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A NOVEL MODULATION STRATEGY FOR INTEGRATING DIGITAL SUB-CHANNELS WITHIN A PAL/PAL PLUS SIGNAL

G. Schmidt[1], W. P. Buchwald[2] and L. S. Dooley[3]

[1,2]Fachhochschule Braunschweig/Wolfenbuettel, Fb-Elektrotechnik, Germany

[3]University of Glamorgan, Dept. of Electronics & I.T., Wales, UK

Abstract—This paper presents an original methodology which facilitates the modulation of digital signals within the active video portion of a conventional analogue PAL/ PALplus television signal. The resultant crosstalk distortion errors which ensue are analysed and a model postulated that enables optimization of a number of important system parameters. It will also be shown that applying this model enables a   balancing of subjective quality with data-rate.

I. INTRODUCTION

Substantial research has been undertaken over the last few decades with the explicit goal of enabling digital data transmissions to be embodied within a standard analogue television (TV) channel. The potential benefits accruing from such an intent are manifold, since for a given infrastructure extra multimedia services are feasible. Supplementary programme information, electronic TV guides, multi-lingual high quality audio and special Personal Computer (PC) downloading services are only a flavour of some of the possibilities afforded.

Previous research activities which have explored the use of sub-channels within a television signal, have primarily focused upon high definition (HDTV) and extended definition (EDTV) compatibility approaches [1,2], where the extra resolution is analogue modulated, so that it can be transmitted within these channels. The crucial compatibility issue when attempting to integrate digital data within a TV signal, is to ensure that the appearance of any picture distortions is not perceptible, which in reality tends to involve a trade-off between subjective quality and achievable data rate. To accomplish this objective three distinct possibilities can be identified :

(1) data insertion in the blanking period,

(2) data insertion in the active video,

(3) data insertion outside the video signal, but within the same channel.

In Europe, a practical example of TV data transmission from the first category, is the well-known Teletext system, which modulates digital information on the unused lines in the vertical blanking period. The maximum data rate that can be achieved however is far too low for multimedia applications. Another fully compatible system presented in [3], provides a raw 150kBit/s data rate using spread spectrum technology, while a proposition for the American NTSC television system, called VBI (Vertical Blanking Interval) [4], was made by WavePhore, USA. This system occupies the first ten lines of each field and thus also provides a 150kBit/s data rate.

Interestingly, another WavePhore system, called TVT1 includes data outside the video signal [4], by placing an additional carrier between the colour and sound carriers. This is an example of the third category, which also includes such systems as that proposed by Dinsel [5], involving an additional carrier, modulated by a 16 Quadrature Amplitude Modulation (QAM), which is subsequently   modulated by the sound carrier. This technique enables a typical throughput of between 128 and 196kBit/s.

Summarising these general findings suggests that the maximum achievable data rate is bound to approximately 200 kBit/s. To achieve higher rates means that the second of the above alternatives must be considered, where data is inserted within the active video signal. In adopting this strategy, one must always be mindful that such methods inevitably encroach upon the sensitive issue of compatibility. Early research in this area [6, 7] used a correlation decoder for demodulating the data signal, which was modulated with a subjective optimised carrier at very low amplitudes. Another novel approach was proposed by Ruppel [8], who employed QAM of the picture carrier and obtained a data rate of 500kBit/s.

The technique discussed in this paper also belongs to this second category and is based upon a QAM of the colour sub-carrier [9]. In [10, 11, 12] during the development of the European PALplus widescreen standard, a variant of this arrangement was proposed for modulating additional widescreen information. In practice however, the proposed method was purely analogue-based and never implemented as part of the standard.
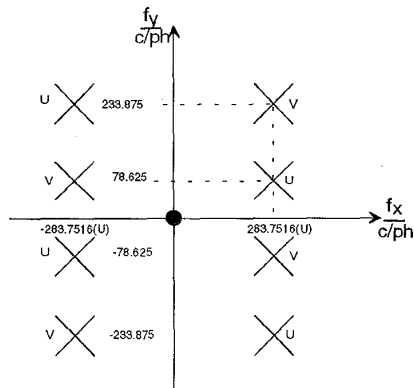
Figure 1: Colour carrier positions for U and V components

II. OVERVIEW

A. Principles

In contrast to the NTSC-system, where the two colour difference signals I and Q are quadrature modulated, PAL alternates the phase of the V-component carrier between 90 and 270 degrees from line to line, where the U-component is fixed to the 0 degree carrier phase. **Figure 1** shows the location for the two modulated colour components in the horizontal / vertical frequency plot of the PAL television signal. The switching leads to a spectral offset of the two colour components in the three dimensional frequency domain, with the V-carrier modulated on its 90-degree phase and the U-carrier on its 0-degree. Hence, both frequencies can be additionally modulated by using the respective orthogonal components and provide two sub-channels which are suitable for further digital transmission. For realisation, the carrier phase of the "digital U-component", D_U, must turn between 0 and 180 degrees from line to line during the carrier phase of D_V is fixed to 90 degrees. **Figure 2a)** displays this more graphically for the given colour and data vector F and D in two consecutive lines n and n+1. Their addition forms the output vector S, which undergoes the usual further processing before transmission. In the receiver, at the PAL line delay, the vector sum of two neighboured lines is derived so that the U and D_V signals are obtained from the in-phase and quadrature components respectively and also in the same way V and D_U from the colour vector difference (**Figure 2b)**). This perfect possibility of separation is only valid if the neighboured lines have identical content, which is not what happens in reality so that crosstalk distortions will occur.

