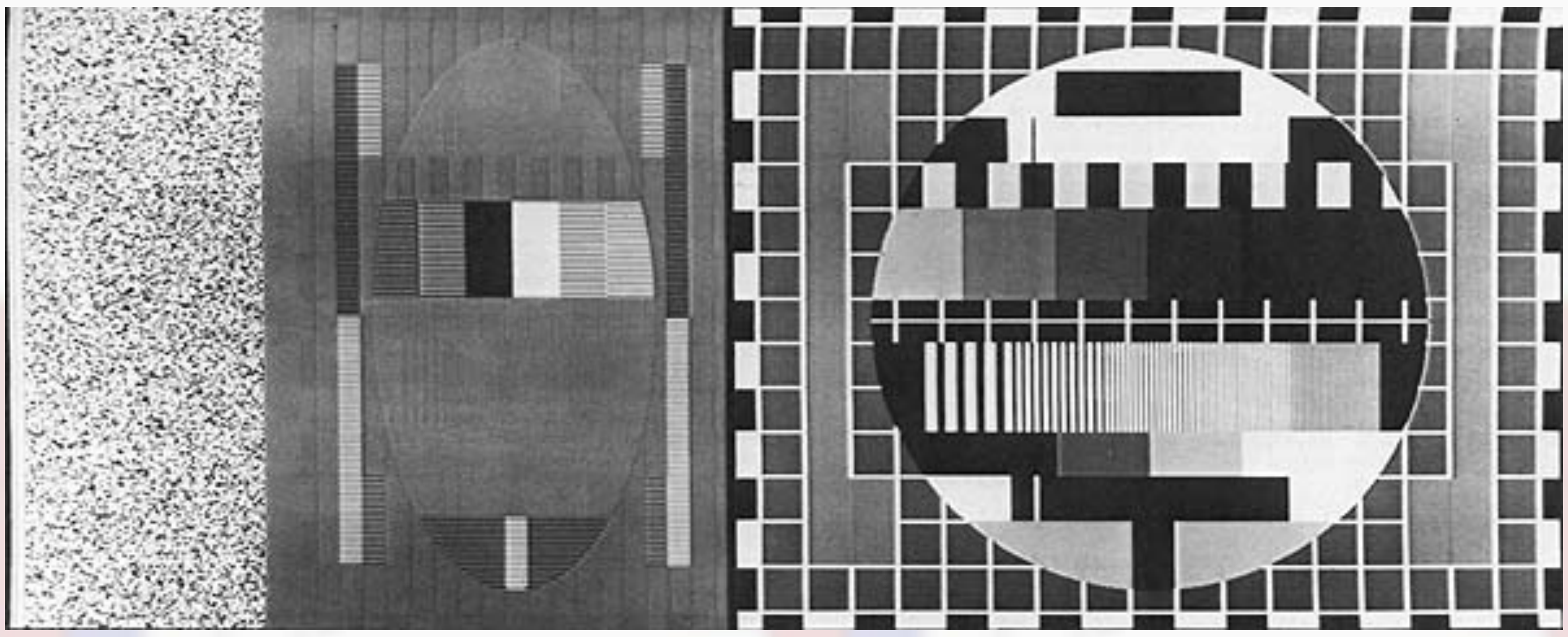
MAC

A new standard for a new platform

MAC, *Multiplexed Analogue Component* was a standard devised in the UK by the Independent Broadcating Authority (IBA) for delivering high quality colour pictures via direct broadcast satellites that would be independent of European countries' individual choice of (terrestrial) colour coding standard.

In satellite transmissions the vision signal, including colour and sound subcarriers, is frequency modulated onto the main carrier with a channel bandwidth of 27MHz. FM has a particular characteristic in that the level of noise that is inevitably added to the signal rises with modulation frequency. This is countered by increasing the amplitude of higher modulation frequency components on transmit (pre-emphasis) and reducing them on receive (de-emphasis) to mask the noise introduced by the modulation process. This works well with audio and monochrome video signals which have few large high-frequency amplitudes, and so raising their level does not cause problems with over-modulation. However, encoded colour video signals contain a great deal of high-amplitude high-frequency components thanks to the colour subcarrier, and pre-emphasising them can result in noisy and distorted colour signals.

