SUBCARRIER TO LINE RELATIONSHIPS

INTRODUCTION

This information sheet outlines the reasons for choosing 4.43361875MHz as the colour sub-carrier frequency for the PAL chrominance information.

Some years before the full colour service was introduced in 1969 the U.K. Television transmission system had been re-engineered into the UHF band.

Four monochrome 625-line T.V. channels, on UHF carrier frequencies, were to be distributed to the majority of the population by the time the system was fully installed.

The forty UHF channels allocated to T.V. were all used to ensure minimum co-channel interference between adjacent transmitting stations.

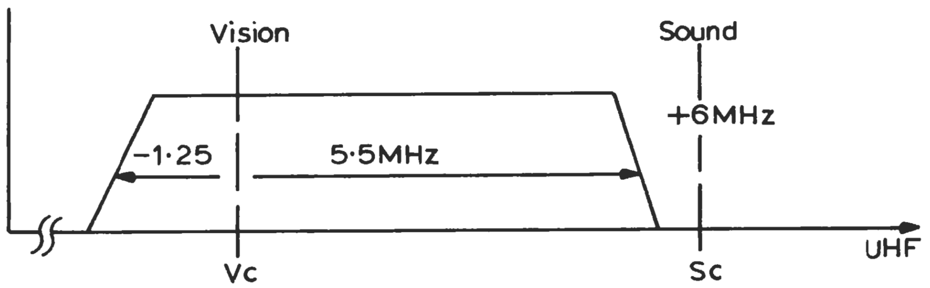

Figure 0.1 An 8MHz UHF Channel

Each 8MHz channel had no room for modulating signals outside the basic 5.5MHz vision channel provided for monochrome.

However it had already been proved that the colour information, modulated onto its subcarrier, could be fitted in the upper part of the monochrome signal spectrum, without serious loss of quality to existing monochrome receivers and also giving a compatible picture in monochrome.

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(The term "subcarrier" was coined to describe the colour carrier to avoid confusion with the main UHF vision carrier when talking about the UHF signal).

1. Choice of CSC Frequency

1.1 The colour subcarrier must lie within the 5.5MHz of the baseband video signal.

1.2 It must allow double sideband operation of the chrominance, which has a bandwidth of ≃1.3MHz.

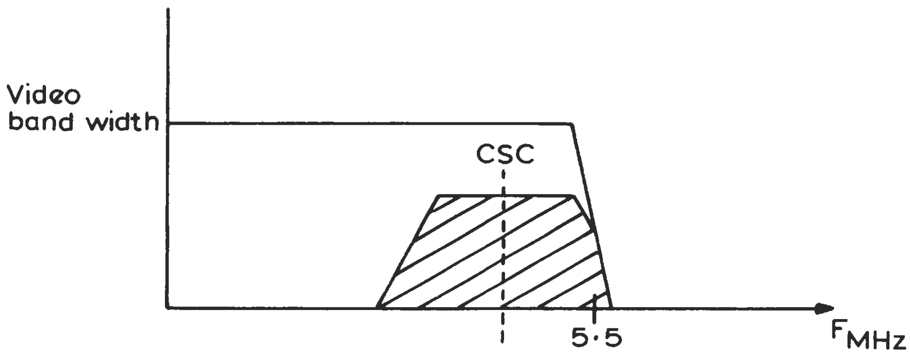

Figure 1.1 Chrominance inside the 5.5MHz Luminance Bandwidth

This puts the choice in the region 4 to 4.5MHz or so.

1.3 The final choice is made to reduce the visibility of the patterning, which occurs on a monochrome display, due to the superimposed colour subcarrier.

2. BRIGHTNESS MODULATION BY CSC

Figure 2.1 shows the effect of displaying a mid-grey on a monochrome picture tube.