The block diagram in **Figure 3** provides an insight into the conceptual implementation of the aforementioned technique. The colour signals, U and V, are processed as

usual with the subtle difference that a vertical lowpass, $H_U(f_y)$ and $H_V(f_y)$ component is added in each signal path (see next section). The data stream is initially split into two channels which operate at half the original data rate before subsequently form filtering. This filter together with the ensuing up-sampling and vertical interpolation is part of the two dimensional form filtering technique detailed in Section III. Following modulation as alluded to above, the resulting data vector is added to the colour and multiplexed with the luminance. At the decoder, after luminance / chrominance separation, the colour data signal is processed by the PAL line delay, which splits it into components whose carrier phase respectively alternates and remains fixed (V, D_U and U, D_V respectively). Finally the demodulation provides the reconstruction of each signal. The post filters are necessary to suppress higher order frequency parts from the demodulation and for the data signal parts, to suppress the single sideband components from the colour signal. At the end, the two data channels are combined to rebuild the original data stream.
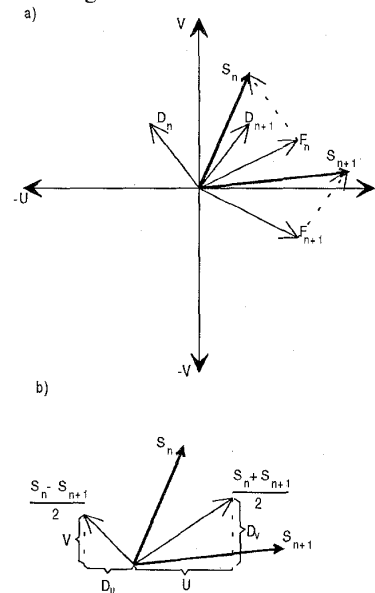

Figure 2: a) Colour and data vector addition at the encoder and b) demodulation at the receiver

B. Cross talk distortions

The highest priority must be given to the issue of compatibility with standard TV-sets, which is the consistency of an implemented data stream with the ordinary decoded video signal. The previously mentioned crosstalk effects are the major error source for degrading the subjective quality of the compatible video signal.

Two specific forms of crosstalk distortion will be considered. Firstly, *intra-carrier crosstalk*, where D_U
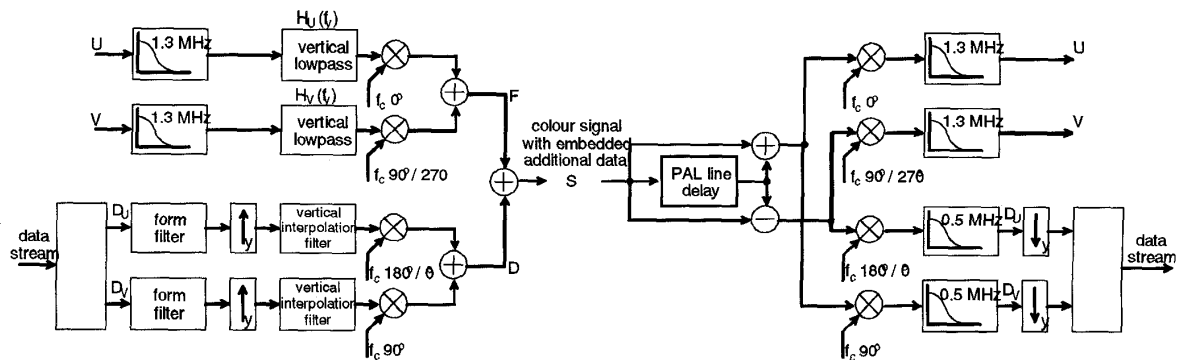
Figure 3: Block diagram of the encoder-decoder structure

and D_V crossover and appear as their quadrature parts, which are of course the colour signals, and secondly *inter-carrier crosstalk*, where the two digital components are demodulated at the wrong carrier frequency. In both cases, the resulting distortions will appear as visible colour noise, which directly impinges upon the perceived picture quality.

The cause of intra-carrier crosstalk distortion is the non-symmetrical interference of the side-bands around the colour carrier, so that perfect demodulation of the in-phase and quadrature components is limited. This happens either because of the overall frequency response during transmission or the data signals exceed their maximum bandwidth range. Employing an equalisation filter, as in the well-known peaking technique for the NTSC system [13], will reduce this first particular effect. The maximum data channel bandwidth is given from the PAL standard. It derivatives B,G,H and I defines a colour carrier frequency of 4.433 MHz together with an overall video bandwidth of 5 and 5.5 MHz for B,G,H and I respectively. This implies that for colour frequencies higher then, approximately 0.5 MHz (1 MHz) the modulation becomes single side band and therefore a limitation of the bandwidth where additional quadrature modulation is possible. The design, however, has to guarantee that the bandwidth of the additional data streams does not exceed 0.5 MHz.

