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BROADCASTING DIVISION

Application Note

ZONE PLATE SIGNALS
625 Lines
Standard BG/PAL

Products:

CCVS+COMPONENT GENERATOR	***SAF***
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ZONE PLATE SIGNALS
625 lines PAL

Back in the early days of television measurements in the baseband, the analog insertion test lines commonly known today were invented and standardized worldwide, constituting an indispensable tool for assessing picture quality. Now the development is beginning to depart from the analog TV world and turn towards digital image processing and transmission. This necessitates new test signals. An important group of signals used in this connection are the zone plate signals which of course also provide valuable information on analog systems and components, eg monitors.

1. Structure of Zone Plate Signal

The zone plate signal in its original form is an optical pattern of alternately black and white concentric circles spaced increasingly closer as their diameters increase.

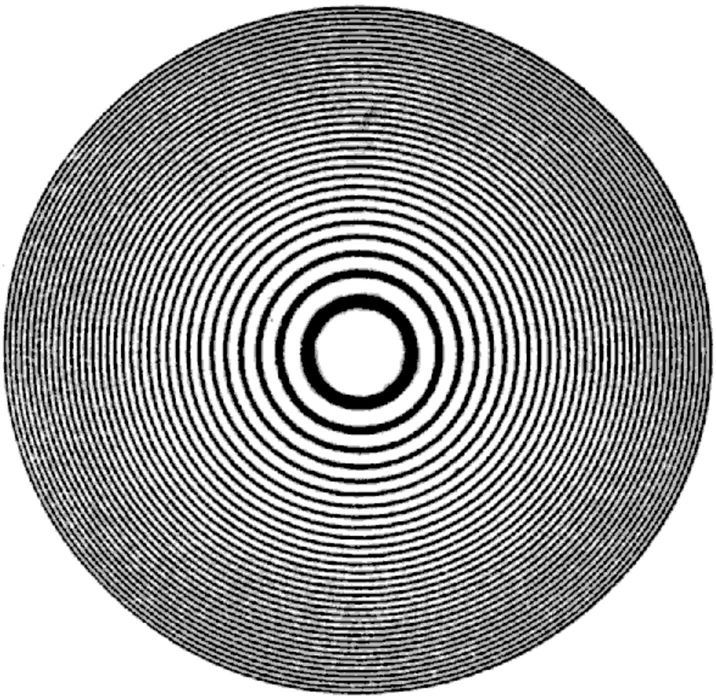

Fig.1

A section through the centre point of the concentric circles will always reveal the same signal structure no matter at what angle the section is made. A section in the horizontal direction (corresponding to the line structure of a television picture) is referred to as H sweep.

Fig.2 H sweep

Looking for a universally applicable formula describing the zone plate signal, the following equation was found:

$$A\,(x, y, t) = \text{const.} + \sin.\,(K_{\phi} + K_x\, x + K_y\, y + K_{x^2}\, x^2 + K_{y^2}\, y^2 + K_{xy}\, x\, y + k_{xt}\, x\, t + K_{yt}\, y\, t + K_t\, t + K_{t^2}\, t^2)$$

where

x = horizontal distance from a defined zero point, eg the centre of the screen

y = vertical distance from the defined zero point

t = time variable at which the signals change

By setting specific coefficients of the above equation to zero, different types of zone plate signals will be generated, eg:

- H sweep (K_y,, K_{y^2}, $K_{xy} = 0$)
- V sweep (K_x,K_{x^2} , $K_{xy} = 0$)
- circular and hyperbolic diagonal zone plate signals depending on the sign of the quadratic coefficient ($K_{xy} = 0$)
- hyperbolic vertical zone plate signal (K_{x^2},K_{y^2} = 0)

If K_t is also set to zero, stationary patterns will be generated.

