(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
15 February 2001 (15.02.2001)

PCT

(10) International Publication Number
WO 01/11894 A2

(51) International Patent Classification[7]: H04N 13/00

(21) International Application Number: PCT/DK00/00448

(22) International Filing Date: 10 August 2000 (10.08.2000)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
PA 1999 01115 10 August 1999 (10.08.1999) DK
PA 2000 00748 5 May 2000 (05.05.2000) DK

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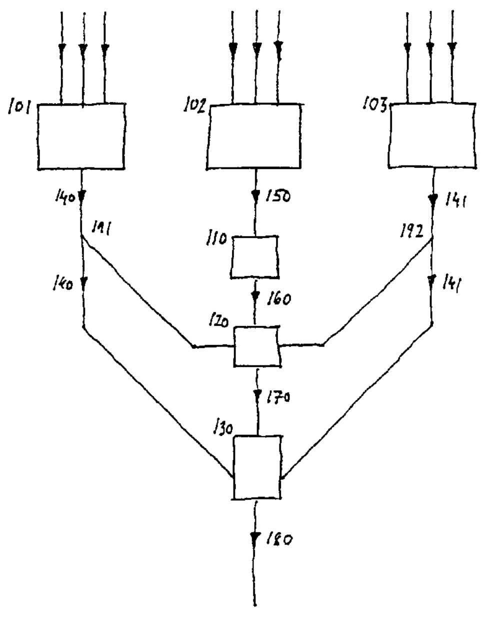
(81) Designated States *(national)*: AE, AG, AL, AM, AT, AT (utility model), AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, CZ (utility model), DE, DE (utility model), DK, DK (utility model), DM, DZ, EE, EE (utility model), ES, FI, FI (utility model), GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SK (utility model), SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

**Published:**
— *Without international search report and to be republished upon receipt of that report.*

*For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

(54) Title: METHODS AND APPARATUSES FOR ENCODING AND DISPLAYING STEREOGRAMS




(57) Abstract: Improved methods and means for recording or encoding and displaying stereograms as single colour images for viewing through multichrome optical filters is obtained by the use of a combination of colour balanced viewing filters on the one hand, and on the other hand image encodings based on numerical optimisation techniques and colour science. Also, filters and encodings can be so selected and realized, that their application allows for a simultaneous use of some of the implements of the prior art.

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Title: Methods and apparatuses for encoding and displaying stereograms

The present invention relates to the encoding, or recording, and subsequent displaying and viewing of a stereogram as one colour image for viewing through a pair of filters, the filters transmitting light in the visible spectral range, each with a different transmission profile.

## Background of the invention

Colour encoded stereograms are conventionally known as anaglyphs, although this term in the present context will be reserved for a sub-class of colour-encoded stereograms. This subclass of images contains the vast majority of images made with the prior art and will be more precisely defined shortly.

The nomenclature surrounding anaglyphs and anaglyph techniques can occasionally lead to ambiguities. Thus, the viewing filters are as a rule said to be "complementary". In colour science, two colours are called complementary if, plotted in the colour diagram, they lie on a line passing through the white point of current relevance, and on opposite sides of the white point. When greater precision is needed, complementary colours are thought of as yielding a neutral grey in additive mixing. When filters are discussed, complementarity can be tested for by shining two neutral white lights through the filters separately and observing the outcome of letting the resulting lights simultaneously fall on a neutrally white surface, where they should add up to white light. When no constraints are placed on the strengths of the two white lights, the wider definition is arrived at; and when the two white lights are required to be of equal strength, the definition is correspondingly narrowed.

Either way, it is easy to find in the prior art filter pairs which are not complementary, just as complementary filters can be found, which are of no use for anaglyph viewing, whence a better description is needed:

To allow stereopsis, i.e. the psycho-physiological response to a stereogram that results in its interpretation as a "three-dimensional image", the viewing filters must be separating. This word is here chosen to mean that there must be a first range of the visible spectrum transmitted by a first filter and excluded by a second; and a second range of the visible spectrum, not overlapping the first range and transmitted by the second filter and excluded by the first.

So-called "monochrome" anaglyphs are produced for viewing through filter pairs which are separating but not of necessity complementary, the most popular combinations being red-green or red-blue. "Monochrome" anaglyphs are in fact multichrome when considered as images in themselves. The adjective is chosen to convey the fact that no attempt is made to encode anything more than the luminance levels of the original scene, as is done in a conventional two-dimensional gray-scale image.

To avoid possible confusion surrounding the phrases "black and white (image)", "monochrome (image)" and "gray-scale (image)", the phrase "luminance level (image)" will be used, whenever the intended meaning is that only one channel or colour variable is represented (in the image). The visual appearance of a luminance level image may or may not be gray. If it is not gray, only one nameable colour (i.e. one hue) is present in it, in varying intensities.

If the two ranges of a separating filter pair together cover the entire range of the visible spectrum, the filters will in the present context be called "disjoint" (although the word may have other connotations). Also for convenience, the full range of the visible light can be divided into three: visible light of wavelengths less than 500 nanometers, light in the range from 500 nanometers to 600 nanometers, and visible light having wavelengths greater than 600 nanometers. These ranges correspond to the basic concepts of "blue light", "green light" and "red light", respectively, but it should be borne in mind that the use of these words is subjective, and also that, e.g., a "green dye" or, for that matter, a "green filter" can reflect, respectively transmit, light outside the range from 500 nanometers to 600 nanometers. The boundaries themselves can be varied some 10-20 nanometers in accordance with the task at hand. A filter pair for anaglyph viewing can be termed a (1,1)-pair, if each filter transmits light from only one of these three ranges, and a (1,2)-pair if one filter transmits light from only one range, the other from the remaining two. When it is necessary to state more precisely which ranges are transmitted and excluded, this notation can be extended. In accordance with the common terminology, the ranges will be ordered red-green-blue. A red-green filter pair is then denoted as a ([1 0 0], [0 1 0])-pair, a red-cyan filter pair as a ([1 0 0], [0 1 1])-pair etc. (As a colour, cyan is complementary to red, the word "cyan" being here used to denote an ideal mixture of green and blue. In the present parlance, a red-cyan filter pair is disjoint). Incidentally, the numbers 1 and 0 do not literally mean "all" and "none", respectively, as no physical filter transmits all light in one spectral range and no light in another. Also, where the need arises to balance filters for complementarity in the narrower sense mentioned above, exact numbers would yield ratios appreciable different from 1:1.

A stereogram will be said to consist of two part-images, a left and a right. Terms such as "half images" are sometimes seen, but it must be kept in mind that the two constituents of a (colour) stereogram are full two-dimensional (colour) images in themselves.

In the prior art, so-called "colour anaglyphs" are intended for viewing through disjoint filter pairs, the most popular being red-cyan filters (one exception to the use of disjoint filters is mentioned below). In the basic form of the prior art, the images are encoded by partitioning: from the left part-image, colours and colour constituents are extracted which are transmitted by one filter in the viewing filter pair; from the right part-image, colours and colour constituents are extracted which are transmitted by the other filter; and the extracted colours and colour constituents joined to form the anaglyph.

The human eye-brain responds in a numbers of ways, and in combinations of these ways, to the simultaneous presentation of distinct stimuli, one set of stimuli to each eye:

- fusion of the two perceived stimuli into one, usually recognizable as a kind of average;

- stereopsis, the combined fusion and re-interpretation, whereby differences in the two stimuli are seen as depth information;

- rivalry, wherein fusion is impossible, yet only one actual image is seen at a time, but with the possibility of vacillations between two or more interpretations; and

- diplopia, the perception of two simultaneous images.

Thus, the aim of the art is to present a stereogram in such a fashion as to allow the eye-brain system to perform fusion of colours as well as stereoscopic interpretation, and to eliminate or at least reduce rivalry where it should not appear. It is to be noted that the lustre of smooth fabrics, the gloss of polished metals and the glimmer of gems are all perceptive phenomena, produced by rivalry. These, of course, should not be suppressed. A special form of stereoscopic rivalry, commonly known as "sheen", can only be reduced, not removed: when a specific colour is transmitted by only one of the viewing filters, it may be perceived as having the right or nearly the right hue (the nameable quality, such as "pink", "lavender", "moss green"), but being materially different from other colours in the image. In reflection prints, it may e.g. seem translucent, on emissive screens it may e.g. take on a perceived luminance in excess of what the display can otherwise deliver. Apart from that, the prior art in its basic form most commonly fails to reproduce certain colours as recognizably equal to those of the original stereogram, even when complete fusion takes place; in fact, for any known embodiment of the prior art, as based on (1,2)-filter pairs and image partitioning, colours can be found that do not reproduce well.

Stereopsis is usually achieved, except when the original stereogram relies on, say, texture perspective as a support of parallactic differences, and this texture perspective happens to suffer from the colour loss. Large areas of a pure colour can loose their stereoscopic effect, if the colour is only transmitted by one of the viewing filters. Rivalry, over and above the "sheen", is typically seen where strong contrasts exist in the stereogram, or where the surrounds of the display are not sufficiently dimmed, and may in some individuals lead to discomfort (nausea, headaches etc.), sometimes ascribed to "colour bombardment". Diplopia can occur, over and above what is caused by transgression of stereoscopic parameter limits, when the recording medium, the display or the filters, or any combination of these, fail to separate the part-images of the stereogram.

The prior art

Various extensions and amendments to the art in its basic form can be found in the prior art, addressing one or more of the above problems:

In Patent US 5491646, diplopia caused by insufficient separation is subjected to the countermeasure of subtracting a scaled copy of the colour values extracted from one part-image from those extracted from the other "so that said first image is entirely, or almost entirely removed from said second image", a digital counterpart of the masking technique used in printing. The prescriptions in Patent US 5491646 otherwise address the use of (1,2)-filters.

In Patent US 4236172, the complete loss of image information in one eye in areas of pure colour is counteracted by replacing straightforward partitioning with weighted averages. The averaging concurrently serves the purpose of sharpening the perceived image, seeing that colour signals in a television are re-interpreted from RGB-representation to a high resolution luminance signal combined with lower resolution signals carrying the chrominance information. Again, the prescriptions address the use of (1,2)-filters.

In Patent US 4217602, use is made, not of two part-images, but three. The purpose, however, is to allow non-stereoscopic, full-colour viewing, the stereoscopic effect being obtained by the use of (1,1)-filters and thus giving a "monochrome" stereo image in the sense described above and discarding the third image. For comparison with an embodiment of the present invention, described below, it should also be noted that the three lenses or lens systems of Patent US 4217602 are identical.

In Patent US 4620770, use is made of two outline images and a colour filling, rather than two definite images.

The method as described pertains to hand-drawn a anaglyphs, the viewing filters are referred to simply as "3-D glasses" and appear to be intended as (1,2)-pairs, and no procedure is given for the production of specific colours.

In Patents FR2560398 and IT1175546, rivalry effects are eliminated by the use of disjoint filter pairs each member of which partition each of the three colour ranges into two. Extending the notation used above, such a filter pair could be referred to as a ([1/2 1/2 1/2], [1/2 1/2 1/2]), it being understood that any of the "1/2"'s is disjoint from any other. Apart from the practical difficulty of producing such filters at an acceptable cost, display of stereograms using this mode of encoding requires a conventional two-image full-colour stereo projector, or its equivalent. (Also, let it be noted in passing that the principle underlying Patent FR2560398 is already fully described in one of the standard references of stereoscopy, N.A. Valyus "Stereoscopy", Moscow 1962, English translation published by The Focal Press, 1966).

In Patent Application PCT/DK99/00568, colour loss is reduced by the use of non-disjoint filter pairs. For example, a ([0 0 1], [1 1 0])-pair (blue-yellow) is replaced by a ([0 0 1], [1 1 e])-pair (blue-amber), where the letter "e" denotes a small, but still significant transmission rate, and the encoding by partitioning is replaced by a suitable weighted-average encoding. Then according to the descriptions in the application, loss of perceived colour, as well as sheen, can be kept at a minimum. One of the filters in the pair still transmits from only one of the three colour ranges, though; there is a small amount of "ghost imaging"; and at least in the blue-amber combination here given as an example, the blue filter transmits only a small portion of the actual light.

Valyus (op. cit.) p. 109, describes the use by L. Lumière of a blue-yellow filter pair which in fact, according to the few spectral data cited, must have been a violet-yellow ([1 0 1/2], [0 1/2 1/2])-pair. Obviously, L. Lumière can not have attempted to display full-colour images - in fact, Valyus writes: "One of his [L. Lumière's] images was coloured yellow, the other blue", suggesting "monochrome" anaglyphs - and there is no explicit record of further attempts with filters of this kind.