The inter-carrier crosstalk distortion compromises the compatibility aspect in a very critical manner. The data signal combination D_U / D_V is uncorrelated, so their spectra are uniform within the three dimensional video frequencies, f_x, f_y, f_t. The consequence of this is a total spectral overlap between the colour and data signals, and further visible colour noise. Filters must be included to define definite locations for each component and thus attenuate these effects. The U / V separation of the PAL line delay at the receiver also has to be considered, because its poor separation limits the possibility of a perfect overall separation.

Another source of cross distortion is the converse scenario of the above discussion, where the colour is crossing over and affects the data channels. These errors are not so critical, because the issue of compatibility is not influenced and the subsequent disturbances impinge only upon the digital data stream, which is inherently more robust. Two different sources for these distortions can be distinguished. Firstly, the colour signals cross over and secondly inter-carrier crosstalk between the two data channels.

The colour signal crosstalk arises from high vertical frequency components in the picture contents. The probability of those components is generally less in a natural scene however, a vertical filter with a cut-off frequency of at least one half of the vertical Nyquist frequency has still to be included in order to attenuate this effect and thus reduce the error rates. As well documented in the D2MAC TV [14] transmission system, such filtering does not compromise subjective quality, so the same vertical colour pre-filter is suggested in this application.

The inter crosstalk between data channels is limited due to the aforementioned spectral forming. In formalising the development of the proposed solution, the encoder-decoder implementation for the data stream is directly equivalent to the transmultiplexer structure proposed by Verterli [15]. By selecting a special set of filter responses, all aliasing, amplitude and phase errors can be eliminated and perfect separation achieved. This however excludes the possibility of using the PAL line delay for data channel separation, so an additional filter set must be included in the configuration.

III. ENCODER DESIGN AND SUBJECTIVE PERFORMANCE

The encoder design discussed in this paper concentrates primarily on a number of different possible spectral forming filters for the data signals, to avoid inter-carrier cross-colour noise distortion. Their role is most crucial in the context of compatibility and subjective performance.

A. Theoretical analysis

An understanding of the three dimensional spectral position is provided in **Figure 4**. The locations of the modulated colour signals U and V, are given with their carrier position at the centre. The spectra of the embedded data signals are in theory uniformly distributed along the three axes of the 3-D frequency plot, since each data value is uncorrelated both with respect to adjacent line and frame samples. To constrain these spectra to specific locations so avoiding the aforementioned crosstalk effects, form filtering must be applied. Horizontal forming is performed using the traditional filter included to avoid intersymbol interference and ensures that the bandwidth is limited to 0.5 MHz. In addition, either vertical or temporal filtering is necessary to provide non-overlapping frequency regions for the data spectra. Due to the fact that for the colour signal separation at the decoder a vertical filter, the PAL line delay, is used, also for the data channel vertical forming filters are essential.

The vertical filters providing these spectral locations for each data component have to be lowpass. Analysing the distortions raising from crossing over into the colour channels, the data signals passing through mentioned vertical lowpass before subsequently processed by the PAL line delay, which is a sine-shaped high pass response for D_V. Similar argument can be applied to D_U, so the crosstalk attenuation response is the same in both cases and can be readily computed from the relationship:

$$C_A(f_y) = H_D(f_y) \; H_P(f_y) \qquad (1)$$

where $H_P(f_y)$ is the sine-shaped PAL line delay separation, and $H_D(f_y)$ the vertical low pass forming filter for the data signal at the encoder.

Quantifying the aforementioned cross-distortions is very difficult since they only interfere in the colour channel. Their appearance is blocky colour noise which is unusual in comparison with normal noise degradation's and therefore is perceptually very annoying. To provide a quantitative measure, the noise power accruing from the crosstalk data signals is evaluated so both the signal to noise ratio within each colour channel (SNR$_U$ and SNR$_V$), together with the display signal to noise ratio (DSNR) can be derived. This latter measure is similar to the model published in [16].

