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(54) FOUR COLOR ARRANGEMENTS OF EMITTERS FOR SUBPIXEL RENDERING

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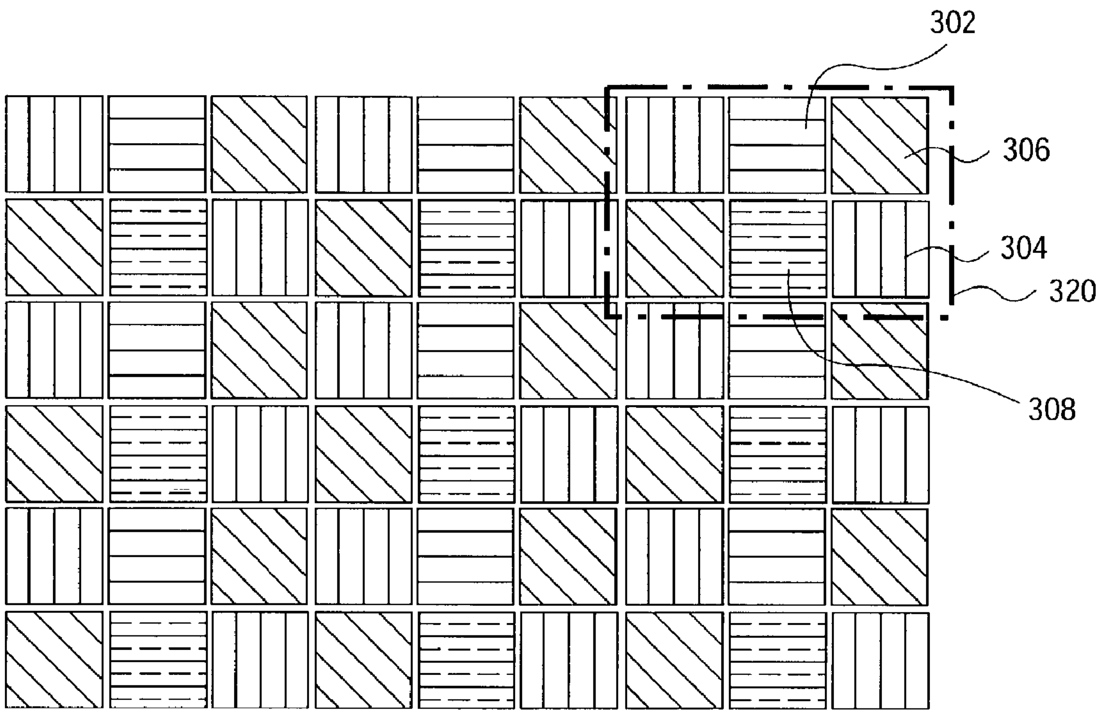
(52) **U.S. Cl.** ........................................ **345/694**; 345/589

(57) **ABSTRACT**

Novel three-color and four-color subpixel arrangements and architectures for display and the like are herein disclosed. Novel techniques for subpixel rendering on the above subpixel arrangements are also herein disclosed.