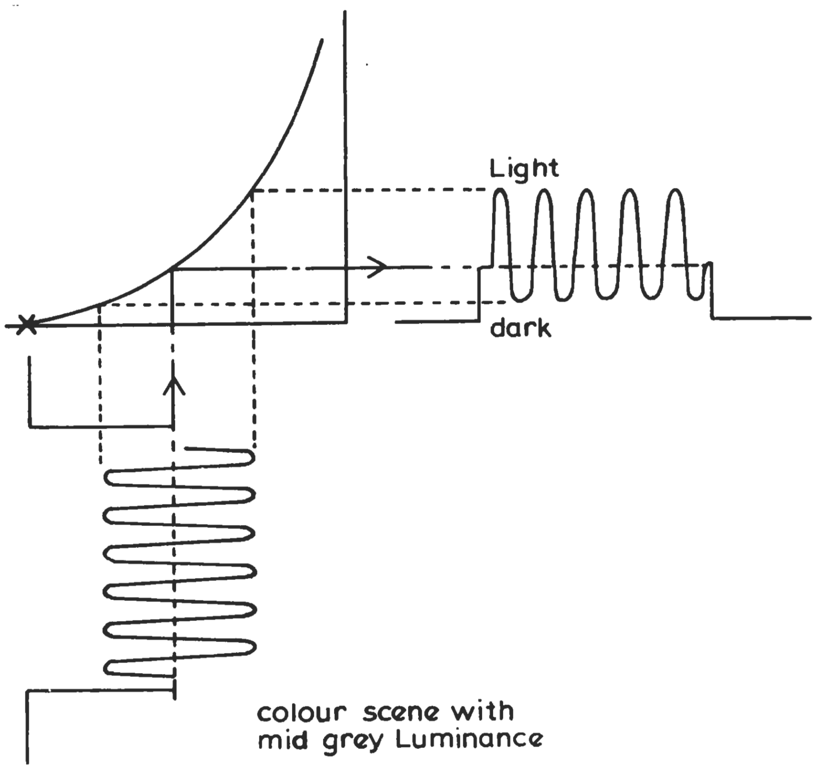

Figure 2 Brightness Modulation of the Picture Signal

The half-cycles of colour subcarrier cause alternate light/dark brightness variations across the line.

The picture tube is non-linear, and it amplifies positive half-cycles more than negative half-cycles. When subcarrier is added, the picture area therefore gets an average brightness increase as well as the light/dark individual variations across each line.

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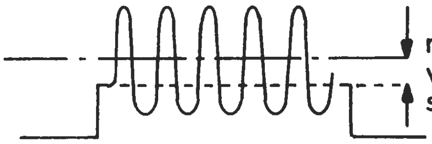


Figure 2.2 Overall Brightness Change with CSC

Colour receivers contain a trap filter to prevent colour subcarrier reaching the display. However it was not feasible to "retro-fit" this to all the monochrome sets in use b.c. (before colour).

It is actually useful to have the mean brightness shift caused by subcarrier on the mono display.

2.1 Y Signal

The basic brightness, or Y signal, is made by taking 0.3 Red + 0.59 Green + 0.11 Blue from the colour camera outputs.

This would be a true brightness signal if it were matrixed from the camera tube outputs, which are linearly proportional to the scene light in the red, green and blue regions.

However, the camera channel outputs have been pre-corrected for the display tube gamma, so the R G and B reaching the coder are non-linearly related to scene light. They are sometimes called R', G' and B' to remind us of this. The matrix which takes 0.3R + 0.59G + 0.11B in the coder is combining non-linear signals, and does not give a true luminance signal.

It's the best we can do however. The colour decoder uses this Y and R-Y, B-Y (and G-Y) to regenerate R G and B. E.g. Y + (R-Y) = R. Errors in the Y term only cancel out!

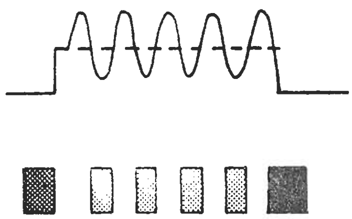
The monochrome receiver can use this Y signal, which is smaller than a true Y in areas of highly saturated colour. The overall brightness shift upwards caused by the colour subcarrier helps to restore the correct tonal gradation of a colour signal seen on the mono display.

3. FINAL CHOICE OF CSC FREQUENCY

A subcarrier frequency which is not locked to the line structure, but is free running, gives a moving patterning effect. The eye/brain is very sensitive to movement, and responds to this even at low voltage levels.

A locked pattern is much less visible.

3.1 Line-Locked



Light / dark variations in same place on each line

The use of a line-locked subcarrier means that there are an exact number of cycles of CSC in each television line. The light/dark brightness variation, caused by subcarrier, repeat in the same phase for every television line, causing vertical lines of brightness modulation, which are very visible.