Assuming the data signal U_D has a uniform probability distribution function with zero mean over a range from -α to α, the noise power can be computed directly from the variance σ^2. Depending on the number of symbol levels per data channel, which will be for example N=2
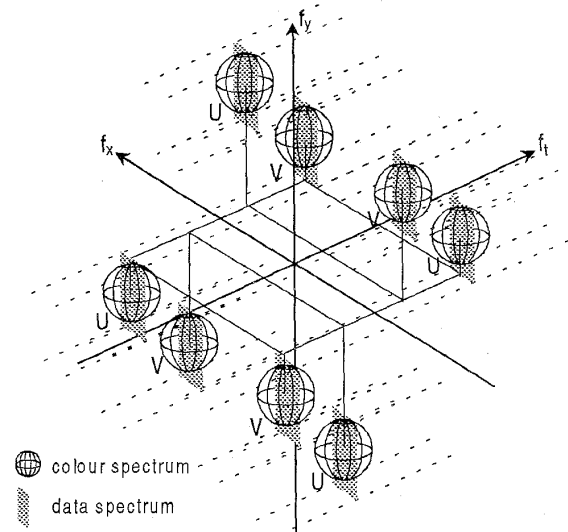

Figure 4: Three dimensional spectrum perspective

for 4 QAM, N=4 for 16 QAM [1] and so on, the following relationship can be used:

$$\sigma^2 = \frac{\alpha^2}{3} \frac{N+1}{N-1} \; ; \quad N \geq 2 \qquad (2)$$

Assuming the conditions of a noise-free transmission, which means ideal filter characteristics for both luminance and chrominance splitting, as well as chroma demodulation at the receiver, so that only the colour difference signals are effected by cross colour noise distortions. The noise power in each colour channel introduced from the data signal is then given as:

$$P_N = \int_0^{f_{sx}} \int_0^{f_{sy}} \sigma^2 \left| H_F(f_x) \right|^2 \left| C_A(f_y) \right|^2 df_x df_y \qquad (3)$$

where $C_A(f_y)$ is the crosstalk attenuation response introduced in Eq. 1 and $H_F(f_x)$ the horizontal forming filter. f_{sx} and f_{sy} are the horizontal and vertical sampling frequency, respectively. If no vertical forming filter is used in the encoder, so that $C_A(f_y) = H_P(f_y)$, Eq. 3 is simplified to

$$P_R = \frac{\sigma^2}{2} \int_0^{f_{sx}} |H_F(f_x)|^2 \, df_x \qquad (4)$$

In evaluating the noise performance, the eye weighting function has to be taken into account. In this case however, the noise bandwidth is less than 0.5MHz where the eye's perception has nearly no degradation [17]. The same situation is assumed for the luminance/chrominance separation and also for the

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[1] The noise power is evaluated separately for each channel.

colour post filters, so that only $C_A(f_y)$ and $H_F(f_x)$ have to be considered.

From Eq. 3 the signal to noise ratio (SNR) is given as

$$\left.\frac{SNR}{[dB]}\right|_{U,V} = 10\log\frac{P_{U,V}}{P_N} \qquad (5)$$

The maximum peak-to-peak signals for U and V are different and are [18]:

$$U=0.612V_{p\text{-}p}$$

$$V=0.861V_{p\text{-}p}$$

So the inter carrier crosstalk can be qualified:

$$SNR\big|_U = 10\log\frac{0.375V^2}{P_N} \qquad (6)$$

$$SNR\big|_V = 10\log\frac{0.741V^2}{P_N} \qquad (7)$$

From this objective SNR measure, a more subjectively oriented method is derived, whose basis is a modification of the DSNR definition in [16]. This technique takes cognisance of the fact that the crosstalk noise encroaches upon the principle of constant luminance, which implies an additional crosstalk into the luminance component, because of the non-linearity of the picture tube, a phenomena known as the gamma law.

Eq. 3 quantifies the distortion within each colour signal, U′ and V′. To assess the visibility at the display, the expression for signal plus noise at the output of the decoder matrix must be derived. With R′-Y′=1.14V′ and B′-Y′=2.03U′ the three distorted primary colour signals are given as:

$$R'+n_R = R'+1.14\sqrt{P_N}$$

$$G'+n_G = G'+0.96\sqrt{P_N}$$

$$B'+n_B = B'+2.03\sqrt{P_N}$$

where R′=R$^{1/\gamma}$, G′=G$^{1/\gamma}$, B′=B$^{1/\gamma}$ are the pre-gamma corrected colour signals and n_R, n_G, n_B the respective cross colour noise distortions. The displayed luminance Y_D at the output of the display tube can be obtained by separately weighting the three primary colour signals and adding each term after applying the gamma law [16].

$$Y_D = 0.3(R'+1.14\sqrt{P_N})^\gamma + 0.59(G'+0.96\sqrt{P_N})^\gamma + \qquad (8)$$
$$0.11(B'+2.03\sqrt{P_N})^\gamma$$

Using the relationship $(1+a)^\gamma \approx 1+\gamma a$, for a << 1 Eq. 8 can be written as

$$Y_D = 0.3R + \gamma\frac{0.342R\sqrt{P_N}}{R'} + 0.59G + \gamma\frac{0.566G\sqrt{P_N}}{G'} + \qquad (9)$$
$$0.11B + \gamma\frac{0.22B\sqrt{P_N}}{B'}$$

and letting $\delta = 1-\dfrac{1}{\gamma}$ and adding signal terms in voltage and noise terms in power [16]

$$Y_D = 0.3R + 0.59G + 0.11B +$$
$$\gamma\sqrt{P_N}\sqrt{((0.342R^\delta)^2 + (0.566G^\delta)^2 + (0.22B^\delta)^2)}$$

The DSNR is then given by

$$DSNR = 20\log$$
$$\frac{Y}{\gamma\sqrt{P_N}\sqrt{((0.342R^\delta)^2 + (0.566G^\delta)^2 + (0.22B^\delta)^2)}} \qquad (10)$$

which can be computed for a given P_N and γ, where P_N is direct related to both α, the data signal amplitude and the number of symbol levels N. For increasing N, Eq. 1 shows that σ^2 moves to a threshold of 1/3 for α =1, so a 16-QAM or 64-QAM, N=4 or N= 8 respectively, will balance the DSNR gain with complexity.