For that reason a new non-compatible colour standard was devised that transmitted baseband luminance and colour signals. The luminance signal is time-compressed by a factor of 3:2 and the two colour difference signals are compressed by 3:1 and transmitted individually on alternate lines prior to the luminance signal. Instead of a line synchronising pulse, the remaining 10-12μs of the line period is filled with a digital signal which contains audio, sync information and other housekeeping data. The 25 lines of each field synchronising period are available for other data such as teletext. The MAC receiver stores the separate components and from them assembles a combined video signal to pass on to the receiver. This can be in the form of component (RGB or YPbPr), S-video (Y + C) or even CVBS (Colour/Video/Blanking/Syncs - the standard encoded video signal, which could also be UHF modulated to feed a standard receiver). A representation of how a 'raw' MAC picture might be displayed on a conventional receiver (with height reduced and infinitely fast line flyback) is shown below.



Other advantages of MAC over encoded pictures are the wider luminance and chrominance frequency responses that can be accommodated and the absence of any cross-colour effect on the picture. Various versions of MAC have been proposed, the latest being an 'extended' version that allows 16:9 pictures to be transmitted, but the standard was quickly superseded in the early years of direct-to-home satellite broadcasting by entrepreneurs who realised that a cheap and cheerful way of transmitting existing format PAL, SECAM or NTSC pictures to unmodified television sets would generate more revenue more quickly, despite the poorer technical quality, and MAC transmissions are now few and far between.

The main differences between the various 'flavours' of MAC concern themselves with the way the 12μs of audio/data information is modulated and the resultant bandwidth of the whole signal. In some variants the audio, data and video signals may be combined at baseband, whereas with others the modulation mode is different for the vision and sound/data. Other variants are designed for non-satellite use such as cable distribution or studio-studio links.

A-MAC carries the digital information - sound, data (teletext etc) - on an fm subcarrier at 7MHz. Since the vision bandwidth of a standard MAC signal is 8.4MHz, the horizontal resolution on A-MAC has to be reduced to make room for the 7MHz carrier. A-MAC has not been used in service.

B-MAC uses teletext-style non-return-to-zero (NRZ) signalling with a capacity of 1.625Mb/s. The video and audio/data signals are therefore combined at baseband. This system has been used in Australia.

C-MAC was the variant approved by the European Broadcasting Union (EBU) for satellite transmissions. The digital information is modulated using 2-4PSK (phase-shift keying), a variation of quadrature PSK where only two of the phasor angles (±90°) are used. The data capacity is 3Mb/s, but the data has to be sent to the transmitter separately from the vision, and the transmitter switches between fm (vision) and PSK (sound/data) modulation during each television line period..

D-MAC is a reduced bandwidth variant designed for transmission down cable, and was the one chosen by the IBA for the UK satellite service. In it the data is duo-binary coded with a data burst rate of 20.25Mb/s so that 0° as well as ±90° phasors are used, resulting in a bandwidth of 8.4MHz instead of the 27MHz of C-MAC. However, most continental cable systems work on 7MHz channel spacing for which even D-MAC is too wide, hence D2-MAC:

D2-MAC uses half the data rate of D-MAC (ie 10.125Mb/s) and a reduced vision bandwidth in order to squeeze the whole signal (which is combined at baseband) into 5MHz.

E-MAC (Extended MAC) is a widescreen version of C-MAC. Originally designed for 15:9 pictures, it later adopted the 16:9 aspect ratio. The point about E-MAC is that all the 4:3 information is transmitted exactly as in C-MAC so that C-MAC receivers are still compatible. The extra luminance and chrominance information is tucked away in the field blanking interval and parts of the line blanking interval that are made available by reducing the sound/data capacity. A 'steering' signal is transmitted to indicate to the 16:9 receiver whereabouts the 4:3 picture belongs in relation to the two pieces of extra side information and the receiver then stitches the three seamlessly together to produce a 16:9 picture.

S-MAC ('Studio MAC') is a standard used mainly in the USA where handling component signals gives better results than manipulating NTSC directly. It is not possible to mix standard MAC signals in the studio environment because the (R-Y) and (B-Y) components are carried on alternate lines, so in S-MAC, the luminance is compressed by 2:1 and the two chrominance signals by 4:1 so that all three may occupy the same line. The vision bandwidth required is therefore 11MHz, and S-MAC can be carried on a single circuit and converted losslessly to and from C-MAC at any stage.

