Description

This invention relates to spatial-temporal frequency interleaving of a video signal.

A desirable objective of high definition television is a picture that is sharper and more pleasing than is provided by broadcast and television receiver equipment presently in general use. Some of the features proposed for a high definition television system include the following: increasing the line rate over the conventional 525 or 625 lines per frame to, for example, 1,050 or 1,250 lines per frame; extending the aspect ratio from a conventional 4:3 aspect ratio to an aspect ratio such as 5:3; and increasing the effective resolution of the picture.

A high definition television system that attempts to provide most or all of these features has heretofore required either a substantial increase in bandwidth of the transmission channel or a substantial compromise in the specifications for one or more of the features described above. In accordance with an aspect of the invention, spatial-temporal frequency interleaving techniques are used to rearrange the spatial-temporal frequency spectrum of the image in such a way as to reduce the channel bandwidth requirement for transmission of the image without substantially reducing the desired information content of the image.

The concept of spatial-temporal frequency interleaving involves the separation of high spatial and/or temporal frequency information of an image and modulating this information on a spatial-temporal carrier which interleaves the high frequency information with the low frequency information of the baseband spectrum. An advantage of interleaving high frequency information is that since the eye is relatively insensitive to distortion at high spatial frequencies, artifacts introduced by the interleaving will, in general, not be objectionable.

When the high definition television signal processing system incorporates sampling techniques, high frequency carriers are inherently introduced in the form of spectral repeat centers by means of the sampling procedure. As a feature of the invention, great flexibility is available in selecting the carriers or repeat centers at particular points in the spatial-temporal frequency volume. The effect of using spatial-temporal carrier generation is to reconfigure the spectrum of the image, transmitting a portion of the baseband spectrum in a different location of the spatial-temporal frequency volume (see for example "Frequenz", Vol. 27, no. 11/12, Nov/Dec 1983, pages 288-299, Berlin; H. Sauerburger et al.: "Verarbeitung und digitale Codierung von HDTV-Signalen").

In accordance with an aspect of the invention, a video signal is developed that contains an image having associated therewith a spatial-temporal frequency spectrum of at least two dimensions. A modulated signal is produced that represents spatial-temporal carrier modulation by the image contained in the video signal to generate repeat spectra of at least a section of the image spectrum. The carrier modulation is designed to position a repeat spectrum adjacent to the image spectrum, such that a section of the adjacent repeat spectrum is interleaved in a complementary location adjacent the image spectrum. The video signal is filtered prior to the production of the modulated signal to remove spectral contents of the image that are positioned at the complementary location adjacent that portion of the image spectrum that is to be transmitted. Thus, for example, if the image spectrum includes a temporal dimension, scene motion artifacts are avoided that are due to interaction between the frequency interleaved sections and the temporal content of the original image spectrum.

In accordance with another aspect of the invention, to reconstruct the spatial-temporal spectrum of the frequency interleaved video signal, a first signal is produced that represents spatial-temporal carrier modulation of the spatial-temporal frequency spectrum of the frequency interleaved signal and that contains the removed section of the image spectrum restored to its original location. The first signal is filtered to remove from its spectrum undesirable portions of repeat spectra. A second signal is developed from the filtered signal that contains the reconstructed image spectrum.

As will be described, the carrier modulation tends to introduce a full-strength alias which could result in undesirable artifacts being displayed together with the picture information. These effects may be substantially reduced by transmitting the interleaved spectral section with diminished amplitude relative to a remaining spectral section of the transmitted video signal.At the receiver, a complementary process is performed that represents spatial-temporal carrier modulation of the spatial-temporal frequency interleaved video signal. The interleaved section is restored to its original position in the image spectrum, while at the same time, its amplitude is increased.

When a high-definition television signal processing system incorporates sampling techniques, high frequency carriers are inherently introduced in the form of spectral repeat centers by means of the sampling procedure. When analog processing circuitry is used, spatial repeat spectra may be introduced, for example, by modulating an appropriately selected carrier wave with the video signal.

Great flexibility is available in selecting the spatial-temporal carriers that generate repeat centers at particular points in the spatial-temporal frequency volume. The effect of using spatial-tempo-

ral carrier generation is to reconfigure the spectrum of the image, transmitting a portion of the baseband spectrum in a different location of the spatial-temporal frequency volume. In an embodiment of the invention, the baseband spatial-temporal frequency spectrum of the video signal is configured so as to enable rectangular sections of the spectrum to be interleaved. The baseband frequency spectrum used may, for instance, be a cruciform-shaped region.Such a spectrum is capable of providing improved horizontal and vertical resolution at the expense of diagonal resolution. This type of trade off may produce a more pleasing picture, taking into account the physiology of the eye and the perception of images by the visual system. Additional advantages ensue if one extracts from the baseband video spectrum for the purpose of frequency interleaving, a spectral section of such shape and orientation as to enable the sides of the section to be oriented parallel to the horizontal and vertical directions.

In general, spatial-temporal frequency interleaving techniques substitute one piece of spatial information, such as information contained in the high horizontal frequencies, in place of another piece of information, such as information contained in diagonal frequencies, both of which are relatively high frequency spatial information. In accordance with another aspect of the invention, different pieces of spatial information, such as diagonal and high horizontal frequency information, are advantageously transmitted to the receiver by alternating or temporally multiplexing transmission of the pieces of information at a given rate such as at the frame rate. Thus, the video signal of an image containing diagonal frequency information is transmitted in one frame, while the video signal of an image containing high horizontal frequency information is transmitted in the alternate frame. Assuming a frame rate of 30 Hertz, the visual artifacts introduced into such a transmission system is a half-frame rate, 15 Hertz flicker.

In the accompanying drawings:

FIGURES 1A, 1B, 2A, 2B, 3, 4A through 4D illustrate spatial frequency spectra at various points in the frequency interleaving process;

FIGURE 5 illustrates a spatial-temporal frequency interleaving encoder, embodying the invention;

FIGURE 6 illustrates a spatial-temporal frequency interleaving decoder, embodying the invention;

FIGURE 7 illustrates a specific embodiment of the horizontal low pass filter of FIGURE 5;

FIGURE 8 illustrates a spatial quincunx switching arrangement useful in explaining the analogy between sampling of a signal and carrier modulation by a signal; and

FIGURE 9A illustrates a signal modulated carrier and sampling points thereon.

FIGURE 9B illustrates the frequency spectrum of the signal modulated carrier of FIGURE 9A;

FIGURE 10A illustrates a signal modulated carrier with sample points thereon wherein alternate samples of the signal modulated carrier are of reduced amplitude, in accordance with an aspect of the invention;

FIGURE 10b illustrates the frequency spectrum of the signal modulated carrier of FIGURE 10A;

FIGURE 11 illustrates a spatial-temporal frequency interleaving encoder, embodying the invention, wherein the interleaved section is of reduced amplitude;

FIGURE 12 illustrates a spatial-temporal frequency interleaved decoder, embodying the invention, wherein the frequency interleaved section is restored to its original position in the image spectrum while at the same time having its amplitude increased.

FIGURE 13 illustrates a specific embodiment of the interpolator of FIGURE 11;

FIGURES 14A-14D and 15 illustrate spatial frequency spectra at various points in the frequency interleaving and reconstructing processes according to another aspect of the invention;

FIGURE 16 illustrates a spatial-temporal frequency interleaving encoder for this latter aspect of the invention;

FIGURE 17 illustrates a decoder for a spatial-temporal frequency interleaved video signal such as provided by the FIGURE 16 encoder;

FIGURE 18 illustrates a time multiplexing, spatial-temporal frequency interleaving encoder for another aspect of the invention;

FIGURES 19-21 illustrates respective time-multiplexing, spatial -temporal frequency interleaving decoders; and

FIGURES 22-24 illustrate spatial frequency spectra at various points in the frequency interleaving and reconstructing processes of the encoder and decoders of FIGURES 18-21.

By way of illustration only, assume that it is desired to reconfigure the transmitted luminance spatial frequency spectrum of an image so that the spectrum better matches the properties of the human visual system. For the purposes of this discussion only, assume that the original baseband spatial frequency spectrum, f_x versus f_y, of a video signal is rectangular, as illustrated in FIGURE 1A, by rectangle 22, where f_x is measured in cycles per picture width and f_y is measured in cycles per picture height.

One of the factors determining the maximum horizontal spatial resolution transmitted is the bandwidth of the channel allocated to carry the video

signal. Channel bandwidth is therefore an important factor in determining the maximum horizontal spatial frequency, f_{mx},of the image being transmitted. Vertical resolution as measured by the maximum vertical spatial frequency f_{my} is a function of the number of lines scanned per frame. Thus, in a conventional transmission system, only the spatial frequency spectrum bounded by rectangle 21 of FIGURE 1B is transmitted.

Experiments have indicated, however, that the human visual response to spatial frequencies is limited to be within a diamond shaped area as suggested by the spatial frequency spectrum 23 of FIGURE 1A. The diamond shaped area 23 of FIGURE 1A has the same Nyquist area as the rectangular shaped area 21 of FIGURE 1B. Thus, an improvement in the displayed image quality may be realized by decreasing the diagonal resolution available in the frequency spectrum of FIGURE 1B in exchange for increasing either vertical or horizontal resolution. In FIGURE 1A, the increased resolution is in the horizontal direction. The horizontal spatial frequencies in diamond shaped spectrum 23 of FIGURE 1A extend out to a frequency $2f_{mx}$,twice the maximum spatial frequency in the horizontal direction of the spectrum of FIGURE 1B.

In accordance with an aspect of the invention, by means of spatial frequency interleaving, a signal having a spectrum like that of area 23 of FIGURE 1A may be transmitted through the same narrowband transmission channel used to transmit a signal having a spectrum like that of FIGURE 1B.

Before frequency interleaving is attempted so as to permit the transmission of an image containing $2f_{mx}$ horizontal resolution, the signal is diagonally filtered to change the spatial frequency spectrum of the signal from that of dashed-line rectangle 22 to that of diamond-shaped area 23. To simplify the hardware, the filtering may be performed digitally. First, the image is sampled in the horizontal direction according to the orthogonal sampling point grid of the x-y image space of FIGURE 2A, with sampling points being indicated by the solid dots. In accordance with Nyquist's theorem, to preserve the original $2f_{mx}$ resolution in the horizontal direction, the image is sampled in the horizontal direction at twice the maximum horizontal spatial frequency that occurs in the image. Thus, if N_x represents the number of samples per picture width, then to satisfy Nyquist's criteria,$N_x = 1/(4f_{mx})$. The period R_1 between horizontal samples of the orthogonal sampling grid of FIGURE 2A is $R_1 = 1/N_x = 1/(4f_{mx})$. The period R_2 between vertical samples of FIGURE 2A is $R_2 = 1/N_y = 1/(2f_{my})$, where the value of N_y equals the number of lines per picture height.

The two-dimensional orthogonal sampling procedure schematically illustrated by the sampling point grid of FIGURE 2A gives rise to a plurality of rectangular repeat spectra 22r in the spatial frequency domain, as illustrated in FIGURE 2B. The repeat spectra 22r have repeat centers C that form an orthogonal grid with frequency spacing in the horizontal direction of $4f_{mx}$ and in the vertical direction, of $2f_{my}$. Each of the repeat spectra 22r ideally contains substantially the same picture information as contained in the baseband spectrum 22 that is centered about the origin O.

The sampled signal is then two-dimensionally digitally filtered to filter the baseband spectrum into the diamond-shaped area 23 and to filter the repeat spectra into diamond-shaped areas 23r, as indicated by all the shaded areas of FIGURE 3.

The next step in the frequency interleaving process is the appropriate sampling of the signal to create additional repeat spectra in the void areas adjacent the baseband spectrum 23 of FIGURE 3. By choosing quincunx subsampling, one may locate additional repeat spectra in a complementary and nonoverlapping manner with respect to the existing diamond-shaped baseband spectrum 23 and diamond-shaped repeat spectra 23r of FIGURE 3. One type of quincunx subsampling is the field quincunx sampling procedure illustrated by the sampling point grid of FIGURE 4A. Other quincunx subsampling such as line and frame quincunx subsampling may be used.

In field quincunx subsampling, alternate ones of the original pixels are discarded on a line-interleaved basis. The sampling point grid that results is illustrated in FIGURE 4A and forms a non-orthogonal quincunx, or figure-of-five pattern. The field quincunx subsampling may be achieved by subsampling interlaced video lines at half the original horizontal sampling rate and by additionally altering the phase of the sampling clock on a field-by-field basis, as will be later explained during the discussion of hardware implementation.

The effect of field quincunx subsampling in the frequency domain is illustrated in FIGURE 4B. Additional repeat spectra 23r are introduced having repeat centers C' such that the origin O or any one of the repeat centers C or C', together with the corresponding 4 adjacent repeat centers, form a figure-of-five pattern. The shape of the additional repeat spectra 23r is identical to the shape of baseband spectrum 23. The repeat center C' is spaced apart from another center C' by an amount $4f_{mx}$ in the horizontal direction and $2f_{my}$ in the vertical direction.

FIGURE 4C illustrates a portion of the frequency space of FIGURE 4B that includes only those repeat spectra 23r that are adjacent to baseband spectrum 23 and are centered on repeat centers C'. In FIGURE 4C, one may partition the baseband frequency spectrum 23 into four sec-

tions, 1, 2, 3, 4. Corrresponding sections, containing identical image and spatial frequency content but centered around a repeat center C', are identified as sections 1', 2', 3', 4'.

In accordance with an aspect of the invention, after subsampling has been performed, the signal is postfiltered to keep the spatial frequencies of the signal within the limits required for transmission through a limited bandwidth channel. Assume, illustratively, that for various reasons, including limited channel bandwidth, it is desirable to transmit a signal having associated therewith spatial frequencies no greater than f_{mx}. Thus, for example, when using field quincunx subsampling on a signal that has a diamond-shaped baseband area 23 of FIGURE 4B, wherein the signal has horizontal spatial frequencies extending to a maximum frequency of $\pm 2f_{mx}$, postfiltering of the quincunx subsampled signal is performed to limit the extent of the horizontal spatial frequencies to a maximum of $\pm f_{mx}$. Postfiltering need not be performed to remove repeat spectra associated with repeat centers having locations on the vertical axis f_y,since the scanning processes at the camera and the television receiver combine to attenuate such spectra. For simplicity such repeat spectra are not illustrated in FIGURE 4D.

The resultant transmitted spatial frequency spectrum after post-filtering has the rectangular shape of solid line rectangle 121 of FIGURE 4D, with a horizontal cutoff at the frequency f_{mx} and a vertical cutoff at the frequency f_{my}. The total Nyquist area bounded by the solid-line rectangle 121 of FIGURE 4D is the same as the total Nyquist area of the baseband diamond-shaped spectrum 23.

In addition, because of spatial frequency interleaving, the image content of the entire baseband spectrum 23 has been preserved in rectangular shaped spectrum 121 of FIGURE 4D without loss of any baseband frequency information. The baseband information for frequencies extending beyond f_{mx}, originally located in triangular sections 1a, 2a, 3a and 4a of diamond-shaped baseband spectrum 23 of FIGURE 4D, have been repositioned into the corners of rectangular frequency spectrum 121 as the corresponding triangular sections 1a', 2a', 3a' and 4a' of the repeat spectra associated with the four adjacent centers C'.

In FIGURE 4D, frequency sections 1a, 2a, 3a, 4a, of baseband spectrum 23 have been removed due to the low frequency cutoff f_{mx} produced by postfiltering of the quincunx subsampled signal. However, as a result of quincuinx subsampling, complementary sections 1a', 2a', 3a', 4a', of respective adjacent repeat spectra have been substituted or interleaved with remaining sections 1b, 2b, 3b, 4b, of baseband spectrum 23.

One notes that a feature of the inventive frequency interleaving technique just described is the ability of a limited bandwidth channel to transmit high spatial frequency content information by rearranging the original spectrum to fill up the entire Nyquist area of the transmitted signal.

At the receiver, the original baseband spectrum, such as the diamond-shaped baseband spectrum 23 of FIGURE 1A, may be reconstructed from a signal having a spatial frequency spectrum such as rectangular spectrum 121 of FIGURE 4D, by means of a complementary quincunx subsampling process, as will be described later.

FIGURE 5 illustrates an encoder 20 which implements the spatial-temporal frequency interleaving technique previously described. In FIGURE 5, a two-to-one interlaced baseband video signal V_b, such as the luminance signal component, by way of example, in a time division multiplexed component format, such as a conventional multiplexed analog component or MAC format prior to compression, is developed at a terminal 19. The baseband video signal may be obtained from conventional camera and studio hardware, not illustrated, and has a spatial frequency spectrum of a rectangular shape such as spectrum 22 of FIGURE 1A, with horizontal frequencies extending to a frequency $2f_{mx}$ and vertical frequencies extending to f_{my}. Repeat spectra existing due to the scanning process and having repeat centers on the f_y axis are not illustrated as they are of no importance for the purposes of this discussion.

Baseband video signal V_b is applied to a clock generator 27 that generates clock signals for frequency interleaving encoder 20 that is synchronized with the synchronizing information in the baseband video signal. Clock generator 27 generates a clock signal V,ck at the field rate of the baseband video signal and generates several sampling and subsampling clocks for the various digital sections of encoder 20.

Baseband video signal V_b is also applied to an analog-to-digital converter, APC 25, for sampling the signal at a sampling rate f_s in response to a clock signal f_s,ck developed by clock generator 27. The sampling rate f_s is selected so as to produce sample points in the sampling grid of FIGURE 2A that are spaced apart by the distance R_1. Thus, the frequency spectrum of the digitized video signal at the output of ADC 25 is that of the one shown in FIGURE 2B with a baseband rectangular spectrum 22 and replicated rectangular spectrums 22r centered on the repeat centers C.

The digitized and sampled video signal is then applied to a spatial low pass filter 26 that filters baseband spectrum 22 into diamond-shaped baseband area 23 of FIGURE 3 and filters repeat spectra 22r into diamond-shaped repeat spectra

23r. Spatial low pass filter 26 may be any one of several conventional type digital filters such as a maximally flat filter of order N. The higher the order of the filter, the sharper the frequency cutoff characteristics of the filter. However, the higher the order of the filter, the more complex is the hardware rehired to implement the filter. On the other hand, sharp cutoff spatial filters may introduce perceptually undesirable sidelobes into the image space of the transformed spatial frequency impulse response functions. The filter also incorporates a field store to enable the filter to process adjacent lines of the interlaced signal. If a non-interlaced signal were to be processed, then the filter would not require a full-field store.