2 . Example

In the example given below, the coefficients of a circular zone plate pattern moving at a frequency of 1 Hz are to be calculated. The horizontal frequency resolution is assumed to be 5 MHz at the beginning of the line, decreasing to 0 Hz in the centre, and increasing to 5 MHz again at the end of the line. The vertical frequency resolution is assumed to be the same. First, some terms and constants are to be defined:

- Terms:

pw = picture width
ph = picture height

c = cycle (1/13.5 MHz = 74.074 ns to CCIR Rec. 601)
l = line

- Constants for B/G standard:

Complete line:	c / pw	= 64 µs / 1 / 13.5 Mhz	= 864
Complete picture height:	l / ph		= 625

Visible part

of line:	c / pw	= 864 x 52 µs / 64 µs	= 702
of picture:	l / ph	= 625 - (2 x 25)	= 575

To clarify the calculation, the meaning of the coefficients is to be explained:

K_x^2: describes the frequency deviation over one line period, eg 13.5 MHz / 64 µs

K_x: describes the location of a specific frequency on the active line, eg 5.5 MHz at the beginning of the line

K_y^2: describes the frequency deviation over the picture height referred to the 4:3 picture format, eg 10.125 MHz vertical frequency deviation derived from 625 lines: 13.5 MHz / 4 x 3.

K_y: describes the vertical frequency at the beginning of the visible vertical picture range, eg (10.125 MHz x 575) / 625 = 8.505 MHz

The coefficients K_y^2 and K_y are for the time being applied to a progressively built-up frame, ie without 2:1 interlace.

The coefficients of the circular zone plate signal to be calculated can be determined with the aid of the above definitions:

K_x^2 frequency deviation ⇨ 5 MHz per 26 µs ⇨ 12.31 MHz per 64 µs
= 64 µs x 12.31 MHz [c/pw^2]
K_x^2 = 787.7 [c / pw^2]

K_x = 787.7 x 52 / 64 / 2 = - 320.0 [c / pw] (negative since located left of centre)

K_y^2 = 787.7 / 864 x 3 / 4 x (575 x 625 / 625) = 393.2 [l / ph^2]

K_y = 393.2 x (575 / 625) / 2 = - 180.9 [l / ph]

As the picture is to move at a rate of 1 Hz, the "coefficients of motion" are to be set as follows:
K_t = 1 Hz, K_ϕ= 0° and K_t^2 = 0 [1/sec].

Applying the above formulas, the user can fast and easily program any horizontal and vertical starting and stop frequencies, as well as linear, circular and hyperbolic, moving and phase-swept zone plate patterns within the 625-line standard.

3. Linear Distortion

The circular zone plate pattern is the most commonly known of the family of zone plate signals. All measurements relevant in practice can be performed using this pattern. For this reason, the considerations made in the following are all based on this signal which is governed by the equation:

$$A(x,y,t) = \text{const.} + \sin.(K_\phi + K_x x + K_y y + K_x^2 x^2 + K_y^2 y^2 + K_t t)$$

The coefficients of this signal are predefined to have the following values:

K_x = - 320.0
K_y = - 180.9
K_x^2 = 787.7
K_y^2 = 393.2
K_t = 0 (taking a stationary pattern for the sake of simplification)

3.1 Amplitude Frequency Response in Horizontal Direction

When a lowpass filter with a cutoff frequency of approx. 3 MHz is connected between the signal source and the monitor, a pattern of rather unexpected form will appear on the monitor. While the original pattern is circularly symmetric about the centre of the screen, vertical boundary lines will now be seen to the left and right of the centre, and beyond these lines grey level only. The grey level is generated as a result of the sinewave components being suppressed by the lowpass filter. Why vertical lines?