All methods in the prior art have one thing in common: they encode the images in a point-for-point or position-for-position fashion. The word anaglyph ("drawn twice") should be used for such colour encodings.

An argument to the effect that full-colour stereoscopy by colour encoding is fundamentally an impossibility, and the efforts of the prior art therefore in vain, might run as follows:

To produce a "monochrome" stereogram, two channels are required, one for each of the luminance level images. (A "channel" is here a single valued function, such as a luminance level function, defined on the image area. The function may take values in a circular domain, as with the hue, cp. the expression "hue circle"). To further colorate this virtual 3-D scene, a further two channels are required, typically representing the hue and saturation, respectively, of each scene point. Thus, a minimum of four colour channels is required to produce a full-colour stereogram. But a single printed, projected or displayed image contains, when no use is made of polarized light or time-multiplexing, only three channels, red, green and blue, or their re-interpretations in terms of other three-channel colour spaces. (A colour space, often more correctly termed a "colour solid" is a representation of all possible colours assignable to an image point, for instance the available range of RGB-values. To avoid multiple meanings of the word "dimension", the phrase "three-channel colour space" is here used to denote the extension to a full image). The failure to address this problem directly is at the heart of the various shortcomings observable in the prior art.

In opposition to the argument just given stands the observation, often made in colour science, and forming the basis of colour management, that "almost any individual colour can be made to appear as almost any other individual colour". The stress is on "individual", because the various means of controlling the appearance of a single colour all involve controlling surrounding colours. From the argument presented above, as well as from known observations (see, e.g. Valyus op. cit. pp. 109-110) the present inventor has concluded that to achieve this in any significant measure requires use of a combination of colour balanced viewing filters on the one hand, and on the other hand image encodings that make it possible to avoid the diplopia otherwise invariably arising from the colour balancing. Also, filters and encodings should be so selected and realized, that their application allows for a simultaneous use of at least some of the implements of the prior art.

Summary of the invention

The principle of the invention can be described as follows: in a viewing filter pair designed as prescribed by the invention, both of the filters must transmit light in two of the ranges red, green or blue; to avoid double imaging and allow the use of optimisation and colour management, recording and encodings are no longer point-to-point; and display, even of existing stereograms, is colour-balanced, as far as the pertinent choice of media allows.

The present invention offers in its different aspects:

- means for selecting the viewing filters to balance both the light transmission and perceived colour transmission so as to obtain a distribution of light and colours between the two eyes more even than in the prior art, while preserving a separation property;

- means for encoding existing or conventionally recorded or rendered stereograms, allowing: the use of picture elements larger than individual pixels; the use of colour management techniques as integral parts of the encoding; and the use of computational optimisation techniques, likewise as integral parts of the encoding, altogether allowing full use of a four-channel projection, when this is available, or simulating its presence on a conventional three-channel display;

- means for directly recording a stereogram in the form of one colour-balanced colour image and without the formation of artefacts that would otherwise be visible in stereoscopic viewing as double images;

- means for displaying optimally encoded as well as conventionally recorded stereograms in the form of one colour-balanced colour image and without the formation of artefacts that would otherwise be visible in stereoscopic viewing as double images.

With reference to the division of the visible spectrum into three ranges, red, green and blue, let two of these be designated "the carrier colour ranges" and the third "the mediant colour range". A filter pair as prescribed by the invention must then be a "(3/2, 3/2)-pair" in the sense that the filters must be separating with respect to the carrier colour ranges; but both filters must transmit the mediant colour range. This latter can take the form of a joint transmission in the entire mediant colour range; or each filter can transmit a part of this range. Transmission in the mediant colour range may involve some reduction, relative to transmission in the pertinent carrier colour range. Henceforth, where no misunderstanding can arise, the phrase "colour range" will be replaced by the simpler "colour". In a stereogram, encoded as prescribed by the invention, three separate images can then be recognized: one in each of the carrier colours and one in the mediant colour.

When the viewing filters are so chosen that, apart from their respective transmittance and mutual exclusion of carrier colour range, they each transmit one part of the mediant colour range and exclude the part transmitted by the other, the same filters can be used as barrier filters in a display device. If this device is a conventional stereoscopic projector, the filters can thus take the place of polarizing barrier filters. In a digital projector, the filters can again take the place of polarizing filters, but there is the further advantage that in the left part-image, no constituent corresponding to the carrier colour of the right part-image need ever be formed (or it can be suppressed); and vice versa. Such a digital projector therefore, in a sense, projects four colour channels: the carrier colour associated with the left part-image and transmitted by the left-image filter; the mediant colour associated with the left part-image, but projected only in the sub-range transmitted by the left-image filter; the mediant colour associated with the right part-image, but projected only in the sub-range transmitted by the right-image filter; and the carrier colour associated with the right part-image and transmitted by the right-image filter. In this case, the requirement of four perceptual colour channels is met directly and can be fully utilized by an optimising encoding of the stereogram, while in the remaining encodings described below, primarily aimed at conventional three-channel displays, the impression of a four-channel display is created by colour management.

Fully developed, the encoding of a stereogram as prescribed by the invention involves an optimisation process. Generally, the precise effects of an implicitly defined process cannot be predicted (since otherwise the prediction would be an explicit process replacing the implicit one), but some qualitative features of this optimisation are evident:

The resulting mediant colour image, considered as an image in itself, is visible to both eyes and can therefore not be a single, sharp image, as this would cause diplopia. It must therefore, considered as an image in itself, appear blurred or double (or both), these effects being strongest in areas which represent scene objects far from the zero parallax depth.

It follows that the two carrier colour images, considered as images in themselves, must, at least to some extent, compensate for any loss of sharpness caused by this blurring of the mediant colour image. Thus, the amplitudes of the left carrier colour image will be enhanced, wherever the amplitude of the mediant colour image is smaller than that of the mediant colour component of the original left part-image; and it will be dampened, wherever the amplitude of the mediant colour image is larger than that of the mediant colour component of the original right part-image. The same thing holds, mutatis mutandis, for the right carrier colour image.

Also, as an integral part of the encoding, double images will be removed or reduced, seeing that contributions to the luminance variation from the original right part-image to the encoded left part-image will become part of the overall luminance variation of the encoded left part-image. Again, the same holds, mutatis mutandis, for the right part-image.

Finally, among the possible changes that will produce the desired effects on the luminance levels, an optimisation process will, when it is operating on a so-called "cost function" that also takes into account the final perceived colours, select those that cause the smallest changes (and hence, if possible: no changes) in the fused colours, compared with the fused colours perceived in the original stereogram, when this is stereoscopically viewed.

The re-distribution of luminance between the three images thus serves to obtain a balance between the four distinct requirements:

- that the luminance impression of the part-image received by the left eye when observing the encoded stereogram through the assigned left filter resembles (a scaled version of) the luminance impression received when observing the original left part-image;

- that the luminance impression of the part-image received by the right eye when observing the encoded stereogram through the assigned right filter resembles (a scaled version of) the luminance impression received when observing the original right part-image;

- that the fused hues resemble those observed in the original stereogram as stereoscopically viewed; and

- that the fused saturations resemble those observed in the original stereogram as stereoscopically viewed.

To obtain this, the encoding must replace some amount of one or both carrier colour with mediant colour, and vice versa, and this replacement can not be performed on a point-by-point basis, as this would create visible discontinuities that would give rise to both diplopia and abrupt colour casts.

Arguably, the simplest instantiation of the encoding, here expressed in photographical terms, is obtained by first photographically recording, along three parallel lines of sight, three (luminance level) images, the middle one having a restricted depth of field in the sense of being visually sharp only in the distance range intended for zero parallax in the final stereogram, then encoding the outermost two in the respective carrier colours and the middle one in the mediant colour, and finally mounting the three in register, i.e. with the zero parallax motif parts coalescent and homologous points horizontally aligned, to form a full-colour image. As an alternative to recording gray scale images, colour separation filtered images can be recorded. Note, that for direct recording, the lens system must allow in-place registration through a shift of the image frame. A recording process of this kind can be accomplished by an optical apparatus, but it should be noted that such an apparatus performs no amplitude enhancements of the carrier colour constituents. Note, also, that most analog films will give rise to double (actually: triple) images owing to insufficient spectral separation. The process can also be accomplished by an electronic filter, forming part of e.g. an electronic camera or image recorder. Digital image recorders can avoid the double imaging caused by spectral separation failures; and an electronic filter can perform enhancements of the carrier colour constituents and indeed other cross-constituent operations, as they are described in the following.

The description of the image encoding as prescribed by the invention can proceed in steps, each resulting instantiation being a variation over or an improvement of this theme:

- Leaving the world of analog photography: the middle image need not be directly recorded, but can be computed as an average of the mediant colour "planes" of the two outer images, each of which must then be recorded in at least two colours, the mediant colour and the relevant carrier colour. The averaging can be simple (half the sum), weighted using pre-determined weights, or adaptively weighted, taking into account the fact that areas which are low in one of the carrier colours provide less room for subsequent colour manipulations.

- If the averaging itself is a simple point-to-point weighted summation, the optical blurring can be simulated by a smoothing process. The smoothing operator can be a simple "sliding strip" technique, one or two-dimensional, or a genuine approximation to the point spread function of a lens with finite (as opposed to point-shaped) aperture. The local strength of the smoothing can vary according to any measure of local parallactic separation. Assuming that the stereo registration has been decided, this can be put in simpler terms: if there is very little difference between the mediant colour contents (or, alternatively, the gray scale contents) of the left and right images in and around a given position, the mediant colour should be only gently smoothed, in and around that position.

- Once an averaged and smoothed (henceforth just referred to as: "averaged") mediant colour image is available, the relationships between each carrier colour and the mediant colour can be reconsidered: to reduce loss of sharpness, which may occur when, in and around a given location, the averaged mediant colour differs from the mediant colour image of the one or the other of the part-images, the relevant carrier colour may be proportionally enhanced or reduced, in and around that location.

- Such a replacement may also be used to remedy double image phenomena: if, owing to the spectral imperfections of recording media, display media or filters, an "echo" of the left part-image is visible to the right eye or vice versa, the one carrier colour image may be modified by subtraction of a scaled version of the other carrier colour image. (Lest it may seem that this procedure leads to an infinite regress, it should be noted that the problem can be stated as two simultaneous equations in two unknowns; that the repeated procedure, if in fact performed, has the character of a "relaxation solution" of this problem; and that the smallness of the scaling factors implies a rapid convergence).

- The actual measures of equiluminant replacement will not be simply linear (proportional) as expressed in terms of colour coefficients (typically: "RGB"-values in digital representation), not even after taking into account the "gamma" of the medium at hand. (The "gamma" is the coefficient in the logarithmic/exponential relationship between e.g. image coefficients and CRT voltages, more generally: between numerical representation and light effect). They are therefore better based on spectrally measured colour gamuts. In practice, conversion back and forth is typically performed by table look-ups and interpolation. This is no different from all other colour computations, and can be built into the stereogram encoding.

- Rather than basing the smoothing strength on estimates of parallactic separation of the left and right part-images in and around a given location, it can be based directly on a correspondence map of the stereogram. This latter is a representation, typically in the form of a gray scale image, of the separation at any location, of the point at that location in one of the part-images and its homologous point in the other part-image. (Homologous points are images of one and the same scene point. Their separation is geometrically related to the depth of the scene point). Algorithms for solving the correspondence problem exist in great number in the arts of photogrammetry and machine vision.

- With the help of an algorithm for solving the correspondence problem, the stereogram can be artificially desaturated with little loss of image quality: if the saturation of colours of distant areas is reduced, they will be more easily encoded without causing artefacts of discontinuities in, or mis-coloration of, areas closer to the foreground. As with the adaptive averaging, this is again a question of providing room for colour redistribution.

Finally, most or all of the above can be combined. But to make the description of a combined algorithm understandable, one technical detail must be inserted:

In a conventional stereo viewer (e.g. a Brewster-viewer), the two part-images of a given stereogram are placed side by side and optically brought to seem coalescent. In an anaglyph, or a stereogram encoded by the present invention, two images actually coalesce by construction. Hence, any given image area serves two purposes simultaneously: it is the representation of an area in the original left part-image - and a representation of a different area in the original right part-image. Hence, to a given area in a colour-encoded stereogram, considered as seen by the left eye, a homologous area can be found. For convenience, the stereogram is assumed to be an endo-stereogram (all scene points are perceived as lying behind the image plane), so the homologous area lies to the right of the given area. When next the latter area is considered as seen by the left eye, a new homologous area can be found further to the right, etc. A model for what is actually perceived in a colour encoded stereogram must represent such chains of homologous areas, typically in the form of lists of selected representative homologous point pairs and their surroundings. Colour fusion will be between the colours seen in an area and its homologous counterpart. The areas must be found in (and referred back to) the original stereogram.