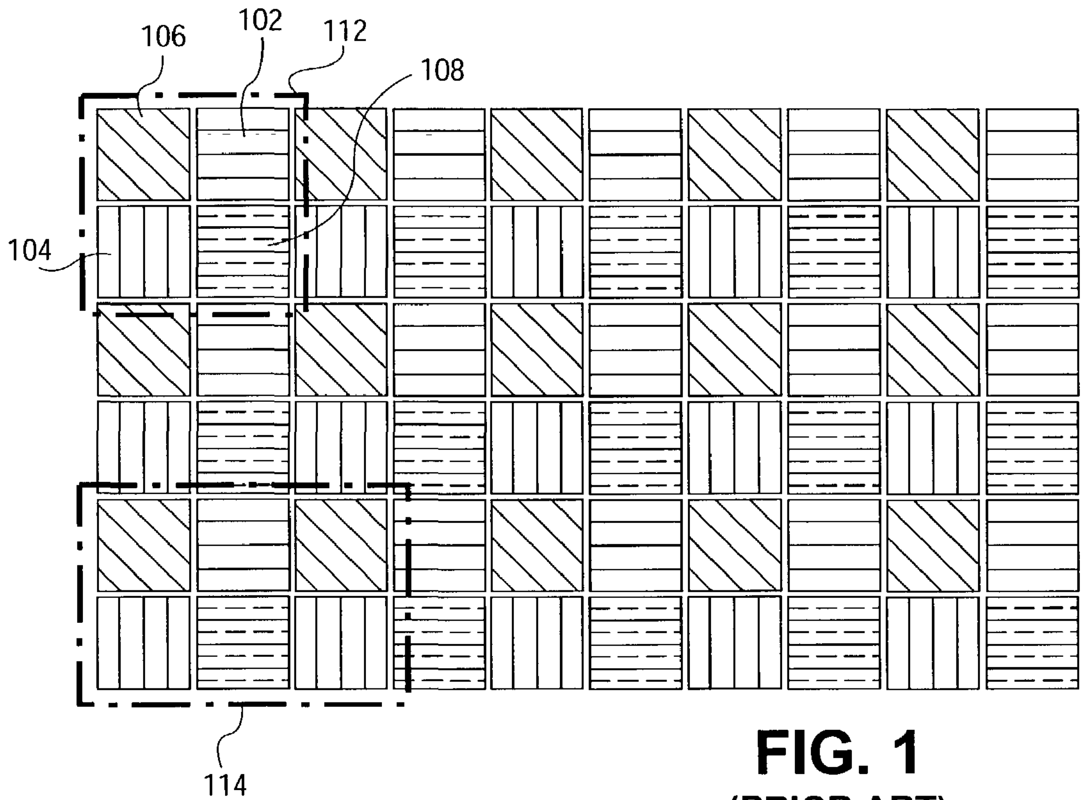



**FIG. 1**
**(PRIOR ART)**

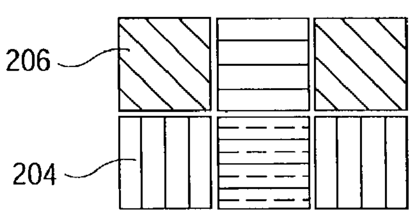



**FIG. 2A**

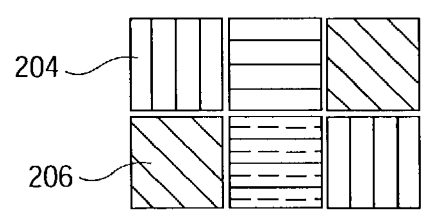



**FIG. 2B**

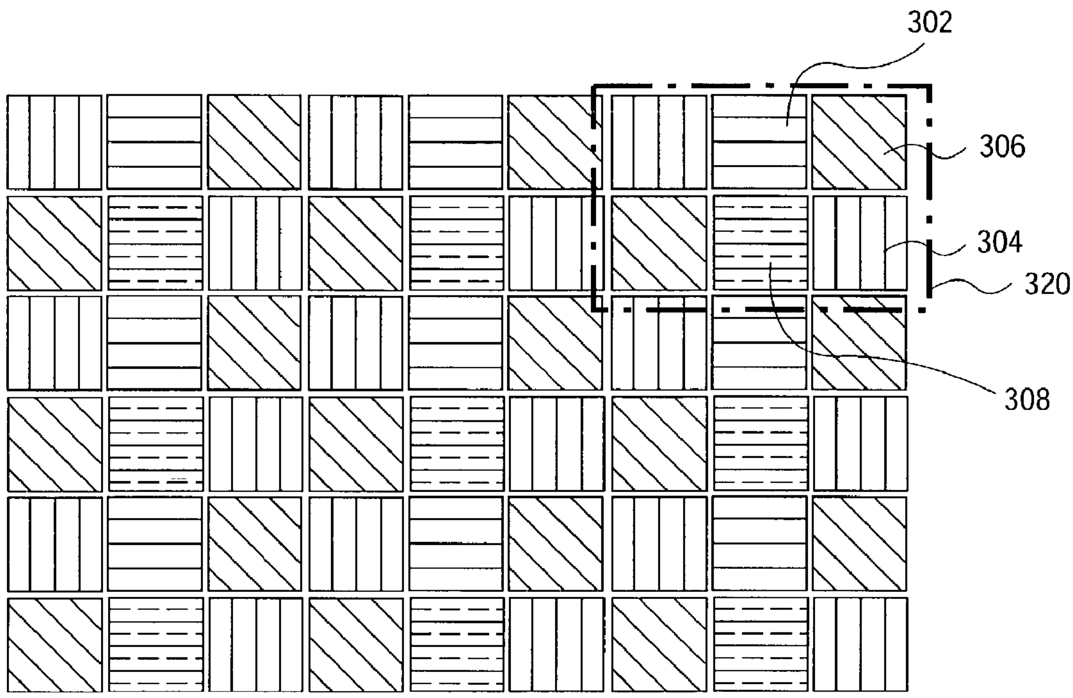



FIG. 3

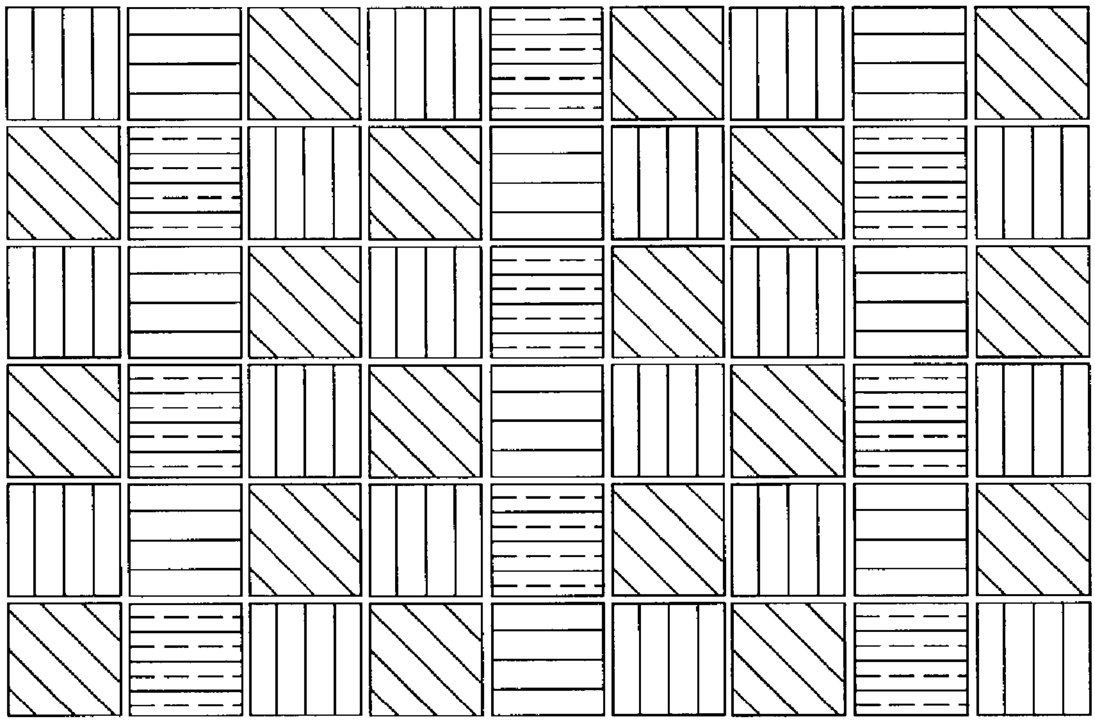


FIG. 4

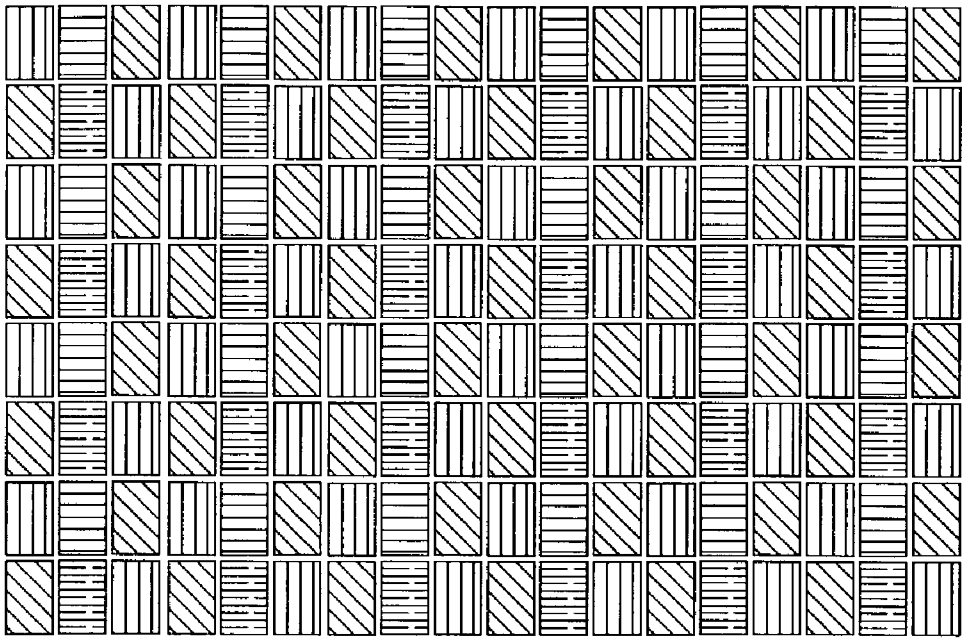


FIG. 5A

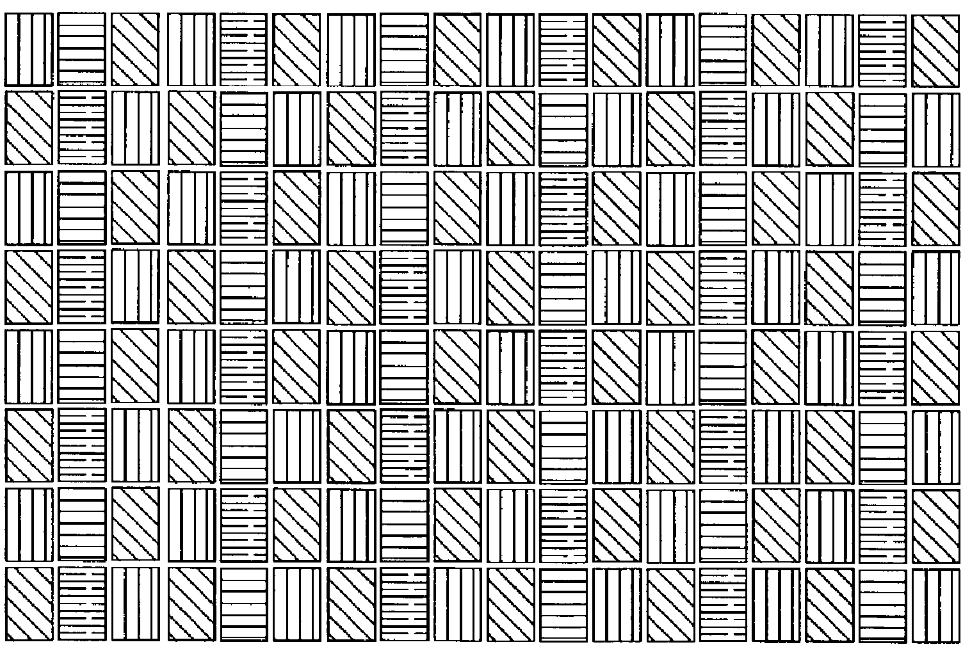


FIG. 6A

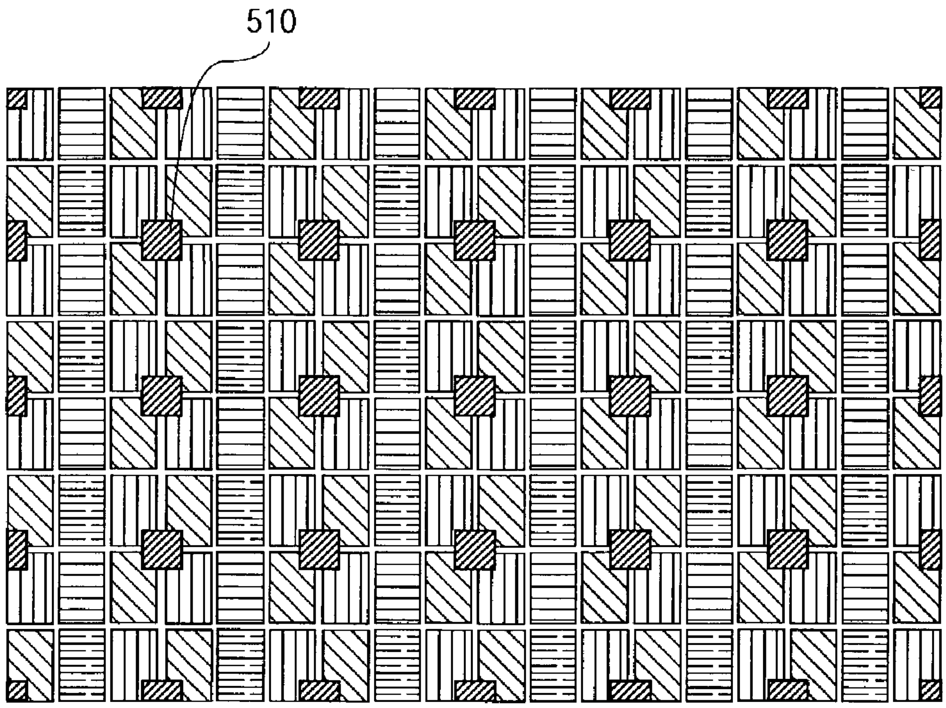



FIG. 5B

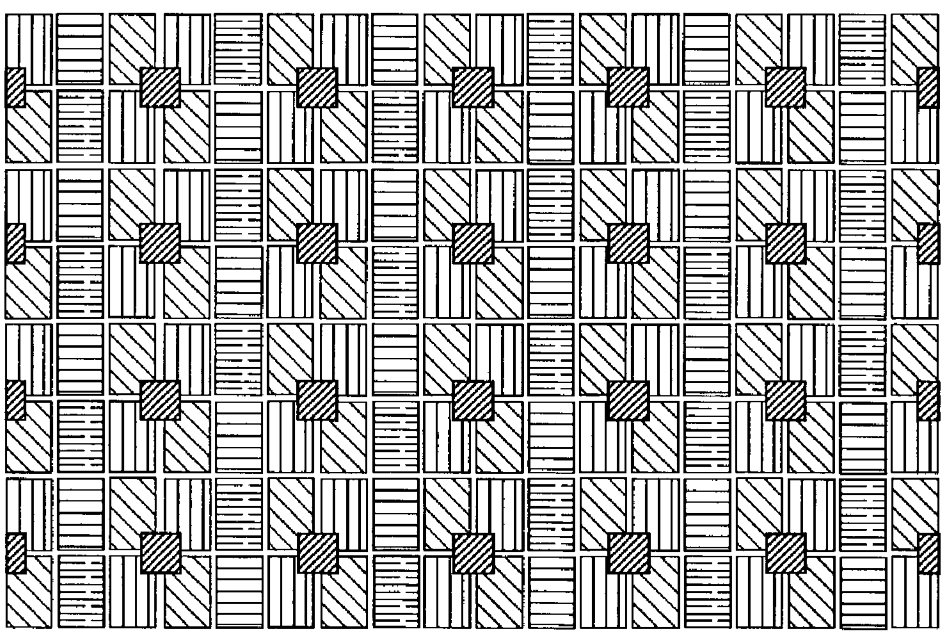


FIG. 6B

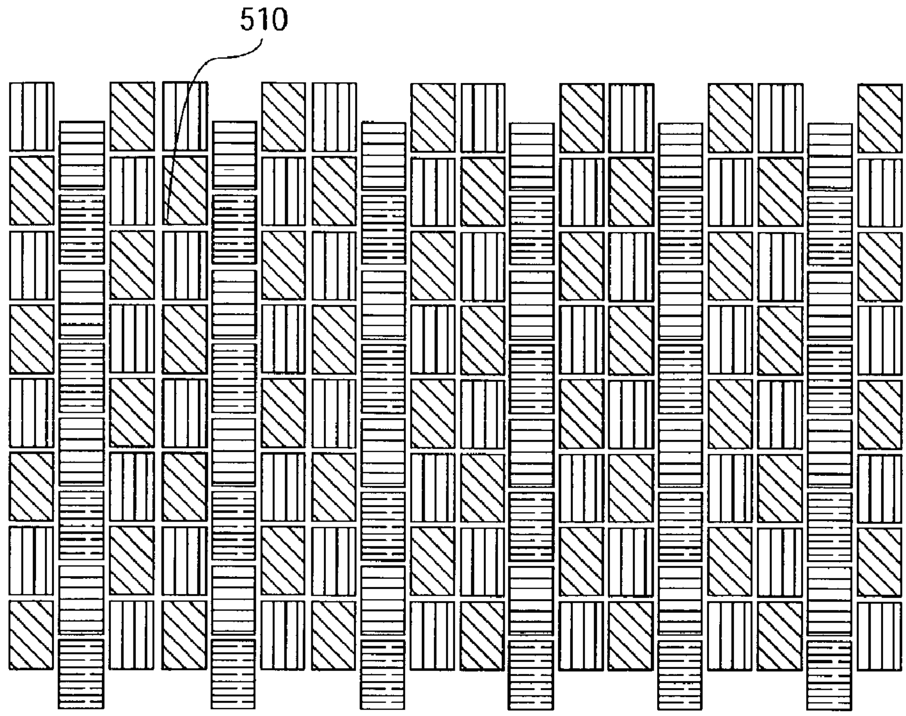



FIG. 7A

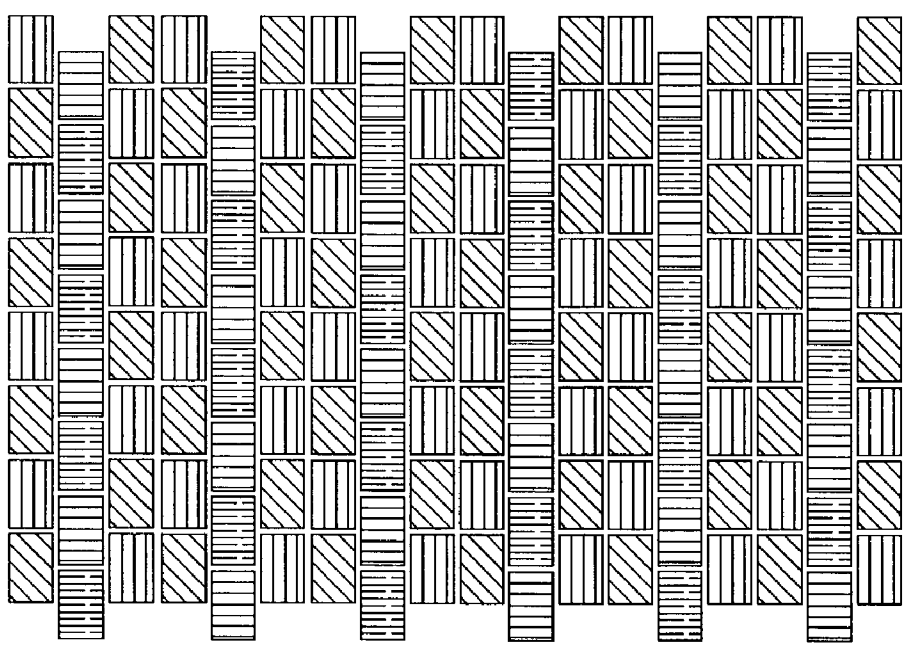


FIG. 8A

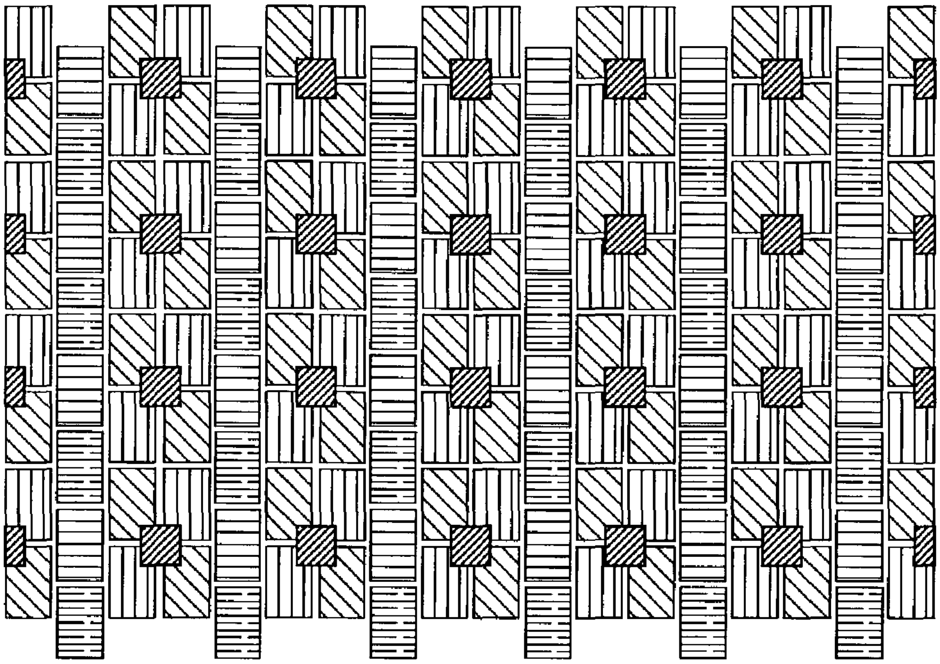


FIG. 7B

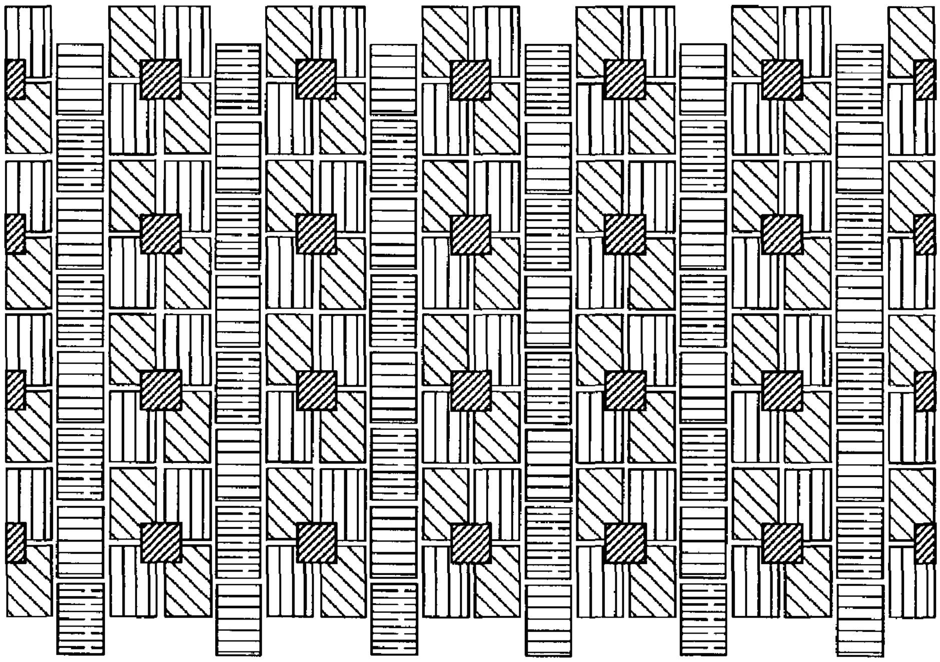


FIG. 8B

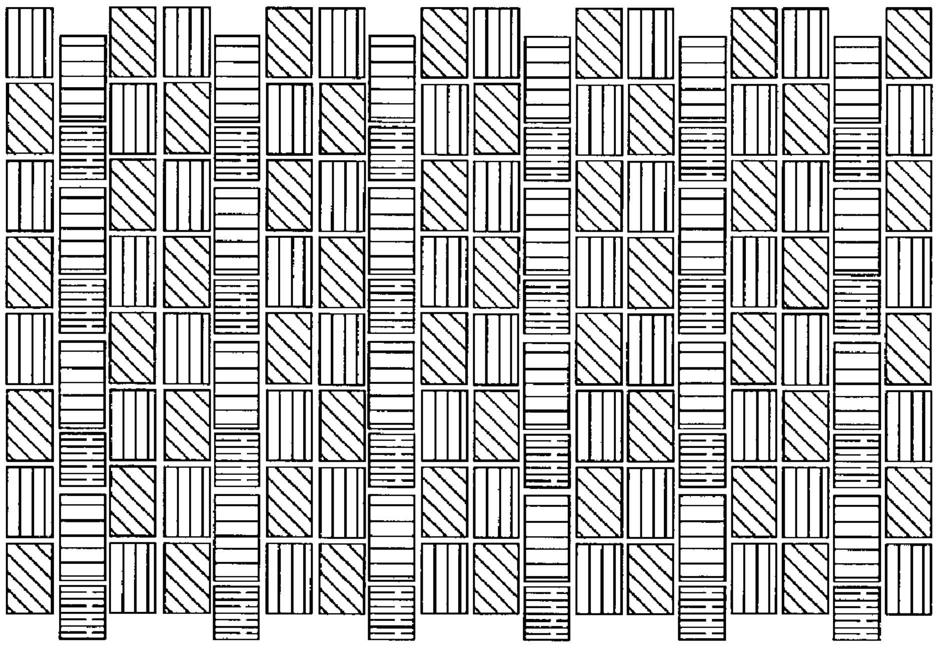


FIG. 9

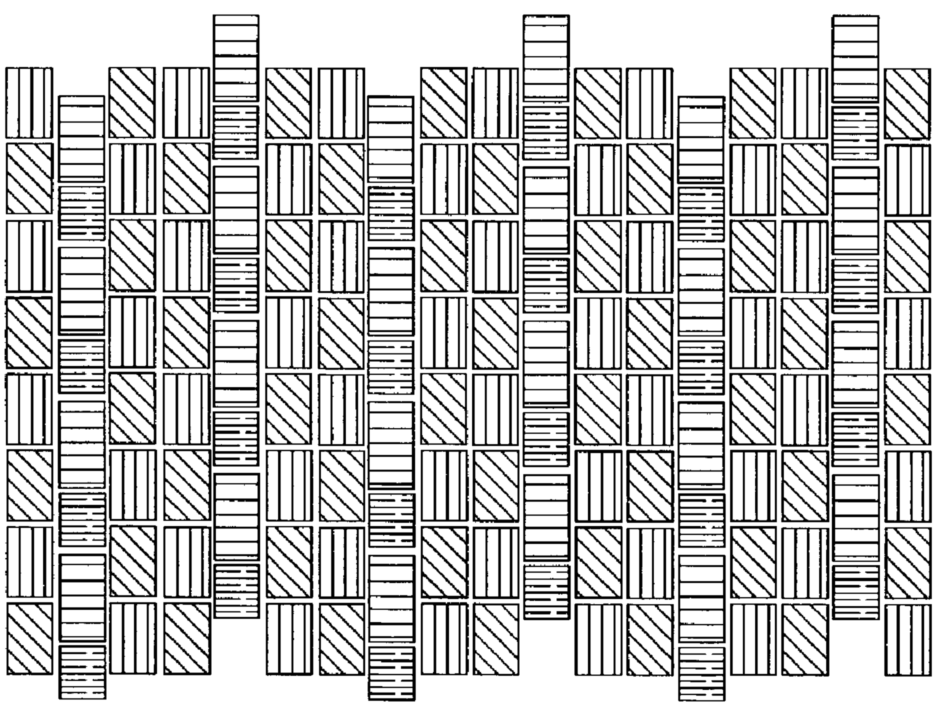


FIG. 10

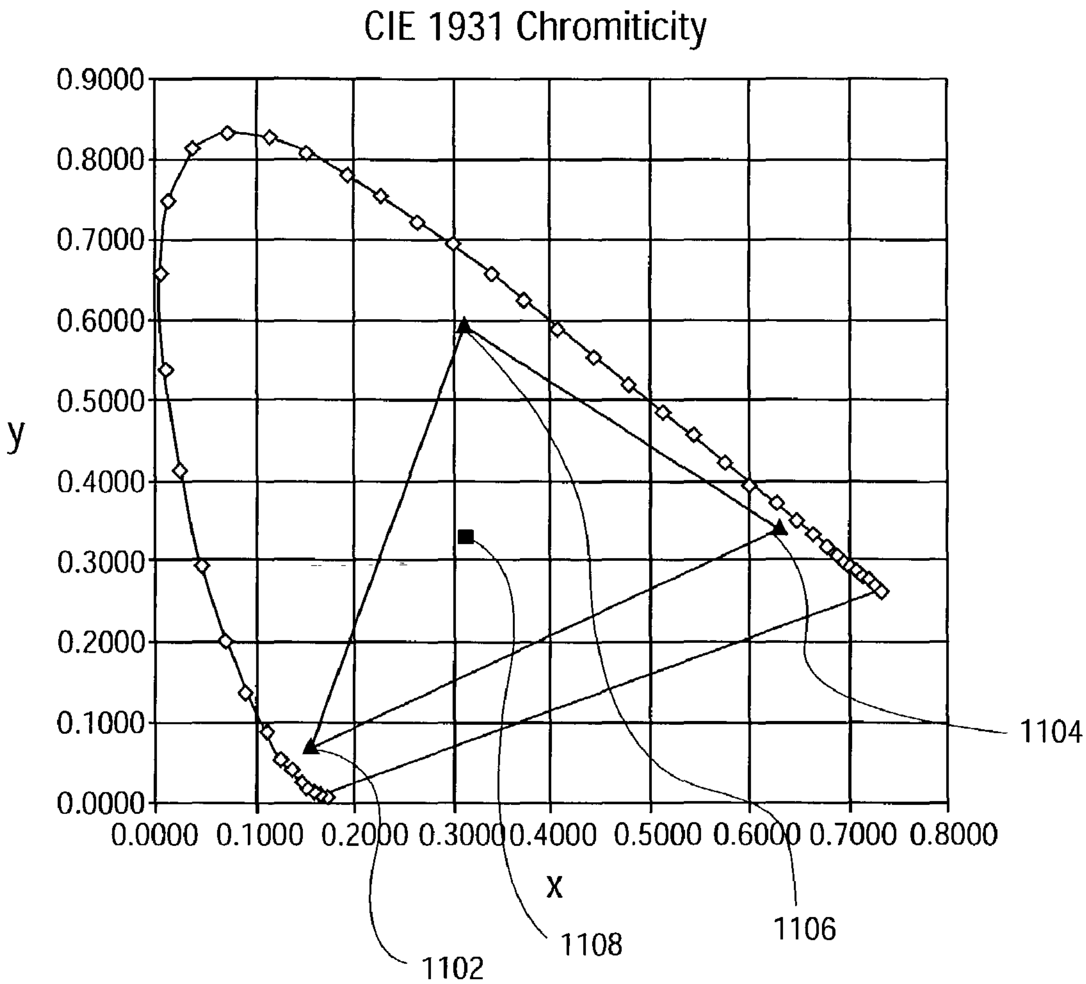
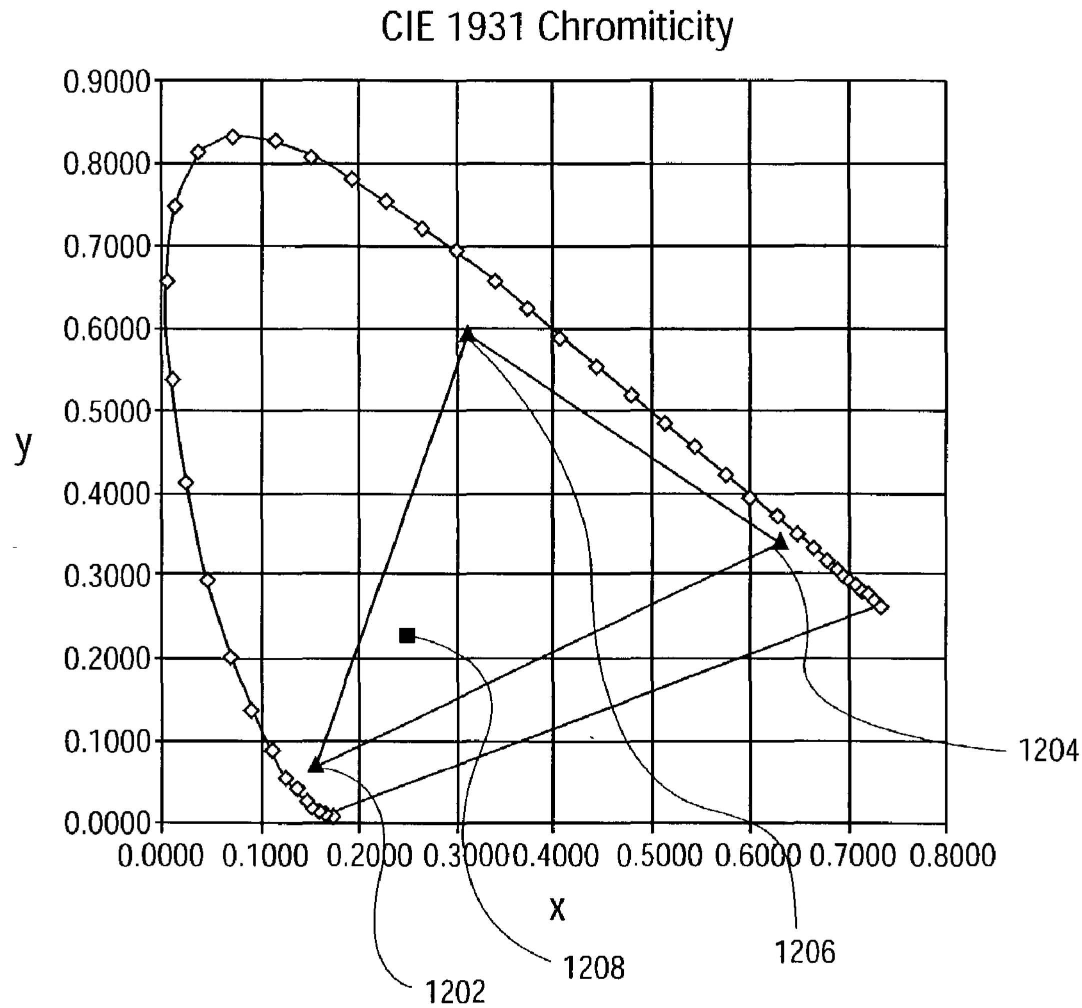