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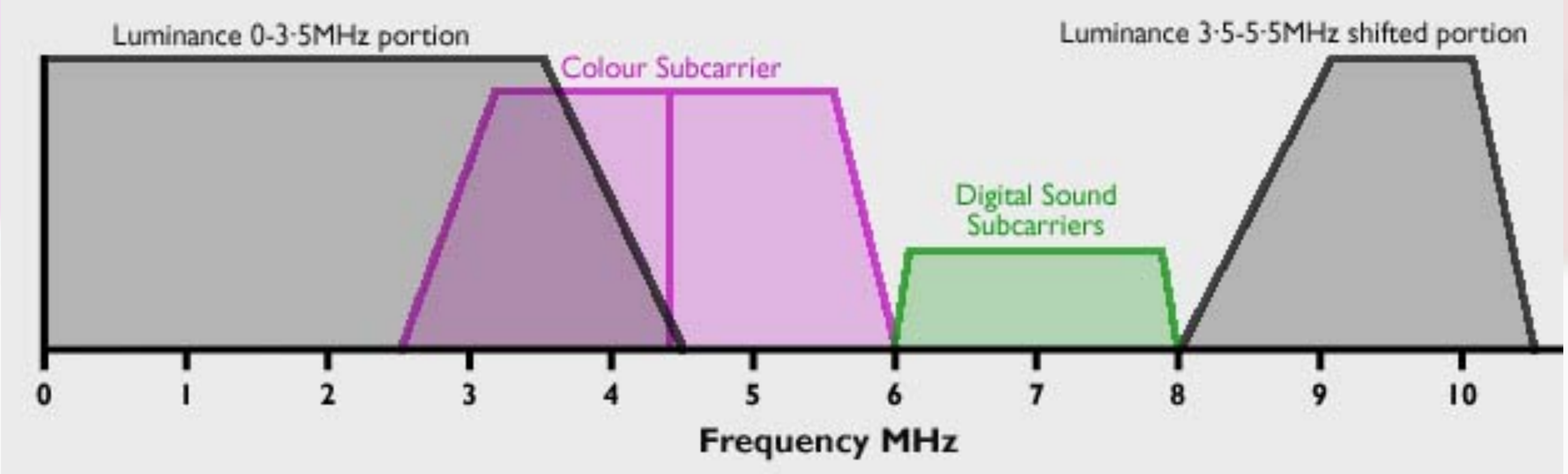
Extended PAL

A Great British Compromise

Extended PAL was the BBC's counter-proposal in 1982 to the IBA's MAC standard for direct broadcast to home (DBH) via satellite. The BBC believed that agreement on standards other than PAL or SECAM was unlikely to be reached in time for the planned start of DBH.

One of the drawbacks of PAL (and all the other compatible coded colour standards) is that the chrominance signal, modulated onto a subcarrier, occupies the same frequency space as part of the luminance signal. The BBC argued that since standard PAL decoders filter out most of the luminance information above about 3.5MHz in order to reduce the visibility of the chrominance subcarrier as crawling dots or hatching, and since the presence of these high luminance frequencies in the transmission inevitably results in false colour artifacts when they find their way into the chrominance channel of the decoder, it would be better if they were not transmitted at the same frequency as the chrominance signals. Instead, in Extended PAL they are frequency shifted by an amount equal to the colour subcarrier frequency (4.43361875MHz) and transmitted between around 8.5-10.5MHz. This leaves a 2MHz gap between the chroma information and shifted luma (at 6-8MHz) which is available for digital audio and data carriers.

Thus, an Extended PAL receiver would separate out the two portions of luminance signal and the chrominance signal, shift back the higher luminance frequencies to their proper position by using the colour reference oscillator as a beat-frequency oscillator, and produce a colour picture with full luminance bandwidth (up to 5 or 6MHz) and no false colour or dot-crawl artefacts. A standard PAL receiver would simply ignore the high-frequency luminance component of the signal and produce a colour picture with 3.5MHz bandwidth but with no false colour or dot-crawl artefacts.



Frequency spectrum of an Extended-PAL baseband signal

The vision signal and subcarriers are frequency-modulated onto the satellite carrier with a transponder channel width of 27MHz. The levels and slopes of the curves are stylised for clarity. The attenuation on the 'plateaux' is <3dB and is >20dB where the curves meet the x-axis.