Now, given: a norm or metric on a device-independent colour space; an algorithm to solve the correspondence problem; a model for colour fusion; spectral measurements and models to convert device and image colour values into device-independent values; an algorithm for numerical optimisation; a viewing filter pair chosen as prescribed by the invention; and a stereogram - the image encoding prescribed by the invention:

- solves the correspondence problem for the original stereogram, representing the solution as a list or lists of homologous areas;
- computes the perceived fused colours in these areas, according to the fusion model;
- sets up the optimisation problem of encoding the stereogram in such a fashion as to express that what is actually perceived (as fused colours in the same areas) in the encoded stereogram, when this is observed through the viewing filters, has the smallest deviation in terms of the norm or metric on the colour space from the fused colours in the original stereogram;
- solves the optimisation problem using the numerical method, arriving at the encoding as the solution of this problem; and
- computes the image or device representation from the resulting device-independent colour representation.

It remains to be mentioned, that display of the recorded or encoded images can be made using any conventional (colour) display medium, including the media of prints or colour photos. If circumstances allow, though, use can advantageously be made of special stereoscopic projectors (designed as prescribed by the invention) accommodating coloured filters, which must then be functionally matched by the viewing filters.

In the following a short vocabulary will be given to more precisely set out the terms and their intended meaning used in the context of the present application, in the description as well as in the claims.

A part of the spectrum will be called a "range" if it forms a single, connected interval. A range, including the complete visible range, can be "partitioned", meaning divided into smaller ranges, which together exhaust the original. A typical partitioning of the entire visible range has been mentioned previously: blue light with wavelengths less than to 500nm, green light with wavelengths from 500nm to 600nm and red light with wavelengths greater than 600nm.

It is customary to think of a colour image as consisting of "components", such as its R-, G- and B-components, and this is done in the following, even if the actual display medium uses "primaries" of a different composition than suggested by the partitioning considered. An image will be said to have components "after" each of a given set of ranges, meaning that it could be composed from these components if ideal primaries existed, each emitting light at unit strength over a range and at zero strength outside it. Conversely, adding up the spectral distributions of such components is one way of "combining" the components into a resulting image.

These ideal operations have their well-known physical counterpart: separating an RGB-signal into an R-, a G- and a B-signal (whether analog or digital) is conceptually equivalent to passing light through "colour separation filters", such as the photographic filters mentioned above. In the case of physical light, practical sense must be made of some of these idealizations: an ideal clear filter would have a transmission rate of 1 everywhere; a physical filter can be thought of as having a "transmittance", a function taking values less than or equal to 1 everywhere on the range of visible light or a sub-range of it. Rather than referring to point values, the transmittance over a range shall mean the area under the transmission rate function graph divided by the width the range; and a filter will be said to "transmit a range", if its transmittance over that range is larger than 0.06 (6%), and to "exclude a range" if its transmittance over that range is less than 0.06. (This value corresponds to a damping of four photographic "stops" and marks a practical limit at which e.g. the presence of "ghost images" begins to cause diplopia). Two filters will be said to have a "significant common transmission" of a range, if the common area of their transmission rate functions restricted to that range is no less than 10% of either area.

From the realm of stereoscopy: two points in two part-images of a stereogram are said to be "homologous" if they are the projected images of one and the same point in the scene depicted. The extension to areas is obvious. "Fusional areas" are usually considered to be such areas, the images of which jointly fall on the foveas of an observer's eyes; but the definition can be slackened or tightened as the application at hand requires, the meaning being always that the areas are homologous, and that their contents are candidates for stereoscopic fusion. A "correspondence map" is defined elsewhere in the text and it remains only to note, that it is understood that homologous point pairs are at least approximately brought to lie on parallel lines ("horizontal lines"), and that such a map may take on negative values (negative parallaxes), if part of the scene depicted lies in front of the image plane used in the depiction. If the left and right part-images of an alleged stereogram are actually identical, the scene depicted is a flat object, parallel to the image plane, and its correspondence map is constant, possibly everywhere zero.

Finally: an image can be considered a two-dimensional signal, and concepts such as discrete Fourier transforms applied to it. Using such a transform one may define frequency ranges and their energy contents. Reference is made to the literature on the subject. Only the idea of "smoothing" an image by removing or reducing some of its "energy" in the "high frequency range" is needed in the following. Such a description is valid, even if the actual smoothing is carried out by other means.

## Description of the drawings

In the following different preferred embodiment of the present invention will be described in more detail with reference to the figures in which:

Figure 1 is a diagram showing the signal routes and operational units of an apparatus that performs the encoding of a stereogram as prescribed by the invention;

figure 2 is a diagram showing the functional elements in an optical apparatus that performs the encoding of a stereogram as prescribed by the invention;

figure 3 is a diagram showing the signal routes and operational units of an apparatus that performs the encoding of a stereogram as prescribed by the invention;

figures 4 to 6 show idealized transmission rates of viewing filter pairs as prescribed by the invention;

figures 7 to 9 show transmission rates of physical viewing filter pairs designed as prescribed by the invention;

figures 10 to 12 show idealized transmission rates of filter pairs for use, as viewing filters, and, in the projection apparatuses prescribed by the invention, simultaneously as barrier filters;

figure 13 is a diagram showing the application of a filter pair with spectral properties derived from the ideal transmission rates of one of figures 10 to 12 as barrier filters in a conventional stereo projector; and

figure 14 shows one light ray path and a possible positioning of one of the filters of figure 10 to 12, jointly with a colour separation filter, in a projector as prescribed by the invention.

Detailed description of preferred embodiments of the invention

In a first preferred embodiment of the image encoding method according to the invention, a stereogram is given as two part-images in digital form, represented by their "RGB" value arrays (as is customary in e.g. computer graphics). To make the following description specific, the left carrier colour is exemplified by B (blue), the right carrier colour by G (green) and the mediant colour by R (red), other choices being immediately obtainable by exchange of letters. The R components of the left and right images are then halved, added up and subjected to a smoothing in the form of a "sliding strip" averaging with a weight function in the form of a "Gaussian bell" (both terms defined and described in detail in standard references on numerical analysis and image analysis). The encoded image is obtained as the combination of this averaged R component with the B component from the left image and the G component of the right image. The simplicity of this embodiment is evident, but it is only truly applicable to stereograms with low contrasts and restricted depth.

The use of definite colour letters is maintained everywhere in the following, with the same proviso that other combinations can be obtained by exchange of letters. Also, the "RGB" readings must be considered as transferred to additive values using the pertinent "gamma" relation, prior to all computations, and back again prior to display of the encoded image.

In a second preferred embodiment of the image encoding, an approximate correspondence map is first obtained, for example by simply computing the point-wise differences in luminance levels everywhere over the two part-images of the stereogram (this is crude, but remarkably effective for its present use). An adaptive averaging of the two R-components of the part-images is then computed: First, a point-wise sum is formed of the minimum of the two R-values with a weighted sum of the two differences between the minimum and the actual values (thus, in any given point, one or the other of the contributions is zero). The weights are so chosen, relative to the luminances of red, green and blue in the display medium and to a selection of test images, so that colour casts in the test images are found acceptable by visual inspection. The choice of weights is thus empirical (psycho-physiological). The result is smoothed, as described with reference to the first embodiment, with the smoothing strength now coupled to the values of the correspondence map. The coupling is again determined by visual inspection, in order to avoid diplopia. The encoded image is obtained as the combination of this averaged R component with the B component from the left image and the G component of the right image.

In a third preferred embodiment of the image encoding, encoding proceeds as in the second embodiment, but the B and G components are further corrected to eliminate or nearly eliminate luminance variations ("ghost images") caused by the failure of the recording medium or of the viewing filters relative to the display medium or both to preserve ideal spectral separation.

In a fourth preferred embodiment of the image encoding, a genuine, if not exact, correspondence map is first obtained (by any method of choice) and the saturation of colours in the part-images of the stereogram reduced, increasingly with increasing depth, colours of the nearest points remaining unreduced. Encoding proceeds as in the third embodiment, except that the degree of smoothing is now more precisely controllable, a more precise correspondence map being available.

It should be noted here, that for artificially generated (digitally rendered) stereo images, an exact correspondence map can be generated in the course of the rendering process, either directly by the expedient of monitoring the projection of scene points, or indirectly from the so-called depth buffers of the part-images.

A fifth preferred embodiment of the image encoding requires a veritable battery of auxiliary tools:
- a method for determining a correspondence map of a stereogram;
- a choice of a size of fusional area(s) and with this, and with the correspondence map, a partitioning of the stereogram into chains of homologous areas;
- a device-independent colour space with a metric (colour distance) defined on it (several such are described in colour science);
- an extension of the metric, such as an integration or weighted summation of point-wise values of the metric, to an error measure allowing comparison of colours of fused homologous areas, as these are seen in the original stereogram, and in the encoding, respectively;
- a model for colour fusion (with additive mixture as the very simplest); and
- a numerical optimisation method (many examples of which can be found in the art of numerical analysis).

The encoding, as prescribed by the invention, is then found as the solution to the optimisation problem of reducing the error, as determined by the error measure, of the fused colours seen in the encoded image, compared with the fused colours in the stereogram, as these are determined according to the colour fusion model, acting over homologous areas in the chains partitioning the stereogram.

There are three preferred embodiments of the invention in the form of apparatuses aiding the recording of stereograms:

A sixth preferred embodiment of the invention, the first preferred embodiment of the apparatus aiding the recording of stereograms, takes the form of an electronic filter converting three incoming full-colour (or: a two-colour, a one-colour and a two-colour) image signals to one outgoing full-colour image signal. This embodiment comprises, as shown in figure 1:

- a component, 101, for separating the partial signal representing the first carrier colour and the mediant colour from the first image signal;
- a component, 102, for separating the partial signal representing the mediant colour from the second image signal;
- a component, 103, for separating the partial signal representing the second carrier colour and the mediant colour from the third image signal;
- a component, 110, for the pre-smoothing (low pass filtering) of the mediant colour image signal;
- a component, 120, for the comparison of the smoothed second mediant colour image signal with the signals representing the first and third mediant colour images and with the signals representing the first and third carrier colour images (and optionally modifying the second mediant colour image signal in accordance with the outcome of the comparison, the modification taking the form of a further smoothing or change of amplitude or both); and
- a component, 130, for the combination of a modified first carrier colour image signal, a smoothed second mediant colour image signal (optionally modified) and a

modified third carrier colour image signal, modifications being controlled by the outcome of the comparisons in the component 120.

It should be noted that if the original incoming signals are made, by some means external to the apparatus, to represent a conforming two-colour, a one-colour, and a two-colour image, respectively, then components 101, 102 and 103 are passive and, in a sense, superfluous. In the figure, the following signal routes are identified by numbers: Through 140 runs the signal representing the first carrier colour and mediant colour images. At the branching point 191, copies of both signals are directed towards 120. Optionally, only the carrier colour signal proceeds from there to 130. Through 141 runs the signal representing the third carrier colour and mediant colour images. At the branching point 192, copies of both signals are directed towards 120. Optionally, only the carrier colour signal proceeds from there to 130. Through 150 runs the signal representing the second mediant colour image. Through 160 runs the signal representing the smoothed second mediant colour image. Through 170 runs the (optionally modified) smoothed mediant colour image signal and signals representing the outcome of the comparisons made in 120. Through 180 runs the signal representing the final, encoded image.

It should be noted that it is not difficult in the sixth preferred embodiment described above to recognize the elements of the second and third embodiments. What was said in their descriptions about choices of weights and elimination of "ghost" images holds true in their electronic counterpart.