B. Filter Optimisation

Two methods will be discussed for the implementation of the vertical spectral forming filter, namely vertical partial response coding and a vertical interpolation technique.

Partial response coding performs a spectral forming by introducing more than two symbols and therefore an energy concentration within a smaller bandwidth. If Duo-Binary coding is considered for instance, the data spectrum becomes cosine shaped, which reduces the crosstalk effects, the cross talk attenuation of $C_A(f_y)$ is however insufficient. Higher order partial response codes will increase this attenuation and the overall subjective performance, but also the number of symbol levels, which decreases the transmission robustness.

The other spectral forming technique involves transmitting data only every nth line, where n is the interpolation factor. This has the effect of reducing the bandwidth of the data signal by 1/n. An interpolation filter interpolates the omitted lines and performs the vertical spectral forming. To preserve the data rate a higher order QAM technique is suggested which gives 1/n, 2/n or 3/n for a 4-, 16- or 64-QAM respectively of the original data rate. At the decoder, to ensure optimal reconstruction of the data signals, the overall vertical filter chain during transmission must maintain the original data samples. This prerequisite is fulfilled provided every nth sample of the overall filter's impulse

response is zero in the aforementioned cases. A specially designed interpolation filter family has therefore to be applied at the encoder, exhibiting these properties. and then exclude the other vertical filters of the chain, which is the PAL line delay, if this will used for separation of the data channels. Otherwise the PAL line delay must be considered only for the compatibility issue and for the decoding process additional filters must be applied.

The frequency response of any filter where only the nth coefficient is non-zero has the property of providing an attenuation of more than 6dB at $1/n$ of the Nyquist frequency. Excluding the frequency response of the PAL line delay which is cosine shaped, such attenuation is limited and nearly independent from the filter design. This confines any crosstalk improvement within the filter design process, so that only minor changes are possible by varying for example, filter complexity.

A combination of the interpolation technique together with the duobinary coding will provide a possible solution of this lemma. A duobinary coded signal spectrum is cosine shaped, so it has a zero at the Nyquist frequency. Up-sampling by a factor of n moves this null point to $1/n$ of the new Nyquist frequency and thus introduces a notch at the aforementioned critical location. The pyrrhic effect however, is that this is only possible with two symbol levels per data channel leading to a lower data rate, otherwise, due to the combination, to much symbol levels occur.

IV. DISCUSSION OF RESULTS

The technique presented in this paper is based upon modulating the active video part of a PAL signal. To be compatible with the PALplus standard, only 432 of the total 576 active PAL lines are available, which forms the kernel 16:9 widescreen signal. The remaining 144 lines are reserved for the transmission of the so-called vertical helper signal. The ensuing discussion and results relate to the 432 line core signal. The helper components remain unaffected, also for a pure PAL signal.

For the initial simulations the horizontal form filter, avoiding inter-symbol interference, is chosen with a roll off slope of 0.5. The overall data channel bandwidth is, as given in II.B.:

$$f_{Bdata} = 5MHz - 4.433 \ MHz = 0.567 \ MHz$$

so that the bit duration might not exceed

$$T_{Bit} = \frac{1}{2 f_{Bdata}} 1.5 = 1.323 \mu s$$

With an active line length of 52µs, this results in a maximum of 39 symbols per line and per additional data
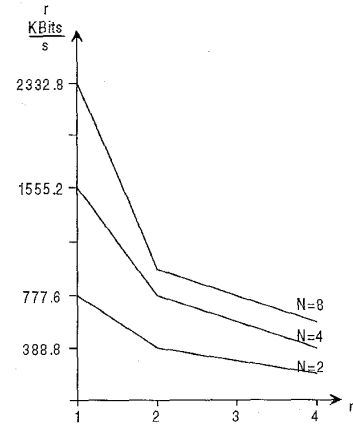

Figure 5: Achievable data rates versus interpolation factor.

channel. For simplification of the simulation and to avoid the worst case, 36 symbols are used, so for both channels 72 symbols per line are available and every line contains an integer number of bytes. The overall data rate provided can be derived as follows:

$$r = 72 \frac{symbols}{line} 432 \frac{line}{frame} 25 \frac{frame}{s} ldN \frac{Bits}{symbols} \frac{1}{n}$$

$$= 777.6 \frac{KBits}{s} \frac{ldN}{n}$$

where N is the number of symbol levels per channel and n the interpolation factor (**Figure 5**).