After the signal has been filtered into diamond-shaped baseband and repeat spectra, the signal is reconfigured in its spatial frequencies to satisfy the bandwidth requirements imposed upon it by the transmission channel used. For example, assume the bandwidth of the channel that receives the frequency interleaved signal from the output of encoder 20 has a limited bandwidth that enables the transmission of horizontal spatial frequencies only up to a maximum frequency of f_{mx}. A field quincunx sampling technique such as described previously may be used to reconfigure the baseband frequency spectrum 23 of FIGURE 4C to a rectangular frequency spectrum 121 of FIGURE 4D.

To accomplish this reconfiguration, the output of spatial low pass filter 26 of FIGURE 5 is applied to a switch 30 that produces field quincunx subsampling of the video signal in the sampling pattern illustrated in FIGURE 4A. Switch 30 passes every other input sample from low pass filter 26 on a phase alternating, line-by-line basis, in response to the application of the half rate sampling clock signal $f'_s/2,ck$.

The signal $f'_s/2,ck$ is generated by selecting alternately, on a field-by-field basis, one of two available clock signals $+f_s/2,ck$ and $-f_s/2,ck$ developed by clock generator 27. The two clock signals, $\pm f_s/2,ck$, are 180° out-of-phase with each other and are synchronized with and have one-half the frequency of the sampling clock signal f_s,ck of ADC 25.

To produce the correct switching of quincunx switch 30, the signal V,ck toggles a T-type flip-flop 28 to develop on a field alternating basis high and low states at the output of the flip-flop. The output of flip-flop 28 is coupled to the select input terminal S of a multiplexer MUX 29. The signal $+f_s/2,ck$ is applied to the A input and the signal $-f_s/2,ck$ is applied to the B input. The output of MUX 29 is the clocking signal $f'_s/2,ck$ needed to produce the quincunx subsampling operation of switch 30.

Because of quincunx subsampling, the spectrum of the sampled video signal samples x_i, at the output of switch 30, is the one shown in FIGURE 4B, having a diamond-shaped baseband spectrum 23 together with repeat spectra 23r located not only around repeat centers C' but also around repeat centers C. To obtain the rectangular spectrum 121 of FIGURE 4D with a reduced horizontal cutoff frequency of f_{mx}, the video samples x_i are applied to an interpolator 12 that includes a horizontal low pass filter 50a. Filter 50a produces interpolated subsamples x'_i at the $f_s/2$ rate. At a suitable tap in filter 50a, the unprocessed video samples x_i are brought out of the filter.

Samples x_i are applied to the A input of a multiplexer MUX 32 of interpolator 12. Interpolated samples x'_i are applied to the B input. The A or B inputs to MUX 32 are clocked out of the multiplexer in response to a selection clock signal f'_s,ck applied to a select terminal S. The f'_s,ck is developed from the $f'_s/2,ck$ by frequency doubling in a doubler section 31. The use of the clock signal f'_s,ck preserves the line-by-line phase alternation required by the quincunx subsampling procedure.

The video samples x''_i developed at the output of MUX 32 has the frequency interleaved baseband spectrum of rectangular baseband spectrum 121 illustrated in FIGURE 4D. All the picture information of the original signal samples developed at the output of spatial low pass filter 26 is contained in the frequency interleaved spectral signal of samples x''_i, but rearranged so as to accommodate the narrowband transmission requirements.

The digital video samples x''_i are applied to a digital-to-analog converter DAC 33 to generate an analog video signal having the rectangular baseband spectrum 121 of FIGURE 4B. This signal is then passed through a channel low pass filter 34 to develop the frequency interleaved baseband video signal V_{fi}, prior to being sent to the transmitter stage, for transmission by way of broadcast, cable or other suitable transmission media. Channel low pass filter 34 has a horizontal spatial frequency cutoff of f_{mx} to match the transmitter channel bandwidth limitations. Filter 34 may be a separate filter or may schematically represent the overall filtering effect of the limited bandwidth transmission channel selected. Not illustrated in FIGURE 5 or in the later FIGURES showing other forms of encoder, are the additional, conventional stages of MAC processing that compress the luminance signal and combines it with the compressed chrominance signal, the reference burst or other timing signal and the pulse code modulated portion to obtain a MAC formatted signal.

FIGURE 7 illustrates interpolator 12 of FIGURE 5 including a detailed embodiment of horizontal low pass filter 50a. A three-stage delay line comprises delay elements 61, 62 and 63. Each of the delay

elements is clocked by the $f'_s/2$,ck. The quincunx sample x_i is applied to the first delay element 61 and to an input of an adder 66. The output of the third delay element 63 is applied to the other input of adder 66. The output of adder 66 is weighted by a coefficient multiplier 67 having a weighting coefficient value of a_2. The output of coefficient multiplier 67 is coupled to an input of a summer 68. The output of delay element 62 is applied to one input of an adder 64 and the output of delay element 61 is applied to the other input of the adder. The output of adder 64 is applied to a coefficient multiplier 65 having a weighting coefficient value of a_1. The output of coefficient multiplier 65 is applied to the other input of adder 68.

The output of adder 68 is the interpolated sample x'_i that is applied to the B input of MUX 32. The output of delay stage 61 is the unprocessed sample x_i which is applied to the A input of multiplexer 32. The output sample x''_i of multiplexer 32 comprises alternating real and interpolated samples. Filter 50a, therefore, provides an interpolated sample x'_i that is an interpolation of the preceding and succeeding two real samples x_i.

FIGURE 6 illustrates a decoder 40 in the television receiver that will reconstruct the diamond-shaped baseband spectrum 23 of FIGURE 1A from the frequency interleaved baseband video signal V_{fi} producedby frequency interleaving encoder 20 of FIGURE 5. After the transmitted video signal has been received by the television receiver and processed by the front end stages, such as the tuner and IF stages, assuming transmission by way of an RF modulated broadcast carrier, and has been demultiplexed and decompressed in a MAC processor, the baseband frequency interleaved video signal V_{fi} is developed at a terminal 119 of FIGURE 6. Items of FIGURES 5 and 6 that are similarly identified function in a similar manner or represent similar quantities.

As the first step in reconstructing the diamond shaped baseband spectrum, the frequency interleaved video signal V_{fi} is quincunx subsampled at the half sampling rate of $f_s/2$, in order to generate signal samples y_i. Due to quincunx subsampling, the frequency spectrum of the signal samples y_i is that of the frequency spectrum of FIGURE 4B. To perform the quincunx subsampling, while at the same time digitizing analog signal V_{fi}, an analog-to-digital converter APC 125 receives frequency interleaved signal V_{fi} and subsamples it in a quincunx manner in accordance with the clocking signal $f'_s/2$,ck being provided by multiplexer MUX 29.

The subsampled signal y_i is applied to an interpolator 13 that includes a spatial low pass filter 26'. The function of spatial low pass filter 26' is to filter the signal samples y_i to remove all the repeat spectra 23r of FIGURE 4B that are located about the repeat centers C'. Samples y'_i at the output of spatial low pass filter 26' are coupled to the B input of a multiplexer MUX 32. The unprocessed samples y_i are coupled to the A input. Digital samples y''_i are developed at an f_s rate at the output of MUX 32. Digital samples y''_i alternate between unprocessed samples y_i and interpolated samples y'_i and contain the spatial frequency spectrum of FIGURE 3.

To convert samples y''_i into an analog video signal, the samples are applied to digital-to-analog converter 33 that is clocked by the field-by-field, phase alternating signal f'_s,ck. A low pass filter 134 has a horizontal spatial frequency cutoff of $2f_{mx}$ to remove repeat spectra having horizontal frequencies that are greater in magnitude than $2f_{mx}$. The output of low pass filter 134 provides a reconstructed baseband video signal, V_{bd}, having the diamond-shaped baseband spectrum 23 of FIGURE 1A. The signal V_{bd} also contains repeat spectra, not illustrated in FIGURE 1A, that are positioned on the vertical axis f_y. These vertical repeat spectra are of no importance for the purposes of this discussion, as they are attenuated by the scanning process in the television receiver.

Filter 26 of FIGURE 5 and filter 26' of FIGURE 6 perform analogous functions in frequency interleaving encoder 20 and frequency reconstructing decoder 40, respectively. Each of the two filters takes its respective signal samples and processes them to generate signal samples having diamond-shaped spectra. Thus, spatial low pass filters 26 and 26' may be similarly constructed, taking into account the fact that the input sample rate for filter 26 is twice that for filter 26'.

The use of sampling for frequency interleaving a high definition television signal is comparable in analog processing to modulating the signal on a carrier in order to interleave the high spatial frequency information with the low spatial frequency information. Assume that the quincunx subsampling of the digitized video signal V_b ofFIGURE 5 is arranged so as to force every other digital sample to zero at the output of quincunx switch 30. FIGURE 8 illustrates a portion of the system of FIGURE 5 having such quincunx switching, including a D-type flip flop 130. FIGURE 9 illustrates real samples x_i of the video signal V'_b, where the signal V_b' is the analog equivalent of the digitized video signal after spatial low pass filtering by filter 26 of FIGURE 8. The samples x_j of FIGURE 9 represent alternate samples that were forced to zero by the operation of D- type flip-flop 130 of FIGURE 8.

In FIGURE 9, a carrier signal s(t) may be drawn that has maxima and minima corresponding to the values of the samples x_i and x_j, respectively. Thus, from FIGURE 9 one may conclude that the subsampling procedure is equivalent to multiplying

the video signal V'_b by the carrier signal

$$s(t) = 1/2 + 1/2 \cos(\pi f_s t).$$

The sampling or equivalent carrier modulation tends to introduce a full-strength alias described below which could result in undesirable artifacts being displayed together with the picture information. As previously indicated, the effects of aliasing can be substantially reduced by transmitting the interleaved spectral section with diminished amplitude relative to a remaining spectral section of the transmitted video signal. At the receiver, a complementary process is performed that represents spatial-temporal carrier modulation of the spatial-temporal frequency interleaved video signal. The interleaved section is restored to its original position in the image spectrum, while, at the same time, its amplitude is increased.

To explain the origin of the aliasing, one notes that the frequency spectrum of the video modulated carrier signal $V'_b \cdot s(t)$ of FIGURE 9A is similar to the one illustrated in FIGURE 9B. The spectrum includes the solid line baseband spectrum out to the frequency $f_s/2$ and a dashed-line replicated spectrum illustratively having maximum amplitude at the frequency $f_s/2$ and decreasing toward zero as the origin is approached.

One observes that in FIGURE 9B, the replicated spectrum is at full amplitude compared to the baseband spectrum. To avoid the introduction of objectionable artifacts in the displayed picture, it is desirable to reduce the amplitude of the replicated spectrum relative to the baseband spectrum.

To reduce the amplitude of the replicated spectrum, the signal V'_b is sampled at the f_s rate and the value of every other sample is reduced below its unity value, but to a nonzero value. As illustrated in FIGURE 10A, the original samples x_i retain their original unity values; the alternate samples x_j are of reduced value.

The effect of reducing the value of samples x_j is the equivalent of carrier modulating the signal V'_b by the signal

$$s'(t) = (1-c) + (c)\cos(\pi f_s t),$$

where c is greater than zero but less than 1. For illustrative purposes, c = 1/4 in FIGURE 10A.

The spectrum of the carrier modulated signal $V'_b * s(t)$ is illustrated in FIGURE 10B and includes the original baseband spectrum and a replicated spectrum that is substantially reduced in amplitude compared to the baseband spectrum. For the example of c = 1/4 the replicated spectrum is reduced to 1/3 the amplitude of the baseband spectrum, thereby reducing the noticeability of any artifacts caused by aliasing.

FIGURE 11 illustrates an encoder 20' which implements the spatial-temporal frequency interleaving technique previously described, including a reduced amplitude carrier quincunx switching stage 330. Items in FIGURE 5 and FIGURE 11 that are similarly identified function in a similar manner or represent similar quantities.

In FIGURE 11, baseband video signal V_b is applied to ADC 25, for sampling the signal at the sampling rate f_s in response to a clock signal f_s,ck developed by clock generator 27 of FIGURE 11. The sampling rate f_s is selected so as to produce sample points in the sampling grid of FIGURE 2A that are spaced apart by the distance R_1. Thus, the spatial frequency spectrum of the digitized video signal at the output of ADC 25 is that of the one shown in FIGURE 2B with a baseband rectangular spectrum 22 and replicated rectangular spectrums 22r centered on the repeat centers C.

The digitized and sampled video signal is then applied to spatial low pass filter 26 that filters baseband spectrum 22 into diamond-shaped baseband area 23 of FIGURE 3 and filters repeat spectra 22r into diamond-shaped repeat spectra 23r.

To accomplish the reconfiguration of the filtered signal into spatial frequencies that satisfy the bandwidth requirements of the transmission channel used, the output of spatial low pass filter 26 is applied to a quincunx switch 330 that produces quincunx subsampling of the video signal in the sampling pattern illustrated in FIGURE 4A. Switch 330 passes through unmodified, to output line 91, every other one of the input samples x_i obtained from low pass filter 26. This pass through is performed on a phase alternating, field-by-field basis, in response to the application of the half-rate sampling clock signal $f'_s/2$,ck to multiplexer 230 of switch 330.

The samples x_i at the output of spatial low pass filter 26 of FIGURE 11 ale also applied to a coefficient multiplier 71 within switch 330 which multiplies the samples x_i by the coefficient (1-2c) to develop the samples x_j at the B input of multiplexer 230. By clocking the select input terminal S with the clock signal f'_s,ck, a stream of samples x_i and x_j are produced in the form illustrated in FIGURE 10A. Due to the reduced amplitude spatial carrier equivalent to the reduced amplitude carrier of FIGURE 10A, the amplitudes of the spatial frequencies in sections 1' through 4' of the replicated spectra 23r of FIGURES 4C and 4D are of reduced amplitude relative to the frequencies in baseband sections 1 through 4.

Because of quincunx sampling, the spectrum of the sampled video signal, samples x_i, x_j, at the output of switch 330, is the one shown in FIGURE 4B, having a diamond-shaped baseband spectrum

23 together with repeat spectra 23r located not only around repeat centers C' but also around repeat centers C. To obtain the rectangular spectrum 121 of FIGURE 4D at the lower horizontal cutoff frequency of f_{mx}, the video samples x_i, x_j are applied to a horizontal low pass filter 150a.

In filter 150a, the samples x_i, x_j are stored in a latch 72 clocked by the clock signal f'_s,ck. The clock signal f'_s,ck is developed from the f'_s /2,ck signal by frequency doubling as in the doubler stage 31 in Figure 5. The samples are then clocked out of latch 72 to a two-stage delay comprising delay stages 73 and 74. Additionally, the samples at the output of latch 72 are multiplied by a coefficient multiplier 75 and then applied to an adder 78. The samples developed at the output of delay stage 73 are multiplied by a coefficient multiplier 76 and then applied to adder 78. The samples at the output of delay stage 74 are multiplied by coefficient multiplier 77 and then applied to adder 78. The samples at the output of adder 78 are multiplied by coefficient multiplier 79 to produce the frequency interleaved digital samples x'_i of FIGURE 11. To preserve overall unity gain between the samples x_i, x_j and the samples x'_i, the value of coefficient multiplier 79 is 1/(1-c).

The video samples x'_i developed at the output of filter 150a have the frequency interleaved baseband spectrum of rectangular baseband spectrum 121 illustrated in FIGURE 4D. All the picture information of the original signal samples developed at the output of spatial low pass filter 26 is contained in the frequency interleaved spectral signal of samples x'_i, but rearranged so as to accommodate the narrowband transmission requirements.

The digital video samples x'_i are applied to a digital-to-analog converter DAC 33 to generate an analog frequency interleaved baseband video signal having the rectangular baseband spectrum 121 of FIGURE 4D. As in FIGURE 5, this signal is then passed through a channel low pass filter 34 prior to being sent to the transmitter stage.

The frequency interleaved video signal V_{fi} developed at the output of filter 34 contains the rectangular baseband spectrum 121 of FIGURE 4D.

The concept of reducing the relative amplitude of the interleaved sections to avoid the introduction of aliasing artifacts may be also beneficially used in other embodiments of the invention. Thus in embodiments employing analog processing such as that to be described with reference to FIGURE 14-17, the amplitude of the interleaved sections may be reduced by using a reduced amplitude carrier wave: then at the receiver, where complementary carrier modulation process reconstructs the original image spectrum, an increased amplitude carrier wave is used to restore the amplitude of the relocated section to its original level.

FIGURE 12 illustrates a decoder 40' in the television receiver that will reconstruct the diamond-shaped baseband spectrum 23 of FIGURE 1B from the frequency interleaved baseband video signal V_{fi} producedby frequency interleaving encoder 20' of FIGURE 11. After the transmitted video signal has been received by the television receiver and processed by the front end stages, such as the tuner and IF stages, assuming transmission by way of an RF modulated broadcast carrier, and has been demultiplexed and decompressed in a MAC processor, the baseband frequency interleaved video signal V_{fi} is developed at a terminal 119 of FIGURE 12. Items of FIGURES 11 and 12 that are similarly identified function in a similar manner or represent similar quantities, as do similarly identified items in FIGURES 6 and 12.

As the first step in reconstructing the diamond shaped baseband spectrum, the frequency interleaved video signal V_{fi} is quincunx subsampled at the half sampling rate of $f_s/2$, in order to generate signal samples y_i. Due to quincunx sampling, the frequency spectrum of the signal samples y_i is that of the frequency spectrum of FIGURE 4B. To perform the quincunx subsampling, while at the same time digitizing analog signal V_{fi}, an analog-to-digital converter ADC 125 receives frequency interleaved signal V_{fi} and subsamples it in a quincunx manner in accordance with the clocking signal $f'_s/2$,ck.