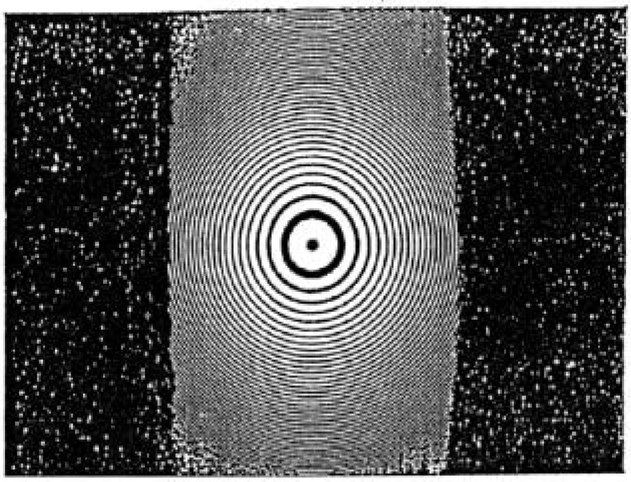

Fig. 3 Circular Zone Plate with horizontal bandlimitting at 3 MHz

This can be best understood by looking at the equation. By differentiating the argument ϕ of the sinewave signal partially with respect to x, the frequency variation in the x direction will be obtained:

$$\delta\phi\,(x,y,t) / \delta x = \delta\,(K_{\phi} + K_x x + K_y y + K_x^2 x^2 + K_y^2 y^2 + K_t t) / \delta x = K_x + 2K_x^2 x$$

This variation of the frequency is a function of the x coefficient exclusively. This means that at the same x locations the same frequencies will occur across the entire picture. Hence the straight vertical boundary lines described above are formed.

3.2 Amplitude Frequency Response in Vertical Direction

Analogously to the frequency response in the horizontal direction, the symmetrical pattern of the circular zone plate signal makes the vertical signal structure appear as a frequency sweep. In accordance with the 4:3 picture format, the starting and end frequencies at the upper and lower margins of the picture are reduced by a factor of 3 / 4 compared with those in the horizontal direction. The fine patterns at the upper and lower margins of the picture can be removed by means of a "vertical filter" having a cutoff frequency corresponding to that of the "horizontal filter" and converted accordingly. Grey bars will then appear at the top and bottom of the picture, corresponding to the grey bars obtained right and left of the centre with horizontal filtering. Such a "vertical filter" is not a filter in a conventional sense (that is, made up of coils, capacitors, etc) but a digital filter with a line or frame memory capable of calculating points of identical x locations and variable y loations by employing suitable algorithms (eg FIR filters).

3.3 Diagonal Filtering

The circular zone plate signal considered here has now undergone horizontal and vertical filtering (see sections 3.1 and 3.2). The result is a square window symmetrical about the centre of the screen, with the concentric circles of the zone plate pattern inside the window. It will be seen at a glance that at the margins of the square the resolution is varying: at the corners of the square the resolution is higher by $\sqrt{2}$ compared with that encountered in the middle of the square sides. To achieve approximately equal resolution along the margins of the square, diagonal filtering can be used employing the same type of digital filter as used for vertical filtering.

3.4 Temporal Filtering

But that's not all there is to filtering. There is still one dimension to be dealt with : the time.
With 2:1 interlaced scanning used in today's TV transmission, large picture areas are reconstructed with a 25-Hz flicker, and fine-structured areas and edges with a 12.5-Hz flicker. The flicker effects can be eliminated by filtering them out from several consecutive frames. The effects of filtering can again be checked by means of a zone plate pattern, which clearly shows the described flicker effects for the normal interlaced scanning operation.
The calculations in the above example (see section 2) are based on a maximum horizontal frequency of 5 MHz. From this a maximum "vertical frequency"

$$f_V = 12.31 \text{ MHz} \times 3 / 4 = 9.23 \text{ MHz}$$

is obtained that can be represented for the vertical 625-line structure. With 2:1 interlaced scanning, however, only 312.5 lines per field are written on the screen, yielding a maximum frequency of only 9.23 MHz / 2 = 4.62 MHz. As a result, aliasing components will be formed at this "vertical frequency", flickering at a rate of 12.5 Hz since the phase of the aliasing signals is shifted by no more than 180° per frame (also see section 4). Looking at the 2 x 312.5-line-per-frame scanning method, it becomes evident for the first time that television has always had a "digital" character.