The roll-off filter design is straight forward and implemented as usual separated in a pre- and post filter at the encoder and decoder, respectively. Considering the vertical forming filter, not much flexibility in designing this filter is given, neither for the partial response coding, where the vertical filter are fixed due to the chosen order, nor for the interpolation technique as alluded in the previous section. The most important parameters, which having an impact to the overall efficiency, that is data rate and subjective quality, are the amplitude of the data signal, α, the number of symbol levels, N, and the interpolation factor n. With Eq. 1 and Eq. 2 the power of the intercarrier crosstalk can be derived within each colour channel and an objective quality is given using Eq. 10.

Example	N	n	r KBits/s	α=0.15			α=0.075		
				P_N	$SNRI_U$	$SNRI_V$	P_N	$SNRI_U$	$SNRI_V$
P1	2	1	777.6	$3.574\ 10^{-4}$	30.21 dB	33.17 dB	$0.934\ 10^{-4}$	33.17 dB	39.19 dB
P2	2	1	777.6	$1.768\ 10^{-4}$	33.22 dB	36.17 dB	$0.447\ 10^{-4}$	39.24 dB	42.20 dB
I1	2	2	388.8	$3.015\ 10^{-4}$	30.94 dB	33.91 dB	$0.753\ 10^{-4}$	36.97 dB	39.93 dB
	4	2	777.6	$1.675\ 10^{-4}$	33.50 dB	36.46 dB	$0.419\ 10^{-4}$	39.52 dB	42.48 dB
I4	2	3	259.2	$0.705\ 10^{-4}$	37.26 dB	40.22 dB	$0.176\ 10^{-4}$	43.28 dB	46.24 dB
	4	3	518.4	$0.392\ 10^{-4}$	39.82 dB	42.77 dB	$0.098\ 10^{-4}$	45.83 dB	48.79 dB
P1/I1	2	2	388.8	$0.628\ 10^{-4}$	37.76 dB	40.72 dB	$0.157\ 10^{-4}$	43.78 dB	46.73 dB
P1/I4	2	3	259,2	$0.160\ 10^{-4}$	43.69 dB	46.65 dB	$0.040\ 10^{-4}$	49.71 dB	52.67 dB

Table 1: Comparison of different crosstalk noise

Three different design methods together with their parameters are compared in **Table 1**. Px refers to partial response coding, Ix to interpolation and Px/Ix to the combination of both methods. I1 and I4 are designed as alluded in Sec. IIIB. with an amplification of the interpolation factor, n, to keep the data signal power independent from the interpolation factor. The corresponding filter responses $H_D(f_y)$ and $C_A(f_y)$ are given from with **Figure 7**. Is obvious that with an increasing cross talk attenuation the achieving data rate decreases. Giving the priority to the subjective picture quality the values from example I4, P1/I1 and P1/I4 produce the best compromise, where the 16 QAM version of I4 provides a superb bit rate efficiency. The data amplitude, α, should be within the limits of 0.075 and 0.15 in relation to the normalised video range. A value of 0.15 causes an overshoot of 20% of the resulting video signal (**Figure 6**), which is a little bit less than for saturated yellow and therefore acceptable. Further α should not be below 0.075, because of an increasing data error rate in noisy transmission channels.

Table 2 shows the DSNR of an EBU colour bar for the examples given in **Table 1**. It gives a very good impression of what distortions are definite visible within the possible signal parts of a video signal. Surely, the degradation's are more visible in dark uniform areas than in bright parts. The DSNR varies within a range of approximately 20 dB depending on the form filtering. For values greater than 35dB, almost no visible distortions are perceived by non expert viewers.

The previous discussion relates only to the issue of compatibility, which as alluded earlier is of paramount

importance and parameter settings are consequently chosen to reflect this. Also of interest however are the properties of the data channels, is respect of their achievable data rate and also the Bit Error Rate (BER). The data rates have already been discussed, the BER is direct dependent upon the data signal amplitude α, and the numbers of signal levels, N. **Figure 9** and **Figure 10**

show the measured eye patterns and corresponding signal space for 2 and 4 signal levels per data channel, respectively. The asymmetric shape of the symbol positions is caused by arithmetic rounding being used in the signal processing. Despite this, the example reveals that perfect data reconstitution is certainly possible. This ideal situation inevitably deteriorates when white Gaussian noise is added during transmission. The noise degrades the symbol positions within the signal space, so they become less and less defined and the openness of the eye narrows, leading to an increased probability of bit errors with the number of symbol levels. **Figure 8** compares the examples for signal to noise ratios within the range 30dB to 40 dB for the 16 QAM case. The 4 QAM together with the duo-binary coding technique provides a BER greater than 10^{-5} within these tests.