**FIG. 11**
**(PRIOR ART)**


CIE 1931 Chromiticity
0.9000
0.8000
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y
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x
1204
1206
1208
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FIG. 12

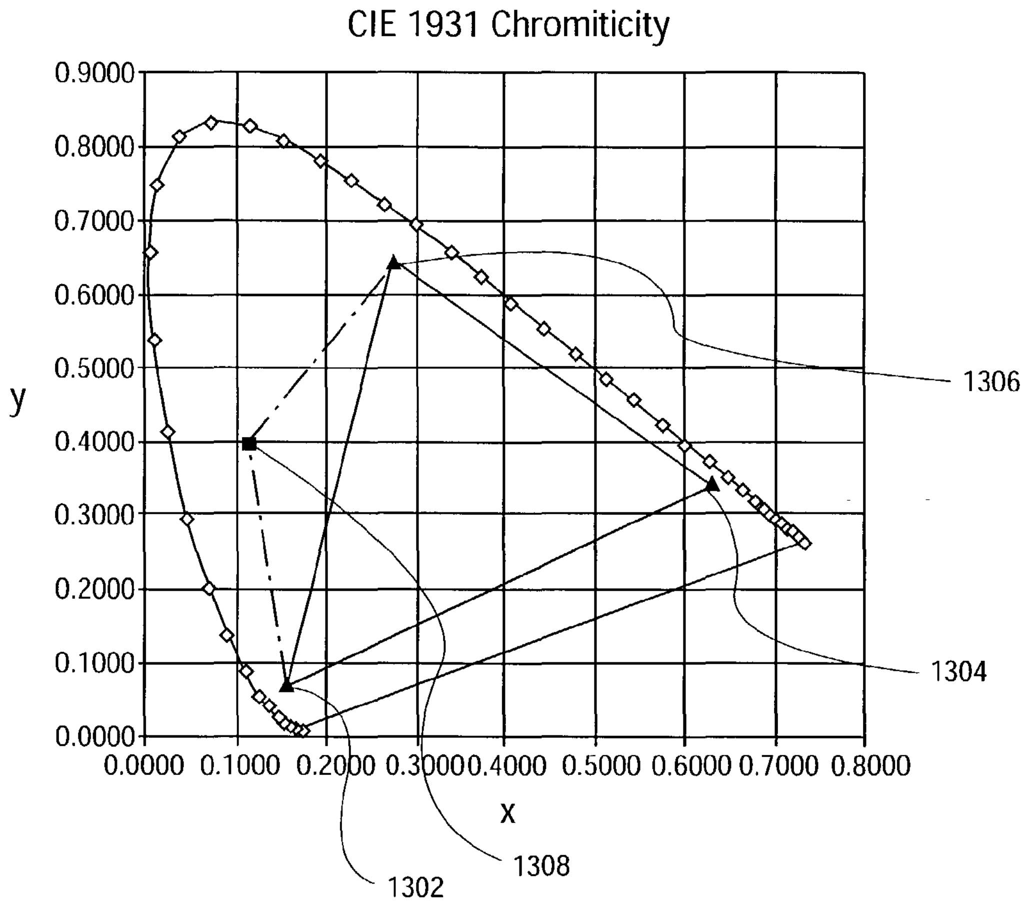
CIE 1931 Chromiticity
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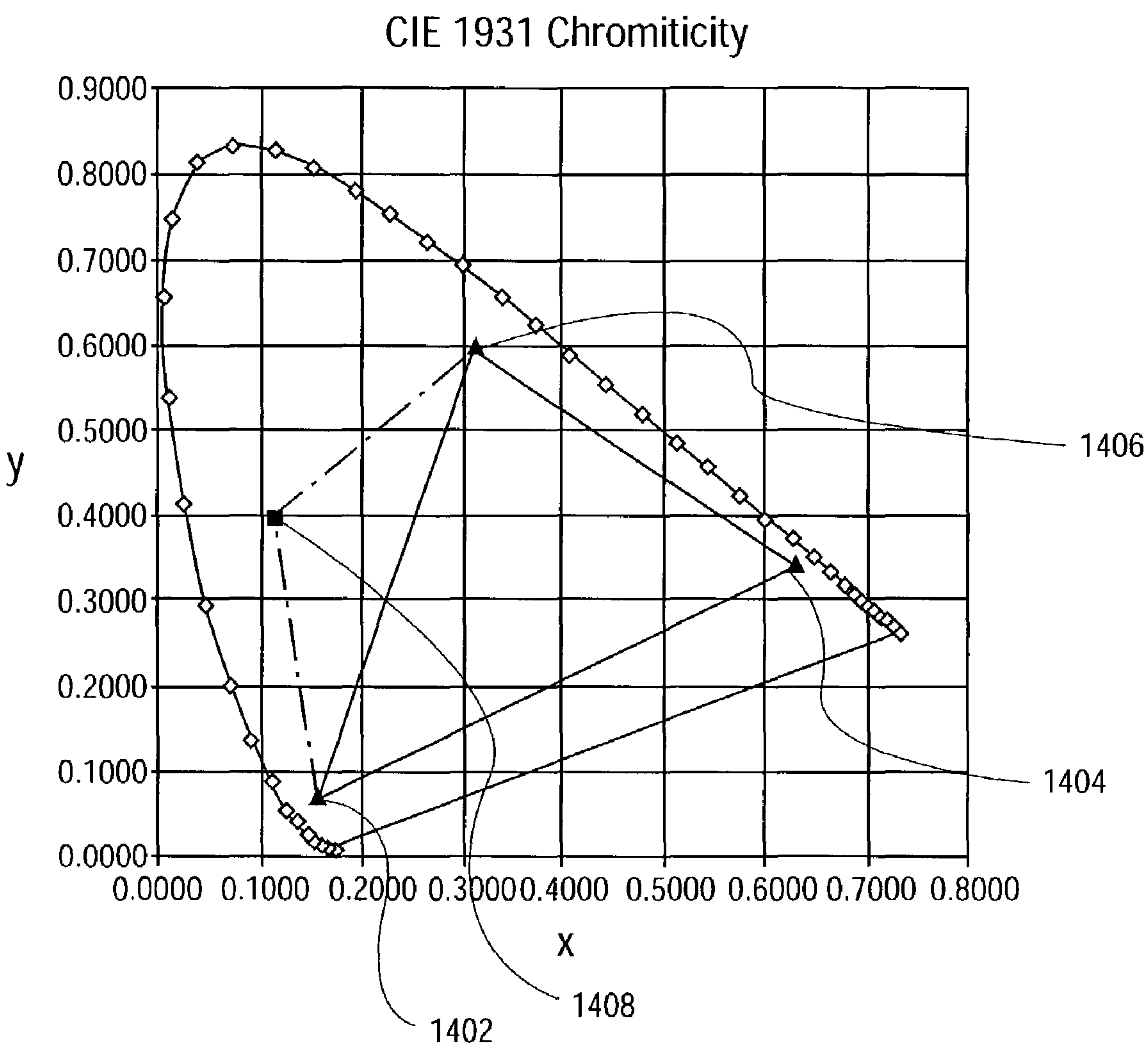
FIG. 13


CIE 1931 Chromiticity
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0.1000
0.0000
y
0.0000 0.1000 0.2000 0.3000 0.4000 0.5000 0.6000 0.7000 0.8000
x
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**FIG. 14**