A seventh preferred embodiment of the invention, the second preferred embodiment of the apparatus aiding the recording of stereograms, takes the form of an optical adaptor converting three visual image signals to one outgoing visual image signal. The embodiment comprises, as shown in figure 2:

- optical colour separation filters 201, 202 and 203. These can for instance be the filters most frequently used in other photographic colour separation work, Kodak Wratten 25 (red), Kodak Wratten 58 (green) and Kodak Wratten 47B (blue) in some order. (The spectral properties of these filters are described in Kodak's technical references, and also elsewhere);
- lenses or lens systems, 210, 211 and 212, with 211 having a reduced depth of field relative to 210 and 212 (which are identical);
- mirrors 220 and 221; and
- prismatic mirrors 230, allowing passage of an image-forming light ray (bundle) from 211 and reflecting an image-forming light ray (bundle) from each of 220 and 221 in such a fashion as to produce a combined image.

As described so far, the device would be of fixed stereoscopic registration. A coupling (not shown separately in the drawing) between the lens system of the camera, on which the adaptor is mounted, and e.g. the lenses or lens systems 210 and 212 can be added to allow variable stereoscopic registration.

An eighth preferred embodiment of the invention, the third preferred embodiment of the apparatus aiding the recording of a stereogram, takes the form of an electronic filter to be mounted in a three-lens camera, in which colour separation is carried out by means of e.g. optical filters, i.e. externally to the filter. Also, the conversion from optical signals to one-channel (essentially: luminance level) signals takes place externally to the apparatus. The available signals thus represent a reduced amount of information about the three images, but the modus operandi otherwise resembles that of the sixth embodiment. The eighth embodiment comprises, as shown in figure 3:

- a component, 310, for (pre-)smoothing the second (mediant colour) image
signal;
- a component, 320, for the comparison of the smoothed second (mediant colour) image signal with the signals representing the first and third (carrier colour) images and optionally modifying the mediant colour image signal in accordance with the outcome of the comparison, the modification taking the form of a further smoothing or change of amplitude or both; and
- a component, 330, for the combination of a modified first carrier colour image signal, a smoothed second (mediant colour) image signal, optionally modified, and a modified third (carrier colour) image signal, modifications being controlled by the outcome of the comparisons in the component 320.

In figure 3 the following signal routes are identified by numbers: Through 340 runs the signal representing the first carrier colour image. At the branching point 391, a copy of the signal is directed towards 320. Through 341 runs the signal representing the third carrier colour and mediant colour images. At the branching point 392, a copy of the signal is directed towards 320. Through 350 runs the signal representing the second mediant colour image. Through 360 runs the signal representing the smoothed second mediant colour image. Through 370 runs the (optionally modified) smoothed mediant colour image signal and signals representing the outcome of the comparisons made in 320. Through 380 runs the signal representing the final, encoded image. Electronically variable stereoscopic registration can be added; but no component effecting this operation is shown in the figure.

There are two preferred embodiments of the viewing filters, as they are prescribed by the invention:

In a ninth preferred embodiment of the invention, the first embodiment of the viewing filters, the range of visual light from 400nm to 700nm (light outside this range being ignored) is divided into three: the range from 400nm to 500nm (blue light), the range from 500nm to 600nm (green light) and the range from 600nm to 700nm (red light); and a unit function, i.e. a function of constant value 1, over the full range is partitioned into three, defined as taking the value 1 on the respective sub-ranges and 0 outside. On one of the three ranges, which will act as the mediant colour, the unit "block" is divided "horizontally", as it were; and ideal transmission rates are obtained as functions of unit value over one range, zero value over another range and a constant ("partial") value over a third range. If complementarity is not required, the partial blocks need not add up to a constant unit function; but the zeros and ones must always do just this. Figures 4, 5 and 6 show examples of idealized filter pairs obtained this way. When such idealized transmission functions are approximated by practical filters, the block curves will be replaced by more irregular shapes. Figures 7, 8 and 9 show examples of practical filter pairs. In the notation introduced in the outline of the background of the invention, figures 4 and 7 display ([0 1/2 1], [1 1/2 0])-pairs, figures 5 and 8 display ([1/2 1 0], [1/2 0 1])-pairs and figures 6 and 9 display ([1 0 1/2], [0 1 1/2])-pairs.

In a tenth preferred embodiment of the invention, the second embodiment of the viewing filters, the division of the mediant block is "vertical". Idealized transmission curves are shown in figures 10, displaying a ([0 1/2 1], [1 1/2 0])-pair; 11, displaying a ([1/2 1 0, [1/2 0 1])-pair; and 12, displaying a ([1 0 1/2], [0 1 1/2])-pair, respectively.

The first embodiment of the viewing filters allows the better colour balance of the two. Both preserve the separation property in regards to certain conventional "monochrome" stereograms (replace the "1/2" by a "0" in the descriptions to obtain the corresponding non-complementary "monochrome" viewing filter descriptions). The second embodiment, alongside with its use with optimally encoded stereograms, also allows use as barrier filters in a stereo projector:

There are two preferred embodiments of stereo projectors, as they are prescribed by the invention:

In an eleventh preferred embodiment of the invention, the first embodiment of a stereo projector, the filters of the tenth embodiment are mounted in a conventional stereo projector, where they replace polarizing filters. Figure 13 is a schematic diagram of a conventional stereo projector, such as a slide projector or a twin digital projector system, equipped with barrier filters functionally identical to a pair of viewing filters, as these are described in the tenth preferred embodiment above. Elements 1301 and 1302 represent projector units, elements 1310 and 1311 lenses or lens systems, and elements 1320 and 1321 two filters of a pair, e.g. 1320 a [0 1/2 1]-filter, 1321 a [1 1/2 0]-filter, where the "1/2"s are disjoint parts of the visible spectrum.

In an twelfth preferred embodiment of the invention, the second embodiment of a stereo projector, the filters of the tenth embodiment are mounted in the light paths of a four-channel digital projector. The projector is constructed like any other digital projector, be it based on LCDs, digital mirror devices (rapidly adjustable micromirrors) or any other technique that allows projection of full-colour images. The only difference between the projector, as it is prescribed by the invention, and its conventional counterpart is that four, not three, image forming elements are required. (With projectors based on digital mirror devices (DMDs) only the time-multiplexed partitioning of the projection light need changing from a cycle of three to a cycle of four). With the previously introduced proviso of letter exchangeability, if a conventional projector uses three units, one for each of R, G and B, or a DMD runs a cycle of R,G,B, these must be expanded to RGGB and RGBG, respectively. Then the first pair, say, of these is used to form the left image, the light being further passed through a [0 1/2 1]-filter; and the second pair is used to form the right image, the light being passed through a [1 1/2 0]-filter. If the filters are complementary, an ordinary image will be projected as it is; and a stereo image projected this way can be viewed with an identically, or functionally equivalent viewing filter pair. The special optimisation encoding technique of the fifth preferred embodiment applies directly to this situation, since only the fusion model need differ from the three-channel case. But the option of actually encoding the image in four channels is evident, only it has no application outside the use of this class of projectors. The diagram in figure 14 shows a light path inside part of such an apparatus, with a possible positioning of one of the filters prescribed by the invention, here thought of as a distinct from the colour separation filter employed. Component 1401 illustrates a timer unit, 1410 a unit controlling intensity of light, 1420 a light source, 1430 a primary separation filter (R, G or B), 1431 one of the filters prescribed by the invention, and 1440 a component for controlling the exit direction of the light.

It will be appreciated that many modifications of the invention are possible without departing from the scope of the invention as defined in the accompanying claims.

Claims:

1. A method for encoding a stereogram as a single colour image A, the stereogram comprising a first part-image S and a second part-image D, the method comprising the steps of:

- partitioning of the visible part of the spectrum into a first range K, a second range L and a third range M:
- separating from the part-image D a component image DK after K and a component image DM after M;
- separating from the part-image S a component image SL after L and a component image SM after M;
- forming a modified image AM after M from SM and DM, for instance a smoothed average of SM and DM;
- forming a modified image AK after K from SK, for instance a sum of SK and a luminance correction CK;
- forming a modified image AL after L from DL, for instance a sum of DL and a luminance correction CL; and
- combining AK, AL and AM to obtain the single colour image A.

2. A method for encoding a stereogram as a single colour image A as defined in claim 1, the method comprising the further steps of:

- separating from the part-image D a component image DK after K and a component image DM after M;
- separating from the second part-image S a component image SL after L and a component image SM after M;
- forming an average image TM after M from SM and DM;

- applying a smoothing operator OS to TM to obtain a smoothed image AM after M from TM;

- forming AK by letting AK equal SK;

- forming AL by letting AL equal DL; and

- combining AK, AL and AM to obtain A.

3. A method for encoding a stereogram as a single colour image A as defined in claim 2, the method comprising the further steps of:

- forming from S and D an approximate correspondence map C of the stereogram and associating points of C with points of TM;

- allowing the smoothing operator OS to have a controllable, variable effect depending on a single parameter p, such that the effect of OS is smallest, when p is equal to zero, and such that the effect of OS grows monotonically with the numerical value of p; and

- controlling the effect of OS on a region RM of TM by taking as a value PR of p, a numerical value of C in RM.

4. A method for encoding a stereogram as a single colour image AAA as defined in claim 3, the method comprising the further steps of:

- adding to A a component image ADK after K in the form of scaled copy, for instance a negatively scaled copy, of the values of DL, to obtain an image AA; and

- adding to AA a component image ASL after L in the form of scaled copy, for instance a negatively scaled copy, of the values of SK, to obtain AAA.

5. A method for encoding a stereogram as a single colour image AAA as defined in claim 4, the method comprising the further steps of:

- modifying, after the formation of the correspondence map C, and prior to the remaining steps of claim 4, and as part of the steps of separating SL and SM from S and DK and DM from D, the part-images S and D by applying a saturation-diminishing operator OSD to S and D respectively, allowing the operator OSD to have a controllable, variable effect depending on a single parameter p, such that the effect of OSD is smallest, when p takes a value equal to the minimal value found in C, and such that the effect of OS grows monotonically with the value of p, controlling the effect of OSD on S and D respectively by taking as a value P of p, in a region RS of S, respectively a region RD of D, a value of C formed from RS and RD.

6. A method for encoding a stereogram as a single colour image AAA as defined in any of claims 1-5, wherein the component images AM, AK and AL of the method as described in claim 1 being implicitly defined as solution elements of an optimisation problem P, formulation and solution of P comprising the steps of:

- determining a correspondence map C from S and D;

- choosing a size Z of fusional area(s) and with this and C, partitioning the stereogram into a collection H of chains of homologous areas;

- choosing a device-independent colour space with a colour distance defined on it, for instance the L*u*v* space;

- defining an extension V of the colour distance, for instance as the sum of colour distances of regularly spaced points within a fused area, to allow comparison of fused colours in homologous areas of the original stereogram with fused colours in the same homologous areas in an encoding;

- defining a further extension of the error measure, such as summation over the fused areas in a chain, to allow computation of a total error over a chain of fused homologous areas;

- choosing a model for colour fusion, for instance additive mixture;

- defining P as the problem of modifying AM, AK and AL to reduce to a minimum the error, as determined by the error measure, of the fused colours seen in A, compared with the fused colours in the stereogram, as these are determined according to the colour fusion model, acting over homologous areas in the collection H of chains partitioning the stereogram; and

- solving P for AM, AK and AL.

7. An apparatus for aiding in encoding of a stereogram, the apparatus comprising:

- means for separately receiving a representation of a left part-image S, a representation of a central part-image C and a representation of a right part-image D;

- means for effecting a separation from S of a component SK;

- means for effecting a separation from C of a component CM;

- means for effecting a separation from D of a component DL;

- means for effecting a modification of CM, for instance a smoothing operation, to form a component AM;

- means for effecting a modification of SK, for instance an amplitude correction, to obtain a component AK;

- means for effecting a modification of DL, for instance amplitude correction, to obtain a component AL; and

- means for collecting AK, AM and AL into the representation of one image.

8. An apparatus as defined in claim 7, the apparatus further comprising:

- means for accommodating a first colour separation filter FFK transmitting a first spectral distribution KK;

- means for accommodating a second colour separation filter FFL transmitting a second spectral distribution LL;

- means for accommodating a third colour separation filter FFM, transmitting a third spectral distribution MM;

- means LSK, such as a first lens or lens system, for image formation from light that has passed through FFK, LSK having a first depth-of-field function F;

- means LSL, such as a second lens or lens system, for image formation from light that has passed through FFL, LSL having a second depth-of-field function G being significantly different from F;

- means LSM, such as a third lens or lens system, for image formation from light that has passed through FFM, LSM having a third depth-of-field function H equalling F; and

- means, for instance in the form of a combination of mirrors and prisms, for gathering images formed by LSK, LSL and LSM into one image.