Another source of bit errors are introduced from high vertical colour frequencies, which cross over into the data channel. Due to the probability occurrence of those frequencies the resulting errors appear as burst errors. The previous mentioned vertical filter in the colour signal paths will prevent these effects.
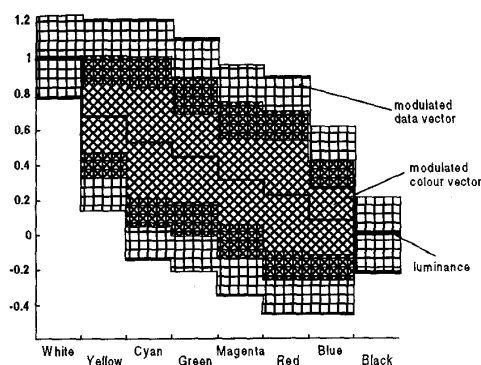

Figure 6: EBU colour bar added with the modulated data signal

Example							
P1 α=0.15	30.7587 dB	29.0814 dB	27.7221 dB	26.8687 dB	26.5172 dB	25.3461 dB	20.3343 dB
P1 α=0.0.75	36.5868 dB	34.9095 dB	33.5502 dB	32.6968 dB	32.3453 dB	31.1742 dB	26.1624 dB
P2 α=0.15	33.8154 dB	32.1381 dB	30.7789 dB	29.9254 dB	29.5739 dB	28.4028 dB	23.3910 dB
P2 α=0.0.75	39.7872 dB	38.1099 dB	36.7506 dB	35.8971 dB	35.5457 dB	34.3746 dB	29.3627 dB
I1 α=0.15	31.4974 dB	29.8201 dB	28.4608 dB	27.6074 dB	27.2559 dB	26.0848 dB	21.0729 dB
I1 α=0.0.75	37.5223 dB	35.8450 dB	34.4857 dB	33.6323 dB	33.2808 dB	32.1097 dB	27.0979 dB
I1 α=0.15	34.0501 dB	32.3728 dB	31.0135 dB	30.1601 dB	29.8086 dB	28.6375 dB	23.6257 dB
I1 α=0.0.75	40.0681 dB	38.3908 dB	37.0315 dB	36.1781 dB	35.8266 dB	34.6555 dB	29.6437 dB
I4 α=0.15	37.8084 dB	36.1311 dB	34.7718 dB	33.9183 dB	33.5669 dB	32.3958 dB	27.3839 dB
I4 α=0.0.75	43.8351 dB	42.1578 dB	40.7986 dB	39.9451 dB	39.5936 dB	38.4225 dB	33.4107 dB
I4 α=0.15	40.3574 dB	38.6801 dB	37.3208 dB	36.4674 dB	36.1159 dB	34.9448 dB	29.9330 dB
I4 α=0.0.75	46.3780 dB	44.7007 dB	43.3414 dB	42.4880 dB	42.1365 dB	40.9654 dB	35.9536 dB
P1/I1 α=0.15	38.3106 dB	36.6334 dB	35.2741 dB	34.4206 dB	34.0692 dB	32.8980 dB	27.8862 dB
P1/I1 α=0.0.75	44.3312 dB	42.6540 dB	41.2947 dB	40.4412 dB	40.0898 dB	38.9186 dB	33.9068 dB
P1/I4 α=0.15	44.2490 dB	42.5717 dB	41.2125 dB	40.3590 dB	40.0076 dB	38.8364 dB	33.8246 dB
P1/I4 α=0.0.75	50.2696 dB	48.5923 dB	47.2331 dB	46.3796 dB	46.0282 dB	44.8570 dB	39.8452 dB

Table 2: DSNR of an EBU Colour bar for various examples

V. CONCLUSIONS

The paper introduces a novel modulation possibility which enables embedded digital subchannels within a standard video signal. The technique uses the active video part, so that crosstalk distortions occur. These degradation of compatibility has been fully analyzed and qualified. The concept of a more dimensional form filtering is proposed to suppress these effect, which, however, balance the data rate efficiency. Looking at noisy transmission channels, the proposed system provides acceptable bit error rates for signal to noise ratios better than 30 dB.

The subjective quality of the standard video signal, data rate and also the noise robustness are the major properties, which compromises each other. The best solution is found for the example P1/I1 with the priority on subjective quality. Shifting the focus a bit more to the data rate efficiency, the 16 QAM example of I4 is the best.