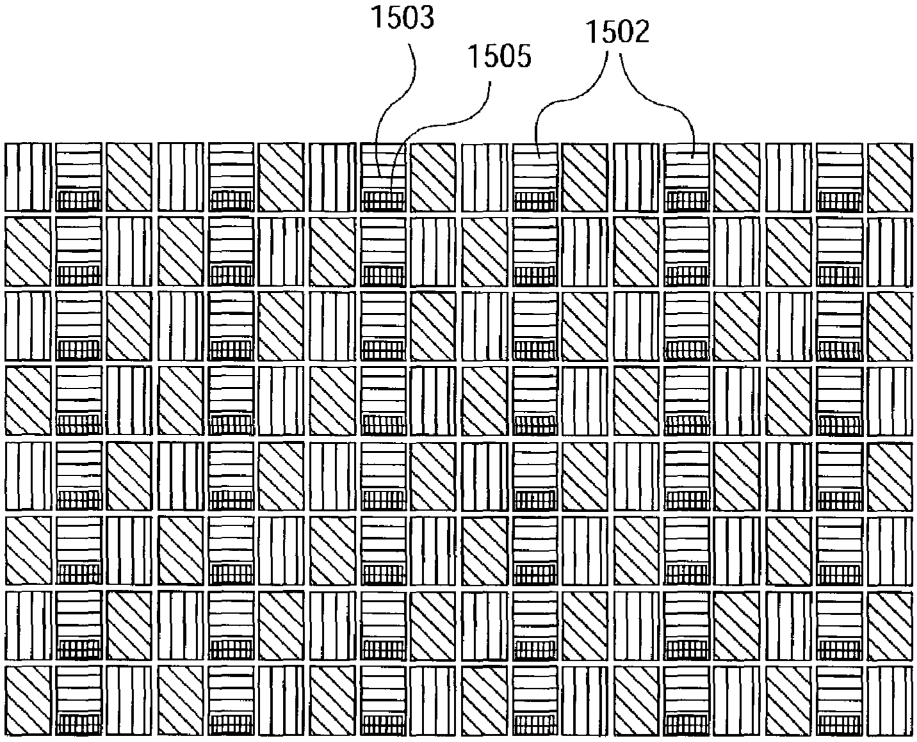


FIG. 15

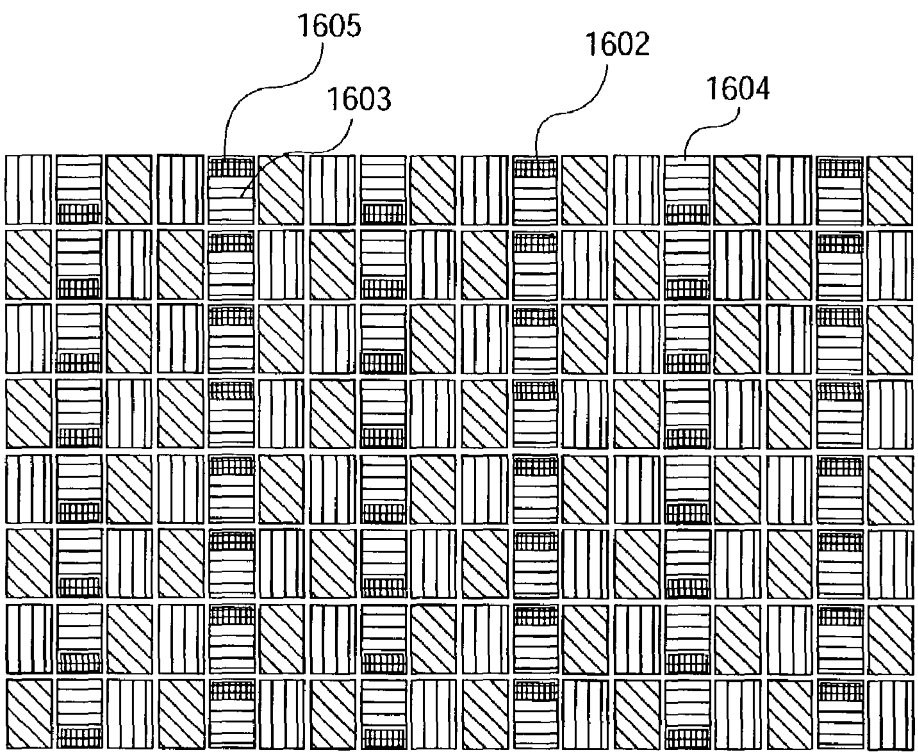


FIG. 16

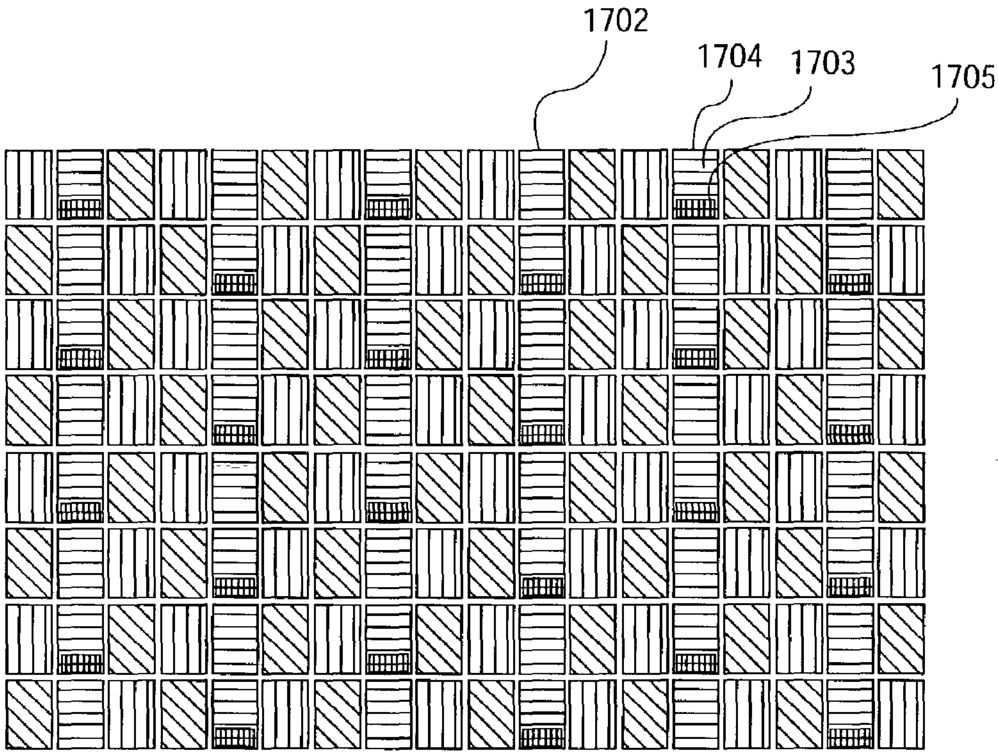


FIG. 17

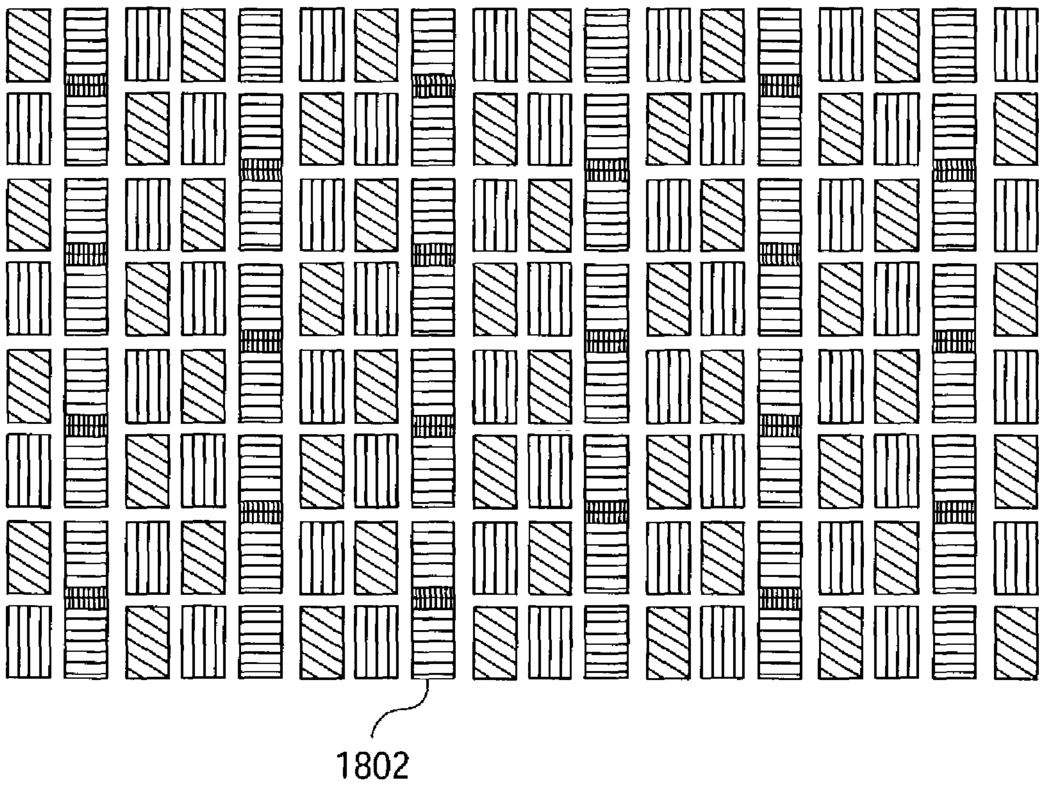


FIG. 18

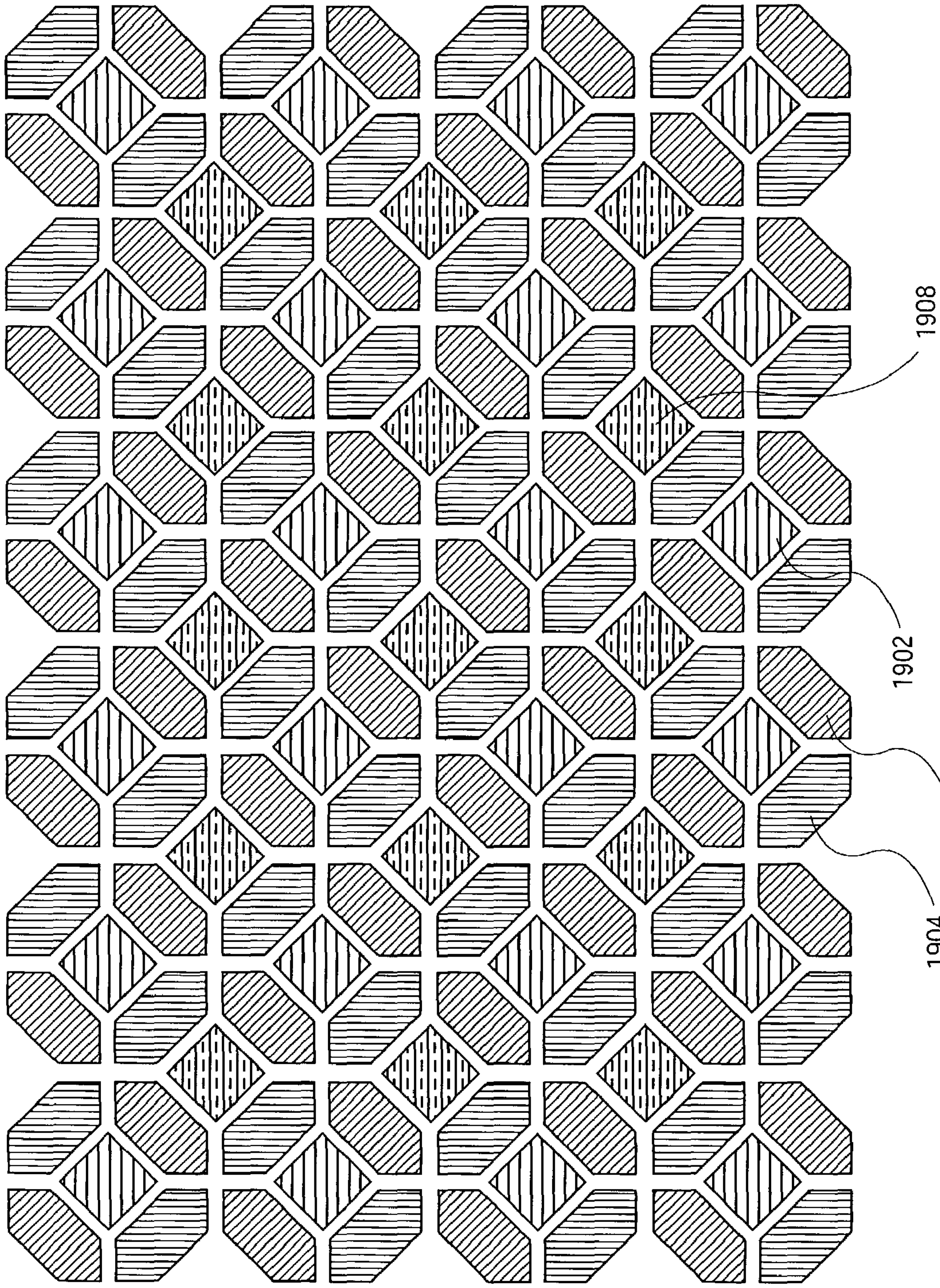


FIG. 19

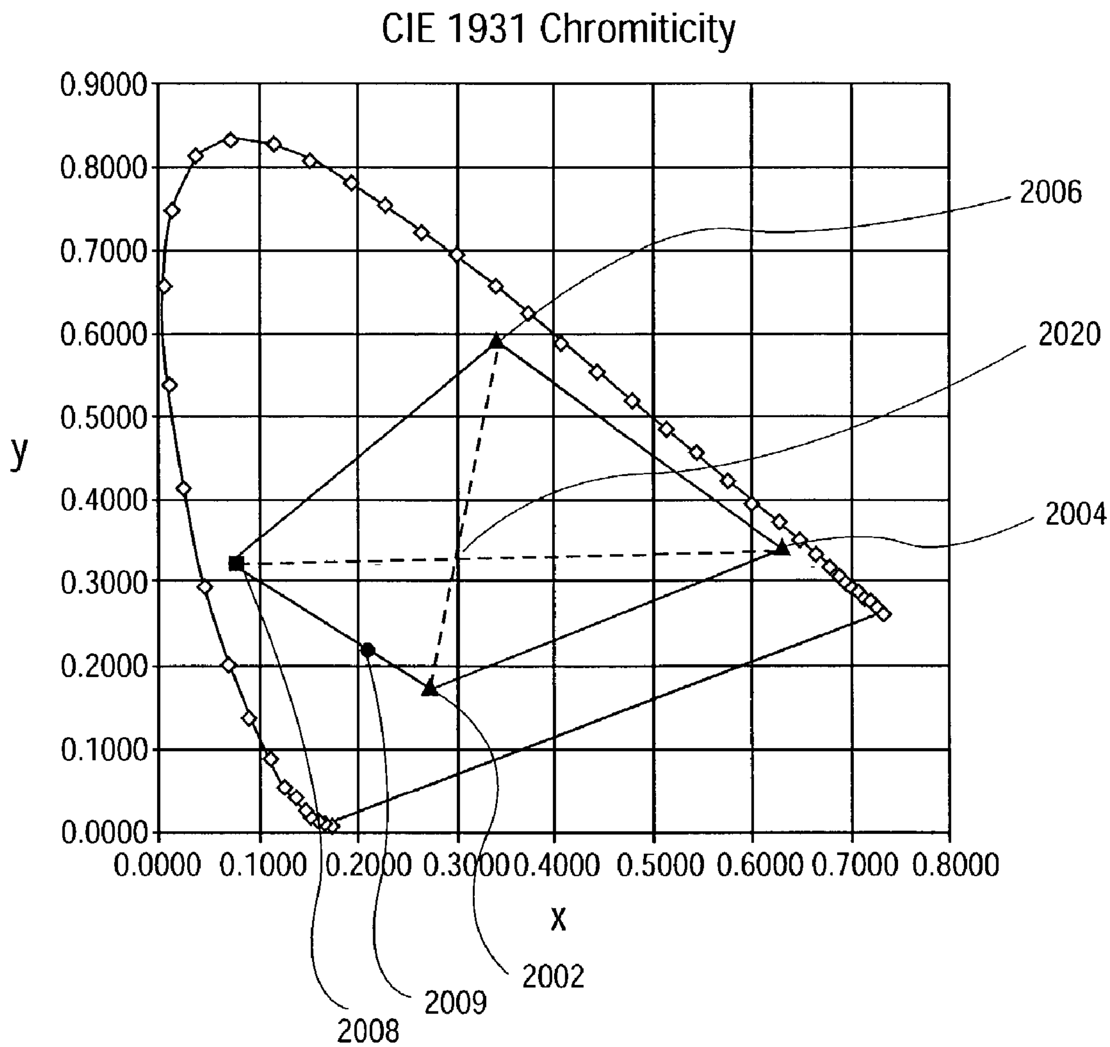
CIE 1931 Chromiticity
0.9000
0.8000
0.7000
0.6000
0.5000
0.4000
0.3000
0.2000
0.1000
0.0000
y
0.0000 0.1000 0.2000 0.3000 0.4000 0.5000 0.6000 0.7000 0.8000
x
2006
2020
2004
2002
2009
2008

FIG. 20

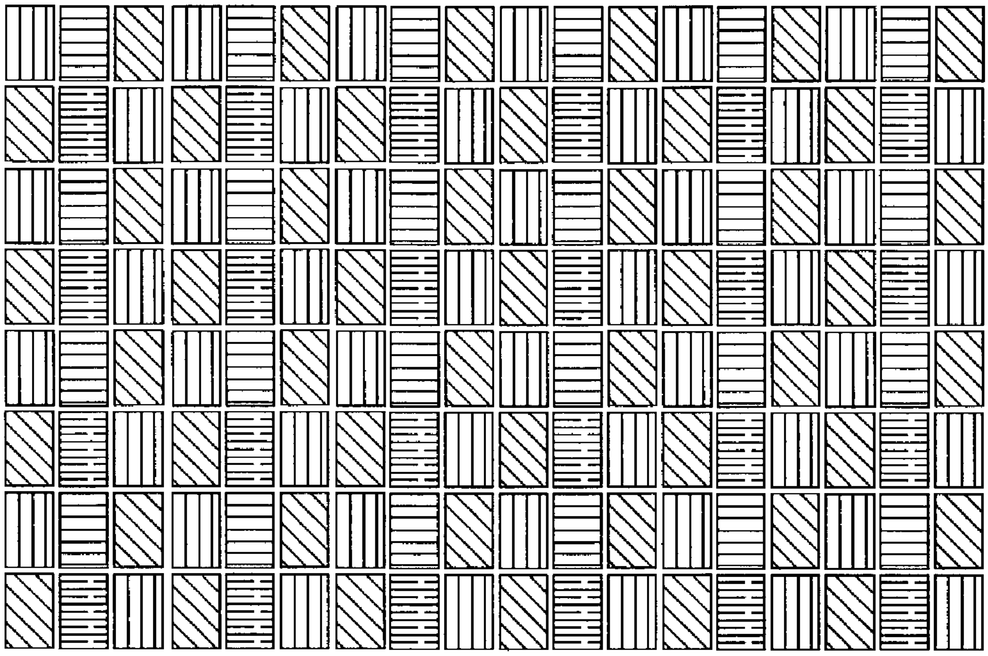

FIG. 21

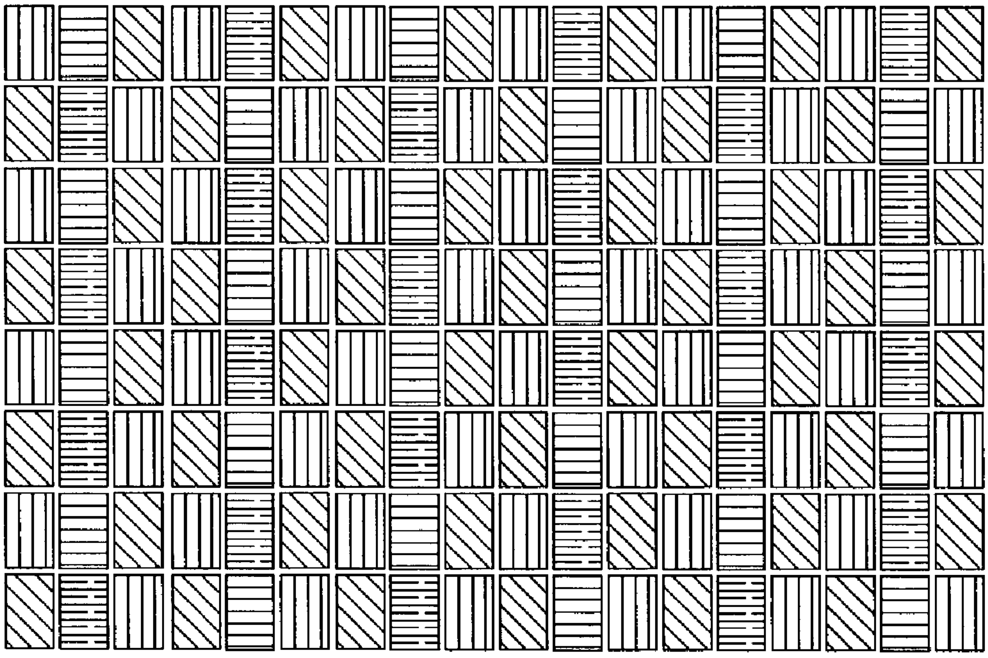

FIG. 22

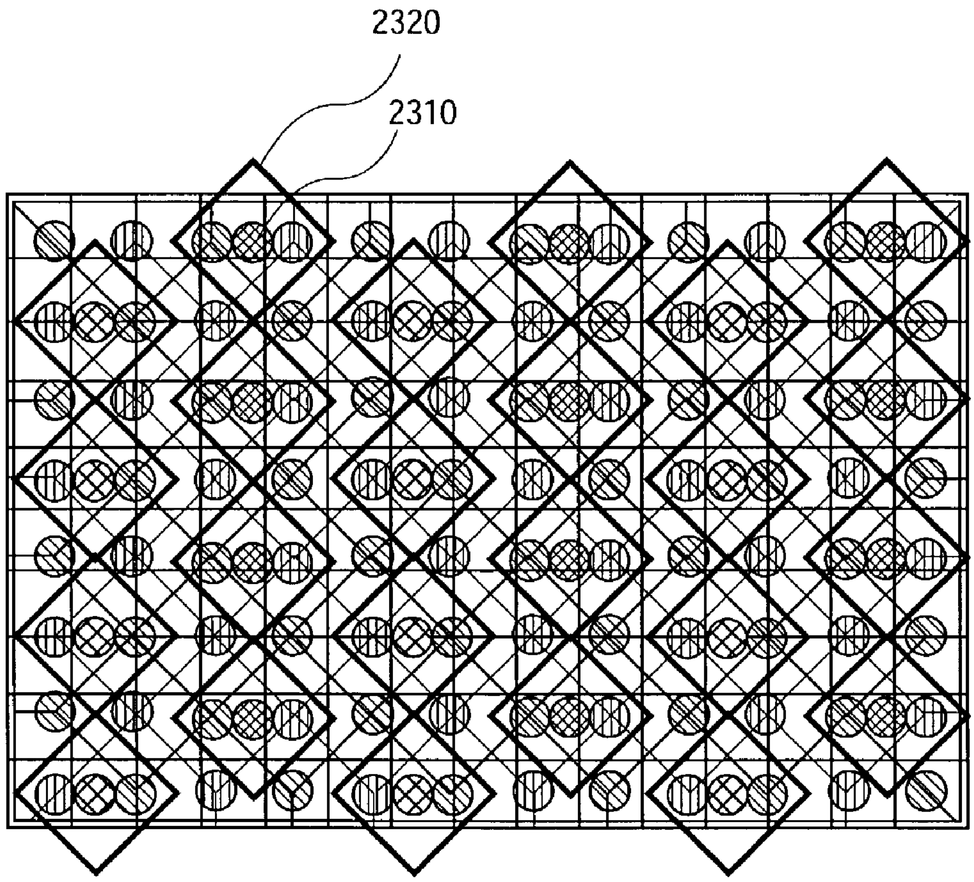


FIG. 23

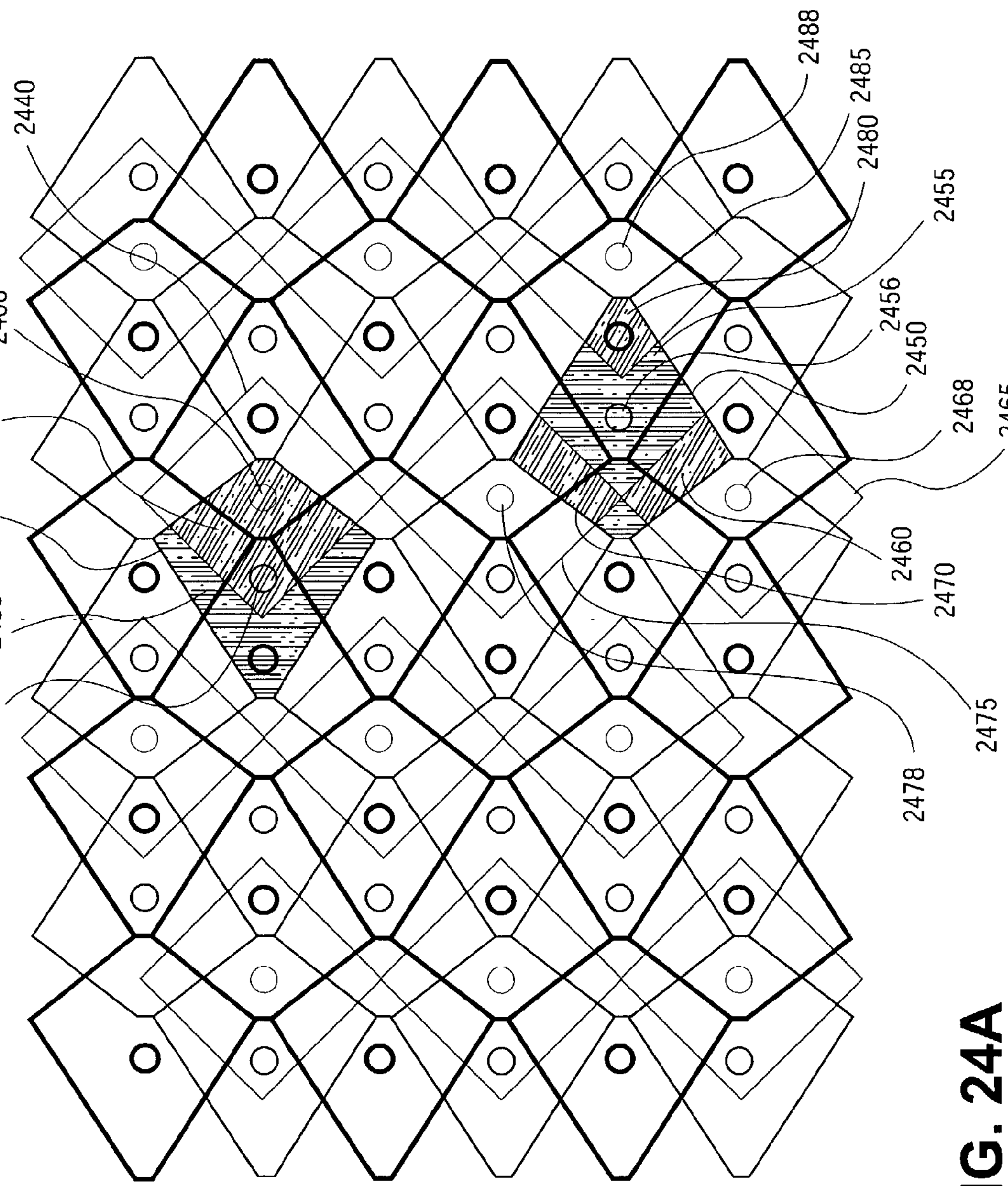
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FIG. 24A