The subsampled signal y_i is applied to an interpolator 13 that produces digital samples y''_i at its output at an increased rate of f_s. A specific embodiment of interpolater 13 is illustrated in FIGURE 13, including a spatial low pass filter 26'. The function of spatial low pass filter 26' is to filter the signal samples y_i to remove all the repeat spectra 23r of FIGURE 4B that are located about the repeat centers C'. Samples y'_i at the output of spatial low pass filter 26' are coupled to the B input of a multiplexer MUX 32. The unprocessed samples y_i, obtained at a suitable tap of filter 26', are coupled to the A input. Digital samples y''_i are developed at an f_s rate at the output of MUX 32. Digital samples y''_i alternate between unprocessed samples y_i and interpolated samples y'_i and contain the spatial frequency spectrum of FIGURE 3, including baseband spectrum 23 of FIGURE 1A.

Due to the technique, previously described, of reducing the amplitude of the modulated carrier, reconstructed sections 1a' through 4a' of FIGURE 1A contained in the samples y''_i are still of reduced amplitude. To restore these frequencies and these sections to their original amplitude, the samples y''_i are horizontally high pass filtered, multiplied by a gain factor of (1-c)/c and then added back to the original samples y''_i after these same samples y''_i have been horizontally low pass filtered.

As illustrated in FIGURE 12 samples y''_i at the

output of interpolator 13 are coupled to a horizontal high pass filter 86 that removes horizontal spatial frequencies smaller in magnitude than f_{mx}. The baseband spectrum of the output of high pass filter 86 contains only sections 1a' through 4a'. The output samples of high pass filter 86 are coupled to a coefficient multiplier 81 that results in the restoration of sections 1a' through 4a' to their full amplitude.

Samples y''_i at the output of interpolator 13 are also coupled to a horizontal low pass filter 83 that removes all spatial frequencies extending beyond $\pm f_{mx}$. The baseband spectrum of the output of low pass filter 83 contains only sections 1b through 4b of FIGURE 1A.

The samples at the outputs of horizontal low pass filter 83 and coefficient multiplier 81 are coupled to an adder 82 to redevelop signal samples y''_i but with sections 1a' through 4a' of FIGURE 1A restored to full amplitude.

To convert samples y''_i into an analog video signal, the samples are applied to digital-to-analog converter 33 that is clocked by the field-by-field, phase alternating signal f'_s,ck. A low pass filter 134 has a horizontal spatial frequency cutoff of $2f_{mx}$ to remove repeat spectra having horizontal frequencies that are greater in magnitude than $2f_{mx}$. The output of low pass filter 134 provides a reconstructed baseband video signal, V_{bd}, having the diamond-shaped baseband spectrum 23 of FIGURE 1A. The signal V_{bd} also contains repeat spectra, not illustrated in FIGURE 1A, that are positioned on the vertical axis f_y. These vertical repeat spectra are of no importance for the purposes of this discussion, as they are attenuated by the scanning process in the television receiver.

Filter 26 of FIGURE 11 and filter 26' of FIGURE 12 perform analogous functions in frequency interleaving encoder 20' and frequency reconstructing decoder 40', respectively. Each of the two filters takes its respective signal samples and processes them to generate signal samples having diamond-shaped spectra. Thus, spatial low pass filters 26 and 26' may be similarly constructed, taking into account the fact that the input sample rate for filter 26 is twice that for filter 26'.

When the high definition television signal processing system incorporates sampling techniques, high frequency carriers are inherently introduced in the form of spectral repeat centers by means of the sampling procedure. When analog processing circuitry is used, spatial repeat spectra may be introduced, for example, by modulating an appropriately selected carrier wave with the video signal.

Great flexibility is available in selecting the spatial-temporal carriers that generate repeat centers at particular points in the spatial-temporal frequency volume. The effect of using spatial-temporal carrier generation is to reconfigure the spectrum of the image, transmitting a portion of the baseband spectrum in a different location of the spatial-temporal frequency volume.

As previously indicated, the baseband spatial-temporal frequency spectrum of a video signal maybe configured so as to enable rectangular sections of the spectrum to be interleaved. The baseband frequency spectrum used may be a cruciform-shaped region illustrated in solid-line in FIGURE 14. Such a spectrum is capable of providing improved horizontal and vertical resolution at the expense of diagonal resolution. This type of trade off may produce a more pleasing picture, taking into account the physiology of the eye and the perception of images by the visual system. Moreover, additional advantages ensue if one extracts from the baseband video spectrum, for the purpose of frequency interleaving, a spectral section of such shape and orientation so as to enable the sides of the section to be oriented parallel to the horizontal and vertical directions. Both the frequency interleaved encoding of the video signal at the transmitter and the decoding of the frequency interleaved signal at the television receiver may be readily accomplished using analog processing circuitry and a simplified filtering arrangement that is separable into a plurality of one-dimensional filters. The analog circuitry encoder modulates an appropriately selected carrier wave, and the analog circuitry decoder demodulates the received spatial-temporal frequency interleaved signal.

In the analog circuitry illustrated in FIGURE 16, a baseband video signal V_b is developed by conventional camera and studio equipment at a terminal 219 of a frequency interleaving encoder 220.

Video signal V_b may comprise the luminance signal component, by way of example, in a time division multiplexed component format, such as a multiplexed analog component or MAC format, prior to compression. The spatial-temporal frequency spectrum of video signal V_b may be considered for explanatory purposes as arbitrarily encompassing the rectangular area 117 of FIGURE 14A that includes cruciform region 118.

Baseband video signal V_b is coupled to a horizontal low pass filter 223 that limits the extent of the horizontal spatial frequencies of the image to the frequencies $\pm f_{h3}$ cycles per picture width (c.p.w.). Not illustrated in FIGURES 14A - D are repeat spectra having repeat centers located on the vertical axis f_v. These repeat spectra are inherently generated in the scanning process. However, the very same process when performed in the camera and in the television receiver causes these spectra to be attenuated.

The spatial frequency spectrum of the video signal V'_b, developed at the output of horizontal low

pass filter 223, is the spectrum illustrated in FIGURE 14B that includes the desired cruciform region 118 and the corner regions 6a through 6d.

Assume that the transmission channel used is capable of transmitting a signal having a Nyquist area equal to that of cruciform region 118 of FIGURES 14A and 14B but is incapable of transmitting horizontal spatial frequencies greater in extent than the spatial frequency $\pm f_{h2}$. A frequency interleaving technique in accordance with an aspect of the invention may be used to take sections 1a, 1b, 5a, 5b, in cruciform region 118 of FIGURE 14E and transfer the contents of these regions next to the corners of cruciform region 118, as illustrated in FIGURE 14D The rectangular spatial frequency spectrum 221 of FIGURE 14D contains the identical spectral content as that of the original cruciform spectrum 118 of FIGURES 14D and 14B rearranged to permit transmission over a limited capacity channel.

The rearrangement is produced in the following manner by encoder 220. The filtered video signal V'_b is applied to a horizontal filter 224 for the purposes of removing the unwanted spatial frequencies located in corners 6a through 6d of FIGURE 14B A low pass output signal line 231 of filter 224 develops a video signal A derived from signal V'_b that contains horizontal spatial frequencies extending below $\pm f_{h1}$. Thus, signal A contains the spatial frequencies of rectangular section 3 of FIGURE 14B A high pass output signal line 232 of filter 224 develops a video signal D derived from signal V'_b that contains horizontal spectral frequencies greater in magnitude than the frequency f_{h1}. Thus, signal D contains the spatial frequencies of sections 1, 2, 4, 5, 6a -6d of FIGURE 14B.

Signal D on high pass output line 232 is coupled to a vertical low pass filter 225 which removes vertical spatial frequencies greater in magnitude than the frequency f_{v1} cycles per picture height (c.p.h.). The output of vertical low pass filter 225 on a signal line 233 comprises a video signal E that contains the spatial frequencies of sections 1, 2, 4, 5 of FIGURE 3B. Corner sections 6a - 6d have therefore been removed from signal E.

Signal E on line 233 is coupled to a horizontal low pass filter 226 that removes horizontal spatial frequencies greater in magnitude than the frequency f_{h2}.The output of horizontal low pass filter 226 on signal line 234 comprises a video signal B that contains the spatial frequencies of only sections 2 and 4 of FIGURE 14B Signal E on line 233 is also coupled to a horizontal high pass filter 227 that removes all horizontal spatial frequencies smaller in magnitude than the frequency f_{h2}. The output of horizontal high pass filter 227 on a signal line 235 comprises a video signal C that contains the spatial frequencies of sections 1 and 5 of FIGURE 14B. It is these sections 1 and 5 that are to be spatially modulated onto an appropriate spatial carrier signal that spatially frequency interleaves these sections into corners of cruciform region 118.

Consider an image i(x,y) that is to be transmitted by means of a raster scanning system, where, for simplicity, the temporal dimension associated with the image is omitted from consideration. In the spatial frequency domain, the transform of the image is $I(f_h, f_v)$, where $I(f_h, f_v)$ is the fourier transform of i(x,y). The image i(x,y) may be considered as a superposition of spatial sinewave gratings $S(f_h,f_v)$.

A sinewave grating of given spatial frequency and orientation may be viewed a spatial carrier having two diagonally opposed spectral centers $(+f'_h, +f'_v)$ and $(-f'_h, -f'_v)$ in the spatial frequency domain. By spatially modulating the image i(x,y) onto the spatial carrier $S(f'_h,f'_v)$, the spectrum $I(f_h,f_v)$ of the image is repositioned from its location referenced to the origin to each of two locations referenced to the spectral centers $(+f'_h,+f'_v)$ and $(-f'_h,-f'_v)$, respectively.

The raster scanning process maps a given image i(x,y) onto a given video signal v(t). Similarly, the scanning process maps a given spatial carrier $S(f_h,f_v)$ onto a given video carrier signal s'(t).

Each line n of the video carrier signal s(t) may be of the form $\cos 2\pi(f'_h f_\ell t + \Delta\phi_n)$, where f_ℓ is the line scanning frequency of, illustratively, 15,734 lines per second for a system using an NTSC two-to-one interlace, or 31,468 lines per second in a double-line-rate progressive scanning system, and where $\Delta\phi_n$ is an added phase term for the nth line of video carrier signal v(t). The phase term $\Delta\phi_n$ is a function of the spatial frequency and orientation of a spatial carrier having spatial centers $(+f'_h,+f'_v)$ and $(-f'_h,-f'_v)$. By proper selection of the spatial spectral centers, the phase term $\Delta\phi_n$ may be made equal to zero for all video lines, allowing the video carrier signal s(t) to be a continuous wave signal $v(t) = \cos 2\pi f'_h f_\ell t$.

Returning now to FIGURE 16 the video signal C on line 235 modulates a carrier signal s'(t) in a modulator 228. By proper selection of s'(t), the modulation of carrier signal s'(t) by the signal C generates a modulated signal S_c that is selected to produce spectral centers C_{mod1} through C_{mod4} of FIGURE 14C. The positions of the four centers are the coordinates $(\pm f_{h0}, \pm f_{v2})$.

When video signal C, containing only sections 1 and 5 of FIGURE 14B modulates the video carrier s'(t), the modulated video signal S_C has the spatial spectral content illustrated by the solid line rectangular sections 1a', 1b', 5a', 5b' of FIGURE 14C located adjacent the corners of cruciform region 118. Sections 1a', 1b', 5a', 5b' correspond to respective upper and lower portions 1a, 1b,5a,5b of sections 1 and 5 in FIGURE 14B.

The output of an adder 229 is the sum of video signals A, B and S_C. A channel low pass filter 237 removes any spuriously introduced spatial components greater in magnitude than f_{h2}. The output of filter 237 comprises the frequency interleaved baseband video signal vf_i that is then sent to conventional transmitter stages, such as the RF modulator stages in a broadcast transmission system.

The spatial spectral content of video signal V_{fi} is illustrated in FIGURE 14D and includes section 3 obtained from video signal A, sections 2 and 4 obtained from video signal B and sections 1a', 5a' 5b' obtained from modulated video carrier signal S_C. Thus, by means of the frequency interleaving process, the original cruciform region 118 of FIGURE 14A is transmitted as the rectangular region 221 of FIGURE 14D.

As previously noted, by filtering the image spectrum to remove original image spectral content at the interleaved locations, artifacts will be avoided that are due to the interaction between the interleaved spectral information. These artifacts will be avoided not only when the image is stationary but even when motion occurs in the image.

At the television receiver, a decoder 340, illustrated in FIGURE 17, restores the baseband spatial frequency spectrum of incoming video signal V_{fi} to its original cruciform shaped spectrum 118. After the transmitted video signal has been received by the television receiver and processed by the front end stages, such as the tuner and IF stages, assuming transmission by way of an RF modulated broadcast carrier, and has been demultiplexed and decompressed in a MAC processor, the frequency interleaved baseband video signal V_{fi} representing the luminance component of a MAC signal is developed at a terminal 319 of FIGURE 17. The spatial frequency spectrum of signal V_{fi} is the rectangular spectrum 221 illustrated in FIGURE 14D.

To separate the interleaved spectral components, video signal V_{fi} is coupled to a horizontal filter 341. A video signal M is developed on a low pass output signal line 348 that contains only spatial frequencies smaller in magnitude than the frequency f_{h1} of FIGURE 14D. Thus the spatial spectral content of video signal M is that of section 3 of FIGURE 14D.

A video signal N is developed on a high pass output signal line 345 of horizontal filter 341. The spatial frequency content of signal N contains only frequencies that are greater in magnitude than the spatial frequency f_{h1}. Therefore, video signal N contains the spatial frequencies of sections 2, 4 and sections 1a', 1b', 5a', 5b' of FIGURE 14D.

Signal N is coupled to a vertical filter 342. A video signal Q developed on a low pass output line 347 contains vertical spatial frequencies no greater in magnitude than the frequency f_{v1}. signal Q, therefore, contains the spectral sections 2 and 4 of FIGURE 14D.

A video signal P is developed on a high pass output signal line 346 of vertical filter 342 and contains vertical spatial frequencies that are greater in magnitude than the frequency f_{v1}. Signal P, therefore, contains only the spectral contents of sections 1a', 1b', 5a', 5b' in the positions shown in FIGURE 14C.

The spectral contents of sections 1a', 1b', 5a', 5b' must be returned to their original locations as sections 1a, 1b, 5a, 5b adjacent the horizontal axis f_h of FIGURE 15 To accomplish this result, video signal P is coupled to one input of a demodulator 343. The same carrier signal s'(t), is coupled to the other input of demodulator 343. The modulation of the carrier signal s'(t) by the video signal P produces the modulated video carrier signal S'_p on a signal line 349.

The effect of the video carrier modulation of the video signal P is to produce spatial carrier modulation which introduces spectral centers C_{dem1} -C_{dem4} in the positions illustrated in FIGURE 15. These positions are identical to the positions of the spatial spectral centers of FIGURE 14C. The spatial spectra associated with these centers include the very same baseband spectral sections 1a, 1b, 5a, 5b in the proper baseband locations of cruciform spectral region 118 of FIGURE 15.

The modulation process also introduces undesired spectral sections, not illustrated in FIGURE 15, of horizontal spatial frequencies smaller in magnitude than f_{h2}. A horizontal high pass filter 352 having a cutoff frequency of f_{h2} receives video signal S'_p, removes the undesired spectral sections and develops a video signal S_p on a line 351 that contains only baseband spectral sections 1a, 1b, 5a, 5b. As indicated previously, vertical repeat spectra, not illustrated in FIGURE 15 are of no importance for the purposes of this discussion, since they are attenuated by the scanning process in the television receiver.

To reconstruct the cruciform baseband spectral region 118 of FIGURE 14A video signals M, Q, and S_p are summed in an adder 344 to develop at an output signal line 350 a reconstructed baseband video signal V''_b, representing luminance channel information. The spatial frequency spectrum of baseband video signal V''_b is the desired cruciform shaped spectrum 118.

By making certain simplifying selections for the locations of the spatial spectral centers, $(\pm f_{ho}, \pm f_{v2})$, the video carrier signal s'(t) may comprise a continuous wave sinusoidal signal. For example, to generate an interleaved spectrum 221 in FIGURE14D of rectangular shape, assume that:

$f_{h3} = 4f_{ho}$, $f_{h2} = 3f_{ho}$, $f_{h1} = 2f_{ho}$, $f_{v2} = 2f_{v1}$.

Select f_{h2} to be the greatest horizontal spatial frequency that is an integral multiple m of half-cycles per picture width, consistent with a given transmission channel bandwidth of f_{BN} cycles per second. Then, $f_{h2} \sim f_{BN}/f_\ell$, and $f_{ho} \sim f_{BN}/3f_\ell$. A continuous wave video carrier s'(t) that generates spatial spectral centers C_{mod1} through C_{mod4} of FIGURE 14C having a horizontal spatial frequency of f_{ho} in magnitude is:

$$s'(t) = \cos 2\pi f_{ho} f_\ell t \sim \cos(2\pi f_{BN} t/3).$$

Assuming a two-to-one interlace is used in raster scanning the image, the video carrier s'(t) establishes vertical spatial frequencies of the spatial spectral centers. The magnitude f_{v2} is: $f_{v2} = N_{FR}/4$ cycles per picture height, where N_{FR} equals the number of scan line per picture height (or frame), e.g., $N_{FR} = 525$ for an NTSC scanning format.

As a specific example consider a MAC system using an NTSC two-to-one scanning interlaced format of 525 scan lines per picture frame, 29.97 frames per second, and a horizontal scanning rate of $f_\ell = 15{,}734$ lines per second. The video transmission channel bandwidth for the MAC signal is 5.61 megahertz. Assuming a 4 to 3 compression ratio for the luminance component of the MAC signal, then the bandwidth f_{BN} of the MAC channel in relation to the uncompressed luminance component is 4.21 megahertz. The horizontal spatial frequency f_{h2} is the closest frequency to f_{BN}/f_ℓ that is an integral multiple of half-cycles or $f_{h2} = 267\frac{1}{2}$ cycle per picture width. The frequency f(t) of the video carrier wave s'(t) used for spatial frequency interleaving purposes is $f(t) = f_{h2}f_\ell/3 \sim f_{BN}/3 = 1.40$ megahertz. The horizontal spatial frequency f_{ho} of the spectral centers is $f_{ho} = f_{h2}/3 = 89.2$ cycles per picture width. The vertical spatial frequency f_{v2} of the spectral centers is $f_{v2} = N_{FR}/4 = 525/4 = 131\frac{1}{4}$ cycles per picture height. The increase in horizontal spatial resolution is by an amount: $(f_{h3} - f_{h2})/f_{h2} = 1/3$. In other words, by using the inventive spatial-temporal frequency interleaving techniques just described, the horizontal spatial frequencies that can be transmitted for a given channel bandwidth is increased by one-third.