9. An apparatus as defined in claim 7, the apparatus providing upon reception of S, C and D as defined in claim 7, an electronic representation EA of a single image A, the apparatus comprising:

- means for receiving an electronic representation ES of S;

- means for receiving an electronic representation ED of D;

- means for receiving an electronic representation EC of C;

- means for partitioning from ES a first contribution ESK and a second contribution ESM;

- means for partitioning from ED a first contribution EDL and a second contribution EDM;

- means for partitioning from EC a contribution ECM - means for forming a first contribution EAK to EA, EAK being essentially equal to ESK;

- means for forming a second contribution EAL to EA, EAL being essentially
equal to EDL;

- means for forming a third contribution EAM to EA after MM, EAM being essentially an average of ESM, EDM and ECM, the average being optionally weighted and optionally subjected to a smoothing; and

- means for assembling EA from the contributions EAK, EAL and EAM.

10. An apparatus as defined in claim 7 for transmitting an electronic representation EA of a single image A composed from a first part-image S and a second part-image D, the apparatus further comprising:

- means for receiving an electronic representation ESK of a component of S;
- means for receiving an electronic representation EDL of a component of D;
- means for receiving an electronic representation ECM of a component of C;
- means for forming a first contribution EAK to EA, EAK being essentially equal to ESK;
- means for forming a second contribution EAL to EA, EAL being essentially equal to EDL;
- means for forming a third contribution EAM to EA after MM, EAM being essentially a smoothing of ECM; and
- means for assembling EA from the contributions EAK, EAL and EAM.

11. An optical filter pair for displaying or viewing a stereogram, the filter pair comprising a first filter FS and a second filter FD, such that relative to a partitioning of the visible part of the spectrum into a first range K, a second range L and a third range M, in which each of the parts K, L and M corresponds essentially to one of the named colours "red", "green" and "blue":

- FS transmits K and transmits M and excludes L;
- FD transmits L and transmits M and excludes K.

12. An optical filter pair for displaying or viewing a stereogram as defined in claim 11, wherein the filter pair further has a significant common transmission of M.

13. An optical filter pair for displaying or viewing a stereogram as defined in claim 11, further comprising a partitioning of MM into a range MS and a range MD, such that:

- FS transmits MS and excludes MD; and
- FD transmits MD and excludes MS.

14. An optical filter pair for displaying or viewing a stereogram as defined in claim 11, wherein the filter FS has a transmittance TSK of K, a transmittance TSL of L and a transmittance TSM of M, the filter FD having a transmittance TDK of K, a transmittance TDL of L and a transmittance TDM of MM, such that:

- TSM is no greater than 150% of TSK and no less than 10% of TSK;
- TDM is no greater than 150% of TDL and no less than 10% of TDL;
- TSM is no greater than 1000% of TDM and no less than 10% of TDM;
- TSL is no greater than 6% of TSK; and
- TDK is no greater than 6% of TDL.

15. An optical filter pair for displaying or viewing a stereogram as defined in claim 14, the filter pair further having a significant common transmission of M.

16. An optical filter pair for displaying or viewing a stereogram as defined in claim 14, comprising a further partitioning of MM into a range MS and a range MD, FS having a transmittance TSMS of MS and a transmittance TSMD of MD, and FD having a transmittance TDMS of MS and a transmittance TDMD of MD, such that:

- TSMD is no greater than 6% of TDMD; and
- TDMS is no greater than 6% of TSMS.

17. An apparatus for displaying a stereogram, the stereogram comprising a first part-image S and a second part-image D, the apparatus comprising a first optical filter FS and a second optical filter FD as defined in any of claims 13-16, the apparatus comprising:

- means for transmitting a projection, or transmitting light forming a projection, of at least a component CS of S through FS;
- means for transmitting a projection, or transmitting light forming a projection, of at least a component CD of D through FD; and
- means for adjusting the transmitted projections of S and D, or components CS and CD of S and D, to bring at least a first point PS in the transmitted projection of S or CS, into coalescence with a second point PD in the transmitted projection of D or CD.

18. An apparatus for displaying a stereogram, as defined in claim 17, the apparatus further comprising:

- means, such as electronic filtering means, for removing from the second part-image D or its electronic representation, a substantial part of its contribution after the first spectral distribution K; and
- means, such as electronic filtering means, for removing from the first part-image S or its electronic representation, a substantial part of its contribution after the second spectral distribution L, the distribution L being excluded by the filter FS and the distribution K being excluded by the filter FD.

19. An apparatus for displaying a stereogram, as defined in claim 17, the apparatus further comprising:

- a first image-forming unit USK, a second image-forming unit USM, a third image-forming unit UDM and a fourth image-forming unit UDL;

- means for partitioning from S a first contribution CSL and a second contribution CSM;

- means for partitioning from D a first contribution CDK and a second contribution CDM;

- means for passing light emitted by USK through FS;

- means for passing light emitted by USM through FS;

- means for passing light emitted by UDM through FD; and

- means for passing light emitted by UDL through FD.

20. A physically realized image, for example a printed or photographically reproduced image, the image comprising:

- a first component image PK, observable or rerecordable through a first colour separation filter FK;

- a second component image PL, observable or rerecordable through a second colour separation filter FL;

- a third component image PM, observable or rerecordable through a third colour separation filter FM, such that

- a disparity map constructed from a pair of images, comprising as a first image a luminance level image LIK made from PK and as a second image a luminance level image LIL made from PL, differs substantially from a constant-parallax map;

- a first energy difference, being the difference between energies in the high-frequency range of the component image PM and in the high-frequency range of the component image PK being substantially different from zero; and

- a second energy difference, being the difference between energies in the high-frequency range of the component image PM and in the high-frequency range of the component image PL being substantially different from zero.