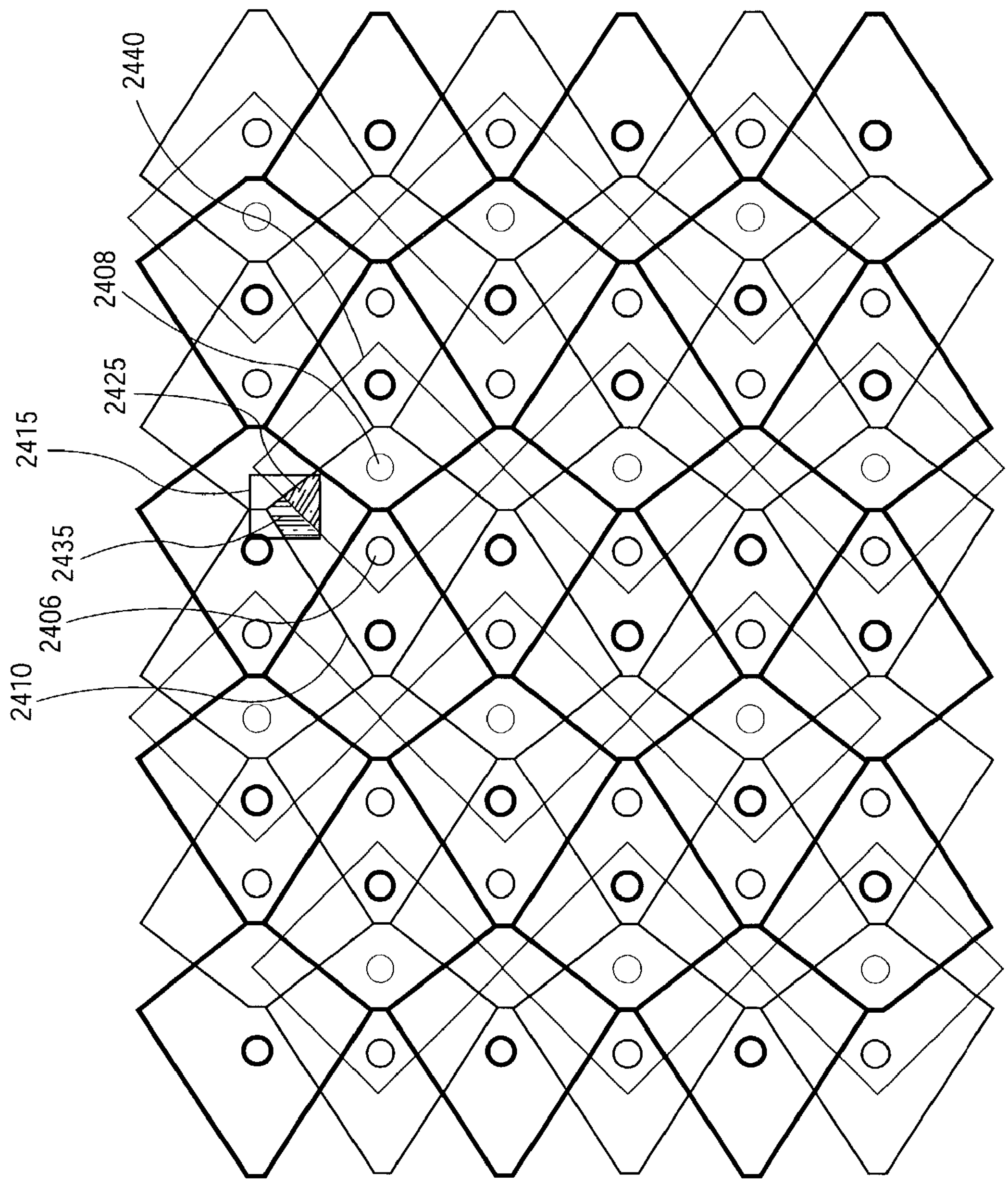


FIG. 24B

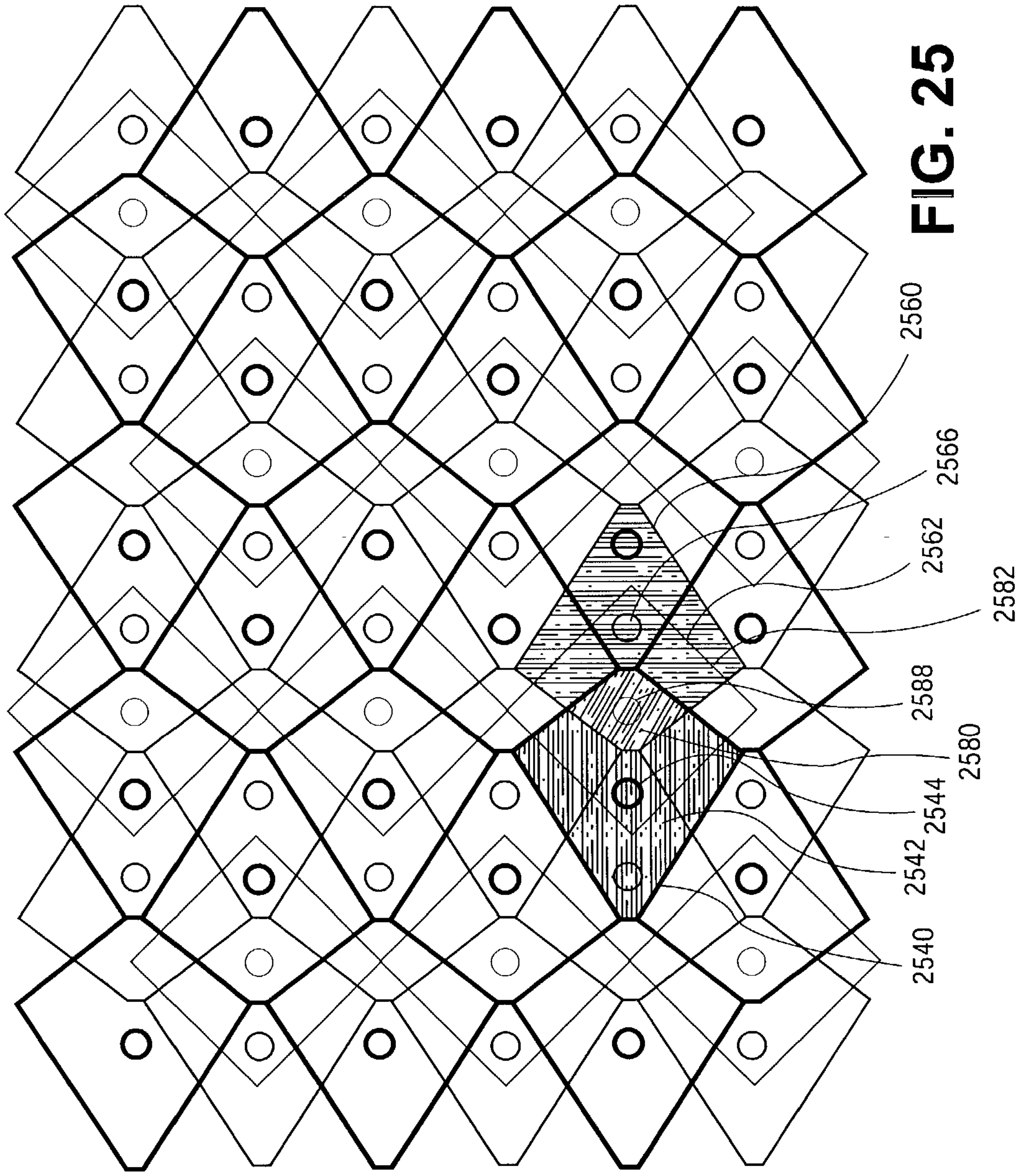


FIG. 25

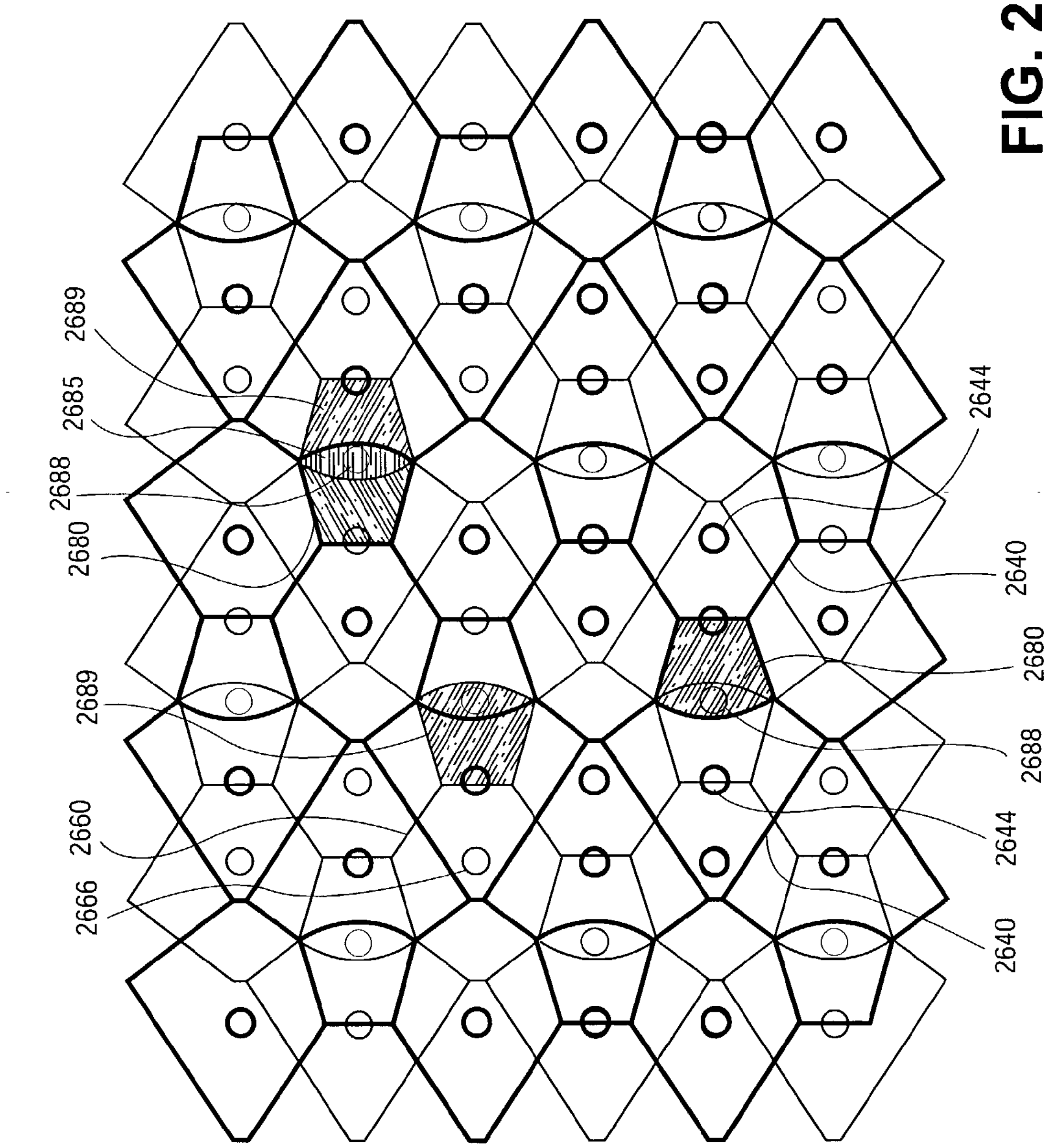
2689
2685
2688
2680
2689
2660
2666
2644
2640
2680
2688
2644
2640

FIG. 26

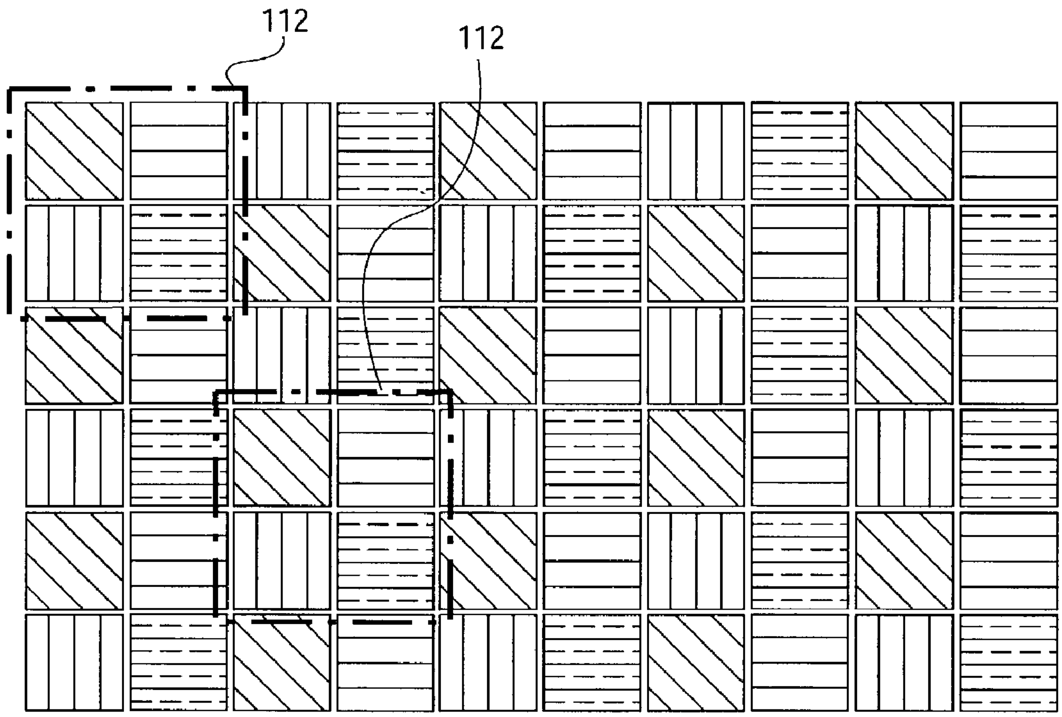


FIG. 27

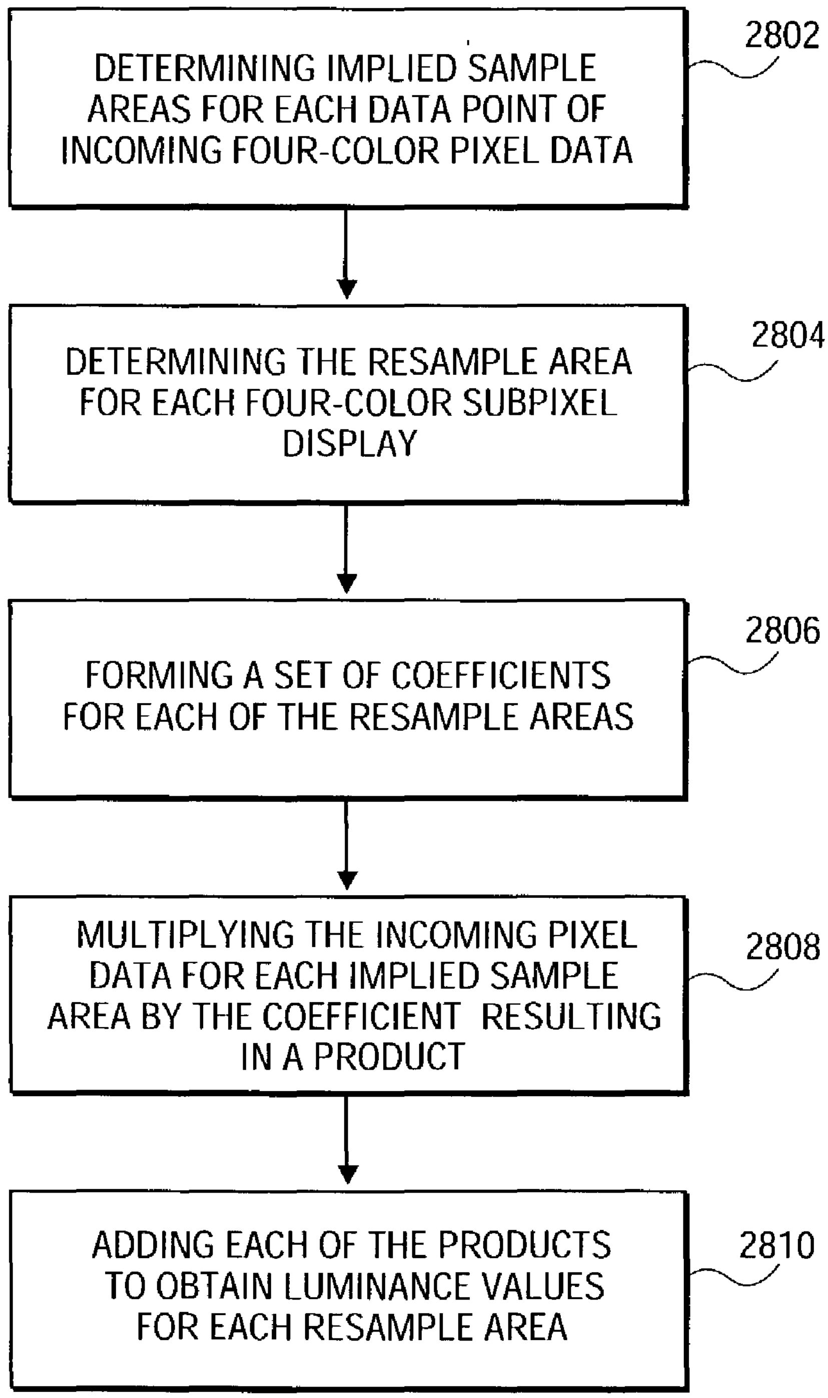
DETERMINING IMPLIED SAMPLE AREAS FOR EACH DATA POINT OF INCOMING FOUR-COLOR PIXEL DATA
2802
DETERMINING THE RESAMPLE AREA FOR EACH FOUR-COLOR SUBPIXEL DISPLAY
2804
FORMING A SET OF COEFFICIENTS FOR EACH OF THE RESAMPLE AREAS
2806
MULTIPLYING THE INCOMING PIXEL DATA FOR EACH IMPLIED SAMPLE AREA BY THE COEFFICIENT RESULTING IN A PRODUCT
2808
ADDING EACH OF THE PRODUCTS TO OBTAIN LUMINANCE VALUES FOR EACH RESAMPLE AREA
2810

FIG. 28

# FOUR COLOR ARRANGEMENTS OF EMITTERS FOR SUBPIXEL RENDERING

## RELATED APPLICATIONS

**[0001]** This application is related to U.S. patent application Ser. No. 10/051,612 ("the '612 application"), entitled "CONVERSION OF A SUB-PIXEL FORMAT DATA TO ANOTHER SUB-PIXEL DATA FORMAT," filed on Jan. 16, 2002, which is hereby expressly incorporated herein by reference. This application is also related to U.S. patent application Ser. No. 10/150,355 ("the '355 application"), entitled "METHODS AND SYSTEMS FOR SUB-PIXEL RENDERING WITH GAMMA ADJUSTMENT," filed on May 17, 2002, which is hereby expressly incorporated herein by reference.

## BACKGROUND

**[0002]** Most conventional subpixelated displays utilize three emitter colors, providing a color gamut that includes the inside of a triangle when charted on the 1931 CIE Color Chart, an example of which is shown in **FIG. 11**. These colors are typically, substantially, red **1104**, green **1106**, and blue **1102**. The luminance of these color emitters are typically unequal. For several reasons, some displays are constructed with a fourth color emitter. Prior art four color displays usually use white as the fourth color. This is typically done to increase the brightness of the display, as the colors are usually created using a color filter. The white is created by removing a color filter; and the light of the backlight which, being white already, is allowed to pass to the observer unobstructed. The four colors collectively are grouped into a pixel that may show any color within the triangle defined by the saturated colors, with the added ability to show lower saturation colors at a higher brightness by the addition of the appropriate amount of white.

**[0003]** For displays that are to be driven using a technique known in the art as Subpixel Rendering (SPR), an example of which is disclosed the '355 application, the choice of a non-filtered white subpixel creates a serious problem. Subpixel rendering depends on the ability to shift the apparent center of luminance by varying the brightness of the subpixels. This may work well when each of the colors has the same perceptual brightness. As was disclosed in copending and commonly assigned U.S. patent application Ser. No. 09/916,232 entitled "Arrangement of Color Pixels for Full Color Imaging Devices with Simplified Addressing" to Elliott and herein incorporated by reference, the blue subpixels are perceived as substantially darker than the red and green, thus do not significantly contribute to the perception of increased resolution with subpixel rendering, leaving the task to the red and green subpixels. With the addition of an unfiltered white, the white subpixel, being significantly brighter than both the red and green subpixels, the red and green lose much of their effectiveness in subpixel rendering.

**[0004]** In **FIG. 1, a** prior art arrangement of four colors, sometimes called the Quad Arrangement, similar to the earlier Bayer pattern, but with one of the green subpixels replaced with a white, the repeat cell **112** consists of four subpixels, each of a different color, often red **104**, green **106**, blue **102**, and white **108**. The display is typically addressed using "whole pixel rendering" wherein the repeat cell is defined as the location of luminance information, without regard to the locations of the colored subpixels within. The colors typically have chromaticity coordinates such as those shown in **FIG. 11**; red **1104**, green **1106**, blue **1102**, and white **1108**. The white subpixel of this arrangement may typically be formed by removing the filter from the light path of a monochromatic LCD modulation pixel. This unfiltered white thus has significantly higher luminance than the other subpixels, which is typically the goal of the display designer.

**[0005]** When subpixel rendering is attempted on a four color system that has an unfiltered white, the subpixel rendering performance is substantially impaired due to the significantly higher luminance of the white subpixel. In an ideal display (of three or more color subpixel arrangement), the luminance of each of the subpixels would be equal, such that for low saturation image rendering, each subpixel has the same luminance weight. However, the human eye does not see each wavelength of light as equally bright. To the human eye, the ends of the spectrum are seen as darker than the middle. That is to say that a given energy intensity of a green wavelength is perceived to be brighter than that same energy intensity of either red or blue. Further, due to the fact that the short wavelength sensitive cones of the human eye, the "S-cones", those giving rise to the sensation of 'blue', do not feed the Human Vision System's luminance channel. As a result, blue colors appear even darker.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0006]** The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate the invention and, together with the description, serve to explain the principles of the invention. In the figures,

**[0007]** **FIG. 1** shows a prior art four color arrangement for a display using a repeat cell consisting of four subpixels.

**[0008]** **FIG. 2***a* shows a portion of **FIG. 1**, six subpixels as a group.

**[0009]** **FIG. 2***b* shows another four-color six subpixel arrangement made in accordance with the principles of the present invention.