The frequency interleaving techniques just described generates a spatial frequency interleaved video signal V_{fi} of FIGURE 16 that can be compatibly processed by television receivers that do not incorporate a decoder, such as decoder 340, in their video processing stages. The artifacts introduced into the displayed picture is a fine, checkerboard dot pattern due to the display on the screen of the television receiver of the spatial frequency interleaving video carrier s'(t) and the modulated sections 1a' through 5a' of FIGURE 14C. Such artifacts, because they are produced in only the relatively high spatial frequency regions of the displayed picture are not significantly noticeable by the viewer.

In the simplified example, discussed previously, where the frequency of the video carrier signal s'(t) was selected to be an integer multiple of one-half the horizontal line frequency, the phase of the video carrier at any given instant is 180 degrees out-of-phase with the phase of the video carrier one frame time later. The artifacts introduced when processing the interleaved video signal without using a decoder tends to include line crawl along edges of the picture. Such line crawl may be eliminated, if so desired, by inverting the phase of video carrier s'(t) in alternate frames.

Several advantages ensue by using a cruciform shaped baseband video signal for frequency interleaving purposes and rectangular sections as the interleaved sections. Encoder 220 of FIGURE 16 and decoder 340 of FIGURE 17 may use relatively simple analog processing stages rather than digital processing stages. Relatively uncomplicated separable horizontal and vertical filters may be used in both the encoder and decoder. The reduced filter complexity facilitates the use of carrier signals selected with relatively few constraints imposed on the choice of signals. The use of rectangular regions 1a, 1b, 5a, 5b, of FIGURES 14B and 15 for the interleaving process substantially reduces visual artifacts in the displayed picture, because separable horizontal and vertical filters approaching ideal filters are readily realizable.

In general the use of nonseparable filters with similar roll off characteristics to separable filters requires that substantially more arithemtic operations be performed. For example, an 11 x 11 nonseparable filter nominally requires the use of approximately 121 filter coefficients (implemented via multiply and add operations). In contrast, a separable filter arrangement, comprising two nth order one-dimensional filters requires the use of only 22 coefficients, approximately, thus resulting in a significant reduction in hardware.

If digital processing circuitry is used to sample a baseband video signal at a sampling rate f_s, then equivalent modulation by the aforementioned carrier s'(t) may be accomplished using a memory to store values of a carrier term: $\cos(2\pi f_{mod} t)$, developed over one cycle, wherein each value is separated in time from an adjacent value by an amount $1/f_s$, and where f_{mod} is a carrier frequency. The samples of the baseband video signal are then multiplied by the corresponding values of the carrier term in a combinatorial multiplier to obtain samples of a modulated carrier video signal that contains the spatial-temporal frequency interleaved

spectrum of FIGURE 14D.

Having regard to the foregoing description, and in general, one may again state that spatial-temporal frequency interleaving techniques substitute one piece of spatial information, such as information contained in the high horizontal frequencies, in place of another piece of information, such as information contained in diagonal frequencies, both of which are relatively high frequency spatial information. FIGURES 18-24 relate to a system in which different pieces of spatial information, such as diagonal and high horizontal frequency information, are transmitted to the receiver by alternating or temporally multiplexing transmission of the pieces of information at a given rate such as at the frame rate. Thus, the video signal of an image containing diagonal frequency information is transmitted in one frame, while the video signal of an image containing high horizontal frequency information is transmitted in the alternate frame. Assuming a frame rate of 30 Hertz, the visual artifacts introduced into such a transmission system is a half-frame rate, 15 Hertz flicker.

In video signal generator 400 of FIGURE 18, a baseband video signal V_b is developed by conventional camera and studio equipment at a terminal 419. Video signal V_b may comprise a two-to-one interlaced luminance signal component, by way of example, in a time division multiplexed component format, such as a conventional multiplexed analog component or MAC format, prior to compression.

The spatial-temporal frequency spectrum of video signal V_b may be considered for explanatory purposes as arbitrarily encompassing the rectangular area 117 of FIGURE 22A that includes, similarly to FIGURE 14A, a cruciform region 118. As explained in connection with FIGURE 14A, the spectral contents of interest are those encompassed within cruciform region 118, including high horizontal spatial frequency sections 1a, 2a, 5a, 5b. Assume as before, however, that the channel utilized to transmit video signals to a receiver, such as an RF broadcast channel, is of limited capacity and is not capable of transmitting video signals having horizontal spatial frequencies greater in magnitude than f_{h2} of FIGURE 22A. Video signal generator 400 of FIGURE 18 may use a frequency interleaving encoder 220 to reconfigure the spatial spectrum of video signal V_b intospectrum 221 of FIGURE 22B, similar to FIGURE 14D. The high horizontal sections 1a, 1b, 5a, 5b of spectrum 118 of FIGURE 22A have been positioned next to the corners of the cruciform spectrum to respectively form the complementary sections 1a', 1b' 5a', 5b' of rectangular spectrum 221 of FIGURE 22B. Rectangular spectrum 221 contains horizontal spatial frequencies of magnitude no greater than the aforementioned frequency f_{h2}.

To accomplish the spectral reconfiguration, video signal Vb, a frequency interleaving encoder 220 which may be similar to that described in FIGURE 16, produces a frequency interleaved video signal V_{fi} on a signal line 426. The spatial frequency spectrum of video signal V_{fi} is the previously described rectangular spectrum 221, illustrated in FIGURE 14D, and again illustrated in FIGURE 22A. The signal V_{fi} includes high horizontal spatial frequencies, moved or interleaved into the corners of spectrum 221 as sections 1a', 1b', 5a', 5b'. Video signal V_{fi} therefore does not contain any diagonal information.

Baseband video signal V_b is also coupled to a horizontal low pass filter 422 which removes from the video signal spatial frequencies that extend beyond $\pm f_{h2}$. After suitable delay in a delay unit 423, a filtered video signal V_{b1} is developed on a signal line 427 having the spatial frequency spectrum 321 illustrated in FIGURE 22B. The spectrum of video signal V_{b1} includes diagonal spatial frequencies D1 through D4 located in the same corners as those in which the high horizontal spatial frequencies are located for the frequency interleaved signal V_{fi}. Comparing FIGURES 22B and 22A, one notes that both signals have a common spectral section 180. Where the spectral content of the two signals differs is in the corners where signal V_{b1} favors diagonal spatial frequencies, and signal V_{fi} favors high horizontal spatial frequencies.

Video signal V_{b1} is coupled to a contact S1 of a single-pole-double-throw switch 424. Video signal V_{fi} is coupled to a contact S2. A vertical sync signal, conventionally derived, is coupled to switch 424 to enable the arm of the switch to move between contacts S1 and S2 at a frame rate. During Frame 1, for example, video signal V_{b1} is coupled to pole S3 of switch 424, and during Frame 2, the alternate frame, video signal V_{fi} is coupled to pole S3. Video signal V_s developed on a signal line 428 is a luminance signal that comprises video signal V_{b1} during Frame 1 and video signal V_{fi} during the alternate frame, Frame 2. The spatial frequency spectrum of video signal V_s, therefore, alternates between that of spectrum 321 of FIGURE 22B during Frame 1 and that of spectrum 221 of FIGURE 22A during Frame 2.

Video signal V_s, after being filtered by a channel low pass filter 425, is then sent to conventional transmitter stages, such as the RF modulating stages in a broadcast transmission system.

FIGURE 19 illustrates a video signal processor 500 in a television receiver that takes the baseband, temporally multiplexed video signal V_s and generates an extended spatial frequency video signal V_{b2} that contains both diagonal spatial frequency information and high horizontal spatial frequency information, but not in the same frame.

After the transmitted video signal has been received by the television receiver and processed by the front end stages, such as the tuner and the IF stages, assuming transmission by way of an RF modulated broadcast carrier, and has been demultiplexed and decompressed in a MAC processor, the temporally multiplexed, baseband video signal V_s representing the luminance component of a MAC signal is developed at a terminal 519 of FIGURE 19.

In FIGURE 19 video signal V_s is coupled to a frequency interleaved decoder 340, such as that of FIGURE 17 to develop a video signal V''_b on a signal line 526. The spatial frequency spectrum of video signal V''_b during alternate frames corresponding to the aforementioned Frame 2 is the reconstructed spatial frequency spectrum 118, illustrated in FIGURE 14A.

Video signal V''_b is coupled to contact S2 of switch 424 and video signal V_s is coupled to contact S1 via a delay 523 along a signal line 527. Switch 424 of FIGURE 19 is constructed and operated identically to switch 424 of FIGURE 18. During Frame 1, therefore, the arm of switch 424 is coupled to contact S1 and passes through video signal V_s to pole S3. During Frame 1, video signal V_s comprises the aforementioned video signal V_{b1} of FIGURE 18 that contains diagonal spatial frequencies D1 through D4.

Video signal V_{b2} developed on signal line 528 comprises, during Frame 1, video signal V_{b1}. During Frame 2, the arm of switch 424 is coupled to contact S2, to pass through video signal V''_b to signal line 528. During Frame 2, therefore, video signal V_{b2} comprises reconstructed video signal V''_b.

Video signal V_{b2} comprises a luminance signal that contains the spatial frequency spectrum 510 illustrated in FIGURE 23. Spatial frequency spectrum 510 comprises center section 180 that is common to both reconstructed video signal V''_b and video signal V_{b1}. During Frame 1, spectrum 510 includes diagonal frequency sections D1 through D4 but not high horizontal frequency sections 1a, 1b, 5a, 5b. During Frame 2, spectrum 510 includes high horizontal frequency sections 1a, 1b, 5a, 5b, but not diagonal frequency sections D1 through D4.

When using video processor 500 of FIGURE 2 to obtain video signal V_{b2}, containing spatial frequency spectrum 510 of FIGURE 23, a 15 Hertz flicker is introduced into the diagonal spatial frequency content of the displayed picture and into the high horizontal spatial frequency content. Video processor 600 of FIGURE 20 illustrates another embodiment of the invention that produces an extended spatial frequency video signal V'_{b2} from the video signal V_s such that V'_{b2} has the same spatial frequency spectrum 510 but does not have a 15 Hertz flicker.

In FIGURE 20 the temporally multiplexed video signal V_s developed at a terminal 619 is coupled to a horizontal and vertical filter 620 that separates the high spatial frequencies of the signal V_s from the low spatial frequencies. On an output line 625, a signal M is developed having a spatial frequency content that comprises common section 180 of the spectrum of the signals V_{fl} and V_{b1} of FIGURES 22A and 22B. On an output line 626, a signal T is developed that contains the high spatial frequency content of the signal V_s. During Frame 1 signal T contains the diagonal spatial frequencies of sections D1 through D4 of FIGURE 22B and during Frame 2 signal T contains the high horizontal spatial frequencies of section 1a', 1b', 5a', 5b' of FIGURE 22A.

Signal T is coupled to a frame store 621 to produce a frame delayed output on a signal line 631 that provides access in two adjacent frames to diagonal sections D1 through D4 and frequency interleaved high horizontal sections 1a', 1b', 5a', 5b'.

Frame store 621 is clocked at a frequency f_1 by the clock signal F_1,ck. The sampling frequency f_1 and the pixel capacity of frame store 621 is such as to provide full resolution out to horizontal spatial frequencies $\pm f_{h2}$ and vertical spatial frequencies $\pm f_{v2}$.

The undelayed signal T developed on signal line 626 and the frame delayed signal T developed on signal line 631 are coupled to a double-pole-double-throw switch 624. The two arms of switch 24 are ganged so as to simultaneously switch between their respective contact terminals at a frame rate. During Frame 1, for example, the arm of pole S3 makes contact with terminal S2 and the arm of pole S6 makes contact with terminal S4. During the alternate frame, Frame 2, the arm of pole S3 makes contact with terminal S1 and the arm of pole S6 makes contact with terminal S5. Signal line 626 is coupled to terminals S1 and S4, and signal line 631 is coupled to terminals S2 and S5.

During operation, switch 624 temporally demultiplexes the diagonal frequency sections D1 through D4 of signal T from the interleaved high horizontal frequency sections 1a', 1b', 5a', 5b' to develop a signal F on a line 627 coupled to pole S3 and a signal G on a line 629 coupled to pole S6. Signal F contains only the interleaved high horizontal frequency sections 1a', 2b', 5a', 5b' during Frame 2, when these sections appear in input video signal V_s, and, due to operation of the frame store, also during Frame 1 when diagonal sections D1 through D4 appear in video signal V_s. Similarly, signal G contains only the diagonal frequency sec-

tions D1 through D4 during Frame 1 when these sections appear in input video signal V_s and, due to operation of the frame store, also during Frame 2 when the interleaved high horizontal frequency sections appear in video signal V_s.

Signal F is coupled to a modulator 343. A carrier wave signal s'(t) is also coupled to modulator 343 to produce a carrier demodulated signal S'_P on a signal line 628. A high pass filter 352 removes undesired spectral sections having horizontal spatial frequencies smaller in magnitude than f_{h2}. As already explained, due to the demodulation process, the spatial frequency spectrum of signal S_P at the output of filter 352 is the frequency reconstructed high horizontal sections 1a, 1b, 5a, 5b of FIGURE 23 Signals M, S_p and G are summed in an adder 623 to produced extended spatial frequency video signa V'_{b2} on signal line 630, containing spatial frequency spectrum 510, illustrated in FIGURE 23 wherein both diagonal spatial frequencies and high horizontal spatial frequencies are simultaneously contained in the video signal during any given frame.

In video signal processor 600 of FIGURE 20 both the diagonal spatial frequency sections D1 through D4 and the high horizontal spatial frequency sections 1a, 1b, 5a, 5b of FIGURE 23 are simultaneously contained in extended video signal V'_{b2}. In contrast, video signal processor 500 of FIGURE 19 produces an extended video signal V_{b2} that alternately contains, on a frame-by-frame basis, the diagonal spatial frequencies and the high horizontal spatial frequencies.

Video signal processor 600 is not subject to a 15 Hertz flicker of the diagonal and high horizontal frequency information. However, because this information is repeated in both Frames 1 and 2, other artifacts may be introduced, such as misregistration of the diagonal and/or high frequency horizontal spatial frequencies on moving objects.

FIGURE 24A illustrates the spatial frequency spectrum of signal T at the output of horizontal vertical filter 620 of FIGURE 20. Sections H1 through H4 are the high spatial frequency sections that comprise either diagonal sections D1 through D4 during Frame 1 or high horizontal frequency sections 1a', 1b', 5a', 5b' during Frame 2. Sections H1 through H4 are spaced from the origin at locations corresponding to the corner locations of spectrums 221 and 321 of FIGURES 22A and 22B. However, unlike spectrums 221 and 321, the spatial frequency spectrum of signal T of FIGURE 24A is devoid of any information inside dashed-line rectangle 421 other than the information contained in Sections H1 through H4.

Because the range of spatial frequencies in the horizontal direction is the relatively narrow range $\Delta f_h = f_{h2} - f_{h1}$, a full resolution frame store, such as frame store 621 of FIGURE 20, is not required to resolve the spatial frequencies contained in sections H1 through H4. Similarly, because vertical spatial frequencies lower than f_{v1} are absent from the spectrum of signal T, frame store 621 has more line storage capacity than is needed to resolve the range of vertical spatial frequencies $\Delta f_v = f_{v2} - f_{v1}$.

In accordance with another aspect of the invention, an extended spatial frequency video signal processor 700, illustrated in FIGURE 21, may be used in conjunction with a low capacity frame store 721. In FIGURE 21 the temporally multiplexed video signal V_s, developed at terminal 719, is coupled to horizontal and vertical filter 620 for developing one line 626 signal T containing the spatial frequency spectrum illustrated in FIGURE 24A and for developing on signal line 625 signal M containing the spatial frequency spectrum of section 180 of FIGURE 22A and 22B.

Signal T is coupled to one input of a modulator 722. A carrier wave signal s"(t) is coupled to the other input of the modulator. Modulator 722 produces an amplitude modulation of carrier signal s"(t) by signal T. The amplitude modulated carrier signal S'_T developed on a line 728 has the spatial frequency spectrum illustrated in FIGURE 24B. Due to the modulation process, repeat centers in the spatial frequency domain are introduced that include repeat centers C1 through C4 adjacent origin O. Only repeat centers C1 through C4 are illustrated in FIGURE 24B as they are the repeat centers of importance for the purposes of this discussion. The locations of repeat centers C1 through C4 are chosen so as to move sections H1 through H4 of FIGURE 24A into new positions about origin O to form corresponding spatial frequency sections H1' through H4' of FIGURE 22B A low pass filter 735 removes undesired spectral sections, not illustrated in FIGURE 22B having horizontal spatial frequencies greater in magnitude than f_{h0}, to develop at the filter output the amplitude modulated carrier signal S_T.

Because the high frequency spatial information sections H1' through H4' are grouped near origin O, a relatively low capacity frame store 721 may be used to sample signal S_T that contains the relocated spectrum of FIGURE 22B The horizontal sampling rate f_2 of the clocking signal f_2,ck for frame store 721 is of a lower frequency than the corresponding frequency f_1 of full resolution frame store 621 of FIGURE 20.

In addition, the lower vertical spatial frequency resolution of signal S_T permits one to omit entire lines of samples. To omit lines of samples, signal S_T at the output of filter 735 is coupled to low capacity frame store 721 via a switch 723 controlled by horizontal sync signals. If, for example, the vertical spatial resolution contained in signal S_T

is half that contained in signal T, then switch 723 passes through only every other horizontal line.

Signal S_T developed on line 729 at the output of switch 723 and the frame delayed signal S_T developed on line 730 at the output of low capacity frame store 721 are coupled to the double-pole-double-throw switch 624 that operates identically to switch 624 previously described with respect to the circuit of FIGURE 20. A signal I developed on line 731 coupled to pole S3 of switch 624 contains high horizontal spatial frequency sections 1a", 1b", 5a", 5b" of FIGURE 24B A signal J developed on line 732 coupled to pole S6 contains diagonal spatial freuqency sections D1' through D4' of FIGURE 24B.