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PAL Plus

Compatible Analogue Widescreen

PAL Plus is not a different colour standard as such. It is a widescreen system designed to transmit 16:9 aspect ratio pictures that are compatible with standard 4:3 receivers within normal terrestrial analogue channels. Full-height anamorphic (FHA) pictures are generated at the studio with 16:9 aspect ratio and using all 575 available television lines. The pictures are then converted to 'letterbox' format with so called 'helper' signals transmitted on the unused black lines above and below the picture which are intended to be invisible to the 4:3 viewer. A PAL Plus receiver uses these helper signals to reconstruct the missing vertical information, and presents a full-resolution 575-lines high picture to the widescreen viewer.

Although the colour standard is essentially identical to normal PAL, some optimisation and processing of the signal is done at the transmitter and receiver to improve some of the shortcomings, such as chroma and luma resolution and cross-colour artefacts. These techniques are called 'Clean PAL' encoding and decoding or 'Colour Plus' and improve the colour pictures on both standard and PAL Plus receivers.

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Summary of equations and vectors

in the coding and decoding processes

Here is a summary of the main relationships between the signals used in the coding and decoding of analogue colour pictures. Different sets of coefficients for converting R'G'B' to Y', (R'-Y') and (B'-Y') have been adopted for standard and high definition standards. The HD equations apply only to component and not composite encoded signals.

P'_b and P'_r are scaled values of (B'-Y') and (R'-Y') used in analogue component systems. C'_b and C'_r are scaled and offset (by +350mV) values of (B'-Y') and (R'-Y') used for digital quantisation.

In this section I have included the prime mark (') to indicate a gamma-corrected value.

Coding

Standard Definition 525/60i, 625/50i and 1250/50i HD	High Definition 1125/60i and 750/60p	High Definition 1920x1080 and 1280x720
$Y' = 0.299R' + 0.587G' + 0.114B'$ $(R'-Y') = 0.701R' - 0.587G' - 0.114B'$ $(G'-Y') = -0.299R' + 0.413G' - 0.114B'$ $(B'-Y') = -0.299R' - 0.587G' + 0.886B'$	$Y' = 0.2126R' + 0.7152G' + 0.0722B'$ $(R'-Y') = 0.7874R' - 0.7152G' - 0.0722B'$ $(G'-Y') = -0.2126R' + 0.2848G' - 0.0722B'$ $(B'-Y') = -0.2126R' - 0.7152G' + 0.9278B'$	$Y' = 0.2126R' + 0.7152G' + 0.0722B'$ $(R'-Y') = 0.7874R' - 0.7152G' - 0.0722B'$ $(G'-Y') = -0.2126R' + 0.2848G' - 0.0722B'$ $(B'-Y') = -0.2126R' - 0.7152G' + 0.9278B'$
$P'_b = 0.564(B'-Y')$ $P'_r = 0.713(R'-Y')$ $C'_b = 0.564(B'-Y') + 350mV$ $C'_r = 0.713(R'-Y') + 350mV$	**1125/60i** $Y' = 0.212R' + 0.701G' + 0.087B'$ $P'_b = (B'-Y')/1.826$ $P'_r = (R'-Y')/1.576$	$P'_b = 0.5(B'-Y')/(1-0.0722) = 0.5389(B'-Y')$ $P'_r = 0.5(R'-Y')/(1-0.2126) = 0.6350(R'-Y')$ $C'_b = 0.5389(B'-Y') + 350mV$ $C'_r = 0.6350(R'-Y') + 350mV$