As mentioned earlier, only the center signal is used for additional modulation, which is ¾ of the overall picture space. To improve bit rate efficiency the consistency of the proposed modulation, or a modification of it, with the PALplus helper is currently under development.
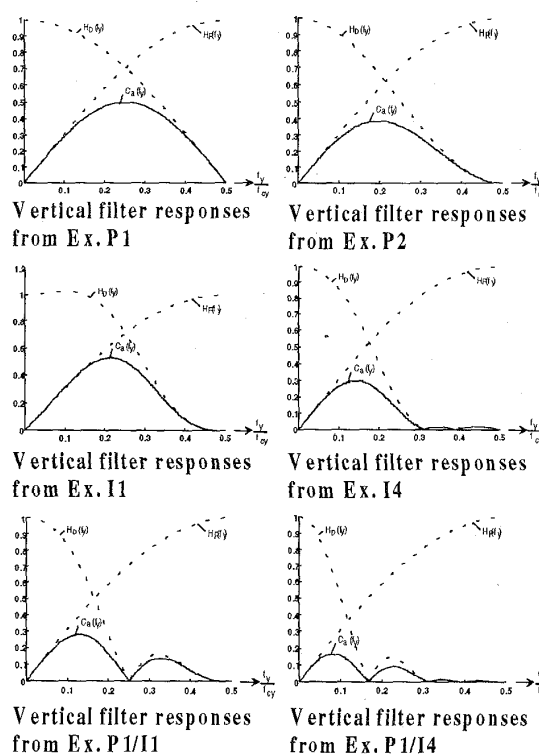

Vertical filter responses
from Ex. P1

Vertical filter responses
from Ex. P2

Vertical filter responses
from Ex. I1

Vertical filter responses
from Ex. I4

Vertical filter responses
from Ex. P1/I1

Vertical filter responses
from Ex. P1/I4

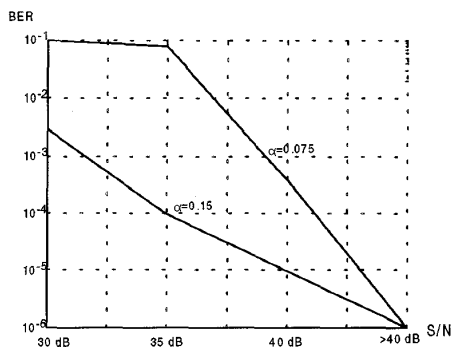**Figure 7: Filter responses for various examples**

Figure 8: Measured bit error rate (BER) for the 16 QAM approach
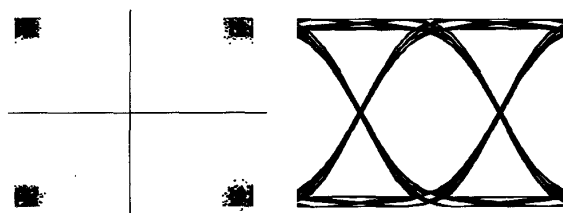

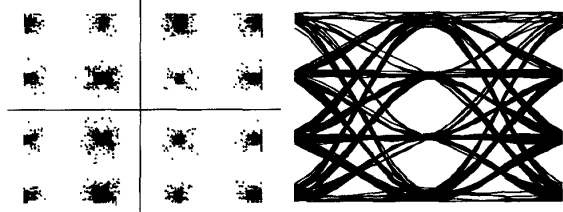**Figure 9: Eye pattern and signal space for 4 QAM**

Figure 10: Eye pattern and signal space for 16 QAM

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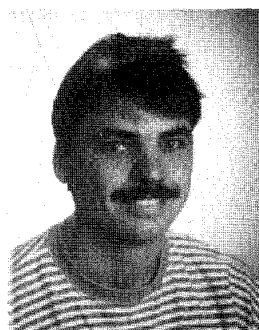
Gunnar Schmidt (M'93) was born in Braunschweig, Germany in 1966. He received his Dipl-Ing. degree in Electronics and Communication Technology in 1990 from the Fachhochschule Braunschweig/Wolfenbuettel, Germany. From 1990 to 1997 he worked with the video

signal processing group in the Department of Communication Technology at the Fachhochschule Braunschweig / Wolfenbuettel. He is a registered research student in the Department of Electronics and Information Technology at the University of Glamorgan, Wales, studying for his Ph.D. degree. Since 1997 he is been employed with Robert Bosch GmbH, Advanced Development Multimedia Systems.

His main research interests are in the fields of digital signal processing, related to the area of data communication

Laurence S. Dooley (M'81-SM'92) was born in Cwmbran, Wales in 1959. He received his B.Sc. (Hons), M.Sc. and Ph.D. degrees in Electrical and Electronic Engineering from the University College of Wales, Swansea in 1981, 1983 and 1987 respectively. He worked as an Industrial Consultant, principally in the area of digital sound systems for Marine and Bridge Simulators before joining the School of Electronics at the University of Glamorgan, in 1986, where he is currently a Senior Lecturer. In 1989 he was a Visiting Scholar in the Department of Electrical Engineering at the University of Sydney, Australia.

His main research interests are in the fields of digital signal processing, HDTV, multimedia and video technology. He is a Senior member of the IEEE, a Chartered Engineer (C.Eng.) and corporate member of the British Computer Society.

Prof. Dr. Wolf-Peter Buchwald was born in 1954. He studied Communication Technology at the Technical University of Braunschweig, Germany, where he received his Ph.D. degree in 1986. In 1989 he was appointed Professor in Communication Technology and Digital TV techniques at the Fachhochschule Braunschweig/ Wolfenbuettel, Germany. He has provided a number of course for industry in the general area of digital video technology.

His main research interests are in the fields of digital signal processing, in particular relating to CCD sensors and digital video signal processing.