Signal J is coupled to one input of a modulator 726. Carrier wave signal s"(t), previously referred to, is coupled to the other input of modulator 726. The modulated signal G' developed on line 734 contains the reconstructed diagonal spatial frequency sections D1 through D4, located in their proper corner positions, illustrated in FIGURE 23. Additional undesired low frequency spectral sections, not illustrated, are removed by a low pass filter 737 having a cutoff frequency of f_{h1} to develop a signal G on a line 738 that contains only diagonal spatial frequency sections D1 through D4.

Signal I is coupled to one input of a modulator 725. A carrier wave signal $S_a(t)$ is coupled to the other input of the modulator to develop the signal S'_p on a line 733. Carrier wave signal $S_a(t)$ is chosen to produce repeat spectra that have repeat centers C_a and C_b located on the horizontal axis f_h in the positions illustrated in FIGURE 24B. Only repeat centers C_a and C_b are illustrated in FIGURE 24B, as they are the only repeat centers of importance in this discussion.

By having repeat centers C_a and C_b located as illustrated, sections 1a", 1b", 5a", 5b" are moved from their locations adjacent origin O to locations adjacent repeat centers C_a and C_b. Thus, the high horizontal spatial frequency information of sections 1a, 1b, 5a, 5b is restored to its proper location in the spatial frequency domain, at the locations illustrated in FIGURE 23. To remove undesired lower frequency spectral sections, signal S'_p is filtered in a high pass filter 739 having a cutoff frequency f_{h2} to develop signal S_p on a line 740 having only the spectral sections 1a, 1b, 5a, 5b.

Signals M, S_p and G are summed in adder 623 to develop on line 630 the extended spatial frequency video signal V'_{b2} having the spatial frequency spectrum 510 of FIGURE 23 that includes both diagonal spatial frequency information and high horizontal spatial frequency information.

It should be understood that time-multiplexing spatial frequency spectra such as described may be extended to multiplexing arrangements other than multiplexing, on a frame alternating basis, the spatial frequency spectrums 221 and 321 of 22A and 22B. For example, a time-multiplexing scheme may be provided that transmits diagonal spatial frequency information, high horizontal spatial frequency information and high vertical spatial frequency information. During Frame 1, for example, diagonal spatial frequency information is transmitted; during Frame 2, high horizontal spatial frequency information is transmitted; and during Frame 3, high vertical spatial frequency information is transmitted. Furthermore, the time-multiplexing may be performed on a field-by-field basis rather than a frame-by-frame basis. In each of the schemes, tradeoffs must be considered between introducing flickering artifacts, introducing spatial artifacts, and introducing motion artifacts.

It will be appreciated that in receivers of MAC type transmissions, the extended spatial frequency luminance signal provided by the described decoders and the chrominance signal components generated by a MAC processor not illustrated in the FIGURES, are matrixed and supplied to the picture tube driver stages for display of the high definition picture content contained in these signals. Although the frequency interleaving techniques have been described by way of example for the luminance signal component of a MAC signal, similar frequency interleaving techniques may be used to extend the spatial frequencies in the chrominance signal components or in other signal formats.

Claims

1. Apparatus for processing the spatial-temporal frequency spectrum of an image contained in a video signal to provide a frequency-interleaved video signal for transmission on a single channel comprising: having a

means (Fig. 11) for receiving a first signal (Vb) containing an image having associated therewith an image spectrum (22, Fig. 1A) in a spatial-temporal frequency volume;

means (330) responsive to said first signal for producing a second signal (xi,x) that represents spatial-temporal carrier modulation (Fig. 10A) of an original spectral section (1a -4a) of said image spectrum into an interleaved location(1a'-4a') adjacent said image spectrum, the interleaved spectral section being made (71) to be of reduced amplitude relative to the amplitude of the corresponding spectral section of the image spectrum;

means for bandwidth limiting said image spectrum to omit therefrom said original spectral section (1a-4a); and

means (150a) responsive to said second signal for producing an interleaved video signal

is half that contained in signal T, then switch 723 passes through only every other horizontal line.

Signal S_T developed on line 729 at the output of switch 723 and the frame delayed signal S_T developed on line 730 at the output of low capacity frame store 721 are coupled to the double-pole-double-throw switch 624 that operates identically to switch 624 previously described with respect to the circuit of FIGURE 20. A signal I developed on line 731 coupled to pole S3 of switch 624 contains high horizontal spatial frequency sections 1a", 1b", 5a", 5b" of FIGURE 24B A signal J developed on line 732 coupled to pole S6 contains diagonal spatial freuqency sections D1' through D4' of FIGURE 24B.

Signal J is coupled to one input of a modulator 726. Carrier wave signal s"(t), previously referred to, is coupled to the other input of modulator 726. The modulated signal G' developed on line 734 contains the reconstructed diagonal spatial frequency sections D1 through D4, located in their proper corner positions, illustrated in FIGURE 23. Additional undesired low frequency spectral sections, not illustrated, are removed by a low pass filter 737 having a cutoff frequency of f_{h1} to develop a signal G on a line 738 that contains only diagonal spatial frequency sections D1 through D4.

Signal I is coupled to one input of a modulator 725. A carrier wave signal $S_a(t)$ is coupled to the other input of the modulator to develop the signal S'_p on a line 733. Carrier wave signal $S_a(t)$ is chosen to produce repeat spectra that have repeat centers C_a and C_b located on the horizontal axis f_h in the positions illustrated in FIGURE 24B. Only repeat centers C_a and C_b are illustrated in FIGURE 24B, as they are the only repeat centers of importance in this discussion.

By having repeat centers C_a and C_b located as illustrated, sections 1a", 1b", 5a", 5b" are moved from their locations adjacent origin O to locations adjacent repeat centers C_a and C_b. Thus, the high horizontal spatial frequency information of sections 1a, 1b, 5a, 5b is restored to its proper location in the spatial frequency domain, at the locations illustrated in FIGURE 23. To remove undesired lower frequency spectral sections, signal S'_p is filtered in a high pass filter 739 having a cutoff frequency f_{h2} to develop signal S_p on a line 740 having only the spectral sections 1a, 1b, 5a, 5b.

Signals M, S_p and G are summed in adder 623 to develop on line 630 the extended spatial frequency video signal V'_{b2} having the spatial frequency spectrum 510 of FIGURE 23 that includes both diagonal spatial frequency information and high horizontal spatial frequency information.

It should be understood that time-multiplexing spatial frequency spectra such as described may be extended to multiplexing arrangements other than multiplexing, on a frame alternating basis, the spatial frequency spectrums 221 and 321 of 22A and 22B. For example, a time-multiplexing scheme may be provided that transmits diagonal spatial frequency information, high horizontal spatial frequency information and high vertical spatial frequency information. During Frame 1, for example, diagonal spatial frequency information is transmitted; during Frame 2, high horizontal spatial frequency information is transmitted; and during Frame 3, high vertical spatial frequency information is transmitted. Furthermore, the time-multiplexing may be performed on a field-by-field basis rather than a frame-by-frame basis. In each of the schemes, tradeoffs must be considered between introducing flickering artifacts, introducing spatial artifacts, and introducing motion artifacts.

It will be appreciated that in receivers of MAC type transmissions, the extended spatial frequency luminance signal provided by the described decoders and the chrominance signal components generated by a MAC processor not illustrated in the FIGURES, are matrixed and supplied to the picture tube driver stages for display of the high definition picture content contained in these signals. Although the frequency interleaving techniques have been described by way of example for the luminance signal component of a MAC signal, similar frequency interleaving techniques may be used to extend the spatial frequencies in the chrominance signal components or in other signal formats.

Claims

1. Apparatus for processing the spatial-temporal frequency spectrum of an image contained in a video signal to provide a frequency-interleaved video signal for transmission on a single channel comprising: having a

means (Fig. 11) for receiving a first signal (Vb) containing an image having associated therewith an image spectrum (22, Fig. 1A) in a spatial-temporal frequency volume;

means (330) responsive to said first signal for producing a second signal (xi,x) that represents spatial-temporal carrier modulation (Fig. 10A) of an original spectral section (1a -4a) of said image spectrum into an interleaved location(1a'-4a') adjacent said image spectrum, the interleaved spectral section being made (71) to be of reduced amplitude relative to the amplitude of the corresponding spectral section of the image spectrum;

means for bandwidth limiting said image spectrum to omit therefrom said original spectral section (1a-4a); and

means (150a) responsive to said second signal for producing an interleaved video signal

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that contains the reduced amplitude interleaved spectral section and a section of said bandwidth limited image spectrum having also omitted therefrom (26) the spectral section corresponding to said interleaved spectral section, which in said video signal for transmission occupies the location of said also omitted section instead of that omitted section.

2. Apparatus according to Claim 1 wherein said second signal producing means includes means for filtering said first signal to remove from the spectrum thereof spectral content at said interleaved location.

3. Apparatus according to Claim 1 wherein said second signal producing means includes means responsive to said first signal for generating digital samples therefrom to create repeat spectra that includes said interleaved spectral section.

4. Apparatus according to Claim 3 wherein said digital sample generating means includes means for reducing the amplitude of selected ones of said digital samples to reduce the amplitude of said interleaved spectral section.

5. Apparatus according to claim 4 wherein the corresponding spectral section of said image spectrum contains frequencies in at least one dimension of said spatial-temporal frequency volume that are greater than the maximum frequency in that dimension that is contained in said interleaved spectral section.

6. Apparatus according to Claim 5 wherein said interleaved video signal producing means includes a lowpass filter coupled to said amplitude reducing means having said maximum frequency as a cutoff frequency.

7. Apparatus according to Claim 3 including a spatial filter responsive to said digital samples for removing from the spectrum thereof spectral content at said interleaved location.

8. Apparatus for reconstructing the spatial-temporal frequency spectrum of an image contained in a spatial-temporal frequency interleaved video signal having a reduced amplitude interleaved section, comprising:

means (Fig 12) for receiving a spatial-temporal frequency interleaved video signal Vfi containing a spatial-temporal frequency spectrum of an image with a section of the image spectrum being omitted therefrom, said interleaved video signal further containing an interleaved section located in a complementary position adjacent said image spectrum, said interleaved section corresponding to the omitted section of said image spectrum, said interleaved section being of reduced amplitude relative to the amplitude of another section of the spectrum of said interleaved video signal;

means (125, 86, 81) responsive to said interleaved video signal for producing a second signal that represents spatial-temporal carrier modulation of said interleaved section to restore that section (1a' - 4a') to its original position in the image spectrum while increasing the amplitude of the restored section over its reduced amplitude value;

means (83) responsive to said interleaved video signal for producing a third signal that represents said another section (1b - 4b) of said image spectrum; and

means (33) responsive to said second and third signals for producing a signal that represents a reconstruction of said image spectrum with the restored section having increased amplitude relative to the corresponding interleaved section in the received video signal.

9. Apparatus according to Claim 8 wherein said second signal producing means comprises means for generating digital samples of said interleaved video signal and means for increasing the amplitude of selected ones of said digital samples relative to other ones of said digital samples.

10. Apparatus according to Claim 8 wherein the restored section of the reconstruction of said image spectrum contains spatial frequencies in at least one dimension that are greater than the maximum frequency in said one dimension that is contained in said interleaved section.

11. Apparatus according to Claim 8, wherein said second signal producing means comprises means for generating quincunx samples of said interleaved video signal, a spatial highpass filter coupled to said quincunx sample generating means and a gain device coupled to said spatial highpass filter for increasing the amplitude of the samples developed and the output of said spatial highpass filter.

12. Apparatus according to Claim 11 wherein said third signal producing means comprises a spatial lowpass filter coupled to said quincunx sample generating means and wherein said means responsive to said second and third signal comprises an adder coupled to said low and highpass filters.

13. Apparatus according to Claim 12 wherein the restored section of the reconstruction of said image spectrum contains spatial frequencies in at least one dimension that are greater that the maximum frequency in said one dimension that is contained in said interleaved section and wherein the cutoff frequencies of said low and highpass filters are each substantially that of said maximum frequency.

14. Apparatus for generating, for transmission on a single channel, a video signal containing a spatial-temporal frequency spectrum, comprising:

means (Fig. 18) for receiving a first video signal (Vb2) containing an image having associated therewith an image spectrum in a spatial-temporal frequency volume;

means (422,423) responsive to said first video signal for generating a second video signal that contains a first portion (Fig. 22B) of said image spectrum;

means (220) including a two-dimensional filter responsive to said first video signal (Vfi) for generating a third video signal that contains a spectrum (Fig.22A) having a spatial-temporal interleaved section (1a',1b,5a', 5b') that is derived by spatial temporal carrier modulation from a corresponding section of said image spectrum, said corresponding section being itself omitted in the spectrum of said third signal; and

means (424) responsive to said second and third video signals for generating a fourth video signal (Vs) the frequency spectrum of which alternates in time between said first portion of said image spectrum and said spatial-temporal interleaved section.

15. Apparatus according to Claim 14 wherein said corresponding section of said image spectrum contains horizontal spatial frequencies that are all high frequencies greater than a given frequency.

16. Apparatus according to Claim 14 wherein said first portion of said image spectrum comprises a diagonal section of a generally rectangularly shaped spectrum.

17. Apparatus according to Claim 14 wherein the spectrum of said third video signal is generally of rectangular shape, with said interleaved section being located in a corner of the spectrum.

18. Apparatus according to Claim 17 wherein said interleaved section is derived from a corresponding section of said image spectrum that contains horizontal spatial frequencies that are all high frequencies greater than a given frequency and wherein said first portion of said image spectrum comprises a diagonal section of a generally rectangularly shaped spectrum positioned in the location of said interleaved section.

19. Apparatus for processing for image reproduction, a first video signal that contains a spatial-temporal frequency spectrum comprising a first portion of a spectrum of an image and, alternatingly in time therewith, a spatial-temporal interleaved spectral section that is derived by spatial temporal carrier modulation from a corresponding spectral section omitted from the spectrum of said first video signal; comprising means (340,Fig 19) including a filter (341,342,Fig.17) in said two dimensions responsive to said first video Vs for generating a second video signal V"b that contains a reconstructed spectrum with said interleaved section repositioned to the location in the image spectrum occupied by said corresponding section of said image spectrum; and

means (424) responsive to said first and second video signals for generating a third video signal Vb2 that contains a spectrum that includes both said reconstructed spectrum and said first portion of said image spectrum.

20. Apparatus according to Claim 19 including means responsive to said first video signal for generating a fourth signal that contains a common spectral section occupying a location in said image spectrum adjacent to both said first portion of said image spectrum and said corresponding section of said image spectrum and wherein said third video signal generating means is responsive to said fourth video signal for including into the spectrum of said third video signal said common spectral section.

21. Apparatus according to Claim 20 wherein the spectrum of said first portion of said image spectrum comprises a diagonal section of a generally rectangularly shaped spectrum and wherein said reconstructed section of said image spectrum contains horizontal spatial frequencies that are all high frequencies greater than a given frequency.

22. Apparatus according to Claim 19 including a delay element responsive to said first video signal and providing sufficient delay time for generating at an output signal line thereof a delayed video signal containing one of the time-multiplexed spectra when the video signal

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at an input signal line thereof contains the other of the time-multiplexed spectra, and including switching means coupled to said delay element and to said second and third video signal generating means to enable the spectrum of said third video signal to simultaneously include said reconstructed spectrum and said first portion of said image spectrum.

23. Apparatus according to Claim 22 wherein said first portion of said image spectrum and said interleaved spectral section contain frequencies in one dimension that are all higher than a given frequency, said apparatus including means for producing a fourth video signal on the input signal line of said delay element that represents carrier modulation of said fifth portion of said image spectrum and of said interleaved spectral section to position said first portion of said image spectrum and said interleaved spectral section to frequencies lower than said given frequency.

24. Apparatus according to Claim 23 wherein said third video signal generating means comprises means responsive to the output of said switching means for producing fifth and sixth video signals that respectively represents further carrier modulation of the carrier modulated first portion of said image spectrum and of the carrier modulated interleaved spectral section such that said fifth signal contains said reconstructed spectrum and said sixth signal contains said first portion of said image spectrum restored to its original location in the image spectrum, and including means responsive to said fifth and sixth signals for developing said third signal therefrom.

25. Apparatus according to Claim 22 including means responsive to said first video signal for generating a fourth video signal that contains a common spectral section occupying a location adjacent said image portion of said image spectrum and adjacent said corresponding section of said image spectrum and wherein said third video signal generating means is responsive to said fourth video signal for including into the spectrum of said third video signal said common spectral section.

26. Apparatus according to Claim 25 wherein the spectrum of said first portion of said image spectrum comprises a diagonal section of a generally rectangularly shaped spectrum and wherein said reconstructed section of said image spectrum contains horizontal spatial frequencies that are all high frequencies greater than said given frequency.

27. Apparatus for processing a first video signal Vs that contains a first spatial-temporal frequency spectrum in at least first and second dimensions that contains the image content of an image spectrum, said first spectrum including a first section representative of a first portion of said image spectrum and a spatial-temporal frequency interleaved second section which is representative of a second portion of said image spectrum and which in said first video signal alternates in time with said first section, one of said first and second sections comprising a high frequency section that contains high spectral frequencies in said first dimension;

first modulation means (722,Fig 21) responsive to said first video signal for generating a second video signal (ST) that contains a modulated spectral section (Fig 24B) that is representative of the image content of said high frequency section and that is located in a low frequency spatial-temporal region that has spectral frequencies in said one dimension that are lower than said high spectral frequencies;

a delay element(721) coupled to said first modulation means for storing said modulated signal to generate a delayed video signal that contains the image content of said high frequency section;

means (624) responsive to said delayed video signal and to said modulated signal for timewise separating said first and second portions of said image spectrum;

means including second modulation means (725,726) responsive to said delayed video signal for generating a second modulated spectral section representative of the image content of said high frequency section restored to its corresponding location in said image spectrum; and

means (623) coupled to said separating means and to said second modulation means for generating a reconstructed spectrum inclusive of said separated first and second portions.

28. Apparatus according to Claim 27 wherein said second modulation means includes a first modulator for generating a first component of said second modulated spectral section that is representative of the image content of the first portion of said image spectrum properly repositioned therein and includes a second modulator for generating a second component of said second modulated spectral section that is representative of the image content of the second portion of said image spectrum prop-



erly repositioned therein.

29. Apparatus according to Claim 27 wherein said delay element stores samples of said modulated signal that are separated from one another in the horizontal scanning direction corresponding to said first dimension, the sampled spatial frequencies being lower than said high spectral frequencies.