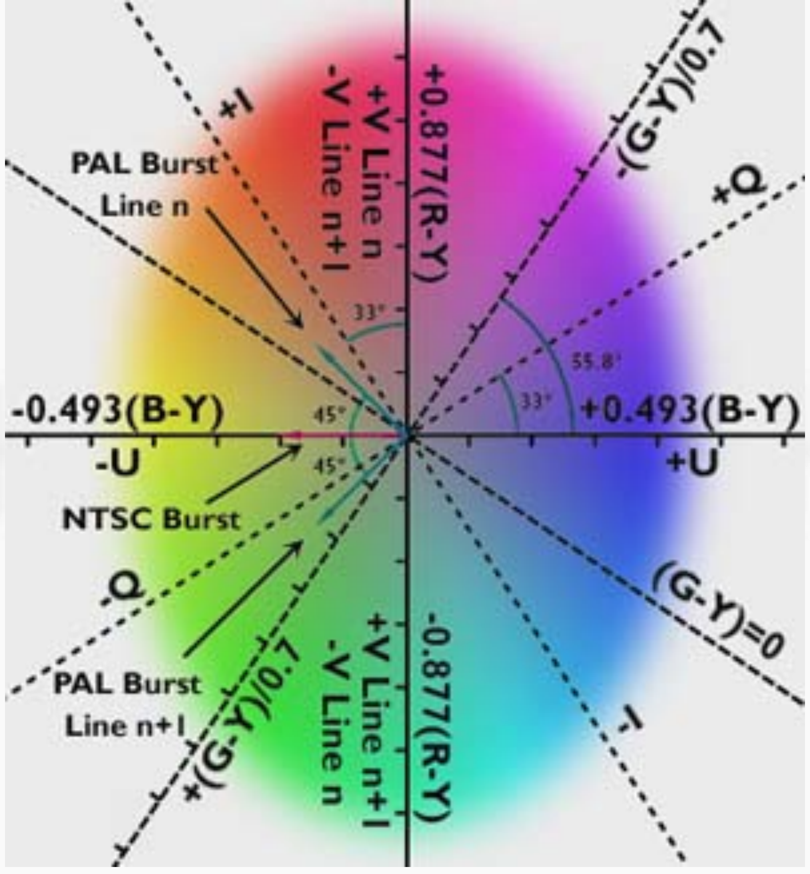
$U' = 0.493(B'-Y')$
$V' = 0.877(R'-Y')$

$I' = 0.74(R'-Y') - 0.27(B'-Y')$
$Q' = 0.48(R'-Y') + 0.41(B'-Y')$
or
$I' = 0.60R' - 0.28G' - 0.32B'$
$Q' = 0.21R' - 0.52G' + 0.31B'$

Decoding

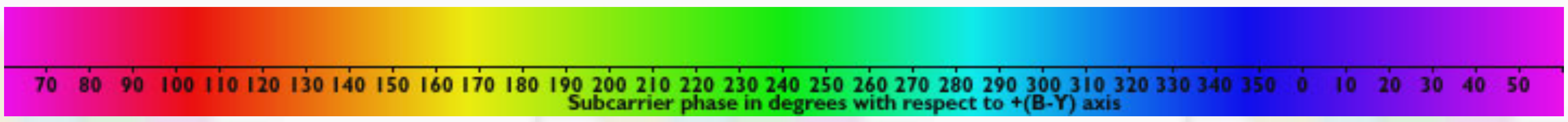
$(R'-Y') = 0.96I' + 0.62Q'$
$(G'-Y') = -0.28I' - 0.54Q'$
$(B'-Y') = -1.10I' + 1.70Q'$
or
$(R'-Y') = 1.13U$
$(G'-Y') = -0.575U - 3.94V = -0.509(R'-Y') - 0.194(B'-Y')$
$(B'-Y') = 2.03V$
or
(R'-Y') = 1.13[resultant of subcarrier sampled at 90.0 deg wrt +(B'-Y') axis]
(G'-Y') = 0.70[resultant of subcarrier sampled at 55.8 deg wrt +(B'-Y') axis]
(B'-Y') = 2.03[resultant of subcarrier sampled at 0.00 deg wrt +(B'-Y') axis]

$R' = Y' + (R'-Y')$
$G' = Y' + (G'-Y')$
$B' = Y' + (B'-Y')$



The diagram on the left shows the vectors and phasors involved in encoding NTSC, PAL and SECAM signals. The I and Q axes relate to NTSC signals only. The background colours and the (G-Y) axes are shown for (Line n) only in the case of PAL signals. In the case of SECAM signals the vectors relate to the baseband U and V signals only.

The diagram below shows the gamut of saturated colours. The horizontal axis shows the phase of the NTSC subcarrier, or the the PAL subcarrier on (Line n).



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Television Website Bookmarks

Mike Brown/MB21/Ether.net
Andrew Emmerson/Paul Stenning/405 Alive/British Vintage Wireless Society
Keith Hamer
Darren Meldrum
Richard Russell
Justin Smith/Aerials and TV
Andrew Wiseman/625 Room
Bill Wright

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Pembers' Ponderings

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Last updated on 06/28/2017 16:38:10Last updated on 06/28/2017 16:37:33