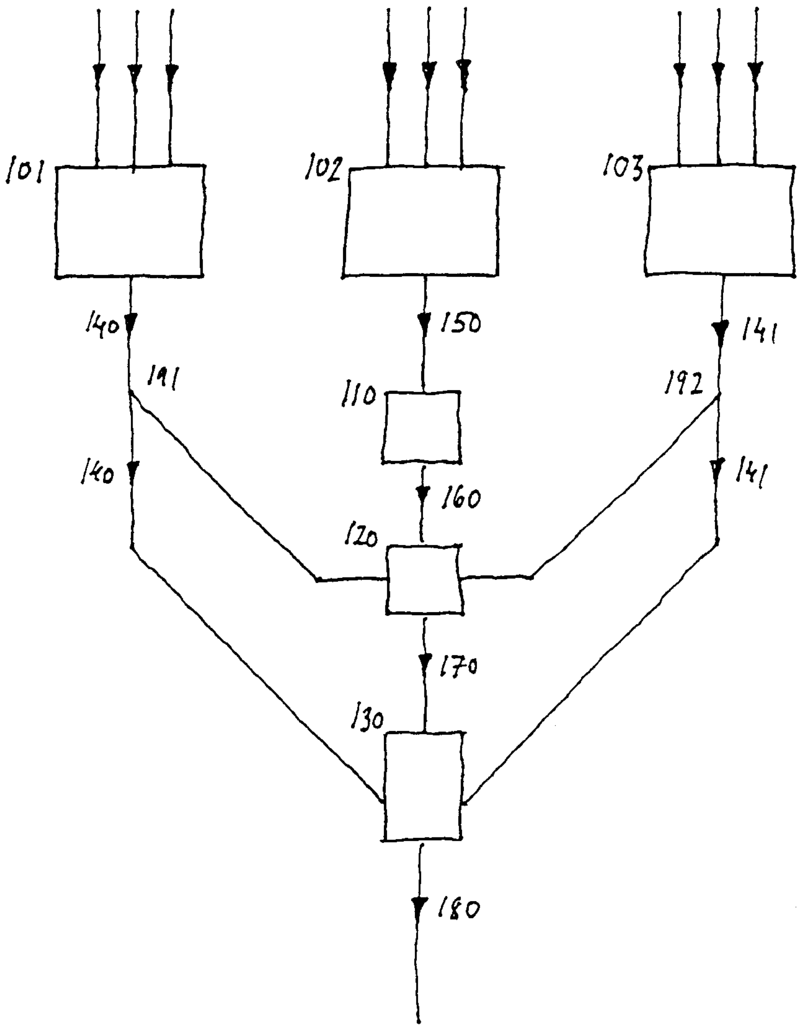



FIG. 1

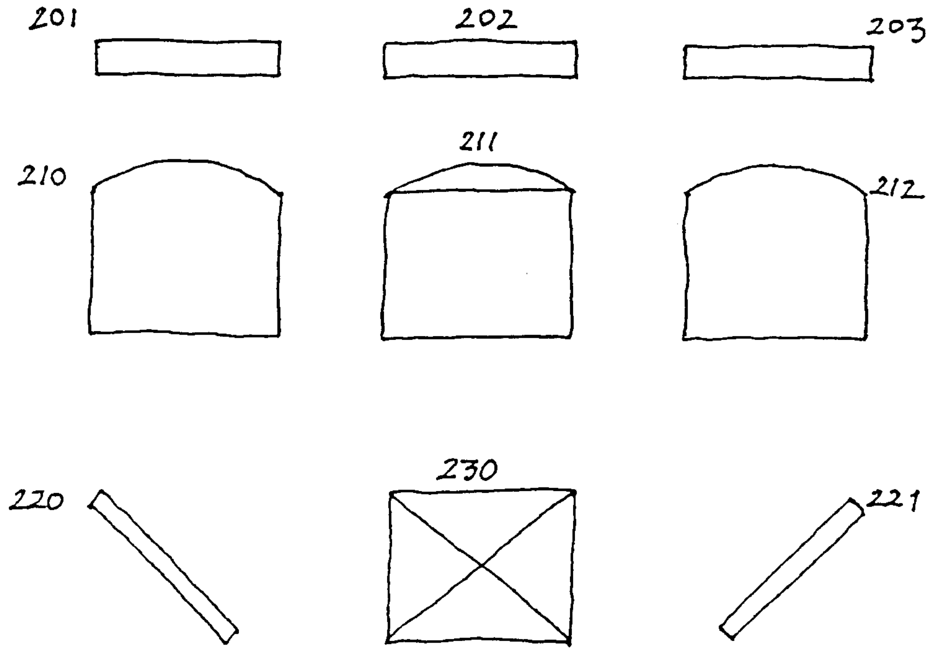



FIG. 2

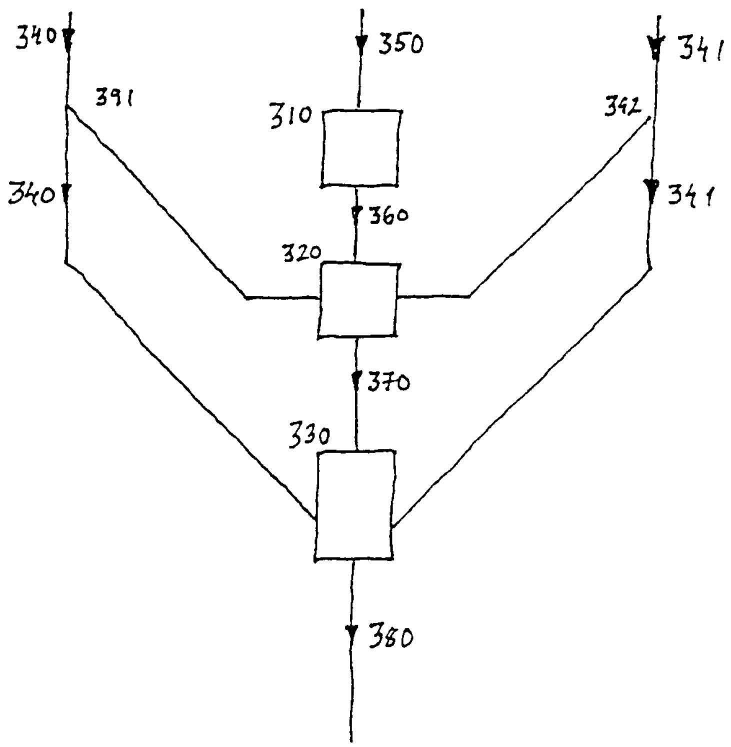



FIG. 3

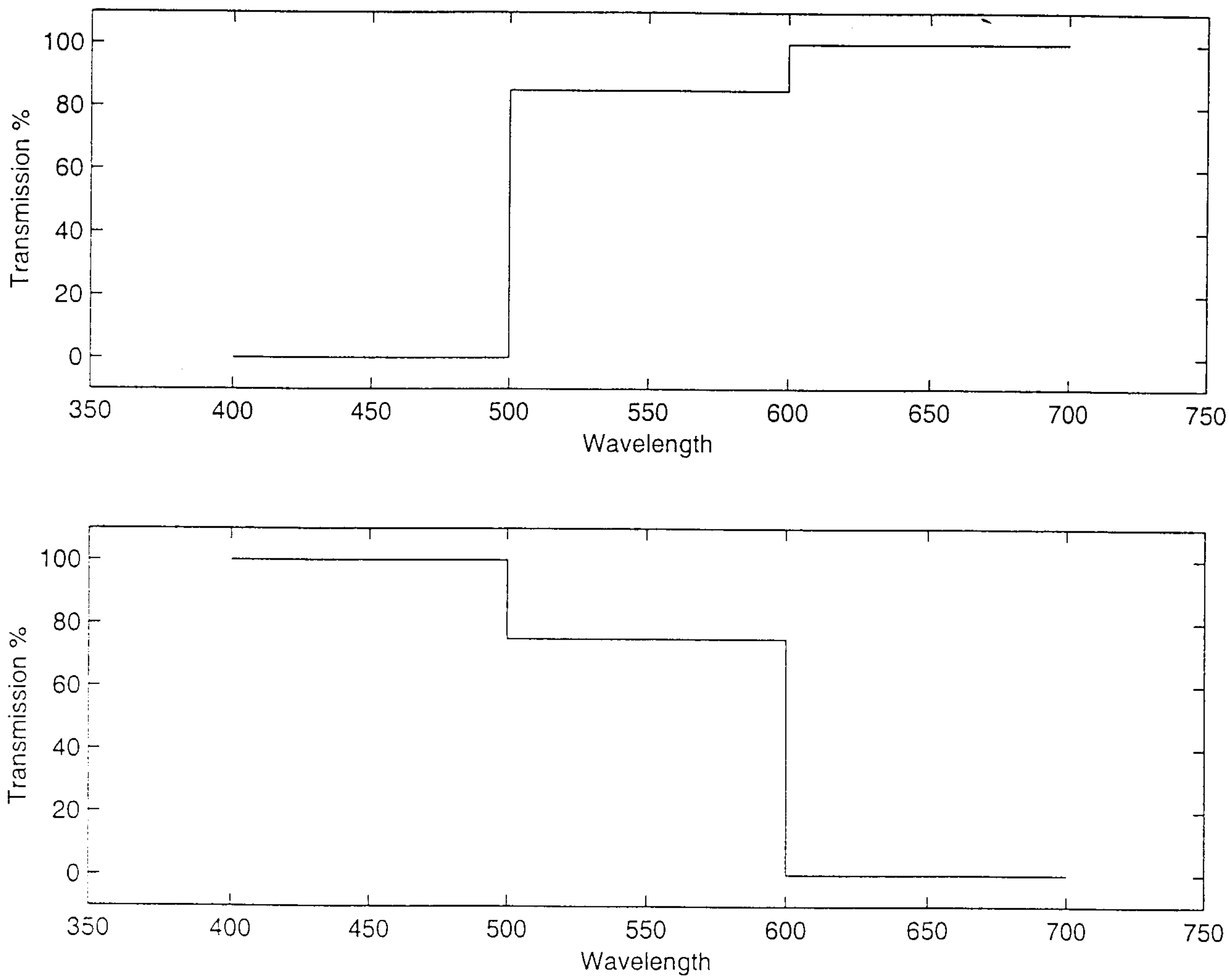

Transmission %
100
80
60
40
20
0
350
400
450
500
550
600
650
700
750
Wavelength
Transmission %
100
80
60
40
20
0
350
400
450
500
550
600
650
700
750
Wavelength

FIG. 4

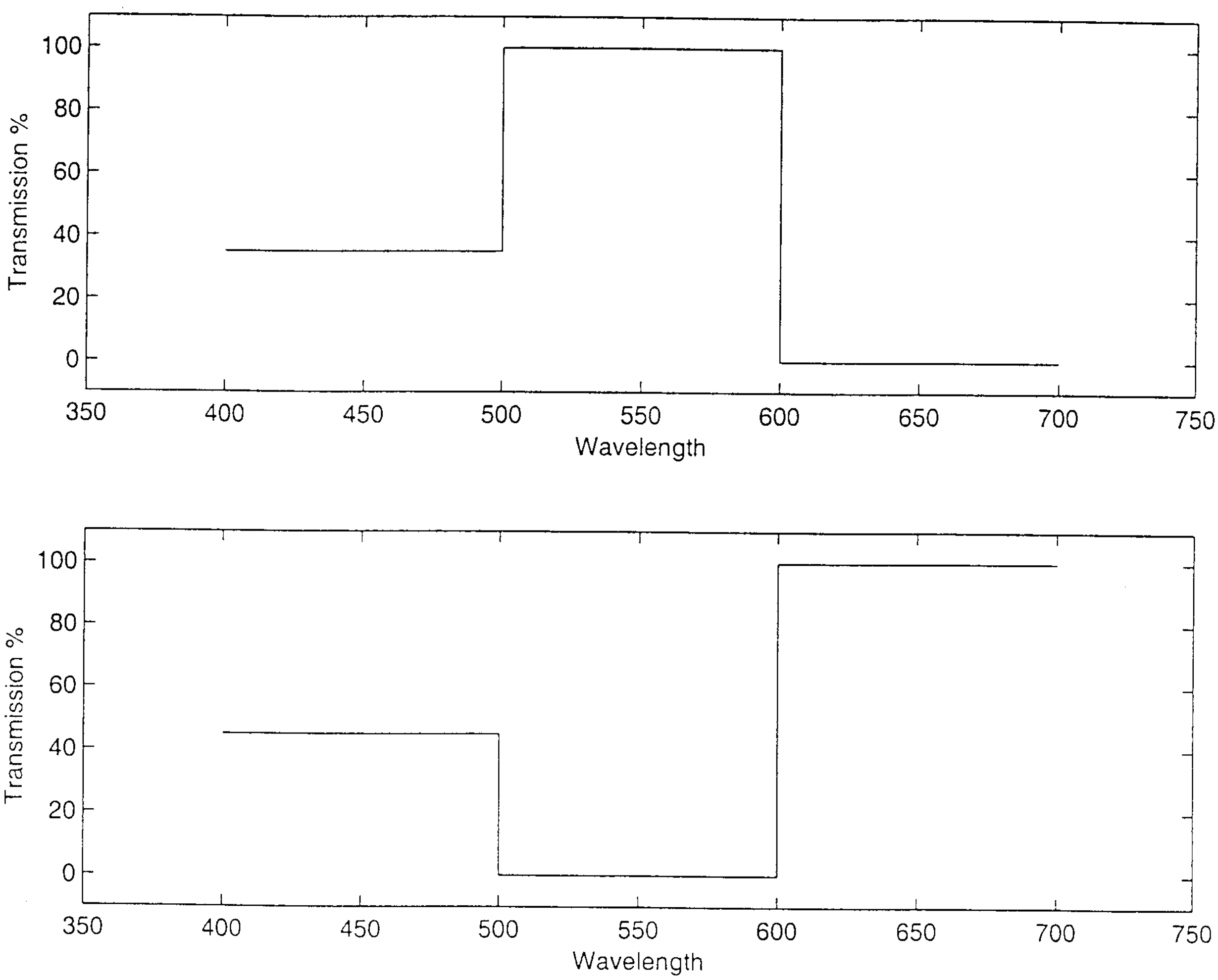

100
80
60
40
20
0
Transmission %
350
400
450
500
550
600
650
700
750
Wavelength
100
80
60
40
20
0
Transmission %
350
400
450
500
550
600
650
700
750
Wavelength

FIG. 5

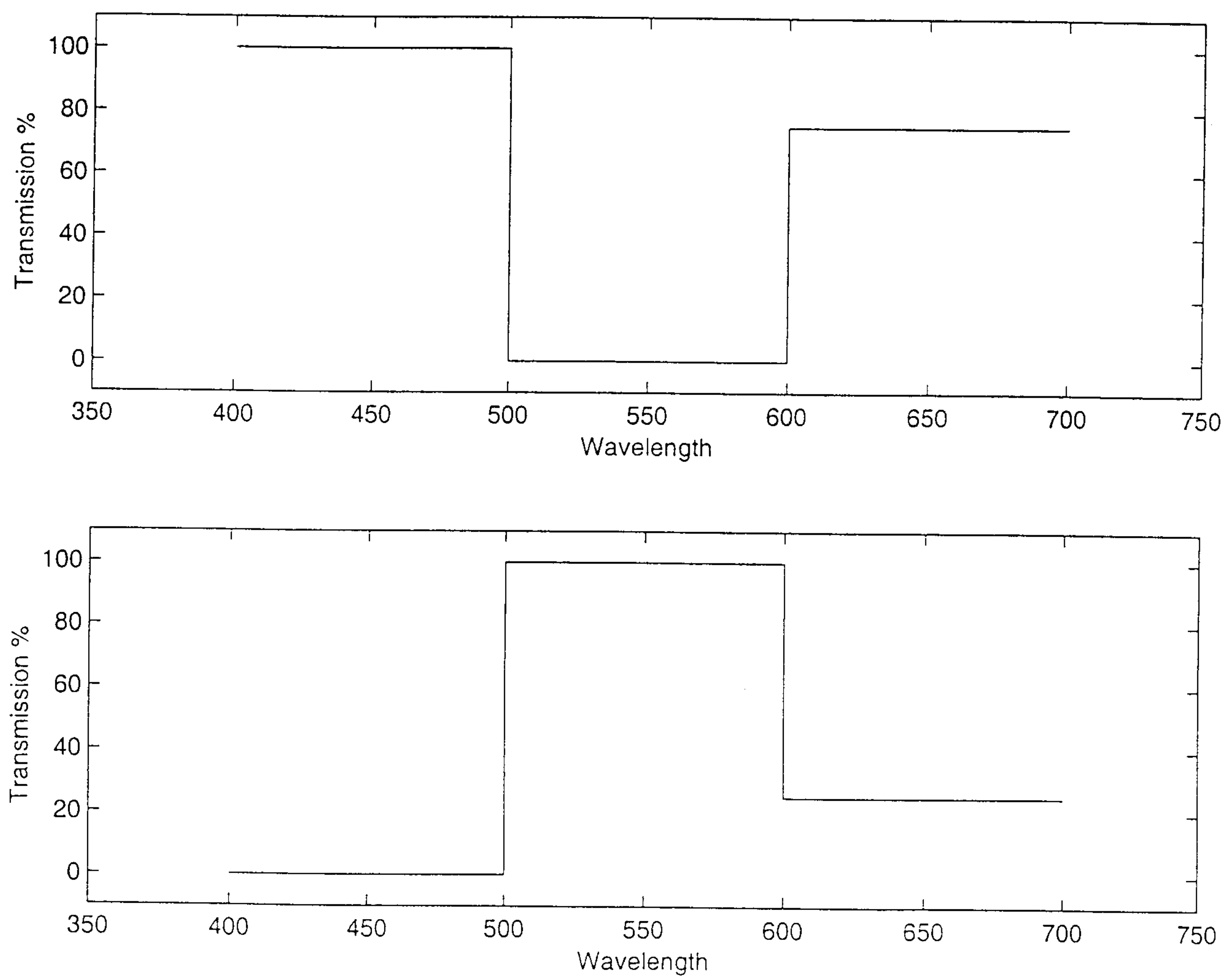

100
80
60
40
20
0
Transmission %
350
400
450
500
550
600
650
700
750
Wavelength
100
80
60
40
20
0
Transmission %
350
400
450
500
550
600
650
700
750
Wavelength