30. Apparatus according to Claim 29 wherein said delay element stores samples of said modulated signal that are separated from one another in the vertical scanning direction, with the sampled spatial frequencies in the vertical scanning direction being lower than vertical spectral frequencies of said high frequency section.

31. Apparatus according to Claim 30 wherein said first section is of rectangular shape containing only diagonal spatial frequencies of said image spectrum and wherein said interleaved second section is of rectangular shape located in the same spectral region as said first section and is representative of said second portion of said image spectrum that contains only higher horizontal and lower vertical spatial frequencies than said diagonal spatial frequencies.

32. Apparatus according to Claim 31 wherein said second modulation means includes a first modulator for generating a first component of said second modulated spectral section that is representative of the image content of the first portion of said image spectrum properly repositioned therein and includes a second modulator for generating a second component of said second modulated spectral section that is representative of the image content of the second portion of said image spectrum properly repositioned therein.

33. Apparatus for generating in a luminance channel a spatial-temporal luminance video signal using one-directional filters, comprising:

means (219) for receiving a first luminance video signal containing an image having associated therewith a baseband spatial-temporal frequency spectrum in at least first and second dimensions corresponding to horizontal and vertical scanning directions, respectively;

a filtering arrangement in said first and second dimensions comprising a plurality of separate one-dimensional filters (223,224) coupled to said receiving means for filtering said baseband spectrum in both of said first and second dimensions to obtain a first luminance spectral section of cruciform shape containing baseband frequencies of said baseband spectrum, and to obtain a second luminance spectral section of said baseband spectrum that contains spectral frequencies in said first dimension higher than those in said cruciform shaped first spectral section to the exclusion of lower spectral frequencies in said first dimension, and that contains lower spectral frequencies in said second dimension to the exclusion of higher spectral frequencies in said second dimension; and

means (225,227,228) for carrier modulating said second luminance section by a modulation process that locates said second section as an interleaved section in said luminance channel, positioned at an interleaved location adjacent said cruciform shaped first spectral section, at a point in the-higher frequency regions of both said first and second dimensions, the filtering arrangement of separate one-dimensional filters providing filtering of said second luminance spectral section vertically as well as horizontally in order to cooperate with said modulation process in generating said interleaved luminance video signal in a manner tending to avoid interference between said first and interleaved spectral sections.

34. Apparatus according to Claim 33 wherein said filtering arrangement additionally provides a third spectral section which is combined with the spectrum of said interleaved section.

35. Apparatus according to Claim 33 wherein said interleaved section is positioned at an interleaved location in a corner of the cruciform shaped first spectral section.

36. Apparatus according to Claim 33 wherein the cruciform shaped first spectral section and the interleaved spectral section together form a combined artifact free, generally rectangularly shaped luminance spectrum for a limited capacity transmission channel that is filled to capacity by said combined luminance spectrum.

37. Apparatus according to Claim 36 wherein said first spectral section contains frequencies in one of said first and second dimensions that are all higher than a given frequency and wherein the rectangularly shaped spectrum contains frequencies in that one dimension that are no higher than said given frequency.

38. Apparatus for processing in a luminance channel a spatial-temporal frequency interleaved lu-

minance video signal using one-dimensional filters, comprising:

means (319,Fig 17) for receiving a first luminance video signal that contains a spatial-temporal frequency spectrum in at least first and second dimensions corresponding to horizontal and vertical scanning directions, respectively, that includes a first, cruciform shaped luminance portion of an image spectrum and an interleaved spectral luminance section that corresponds to a second portion of said image spectrum that is omitted from the spectrum of said first video signal, said second portion containing higher spectral frequencies in said first dimension to the exclusion of lower spectral frequencies in said first dimension, and further containing lower spectral frequencies in said second dimension to the exclusion of higher spectral frequencies in said second dimension, said interleaved spectral section being positioned at a location in the higher frequency regions of both said first and second dimensions that is adjacent said first, cruciform shaped portion where the image spectrum has been filtered to remove spectral content of the image;

a filtering arrangement in said first and second dimensions comprising a plurality of separate one-dimensional filters (341,342) for filtering said first luminance video signal in both of said first and second dimensions to generate a second luminance video signal containing said interleaved spectral section;

means (343) responsive to said second luminance video signal and cooperating with said filtering arrangement or generating a third luminance video signal (S'p) representing carrier modulation of the interleaved spectral section in the luminance channel in a manner that separates and restores said second portion of said image spectrum to its original position in the image spectrum; and

means (344) responsive to said third luminance video signal for generating a fourth luminance video signal that contains a reconstruction of said image spectrum including said first and second portion.

39. Apparatus according to Claim 38 wherein said filtering arrangement additionally generates a fifth video signal containing said first portion of said image spectrum, said fourth video signal generating means being responsive to said fifth video signal for combining the spectrum of said fifth video signal with the spectrum of said third video signal to obtain the reconstruction of said image spectrum.

40. Apparatus according to Claim 38 wherein said interleaved spectral section is positioned at an interleaved location corresponding to a corner location adjacent the first cruciform shaped portion of the image spectrum.

41. Apparatus according to Claim 40 wherein the interleaved spectral section and the first portion of said image spectrum form a rectangularly shaped spectrum contained within said first video signal.

42. Apparatus according to Claim 41 wherein the second portion of said image spectrum contain frequencies in one of said first and second dimensions that are all frequencies higher than a given frequency and wherein the rectangularly shaped spectrum of said first signal contains frequencies in that one dimension that are no higher than said given frequency.

Patentansprüche

1. Anordnung zur Verarbeitung des Raumzeitfrequenz-Spektrums eines in einem Videosignal enthaltenen Bildes zur Lieferung eines frequenzverkämmten Videosignals für die Übertragung über einen einzigen Kanal, bestehend aus:

einer Einrichtung (Fig. 11) zum Empfang eines ersten Signals (Vb), das ein Bild enthält, zu dem ein Bildspektrum (22, Fig. 1A) in einem Raumzeitfrequenzvolumen gehört;

einer auf das erste Signal ansprechenden Einrichtung (330) zur Erzeugung eines zweiten Signals (xi, x), das eine Raumzeitträgermodulation (Fig. 10A) eines ursprünglichen Spektralabschnittes (1a-4a) des Bildspektrums in eine verkämmte Stelle (1a'-4a') neben dem Bildspektrum darstellt, wobei der verkämmte Spektralabschnitt so hergestellt wird (71), daß er eine reduzierte Amplitude gegenüber der Amplitude des entsprechenden Spektralabschnittes des Bildspektrums hat;

einer Einrichtung zur Begrenzung der Bandbreite des Bildspektrums, um den ursprünglichen Spektralabschnitt (1a-4a) wegzulassen, und

einer auf das zweite Signal ansprechenden Einrichtung (150a) zur Erzeugung eines verkämmten Videosignals, das den amplitudenreduzierten verkämmten Spektralabschnitt und einen Abschnitt des bandbreitenbegrenzten Bildspektrums enthält, aus dem derjenige Spektralabschnitt ebenfalls weggelassen ist, der dem verkämmten Spektralabschnitt entspricht, welcher im Videosignal für die Übertragung den Ort des ebenfalls weggelassenen

Abschnittes anstatt den weggelassenen Abschnitt belegt.

2. Anordnung nach Anspruch 1, worin die das zweite Signal erzeugende Einrichtung eine Einrichtung zur Filterung des ersten Signals enthält, um aus dessen Spektrum Spektralinhalt am verkämmten Ort zu entfernen.

3. Anordnung nach Anspruch 1, worin die das zweite Signal erzeugende Einrichtung eine auf das erste Signal ansprechende Einrichtung enthält, um digitale Abtastwerte aus diesem Signal zu erzeugen und dadurch Wiederholungsspektren zu bilden, die den verkämmten Spektralabschnitt enthalten.

4. Anordnung nach Anspruch 3, worin die Einrichtung, die digitale Abtastwerte erzeugt, eine Einrichtung zur Reduzierung der Amplitude ausgewählter Exemplare der digitalen Abtastwerte enthält, um die Amplitude des verkämmten Spektralabschnittes zu reduzieren.

5. Anordnung nach Anspruch 4, worin der entsprechende Spektralabschnitt des Bildspektrums in mindestens einer Dimension des Raumzeitfrequenzvolumens Frequenzen enthält, die höher sind als die im verkämmten Spektralabschnitt enthaltene Maximalfrequenz in der betreffenden Dimension.

6. Anordnung nach Anspruch 5, worin die Einrichtung, die das verkämmte Videosignal erzeugt, ein mit der amplitudenreduzierenden Einrichtung gekoppeltes Tiefpaßfilter enthält, das die besagte Maximalfrequenz als Grenzfrequenz hat.

7. Anordnung nach Anspruch 3, enthaltend ein auf die digitalen Abtastwerte ansprechendes Raumfilter, um aus deren Spektrum Spektralinhalt am verkämmten Ort zu entfernen.

8. Anordnung zur Rekonstruktion des Raumzeitfrequenzspektrums eines Bildes, das in einem raumzeitfrequenzverkämmten Videosignal enthalten ist, welches einen verkämmten Abschnitt reduzierter Amplitude hat, bestehend aus:

einer Einrichtung (Fig. 12) zum Empfang eines raumzeitfrequenzverkämmten Videosignals Vfi, das ein Raumzeitfrequenzspektrum eines Bildes enthält, aus dem ein Abschnitt des Bildspektrums weggelassen ist, und ferner einen verkämmten Abschnitt enthält, der an einem komplementären Ort neben dem Bildspektrum liegt und dem weggelassenen Abschnitt des Bildspektrums entspricht und der reduzierte Amplitude gegenüber der Amplitude eines anderen Abschnittes des Spektrums des verkämmten Videosignals hat;

einer Einrichtung (125, 86, 81), die auf das verkämmte Videosignal anspricht, um ein zweites Signal zu erzeugen, das eine Raumzeitträgermodulation des verkämmten Abschnittes darstellt, um diesen Abschnitt (1a'-4a') an seinen ursprünglichen Ort im Bildspektrum zurückzubringen unter Erhöhung der Amplitude des zurückgebrachten Abschnittes gegenüber dem reduzierten Amplitudenwert;

einer Einrichtung (83), die auf das verkämmte Videosignal anspricht, um ein drittes Signal zu erzeugen, das den besagten anderen Abschnitt (1b-4b) des Bildspektrums darstellt, und

einer Einrichtung (33), die auf das zweite und das dritte Signal anspricht, um ein Signal zu erzeugen, das eine Rekonstruktion des Bildspektrums darstellt, in welchem der zurückgebrachte Abschnitt erhöhte Amplitude gegenüber dem entsprechenden verkämmten Abschnitt im empfangenen Videosignal hat.

9. Anordnung nach Anspruch 8, worin die Einrichtung, die das zweite Signal erzeugt, eine Einrichtung zur Erzeugung digitaler Abtastwerte des verkämmten Videosignals und eine Einrichtung aufweist, um die Amplitude ausgewählter Exemplare der digitalen Abtastwerte gegenüber anderen Exemplaren der digitalen Abtastwerte zu erhöhen.

10. Anordnung nach Anspruch 8, worin der zurückgebrachte Abschnitt der Rekonstruktion des Bildspektrums in mindestens einer Dimension Raumfrequenzen enthält, die höher sind als die im verkämmten Abschnitt enthaltene Maximalfrequenz in der betreffenden Dimension.

11. Anordnung nach Anspruch 8, worin die Einrichtung, die das zweite Signal erzeugt, eine Einrichtung zur Erzeugung von Schachbrett-Abtastwerten des verkämmten Videosignals, ein mit der die Schachbrett-Abtastwerte erzeugenden Einrichtung gekoppeltes Raum-Hochpaßfilter und eine Verstärkungseinrichtung enthält, die mit dem Raum-Hochpaßfilter gekoppelt ist, um die Amplitude der am Ausgang des Raum-Hochpaßfilters entwickelten Abtastwerte zu erhöhen.

12. Anordnung nach Anspruch 11, worin die Einrichtung, die das dritte Signal erzeugt, ein Raum-Tiefpaßfilter enthält, das mit der die Schachbrett-Abtastwerte erzeugenden Einrich-

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tung gekoppelt ist, und worin die auf das zweite und das dritte Signal ansprechende Einrichtung einen Addierer aufweist, der mit dem Hoch- und dem Tiefpaßfilter gekoppelt ist.

13. Anordnung nach Anspruch 12, worin der zurückgebrachte Abschnitt der Rekonstruktion des Bildspektrums in mindestens einer Dimension Raumfrequenzen enthält, die höher sind als die im verkämmten Abschnitt enthaltene Maximalfrequenz der betreffenden Dimension, und worin die Grenzfrequenzen des Hoch- und des Tiefpaßfilters im wesentlichen gleich der besagten Maximalfrequenz sind.

14. Anordnung zur Erzeugung eines ein Raumzeitfrequenzspektrum enthaltenden Videosignals für die Übertragung über einen einzigen Kanal, bestehens aus:

einer Einrichtung (Fig. 18) zum Empfang eines ersten Videosignals (Vb2), das ein Bild enthält, zu dem ein Bildspektrum in einem Raumzeitfrequenzvolumen gehört;

einer Einrichtung (422, 423), die auf das erste Videosignal anspricht, um ein zweites Videosignal zu erzeugen, das einen ersten Teil (Fig. 22B) des Bildspektrums enthält;

einer Einrichtung (220), die ein zweidimensionales Filter enthält, das auf das erste Videosignal (Vfi) anspricht, um ein drittes Videosignal zu erzeugen, das ein Spektrum (Fig. 22A) mit einem raumzeitfrequenzverkämmten Abschnitt (1a', 1b, 5a', 5b') enthält, der durch Raumzeitträgermodulation aus einem entsprechenden Abschnitt des Bildspektrums abgeleitet ist, der selbst im Spektrum des dritten Signals weggelassen ist, und

einer Einrichtung (424), die auf das zweite und das dritte Videosignal anspricht, um ein viertes Videosignal (Vs) zu erzeugen, dessen Frequenzspektrum zeitlich zwischen dem ersten Teil des Bildspektrums und dem raumzeitverkämmten Abschnitt abwechselt.

15. Anordnung nach Anspruch 15, worin der entsprechende Abschnitt des Bildspektrums Horizontal-Raumfrequenzen enthält, die sämtlich hohe Frequenzen oberhalb einer gegebenen Frequenz sind.

16. Anordnung nach Anspruch 14, worin der erste Teil des Bildspektrums einen Diagonalabschnitt eines allgemein rechteckig geformten Spektrums aufweist.

17. Anordnung nach Anspruch 14, worin das Spektrum des dritten Videosignals im allgemeinen rechteckige Form hat. wobei der verkämmte Abschnitt in einer Ecke des Spektrums liegt.

18. Anordnung nach Anspruch 17, worin der verkämmte Abschnitt aus einem entsprechenden Abschnitt des Bildspektrums abgeleitet ist, der Horizontal-Raumfrequenzen enthält, die sämtlich hohe Frequenzen oberhalb einer gegebenen Frequenz sind, und worin der besagte erste Teil des Bildspekrums einen Diagonalabschnitt eines allgemein rechteckig geformten Spektrums aufweist, der am Ort des verkämmten Abschnittes liegt.

19. Anordnung für eine zur Bildwiedergabe dienende Verarbeitung eines ersten Videosignals, das ein Raumzeitfrequenzspektrum enthält, welches einen ersten Teil eines Spektrums eines Bildes und, zeitlich damit abwechselnd, einen raumzeitfrequenzverkämmten Spektralabschnitt hat, der durch Raumzeitträgermodulation aus einem entsprechenden Spektralabschnitt abgeleitet ist, welcher aus dem Spektrum des ersten Videosignals weggelassen ist, bestehend aus:

einer Einrichtung (340, Fig. 19), die ein Filter (341, 342, Fig. 17) in den beiden Dimensionen enthält, das auf das erste Videosignal Vs anspricht, um ein zweites Videosignal V"b zu erzeugen, welches ein rekonstruiertes Spektrum enthält, worin der verkämmte Abschnitt an denjenigen Ort des Bildspektrums verlegt ist, der vom besagten entsprechenden Abschnitt des Bildspektrums eingenommen wird, und

einer Einrichtung (424), die auf das erste und das zweite Videosignal anspricht, um ein drittes Videosignal Vb2 zu erzeugen, das ein Spektrum enthält, welches das rekonstruierte Spektrum und den ersten Teil des Bildspektrums enthält.

20. Anordnung nach Anspruch 19 mit einer Einrichtung, die auf das erste Videosignal anspricht, um ein viertes Signal zu erzeugen, das einen gemeinsamen Spektralabschnitt enthält, der im Bildspektrum einen Ort einnimmt, welcher sowohl dem ersten Teil des Bildspektrums als auch dem besagten entsprechenden Abschnitt des Bildspektrums benachbart ist, und wobei die das dritte Videosignal erzeugende Einrichtung auf das vierte Videosignal anspricht, um den gemeinsamen Spektralabschnitt in das Spektrum des dritten Videosignals einzuschließen.

21. Anordnung nach Anspruch 20, wobei das Spektrum des ersten Teils des Bildspektrums aus einem Diagonalabschnitt eines allgemein

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rechteckförmigen Spekrums besteht und wobei der rekonstruierte Abschnitt des Bildspektrums Horizontal-Raumfrequenzen enthält, die sämtlich hohe Frequenzen oberhalb einer gegebenen Frequenz sind.

22. Anordnung nach Anspruch 19 mit einem Verzögerungselement, das auf das erste Videosignal anspricht und eine genügende Verzögerungszeit liefert, um auf einer Ausgangssignalleitung des Verzögerungselementes ein verzögertes Videosignal zu erzeugen, welches eines der zeitmultiplexierten Spektren enthält, wenn das Videosignal auf einer Eingangssignalleitung des Verzögerungselementes das andere der zeitmultiplexierten Spektren enthält, und mit einer Schalteinrichtung, die mit dem Verzögerungselement und mit den das zweite und das dritte Videosignal erzeugenden Einrichtungen gekoppelt ist, um zu ermöglichen, daß das Spektrum des dritten Videosignals gleichzeitig das rekonstruierte Spektrum und den ersten Teil des Bildspektrums enthält.