3.5 Data Reduction in Digital TV

Fast movements in a TV system can be transmitted at the frame repetition rate as the maximum rate of change. For practical requirements, however, this rate is far too high in the case of a great many, if not all, of the pictures transmitted, or at least in the case of large parts thereof. Temporal filtering, on the other hand, allows stationary picture areas to be transmitted at a lower repetition rate, ie at a reduced bandwidth.

The various types of filtering discussed so far all serve one main purpose:
to achieve maximum data reduction while maintaining optimum picture quality at the receiver end.

Data reduction is necessary in the "digital TV era" to enable digital serial transmission of the complete TV signal. Zone plate signals are a suitable, easy-to-handle tool for on-the-screen verification of error-free data reduction in all four filter dimensions. There are other data reduction algorithms, eg DCT (Discrete Cosine

Transform), which are to be mentioned only briefly in this context. To understand these algorithms, it is necessary to engage in the topic of digital signal processing. As an introduction to this topic we would like to refer the reader to the book "Digitale Filter in der Videotechnik" (Digital Filters in Video Engineering) by H. Schönfelder, published by Drei-R, Berlin.

4. Effects of Nonlinear Distortion

Television has always been a digital system due to its line structure. To sample and reproduce the original signal undistorted within such a system, an antialiasing filter matched to the sampling frequency is required. Since most of the monitors and television receivers do not incorporate such a lowpass filter, aliasing effects occur which are clearly visible on the screen.

In a band-limited system (5 MHz in the BG/PAL standard), nonlinear distortion may occur which means that harmonics of the original frequency are generated far beyond the standard bandwidth. The out-of-band signal components are sampled with the digital system clock which produces aliasing effects clearly visible on the screen (see Fig). Such effects are described in section 3.4, "Temporal Filtering", for the 2 x 312.5 line structure of the BG/PAL signal; in that example, however, the aliasing components remain within the standard band.

A typical example of nonlinearity is the γ - precorrection ensuring linear brightness variation of the CRT phosphor. CCIR Rec. 624 prescribes γ to be 2.8 for the BG/PAL standard, ie the camera output voltage is weighted according to the equation $V_P \sim V_C^{0.357}$ (V_P = precorrected voltage; V_C = camera voltage; 0.357 = 1/2.8). If this equation is applied to a sinewave voltage, the negative halfwave of the resulting waveform will be relatively flat and the positive halfwave very pointed. The peak of the positive halfwave contains a high proportion of harmonics that may produce aliasing patterns in the digital representation.

5. (Circular) Zone Plate Signal in CCVS Format

A zone plate signal without chroma components, ie generated in the Y channel only, will still show colour components on the screen due to cross-luminance effects. These becomes particularly evident from the BG/PAL circular zone plate pattern. The locations and movements of the colour components can be explained on the basis of the definitions for the BG/PAL format, using the calculations given above:

* Horizontal location of cross-luminance components

As explained in section 3.1, the circular zone plate pattern will have identical horizontal frequencies at identical x coordinates. For this reason, 4.433-MHz colour centres are obtained symmetrically about the centre of the pattern at the left and right margins.

* Vertical location of cross-luminance components

There will be identical vertical frequencies at identical y coordinates. The y coordinates are counted in lines per picture height. Where will the "colour subcarrier frequency" in the vertical direction be found?

In BG/PAL, the colour subcarrier is displaced by -90° from line to line. This means that the colour subcarrier will have completed a full cycle in the vertical direction (4x (-90°) = -360°) after four lines. In other words, the "vertical" colour subcarrier frequency will be found where the four-line sequence repeats itself vertically in each field on the circular zone plate pattern. Applied to the line structure this means:
f_{SCV} = 312.5/4 = 78.1 [l/ph] with maximum vertical deviation (K_y^2 = 625 c/ph ph)

Using the above formula the distribution of the colour centres on the screen can be accurately determined:

In our example, K_y^2 = 392.2 [c/ph ph] corresponding to 226.49 [° / l ph]

The colour centres are located where the "vertical line phase" is shifted by 90° per line:
l_V = 90 x 312.5 / 226.49 = 124.2 lines (interlaced mode) or
l_V = 45 x 625 / 226.49 = 124.2 lines (progressiv mode)

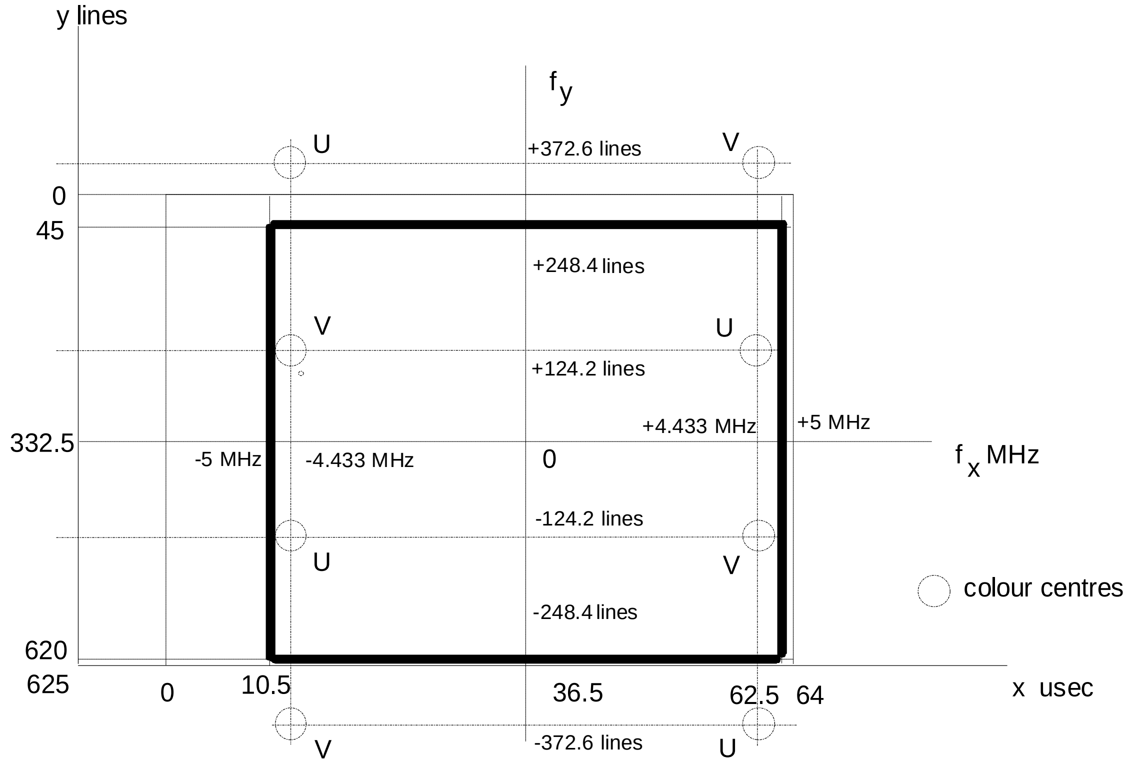

Fig. 4 The two dimensional Zone Plate

In this example, the 25-Hz offset of the colour subcarrier is not taken into account. With 15625 Hz / 4 = 3906.25 Hz $\gg$ 25 Hz, this simplified approach is permissible. However, the 25-Hz offset is to be dealt with separately.