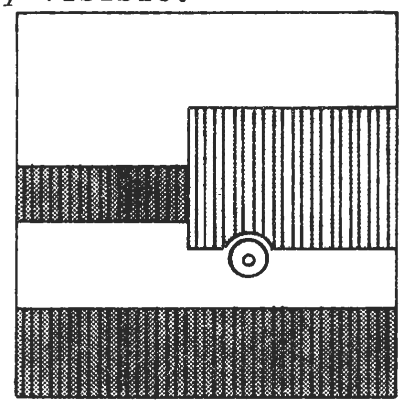


Figure 3.2 Visibility of Line-Locked Subcarrier

3.2 Odd Multiple of 1/2 Line Frequency [(N + 1/2) x H]

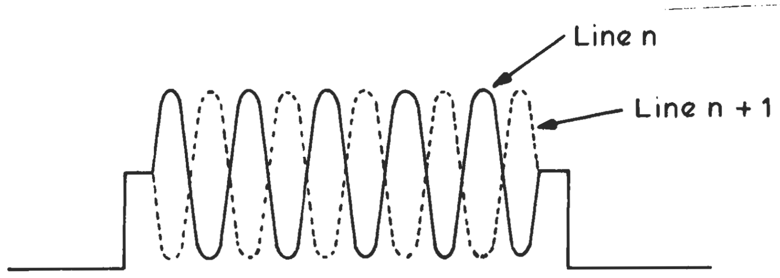


Figure 3.3 Effect of 1/2 Cycle Extra Per Line

Now the light/dark variations of one line fall adjacent to the dark/light variations (ie opposite phase) on the next.

Due to interlace, the display shows a line in between from the alternate field.

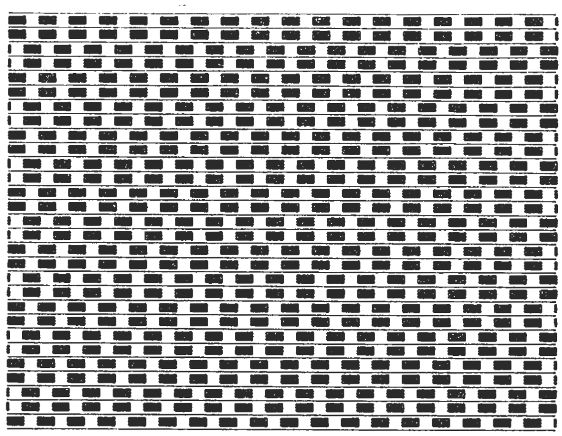


Figure 3.4 (N + 1/2) H Dot Patterns

This is the ideal choice for an NTSC-type coding system.

A 625/50Hz NTSC colour system would use 283 1/2 x H as its subcarrier frequency - (4.4296875MHz).

At this high frequency, the dot pattern is difficult to see, even with quite high levels of colour subcarrier.

3.3 (N + 1/2) H with PAL Systems

(N + 1/2) H subcarrier is fine for transmission of U signals. In a PAL system, however, the V signal is inverted on alternate lines. When a V inversion occurs, the V chroma undergoes a 1/2 cycle phase change, which then gives it the same phase, relative to the line structure, on each line.

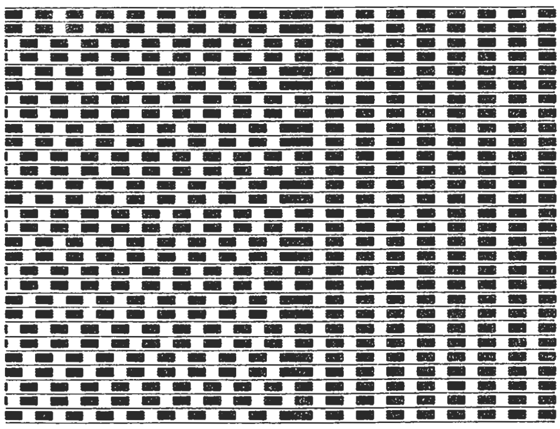


Figure 3.5 (N + 1/2) H Subcarrier for PAL U & V Signals

Figure 3.5 shows, using (N + 1/2) H csc, the visibility of a predominantly U colour (e.g. yellow) and a predominantly V colour (e.g. cyan).

3.4 (N + 3/4) x H Colour Subcarrier for PAL

By adding an extra 1/4 line frequency to the NTSC subcarrier, a more suitable dot pattern is generated for both U chroma and PAL-switched V chroma.