23. Anordnung nach Anspruch 22, worin der erste Teil des Bildspektrums und der verkämmte Spektralabschnitt in einer Dimension Frequenzen enthalten, die sämtlich höher als eine gegebene Frequenz sind, und wobei die Anordnung eine Einrichtung enthält, um auf einer Eingangssignalleitung des Verzögerungselementes ein viertes Videosignal zu erzeugen, das eine Trägermodulation des fünfen Teils des Bildspektrums und des verkämmten Spektralabschnitts darstellt, um den ersten Teil des Bildspektrums und den verkämmten Spektralabschnitt auf Frequenzen zu legen, die niedriger als die gegebene Frequenz sind.

24. Anordnung nach Anspruch 23, worin die das dritte Videosignal erzeugende Einrichtung eine Einrichtung aufweist, die auf den Ausgang der Schalteinrichtung anspricht, um ein fünftes und ein sechstes Videosignal zu erzeugen, die eine weitere Trägermodulation des trägermodulierten ersten Teils des Bildspektrums bzw. des trägermodulierten verkämmten Spektralabschnitts darstellen, so daß das fünfte Signal das rekonstruierte Spektrum und das sechste Signal den ersten Teil des Bildspektrums wiederhergestellt an ihrem ursprünglichen Ort im Bildspektrum enthalten, und mit einer Einrichtung, die auf das fünfte und das sechste Signal anspricht, um daraus das dritte Signal abzuleiten.

25. Anordnung nach Anspruch 22, mit einer Einrichtung, die auf das erste Videosignal anspricht, um ein viertes Videosignal zu erzeugen, das einen gemeinsamen Spektralabschnitt enthält, der einen Ort angrenzend an den besagten Bildteil des Bildspektrums und angrenzend an den besagten entsprechenden Abschnitt des Bildspektrums einnimmt, und wobei die das dritte Videosignal erzeugende Einrichtung auf das vierte Videosignal anspricht, um den gemeinsamen Spektralabschnitt in das Spektrum des dritten Videosignals einzuschließen.

26. Anordnung nach Anspruch 25, worin das Spektrum des ersten Teils des Bildspektrums aus einem Diagonalabschnitt eines allgemein rechteckförmigen Spektrums besteht und worin der rekonstruierte Abschnitt des Bildspektrums Horizontal-Raumfrequenzen enthält, die sämtlich hohe Frequenzen oberhalb der gegebenen Frequenz sind.

27. Anordnung zur Verarbeitung eines ersten Videosignals Vs, das en erstes, den Bildinhalt eines Bildspektrums enthaltendes Raumzeitfrequenzspektrum in mindestens einer ersten und einer zweiten Dimension enthält, wobei das erste Spektrum einen ersten Abschnitt enthält, der einen ersten Teil des Bildspekrums und einen raumfrequenzverkämmten zweiten Abschnitt darstellt, welcher einen zweiten Teil des Bildspektrums darstellt und im ersten Videosignal zeitlich mit dem ersten Abschnitt abwechselt, wobei einer der ersten und zweiten Abschnitte einen hochfrequenten Abschnitt aufweist, der hohe Spektralfrequenzen in der ersten Dimension enthält;

eine erste Modulationseinrichtung (722, Fig. 21), die auf das erste Videosignal anspricht, um ein zweites Videosignal (S_T) zu erzeugen, das einen modulierten Spektralabschnitt (Fig. 24B) enthält, der den Bildinhalt des hochfrequenten Abschnittes darstellt und in einem niedrigfrequenten Raumzeitbereich liegt, dessen Spektralfrequenzen in der besagten einen Dimension niedriger sind als die besagten hohen Spektralfrequenzen;

ein Verzögerungselement (721), das mit der ersten Modulationseinrichtung gekoppelt ist, um das modulierte Signal für die Erzeugung eins verzögerten Videosignals zu speichern, das den Bildinhalt des hochfrequenten Abschnittes enthält;

eine Einrichtung (624), die auf das verzögerte Videosignal und auf das modulierte Signal anspricht, um den ersten und den zweiten Teil des Bildspektrums zeitlich voneinander zu trennen;

eine Einrichtung, die eine zweite Modula-

tionseinrichtung (725, 726) enthält, welche auf das verzögerte Videosignal anspricht, uni einen zweiten modulierten Spektralabschnitt zu erzeugen, der den Bildinhalt des hochfrequenten Abschnittes wiederhergestellt an seinem entsprechenden Ort im Bildspektrum darstellt;

eine Einrichtung (623), die mit der besagten trennenden Einrichtung und mit der zweiten Modulationseinrichtung gekoppelt ist, um ein rekonstruiertes Spektrum unter Einschluß der getrennten ersten und zweiten Teile zu erzeugen.

28. Anordnung nach Anspruch 27, worin die zweite Modulationseinrichtung einen ersten Modulator enthält, um eine erste Komponente des zweiten modulierten Spektralabschnittes zu erzeugen, die den Bildinhalt des ersten Teils des Bildspektrums in einer darin passend neu positionierten Weise darstellt, und einen zweiten Modulator zur Erzeugung einer zweiten Komponente des zweiten modulierten Spektralabschnittes, die den Bildinhalt des zweiten Teils des Bildspekrums in einer darin passend neu positionierten Weise darstellt.

29. Anordnung nach Anspruch 27, worin das Verzögerungselement Abtastwerte des modulierten Signals speichert, die voneinander in der Horizontalabtastrichtung, welche der ersten Dimension entspricht, beabstandet sind, wobei die abgetasteten Raumfrequenzen niedriger sind als die besagten hohen Spektralfrequenzen.

30. Anordnung nach Anspruch 29, worin das Verzögerungselement Abtastwerte des modulierten Signals speichert, die voneinander in der Vertikalabtastrichtung beabstandet sind, wobei die abgetasteten Raumfrequenzen in der Vertikalabtastrichhung niedriger sind als die Vertikal-Spektralfrequenzen des besagten hochfrequenten Abschnittes.

31. Anordnung nach Anspruch 30, wobei der erste Abschnitt rechteckige Form hat und nur Diagonal-Raumfrequenzen des Bildspektrums enthält und wobei der verkämmte zweite Abschnitt rechteckige Form hat und im selben Spektralbereich wie der erste Abschnitt liegt und repräsentativ für den zweiten Teil des Bildspektrums ist, der nur Horizontal-Raumfrequenzen enthält, die höher sind als die Diagonal-Raumfrequenzen, und nur Vertikal-Raumfrequenzen, die niedriger sind als die Diagonal-Raumfrequenzen.

32. Anordnung nach Anspruch 31, worin die zweite Modulationseinrichtung einen ersten Modulator enthält, um eine erste Komponente des zweiten modulierten Spektralabschnittes zu erzeugen, die den Bildinhalt des ersten Teils des Bildspekrums in einer darin passend neu positionierten Weise darstellt, und einen zweiten Modulator zur Erzeugung einer zweiten Komponente des zweiten modulierten Spektralabschnittes, die den Bildinhalt des zweiten Teils des Bildspektrums in einer passend neu positionierten Weise darstellt.

33. Anordnung zur Erzeugung eines raumzeitlichen Leuchtdichte-Videosignals in einem Leuchtdichtekanal unter Verwendung eindimensionaler Filter, bestehend aus:

einer Einrichtung (219) zum Empfang eines ersten Leuchtdichte-Videosignals, das ein Bild enthält, zu dem ein Basisband-Raumzeitfrequenzspektrum in mindestens einer ersten und einer zweiten Dimension entsprechend der Horizontal- bzw. der Vertikalabtastrichtung gehört;

einer Filteranordnung in der ersten und der zweiten Dimension, bestehend aus einer Vielzahl getrennter eindimensionaler Filter (223, 224), die mit der empfangenden Einrichtung gekoppelt sind, um das Basisbandspektrum sowohl in der ersten als auch in der zweiten Dimension zu filtern und dadurch einen ersten Leuchtdichte-Spektralabschnitt kreuzförmiger Gestalt zu erhalten, der Basisbandfrequenzen des Basisbandspektrums enthält, und einen zweiten Leuchtdichte-Spektralabschnitt des Basisbandspektrums zu erhalten, der in der ersten Dimension Spektralfrequenzen enthält, die höher sind als diejenigen im kreuzförmig gestalteten ersten Spektralabschnitt, unter Ausschluß niedrigerer Spektralfrequenzen in der ersten Dimension, und der in der zweiten Dimension niedrigere Spektralfrequenzen enthält, unter Ausschluß höherer Spektralfrequenzen in der zweiten Dimension, und

einer Einrichtung (225, 227, 228) zur Trägermodulation des zweiten Leuchtdichteabschnittes mittels eines Modulationsprozesses, der den zweiten Abschnitt als einen verkämmten Abschnitt im Leuchtdichtekanal anordnet, gelegen an einer verkämmten Stelle angrenzend an den kreuzförmigen ersten Spektralabschnitt an einem Ort in den höherfrequenten Bereichen sowohl der ersten als auch der zweiten Dimension, wobei die Filteranordnung der getrennten eindimensionalen Filter den zweiten Leuchtdichte-Spektralabschnitt sowohl vertikal als auch horizontal filtert, um in Zusammenwirkung mit dem Modulationsprozeß das verkämmte Leuchtdichte-Videosignal in ei-



ner Weise zu erzeugen, bei welcher die Neigung besteht, gegenseitige Störung zwischen dem ersten und dem verkämmten Spektralabschnitt zu vermeiden.

34. Anordnung nach Anspruch 33, worin die Filteranordnung zusätzlich einen dritten Spektralabschnitt liefert, der mit dem Spektrum des verkämmten Abschnittes kombiniert ist.

35. Anordnung nach Anspruch 33, wobei der verkämmte Abschnitt an einer verkämmten Stelle in einer Ecke des kreuzförmigen ersten Spektralabschnitts liegt.

36. Anodnung nach Anspruch 33, wobei der kreuzförmige erste Spektralabschnitt und der verkämmte Spektralabschnitt gemeinsam ein kombiniertes, von Artefakten freies und allgemein rechteckförmiges Leuchtdichtespektrum für einen Kanal begrenzter Kapazität bilden, der von diesem kombinierten Leuchtdichtespektrum bis auf seine Kapazität ausgefüllt ist.

37. Anordnung nach Anspruch 36, wobei der erste Spektralabschnitt in einer der ersten und zweiten Dimensionen Frequenzen enthält, die sämtlich höher sind als eine gegebene Frequenz, und wobei das rechteckförmige Spektrum in dieser einen Dimension keine höheren Frequenzen als die gegebene Frequenz enthält.

38. Anordnung zur Verarbeitung eines raumzeitfrequenzverkämmten Leuchtdichte-Videosignals in einem Leuchtdichtekanal unter Verwendung eindimensionaler Filter, bestehend aus:

einer Einrichtung (319, Fig. 17) zum Empfang eines ersten Leuchtdichte-Videosignals, das ein Raumzeitfrequenzspektrum in mindestens einer ersten und einer zweiten Dimension entsprechend der horizontalen bzw. vertikalen Abtastrichtung aufweist und einen ersten kreuzförmig gestalteten Leuchtdichteteil eines Bildspektrums und einen verkämmten Leuchtdichte-Spektralabschnitt enthält, der einem zweiten Teil des Bildspektrums entspricht, welcher aus dem Spektrum des ersten Videosignals weggelassen ist und höhere Spektralfrequenzen in der ersten Dimension unter Ausschluß niedrigerer Spektralfrequenzen in der ersten Dimension enthält und ferner niedrigere Spektralfrequenzen in der zweiten Dimension unter Ausschluß höherer Spektralfrequenzen in der zweiten Dimension enthält, wobei der verkämmte Spektralabschnitt an einer Stelle in den höherfrequenten Bereichen sowohl der ersten als auch der zweiten Dimension liegt, die dem ersten kreuzförmigen Teil benachbart ist, wo Spektralgehalt des Bildes aus dem Bildspektrum ausgefiltert worden ist;

einer in der ersten und der zweiten Dimension wirkenden Filteranordnung, bestehend aus einer Vielzahl getrennter eindimensionaler Filter (341, 342) zur Filterung des ersten Leuchtdichte-Videosignals sowohl in der ersten als auch in der zweiten Dimension, um ein zweites Leuchtdichte-Videosignal zu erzeugen, das den verkämmten Spektralabschnitt enthält;

einer Einrichtung (343), die auf das zweite Leuchtdichte-Videosignal anspricht und mit der Filteranordnung zusammenwirkt, um ein drittes Leuchtdichte-Videosignal (S'p) zu erzeugen, das eine derartige Trägermodulation des verkämmten Spektralabschnittes im Leuchtdichtekanal darstellt, daß der zweite Teil des Bildspektrums abgetrennt und an seiner ursprünglichen Stelle im Bildspektrum wiederhergestellt wird, und

einer Einrichtung (344), die auf das dritte Leuchtdichte-Videosignal anspricht, um ein viertes Leuchtdichte-Videosignal zu erzeugen, das eine den ersten und den zweiten Teil enthaltende Rekonstruktion des Bildspektrums darstellt.

39. Anordnung nach Anspruch 38, worin die Filteranordnung außerdem ein fünftes Videosignal erzeugt, das den ersten Teil des Bildspektrums enthält, wobei die das vierte Videosignal erzeugende Einrichtung auf das fünfte Videosignal anspricht, um das Spektrum des fünften Videosignals mit dem Spektrum des dritten Videosignals zu kombinieren und dadurch die Rekonstruktion des Bildspektrums zu erreichen.

40. Anordnung nach Anspruch 38, wobei der verkämmte Spektralabschnitt an einer verkämmten Stelle liegt, die einer Eckposition angrenzend an den ersten kreuzförmigen Teil des Bildspektrums entspricht.

41. Anordnung nach Anspruch 40, wobei der verkämmte Spektralabschnitt und der erste Teil des Bildspektrums ein rechteckförmiges Spektrum bilden, das innerhalb des ersten Videosignals enthalten ist.

42. Anordnung nach Anspruch 41, wobei der zweite Teil des Bildspektrums in einer der ersten und zweiten Dimensionen Frequenzen enthält, die sämtlich höher sind als eine gegebene Frequenz, und wobei das rechteckförmige Spektrum des ersten Signals in dieser einen Dimension Frequenzen enthält, die nicht höher

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als die gegebene Frequenz sind.

Revendications

1. Dispositif pour traiter le spectre de fréquence spatio-temporel d'une image contenue dans un signal vidéo pour fournir un signal vidéo à fréquences entrelacées pour transmission sur un seul canal comprenant :

des moyens (Figure 11) de réception d'un premier signal (Vb) contenant une image ayant un spectre d'image associé à lui (22, Figure 1A) dans un volume de fréquence spatio-temporel ;

des moyens (330) sensibles audit premier signal pour produire un second signal (xi,x) qui représente la modulation d'une porteuse spatio-temporelle (Figure 10A) d'une zone spectrale origine (1a-4a) dudit spectre d'image dans une position entrelacée (1a'-4a') adjacente audit spectre d'image, la zone spectrale entrelacée étant faite (71) pour être d'amplitude réduite par rapport à l'amplitude de la zone spectrale correspondante du spectre d'image ;

des moyens pour limiter en largeur de bande ledit spectre d'image afin de lui supprimer ladite zone spectrale origine (1a-4a) ; et

des moyens (150a) sensibles audit second signal pour produire un signal vidéo à entrelacement qui contient la zone spectrale entrelacée d'amplitude réduite et une zone dudit spectre d'image limité en largeur de bande ayant également supprimé de lui (26) la zone spectrale correspondant à ladite zone spectrale entrelacée, laquelle dans ledit signal vidéo pour transmission occupe la position de ladite zone également supprimée à la place de cette zone supprimée.

2. Dispositif selon la revendication 1, dans lequel lesdits moyens de production du second signal incluent des moyens pour filtrer ledit premier signal pour éliminer de son spectre le contenu spectral à ladite position d'entrelacement.

3. Dispositif selon la revendication 1 dans lequel lesdits moyens de production du second signal incluent des moyens sensibles audit premier signal pour générer des échantillons numériques afin de créer des spectres de répétition qui incluent ladite zone spectrale entrelacée.

4. Dispositif selon la revendication 3, dans lequel lesdits moyens de création d'échantillon numérique incluent des moyens pour réduire l'amplitude des échantillons choisis parmi lesdits échantillons numériques pour réduire l'amplitude de ladite zone spectrale entrelacée.

5. Dispositif selon la revendication 4, dans lequel la zone spectrale correspondante dudit spectre d'image contient des fréquences dans au moins une dimension dudit volume de fréquence spatio-temporel, lesquelles sont supérieures à la fréquence maximale dans cette dimension qui est contenue dans ladite zone spectrale entrelacée.

6. Dispositif selon la revendication 5, dans lequel lesdits moyens de production du signal vidéo à entrelacement incluent un filtre passe-bas couplé auxdits moyens de réduction d'amplitude ayant ladite fréquence maximale comme fréquence de coupure.

7. Dispositif selon la revendication 3 incluant un filtre spatial sensible auxdits échantillons numériques pour éliminer de leur spectre le contenu spectral à ladite position d'entrelacement.

8. Dispositif pour reconstruire le spectre de fréquences spatio-temporel d'une image contenue dans un signal vidéo à fréquences entrelacées spatio-temporelles ayant une zone entrelacée d'amplitude réduite comprenant :

des moyens (Figure 12) pour recevoir un signal vidéo à fréquences entrelacées spatio-temporelles, Vfi , contenant un spectre de fréquences spatio-temporel d'une image dont une zone du spectre d'image a été supprimée, ledit signal vidéo à entrelacement contenant de plus une zone entrelacée située dans une position complémentaire adjacente audit spectre d'image, ladite zone entrelacée correspondant à la zone supprimée dudit spectre d'image, ladite zone entrelacée étant d'amplitude réduite par rapport à l'amplitude d'une autre zone du spectre dudit signal vidéo à entrelacement ;

des moyens (125, 86, 81) sensibles audit signal vidéo à entrelacement pour produire un second signal qui représente une modulation de porteuse spatio-temporelle de ladite zone entrelacée pour restituer cette zone (1a'-4a') à sa position d'origine dans le spectre d'image tout en augmentant l'amplitude de la zone restituée au-dessus de sa valeur d'amplitude réduite ;

des moyens (83) sensibles audit signal vidéo à entrelacement pour produire un troisième signal qui représente ladite autre zone (1b-4b) dudit spectre d'image ; et

des moyens (33) sensibles auxdits second et troisième signaux pour produire un signal qui représente une reconstruction dudit spectre d'image avec la zone restituée ayant une amplitude accrue par rapport à la zone entrela-

cée correspondante dans le signal vidéo reçu.