* Effect of 25-Hz colour subcarrier offset (PAL 8-field sequence)

The colour centres, whose locations in the above pattern have been exactly defined, change their phases at the rate of the 25-Hz offset, from which the moving, coloured concentric circles result. The rate of motion can be best seen from the following diagram:

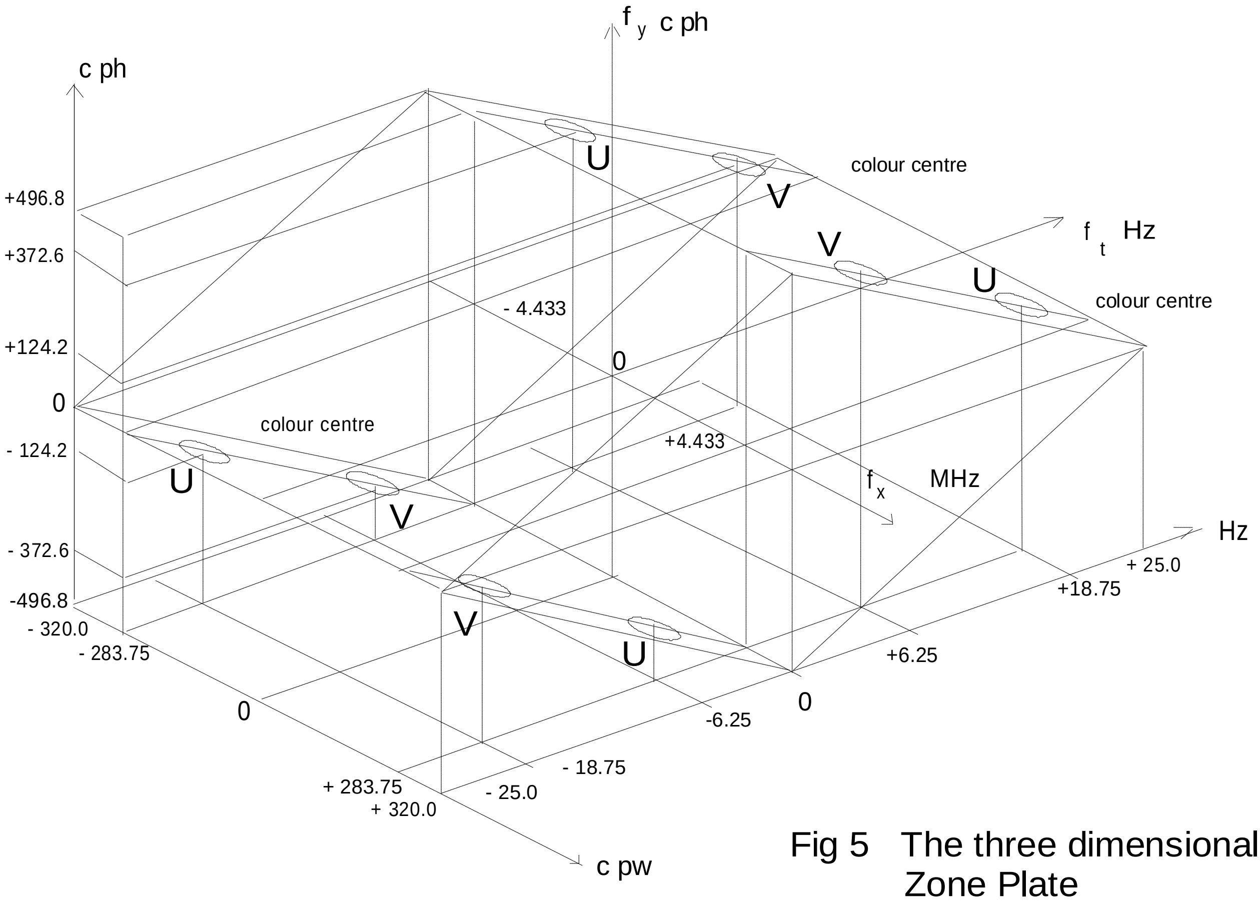

Fig 5 The three dimensional Zone Plate

The diagram shows that the colour centres change at a rate of

$\pm$ 18.75 Hz at $\pm$ 124 lines

about the centre of the picture, while the coloured circles just about visible at the upper and lower margins of the picture change at a rate of

$\pm$ 6.25 Hz.