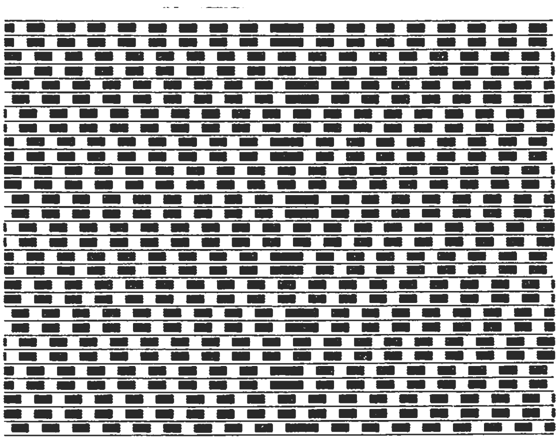


Figure 3.6 (N + 3/4) x H Subcarrier for PAL U & V Signals

The result is a pattern which shifts to the right or left by a quarter cycle per line, i.e. the pattern repeats over four lines.

After a complete picture, 625 lines, the pattern repeats, but is one line higher giving an apparent slow vertical crawl to the pattern.

Figure 3.7 shows the top of active picture with standard line numbers.

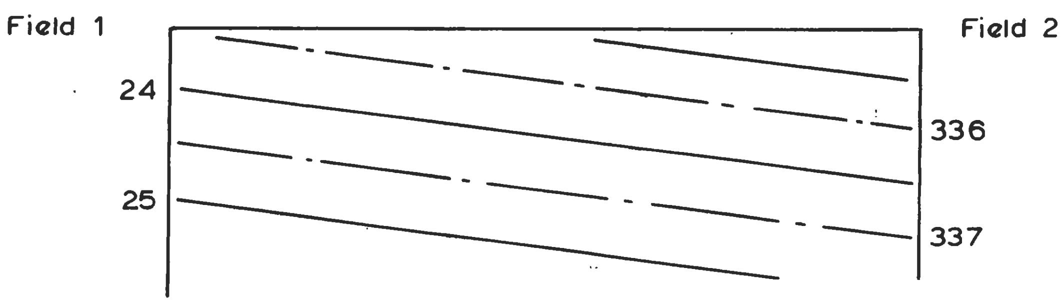


Figure 3.7 Interlaced Display

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The line above any chosen line is displayed 312 lines after the chosen line, i.e. an exact number of cycles of CSC at N + 3/4 cycles per line.

This explains the pairing of lines with the same dot pattern on alternate fields; and the dot pattern "crawl" due to the sequential display of fields.

3.5 PAL Precision OFFset of 25Hz

If the subcarrier frequency is now increased by an extra 25Hz (1/625 x H), the phase of dot pattern on the interlaced line will be 1/2 cycle shifted from that in section 3.4.

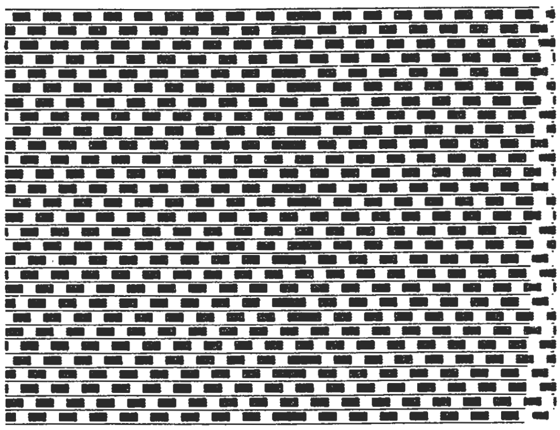

Figure 3.6 Dot Pattern with added 25Hz

This gives a further reducton of dot pattern visibility on the monochrome display.

3.6 PAL Subcarrier Frequency

PAL subcarrier therefore has a frequency of (283 + 1/2 + 1/4 + 1/625) x line frequency, for the 625/50Hz line standard.

3.7 Non-standard Colour Subcarrier to Line Frequency Relationship

The precise relationship quoted in 3.6 was originally proposed to reduce the visibility of CSC on a monochrome display tube. If this relationship is lost, the CSC will produce a pattern which moves relative to the line structure of the scanning process. The eye finds rapid movement produces a greater stimulus than static patterns and the subcarrier visibility increases.