FIG. 6

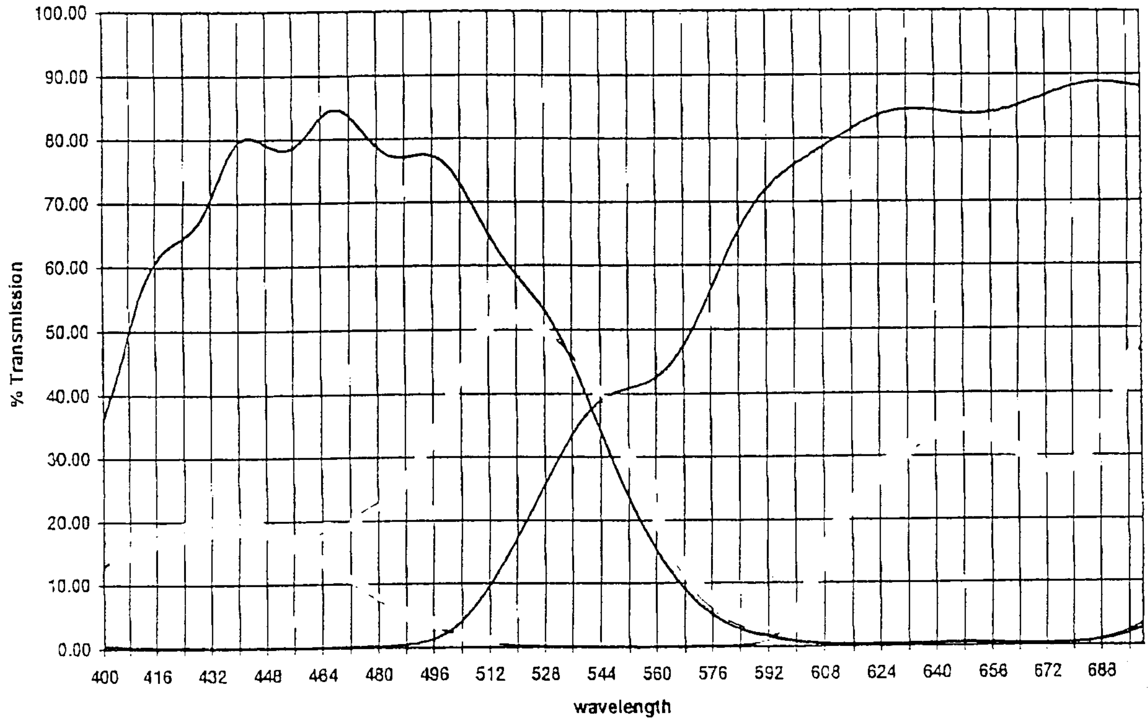
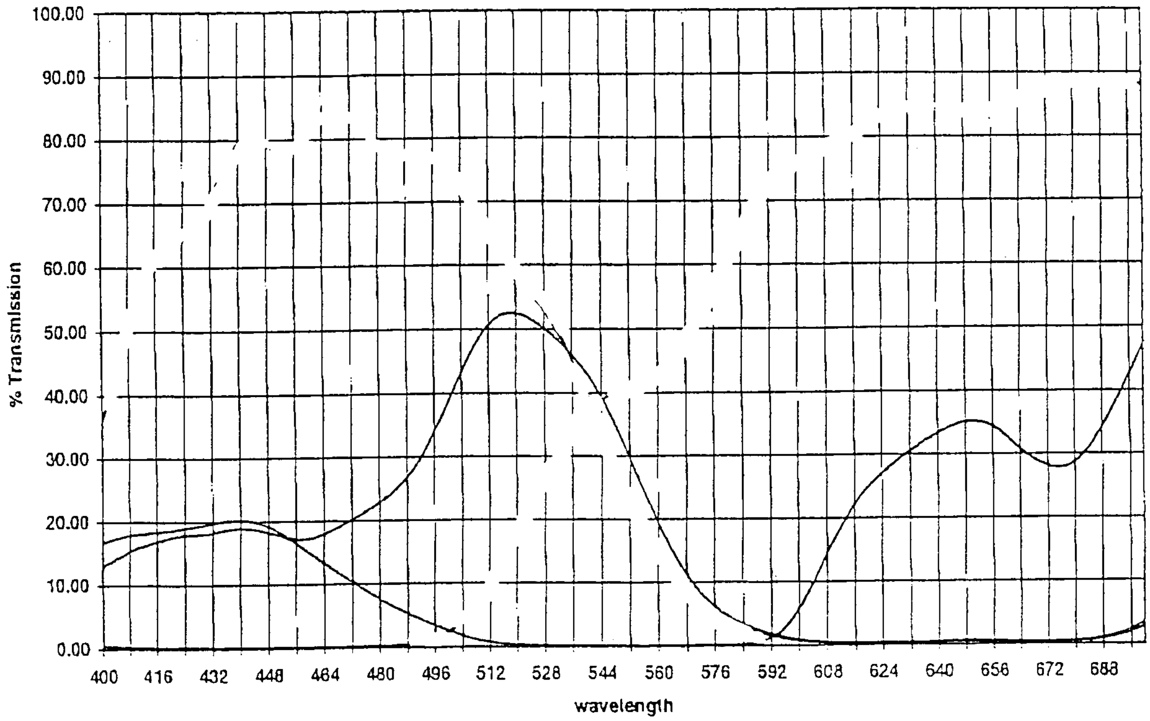

100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
% Transmission
400 416 432 448 464 480 496 512 528 544 560 576 592 608 624 640 656 672 688
wavelength

FIG. 7



100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
% Transmission
400
416
432
448
464
480
496
512
528
544
560
576
592
608
624
640
656
672
688
wavelength


FIG. 8

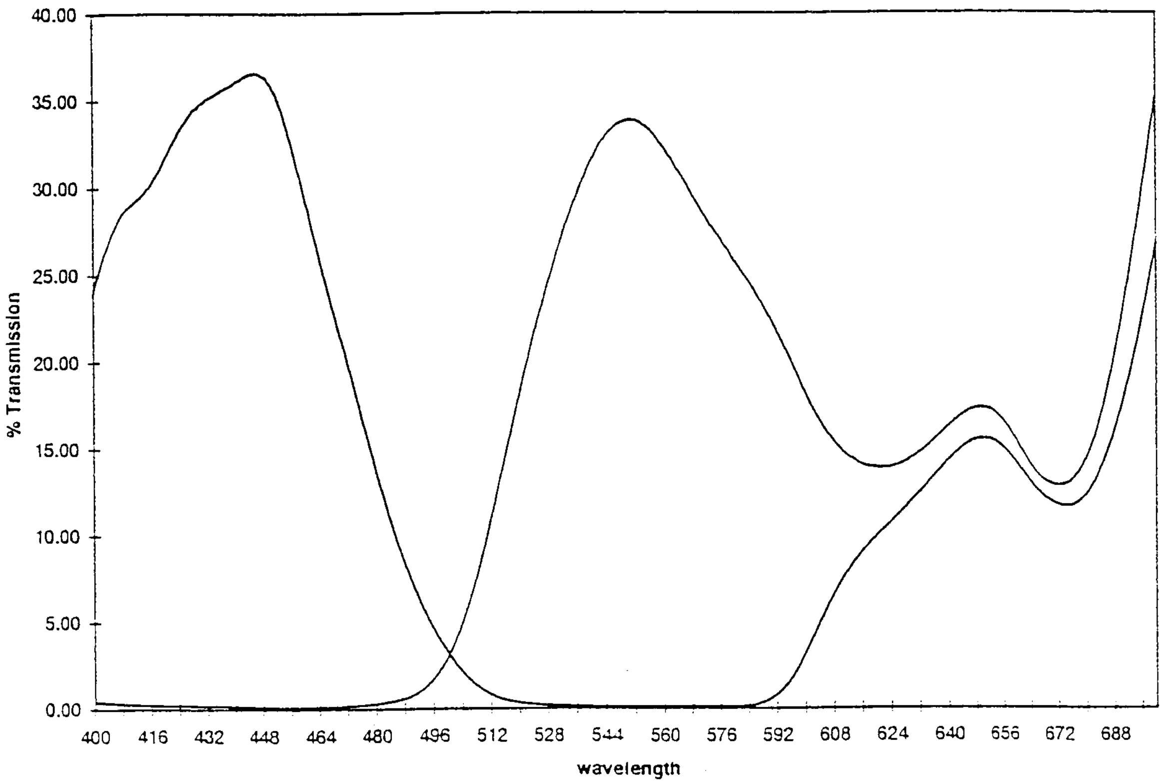
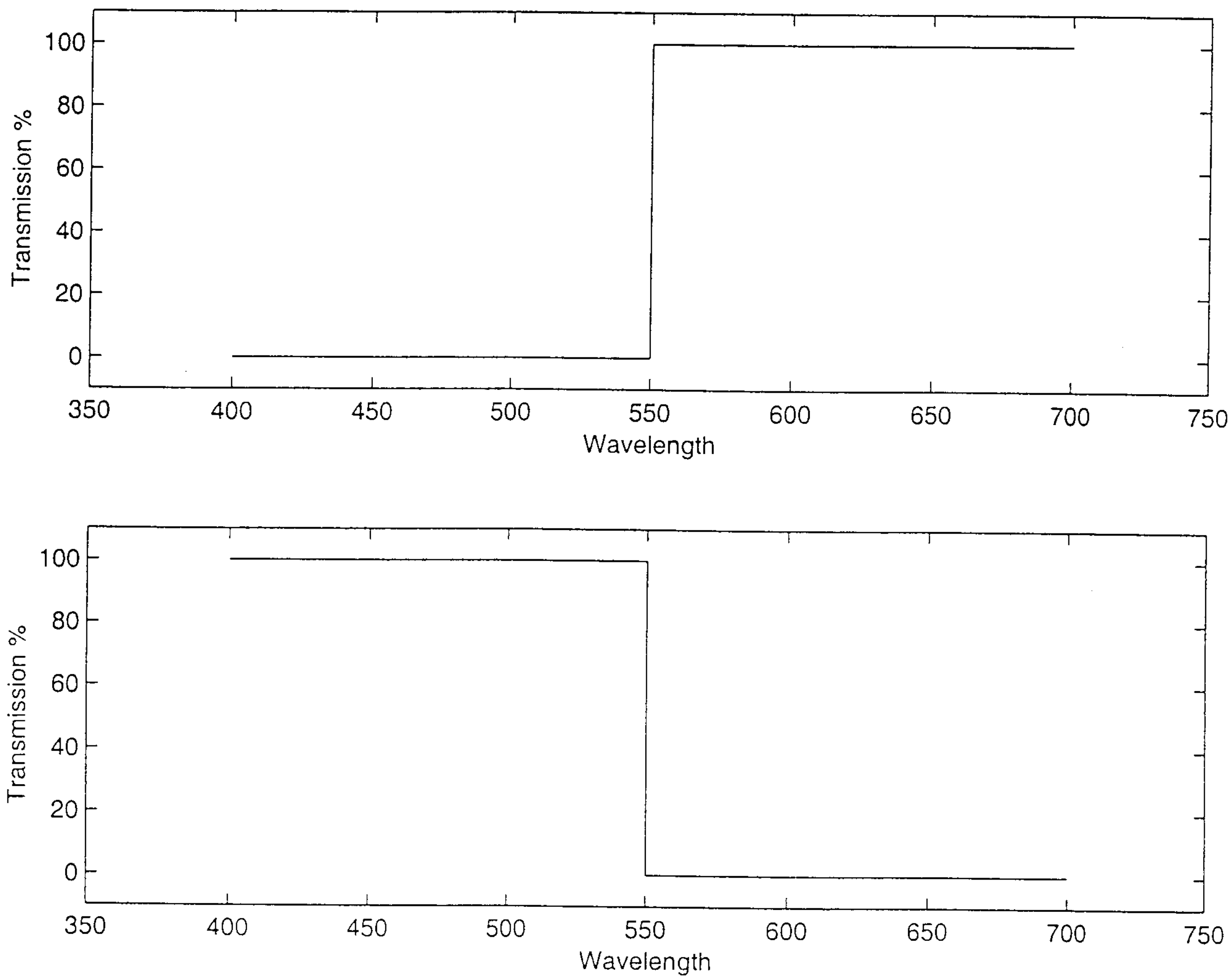

40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
% Transmission
400 416 432 448 464 480 496 512 528 544 560 576 592 608 624 640 656 672 688
wavelength

FIG. 9



Transmission %
100
80
60
40
20
0
350
400
450
500
550
600
650
700
750
Wavelength
Transmission %
100
80
60
40
20
0
350
400
450
500
550
600
650
700
750
Wavelength