* Application

In addition to the various possibilities of direct on-the-screen evaluation of linear and nonlinear distortion, circular zone plate signals enable another, very important parameter to be measured: cross-colour effects. Zone plate signals are made up of luminance components only, which may also contain frequencies close to the colour subcarrier due to the 5-MHz bandwidth on which our example is based. These frequencies produce the coloured circles generated about the centres whose locations were determined above. The cross-colour effects can be suppressed by means of comb filters more or less effectively, taking into account that movements of the colour components are to be eliminated as well. The efficiency of such filters, which should be provided on all colour TV sets in the upper price range, can be made visible directly and immediately on the screen, again by means of zone plate patterns.

Hyperbolic vertical zone plate signal

Definiton of the coefficients in the sine argument

$K_\phi + K_x x + K_y y + K_x2\ x^2 + K_y2\ y^2 + K_t t + K_t2\ t^2$)

K_x defines the frequency at field start with a correction factor depending on the frequency deviation per line determined by K_{xy}.

$K_y = 0$

K_x2 and $K_y2 = 0$, ie there is no additional frequency deviation in the x or y - direction.

K_{xy} defines the frequency deviation per picture height as a factor of the frequency deviation per line. For example: desired frequency deviation
15kHz up to 5 MHz over a 625-line frame
at a field frequency of 50 Hz.

$$K_{xy} = \frac{5\ \text{MHz}}{625 \times 50\ \text{Hz}/2} = \frac{5\ \text{MHz}}{15\ 625\ \text{Hz}} = 320\ \frac{\text{c}}{\text{pw ph}}$$

As an example a zone plate signal corresponding to the V SWEEP of the SAF/SFF signal group SWEEP+BURST is calculated:

V Sweep	Beginning	End
frequency	50 kHz	6 MHz
line in 1st field	48	286
duration in lines	239	

The frequency deviation of (6.000 - 0.050) MHz = 5.95 MHz is to occur in the frame during 2 x 239 = 478 lines:

$$K_{xy} = \frac{5.95\ \text{MHz}}{625 \times 50\ \text{Hz}/2} \times \frac{625}{478} = 497.7\ \frac{\text{c}}{\text{pw ph}}$$

Here 5.95 MHz per 239 lines correspond to a deviation of
5.95 MHz/239 lines = 24.895 kHz/line and the correction factor calculated for K_x is
k = 24.895/15.625 = 1.5933

In line 48, the zone plate signal should have the frequency of 50 kHz. The factor K_x is to be determined accordingly.

The frequency 0 Hz is located in line Z_0:

Z_0 = 48 - (50 kHz / 24.895 kHz)

$= 48 - 2.0008 = 45.992$

The zone plate signal starts in line 24. Therefore the new reference line is:

$Z_0 - 23 = 22.992$

The factor K_X is thus obtained from the reference line and the correction factor:

$K_X = - 22.992 \times 1.5933$
$K_X = - 36.63$ c/pw

K_X is negative as the frequencies of the first 22.992 zone plate lines in the field decrease from 572 kHz in line 24 to 0 Hz in line 45.992.

Due to the zone plate signal pattern with half line offset, the sinewave zero crossing at the upper righthand picture edge is flickering at 25 Hz as opposed to the V SWEEP since for the latter the half line offset is taken into account.i

Nyquist condition in vertical direction

The highest vertical frequency within the 625 line system is:

$k_{y\ max} = 625/2 = 312.5$ c/ph

If furthermore the value of k_φ

$k_\varphi = 0°$

the samples are calculated in the first field at 0° and in the second field at 180°. The (vertical) sinewave has in both arguments the same value:
sin (0°) = sin (180°) = 0. A DC voltage is generated.
The highest vertical frequency with greatest amplitude is only generated, if additional the value of k_φ is

$k_\varphi = 90°$ or 270°.

Here you recognize at once, that digitizing a sinewave signal is not possible up to half the sampling frequency. Real values arrive at appoximately 0.4 times the sampling rate.