However, more important to the production of television programmes is the effect on video tape replay. Due to the mechanical write-read process of VT, the off-tape signal has timing variations which must be smoothed out before the signal will satisfactorily lock a monitor. The Timebase Corrector of a VT compares the tape signal timing with a local reference syncs and burst, of stable timing, from the station spg. The TBC then dynamically adjusts the delay applied to the off-tape signal, each line, to make the output timing match the stable reference.

At the output of the TBC, the signal's line and field components are therefore the same frequency as the reference syncs supplied to the TBC. Also the phase and frequency of the off-tape colour subcarrier is the same as that of the reference subcarrier.

If the reference spg has a <u>correct</u> CSC-H frequency relation, but the recording source was wrong, then either:

1. The TBC can match the line timing, and the colour subcarrier timing will drift out due to the frequency difference

OR 2. The TBC can correctly match the colour subcarrier off-tape to the reference, in which case the line timing will drift out!

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In practice it tries to do both and a conflict occurs which results in colour dumping. Correction of colour phase occurs until the line timing error is beginning to be serious, when the TBC then restores correct line timing:- to do which it must temporarily lose colour correction, i.e. colour dump, causing a flash on the output picture.
The greater the loss of CSC-H, the more often it must dump colour correction to hold line timing somewhere near correct.

4. PHASE RELATIONSHIP OF CSC-H

Take a test signal containing only U (Unswitched) subcarrier.

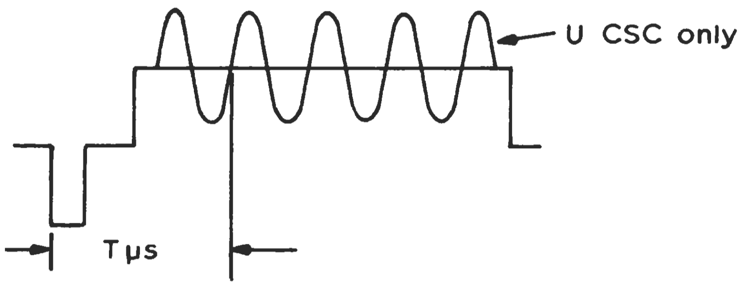

Figure 4.1 Test Signal with U CSC

A delayed T/B scope is used to examine the CSC phase at a fixed point on each line, say Tμs after line sync leading edge.
Let's just look at one line, say line N.

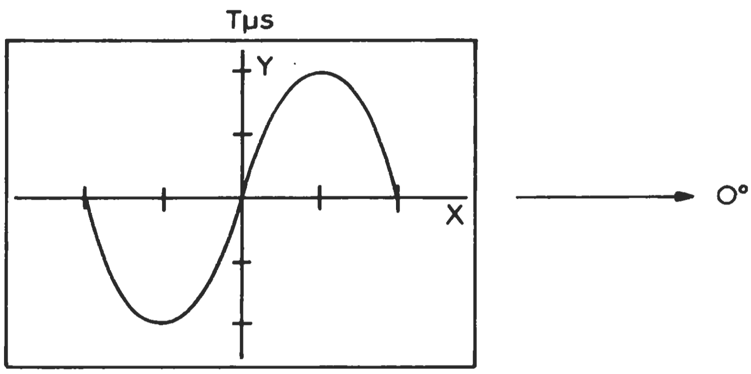

Figure 4.2(a) Phase of CSC at line, T, on Line N

Assume that on line N, a CSC zero crossing, +ve going, is displayed on the centre of the X scale. Call this 0° of phase.
Now if we look on line N + 1 at the same point, 283 and 3/4 cycles of CSC have occurred since the last time we looked.

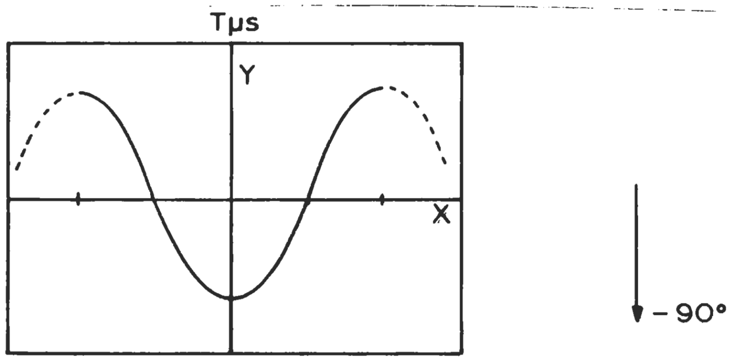

Figure 4.2(b) Phase of CSC at line T, Line N + 1

The nearest +ve zero crossing occurs 1/4 cycle later along this line, and therefore the phase at the time we looked was -90° relative to line N.