9. Dispositif selon la revendication 8 dans lequel lesdits moyens de production du second signal comprennent des moyens pour générer des échantillons numériques dudit signal vidéo à entrelacement et des moyens pour augmenter l'amplitude des échantillons choisis parmi lesdits échantillons numériques par rapport aux autres échantillons desdits échantillons numériques.

10. Dispositif selon la revendication 8 dans lequel la zone restituée de la reconstruction dudit spectre d'image contient des fréquences spatiales dans au moins une dimension qui sont supérieures à la fréquence maximale de ladite dimension qui est contenue dans ladite zone entrelacée.

11. Dispositif selon la revendication 8 dans lequel lesdits moyens de production du second signal comprennent des moyens pour générer des échantillons en quiconce dudit signal vidéo à entrelacement, un filtre passe-haut spatial couplé auxdits moyens de productions des échantillons en quinconce et un dispositif de gain couplé audit filtre passe-haut spatial pour augmenter l'amplitude des échantillons développés et de la sortie dudit filtre passe-haut spatial.

12. Dispositif selon la revendication 11 dans lequel lesdits moyens de production du troisième signal comprennent un filtre passe-bas spatial couplé auxdits moyens de production des échantillons en quinconce et dans lequel lesdits moyens sensibles auxdits second et troisième signaux comprennent un additionneur couplé auxdits filtres passe-bas et passe-haut.

13. Dispositif selon la revendication 12 dans lequel la zone restituée de la reconstruction dudit spectre d'image contient des fréquences spatiales dans au moins une dimension qui sont supérieures a la fréquence maximale de ladite dimension qui est contenue dans ladite zone entrelacée et dans lequel les fréquences de coupure desdits filtres passe-haut et passe-bas sont chacune sensiblement celle de ladite fréquence maximale.

14. Dispositif pour générer, pour transmission sur un seul canal, un signal vidéo contenant un spectre de fréquence spatio-temporel, comprenant :

des moyens (Figure 18) pour recevoir un premier signal vidéo (Vb2) contenant une image ayant associé avec elle un spectre d'image dans un volume de fréquences spatio-temporelles ;

des moyens (422, 423) sensibles audit premier signal vidéo pour générer un second signal vidéo qui contient une première partie (Figure 22B) dudit spectre d'image ;

des moyens (220) incluant un filtre bidimensionnel sensible audit premier signal vidéo (Vfi) pour générer un troisième signal vidéo qui contient un spectre (Figure 22A) ayant une zone entrelacée spatio-temporelle (1a', 1b, 5a',5b) qui est dérivée par une modulation de la porteuse spatio-temporelle d'une zone correspondante dudit spectre d'image, ladite zone correspondante étant elle-même supprimée dans le spectre dudit troisième signal ; et

des moyens (424) sensibles auxdits second et troisième signaux vidéo pour générer un quatrième signal vidéo (Vs) dont le spectre de fréquence alterne dans le temps entre ladite première partie dudit spectre d'image et ladite zone entrelacée spatio-temporelle.

15. Dispositif selon la revendication 14 dans lequel ladite zone correspondante dudit spectre d'image contient des fréquences spatiales horizontales qui sont toutes des fréquences élevées supérieures a une fréquence donnée.

16. Dispositif selon la revendication 14 dans lequel ladite première partie dudit spectre d'image comprend une section diagonale d'un spectre de forme généralement rectangulaire.

17. Dispositif selon la revendication 14 dans lequel le spectre dudit troisième signal vidéo est généralement de forme rectangulaire, avec ladite zone entrelacée située dans un angle du spectre.

18. Dispositif selon la revendication 17 dans lequel ladite zone entrelacée est dérivée d'une zone correspondante dudit spectre d'image qui contient les fréquences spatiales horizontales qui sont toutes de hautes fréquences supérieures à une fréquence donnée et dans lequel ladite première partie dudit spectre d'image comprend une section diagonale d'un spectre de forme généralement rectangulaire située dans la position de ladite zone entrelacée.

19. Dispositif pour le traitement destiné à la reproduction d'image, un premier signal vidéo qui contient un spectre de fréquence spatio-temporel comprenant une première partie d'un spectre d'une image, et, en alternance dans le temps avec elle, une section spectrale entrela-

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cée spatio-temporelle qui est dérivée par modulation de porteuse spatio-temporelle d'une zone spectrale correspondante supprimée à partir du spectre dudit premier signal vidéo ; comprenant

des moyens (340, Figure 19) incluant un filtre (341, 342 Figure 17) dans lesdites deux dimensions sensible audit premier signal vidéo Vs pour générer un second signal vidéo V'' qui contient un spectre reconstruit avec ladite zone entrelacée replacée à la position dans le spectre d'image occupée par ladite zone correspondante dudit spectre d'image ; et

des moyens (424) sensibles auxdits premier et second signaux vidéo pour générer un troisième signal vidéo Vb2 qui contient un spectre qui inclut à la fois ledit spectre reconstruit et ladite première partie dudit spectre d'image.

20. Dispositif selon la revendication 19 incluant des moyens sensibles audit premier signal vidéo pour générer un quatrième signal qui contient une zone spectrale commune occupant une position dans ledit spectre d'image adjacente à la fois à ladite première partie dudit spectre d'image et à ladite zone correspondante dudit spectre d'image et dans lequel les moyens de création du troisième signal vidéo sont sensibles audit quatrième signal vidéo pour inclure dans le spectre dudit troisième signal vidéo ladite zone spectrale commune.

21. Dispositif selon la revendication 20, dans lequel le spectre de ladite première partie dudit spectre d'image comprend une section diagonale d'un spectre de forme généralement rectangulaire et dans lequel ladite zone reconstruite dudit spectre d'image contient des fréquences spatiales qui sont toutes de hautes fréquences supérieures à une fréquence donnée.

22. Dispositif selon la revendication 19 incluant un élément retard sensible audit premier signal vidéo et fournissant un retard suffisant pour générer à sa ligne de signal de sortie un signal vidéo retardé contenant un des spectres multiplexés dans le temps quand le signal vidéo, à sa ligne de signal d'entrée, contient l'autre spectre multiplexé dans le temps, et incluant des moyens de commutation couplés audit élément retard et auxdits moyens de création des second et troisième signaux vidéo pour permettre au spectre dudit troisième signal vidéo d'inclure simultanément ledit spectre reconstruit et ladite première partie dudit spectre d'image.

23. Dispositif selon la revendication 22 dans lequel ladite première partie dudit spectre d'image et ladite zone spectrale entrelacée contiennent des fréquences dans une dimension qui sont toutes supérieures à une fréquence donnée, ledit dispositif incluant des moyens pour produire un quatrième signal vidéo sur la ligne du signal d'entrée dudit élément retard qui représente la modulation de la porteuse de ladite cinquième partie dudit spectre d'image et de ladite zone spectrale entrelacée pour situer ladite première partie dudit spectre d'image et ladite zone spectrale entrelacée aux fréquences inférieures à ladite fréquence donnée.

24. Dispositif selon la revendication 23 dans lequel lesdits moyens de création du troisième signal vidéo comprennent des moyens sensibles à la sortie desdits moyens de commutation pour produire des cinquième et dixième signaux vidéo qui représentent respectivement une modulation supplémentaire de la porteuse de la première partie modulée pour porteuse dudit spectre d'image et de la zone spectrale entrelacée modulée par porteuse de telle sorte que ledit cinquième signal contient ledit spectre reconstruit et ledit sixième signal contient ladite première partie dudit spectre d'image restituée à sa position d'origine dans le spectre d'image, et incluant des moyens sensibles auxdits cinquième et sixième signaux pour développer ledit troisième signal à partir d'eux.

25. Dispositif selon la revendication 22 incluant des moyens sensibles audit premier signal vidéo pour générer un quatrième signal vidéo qui contient une zone spectrale commune occupant une position adjacente à ladite partie d'image dudit spectre d'image et adjacente à ladite section correspondante dudit spectre d'image et dans lequel lesdits moyens de création du troisième signal vidéo sont sensibles audit quatrième signal vidéo pour inclure dans le spectre dudit troisième signal vidéo ladite zone spectrale commune.

26. Dispositif selon la revendication 25 dans lequel le spectre de ladite première partie dudit spectre d'image comprend une section diagonale d'un spectre de forme généralement rectangulaire et dans lequel ladite zone reconstruite dudit spectre d'image contient des fréquences spatiales horizontales qui sont toutes des hautes fréquences supérieures à ladite fréquence donnée.

27. Dispositif pour traiter un premier signal vidéo Vs qui contient un premier spectre de fréquences spatio-temporel dans au moins une première et une seconde dimensions qui contient le contenu image d'un spectre d'image, ledit premier spectre incluant une première zone représentative d'une première partie dudit spectre d'image et une seconde zone à fréquences spatio-temporelles entrelacées qui est représentative d'une seconde partie dudit spectre d'image et qui dans ledit premier signal vidéo alterne dans le temps avec ladite première zone, une desdites première et seconde zones comprenant une zone de hautes fréquences qui contient des fréquences spectrales élevées de ladite première dimension ;

un premier moyen de modulation (722, Figure 21) sensible audit premier signal vidéo pour générer un second signal vidéo (ST) qui contient une zone spectrale modulée (Figure 24B) qui est représentative du contenu image de ladite zone de haute fréquence et qui est située dans une région spatio-temporelle de basse fréquence qui a des fréquences spectrales de ladite une dimension qui sont inférieures auxdites hautes fréquences spectrales ;

un élément retard (721) couplé audit premier moyen de modulation pour enregistrer ledit signal modulé afin de générer un signal vidéo retardé qui contient le contenu image de ladite zone de haute fréquence ;

des moyens (624) sensibles audit signal vidéo retardé et audit signal modulé pour séparer dans le temps lesdites première et seconde parties dudit spectre d'image ;

des moyens incluant un second moyen de modulation (725, 726) sensibles audit signal vidéo retardé pour générer une seconde zone spectrale modulée représentative du contenu image de ladite zone de haute fréquence restituée à sa position correspondante dans ledit spectre d'image ; et

des moyens (623) couplés auxdits moyens de séparation et audit second moyen de modulation pour générer un spectre reconstruit incluant lesdites première et seconde parties séparées.

28. Dispositif selon la revendication 27 dans lequel ledit second moyen de modulation inlut un premier modulateur pour générer une première composante de ladite seconde zone spectrale modulée qui est représentative du contenu image de la première partie dudit spectre d'image qui y est correctement replacée et inclut un second modulateur pour générer une seconde composante de ladite seconde zone spectrale modulée qui est représentative du contenu image de la seconde partie dudit spectre d'image qui y est correctement replacée.

29. Dispositif selon la revendication 27 dans lequel ledit élément retard enregistre des échantillons dudit signal modulé qui sont séparés les uns des autres dans la direction de balayage horizontale correspondant à ladite première dimension, les fréquences spatiales échantillonnées étant inférieures auxdites hautes fréquences spectrales.

30. Dispositif selon la revendication 29 dans lequel ledit élément retard enregistre des échantillons dudit signal modulé qui sont séparés les uns des autres dans la direction de balayage verticale, les fréquences spatiales échantillonnées dans la direction de balayage verticale étant inférieures aux fréquences spectrales verticales de ladite zone de haute fréquence.

31. Dispositif selon la revendication 30 dans lequel ladite première zone est d'une forme rectangulaire contenant seulement des fréquences spatiales diagonales dudit spectre d'image et dans lequel ladite seconde zone entrelacée est d'une forme rectangulaire située dans la même région spectrale que ladite première zone et est représentative de ladite seconde partie dudit spectre d'image qui contient seulement des fréquences spatiales horizontales supérieures auxdites fréquences spatiales diagonales et verticales inférieures auxdites fréquences spatiales diagonales.

32. Dispositif selon la revendication 31 dans lequel ledit second moyen de modulation inclut un premier modulateur pour générer une première composante de ladite seconde zone spectrale modulée qui est représentative du contenu image de la première partie dudit spectre d'image qui y est correctement replacée et inclut un second modulateur pour générer une seconde composante de ladite seconde zone spectrale modulée qui est représentative du contenu image de la seconde partie dudit spectre d'image qui y est correctement replacée.

33. Dispositif pour générer dans un canal de luminance un signal vidéo de luminance utilisant un filtre unidirectionnel comprenant :

des moyens (219) pour recevoir un premier signal vidéo de luminance contenant une image ayant associé avec lui un spectre de fréquence spatio-temporel en bande de base dans au moins les première et seconde dimen-

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sions correspondant respectivement aux directions de balayage horizontale et verticale ;

un agencement de filtrage dans lesdites première et seconde dimensions comprenant une pluralité de filtres unidirectionnels séparés (223, 224) couplés auxdits moyens de réception pour filtrer ledit spectre en bande de base à la fois dans lesdites première et seconde dimensions pour obtenir une première zone spectrale de luminance cruciforme contenant des fréquences de bande de base dudit spectre en bande de base, et pour obtenir une seconde zone spectrale de luminance dudit spectre en bande de base qui contient des fréquences spectrales dans ladite première dimension plus élevées que celles de ladite première zone spectrale cruciforme à l'exclusion des fréquences spectrales inférieures de ladite première dimension, et qui contient des fréquences spectrales inférieures de ladite seconde dimension à l'exclusion des fréquences spectrales supérieures de ladite seconde dimension ; et

des moyens (225, 227, 228) pour modulation de porteuse de ladite seconde zone de luminance par un processus de modulation qui situe ladite seconde zone comme une zone entrelacée dans ledit canal de luminance, située à une position entrelacée adjacente à ladite première zone spectrale cruciforme, au niveau d'un point dans les régions de fréquence supérieure à la fois desdites première et seconde dimensions , l'agencement de filtrage des filtres unidirectionnels séparés prévoyant un filtrage de ladite seconde zone spectrale de luminance verticalement aussi bien qu'horizontalement afin de coopérer avec ledit processus de modulation en générant ledit signal vidéo de luminance à entrelacement d'une manière tendant à éviter une interférence entre ladite première zone spectrale et ladite zone spectrale entrelacée.

34. Dispositif selon la revendication 33 dans lequel ledit agencement de filtrage prévoit de plus une troisième zone spectrale qui est combinée avec le spectre de ladite zone entrelacée.

35. Dispositif selon la revendication 33 dans lequel ladite zone entrelacée est située à une position entrelacée dans un angle de la première zone spectrale cruciforme.

36. Dispositif selon la revendication 33 dans lequel la première zone spectrale cruciforme et la zone spectrale entrelacée forment ensemble un spectre combiné de luminance de forme généralement rectangulaire, sans artifice pour un canal de transmission à capacité limitée qui est rempli totalement par ledit spectre combiné de luminance.

37. Dispositif selon la revendication 36 dans lequel ladite première zone spectrale centrant des fréquences dans une desdites première et seconde dimensions qui sont toutes supérieures à une fréquence donnée et dans lequel le spectre de forme rectangulaire contient des fréquences dans cette dimension qui sont inférieures à ladite fréquence donnée.

38. Dispositif pour traiter dans un canal de luminance un signal vidéo de luminance à fréquences spatio-temporelles entrelacées utilisant des filtres unidirectionnels comprenant :

des moyens (319, Figure 17) pour recevoir un premier signal vidéo de luminance qui contient un spectre de fréquences spatio-temporel dans au moins les première et seconde dimensions correspondant respectivement aux directions de balayage horizontale et verticale, qui inclut une première partie de luminance cruciforme d'un spectre d'image et une zone de luminance spectrale entrelacée qui correspond à une seconde partie dudit spectre d'image qui est supprimé du spectre dudit premier signal vidéo, ladite seconde partie contenant des fréquences spectrales supérieures dans ladite première dimension à l'exclusion de fréquences spectrales inférieures dans ladite première dimension et contenant de plus des fréquences spectrales inférieures dans ladite seconde dimension à l'exclusion de fréquences spectrales supérieures dans ladite seconde dimension, ladite zone spectrale entrelacée étant située à une position dans les régions de fréquence supérieure des deux dites première et seconde dimensions qui est adjacente à ladite première partie cruciforme où le spectre d'image a été filtré pour éliminer le contenu spectral de l'image ;

un agencement de filtrage dans lesdites première et seconde dimensions comprenant une pluralité de filtres unidirectionnels séparés (341, 342) pour filtrer ledit premier signal vidéo de luminance dans led deux dites première et seconde dimensions pour générer un second signal vidéo de luminance contenant ladite zone spectrale entrelacée ;

des moyens (343) sensibles audit second signal vidéo de luminance et coopérant avec ledit agencement de filtrage pour générer un troisième signal vidéo de luminance (S'1) représentant la modulation de la porteuse de la zone spectrale entrelacée dans le canal de luminance d'une manière qui sépare et restitue

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ladite seconde partie dudit spectre d'image à sa position d'origine dans le spectre d'image ; et

des moyens (344) sensibles audit troisième signal vidéo de luminance pour générer un quatrième signal vidéo de luminance qui contient une reconstruction dudit spectre d'image incluant lesdites première et seconde parties.

39. Dispositif selon la revendication 38 dans lequel ledit agencement de filtrage génère en plus un cinquième signal vidéo contenant ladite première partie dudit spectre d'image, lesdits moyens de création du quatrième signal vidéo étant sensibles audit cinquième signal vidéo pour conbiner le spectre dudit cinquième signal vidéo avec le spectre dudit troisième signal vidéo pour obtenir la reconstruction dudit spectre d'image.

40. Dispositif selon la revendication 38 dans lequel ladite zone spectrale entrelacée est située à une position entrelacée correspondant à une position d'angle adjacente à la première partie cruciforme du spectre d'image.

41. Dispositif selon la revendication 40 dans lequel la zone spectrale entrelacée et la première partie dudit spectre d'image forment un spectre de forme rectangulaire contenu à l'intérieur dudit premier signal vidéo.

42. Dispositif selon la revendication 41 dans lequel la seconde partie dudit spectre d'image contient des fréquences dans une desdites première et seconde dimensions qui sont toutes des fréquences supérieures à une fréquence donnée et dans lequel le spectre de forme rectangulaire dudit premier signal contient des fréquences dans cette même dimension qui ne sont pas supérieurs à ladite fréquence donnée.