**[0010]** **FIG. 3** shows a novel arrangement of four colors utilizing the arrangement of **FIG. 2***b* as the repeat cell.

**[0011]** **FIG. 4** shows another novel arrangement of four colors.

**[0012]** **FIG. 5A** shows the arrangement of **FIG. 3** with rectangular, non-square, subpixels.

**[0013]** **FIG. 5B** shows the arrangement of **FIG. 5A** with an embodiment of thin film transistors and/or associated storage capacitors comprising thereof.

**[0014]** **FIG. 6A** shows the arrangement of **FIG. 4** with rectangular, non-square, subpixels.

**[0015]** **FIG. 6B** shows the arrangement of **FIG. 6A** with an embodiment of thin film transistors comprising thereof.

**[0016]** **FIG. 7A** shows another novel arrangement of four colors.

**[0017]** **FIG. 7B** shows the arrangement of **FIG. 7A** with an embodiment of thin film transistors comprising thereof.

**[0018]** **FIG. 8A** shows another novel arrangement of four colors.

[0019] **FIG. 8B** shows the arrangement of **FIG. 8A** with an embodiment of thin film transistors comprising thereof.

[0020] **FIG. 9** shows the arrangement of **FIG. 7** with a subset of the pixels smaller than the others, and a subset larger than the others.

[0021] **FIG. 10** shows the arrangement of **FIG. 8** with a subset of the pixels smaller than the others, and a subset larger than the others.

[0022] **FIG. 11** is a chart showing the chromaticity coordinates of the emitters of a prior art four color display.

[0023] **FIG. 12** is a chart showing the chromaticity coordinates of the emitter of a novel four color display.

[0024] **FIG. 13** is a chart showing the chromaticity coordinates of the emitter of another novel four color display.

[0025] **FIG. 14** is a chart showing the chromaticity coordinates of the emitter of another novel four color display.

[0026] **FIG. 15** shows a novel arrangement of colors in which some of the subpixels have two colored regions.

[0027] **FIG. 16** shows another novel arrangement of colors in which some of the subpixels have two colored regions.

[0028] **FIG. 17** shows another novel arrangement of colors in which some of the subpixels have two colored regions.

[0029] **FIG. 18** shows yet another arrangement of colors in which some of the subpixels have two colored regions.

[0030] **FIG. 19** shows a novel arrangement of four colors consisting of a repeat cell of six subpixels.

[0031] **FIG. 20** is a chart showing the chromaticity coordinates of the emitters of a novel four color display.

[0032] **FIG. 21** shows a novel arrangement of four colors emitters for a display

[0033] **FIG. 22** shows another novel arrangement of four colors.

[0034] **FIG. 23** shows the reconstruction points and a novel set of resample areas for the arrangement of **FIG. 22** overlaid a grid of implied sample areas of an input image data set in which one of the minority color plane reconstruction points is not shown for clarity.

[0035] **FIGS. 24A and 24B** show the reconstruction points and another novel set of resample areas for the arrangement of **FIG. 22** in which one of the minority color plane resample areas is not shown for clarity.

[0036] **FIG. 25** shows the reconstruction points and another novel set of resample areas for the arrangement of **FIG. 22** in which one of the minority color plane resample areas is not shown for clarity.

[0037] **FIG. 26** shows the reconstruction points and yet another novel set of resample areas for the arrangement of **FIG. 22** in which one of the minority color plane resample areas is not shown for clarity.

[0038] **FIG. 27** shows a novel arrangement of four color elements.

[0039] **FIG. 28** is a flowchart of one embodiment for achieving subpixel rendering on a four-color subpixel arrangement.

## DETAILED DESCRIPTION

[0040] Reference will now be made in detail to implementations and embodiments of the present invention as illustrated in the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings and the following description to refer to the same or like parts.

### A. Subpixel Arrangements and Architectures

[0041] Now, there will be described a number of novel embodiments of three and four color subpixel arrangements.

[0042] To address a first concern mentioned above, the red and green subpixels may be adjusted to be of equal luminance by several techniques. One embodiment comprises keeping the same chromaticity points but increase the transmission of the lower luminance filter. There are several ways to accomplish this result: (1) make the red filter physically thinner than the green filter; (2) change the red pigment to either (a) reduce the amount of pigment in the filter; or (b) apply a different pigment comprising the same chromaticity but allows for greater transmissivity of light; or (3) apply a red filter that maintains substantially the same center of chromaticity but broadens the range of frequencies on either side of the center point.

[0043] Another embodiment would keep the same chromaticity point but decrease the transmission of the higher luminance filter. As above, there are several ways to accomplish this result: (1) make the green filter physically thicker than the red filter; (2) change the green pigment to either (a) increase the amount of pigment; or (b) apply a different pigment comprising the same chromaticity but allows for a lesser transmissivity of light; or (3) apply a green filter that maintains substantially the same center of chromaticity but narrows the range of frequencies passed through on either side of the center point.

[0044] Another embodiment may be to increase the energy from the backlight of the transmissive panel (e.g. LCD) in the pass band of the lower luminance color filter relative to the higher luminance color filter pass band. For example, in a florescent backlight, the relative ratio of longer wavelength emitter phosphors to the shorter wavelength could be changed to favor the longer wavelength. In a multicolor LED backlight, the current or the pulse width modulated duty cycle of the longer wavelength LED (or groups of such LEDs) could be increased. These changes will cause a shift in the white point of the display, unless compensated for, as will be described further below.

[0045] Yet another embodiment narrows the pass band of the green subpixel such that the overall energy is reduced, while simultaneously shifting the chromaticity of the filter of the green subpixel. More specifically, it is possible to attenuate more of the longer wavelengths of the “green” band; while holding the red and the blue bands substantially unchanged. This may have two benefits. First, matching the luminance may allow for better subpixel rendering performance. Secondly, the reduced band pass increases the saturation and color gamut by pushing the green further from the white point. By being further from the white point, the white point of the display, with all of the subpixels turned on to maximum brightness, is allowed to remain at the desired point. The overall brightness of the display, for a given backlight will be reduced; but may be compensated for by increasing the backlight brightness.

[0046] Using a green subpixel that has been adjusted for lower luminance will shift the all-subpixels-on color point towards the magenta, unless compensated for in some manner. One such compensation technique includes a fourth color emitting subpixel that has substantial amounts of green light. For example, the arrangements in **FIGS. 1, 3, 4, 5, 6, 7, 8, 9**, and **10**, may include a fourth color emitter subpixel that has significant green (medium wavelength light) emission such as cyan, greenish-blue, greenish-grey, and the like.

[0047] In **FIG. 1**, this may be one of the four subpixels in the repeat cell group **112**, such as the lower right subpixel **108**. In this example, the upper left subpixel **106** may be the luminance adjusted green. The color of the lower right subpixel **108** may also be chosen to be the same as that of the upper left subpixel **1106**, thus making this arrangement a luminance adjusted, improved Bayer Pattern of three colors.

[0048] **FIG. 27** shows another embodiment based upon the Quad arrangement of **FIG. 1**, in which every other column of repeat cell **112** is shifted by one subpixel. Such an arrangement scatters the Fourier signal energy of any luminance mismatch between subpixels into additional directions.

[0049] Another embodiment using the Quad arrangement of **FIG. 1** might be to chose the color points shown in **FIG. 20**, the four colors being red **2004**, green, **2006**, cyan **2008**, and magenta **2002**. It will be appreciated that there are a number of combinations for the choice of positions for each of the colors. All such combinations of which are to be considered to be in the scope of the present invention. One advantage of these arrangements of color points **2004, 2006, 2008**, and **2002** is to improve subpixel rendering performance in which every color has substantial luminance such that each subpixel of a display using this arrangement is the center of a logical pixel.

[0050] In yet another embodiment, the Quad arrangement **112** of **FIG. 1** may be modified to improve subpixel rendering performance. To envision this improved arrangement, a larger group of subpixels **114** is removed from the context of the rest of the array, as in **FIG. 2***a*. As shown, two green subpixels **206** are in the same upper row, while the two red **204** subpixels are in a same lower row. To enhance the subpixel rendering process, an improved layout may have one of each color (red and green) in every column and row, save for the column that includes the blue—to form a red and green checkerboard. Thus, the red **204** and green **206** subpixels are reversed in one of the columns, for example, the left, to form the arrangement of **FIG. 2***b*. It will be appreciated that interchanging the right hand column would produce the same result. Taking the arrangement of **FIG. 2***b*, and using it as the repeat cell **320** for a larger array, the arrangement of color subpixels is obtained as shown in **FIG. 3**.

[0051] Examining **FIG. 3**, every row contains both red **304** and green **306** subpixels in an alternating manner. Two out of three columns contains both red **304** and green **306** subpixels, alternating. The alternation of the red **304** and green **306** subpixels in both columns and rows forms an approximate red and green subpixel checkerboard. One out of three columns contains two other colors that are in the numerical minority. These two other colors may be blue **302** and a suitable fourth color **308**. In **FIG. 3**, the number of red subpixels **304** and the number of green subpixels **306**, per repeat cell is two each, while there is only one blue and one fourth color. As previously mentioned, it may be a desired property of a subpixelated color display that, when all of the subpixels are turned on to their brightest point, the panel appears white. In addition, a desired property may have all of the subpixels of the same luminance. Given these properties, a number of color combinations are possible as described herein.

[0052] It will be appreciated, though, that suitable subpixel rendering could occur on a four-color arrangement whereby, when all subpixels in a group are fully "on", the color is off the white point. It may be desirable to compensate and adjust the relative energy of each of the subpixels to display a pleasing white. This could be accomplished by electronically, or by software (machine readable medium), reducing the output of the dominant color or colors by an appropriate scaling factor.

[0053] As for suitable color combinations, the same red **1104**, blue **1102**, and green **1106** can be used. In prior art panels, the fourth color was white **1108**, as shown in **FIG. 11**. However, since there is only one blue subpixel **302** compared to two red subpixels **306** and two green subpixels **304** per repeat cell **320**, the choice of white, adding equal parts red, green, and blue, may cause the panel to have a yellowish cast when all of the pixels are turned on. Further, in prior display systems, the white subpixel was usually formed by removing the filter over the subpixel, allowing all of the light through the subpixel, creating a very bright subpixel. This was possibly good for increasing the brightness of the display, but it interferes with the operation of subpixel rendering and may create a very "dotted" or "grainy" appearance. One improved embodiment of this arrangement is to use a neutral grey filter—keeping the same white color point, but reducing the luminance to be approximately that of the red **1104** and/or green **1106**, or somewhere between them. Another improved embodiment would be to increase the amount of blue, as compared to red and green light, of the backlight, in which case the actual color point of the backlight would be more blue-ish than white. Thus, the yellowish cast may be improved by increasing the color temperature of the backlight.

[0054] Another suitable embodiment for choice of colors is shown in **FIG. 12**. Here, the traditional red **1204**, green **1206**, and blue **1202** are chosen, but the fourth color is selected to be "blue-grey" with the luminance set to be approximately that of the red **1102** and/or green **1104**, or somewhere between them if they are not equal. The luminance may be so set either electronically or by the adjusting the filter and/or pigment as discussed above. This blue-grey filter allows more blue to pass through, or emit more blue, than red and green. This is akin to using a bluer backlight. As yet another embodiment, a combination of a higher color temperature backlight and blue-grey filter may be used. Such a resulting system might provide a more pleasing white point for the display when all subpixels are turned on.

[0055] Shown in **FIG. 13**, still another embodiment for choice of color and luminance points uses a deeper green **1306** than that shown in either **FIG. 11** or **12**. For example, green **1306** could be one that is further saturated and shifted towards the green corner, as described above. As an alternative, it might be possible to use the prior red color point **1304**, prior art blue color point **1302** and luminance, and a cyan (or greenish-blue, bluish-green) color **1308** allowing both blue and green (short and medium wavelength) light to pass through the filter. The result might provide a more pleasing white point for the display when all subpixels are turned on. Additionally, this panel may have the same brightness as a traditional three color panel. The panel may exhibit lower visibility of blue subpixel related artifacts, as will be explained further below.

[**0056**] The resulting display has the further benefit of having a greater range of colors, color gamut, than the conventional three color display panels. The traditional three colors create a color gamut triangular area formed by the boundaries (dark lines) running from red **1304**, green **1306**, and blue **1302** color points. The addition of a fourth cyan color, outside the traditional boundary, extends the boundary (dash dot line) to include the space formed by the triangle running from the blue **1304**, green **1306**, and cyan **1308** color points.

[**0057**] Yet another embodiment for choice of colors is shown in **FIG. 14**. Here the traditional red **1404**, green **1406**, and blue **1402** may be chosen, but the green emitter subpixel has a lower luminance via one or more of the proposed methods above or by any other suitable method or means, more closely approximating the luminance of the red emitter subpixel, and a cyan color **1408** allowing both blue and green (short and medium wavelength) light to pass through the filter, having a luminance approximating the luminance of the red and/or green emitter subpixel, the goal and result being a pleasing white point for the display when all subpixels are turned on. The panel may have the same brightness as a prior art three color panel. The panel will exhibit lower visibility of blue subpixel related artifacts as will be explained further below. The resulting display has the further benefit of having a greater range of colors, color gamut, than the prior art display panels, as described above.

[**0058**] Another embodiment for choice of colors is shown in **FIG. 20**. Here the traditional red **2004** and green **2006** may be chosen, but the green emitter subpixel has a lower luminance via one or more of the proposed techniques above or by any other suitable techniques, more closely approximating the luminance of the red emitter subpixel. Cyan color **2008**—allowing both blue and green (short and medium wavelength) light to pass through the filter—is opposed to the red **2004** and a purple or magenta color is opposed to the green **2006**, both colors having a luminance approximating the luminance of the red and/or green emitter subpixel, the result being a pleasing white point for the display when all subpixels are turned on. The panel may have the same brightness as a prior art three-color panel. In this embodiment, the color points of the green **2006** and magenta **2002** may be selected to provide a pleasing white point **2020** when the two colors are turned on full brightness, while the same may be true of the red and cyan. This creates two dichromatic metamers—i.e. combinations of just two colors, that both produce white—as well as the tetra chromatic metamer—i.e. the combination of all four colors, that produces white. The perception of a blue color **2009** may be produced by a suitable combination of intensities from the cyan **2008** and magenta **2002**.

[**0059**] While it is appreciated that many positional combinations are possible, all of which are contemplated in the present invention, certain combinations are worth noting for their properties. For example, placing a pair of the dichromatic metamers on the 'checkerboard' at the majority subpixel locations, and the other dichromatic metamer on the minority subpixel locations of **FIGS. 3, 4, 5A, 6A, 7A, 8A, 9, 10,** and **19** will create a panel in which every column may create a narrow, single subpixel wide white line when turned on by itself, and narrow, single subpixel wide white lines in rows when only the majority subpixels are turned on. This property may allow for very high subpixel rendering performance, especially for black text on white backgrounds, as is performed.

[**0060**] In one embodiment, the arrangement of subpixels shown in **FIG. 3**, when the fourth color **308** has sufficient luminance, approximately that of the red **304** and/or green **306**, or somewhere between them, the visibility of the dark blue **302** subpixels is reduced compared to an arrangement where the fourth color **308** is the same color as the blue **302**. This is because in this latter case, dark blue stripes formed by the two subpixels **302** and **308** would be seen against a bright background formed by the red **304** and green **306** subpixels. Such dark stripes are strongly visible because the two dimensional spatial frequency Fourier Transform shows a single strong signal at one point in the horizontal axis. The visibility of the blue subpixels of the arrangement shown in **FIG. 3** is reduced by the presence of the higher luminance fourth color, compared to one with blue stripes, first by the fact that half of the total "dark" signal energy is present and secondly because much of the energy is scattered into both the horizontal and vertical axis while some is scattered into the diagonal at a lower spatial frequency.

[**0061**] In another embodiment, the arrangements of the present invention may be improved by using the Active Matrix Layout techniques as disclosed in copending and commonly assigned U.S. patent application Ser. No. 10/024,326 entitled "Improvements to Color Flat Panel Display Sub-Pixel Arrangements and Layouts" to Elliott and herein incorporated by reference—in which the Thin Film Transistors and/or their associated storage capacitors **510** are grouped together closely, into a low luminance structure that is substantially 180° out of phase with the blue subpixels, thus increasing the apparent spatial frequency of the low luminance spots formed by the blue subpixels. These arrangements are shown in **FIGS. 5B, 6B**, 7B, and **8B** as illustrations. It will be appreciated that these TFT and capacitor groupings might apply to the other embodiments described herein.

[**0062**] In yet another embodiment, the visibility of the dark blue stripes may be further reduced by switching the position of the blue and the fourth color every other column in which they reside as shown in **FIG. 4**. This will scatter the bulk of the "dark" Fourier energy into the three directions with some scattered into three more directions between the first three at a lower spatial frequency. With increasing division of the Fourier energy, the visibility is reduced as each spatial frequency that has energy has less visibility, the total energy being constant.

[**0063**] In FIGS. **5A-5B** and **6A-6B**, non-square subpixels are used as separate embodiments. These are the same relative arrangements of color emitter subpixels as **FIGS. 3** and **4** respectively, but with a different repeat cell aspect ratio. The aspect ratio of the repeat cell may be adjusted as desired. One possible repeat cell aspect ratio is that of one-to-one (1:1), that is, a square. A different ratio is shown in FIGS. **5**A-**5**B, **6**A-**6**B, **7**A-**7**B, **8**A-**8**B, **9**, and **10**. This aspect ratio naturally results in the subpixels having the aspect ratio of two-to-three (2:3) as shown in the above Figures, save for the purposefully altered subpixel areas and aspect ratios of the minority color subpixels shown in **FIGS. 9 and 10**.

[**0064**] FIGS. **7**A-**7**B and **8**A-**8**B show the similar arrangements as FIGS. **5**A-**5**B and **6**A-**6**B respectively, save that the minority colors are shifted by some amount. These may be shifted by half the subpixel length, placing the colors 180° phase shifted from the majority subpixels. The advantage of this may be that these subpixels may reconstruct high spatial frequencies with phases other than the majority subpixels in the vertical direction. The mere presence of the minority subpixels between the majority subpixels might allow these phases to be reconstructed. Spatial frequencies can be represented up to the Nyquist Limit as is well known in the art. However, that spatial frequency should be in phase with the sample and reconstruction points or the modulation depth may be reduced. If they are 180° out of phase, then the modulation depth is zero. With the shifted minority subpixels, spatial frequency image components of all phases may be represented, with non-zero modulation depth, up to the Nyquist Limit by the display. This improves the perceived image quality of the display considerably.

[**0065**] The arrangements of FIGS. **7**A-**7**B may have the advantage that the reconstruction points that the subpixels represent are four fold rotationally symmetrical, which enable rotation of the display as disclosed in copending and commonly assigned U.S. patent application Ser. No. 10/150, 394 entitled "ROTATABLE DISPLAY WITH SUB-PIXEL RENDERING" to Elliott and herein incorporated by reference. The arrangement of FIGS. **8**A-**8**B may have the advantage of further reduced blue pixel visibility as described above.

[**0066**] In **FIGS. 9 and 10**, as separate embodiments, the minority subpixels have unequal areas. These embodiments allow one subpixel to emit more light of that color. This may be useful when more light of one of the minority colors is desired without increasing its per area luminance. For example, this technique may be used to increase the amount of pure blue light such that the resulting display may display bright saturated blue images. Alternatively, the smaller of the two minority subpixels may have an increased luminance to compensate for the decreased area.