Now, on line N + 2 a further 283 and 3/4 cycles have been produced, and when we look at time, T, and the positive zero crossing is 180° away, compared to line N.

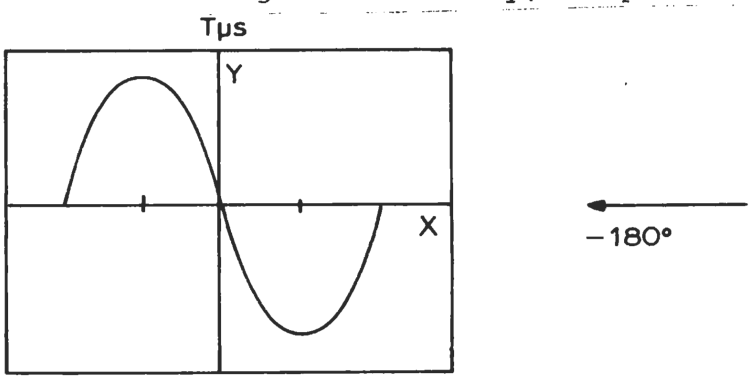

Figure 4.2(c) Phase of CSC at time T, Line N + 2

On line N + 3, the zero crossing is 270° away from that of line N, and the whole sequence will repeat after 4 lines, when a complete number of cycles of colour subcarrier have occurred (1135).

4.1 We have assumed 283 3/4 times line frequency for our subcarrier, when in fact there is an offset of 25Hz added for the correct PAL subcarrier. This 25Hz is one extra cycle per two fields, i.e. 360° in 625 lines, or ≃ 1/2 degree per line. i.e. the retardation per line is only 89.5°, not 90°.

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4.2 Over a two-field frame, its effect is cancelled, so after 625 lines (156 of the 4-line sequences + 1 line) the CSC phase on line 1 of the new frame is 90° away from that at the start of the last frame.

The CSC phase will return to its original value, relative to the scanning sequence, after four frames i.e. 8 fields

This is known as the PAL 8-field sequence. These eight-field sequences occur at a rate of 50/8 = 6.25Hz, and each one contain exactly 709,379 cycles in eight fields.

This can easily be verified by a counter activated for eight fields exactly.

4.4 Standard Phase Relationship, CSC-H

PAL csc = (283 3/4 + 1/625) x H

The above frequency relationship doesn't include any information about the start-up phase of CSC relative to a given line in the eight-field sequence.

The EBU have defined a standard 8-field sequence. Field 1 start is defined as a line one, having positive VAS polarity (4 Field sequence) and a positive zero-crossing of U CSC within ±90° of the mid point of sync leading edge.

Current sync pulse generators produce the same 8-field sync-to-subcarrier phase each time they are switched on, to within typically ± 20°.

5. Burst Blanking Sequence of the PAL Colour Signal

The colour burst cannot be radiated during the field sync period. A burst appearing during broad pulses would cause excessive modulation of the transmitter (sync - tip = 100% mod.). Bursts occurring during pre- or post-sync equalising pulses might affect interlace by upsetting the field sync separator.

For this reason, the burst-gate pulses, from the SPG, are inhibited for 9 lines each field. A modern crystal burst-locked oscillator in a PAL decoder will suffer little change in its output frequency or phase during this time.

However, the experimental PAL decoders in use when PAL was developed, showed a large frequency drift and an irregular pattern of re-locking of phase at the start of each new field. If this re-locking extended into active picture, a slight desaturation would be observed at the top of picture (not serious). If the re-locking was longer on some fields than others, the desaturation would change on a field-by-field basis giving a brightness flicker (very noticeable).

5.1 Bruch Blanking

Bruch developed a pattern of blanking such that the last burst of one field and the first burst in the next were always of +ve V-axis polarity. The last kick to the oscillator control on one field and the first kick on the next from the burst phase-comparator were always the same, giving a more consistent re-locking pattern to the early decoders.

The last burst of any field is on "the last complete line of positive V-axis polarity occurring before the first equalising pulse (i.e. start of field blanking of the picture signal)".

9 lines of burst are blanked.