FIG. 10

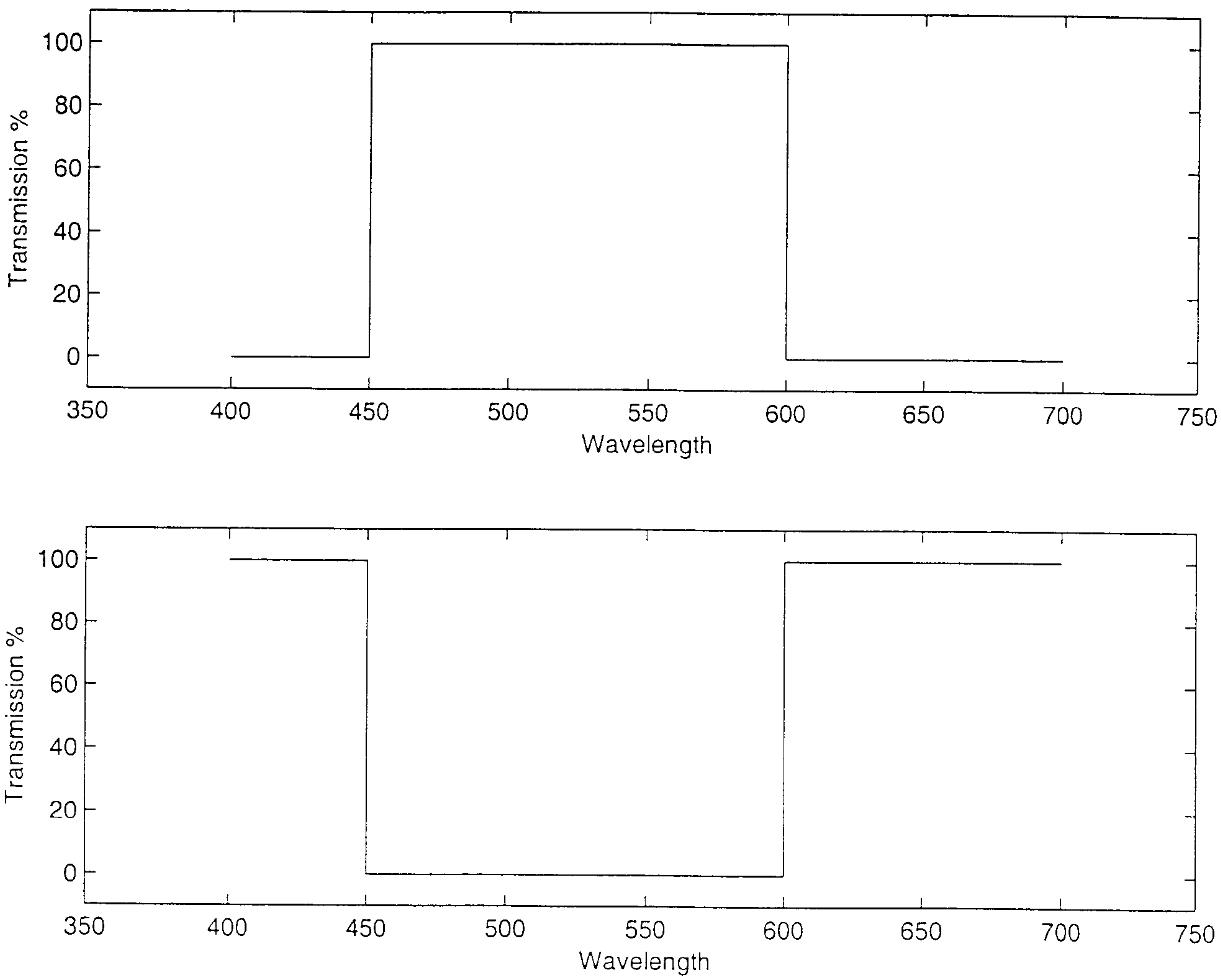

100
80
60
40
20
0
Transmission %
350
400
450
500
550
600
650
700
750
Wavelength
100
80
60
40
20
0
Transmission %
350
400
450
500
550
600
650
700
750
Wavelength

FIG. 11

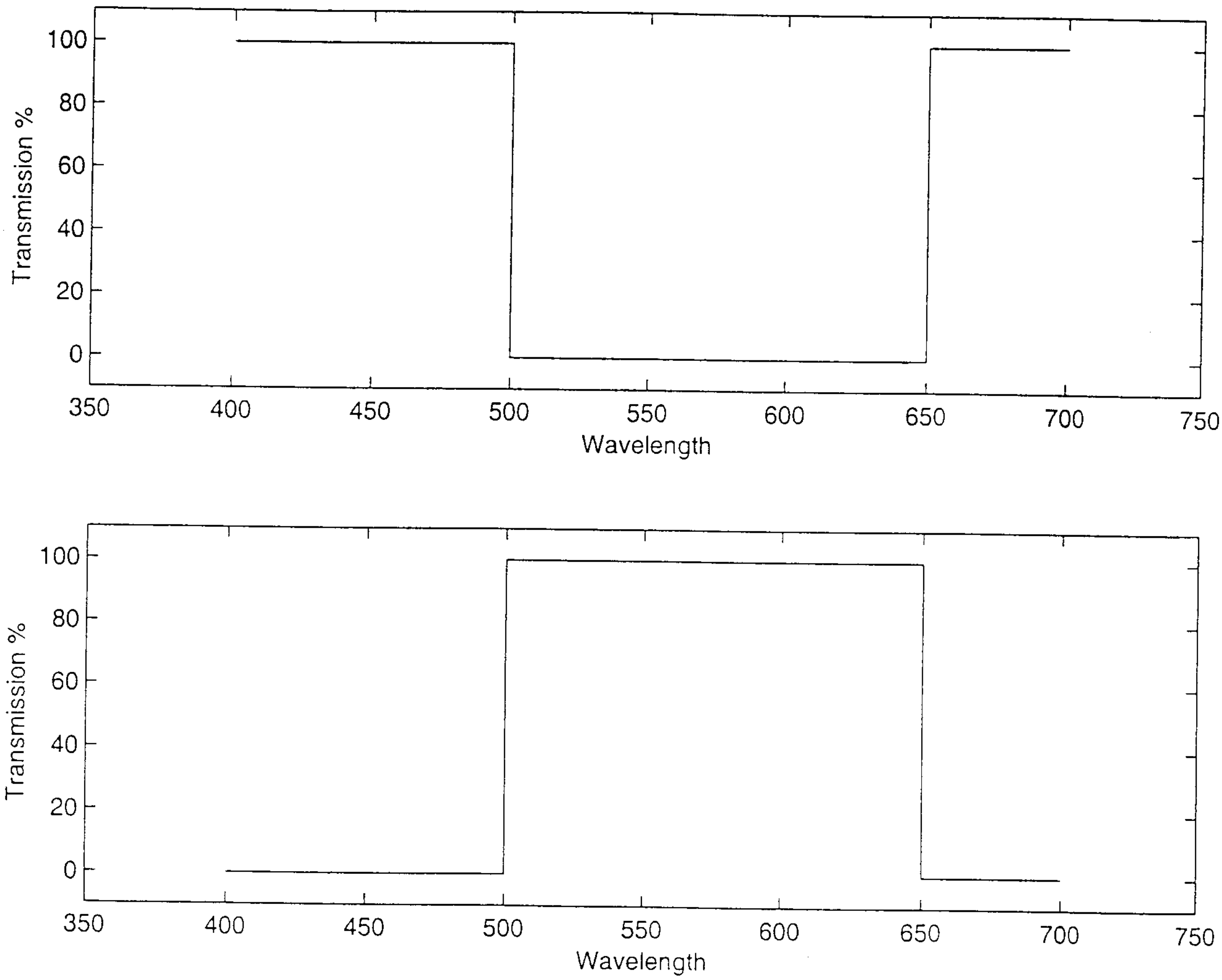

100
80
60
40
20
0
Transmission %
350
400
450
500
550
600
650
700
750
Wavelength
100
80
60
40
20
0
Transmission %
350
400
450
500
550
600
650
700
750
Wavelength

FIG. 12

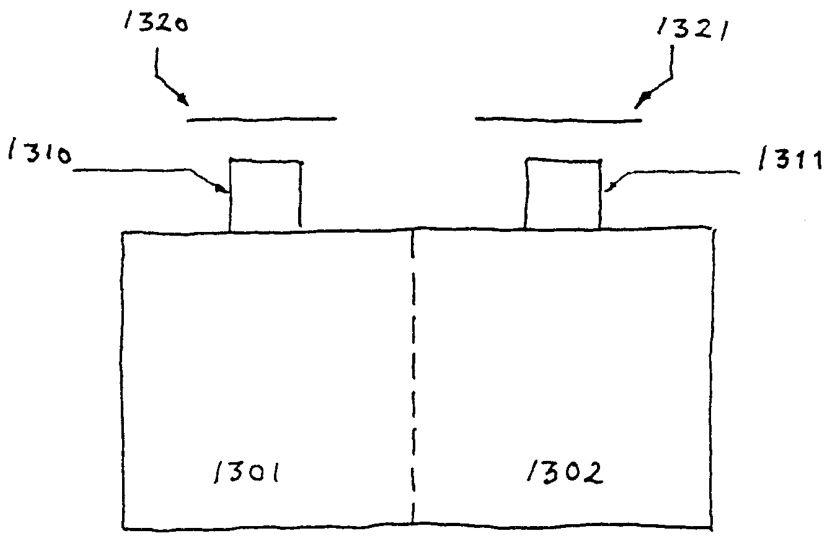



FIG. 13

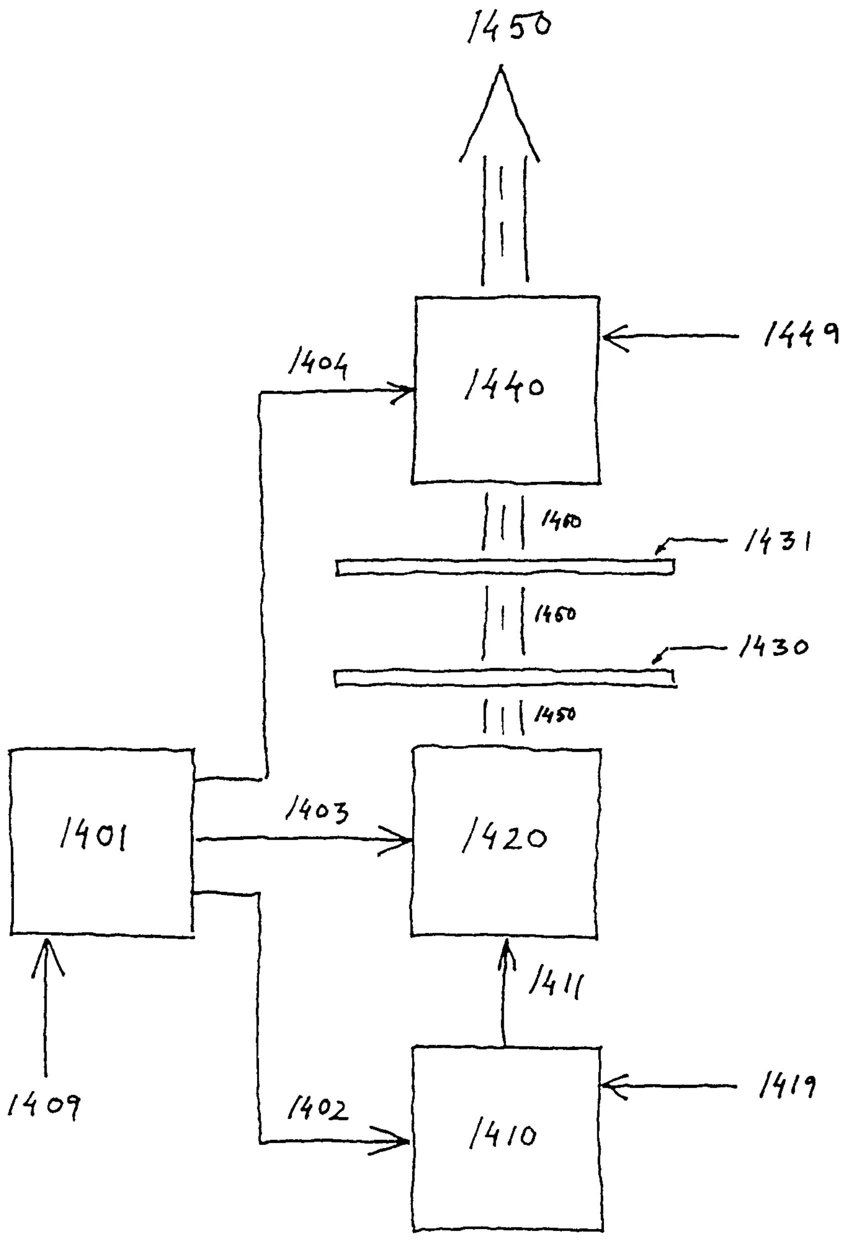

1450
1449
1404
1440
1450
1431
1450
1430
1450
1401
1403
1420
1411
1409
1402
1410
1419

FIG. 14