[**0067**] **FIGS. 15, 16, 17**, and **18** show embodiments in which a fourth-color element is fabricated as an integral part of another color subpixel. This may have the advantage that the fourth-color, being of greater luminance than the conventional color, e.g. blue, will break up the stripe pattern, sending the "dark" Fourier energy into various directions to reduce the visibility of the dark stripe as earlier described. It is to be appreciated that the relative areas of the two colors may be adjusted depending on the amount of "dark" stripe visibility reduction desired and the reduction of first color saturation tolerable.

[**0068**] **FIG. 15** shows a plurality of subpixels **1502** comprising two color regions, one being a first color **1503** and a second color **1505**. The first color region **1503** may be a "dark" color, e.g. blue. The second color region may be chosen to be one with a higher luminance has as described above. In this embodiment, each of the subpixels comprising the first color also has the second color, each in the same relative positions and area.

[**0069**] **FIG. 16** shows a similar arrangement of subpixels **1602** and **1604** that comprise two colored regions **1603** and **1605**. In this embodiment, the relative positions are shifted. Although the drawing shows only two relative positions, it will be appreciated that there is no limit on the number of relative positions of the two colored regions within the subpixels. As shown, one set of two color subpixels **1604** has the second color **1605** substantially on the lower portion of the subpixel, while the second set of two color subpixels **1602** has the second color **1605** in the upper portion of the subpixel. This particular arrangement further scatters the "dark" Fourier energy into additional directions as described above. In addition, the second color regions **1605**, having luminance and being in more than one relative position within the subpixels **1602** and **1604**, allow for additional subpixel rendering luminance reconstruction points. The second colored regions **1605**, being in positions that place them off of the grid formed by the centers of the majority subpixels (e.g. the red/green checkerboard), allows for reconstruction of image signals that are various phases up to the Nyquist Limit as earlier described.

[**0070**] **FIG. 17** shows two classes of minority subpixels **1702** and **1704**. The first class of subpixels **1702** is that of a single color. The second class **1704** is comprised of two colored regions **1703** and **1705**. The first colored region **1703** may comprise the same color as that of the first class **1702** of subpixels. By having two classes, the benefits of the added luminance breaking up the "dark" stripes is gained while simultaneously maintaining the ability to display a saturated first color.

[**0071**] **FIG. 18** shows an embodiment in which there are fewer of the two color subpixels **1802**, allowing a reduction of driver count as was disclosed in copending and commonly assigned U.S. patent application Ser. No. 09/916,232 entitled "Arrangement of Color Pixels for Full Color Imaging Devices with Simplified Addressing" to Elliott and herein incorporated by reference.

[**0072**] **FIG. 19** shows a novel layout of four colors according to another aspect of the present invention. The arrangement uses two majority colors **1904** and **1906** in a checkerboard. These two colors may be substantially red and green. One of the minority colors **1902** or **1908** may be blue. The other minority color **1908** or **1902** respectively may be chosen from a group of fourth-colors as described above. One advantage of this arrangement is that the majority color subpixels are on a rectangular and/or square grid, while the minority colors are 180° out of phase with that checkerboard grid. The fourth-color, which may have appreciable luminance, may provide for reconstruction of signals which are out of phase with the majority color subpixel checkerboard. The minority subpixels **1902** and **1908** may be the same color, e.g. blue, as a possible embodiment.

[**0073**] Although it might be desirable for all of the subpixel emitters to have the same luminance, for various reasons, this may not be practical. For instance, the blue emitting subpixels may be lower luminance than the emitters of other colors, or the green or the fourth color (white, cyan, or blue-grey) may be higher luminance than the other colors. In these cases, some of the objectionable artifacts caused by the differences in luminance may be reduced with the use of a suitably selected optical low-pass spatial filter. This low-pass spatial filter may blur the edges of the subpixels, reducing the visibility of the sudden, undesired, change in luminance between the subpixel color emitters. Such a filter may further comprise or include an anti-glare function, the surface of the filter scattering reflected light to avoid specular reflections. The filter may also comprise a Holographic Optical Element (HOE) that scatters or blurs the light emitted by the display. Both of the above said filter types are commercially available.

[**0074**] The amount of scatter or blur may be a function of both the display subpixel density and the distance from the light modulation plane. As a general rule, the higher the density, the higher the resolution may be; and the lower the total blur required to achieve the effect. Additionally, the further the blur filter plane is from the light modulation plane, the lower the intrinsic blurring power (i.e. higher spatial frequency pass) of the filter is required. Generally speaking, the amount of blur required to improve the appearance of the subpixel rendered display is a bit more than is currently provided by the presence of conventional anti-glare filters. Two further embodiments of increasing blur to a suitable level are; increasing the intrinsic scattering of the anti-glare filter, or; increasing the distance between the light modulation plane and the anti-glare filter surface. This can be achieved by introducing a thicker film, or second film, between the filter and the display substrate.

[**0075**] The above use of transmissive liquid crystal displays is exemplary and not to be construed as restricting the scope of this invention. The present invention encompasses the scope of all such embodiments for adjusting the luminance and chrominance and positions of the emitters of non-transmissive display panels, such as reflective Liquid Crystal Displays, emissive ElectroLuminecent Displays (EL), Plasma Display Panels (PDP), Field Emitter Displays (FED), Electrophoretic displays, Iridescent Displays (ID), Incandescent Display, solid state Light Emitting Diode (LED) display, and Organic Light Emitting Diode (OLED) displays.

B. Subpixel Rendering Methods

[**0076**] Having described a number of novel four color subpixel arrangements, there will now be described some novel embodiments of methods and manners of performing subpixel rendering on those novel arrangements. It will be appreciated that the following description is given for two particular novel arrangements; however, other arrangements follow similarly and that the present invention contemplates and encompasses all suitable methods and modifications to the same to perform subpixel rendering on these other arrangements.

[**0077**] Three color (red, green, & blue) subpixel arrangements have a simple one-to-one mapping of the conventional three color plane data sets (RGB). Four color subpixel arrangements may not have that simple mapping. For example, the fourth color, often white, may be mapped as a function of several, perhaps all, of the three color planes.

[**0078**] Several embodiments are disclosed herein. One embodiment is meant to keep the computation as simple as possible to keep the cost of implementation low. Other embodiments provide successively higher image quality, trading off computation complexity.

[**0079**] One embodiment uses the same area resample theory as described in the '355 application wherein the resample areas are drawn to minimize the distance from any point in the input data image to the reconstruction point grid. This allows data areas to be represented by the closest reconstruction point. As described below, a novel method adds a fourth resample plane for the fourth-color. The resample areas overlap and cover the entire incoming data space, as though for its own color plane. Thus, if the incoming data comprises a four-color data format, then the shapes, and therefore, the filter coefficients are generated as per the method disclosed in the '355 application.

[**0080**] As shown in **FIG. 28**, one embodiment of the method proceeds as follows: (1) determining implied sample areas for each data point of incoming four-color pixel data as in step **2802**; (2) determining the resample area for each four-color subpixel in the display as in step **2804**; (3) forming a set of coefficients for each said resample area as in step **2806**, whereby one possible embodiment has said coefficients comprising fractions whose denominators are a function of the resample area and the numerators are a function of an area of each said implied sample areas that may partially overlap said resample areas; (4) multiplying the incoming pixel data for each implied sample area by the coefficient resulting in a product as in step **2808**; and (5) adding each said product to obtain luminance values for each resample area as in step **2810**.

[**0081**] If, however, there is no fourth-color data plane from which the fourth-color resample plane may resample, the fourth color resample area grid must therefore resample from the other color planes—as a refinement of step **2804**. Assuming that the fourth-color is white, grey, or blue-grey, for each white, grey, or blue-grey subpixel the following equation is used to map the fourth color data:

$$Wout = \mathrm{Min}\left(\sum (R_{in} \cdot c_k), \sum (G_{in} \cdot c_k), \sum (B_{in} \cdot c_k)\right)$$

[**0082**] Where $C_k$ is the filter coefficient matrix, $R_{in}$, $G_{in}$, $B_{in}$ are values of the red, green, and blue components of the input data set that the filter matrix is operating upon, and $W_{out}$ is the value to be applied to the white, grey, or blue-grey subpixel. Another embodiment assumes that the incoming three-color input data match substantially three out of the four colors in the display. In operation, the filter coefficient is applied to each of the color channels separately, then the minimum color component value, (i.e., the color value that has the lowest value) is selected and applied to the white, grey, or blue-grey subpixel. The minimum is chosen to minimize the change in color saturation of the image, to maintain color saturation.

[**0083**] If the fourth-color is selected to represent a combination of only two color planes, for example, green and blue, by emitting light that represents these two colors together, such as cyan, then only two color planes are evaluated in calculating the value of the fourth-color subpixel:

$$C_{out} = \mathrm{Min}\left(\sum (G_{in} \cdot c_k), \sum (B_{in} \cdot c_k)\right)$$

[0084] Another embodiment uses smaller resample areas for the fourth-color subpixels. The total resample area does not cover the entire data space. This is to localize the effect of the data on the fourth color subpixels to increase the image sharpness. For example, the area of each fourth-color subpixel could be set equal to the area of each red and green subpixel, as it will have a similar effect on the reconstruction of the image. Such an arrangement is shown in **FIG. 23**.

[0085] The exact values of the subpixel rendering coefficient matrices depend on the input data set definition and scale, as was described in the '355 application. Summarizing here, the coefficients are generated by calculating the fractional coverage, or overlap, of each implied sample area for each input data point to the area of the resample area. **FIG. 23** shows a conventional image data set overlaying a set of resample areas.

[0086] Shown in **FIG. 23** are the reconstruction points **2310** and one possible associated resample areas **2320**. The blue resample areas are not shown for clarity. In one embodiment, there are areas where a primary color resample area overlaps the fourth-color resample areas, and areas where it does not. This creates two classes of sub-resample area. When data occurs in the overlap area, it is desirable for the fourth color subpixel to represent the data, shifting the luminance from the primary color to the fourth-color subpixel. However, as the fourth-color subpixel takes over this area, it is desirable to boost the effect of the non-overlap areas to keep color and brightness constant. This leads to the following formulas:

$$W_{out} = \min\left(\sum R_{in} \times c_k, \sum G_{in} \times c_k, \sum B_{in} \times c_k\right)$$

$$R_{out} = \sum c_{kl}\left(R_{in} - \frac{1}{2}W_{out}\right) + R_{in}\left(c_{k2} + \left(c_{k3} \times \frac{1}{2}W_{out}\right)\right)$$

$$G_{out} = \sum c_{kl}\left(G_{in} - \frac{1}{2}W_{out}\right) + G_{in}\left(c_{k2} + \left(c_{k3} \times \frac{1}{2}W_{out}\right)\right)$$

$$B_{out} = \sum c_{kl}\left(B_{in} - \frac{1}{2}W_{out}\right) + B_{in}\left(c_{k2} + \left(c_{k3} \times \frac{1}{2}W_{out}\right)\right) \text{ OR}$$

$$B_{out} = \sum c_k B_{in}$$

[0087] Where: $c_{k1}$ is the coefficient matrix for that portion that is overlapped by both the primary color resample area and the fourth color resample areas. $c_{k2}$ is the coefficient matrix for the portion that is not overlapped by the fourth resample areas with respect to the total resample area for that reconstruction point. It is noted that $c_{k3}$ is a modifier coefficient matrix whereby $c_{k2}+c_{k3}=c_{kx-w}$, where $c_{kx-w}$ is the coefficient matrix that would be generated if the primary color resample area were restricted to only that area not overlapped by the fourth-color resample areas.

[0088] The form of the expression allows the luminance energy in the overlapping resample area to be transferred to the fourth-color, while simultaneously increasing the effect of the non-overlapped area to ensure that when a full white field is present, that all of the subpixels are turned on full. The use of the constant of "one half (½)" as a multiplier for the fourth color data is because when the fourth color "borrows" luminance from both the red and green, it replaces only one half of the combined red and green total. The choice of using the simple or more complicated form of the formula for the blue component depends on the level of accuracy vs. computational complexity and cost that is tolerable. The blue image component has negligible luminance and may exhibit greater color error before it is noted by the Human Vision System. Thus, the simplification for the blue data may be acceptable.

[0089] As before, where the fourth-color only represents two of the color planes, for example, blue and green, by using a cyan as the fourth-color, the algorithm is given below, wherein $W_{out}$ is the energy applied to the cyan color:

$$W_{out} = \min\left(\sum G_{in} \times c_k, \sum B_{in} \times c_k\right)$$

$$R_{out} = \sum c_k R_{in}$$

$$G_{out} = \sum c_{kl}(G_{in} - W_{out}) + G_{in}(c_{k2} + (c_{k3} W_{out}))$$

$$B_{out} = \sum c_k B_{in}$$

[0090] The resample areas shown in **FIGS. 24A and 24B** treat all of the reconstruction areas exactly in the center of the colored subpixels shown in **FIG. 22**, as opposed to the resample areas shown in **FIG. 23** that treat the red and green reconstruction points as though they were on an idealized checkerboard for computational simplicity. The value of treating the reconstruction points exactly is that the fourth-color subpixels, when considered along side the majority subpixels, may reconstruct the phase relationships of scaled input image data sets better than the idealized checkerboard of **FIG. 23**.

[0091] Examining the meaning and relationships between the various coefficient matrices, using the example of the resample areas in FIGS. **24A** and **24B**: A randomly chosen example green reconstruction point **2406** has an associated resample area **2410**. Next to it is a fourth-color reconstruction point **2408** and an associated resample area **2440**. The resample area **2410** is divided into two sub-resample areas **2420** and **2430**. The overlapping area **2420** of the fourth-color resample area **2440** and the green resample area **2410** is used to calculate the subpixel rendering coefficient matrix $c_{k1}$ for the green subpixel associated with the reconstruction point **2406**. The non-overlapping green resample area **2430** is used to calculate the subpixel rendering coefficient matrices $c_{k2}$ and $c_{k3}$ for the green subpixel associated with the reconstruction point **2406**.

[0092] Some, in this instance half, of the green and red resample areas will overlap more than one fourth color resample area. For example, another green reconstruction point **2456** has an associated resample area **2450**. This resample area is divided in four sub-resample areas **2455**, **2460**, **2470**, and **2480**. The resample area **2450**, overlaps three of the nearby fourth-color resample areas **2465**, **2475**, and **2485**, associated with the nearby fourth-color reconstruction points **2468**, **2478**, and **2488** respectively. The overlaps of the green resample area **2450** and the nearby fourth-color resample areas **2465**, **2475**, and **2485**, form the overlap areas **2460**, **2470**, and **2480** respectively. The existence of more than one overlap area with more than one fourth-color resample areas requires a modification to the above algorithms:

$$W_{out} = \min\left(\sum R_{in} \times c_k, \sum G_{in} \times c_k, \sum B_{in} \times c_k\right)$$

$$R_{out} = \sum c_{k1}\left(R_{in} - \frac{1}{2}W_{out}\right) + R_{in}\left(c_{k2} + \left(c_{k3} \times \frac{1}{2}W_{out}\right)\right) \text{ OR}$$

$$R_{out} = \sum c_{k11}\left(R_{in} - \frac{1}{2}W_{out-1}\right) + c_{k12}\left(R_{in} - \frac{1}{2}W_{out-2}\right) + c_{k13}\left(R_{in} - \frac{1}{2}W_{out-3}\right) + R_{in}\left(c_{k2} + \left(c_{k31} \times \frac{1}{2}W_{out-1}\right) + \left(c_{k32} \times \frac{1}{2}W_{out-2}\right) + \left(c_{k33} \times \frac{1}{2}W_{out-3}\right)\right)$$

$$G_{out} = \sum c_{k1}\left(G_{in} - \frac{1}{2}W_{out}\right) + G_{in}\left(c_{k2} + \left(c_{k3} \times \frac{1}{2}W_{out}\right)\right) \text{ OR}$$

$$G_{out} = \sum c_{k11}\left(G_{in} - \frac{1}{2}W_{out-1}\right) + c_{k12}\left(G_{in} - \frac{1}{2}W_{out-2}\right) + c_{k13}\left(G_{in} - \frac{1}{2}W_{out-3}\right) + G_{in}\left(c_{k2} + \left(c_{k31} \times \frac{1}{2}W_{out-1}\right) + \left(c_{k32} \times \frac{1}{2}W_{out-2}\right) + \left(c_{k33} \times \frac{1}{2}W_{out-3}\right)\right)$$

$$B_{out} = \sum c_k B_{in}$$

[**0093**] Where: $c_{k11}$, $c_{k12}$, and $c_{k13}$, are the coefficient matrices for that portion that is overlapped by both the primary color resample area and the 3 fourth color resample areas. $c_{k2}$ is the coefficient matrix for that portion that is not overlapped by the fourth resample areas with respect to the total resample area for that reconstruction point. $c_{k31}$, $c_{k32}$, and $c_{k33}$, are modifier coefficient matrices whereby $c_{k2}+c_{k31}+c_{k32}+c_{k33}=c_{kx-w}$, where $c_{kx-w}$ is the coefficient matrix that would be generated if the primary color resample area were restricted to only that area not overlapped by the fourth color resample areas. $W_{out-1}$ and $W_{out-2}$ and $W_{out-3}$ are calculated the same as $W_{out}$ but from the three surrounding resample points—e.g. points **2468**, **2478** and **2488**.

[**0094**] Each implied sample area (for example, the orthogonal grid as shown in **FIG. 23**) from the input image data creates entries in the coefficient matrices. For each resample area, only the input data points that have an overlapping implied sample area have an entry in the associated coefficient matrix. Examining **FIG. 24**B, with reference where needed to **FIG. 24**A, an input image pixel's implied sample area **2415** is shown overlapping the green resample area **2410** and the fourth-color resample area **2440**. The input sample area **2415** is subdivided by the two overlapping resample areas. One sub-area of the implied input sample area **2415** is the overlap of the input sample area **2415** and the intersection set overlap **2420**, that is itself the overlap of the green resample area **2410** and the fourth-color resample area **2440**, to form a new, triple intersection set area **2425**. This area **2425**, when measured by a suitable integration, divided by the total area of the green resample area **2410**, is the coefficient for the input image data point associated with the implied sample area **2415** in the coefficient matrix $c_{k1}$ for the green color subpixel associated with the green reconstruction point **2406**. Another sub-area of the implied input sample area **2415** is the overlap with the green resample area **2410** not overlapping the fourth-color resample area **2430**, forming a double intersection set overlap area **2435**. This area **2435** divided by the area of the green resample area **2410** is the coefficient for the input image data point associated with the implied sample area **2415** in the coefficient matrix $c_{k2}$ for the green color subpixel associated with the green reconstruction point **2406**. This same area divided by the non-fourth-color-overlap area **2430** is the coefficient in the phantom coefficient matrix $c_{kx-w}$ used to calculate the modifier coefficient in the coefficient matrix $c_{k3}$. The rest of the coefficients in the various matrices are derived in like manner.

[**0095**] The complexity of the above algorithms can be avoided using a simplification in which the resample areas of both the red and green are reduced by the amount that is covered by the fourth-color resample area. Several methods of determining the area of the fourth-color resample are given below.

[**0096**] One straight forward method of determine the area of the fourth-color resample area **2580** associated with the fourth-color reconstruction point **2588** is to define it as the overlap of the red resample area **2540** associated with the red reconstruction point **2544** and the green resample area **2560** associated with the green reconstruction point **2566** as is shown in **FIG. 25**. The effective red resample area **2542** is thus defined as the resample area **2540** not overlapping the green resample area **2560**. The effective green resample area **2562** is similarly defined as the resample area **2560** not overlapping the red resample area **2540**. Thus, the fourth-color subpixel has an associated resample area **2580** coverage of the input image data set to itself. The algorithm to subpixel render the data simplifies to:

$$W_{out} = \min\left(\sum R_{in} \times c_k, \sum G_{in} \times c_k, \sum \boldsymbol{B}_{in} \times c_k\right)$$

$$R_{out} = \sum c_{k-w} R_{in}$$

$$G_{out} = \sum c_{k-w} G_{in}$$

$$B_{out} = \sum c_k B_{in}$$

[**0097**] Where $c_{k-w}$ is the coefficient matrix for the effective resample area for the given color reconstruction point, considering it to be the only area covered.

[0098] The above resample areas for the fourth-color cover the same, coincident, area in each of the color planes. This coincident area may be defined by some "natural" boundaries as above, or by fiat to some other shape or shapes. The fourth-color resample areas do not have to be coincident for each color plane. An example of which is described below.

[0099] Examining **FIG. 26**, the red resample areas **2640** associated with the red reconstruction points **2644** and green resample areas **2660** associated with green reconstruction points have been reduced in area to accommodate the fourth-color resample areas **2680** and **2689** associated with fourth color reconstruction points **2688**. With this arrangement of resample areas, the fourth-color resample areas **2680** that are resampling the red color plane is not coincident with the fourth-color resample areas **2689** that are resampling the green color plane. There are overlap regions **2685** directly over the fourth-color reconstruction points.

[0100] The novel arrangement of resample areas shown in **FIG. 26** is generated by a modification to the algorithm that is used to generate the resample areas shown in **FIGS. 24A and 24B** in which the fourth-color is treated as belonging to the set of reconstruction points for the majority colors. The method of generating the arrangements in **FIGS. 24A and 24B** is to "seed a crystal" at each reconstruction point within a color plane, then allowing the seed to grow isotropically in diameter until it "touches" another crystal, thus forming the boundaries of the resample areas. This generates boundaries in which a given random point is enclosed along with the nearest reconstruction point, in accordance with the teaching in '355 application. The modification to the resample area generation algorithm that generated **FIG. 26** is both to include the fourth-color reconstruction points and to delay the start of the fourth-color "seed crystal" growth. By delaying the start of the "seed crystals" the fourth-color resample areas are reduced in area. The greater the delay, the smaller the fourth-color resample areas.

[0101] To help illustrate some of the principles developed herein, the following is a numerical example of calculating filter coefficients. As such, this example is not offered to limit the scope of the present invention in anyway. Indeed other numerical example are possible from other configurations thus, the following is merely illustrative.

[0102] In this example of how to calculate all the coefficient matrices described above, the case is considered where the implied input sample points are coincident with the resample points. This is true when the input image is not being scaled, or when there is one input sample point for each output red or green resample point.

[0103] Consider the resample areas **2410** and **2450** of **FIG. 24A** together with each of the sub-resample areas **2420, 2430, 2455, 2460, 2470** and **2480**. The numerical area of each sub-resample area is computed. The area of each sub-resample area that falls into each of the implied input sample areas is summed so that the proportion of these areas to the total area can be calculated. This would result in coefficient tables that are typically 3×3 and contain fractional numbers that sum to one. Of course, other matrices dimensions and scaling could be employed. For ease of use in hardware designs these coefficients are converted to fixed-point binary numbers by multiplying them all by 256. The result for sub-resample area **2430** would be the intermediate coefficient matrix $c_{kx-w}$ mentioned above:

$$C_{kx-w} = \begin{array}{|c|c|c|} \hline 0 & 42 & 0 \\ \hline 102 & 70 & 0 \\ \hline 0 & 42 & 0 \\ \hline \end{array}$$

[0104] This $C_{kx-w}$ matrix was calculated with respect to the sub-resample area but the $C_{k2}$ matrix must be calculated with respect to the whole resample area. This can be done by multiplying the $C_{kx-w}$ matrix by the ratio of the sub-resample area over the whole resample area (4010/8712 in the case of sub-resample area **2430** and whole resample area **2410**). The result in case would be:

$$C_{k2} = \begin{array}{|c|c|c|} \hline 0 & 19 & 0 \\ \hline 47 & 32 & 0 \\ \hline 0 & 19 & 0 \\ \hline \end{array}$$

[0105] In a similar procedure the sub-resample area **2420** is measured to produce the coefficient matrix $C_{k1}$:

$$C_{k1} = \begin{array}{|c|c|c|} \hline 0 & 9 & 0 \\ \hline 0 & 96 & 0 \\ \hline 0 & 9 & 0 \\ \hline \end{array}$$

[0106] Note that neither of these matrices sums to 256 but together they do. Some care must be taken when rounding the numbers to small integers to make sure that this relationship remains true.

[0107] From the relationship $c_{k2}+c_{k3}=c_{kx-w}$ given above it is now possible to calculate the modifier coefficient matrix $C_{k3}=C_{kx-w}-C_{k2}$ giving the result below:

$$C_{k3} = \begin{array}{|c|c|c|} \hline 0 & 23 & 0 \\ \hline 55 & 38 & 0 \\ \hline 0 & 23 & 0 \\ \hline \end{array}$$

[0108] In resample area **2450** the sub-resample area **2455** lies outside three overlap areas **2460, 2470** and **2480**. Note that this area **2455** includes two separate areas that do not necessarily connect but must be taken into account. When the coefficient table for this area is built the result is another intermediate matrix:

$$C_{kx-w} = \begin{array}{|c|c|c|} \hline 0 & 12 & 0 \\ \hline 18 & 180 & 34 \\ \hline 0 & 12 & 0 \\ \hline \end{array}$$

[0109] In this case even with multiple overlap areas there is still only one $C_{k2}$ matrix and multiplying the above matrix by 4602/8712 (the ratio of the areas of sub-resample area **2455** over the whole resample area **2450**) results in:

$$C_{k2} = \begin{array}{|c|c|c|}\hline 0 & 6 & 0 \\ \hline 10 & 95 & 18 \\ \hline 0 & 6 & 0 \\ \hline\end{array}$$

**[0110]** In the case of resample area **2450** there are three overlapping sub-resample areas **2460**, **2470** and **2480**. Each of these areas must be treated separately resulting in three coefficient matrices. Each of these is calculated in a manner similar to the way that $C_{k2}$ is calculated above resulting in:

$$C_{k11} = \begin{array}{|c|c|c|}\hline 0 & 0 & 0 \\ \hline 7 & 17 & 0 \\ \hline 0 & 22 & 0 \\ \hline\end{array} \quad C_{k12} = \begin{array}{|c|c|c|}\hline 0 & 22 & 0 \\ \hline 7 & 17 & 0 \\ \hline 0 & 0 & 0 \\ \hline\end{array} \quad C_{k13} = \begin{array}{|c|c|c|}\hline 0 & 0 & 0 \\ \hline 0 & 0 & 41 \\ \hline 0 & 0 & 0 \\ \hline\end{array}$$

**[0111]** Where $C_{k11}$, $C_{k12}$ and $C_{k13}$ are the coefficient matrices for sub-resample areas **2460**, **2470** and **2480** respectively.

**[0112]** Finally three modifier matrices must be calculated. $C_{k31}$, $C_{k32}$ and $C_{k33}$ for sub-resample areas **2460**, **2470** and **2480** respectively. From the relationship $c_{k2}+c_{k31}+c_{k32}+c_{k33}=c_{kx-w}$ it can be seen that the three modifier matrices must sum to $C_{kx-w}-C_{k2}$.

$$C_{kx\text{-}w}\text{-}C_{k2} = \begin{array}{|c|c|c|}\hline 0 & 6 & 0 \\ \hline 8 & 85 & 16 \\ \hline 0 & 6 & 0 \\ \hline\end{array}$$

**[0113]** Each of the three modifiers is apportioned a fraction of this matrix according to the relative size of its area. In this example, the areas of sub-resample areas **2460**, **2470** and **2480** are 1557, 1557 and 1392 respectively resulting in a total of 4506. So to calculate $C_{k31}$, multiply the above matrix by 1557/4506. The result is identical for $C_{k32}$. To calculate $C_{k33}$ we multiply the above matrix by 1392/4506. Thus the three modifier matrices are:

$$C_{k31} = \begin{array}{|c|c|c|}\hline 0 & 2 & 0 \\ \hline 3 & 29 & 6 \\ \hline 0 & 2 & 0 \\ \hline\end{array} \quad C_{k32} = \begin{array}{|c|c|c|}\hline 0 & 2 & 0 \\ \hline 3 & 29 & 6 \\ \hline 0 & 2 & 0 \\ \hline\end{array} \quad C_{k33} = \begin{array}{|c|c|c|}\hline 0 & 2 & 0 \\ \hline 3 & 26 & 5 \\ \hline 0 & 2 & 0 \\ \hline\end{array}$$

**[0114]** Examining **FIG. 24A** it is possible to see that all the other sub-resample areas are either identical to the ones described above, or are mirror images of the ones described. The coefficient matrices calculated in the above example can simply be flipped left-to-right to create a set of matrices for the mirrored resample areas. No more calculations are necessary to produce all the coefficients necessary for this example.

**[0115]** All the above calculations were done with the assumption that the implied input sample points were coincident with the resample points. This is true when the input image is not being scaled, when there is one input sample point for each output red or green resample point. When the input image is being scaled the calculations are made more complex by the introduction of a "repeat cell" of coefficients. A different set of coefficients must be calculated for each cell of the repeat cell.

**[0116]** The above use of transmissive liquid crystal displays as example embodiments is not to be construed as restricting the scope of this invention. It will be obvious to those skilled in the art, that adjusting the luminance and chrominance and positions of the emitters of non-transmissive display panels, such as reflective Liquid Crystal Displays, emissive Electro Luminescent Displays (EL), Plasma Display Panels (PDP), Field Emitter Displays (FED), Electrophoretic displays, Iridescent Displays (ID), Incandescent Displays, solid state Light Emitting Diode (LED) display, and Organic Light Emitting Diode (OLED) displays, will also be improved using this teaching and are to be considered within the scope of the present invention. Variations on the resample area definitions, coefficient matrices, and algorithms may suggest themselves to those knowledgeable in the art and should be considered to be within the scope of the present invention.

**[0117]** The foregoing description has not been limited to a specific embodiment of this invention. It will be apparent, however, that various variations and modifications may be made to the invention, with the attainment of some or all of the advantages of the invention. It is the object of the appended claims to cover these and such other variations and modifications as come within the true spirit and scope of the invention.

**[0118]** Other embodiments of the invention will be apparent from consideration of the specification and practice of the invention disclosed herein. It is intended that the specification and examples be considered as exemplary only, with a true scope and spirit of the invention being indicated by the following claims.

What is claimed is:

**1**. An arrangement of at least three color subpixels, said at least three colors comprising a red and a green subpixel, said red and green subpixels comprising a red and a green filter respectively and further wherein said red and green subpixels comprise substantially the same luminance when the same energy level is applied to said red and green subpixels.

**2**. The arrangement as recited in claim 1 wherein said red subpixel filters comprise a more transmissive filter than said green subpixel filters.

**3**. The arrangement as recited in claim 2 wherein said red subpixel filters comprises one of a group, said group comprising: a red filter comprising a physically thinner filter than said green filter; a red filter comprising a red pigment comprising a reduced amount of pigment as compared to said green filter; a red filter comprising a pigment comprising greater transmissivity of light than said green filter; and a red filter comprising a broad transmissivity range of frequencies on either side of the red center point.

**4**. The arrangement as recited in claim 2 wherein said green subpixel filters comprises one of a group, said group comprising: a green filter comprising a physically thicker filter than said red filter; a green filter comprising a green pigment comprising a increased amount of pigment as compared to said red filter; a green filter comprising a pigment comprising lesser transmissivity of light than said red filter; and a green filter comprising a narrow transmissivity range of frequencies on either side of the green center point.

**5**. The arrangement as recited in claim 1 wherein the backlight comprises more frequencies in the red range.

**6**. The arrangement of claim 1 wherein said green subpixels comprises a green filter such that the pass band of said green filter is narrowed and such that the chromaticity of said green filter broadens the color gamut into a deeper green color.

**7**. The arrangement of claim 6 wherein said arrangement comprises at least a four color arrangement wherein said fourth color comprises a substantial amount of green color.

**8**. The arrangement of claim 7 wherein said fourth color comprises one of a group, said group comprising: cyan, magenta, greenish-blue, and greenish-grey.

**9**. The arrangement of claim 8 wherein said arrangement comprises a repeat cell of four subpixels.

**10**. The arrangement of claim 7 wherein said arrangement comprises a repeat cell of at least six subpixels.

**11**. The arrangement of claim 10 wherein said arrangement comprises a repeat cell wherein said red and green subpixels further comprise a checkerboard pattern.

**12**. The arrangement of claim 1 wherein said arrangement comprises at least a four color arrangement wherein said fourth color comprises one of a group, said group comprising grey, blue grey, and filtered white.

**13**. The arrangement of claim 12 wherein the backlight comprises more energy in the blue spectrum than red or green spectrum.

**14**. An arrangement of four color subpixels, said arrangement comprising a red subpixel, a green subpixel, a cyan subpixel and a magenta subpixel such that when said red subpixel and said cyan subpixel are substantially fully on and when said green and said magenta subpixels are off, said arrangement displays a substantially white color.

**15**. An arrangement of four color subpixels, said arrangement comprising a red subpixel, a green subpixel, a cyan subpixel and a magenta subpixel such that when said green and said magenta subpixels are substantially fully on and when said red subpixel and said cyan subpixel are off, said arrangement displays a substantially white color.

**16**. An arrangement of at least six four-color subpixels, said arrangement comprising two red subpixels, two green subpixels, a blue subpixel and a fourth color subpixel such that said arrangement further comprises a first row and a second row, said first row comprising a red subpixel, a green subpixel and said blue subpixel, said second row comprising a red subpixel, a green subpixel and said fourth color subpixel.

**17**. The arrangement of claim 16 wherein further horizontally adjacent arrangements comprise a first row and a second row, said first row comprising a red subpixel, a green subpixel and said fourth color subpixel, said second row comprising a red subpixel, a green subpixel and said blue subpixel.

**18**. The arrangement of claim 16 wherein said subpixels comprise one of a group, said group comprising: square subpixels and rectangular subpixels.

**19**. The arrangement of claim 16 wherein said red subpixels and said green subpixels form substantially a checkerboard pattern.

**20**. The arrangement of claim 18 wherein said blue subpixel and said fourth color subpixel are shifted out of alignment from said red subpixel and said green subpixel checkerboard pattern.

**21**. The arrangement of claim 19 wherein said blue subpixel and said fourth color subpixel are shifted out of alignment by substantially half the length of said subpixel.

**22**. The arrangement of claim 20 wherein horizontally adjacent arrangements comprise a first row and a second row, said first row comprising a red subpixel, a green subpixel and said fourth color subpixel, said second row comprising a red subpixel, a green subpixel and said blue subpixel.

**23**. The arrangement of claim 16 wherein said subpixels are comprised substantially of equal area.

**24**. The arrangement of claim 16 wherein said subpixels are not comprised substantially of equal area.

**25**. The arrangement of claim 24 wherein said fourth color subpixel comprises a smaller area than said blue subpixel.

**26**. An arrangement of at least six four-color subpixels, said arrangement comprising two red subpixels, two green subpixels, two two-color subpixels such that said arrangement further comprises a first row and a second row, said first row and said second row comprising a red subpixel, a green subpixel and a two-color subpixel.

**27**. The arrangement of claim 26 wherein said two-color subpixel comprises a filter, said filter further comprising a first color filter and a second color filter.

**28**. The arrangement of claim 27 wherein said first color filter comprises a larger area than said second color filter.

**29**. The arrangement of claim 28 wherein said second color filter comprises a filter of higher luminance than said first color filter.

**30**. The arrangement of claim 26 wherein horizontally-adjacent arrangements comprise a two-color filter rotated by 180 degrees.

**31**. An arrangement of at least six four-color subpixels, said arrangement comprising two red subpixels, two green subpixels, a third color subpixel and a two-color subpixels such that said arrangement further comprises a first row and a second row, said first row comprising a red subpixel, a green subpixel and the two-color subpixel.

**32**. The arrangement of claim 31 wherein a second adjacent arrangement comprises a first row and a second row, said first row comprising a red subpixel, a green subpixel and the third color subpixel.

**33**. An arrangement of five four-color subpixels, said arrangement comprising two red subpixels, two green subpixels, a two-color subpixel such that said arrangement further comprises a first column, a second column, and a third column, said first and third column comprising a red and green subpixel checkerboard and said second column comprising said two-color subpixel.

**34**. A method of converting a incoming pixel data of a first format comprising a plurality of four-color pixel elements for a display of a second format comprising a plurality of four-color pixel elements, the steps of said method comprising:

determining implied sample areas for each data point of incoming four-color pixel data;

determining the resample area for each four-color subpixel in the display;

forming a set of coefficients for each said resample area, said coefficients comprising fractions whose denominators are a function of the resample area and the numerators are a function of an area of each said implied sample areas that may partially overlap said resample areas;

multiplying the incoming pixel data for each implied sample area by the coefficient resulting in a product; and

adding each said product to obtain luminance values for each resample area.

**35**. A method of converting a incoming pixel data of a first format comprising a plurality of three-color pixel elements for a display of a second format comprising a plurality of four-color pixel elements wherein said three-color input substantially matches three of the four colors in the display, the steps of said method comprising:

determining implied sample areas for each data point of incoming three-color pixel data;

determining the resample area for each four-color subpixel in the display;

for each of the three matching colors in the display, forming a set of coefficients for each said resample area of the three matching colors in the display, said coefficients comprising actions whose denominators are a function of the resample area and the numerators are a function of an area of each said implied sample areas that may partially overlap said resample areas;

multiplying the incoming pixel data for each implied sample area by the coefficient resulting in a product;

adding each said product to obtain luminance values for each resample area; and

for the fourth color in the display,

computing a luminance value for said fourth color, said fourth color luminance value comprising a function of computed luminance values of said matching three color display data.

**36**. The method as recited in claim 35 wherein said fourth color is one of a group, said group comprising white, grey, and blue-grey.

**37**. The method as recited in claim 36 wherein the step of computing a luminance value comprises computing the following function:

$$Wout = \mathrm{Min}\left(\sum (R_{in} \cdot c_k), \sum (G_{in} \cdot c_k), \sum (B_{in} \cdot c_k)\right);$$

wherein $C_k$ comprises said coefficient, and $R_{in}$, $G_{in}$, $B_{in}$ comprise the values of the red, green, and blue components of the input data set.

**38**. The method as recited in claim 35 wherein said fourth color comprises a combination of only two or said three matching colors.

**39**. The method as recited in claim 38 wherein said fourth color is one of a group, said group comprising blue-green and cyan.

**40**. The method as recited in claim 39 wherein said luminance value for said fourth color comprises:

$$W_{out} = \min\left(\sum G_{in} \times c_k, \sum B_{in} \times c_k\right).$$

**41**. The method as recited in claim 35 wherein said fourth-color subpixels comprise a resample area that does not cover the entire data space.

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